2002 outfall benthic monitoring report

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2002 Outfall Benthic Monitoring Report

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EXECUTIVE SUMMARY

The Outfall Benthic Surveys began in 1992 as part of the Benthic (Sea-Floor) Monitoring component of the MWRA Harbor and Outfall Monitoring (HOM) program. This study is designed to address three main concerns relative to the response of the benthic community to MWRA' s relocation of the effluent discharge into Massachusetts Bay: eutrophication, contaminants, and particulate inputs. The Outfall Benthic Surveys provide quantitative measurements of benthic community structure and patterns of contaminant concentrations in sediments of Massachusetts and Cape Cod Bays. The 9-year pre-discharge monitoring provided an extensive understanding of the baseline conditions and changes through time. The focus of the program since effluent discharge began in September 2000 has been an evaluation of the effects of the discharge on the bay ecosystems. The objectives of the monitoring program are (1) to monitor versus NPDES permit requirements, (2) to test whether or not the discharge-related impacts are within the limits predicted by the SEIS, and (3) to determine if changes in the system exceed Contingency Plan thresholds (MWRA 2001).

To support the benthic monitoring, four types of surveys are conducted annually in the vicinity of the outfall:

- Sediment-profile image (SPI) surveys are conducted in nearfield locations in August of each year to give a rapid, area-wide assessment of sediment quality and benthic community status;
- Traditional grab sampling is used to provide data on infaunal community structure, contaminant concentrations, and sediment composition. Twenty-three stations are sampled in the nearfield (defined as <8km from the outfall) and eight in the farfield (reference stations >8km from the diffuser);
- Contaminant Special Study surveys supplement the contaminant data collected in August; four stations in close proximity to the outfall are sampled again in the fall and early winter; and
- Video and photographic surveys of the hard-bottom habitats are conducted once per year in late June in rocky areas near the outfall, at two diffusers, and at hard-bottom reference locations.

The 2002 outfall benthic monitoring results represent the second year of discharge data after the 9-year baseline period. The extensive baseline allowed an understanding of the natural variability of the bay system to be developed, so that natural changes would not be confused with potential outfall impacts. All indications are that although there have been a few subtle changes in the sedimentary environment, as described below, there was no acute impact from the outfall discharge during its first two years of operation. No Contingency Plan benthic monitoring thresholds were exceeded. These results are not unexpected, because any impacts from the MWRA discharge to sediments or to seafloor communities are expected to be both modest and gradual. The most recent results are highlighted in the paragraphs below, followed by an expanded discussion of each study parameter.

- **SPI:** Most of the biogenic activity in the study area is related to small tube-building worms or amphipods, and burrowing organisms that create feeding mounds and pits in the sediment surface. There does not appear to be any relationship between RPD layer depth and the outfall: the mean RPD layer depth in 2002 was statistically the same as the mean RPD for all baseline years. The Organism Sediment Index (OSI), a measure of benthic habitat quality, increased each year for the last three years of the baseline period (1998–2000), but started to decline in 2001. This decline, which continued into 2002, may represent a shifting balance between biological and physical processes, with 2000 being the peak year (of the eight years SPI data were collected) for biological processes. Overall, it appeared that biological processes were still predominant in structuring surface sediments, but signs of physical processes, such as bedforms, were also present but reduced in 2002 relative to other years.

- **Sediment Contaminants:** The first year of discharge data suggested that a possible effluent signal may have been detected in the increased concentration of *Clostridium perfringens*, especially at stations located within 2 km of the western end of the outfall. This signal was also present in 2002 at many of the nearfield stations, suggesting that effluent discharge is having, as expected, a localized but modest influence on nearby sediments. Sediment data available to date suggests that the treated effluent discharged from the diffuser has not caused an increase in contaminants of environmental concern to the Massachusetts and Cape Cod Bay systems. Increases in some metals and organic contaminants were observed at NF10, NF14, and NF17, but values for both 2001 and 2002 fell within the general distribution of samples collected during the baseline period (1992–2000). Annual mean values for organic and metal contaminants in the nearfield continued to be well below the MWRA thresholds in 2001 and 2002.

- **Soft-bottom Benthic Communities:** In the two years since the outfall became operational, there have been no patterns in benthic community structure that can be considered even a potential outfall effect. Abundance of soft-bottom infauna has increased dramatically from 1992–2002, but this change has occurred in both the nearfield and farfield. Species richness (number of taxa per sample and in the regional species pool) also has increased, primarily in the number of relatively rare species. Numerically dominant species have been for the most part invariant for the last several years. There is a similar pattern of change in both the nearfield and farfield communities: the successional half-life is roughly 30 years when the similarity index NNESS *m* is set at 15, which is sensitive to both the rare and abundant species. This is true for the years prior to the outfall coming on-line and also for post-discharge samples.

- **Hard-bottom Communities:** The hard-bottom habitats in the vicinity of the diffuser are spatially quite variable, but year-to-year variations in habitat characteristics have tended to be relatively small. Location on the drumlins is a primary factor in determining habitat relief. The tops of the drumlins are relatively homogeneous, whereas the edges of the drumlin tops and the flanks are more heterogeneous. Several trends in the population structure of individual taxa have been noted, but these changes do not appear to be related to the outfall discharge, since they started before the outfall went on line and have continued post-discharge. A general increase has been noted in the abundance of codfish, crabs, and lobsters. The first two years of discharge monitoring have shown only modest changes suggestive of outfall impact at a subset of five stations. Lush epifaunal growth continues to thrive on both diffuser heads surveyed for this study, and throughout many of the other stations visited.

Sediment Profile Images

The nearfield baseline years for Sediment Profile Images (SPI) were the six collections made between 1992 and 2000. These years provided the database for assessing change in the apparent color redox potential discontinuity (RPD) layer depth as described in the MWRA monitoring plan (MWRA 2001). During the baseline period, the grand mean RPD layer depth varied from a low of 1.7 cm (SE = 0.18) in 1995 to a high of 2.6 cm (SE = 0.14) in 2000. The largest difference in RPD from one sampling year to the next was a shallowing of 0.8 cm that occurred between 1995 and 1997. Unfortunately, this was also associated with a shift in sampling from August to October, which may have contributed to the change. The largest deepening of the RPD layer was 0.6 cm between 1999 and 2000, and was associated with an increase in the levels of biogenic activity. In 1999 and 2000 the increased occurrence of Stage II communities, and Stage III in 2000, was a key factor in the deepening of the RPD. Most of the biogenic activity was related to small tube-building worms and to burrowing organisms that created feeding mounds and pits in the sediment surface.

Factors responsible for the depth of the RPD layer in the nearfield were acting at regional scales with yearly patterns in RPD depth consistent across stations. The dynamics of the RPD layer were related principally to the interaction of physical and biological processes that structured surface sediments and infaunal communities. Bottom instability driven by waves and currents created a patchy mosaic of successional Stage I pioneering communities that dominated the nearfield stations from the start of SPI sampling in 1992 to 1997. Starting in 1998 intermediate successional Stage II communities dominated to the end of the baseline period in 2000 and into 2002.

The Organism Sediment Index (OSI), a measure of benthic habitat quality, indicated that infaunal communities at 30% of the nearfield stations were stressed for three or more years during the baseline period (OSI values <6) (Rhoads and Germano, 1996). The likely stressors were the physical processes shaping the dynamic sedimentary environment and not water or sediment quality since these were always reported to be good. From 1998 to 2000 there was an increasing tend in the OSI that reflected the increased importance of biological processes in structuring surface sediments.

In summary, there does not appear to be any relationship between RPD layer depth and the outfall, which started operation in September 2000. The mean RPD layer depth in 2002 of 2.5 cm was statistically the same as the baseline RPD of 2.3 cm. On a station by station basis, there did not appear to be any change in the sediment color or fabric in 2002 relative to 2001 or the baseline years. There was little change in the sedimentary environment in 2002.

The prominence of sediment surface biogenic structures and organism activity in 2002 appeared to be less relative to 2001, but subsurface biogenic activity was similar to 2001. Stations with *Ampelisca* spp. tubes increased from 2 to 5 from 2001 to 2002. *Ampelisca* spp. tubes were first observed in the nearfield SPI images in 1999.

The OSI increased each year for the last three years of the baseline period (1998–2000), but started to decline in 2001. This decline from 7.2 in 2000 to 6.4 in 2002 may represent a shifting balance between biological and physical processes at the nearfield stations, with 2000 being the peak year for biological processes of the eight years SPI data were collected at the nearfield stations. Overall, it appeared that biological processes were still predominant in structuring surface sediments, but signs of physical processes, such as bedforms, were also present but reduced in 2002 relative to other years.

Sediment Geochemistry

The spatial distribution and temporal response of grain size and total organic carbon (TOC) in 2001 and 2002 were not substantially different from previous years (1992–2000). The trend toward decreasing abundance of *Clostridium perfringens* observed in the system since 1998 also continued in 2001 and 2002 for stations located closer to Boston Harbor. This suggests that the documented reductions in effluent solids loading during the 1990s (Werme and Hunt, 2001) also reflect a reduction in *Clostridium* spore loads.

Post-diversion concentrations of *C. perfringens* (normalized to percent fines) increased at nearly all nearfield stations, with the largest increases observed at stations located within 2 km from the western end of the outfall. These findings suggest that effluent discharge is having, as expected, a localized, but modest, influence on nearby sediments. In contrast, post-diversion concentrations of *C. perfringens* (normalized to percent fines) did not change substantially at regional locations, except at stations located close to the harbor where abundance decreased slightly after the diversion. Overall, these findings indicate that *C. perfringens* is an excellent indicator of the early response in the sediments to the outfall diversion.

Sediment Contaminants

The addition of post-diversion (2001 and 2002) data to the baseline continued to support a picture of two regions – *nearfield* and *regional* – each defined in physical and chemical terms. In the nearfield sediments of Massachusetts Bay, there is a series of stations with heterogeneous sediments in relatively close proximity to, and roughly equidistant from, the historic source of contaminants (*i.e.*, Boston Harbor). Factors that influence contaminant variability in the nearfield include local (Boston Harbor) and distributed sources, primarily related to grain-size factors suggestive of different sediment depositional environments. The primary factor associated with the variance in the data was sand content. The secondary factors were associated with anthropogenic analytes and fine particles.

In contrast, regional stations are spatially distributed within the Massachusetts and Cape Cod Bay systems, with some stations located close to, and others far away from, Boston Harbor. Sediments collected from regional stations are compositionally distinct from the nearfield data. The variability among contaminants at regional stations decreased when stations located closer to the harbor were excluded from the correlation analysis, indicating that the factors that influence contaminant variability at offshore regional locations include distributed sources (*e.g.*, atmospheric input). Indeed, the PCA results showed that the composition of sediments at offshore regional sampling locations was governed by the analytes associated with fines and may reflect regional sediment inputs distinct from Boston Harbor. As evident in the nearfield data, sand content strongly influenced the variance in the regional data. In addition, the sewage tracer data showed that the proximity to the harbor (the historic source of sewage contaminants) influenced the concentration of *C. perfringens* and total linear alkylbenzenes (LAB) at some regional stations.

While localized increases in some metals and organic contaminants were observed at individual stations, post-diversion data (2001 and 2002) fell within the general distribution of samples collected during the baseline period (1992–2000). Local increases observed at NF10, NF14, and NF17 were qualitatively confirmed by the multidimensional statistical analysis using principal components analysis (PCA). Sediment data available to date suggests that the treated effluent discharged from the diffuser has not caused an increase in contaminants of environmental concern to the Massachusetts and Cape Cod Bay systems.

Coats (1995) estimated the length of time it would take to detect contaminant increases between the onset of secondary effluent discharge at the Massachusetts Bay outfall as the mean of nearfield sediments located within 2 km of the outfall *(i.e.,* NF13, NF14, NF17, NF19, NF23 and NF24). He suggested that

Cd and Ag would show detectable increases in the nearfield sediments within 1.1 and 1.5 years of the new outfall coming online, respectively, based on estimated levels of contaminants in secondary treated effluent. Other contaminants were not expected to show increases until at least six or more years after the offshore effluent discharge began (Coats, 1995). Results from the first two post-diversion sampling events (August 2001 and 2002) represent approximately two years after onset of effluent discharge. The post-diversion results do not conform with Coats' predictions, in that detectable increases in Cd and Ag were not observed at stations located within the vicinity of predicted increase following outfall startup. However, apparent increases in Pb were observed at three stations (NF14, NF17, and NF23) located within the vicinity of predicted increase in 2001, and remained above baseline at two of these stations in 2002 (NF14 and NF23). In addition, total Chlordane, Al, Cr, Cu, Fe, Hg, Ni, and Zn increased in 2002 at NF13, a station located within the vicinity of the predicted increase. Selected contaminants have also increased at other stations (*i.e.*, NF10, NF21) located outside the vicinity of the predicted increase. Post-diversion increases in contaminant concentrations at some stations identified here appear to be related to grain size and TOC factors, but not others. Since the results from August 2001 and 2002 represent only the first two sampling events after onset of effluent discharge, additional sampling (*i.e.*, more data points) in the future will allow for a more robust evaluation against Coats' model.

While localized increases in selected contaminants and *C. perfringens* abundances were observed in the system following outfall startup, annual mean values for organic and metal contaminants in the nearfield continued to be well below the MWRA thresholds in 2001 and 2002.

Soft-bottom Benthic Communities

The nine-year baseline dataset acquired by the MWRA on the soft-bottom benthic communities of Massachusetts Bay provides an excellent basis for understanding potential responses of the system to the secondary-treated effluent. The variability at some stations, possibly due to impacts by winter storms, contrasted with the stability of other stations over time, provides documentation on long-term changes in regional benthic community structure. With the two additional years of data since the outfall became operational, patterns previously suggested by the data are now becoming clearer. These patterns include:

- Abundance of soft-bottom infauna has increased dramatically, approximately 60%, in both the nearfield and farfield from 1992–2002.
- Species richness (number of taxa in the species pool) and log-series *alpha* (a measure of species richness) also have increased dramatically in an apparent sine-wave pattern with a seven-year cycle. The increase in species richness is primarily an increase in the relatively rare species.
- Population densities of many species have also fluctuated cyclically.
- The numerically dominant species at specific stations have been for the most part invariant, such as *Cossura longicirrata* continuing to dominate the muddy offshore stations, especially those in Cape Cod Bay. There are some notable exceptions, *e.g.*, *Spio limicola* was replaced by *Prionospio steenstrupi*, which is now dominant at 17 of the 23 nearfield stations.
- The second tier of dominants, those species which rank fifth through fifteenth and are neither the top numerical dominant nor rare, have changed subtly over the past decade.

- There is a similar pattern of change in both the nearfield and farfield: the successional half-life is roughly 30 years when the similarity index NNESS *m* is set at 15, which is sensitive to both the rare and abundant species. This is true for the years prior to the outfall coming on-line and also for contrasts involving the post-discharge samples.

- There has been virtually no increase in any of the diversity indices that are sensitive to dominant species (H', ESN).

- There are no patterns that can be considered even a potential outfall effect.

There are several hypotheses about the possible causes behind the observed changes in infaunal community structure (increase in abundance and change in species composition among the dominants); one or more of these processes may be operative in the study area. The *perfect storm hypothesis* implies that during the 1990s, benthic communities were recovering from the devastating impacts of the 1992 winter storms, when the nearfield infaunal abundances seen in the previous year's samples were essentially halved. The *chance hypothesis* supposes that the dominant species each year is from a group of select species and can not be readily predicted. Whichever species, due to its reproductive mode or chance, that got a head start each year will dominate the abundance patterns. This concept assumes that all species are identical in terms of per capita chances of competing, dying, and reproducing, but it is probably not correct that all species are identical in this way. The *productivity hypothesis* suggests that increased loading of organic matter to the sediments bay-wide could account for the approximate doubling of infaunal abundance since 1993. This increased loading might be coupled to an overall increased intensity and magnitude of the spring and fall phytoplankton blooms, which play a disproportionate role in the flux of labile organic matter in the form of phytodetritus to the benthos. The *climate change hypothesis* assumes a change in biogeographic regime. A change of a few degrees in bottom temperatures, perhaps associated with the North Atlantic Oscillation (NAO), could alter species composition through the effects of temperature on larval availability (including advection from source populations) and habitat preferences (temperature cues for cold- and warm-water species at the time of settlement). An NAO-coupled change in NO_3-rich, slightly colder, bottom water to the bay in the late 1990s could account for the increased abundance of infauna.

Hard-bottom Communities

The nearfield hard-bottom communities in the vicinity of the outfall have been surveyed annually for nine years. Seven of the surveys occurred under pre-discharge baseline conditions, while the last two surveys occurred under post-discharge conditions. The baseline surveys provided a substantial database that allowed characterization of the habitats and benthic communities found on the drumlins in the vicinity of the outfall. The hard-bottom habitats are spatially quite variable, but have shown several consistent trends. At many of the waypoints, year-to-year variations in habitat characteristics tended to be relatively small. Location on the drumlins appears to be a primary factor in determining habitat relief. Sediment drape tended to be light on the shallowest part of the drumlins adjacent to the outfall (T1-2, TI-3, T1-4 and T4/6-1), moderately light at the southernmost reference sites (T8), and moderately heavy or heavy at the other southern reference site (T10), the northern reference stations (T7-2 and T9-1), and some of the flank stations (T4-1 and T6-1). The tops of the drumlins were relatively homogeneous, so that lateral shifts in position did not result in widely different habitat characteristics (*i.e.*, T1-3, T1-4, T4/6-1, T8, T9 and T10). In contrast, the edges of the drumlin tops and the flanks were more heterogeneous, such that small lateral shifts in position frequently resulted in substantially different habitat characteristics *(i.e.*, T1-1, T1-2, T1-5 and T4-2. Several stations north of the outfall had slightly more sediment drape in 2001 than at any time during the baseline period. This trend has continued into 2002, but the amount of drape did not increase between 2001 and 2002.

Several trends that appear to reflect widespread temporal changes in the population structure of individual taxa have been noted over the time course of the nearfield hard-bottom surveys. These changes do not appear to be related to the outfall discharge, since they started before the outfall went on line and have continued post-discharge. Abundances of the green sea urchin *Strongylocentrotus droebachiensis* declined from 0.85 individuals per photograph in 1996 to 0.23 individuals per photograph in 2000, and increased slightly in 2001 and 2002 (0.28 and 0.35 individuals per photograph, respectively). In contrast, two other species, the crab *Cancer* sp. and the cod *Gadus morhua*, appear to be increasing. In the still photographs, one to six *Cancer* crabs were seen annually between 1996 and 1999, 20 were seen in 2000, 54 were seen in 2001, and 79 were seen in 2002. This pattern was also reflected in the video data, with 3–17 *Cancer* crabs observed annually between 1996 and 1999, 105 in 2000, 147 in 2001, and 205 in 2002. A similar trend was seen in the video data for codfish, with none seen in 1996 to 41 seen in 2001 and 53 seen in 2002. Interestingly, no cod had been seen at the diffuser stations during the baseline years, yet in both 2001 and 2002 cod have been seen at both active (Diffuser #2 at T2-5) and inactive (Diffuser #44) heads. Additionally, the codfish appear to be behaving differently at the outfall than at the other hard-bottom stations. At most of the stations codfish tend to shy away from the ROV, usually ducking behind large boulders, but at the diffuser sites they were much less hesitant and occasionally came right up to the vehicle. A general increase has also been noted in the abundance of lobsters, from one individual seen in the still photographs in 1996 to 13 individuals in 2002; and six individuals seen in the video footage in 1996 to 29 individuals seen in 2002. The gradual increase in the number of codfish and *Cancer* crabs in recent years has also been noted by local fishermen (Frank Mirarchi, personal communication to Dr. Hecker, June 2002). The first two years of discharge monitoring have shown only modest changes suggestive of outfall impact at a subset of five stations. Lush epifaunal growth continues to thrive on both diffuser heads surveyed for this study, and throughout many of the other stations visited. However, despite the fact that outfall impacts appear to be minimal at this time, changes in the hard-bottom communities could be chronic and/or cumulative, and may take a longer time to manifest themselves.

1. INTRODUCTION

1.1 Regulatory Framework

Since 1985, The Massachusetts Water Resources Authority (MWRA) has been responsible for the Boston area's water and sewerage treatment; the MWRA also has responsibility for associated environmental monitoring. Major improvements to the water and sediment quality in Boston Harbor began with the abatement of sludge discharge into the harbor in late 1991. In 1995, a new primary treatment facility at the Deer Island plant was brought online. Secondary treatment at the Deer Island plant was achieved in two phases in 1997 and 1998. Also in 1998, a major source of discharge to the south harbor was eliminated when the final diversion of effluent from Nut Island to Deer Island was complete. The final phase of secondary treatment at Deer Island was completed in 2000 and became operational in 2001. In September 2000 the effluent from Deer Island was diverted to the offshore outfall in Massachusetts Bay. The transfer was designed to improve the water quality in Boston Harbor and to increase effluent dilution with minimal impact on the offshore environment.

A permit issued to MWRA by U.S. EPA and the Massachusetts Department of Environmental Protection (MADEP) under the National Pollutant Discharge Elimination System (NPDES) regulates the new outfall. Among other things, the permit requires MWRA to monitor the outfall effluent and the ambient receiving waters. While some ecological studies began during 1989- 1991, a broader baseline marine environmental monitoring program began in 1992. Baseline monitoring was initially planned to last for approximately three years, but delays in outfall construction allowed a relatively long period for baseline studies. As a result, greater documentation of natural variability and a better understanding of the Massachusetts Bay ecosystem have been developed.

The Outfall Benthic Surveys began in 1992 as part of the Benthic (Sea-Floor) Monitoring component of the MWRA Harbor and Outfall Monitoring (HOM) program. These surveys provided quantitative measurements of benthic community structure and patterns of contaminant concentrations within sediments of Massachusetts and Cape Cod Bays. The pre-discharge monitoring (1992- 2000) has provided an extensive understanding of the baseline conditions and changes through time. Each section of this report includes an introduction that characterizes baseline conditions. Conclusions about the nature of post-discharge (2001-2002) findings in relation to the baseline (1992-2000) understanding of the system are also presented.

1.2 Overview of the Present Study

The 2002 outfall benthic surveys detailed in this report represent the second full year of post-discharge benthic monitoring. Data were collected from each of the benthic monitoring program's four components: (1) sediment profile images; (2) geochemical properties, contaminants, and sewage tracers in sediment; (3) benthic infaunal community; and (4) hard-bottom community. Survey methods are described in Section 2. The results and analysis of the sediment profile images are presented in Section 3. Sediment geochemistry studies, conducted via the collection of sediment grab samples, consist of grain-size analysis, total organic carbon (TOC) content determination, and contaminant concentration analyses and are presented in Section 4. Soft-bottom infaunal communities in Massachusetts Bay and Cape Cod Bay are described in Section 5 and include an evaluation of infaunal communities in relation to a suite of sediment parameters.

The benthic monitoring program as initiated in 1992 included 10 special stations at farfield locations sampled for biology in May 1992, 20 stations in the nearfield sampled in August 1992, and 12 stations in the farfield also sampled in August 1992. At each of the August 1992 stations, samples were taken to evaluate 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 three replicates at each station.

Achieving a good monitoring design for the nearfield was difficult due to the heterogeneity of habitats. As a result, the sampling protocol has been modified several times to find the best approach. In 1993 the design for the nearfield was changed to include nine stations, with three replicates each. One of the farfield stations was dropped (Coats *et al.*, 1995a). In 1994, the non-replicated design was reinstated with retention of three replicated stations (Coats, 1995); that design was repeated in 1995 and has continued through 2002 and is planned for 2003. The shift in station design presented some problems in comparing year-to-year trends because the 1993 nearfield design departs significantly from that of 1992 and 1994-2002. Nevertheless, the nine-year baseline database accumulated from 1992-2000 represents a timeframe that is sufficient to assess long-term regional trends and to establish thresholds to interpret potential impacts from the effluent discharge that was initiated in the fall of 2000.

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

2. FIELD OPERATIONS

By Isabelle P. Williams

2.1 Sampling Design

2.1.1 Soft Bottom

Sediment Samples—The nearfield benthic surveys are conducted each year in August. The station array is designed to provide detailed spatial coverage of the infaunal communities inhabiting depositional sediments within ca. 8 km of the diffuser. Benthic infaunal and sediment chemistry samples were collected from 23 nearfield stations (Figure 2-1). The target locations for the nearfield stations are listed in Table 2-1. The actual locations for each biology and chemistry grab sample along with a brief description of each sample is given in Appendix A.

Farfield stations, located more than 8 km from the outfall diffuser pipe, serve primarily as reference areas for the nearfield. These stations are located throughout Massachusetts and Cape Cod Bays (Figure 2-2.). Sampling in the Stellwagen Bank National Marine Sanctuary (Stations FF04 and FF05) was conducted under sampling permit SBNMS-2002-007. The target locations for the farfield stations are presented in Table 2-1.

The Nearfield Contaminant Special Study Surveys are designed to examine the possible short-term impacts of the outfall discharge on sedimentary contaminant concentrations and their interrelationships with possible sedimentary organic carbon changes in depositional environments near the effluent outfall. Contaminant Special Study surveys are scheduled to be conducted three times per year (February, August, and October). The nearfield contaminant special study stations include NF08, NF22, NF24, and FF10. These four locations were selected because:

- With the exception of FF10, these stations were comprised of fine-grained material (>50% sand/silt);
- They were in relatively stable areas (except for FF10, grain size composition was consistently >50% sand/silt over the period monitored);
- With the exception of FF10, these stations had high total organic carbon (TOC) content relative to other nearby locations (at least 1% TOC);
- These stations were within the zone of increased particulate organic carbon deposition predicted by the Bay Eutrophication Model (BEM) (Hydroqual, 2000); and
- Selection of these stations complemented and expanded on stations (NF12, NF17) periodically sampled by the United States Geological Survey (USGS).

Stations FF10, NF08, and NF24 lie on a line extending to the northwest from the west end of the diffuser. Along with NF12, which is sampled separately by the USGS, they provide a spatial gradient extending from the diffuser (Figure 2-1) towards the predicted high-deposition area. Station NF22 lies to the southwest of the west end of the diffuser and is along the projected long-term effluent transport path from the diffuser. Station FF10 is sandier than the other three stations, and extends the area of potential impact sampled under the contaminant special studies task. FF10 also represents a farfield location near the center of the high-deposition location predicted by the BEM model.

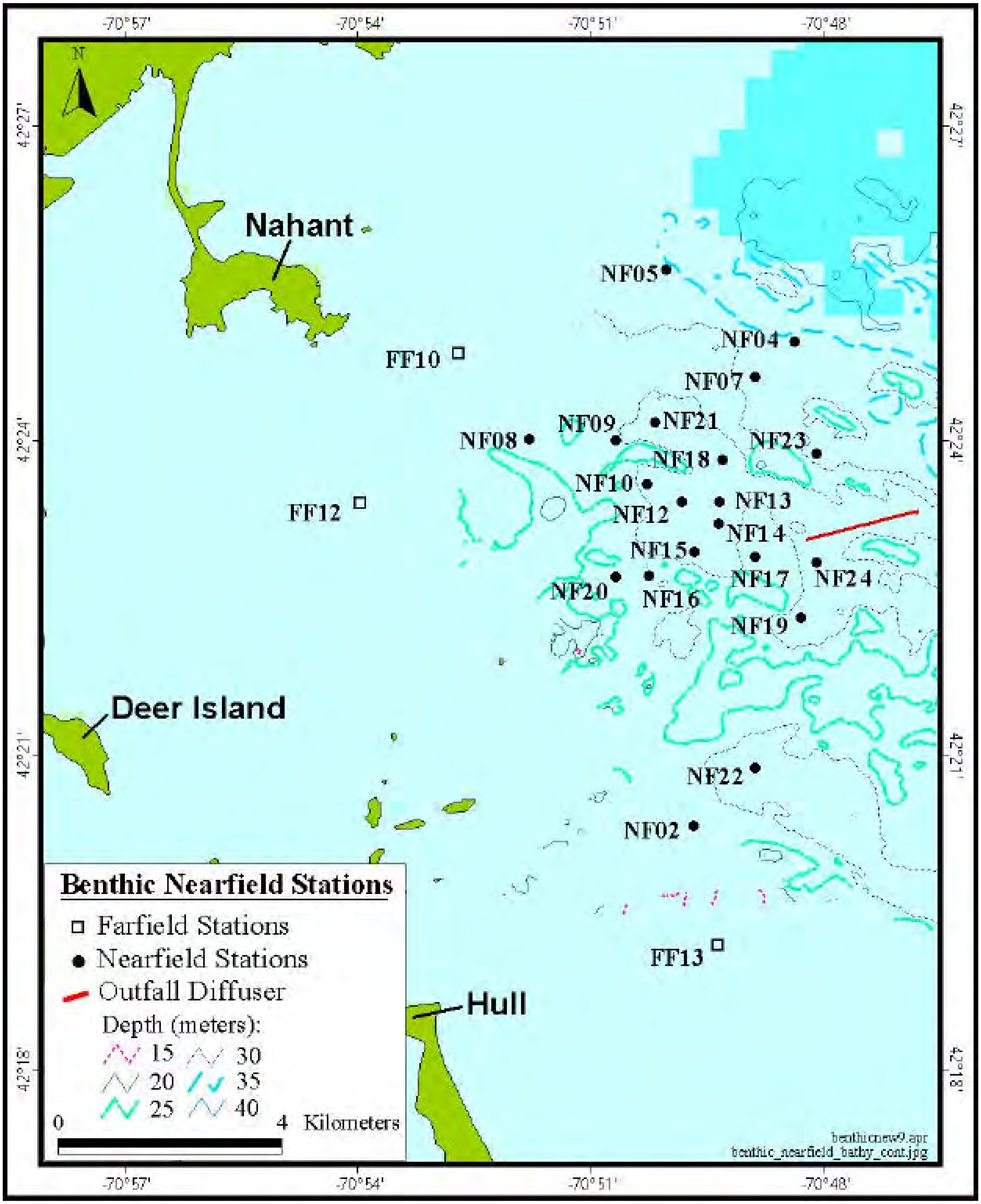

Figure 2-1. Locations of nearfield grab stations sampled in August 2002.

Table 2-1. Target locations for outfall survey grab and SPI stations.

Station	Latitude	Longitude	Depth (m)
Nearfield Stations			
NF02	42E20.31NN	70E49.69NW	26
NF04	42E24.93NN	70E48.39NW	34
NF05	42E25.62NN	70E50.03NW	36
NF07	42E24.60NN	70E48.89NW	32
NF08[+]	42E24.00NN	70E51.81NW	28
NF09	42E23.99NN	70E50.69NW	29
NF10	42E23.57NN	70E50.29NW	33
NF12	42E23.40NN	70E49.83NW	35
NF13	42E23.40NN	70E49.35NW	34
NF14	42E23.20NN	70E49.36NW	34
NF15	42E22.93NN	70E49.67NW	33
NF16	42E22.70NN	70E50.26NW	31
NF17	42E22.88NN	70E48.89NW	31
NF18	42E23.80NN	70E49.31NW	33
NF19	42E22.30NN	70E48.30NW	33
NF20	42E22.69NN	70E50.69NW	29
NF21	42E24.16NN	70E50.19NW	30
NF22[+]	42E20.87NN	70E48.90NW	30
NF23	42E23.86NN	70E48.10NW	36
NF24[+]	42E22.83NN	70E48.10NW	37
Farfield Stations			
FF01A	42E33.84NN	70E40.55NW	35
FF04	42E17.30NN	70E25.50NW	90
FF05	42E08.00NN	70E25.35NW	65
FF06	41E53.90NN	70E24.20NW	35
FF07	41E57.50NN	70E16.00NW	39
FF09	42E18.75NN	70E39.40NW	50
FF10[+]*	42E24.84NN	70E52.72NW	29
FF11	42E39.50NN	70E30.00NW	88
FF12*	42E23.40NN	70E53.98NW	24
FF13*	42E19.19NN	70E49.38NW	21
FF14	42E25.00NN	70E39.29NW	73

[+] Also Nearfield Contaminant Special Study Stations.

*Farfield Stations FF10, FF12, and FF13 are analyzed with the nearfield stations.

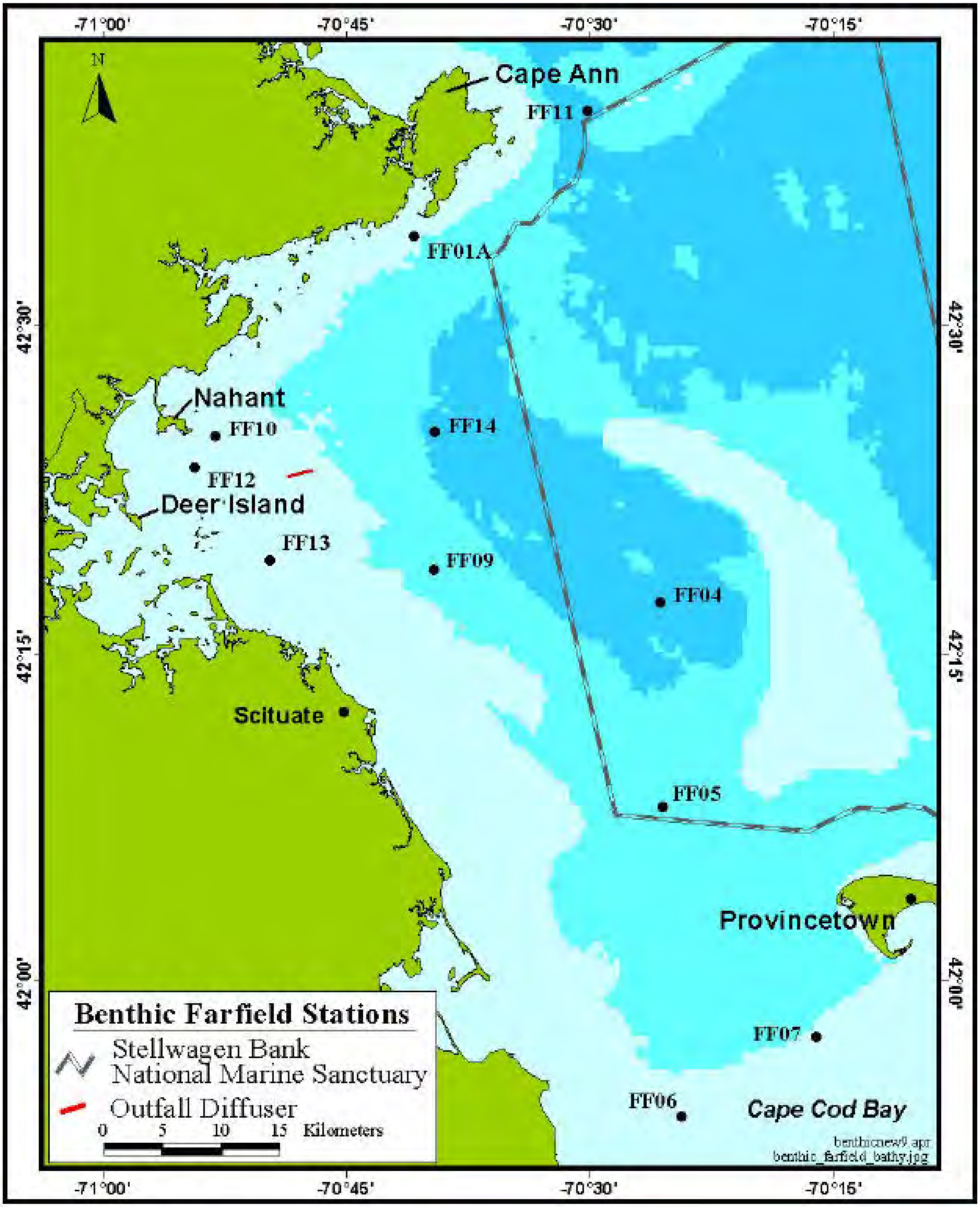

Figure 2-2. Locations of farfield grab stations sampled in August 2002.

Sediment Profile Images—The nearfield Sediment Profile Image (SPI) surveys are conducted in August of each year at 20 nearfield and 3 farfield stations (Figure 2-1) within 8 km of the outfall. The SPI survey allows a rapid comparison to be made of benthic conditions to the benthic triggering thresholds; this qualitative evaluation can then be integrated with the quantitative results from the infaunal and sediment chemistry analyses. Sediment profile imagery, whether using 35-mm film as in past years, or digital technology as in 2002, permits a faster evaluation of the benthos than can be made by traditional infaunal analyses. The target locations for SPI stations are the same as those of the nearfield grab stations (Table 2-1). Specific locations of all sediment profile images collected in 2002 are listed in Appendix B.

2.1.2 Hard Bottom

Because of the relative sparseness of depositional habitats in the vicinity of the diffusers and adjacent nearfield, a photographic study of hard-bottom habitats is conducted each June. The hard-bottom ROV (remotely operated vehicle) survey of the outfall area is designed to provide semi-quantitative data about the hard-bottom community and its responses to the operation of the outfall. Video and 35-mm photographic images were collected at 20 waypoints/stations along six transects and three additional waypoints (Diffuser #44, T9-1 and T10-1) (Table2-2, Figure 2-3).

2.2 Field Program Results

2.2.1 Survey Dates and Samples Collected

A summary of the samples collected on surveys conducted in 2002 is presented in Table 2-3.

Table 2-3. Survey dates and numbers of samples collected on benthic surveys in 2002.

Survey Type	Survey ID	2002 Date(s)	Samples Collected								
			Inf	**TOC**	**GS**	**Cp**	**C**	**TM**	**SPI**	**35**	**V**
Nearfield * Benthic	BN021	12–14 Aug	35	35	35	35	35	35			
Farfield Benthic	BF021	12, 14–15 Aug	24	16	16	16	16	16			
SPI	BR021	26–27 Aug							92		
Hard-bottom	BH021	23–28 June								~720	54
Nearfield Contaminant	BC021	20 Feb		12	12	12	12	12			
Nearfield Contaminant	NF021	13–14 Aug		12	12	12	12	12			
Nearfield Contaminant	BC022	22 Oct		12	12	12	12	12			

* Nearfield survey includes Stations FF10, FF12, FF13.

Key: Inf: Infauna, TOC: total organic carbon, GS: grain size, Cp, *Clostridium perfringens* C: contaminant; TM: trace metals; SPI: individual sediment profile images; 35: 35-mm slides (hard-bottom); V: video segments (hard-bottom)

Table 2-2. Target locations for hard-bottom survey transects.

Transect	Waypoint/ Station	Latitude	Longitude	Depth (m)
T1	1	42E23.606'N	70E48.201'W	25
T1	2	42E23.625'N	70E48.324'W	24
T1	3	42E23.741'N	70E48.532'W	22
T1	4	42E23.815'N	70E48.743'W	20
T1	5	42E23.869'N	70E48.978'W	27
T2	1	42E23.634'N	70E47.833'W	26
T2	2	42E23.570'N	70E47.688'W	27
T2	3	42E23.525'N	70E47.410'W	26
T2	4	42E23.457'N	70E47.265'W	32
T2	5 (Diffuser #2)	42E23.331'N	70E46.807'W	34
T4	1	42E23.046'N	70E46.502'W	31
T4	2	42E23.012'N	70E46.960'W	29
T4	3	42E22.877'N	70E47.580'W	30
T4/6	1	42E22.948'N	70E47.220'W	23
T6	1	42E22.993'N	70E47.712'W	30
T6	2	42E22.855'N	70E47.082'W	27
T7	1	42E24.565'N	70E47.015'W	23
T7	2	42E24.570'N	70E46.920'W	24
T8	1	42E21.602'N	70E48.920'W	23
T8	2	42E21.823'N	70E48.465'W	23
T9	1	42E24.170'N	70E47.768'W	24
T10	1	42E22.680'N	70E48.852'W	26
	Diffuser # 44	42E23.116'N	70E47.931'W	33

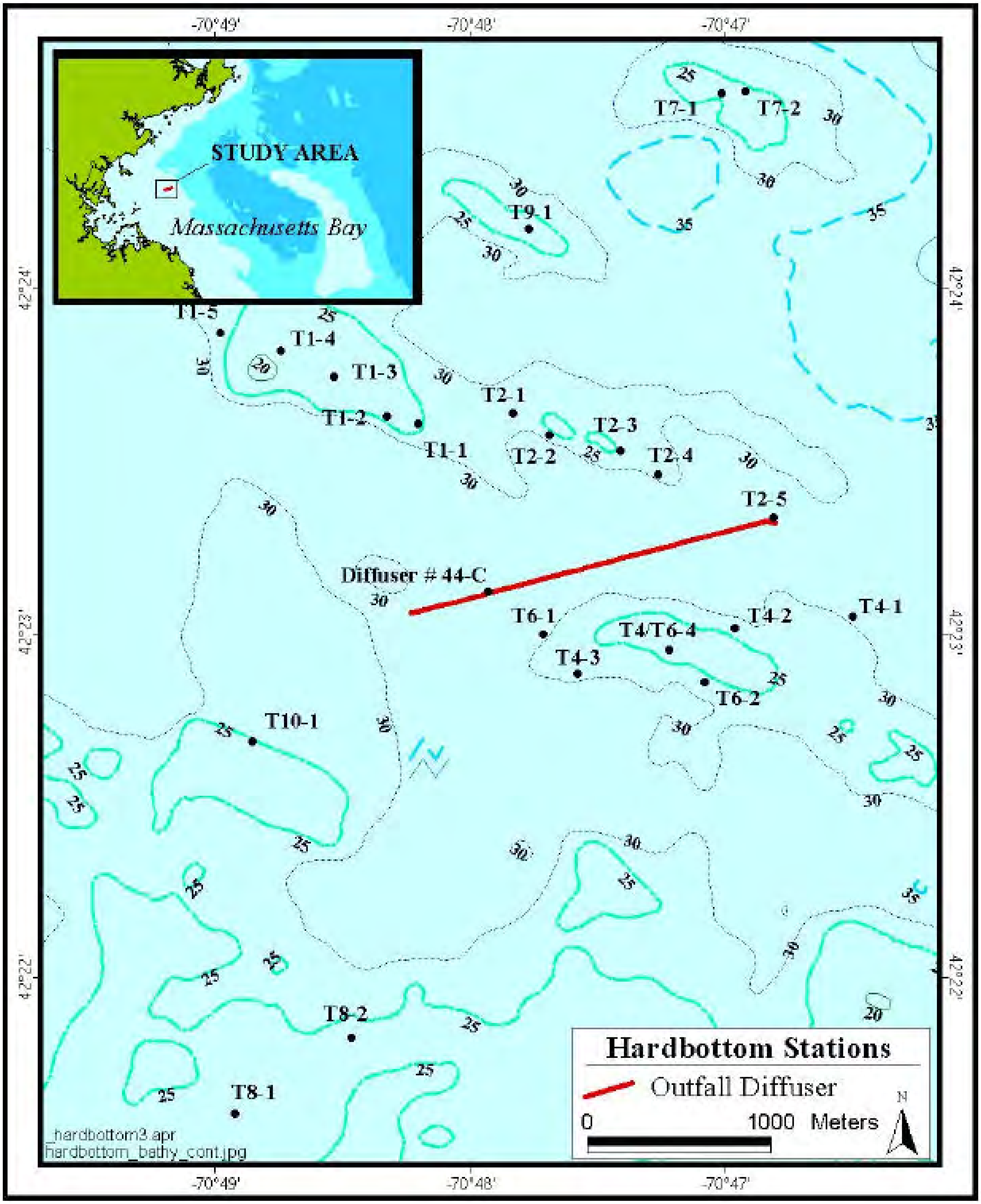

Figure 2-3. Locations of hard-bottom stations sampled in June 2002.

2.2.2 Vessel and Navigation

Except for the hard-bottom survey, which was completed on board the F/V *Christopher Andrew*, the 2002 outfall benthic surveys were conducted from Battelle's research vessel, the R/V *Aquamonitor*. On the R/V *Aquamonitor*, vessel positioning was accomplished with the Battelle Oceans Sampling Systems (BOSS) Navigation system. BOSS consists of a Northstar differential global positioning system (DGPS) interfaced to an on-board computer. Data are recorded and reduced using NAVSAM© data acquisition software. The GPS receiver has six dedicated channels and is capable of locking onto six satellites at once. The system is calibrated with coordinates obtained from USGS navigation charts at the beginning and end of each survey day. For the hard-bottom survey, a DGPS and ORE International LXT Underwater positioning system was used for positioning the vessel and the ROV. The Windows-based software, HYPACK, was used to integrate these positioning data and provide real-time navigation, including position and heading of the vessel and position of the ROV relative to the vessel.

At each sampling station, the vessel is positioned as close to target coordinates as possible. The NAVSAM© navigation and sampling software collects and stores navigation data, time, and station depth every 2 seconds throughout the sampling event, and assigns a unique designation to each sample when the sampling instrument hits bottom. The display on the BOSS computer screen is set to show a radius of 30 m around the target station coordinates (six 5-m rings) for all MWRA benthic surveys. A station radius of up to 30 m is considered acceptable for benthic sampling in Massachusetts Bay.

2.2.3 Grab Sampling

Nearfield/Farfield Benthic Surveys—The Nearfield/Farfield Benthic Survey BN021/BF021 was conducted in August 2002. There are four separate sampling protocols used for the 23 stations included in the nearfield survey. At stations NF12, NF17, FF12, and FF13, a modified van Veen grab sampler was used to collect three replicate samples for infaunal analysis and two replicate samples for chemical analyses, which include *Clostridium perfringens*, sediment grain size, metals, organics, and total organic carbon. A 0.04-m^2 grab was used for infaunal samples, and a 0.1-m^2 Kynar-coated grab for the chemistry samples. At stations FF10 and NF24, three faunal and three chemistry grabs were collected, and at stations NF08 and NF22, one faunal and three chemistry grabs were collected. At each of the remaining 15 nearfield stations, one faunal and one chemistry grab sample were collected, and at each of the eight remaining farfield stations, three infaunal and two chemistry grabs were collected.

Infaunal samples were sieved onboard with filtered seawater over a 300-μm-mesh sieve and fixed in 10% buffered formalin. For chemistry samples, the top 2 cm of the sediment in the grab was removed by using a Kynar-coated scoop and homogenized in a clean glass bowl before being distributed to appropriate storage containers. The TOC, metals, and organics samples were frozen, whereas the *C. perfringens* and grain size samples were placed on ice in coolers.

Nearfield Contaminant Special Study—Contaminant Special Study surveys were conducted in February, August, and October 2002. The August sample collection was carried out in conjunction with the nearfield/farfield benthic survey, BN/BF021, described above. Three replicate samples from each of the contaminant special study stations were collected for the analysis of TOC, grain size, *Clostridium*, and contaminants (organic and metals). Samples were collected from the top 2 cm of the 0.1-m^2 Kynar-coated grab and processed as described above.

2.2.4 Sediment Profile Imagery (SPI)

During the August 2002 SPI Survey (BR021), a digital camera recording to a 4.5-megabyte flash card was used in place of the 35-mm film camera with attached video camera that was described in the QWAPP for this project (Williams *et al*., 2002). The flash card was capable of recording 415 images and reached capacity after 13–16 stations. This new digital capability allowed a review of all images within 20 min of downloading the flash card to a laptop computer carried onboard.

At each station, the camera was lowered to the seafloor four times to ensure that at least three useable images were obtained. A series of 6–9 photographs was taken each time the camera was on the bottom: the first three were taken immediately after the camera frame settled on the bottom, and the remaining at ~3 sec intervals until the frame was lifted off the seafloor.

Dr. Robert Diaz was the Senior Scientist for the survey. The date, time, station, water depth, photo number and estimated camera penetration were recorded in a field log, with each touch down of the camera also marked as an event on the NAVSAM©.

2.2.5 Hard Bottom

The June 2002 Hard-bottom Survey (BH021) of the nearfield examined 20 waypoints along six transects (T1, T2, T4, T6, T7, and T8), plus three additional waypoints (T9-1, T10-1, and Diffuser 44). A MiniRover MK II ROV equipped with a Benthos low-light, high-resolution video camera, a Benthos Model 3782 35-mm minicamera with strobe, 150-W halogen lamps, a compass, and a depth gauge was deployed from the survey vessel to obtain the necessary video and photographic images. The ROV was guided as close to the bottom as possible so that the clarity of the video and photographs was maximized. Approximately 20 minutes of video footage per waypoint were recorded along a randomly selected heading. Along this route, still photographs were taken as selected by the Senior Scientist, Dr. Barbara Hecker, until an entire (36 exposure) roll of 35-mm film was exposed at each waypoint.

The date, time, and ROV depth were recorded on the videotapes and appeared on the video monitor during the recording. The beginning and end of each video tape, the start of each roll of film, and the capture of each 35-mm image were recorded as separate events on the NAVSAM© system. The time displayed on the video monitor (and recorded on the tape) was synchronized with the NAVSAM© clock. When a still photograph was taken, the event and frame-identifying observations (made by the Senior Scientist) were recorded on the videotape. The NAVSAM© produced labels that were attached to each video cartridge and each film canister. All slides were developed onboard to monitor camera performance, then mounted and labeled upon return to ENSR. Additionally, each 35-mm slide was digitized and copied onto a compact disc (CD) for archival.

3. 2002 SEDIMENT PROFILE CAMERA RECONNAISSANCE OF NEARFIELD BENTHIC HABITATS

by Robert J. Diaz

3.1 Baseline Nearfield SPI

The nearfield baseline years for Sediment Profile Images (SPI) were the six collections made between 1992 and 2000. These collections provided the baseline for assessing change in the apparent color redox potential discontinuity (RPD) layer depth as described in the MWRA monitoring plan (MWRA 2001). During the baseline period the grand mean RPD layer depth varied from a low of 1.7 cm (SE = 0.18) in 1995 to a high of 2.6 cm (SE = 0.14) in 2000. The largest difference in RPD from one sampling to the next was a 0.8 cm shallowing that occurred between 1995 and 1997. Unfortunately, this was also associated with a shift in sampling from August to October, which may have contributed to the change. The largest deepening of the RPD layer was 0.6 cm from 1999 to 2000 and was associated with an increase in the levels of biogenic activity. The increased occurrence of Stage II communities in 1999 and 2000, and Stage III in 2000, was a key factor in the deepening of the RPD. Most of the biogenic activity was related to burrowing organisms that created feeding mounds and pits in the sediment surface and small tube-building worms.

Factors responsible for the depth of the RPD layer in the nearfield were acting at regional scales with yearly patterns in RPD depth consistent across stations. The dynamics of the RPD layer were related principally to the interaction of physical and biological processes that structured surface sediments and infaunal communities. Bottom instability driven by waves and currents created a patchy mosaic of successional Stage I pioneering communities that dominated the nearfield stations from the start of SPI sampling in 1992 to 1997. Starting in 1998, intermediate successional Stage II communities dominated to the end of the baseline period in 2000 and into 2002.

The Organism Sediment Index (OSI), a measure of benthic habitat quality, indicated that infaunal communities at 30% of the nearfield stations were stressed for three or more years during the baseline period (OSI values <6; Rhoads and Germano, 1996). The likely stressors were the physical processes shaping the dynamic sedimentary environment and not water or sediment quality since these were always reported to be good. From 1998 to 2000, there was an increasing tend in the OSI that reflected the increased importance of biological processes in structuring surface sediments.

3.2 Image Analysis Materials and Methods

3.2.1 Field

Sediment profile images were collected 26 August 2002 at 20 nearfield and 3 farfield stations using a digital sediment profile camera. Station locations are give in Appendix B. After sampling, all images were reviewed to insure that at least three replicates were collected at each station. Missed replicates at Stations NF08 and NF15 were retaken on 27 August.

The digital SPI captured a 5.2-megapixel image that produced a 14.1-megapixel RGB image. Images were stored on 1-gigabyte IBM microdrives. The camera was set to take a series of images on bottom contact at about a 1.5-sec interval. Images were transferred from the microdrive to a computer and then - to a CD for long-term storage while still in the field.

3.2.2 Quick Look Analysis

The Quick Look analysis was developed in 1998 to meet the needs of rapid data turn around for assessment of benthic triggers, one of which is an area-wide 50% reduction in the average depth of the redox potential discontinuity (RPD) layer (MWRA , 1997). The digital SPI images were evaluated on 29 August, the day after field operations, and the Quick Look analysis was completed 30 August 2002. See Williams *et al*. (2002) for details on the Quick Look analysis.

3.2.3 Image Analysis

The digital SPI images were analyzed using the Adobe PhotoShop and NTIS Image programs. Data from each image were sequentially saved to a spreadsheet file for later analysis. Details of how these data were obtained can be found in Diaz and Schaffner (1988) and Rhoads and Germano (1986). Table 3-1 is reproduced from Williams *et al*. (2002).

Table 3-1. Parameters measured from Sediment Profile Images.

Parameter	Units	Method	Description
Sediment Grain Size	Modal phi interval	V	An estimate of sediment types present. Determined from comparison of image to images of known grain size
Prism Penetration	cm	CA	A geotechnical estimate of sediment compaction. Average of maximum and minimum distance from sediment surface to bottom of prism window
Sediment Surface Relief	cm	CA	An estimate of small-scale bed roughness. Maximum depth of penetration minus minimum
Apparent Reduction-oxidation Potential Discontinuity Depth (from color change in sediment)	cm	CA	Estimate of depth to which sediments are oxidized. Area of aerobic sediment divided by width of digitized image
Thickness of Sediment Layers	cm, cm^2	CA	Measure thickness above original sediment surface and delineate area
Methane/Nitrogen Gas Voids	Number, cm, cm^2	V, CA	Count, measure depth from sediment surface, delineate area
Epifaunal Occurrence	Number	V	Count, identify
Tube Density	Number /cm^2	V, CA	Count
Tube Type			
Burrow Structures	—	V, CA	Identify
Pelletal Layer	cm, cm^2	V, CA,	Measure thickness, area
Bacterial Mats	—	V	Determine presence and color
Infaunal Occurrence			Count, identify
Feeding Voids	Number Number, cm, cm^2	V, CA	Count, measure thickness, area
Apparent Successional Stage	—		
Organism Sediment Index	—	CA	Derived from RPD, successional stage, voids (Rhoads and Germano, 1986)

V: Visual measurement or estimate
CA: Computer analysis

3.3 Results

3.3.1 Apparent Color RPD Depth

Overall there was a high degree of correspondence between the depth of the apparent color RPD layer, one of the benthic trigger parameters (MWRA , 1997), from the Quick Look and full detailed image analyses. The correlation for RPD between the two analyses was 0.97 (n = 23, p = <0.001) with no significant difference between the mean RPD from two analyses (paired t-test, df = 22, p = 0.200). The detailed analysis mean was 2.5 cm (SD = 0.69) and the Quick Look analysis mean was 2.4 cm (SD = 0.72).

The apparent color RPD layer depth averaged for the three replicate images at a station ranged from >1.2 cm (FF13) to 4.1 cm (NF14) with a grand mean of 2.5 cm (SD = 0.69 cm) for all 23 stations in 2002, which was above the long-term mean of 2.3 cm (Figure 3-1). At the eight porous coarse-sediment stations (FF12, FF13, NF04, NF13, NF14, NF15, NF17, and NF23), the apparent color RPD layer depths were deeper than the prism penetration for all replicates. For these stations, prism penetration was then assumed to be a conservative minimum estimate of the RPD layer depth and was included in the calculation of the average RPD layer depth for 2002. At two other stations (FF10 and NF02), one of the three replicate images had RPD layers that were deeper than the prism penetration.

Because of the disparity in sample size, a t-test or ANOVA is not the most appropriate test for comparing the mean RPD for 2002 (n = 23) with the six baseline years from 1992 to 2000 (n = 123). A bootstrap randomization (Efron and Tibshirani, 1993) was applied. Six sampling distributions, one for each year, were generated from all 123 RPD-layer-depth values from the baseline years by randomly drawing 10,000 samples of size 23 (because there are 23 nearfield stations) to form each distribution. The mean RPD of 2.5 cm for 2002 was then compared to the pooled mean of the six sampling distributions. The difference between 2002 and the other years was the statistic used to assess if the mean RPD for 2002 significantly differed from the long-term mean condition. The range for the pooled means of the 10,000 random draws for each year was 2.04 to 2.62 cm. The difference statistics (baseline mean – 2002 mean) ranged from –0.43 to +0.14 cm with 95% of the values falling between –0.29 to –0.01 cm. The actual change in RPD layer depth between the baseline years and 2002 was –0.15 cm, well within the estimated 95% confidence interval. Thus there was no change in RPD layer depth at the 23 nearfield stations in 2002 relative to the baseline period. Given unequal variance and >4:1 ratio in sample size, a t-test between baseline and 2002 RPD layer depth was performed for comparison purposes,; this test did not detect a significant difference (p = 0.371).

At many stations, biogenic activity in the form of burrow structures increased the depth to which oxic sediments occurred. Sediments that appeared to be oxic, light-brown to reddish in color, extended >10 cm below the sediment-water interface at Stations NF08, NF16, and NF21. The deepest RPD layers were associated with mixed fine-sand-silt-clay sediments that had higher levels of biogenic activity (for example, compare NF10 to NF16, Figure 3-2).

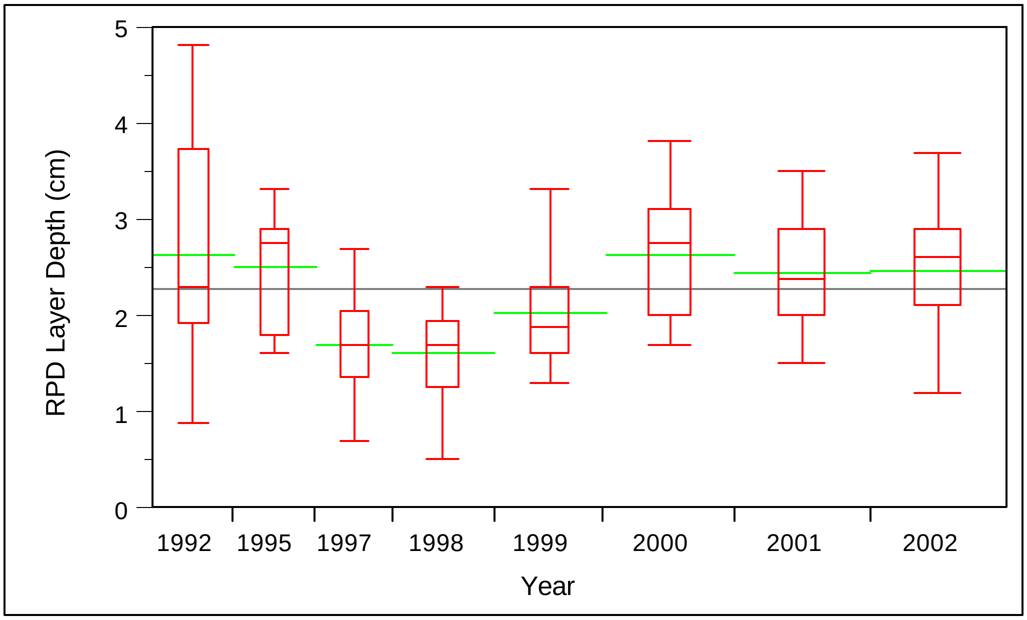

Figure 3-1. Apparent color RPD layer depth (cm) summarized by year for all data from nearfield stations. Box is interquartile range, short bar is median, wide bar is mean, and whiskers are data range. Horizontal line is grand mean for all years.

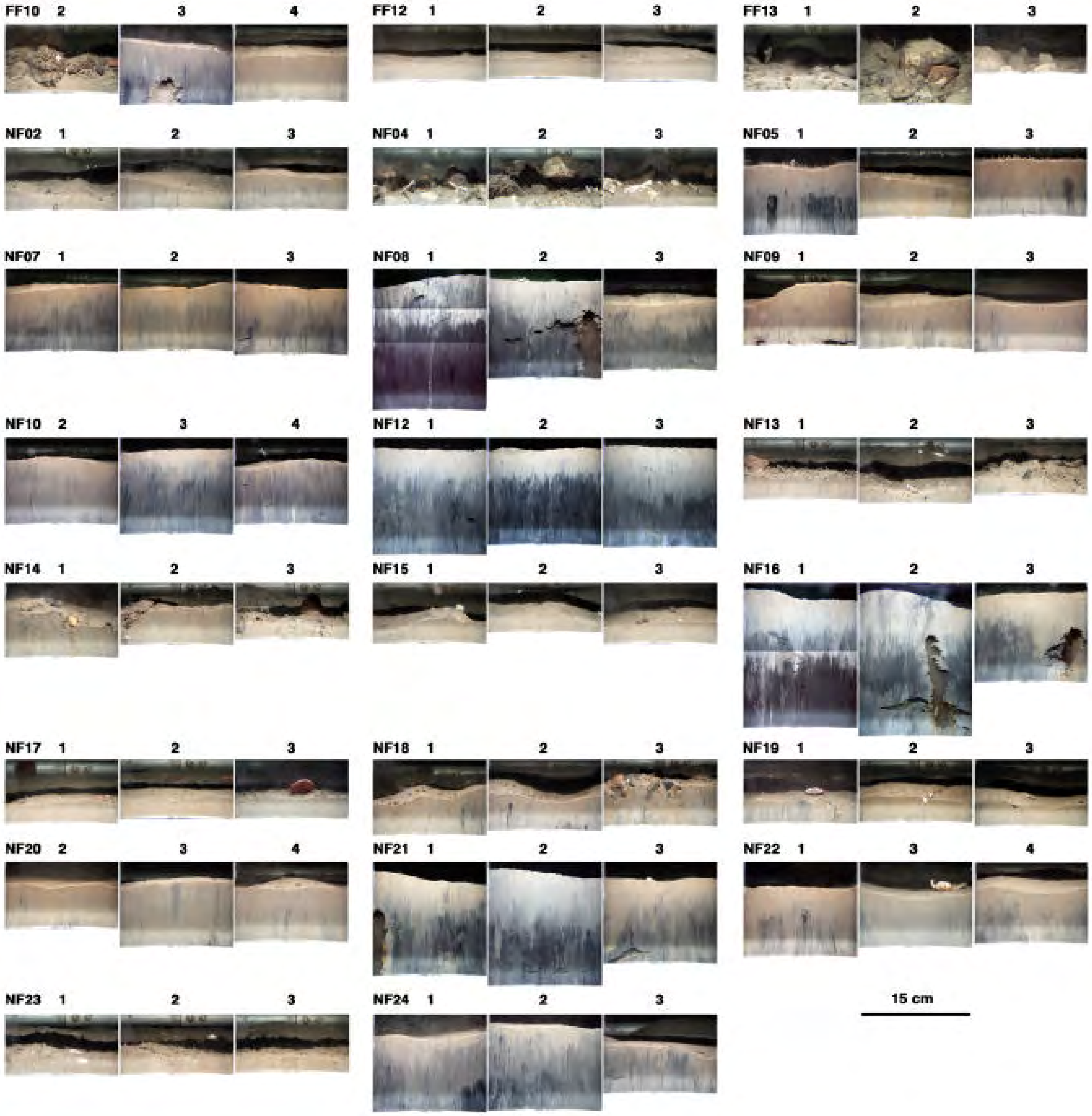

Figure 3-2. Replicate SPI images from 2002 nearfield stations. Light band at the bottom of the images is an artifact.

3.3.2 Sediments

Sediment grain size ranged from cobble (CB) and pebble (PB) to fine-sand-silt-clay (FSSICL), with eight stations having a mixture of coarse (fine-sand and larger grain size) and fine (silt and clay) sediments, and 15 stations being primarily fine sediments. Sandy sediments that ranged from very-fine-sand (VFS) to fine-medium-sand (FSMS) occurred at eight stations. The modal grain size descriptor was fine-sand-silt-clay and occurred at 10 stations (Table 3-2). Prism penetration and grain size were related, with lowest penetration occurring at sand to pebble stations and the highest at mixed muddy stations. The lowest average penetration was 0.6 cm at Station NF04, with fine-sand to pebble sediments, and the highest was 17.1 cm at Station NF16, with fine-sand-silt-clay sediments (Table 3-2).

Sediment surfaces appeared to be structured by a combination of biological and physical processes, with 15 of the 23 stations(*e.g.*, NF09) having biogenic structures in combination with physical features such as bedforms. At seven stations, physical processes dominated. Surface relief or bed roughness was less at stations that appeared to have sediment surfaces shaped by both biological and physical processes relative to stations dominated by physical processes (t-test, df = 20, p = 0.022). Mean roughness at physically dominated stations was 1.5 cm (SE = 0.13) and 1.1 cm (SE = 0.09) at stations dominated by both. Only Station NF05 appeared to be biologically dominated, with a surface relief of 1.2 cm (Table 3-2). Biological bed roughness typically consisted of irregular surfaces such as feeding mounds (NF16) or tubes (NF21) caused by the biogenic activity of benthic organisms. Physical bed roughness was related to bedforms or large sediment grains such as pebbles or cobbles (FF10). Most of the sediment grains larger than gravel were not covered with thin layers of fine sediment, but did have tubes covering much of their surfaces, for example FF13 (Figure 3-2).

3.3.3 Biogenic Activity

Biogenic structures associated with activities of successional stage II and III fauna dominated biological processes and included *Ampelisca* spp. tubes (NF05), biogenic whips or sticks of *Dyopedos* spp. (NF10), large worm tubes (NF05), biogenic mounds (NF12), and shells (NF04). Subsurface biogenic structures and actives associated with infaunal organisms included active oxic burrows (NF10) and water-filled oxic voids (NF21). Free-burrowing infaunal worms occurred at 18 stations. At Station NF24 the average number of worms was 8.0 per image, with a maximum of 13 worms at NF24-2. All stations, except NF08, had high densities of small polychaete tubes, >1 tube per cm^2; based on tubes that were within 1 cm of the 15-cm wide prism faceplate this would scale to >10,000 tubes per m^2. The majority of the tubes were small, <1 mm in diameter, and straight but at eight stations a medium size, 1 to 2 mm in diameter, twisted tube projecting 1 to 2 cm above the sediment surface occurred. These tubes possibly belonged to the polychaete *Ampharete* spp. (Maciolek, personal communication).

Table 3-2. Summary of SPI parameters for nearfield stations, August 2002. Data from all replicates were averaged for quantitative parameters and summed for qualitative parameters (*e.g.*, the presence of tubes in one replicate resulted in a + for the station).

Station	PEN[1] (cm)	SR[2] (cm)	RPD[3] (cm)	GRAIN SIZE		PROCESS	AMPHIPOD		WORM TUBE	BED FORMS	WORM	BUR[4]	Oxic	Anaerobic	SS[5]	OSI[6]
				Modal	Max		Tube	Stick								
FF10	5.5	1.5	2.7	FSSICLGR	PB	BIO/PHY	FEW	-	MANY	-	3.0	0.7	0.3	0.0	I-III	6.0
FF12	2.9	0.7	>2.9	VFS	VFS	BIO/PHY	FEW	+	MANY	-	1.3	0.0	0.0	0.0	I-II	6.3
FF13	1.0	1.6	>1.2	FSGRPB	CB	PHY	NONE	-	SOME	-	0.0	0.0	0.0	0.0	I	3.0
NF02	3.5	1.5	2.0	FSSI	FS	PHY	NONE	-	SOME	+?	0.7	1.7	0.3	0.0	I-II	5.3
NF04	0.6	0.8	>1.2	FSPB	PB	PHY	NONE	-	MANY	-	0.0	0.0	0.0	0.0	I	3.0
NF05	7.6	1.2	3.7	FSSICL	FS	BIO	SOME	+	SOME	-	2.7	3.3	0.3	0.0	II-III	9.0
NF07	9.3	1.1	2.9	FSSICL	FS	BIO/PHY	NONE	-	MANY	-	4.0	4.3	0.7	0.0	II	7.3
NF08	14.1	1.2	2.0	FSSICL	FS	BIO/PHY	FEW	-	FEW	-	1.7	2.0	2.3	0.0	II-III	7.0
NF09	6.9	1.7	2.8	FSSI	FS	BIO/PHY	NONE	-	MANY	+?	6.0	1.7	1.3	0.0	II-III	8.3
NF10	9.8	1.1	2.1	FSSICL	FS	BIO/PHY	NONE	+	MANY	-	5.0	4.3	1.0	0.0	II-III	7.3
NF12	14.3	0.5	2.6	FSSI	FS	BIO/PHY	NONE	-	SOME	-	5.7	4.0	2.0	0.0	II-III	8.3
NF13	2.1	1.4	>2.1	FSMSGR	PB	PHY	NONE	-	MANY	+?	0.0	0.0	0.0	0.0	I-II	5.7
NF14	4.1	1.8	>4.1	FSSIGR	PB	PHY	NONE	-	SOME	-	2.0	0.3	0.0	0.0	I	5.7
NF15	2.3	1.8	>2.3	VFS	GR	PHY	FEW	-	MANY	+?	1.7	0.0	0.0	0.0	I-II	5.7
NF16	17.1	1.6	2.7	FSSICL	FS	BIO/PHY	NONE	-	SOME	-	2.3	2.7	1.3	0.0	II-III	8.3
NF17	2.9	0.7	>2.9	FSMS	MS	BIO/PHY	NONE	-	SOME	-	0.0	0.0	0.0	0.0	I-II	6.0
NF18	5.4	1.7	2.1	FSSICL	FS	PHY	NONE	-	SOME	-	2.0	1.0	0.0	0.0	I-II	5.3
NF19	3.1	1.2	2.2	VFS	VFS	BIO/PHY	NONE	-	MANY	-	2.7	1.7	0.0	0.0	I	4.3
NF20	7.5	0.9	2.9	FSSI	FS	BIO/PHY	NONE	-	SOME	-	5.3	2.7	1.0	0.0	I-II	6.3
NF21	14.0	1.4	2.9	FSSICL	FS	BIO/PHY	NONE	-	SOME	-	6.0	3.0	2.7	0.0	III	9.3
NF22	8.3	1.0	2.8	FSSICL	FS	BIO/PHY	NONE	-	SOME	+?	5.0	2.7	1.0	0.0	II-III	8.0
NF23	2.3	1.1	>2.3	FSMS	GR	BIO/PHY	NONE	-	MANY	-	0.0	0.0	0.0	0.0	I-II	5.3
NF24	9.5	1.2	1.5	FSSICL	FS	BIO/PHY	NONE	-	SOME	-	8.0	4.0	0.3	0.7	I-II	4.3

[1] Penetration depth; [2] SR = Surface roughness; [3] ">" indicates the RPD was deeper than the prism penetration depth; [4] BUR= burrows; [5] Successional Stage; [6] Organism-Sediment Index

3.3.4 Successional Stage and Organism Sediment Index

The distribution of estimated successional stage of the infaunal communities was bimodal with a peak between pioneering (Stage I) and intermediate (Stage II) and another peak between intermediate and equilibrium (Stage III) (Figure 3-3). Most of the stations (17 of 23) appeared to be a mixture of successional stages (Table 3-2). Stage I appeared to dominate four of the stations while Stage II and Stage III communities dominated at one station each. The high degree of biogenic sediment reworking observed in many images was consistent with Stage II and III successional designation. Stations that included the lower successional stage designation (Stage I) had little indication of biogenic activity other than small worm tubes on the sediment surface and tended to have coarser grained sediments (Table 3-2).

In 2002 the mean Organism Sediment Index (OSI) was 6.3 (SE = 0.32), which was statistically the same as the 2001 mean of 6.6 (SE = 0.32) and the long-term mean of 6.4 (Figure 3-4). Rhoads and Germano (1986) developed the OSI for assessing stress in estuarine and coastal embayments and found that for the northeast region OSI values <6 were associated with benthic communities under some form of stress, either from organic loading or physical processes, while higher values were associated with well-developed communities. Ten stations had OSI values <6; these stations all appeared stressed by physical processes with no signs of stress from organic loading. Six of these stations had coarse heterogeneous or sandy sediments and RPD layers deeper than the prism penetration, which leads to possible underestimation of the OSI. NF19 was the only sand station with an unqualified OSI that was <6. The three stations with low OSI and fine sediments were NF02, NF18, and NF24 (Table 3-2).

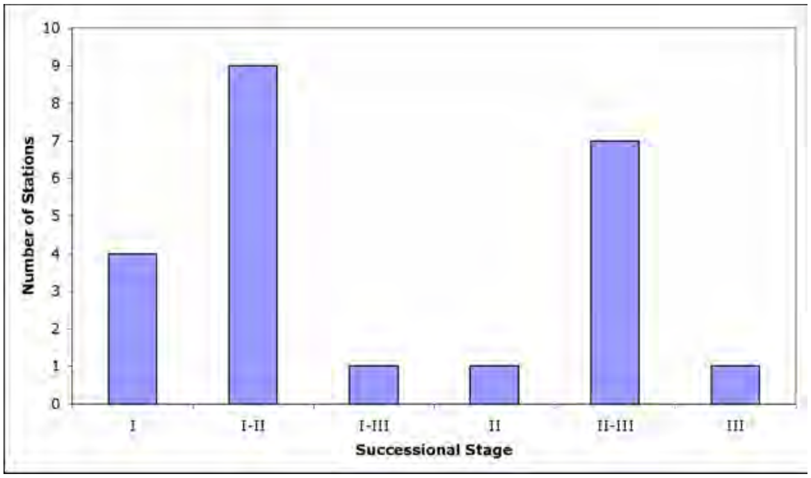

Figure 3-3. Estimated successional stage from nearfield SPI images for 2002.

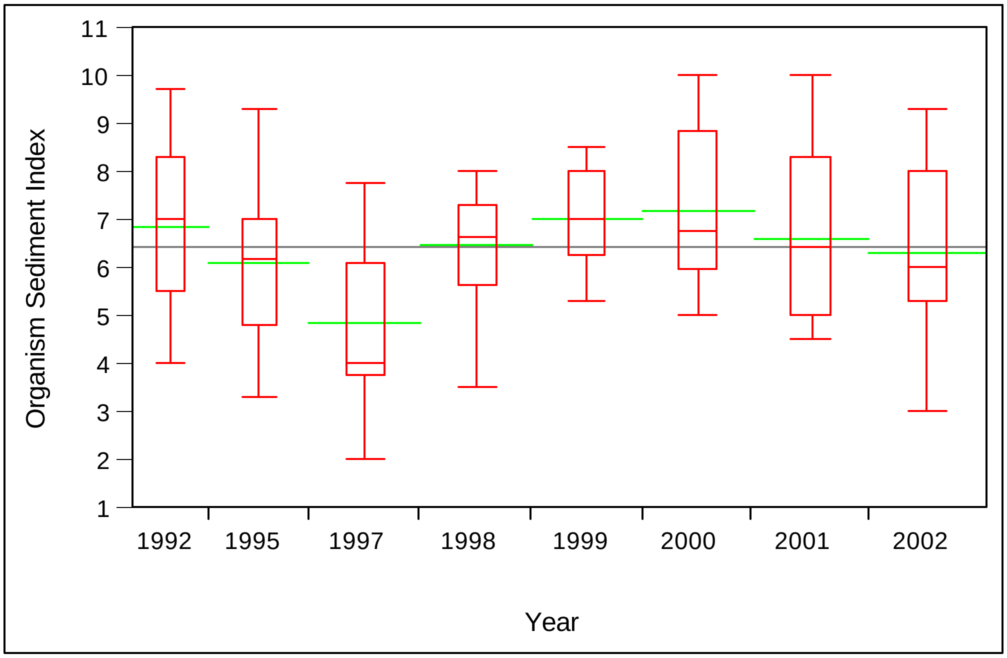

Figure 3-4. Organism Sediment Index (OSI) summarized by year for all data from nearfield stations. Box is interquartile range, short bar is median, wide bar in mean, and whiskers are data range. Horizontal line is grand mean for all years.

3.4 Discussion

There did not appear to any regional trends between RPD layer depth and the outfall, which started operation in September 2000. For assessing outfall effects, the MWRA (1997) set a 50% reduction in the apparent color RPD layer depth over the study area as a critical trigger level. Similarly, a 50% increase in apparent color RPD over the baseline would be noteworthy, although not a threshold exceedance. The average apparent color RPD for 2002 of 2.5 cm was not different from the long-term baseline RPD of 2.3 cm for all stations from the seven collections between 1992 and 2001, based on a randomization test. A 50% change in RPD layer depth would require the mean RPD for a year to be <1.1 or >3.4 cm. The average RPD for 2002 was well within the range of annual RPDs, with 1998 being the shallowest year at 1.6 cm and 1992 the deepest year at 2.7 cm. Overall, the grand mean RPD layer depth from 2002 was above the long-term average as it has been for the last three years (Figure 3-1).

Based on the color and texture of sediments in the SPI images, it did not appear that the amount of sedimented organic matter had changed in 2002 relative to the operation of the outfall or the long-term database for the nearfield (Figure 3-5a,b). Mean annual TOC for the same years that the SPI images were collected were also not different and ranged from 0.6% to 1.2% (see Chapter 4).

Figure 3-5a. Representative SPI images from nearfield stations FF10–FF13 and NF02-NF13 taken 1992–2002.

Figure 3-5b. Representative SPI images from nearfield stations NF14–NF24 taken 1992–2002.

The depth of the apparent color RPD layer at the nearfield stations reflected the combination of biological and physical processes that appeared to be structuring surface sediments. In sandy porous sediments, for example NF17, deep RPD layers were primarily a function of pore water circulation that would pump oxygenated water into the sediments. In finer sediments, those with a significant silt and clay component, physical diffusion would limit oxygen penetration to <1 cm (Jørgensen and Revsbech, 1985). When the RPD layers in fine sediments are >1 cm (as, for example, at NF05), it is bioturbation by infauna (Rhoads 1974) or major resuspension/deposition events (Don Rhoads, personal communication) that are responsible for oxygenating sediments. At all 15 fine-sediment stations, those with fine-sand-silt-clay and fine-sandy-silt, RPD layer depth was >1.5 cm and SPI images confirmed the importance of bioturbation in deepening RPD layers at these stations.

The sediments at many stations in 2002 continued to be heterogeneous, with a mixture of grain sizes ranging from sandy-silts-clays to cobbles. This sediment heterogeneity was consistent over the years SPI images were collected at the nearfield (Table 3-3 and Figure 3-5). The predominance of coarse-grained sediments reflected the importance of physical processes in structuring benthic habitats, but even at stations completely dominated by physical processes, small- to medium-size tubes occurred on the surface of pebbles and cobbles. Tubes were the most numerous surface biogenic structures and occurred at all stations in 2002. Estimated density of tubes from the SPI images was approximately 2,000 to >10,000 per m^2; however, these estimates were not correlated to total infaunal abundance, likely due to the categorical nature of tube density in the SPI analysis. Subsurface biogenic structures and organisms were also common and widely distributed but also poorly correlated with infaunal abundance. The highest correlation was between burrow numbers and infaunal abundance ($r = 0.41$, $p = 0.054$). Even though the relationships between the SPI and infaunal data were not strong, the predominance of biological activity observed in the SPI images at most stations was indicative of a well-developed fauna that was characterized as being intermediate to equilibrium in successional stage (Stage II to III). The number of infaunal species and diversity also indicated advanced successional stages were present at the nearfield stations (see Chapter 5).

While the general appearance of the sediments and benthic habitat conditions at the nearfield stations in 2002 was similar to that of the last several years (Figure 3-5), the overall dominance of surface sediments by biogenic structures and organism activity in 2002 appeared to be less relative to 2001. For example, in 2001 four stations had tube mat densities >50,000 m^{-2}, but in 2002 tube mats were not observed. Also, the medium-size twisted tube that was widespread at nearfield stations in 2001 occurred in lower densities in 2002. However, the number of stations with *Ampelisca* spp. tubes increased from two to five from 2001 to 2002. *Ampelisca* spp. tubes were first observed in the nearfield SPI images in 1999. While biogenic activity at the sediment surface appeared to be reduced relative to 2001, the level of subsurface biogenic activity in 2002 appeared similar to 2001.

Another indication that biogenic activity may have declined in 2002 was that the grand mean OSI, while not significantly lower than 2001, was below the long-term mean of 6.4 (Figure 3-4). The OSI provides an estimate of benthic habitat quality and is a process-oriented index in that the SPI images recorded the end products of biological and physical processes that structured the physical habitat and benthos. The declining trend in the mean OSI, from a high in 2000 of 7.2 to 6.3 in 2002, may represent a shifting balance between biological and physical processes at the nearfield stations, with 2000 being the peak year for biological processes of the eight years SPI data were collected at the nearfield stations.

Overall, it appeared that biological processes were still predominant in structuring surface sediments, but signs of physical processes, such as bedforms, were also present in 2002 although reduced relative to other years. Bedforms, typically associated with higher energy bottoms, were observed at five stations in 2002, eight in 2001, and six in 2000. In the absence of storm-induced bottom currents, benthic organisms tend to eradicate physical structures such as bedforms during quiescent periods such as those experienced in 1998 and 1999 when biogenic activity at the sediment surface increased and bedforms occurred at four and two stations, respectively.

Table 3.3. Sediment grain size estimated from sediment profile images for nearfield stations from 1992 to 2002.

Station	1992	1995	1997	1998	1999	2000	2001	2002
NF02	VFS	CS	SIFS	PB to GR	CB to FSSI	CB to MSCS	FSSI	FSSI
NF04	FS	FS	VFS	FS	GR to FS	FS	PB to FSMS	PB to FS
NF05	FS	VFS	VFS	VFS	FS/SICL*	FS/SICL*	FSSICL	FSSICL
NF07	VFS	VFS	VFS	VFS	SIFS	SIFS/CL*	FSSICL	FSSICL
NF08	VFS	SIFS	VFS	VFS	SIFS	SIFS	SIFS	FSSICL
NF09	VFS	VFS	VFS	VFS	FSSI	FSSI	FSSICL	FSSI
NF10	VFS	VFS	VFS	VFS	FSSICL	FSSICL	FSSICL	FSSICL
NF12	VFS	SI	SIFS	SIFS	FSSICL	FSSICL	FSSICL	FSSI
NF13	FS	FS to VFS	FS	PB to SIFS	FSMS	PB to FSMS	GR to FSMS	PB to FSMS
NF14	FS	VFS	VFS	PB to VFS	PB to SIFS	PB to FSSICL	PB to FSSI	PB to FSSI
NF15	FS	VFS	VFS	GR to FS	PB to FSSI	PB to FSSI	PB to FSSI	GR to VFS
NF16	VFS	SIFS	VFS	SIFS	FSSICL	PB to FSSI	CB to FSSICL	FSSICL
NF17	FS	FS	FS	FS	GR to FSMS	PB to FSMS	FSMS	FSMS
NF18	VFS	VFS	VFS	GR to VFS	PB to SIFS	FSSICL	PB to FSSICL	PB to FSSICL
NF19	.	CS to VFS	VFS	FSSICL	FSSICL	CB to FSSICL	GR to FSSI	VFS
NF20	VFS	CS to VFS	GR to FSMS	GR to SICL	PB to SIFS	PB to SIFS	PB to FSSI	FSSI
NF21	.	SIFS	VFS	SIFS	SIFS	SIFS	SIFS	FSSICL
NF22	.	SIFS	SIFS	SIFS	SIFS	SIFS	FSSICL	FSSICL
NF23	.	CS to VFS	FS	FS	PB to FSSICL	GR to FSMS	PB to FSMS	GR to FSMS
NF24	.	SI	SIFS	FSSICL	PB to FSSICL	FSSICL	FSSICL	FSSICL
FF10	VFS	.	VFS	VFS	CB to SIFS	PB to GR	CB to FS	PB to FSSICL
FF12	.	.	VFS	FS	FS	VFS	VFS	VFS
FF13	.	.	SIFS	SIFS	CB to FSSI	CB to SI	FSSI	CB to FSGR

*Layered

Key: CB=cobble
GR= gravel
PB=pebble
CS= coarser sand
MS =medium sand
FS= fine sand
VFS =very fine sand
SI= silt
CL=clay

4. CHEMISTRY

by Deirdre T. Dahlen, Stephen Emsbo-Mattingly and Carlton D. Hunt

4.1 Status of the Bay

Baseline data collected in Massachusetts Bay from 1992 to 2000 showed multiple regions defined by physical and chemical composition. The heterogeneous sediments at MWRA nearfield stations (Figure 2-1) were in close proximity to, and roughly equidistant from, the primary historic source of contaminants, Boston Harbor. Factors that influence contaminant variability in the nearfield include local (Boston Harbor) and distributed sources (*e.g.*, atmospheric input, distant rivers), primarily related to grain-size factors suggestive of different sediment depositional environments. The primary factor associated with the variance in the data is sand content. The secondary factors are associated with anthropogenic [1] analytes (selected pesticides and metals) and fine particles (selected metals).

In contrast, the sediments collected from regional stations (Figure 4-1), which are spatially distributed within the Massachusetts and Cape Cod Bay systems, are compositionally distinct from the nearfield data. The variability among contaminants at regional stations decreased when stations located closer to the harbor were excluded from the correlation analysis, indicating that the factors that influence contaminant variability at offshore regional locations include distributed sources (*e.g.,* atmospheric input, distant rivers). The PCA results support this, and showed that the composition of sediments at offshore regional sampling locations was governed by the analytes associated with fines and may reflect regional sediment inputs distinct from Boston Harbor. As evident in the nearfield data, sand content strongly influenced the variance in the regional data. In addition, the sewage tracer data showed that the proximity to the harbor (the historic source of sewage contaminants) influenced the concentration of *Clostridium perfringens* and total linear alkylbenzenes (LAB) at some regional stations.

Results from the correlation analysis also support a system with two regions, nearfield and regional, and shows the influence that a local source (Boston Harbor) has on the underlying regional contaminant signature.

Concentrations of contaminants on average have remained relatively constant over time and were well below MWRA (2001) thresholds. Concentrations of the sewage tracers, *C. perfringens* and total LAB, have decreased in recent years for stations in Massachusetts Bay located closer to the Harbor. This suggests that the documented reductions in effluent solids loading during the 1990s (Werme and Hunt, 2001) also reflect a reduction in *Clostridium* spore loads.

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[1] Anthropogenic analytes are generated or enriched in the environment by human activity. They are functionally defined in this analysis as TPAH, TPCB, TDDT, TCHLOR, TLAB, and CPERF. In addition, they include metals like Al, Cd, Cr, Cu, Fe, Pb, Hg, Ni, Ag and Zn. All of these can be enriched by anthropogenic activities. However, Al and Fe are crustal metals that do not typically spike unless there is a nearby metallurgical industry (*e.g*., steel mill or aluminum smelter). Under normal circumstances, Al and Fe can be used as reference values for comparing the metal composition of samples collected at different locations.

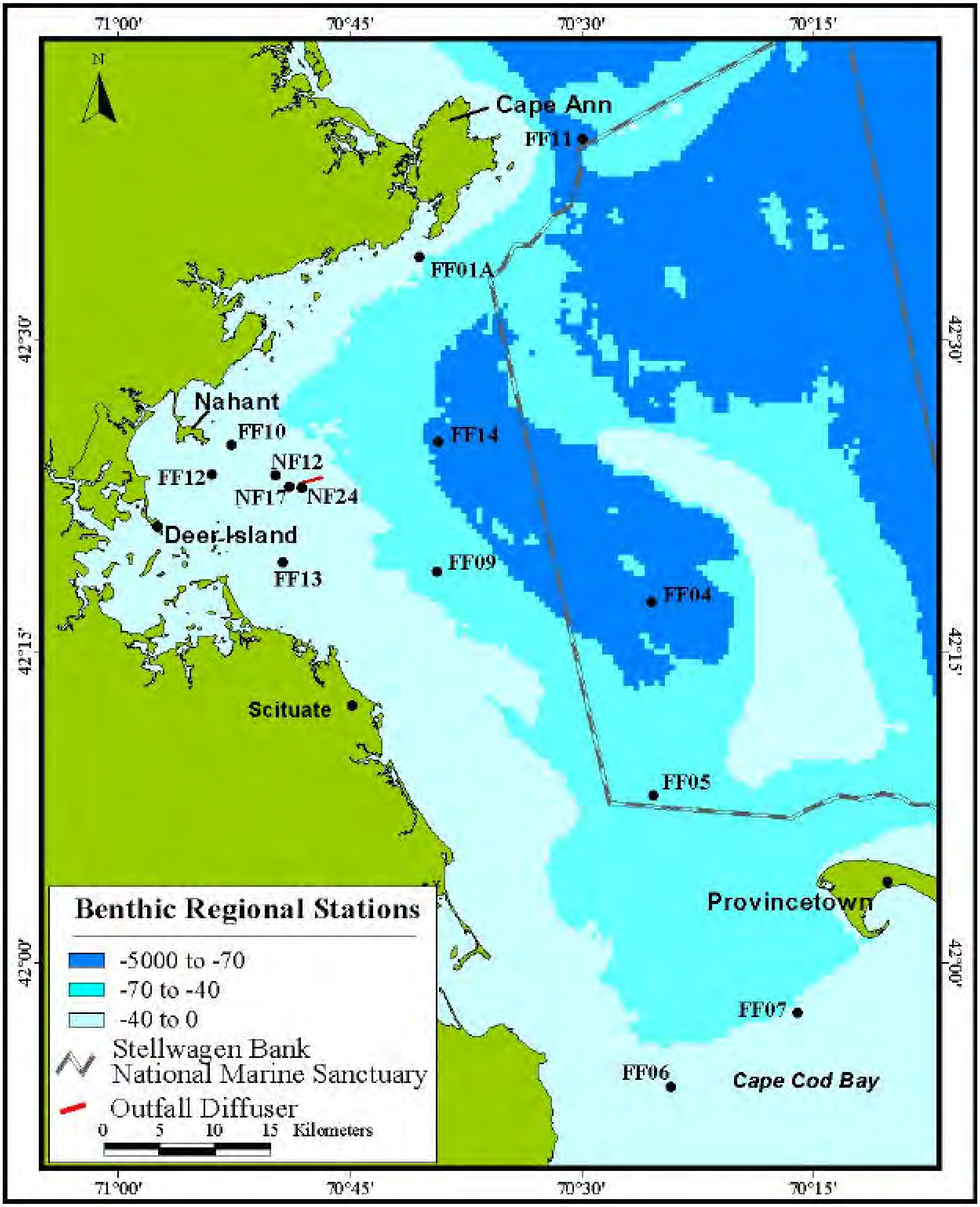

Figure 4-1. Stations included in regional analyses.

4.2 Methods

4.2.1 Grain Size, Total Organic Carbon, and *Clostridium perfringens*

Laboratory procedures followed those outlined in the Benthic Monitoring CW/QAPP (Williams *et al.*, 2002). Summaries of the procedures are provided below.

Grain Size—Samples were analyzed for grain size by the sequence of wet and dry sieving methodologies following Folk (1974). Data were presented in weight percent by size class. In addition, the gravel:sand:silt:clay ratio and a numerical approximation of mean size and sorting (standard deviation) were calculated. Grain size determinations were made by GeoPlan Associates.

Total Organic Carbon (TOC)—Samples were analyzed for TOC using a coulometric carbon analyzer following SOP AMS-2201 (formerly AMS-TOC94). Data were presented on a percent dry weight basis. TOC determinations were performed by Applied Marine Sciences, Inc.

***Clostridium perfringens*—**Sediment extraction methods for determination of *C. perfringens* spores followed those developed by Emerson and Cabelli (1982), as modified by Saad (1992). Data are reported here as colony-forming units (cfu) per gram dry weight of sediment. This analysis was performed by MTH Environmental Associates.

4.2.2 Contaminants

Analyses of sediments for organic constituents and metals were performed following methods outlined in Table 4-1. Samples were analyzed for the parameters listed in Table 4-2, including linear alkyl benzenes (LABs), polycyclic aromatic compounds (PAH), polychlorinated biphenyls (PCBs), chlorinated pesticides, and metals. Analytical methods followed general NS&T methodologies (Peven *et al.*, 1993a, Peven *et al.*, 1993b). More detailed information is provided in the CW/QAPP (Williams *et al.*, 2002).

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

Parameter	Unit of Measurement	Method[a]
Linear Alkylbenzenes	ng/g	GC/MS
Polycyclic Aromatic Compounds	ng/g	GC/MS
Polychlorinated Biphenyls/ Pesticides	ng/g	GC/ECD
Major Metals (Al, Fe)	% Dry Weight	EDXRF
Trace Metals (Cr, Ni, Pb, Zn, Cu)	µg/g	EDXRF
Trace Metals (Ag, Cd, and Hg)	µg/g	ICP-MS (Ag, Cd) CVAA (Hg) GFAA (as required)

[a] See CW/QAPP (Williams *et al.*, 2002) for complete details regarding analytical methods.

Table 4-2. Sediment chemistry analytical parameters.

Parameter	Parameter	Parameter
Polycyclic Aromatic Compounds	**Polychlorinated Biphenyls**	**Metals**
Naphthalene	Cl2(8)	Al Aluminum
C_1-Naphthalenes	Cl3(18)	Cd Cadmium
C_2-Naphthalenes	Cl3(28)	Cr Chromium
C_3-Naphthalenes	Cl4(44)	Cu Copper
Acenaphthylene	Cl4(52)	Fe Iron
Acenaphthene	Cl4(66)	Pb Lead
Biphenyl	Cl4(77)	Hg Mercury
Dibenzofuran	Cl5(101)	Ni Nickel
Fluorene	Cl5(105)	Ag Silver
C_1-Fluorenes	Cl5(118)	Zn Zinc
C_2-Fluorenes	Cl5(126)	
C_3-Fluorenes	Cl6(128)	**Physical Sediment Parameters/Sewage Tracers**
Dibenzothiophene	Cl6(138)	
C_1-Dibenzothiophenes	Cl6(153)	Grain Size
C_2-Dibenzothiophenes	Cl7(170)	Gravel
C_3-Dibenzothiophenes	Cl7(180)	Sand
Phenanthrene	Cl7(187)	Silt
Anthracene	Cl8(195)	Clay
C_1-Phenanthrenes/Anthracenes	Cl9(206)	phi<-1
C_2-Phenanthrenes/Anthracenes	Cl10(209)	!1<phi<0
C_3-Phenanthrenes/Anthracenes		0<phi<1
C_4-Phenanthrenes/Anthracenes	**Chlorinated Pesticides**	1<phi<2
Fluoranthene	Aldrin	2<phi<3
Pyrene	Dieldrin	3<phi<4
C_1-Fluoranthenes/Pyrenes	Endrin	4<phi<8 (silt)
Benz(a)anthracene	Hexachlorobenzene	phi>8 (clay)
Chrysene	Lindane	Total Organic Carbon
C_1-Chrysenes	Mirex	*Clostridium perfringens*
C_2-Chrysenes	2,4-DDD	Linear Alkyl Benzenes
C_3-Chrysenes	2,4-DDE	Phenyl decanes (C_{10})
C_4-Chrysenes	2,4-DDT	Phenyl undecanes (C_{11})
Benzo(b)fluoranthene	4,4-DDD	Phenyl dodecanes (C_{12})
Benzo(k)fluoranthene	4,4-DDE	Phenyl tridecanes (C_{13})
Benzo(e)pyrene	4,4-DDT	Phenyl tetradecanes (C_{14})
Benzo(a)pyrene	DDMU	
Perylene	Cis-chlordane	
Indeno(1,2,3-c,d)pyrene	Heptachlor	
Dibenzo(a,h)anthracene	Heptachlorepoxide	
Benzo(g,h,i)perylene	Trans nonachlor	
Benzothiazole		

4.2.3 Statistical Analysis, Data Terms, and Data Treatments

Statistical Analysis—Numerical analysis techniques used to evaluate sediment chemical data included correlation and principal component analyses.

Correlation analysis was performed on sediment grain size, TOC, *C. perfringens*, and contaminant data to examine the correspondence between these parameters. Probability values were taken from Rohlf and Sokal (1969).

Principal components analysis (PCA) was employed to evaluate sediment grain size, TOC, *C. perfringens* and contaminant data for individual sample replicates from August surveys only. A log transformation of all analytes was performed to minimize bias associated with the large range of parameter values. Such analyses are an effective means of comparing multiple analyte results from many samples (Gabriel, 1971; Boon *et al.*, 1984; Wold *et al.*, 1987; Oygard *et al.*, 1988; Stout, 1991; de Boer *et al.*, 1993; Kannan *et al.*, 1998). In addition, the transformed data were z-score normalized to improve inter-analyte comparability. PCA has the additional advantage of being able to convey the complex chemical differences or similarities among many samples in a visual manner that is more easily understood.

PCA was performed by using Pirouette (Version 3.02; Infometrix, Inc., Seattle, WA).

Data Terms—In the discussion of nearfield results, the term *nearfield* refers to all nearfield stations plus farfield stations FF10, FF12, and FF13. These farfield stations were included in the nearfield analyses because of their geographic association with the Massachusetts Bay outfall and Boston Harbor and the potential for transport of carbon from the outfall (see the Bays Eutrophication Model in Hydroqual, 2000). Similarly, the term *regional* refers to all farfield stations, plus traditionally replicated nearfield stations NF12, NF17, and NF24.

Data Treatments— In the discussion of bulk sediment and contaminant data, numerous terms are used to describe the data. See Appendix C1 for a complete listing of terms referenced in this report. Appendix C1 also summarizes data analyses (*e.g.*, PCA, correlations) and evaluations (*e.g.*, histogram plots) performed on the data to assess temporal and spatial trends over time.

4.3 Results and Discussion

Bulk sediment, *C. perfringens*, and contaminant results for all nearfield and regional samples (August surveys only) were evaluated separately to examine spatial and temporal characteristics. All sediment results are discussed in terms of dry weight using baseline range, baseline station mean, station, and nearfield baseline mean values.

PCA was used to visualize the intersample and intervariable relationships among the sediment chemical data. PCA yields a distribution of samples (*e.g.*, sediment samples) in *n*-dimensional space, where *n* is the number of variables (*e.g.*, PAH). The Euclidean distances between sample points on these factor score plots are representative of the variance captured in each principal component (PC). In simple terms, samples that cluster together are chemically similar and outliers are chemically distinct. A factor loading is calculated for each variable (*e.g.*, PAH) contributing to each PC. A crossplot of the factor loadings for the first two PCs reveals the individual variables associated with the primary variance in each PC.

4.3.1 Nearfield Chemistry 1992–2002

As described in Section 4.1, baseline data for the nearfield showed a system that is highly variable with heterogeneous sediments in relatively close proximity to the historic leading source of contaminants (*i.e.,* Boston Harbor). Sample data for August 2001 and 2002, the first two sediment sampling periods after the offshore outfall came on-line, show that post-diversion data are not substantially different from the baseline period for any given station.

To demonstrate this, the baseline range (*i.e.,* minimum and maximum concentration over the baseline period) and mean (*i.e.,* average concentration, by parameter and station, over the baseline period) values were determined, by station, for bulk sediment properties, *C. perfringens*, and contaminant parameters as described in Section 4.2.3 and Appendix C1. Post-diversion (August 2001 and 2002) data were then compared to the baseline range and mean values for each nearfield station to evaluate how the post-diversion data fit in with our understanding of the baseline system. Nearfield stations were sorted by order of increasing TOC content using baseline mean data. While localized increases in selected parameters were observed at one or more stations, results from the range plots shows that most of the 2001 and 2002 data fall within the general distribution of samples collected during the baseline period (1992–2000), indicating that activation of the new outfall did not cause a systematic or widespread increase in contaminants of environmental concern to the Massachusetts Bay system (representative parameters shown in Figure 4-2; all data in Appendix C2). Notable examples of localized increases or decreases from baseline include:

- Post-diversion concentrations for total LAB, total DDT and Cd were generally below the baseline station mean value at each station.
- Post-diversion concentrations for total PAH, total PCB, Cr, Cu, Ag, and Zn were above the baseline range at one or two stations. Post-diversion concentrations for TOC, Pb, Hg and Ni were above the baseline range at three to five stations. Where post-diversion concentrations fell above baseline, increases were generally modest (less than five times above baseline) and were more often observed with metals as compared to organic contaminants. For example, post-diversion concentrations of Pb were above the baseline range in 2001 at more stations (NF17, NF23, NF15, NF20 and NF14) than were other metals. Concentrations of Pb remained above the baseline range in 2002 at NF14, NF15 and NF23 (Figure 4-2b).
- Some stations had several parameters with post-diversion concentrations that were above the baseline range, such as
    - NF10 in 2001 had total PAH, Cu, Pb, Hg, Ni, Ag, and Zn concentrations that consistently were above the baseline range, while TOC fell within the baseline range. Concentrations of these contaminants at NF10 were within the baseline range in 2002.
    - NF21 in 2001 also showed several contaminant concentrations that consistently were above the baseline range (*i.e.,* total DDT, Al, Cu, Fe, Hg, Ni, and Zn). Unlike NF10, concentrations at NF21 remained above the baseline range in 2002 for all but total DDT, Hg, and Ni.
    - NF13 in 2002 had total Chlordane, Al, Cr, Cu, Fe, Hg, Ni, and Zn concentrations that consistently were above the baseline range, while TOC fell within the baseline range.

Where localized increases were observed, the largest increases in post-diversion concentrations for selected parameters do not appear to be outfall related, rather the increases may be due to analytical interferences (total DDT at NF21 in 2001[2]), random spikes (total PAH at FF10 in 2002[3]), and/or unknown contamination (Pb at NF15 in 2002[4]).

The PCA results revealed four generalized trends among the data collected from the nearfield sediment samples (Figure 4-3 a, b, c). First, high percent sand was inversely correlated with organic and inorganic analyte concentrations. Notice how one or more samples collected from NF02, NF04, NF17, NF13, NF19, and NF23 plotted towards the left side of the scores plot for each of these stations. This location corresponded to the location of SAND on the loading plot (Figure 4-3a; top center). Presumably, this relationship reflected the dilution of organic and inorganic analytes with sand.

Second, anthropogenic analytes (*e.g.,* TPEST, TCHLOR, TDDT, and Cd) were measured at relatively high levels in the early years of the baseline study (*e.g.,* 1992 to 1994) at stations FF10, FF12, FF13, NF05, NF07, NF08, NF09, NF10, NF12, NF16, NF20, NF21, NF22, and NF24. Notice how one or more of these samples collected during the early monitoring years plotted towards the upper right side of the scores plot for each of these stations. The upper right quadrant corresponded to the location of TPEST, TCHLOR, TDDT, and Cd on the loading plot (Figure 4-3a; top center). These sample locations received higher pollutant loading during the baseline years. Other anthropogenic analytes (*e.g.,* TPCB, CPERF, and Cd) were influential, but did not further differentiate the samples due to a more uniform distribution in the nearfield sediments.

Third, for most of the baseline and post-diversion periods, small particles (fines = silt+clay), Ni, Zn, Fe, Hg, Al, Cu, and TPAH were elevated in one or more samples from FF13, NF08, NF09, NF12, NF13, NF16, NF21, NF22, and NF24. Notice how one or more of these samples plotted towards the lower right side of the scores plot for each of these stations. The lower right quadrant corresponded to the location of Fines, Silt, Clay, Ni, Zn, Fe, Hg, Al, Cu, and TPAH on the loading plot (Figure 4-3a; top center). This grouping was consistent with naturally occurring mineral matter (*e.g.,* Fines, Clay, Silt, Al and Fe). Other anthropogenic analytes (*e.g.,* TPAH and Hg) were influential, but did not further differentiate the samples due to a more uniform distribution in the nearfield sediments.

The samples that were largely undifferentiated into the first three groups constituted the fourth sample grouping. These samples plotted loosely in the central quadrant of the scores plot. Samples in the fourth group contained intermediate amounts of sand and fines during most of the baseline and post-diversion periods. This group included FF10, FF12, NF05, NF07, NF10, NF14, NF15, NF18, and NF20.

The PCA score plots demonstrate the relative variability among baseline and post-diversion sediment samples. For example, the anthropogenic and metal composition of NF08 and NF12 varied more widely

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[2] NF21 had an unusually high concentration of total DDT in 2001, yet stations closer to the outfall did not show DDT elevated over baseline concentrations (Kropp *et al.*, 2002b). Total DDT fell within the baseline range in 2002, suggesting that either the 2001 data was elevated due to an analytical interference or was an isolated occurrence.

[3] One of the three replicates at FF10 in 2002 had approximately 20 times higher PAH compared to the other replicates, yet all replicates had similar PAH signatures (pyrogenic) suggestive of a common source of contamination. Concentrations of PAH at FF10 in October 2002 were within the baseline range, suggesting that the anomalously high PAH in August 2002 was a rare PAH spike that has been observed on occasion in the nearfield.

[4] For Pb at NF15, the concentration was above background in 2001 and 2002. Even so, the increase in Pb at NF15 in 2002 was well above the 2001 value, and may be due, in part, to an unknown source of contamination, as suspiciously high Pb values were also evident at NF20 and NF13 in 2002, and were excluded from the data evaluation as a result. The anomalous Pb values at NF20 and NF13 in 2002 were higher than observed in most contaminated sediments in Boston Harbor. Further, triplicate sampling conducted at NF20 in October 2002 showed that Pb values were comparable to background (~20 ppm dry), and significantly below the value determined in August 2002 (7,690 ppm dry).

than NF18 and NF13. In general, the reduction in compositional variability was inversely proportional to the sand composition; *i.e.*, sediment samples with high sand content (NF13, NF04, and NF17) exhibited some of the smallest variability as demonstrated by the relative tightness of these clusters. More importantly, the post-diversion samples (colored red in Figure 4-3) typically fell within the overall variability of the baseline samples (colored blue in Figure 4-3). In addition, the post-diversion samples did not deviate strongly in the direction of the anthropogenic analytes. The consistent trend away from the anthropogenic analytes among numerous sampling stations over time (including 2001 and 2002) suggests the sediments are no longer receiving harmful organic and inorganic compounds associated with the historical discharges of untreated or inadequately treated sewage from Boston Harbor. However, many post-diversion samples from stations NF04, NF05, NF10, NF12, NF14, NF17, NF21, and NF23 trended slightly towards the "Fines" analyte group (bottom right) relative to the baseline samples. While this movement was very subtle and within the apparent variability of the measurement methods, samples collected from these locations should be evaluated for the reproducibility of these trends in the future. It may be necessary in the future to revise the PCA model to improve the resolution of analytes, like CPERF.

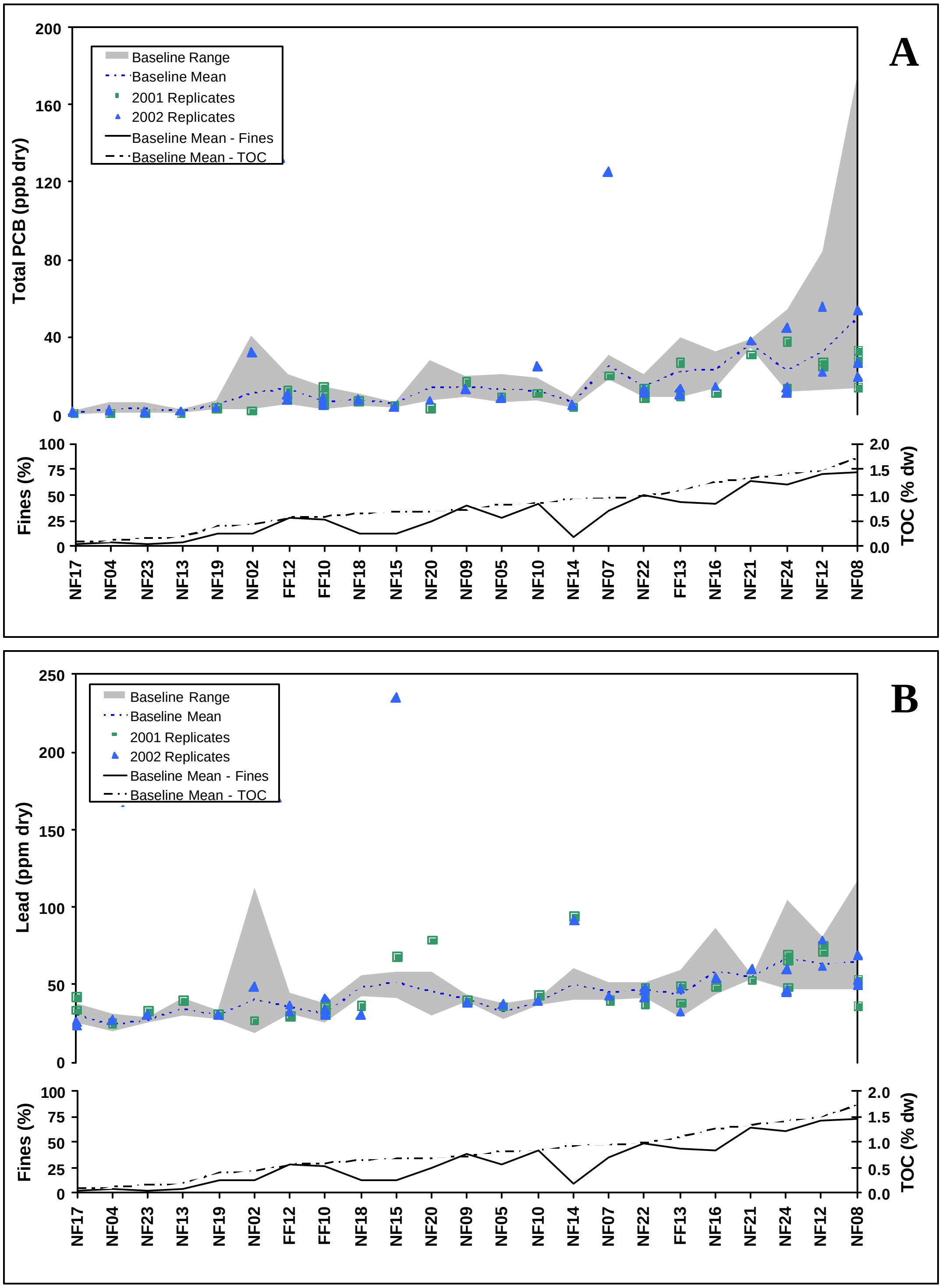

Figure 4-2. Total PCB (A) and lead (B) for each nearfield station sampled in 2001 (squares), 2002 (triangles) and the range of values occurring during the baseline period (gray band). The baseline mean values are indicated (dashed line within gray band). Stations are presented in order of increasing mean TOC concentration (dashed line in sub-plot). Baseline station mean values for TOC and percent fines, plotted by station, are shown in the sub-plot.

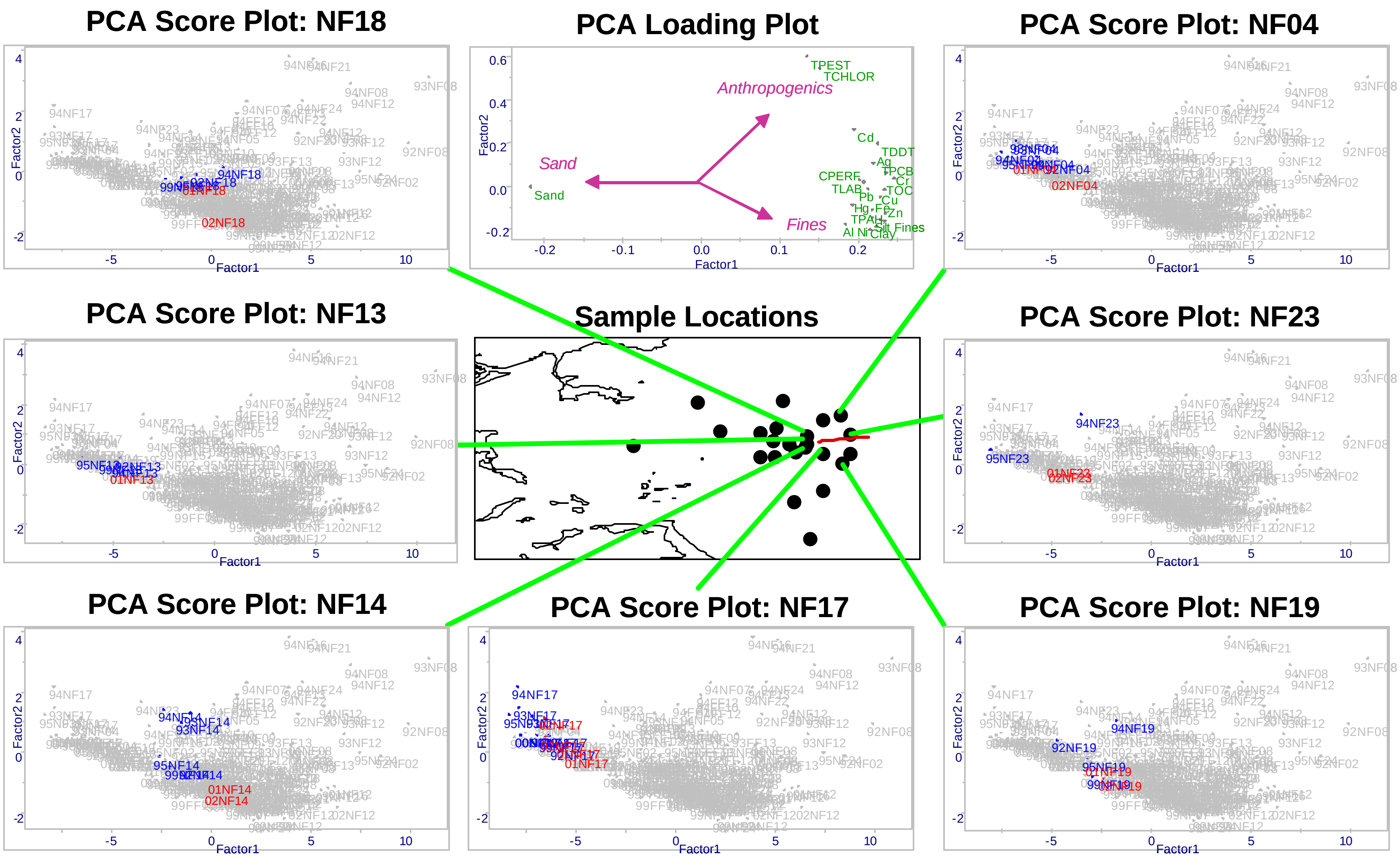

Figure 4-3a. Comparison of nearfield sediments from the baseline (1992–2000) and post-diversion (2001–2002) periods using PCA. Principal components 1 and 2 represented 69% and 6% of the variability, respectively. Score plots are replicated to demonstrate the relative spatial and temporal composition of all nearfield samples. Location-specific baseline and post-diversion data are colored blue and red, respectively.

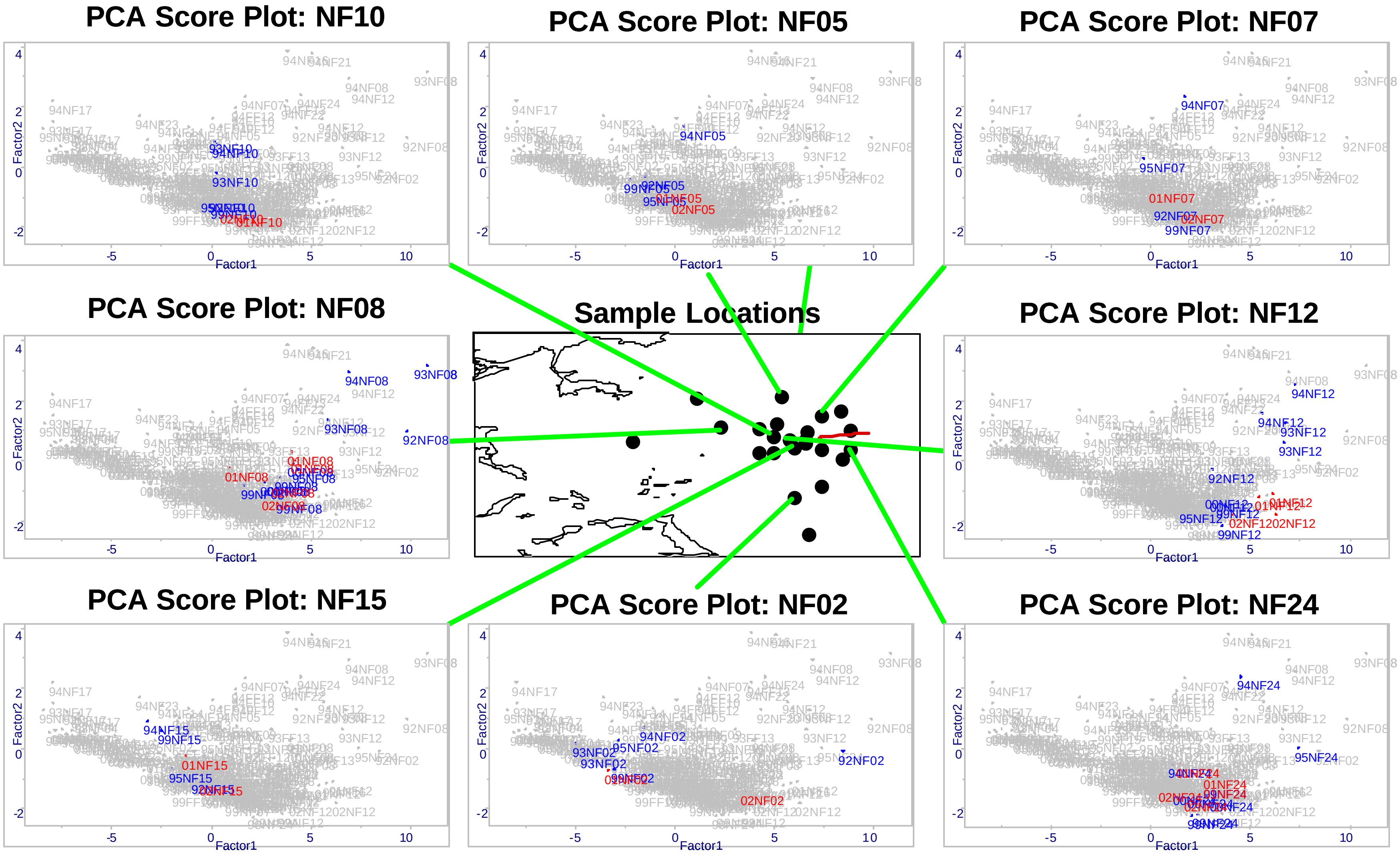

Figure 4-3b. Comparison of nearfield sediments from the baseline (1992–2000) and post-diversion (2001–2002) periods using PCA. Principal components 1 and 2 represented 69% and 6% of the variability, respectively. Score plots are replicated to demonstrate the relative spatial and temporal composition of all nearfield samples. Location-specific baseline and post-diversion data are colored blue and red, respectively. Refer to Figure 4-3a for the Loading Plot.

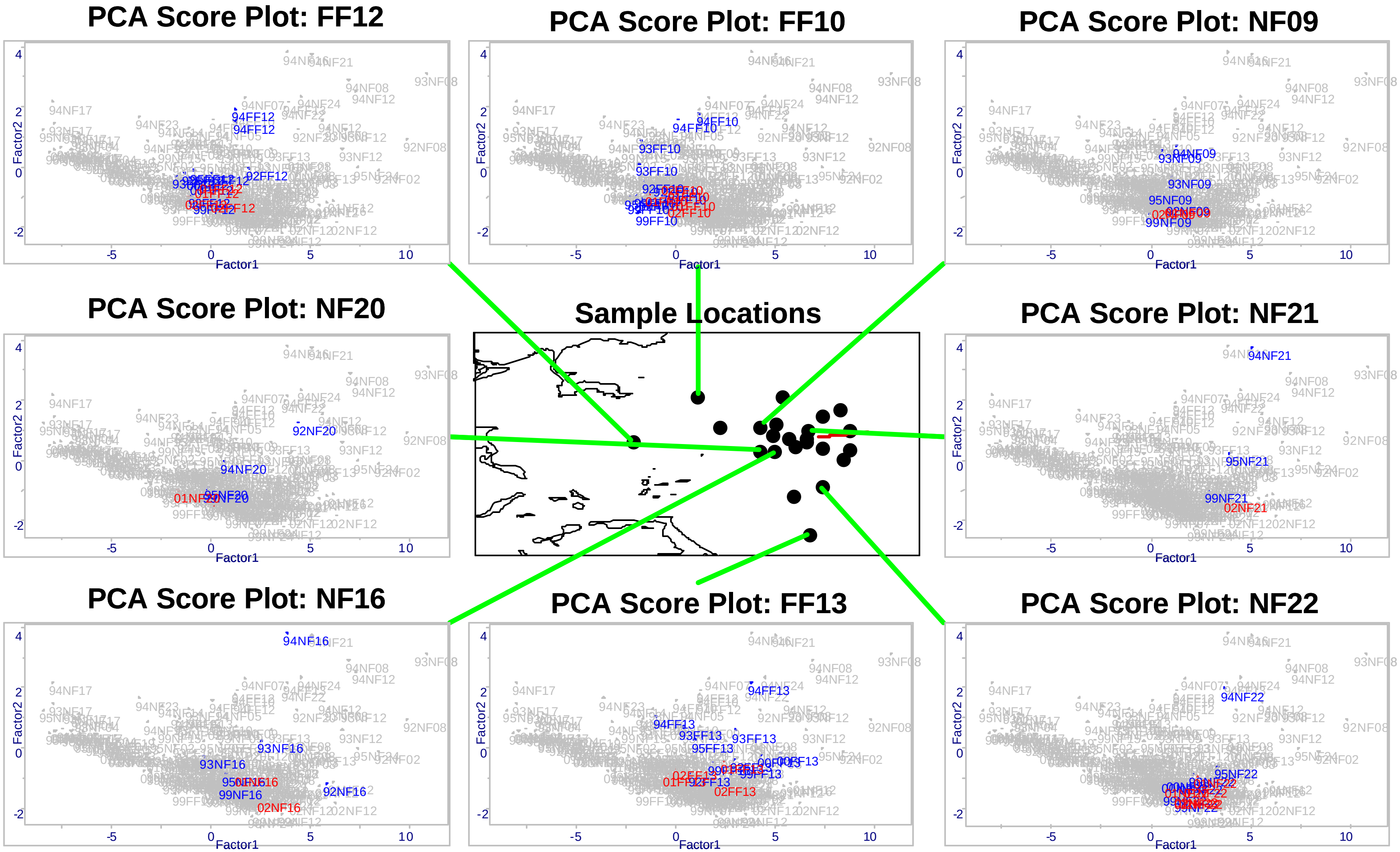

Figure 4-3c. Comparison of nearfield sediments from the baseline (1992-2000) and post-diversion (2001-2002) periods using PCA. Principal components 1 and 2 represented 69% and 6% of the variability, respectively. Score plots are replicated to demonstrate the relative spatial and temporal composition of all nearfield samples. Location specific baseline and post-diversion data are colored blue and red, respectively. Refer to Figure 4-3a for the Loading Plot.

4.3.2 Regional Chemistry 1992–2002

Baseline data for the regional stations showed a system that was more spatially dispersed and compositionally distinct. *C. perfringens* and total LAB data showed that the proximity to the historic source of sewage contaminants influenced the concentration at regional stations. Data for August 2001 and 2002 show that post-diversion data at regional stations are not substantially different from the baseline period for any given station.

To demonstrate these observations, the baseline range and mean values were determined, by station, for bulk sediment properties, *C. perfringens*, and contaminant parameters as described in Section 4.2.3 and Appendix C1. Post-diversion (August 2001 and 2002) data were then compared to the baseline range and mean values for each regional station to evaluate how post-diversion data fit within the baseline information. Regional stations were sorted as a function of their north to south location relative to the new outfall. With few exceptions, post-diversion data for all parameters fell within the baseline range indicating that 2001 and 2002 continued to be representative of the baseline period (1992-2000), and activation of the new outfall did not cause systematic or widespread increases in contaminants of environmental concern to the Massachusetts and Cape Cod Bay systems (representative parameters shown in Figure 4-4; all data shown in Appendix C3).

Unlike the nearfield, there were few cases where post-diversion data fell outside the baseline range for the regional stations, and even then the increases were very small. Exceptions included:

- Post-diversion concentrations of TOC were slightly above the baseline range at three stations in 2001 (NF12, NF17, and FF07) and four stations in 2002 (FF11, NF12, FF04, and FF07).
- 2002 concentrations of PAH were anonymously high in one of the three replicates at FF10 but were within the baseline values in October 2002 (Figure 4-4a; see Section 4.3.1).
- Cr concentrations were slightly above the baseline range at NF17 (for one replicate only) in 2001 and 2002.
- Pb concentrations were slightly above the baseline range at one replicate each at NF17 (2001 only) and FF10 (2002 only).
- Hg concentrations were slightly above the baseline range in 2001 at FF12 and FF13, but were within baseline values in 2002 (Figure 4-4b).
- Ag concentrations were slightly above the baseline range in 2001 at FF04 but were within the baseline range in 2002; whereas Ag concentrations at FF07 were slightly above the baseline range in 2001 and 2002.

Consistent with the nearfield, 2001 and 2002 concentrations of sewage tracer and organic contaminants at regional stations were within the baseline range (1992–2000), and values were frequently measured at levels equal to or below the baseline station mean (Appendix C3).

The PCA results revealed four generalized trends among the data collected from the regional sediment samples (Figure 4-5a, b). First, high percent sand was inversely correlated with organic and inorganic analyte concentrations. Samples with higher sand content plotted in the upper left quadrant of the score plots (Figure 4-5a; top center); whereas, samples with less sand content plotted in the right quadrants of the score plots. Stations NF17, FF09 and FF01 (post-1993) contained the highest levels of sand.

Second, anthropogenic analytes (*e.g.,* TLAB, Ag, CPERF, Hg, Cd, and TCHLOR) were measured at relatively consistently high levels in the baseline period at the following locations: FF12, FF13, NF12, and NF24. These samples grouped in the upper right quadrant of the score plot, and may have received higher pollutant loadings, especially during the early 1990s, from Boston Harbor. Other anthropogenic analytes (*e.g.,* TPCB, TPAH, Pb, and Cr) were influential on the compositional signature, but did not further differentiate the samples due to a more uniform distribution in the regional sediments.

Third, for most of the baseline and post-diversion periods, relatively high concentrations of fines and associated parameters (TOC, Ni, Zn, Al, and Fe) were enriched in one or more samples from FF01 (sampled in 1992 and 1993 only), FF04, FF05, FF06, FF07, FF11, and FF14. These samples grouped in the lower right quadrant of the score plot, and contained high silt and clay without large anthropogenic chemical content.

The fourth sample group was largely undifferentiated from the first three groups. This less distinctive group contained multiple samples from FF05, FF06, FF09, and FF10. These samples generally grouped in the central quadrant, and contained intermediate amounts of sand, fines, and anthropogenic analytes during most of the baseline and post-diversion periods.

Relative to the nearfield sediments, the regional sample groupings exhibited greater compositional definition from one another. This increased definition was attributed to the greater spatial separation of the sampling locations and local isolation of compositional features. Consequently, the loading factors differ slightly from the nearfield and regional PCA runs presented in Figures 4-3 (a,b,c) and 4-5 (a,b), respectively. The separation of sampling locations also explains why the anthropogenic and metal compositions of NF12 and FF13 varied more widely than FF04, FF05, FF07, FF09, and FF14. In general, the more distant the sampling location from Boston Harbor, the more tightly samples from that location tended to cluster; *i.e.*, the more reproducible its local compositional character. Perhaps more importantly, the post-diversion samples (colored red in Figure 4-5a,b) fell within the overall variability of the baseline samples (colored blue in Figure 4-5 a,b). In addition, the post-diversion samples did not deviate strongly in the direction of the anthropogenic analytes. As in the nearfield, the sediments in the post-diversion period were not spatially or temporally accumulating harmful organic or inorganic compounds relative to the baseline period.

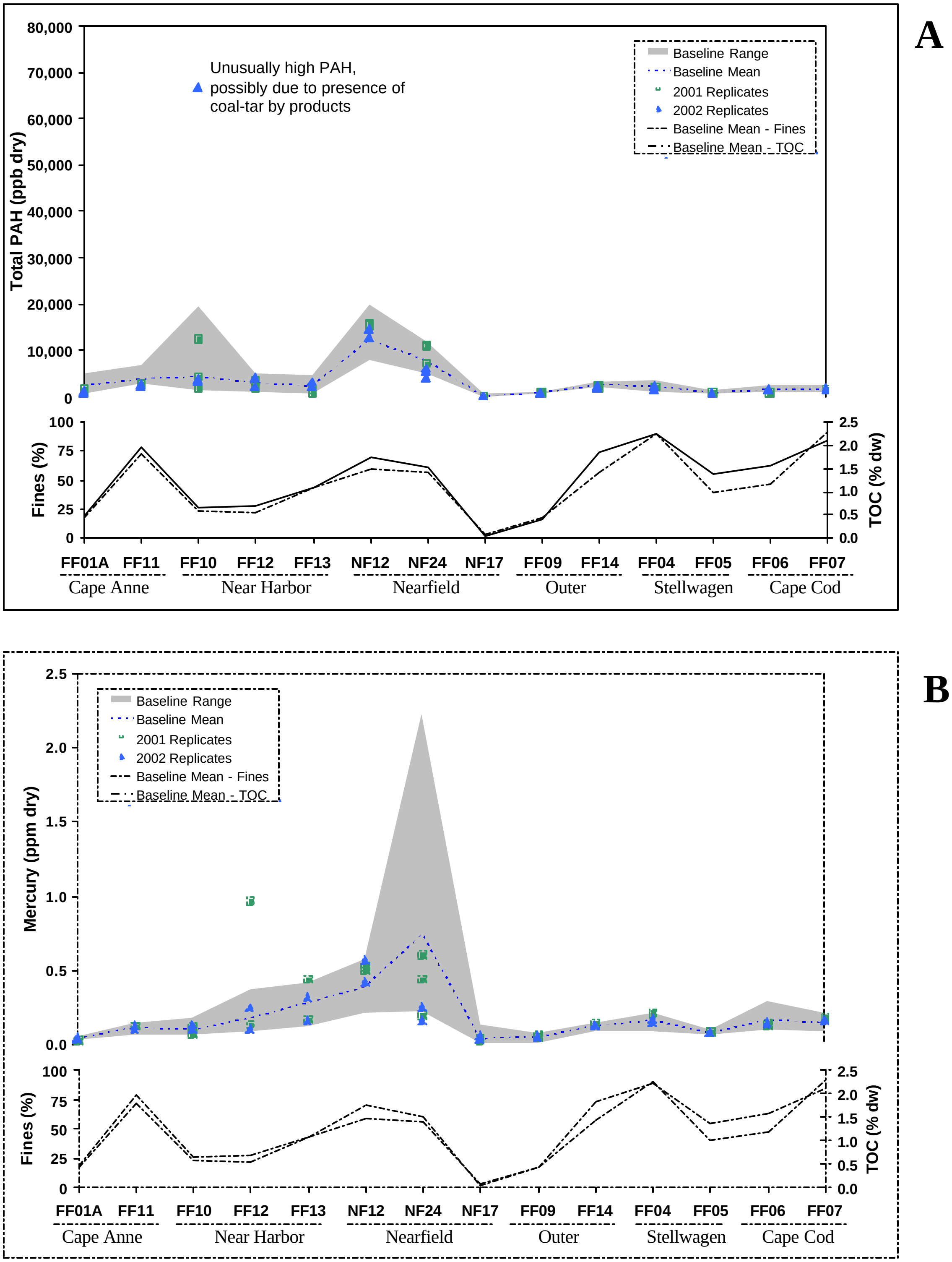

Figure 4-4. Total PAH (A) and mercury (B) for each regional station sampled in 2001 (squares), 2002 (triangles) and the range of values occurring during the baseline period (gray band). The baseline mean values are indicated (dashed line within gray band). Stations are presented in order of location relative to the outfall, from north to south. Baseline station mean values for TOC and percent fines, plotted by station, are shown in the sub-plot.

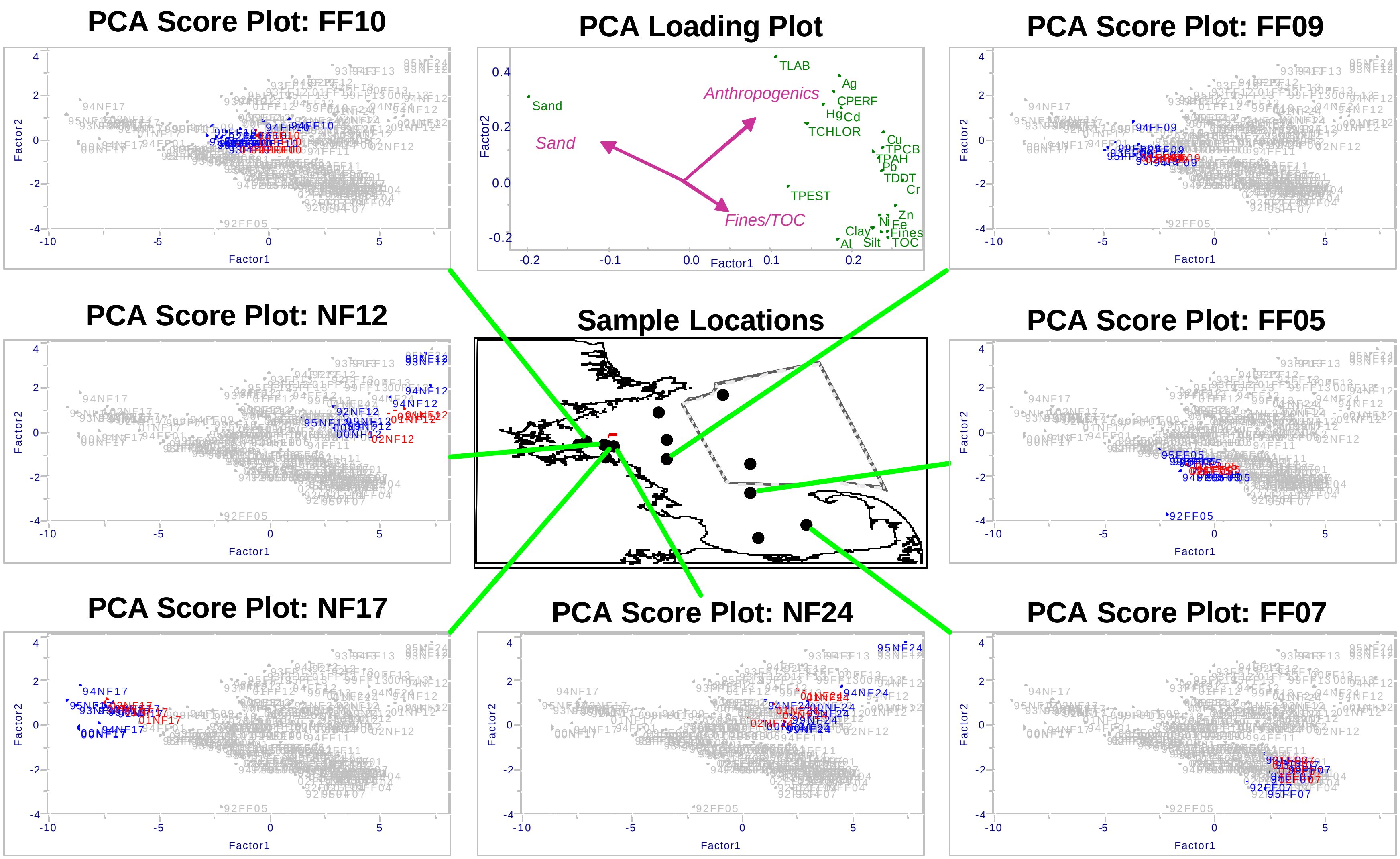

Figure 4-5a. Comparison of regional sediments from the baseline (1992–2000) and post-diversion (2001–2002) using PCA. Principal components 1 and 2 represented 58% and 12% of the variability, respectively. Score plots are replicated to demonstrate the relative spatial and temporal composition of all nearfield samples. Location-specific baseline and post-diversion data are colored blue and red, respectively.

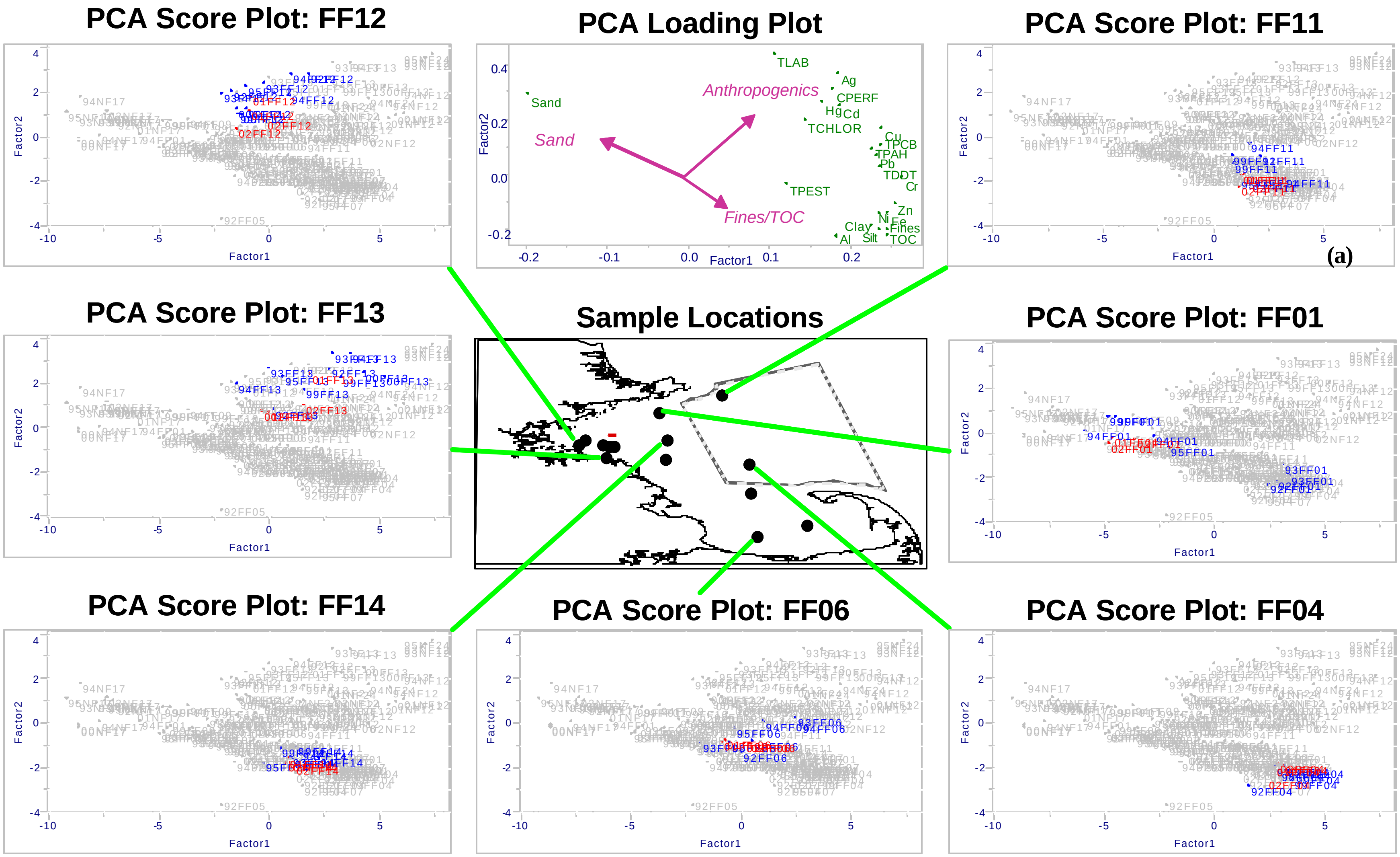

Figure 4-5b. Comparison of regional sediments from the baseline (1992–2000) and post-diversion (2001–2002) using PCA. Principal components 1 and 2 represented 58% and 12% of the variability, respectively. Score plots are replicated to demonstrate the relative spatial and temporal composition of all nearfield samples. Location-specific baseline and post-diversion data are colored blue and red, respectively. (a) 1992 and 1993 data for Stellwagen basin station FF01 are included with FF01A, which is located more than 10 km away and in shallower water.

4.3.3 Spatio/Temporal Response of Sewage Tracers 1992–2002

The spatio/temporal distribution of *C. perfringens* at all nearfield and regional (excluding northern farfield stations FF01, FF01A, and FF11) stations from 1992–2002 (August surveys only) was evaluated to determine if the gradient in *C. perfringens* has changed as harbor cleanup has proceeded.

The gradient in *C. perfringens* densities with distance from Boston Harbor (defined as the Deer Island Light) was evaluated for the period 1992–2002. *Clostridium perfringens* data were normalized to percent fines because spores preferentially attach to fine-grained particles (Parmenter and Bothner 1993). Further, evaluations in Kropp *et al.* (2001) showed that grain size was likely a major controlling factor influencing *C. perfringens* abundance. Each sampling year showed trends consistent with USGS findings and indicated that *C. perfringens* densities (normalized to percent fines) decreased with distance from Boston Harbor (representative years 1992 and 2002 shown in Figure 4-6). More importantly, since 1998 *C. perfringens* densities (normalized to percent fines) have shown sustained decreases at harbor locations from 1992 to 1997 values, suggesting that MWRA facility upgrades (*e.g.*, cessation of sludge disposal, primary and secondary treatment) had a positive impact on harbor sediments (representative years 1992 and 2002 shown in Figure 4-6). Outfall stations located within 20 km of the harbor also showed modest decreases in *C. perfringens* densities (normalized to percent fines) over time, however, abundances increased slightly in 2001 and 2002.

Clostridium perfringens data were further evaluated to determine if the observed increase in 2001 and 2002 at outfall stations located within 20 km of the harbor was evident for all nearfield stations, or whether the increase was isolated to selected stations. Station mean values of *C. perfringens* (normalized to percent fines) from 2000 to 2002 were evaluated across all nearfield stations. While *C. perfringens* abundances (normalized either to percent fines or percent clay) increased in 2001 and 2002 at nearly all nearfield stations, the greatest increases generally occurred at those stations located within 2 km of the western end of the outfall (Figure 4-7). These findings suggest that effluent discharge from the new outfall is having, as expected, a localized, but modest, influence on nearby sediments. In contrast, excluding regional stations located close to the outfall (*i.e.*, NF12, NF17, and NF24), 2001 and 2002 abundances of *C. perfringens* (normalized to percent fines) showed no such increase at regional locations (Dahlen *et al.*, 2003[5]). This indicates that effluent discharged from the new outfall is not having an influence on regional sediments. More interesting, abundances of *C. perfringens* (normalized to percent fines) decreased slightly in 2001 and 2002, at regional stations located near Boston Harbor (*i.e.*, FF10, FF12 and FF13 (Dahlen *et al.*, 2003), which suggests that diversion of the effluent discharge to the new outfall is having a positive influence on the near harbor sediments.

Trends in another effluent marker, total LAB, were also evaluated to determine if total LAB also changed as harbor cleanup has proceeded. Concentrations of total LAB measured at near-in stations (<20 km) decreased markedly (60 to 80%) in 1995 compared to previous years; with similar low concentrations observed in 1999–2002 (Figure 4-8). While primary treatment came on-line in 1995, there is no clear evidence that it resulted in the marked decrease in total LAB concentrations. The largest decrease in LAB loadings to the harbor occurred in the late 1980s and early 1990s when Proctor and Gambel installed pretreatment equipment to cleanup their industrial discharge to the south system (*i.e.*, reduction in surfactant loadings to the influent) and subsequently closed their plant (personal communication with Ken Keay, 2002). The observed decrease in 1995 may therefore be attributed to a combination of removal of discharge to the harbor (*i.e.*, Proctor and Gambel discharge), facility improvements, and natural attenuation. Silver, another sewage tracer, was fairly constant over time (in the <20 km sample set) and did not show the marked decrease observed with *C. perfringens* and total LAB.

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[5] Attachment 1 to Chapter IV of MWRA 2003. Briefing for OMSAP workshop on ambient monitoring revisions, March 31-April 1, 2003. Boston: Massachusetts Water Resources Authority. Report ENQUAD ms-083. 96p.

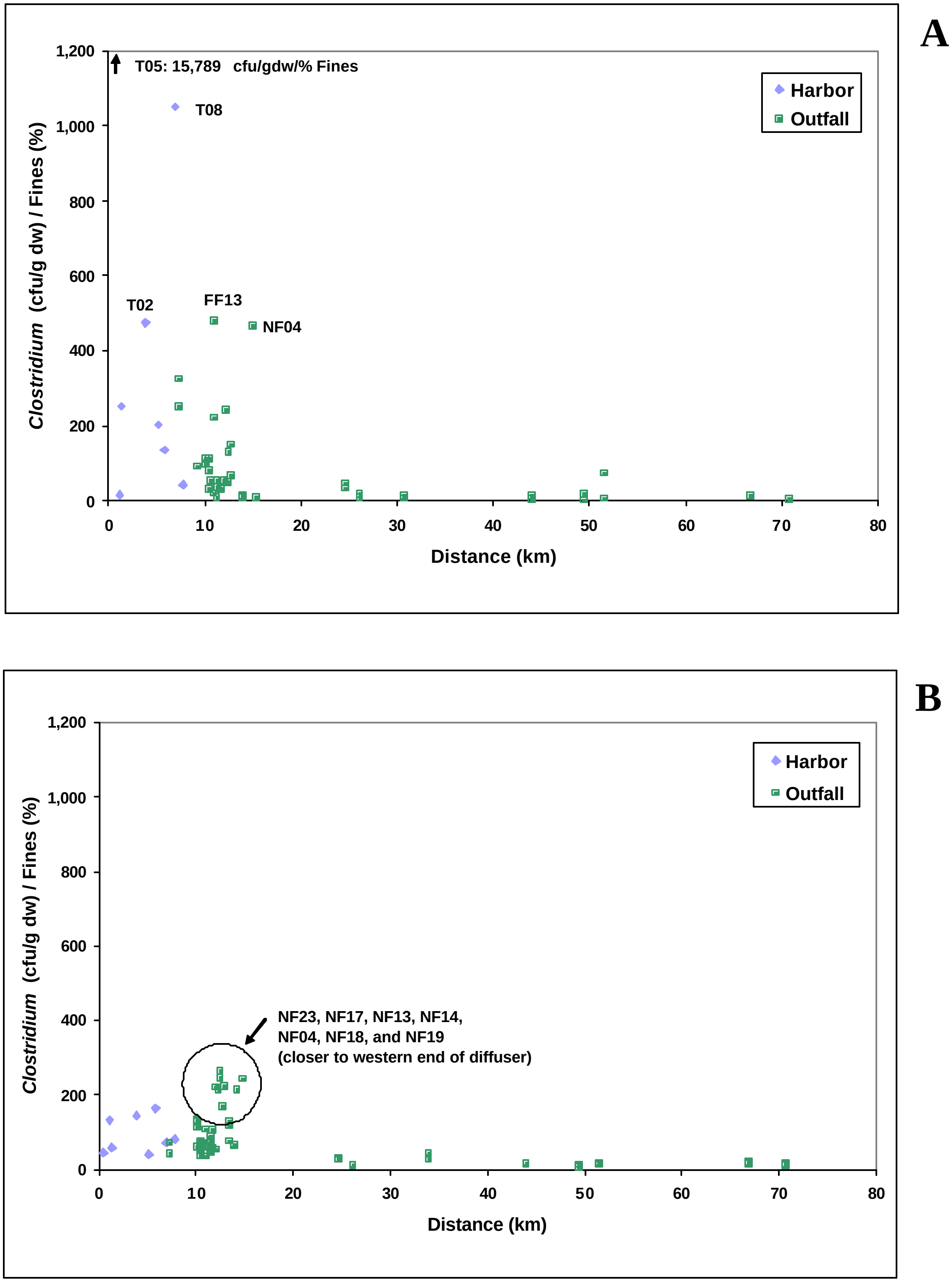

Figure 4-6. Distribution of *Clostridium perfringens* (normalized to percent fines) with distance from Deer Island Light in 1992 (A) and 2002 (B).

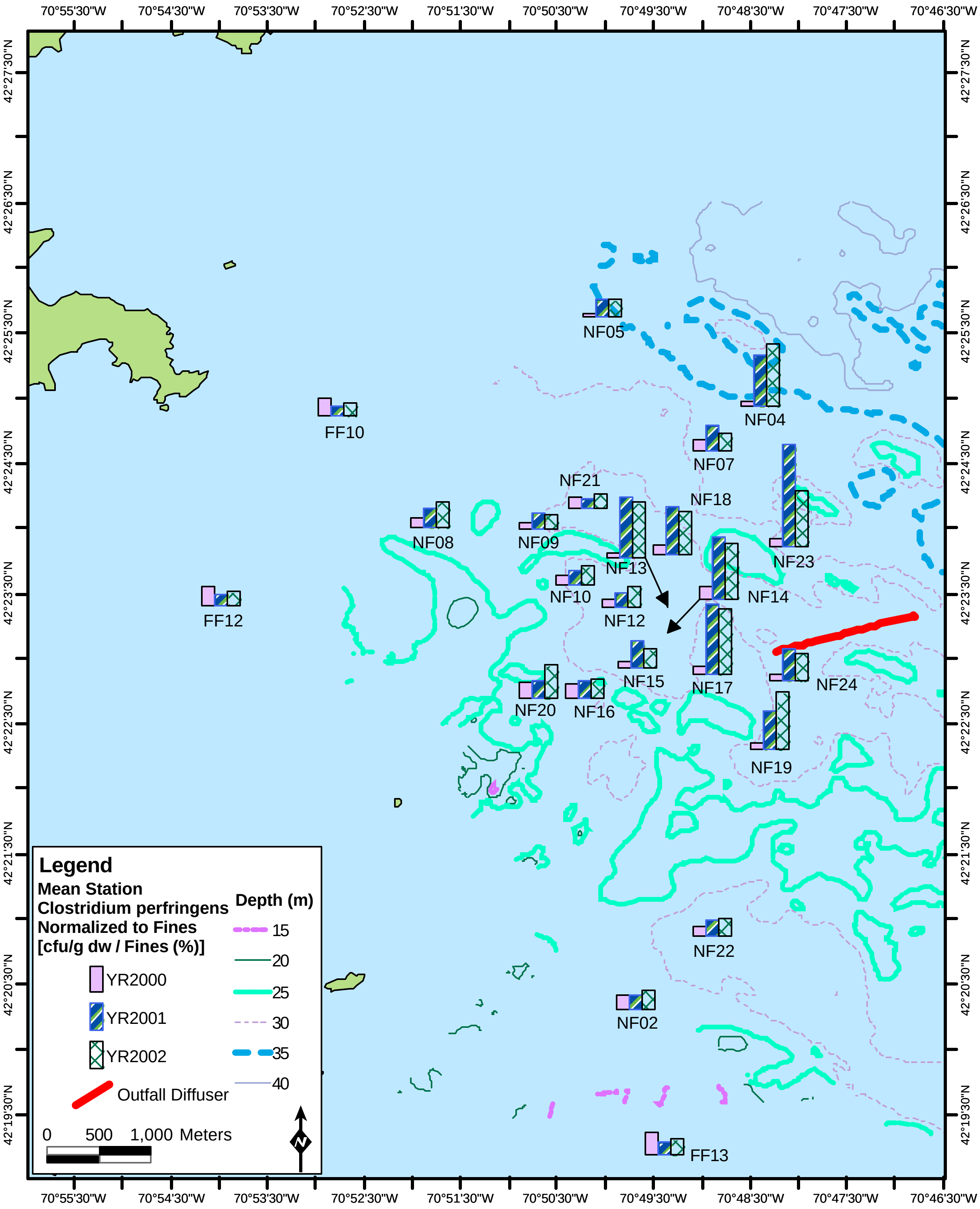

Figure 4-7. Station mean concentrations of *Clostridium perfringens* (normalized to percent fines) in nearfield sediments collected in August 2000, 2001, and 2002.

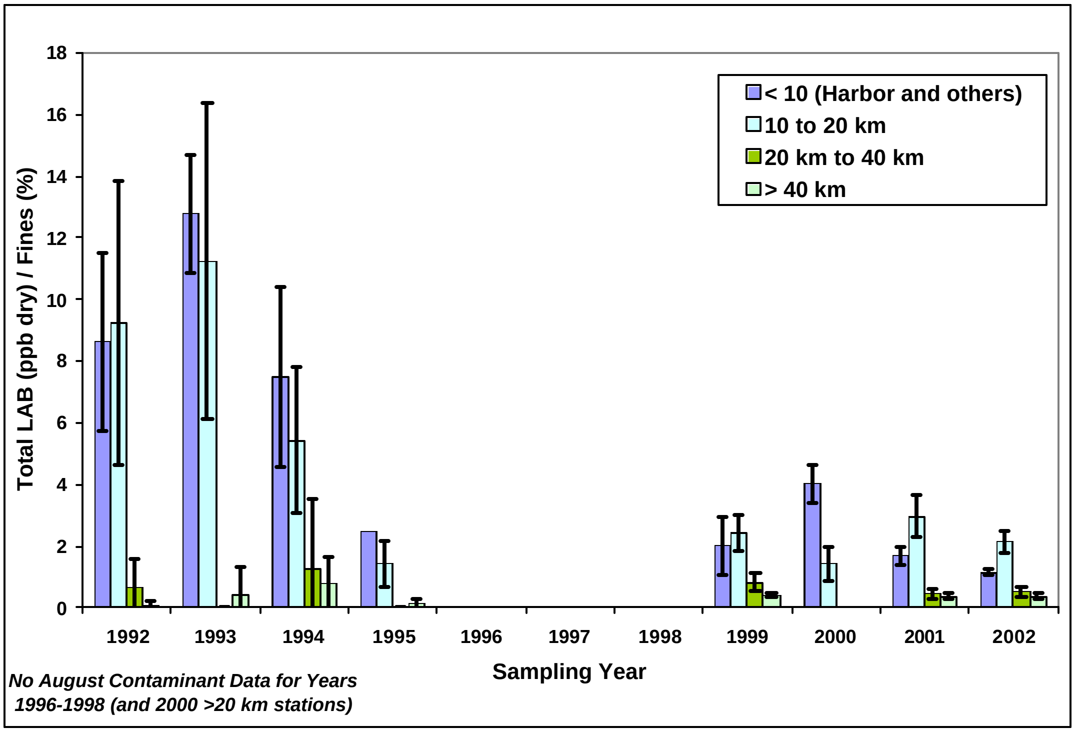

Figure 4-8. Yearly mean concentrations of total LAB (normalized to percent fines) from 1992 to 2002, by distance classification from Deer Island Light. (10 to 20 km distance classification includes nearfield stations located closer to the new outfall). (Error bars represent 95% confidence limits.)

4.3.4 Chemistry Interrelationships

Baseline data showed a system with two regions – *nearfield* and *regional* areas – with different controlling factors that influence the concentrations of contaminants. Contaminant concentrations at nearfield stations, located close to and roughly equidistant from the historic source of contamination, are influenced by local (Boston Harbor) and distributed sources, primarily related to grain-size factors suggestive of different sediment depositional environments. In contrast, the correlation analyses suggest that contaminant concentrations at regional stations located further away from the harbor are primarily influenced by distributed sources (e.g., atmospheric inputs, distant rivers).

Correlation analyses were performed for nearfield and regional stations (August surveys only), using station mean values from the two-year period before (1999 and 2000) and after (2001 and 2002) the new outfall came on-line. Data from this period was used for this evaluation because those data most represent the system after it responded to early improvements (*e.g.*, various MWRA facility upgrades) and shows the most representative conditions before diversion of effluent discharge to the new outfall. Correlation coefficients (r values) were then compared for the two datasets, *i.e.*, pre- and post-diversion, to determine if the correspondence between controlling variables and contaminants in the system were substantially different since the new outfall came on-line in September 2000.

Nearfield—Tabular results from the correlation analysis (*i.e.*, r values) are presented in Appendix C4 (Table C4-1); representative correlation plots are shown in Figures 4-9, 4-10, and 4-11. In cases where a single sample had an unusually high value (*e.g.*, TOC at NF14 in 2002, see Figure 4-9), the sample was excluded from the correlation analysis (excluded data are documented in Appendix C4).

There were no substantial changes to the strength of the correlation within bulk sediment properties and against contaminants in the nearfield after the new outfall came on-line. For example, grain size continued to be strongly correlated with TOC (Figure 4-9). Similarly, contaminants and bulk sediment properties were strongly correlated (r^2 generally above 0.5) during the two-year period before and after the new outfall came on-line, with most correlations against percent fines being slightly stronger overall than those with TOC (Appendix C4, Table C4-1; representative parameters shown in Figure 4-10). The correlation between bulk sediment properties and Pb did degrade after activation of the outfall, primarily due to unusually high Pb values at stations NF14, NF15 and NF20 (Figures 4-10c, d).

The strength of the correlation between bulk sediment properties and the sewage tracer, *C. perfringens,* remained similar after the new outfall came on-line. However, the increase in *C. perfringens* abundances observed in 2001 and 2002 are clearly evident when the correlation analysis is performed using data from two years before and after the new outfall came on-line (Figure 4-11). The correlation between *C. perfringens* and bulk sediment properties using data from all years (1992–2002) does not show the clear increase of *C. perfringens* (Kropp *et al.*, 2002). This can be attributed to system changes in *C. perfringens* from early in the program to the late 1990s, which resulted from a variety of factors including various MWRA facility upgrades.

The correspondence between percent fines across years (2000–2002) was also evaluated to confirm the modest increase in percent fines observed from the PCA. The evaluation showed a clear indication of fine-grained material increasing as percentage since 2000 (Figure 4-12). For example, increases in percent fines were observed in 2001 at stations FF10, NF16, NF22, NF21 and NF12 (Figure 4-12a). Percent fines increased yet again in 2002 at stations NF02 and NF20 (Figure 4-12b). Increases in percent fines at other nearfield stations (*e.g.*, NF04, NF14, NF18 and NF23) were apparent, but generally small.

While modest changes in fines and *C. perfringens* were observed, these correlation findings show that the contaminant variability in the nearfield is dominated by grain size and TOC, and that the controlling variables in the nearfield system did not alter substantially as a result of the outfall coming on-line in September 2000.

Regional— Tabular results are presented in Appendix C4 (Tables C4-2a,b); representative correlation plots are shown in Figure 4-13. While the regression coefficients among the parameters were generally high for regional stations, correspondence between contaminant concentrations and bulk sediment properties was weaker overall at regional stations compared to the nearfield (Appendix C4, compare tables C4-1 and C4-2a). Variability among the regional contaminant data was higher because regional stations are more spatially dispersed, with some stations closer to and others far way from the harbor (Figure 4-13a)[6]. Regional stations located far away from the harbor generally had lower contaminant concentrations compared to regional stations located closer to the harbor (Figure 4-13a). The regional correlation analysis was repeated using only data for regional stations located far away from the harbor, hereafter referred to as *offshore regional.* The variability among contaminants decreased when near harbor regional stations (*i.e.*, FF10, FF12, FF13, NF12, NF17, and NF24) were excluded from the correlation analysis, indicating that the factors that influence contaminant variability at offshore regional locations include distributed sources (representative contaminant, Cu, shown in Figure 4-13a; see Appendix C4 for additional correlation plots). Offshore regional metals were more strongly correlated with bulk sediment properties than were organic contaminants, suggesting that metals variability at

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[6] Regional stations located close to the harbor (<20 km from Deer Island Light) include FF10, FF12, FF13, NF12 NF17 and NF24. Regional stations located far away from the harbor (>20 km from Deer Island Light) include FF01A, FF04, FF05, FF06, FF07, FF09, FF11, and FF14.

offshore regional stations was dominated by grain size and TOC, while organic contaminant variability was influenced by factors other the depositional properties of the station (Appendix C4, Table C4-2b).

The correlation analysis also showed that near harbor regional and nearfield stations, with similar grain size to offshore regional stations, generally had higher contaminant concentrations compared to offshore regional values (representative contaminant, Cu, shown in Figure 4-13b; see Appendix C4 for additional correlation plots). Contaminant concentrations present at levels above the underlying offshore regional signature are indicative of a local source (Boston Harbor), as evidenced by a higher slope value from the regression analysis for nearfield data compared to offshore regional data (representative parameters shown in Figure 4-13b; see Appendix C4 for additional correlation plots).

There were no substantial changes to the strength of the correlation within bulk sediment properties and against metals at offshore regional stations after the new outfall came on-line (Appendix C4, Table C4-2b). In contrast, the strength of the correlation between some organic contaminants (total DDT, total LAB) and bulk sediment properties degraded slightly (smaller r value) after the new outfall came on-line, whereas others (total PAH, total PCB) improved (higher r value) (Appendix C4, Table C4-2b). Thus, outfall related changes were not found at stations distant from the outfall.

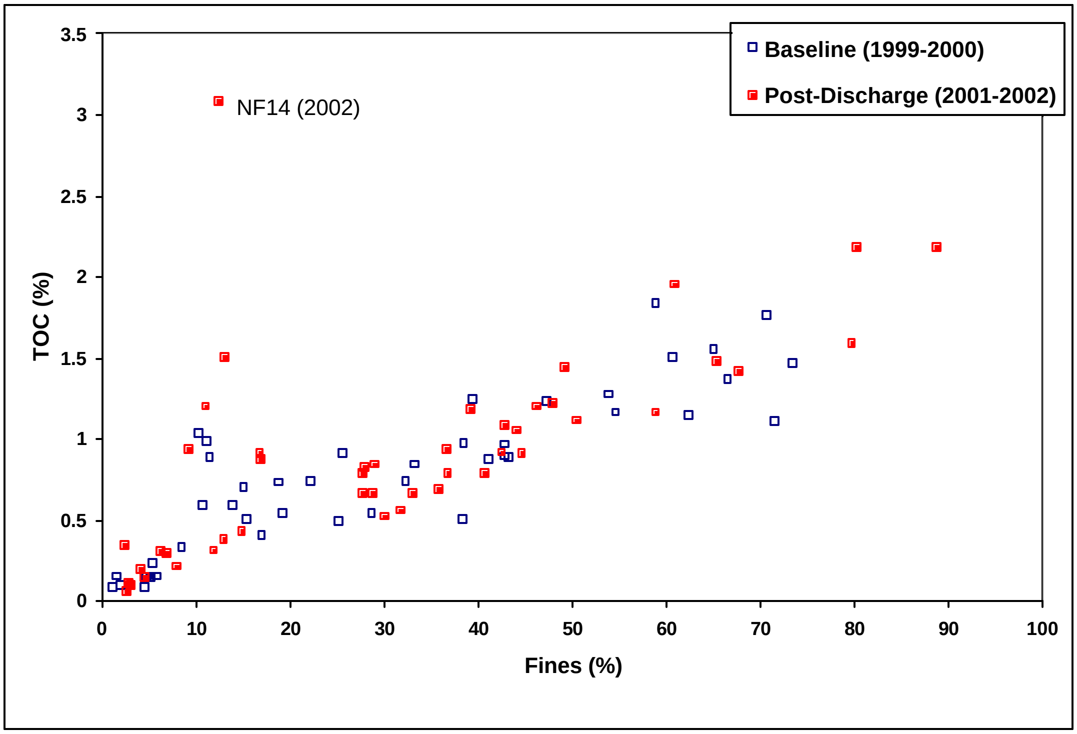

Figure 4-9. Correspondence between percent fines and TOC in the nearfield during the two-year period before (1999–2000) and after (2001-2002) the new outfall came on-line.

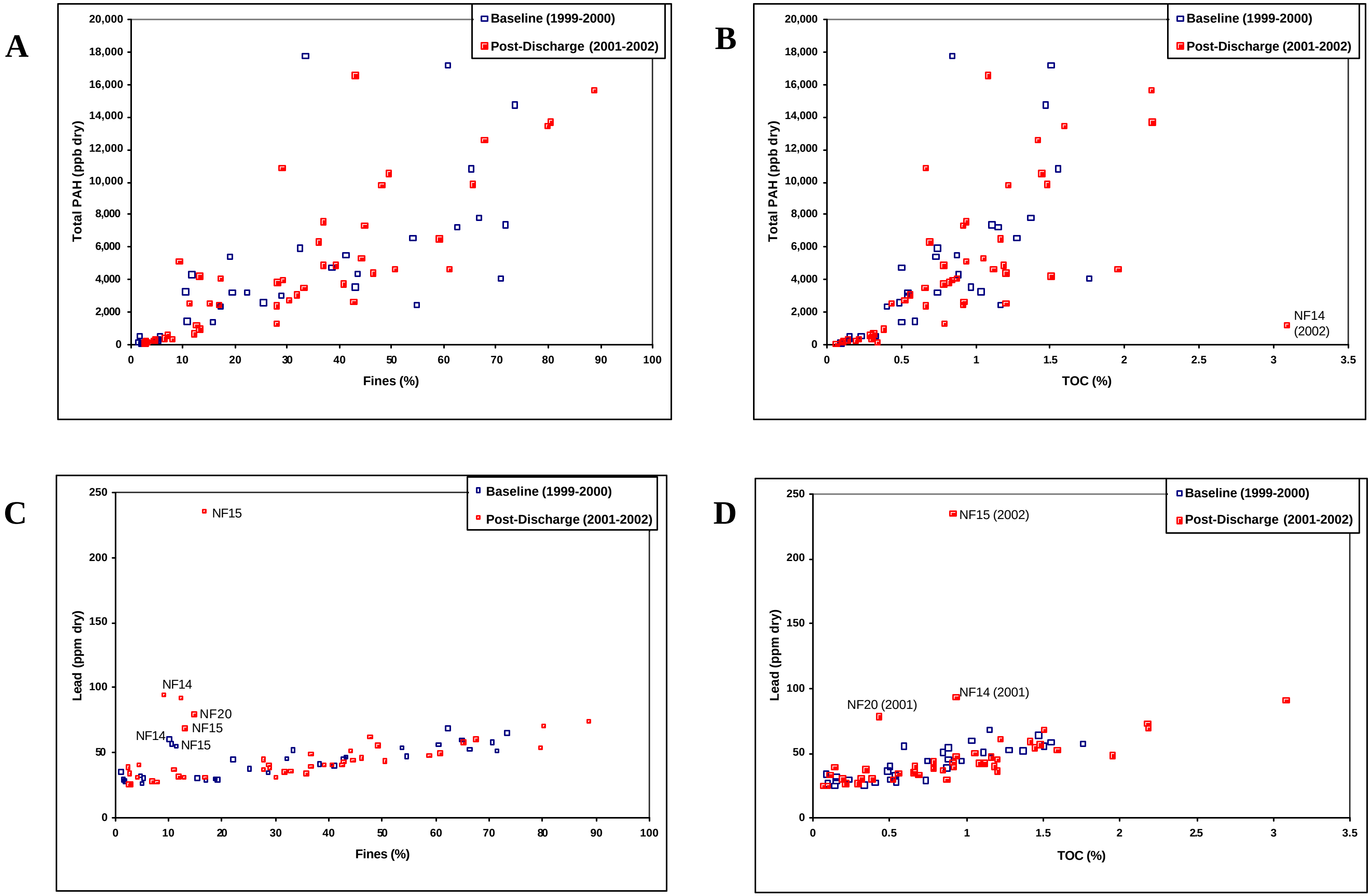

Figure 4-10. Correspondence between bulk sediment properties (percent fines, TOC) and representative contaminants (total PAH, lead) in the nearfield during the two-year period before (1999–2000) and after (2001–2002) the new outfall came on-line.

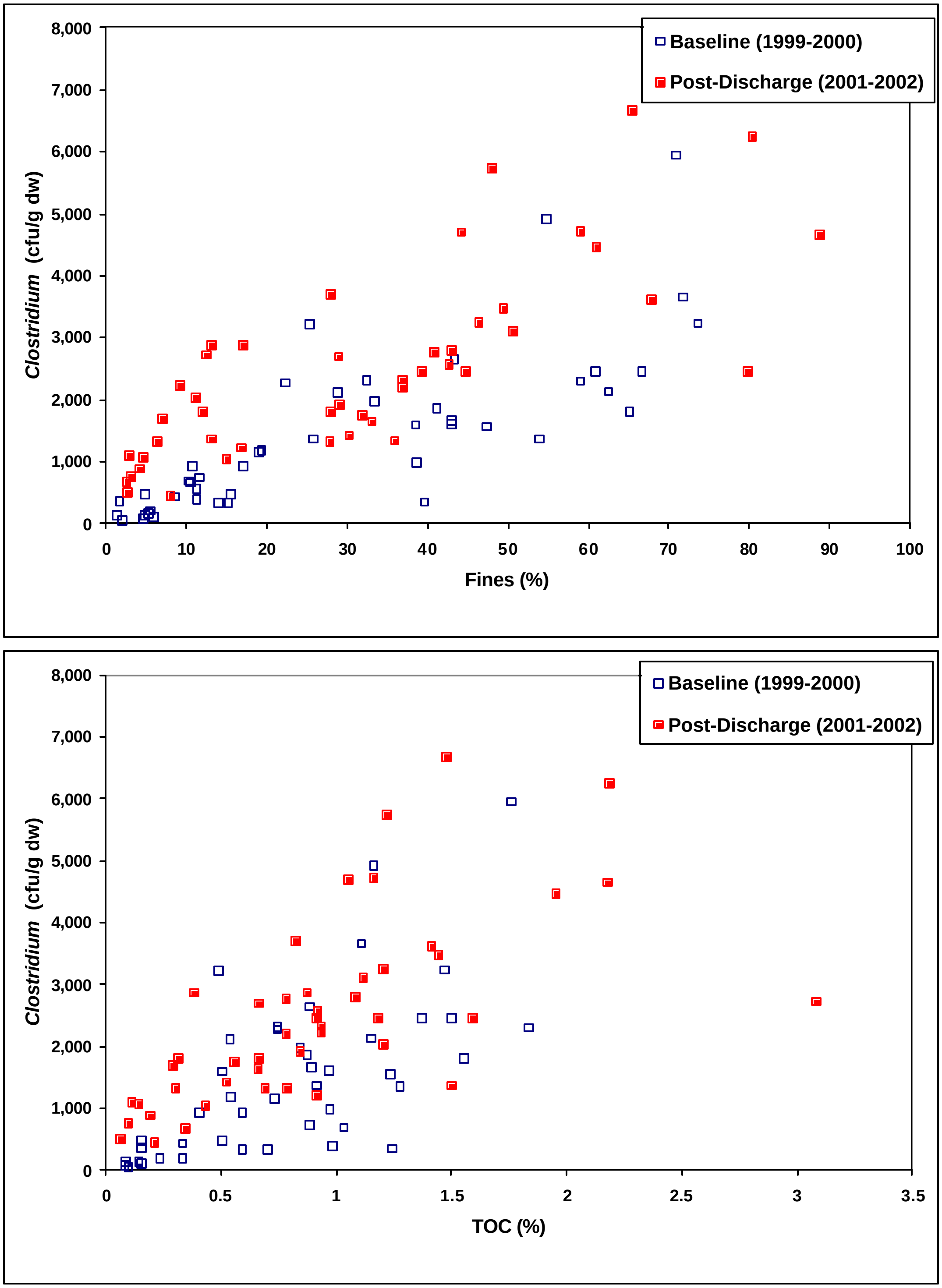

Figure 4-11. Correspondence between bulk sediment properties (percent fines, TOC) and *Clostridium perfringens* in the nearfield during the two-year period before (1999–2000) and after (2001–2002) the new outfall came on-line.

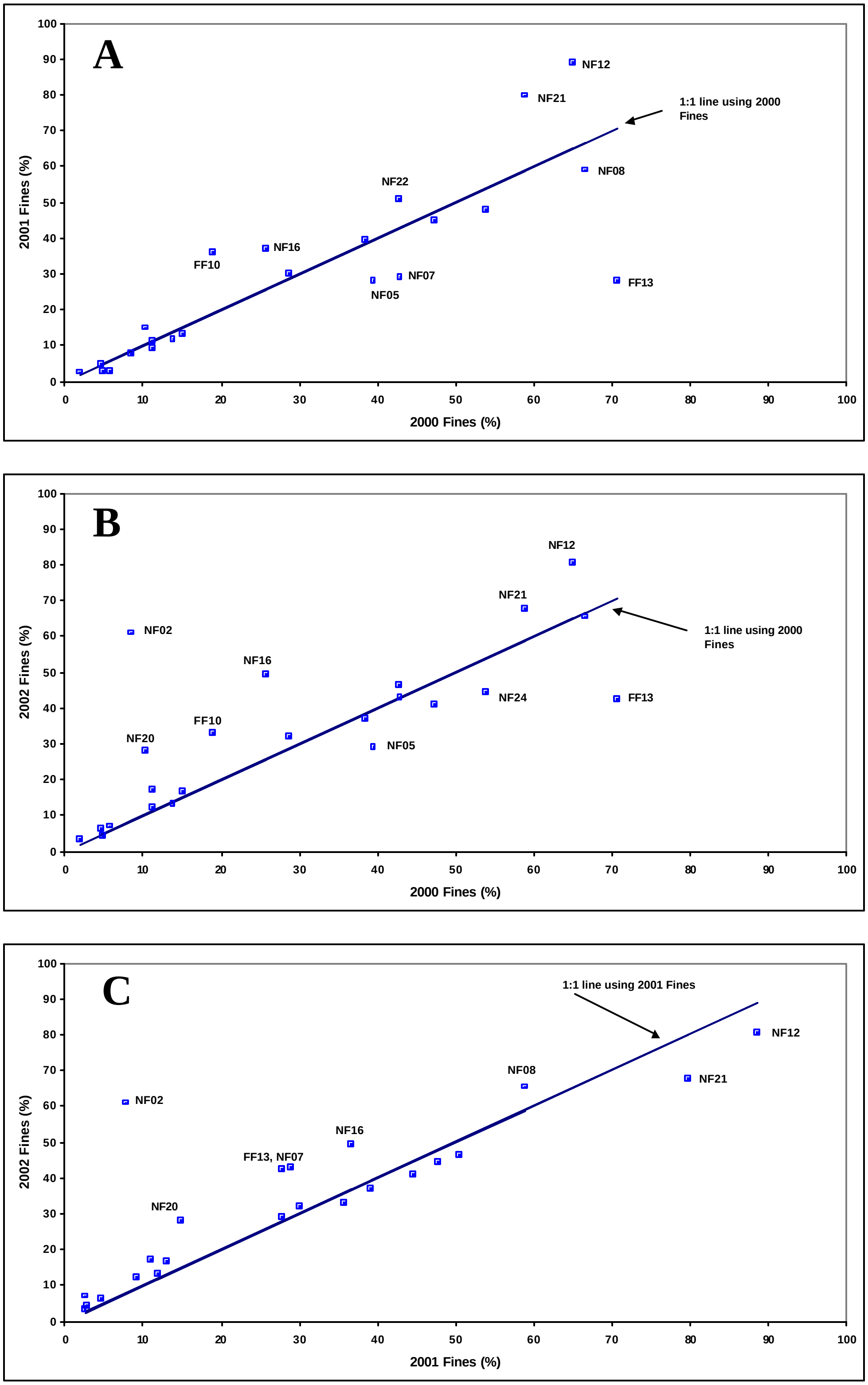

Figure 4-12. Correspondence between percent fines in 2000 and 2001 (A), 2000 and 2002 (B), and 2001 and 2002 (C).

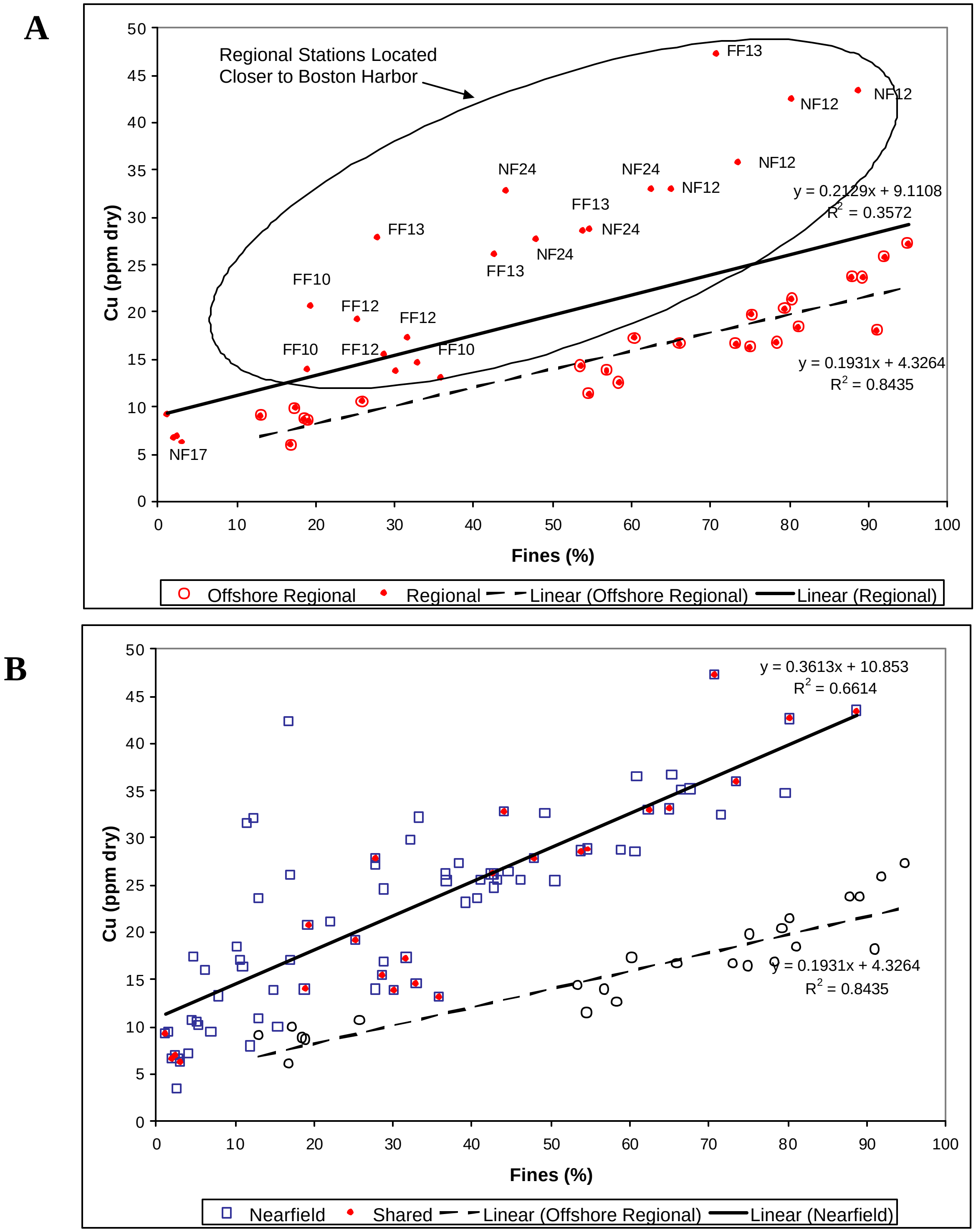

Figure 4-13. Correspondence between percent fines and Copper at regional (A) and nearfield locations (B) during the two-year period before and after the new outfall came on-line (1999–2002). Shared stations (FF10, FF12, FF13, NF12, NF17, and NF24) traditionally classified as both nearfield and regional.

4.3.5 Nearfield Contaminant Special Study 1998–2002

The Nearfield Contaminant Special Study (NCSS) was initiated in October 1998 with the intention of conducting the study three times a year after outfall startup. Prior to the outfall startup in September 2000, NCSS surveys were conducted on an intermittent basis, in October 1998 and in August 1999 and 2000. Following outfall startup, triplicate samples were collected at each station in February, August, and October. The data from this study were intended to provide early indications of rapid organic carbon or contaminant build-up, should those occur.

The grand mean TOC concentrations from the pre-diversion (October 1998, and August 1999 and 2000) and post-diversion (October 2000, 2001 and 2002; February 2001 and 2002; and August 2001 and 2002) periods were compared to determine if the mean TOC concentration had increased following the outfall coming on-line in September 2000 (Appendix C5d). Had the post-diversion mean TOC value increased considerably, then this could justify testing the NCSS results against the hypothesis, which lead to the establishment of the study[7]. Results from the comparison showed that there was only a small (7%), but not statistically significant, increase in the mean TOC concentration on average across all NCSS stations following the outfall diversion (pre-diversion mean value ± standard deviation = 0.97 ± 0.35, n = 35; post-diversion mean value ± standard deviation = 1.04 ± 0.35, n = 84). Further, the post-diversion mean concentration of TOC across all NCSS stations (1.04%) is comparable to the mean concentration of TOC measured at NCSS stations sampled annually in August during the full baseline period (1992–2000; mean TOC = 1.15%). As a result, the NCSS data were not evaluated to test Wallace's hypothesis. While a formal evaluation of the model was not carried out, metals, for which Wallace specifically developed his model, do not appear to show any systematic change at the NCSS stations.

Bulk sediment and contaminant results from the replicate analyses of sediment samples are reported in Appendix C5. Data included in Appendix C5 (a, b, c) are presented as station mean values and standard deviation of the triplicate analyses; data provided in Appendix C5d include pre- and post-diversion grand mean values. All results are reported on a dry weight basis to three significant figures.

Grain Size—Patterns in sediment composition were not substantially different in 2001 and 2002 compared to system trends observed during the baseline period (Figure 4-14; detailed ternary plots by station shown in Appendix C6). FF10 continued to be comprised of coarse-grained sediments, with gravel plus sand content generally 60% and higher (Appendix C6). Sediment collected at NF08 continued to be more silty, with fines content typically 60% and higher (Appendix C6). With the exception of one sample replicate, sediment composition at NF22 was very consistent across sampling years, and was comprised of relatively equal parts coarse and fine-grained particles (Appendix C6). NF22 (replicate 2) sediment from October 2001 contained more fine-grained particles (71% fines) compared to sediments over the baseline period (October 1998 to August 2000). Sediment composition at NF24 continued to be highly variable; with samples having overall slightly higher sand content after the new outfall went on-line (Appendix C6).

TOC—Post-diversion values of TOC did not generally change substantially from the baseline system values (Figure 4-15a). Exceptions included a decrease in TOC content at NF24 in October 2001 compared to earlier sampling periods. However, the station mean value returned to baseline values in August and October of 2002. TOC at NF22 increased since October 1998 (Figure 4-15a), evidenced by an approximate 26% increase in late 2002 relative to pre-diversion values (Appendix C5d). Then again,

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[7] Gordon Wallace first developed his model in the 1995 OBR (Hillbig *et al.*, 1997, Technical Report 96-5). Recommendations leading the NCSS study were made during the 1997 OMTF subcommittee meeting; meeting minutes provided in Appendix C6.

the apparent increase is small when compared to the station mean value for TOC at NF22 measured over the full baseline (1992–2000 baseline station mean value at NF22 = 0.98% vs. 1.07% NF22 station mean value from October 2000 to 2002).

***Clostridium perfringens*—**Following outfall startup, the post-diversion, station mean values of *C. perfringens* increased across all NCSS stations except FF10, which is located further away from the outfall and closer to the Harbor than the other NCSS stations (Figure 4-15b). Increases in post-diversion, station mean values of *C. perfringens* were the highest at NF24, the station located directly adjacent to the outfall, followed by NF08 and NF22 (Appendix C5d). These findings are consistent with results from the *Clostridium* regional analysis (Section 4.3.3), suggesting that the observed increase at NF24, NF08 and NF22 may be due to a localized influence of effluent discharge at the new outfall.

Contaminants—With few exceptions, post-diversion, station mean concentrations of organic contaminants and metals did not change substantially from baseline (October 1998 and August 1999 and 2000) following outfall startup, consistent with the very low levels observed by MWRA in the treated effluent (representative parameters shown in Figure 4-15c,d; Appendix C5d). Exceptions included:

- Approximate 72% increase in total PCB, 38% increase in total DDT, and 64% increase in Cd at FF10
- Approximate 36% decrease in total LAB at NF22
- Approximate 36% increase in Cd at NF08 (Figure 4-15d)

While selected contaminants appeared to increase at some NCSS stations following outfall startup (above), the post-diversion values are within the range of values observed over the full baseline period (August surveys, 1992–2000) for those same NCSS stations. Further, observed increases in Cd should be viewed with caution given that the concentrations measured were less than 10 times the detection limit, where there is inherently greater variability. In addition, most of the post-diversion increase observed at NF08 was attributed to six individual samples with high values. The increase in total PCB and total DDT at FF10 is attributed primarily to two or three single samples with considerably higher concentrations than the majority of samples measured over the two-year period following outfall startup. In general, these findings do not reflect a rapid increase in contaminants and/or TOC since outfall startup.

Chemistry Interrelationships—Correspondence within bulk sediment properties and against contaminants was evaluated for all NCSS stations (NF08, NF22, NF24, FF10) sampled before (October 1998 to August 2000) and after (October 2000 to October 2002) startup of the new outfall. Correspondence was evaluated using the individual replicates from each station, not station mean values. Correlation coefficients (r values) for the two datasets, *i.e.*, pre- and post-diversion, were then compared to determine if there were measurable changes in the system as a result of the new outfall coming on-line in September 2000.

Tabular results from the correlation analysis are presented in Appendix C4 (Table C4-3); representative correlation plots are shown in Figures 4-16, 4-17, and 4-18. Contaminants and bulk sediment properties were moderately correlated before and after the new outfall came on-line. Unlike in the entire nearfield (Section 4.3.4), the correspondence within bulk sediment properties (Figure 4-16) and against *C. perfringens* (Figure 4-17) improved considerably (higher r value) at the NCSS stations after outfall startup. Similarly, the correspondence between bulk sediment properties and organic contaminants also improved, while no substantial changes were observed for most metals (Figure 4-18). The disparity between correlation trends between nearfield (20 nearfield plus FF10, FF12 and FF13) and NCSS (FF10, NF08, NF22 and NF24 only) stations following outfall startup could be associated with subtle seasonal influences in that the nearfield chemistry interrelationships are evaluated using summer only data, while the NCSS correlations are evaluated using winter, summer and fall data.

Comparison to Nearfield—Results presented in Kropp *et al*. (2000) showed that the temporal response of the baseline for representative organic and metal contaminants was similar for both the NCSS stations and the nearfield on average. 2001 and 2002 contaminant results from the NCSS stations on average were similar to the nearfield baseline mean values, suggesting that the four NCSS stations continued to be reasonably representative of the nearfield (see Appendix C5b, c).

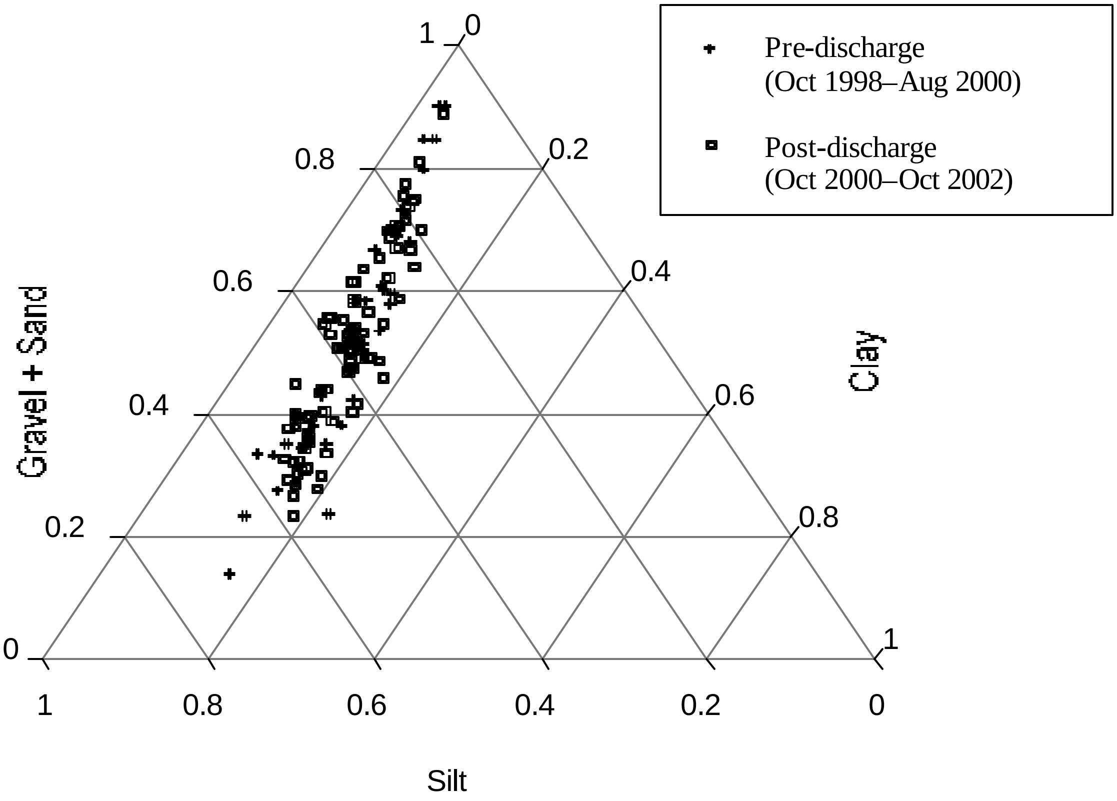

Figure 4-14. Grain size composition at NCSS stations from 1998 to 2002.

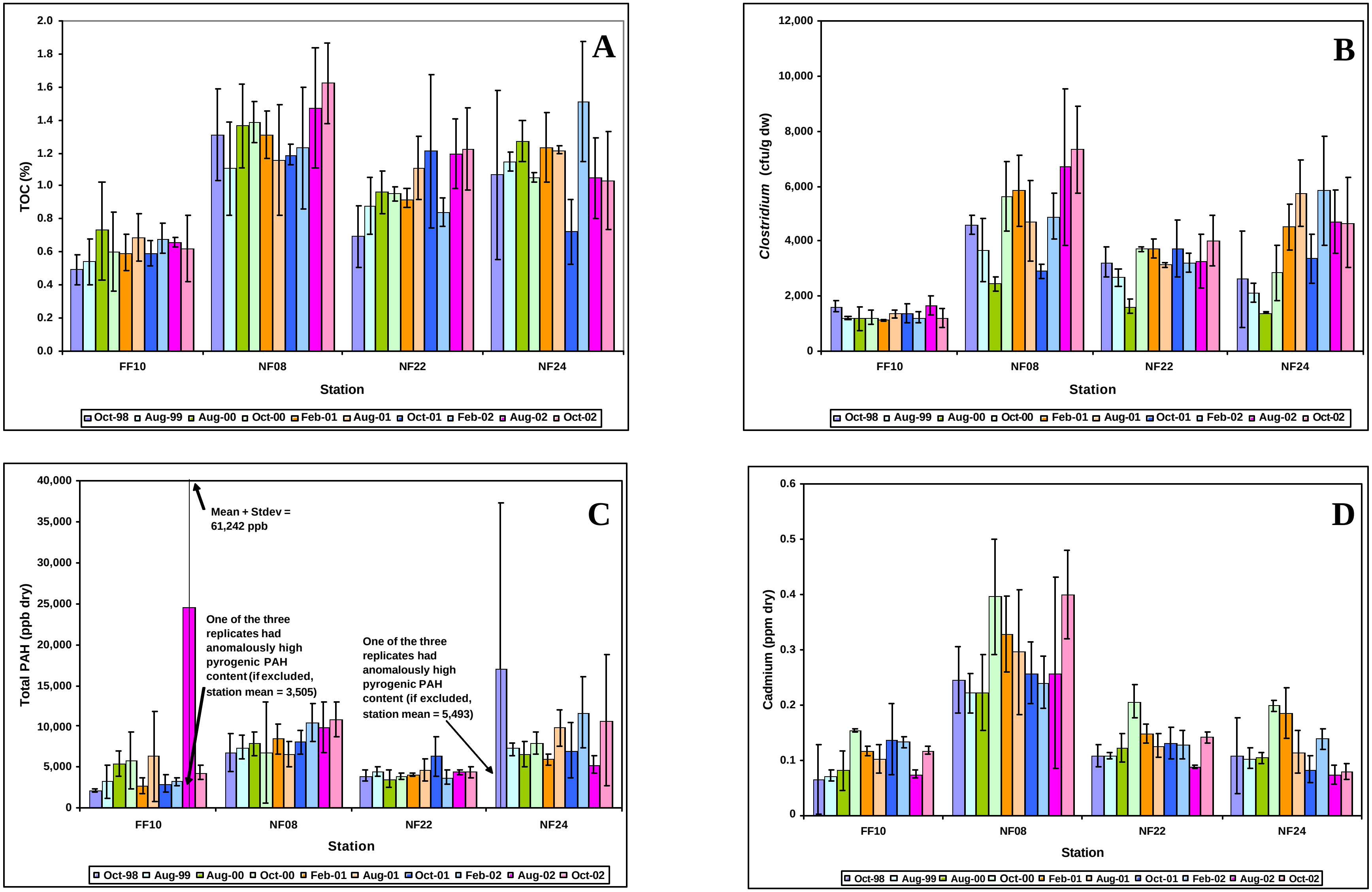

Figure 4-15. Station mean concentrations of TOC (A), *Clostridium perfringens* (B), total PAH (C), and cadmium (D) at NCSS stations from 1998 to 2002.

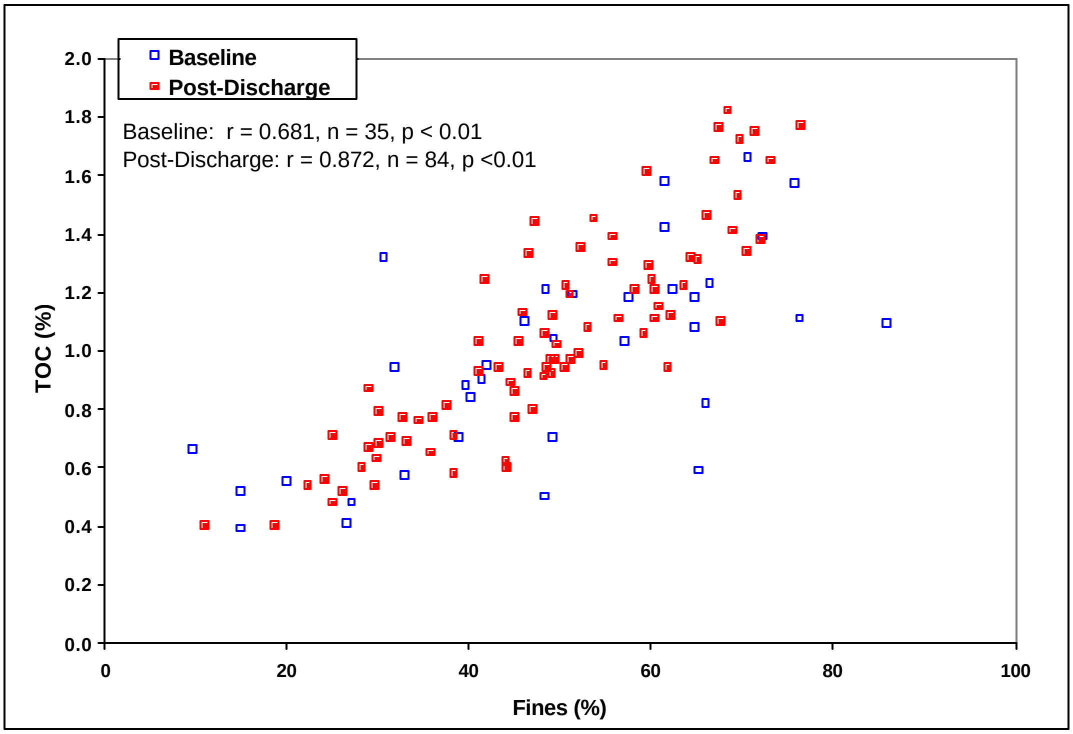

Figure 4-16. Correspondence between percent fines and TOC at NCSS stations before (baseline, October 1998 to August 2000) and after (post-discharge, October 2000 to October 2002) the new outfall came on-line.

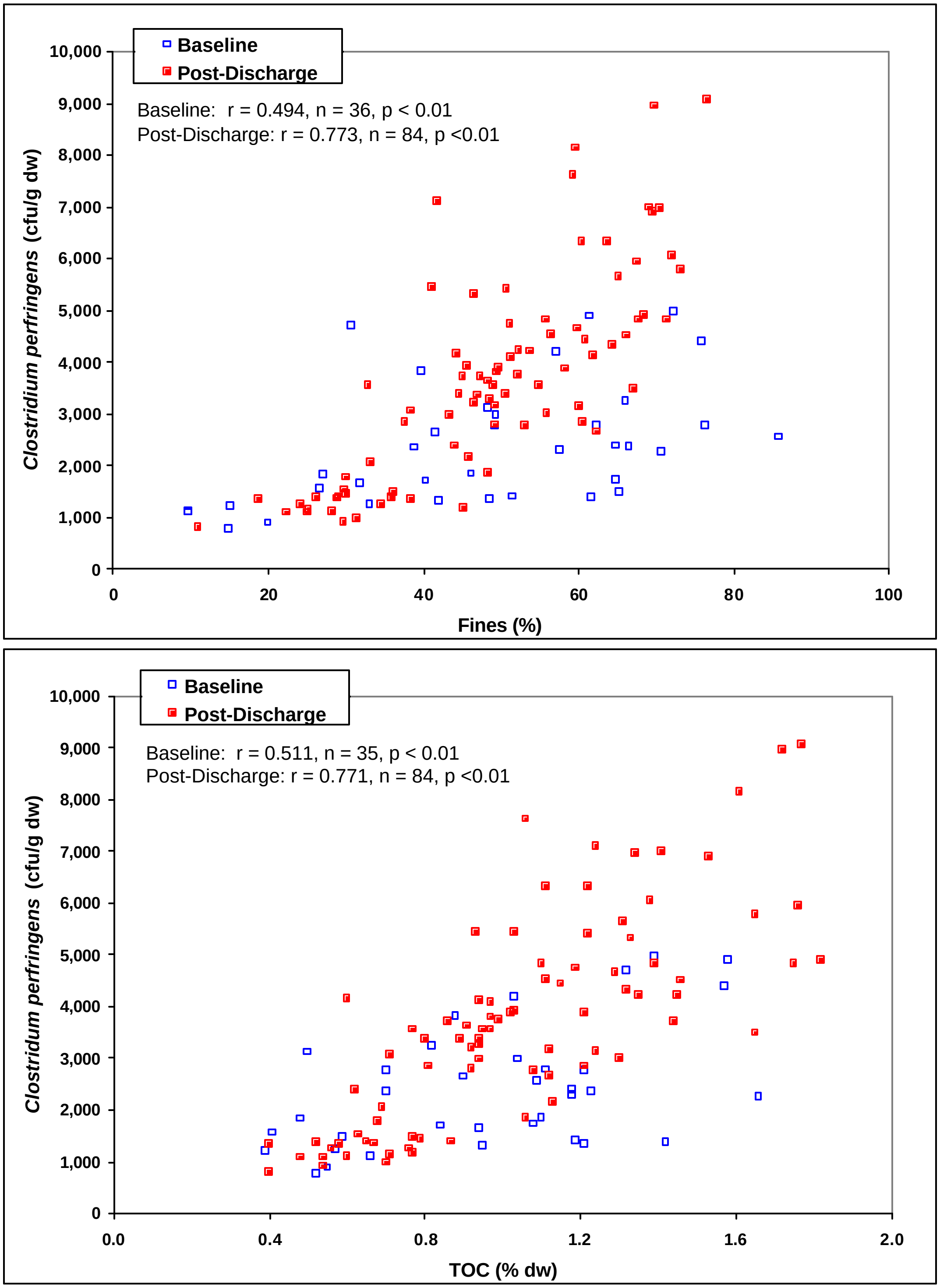

Figure 4-17. Correspondence between bulk sediment properties (percent fines, TOC) and *Clostridium perfringens* at NCSS stations before (baseline, October 1998 to August 2000) and after (post-discharge, October 2000 to October 2002) the new outfall came on-line.

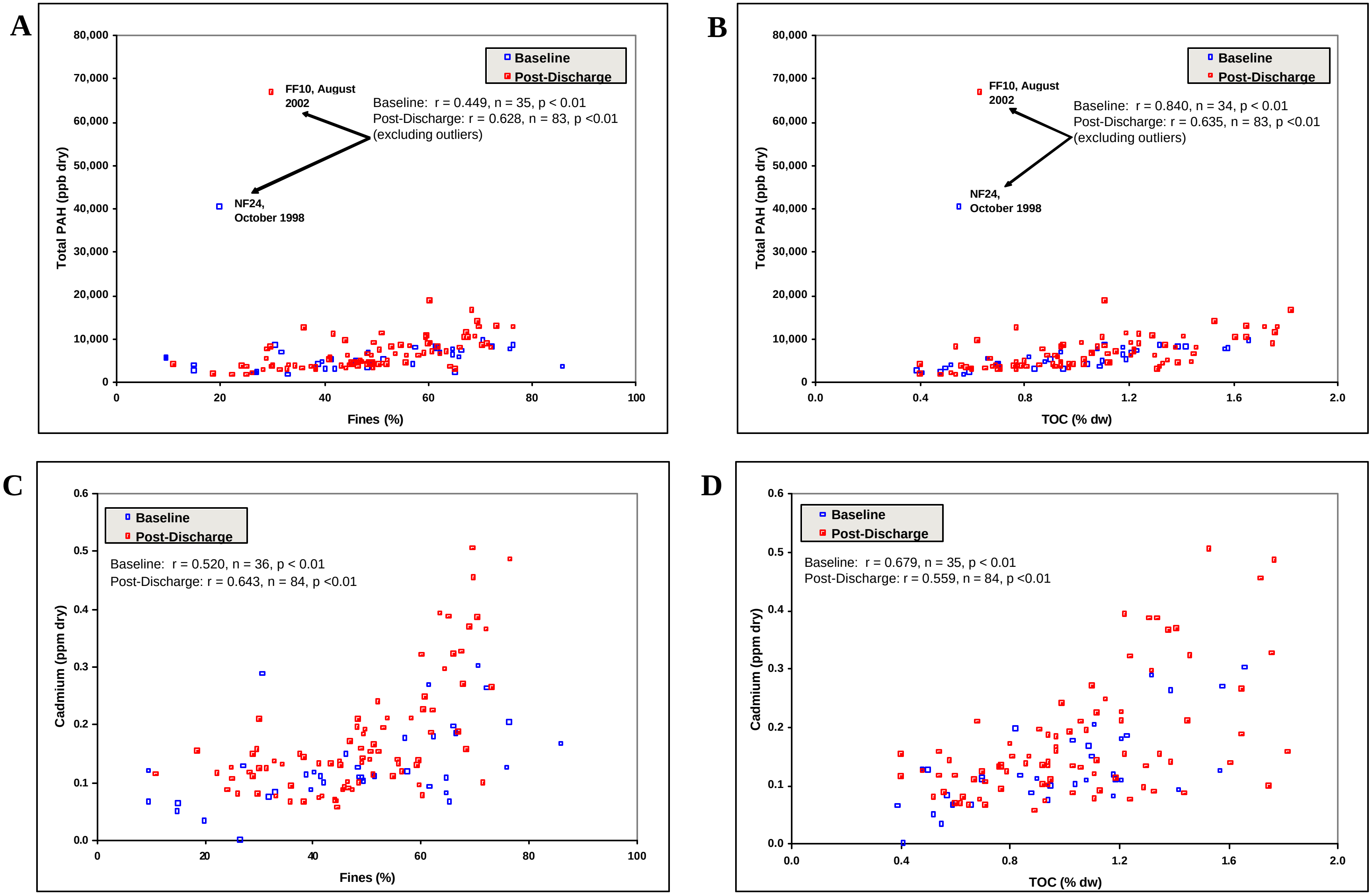

Figure 4-18. Correspondence between bulk sediment properties (percent fines, TOC) and representative parameters (total PAH, cadmium) at NCSS stations before (baseline, October 1998 to August 2000) and after (post-discharge, October 2001 to October 2002) the new outfall came on-line.

4.4 Comparison of Baseline Data to Thresholds

Nearfield baseline levels were established for contaminants in sediment based on the mean areal distribution for nearfield stations. Baseline and 95% confidence intervals were determined for each sampling year from 1992–1995 and 1999–2002 (August surveys only) and were evaluated against the MWRA monitoring thresholds based on the Long *et al.* (1995) ER-M values (Table 4-3). Long *et al.* (1995) values are based loosely on sediment that contains 1% TOC. The list of PAHs included in the Long *et al.* (1995) ER-M total PAH summation differs from the list of PAHs included in the total PAH summations presented in this report. However, the total PAH values presented in this report are more conservative because they include many more PAHs compared to Long *et al.* (1995). Also, note that nearfield samples collected from 1996 to 1998 were not analyzed for contaminant parameters and as a result these sampling years are not included in the threshold comparisons. Further, nearfield contaminant results from 2000 are from a limited sampling year. These baseline data (2000) are included in Table 4-3 and Figure 4-19 for illustrative purposes only.

There were no threshold exceedances in August 2001 and 2002. Further, the temporal response of the baseline for organic and metal contaminants showed relatively constant means without substantial variability (see Figure 4-19 for representative parameters). Annual mean values for any given year were generally representative of the baseline over time and were well below ER-M thresholds (Table 4-3). Interestingly, the 95% upper confidence limit approached or exceeded the significant increase value[8] for total PAH in 2002 and total DDT in 2001 (Figure 4-19a,b). The elevated concentration for total DDT resulted from one station, NF21, that had an unusually high total DDT measured in August 2001 (see Section 4.3). The elevated concentration for total PAH resulted from one replicate sample at station FF10, that had an unusually high PAH content measured in August 2002 (see Section 4.3).

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[8] Determination of significant increase values, and an evaluation of significant increase values to thresholds was presented in Kropp *et al.*, 2001.

Table 4-3. Comparison of annual nearfield baseline mean concentrations and thresholds (ER-M) for the period 1992–2002.

Parameter	Units (dry)	ER-M[a]	1992		1993		1994		1995[b]		1999		2000[c]		2001 Post-Diversion		2002 Post-Diversion	
			Mean	Stdev	Mean	Stdev	Mean	Stdev	Mean	Stdev	Mean	Stdev	Mean	Stdev	Mean	Stdev	Mean	Stdev
Total PAH[d,e]	ng/g	44792	5560	6230	5690	8090	4430	3650	5030	5030	5040	4880	5330	3220	5290	4600	6950	11300
Total PCB[d]	ng/g	180	14.7	16.3	28.6	39.1	15.2	11.9	16	14.5	10.5	8.85	15.3	9.78	12.7	10.3	18.2	23.5
Total DDT[d]	ng/g	46.1	3.3	3.5	3.82	5.44	5.27	6.53	2.59	3.12	2.7	3.2	2.36	1.42	5.28	18.6	2.3	2.21
Total Chlordane[d]	ng/g	6[f]	0.108	0.322	0.52	0.652	0.862	0.826	0.234	0.382	0.175	0.193	0.311	0.225	0.334	0.254	0.191	0.175
Total Pesticide[d]	ng/g	NA	1.18	2.11	1.12	0.993	4.04	2.85	0.269	0.281	0.0664	0.152	0.442	0.26	0.178	0.15	0.242	0.255
Total LAB[d]	ng/g	NR	299	542	392	568	221	282	77.7	97	66.8	60.2	130	77.1	77	61.6	70	53.2
Al	pct dry	NR	5.26	0.686	4.97	0.938	5.14	1.13	4.55	1.02	4.98	0.858	5.26	0.713	5.5	0.607	6.27	0.681
Cd	: g/g	9.6	0.189	0.218	0.228	0.255	0.153	0.136	0.175	0.123	0.0896	0.0644	0.131	0.088	0.12	0.0902	0.0909	0.0774
Cr	: g/g	370	85.1	56	80.2	60.1	86.8	44.6	64.8	39.6	61.9	23.3	77.2	26.4	75.1	32	78.9	32.4
Cu	: g/g	270	27.6	23.9	26.1	19.2	22.8	12.5	19.2	13.1	23.2	9.33	25.6	12.1	24.3	22.2	25.1	11.6
Fe	pct dry	NR	2.31	0.733	2.15	0.829	2.25	0.676	1.8	0.535	2.33	0.446	2.45	0.542	2.38	0.54	2.42	0.515
Pb	: g/g	218	47.2	23.6	42.9	20.7	43.8	14.5	43	17	44.2	13.8	44.7	12.4	46.4	16.6	50.7	36.4
Hg	: g/g	0.71	0.28	0.29	0.199	0.198	0.217	0.22	0.289	0.432	0.225	0.138	0.274	0.217	0.269	0.224	0.202	0.121
Ni	: g/g	51.6	18.2	7.63	18.5	8.9	17	7.49	15.5	6.32	17.3	6.82	22	7.06	18.1	5.25	17.2	6.56
Ag	: g/g	3.7	0.707	0.902	0.575	0.719	0.553	0.495	0.471	0.332	0.493	0.314	0.559	0.504	0.489	0.312	0.486	0.336
Zn	: g/g	410	69.7	45	60.8	38.8	56.9	23.7	56.6	27.2	59.2	19.1	74.7	47.4	60	22.6	64.2	20.9
Gravel	pct	NR	8.04	17.3	4.03	10.7	4.08	9.09	3.3	6.5	5.9	11.3	7.89	14.7	4.95	9.62	3.21	6.41
Sand	pct	NR	59.5	23.6	68	22.8	60	26.1	61.4	26.9	59.6	23.5	57.3	20.7	60.4	22.4	59.3	20.7
Silt	pct	NR	24.7	18.3	23.1	20.2	28.1	22.1	25.5	21.5	26.2	19.8	24.8	18.1	26	18.8	27.4	17.4
Clay	pct	NR	7.74	6.95	4.88	3.98	7.79	6.55	9.8	14.4	8.3	5.92	9.94	6.05	8.7	5.89	10.1	4.99
Fines[d]	pct	NR	32.5	24.3	28	23.7	35.9	27.7	35.3	28	34.5	24.9	34.8	23.7	34.7	24.3	37.5	21.9
TOC	pct	NR	1.05	0.656	0.847	0.924	0.787	0.555	0.802	0.695	0.75	0.422	0.943	0.528	0.885	0.537	1.02	0.655
Clostridium	cfu/g	NR	2850	3110	3090	2600	3600	2540	4980	5750	1940	1410	1460	1370	2490	1690	3150	1970

[a] From Long *et al*. (1995)

[b] No contaminant data collected for August surveys conducted from 1996 to 1998.

[c] The 2000 data represent a reduced sampling year and cannot be compared to the threshold. Data are included for illustrative purposes.

[d] Grain size and contaminant groups defined in Section 4.2.3

[e] Total PAH reported was calculated from an extended list of individual PAHs that were not included in the ERM total PAH group (Long 1995)

[f] ER-M value is for Total Chlordane; ER-M value from Long and Morgan (1991)

NR = Not regulated

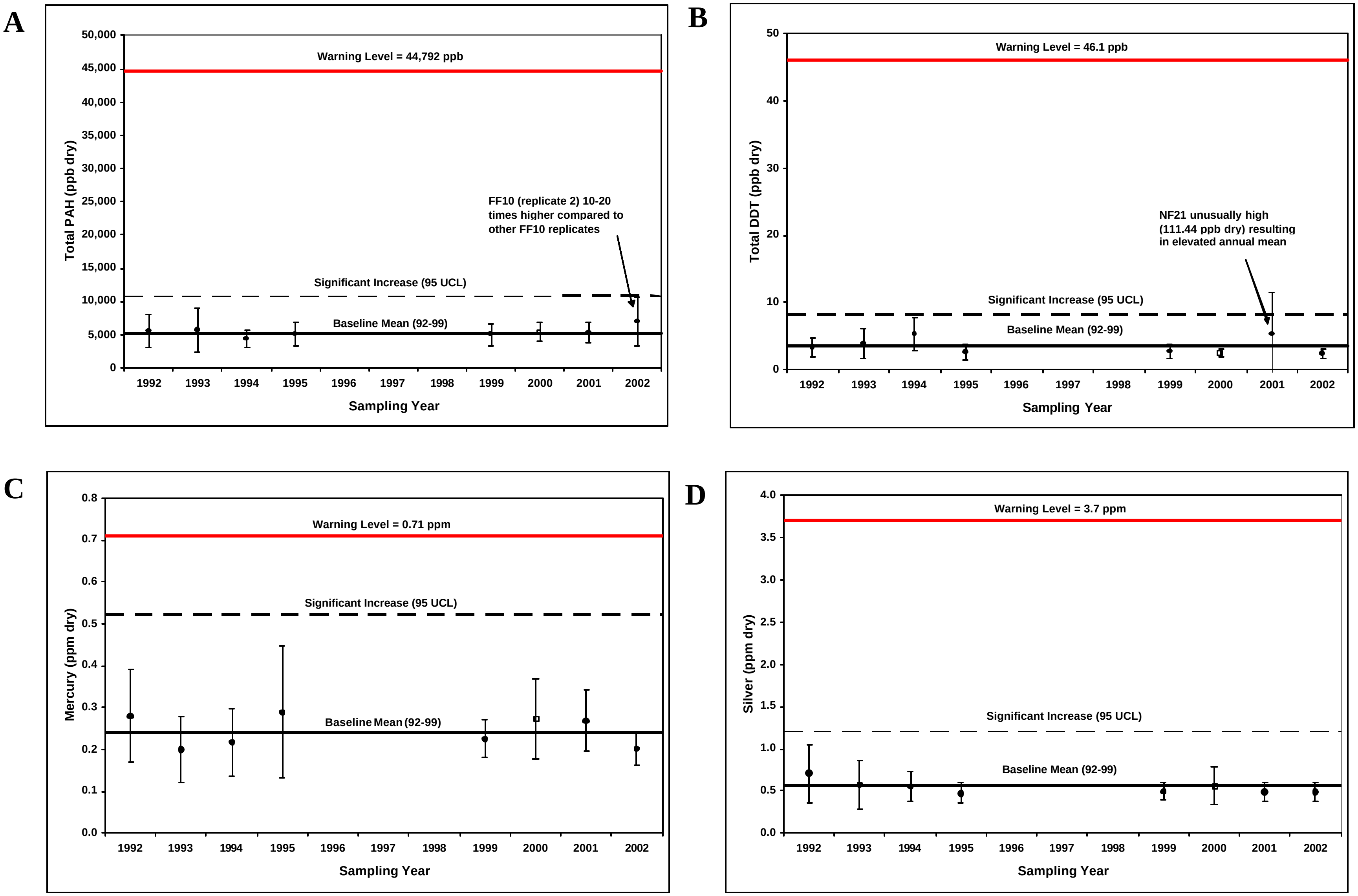

Figure 4-19. Nearfield annual mean values for representative contaminants from 1992 to 2002 showed relatively constant means and were well below the ER-M monitoring thresholds. Post-diversion annual mean values continued to be representative of the baseline over time. (No contaminant data collected from 1996 to 1998; error bars represent 95% confidence limits; UCL = upper confidence limit.)

4.5 Sediment Contaminant Monitoring Plan Revisions

Proposed changes to the sediment contaminant monitoring plan and rationale for those changes were presented by MWRA and Battelle to the Outfall Monitoring Science Advisory Panel (OMSAP) in April 2003, and are summarized below. Complete details of the monitoring design and background, proposed monitoring revisions and rationale behind the proposed revisions were provided in a briefing package prepared by MWRA in support of the April OMSAP meeting (MWRA, 2003a).

4.5.1 Proposed Changes to Monitoring Plan

Based upon a thorough review of the monitoring results from 1992 to 2002, MWRA proposed changes to sediment contaminant monitoring that are consistent with, but more protective than, those that were envisioned in the Monitoring Plan (MWRA, 2003a). MWRA proposes to:

- Continue to collect and analyze sediment contaminant samples in duplicate from stations NF12 and NF17 at least annually through 2005. If feasible, this sampling will be carried out as part of the USGS/MWRA cooperative study.
- Continue to analyze available sediment trap samples for tracers of effluent solids (*e.g.*, silver, *Clostridium*) through 2005.
- Review data from the USGS/MWRA cooperative special study or its successor after the 2005 field season to determine what additional work is warranted.
- Decrease the scheduled frequency of contaminant analyses at other nearfield and all farfield stations to every third year, beginning immediately. Except at NF12 and NF17, analyses would not be scheduled for 2003 and 2004, and would occur again in 2005[9].
- Continue to collect and analyze sediment samples for grain size, TOC, and spores of *C. perfringens* at all benthic community sampling stations during the annual August surveys.

4.5.2 Rationale for Changes to Monitoring Plan

Chemical concentrations in sediments are strongly influenced by grain size and TOC, which influence the redox condition with depth in the sediments. Sediment oxidation in turn influences contaminant retention in sediments, especially metals. In a system like Massachusetts Bay with a relatively constant input term (source(s)) and stable grain size and TOC levels in the sediments, one would not expect substantial changes in contaminant levels in sediments. If any of these forcing functions were to change appreciably, one could expect to see the chemical concentrations change.

The research and monitoring carried out to date documents that:

- Contaminants in effluent are lower than predicted in the outfall Environmental Impact Statement (EIS) and used to plan the monitoring program in the early 1990s,
- Rapid response of contaminants in nearfield and farfield sediments are not expected and have not been observed,
- The time required to detect changes in contaminant concentrations in the nearfield is long (in some cases decades),

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[9] Details of MWRA's proposal for soft-benthic community monitoring are still being worked out, and will be presented at the summer 2003 OMSAP workshops. Changes under consideration for monitoring in 2004+ include reductions in the numbers of both nearfield and farfield stations. Any station reductions proposed at that time would affect both infaunal and contaminant sampling. We anticipate proposing to continue sediment profile imaging at all 23 western Mass Bay stations through 2005.

- The relationship of contaminants to major controlling factors (grain size, TOC, RPD) is understood, and
- *C. perfringens* and silver are excellent effluent tracers, and will serve as early indicators of effluent discharge influence on nearby sediments

Additional details regarding justification for the proposed monitoring plan revisions are provided in the briefing package prepared by MWRA (2003a).

4.5.3 April 2003 OMSAP Meeting

At the April 2003 meeting, OMSAP concurred with MWRA's proposed changes to the sediment contaminant monitoring plan, with the understanding that a set number of stations would continue to be monitored every year for sediment contaminants at least through 2005. MWRA later proposed (at the June 2003 OMSAP meeting) that stations NF12 and NF17 be used for continued sediment contaminant monitoring.

Following the April 2003 OMSAP meeting, MWRA submitted a formal request to the United States Environmental Protection Agency (USEPA), Region 1 to review and approve the proposed changes to the sediment contaminant monitoring. Regulators (USEPA and MADEP) approved these changes on an interim basis in summer 2003; they formed part of the package of monitoring plan modifications proposed for permanent implementation in November 2003.

4.6 Conclusions

The inclusion of post-diversion (2001 and 2002) data to the baseline continued to support a picture of two regions—*nearfield* and *regional*—each defined in physical and chemical terms. In the nearfield sediments of Massachusetts Bay, there is a series of stations with heterogeneous sediments in relatively close proximity to, and roughly equidistant from, the historic source of contaminants (*i.e.*, Boston Harbor). Factors that influence contaminant concentrations in the nearfield include local (Boston Harbor) and distributed sources (e.g., atmospheric input, distant rivers), primarily related to grain size factors suggestive of different sediment depositional environments. The primary factor associated with the variance in the data was sand content. The secondary factors were associated with anthropogenic analytes and fine particles.

In contrast, regional stations are spatially distributed throughout Massachusetts and Cape Cod Bay systems, with some stations closer to, and others far away from, Boston Harbor. Contaminant concentrations at offshore regional stations (>20 km from Deer Island Light) generally had lower concentrations of contaminants compared to near harbor regional stations (<20 km from Deer Island Light). Variability among contaminant data was reduced when near harbor regional stations were excluded from the correlation analysis, indicating that factors that influence contaminant concentrations at offshore regional locations include distributed sources (e.g., atmospheric input, distant rivers). Further, near harbor regional and nearfield stations, with similar grain size to offshore regional stations, generally had higher contaminant concentrations compared to offshore regional values. Contaminant concentrations present at levels above the underlying offshore regional signature are indicative of a local source (Boston Harbor). As evident in the nearfield data, sand content strongly influenced the variance in the regional data. In addition, the sewage tracer data showed that the proximity to Boston Harbor (the historic source of sewage contaminants) influenced the concentration of *C. perfringens* and total LAB at some regional stations.

While localized increases in some metals and organic contaminants were observed at one or more stations, results from the range plots demonstrated that most of the post-diversion data (2001 and 2002) fell within the general distribution of samples collected during the baseline period (1992–2000). Localized increases observed at NF10, NF14, and NF17 were qualitatively confirmed by the multidimensional statistical analysis using principal components analysis (PCA). Otherwise, the PCA results indicated that levels of anthropogenic compounds (pesticides, PCBs, PAH, and selected metals) in the nearfield and regional sediments generally decreased during the year following the activation of the diffuser system. Sediment data available to date suggest that the treated effluent discharged from the diffuser has not caused an increase in contaminants of environmental concern to the Massachusetts and Cape Cod Bay systems.

While no widespread increases were observed in contaminant concentrations, *C. perfringens* abundances (normalized to percent fines) clearly increased in 2001 and 2002 at nearly all nearfield stations. The greatest increases were generally observed at those stations located within 2 km of the western end of the new outfall (Diffuser 55). These findings suggests that effluent discharge from the new outfall is having, as expected, a localized, but modest, influence on nearby sediments. Further, these findings indicate that *C. perfringens* are an excellent indicator of the response in the sediments to diversion of the effluent discharge. Lead concentrations also increased above baseline at five nearfield stations in 2001, four of which also are located within 2 km of the new outfall. Concentrations of Pb remained above baseline in 2002 at three of these stations. However, the increases were either small or random (except at NF14, NF15 and NF20). Thus, the higher values could be due to an unknown source, and do not definitively suggest an effluent signal as observed with the *C. perfringens* data.

Excluding regional stations located close to the outfall (*i.e.,* NF12, NF17, and NF24), post-diversion abundances of *C. perfringens* (normalized to percent fines) showed no such increase at regional locations. This strongly indicates that the effluent discharged from the new outfall is not having a negative effect on regional sediments. Rather, abundances of *C. perfringens* (normalized to percent fines) decreased slightly in 2001 and 2002, at regional stations located near Boston Harbor (*i.e.,* FF10, FF12 and FF13), indicating that diversion of the effluent discharge to the new outfall is having a positive influence on the near harbor sediments.

Coats (1995) estimated the length of time it would take to detect contaminant increases between the onset of secondary effluent discharge at the Massachusetts Bay outfall as the mean of nearfield sediments located within 2 km of the outfall *(i.e.,* NF13, NF14, NF17, NF19, NF23 and NF24). He suggested that Cd and Ag would show detectable increases in the nearfield sediments within 1.1 and 1.5 years of the new outfall coming online, respectively, based on estimated levels of contaminants in secondary treated effluent. Other contaminants were not expected to show increases until at least six or more years after the offshore effluent discharge began (Coats, 1995). Results from the first two post-diversion sampling events (August 2001 and 2002) represent two years after onset of effluent discharge. The post-diversion results[10] do not confirm with Coats' predictions in that detectable increases[11] in Cd and Ag were not observed at stations located within the vicinity of predicted increase following outfall startup. However, apparent increases in Pb, were observed at three (NF14, NF17, NF23) of the six nearfield stations identified above in 2001 (NF14: August 2001 concentration approximately 2 times baseline mean; NF17 and NF23: August 2001 concentrations <1.4 times baseline mean); concentrations remained above baseline at two of these stations in 2002 (NF14 and NF23). In addition, total Chlordane, Al, Cr, Cu, Fe, Hg, Ni and Zn increased at NF13 in 2002, a station located within the vicinity of the predicted increase. Selected contaminants have also increased at other stations (*i.e.,* NF10, NF21) located outside the vicinity of the predicted increase.

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[10] Evaluation of post-diversion results was performed using <u>individual</u> station results, rather than <u>mean</u> results for all stations located within 2 km of the outfall.

[11] Compared to full baseline (August surveys, 1992–2000).

The post-diversion increases in contaminant concentrations at NF14, NF21, and NF23 may be related to small-to-modest increases in percent fines. Otherwise, post-diversion increases identified at NF10, NF13 and NF17 do not appear to be related to grain size or TOC factors, because there was no corresponding or systematic increase in percent fines or TOC in August 2001 and 2002 relative to baseline values (1992–2000). Since the results from August 2001 and 2002 represent only the first two sampling events after onset of effluent discharge, additional sampling (*i.e.*, more data points) in the future will allow for a more robust evaluation against Coats' model.

While local increases in selected contaminants and *C. perfringens* abundances were observed in the system following outfall startup, baseline mean values for organic and metal contaminants in the nearfield continued to be well below the MWRA thresholds in 2001 and 2002.

5. 2002 SOFT-BOTTOM INFAUNAL COMMUNITIES

by Nancy J. Maciolek, Eugene D. Gallagher, and Kenneth E. Keay

5.1 Baseline Conditions in Massachusetts Bay

The soft-bottom benthos of Massachusetts Bay has been studied for several years by the MWRA as part of the program to locate a new treatment plant outfall system in the bay nine miles off Deer Island. Stations have been sampled annually since August 1992. The area near the diffuser array, where potential impacts might occur, is primarily hard-bottom with few areas of soft sediments, resulting in the necessity of positioning benthic stations according to sediment type, rather than randomly. This constraint has resulted in the majority of the 23 nearfield stations being positioned to the north and west of the diffuser array (Figure 2-1). Six of these stations (NF12, NF17, NF24, FF10, FF12, FF13) are sampled in triplicate, and single samples are collected from the remaining 17 stations. Eight farfield stations, also sampled in triplicate, represent an area far enough from the outfall that they are not expected to be impacted by the discharge. These farfield stations are located from near Cape Ann in the north to Cape Cod Bay in the south. Two of the stations (FF04 and FF05) are located within the Stellwagen Basin National Marine Sanctuary, and two stations (FF06 and FF07) are within Cape Cod Bay. All farfield stations are sampled in triplicate.

Only minor repositioning of stations has occurred since the inception of the program (*i.e*., station FF01 was replaced with FF01A). Three stations (FF10, FF12, and FF13) originally considered as farfield stations were reclassified as nearfield beginning in 1996, although the station labels were not changed. Other changes in the sampling program, which occurred primarily during the early years 1992–1994, are discussed in the annual reports to the MWRA (*e.g.,* Blake *et al.* 1998).

During the baseline period, 1992–2000, multivariate analyses of the infauna data indicated that sediment grain size was the dominant factor in structuring the benthic communities. The nearfield stations fall into one of two major sediment regimes: fine sediments characterized by the polychaete annelids *Prionospio steenstrupi*, *Spio limicola*, *Mediomastus californiensis*, and *Aricidea catherinae*; and sandy sediments (primarily NF13, NF17, and NF23) characterized by the sylllid polychaetes *Exogone hebes* and *E. verugera* and the amphipods *Crassicorophium crassicorne* and *Unciola* spp. In addition to the influence of habitat heterogeneity, the nearfield area, in water depths of 27–35 m, is often affected by strong winter storms (*e.g*., Bothner 2001), which cause episodes of sediment resuspension that impact the benthic communities (Hilbig and Blake 2000, Kropp *et al.* 2002).

The fauna that characterizes the farfield differs from that seen in the nearfield. The farfield stations span a greater depth range (33–89 m), are geographically widespread, and have sediment types that are generally finer than those seen in the nearfield. Polychaete worms (*e.g*., *Euchone incolor*, *Aricidea quadrilobata*, and *Levinsenia gracilis*) are the predominant organisms at most of the stations. *Prionospio steenstrupi*, which is dominant at many nearfield stations, is also common at some of the farfield stations. A different species of polychaete, *Cossura longicirrata*, is dominant at station FF06 in Cape Cod Bay.

The influence of winter storms that have impacted the bottom sediments was discussed by Kropp *et al.* (2002a,b), in particular the major storm in late 1992. Following that storm, abundance and species richness in the nearfield region declined considerably, but rebounded during successive years. Kropp *et al.* (2002) pointed out that because of the storm's effects, "the high variability in this baseline may make it difficult to recognize potentially important changes in the benthos resulting from effluent discharges through the outfall."

Samples collected in August 2001, the first year of data after the outfall went online, did not indicate any discernable impact of the discharge on the infauna (Kropp *et al.* 2002). Data discussed in this chapter represent the second year of post-baseline data and are focused on an evaluation of whether any impact can be discerned.

5.2 Methods

5.2.1 Laboratory Analyses

Samples were rinsed with fresh water over 300-μm-mesh screens and transferred to 70–80% ethanol for sorting and storage. To facilitate the sorting process, all samples were stained in a saturated, alcoholic solution of Rose Bengal at least overnight, but no longer than 48 h. After rinsing with clean alcohol, all organisms, including anterior fragments, were removed and sorted to major taxonomic categories such as polychaetes, arthropods, and mollusks. After samples were sorted, the organisms were identified to the lowest practical taxonomic category, usually species.

Voucher specimens of each species were kept as part of the MWRA reference collection. During the past contract year, taxonomists from Cove Corporation, who had been responsible for the last several years of identifications, worked closely with the ENSR taxonomists, who had also participated in the early years of the program. Appendix D1 includes a discussion of taxonomic issues that were resolved as a result of this collaboration and the adjustments that were made to the MWRA Massachusetts Bay database.

5.2.2 Data Analyses

***Preliminary Data Treatment*—**Prior to performing any of the analyses of the 2002 and 1992–2002 MWRA datasets, several modifications were made. These were generally similar to those performed in previous years and are summarized in Appendix D1. Calculations of abundance included all infaunal taxa occurring in each sample, whether identified to species level or not, but do not include epifaunal or colonial organisms. Calculations based on species (number of species, dominance, diversity, evenness, cluster and principle components analysis) included only those taxa identified to species level, or those treated as such. A list of all taxa identified during the Outfall Monitoring Program (1992–2002) is contained in Appendix D2.

Station Groupings—For the infaunal analyses, the stations termed "nearfield" include all stations having NF designations plus stations FF10, FF12, and FF13 (Figure 5-1). This was done to allow all western Massachusetts Bay Stations to be included in a single analysis. Stations termed "farfield" include all remaining eight stations having FF designations.

5.2.3 Statistical Analysis

Initial inspection of the benthic data included production of summaries of species densities by sample, tables of species dominance, and lists of numbers of species and numbers of individuals per sample. Data were inspected for any obvious faunal shifts or species changes between stations. Following these preliminary inspections of the data, a series of community parameters was calculated along with multivariate statistics to assess community patterns and structure. Changes in infaunal community structure that are suspected to be due to the outfall can be assessed by comparing community structure differences between the nearfield and farfield through time, and comparing rates of change in community structure before and after the outfall went online in September 2000.

The multivariate programs are included in COMPAH96, originally written by Dr. Donald Boesch and now available from Dr. Eugene Gallagher (http://www.es.umb.edu/edgwebp.htm). Patterns in benthic communities were analyzed by cluster analysis using CNESS (chord-normalized expected species shared), which was developed by Gallagher and is related to Grassle and Smith's (1976) NESS (normalized expected species shared). CNESS and NESS include several indices that can be made more or less sensitive to rare species in the community and as such are more versatile than other similarity measures such as Bray-Curtis similarity, which is influenced by dominant species. Differences between CNESS and NESS are detailed in Trueblood *et al.* (1994). Both NESS and CNESS are calculated from the expected species shared (ESS) between two random draws of *m* individuals from two samples. For this project, the optimal value of *m* was calculated to value of 15. Results of these analyses were inspected for patterns among and between the different years.

Using MATLAB as an operating platform and additional programs written by Dr. Gallagher, several diversity indices were calculated, including Shannon's H' (base 2), Pielou's evenness values J', the rarefaction (ESn) method (Sanders, 1968) as modified by Hurlbert (1971) and Fisher's log-series *alpha*. May (1975) demonstrated that Sanders-Hurlbert rarefaction curves are often identical to those produced under the assumption that the distribution of individuals among species follows a log-series distribution. Hubble (2001) considers *alpha* the fundamental biodiversity parameter.

Principal Components Analysis of Hypergeometric probabilities (PCA-H) was also applied to the benthic data. PCA-H is an ordination method for visualizing CNESS distances among samples (see Trueblood *et al.*, 1994 for details). The PCA-H method produces a metric scaling of the samples in multi-dimensional space, as well as two types of plots based on Gabriel (1971). The Euclidean distance biplot provides a two-dimensional projection of the major sources of CNESS variation. The species that contribute to the CNESS variation can be determined using matrix methods adapted from Greenacre's correspondence analysis (Greenacre, 1984). These species are plotted as vectors in the Euclidean distance biplot. The second plot, the Gabriel covariance biplot, shows the association among species. Species that co-occur plot with species vectors with very acute angles. Species that have discordant distributions plot with angles approaching 180°.

Canonical PCA-H (CPCA-H) was used to investigate which environmental variables may be associated with differences in species composition. This procedure, in which CNESS distances or correlations are preserved, is based on redundancy analysis and ter Braak's canonical correspondence analysis (CANOCO) (ter Braak *et al.*, 1988). Regression algorithms are from Legendre and Legendre (1998). Transformations are as described in Legendre and Gallagher (2001). Six variables, including depth, percent TOC, percent fines, percent sand, percent gravel, and abundance of *Clostridium perfringens* spores were tested. (Percent sand was ultimately not used because it is so highly inversely correlated with percent fines.)

A series of ***general linear model (GLM***) analyses on the diversity data from all 644 samples was performed. The GLM analyses are ***factorial ANOVA*** models using STATION, YEAR, NEAR VS. FAR, and PRE- AND POST-DISCHARGE as categorical explanatory variables (Neter *et al.*, 1996). In this model, YEAR is nested within PRE- AND POST-DISCHARGE. STATION differences are nested within the NEAR VS. FAR contrast. The syntax tests whether there is a significant difference between PRE and POST given the year-to-year variability in the pre-outfall years, specified by nesting year—year0 in this analysis—within near by the following SPSS convention near(year0). Similarly, one can test whether there is a NEAR VS. FAR difference, given the station-to-station variability in the nearfield and the station-to-station variability in the farfield.

For these analyses, STATION was specified as a random factor. This is appropriate if one wants to generalize beyond the stations being monitored in the outfall design. The NEAR VS. FAR main effect is tested with the station-within-geographic-area mean square (with about 40 degrees of freedom – non integer because of the unbalanced design). This allows us to test the near*pre interaction term over the error mean square (with 597 df). Another design uses the stations as fixed and not a random subset of a larger set of stations. This allows a test of the NEAR VS. FAR effect with an F statistic with the error mean square for the denominator (with 597 df). The NEAR VS. FAR effect is non-significant in the pre-outfall years with both of these designs.

Log-series *alpha* and Pielou's J' were evaluated to investigate whether there were significant differences in species richness (*alpha*) or evenness (J') between the nearfield and farfield or among years; whether any outfall impact can be detected; and how sensitive the design is to changes in species richness that might result from the outfall.

***Time-sorted Similarities*.** As one tool for investigating whether there have been appreciable changes in the temporal changes in infaunal community composition during baseline or since outfall startup, the temporal trend in faunal similarities was examined. The faunal similarities among all samples taken at all sites during all years was created using Grassle & Smith's (1976) NESS faunal similarity index (as modified by Trueblood *et al*. 1994). The faunal similarities within a station were plotted for all of the pre-outfall years and the trend fit with Cleveland's (1993) locally weighted [LOESS] regression. The temporal trend in faunal similarities with samples before and after the outfall were also plotted and the temporal trend fitted. The rate of change of community structure was fit with decaying exponential equation (NESS=Faunal similarities within a year * exp(-Rate*difference in time)); the successional half life can be calculated from the Rate as half life =ln(2)/Rate. The successional half life is the time that it would take for samples within the same site to drop to half the average similarity among replicates within a single time period. The analysis was restricted to similarities calculated between pairs of samples collected at the same station. As an example, for station NF12, the year zero similarities are all those computed between replicate samples from a survey. The three samples collected in 2001 resulted in three year zero similarities. The year 1 comparisons for those three samples are the similarities between those three samples and the samples collected at NF12 one year earlier or later, namely triplicate samples collected in 2000 and 2002. Similarity matrices were generated for the nearfield and farfield monitoring data at three NNESS "*m*" sampling sizes:

- *m* = 1. At a sample size of 1, NNESS similarities are weighted heavily towards the contribution of dominant species; subdominant or rare taxa contribute almost nothing to the computed similarities. At m = 1, NNESS is equivalent to the Morisita-Horn index (Magurran, 1988).

- *m* = 15. This NNESS sample size was determined to be the optimal trade-off between sensitivity of the index to the contribution of both dominant and relatively rare taxa in the dataset.

- *m* = 8. This sample size is achieved by converting the hypergeometric probabilities to 1s and 0s, with the result that all species are equal in importance.

A biplot of within-station faunal similarities as a function of years between samples was constructed. To cut down on computational time and allow more direct comparisons between plots of nearfield and farfield data, each time-sorted NNESS matrix was randomly subsampled to provide 3,000 points for the biplots. X-axis values (years between samples) were jittered to allow better visualization of the patterns in similarity. For example, similarities for samples one year apart were randomly assigned a separation ranging from 1 to 1.25 years.

The slopes of the LOESS fits give an indication of whether and how rapidly species composition may be changing through time. Lines were fit for nearfield and farfield similarities among baseline samples, and also for similarities between discharge samples and those collected during baseline monitoring. Steeper slopes for the discharge curves compared to the baseline curves would indicate that community composition was changing more rapidly after outfall startup than before, and would suggest an outfall impact, especially if the change were restricted to nearfield samples.

5.3 Results

5.3.1 Laboratory Analyses

In Cove Corporation's Quality Assurance Report to ENSR, they noted that on September 3, 2002, sample FF10-1, which had been collected on August 21, 2003, was discovered to lack preservative. The sample was black and smelled of hydrogen sulfide. Formalin was added as soon as the error was discovered and prior to sieving the sample. All animals seemed to be in good condition and they proceeded with identifications; however it is noted that the density recorded below for this sample is about half that recorded in the other replicates from this station.

5.3.2 Species Composition of 2002 Samples and 1992–2002 Summary

During this past contract year, taxonomists from both teams that have worked on the HOM programs had the opportunity to work together and discuss identifications that had been established and perhaps questioned over the past several years. The results of these discussions are summarized in Appendix D1, in a chart that contains detailed information on how various taxa were treated prior to statistical analysis. A list of all species collected as part of the Outfall Monitoring Program is included in Appendix D2 and represents only modest changes from the species lists presented in recent years.

5.3.3 Nearfield Benthic Community Analysis for 2002

In the 2001 Outfall Benthic Report, Kropp *et al.* (2002b) discussed the idea that a significant storm in 1992, which was followed by additional storms that disturbed the sea floor, had had an important impact on the infaunal communities in the nearfield. The low densities and depressed species richness seen in the year or two following the 1992 storm were followed by a rebound, which appeared to have been completed by 2001, with the system approaching 1992 conditions, at least with regard to abundance, species richness, and log-series *alpha*. Two other descriptive community parameters, Shannon diversity (H') and Pielou's evenness (J'), did not show the same temporal pattern, but were highly variable within each year and showed little absolute change during the 1992–2001 period. In this section, the results of previous years are updated with the results of the August 2002 samples, and similarities or differences with previous results are noted. A discussion of pre- and post-outfall results is presented separately below (section 5.3.5.)

Density, Diversity, Evenness, and Dominant Species—Several benthic community parameters have been tracked since the inception of the monitoring program in 1992, including the total number of organisms and species in each sample, and the calculated measures of diversity (Shannon H') and evenness (Pielou's J'). More recently, Fisher's log-series *alpha*, another measure of diversity, was added (Blake *et al.* 1998). All nearfield samples collected prior to the outfall becoming operational in September 2000 were used to determine a baseline average value for each parameter. This baseline value and the mean value for each parameter for each year from 1992–2002 are plotted in Figure 5-1. From this figure, it can be seen that the mean density of infaunal organisms in 2002 was the highest ever recorded in the monitoring program, although the standard deviation around the mean was very large. The average number of species per sample was also high, being equivalent to 1997 and 1998 values. Although the diversity measure log-series *alpha* followed the same trend of higher values than in the past year or two, both Shannon diversity and evenness were lower in 2002 than in 2001. As discussed in Kropp *et al.* (2002a,b) *inter alia*, the precipitous decline in abundance and species richness recorded in 1993 and 1994 might be related to the major storms that disturbed the sea floor and associated benthic communities prior to sampling. Between 1995 and 2000, the mean values of these parameters were seen to approach and then exceed pre-storm conditions. In 2001, it appeared that the benthic communities might be declining again towards baseline conditions. However, the 2002 results present an intriguing increase in three of

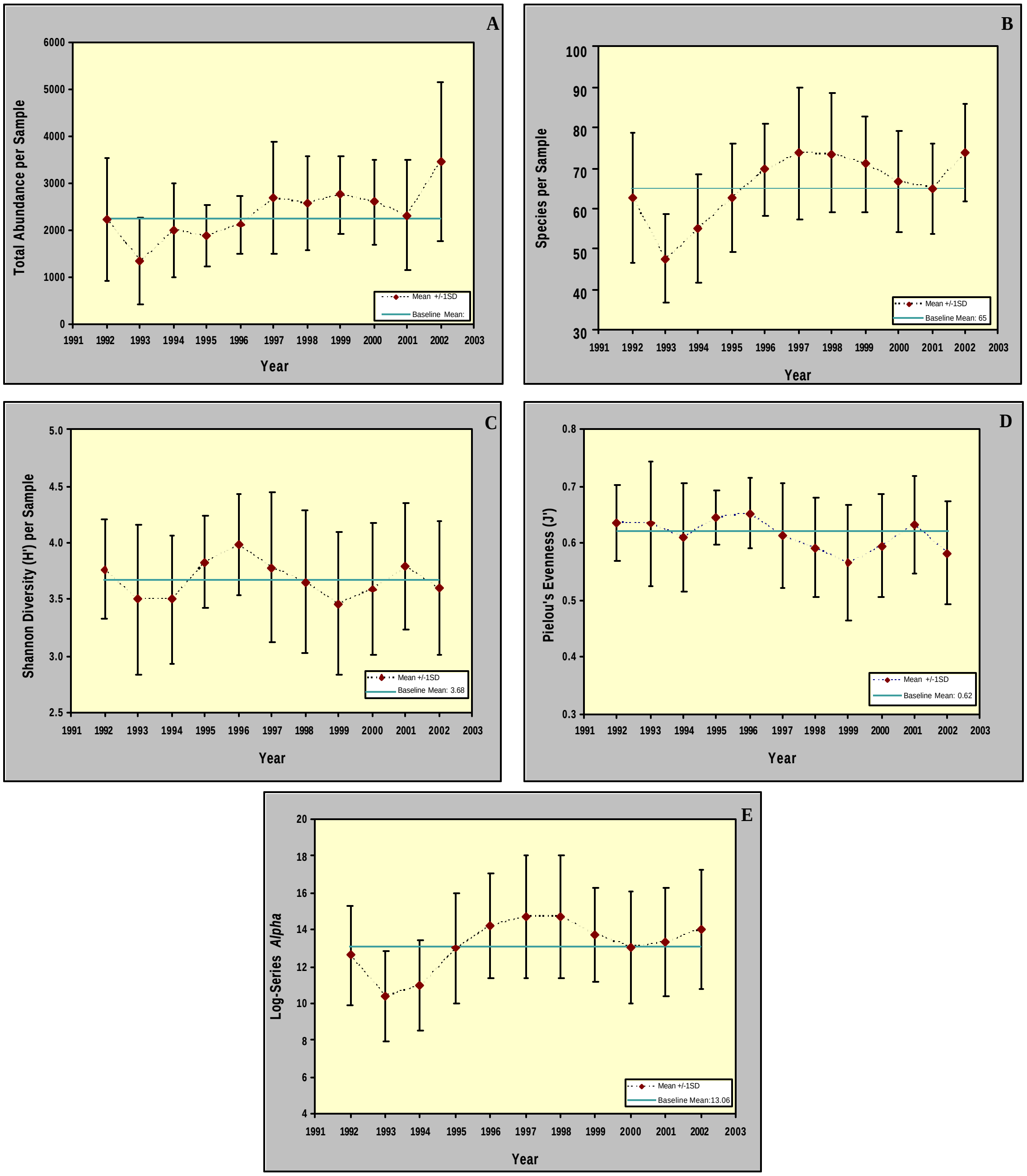

Figure 5-1. Mean benthic community parameters for the 23 nearfield stations sampled 1992–2002. (A) Abundance per sample, (B) Number of species per sample, (C) Shannon diversity H', (D) Pielou's evenness J', and (E) Log-series *alpha*.

the five parameters, with average abundances per sample particularly elevated and species per sample and log-series *alpha* also higher compared with 2001.

In order to evaluate the status of the individual nearfield benthic communities in 2002, the same five parameters were calculated (Appendix D3) and plotted for each of the 23 stations (Appendix D3, Figures D3-1 through D3-5). Because the data were handled in a slightly different manner this year (see Appendix D1), the values for 1992–2001 were recalculated and are also included in Appendix D3. In some instances, the resultant parameter differed from that presented in Kropp *et al.* (2002b) in the second decimal point, but these differences are considered to be minor and did not affect any previously reported patterns.

For four community parameters, the trends were mixed, with only one or two stations having particularly elevated or depressed values in 2002. The pattern of increased number of species per sample was seen at all 23 stations, with a range of 2–38 additional species per station; the majority of stations had a range of about 2–15 additional species per sample (Figure D3-2). The largest increases were seen at NF04 (26 species), NF15 (21 species), and NF21 (38 species), which had nearly double the number of taxa in 2002 compared with 2001 (83 and 45, respectively). The diversity measure log-series *alpha* was particularly high at NF21 (Figure D3-5), and Shannon H' and evenness J' were particularly low at NF18 (Figures D3-3 and 4).

Inspection of the abundance data for individual stations (Figure D3-1) indicated that densities at several stations (*e.g.*, NF16, NF20, and NF21) were sharply elevated compared with previous years, whereas densities at other stations (*e.g.*, NF15, NF18, NF19, NF22, and FF13) were also high compared with 2001, but not necessarily higher than during the baseline period. Abundances at stations closest to the western end of the diffuser array were similar to or only slightly elevated over 2001 levels. Only at station NF05, to the north of the outfall, was the abundance per sample lower in 2002 than in 2001(Figure D3-1). The high abundances at NF16, NF20, and NF21 were specifically due to elevated densities of *Prionospio steenstrupi* (Figure 5-2), which occurred in densities an order of magnitude higher than those recorded in 2001 and accounted for as many as half of the organisms collected at those stations (Appendix D5). Other species dominant at these stations (*Spio limicola*, *Tharyx acutus*, and *Mediomastus californiensis*) showed similar spikes in abundance in 2002, whereas *Aricidea catherinae* and *Exogone hebes* had peak densities prior to 2001 and are now present in relatively low numbers (Figure 5-2).

Dominant species at each nearfield station are listed in Appendix D4, along with the percent contribution of each to the total community. The spionid polychaete *Prionospio steenstrupi* was the numerical dominant at 17 of the 23 nearfield stations, and ranked second at another two stations. The sylllid polychaete *Exogone hebes* was the numerical dominant at two stations (NF04 and NF23), and the cirratulid polychaete *Tharyx acutus* was dominant at NF02, NF08, and NF13, and ranked second at another seven stations. Only station NF17 was not dominated by a polychaete species; at this station, the ascidian *Molgula manhattensis* accounted for more than 25% of the infauna. This species was one that was not identified to species in previous years, and was not reported as a dominant at any station. It is usually considered to be an epifaunal organism (*e.g.*, Dean and Hurd 1980), but in these samples the animals are tiny juveniles covered with sand grains and are most likely functioning as infaunal organisms. In the 2002 samples, some were large enough to identify to species, and were therefore combined with the juvenile ascidians recorded previously. Under this treatment of the data, *M. manhattensis* ranked as the top dominant at NF17 in 2001 and was second in 2000. Similarly, this species was the second most numerous organism at NF23 in 2002, and ranked fourth and sixth in 2001 and 2000, respectively. Other stations where *Molgula* was numerous were NF13 and NF19; it was also recorded at NF14 and NF18.

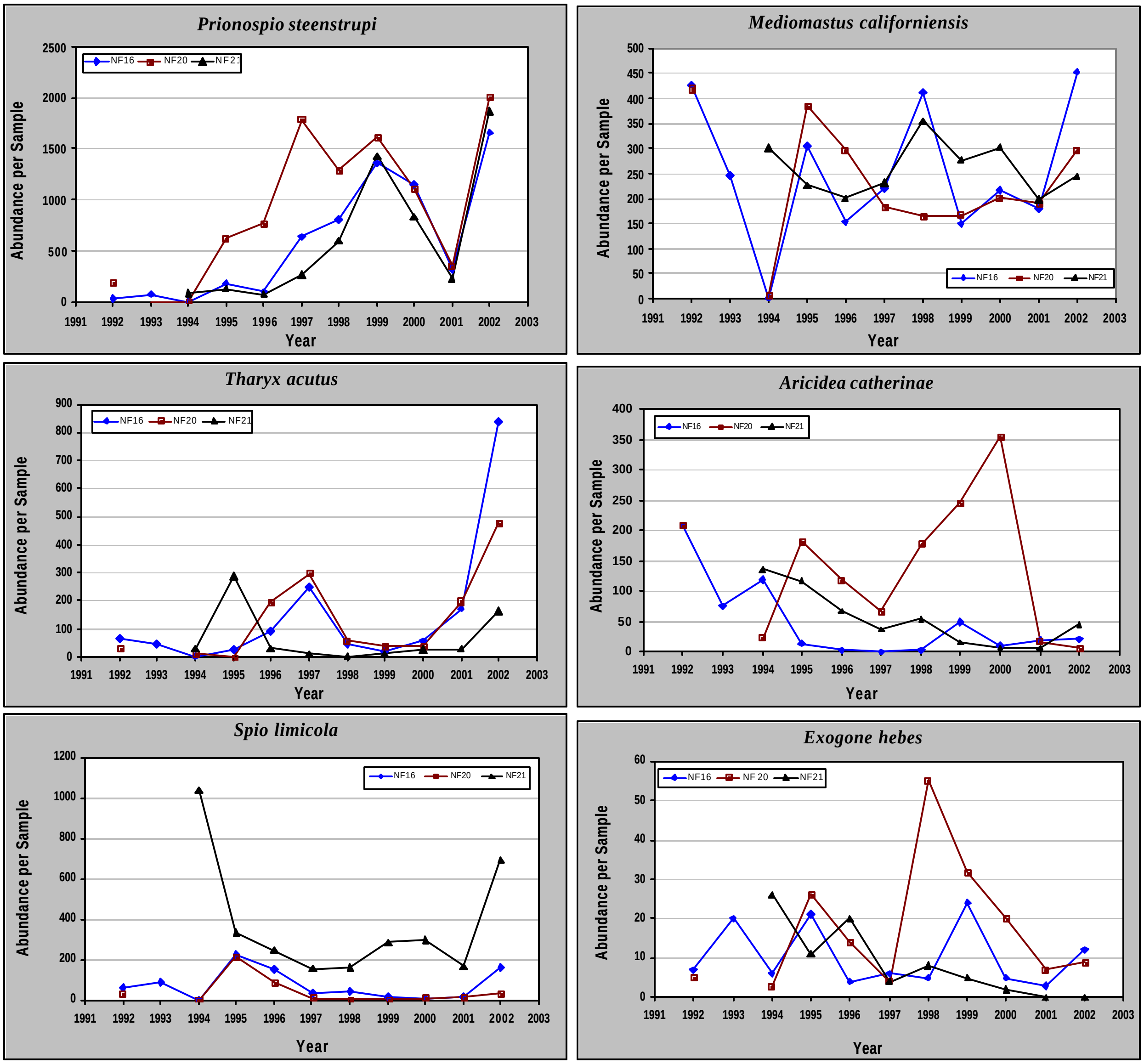

Figure 5-2. Density per sample of six species common at three nearfield stations where densities were especially high in 2002, showing fluctuations in population densities over time.

As seen for the populations recorded at NF16, NF20, and NF21 where, as discussed above, abundances were especially high in 2002 compared with 2001, the fluctuations in densities of the common species were also evident in the wider nearfield area (Figures 5-3 and 5-4). The amphipod *Crassicorophium crassicorne*, which was common at the sandy station NF17 in 1994, is now relatively rare in the area. *Anobothrus gracilis*, a terebellid polychaete, has recently increased in numbers, especially at NF21 and NF22, although these densities are very small compared with dominants such as *P. steenstrupi* (Figure 5-3).

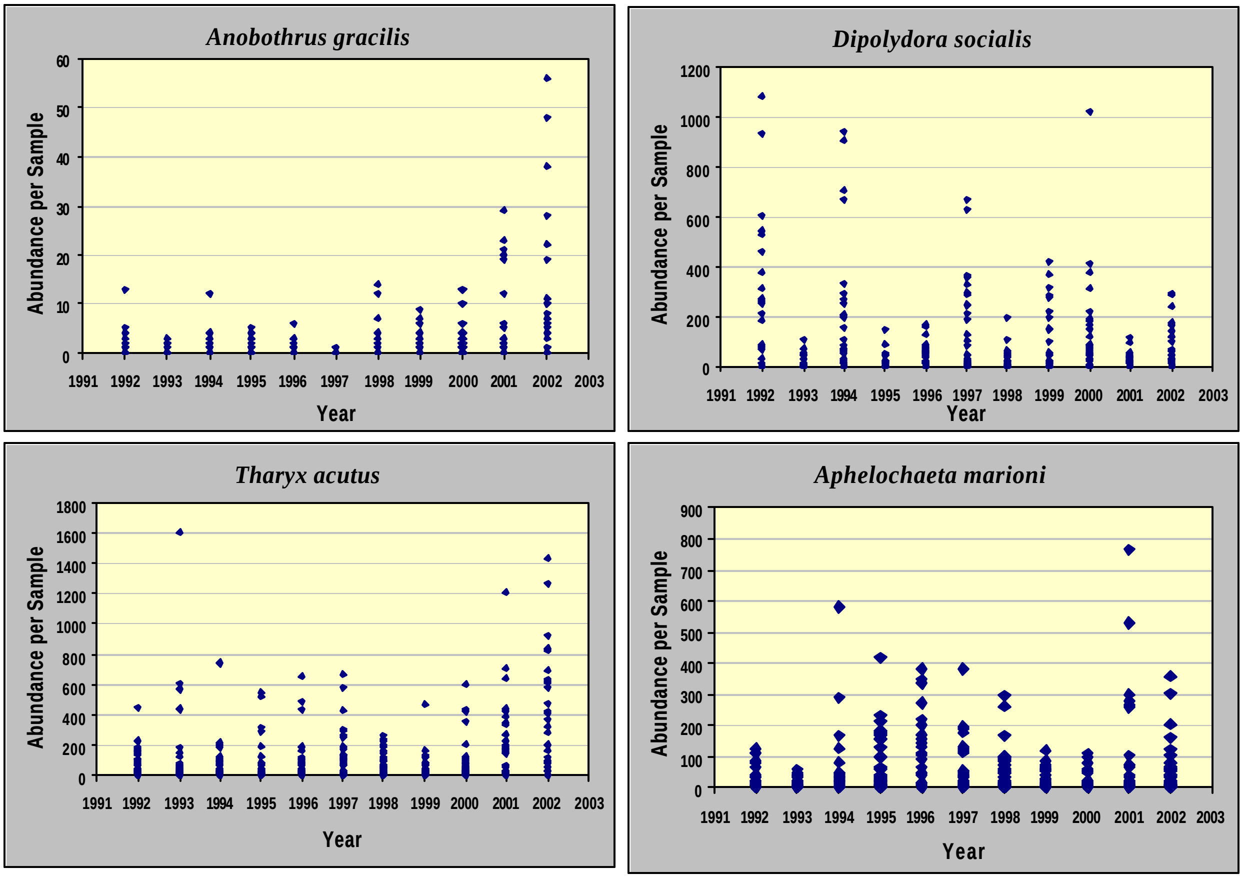

Figure 5-3. Density per sample of four species common at nearfield stations.

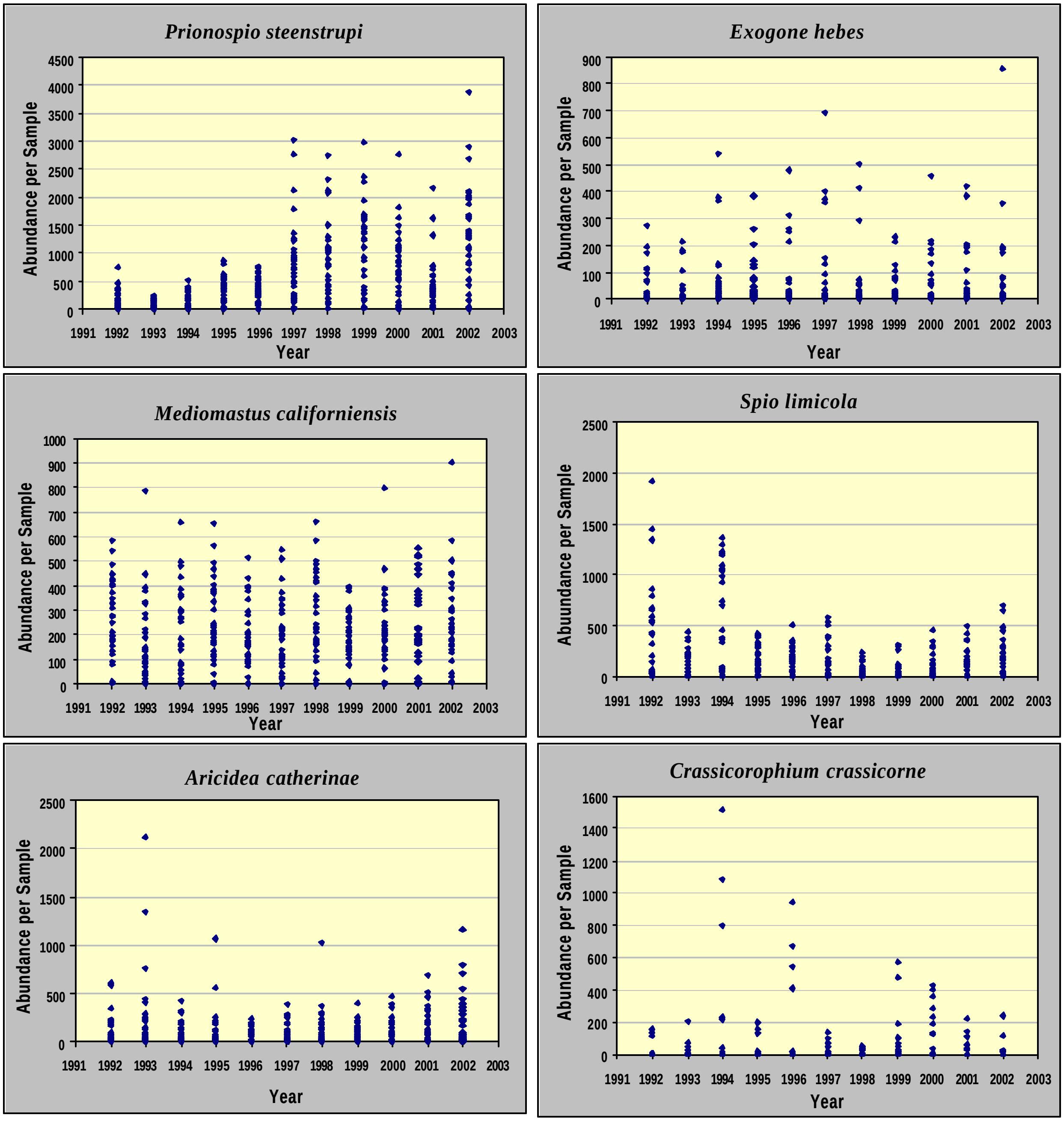

Figure 5-4. Density per sample of six species common at nearfield stations.

Multivariate Community Analysis—CNESS Similarity and PCA-H

Figure 5-5 shows the metric scaling of the 380 samples, with the majority of samples in one large cluster to the right of the diagram. Clustering of the 380 nearfield samples taken in the past 11 years resulted in seven major clusters of stations at a CNESS similarity of about 0.95. The smallest clusters typically have samples from only one or two stations; *e.g.,* one cluster group comprises samples only from NF02 from 5 years, (1993 (3 replicates), 1997–1999, 2001); another small group mainly has NF17 and NF23 replicates. Station FF13 samples are clustered towards one end of the large group to the right in Figure 5-5. NF17 and NF23, both stations with sandy sediments, are seen forming a distinct grouping to the left of the diagram. NF4 and some samples from NF23 cluster near that group. There are three nearfield samples that do not join any of the seven major nearfield clusters; these samples, NF17-1 (2002), NF04-1 (1993), and NF05-1 (1994) are not extremely different from the other clusters, but differ enough to appear separate from the major groups.

Figure 5-6 shows the Gabriel Euclidean distance biplot for the nearfield samples. This plot is the metric scaling of samples according to PCA-H axes 1and 2 (oriented the same way as the diagram in Figure 5-5) with the most important species that affect the relative location of the samples overlain on the diagram. The 13 species that contributed >2% of the variation plotted in Figure 5-6 are detailed in Table 5-1. *Spio limicola*, represented by the longest arrow in the diagram, is responsible for the separation of many of the 1992 samples from the remaining samples, and *Crassicorophium crassicorne* influences the separation of the 1994 and 1996 NF17 samples. *Prionospio steenstrupi*, *Mediomastus californiensis*, and *Tharyx acutus* pull the FF12 and FF13, plus the NF samples from the later 1990s, into the upper right quadrant of the figure. The relative positions of the species vectors also indicate whether or not species co-occur (also see Figure 5-8 below).

Table 5-1. Contributions to PCA-H axes 1 and 2 by the 13 species accounting for >2% of the community variation at the Massachusetts Bay nearfield stations (see Figure 5-6).

PCA-H Rank	Species	Contr.	Total Contr.	Axis 1	Axis 2
1	*Spio limicola*	16	16	7	35
2	*Mediomastus californiensis*	11	26	15	0
3	*Prionospio steenstrupi*	9	36	11	5
4	*Crassicorophium crassicorne*	8	44	12	0
5	*Exogone hebes*	7	51	9	2
6	*Dipolydora socialis*	5	56	1	15
7	*Tharyx acutus*	5	61	4	7
8	*Aricidea catherinae*	3	64	3	5
9	*Aphelochaeta marioni*	3	68	2	6
10	*Ninoe nigripes*	3	70	3	0
11	*Polygordius* sp. A	2	73	3	0
12	*Exogone verugera*	2	75	2	4
13	*Spiophanes bombyx*	2	77	3	2

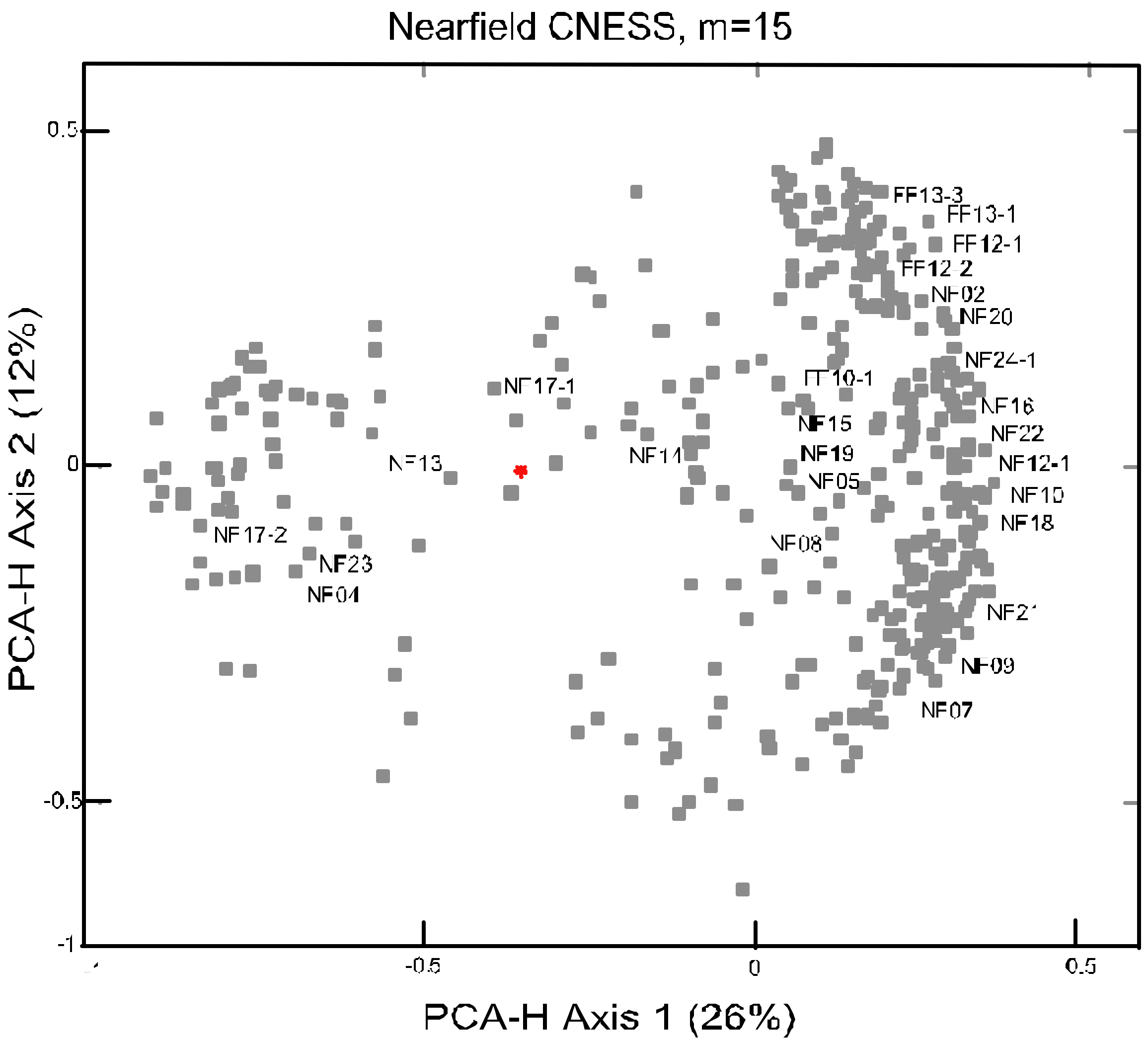

Figure 5-5. Metric scaling of all nearfield samples, with the approximate placement shown for the majority of samples collected in 2002. Hmax, the point of highest possible diversity, is shown by the (red) star near the center of the diagram. 38% of total CNESS variation is explained in two dimensions.

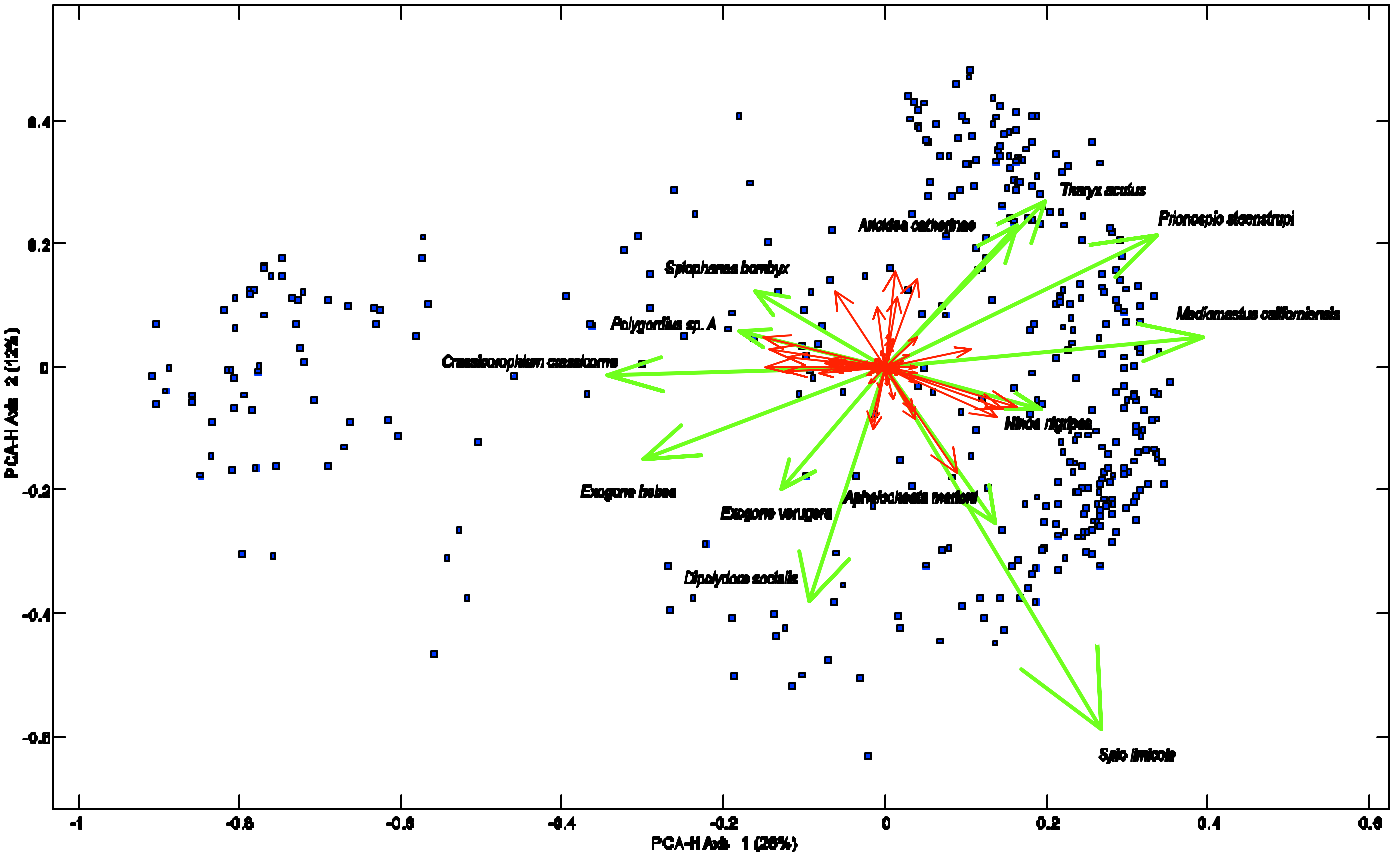

Figure 5-6. Gabriel Euclidean distance biplot for nearfield samples (filled squares), showing the 13 species (larger labeled arrows) that contributed > 2% to the plot variation. Other species vectors are indicated by unlabeled arrows. CNESS m was set at 15.

With CNESS (*m*=15), 37 species accounted for 87% of the variation in nearfield community structure and contributed at least 1% to the PCAH axes (Table 5-2). A cluster analysis of those 37 species reveals that these important taxa are grouped into four assemblages: (1) *Spio limicola –Aphelochaeta marioni–Prionospio steenstrupi–Mediomastus californiensis–Ninoe nigripes*, (2) *Aricidea catherinae–Tharyx acutus–Owenia fusiformis*, (3) *Dipolydora socialis*, and (4) *Exogone hebes–Crassicorophium crassicorne* (Figure 5-7). It should be noted that some of the species that characterize these groups may have been dominant at nearfield stations in the early to mid-1990s but may no longer be present in large numbers. For example, *Crassicorophium crassicorne* reached peak densities in 1994 and 1996, but is no longer a dominant species at the stations (NF04, NF17, NF23) where it once ranked among the top dominants. Similarly, the densities of several other species including *S. limicola*, *A. catherinae*, and *E. hebes* have fluctuated over the years of sampling (see Figure 5-2) and they may or may not have been numerically dominant in the past year or two (see Appendix D4).

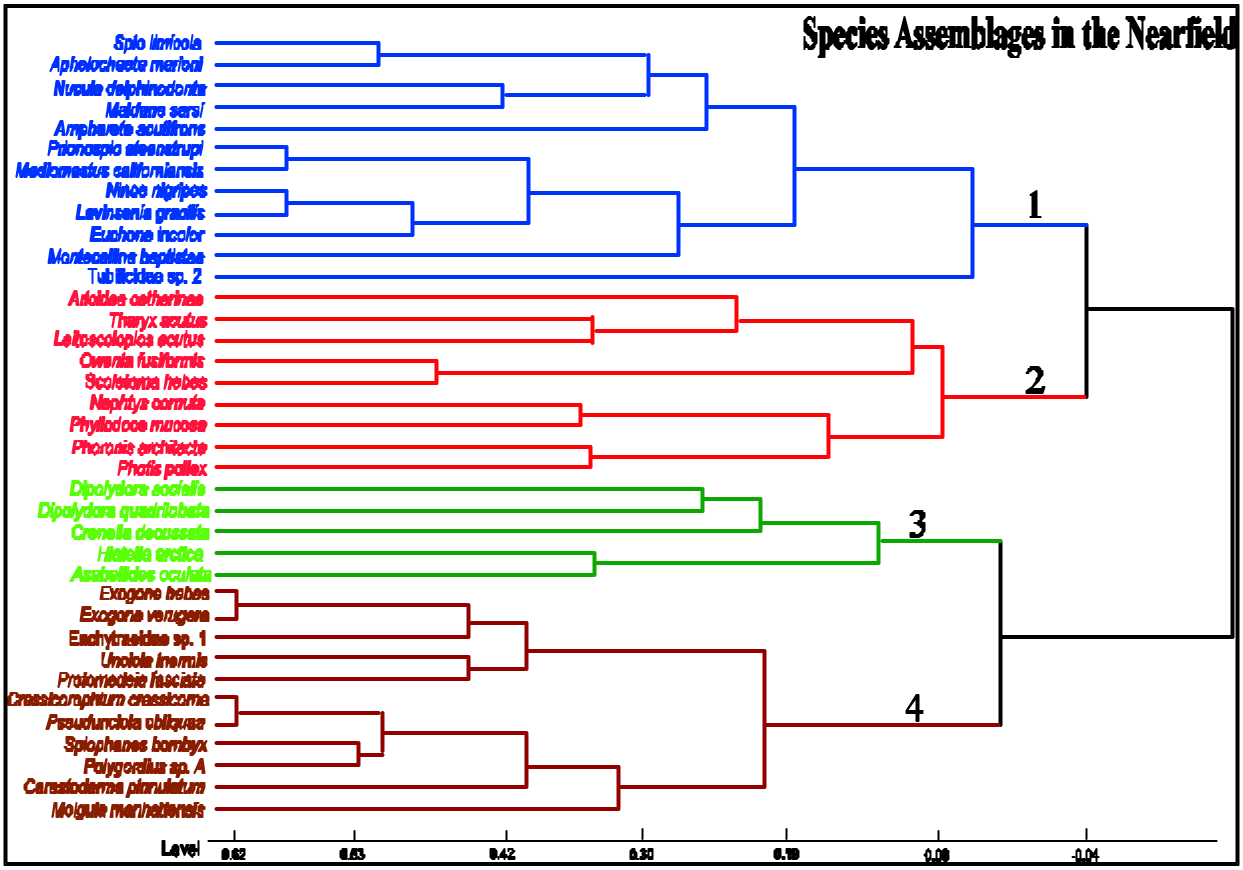

Figure 5-7. The four major species assemblages in the nearfield, as elucidated by CNESS (*m*=15) and cluster analysis.

Table 5-2. The contribution of the 37 important species at the Massachusetts Bay nearfield stations, as elucidated by PCA-H analysis, and their loadings on each of the six PCA-H axes.

(In the color version of this report, the colors used for each name correspond to the colors used to indicate species assemblages in the cluster dendrogram (Figure 5-7) In the non-color version, refer to column 3 in the table).

PCA-H Rank	Species	Species Assembl.	Contr.	Total Contr.	Ax. 1	Ax. 2	Ax. 3	Ax. 4	Ax. 5	Ax. 6
1	***Spio limicola***	1	7	7	7	35	5	1	0	0
2	***Prionospio steenstrupi***	1	7	14	11	5	41	1	0	0
3	***Aricidea catherinae***	2	5	19	3	5	20	11	18	6
4	***Mediomastus californiensis***	1	5	24	15	0	0	0	0	0
5	***Dipolydora socialis***	3	5	29	1	15	0	11	24	3
6	***Tharyx acutus***	2	5	34	4	7	4	2	16	14
7	***Exogone hebes***	4	4	38	9	2	4	4	3	1
8	***Crassicorophium crassicorne***	4	4	42	12	0	0	4	1	0
9	***Aphelochaeta marioni***	1	3	45	2	6	0	1	0	12
10	***Owenia fusiformis***	2	3	48	0	2	2	2	15	21
11	***Ninoe nigripes***	1	3	51	4	0	1	4	2	4
12	***Exogone verugera***	4	2	53	2	4	3	8	3	0
13	***Monticellina baptistae***	1	2	55	2	0	2	3	0	14
14	***Spiophanes bombyx***	4	2	58	3	2	0	6	1	3
15	***Euchone incolor***	1	2	60	2	1	4	5	0	1
16	***Polygordius* sp. A**	4	2	62	3	0	0	3	0	1
17	***Levinsenia gracilis***	1	2	64	3	0	0	5	2	1
18	***Nucula delphinodonta***	1	2	66	1	3	2	0	1	3
19	***Hiatella arctica***	3	2	68	1	0	0	3	0	0
20	***Unciola inermis***	4	2	69	2	0	1	0	1	1
21	***Pseudunciola obliquua***	4	2	71	2	0	1	8	0	0
22	***Cerastoderma pinnulatum***	4	2	73	2	0	0	0	1	0
23	***Molgula manhattensis***	4	2	74	1	0	0	0	0	0
24	**Enchytraeidae sp. 1**	4	1	76	2	0	0	0	0	0
25	***Nephtys cornuta***	2	1	77	0	1	0	1	0	1
26	***Photis pollex***	2	1	78	0	1	0	2	1	0
27	***Phyllodoce mucosa***	2	1	79	0	1	0	0	0	1
28	***Scoletoma hebes***	2	1	80	0	2	0	0	2	5
29	***Leitoscoloplos acutus***	2	1	81	1	0	2	0	0	0
30	***Crenella decussata***	3	1	82	0	1	0	2	1	1
31	***Dipolydora quadrilobata***	3	1	83	0	1	0	0	1	1
32	***Phoronis architecta***	2	1	84	0	0	0	0	2	0
33	***Protomedeia fasciata***	4	1	85	0	0	1	2	1	0
34	***Ampharete acutifrons***	1	1	86	0	0	0	0	1	0
35	**Tubificidae sp. 2**	1	1	86	0	0	0	0	1	0
36	***Asabellides oculata***	3	1	87	0	0	0	1	0	0
37	***Maldane sarsi***	1	1	87	0	1	0	0	0	1

The covariance biplot (Figure 5-8) from the PCA-H analysis shows the relationships among 30 of the species that contribute the most to the separation among the nearfield samples. This figure reflects associations discussed earlier, and also suggests that the species clusters shown in Figure 5-7 grade into each other; *e.g*., *Exogone hebes* and *Dipolydora socialis* are in different cluster groups, but the angle between them in the covariance plot suggests that they might co-occur. In fact, these two species are often found in the same samples. *Mediomastus californiensis*, member of a third cluster (Figure 5-7), generally is not found in the same samples as *E. hebes* and *D. socialis*, and is almost 180° opposite *E. hebes* on the covariance diagram.

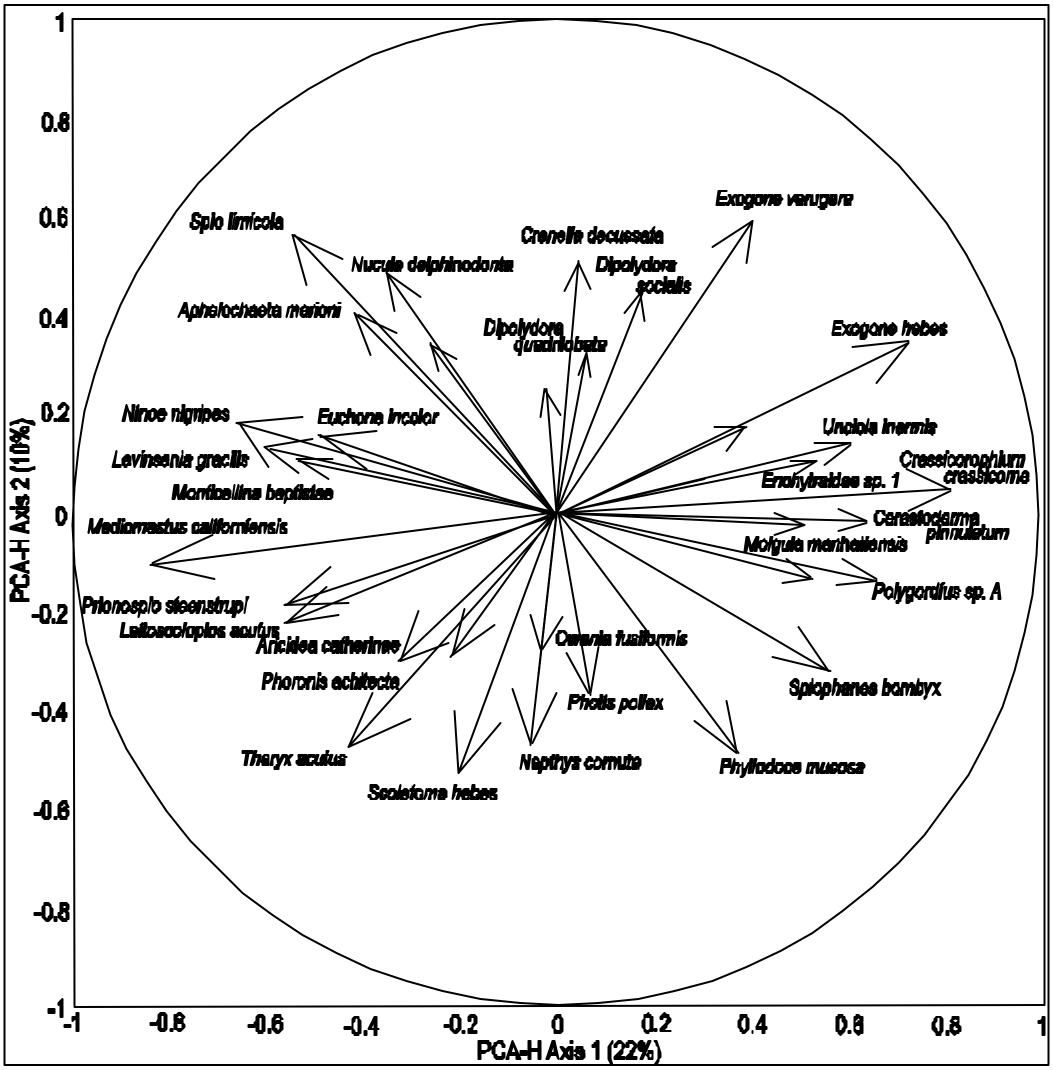

Figure 5-8. Covariance biplot showing species associations in nearfield samples.

Correlation with Environmental Data—Sediment composition has long been recognized as an important factor affecting benthic communities in Massachusetts Bay (Blake *et al*. 1993). The winter storms of 1992 changed the grain-size composition at several nearfield stations by winnowing out the fine material and leaving behind coarse sediments (Figure 5-9). This change was most noticeable at NF02, which had 77% fine (silt-plus-clay) sediments in 1992, but less than 10% fine sediments through 2001. In 2002, this station once again had fine sediments with just over 60% silt-plus-clay. Other nearfield stations that have varied noticeably in sediment grain-size composition over the past decade include NF16, NF21, NF24, and FF13. Some stations, such as NF04 and NF13, have had stable, coarse-grained sediments (Figure 5-11). The inverse relationship of TOC with sediment grain-size composition can be seen clearly in Figure 5-11 for station NF02. The TOC value for NF14 was considered suspect in 2000, and therefore is not plotted, but the 2002 value is also very high compared with previous years.

Canonical analysis of the nearfield data set was used to investigate which environmental variables may be associated with changes in species composition. Figure 5-10 shows the correlation biplot for the nearfield samples and the environmental parameters of depth, sediment composition (percent fines), TOC (which is usually inversely related to grain size), and *Clostridium*, a marker for sewage effluent. Axes 1 and 2 account for only 14% of the variation in community structure.

There is no discernable pattern if the calculated parameters (abundance, species richness, H', J', *alpha*) for each station are plotted against percent fines: the changes are in the species composition of the communities. However, the species composition is not absolutely determined by grain size. Consider NF02 as an example. In 1992, when that station had 77% fine sediments, the numerical dominant was *Mediomastus californiensis*, which accounted for 23% of the community. Between 1993 and 2001, NF02 sediments ranged from 3 to 10 % fines, and the dominant species was usually *Prionospio steenstrupi*, although *Mediomastus* remained in the community and was often among the top 10 dominant species (usually fourth or lower). In 2002, the percent fines was 62%, and the top dominant, accounting for 30% of the community, was *Tharyx acutus*, followed by *Prionospio steenstrupi* (27%). *Tharyx acutus* had also been among the dominants over the past decade, sometimes ranking second or third. The timing of the event that brought fine material to NF02 may account for the fact that the species composition had not changed at that station at the time it was sampled in August 2002. If the fines persist at that location, it is probable that a different species, perhaps *Mediomastus*, may replace *P. steenstrupi* as the numerical dominant.

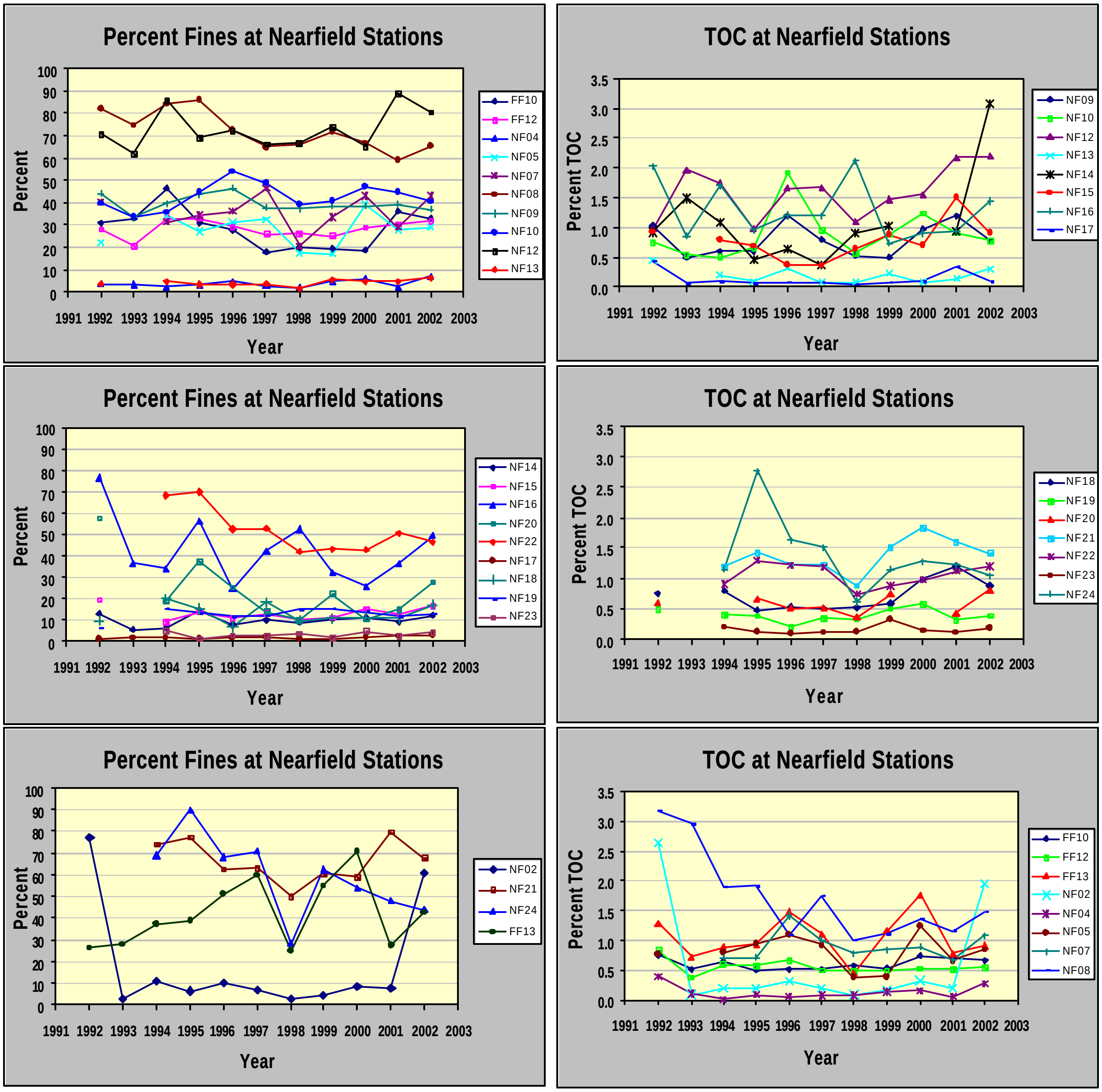

Figure 5-9. Percent fines and TOC in sediments at Massachusetts Bay nearfield stations.

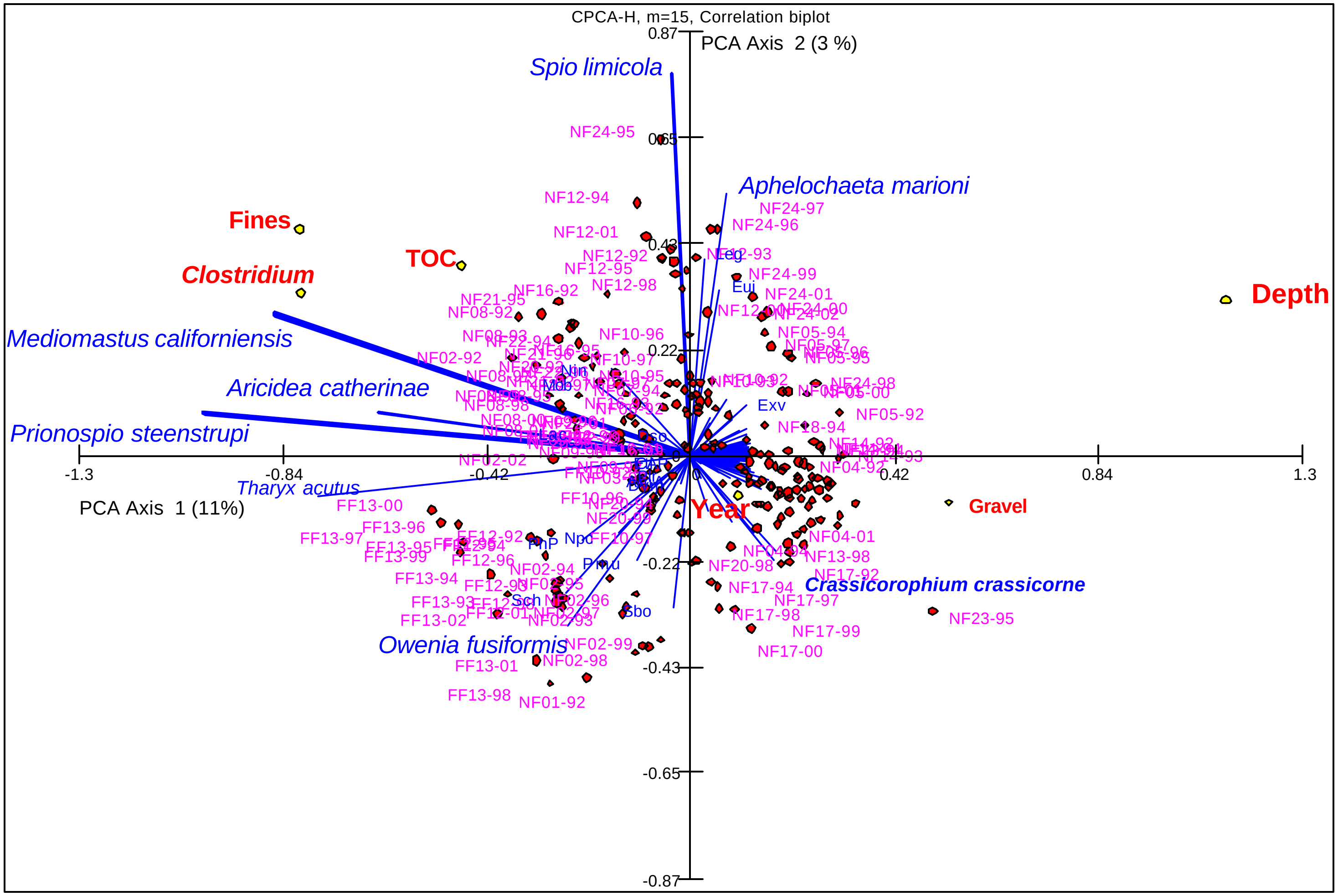

Figure 5-10. Canonical PCA-H of nearfield samples.

5.3.4 Farfield Benthic Community Analysis for 2002

Density, Diversity, Evenness, Dominance—Several benthic community parameters have been tracked since the inception of the monitoring program in 1992, including the total number of organisms and species in each sample, and the calculated measures of diversity (Shannon H') and evenness (Pielou's J'). More recently, Fisher's log-series *alpha*, another measure of diversity, was added (Blake *et al.* 1998). All farfield samples collected prior to the outfall becoming operational in September 2000 were used to determine a baseline average value for each parameter. This baseline value and the mean value for each parameter for each year from 1992–2002 are plotted in Figure 5-11[1]. As seen in this figure, the mean density of infaunal organisms in 2002 was similar to that recorded the previous year, and above the baseline mean of 1615 organisms per sample. The evenness measure (Pielou's J) was also similar to that recorded in 2001; the mean value of this parameter was slightly higher (but not significantly so) than had been recorded for the previous few years (*i.e.*, 1995–2000).

All other parameters were higher in 2002 than in 2001, or, for that matter, for the previous several years. The average number of species per sample (69) was higher than the mean value recorded in 2001 and just one or two species lower than the highest values recorded in 1998 and 1999 (71 and 70, respectively). Similarly, both diversity measures (H' and alpha) were higher in 2002 than recorded for the past several years; the H' value of 4.01 for 2002 was actually the highest annual mean recorded during this program. However, the large standard deviations around the mean reflect the variety of habitats in the farfield and the patchy nature of the infaunal benthos, and suggest that examination of individual stations or habitats would be appropriate.

In order to evaluate the status of the individual farfield benthic communities in 2002, the same five parameters were calculated and plotted for each of the eight stations (Appendix D3). Because the data were handled in a slightly different manner this year (see Appendix D1), the values for 1992–2001 were recalculated and are also included in Appendix D3. In some instances, the resultant parameter differed from that presented in Kropp *et al.* (2002b) in the second decimal point, but these differences are considered to be minor and did not affect any previously reported patterns.

Inspection of the density results for individual farfield stations indicated that the extremely high abundance value seen in the 1999 samples (see Figure D3-6) was due to a replicate from station FF11, in which the density of *Prionospio steenstrupi* was double the density recorded at any other time at that station. In other years, replicates from FF07 in Cape Cod Bay or FF09 west of Stellwagen Basin had the highest densities in individual replicates.

For the other four community parameters, the trends were roughly similar at all farfield stations, with most stations showing an increase in the mean values of each parameter compared with 2001, and values for individual replicates falling within the range of values from last year or slightly higher. The pattern of increased species richness that was seen at all 23 nearfield stations was also seen at six of the eight farfield stations, particularly FF04 and FF06, where the average number of species per sample increased by 12 and 19 species, respectively. At FF09 and FF14, species richness fell slightly but mean station values were well within baseline results (Table D3-10, Figure D3-7). Shannon diversity, evenness, and log-series *alpha* at FF09 were also lower compared with last year's results. The only other parameters that declined slightly in 2002 compared with 2001 were Shannon diversity at FF05 and evenness at FF07 (Tables D3-9–13, Figures D3-6–10).

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[1] Kropp *et al*. (2002b) performed a regional analysis based on data through 2000: in addition to the eight farfield stations, six replicated nearfield stations were also included in the calculation of mean parameters. In this report, only the eight farfield stations are included in these analyses.

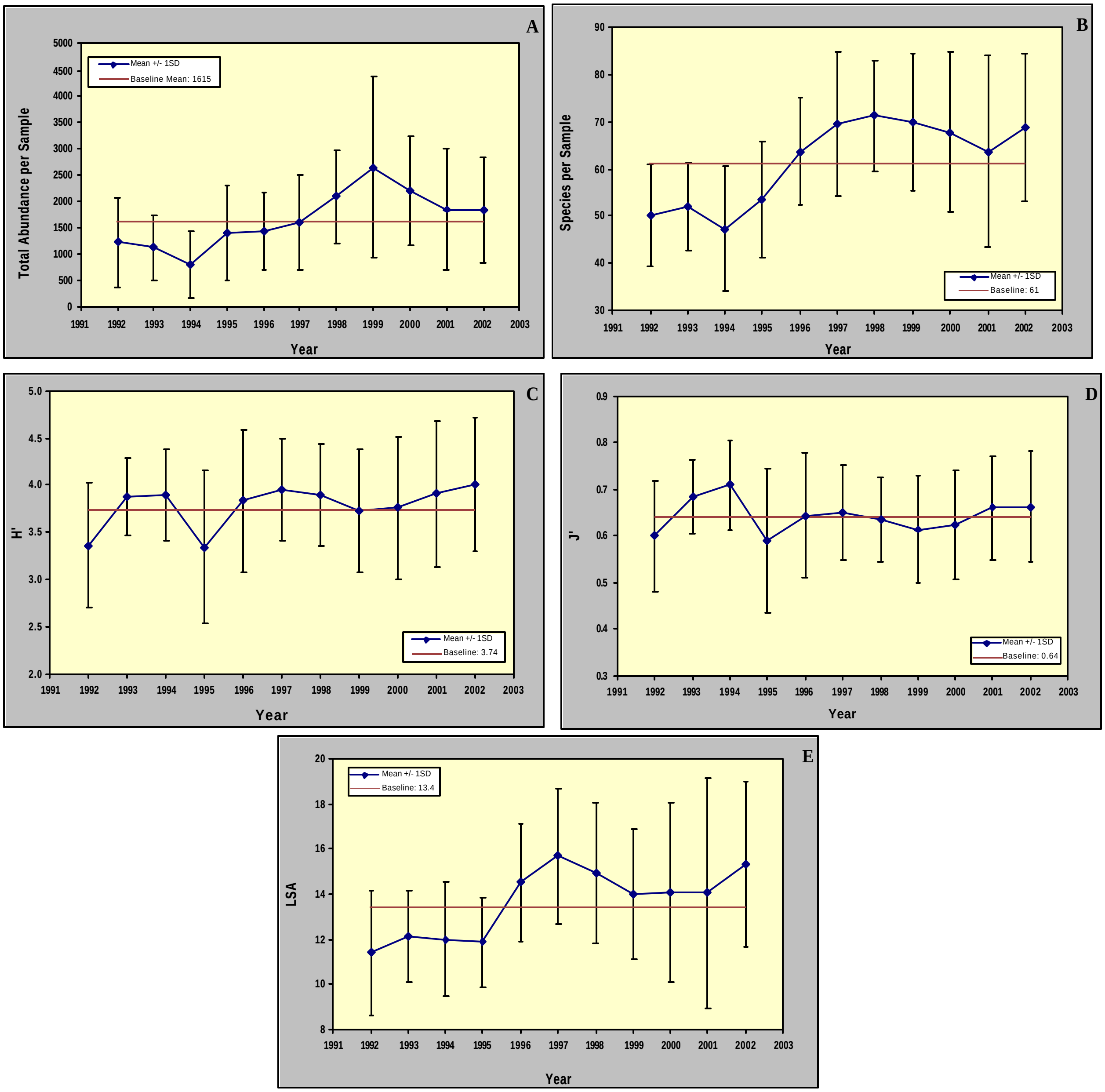


Figure 5-11. Mean benthic community parameters for the eight farfield stations sampled 1992–2002. (A) Abundance per sample, (B) Number of species per sample, (C) Shannon diversity H', (D) Pielou's evenness J', and (E) Log-series *alpha*.

Dominant species at each farfield station are listed in Appendix D5, along with the percent contribution of each to the total community. The density per sample of several of the dominant species is plotted in Figures 5-12 and 5-13. The spionid polychaete *Prionospio steenstrupi* was the numerical dominant at three of the eight farfield stations (FF01A, FF09, FF11), and ranked second or third at another two stations (FF05 and FF14, respectively). *Cossura longocirrata* dominated at stations FF04, FF06, and FF07. At FF14, to the east of the diffuser array, *Spio limicola* was the dominant species.

Fluctuations in the population densities of these species are evident in these plots. For example, *S. limicola* and the amphipod *Leptocheirus pinguis*, which were numerical dominants in the early to mid-1990s, are now present in relatively low numbers. *L. pinguis* was abundant only at FF06 in Cape Cod Bay, but *S. limicola* had been dominant at several stations in the nearfield and farfield. The small sabellid polychaete *Euchone incolor* experienced a population explosion in 1998, but its abundance since then has declined, although not to pre-1998 levels. This species, like *C. longocirrata*, was common at a few of the farfield stations, but relatively uncommon, although present, at the nearfield stations. Other species found at the farfield stations, *e.g.*, *Aricidea quadrilobata*, have increased in abundance in recent years, but the trends typically started prior to 2000 (Figure 5-13).

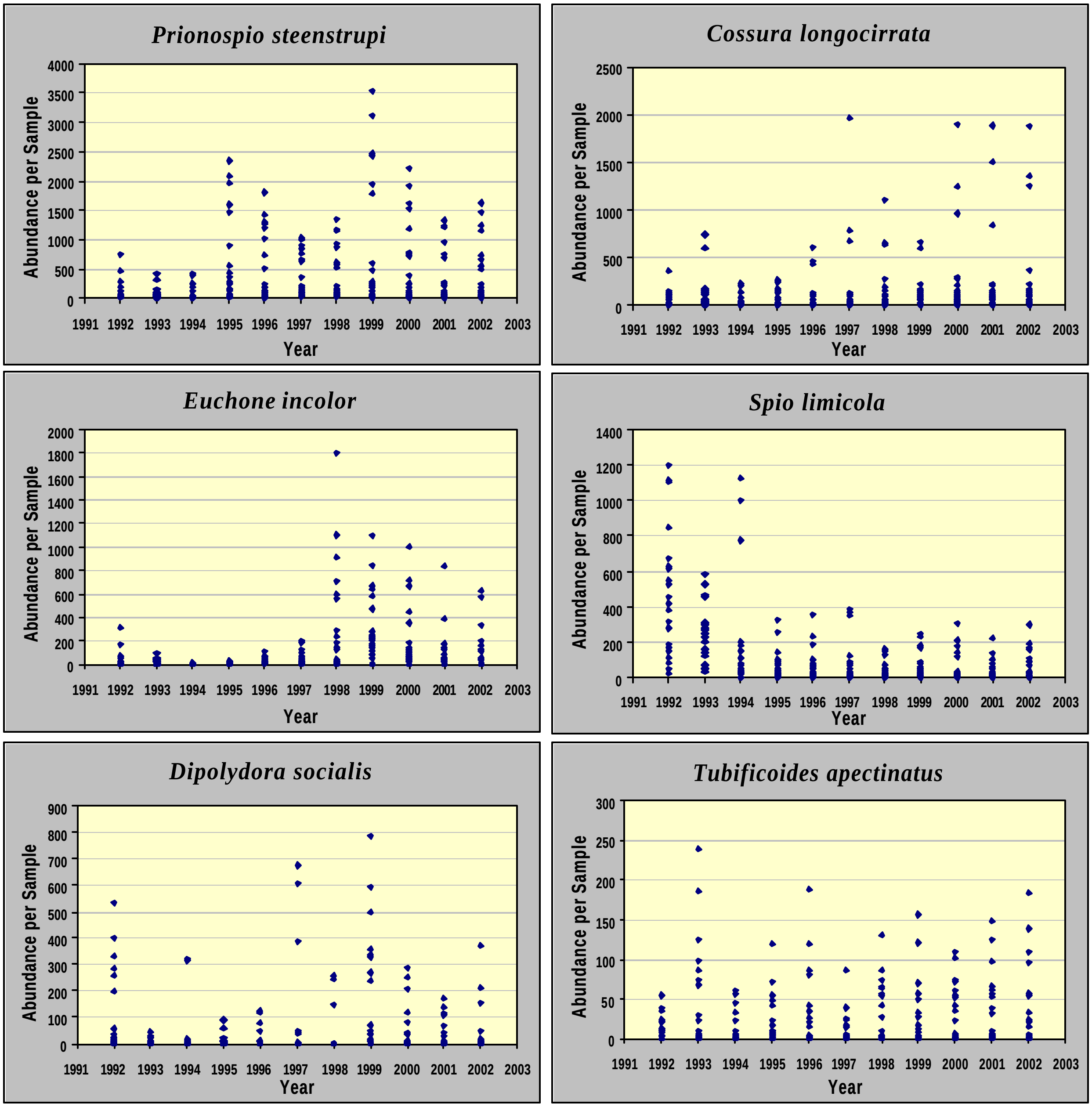


Figure 5-12. Density per sample of several species that are common at the eight farfield stations. The changes in population densities are evident for several of the species, especially *Spio limicola*.

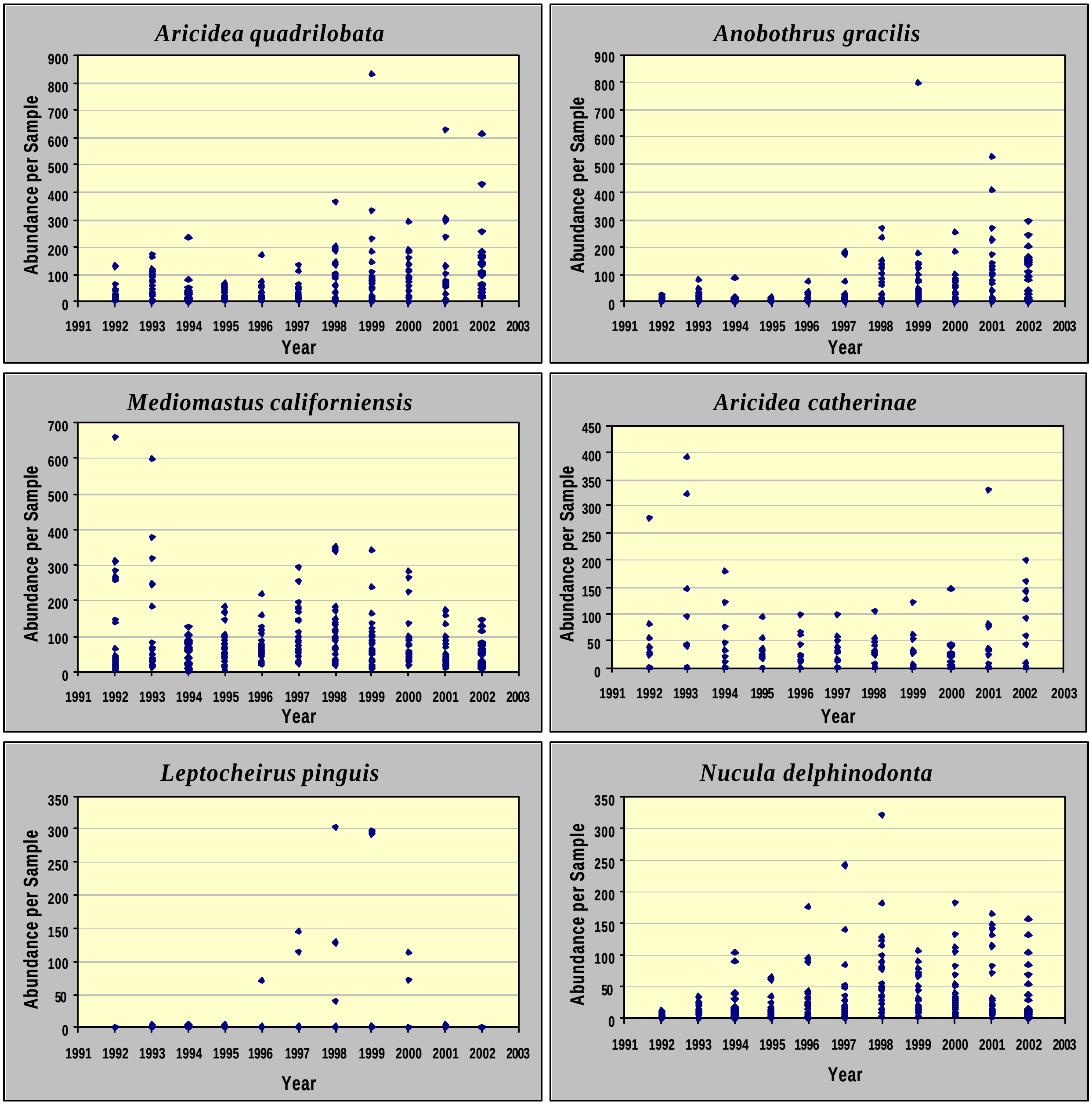


Figure 5-13. Density per sample of six species that are common in the farfield samples, and total infaunal abundance per sample, for the eight farfield stations. The changes in population densities are evident for several species.

Multivariate Community Analysis: Similarity and PCAH analysis—Clustering of the 264 farfield samples resulted in three major station groups, with an additional two or three minor groups. The three major groups are (1) Cape Cod Bay stations FF6 and FF7; (2) the deeper stations FF4 and FF5 in Stellwagen Basin plus FF11 and FF14; and (3) FF9 and FF01A. A distinct minor group included the three replicates collected at FF5 in 1994. All 2002 samples were most similar first to other replicates from the same stations, and then to replicates collected in 2001. The pattern of major (and minor) station clusters was the same as presented in Kropp *et al.* (2002b).

Figure 5-14 shows the metric scaling of the farfield cluster groups according to PCA-H axes 1 and 2, which account for 39% of the variation in the communities. From the 2002 sample points shown in red, it can be seen that these samples were well within the cluster groups defined by the baseline and 2001 data. The inset shows six clusters connected with convex hulls; these clusters comprise both the major station groups and the smaller minor sample groupings.

The Gabriel Euclidean distance biplot (Figure 5-15) shows the most important species, as determined by the PCA-H analysis, that affect the metric scaling of the samples. Six species contributed at least 5% to the total variation on axes 1 and 2, and a total of 14 species contributed >2% of the variation (Table 5-3). Both *P. steenstrupi* and *C. longocirrata* clearly control the respective station groups in which they are found, with *Aricidea catherinae* also important at the stations where *Cossura* is found. A third major station group, the deeper water stations in Stellwagen Bank and offshore Cape Ann, are characterized by an oligochaete, *Tubificoides apectinatus*, plus the polychaetes *Chaetozone setosa* and *Aricidea quadrilobata*.

Table 5-3. Contribution to PCA-H axes 1 and 2 of the 14 species accounting for >2% of the community variation at the Massachusetts Bay farfield stations. See Figure 5-15.

PCA-H Rank	Species	Contr.	Total Contr.	Axis 1	Axis 2
1	*Prionospio steenstrupi*	18	18	23	13
2	*Cossura longocirrata*	16	34	22	8
3	*Chaetozone setosa*	10	44	4	19
4	*Aricidea quadrilobata*	7	51	1	13
5	*Tubificoides apectinatus*	6	56	3	9
6	*Aricidea catherinae*	5	61	8	2
7	*Tharyx acutus*	4	65	4	4
8	*Dipolydora socialis*	4	70	2	7
9	Tubificidae sp. 2	4	73	7	0
10	*Anobothrus gracilis*	3	77	2	5
11	*Levinsenia gracilis*	3	79	4	2
12	*Spio limicola*	3	82	5	0
13	*Nucula delphinodonta*	3	85	0	6
14	*Mediomastus californiensis*	2	87	4	0

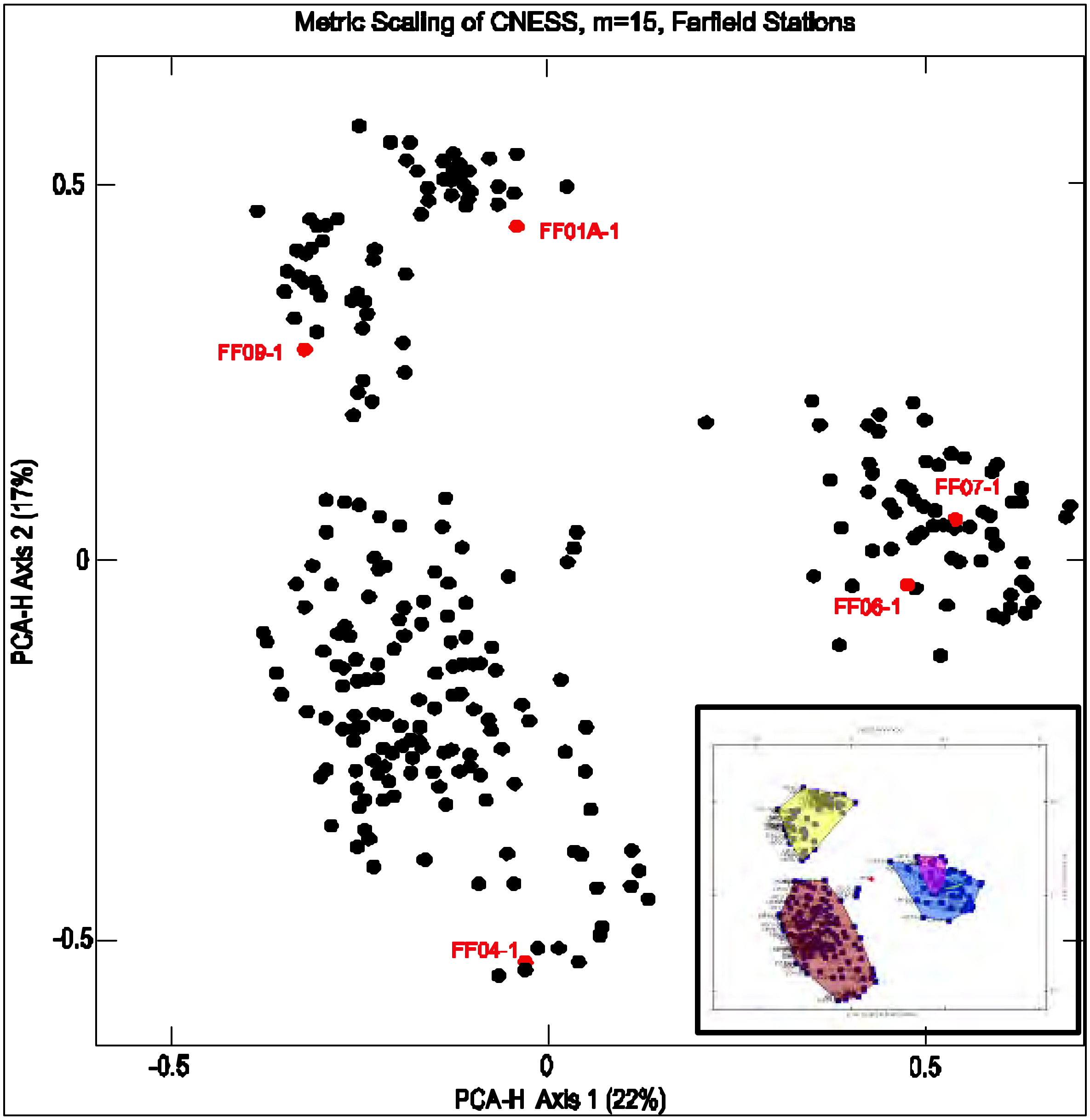


Figure 5-14. Metric scaling of the farfield samples, with some 2002 replicates indicated in red. Inset shows the six major station groups in the farfield. 39% of the total CNESS variation is explained in two dimensions.

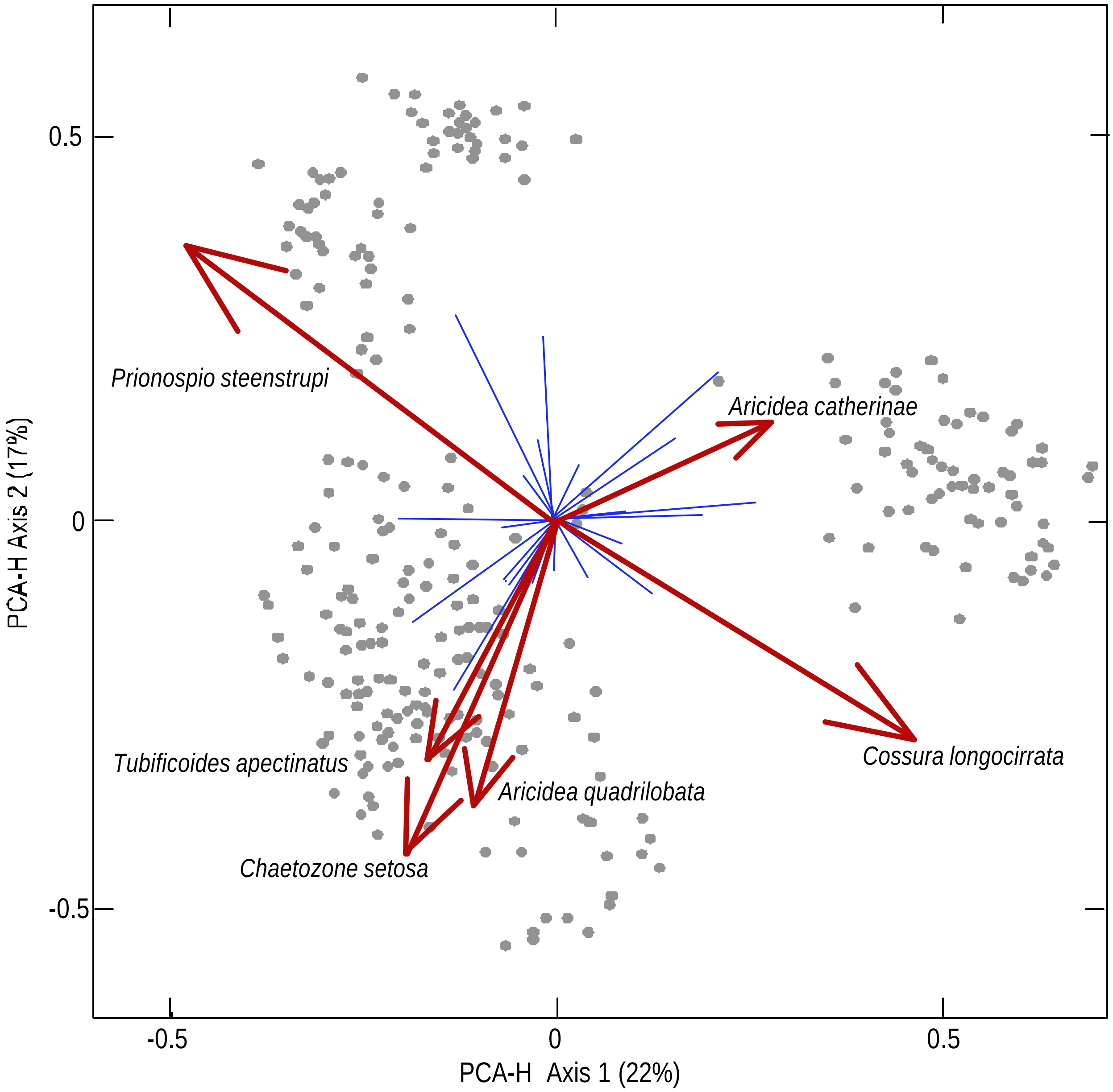


Figure 5-15. Gabriel Euclidean distance biplot for farfield samples (filled circles), with the six species that contribute at least 5% of the total variation indicated by arrows and labeled. Additional species that account for 2–5% of the variation are indicated by the unlabeled lines. CNESS *m* was set at 15.

With CNESS (*m*=15), 34 species accounted for 88% of the variation in community structure and contributed at least 1% to the PCA-H axes (Table 5-4). A cluster analysis of those 34 species revealed that they grouped into three distinct assemblages: (1) *Prionospio steenstrupi/Nucula delphinodonta*, (2) *Dipolydora socialis/Thyasira gouldi*-*Aricidea quadrilobata/Levinsenia gracilis,* and (3) *Cossura longicirrata/Aricidea catherinae* (Figure 5-16). The second assemblage can be further divided into two subgroups, the first (2a in Figure 5-16) containing six species including four polychaetes and two bivalves, and the second subgroup (2b) comprising a nemertean, an oligochaete, a scaphopod mollusc, and ten polychaete species. The first subgroup (2a) is found in slightly finer sediments, whereas the second (2b) is found in slightly coarser sediments. The *Cossura* assemblage is typical of the deeper farfield and Cape Cod Bay stations.

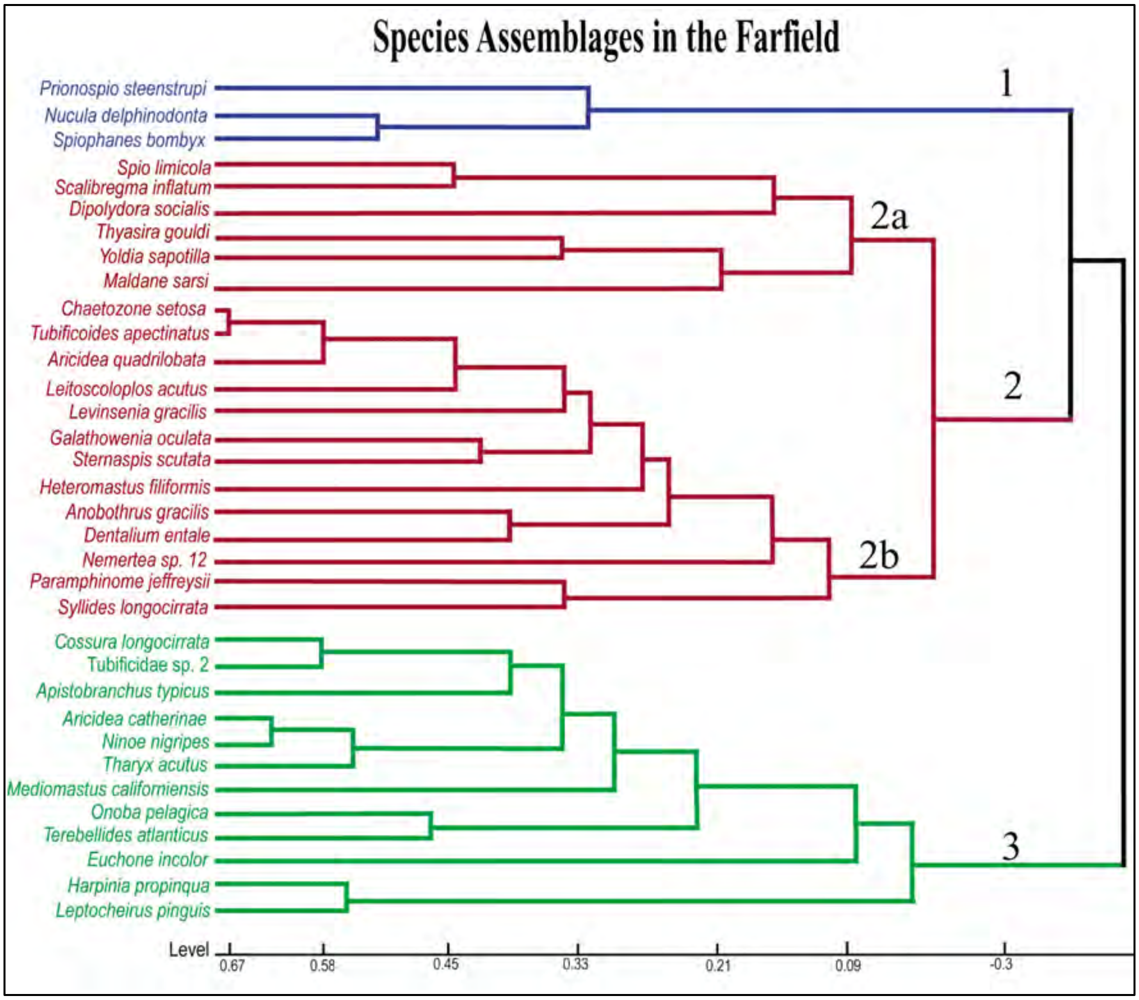


Figure 5-16. Species groups in farfield samples as elucidated by cluster analysis (CNESS, *m*=15) of the 34 species that contribute at least 1% to the PCA-H variation.

Table 5-4. The contribution of the 34 important species at the Massachusetts Bay farfield stations, as elucidated by PCA-H analysis, and their loadings on each of the six PCA-H axes.
(In the color version of this report, the colors used for each name correspond to the colors used to indicate species assemblages in the cluster dendrogram (Figure 5-16)
In the non-color version, refer to column 3 in the table).

PCA-H Rank	Species	Species Assembl.	Contr.	Total Contr.	Ax. 1	Ax. 2	Ax. .3	Ax. 4	Ax. 5	Ax. 6
1	***Prionospio steenstrupi***	1	10	10	23	13	12	0	10	7
2	***Spio limicola***	2a	8	18	5	0	52	4	7	1
3	***Cossura longocirrata***	3	7	24	22	8	0	0	0	4
4	***Euchone incolor***	3	6	30	2	1	14	38	1	0
5	***Dipolydora socialis***	2a	5	35	2	7	3	16	29	0
6	***Chaetozone setosa***	2b	5	40	4	19	0	0	0	1
7	***Aricidea quadrilobata***	2b	4	44	1	13	1	1	1	3
8	***Anobothrus gracilis***	2b	3	48	2	5	2	4	9	13
9	***Tubificoides apectinatus***	2b	3	51	3	9	0	2	2	1
10	***Levinsenia gracilis***	2b	3	55	4	2	0	9	1	4
11	***Aricidea catherinae***	3	3	58	8	2	0	1	1	1
12	***Mediomastus californiensis***	3	3	61	4	0	2	0	1	0
13	***Tharyx acutus***	3	3	64	4	4	0	0	8	8
14	***Nucula delphinodonta***	1	3	67	0	6	2	4	1	21
15	**Tubificidae sp. 2**	3	3	70	7	0	0	1	2	1
16	***Harpinia propinqua***	3	2	72	0	1	0	5	9	4
17	***Scalibregma inflatum***	2a	2	73	0	0	5	0	1	1
18	***Leptocheirus pinguis***	3	1	75	1	0	0	2	4	2
19	***Thyasira gouldi***	2a	1	76	1	0	0	1	1	12
20	***Ninoe nigripes***	3	1	78	3	1	0	2	0	0
21	***Onoba pelagica***	3	1	79	1	0	0	1	1	1
22	***Galathowenia oculata***	2b	1	80	0	1	0	0	0	0
23	***Apistobranchus typicus***	3	1	81	1	0	0	1	1	1
24	***Sternaspis scutata***	2b	1	82	0	1	0	0	0	0
25	***Spiophanes bombyx***	1	1	82	0	1	1	0	0	1
26	***Maldane sarsi***	2a	1	83	0	0	0	0	0	1
27	***Yoldia sapotilla***	2a	1	84	0	0	0	0	0	1
28	***Dentalium entale***	2b	1	85	0	1	0	0	0	0
29	***Terebellides atlanticus***	3	1	86	1	0	0	0	0	0
30	***Paramphinome jeffreysii***	2b	1	86	0	0	0	0	0	0
31	**Nemertea sp. 12**	2b	1	87	0	0	0	0	1	0
32	***Leitoscoloplos acutus***	2b	1	87	0	1	0	0	0	0
33	***Heteromastus filiformis***	2b	1	88	0	1	0	0	0	0
34	***Syllides longocirrata***	2b	1	88	0	1	0	0	0	0

The covariance biplot (Figure 5-17) shows faunal associations for PCA-H axes 1 and 2, which account for 33% of the results. The major dichotomy between the *Cossura* assemblage and the *Prionospio* assemblage detected by the cluster analysis of these 34 species (see Figure 5-16) is also reflected in the biplot. The other two species in the *Prionospio* cluster, *Spiophanes bombyx* and *Nucula delphinodonta*, along with *Dipolydora socialis* from cluster 2, are associated with *P. steenstrupi* in this diagram. Species represented by short arrows, such as *Spio limicola*, have greater contributions to other PCA-H axes than the two that are plotted here.

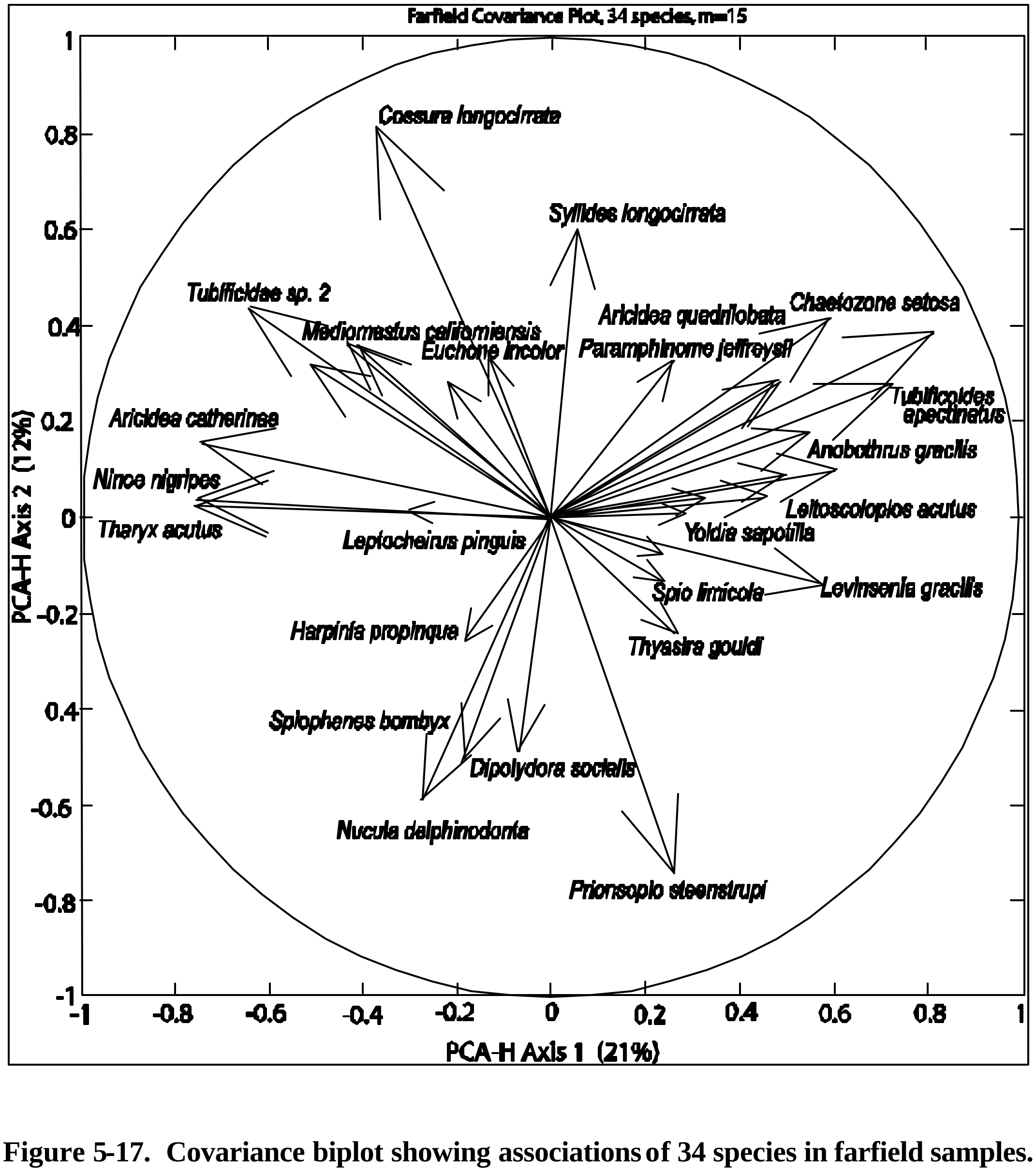


Figure 5-17. Covariance biplot showing associations of 34 species in farfield samples.

Correlation with Environmental Parameters—Canonical analysis of the farfield data set was used to investigate six key environmental variables: depth, % fines, % gravel (% sand was not used because it is too strongly correlated with % fines), % TOC, *Clostridium perfringen*, and year. As can be noted from Figure 5-18, TOC has been low and relatively invariant at the farfield stations. Stations FF06 and FF09 have coarser sediments compared with the other farfield stations. The largest changes in sediment composition at any station took place in the early to mid-1990s, perhaps due to the severe winter storms in the area. In the last several years, sediment composition has been relatively stable, although there was a slight increase in percent fines at two stations (FF07 and FF09) between 2001 and 2002 (Figure 5-18).

A high percentage (38%) of the variation in farfield community structure (CNESS, m=15) is associated with these six variables on axes 1and 2 (Figure 5-19). As in the nearfield, depth is the most important predictor of community structure. TOC and percent fines are related to community structure, but only weakly, and *Clostridium* is a poor predictor of community structure. Perhaps the most interesting result was that axis 3 was determined almost entirely by the year effect (Figure 5-20); however, this axis represents only 7% of the variation. The orientation of species vectors reflects the pattern that *Prionospio steenstrupi* increased in frequency throughout the 1990s. This graph also shows that *Euchone incolor* also increased in relative frequency during the 1990s. On the negative side of axis 3, this graphic shows that the frequency of *Spio limicola* declined dramatically from its peak frequencies in 1992 and 1993. Other species apparently showing increases relative late in the decade are *Anobothrus gracilis* and *Nucula delphinodonta*.

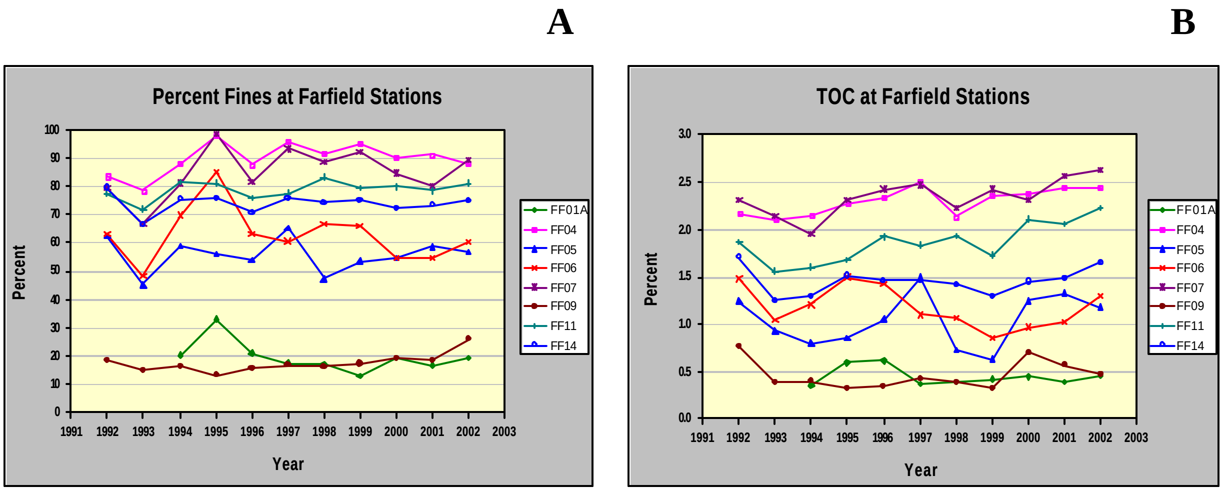


Figure 5-18. Percent fines (A) and TOC (B) of sediments collected at Massachusetts Bay farfield stations 1992–2002. Values are means for replicated stations.

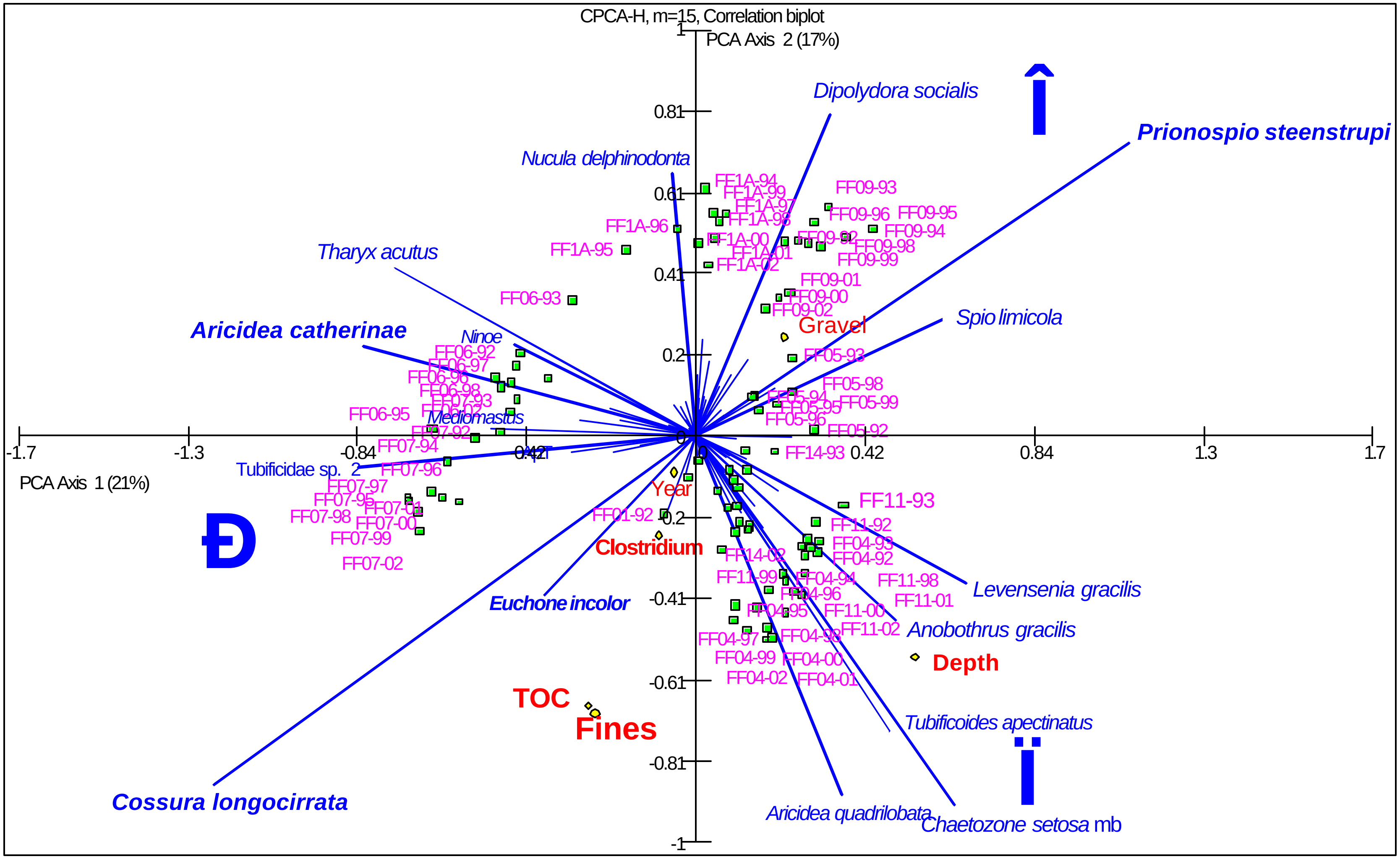


Figure 5-19. Canonical PCA-H of farfield samples. Axes 1 and 2 account for 38 percent of the variation in community structure. Circled numbers correspond to the three species groups identified by cluster analysis (see Figure 5-16). Depth, percent fines, and TOC are the best predictors of farfield community structure.

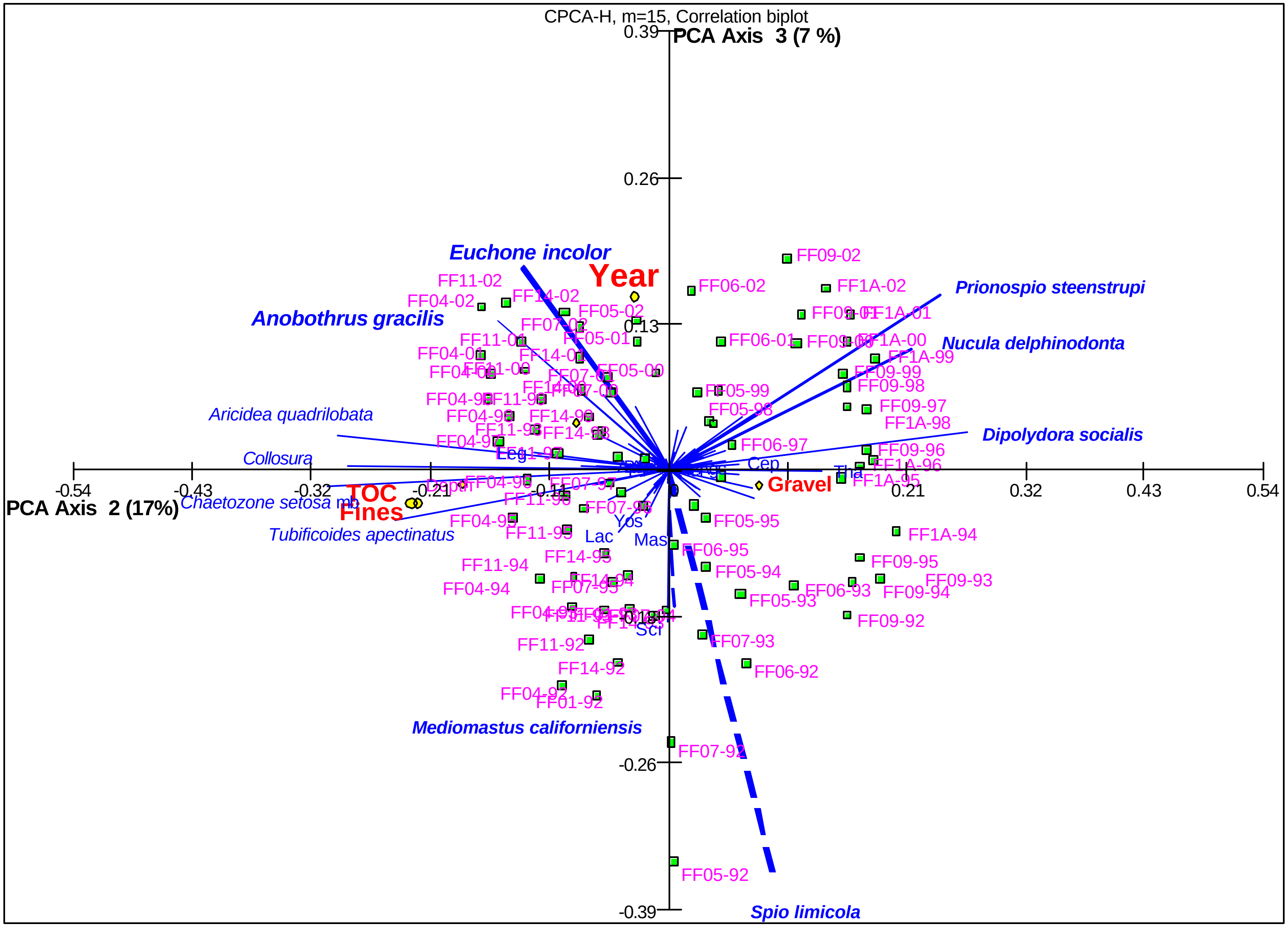
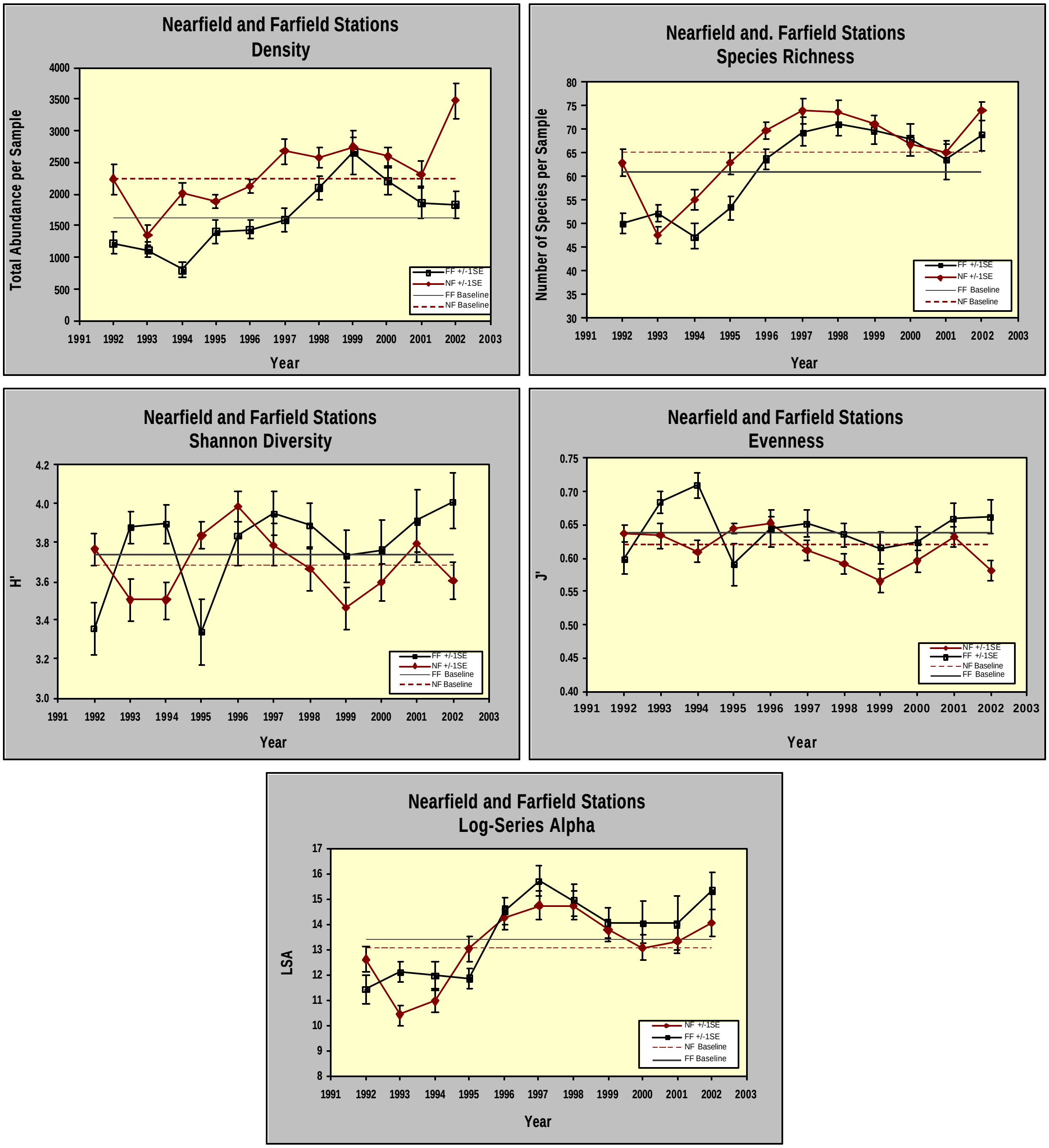


Figure 5-20. Canonical PCA-H of farfield stations. Axis 3 reflects decadal successional change.

5.3.5 Testing for Effects of the MWRA Outfall

Trends in Abundance and Diversity—Annual measurements of community parameters showed somewhat similar temporal patterns in the nearfield and farfield during the nine years of baseline monitoring and some differences in density, evenness, and Shannon diversity since the outfall went online in September 2000 (Figure 5-21). Infaunal abundance increased by 60% between 1992 and 2002. Despite the somewhat different patterns seen between the regions in mean abundance (Figure 5-21), a Generalized Linear Model analysis indicated no significant difference in the year-year abundance patterns between the nearfield and farfield. Figure 5-22 shows the estimated marginal means from that analysis (Carried out on square-root-transformed abundances). The analysis identified significant year-year variability, and overall significantly higher abundances in nearfield samples than in farfield samples, but no significant year*region interaction. If that interaction were significant, the modeled lines would not be parallel.

Overall, the data suggest a long-term cycle, a pattern that must be considered in evaluating data in post-discharge years. Changes in nearfield species richness not observed in the farfield could be indicative of an outfall impact. The cycle in total species indicates eight years between troughs, but this is misleading. The total number of species is affected by sample abundances, while log-series *alpha* is not. There was a dip in abundances in both the nearfield and farfield in 2001, which switched the second minimum in total species to 2001 (eight years from the 1993 minimum). The log-series *alpha* provides the better fit to species richness, showing that the troughs were at 1993 and 2000. Using the farfield as reference, there is no evidence that the nearfield is impacted by the outfall. Both are exhibiting a cycle superimposed on a long-term trend of increasing abundance and species richness.


Nearfield and Farfield Stations Density

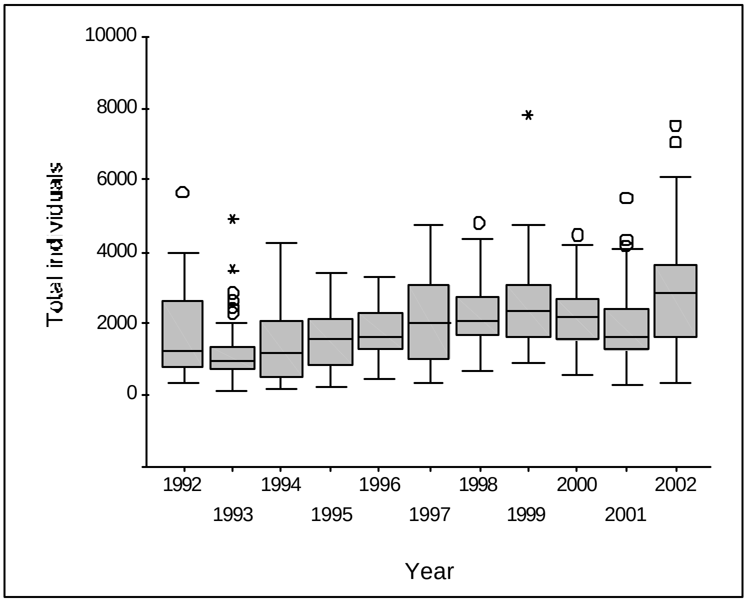
Nearfield and. Farfield Stations Species Richness

Nearfield and Farfield Stations Shannon Diversity

Nearfield and Farfield Stations Evenness

Nearfield and Farfield Stations Log-Series Alpha

Figure 5-21. Mean benthic community parameters for all stations sampled 1992–2002, including number of species per sample, Shannon diversity H', Pielou's evenness J', log-series *alpha*, and density. Nearfield and farfield stations are plotted separately.



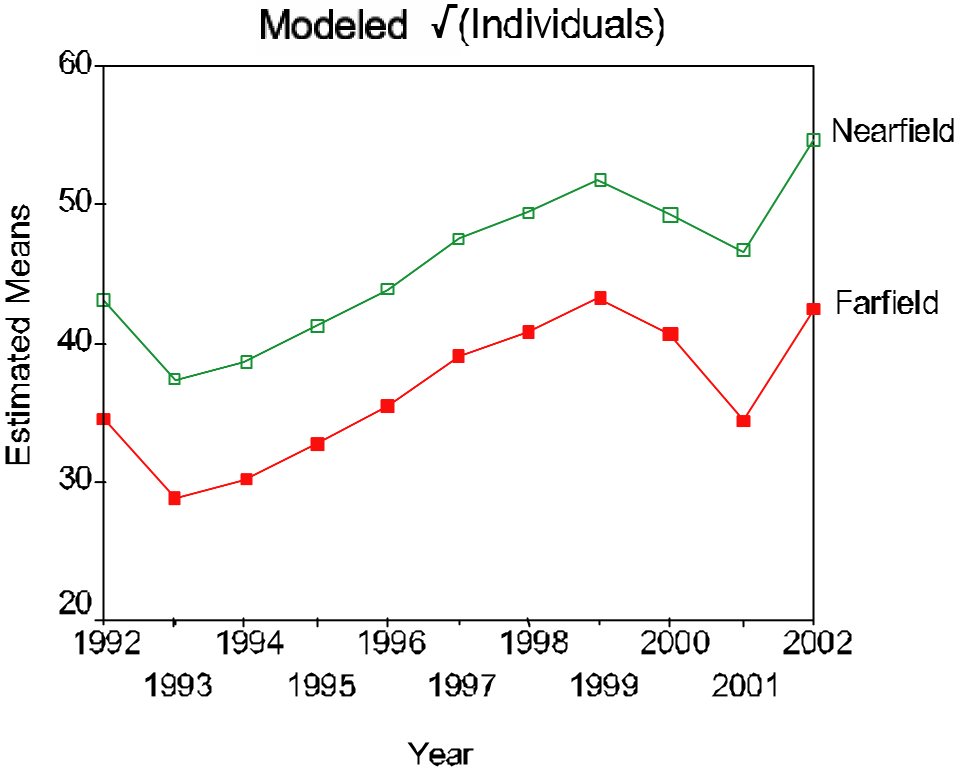


Figure 5-22. Top: Box plot of abundance values for combined nearfield and farfield stations sampled 1992–2002. Box is interquartile range, bar is mean, and whiskers are data range. Bottom: Modeled square-root transformation of abundance values.

Multivariate Analysis—The PCAH analysis of the combined (nearfield and farfield) 644-sample dataset reflects the observations made above for the separate nearfield and farfield datasets. Using a CNESS sample size of 15, the first two factors of the PCAH analysis explained 31% of the variability. Figure 5-23 illustrates that the infaunal communities are arrayed in an arc along what appears to be gradients in grain size and depth (or factors associated with them). Most of the separation along Axis 1 is associated with the distinction between the fine-grained mud communities observed in the nearfield (negative loading) and communities at the deepwater farfield stations off Cape Ann and in Stellwagen Basin (F11, FF14, FF04, FF05), which have positive Axis 1 loadings. Samples from Cape Cod Bay (FF06, FF07) consistently plot between the nearfield and deepwater samples. Axis 2 separates communities along the gradient in grain size observed in the nearfield. The samples from sandy stations such as NF04, NF14, NF17, and NF23 plot at one extreme of Axis 2, with positive loadings, whereas samples from muddier sites such as NF08, NF12, and NF24 have negative loadings on Axis 2. As observed earlier for the nearfield and farfield considered separately, the discharge data do not depart from the patterns observed during baseline.

The Gabriel Euclidean distance biplot for this analysis shows the taxa whose relative abundances contribute significantly to this pattern (Figure 5-24). These tend to be the abundant or dominant taxa for the different environments already described, or, like the polychaete *Cossura longicirrata*, are species routinely present in samples from one region while absent from other regions.

Time-Sorted NNESS—In the PCA-H analysis, LOESS fits document that, at *m*=1, compositional change of community dominants has been slower during discharge monitoring than was characteristic during baseline sampling (Figure 5-25). For both nearfield and farfield samples, LOESS fits for discharge samples document higher similarities and slower change with time (*i.e*., flatter slopes). During baseline, farfield stations showed slightly faster compositional change among community dominants than did nearfield stations, as shown by the steeper initial slopes of the LOESS. These slopes correspond to a successional half-life among community dominants of about nine years (Figure 5-25).

Slopes for the LOESS fits for *m*=15 (Figure 5-25) show a similar pattern, although these similarities (which are sensitive to changes in the presence and abundance of most species) document slower successional rates than seen among community dominants. As with the analysis at *m*=1, the farfield shows slightly faster successional rates than does the nearfield, with a successional half-life of about 20 years. Successional rates are slower for discharge data in both nearfield and farfield samples, documenting a lack of outfall impact.

Finally, for NNESS similarities with *m*= infinity, the analysis documents relatively slow changes in the regional species pools for both the nearfield and farfield, with no indication of faster species turnover for discharge data (Figure 5-25).

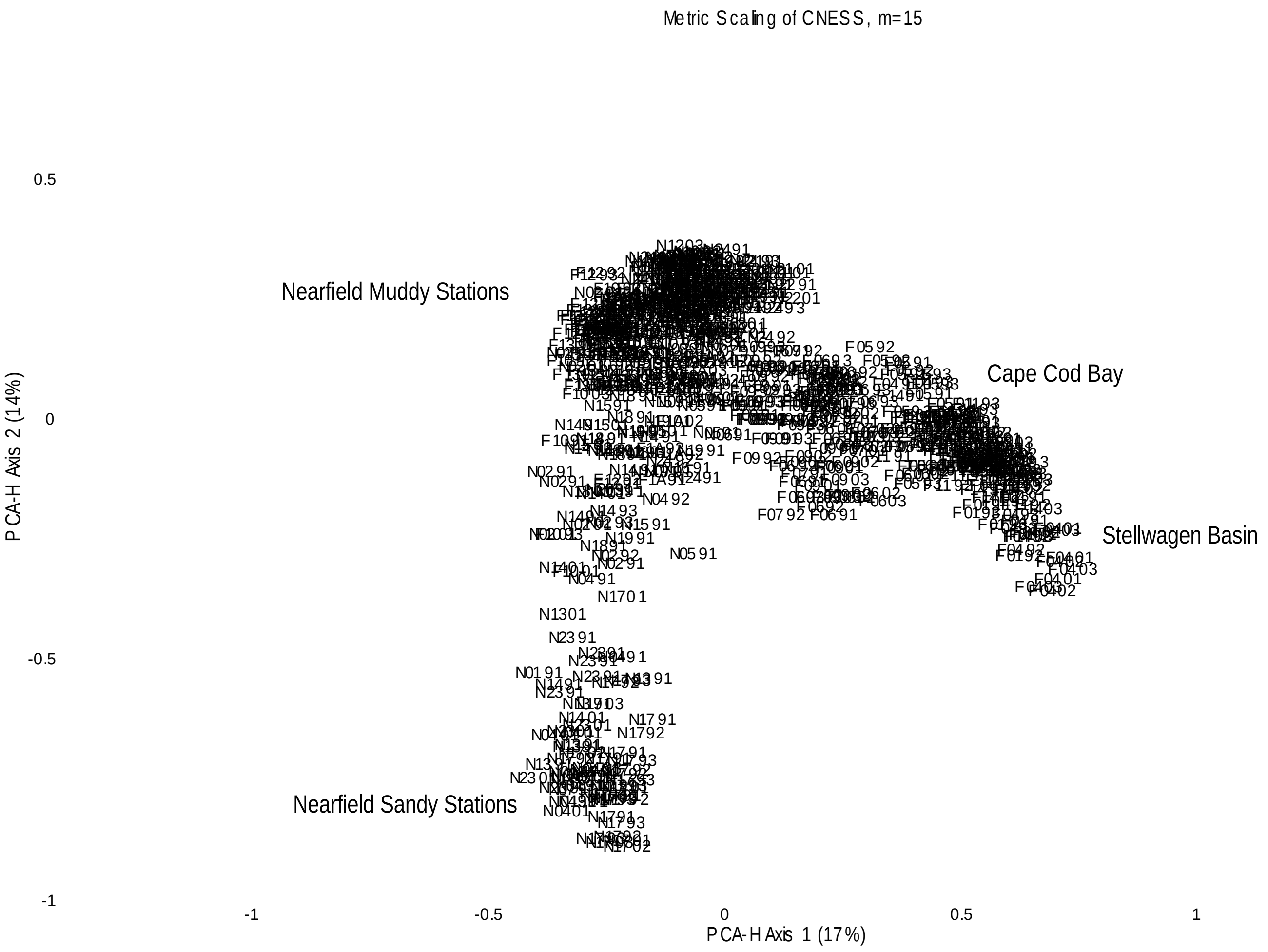


Figure 5-23. Metric scaling of CNESS distances (m=15), PCA-H axis 1 vs. axis 2, of all 644 nearfield and farfield samples collected 1992–2002. Regions whose samples consistently plot in that area of the graph are indicated

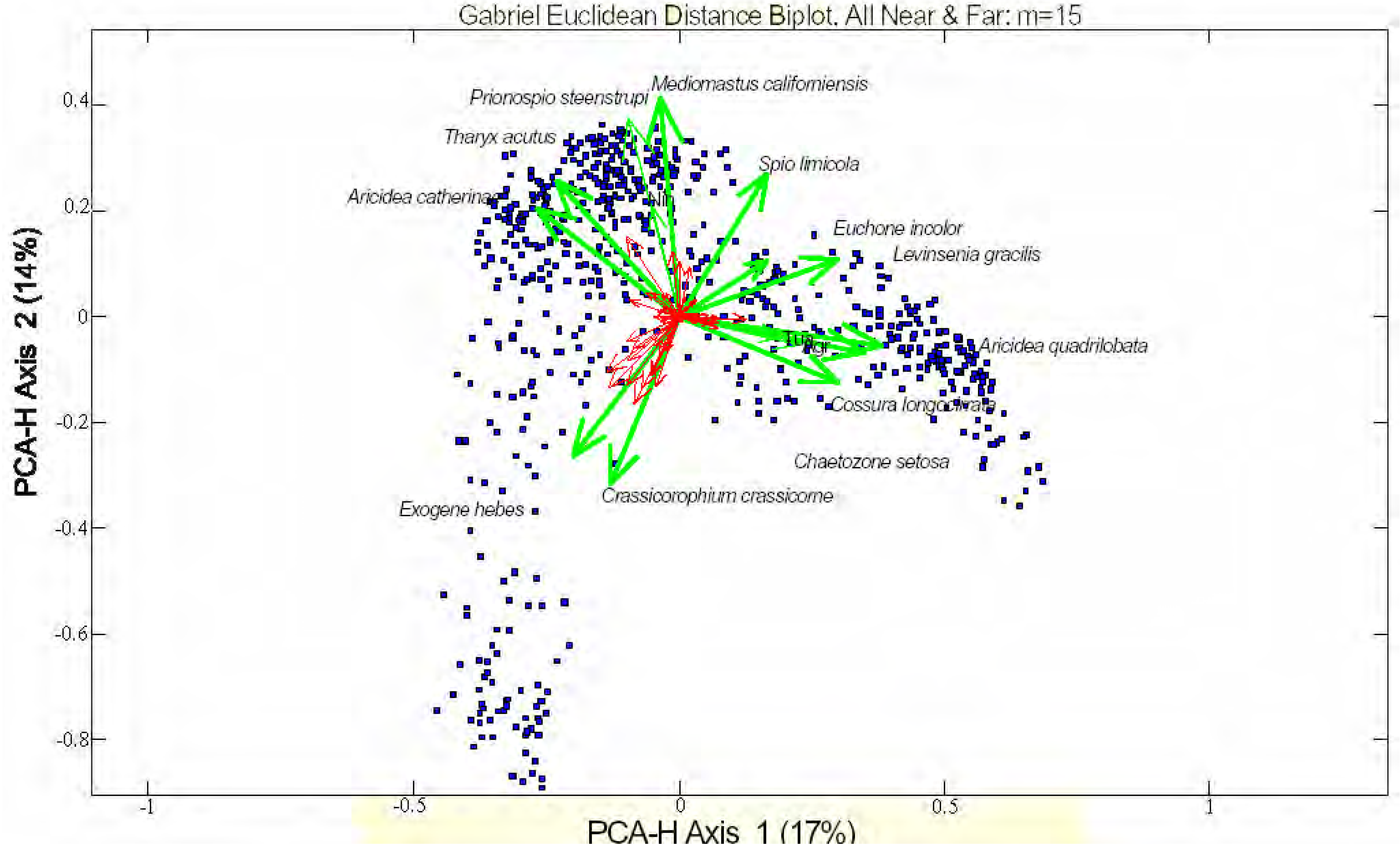


Figure 5-24. Gabriel Euclidean distance plot of all Massachusetts Bay samples.

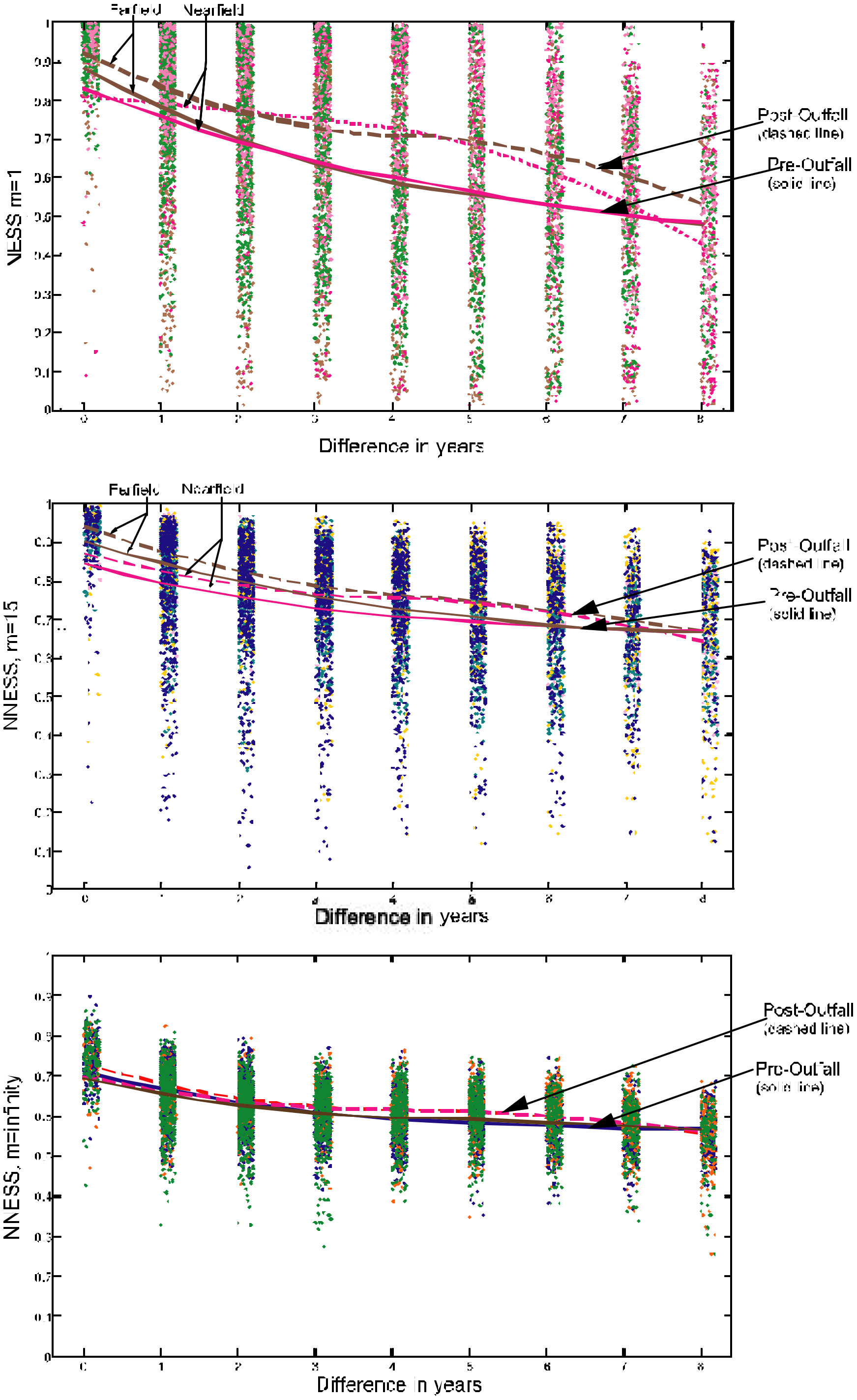


Figure 5-25. Comparison of nearfield and farfield, pre-outfall (solid lines) and post-outfall (dashed lines) at NNESS *m*=1 (top), *m*=15 (middle), and *m*=infinity (bottom).

CPCAH—Canonical analysis of the entire data set was used to investigate six key environmental variables: depth, % fines, % gravel (% sand was not used because it is too strongly correlated with % fines), % TOC, *Clostridium perfringens* spores, and year. A high percentage—25%—of the variation in community structure (CNESS, m=15) is associated with these six variables on axes 1 and 2 (Figure 5-26). As in the separate nearfield and farfield analyses, depth is the most important predictor of community structure (Figure 5-27). TOC is related to community structure, but only weakly, and *Clostridium* is a poor predictor of community structure.

ANOVA—A series of general linear model (GLM) analyses on the diversity data from all 644 samples was performed. The design is a form of Green's (1979) optimal impact design, which he described as one in which baseline data exist adjacent to the site of a potential environmental impact and at a spatially distant control area removed from the potential influence of the impact. Green proposed that an impact could be assessed through the use of a two-factor analysis of variance (ANOVA), but his design was criticized by Hurlbert (1984), who argued that replicated affected areas must be sampled. Green proposed monitoring in just two areas and then testing for an area-by-postimpact interaction effect. Hurlbert rightly argued that all natural communities change through time and that natural differences among areas could be mistakenly interpreted as an impact. A modified version of this design was proposed by Stewart-Oaten *et al.* (1986); their design had been used to assess the effects of nuclear power plant cooling water in nearshore California marine habitats. Underwood (1997) reviewed this class of ANOVA model, which has come to be known as a Before-After-Comparative-Impact (BACI) design. The MWRA study is one of the first that directly tests potential effects of an outfall discharge. We control for station effects and long-term patterns in these analyses, and can detect outfall effects despite long-term cyclic patterns in several of the key response variables in different regions. Because of the long duration of the baseline and the relatively large sample sizes, the tests are quite powerful for detecting potential impacts.

Log-series *alpha*—The first GLM analysis confirmed the pattern of a long-term cycling in species richness and abundance. The analytical model included year and region factors, and the year-region interaction. Neither the region nor the interaction terms in this model are significant (Table 5-5). There was a consistent nonrandom pattern in the untransformed log-series alpha residuals after fitting the model. This problem was resolved by taking the natural logarithm of Fisher's *alpha*. While the test for non-equal variances is still significant, the departures from expectation and test statistic are relatively small (F<2.0), with the significance being driven by the 200-300 degrees of freedom in the numerator and denominator for the Levene's F test for equal variance among groups. The estimated marginal means for the significant year effect (Figure 5-28) emphasize the apparent seven-year cycle in species richness.

Table 5-5. Results of the General Linear Model (GLM) analyses on the dependent variable log-series *alpha* using year and region as factors.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
Corrected Model	1295.06[b]	21	61.67	6.73	.000	141.27	1.000
Intercept	111782.26	1	111782.26	12193.20	.000	12193.20	1.000
NEAR	33.05	1	33.05	3.60	0.58	3.60	.474
YEAR	1102.94	10	110.29	12.03	.000	120.31	1.000
NEAR*YEAR	118.05	10	11.80	1.29	.233	12.88	.670
Error	5702.24	622	9.17				
Total	121976.83	644					
Corrected Total	6997.30	643					

[a] Computed using alpha = .05
[b] R Squared = .185 (Adjusted R Squared = .158)

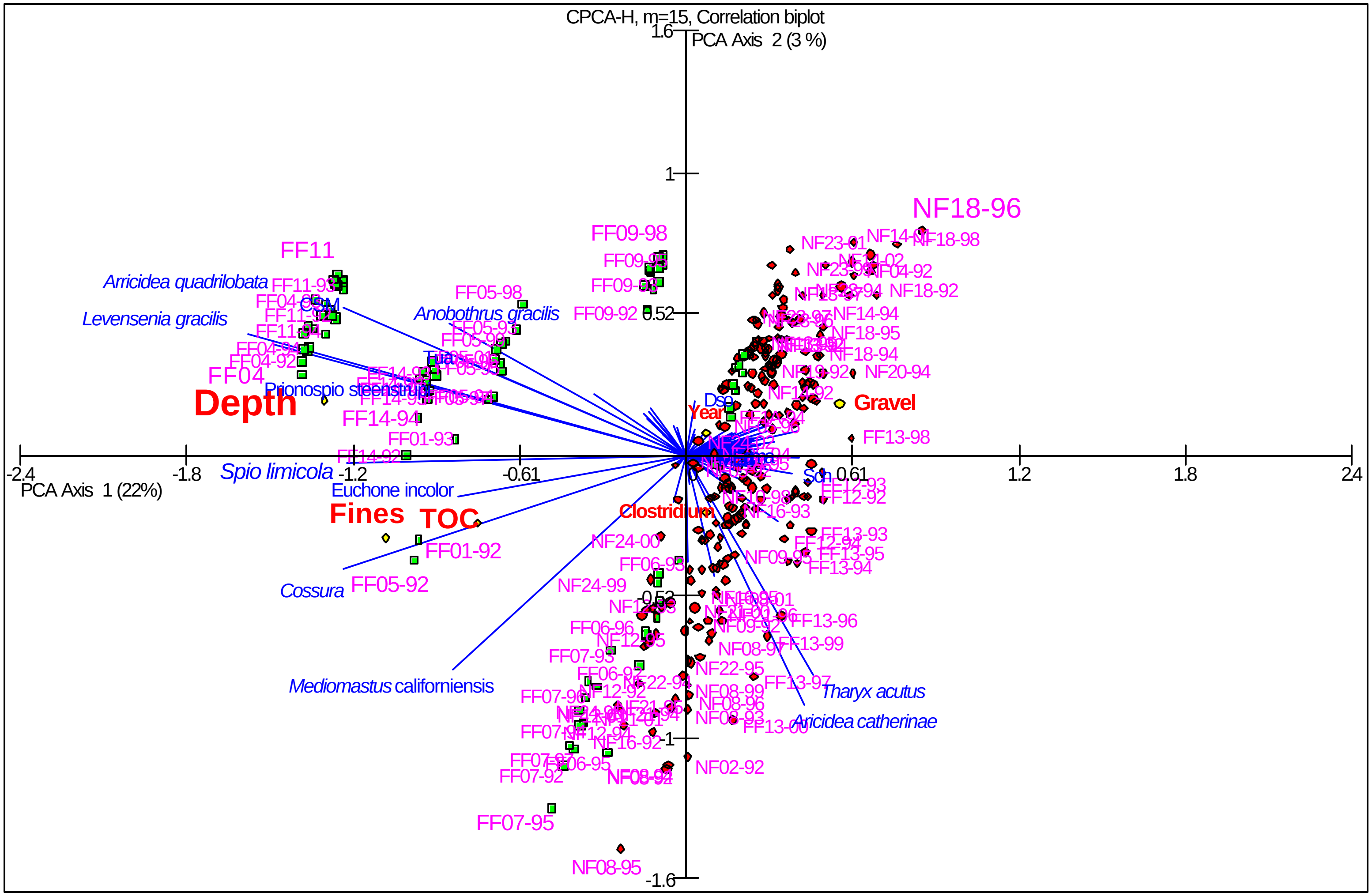


Figure 5-26. Canonical PCA-H axes 1 and 2 for all Massachusetts Bay stations. Depth, grain size, and TOC are the major predictors of Massachusetts Bay species composition.

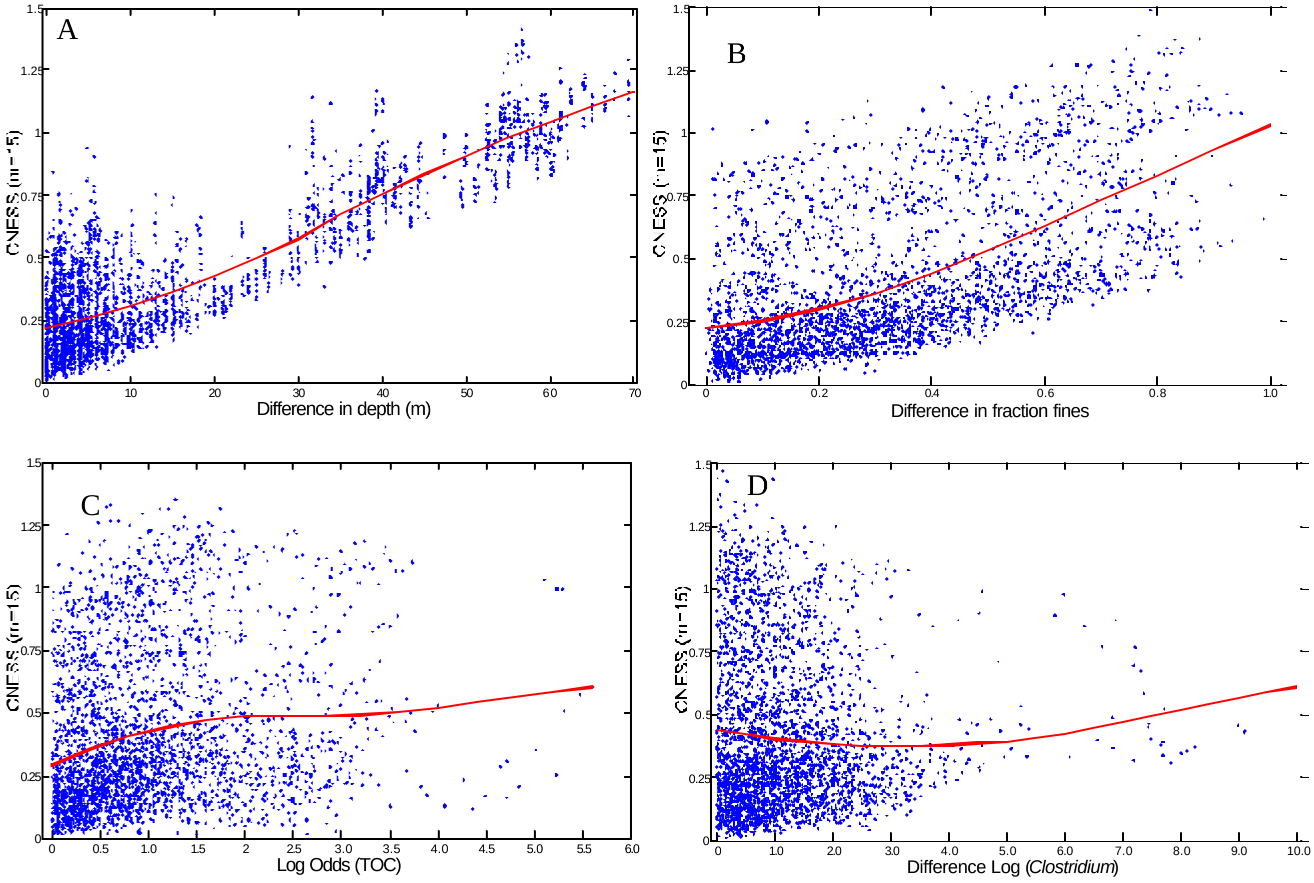


Figure 5-27. Plots of the CNESS variation against four parameters: (A) Change in depth is the best predictor of change in community structure. Only 25% of total CNESS variation shown here. (B) Grain size is a strong predictor of change in species composition. (C) TOC is a weak predictor of change in species composition. (D) *Clostridium* is a poor predictor of change in species composition.

The second GLM model was designed as a sensitive test for possible outfall discharge effects on species richness. Year was nested within pre and post, and station-to-station differences were nested within the nearfield versus farfield contrast. The model tests whether there is a significant difference between pre and post given the year-year variability in the pre-outfall years. The model simultaneously tests whether there are significant differences between the nearfield and the farfield given the station-station variability in each region. The ANOVA table (Table 5-6) contains the F statistic for NEAR*PRE to determine whether the difference in *alpha* between the nearfield and farfield changed after the outfall went online in September 2000. The F statistic for NEAR tests whether there are significant differences in *alpha* between the nearfield and farfield, given station-station differences.

There is no outfall effect: the NEAR*PRE term has a p value of 0.471. The F statistic is 0.5, indicating no change in the difference in alpha between baseline and discharge data. An assessment of the estimated effects sizes indicates that this design could detect about a 6 % change in Fisher's *alpha* due to the outfall discharge. This would be a very small effect, given that Fisher's *alpha* increased by over 45% between 1993 and 1997. Similarly, there are no significant differences between nearfield and farfield samples once station-station differences are accounted for (p for the NEAR contrast is 0.81). The profile plot (Figure 5-28) shows that the Fisher's *alpha* is nearly identical in the nearfield and farfield during the pre-outfall period (virtually no difference in curves). In the post-outfall years, the ln(Fisher's *alpha*) is estimated to be 0.022 units higher in the farfield than the nearfield (the non-significant NEAR*PRE effect). The 95% confidence interval for that estimated parameter is ±0.062.

Pielou's J'—Species evenness results were analyzed using the same GLM model, which suggested a significant outfall effect, even though on average species evenness increased in the nearfield in 2001, and in 2002 was well within the range observed during baseline (see Figure 5-21). Computationally, the GLM analysis fits a parallel-lines model (no evidence for interaction) between NEAR and FAR and then tests whether the difference in evenness between NEAR and FAR has changed after the outfall went online. The baseline vs. discharge differences detected by the model are significant with a p value of 0.024 (Figure 5-29), but are based on a 0.03 difference in the modeled J', compared with the pre-outfall baseline (Figure 5-29). This is a very subtle difference. Only through use of the GLM model including the station effect is the finding significant; models lacking that factor return a non-significant NEAR*PRE interaction term. The nested design used here produces a much more powerful analysis of possible treatment effects than would otherwise be possible, detecting a statistically significant result that does not appear to be ecologically important. Further investigation into station-specific data revealed that this significant effect was due to the extremely low evenness in one sample from NF17, which contained a large number of *Molgula manhattensis* (Figure 5-29). This species is often excluded from community analyses because it is usually epifaunal; it was retained in these analyses because these tiny juvenile specimens were considered to be functioning as infauna.

5.3.6 Benthic Threshold Calculations

Values were calculated for four diversity measures–number of species, Shannon diversity (H'), Pielou's evenness (J'), and log-series alpha and compared to the MWRA threshold values (MWRA, 2002). An additional value, the relative abundance of seven selected opportunist species (*Ampelisca abdita*, *Ampelisca macrocephala*, *Ampelisca vadorum*, *Capitella capitata* complex, *Mulinia lateralis*, *Polydora cornuta*, *Streblospio benedicti*) was calculated and compared to its respective thresholds. No exceedances were found as a result of these calculations (Leo *et al.*, 2003).

Table 5-6. Results of the General Linear Model (GLM) analyses modeling year, station, region*discharge interaction, and year*station interaction terms using hierarchical decomposition of sum of squares. Tests of Between-Subjects effects, with dependent variable ln(*alpha*).

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
Intercept	Hypothesis	1598.576	1	1598.576	5664.135	0.00	5664.135	1
	Error	10.436	36.976	0.282[b]				
NEAR	Hypothesis	1.41E-02	1	1.41E-02	0.051	0.82	0.051	0.056
	Error	10.228	37.134	0.275[c]				
PRE	Hypothesis	0.423	1	0.423	18.809	0.00	18.809	0.991
	Error	13.421	597	0.2248[d]				
NEAR * PRE	Hypothesis	1.17E-02	1	1.17E-02	0.519	0.47	0.519	0.111
	Error	13.421	597	0.02248[d]				
PRE(YEAR)	Hypothesis	6.502	9	0.722	32.134	0.00	289.21	1
	Error	13.421	597	0.02248[d]				
NEAR(STATION)	Hypothesis	19.029	34	0.56	24.896	0.00	846.456	1
	Error	13.421	597	0.02248[d]				

[a] Computed using alpha = .05

[b] .484 MS(NEAR(STATION)) + .516 MS(Error)

[c] .471 MS(NEAR(STATION)) + .529 MS(Error)

[d] MS(Error)

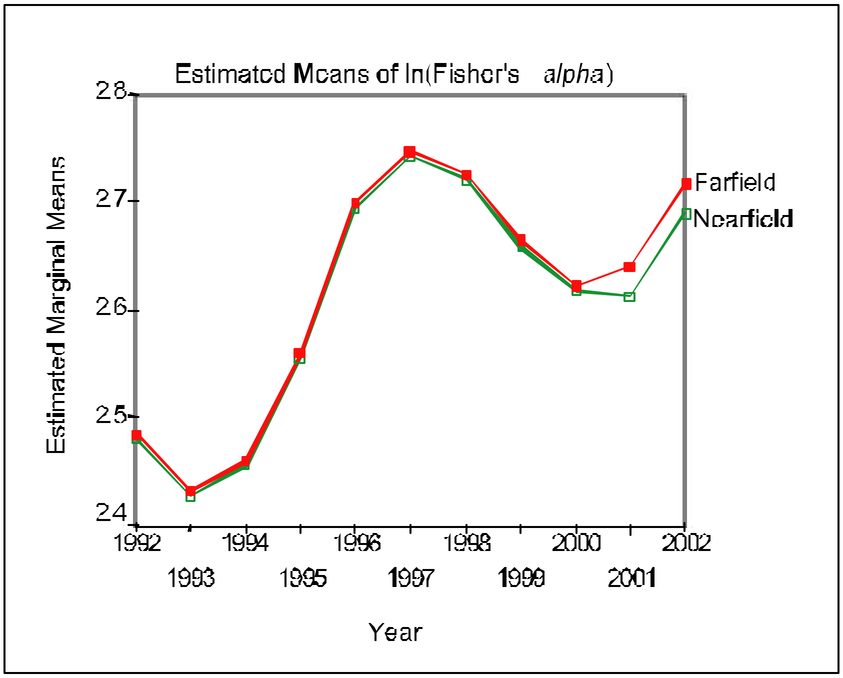
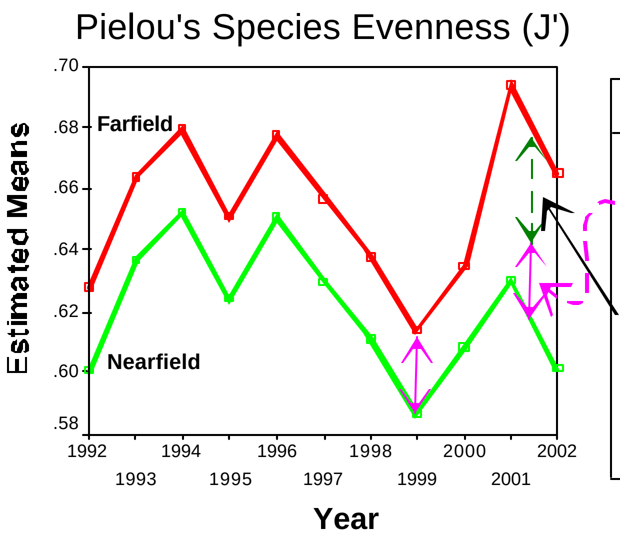


Figure 5-28. Estimated marginal means of (ln) Fisher's log-series *alpha* (see Tables 5-3 and 5-4).



Tests of Between-Subjects Effects

Dependent Variable: Pielou's J'

Source		Type III Sum of Squares	df	Mean Square	F	**Sig.**
Intercept	Hypothesis	95.049	1	95.049	2286.	
	Error	1.654	39.796	.042		
NEAR vs Far	Hypothesis	.114	1	.114	2.9	.102
	Error	1.630	40.108	.041		
PRE vs Post	Hypothesis	.013	1	.013	2.1	.146
	Error	3.645	597	.006		
NEAR * PRE	Hypothesis	.031	1	.031	5.1	**.024**
	Error	3.645	597	.006		
PRE(YEAR)	Hypothesis	.256	9	.028	4.7	< E-05
	Error	3.645	597	.006		
NEAR(STATION)	Hypothesis	2.701	34	.079	13.0	< E-6
	Error	3.645	597	.006[d]		

Figure 5-29. A 5% increase in evenness in the farfield relative to the nearfield in 2001 and 2002. Effect (indicated with dashed line, green arrowheads) tested with the Near vs. Far x Pre - vs. Post -Discharge interaction term.

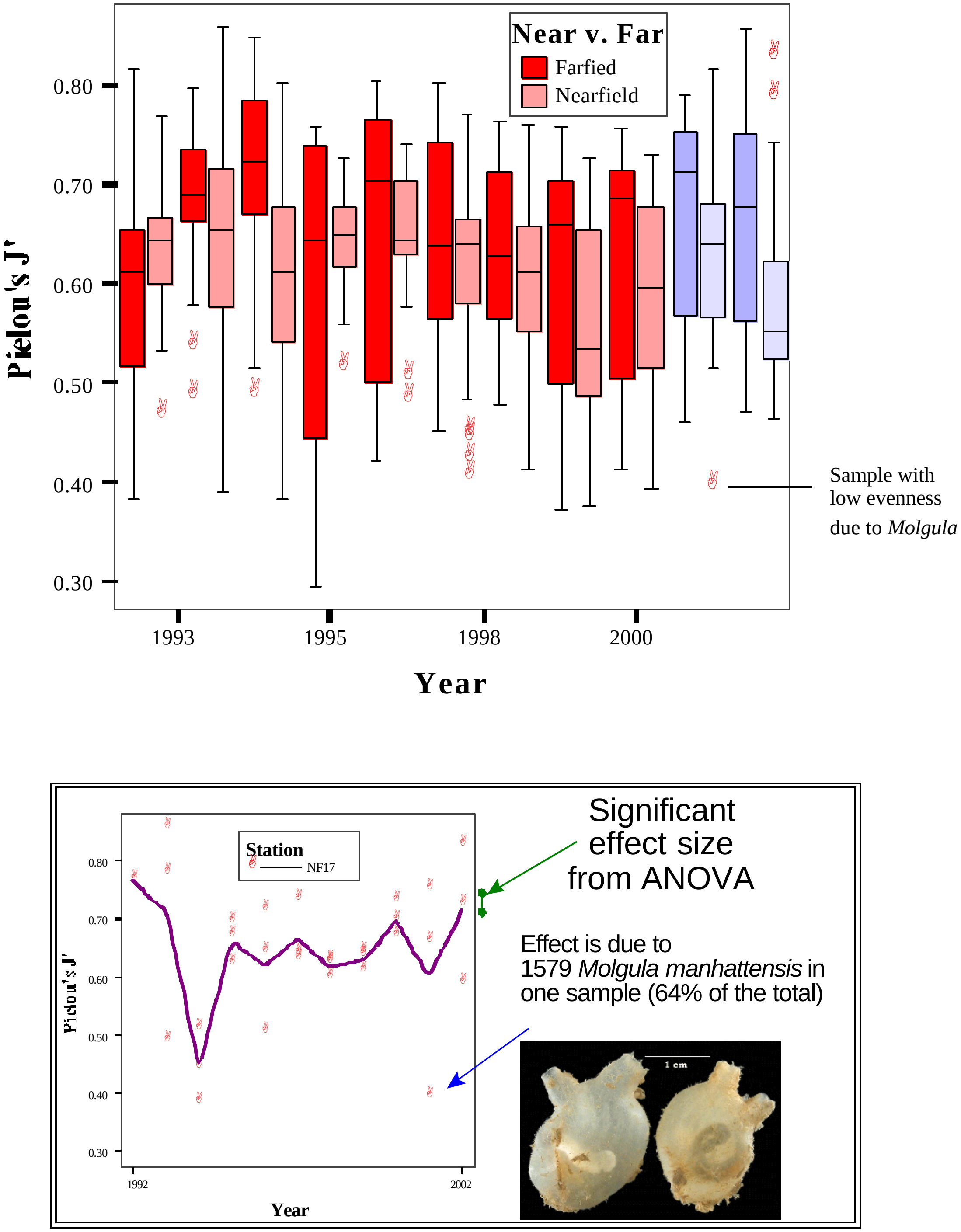


Figure 5-30. Infaunal evenness 1992–2002. (A) Boxplots for evenness at all stations. (B) Evenness at NF 17. The significant discharge effect detected in the GLM analyses stems largely from a single 2001 sample dominated by *Molgula manhattensis*, a tunicate.

5.4 Discussion

5.4.1 Patterns in Massachusetts Bay Soft-Bottom Benthic Communities

The nine-year baseline dataset acquired by the MWRA on the soft-bottom benthic communities of Massachusetts Bay provides an excellent basis for understanding potential responses of the system to the secondary-treated effluent. The variability at some stations due to severe impacts by winter storms, contrasted with the stability of other stations over time, provides documentation on long-term changes in regional benthic community structure. With the two additional years of data since the outfall became operational, patterns previously suggested by the data are now becoming clearer. These patterns include:

- Abundance of soft-bottom infauna has increased dramatically, approximately 60%, in both the nearfield and farfield from 1992–2002.
- Species richness (number of taxa in the species pool) and log-series *alpha* (a measure of species richness) also have increased dramatically in an apparent sine-wave pattern with a seven-year cycle. The increase in species richness is primarily due to an increase in the numbers of relatively rare species.
- Population densities of many species have also fluctuated cyclically.
- The numerically dominant species at specific stations have been for the most part invariant, such as *Cossura longicirrata* continuing to dominate the muddy offshore stations, especially those in Cape Cod Bay. There are some notable exceptions, *e.g*., *Spio limicola* was replaced by *Prionospio steenstrupi*, which is now dominant at 17 of the 23 nearfield stations.
- The second tier of dominants, those species which rank fifth through fifteenth and are neither the top dominant nor rare, have changed subtly over the past decade.
- During baseline, there was a similar pattern of change in both the nearfield and farfield: the successional half-life is roughly 30 years when the similarity index NNESS *m* is set at 15, which is sensitive to both the rare and abundant species. Compositional changes involving discharge data are somewhat slower than those observed during baseline.
- There has been virtually no change (increase or decrease) in any of the diversity indices that are sensitive to dominant species (H', ESN_2).
- There are no patterns that can be considered even a potential outfall effect.

In addition to the bay-wide considerations, results from individual stations were examined for any potential impact of the outfall on the soft-bottom benthos. There do not appear to be any stations showing a distinct break in any parameter between pre- and post-outfall, nor are there any stations with post-outfall indicators that are unexpected given baseline trends. Only one statistically significant effect was noted, but the effect size was very small and not ecologically significant: one sample at a sandy station, NF17, had over 1500 individuals of *Molgula manhattensis*, resulting in a very low Pielou's species evenness (J') for that sample. This species is typically found as an attached epifaunal organism and would therefore usually not be included in an analysis of infaunal benthos; it was included in the current analysis because the specimens were juveniles that were found within the sandy substrate at several nearfield stations. Due mainly to this one sample, the difference in J' between the nearfield and farfield samples in discharge monitoring was statistically significant. However, this is not considered to be a negative result, nor is it considered to be an impact of the outfall. Samples are taken in August of each year, and juveniles of many species are present in the samples. The increase in juvenile *Molgula* may be part of the larger baywide trend of increasing faunal abundances. Many of these juveniles will not survive to maturity at these sandy stations; they settle there because the coarse substrate provides surfaces for attachment, but they will not survive past a certain point in their development.

To address the question of whether there are any sites in the farfield that could be affected by any changes due to the outfall, the individual stations in the farfield were evaluated with respect to *alpha*, J', and the square root of total individuals. FF07, one of the two stations in Cape Cod Bay, had the lowest log-series *alpha* in 2001 and 2002. However, this was part of a long-term decline in *alpha* that began at this station in 1997. Moreover, *alpha* increased between 2001 and 2002 at FF07. In terms of abundance, FF06, the other Cape Cod Bay station, had low abundances in 2001 and 2002, but again this was part of a pattern of declining abundance that started in 1998. Similarly, FF14 showed a sharp decline in abundance in the post-outfall years, but this was also a trend that started in 1998.

5.4.2 Factors affecting Massachusetts Bay Community Structure

It is clear that the numerical dominants have shifted in the bay. In the early years of the monitoring program, and before that during the outfall siting studies (Blake *et al*., 1987), *Spio limicola* was numerically dominant at many sandy or sand-mud stations in the bay. That species has largely been replaced by another spionid polychaete, *Prionospio steenstrupi*, which has been dominant for several years at many stations and in 2002 exhibited a huge increase in abundance. The successional half life at NNESS *m*=15 is roughly 30 years, which could represent a bay-wide change in species composition, as indicated by the increase in *P. steenstrupi*. It might also reflect decadal-scale changes in sediment type due to storms (*e.g*., storms changing a formerly muddy site to a site with more sand). There are several hypotheses about the possible causes behind the observed changes in infaunal community structure (increase in abundance, change in species composition among the dominants, and increases in species richness). Among those possible explanations, more than one of which may be operative in the bay, are:

- The *perfect storm hypothesis*: changes in infaunal abundances are related to the recovery of the benthic communities from severe disturbances by the winter storms in the early 1990s.
- The *productivity hypothesis*: a long-term increase in the supply of organic matter to the benthos has led to increased abundances of infaunal organisms during the 1990s.
- The *climate change hypothesis*: infaunal communities are experiencing a long-term climate-induced change, perhaps related to the North Atlantic Oscillation (NAO).
- The *chance hypothesis*: larvae of *Prionospio steenstrupi* settle earlier and/or out-compete *Spio limicola* or other potential community dominants.

The *perfect storm hypothesis* is related to the devastating impacts of the 1992 winter storms, when the nearfield infaunal abundances seen in the previous year's samples were essentially halved. Mean faunal abundances increased steadily thoughout the later 1990s, perhaps representing a recovery of the benthic communities from the storms.

The *productivity hypothesis* suggests that increased loading of organic matter to the sediments bay-wide could account for the approximate doubling of infaunal abundance since 1993. This increased loading might be coupled to an overall increased intensity and magnitude of the spring and fall phytoplankton blooms, which play a disproportionate role in the flux of labile organic matter in the form of phytodetritus to the benthos.

The *climate change hypothesis* assumes a change in biogeographic regime. A change of a few degrees in bottom temperatures, perhaps associated with the NAO, could alter species composition through the effects of temperature on larval availability (including advection from source populations) and habitat preferences (temperature cues for cold- and warm-water species at the time of settlement). An NAO-coupled change in NO_3-rich, slightly colder, bottom water to the bay in the late 1990s could account for the increased abundance of infauna.

The NAO index, which tracks the behaviour of the NAO through time, exhibits a multiyear cycle, with an average period of 8–10 years. Studies on the soft-bottom infaunal communities off the west coast of Sweden showed a distinct cyclical pattern in macrobenthic abundance and biomass of approximately 7–8 years (Tunberg and Nelson 1998). Tunberg and Nelson proposed that the cycle documented in their study was related to climatic variability in the region, and that this climatic variability, which can affect primary production, may be a more fundamental cause of changes in benthic community structure than eutrophication or other anthropogenic factors.

The *chance hypothesis* supposes that the dominant species each year was from a group of select species and could not be readily predicted. Whichever species, due to its reproductive mode or chance, that got a head start each year tended to dominate the abundance pattern. Hubble (2001) discusses this concept as part of his unified neutral theory, in which all species are identical in terms of *per capita* chances of competing, dying, and reproducing. Although Hubble's ideas have a great deal of merit, it is probably not correct that all species are identical in this way.

5.4.3 Major Predictors of Community Structure

One of the results of the canonical PCA-H analysis was that benthic infaunal community structure was more highly correlated with depth than with other environmental parameters, including sediment grain-size composition (as percent fines), TOC, or *Clostridium*. This was surprising because grain size is usually considered the strongest influence on community structure. Depth appears to be the most important variable in the nearfield due to its distance from the origin on the CPCA-H plot (see Figure 5-10). Those distances are set from the correlation coefficient between depth and the ordination site scores for samples, so this is not a scale effect with depth just being more variable or having a broader range. Like regression analysis, a single outlier can influence the correlation. However, examination of scatterplots did not indicate that the pattern was based on a single sample.

Nearfield stations shallower than ~30 m do tend to be somewhat muddy, while deeper stations (with the exception of NF12 and NF24) tend to be sandier. However, the association between depth and fines was negative in the nearfield dataset (Figure 5-10) but positive in the farfield dataset (Figure 5-19). This trend is reversed in the combined nearfield-farfield dataset. Also, there may be only a weak linear association between % fines and community composition in nearfield sediments, as evidenced by finding many of the species that make up the benthic community in the muddy nearfield stations are not restricted to mud, but are found at many stations with modal grain sizes firmly in the sands. Ecologically, there may be a threshold effect where any sediment with more than some modest percentage of fines can support the *Prionospio–Mediomastus* community, or perhaps the ecologically important sediment structure is to be found in the 3- or 4-phi sands rather than the <4 phi silts and clays.

5.4.4 Proposed Changes in the Monitoring Program

Changes in the number, location, and frequency of sampling Massachusetts Bay stations for infaunal benthos have been proposed to the Outfall Monitoring Science Advisory Panel (OMSAP) (MWRA, 2003b). The proposed changes are meant to refine the monitoring while retaining the ability to detect significant statistical change due to natural or outfall effects. The changes specific to the benthic community analysis component are:

- Continue to collect and analyze infaunal samples from stations NF12 and NF17 every year through 2005;
- Randomly split the remaining stations into two subsets, and collect and analyze infaunal samples from each subset in alternate years so that all stations are sampled every two years;
- Retain current patterns of replication in infaunal and grain-size samples.

Details of the proposed changes, including the rationale for them, can be found in the briefing package for the July 24, 2003 OMSAP meeting (MWRA, 2003b).

6. 2002 HARD-BOTTOM BENTHIC HABITATS AND FAUNA

by Barbara Hecker

6.1 Baseline Conditions

The nearfield hard-bottom communities inhabiting drumlins in the vicinity of the outfall have been surveyed annually for the last nine years. These benthic communities have been surveyed utilizing a remotely operated vehicle (ROV) to photograph the sea floor. The first seven years of surveys provided a baseline database that has allowed characterization of the habitats and communities on the drumlins, as well as insight into their spatial and temporal variability(Kropp *et al.* 2002a and others). During the baseline time period, the sampling design changed from videotaping a series of transects near the outfall in 1994 (Coats *et al.* 1995), to surveying discrete stations (waypoints) on the drumlins immediately north and south of the outfall, and at several reference sites on drumlins further away (1995–2001). The emphasis on data products also has changed from reliance mainly on videotape to more emphasis on still photographs. The video images cover a much broader area and are mainly useful for assessing habitat relief and variability and enumeration of rare, larger mobile fauna, while the still photographs offer much higher resolution for enumeration of most of the fauna.

Analyses of the visual images collected during the last six years of the baseline period (1995–2000) have shown that the hard-bottom habitats are spatially quite variable and the benthic communities inhabiting them are temporally quite stable. The sea floor on the top of drumlins usually consists of a mix of boulders and cobbles, with habitat relief ranging from moderately high to high in areas dominated by larger boulders to moderate to low in areas consisting of a mix of cobbles and occasional boulders. Sediment drape on the top of drumlins varies from light to moderate at most locations and moderately heavy to heavy at a few locations. The sea floor on the flanks of drumlins is frequently quite variable, and usually consists of a cobble pavement interspersed to varying degrees with patches of sand, gravel, and boulders. Habitat relief on the flanks ranges from low to moderate, depending on how many boulders are present. Sediment drape in the flank areas usually ranges from moderate to heavy. The tops of the drumlins generally tend to be more spatially homogeneous than either the edges of the tops or the flanks of the drumlins, which tend to be spatially heterogeneous. As a result, small lateral shifts in position near the edges of the drumlin tops or on the flanks frequently result in substantially different habitat characteristics, and hence different communities.

Algae usually dominate benthic communities on the tops of drumlins, while invertebrates (mostly encrusting or attached forms) become increasingly dominant on the flanks of the drumlins. Both encrusting coralline algae and several species of upright algae are quite common throughout the hard-bottom areas near the outfall. The encrusting coralline algae usually dominate in areas that have little sediment drape, while upright algae frequently dominate in areas with substantial sediment drape. Coralline algae is the most abundant and widely distributed taxon encountered in this area. The areal coverage and distribution of coralline algae was quite stable during the baseline period. The percent cover of coralline algae appears to be strongly related to amount of sediment drape, with cover being highest in areas with little drape and lowest in areas with moderately heavy to heavy drape. This may reflect susceptibility of the encrusting growth form of coralline algae to smothering by fine particles. In contrast, the abundance and distribution of upright algae appear to be mainly controlled by habitat relief. These algae are quite patchily distributed and only abundant in areas of moderate to high relief. Areas supporting high abundances of upright algae also tend to have moderate to heavy sediment drape, with the numerous holdfasts of the algae appearing to actively trap sediment.

The pattern of benthic community structure in the hard-bottom areas was quite consistent throughout the baseline time period. The communities at many of the sites remained the same from 1995 to 2000. Occasional year-to-year differences in cluster designation of specific sites usually appeared to reflect spatial heterogeneity rather than temporal changes in the communities. The benthic communities at the three northern reference sites, and at several sites on the top of drumlins on either side of the outfall, are dominated by upright algae. In contrast, communities at the two southernmost reference sites, as well as at some drumlin top and flank sites on each side of the outfall, are dominated by coralline algae. A reference site located southwest of the outfall represents a relatively extreme habitat characterized by very large boulders with heavy sediment drape. This area has a different community in that it is frequently dominated by a red soft coral, *Gersemia rubiformis,* that is rarely found at any of the other sites. Several of the sites on the flanks of the drumlin located just south of the outfall are relatively depauperate when compared to the other sites. The diffuser heads of the outfall have been colonized by a luxuriant community consisting of the frilled sea anemone, *Metridium senile*, the sea peach tunicate, *Halocynthia pyriformis,* and the northern sea star, *Asterias vulgaris*.

The first post-discharge survey of the nearfield hard-bottom communities was conducted during late June and early July of 2001, nine months after the outfall went online. The hard-bottom benthic communities near the outfall showed patterns that were remarkably similar to those observed pre-discharge. One difference that was noted between the pre- and post-discharge periods was a slight increase in sediment drape and a decrease in percent cover of coralline algae at five of the stations north of the outfall in 2001.

This chapter reports on the results of the second post-discharge survey of the hard-bottom communities that was conducted during late June 2002 and compares these results to pre-discharge baseline conditions. All of the waypoints were successfully surveyed during 2002, including an actively discharging diffuser head at the eastern end of the outfall.

6.2 Methods

Video footage and still photographs were obtained at each of the 23 waypoints (Table 6-1). Waypoint T4/6-1, which is located on top of the drumlin immediately south of the outfall, was surveyed twice. The moderately high habitat relief usually encountered at this station was not found during the first visit, so the station was reoccupied at the end of the survey. Slightly higher habitat relief was encountered during the second survey of this station. Both surveys of waypoint T4/6-1 were used in the data analysis, with the first visit being designated T4/6-1 (1) and the second visit being designated T4/6-1 (2). The photographic coverage ranged from 18 to 31 minutes of video footage and from 20 to 34 still photographs (35-mm slides) at each waypoint. A total of 720 still photographs were taken and used in the following data analysis.

Table 6-1. Photographic coverage at locations surveyed during the 2002 nearfield hard-bottom survey.

Transect	Waypoint	Location on drumlin	Depth (m)	Video (min)	Stills (# frames)
1	1	Top	25.4	20	34
1	2	Top	26.1	24	32
1	3	Top	22.5	27	32
1	4	Top	23.0	22	33
1	5	Flank	29.8	21	31
2	1	Top	25.9	23	32
2	2	Flank	24.5	20	33
2	3	Top	24.8	21	33
2	4	Flank	28.1	23	32
2	5	Diffuser #2	33.1	27	26
4	1	Flank	32.3	21	31
4	2	Flank	29.3	21	33
4	3	Flank	30.0	20	29
4/6	1-1	Top	26.3	31	33
4/6	1-2	Top	23.8	22	32
6	1	Flank	32.7	21	31
6	2	Flank	27.8	21	33
7	1	Top	24.9	20	32
7	2	Top	26.5	20	28
8	1	Top	25.2	24	20
8	2	Top	23.7	23	27
9	1	Top	25.4	24	32
10	1	Top	23.3	22	26
Diffuser	#44		32.3	18	28

6.2.1 Visual Analysis

Each 35-mm slide was projected and analyzed for sea-floor characteristics (*i.e.*, substratum type and size class, and amount of sediment drape) and biota. The amount of sediment draped on the rock surfaces was assessed in terms of relative thickness, ranging from clean when the entire rock surface was visible to heavy when none of the rock surface was visible. To facilitate comparisons among stations and years, these sediment drape categories were assigned the following numerical codes:

Category	Numerical value
clean to very light	0
light	1
moderately light	2
moderate	3
moderately heavy	4
heavy	5

Most recognizable taxa were counted and recorded. Several very abundant taxa (for which accurate counts were impossible to obtain) were assessed in terms of percent cover or relative abundance. The abundance of encrusting coralline algae was assessed as rough estimates of percent cover. Several other taxa , a filamentous red alga (tentatively identified as *Ptilota serrata*), colonial hydroids, and small barnacles and/or spirorbid polychaetes, that were frequently too abundant to count reliably were assessed in terms of relative abundance. The following categories were used to assess abundances of taxa that were not counted on the still photographs:

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

Organisms were identified to the lowest possible taxonomic level, about half of them to species, with the aid of pictorial keys of the local flora and fauna (Martinez and Harlow, 1994; Weiss, 1995). Many of the encrusting species could not be identified to species. Most of these were assigned to descriptive categories (*e.g.*, “orange-tan encrusting”); however, each of these descriptive categories possibly includes several species. Additionally, some species might be split between two similar descriptive categories (*e.g.*, “orange encrusting” and “orange lumpy encrusting”), as a result of differences in viewing angles and lighting. Because of high relief in many of the habitats surveyed, all reported abundances should be considered to be extremely conservative. In many areas, only part of the surfaces of large boulders were visible; thus, actual faunal abundances in these areas were undoubtedly much higher than the counts indicated. A summary of the 2002 slide analysis is included in Appendix E1.

Several changes in taxonomic designations have occurred during the years of this survey. Coralline algae were originally referred to as *Lithothamnion* spp. However, voucher specimens collected in September 2000 indicate that the coralline algae belong to at least five species: *Leptophytum laevae*, *Leptophytum foecundum*, *Phymatolithon lamii*, *Phymatolithon laevigatum*, and *Lithothamnion glaciale*. Differences between these species can not be discerned on the basis of photographs, so all pink encrusting coralline alga were lumped into one taxon. Additionally, a voucher specimen of an abundant red filamentous alga that had previously been designated as *Asparagopsis hamifera* was identified as *Ptilota serrata*. Based on a specimen that was retrieved from the ROV during the 2003 diffuser inspection survey, hydroids on or near the diffuser heads that had previously been referred to as *Campanularia* sp. have been found to be *Tubularia* sp.

The videotapes were viewed to provide additional information about uniformity of the habitat at each of the sites. Notes on habitat relief, substrate size classes, and relative amount of sediment drape were recorded. Rare, large, and clearly identifiable organisms were enumerated. With the exception of the cunner *Tautogolabrus adspersus* (which was frequently very abundant), all fish were enumerated. Counts of abundant motile organisms, cryptic organisms, and all encrusting organisms were not attempted because of the large amount of time accurate counts would require and the general lack of resolution of the video footage. A summary of the 2002 video analyses is included in Appendix E2.

6.2.2 Data Analysis

Data were pooled for all slides taken at each waypoint. Comparisons among waypoints were facilitated by normalizing species counts to mean number of individuals per slide to account for differences in the number of slides collected at each site. Hydroids and small barnacles and/or spirorbids were omitted from the data analysis because they consisted of several species, could not be accurately assessed, and it was impossible to tell if they were alive. General taxonomic categories (*i.e.*, fish, sponge, etc.) were included in estimates of total faunal abundances, but were omitted from community analysis. Only taxa with an abundance of ten or more individuals in the entire data set were retained for community analysis. This process resulted in 43 out of the original 63 taxa being retained for community analysis. The white and pink color-morphs of *Halocynthia pyriformis* (sea peach tunicates) were pooled.

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

6.3 Results

Habitat characterizations and dominant taxa that were determined separately from video images and still photographs were similar, indicating that the still photographs were representative of the areas surveyed. Differences between the two types of coverage were mainly related to a higher occurrence of some sparsely distributed larger taxa observed in the greater geographic coverage afforded by the videotapes, and the higher occurrence of encrusting and/or smaller taxa afforded by the superior resolution of the still photographs. Additionally, larger mobile organisms that actively avoid the ROV, like the cod *Gadus morhua*, were less likely to be seen in the still photographs.

6.3.1 Distribution of Habitat Types

The sea floor on the tops of the drumlins usually consisted of a mix of glacial erratics in the boulder and cobble size categories. At 11 of these areas the sea floor consisted of numerous boulders interspersed with cobbles and was generally characterized by moderate to moderately high relief. These higher relief areas were located on the very top of the drumlins immediately north and south of the outfall (T1-1, T1-2, T1-3, T1-4, T2-2, T2-3, and T4/6-1), at the three northern reference sites (T7-1, T7-2, and T9-1), and at a reference site located southwest of the outfall (T10-1). The sea floor at the remaining drumlin top areas mainly consisted of a mix of cobbles, occasional boulders, and gravel and had moderately low to moderate relief. One of these sites (T2-1) was located on the drumlin directly north of the diffuser, and two were the southernmost reference sites (T8-1 and T8-2). The tops of drumlins had quite variable amounts of sediment drape, ranging from a light to moderately light sediment drape (T4/6-1, T1-2, T1-3, and T1-4) to a heavy sediment drape (T10-1). The sea floor on the flanks of the drumlins usually consisted of a moderately low to moderate relief mix of cobbles, boulders, and gravel. Sediment drape on the flanks ranged from a moderately light drape (T4-1, T4-3, and T6-2) to a moderately heavy mat-like cover (T2-4). Habitat relief and sediment drape frequently were quite variable within many of the sites surveyed. Most moderate to high relief areas also contained small patches of low relief cobbles and gravel, and some of the low relief areas contained occasional patches of higher relief boulders. Additionally, in areas of moderate to heavy sediment drape, occasional bare rock surfaces neighbored heavily draped ones.

Two diffuser heads were visited during the 2002 survey, one that was actively discharging effluent (T2-5, Diffuser #2) and one that was not activated (Diffuser #44). The sea floor in the vicinity of both diffusers consisted of angular rocks in the small boulder size category. This resulted in a high relief island (the diffuser head) surrounded by a moderate relief field of boulders. Sediment drape was moderate at both diffusers. Both diffusers were colonized by numerous frilled anemones, sea peach tunicates, and sea stars.

6.3.2 Distribution and Abundance of Epibenthic Biota

Seventy-one taxa were seen during the visual analyses of the 2002 nearfield hard-bottom survey still photographs and videotapes (Table 6-2). Sixty-three of these taxa were seen on the still photographs. Taxonomic counts or estimates of abundances included 7,588 algae, 20,804 invertebrates, and 1,830 fish (Table 6-3). Coralline algae was the most abundant taxon observed during the survey, with an estimated abundance of 4,903 individuals. Two other algae commonly seen were dulse (*Rhodymenia palmata*) and a red filamentous alga *Ptilota serrata*, with abundances of 1,884 and 771 individuals, respectively. Another alga, the shotgun kelp *Agarum cribosum*, was also seen during this survey.

Table 6-2. Taxa observed during the 2002 nearfield hard-bottom survey.

	Taxon	Common Name
	Algae	
	Coralline algae	pink encrusting algae
	Ptilota serrata	filamentous red algae
	Rhodymenia palmata	dulse
	Agarum cribrosum	shotgun kelp
	Fauna	
	Sponges	
	Sponge	
*	*Aplysilla sulfurea*	yellow sponge
	Halichondria panicea	crumb-of-bread sponge
	Haliclona oculata	finger sponge
	Haliclona spp.	encrusting sponge
*	*Melonanchora elliptica*	warty sponge
**	*Polymastia?*	siphon sponge?
	Suberites spp.	fig sponge
	white divided	sponge on brachiopod
*	orange/tan encrusting	sponge
*	orange encrusting	sponge
*	pink fuzzy encrusting	sponge
*	white translucent	sponge
*	cream encrusting	sponge
*	filamentous white encrusting	sponge
*	general encrusting organism	
	Cnidarians	
	Hydroid	
	Tubularia sp.	hydroid
	Obelia geniculata	zig-zag hydroid
	anemone	
	Metridium senile	frilly anemone
	Urticina felina	northern red anemone
	Cerianthus borealis	northern ceriantid
	Alcyonium digitatum	dead man's fingers
	Gersemia rubiformis	red soft coral
	Mollusks	
*	gastropod	
*	*Tonicella marmorea*	mottled red chiton
*	*Crepidula plana*	flat slipper limpet
	Buccinum undatum	waved whelk
**	*Neptunea decemcostata*	ten-ridged whelk
*	nudibranch	
	Modiolus modiolus	horse mussel
	Placopecten magellanicus	sea scallop
*	*Arctica islandica*	quahog
	Crustaceans	
	Balanus spp.	acorn barnacle
	Homarus americanus	lobster
	Cancer spp.	Jonah or rock crab
*	hermit crab	
*	crab	
	Echinoderms	
	Strongylocentrotus droebachiensis	green sea urchin
	juvenile *Asterias*	small white starfish
	Asterias vulgaris	northern sea star
	Henricia sanguinolenta	blood star
	Crossaster papposus	spiny sun star
	Porania insignis	badge star
*	*Pteraster militaria*	winged sea star
**	*Solaster endeca*	sun star
	Psolus fabricii	scarlet holothurian
	Tunicates	
	Aplidium spp.	sea pork tunicate
*	*Dendrodoa carnea*	drop of blood tunicate
*	*Didemnum albidum*	northern white crust tunicate
	Halocynthia pyriformis	sea peach tunicate
	Boltenia ovifera	stalked tunicate
	Bryozoans	
	bryozoan	
*	*Membranipora* sp.	sea lace bryozoan
*	red crust bryozoan	
	Miscellaneous	
	Myxicola infundibulum	slime worm
	spirorbids/small barnacles	
	Terebratulina septentrionalis	northern lamp shell
	Fish	
	fish	
	Gadus morhua	cod
	Hemitripterus americanus	sea raven
	Pseudopleuronectes americanus	winter flounder
**	*Prionotus* spp.	sea robin
	Macrozoarces americanus	ocean pout
	Myoxocephalus spp.	sculpin
	Tautogolabrus adspersus	cunner

*Seen only on still photographs. **Seen only on video.

Table 6-3. Taxa seen in still photographs taken during the 2002 nearfield hard-bottom survey, arranged in order of abundance.

Taxon	Count	Taxon	Count
Algae		red crust bryozoan	32
Coralline algae	4903[1]	filamentous white encrusting sponge	27
Rhodymenia palmata	1884	*Obelia geniculata*	21
Ptilota serrata	771[1]	*Urticina felina*	20
Agarum cribrosum	30	*Arctica islandica*	17
Total algae	**7588**	*Gersemia rubiformis*	16
		Placopecten magellanicus	15
Invertebrates		anemone	20
Metridium senile	2864	*Homarus americanus*	13
juvenile *Asterias*	2646	*Haliclona* spp. (encrusting)	12
Didemnum albidum	1675	*Pteraster militaria*	10
Aplidium spp.	1360	*Cerianthus borealis*	8
Terebratulina septentrionalis	1350	*Tonicella marmorea*	8
orange/tan encrusting sponge	1338	*Boltenia ovifera*	6
Modiolus modiolus	1241	*Melonanchora elliptica*	5
Henricia sanguinolenta	1031	*Buccinum undatum*	5
white translucent sponge	970	*Crossaster papposus*	5
Dendrodoa carnea	906	*Haliclona* spp. (upright)	3
orange encrusting sponge	662	nudibranch	3
bryozoan	540	*Alcyonium digitatum*	2
white divided sponge	508	hermit crab	2
general encrusting organism	397	*Membranipora* sp.	2
Aplysilla sulfurea	383	gastropod	1
Halocynthia pyriformis	381	general crab	1
white *Halocynthia pyriformis*	353	*Porania insignis*	1
pink fuzzy encrusting sponge	351	hydroids	*
Myxicola infundibulum	320	spirorbid/barnacle complex	*
Strongylocentrotus droebachiensis	254	**Total invertebrates**	**20804**
Psolus fabricii	214		
Asterias vulgaris	211	**Fish**	
Halichondria panicea	185	*Tautogolabrus adspersus*	1785
Suberites spp.	116	*Myoxocephalus* spp.	17
Tubularia sp.	116	*Gadus morhua*	12
Sponge	100	*Pseudopleuronectes americanus*	7
Balanus spp.	94	fish	5
Cancer spp.	79	*Macrozoarces americanus*	3
cream encrusting sponge	75	*Hemitripterus americanus*	1
Crepidula plana	52	**Total fish**	**1830**

* Not counted

[1] Estimated

The most abundant invertebrates observed on the still photographs were the frilled anemone *Metridium senile* (2,864 individuals), the northern sea star *Asterias vulgaris* (2,646 juveniles and 211 adults), the northern white crust *Didemnum albidum* (1,675 individuals) and sea pork *Aplidium* spp. (1,360 individuals) tunicates, the brachiopod *Terebratulina septentrionalis* (1350 individuals), an unidentified orange/tan sponge (1,338 individuals), the horse mussel *Modiolus modiolus* (1,241 individuals) and the blood sea star *Henricia sanguinolenta* (1,031 individuals). Other common invertebrate inhabitants of the drumlins included numerous sponges and encrusting organisms. The most abundant fish observed in the still photographs were the cunner *Tautogolabrus adspersus* (1,785 individuals), sculpin *Myoxocephalus* spp. (17 individuals) and cod *Gadus morhua* (12 individuals).

Coralline algae was the most abundant and widely distributed taxon encountered during the survey. This encrusting alga was seen at 21 of the 23 waypoints, being absent from the two diffuser sites. Mean areal coverage of coralline algae ranged from 1% at T10-1 to 80% at T4/6-1 (2). Figure 6-1 shows the relationships between depth, sediment drape, percent cover of coralline algae, and topography. Amount of sediment drape did not show a strong relationship with either depth or topography. Percent cover of coralline algae was quite variable and showed a weak general trend of higher cover at shallower depths. However, the strongest relationship was between percent cover of coralline algae and degree of sediment drape. Corallines were most abundant in areas that had minimal sediment drape on the rock surfaces and least abundant in areas that had heavy sediment cover. In contrast, the two most abundant upright algae, *Ptilota serrata* and *Rhodymenia palmata,* had much more restricted distributions, with *P. serrata* being common at only five of the sites and *R. palmata* being common at only eight of the sites. These upright algae frequently dominated in areas characterized by high relief and a moderate to heavy sediment drape. The reduced percent cover of coralline algae in areas supporting high abundances of upright algae appeared to be related to fine particles being trapped by the holdfasts of the upright algae and blanketing the rock surfaces. In areas with heterogeneous substrate characteristics, *P. serrata* and *R. palmata* frequently dominated on the tops of boulders, while corallines dominated on the cobbles and smaller boulders in between.

Several of the commonly seen invertebrates also exhibited wide distributional patterns. The northern sea star *Asterias vulgaris* was found at all of the sites. Juvenile *Asterias* were usually much more abundant than adults and were most abundant on the top of drumlins. The highest abundances of juvenile *Asterias* were found at T1-3, T4/6-1, T1-4 and T1-1, and the lowest abundance was found at T4-1. The horse mussel *Modiolus modiolus* was also very widely distributed, being found at all but the two diffuser sites. This mussel was most abundant on the top of drumlins, where large numbers frequently were observed nestled among cobbles and at the bases of boulders (T4/6-1, T1-3, and T2-2). Because of the mussel's cryptic nature of being nestled in among rocks and frequently being almost totally buried, the observed abundances should be considered very conservative. The number of mussels definitely would be underestimated in areas of high relief, because the bases of larger boulders frequently were not visible in the images. Two species of tunicates also were widely distributed. The sea pork tunicate *Aplidium* spp. was found at all but two of the sites and was most abundant at T6-2, T4/6-1, T4-2, T4-3, and T8-2. The northern white crust tunicate *Didemnum albidum* was also found at all but three of the sites surveyed. The blood sea star *Henricia sanguinolenta* was observed at all of the sites, and was most abundant on boulders in areas of high relief (T4/6-1, T2-2, T2-3, T9-1 and T1-3).

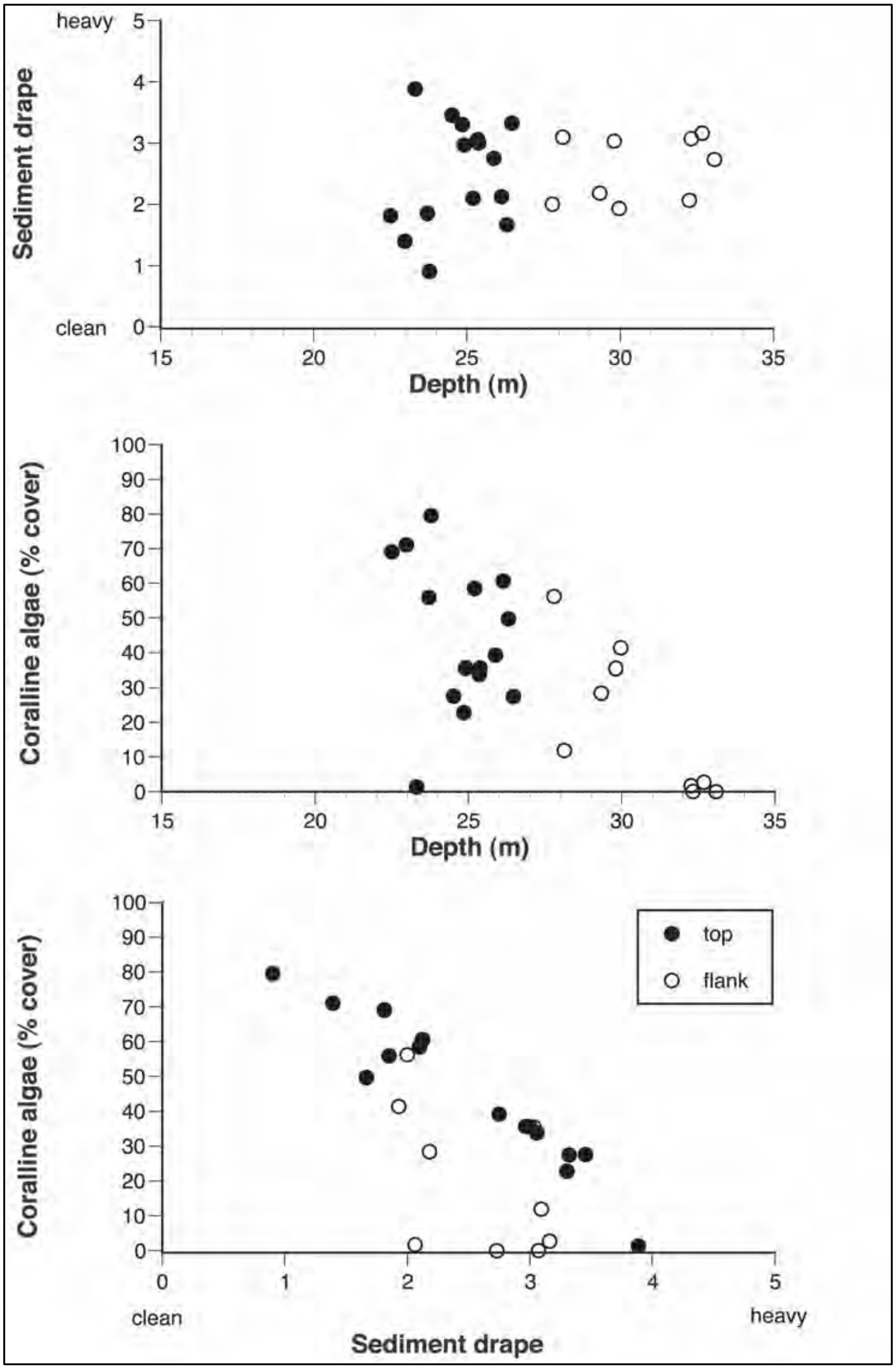


Figure 6-1. Depth, sediment drape, and percent cover of coralline algae of the sites from the 2002 nearfield hard-bottom survey.

Several other abundant invertebrates exhibited much more restricted distributions. Four of these species appeared to be primarily restricted to large boulders. The brachiopod *Terebratulina septentrionalis* was found at nine of the sites, but was only seen in high abundances at five of them (T2-3, T2-2, T4/6-1, T9-1, and T2-4). This species appeared to be restricted to the sides of large boulders where it might be protected from sediment loading, which could clog their filtering apparatuses. Another species that was markedly more abundant on large boulders was the frilled anemone *Metridium senile*. This anemone was found at 16 sites, but was abundant at only five of them. It was abundant on large boulders at T2-4, T2-2, and T2-3, and was very abundant on the two diffuser heads (Diffuser#2 and Diffuser#44). This anemone was usually seen on the tops and upper sides of boulders. The sea peach tunicate *Halocynthia pyriformis* was found at 18 sites but was only found in high abundances on the two diffuser heads. This species was usually seen on the sides of large boulders. The species with the most restricted distribution was the soft coral *Gersemia rubiformis*, which was seen only at T10-1 where it commonly inhabited the tops of large boulders characteristic of this site.

The distribution of the green sea urchin *Strongylocentrotus droebachiensis* appeared to be related to food availability rather than specific substrate characteristics. This urchin was widely distributed, but was only found in high abundances in regions that had high cover of coralline algae (T4/6-1, and T1-4), on which it grazes (Sebens, 1986). The red holothurian *Psolus fabricii* also was widely distributed. This holothurian was found at 16 sites, but was abundant at only three of them (T1-4, T4/6-1, and T8-2). Reasons for its high abundance at some sites, and not at others, were not readily apparent.

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

The fish fauna was dominated by the cunner *Tautogolabrus adspersus*, which was observed all 23 waypoints. This fish was most abundant in moderate to high relief areas, where it tended to congregate among large boulders (T7-1, T1-4, T1-3, T9-1, and T10-1). In areas of heterogeneous relief, *T. adspersus* frequently was seen only in the vicinity of boulders. Five other fish species, sculpin (*Myoxocephalus* spp.), winter flounder *(Pseudopleuronectes americanus*), ocean pout (*Macrozoarces americanus*), cod (*Gadus morhua*), and a sea raven (*Hemitripterus americanus*) also were seen on the still photographs. The sculpin and flounder were usually seen in areas of lower relief, while cod and ocean pout were only observed in areas of higher relief. Only one sea raven was seen.

6.3.3 Community Structure

Classification of the 23 waypoints and 43 taxa (retained for analysis) defined three clusters of stations, with two outlier stations loosely attached to the second cluster (Figure 6-2). The first two clusters further divided into slightly more cohesive subgroups. The first cluster consisted of drumlin tops and one flank area. With one exception, all of the areas in cluster 1 had boulders as their primary substrate, moderate to moderately high habitat relief, and moderate to heavy sediment drape. The drumlin top areas included the three northern reference sites (T7-1, T7-2, and T9) and five sites on the drumlins adjacent to the outfall (T1-1, T2-1, T2-2, T2-3, and T4/6-1(1)). The one flank area in Cluster 1 is also on a drumlin adjacent to the outfall. The remaining site in cluster 1 was T10-1, the reference site located just southwest of the outfall, which is characterized by high relief and heavy sediment drape. The second cluster consisted of drumlin top and flank areas that had variable substrate and habitat relief and mostly light to moderately light sediment drape. These included the two southernmost reference sites (T8-1 and T8-2), as well as

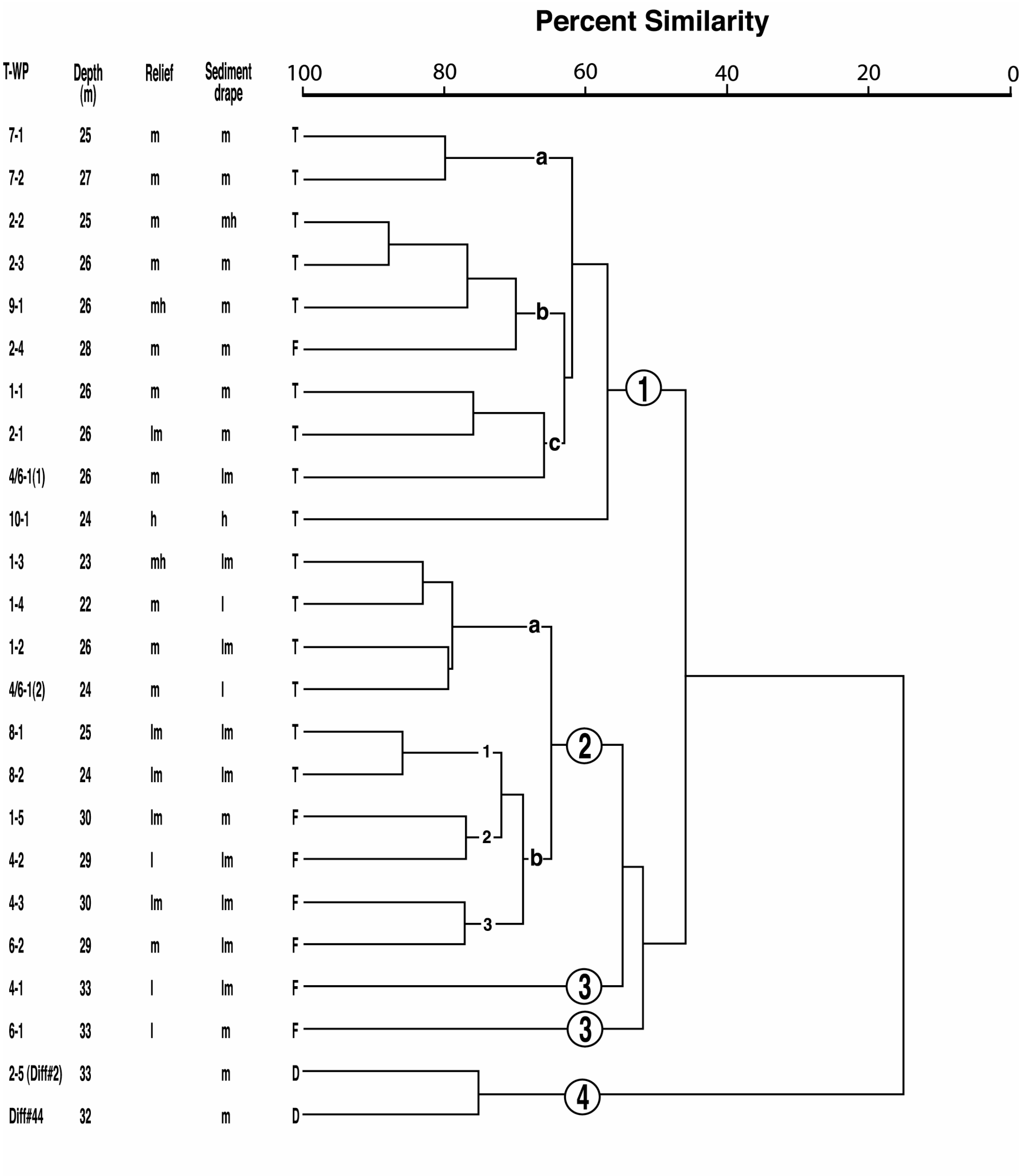


Figure 6-2. Cluster analysis of data collected from still photographs taken during the 2002 nearfield hard-bottom survey.

sites on the drumlins north and south of the outfall. Two low-relief areas that were located on the flanks of the drumlin south of the outfall (T4-1 and T6-1) loosely attach to cluster 2. The third cluster consisted of the two diffuser heads (Diffuser #2 at T2-5 and Diffuser #44) and the areas immediately surrounding them. The clustering structure appeared to be determined by a combination of drumlin topography, habitat relief, sediment drape, and geographic location. Neighboring waypoints with similar habitat characteristics tended to cluster together. Habitat characteristics and range of abundances of dominant taxa for each of the cluster groups are presented in Table 6-4.

Encrusting coralline algae were common inhabitants of all but one of the areas comprising the first two cluster groups. Differences among the areas in these two cluster groups were mainly related to the relative proportion of encrusting and upright algae at each of the sites. The areas in Cluster 1 supported more upright algae, *Ptilota serrata* and *Rhodymenia palmata*, while the areas in Cluster 2 supported more encrusting coralline algae and few, if any, upright algae. The ten areas in Cluster 1 divided into three subgroups and one individual site. The divisions reflected shifts in the composition of the communities inhabiting these areas, as well as differences in the abundances of their biotic inhabitants. All of the areas supported upright algae and the northern white crust tunicate, *Didemnum albidum*. Subgroup 1a, which consisted of the two northernmost reference sites (T7-1 and T7-2), supported the highest abundances of both dulse and filamentous red algae, as well as the horse mussel *Modiolus modiolus*. These areas also supported numerous cunner. The four areas in subgroup 1b supported more dulse than filamentous red algae, as well as high numbers of northern lamp shells *Terebratulina septentrionalis*. The three drumlin-top areas in subgroup 1c supported a mix of dulse and coralline algae, the tunicates *D. albidum* and *Aplidium* spp., and juvenile *A. vulgaris*. One of these sites, T4/6-1(1), also supported numerous northern lamp shells. The sea floor at the remaining area in Cluster 1, T10-1, consisted mainly of large boulders that provided suitable attachment sites for the red soft coral *Gersemia rubiformis,* which is not found at any of the other sites. This site also supported some dulse, very little coralline algae, and numerous cunner. The biota at the northernmost reference sites consisted of roughly an equal mix of algae and invertebrates, while the biota at the remaining sites in this cluster was dominated by invertebrates.

The benthic communities at all of the areas in Cluster 2 were dominated by either coralline algae or invertebrates, but never by upright algae. The areas in this cluster further divided into four subgroups. Coralline algae was the dominant component of the benthic communities found at all six of the drumlin top sites in this cluster (subgroups 2a and $2b_1$), with all of the sites having greater than 56 percent cover of coralline algae. The four sites in subgroup 2a had moderate to moderately high relief and supported numerous juvenile *A. vulgaris*, moderate numbers of green sea urchins *Stongylocentrotus droebachiensis*, and high numbers of mussels and cunner *Tautogolabrus adspersus*. In contrast, the two southernmost reference sites in subgroup $2b_1$ had moderately low relief and supported a moderate percent cover of coralline algae and high numbers of *Aplidium* spp. The two sites in subgroup $2b_3$ also supported the most adult *Asterias vulgaris*. All of the areas in Cluster 2 supported more invertebrates than algae. The two drumlin flank areas loosely attached to Cluster 2 (designated Cluster 3 in this analysis) had low relief, variable sediment drape and were relatively depauperate.

The two diffusers heads (Cluster 4) provided suitable attachment sites for numerous frilled anemones *Metridium senile* and sea peach tunicates *Halocynthia pyriformis*. The active diffuser (Diffuser #2 at T2-5) supported many more *M. senile* than the inactive diffuser (Diffuser #44). Dense aggregations of this anemone were seen on most of the exposed surfaces of the dome, as well as in the indentations of the discharge ports. The rock rubble surrounding the diffusers supported relatively few organisms.

Table 6-4. Habitat characteristics and range of abundance (number per picture) of selected taxa in the clusters defined by classification analysis. Numbers in bold highlight major differences among clusters and subgroups.

	1				2				3	3	4
	a	b	c	T10-1	2a	$2b_1$	$2b_2$	$2b_3$	T4-1	T6-1	
Depth (meters)	25-26	25-28	25-26	23	23-26	24-25	29-30	28-30	32	33	32-33
Habitat relief	M	M-MH	LM-M	H	M-MH	LM	L-LM	LM-M	L	L	
Sediment drape	m	m-mh	lm-m	h	l-lm	lm	lm-m	lm	lm	m	m
Location	T	T & F	T	T	T	T	F	F	F	F	D
Ptilota serrata	**4.85-8.31**	0.00-3.63	0.00-2.32	0.54	0.31-1.78	-	-		-	-	-
Rhodymenia palmata	**8.88-9.57**	**0.97-9.82**	**0.42-5.82**	**2.92**	0.00-0.81	0.00-0.25	-	0.03-0.36	-	-	-
Coralline algae	4.11-6.25	3.00-5.75	6.26-9.67	0.62	**12.19-14.84**	**11.50-11.67**	5.00-5.06	6.72-10.76	0.90	1.00	0.00-0.04
Coralline algae (percent cover)	28-36	12-36	34-50	1	**61-80**	**56-59**	28-35	41-56	2	3	-
Didemnum albidum	**2.56-3.07**	**4.13-6.75**	**2.24-3.91**	**3.12**	0.00-3.38	0.45-0.48	0.33-1.77	0.69-2.85	0.03	-	0.00-2.31
Modiolus modiolus	**2.63-3.45**	0.69-3.67	0.76-2.30	1.35	**1.00-5.03**	2.00-2.10	0.13-0.24	0.79-2.79	0.06	0.84	-
Terebratulina septentrionalis	0.00-1.89	**5.84-11.21**	0.00-7.24		0.00-0.09	-	0.00-0.09	0.00-0.12	-	-	-
juvenile *Asterias*	2.43-2.75	3.12-3.63	2.50-8.09	2.08	**5.16-8.59**	2.40-3.11	1.29-2.03	1.31-5.15	0.32	2.29	0.82-1.38
Strongylocentrotus droebachiensis	0.04-0.09	0.00-0.15	0.06-0.76		**0.66-1.64**	0.40-0.70	0.00-0.03	0.17-0.42	-	-	0.31-0.32
Aplidium spp.	0.00-0.72	0.53-1.18	1.75-2.73		0.19-4.16	**4.00-4.33**	**3.29-3.55**	3.86-4.21	0.03	1.23	0.04-2.54
Asterias vulgaris	0.00-0.28	0.09-1.34	0.06-0.30	0.08	0.09-0.25	0.04-0.10	0.21-0.35	**0.39-0.66**	0.13	**0.58**	0.25-0.54
Metridium senile	0.00-0.29	0.19-7.88	0.00-0.85	0.04	0.66-1.42	0.00-0.26	0.00-0.03	-	-	-	**18.96-60.00**
Halocynthia pyriformis	0.06-0.07	0.34-1.09	0.06-2.91		0.00-0.59	0.00-0.33	0.00-0.03	0.12-0.24	-	-	**7.86-10.19**
Gersemia rubiformis	-	-	-	**0.62**	-	-	-	-	-	-	-
Tautogolabrus adspersus	**3.75-5.38**	2.05-4.16	1.6-2.9	**4.9**	**3.2-5.0**	0.30-1.22	0.0-0.6	1.17-1.61	0.03	0.26	1.71-3.15
Total algae	**18.9-24.2**	4.0-16.6	9.6-14.4	4.1	**12.7-17.0**	**11.7-11.8**	5.0-5.1	6.8-11.1	0.9	1.0	-
Total invertebrates	19.9-26.2	**34.2-51.8**	**20.7-47.8**	19.2	**21.1-31.8**	17.7-19.6	11.2-11.3	**21.6-35.1**	2.1	10.0	**34.8-84.8**
Total fish	3.8-5.4	2.1-4.2	1.7-3.1	5.0	3.3-5.1	0.4-1.3	0.1-0.7	1.3-1.6	0.1	0.4	1.8-3.2
Total	48.6-49.5	54.6-68.9	32.0-61.0	28.3	**38.4-50.4**	**29.8-32.5**	16.3-17.0	29.6-47.8	3.1	11.4	**36.6-88.0**

Key: [a]Habitat relief: L = low, LM = moderately low, M = moderate, MH = moderately high. [b]Sediment drape: l = light, lm = moderately light, m = moderate, mh = moderately heavy, h = heavy. [c]Location: T = drumlin top, F = drumlin flank, D = diffuser.

Interestingly, even though the two visits to T4/6-1 were in very close geographical proximity to each other, they resulted in different cluster designations. The sea floor at the first location consisted of a cobble pavement interrupted by small boulders and a few very large boulders, with moderately light sediment drape. This area supported a few colonies of dulse and had a 50 percent cover of coralline algae. The occasional large boulders supported numerous northern lamp shells and sea peaches. This area clustered into the first group. In contrast, the sea floor at the second location at T4/6-1 consisted of mostly small to moderate boulders, with a rather light sediment drape. This area was dominated by coralline algae (80 percent cover), supported a few colonies of filamentous red algae, but no lamp shells or sea peaches. This area clustered into the second group based mainly on the high percent cover of coralline algae.

6.4 Spatial and Temporal Trends in the Nearfield Hard-bottom Benthos

The nearfield hard-bottom communities in the vicinity of the outfall have been surveyed annually for nine years. Seven of the surveys occurred under pre-discharge “baseline” conditions, while the last two surveys occurred under post-discharge conditions. The baseline surveys provided a substantial database that allowed characterization of the habitats and benthic communities found on the drumlins in the vicinity of the outfall. The sampling design and approach evolved during the baseline period to maximize the probability of detecting potential impacts of future outfall operations. The original survey conducted in 1994 consisted of videotapes taken along a series of transects on drumlins adjacent to the outfall (Coats et al. 1995). Starting in 1995 the sampling protocol was changed to surveying discrete stations (waypoints) on the drumlins immediately north and south of the outfall, and at several reference sites on drumlins further away (Figure 6-3). The 1995 sampling plan consisted of 19 waypoints, 17 near the outfall (on Transects 1, 2, 4 and 6) and one at each of two reference sites (Transects 7 and 8). In 1996, one additional waypoint was added at each of the reference sites and T6-3 was dropped because it was found to be exceptionally depauperate. Two new reference sites (Transects 9 and 10), and the head of Diffuser #44, were added during the 1997 survey. Diffuser #44 was added to the survey protocol because it was not scheduled to go online. Because it was less than 40 m from adjacent diffusers that were to be activated, and, like other diffusers, it had been densely colonized, it was thought to represent a worst-case scenario of potential impact. This general sampling protocol was repeated from 1998 to 2002, with the omission of the two waypoints on or near the diffuser (T2-5 and Diffuser #44) from the 1999 survey (because of concurrent work being conducted in the outfall tunnel) and the omission of T2-5 from the 2000 survey (a dive platform barge was anchored at the eastern end of the outfall). All sites were surveyed during the two post-discharge years, 2001 and 2002, including an actively discharging diffuser head at T2-5 (Diffuser #2).

In addition to a sampling plan that evolved to address specific issues, the emphasis on data products also has evolved. The 1994 and 1995 data sets relied mainly on an analysis of video footage. Some still photographs were also taken at each of the sites during the 1995 survey. Analysis of these photographs showed that the resolution afforded by the still photographs was far superior to that of the video images, and hence subsequent emphasis has been shifted to analysis of still photographs. The video images cover a much broader area than the still photographs, and are primarily used to assess habitat relief, spatial heterogeneity, and the occurrence of large, rare biota. The still photographs are used to provide detailed data on habitat characteristics (substrate size classes and amount of sediment drape), estimated percent cover of encrusting algae, estimated relative abundances of upright algae, and faunal composition of the benthic communities. The hard-bottom habitats are spatially quite variable, but have shown several consistent trends. At many of the waypoints, year-to-year variations in habitat characteristics tended to be relatively small. Figure 6-4 shows the habitat relief observed during the 1995 to 2002 surveys. Location

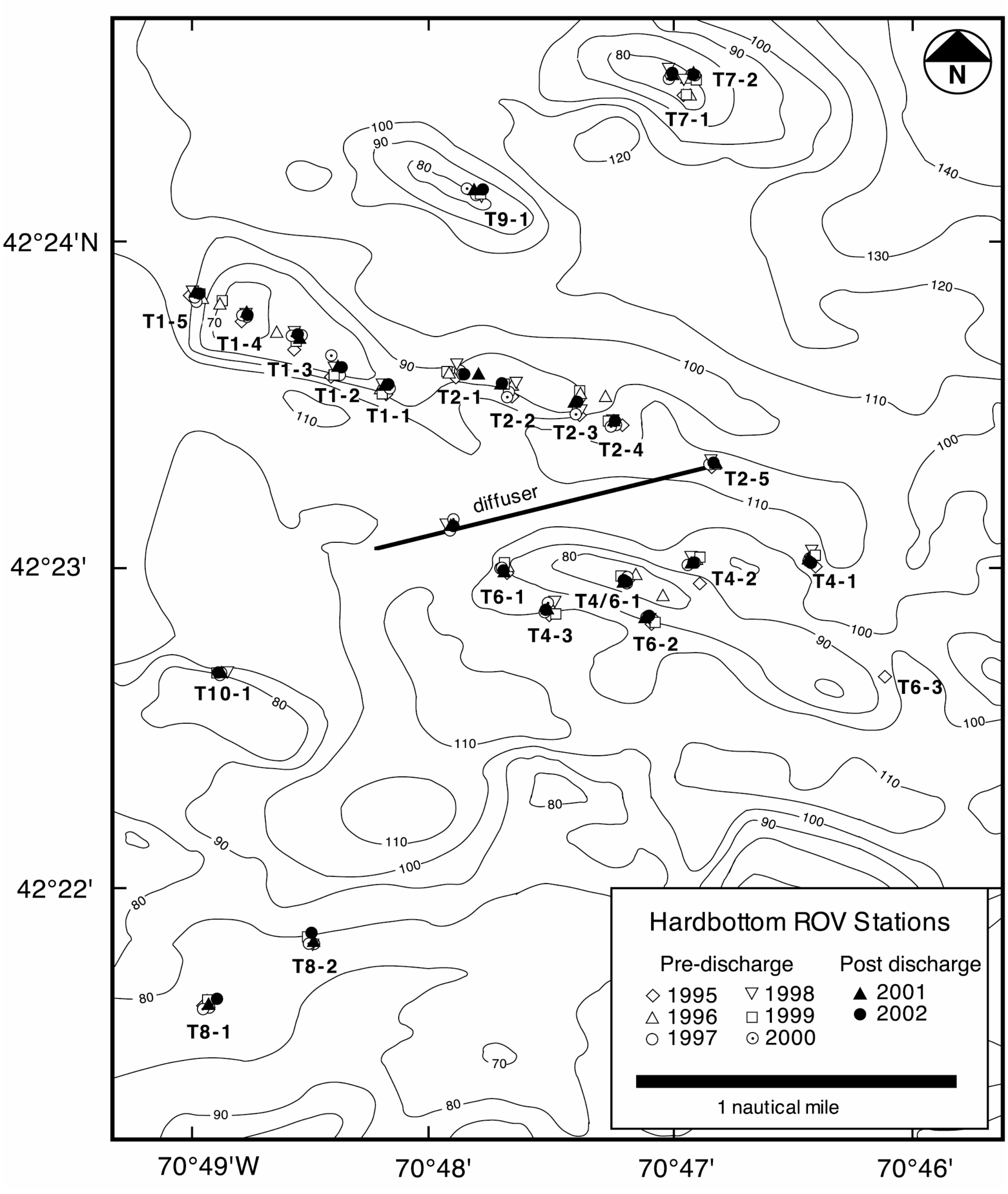


Figure 6-3. Nearfield hard-bottom stations surveyed from 1995 to 2002.

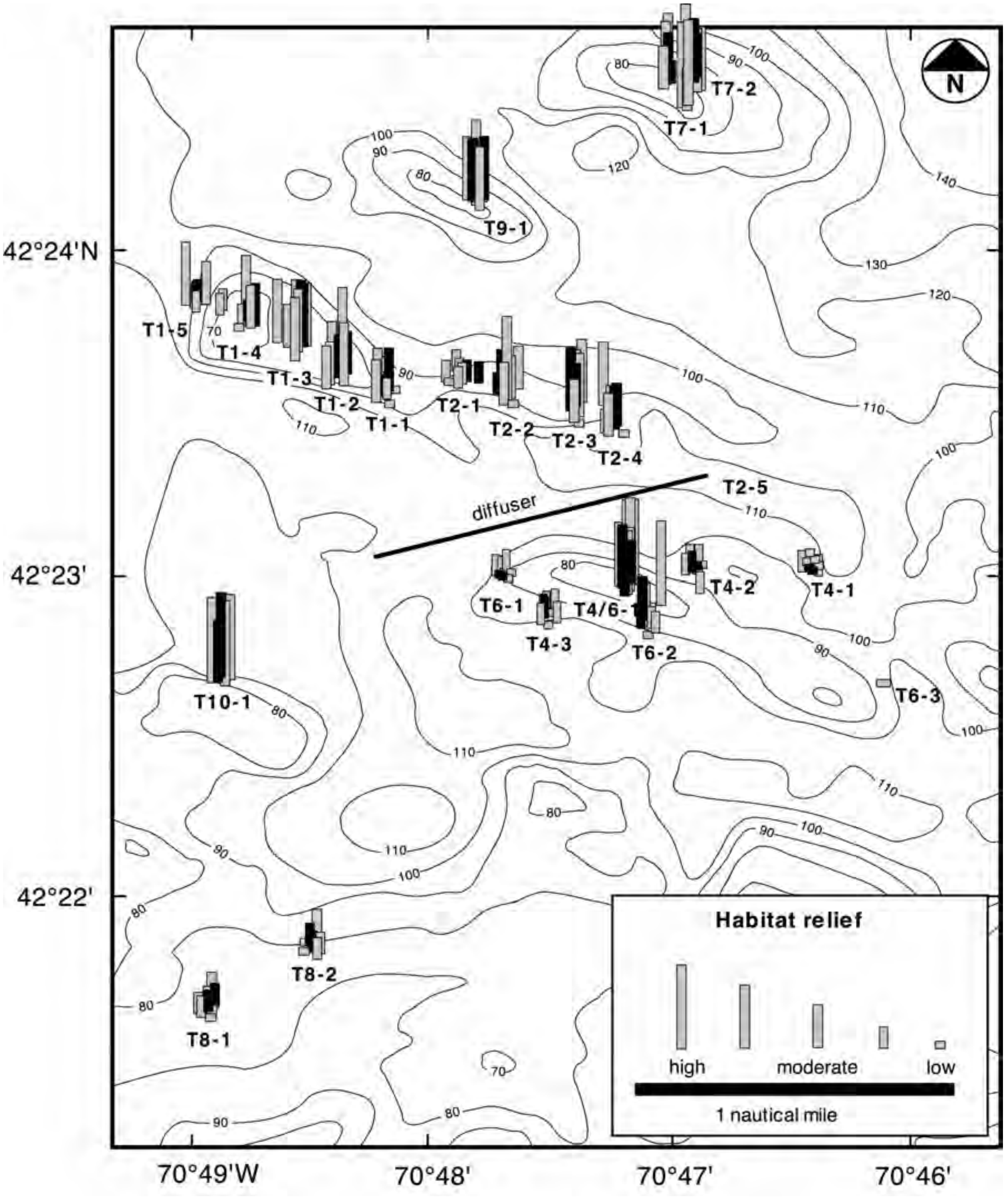


Figure 6-4. Habitat relief determined from the 1995–2002 nearfield hard-bottom surveys. Gray bars are pre -discharge values and black bars are post-discharge values.

on the drumlins appeared to be a primary factor in determining habitat relief. The sea floor on the tops of drumlins usually consisted of a mix of boulders and cobbles. Habitat relief varied from moderately high to high on drumlin tops dominated by boulders (T1-2, T1-3, T2-2, T2-3, T4/6-1, T7, T9, and T10) to moderate to low on drumlins that consisted of a mix of cobbles and boulders (T1-4 and T8). The sea floor on the flanks of drumlins was quite variable, but usually consisted of a cobble pavement interspersed with patches of sand, gravel, and occasional boulders. Habitat relief on the flanks ranged from low (T4-1, T4-2, T4-3, T6-1, and T6-2) to moderate (T1-5 and T2-4), depending on how many boulders were present. Figure 6-5 shows the relative amount of sediment drape seen on the rock surfaces during the 1995 to 2002 surveys. Sediment drape tended to be light on the shallowest part of the drumlins adjacent to the outfall (T1-2, T1-3, T1-4 and T4/6-1), moderately light at the southernmost reference sites (T8), and moderately heavy or heavy at the other southern reference site (T10), the northern reference stations (T7-2 and T9-1), and some of the flank stations (T4-1 and T6-1). The tops of the drumlins were relatively homogeneous, so that lateral shifts in position did not result in widely different habitat characteristics (*i.e.*, T1-3, T1-4, T4/6-1, T8, T9 and T10). In contrast, the edges of the drumlin tops and the flanks were more heterogeneous, such that small lateral shifts in position frequently resulted in substantially different habitat characteristics (*i.e.*, T1-1, T1-2, T1-5 and T4-2). Several stations north of the outfall had slightly more sediment drape in 2001 than at any time during the baseline period. The trend continued in 2002. The same stations north of the outfall had levels of drape similar to those observed in 2001, higher than seen during baseline.

The benthic communities inhabiting the hard-bottom areas showed similar patterns both pre- and post-discharge. Algae dominated on the tops of drumlins, while invertebrates (mostly encrusting or attached forms) were increasingly dominant on the flanks. Encrusting coralline algae was the most abundant and widely distributed taxon encountered during each year of the study. Figure 6-6 shows the percent cover of coralline algae estimated from the 35-mm images taken during the 1995–2002 surveys. Coralline algae were generally most abundant on the top of drumlins (T1-3, T1-4, and T4/6-1) and least abundant on the flanks (T2-4, T4-1, and T6-1). The percent cover of corallines was most variable near the edges of the tops of drumlins or on the flanks, where small lateral shifts in location frequently resulted in different habitat characteristics. This high degree of variability can clearly be seen in the different estimates obtained for percent cover of coralline algae for the two visits to T4/6-1 in 2002. Coralline algal cover was 50 percent at the first location visited and 80 percent at the neighboring location visited the second time. When location is taken into account, the distribution and areal coverage of coralline algae remained quite stable during the 1995–2000 baseline period and at most stations during the post-discharge period. However, several stations located north of the outfall had slight decreases in percent cover in 2001 and continued this trend in 2002. Table 6-5 shows the estimated percent cover of coralline algae for the 1996–2002 time period. The locations that had lower percent cover of coralline algae post-discharge were three neighboring stations on the top of the drumlin immediately north of the outfall (T1-2, T1-3, and T1-4) and the two northernmost reference sites (T7-1 and T7-2).

It is unlikely that light attenuation with depth is a limiting factor for coralline algae, within the range of depths covered during this survey. Vadas and Steneck (1988) reported coralline algal cover of up to 80% at depths >50 m on Ammen Rock Pinnacle in the Gulf of Maine, and Sears and Cooper (1978) reported finding coralline algae at depths of 47 m on offshore ledges in the Gulf of Maine. Additionally, numerous coralline algae have been observed at a depth of 34 m at a hard-bottom site in Massachusetts Bay 10 miles off Scituate (B. Hecker, personal observation). The overall relationships among depth, sediment drape and percent cover of coralline algae can best be seen on Figure 6-7. Sediment drape on rock surfaces shows a slight tendency to increase with increasing depth and coralline algae shows a weak trend of decreasing cover with increasing depth. The plot of percent cover of coralline algae versus sediment drape shows that the abundance of corallines appears to be strongly related to sediment drape; percent

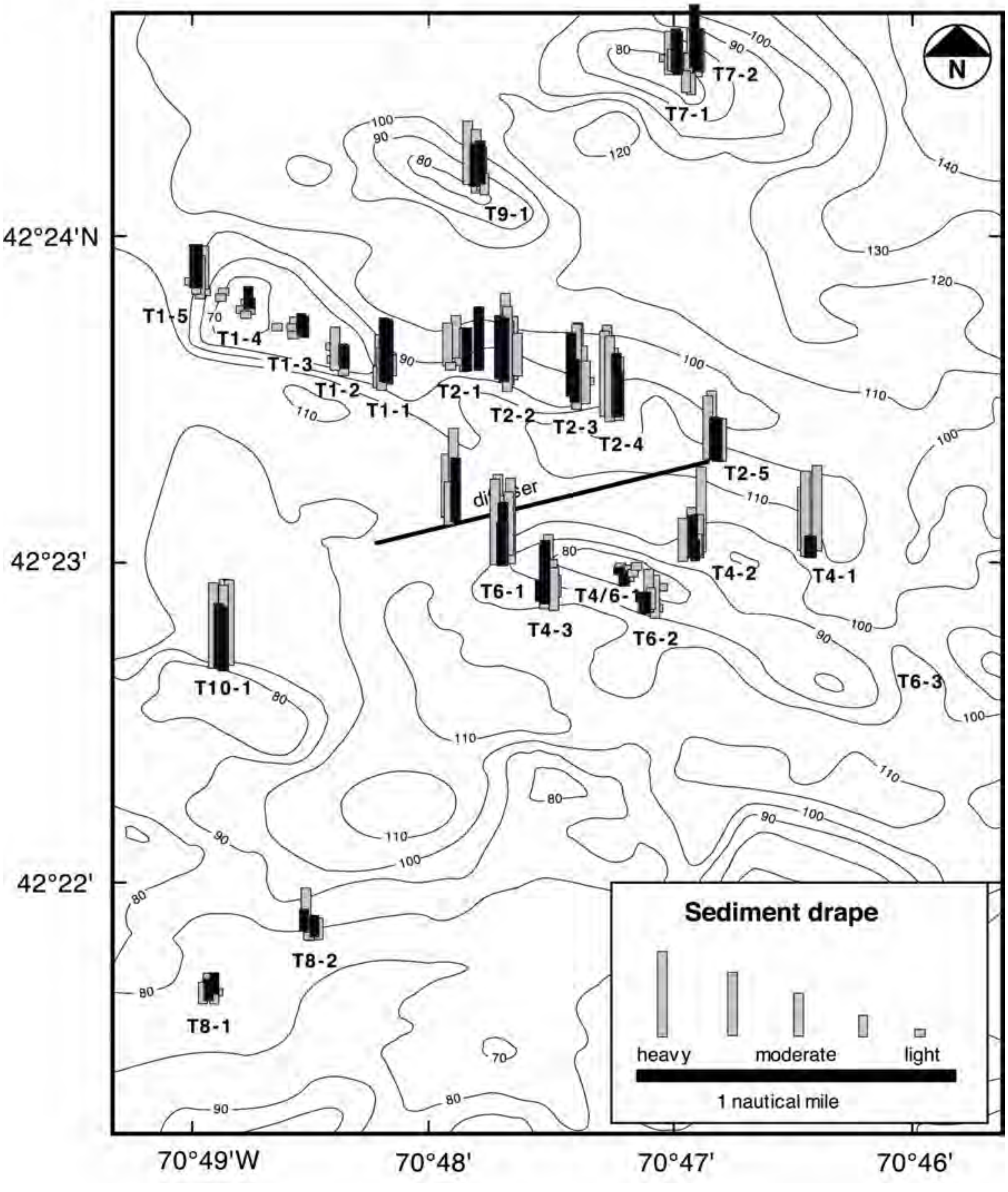


Figure 6-5. Sediment drape determined from the 1995–2002 nearfield hard-bottom surveys. Gray bars are pre-discharge values and black bars are post-discharge values.

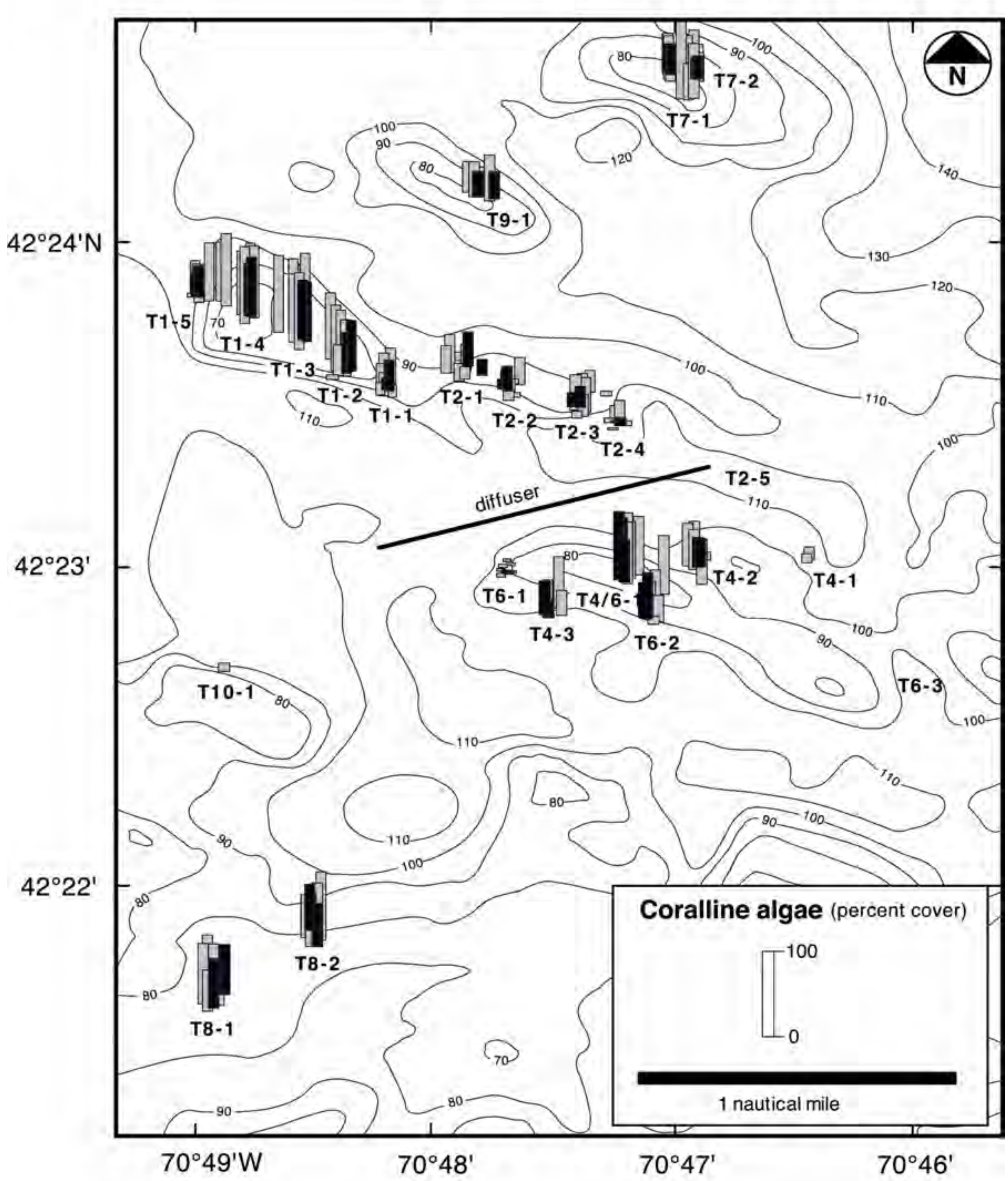


Figure 6-6. Percent cover of coralline algae determined from the 1995–2002 nearfield hard-bottom surveys. Gray bars are pre-discharge values and black bars are post-discharge values.

Table 6-5. Estimated percent cover of coralline algae from 1996 to 2002. Large differences between pre- and post-discharge are highlighted by shading. Asterisks mark differences that appear to be related to shifts in position of the areas surveyed.

Transect	Waypoint	Pre-discharge					Post-discharge	
		1996	1997	1998	1999	2000	2001	2002
1	1	35	42	37	26	16	15	34
	2	71	72	79	36*	79	47	61
	3	90	96	80	83	86	68	69
	4	87	83	82	70*	77	58	71
	5	68*	12	39	37	37	29	35
2	1	45	33	9*	35	14	18	39
	2	5	13	33*	13	10	9	28
	3	27	41	39	21	8*	17	23
	4	7	27	18	4	1	2	12
	5	<1	<1	<1			0	0
4	1		16*	<1	0	11	1	2
	2	41	53	9*	8*	47	37	28
	3	12	12	56*	25	16	19	41
4/6	1	72	67	77	72	71	73	80 (50)
6	1	2	4	5	2	2	3	3
	2	69*	55	45	29	36	42	56
7	1	65	43	49	47	52	32	36
	2	53	54	45	36	36	24	28
8	1		73	74	69	49	58	59
	2	82	75	65	51	58	48	56
9	1		40	54	28	38	30	36
10	1		12	<1	2	3	0	1
Diffuser	#44		<1	<1		<1	0	0

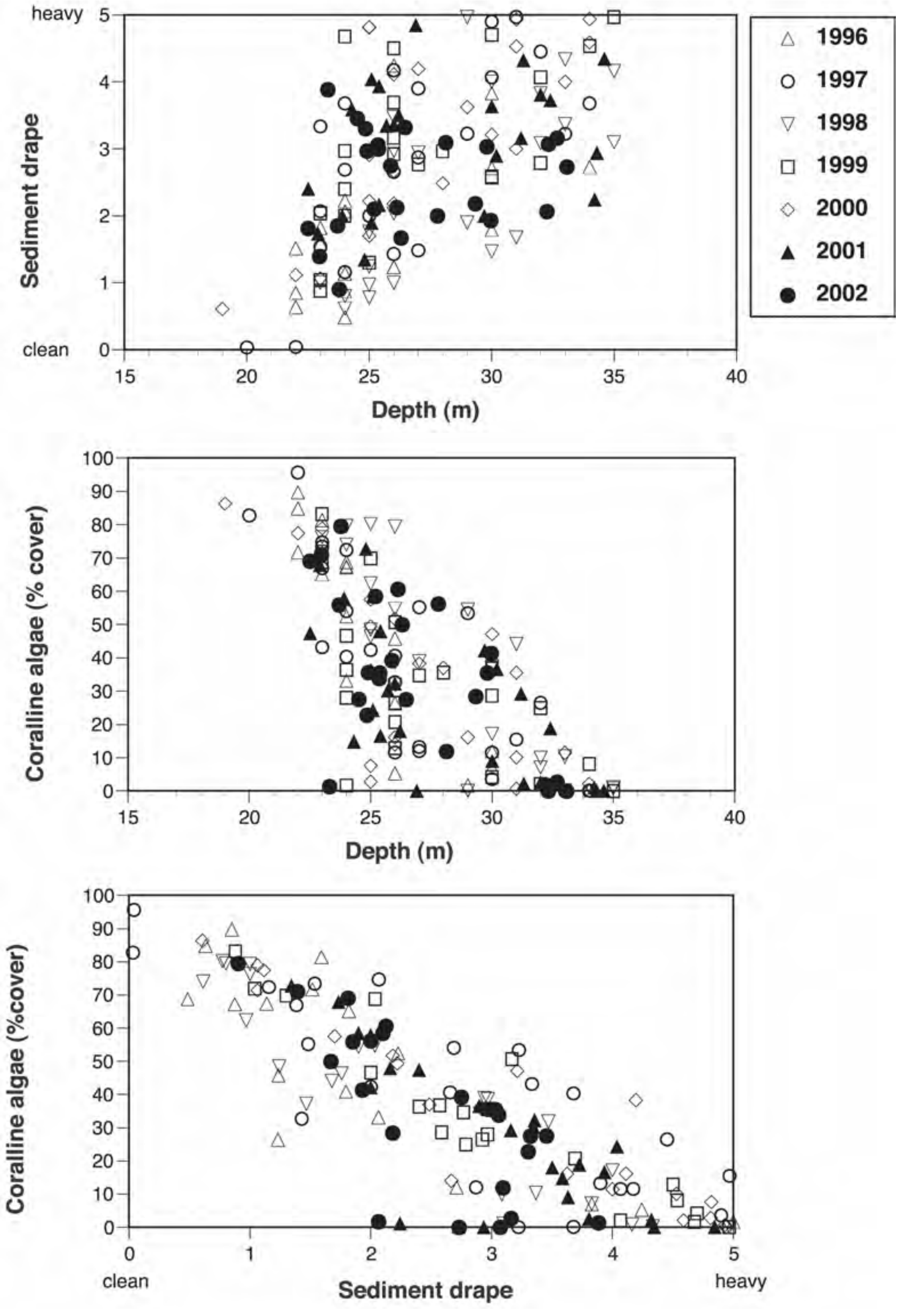


Figure 6-7. Depth, sediment drape, and percent cover of coralline algae determined from the 35-mm images taken at each waypoint during the 1996 to 2002 nearfield hard-bottom surveys.

cover was highest in areas that had little drape and lowest in areas with moderate to heavy drape. This is not surprising, because the encrusting growth form of coralline algae would make them susceptible to smothering by fine particles.

The variability in percent cover of coralline algae at each station can be seen in detail on Figure 6-8, which also shows the variability in sediment drape at each of the stations. The decrease in percent cover of coralline algae noted at five of the stations in 2001 was also observed in 2002. These stations also showed increases in sediment drape. On transect 1 (waypoints 2, 3, and 4), sediment drape increased from clean to light between 1995 and 2000 to moderately light in 2001 and 2002, while on transect 7 it increased from moderately light to moderate at T7-1 and moderately light to moderately heavy at T7-2. In contrast, percent cover of coralline algae was not reduced, and sediment drape was not elevated, at any of the other waypoints. Reasons for the increase in sediment drape and decrease in coralline cover at these five locations and not at any of the other locations are not readily apparent, but may be related to the discharge.

In contrast to the wide distribution of coralline algae, the distribution of the three upright algae inhabiting the drumlins, the filamentous red alga *Ptilota serrata,* the dulse *Rhodymenia palmata*, and the shotgun kelp *Agarum cribosum*, were quite restricted. Additionally, the abundance of these algae varied quite widely during the baseline period (Figure 6-9). This high variance appears to reflect a high degree of patchiness in the small-scale (within station) spatial distributions of the upright algae, rather than temporal changes. Dense stands of upright algae were frequently seen neighboring areas totally devoid of them. The observed spatial patchiness may reflect the fact that upright algae were abundant only on the top of larger boulders in areas of moderate to high relief. The first two species, *P. serrata* and *R. palmata*, were abundant in the middle of transect 2 and at the three northern reference sites (T7 and T9), while *A. cribosum* was abundant only at the northern reference sites. Post-discharge abundances of upright algae were generally within the range of pre-discharge abundances. The exceptions were a decrease in *P. serrata* and shotgun kelp at T9 during both post-discharge years, and an increase in dulse at T7 in 2001 but not in 2002. However, the high spatial variability in the abundance of these upright algae would make it hard to detect subtle changes with any degree of confidence.

One change in the abundance of upright algae that was noted was a dramatic decrease in the number of shotgun kelp at T7-2 in the two post-discharge years. This does not appear to be merely a reflection of spatial patchiness, but may reflect a long-term cyclical pattern in *A. cribosum*. The abundance of *A. cribosum* increased during the baseline period from a low of <0.25 individuals per picture in 1997 to a high of 2.3 individuals per picture in 2000. The abundance then dropped during the post-discharge period to 1.0 individuals per picture in 2001 and 0.2 individuals per picture in 2002. This was particularly interesting because more than half of the *A. cribosum* seen at this station in 2000 were heavily fouled by the lacy bryozoan *Membranipora*. By the following year only a quarter of the shotgun kelp were encrusted and far fewer *A. cribosum* and *Membanipora* were observed. This pattern is suggestive that the heavy encrustation observed in 2000 may have contributed to the decline of shotgun kelp at this station. *Membranipor*a has not been observed at any of the other stations.

The pattern of benthic community structure has been remarkably consistent in the hard-bottom areas. Figure 6-10 shows the distribution of benthic communities defined by hierarchical classification analysis. The dendrogram depicting the 2002 data (Figure 6-2) was similar to those from the baseline period and the first post-discharge year (see Blake *et al*. 1997, 1998; Kropp *et al.* 2000, 2001, 2002a, 2002b for the 1996, 1997, 1998, 1999, 2000, and 2001 dendrograms, respectively). At many of the sites the benthic communities remained stable during both the baseline and post-discharge years (Table 6-6). Good examples of this can be seen at all three of the northern reference sites (T7 and T9) and at T2-2 and T2-3, which were always in Cluster 1, and the two southernmost reference sites (T8) and the top of the drumlin

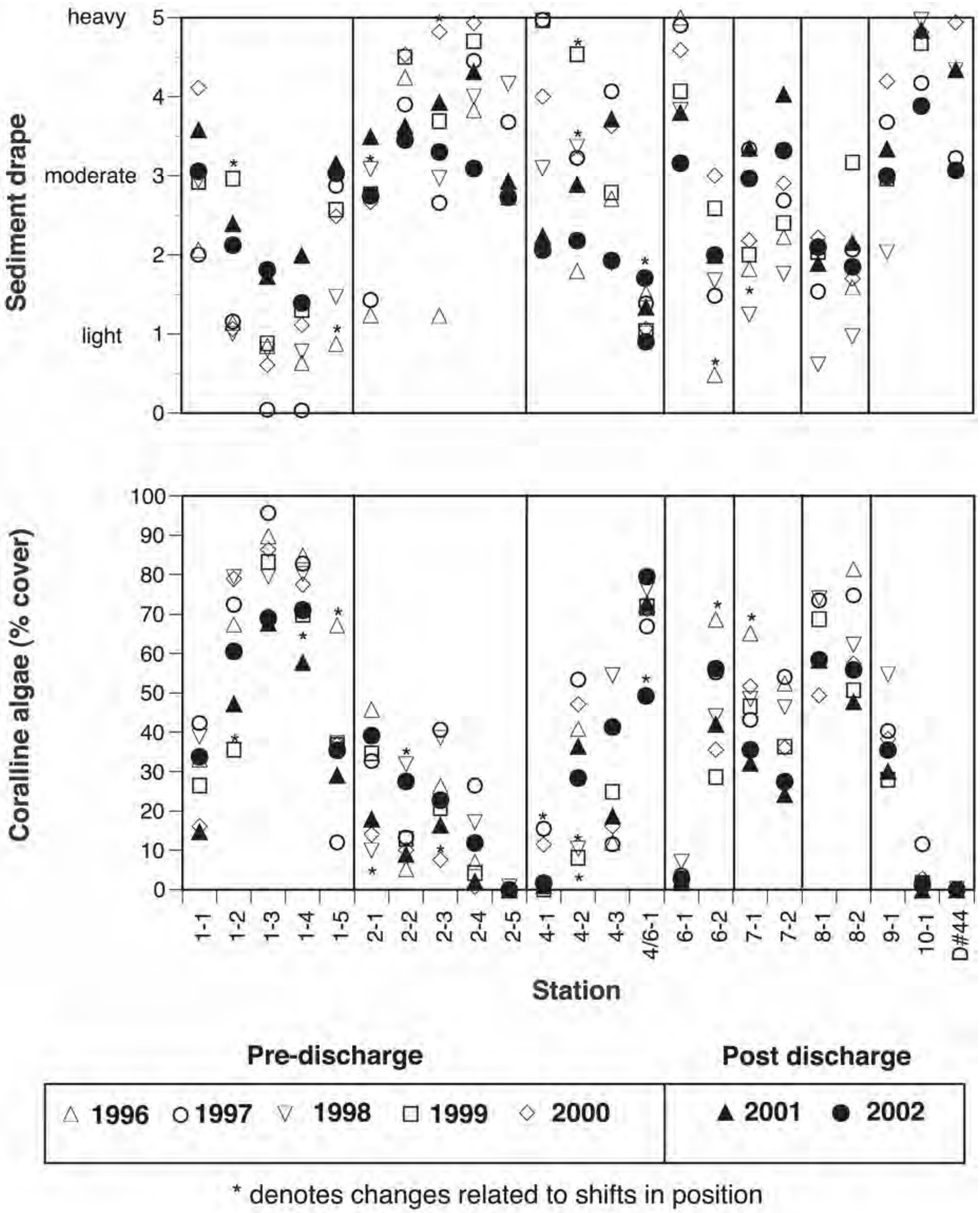


Figure 6-8. Sediment drape and percent cover of coralline algae at the nearfield hard-bottom sites determined from 35-mm slides taken during the 1996 to 2002 surveys.

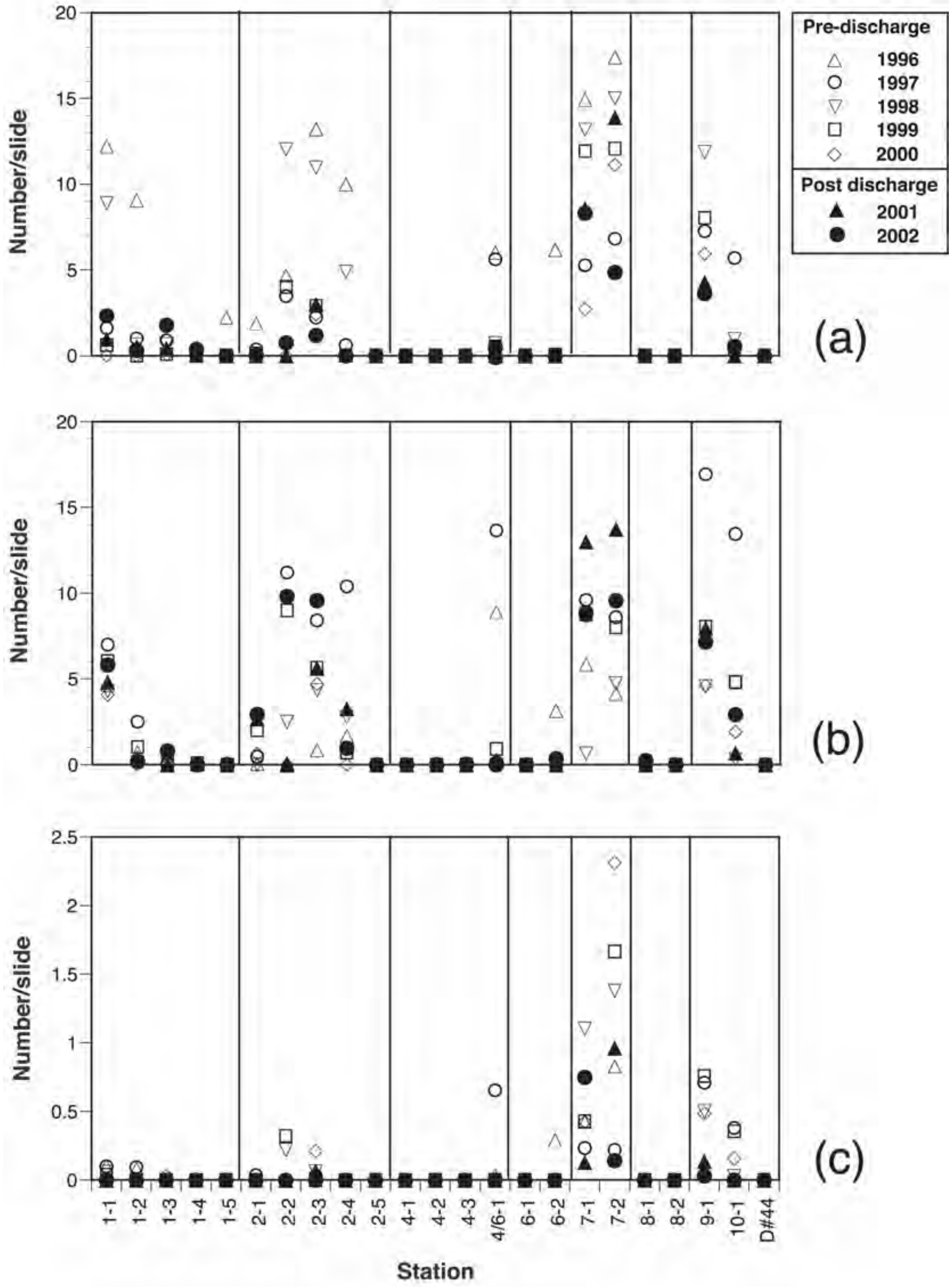


Figure 6-9. Abundance of three species of upright algae: (a) *Ptilota serrata*, (b) *Rhodymenia palmata*, and (c) *Agarum cribosum*, at the nearfield hard-bottom sites determined from 35-mm slides taken during the 1996–2002 surveys.

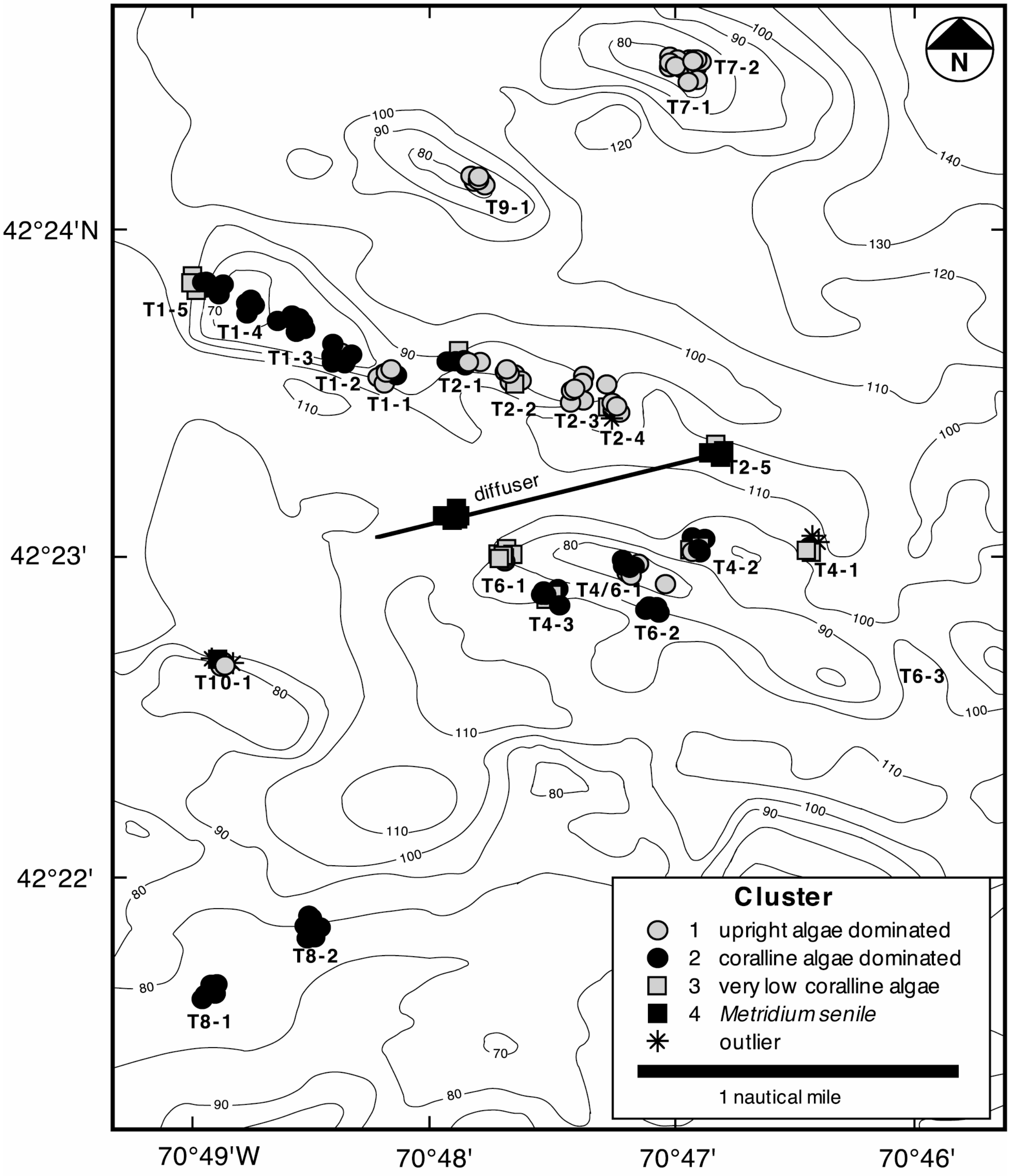


Figure 6-10. Map of benthic communities defined from classification of the 35-mm images taken during the 1995–2002 nearfield hard-bottom surveys.

Table 6-6. Cluster group designations defined by classification analysis of the waypoints surveyed from 1996 to 2002. Differences between pre - and post-discharge are highlighted by shading. Asterisks show differences explained by shifts in location.

Transect	Waypoint	Pre-discharge					Post-discharge	
		1996	1997	1998	1999	2000	2001	2002
1	1	1	1	1	1	2	1	1
	2	1*	2	2	2	2	2	2
	3	2	2	2	2	2	2	2
	4	2	2	2	2	2	2	2
	5	2*	3	3	2*	3	2	2
2	1	2	2	3*	2	2	1*	1
	2	1	1	1	1	3*	1	1
	3	1	1	1	1	1	1	1
	4	1	1	1	3	outlier	1	1
	5	4	4	3*			4	4
4	1		2	outlier	outlier	2	3	3
	2	2	2	3*	3*	2	1	2
	3	3	3	2	2	2	2	2
4/6	1	1	1	2	2	2	2	2 (1)
6	1	3	3	3	3	2	3	3
	2	1*	2	2	2	2	2	2
7	1	1	1	1	1	1	1	1
	2	1	1	1	1	1	1	1
8	1		2	2	2	2	2	2
	2	2	2	2	2	2	2	2
9	1		1	1	1	1	1	1
10	1		1	outlier	outlier	1	4	1
Diffuser	#44		4	4		4	4	4

north of the outfall (T1-2, T1-3, and T1-4), which were always in Cluster 2. Only several instances of departure from baseline conditions in cluster designation were noted in the post-discharge data. Prior to the onset of discharge from the outfall, the benthic community at T2-1 was dominated by coralline algae. In contrast, since discharge began upright algae have been found in increasing abundance at this station. It is presently not known if this shift in dominance merely reflects spatial patchiness or actual changes in the biota. The area surveyed at T2-1 in 2001 was located slightly to the east of the station, and was closer to areas that had historically been dominated by upright algae (T2-2). However, the area surveyed during 2002 was much closer to the T2-1 areas surveyed during the baseline period. The other instances of shifts in cluster designation between pre- and post-discharge (T4-1 in both years and T4-2 in 2001) appear to reflect spatial variability. Station T4-1 is a low-relief, flank area that consists mainly of a cobble pavement with very occasional patches of smaller boulders, and a moderately heavy sediment drape. If the area surveyed includes a few boulders that are encrusted with coralline algae, then the area will cluster differently (Cluster 2) than if only cobble pavement were encountered (Cluster 3). The strong spatial heterogeneity characteristic of the hard-bottom areas can be seen by the different cluster designations of the two visits to T4/6-1, where the biota seen during the first visit was dominated by upright algae and during the second visit by coralline algae.

Another instance of shifts in cluster designation reflecting spatial patchiness can be seen at T10-1. This station is at the edge of a drumlin top located southwest of the diffuser. The sea floor at this station consists of very large boulders perched at the edge of the drumlin and adjacent to much smaller boulders on the upper flank. *Gersemia rubiformis* and *Metridium senile* are common, but patchily distributed, inhabitants of the large boulders. Additionally, a few upright algae are also frequently seen attached to the smaller boulders on the upper flank at this station. As a result, T10-1 has clustered several different ways, depending on which boulders were surveyed. It clustered as an outlier if many *Gersemia* were encountered, because they are found nowhere else. This was seen in 1998 and 1999. In contrast, if fewer *Gersemia* and more *Metridium* were encountered, then T10-1 clustered with the diffuser heads as it did in 2001. However, if some upright algae, usually dulse, were encountered then it clustered with cluster 1 stations, as was seen in 1997, 2000, and 2002, but it was usually only loosely connected to the other stations.

The diffuser heads of the outfall were heavily colonized by *Metridium senile*, *Halocynthia pyriformis* and *Asterias vulgaris* during the baseline period. The same organisms continue to colonize both the active (T2-5, Diffuser #2) and inactive (Diffuser #44) heads post-discharge. The diffuser head at T2-5 had last been surveyed in 1997 when it supported exceptionally dense aggregations of *M. senile*. This diffuser head went online in 2000 and was actively discharging in 2001 and 2002, with dense stands of *M. senile* present on the top and in the port indentations of the diffuser head. Historically, the inactive diffuser (#44), which was colonized by more *H. pyriformis* than *M. senile* during the baseline period, now supports more *M. senile* than *H. pyriformis*. Additionally, a large finger sponge *Haliclona* sp., which was last seen on Diffuser #44 in 2000 had disappeared by 2001 (see Appendix F, Plate 10, in Kropp *et al.*, 2002). Table 6-7 highlights several trends that appear to reflect widespread temporal changes in the population structure of individual taxa that have been noted over the time course of the nearfield hard-bottom surveys. These changes do not appear to be related to the outfall discharge, since they started before the outfall went online and have continued post discharge. Abundances of the green sea urchin *Strongylocentrotus droebachiensis* declined from 0.85 individuals per photograph in 1996 to 0.23 individuals per photograph in 2000, and increased slightly in 2001 and 2002 (0.28 and 0.35 individuals per photograph, respectively). In contrast, two other species, the crab *Cancer* sp. and the cod *Gadus morhua*, appear to be increasing. In the still photographs, one to six *Cancer* crabs were seen annually between 1996 and 1999, 20 were seen in 2000, 54 were seen in 2001, and 79 were seen in 2002. This pattern was also reflected in the video data, with 3–17 *Cancer* crabs observed annually between 1996 and 1999, 105 in 2000, 147 in 2001, and 205 in 2002. A similar trend was seen in the video data for codfish, with none seen in 1996, 41 seen in 2001, and 53 seen in 2002. Interestingly, no cod had been seen at the diffuser stations during the baseline years, yet in both 2001 and 2002 cod have been seen at both the active (Diffuser #2 at T2-5) and inactive (Diffuser #44) heads. Additionally, the codfish appear to be behaving differently at the outfall than at the other hard-bottom stations. At most of the stations codfish tend to shy away from the ROV, usually ducking behind large boulders, but at the diffuser sites they were much less hesitant and occasionally came right up to the vehicle. A general increase has also been noted in the abundance of lobsters, from 1 individual in 1996 to 13 individuals in 2002 seen in the still photographs and 6 individuals in 1996 to 29 individuals in 2002 seen in the video footage. The gradual increase in the number of codfish and *Cancer* crabs in recent years has also been noted by local fishermen (Frank Mirarchi, personal communication, June 2003).

Table 6-7. Number of individuals of selected species observed during the nearfield hard-bottom surveys.

	Pre-discharge					Post-discharge	
	1996	1997	1998	1999	2000	2001	2002
Video							
Minutes of video	441	557	452	467	477	493	536
Cancer spp. (rock crab)	6	3	5	17	105	147	205
Gadus morhua (cod)	-	6	12	22	12	41	53
Homarus americanus (lobster)	6	2	13	4	18	21	29
Still Photographs							
Number of photographs	565	684	695	608	701	641	733
Strongylocentrotus droebachiensis	478	359	300	315	159	181	254
Cancer spp. (rock crab)	4	1	4	6	20	54	79
Gadus morhua (cod)	-	-	2	3	-	9	12
Homarus americanus (lobster)	1	-	3	3	5	4	13

Our results from both the baseline and post-discharge periods were generally similar to those reported by Coats *et al.* (1995) from the 1994 video survey. Four of the eight transects covered in this report (Transects 1, 2, 4 and 6) were the same as those included in the 1994 survey. The 1994 survey consisted of nearly continuous video coverage along the transects, while the present design focuses on topographically selected points (waypoints) along the transects that include representative drumlin top and flank locations. The 1995–2002 surveys respectively identified from 64 to 100 taxa, compared with 37 taxa identified from the 1994 survey. Rather than indicating changes in the benthic communities, the greater number of taxa identified from the post-1994 surveys appear to be related to the enhanced visual resolution of the still photographs. Many of the additional taxa identified in the later surveys are encrusting forms that would be difficult to resolve on video images. Additionally, the ROV has been kept much closer to the sea floor in the post-1994 surveys (right on the bottom as opposed to an altitude of 1 to 3 meters). Differences in taxonomic designations also exist between the 1994 and post-1994 surveys. Coats *et al.* identified an abundant pinnate red alga as *Rhodymenia* sp A, this appears to be the filamentous red alga that we have designated as *Ptilata serrata* based on collection of a voucher specimen (identified as *Asparagopsis hamifera* in the 1995 to 1999 surveys). Additionally, their *Porifera* sp. A was an orange encrusting sponge, which may be the orange/tan sponge commonly seen during the present study.

Another video survey of the area west of the outfall identified 23 taxa (Etter et al. 1987). The lower number of species seen in that survey was probably related to habitat differences between the areas surveyed. The 1987 survey covered mostly depositional sediment areas, whereas the present study concentrated on erosional hard substratum areas (drumlins). At any given depth, sediment generally supports fewer epifaunal species per unit area than does hard substrate (B. Hecker, personal observation). This may be related to the generally more limited availability of hard substrates in subtidal environments. Even in much deeper water, occasional hard surfaces (*i.e.*, boulders, ship wrecks, airplane wrecks, and nuclear-waste drums) are almost always heavily colonized by a variety of attached taxa (B. Hecker, personal observation).

General faunal distribution patterns were similar among the 1994–2002 surveys. All surveys found algae to be most abundant on the tops of drumlins. Coats *et al.* (1995) reported that *Rhodymenia palmata*, *Rhodymenia* sp. A (a pinnate red alga), and *Agarum cribosum* were found together on hard substrata at shallower depths. In the later surveys (1995–2000), coralline algae were found to dominate on cobbles and smaller boulders, while *Ptilata serrata*, *R. palmata*, and *A. cribosum* were found to dominate on the tops of larger boulders. While Coats *et al.* (1995) estimated percent cover of *Lithothamnion*, they did not discuss its distribution. All three sets of surveys (1987, 1994, and 1995–2002) also found that the anemone *Metridium senile* and the cunner *Tautogolabrus adspersus* were most abundant near large boulders. Coats *et al.* (1995) reported that the distribution of the green sea urchin *Strongylocentrotus droebachiensis* was depth related, with the urchins being most abundant at shallower depths. Despite the general decrease in overall abundance of the urchin noted earlier, a similar pattern was found in the 1995–2002 surveys. The highest abundance of urchins is usually found on the top of drumlins where their primary food source, coralline algae, was most abundant (Sebens 1986). Because of the different overall focus of the Coats *et al.* (1995) report, more detailed comparisons of community structure and factors that control it can not be made.

The hard-bottom benthic communities near the outfall were relatively stable over the 1995–2000 baseline time period, and this has not substantially changed with activation of the outfall. The remarkable similarities among all the surveys indicate that major departures from baseline conditions have not occurred during the first two years of discharge. An increase in sediment drape, and a concurrent decrease in percent cover of coralline algae, has been noted on the top of the drumlin north of the outfall and at the two northernmost reference sites since discharge began. Whether these changes are related to the outfall discharge is presently not known. The baseline data did indicate that coralline algae was the most promising indicator species for detecting habitat degradation as a result of the outfall coming on line. It was the most predictable taxon encountered in terms of abundance, distributional pattern, and habitat requirements. Coralline algae was the least patchily distributed taxon, dominated in all areas that were shallower than 33 m and had little sediment drape, and was common in areas of both high and low relief.

The outfall might be expected to alter the amount of particulate material reaching the sea floor. A continued increase of sediment drape, and/or a continued decrease in the percent cover of coralline algae might be expected if the discharge from the outfall were causing accumulation of materials in the vicinity of the drumlins. The changes observed in 2001 have continued into 2002, but they do not appear to have worsened during the intervening year. Changes might also be expected in the depth distribution of coralline algae if discharges from the outfall alter properties of the water column that affect light penetration. If water clarity is reduced it is expected that the lower depth limit of high coralline algal coverage would be reduced. Conversely, if water clarity were increased, then it is expected that high coralline algal coverage could extend into some of the deeper areas. No noticeable changes in the depth distribution of coralline algae have been observed since discharge began.

The first two years of discharge monitoring have shown only modest changes suggestive of outfall impact at a subset of five stations. Lush epifaunal growth continues to thrive on both diffuser heads surveyed for this study, and throughout many of the other stations visited. However, despite the fact that outfall impacts appear to be minimal at this time, changes in the hard-bottom communities could be chronic and/or cumulative, and may take a longer time to manifest themselves. To further enhance the probability of detecting possible long-term changes, several modifications to the sampling design have been implemented for 2003. Two stations, T4-1 and T4-3, were discontinued and replaced with two other locations that substantially increased the geographic coverage of the study. An increase in geographic coverage was deemed desirable because potential changes have been noted at the two northernmost reference sites. One of the stations that was discontinued was T4-1, which consists of a low relief cobble/gravel pavement that is relatively depauperate, making it unlikely that changes in the benthic community could be detected at this location. This site has been replaced with a new distant reference station (T11-1), which is located approximately 10 miles northeast of Scituate. This new hard-bottom site was visited in June 1999 (as part of an unrelated study) and found to support a dense epifaunal community. Analysis of the photographs and video collected at this site in 1999 will provide at least some pre-discharge data. Additionally, station T4-3 has been replaced with a new southern reference station that is slightly further removed than the present stations. Station T4-3 is similar to T6-1, yet spatially more heterogeneous in substrate and biota. The new site (T12-1) is located south of the outfall and has previously been visited as part of studies conducted by the United States Geological Survey, again providing some pre-discharge data. The addition of these new sites provides expanded regional reference coverage for assessing possible outfall impacts seen at nearby stations.

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APPENDIX A

Station Data:
Benthic Grab Samples (BN021/BF021)
Special Contaminant Surveys (BC021, BC022)

Table A-1. Station data and field observations for individual soft-bottom infauna and chemistry grab samples collected August 2002 (BN021/BF021).

Station ID	Sample ID	Date/Time (EDT)	Sample Type	Longitude (W)	Latitude (N)	RPD Depth (cm)	Sediment Texture	Fauna and Miscellaneous Observations
FF14	BF02100F	8/12/02 09:17	Biol	-70.654800	42.416817	0.3	silt with a small amount of sand	Worm tube
	BF021011	8/12/02 09:44	Biol	-70.654884	42.416752	0.2		No odor, no animals noted
	BF021015	8/12/02 09:57	Biol	-70.655014	42.416782	0.4		Tube
	BF021016	8/12/02 10:14	Chem	-70.654846	42.416817	0.3		Worm tubes
	BF02101A	8/12/02 10:57	Chem	-70.655251	42.416916	0.3		Worm tubes
FF11	BF021023	8/12/02 12:34	Chem	-70.499763	42.658466	2.0	silty clay with a small amount of sand	Worm tubes
	BF021024	8/12/02 12:48	Chem	-70.500114	42.658516	1.5		Worm tubes
	BF02102F	8/12/02 13:18	Biol	-70.499931	42.658550	1.5		Worm tubes
	BF021030	8/12/02 13:30	Biol	-70.500053	42.658318	1.7		Worm tubes
	BF021031	8/12/02 13:41	Biol	-70.500031	42.658249	1.0	NR	Worm tubes
FF01A	BF0210A6	8/12/02 14:35	Biol	-70.675552	42.564068	1.2	silty sand	No animals noted
	BF0210A7	8/12/02 14:40	Chem	-70.675850	42.564201	3.0	sandy silt	Worm tubes
	BF0210A8	8/12/02 14:47	Biol	-70.675934	42.563835	2.8	sandy silt	Amphipods, some tubes
	BF0210A9	8/12/02 14:51	Chem	-70.675751	42.563885	1.5	silty sand	Amphipods, worm tubes
	BF0210AA	8/12/02 14:58	Biol	-70.675835	42.564217	2.0	silty sand	Worm tubes, pebbles
NF05	BF0210AF	8/12/02 16:01	Chem	-70.833931	42.426983	1.0	silty sand	Amphipods, worm tubes, bivalves
	BF0210B2	8/12/02 16:21	Biol	-70.833832	42.427216	1.2	sandy silt	Amphipod and worm tubes
NF04	BF0210C0	8/12/02 16:43	Biol	-70.806648	42.415432	2.3	silty sand	Amphipod, tubes
	BF0210C4	8/12/02 16:58	Chem	-70.806267	42.415585	1.5	silty sand	Amphipod tubes, shell hash
NF23	BF0210C8	8/12/02 17:18	Biol	-70.801636	42.397884	1.8	sand	Tubes
	BF0210C9	8/12/02 17:22	Chem	-70.801682	42.397766	0.9	NR	Amphi- and worm tubes, sh. hash
NF13	BF0210D4	8/12/02 18:04	Chem	-70.822670	42.390099	1.5	silty sand	Worm tubes, shell hash, rocks
	BF0210D9	8/12/02 18:15	Biol	-70.822617	42.390217	2.0	sand	A few tubes
NF20	BF0210F1	8/13/02 08:39	Biol	-70.845047	42.378235	1.0	silty sand with gravel	Worm tubes, pebbles and shells
	BF0210F3	8/13/02 08:43	Chem	-70.845016	42.378250	0.5		Worm tubes, shell hash, pebbles
NF08	BF0210FA	8/13/02 09:04	Chem	-70.863335	42.400002	1.5	silty clay	Amphipods
	BF0210FC	8/13/02 09:12	Biol	-70.863434	42.399933	0.8	sandy silt	Amphipods and amphipod tubes
	BF0210FE	8/13/02 09:16	Chem	-70.863281	42.400002	1.0	silty clay	Amphipods and amphipod tubes
	BF021100	8/13/02 09:26	Chem	-70.863365	42.400101	1.0	silty clay	Amphipod and worm tubes
NF21	BF02110A	8/13/02 09:37	Biol	-70.836769	42.402767	0.2	fine sandy	Amphipod and worm tubes
	BF02110C	8/13/02 09:41	Chem	-70.836647	42.402683	1.2	silt	Worm tubes
NF18	BF021115	8/13/02 10:10	Biol	-70.821747	42.396484	0.5	silty sand	Amphipods and worm tubes
	BF021117	8/13/02 10:13	Chem	-70.822136	42.396584	2.5	silty sand	Tubes, gravel, shell bits
NF10	BF02111D	8/13/02 10:22	Biol	-70.837898	42.392849	0.2	sandy silt	Worm tubes
	BF02111F	8/13/02 10:26	Chem	-70.838203	42.392834	0.5	silty sand	Worm tubes
NF15	BF021130	8/13/02 11:03	Chem	-70.827866	42.382099	0.5	sand, gravel	Worm tubes, worm
	BF021131	8/13/02 11:06	Biol	-70.828102	42.382050	0.3	sand	Worm
NF16	BF021135	8/13/02 11:15	Biol	-70.837952	42.378368	2.0	sandy silt	Worm tubes
	BF021137	8/13/02 11:19	Chem	-70.837914	42.378235	2.0	silty sand	Worm tubes, burrows
FF12	BF02113C	8/13/02 11:42	Chem	-70.899696	42.390099	1.2	NR	No animals noted
	BF02113E	8/13/02 11:51	Chem	-70.899681	42.390049	0.3	silty sand	Salt and pepper sand
	BF021142	8/13/02 12:16	Biol	-70.899597	42.390148	0.5	sandy silt	Worm tubes
	BF021143	8/13/02 12:25	Biol	-70.899635	42.390118	0.2	v.f. sandy	Amphipods, tubes, pebbles
	BF021144	8/13/02 12:32	Biol	-70.899780	42.390049	0.2	v.f. sandy	Worm tubes, pebbles
FF10	BF02114B	8/13/02 12:50	Biol	-70.879448	42.414249	0.5	silty sand	Amphipods, worm tubes, pebbles
	BF02114C	8/13/02 12:53	Chem	-70.878899	42.414017	3.0	silty sand	Tubes
	BF02114D	8/13/02 13:01	Biol	-70.878647	42.414051	0.3	silty sand	Isopods, amphipods, worm tubes
	BF02114E	8/13/02 13:04	Chem	-70.878899	42.413982	1.0	silty sand	Worm tubes
	BF021152	8/13/02 13:35	Biol	-70.878899	42.414017	1.7	silty sand	Worm tubes, pebbles
	BF021153	8/13/02 13:39	Chem	-70.878670	42.413982	1.5	silty sand	Worm tubes
NF07	BF02115B	8/13/02 14:10	Biol	-70.814850	42.410084	0.4	sandy silt	Amphipod, tubes, small pebbles
	BF02115C	8/13/02 14:15	Chem	-70.814667	42.410084	0.5	fine sandy	Worm tubes

Station ID	Sample ID	Date/Time (EDT)	Sample Type	Longitude (W)	Latitude (N)	RPD Depth (cm)	Sediment Texture	Fauna and Miscellaneous Observations
NF09	BF021161	8/13/02 14:33	Biol	-70.844933	42.399632	2.0	sandy silt	Worm tubes, amphipods, bivalves
	BF021163	8/13/02 14:37	Chem	-70.844780	42.399616	1.0	sandy silt	No animals noted
NF12	BF021167	8/13/02 14:46	Biol	-70.830582	42.389984	2.0	very fine sandy silt	Worm tubes
	BF021168	8/13/02 14:51	Chem	-70.830780	42.389885	2.6		No animals or tubes noted
	BF021169	8/13/02 14:57	Biol	-70.830330	42.390167	2.0		Amphipods, worm tubes
	BF02116A	8/13/02 15:02	Chem	-70.830399	42.389782	2.0		No animals noted
	BF02116C	8/13/02 15:15	Biol	-70.830353	42.389935	2.0		Worm tubes
NF14	BF02117C	8/13/02 15:52	Chem	-70.822968	42.386482	1.0	silty sand with gravel	Worm tubes, shells
	BF02117E	8/13/02 16:01	Biol	-70.822830	42.386902	2.0		Amphipods, worm tubes, sh. hash
NF17	BF021183	8/13/02 16:18	Chem	-70.814651	42.381317	no apparent RPD	sand	Sand dollars, shells
	BF021184	8/13/02 16:22	Biol	-70.814796	42.381485		coarse sand	No animals, pebbles, shells
	BF021185	8/13/02 16:28	Chem	-70.814796	42.381401			Sand dollars, shells
	BF021186	8/13/02 16:34	Biol	-70.814835	42.381332			Cumacean, tubes
	BF021187	8/13/02 16:43	Biol	-70.814980	42.381485			Worms tubes, snail
NF19	BF02118B	8/13/02 16:53	Chem	-70.804985	42.371651	1.2	sandy	Worm tubes, shell fragments
	BF02118E	8/13/02 17:14	Biol	-70.804802	42.371750	1.0	sandy	Worm tubes
NF24	BF0211A0	8/14/02 08:07	Biol	-70.801750	42.380516	0.3	sandy silt	Tunicates, snail, tubes
	BF0211A1	8/14/02 08:13	Chem	-70.801720	42.380417	0.2	silty sand	Tubes
	BF0211A2	8/14/02 08:18	Biol	-70.801598	42.380516	0.2	sandy silt	Amphipods, worm tubes
	BF0211A3	8/14/02 08:22	Chem	-70.801697	42.380451	0.3	silty sand	Worm tubes
	BF0211A6	8/14/02 08:40	Biol	-70.801537	42.380585	0.1	sandy silt	Worm tubes
	BF0211A7	8/14/02 08:35	Chem	-70.801270	42.377815	0.2	silty sand	Worm tubes
NF22	BF0211AF	8/14/02 08:56	Biol	-70.814697	42.347900	2.0	v.f. sandy silt	Worm tubes
	BF0211B0	8/14/02 08:59	Chem	-70.814919	42.347885	0.2	silty sand	Worm tubes
	BF0211B1	8/14/02 09:10	Chem	-70.814964	42.347866	0.5	silty sand	Worm tubes
	BF0211B2	8/14/02 09:20	Chem	-70.814819	42.347866	1.0	silty sand	Worm tubes
NF02	BF0211B7	8/14/02 09:36	Chem	-70.828367	42.338467	1.0	silty sand	Worm tubes, sulfidic odor
	BF0211BC	8/14/02 10:05	Biol	-70.828201	42.338348	0.5	sandy silt	No animals, sulfidic odor
FF13	BF0211C9	8/14/02 10:32	Chem	-70.823067	42.319881	1.5	fine sandy silt	No animals noted
	BF0211CB	8/14/02 10:43	Chem	-70.823082	42.319950	0.5	sandy silt	No animals noted, gravel
	BF0211D0	8/14/02 11:05	Biol	-70.822914	42.320049	0.2	sandy silt	Tubes
	BF0211D1	8/14/02 11:17	Biol	-70.822968	42.320034	1.2	sandy silt	Amphipods, worm tubes
	BF0211D2	8/14/02 11:25	Biol	-70.822998	42.320000	1.0	sandy silt	Amphipods, worm tubes
FF09	BF0211DF	8/14/02 12:28	Biol	-70.656601	42.312382	3.0	sandy silt	Starfish eating clam, worms
	BF0211E0	8/14/02 12:33	Chem	-70.656815	42.312565	3.0	silty sand	Starfish, worm tubes
	BF0211E1	8/14/02 12:39	Biol	-70.656647	42.312466	3.0	sandy silt	Starfish, bivalve, worm tubes
	BF0211E2	8/14/02 12:43	Chem	-70.656670	42.312466	2.0	silty sand	Worm tubes
	BF0211E3	8/14/02 12:49	Biol	-70.656731	42.312485	3.0	sandy silt	Worm tubes
FF04	BF0211E7	8/14/02 13:43	Biol	-70.424896	42.288235	0.5	silt	Worm tubes, shell fragments
	BF0211E8	8/14/02 13:54	Biol	-70.424881	42.288132	2.0	silt	Amphipod, worm tubes
	BF0211E9	8/14/02 14:06	Biol	-70.425087	42.288265	1.0	silt	Tubes
	BF0211EA	8/14/02 14:20	Chem	-70.425102	42.288284	0.1	silt	Worm tubes
	BF0211ED	8/14/02 14:46	Chem	-70.424850	42.288399	0.5	silt	Worm tubes
FF05	BF0211F4	8/14/02 15:34	Biol	-70.422417	42.133335	1.5	silt	Tubes
	BF0211F6	8/14/02 15:49	Biol	-70.422684	42.133385	1.5	silt	Tubes
	BF0211F7	8/14/02 16:00	Biol	-70.422318	42.133499	1.3	silt	Worm tubes
	BF0211F8	8/14/02 16:13	Chem	-70.422813	42.133450	1.0	sandy silt	Starfish, worm tubes
	BF0211FB	8/14/02 16:37	Chem	-70.422096	42.133465	0.3	sandy silt	Tubes
FF07	BF02120E	8/15/02 08:49	Biol	-70.266983	41.958218	2.5	silt	No animals observed
	BF02120F	8/15/02 08:56	Chem	-70.266747	41.958267	2.0	silt	No animals noted
	BF021210	8/15/02 09:02	Biol	-70.266586	41.958267	1.5	silt	Brittle stars and starfish
	BF021211	8/15/02 09:08	Chem	-70.266632	41.958267	1.6	silt	Worm
	BF021212	8/15/02 09:14	Biol	-70.266647	41.958282	2.8	silt	Brittle stars
FF06	BF021216	8/15/02 10:05	Biol	-70.403336	41.898315	1.0	silt	Brittle stars
	BF021217	8/15/02 10:10	Chem	-70.403336	41.898418	0.2	silt	Brittle stars, bivalve
	BF021219	8/15/02 10:23	Chem	-70.403366	41.898315	0.8	silt	No animals noted
	BF02121B	8/15/02 10:37	Biol	-70.403381	41.898335	0.2	silt	Amphipod, tubes
	BF02121C	8/15/02 10:49	Biol	-70.403282	41.898418	1.0	silt	Brittle stars, worm tubes

Table A-2. Field data from the nearfield Contaminant Special Study survey conducted February 2002 (BC021).

STUDY_ID	EVENT_ID	STAT_ID	STAT_ARRIV (EST)	BEG_LATITUDE	BEG_LONGITUDE	DEPTH_TO_BOTTOM	DEPTH_UNIT_CODE	NAVIGATION_CODE	NAV_QUAL	MATRIX_CODE	GEAR_CODE	DEPTH	DEPTH_UNIT_CODE	SAMPLE_ID	SAMP_VOL	SAMP_VOL_UNIT_CODE	DEPTH_CLASS_CODE
BMBSOFT	BC021	FF10	20-Feb-02	42.413982	-70.878685	29	m	DGPS	+/- 15m	SED	VV01	11	cm	BC0210E1	9.5	L	E
BMBSOFT	BC021	FF10	20-Feb-02	42.413982	-70.878685	29	m	DGPS	+/- 15m	SED	VV01	11	cm	BC0210EC	9.5	L	E
BMBSOFT	BC021	FF10	20-Feb-02	42.413982	-70.878685	29	m	DGPS	+/- 15m	SED	VV01	12.5	cm	BC0210EE	11	L	E
BMBSOFT	BC021	NF08	20-Feb-02	42.399933	-70.86367	30	m	DGPS	+/- 15m	SED	VV01	12	cm	BC0210F6	10	L	E
BMBSOFT	BC021	NF08	20-Feb-02	42.399933	-70.86367	30	m	DGPS	+/- 15m	SED	VV01	12	cm	BC0210F8	10	L	E
BMBSOFT	BC021	NF08	20-Feb-02	42.399933	-70.86367	30	m	DGPS	+/- 15m	SED	VV01	14.5	cm	BC0210FA	11	L	E
BMBSOFT	BC021	NF22	20-Feb-02	42.347866	-70.81517	35	m	DGPS	+/- 15m	SED	VV01	12	cm	BC021107	11	L	E
BMBSOFT	BC021	NF22	20-Feb-02	42.347866	-70.81517	35	m	DGPS	+/- 15m	SED	VV01	14.5	cm	BC021108	10	L	E
BMBSOFT	BC021	NF22	20-Feb-02	42.347866	-70.81517	35	m	DGPS	+/- 15m	SED	VV01	13.5	cm	BC021106	11	L	E
BMBSOFT	BC021	NF24	20-Feb-02	42.380718	-70.801567	36	m	DGPS	+/- 15m	SED	VV01	14.5	cm	BC021100	11	L	E
BMBSOFT	BC021	NF24	20-Feb-02	42.380718	-70.801567	36	m	DGPS	+/- 15m	SED	VV01	14.5	cm	BC021101	11	L	E
BMBSOFT	BC021	NF24	20-Feb-02	42.380718	-70.801567	36	m	DGPS	+/- 15m	SED	VV01	14.5	cm	BC021102	11	L	E

Table A-3. Target vs. actual coordinates for BC021.

BC021	Target Coordinates		Actual Coordinates	
Station ID	**Latitude**	**Longitude**	**Latitude**	**Longitude**
FF10 Rep 1	42.41400	70.87866	42.41398	70.87868
FF10 Rep 2	42.41400	70.87866	42.41413	70.87878
FF10 Rep 3	42.41400	70.87866	42.41413	70.87890
NF08 Rep 1	42.40000	70.86350	42.39993	70.86367
NF08 Rep 2	42.40000	70.86350	42.40002	70.86363
NF08 Rep 3	42.40000	70.86350	42.40018	70.86355
NF24 Rep 1	42.38050	70.80166	42.38072	70.80157
NF24 Rep 2	42.38050	70.80166	42.38050	70.80172
NF24 Rep 3	42.38050	70.80166	42.38042	70.80188
NF22 Rep 1	42.34783	70.81500	42.34712[1]	70.81518[1]
NF22 Rep 2	42.34783	70.81500	42.34787	70.81517
NF22 Rep 3	42.34783	70.81500	42.34810	70.81496

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[1] NAVSAM© technician accidentally unchecked event marker. Technician updated database sampling log table in order to print labels. Sample was taken inside 30-50 meter range but vessel was not within 30-50 meter range when log was updated for this sample. Label on samples reflects position when sampling log table was updated.

Table A-4. Field data for the nearfield Contaminant Special Study survey conducted October 2002 (BC022).

STUDY_ID	EVENT_ID	STAT_ID	STAT_ARRIV (EST)	BEG_LATITUDE	BEG_LONGITUDE	DEPTH_TO_BOTTOM	DEPTH_UNIT_CODE	NAVIGATION_CODE	NAV_QUAL	MATRIX_CODE	GEAR_CODE	PENETRATION_DEPTH	PEN_DEPTH_UNIT_CODE	SAMPLE_ID	SAMP_VOL	SAMP_VOL_UNIT_CODE	DEPTH_CLASS_CODE
BMBSOFT	BC022	FF10	10/22/02 7:05	42.41402	-70.87869	28	m	DGPS	+/- 15m	SED	VV01	12.5	cm	BC02201C	11	L	E
BMBSOFT	BC022	FF10	10/22/02 7:05	42.41402	-70.87869	28	m	DGPS	+/- 15m	SED	VV01	14	cm	BC022020	11	L	E
BMBSOFT	BC022	FF10	10/22/02 7:05	42.41402	-70.87869	28	m	DGPS	+/- 15m	SED	VV01	12.5	cm	BC022007	11	L	E
BMBSOFT	BC022	NF08	10/22/02 8:42	42.39988	-70.8636	30	m	DGPS	+/- 15m	SED	VV01	14	cm	BC02202A	11	L	E
BMBSOFT	BC022	NF08	10/22/02 8:42	42.39988	-70.8636	30	m	DGPS	+/- 15m	SED	VV01	13	cm	BC022031	11	L	E
BMBSOFT	BC022	NF08	10/22/02 8:42	42.39988	-70.8636	30	m	DGPS	+/- 15m	SED	VV01	13.5	cm	BC022034	11	L	E
BMBSOFT	BC022	NF22	10/22/02 10:39	42.34773	-70.81496	36	m	DGPS	+/- 15m	SED	VV01	13.5	cm	BC022051	11	L	E
BMBSOFT	BC022	NF22	10/22/02 10:39	42.34773	-70.81496	36	m	DGPS	+/- 15m	SED	VV01	13.5	cm	BC02205D	11	L	E
BMBSOFT	BC022	NF22	10/22/02 10:39	42.34773	-70.81496	36	m	DGPS	+/- 15m	SED	VV01	14.5	cm	BC022057	11	L	E
BMBSOFT	BC022	NF24	10/22/02 9:51	42.38037	-70.80155	36	m	DGPS	+/- 15m	SED	VV01	12	cm	BC022042	10	L	E
BMBSOFT	BC022	NF24	10/22/02 9:51	42.38037	-70.80155	36	m	DGPS	+/- 15m	SED	VV01	14.5	cm	BC022046	11	L	E
BMBSOFT	BC022	NF24	10/22/02 9:51	42.38037	-70.80155	36	m	DGPS	+/- 15m	SED	VV01	13.5	cm	BC022049	11	L	E

Table A-5. Target vs. actual coordinates for BC022.

BC022	Target Coordinates		Actual Coordinates	
Station ID	**Latitude**	**Longitude**	**Latitude**	**Longitude**
FF10 Rep 1	42.41400	70.87866	42.41402	70.87868
FF10 Rep 2	42.41400	70.87866	42.41425	70.87883
FF10 Rep 3	42.41400	70.87866	42.41417	70.87865
NF08 Rep 1	42.40000	70.86350	42.39988	70.86360
NF08 Rep 2	42.40000	70.86350	42.40014	70.86353
NF08 Rep 3	42.40000	70.86350	42.40000	70.86355
NF24 Rep 1	42.38050	70.80166	42.38037	70.80155
NF24 Rep 2	42.38050	70.80166	42.38054	70.80168
NF24 Rep 3	42.38050	70.80166	42.38057	70.80170
NF22 Rep 1	42.34783	70.81500	42.34773	70.81496
NF22 Rep 2	42.34783	70.81500	42.34778	70.81488
NF22 Rep 3	42.34783	70.81500	42.34795	70.81505

APPENDIX B

Station Data:
Sediment Profile Images (BR021)

Table B-1. Target Positions for Sediment Profile Image stations.

STUDY_ ID	EVENT_ ID	STAT_ ID	LOCATION_DESC	STAT_ARRIV (EST)	BEG_ LATITUDE (N)	BEG_ LONGITUDE (W)	DEPTH (m)	NAV_ CODE	NAV_ QUAL
	BR021	FF10	MASSACHUSETTS BAY NEAR NAHANT	8/26/02 12:12 PM	42.413868	-70.878532	29	DGPS	+/- 15m
BMBSOFT	BR021	FF12	MASSACHUSETTS BAY NEAR NAHANT	8/26/02 12:44 PM	42.390019	-70.899651	24	DGPS	+/- 15m
BMBSOFT	BR021	FF13	MASSACHUSETTS BAY NEAR THIEVES LEDGE	8/26/02 7:34 AM	42.319733	-70.823250	20	DGPS	+/- 15m
BMBSOFT	BR021	NF02	SOUTHWEST OF OUTFALL SITE	8/26/02 7:48 AM	42.338467	-70.828468	26	DGPS	+/- 15m
BMBSOFT	BR021	NF04	NORTH OF OUTFALL SITE	8/26/02 9:49 AM	42.415615	-70.806450	35	DGPS	+/- 15m
BMBSOFT	BR021	NF05	NORTHWEST OF OUTFALL SITE	8/26/02 10:05 AM	42.427116	-70.833817	35	DGPS	+/- 15m
BMBSOFT	BR021	NF07	NORTH OF OUTFALL SITE	8/26/02 9:39 AM	42.410099	-70.814964	33	DGPS	+/- 15m
BMBSOFT	BR021	NF08	NORTHWEST OF OUTFALL SITE	8/27/02 8:04 AM	42.400082	-70.863632	28	DGPS	+/- 15m
BMBSOFT	BR021	NF09	NORTHWEST OF OUTFALL SITE	8/26/02 10:33 AM	42.399700	-70.845032	29	DGPS	+/- 15m
BMBSOFT	BR021	NF10	WEST OF OUTFALL SITE	8/26/02 10:45 AM	42.392819	-70.838120	32	DGPS	+/- 15m
BMBSOFT	BR021	NF12	WEST OF OUTFALL SITE	8/26/02 10:56 AM	42.389935	-70.830551	34	DGPS	+/- 15m
BMBSOFT	BR021	NF13	WEST OF OUTFALL SITE	8/26/02 8:57 AM	42.390019	-70.822502	31	DGPS	+/- 15m
BMBSOFT	BR021	NF14	WEST OF OUTFALL SITE	8/26/02 8:47 AM	42.386768	-70.822670	32	DGPS	+/- 15m
BMBSOFT	BR021	NF15	WEST OF OUTFALL SITE	8/27/02 7:48 AM	42.382168	-70.827965	30	DGPS	+/- 15m
BMBSOFT	BR021	NF16	WEST OF OUTFALL SITE	8/26/02 11:30 AM	42.378315	-70.837601	31	DGPS	+/- 15m
BMBSOFT	BR021	NF17	WEST OF OUTFALL SITE	8/26/02 8:38 AM	42.381352	-70.814964	28	DGPS	+/- 15m
BMBSOFT	BR021	NF18	NORTHWEST OF OUTFALL SITE	8/26/02 9:07 AM	42.396866	-70.821816	32	DGPS	+/- 15m
BMBSOFT	BR021	NF19	SOUTH OF OUTFALL SITE	8/26/02 8:15 AM	42.371716	-70.805183	33	DGPS	+/- 15m
BMBSOFT	BR021	NF20	WEST OF OUTFALL SITE	8/26/02 11:41 AM	42.378151	-70.844765	29	DGPS	+/- 15m
BMBSOFT	BR021	NF21	NORTHWEST OF OUTFALL SITE	8/26/02 10:22 AM	42.402649	-70.836647	32	DGPS	+/- 15m
BMBSOFT	BR021	NF22	SOUTH OF OUTFALL SITE	8/26/02 8:00 AM	42.347916	-70.815117	32	DGPS	+/- 15m
BMBSOFT	BR021	NF23	NORTH OF OUTFALL SITE	8/26/02 9:20 AM	42.397785	-70.801567	32	DGPS	+/- 15m
BMBSOFT	BR021	NF24	SOUTH OF OUTFALL SITE	8/26/02 8:26 AM	42.380600	-70.801567	34	DGPS	+/- 15m

Table B-2. Field Data from SPI Survey conducted in August 2002.

SurveyID	SampleID	Sample Date	Sample Time	StationID	Replicate *analyzed	Longitude	Latitude
BR021	HR0210BE	8/26/2002	1:22:14 PM	FF10	1	-70.8785	42.4139
BR021	HR0210BF	8/26/2002	1:23:20 PM	FF10	2*	-70.8786	42.4139
BR021	HR0210C0	8/26/2002	1:24:17 PM	FF10	3*	-70.8786	42.4140
BR021	HR0210C1	8/26/2002	1:25:22 PM	FF10	4*	-70.8788	42.4141
BR021	HR0210C5	8/26/2002	1:54:49 PM	FF12	1*	-70.8997	42.3900
BR021	HR0210C6	8/26/2002	1:55:52 PM	FF12	2*	-70.8997	42.3901
BR021	HR0210C7	8/26/2002	1:56:50 PM	FF12	3*	-70.8997	42.3901
BR021	HR0210C8	8/26/2002	1:57:55 PM	FF12	4	-70.8997	42.3900
BR021	HR021026	8/26/2002	8:44:15 AM	FF13	1*	-70.8232	42.3197
BR021	HR021027	8/26/2002	8:45:02 AM	FF13	2*	-70.8232	42.3197
BR021	HR021028	8/26/2002	8:46:03 AM	FF13	3*	-70.8232	42.3196
BR021	HR021029	8/26/2002	8:46:47 AM	FF13	4	-70.8232	42.3196
BR021	HR02102D	8/26/2002	8:58:17 AM	NF02	1*	-70.8285	42.3385
BR021	HR02102E	8/26/2002	8:59:05 AM	NF02	2*	-70.8285	42.3385
BR021	HR02102F	8/26/2002	9:00:15 AM	NF02	3*	-70.8285	42.3385
BR021	HR021030	8/26/2002	9:01:16 AM	NF02	4	-70.8284	42.3385

SurveyID	SampleID	Sample Date	Sample Time	StationID	Replicate *analyzed	Longitude	Latitude
BR021	HR021076	8/26/2002	10:59:52 AM	NF04	1*	-70.8064	42.4156
BR021	HR021077	8/26/2002	11:00:38 AM	NF04	2*	-70.8064	42.4156
BR021	HR021078	8/26/2002	11:01:26 AM	NF04	3*	-70.8065	42.4157
BR021	HR021079	8/26/2002	11:02:14 AM	NF04	4	-70.8065	42.4157
BR021	HR02107D	8/26/2002	11:15:19 AM	NF05	1*	-70.8338	42.4271
BR021	HR02107E	8/26/2002	11:16:24 AM	NF05	2*	-70.8338	42.4272
BR021	HR02107F	8/26/2002	11:17:29 AM	NF05	3*	-70.8338	42.4272
BR021	HR021080	8/26/2002	11:18:36 AM	NF05	4	-70.8338	42.4272
BR021	HR02106F	8/26/2002	10:49:57 AM	NF07	1*	-70.8150	42.4101
BR021	HR021070	8/26/2002	10:50:49 AM	NF07	2*	-70.8150	42.4101
BR021	HR021071	8/26/2002	10:51:37 AM	NF07	3*	-70.8150	42.4101
BR021	HR021072	8/26/2002	10:52:24 AM	NF07	4	-70.8150	42.4101
BR021	HR021161	8/27/2002	9:14:27 AM	NF08	1*	-70.8636	42.4001
BR021	HR021162	8/27/2002	9:15:32 AM	NF08	2*	-70.8636	42.4001
BR021	HR021163	8/27/2002	9:16:32 AM	NF08	3*	-70.8637	42.4001
BR021	HR021164	8/27/2002	9:17:34 AM	NF08	4	-70.8637	42.4001
BR021	HR02108D	8/26/2002	11:43:13 AM	NF09	1*	-70.8450	42.3997
BR021	HR02108E	8/26/2002	11:44:14 AM	NF09	2*	-70.8451	42.3997
BR021	HR02108F	8/26/2002	11:45:17 AM	NF09	3*	-70.8450	42.3997
BR021	HR021090	8/26/2002	11:46:25 AM	NF09	4	-70.8450	42.3998
BR021	HR021094	8/26/2002	11:55:46 AM	NF10	1	-70.8381	42.3928
BR021	HR021095	8/26/2002	11:56:56 AM	NF10	2*	-70.8382	42.3929
BR021	HR021096	8/26/2002	11:57:49 AM	NF10	3*	-70.8382	42.3929
BR021	HR021097	8/26/2002	11:58:53 AM	NF10	4*	-70.8382	42.3930
BR021	HR02109B	8/26/2002	12:06:29 PM	NF12	1*	-70.8306	42.3899
BR021	HR02109C	8/26/2002	12:07:31 PM	NF12	2*	-70.8306	42.3900
BR021	HR02109D	8/26/2002	12:08:33 PM	NF12	3*	-70.8306	42.3900
BR021	HR02109E	8/26/2002	12:09:40 PM	NF12	4	-70.8305	42.3901
BR021	HR021057	8/26/2002	10:07:53 AM	NF13	1*	-70.8225	42.3900
BR021	HR021058	8/26/2002	10:08:39 AM	NF13	2*	-70.8225	42.3900
BR021	HR021059	8/26/2002	10:09:27 AM	NF13	3*	-70.8225	42.3900
BR021	HR02105A	8/26/2002	10:10:15 AM	NF13	4	-70.8225	42.3900
BR021	HR021050	8/26/2002	9:57:11 AM	NF14	1*	-70.8227	42.3868
BR021	HR021051	8/26/2002	9:58:04 AM	NF14	2*	-70.8227	42.3868
BR021	HR021052	8/26/2002	9:58:52 AM	NF14	3*	-70.8227	42.3868
BR021	HR021053	8/26/2002	9:59:47 AM	NF14	4	-70.8227	42.3868
BR021	HR02115A	8/27/2002	8:58:39 AM	NF15	1*	-70.8280	42.3822
BR021	HR02115B	8/27/2002	8:59:41 AM	NF15	2*	-70.8280	42.3821
BR021	HR02115C	8/27/2002	9:00:45 AM	NF15	3*	-70.8280	42.3821
BR021	HR02115D	8/27/2002	9:02:00 AM	NF15	4	-70.8281	42.3822
BR021	HR0210A9	8/26/2002	12:40:49 PM	NF16	1*	-70.8376	42.3783
BR021	HR0210AA	8/26/2002	12:41:52 PM	NF16	2*	-70.8377	42.3784
BR021	HR0210AB	8/26/2002	12:42:47 PM	NF16	3*	-70.8377	42.3784

SurveyID	SampleID	Sample Date	Sample Time	StationID	Replicate *analyzed	Longitude	Latitude
BR021	HR0210AC	8/26/2002	12:44:03 PM	NF16	4	-70.8377	42.3785
BR021	HR021049	8/26/2002	9:48:11 AM	NF17	1*	-70.8150	42.3814
BR021	HR02104A	8/26/2002	9:49:00 AM	NF17	2*	-70.8150	42.3814
BR021	HR02104B	8/26/2002	9:49:51 AM	NF17	3*	-70.8151	42.3814
BR021	HR02104C	8/26/2002	9:50:40 AM	NF17	4	-70.8151	42.3814
BR021	HR02105E	8/26/2002	10:17:39 AM	NF18	1*	-70.8218	42.3969
BR021	HR02105F	8/26/2002	10:18:31 AM	NF18	2*	-70.8219	42.3969
BR021	HR021061	8/26/2002	10:19:44 AM	NF18	3*	-70.8219	42.3969
BR021	HR021062	8/26/2002	10:20:27 AM	NF18	4	-70.8219	42.3969
BR021	HR02103B	8/26/2002	9:25:26 AM	NF19	1*	-70.8052	42.3717
BR021	HR02103C	8/26/2002	9:26:19 AM	NF19	2*	-70.8052	42.3717
BR021	HR02103D	8/26/2002	9:27:13 AM	NF19	3*	-70.8052	42.3717
BR021	HR02103E	8/26/2002	9:28:08 AM	NF19	4	-70.8052	42.3718
BR021	HR0210B0	8/26/2002	12:51:35 PM	NF20	1	-70.8448	42.3782
BR021	HR0210B1	8/26/2002	12:52:36 PM	NF20	2*	-70.8449	42.3782
BR021	HR0210B2	8/26/2002	12:53:36 PM	NF20	3*	-70.8450	42.3782
BR021	HR0210B3	8/26/2002	12:54:38 PM	NF20	4*	-70.8451	42.3782
BR021	HR021086	8/26/2002	11:32:41 AM	NF21	1*	-70.8366	42.4026
BR021	HR021087	8/26/2002	11:33:49 AM	NF21	2*	-70.8367	42.4027
BR021	HR021088	8/26/2002	11:35:02 AM	NF21	3*	-70.8367	42.4027
BR021	HR021089	8/26/2002	11:36:20 AM	NF21	4	-70.8367	42.4028
BR021	HR021034	8/26/2002	9:10:20 AM	NF22	1*	-70.8151	42.3479
BR021	HR021035	8/26/2002	9:11:33 AM	NF22	2	-70.8151	42.3480
BR021	HR021036	8/26/2002	9:12:28 AM	NF22	3*	-70.8151	42.3480
BR021	HR021037	8/26/2002	9:13:25 AM	NF22	4*	-70.8150	42.3480
BR021	HR021068	8/26/2002	10:30:47 AM	NF23	1*	-70.8016	42.3978
BR021	HR021069	8/26/2002	10:31:41 AM	NF23	2*	-70.8016	42.3978
BR021	HR02106A	8/26/2002	10:32:32 AM	NF23	3*	-70.8016	42.3979
BR021	HR02106B	8/26/2002	10:33:30 AM	NF23	4	-70.8016	42.3979
BR021	HR021042	8/26/2002	9:36:13 AM	NF24	1*	-70.8016	42.3806
BR021	HR021043	8/26/2002	9:37:10 AM	NF24	2*	-70.8016	42.3806
BR021	HR021044	8/26/2002	9:38:06 AM	NF24	3*	-70.8015	42.3806
BR021	HR021045	8/26/2002	9:39:04 AM	NF24	4	-70.8015	42.3806

APPENDIX C1

Preliminary Data Treatments Performed on Bulk Sediment, *Clostridium perfringens*, and Contaminant Data

1992–2002

In the discussion of bulk sediment and contaminant data, the following terms are used.

- Percent Fines – sum of percent silt and clay
- Total PAH (also referred to as TPAH) – sum of concentrations of all PAH compounds listed in Table 4-2, excluding Benzothiozole
- Total PCB (also referred to as TPCB) – sum of concentrations of all PCB congeners listed in Table 4-2
- Total Pesticide (also referred to as TPEST) – sum of concentrations of Aldrin, Dieldrin, Endrin, Hexachlorobenzene, Lindane, and Mirex
- Total DDT (also referred to as TDDT) – sum of concentrations of the six DDT, DDE, and DDD compounds listed in Table 4-2
- Total Chlordane (also referred to as TCHLOR) – sum of concentrations of Cis-chlordane, Heptaclor, Heptachlorepoxide, and Trans nonachlor
- Total LAB (also referred to as TLAB) – sum of concentrations of C_{10} – C_{14} LABs listed in Table 4-2

In cases where an individual analyte was not detected, a value of 0.0 was assigned to that analyte.

Data analyses (*e.g.*, PCA, correlations) were performed on nearfield and regional data sets from 1992 to 2002; note that data from 2000 represented a reduced sampling year. For PCA, a complete set of analyte data is required and the entire sample must be excluded if any one parameter is missing. The following data were excluded from the data analyses:

- FF08 data was omitted because this station was only sampled in 1992, and was also distinctly different compared to other farfield stations (*e.g.*, different habitat, much deeper water); similarly stations NF01, NF03, NF06 and NF11 were also excluded as they were only sampled in 1992;
- FF01 data from 1992-1993 were omitted from the regional range plots because the station location changed in 1994 (hereafter referred to as FF01A) to a location approximately 10-km away, and in shallower water. Therefore, data for FF01A shown on the regional range plots includes data from 1994 to 2002 only. FF01 (1992-1993) data were included in the PCA, but qualified to indicate the change in station location;
- Data from 1996-1998 were omitted from PCA due to incomplete data acquisition; *i.e.*, the contaminant data were not collected;
- FF10 (rep1), NF14 and NF20 TOC data for 2000 was omitted because of suspected anomalies with the high TOC results (for PCA whole samples excluded);
- FF01A (rep2) mercury data was omitted from 2001 because of a suspiciously high value that was attributed to isolated laboratory contamination (for PCA whole sample excluded);
- NF21 data for 2001 (August survey) was omitted from the PCA due to an unusually high total DDT value;
- FF10 (replicate 2) for 2002 (August survey) was omitted from the PCA due to an unusually high total PAH value;
- NF13 and NF20 for 2002 (August survey) were omitted from the PCA (and other analyses) due to suspiciously high Pb values; and

- NF24 and NF08 (one replicate each, August survey) for 2002 were omitted from the PCA due to suspiciously high Hg values.

Mean parameter (*e.g.*, total PAH) values were determined for three categories:

- Station Mean – Average of all station replicates. Laboratory replicates were first averaged to determine a single value for a given replicate prior to calculation of station means. Station means were determined for each parameter within a given sampling year. Station mean values were used in the chemistry correlation analyses to determine the correspondence within bulk sediment properties and against contaminants in the nearfield and regional areas.
- Baseline Station Mean – Average of data for a given station over the baseline period, sampled during August surveys only. Each field sample replicate was treated as an individual sample. Baseline station mean values were determined for each station and parameter, and were compared to post-discharge (2001) data to evaluate changes in the system (*i.e.*, spatial, temporal).
- Nearfield Baseline Mean – Average of all nearfield stations including FF10, FF12, and FF13 sampled during August surveys only. Each field sample replicate was treated as an individual sample. Nearfield baseline mean values were determined for each parameter within a given sampling year and were used to assess temporal trends in the nearfield from 1992–2002. Data were also evaluated against monitoring thresholds.

Yearly “mean values” and 95 % confidence intervals were determined for representative sewage tracers (*e.g*., *Clostridium perfringens*, total LAB) to evaluate the spatio/temporal distribution of sewage tracers at all nearfield and farfield stations from 1992–2002. Yearly mean values were determined as a function of distance from Deer Island Light as follows:

- Harbor near-in group (< 10 km) – Average of all stations sampled during August surveys and that are within 10 km of Deer Island Light. Stations included all Harbor stations (T01 – T08 and T05A) plus nearfield station NF01 (sampled in 1992 only) and farfield station FF12. These stations are under the general influence of all discharges into the harbor including rivers, effluent, and CSOs.
- Mid-distance group (>10 km but <20 km) – Average of all stations sampled during August surveys and that are more than 10 km but less than 20 km of Deer Island Light. Stations included all nearfield stations plus farfield stations FF10 and FF13. These stations experience substantial influence from the water exchange at the harbor mouth.
- Mid-distance group (> 20 km but < 40 km) – Average of all stations sampled during August surveys and that are more than 20 km but less than 40 km of Deer Island Light. Stations included FF09 and FF14. These stations are generally not under the direct influence of the effluent but experience transport of materials from harbor or other locations.
- Far-distance group (> 40 km) – Average of all stations sampled during August surveys and that are more than 40 km from Deer Island Light. Stations included FF04, FF05, FF06, and FF07. These stations are generally not under the direct influence of the effluent but experience transport of materials from harbor or other locations.

Three farfield stations were excluded from the above listed groupings: FF01 (sampled in 1992 and 1993 only), FF01A (sampled since 1994), and FF11. These three stations are located in the northern part of Massachusetts Bay. Since the long-term transport of sediments and particle associated contaminants along the coast is from north to south (Parmenter and Bothner 1993; Bothner *et al.*, 1994), with some onshore-offshore component, these data were excluded as "upstream" stations which might confound the evaluation of downstream transport. An evaluation of *Clostridium perfringens* concentrations and rationale for excluding these three farfield stations was presented in the 2000 Outfall Benthic Report (OBR; Kropp *et al*., 2001).

Sediment grain size results were evaluated by using ternary plots to visually display the distribution of gravel plus sand, silt and clay in sediment collected from Nearfield Contaminant Special Study (NCSS) stations.

Results for sediment grain size, total organic carbon (TOC), *Clostridium perfringens,* and contaminant analyses were compared from all stations by using histogram plots.

APPENDIX C2

Nearfield Baseline Range (1992–2000), Mean (1992–2000), and 2001 and 2002 Individual Replicate Data for Bulk Sediment, *Clostridium perfringens*, and Contaminant Parameters

August Surveys Only

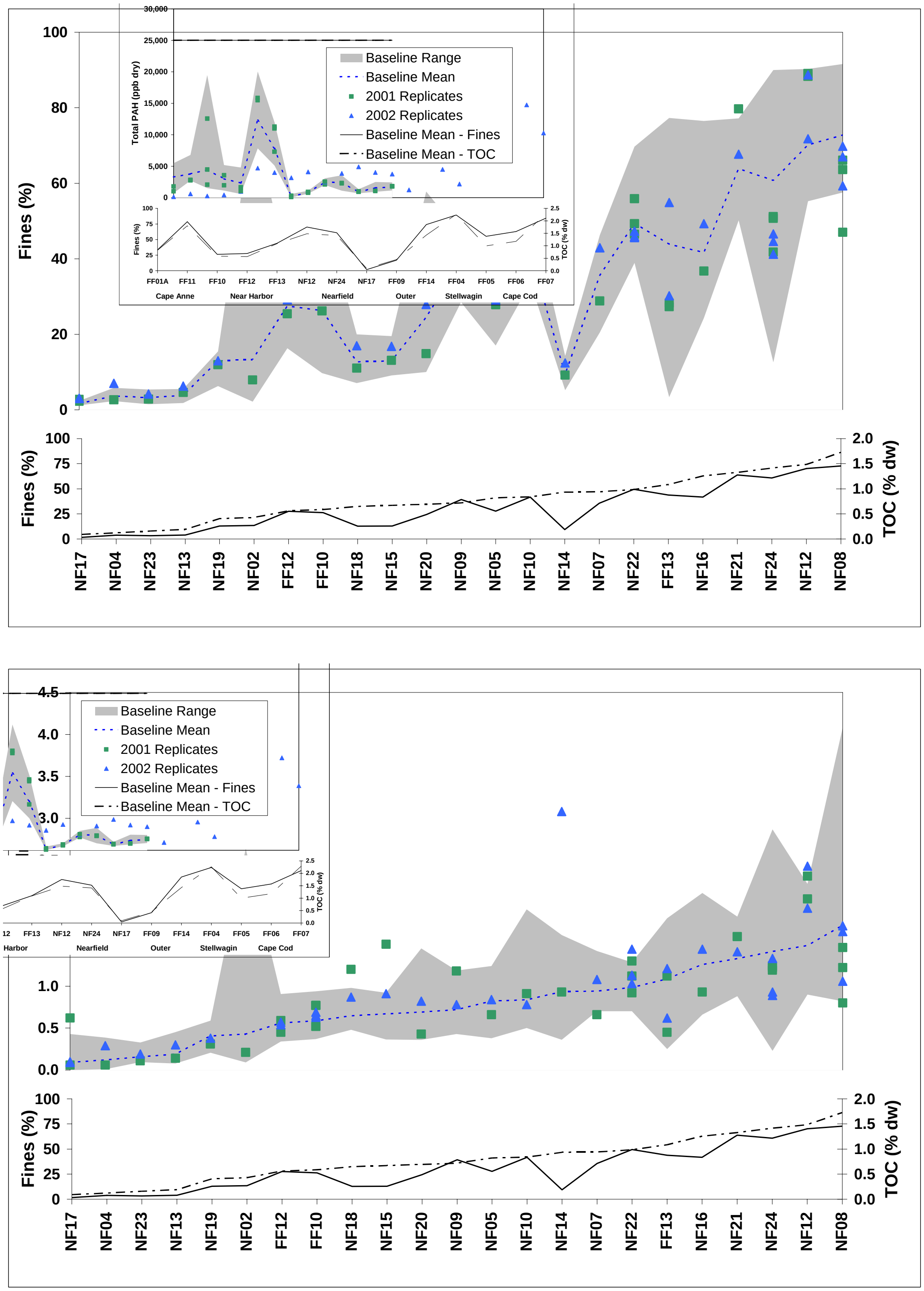


Figure C2-1. Percent fines (top) and TOC (bottom) for each nearfield station sampled in 2001 (squares), 2002 (triangles) and the range of values occurring during the baseline period (gray band). The baseline mean values are indicated (dashed line within gray band). Stations are presented in order of increasing mean TOC concentration (dashed line in sub-plot). Baseline station mean values for TOC and percent fines, plotted by station, are shown in the sub-plot.

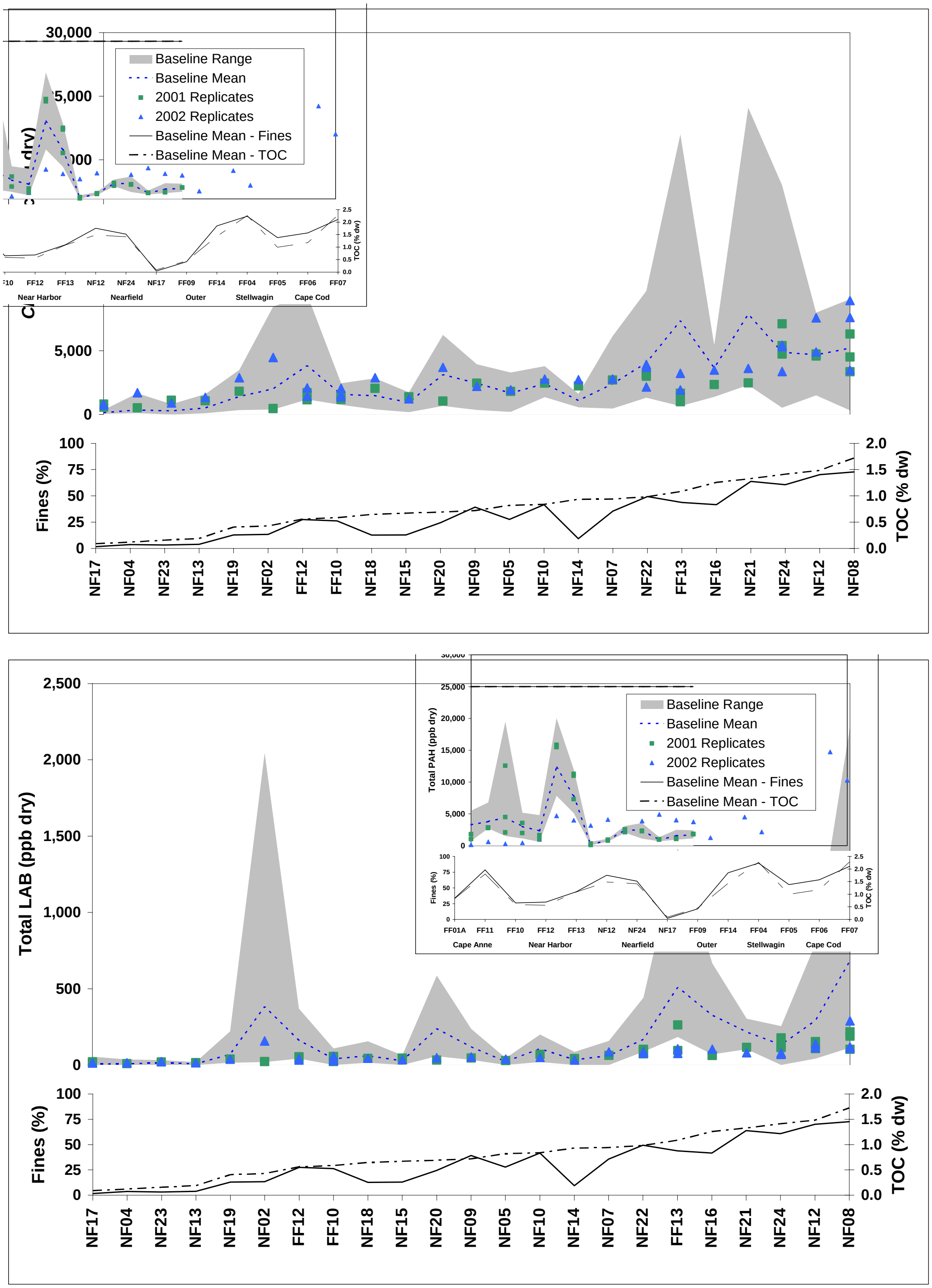
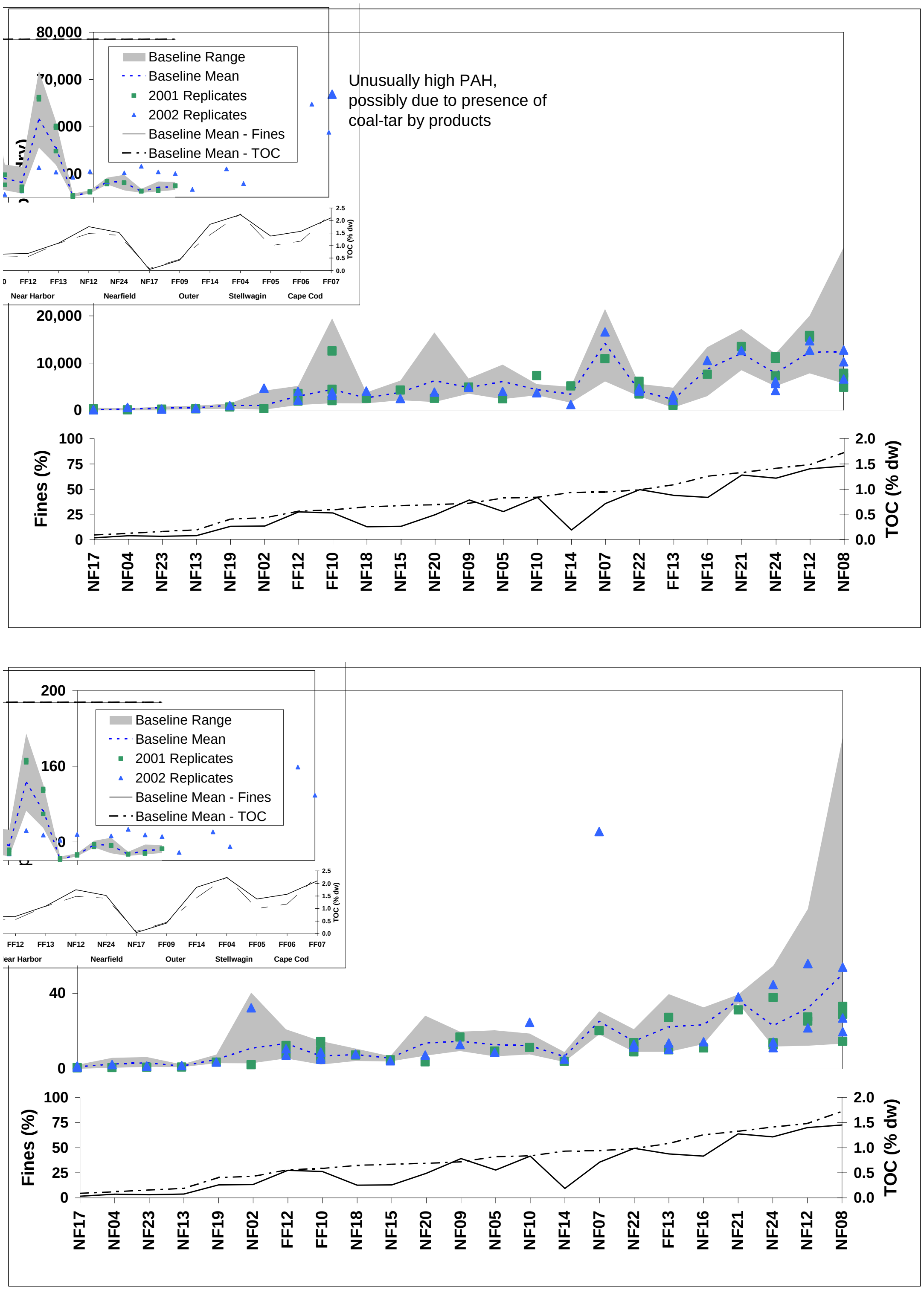


Figure C2-2. *Clostridium perfringens* (top) and total LAB (bottom) for each nearfield station sampled in 2001 (squares), 2002 (triangles) and the range of values occurring during the baseline period (gray band). The baseline mean values are indicated (dashed line within gray band). Stations are presented in order of increasing mean TOC concentration (dashed line in sub-plot). Baseline station mean values for TOC and percent fines, plotted by station, are shown in the sub-plot.



Unusually high PAH, possibly due to presence of coal-tar by products

Figure C2-3. Total PAH (top) and total PCB (bottom) for each nearfield station sampled in 2001 (squares), 2002 (triangles) and the range of values occurring during the baseline period (gray band). The baseline mean values are indicated (dashed line within gray band). Stations are presented in order of increasing mean TOC concentration (dashed line in sub-plot). Baseline station mean values for TOC and percent fines, plotted by station, are shown in the sub-plot.

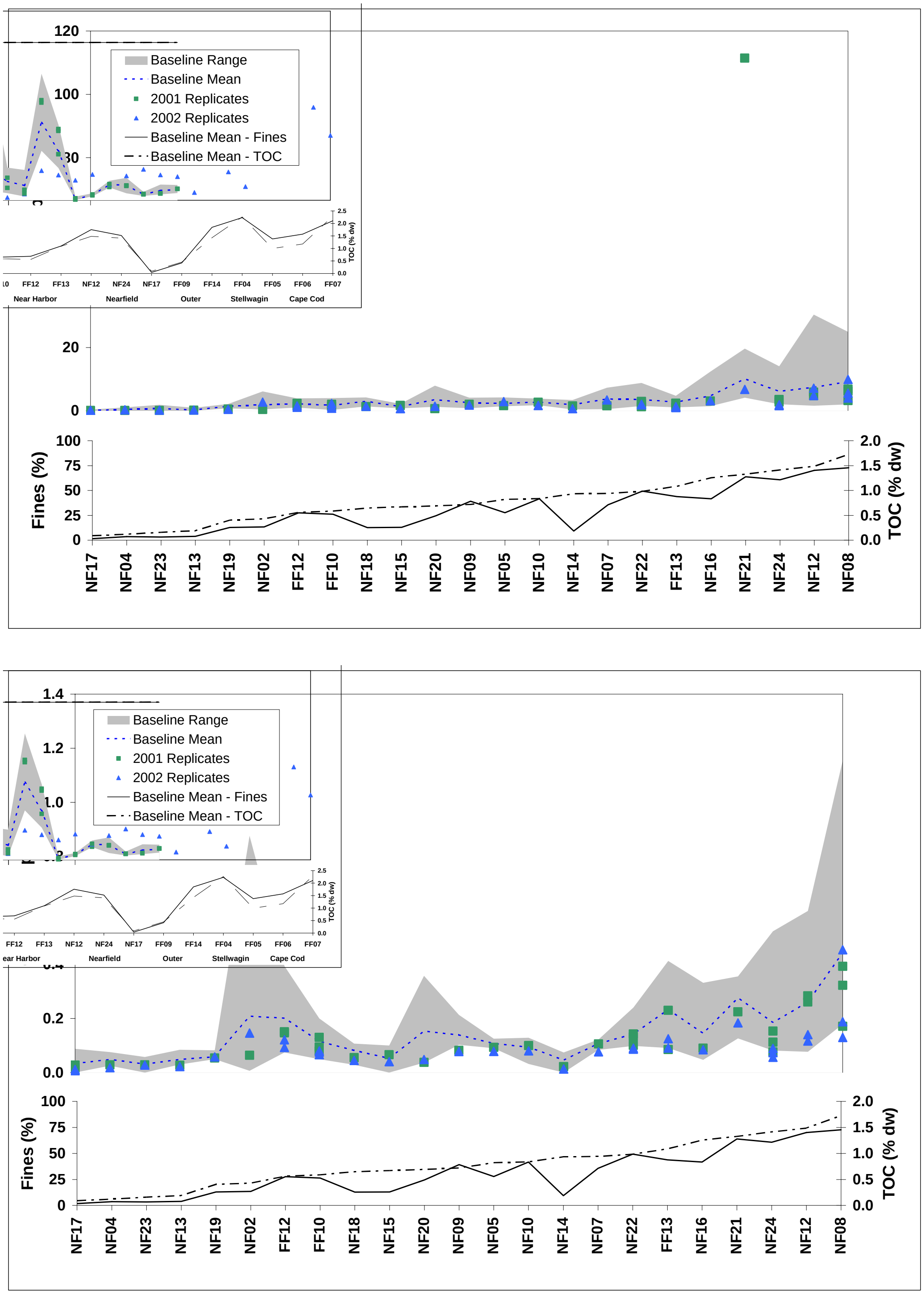


Figure C2-4. Total DDT (top) and cadmium (bottom) for each nearfield station sampled in 2001 (squares), 2002 (triangles) and the range of values occurring during the baseline period (gray band). The baseline mean values are indicated (dashed line within gray band). Stations are presented in order of increasing mean TOC concentration (dashed line in sub-plot). Baseline station mean values for TOC and percent fines, plotted by station, are shown in the sub-plot.

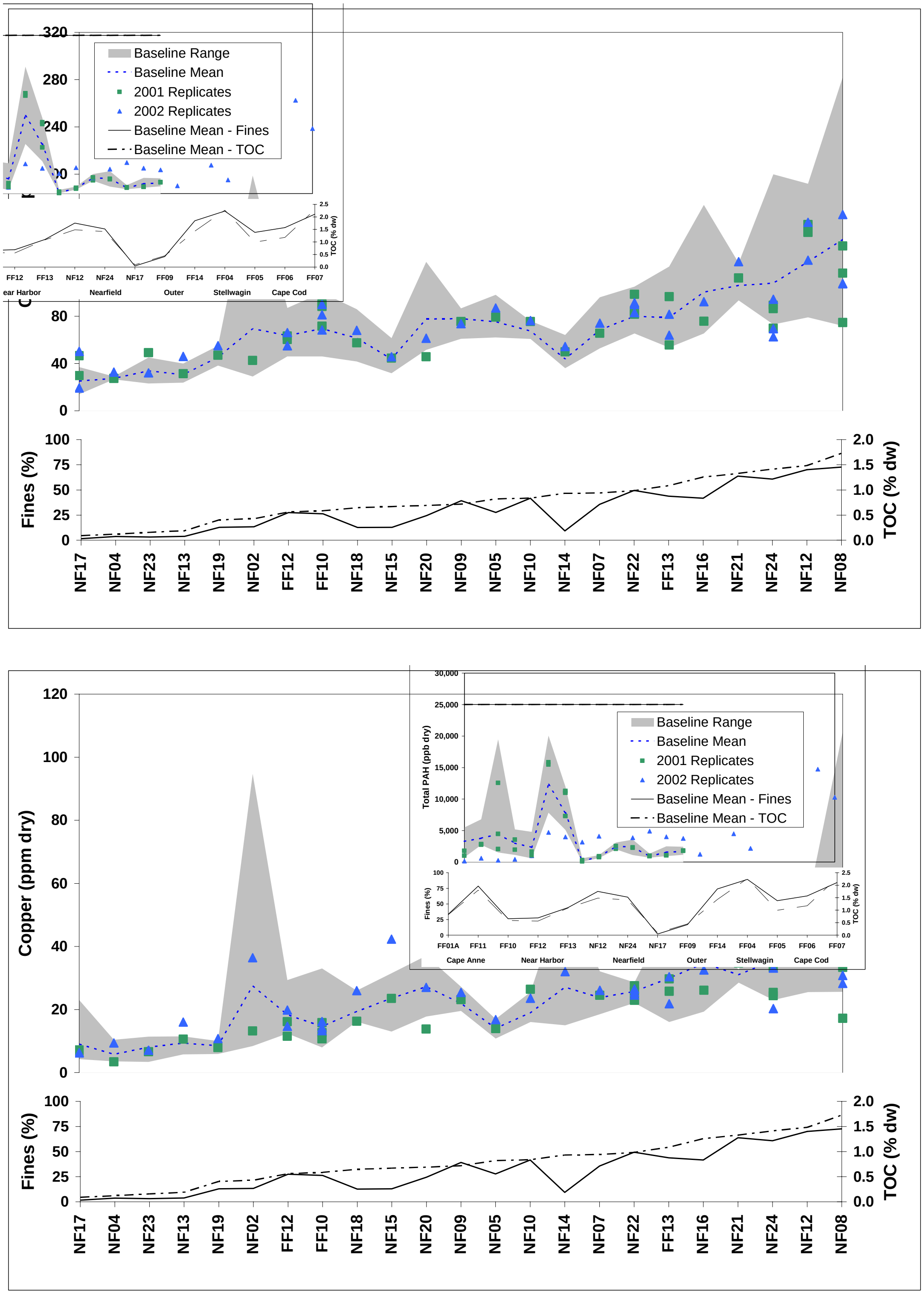
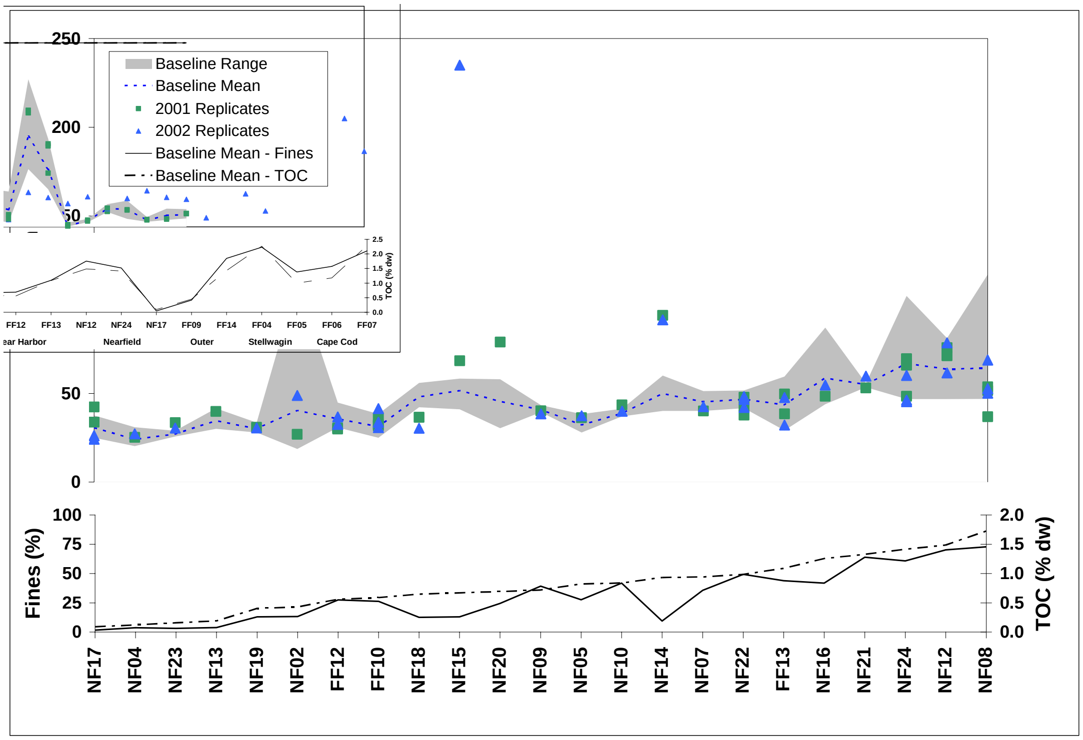


Figure C2-5. **Chromium (top) and copper (bottom) for each nearfield station sampled in 2001 (squares), 2002 (triangles) and the range of values occurring during the baseline period (gray band). The baseline mean values are indicated (dashed line within gray band). Stations are presented in order of increasing mean TOC concentration (dashed line in sub-plot). Baseline station mean values for TOC and percent fines, plotted by station, are shown in the sub-plot.**



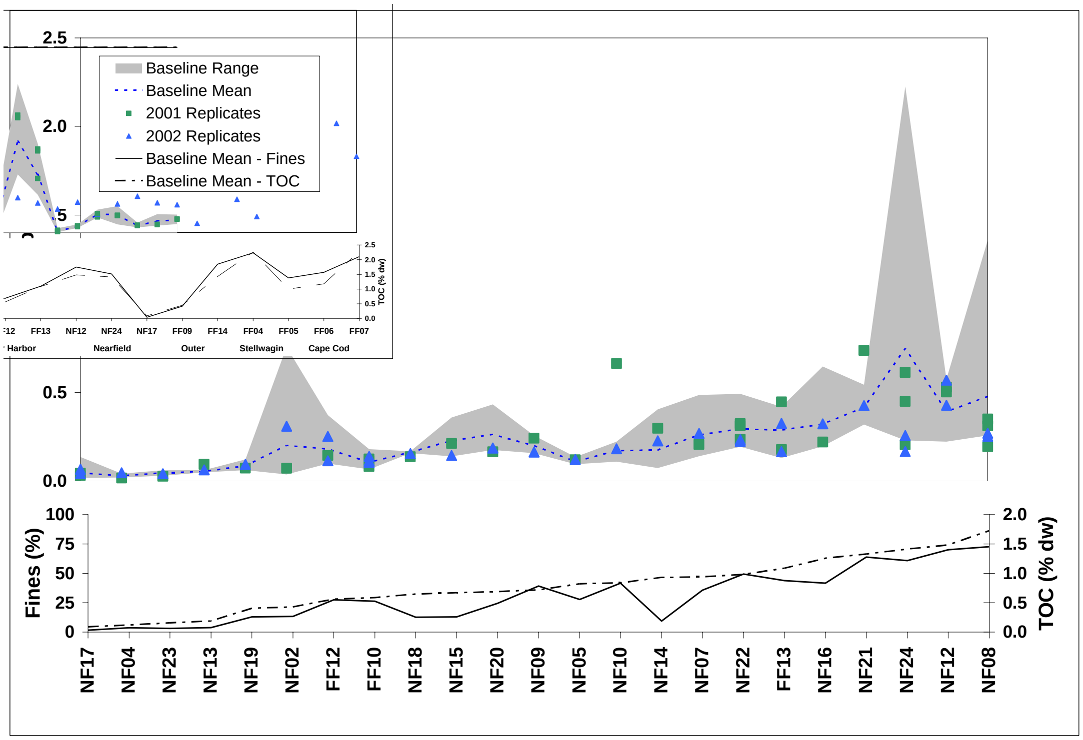


Figure C2-6. Lead (top) and mercury (bottom) for each nearfield station sampled in 2001 (squares), 2002 (triangles) and the range of values occurring during the baseline period (gray band). The baseline mean values are indicated (dashed line within gray band). Stations are presented in order of increasing mean TOC concentration (dashed line in sub-plot). Baseline station mean values for TOC and percent fines, plotted by station, are shown in the sub-plot.

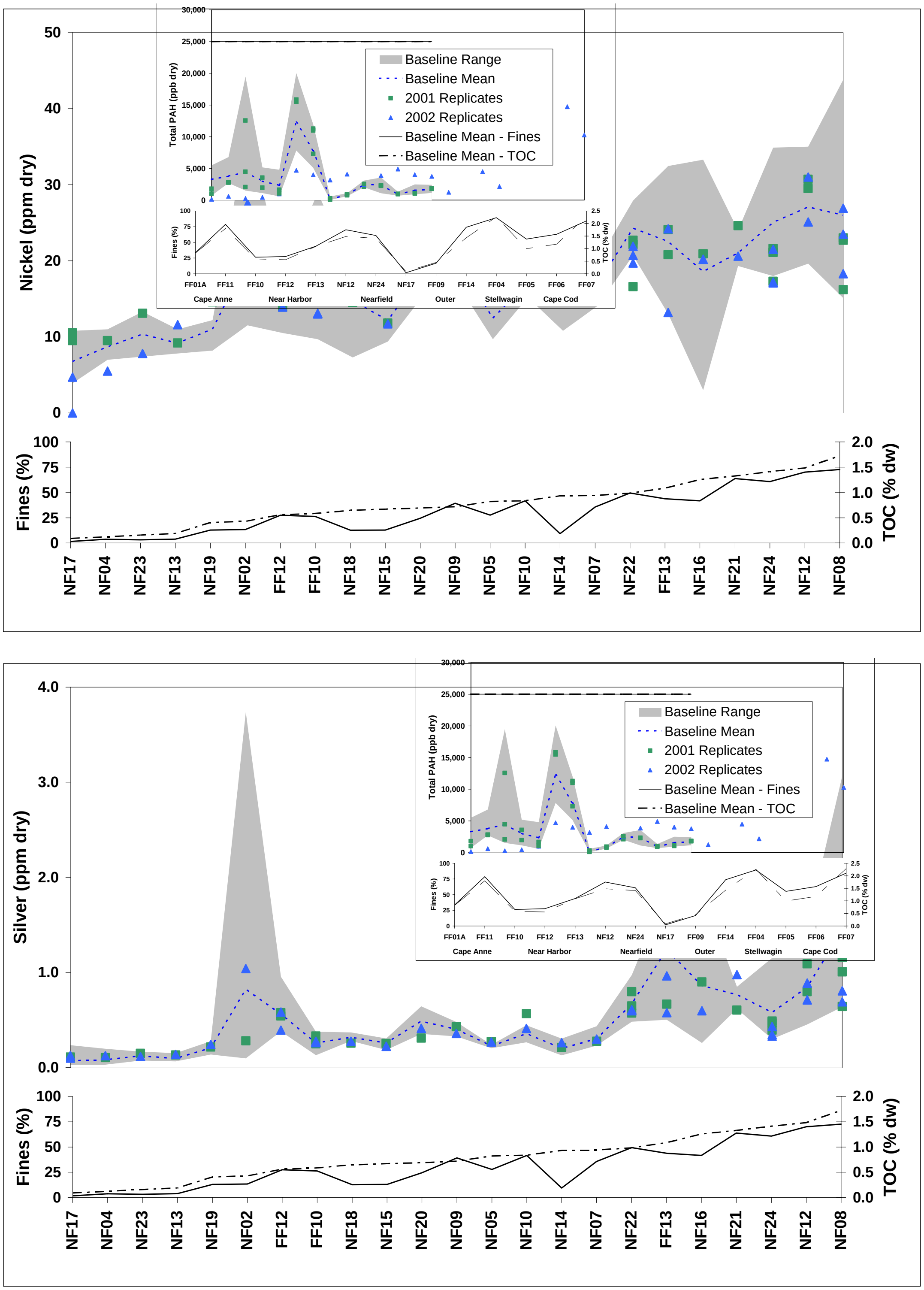


Figure C2-7. Nickel (top) and silver (bottom) for each nearfield station sampled in 2001 (squares), 2002 (triangles) and the range of values occurring during the baseline period (gray band). The baseline mean values are indicated (dashed line within gray band). Stations are presented in order of increasing mean TOC concentration (dashed line in sub-plot). Baseline station mean values for TOC and percent fines, plotted by station, are shown in the sub-plot.

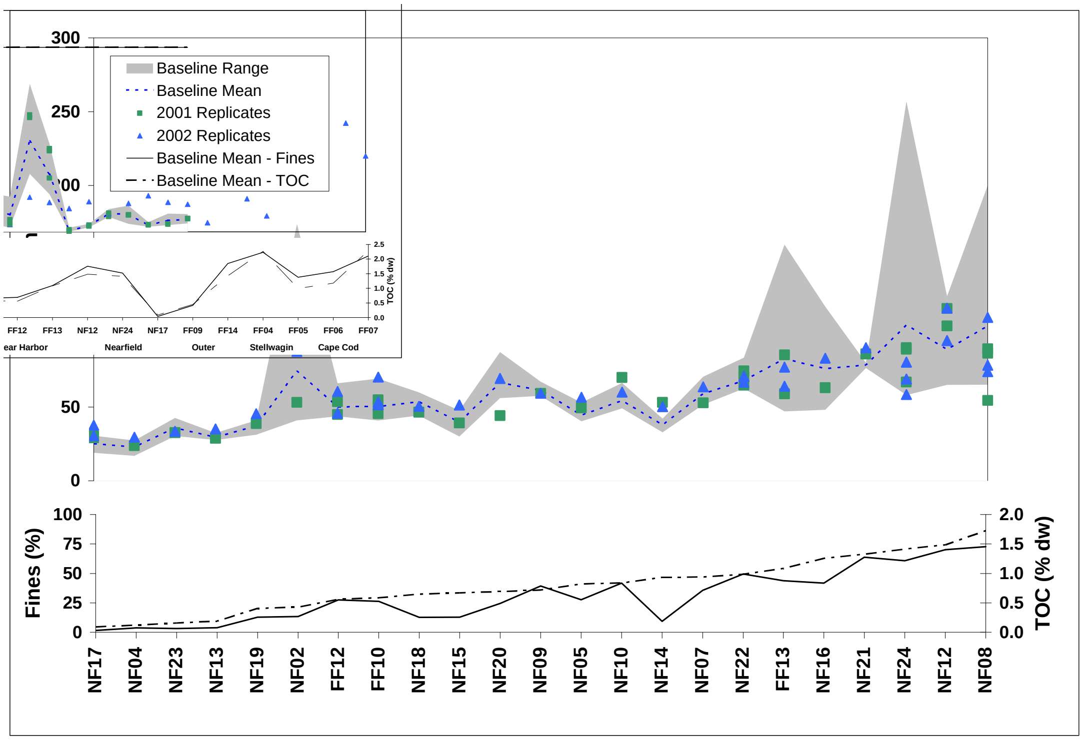


Figure C2-8. Zinc for each nearfield station sampled in 2001 (squares), 2002 (triangles) and the range of values occurring during the baseline period (gray band). The baseline mean values are indicated (dashed line within gray band). Stations are presented in order of increasing mean TOC concentration (dashed line in sub-plot). Baseline station mean values for TOC and percent fines, plotted by station, are shown in the sub-plot.

APPENDIX C3

Regional Baseline Range (1992–2000), Mean (1992–2000) and 2001 and 2002 Individual Replicate Data for Bulk Sediment, *Clostridium perfringens*, and Contaminant Parameters

August Surveys Only

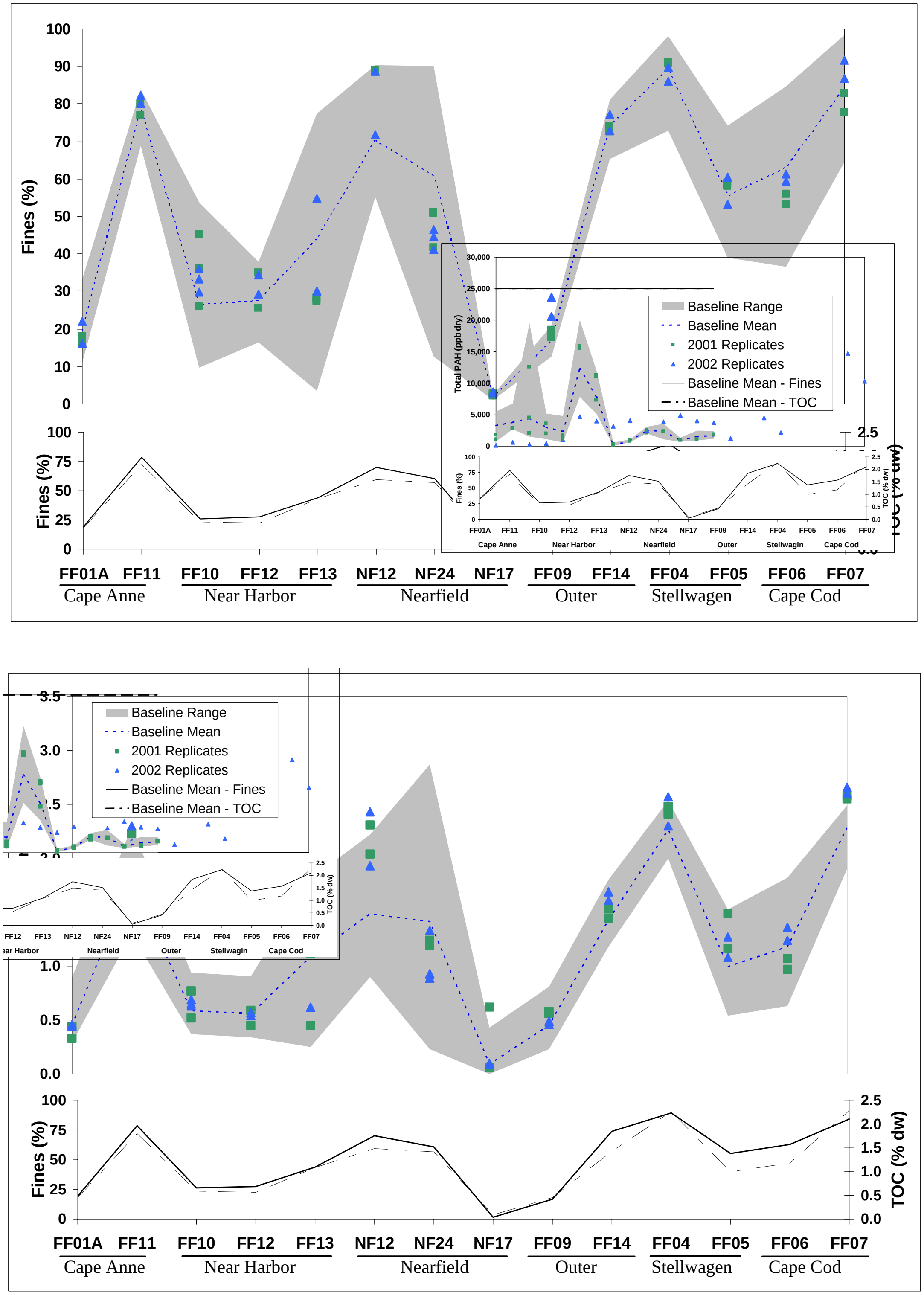


Figure C3-1. Percent fines (top) and TOC (bottom) for each regional station sampled in 2001 (squares), 2002 (triangles) and the range of values occurring during the baseline period (gray band). The baseline mean values are indicated (dashed line within gray band). Stations are presented in order of location relative to the outfall, from north to south. Baseline station mean values for TOC and percent fines, plotted by station, are shown in the sub-plot.

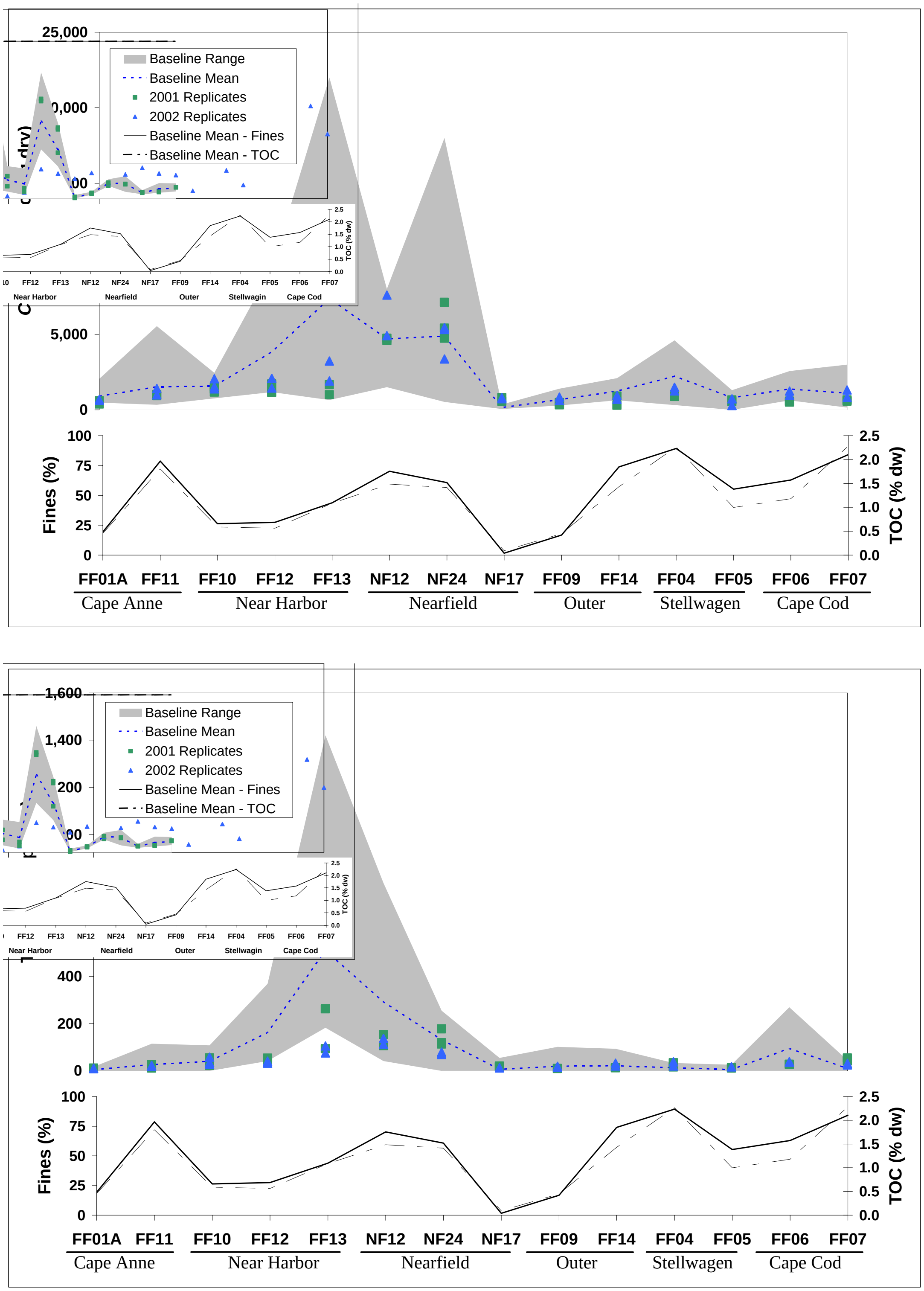


Figure C3-2. *Clostridium perfringens* (top) and total LAB (bottom) for each regional station sampled in 2001 (squares), 2002 (triangles) and the range of values occurring during the baseline period (gray band). The baseline mean values are indicated (dashed line within gray band). Stations are presented in order of location relative to the outfall, from north to south. Baseline station mean values for TOC and percent fines, plotted by station, are shown in the sub-plot.

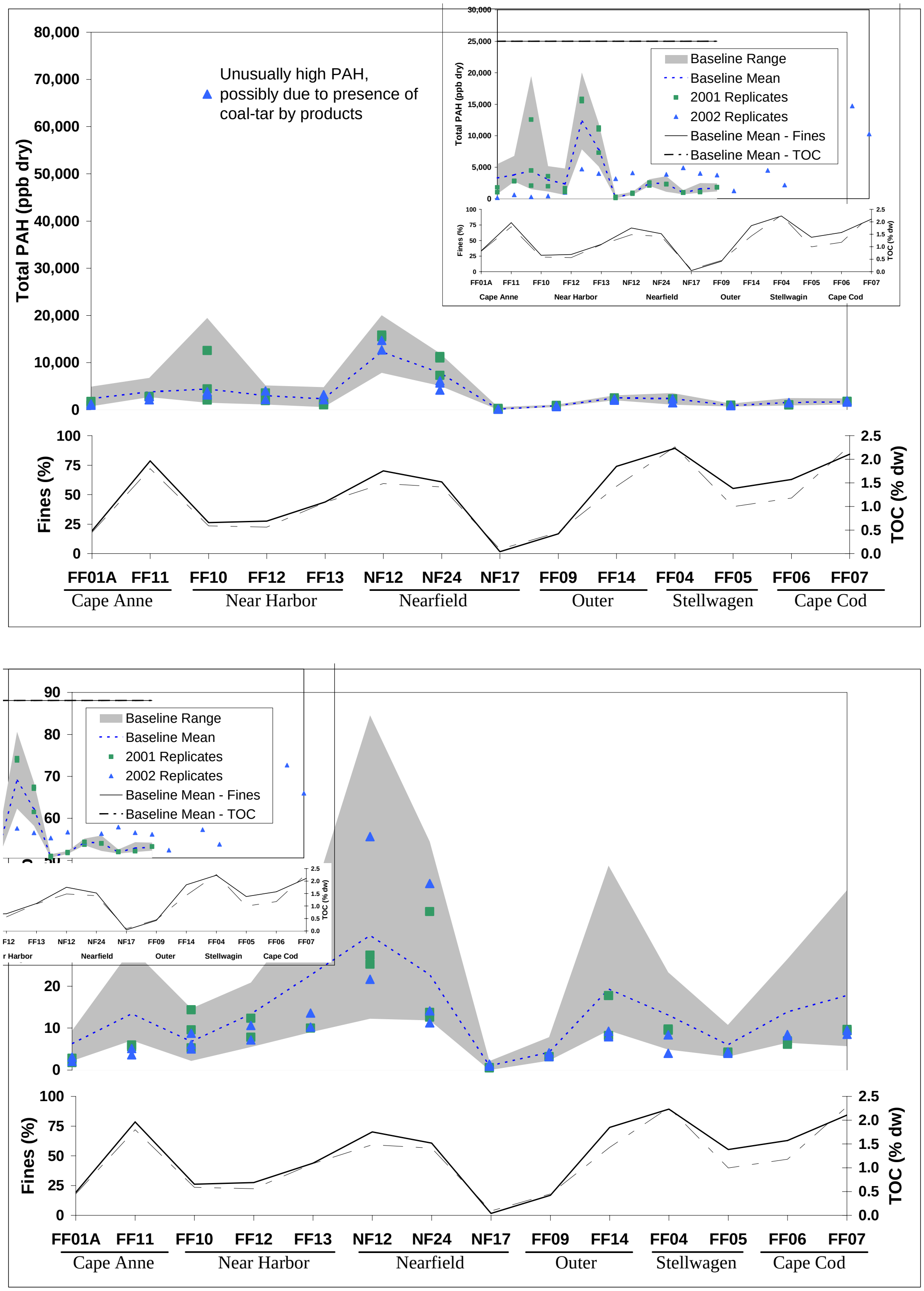
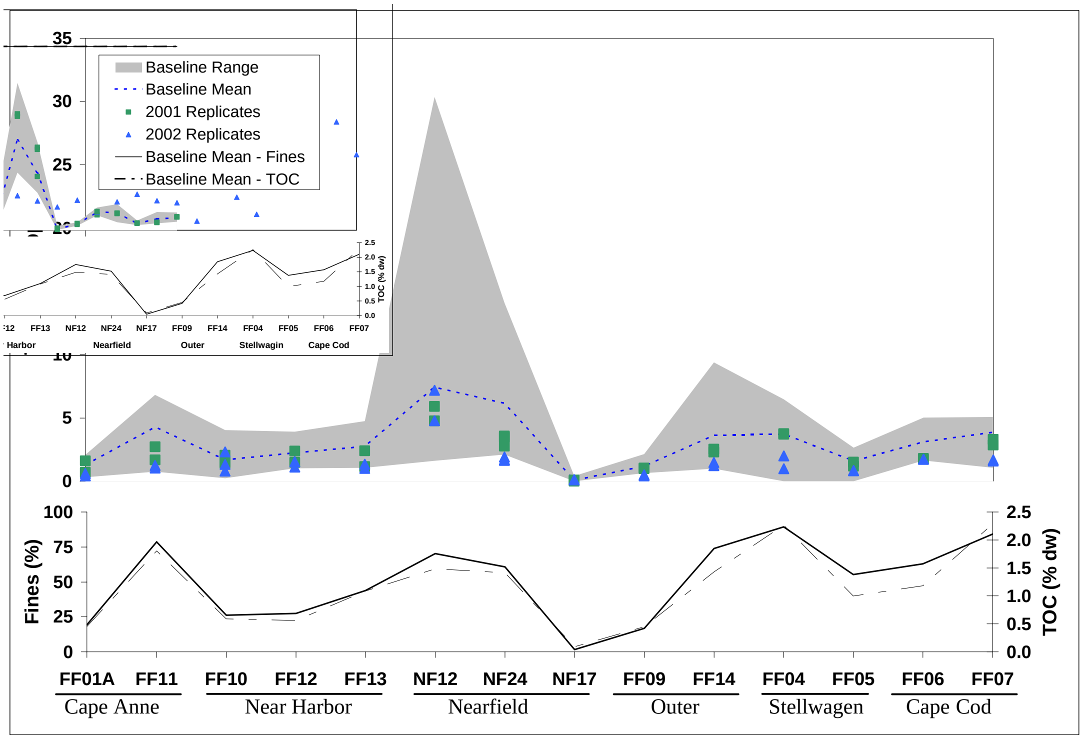


Figure C3-3. Total PAH (top) and total PCB (bottom) for each regional station sampled in 2001 (squares), 2002 (triangles) and the range of values occurring during the baseline period (gray band). The baseline mean values are indicated (dashed line within gray band). Stations are presented in order of location relative to the outfall, from north to south. Baseline station mean values for TOC and percent fines, plotted by station, are shown in the sub-plot.



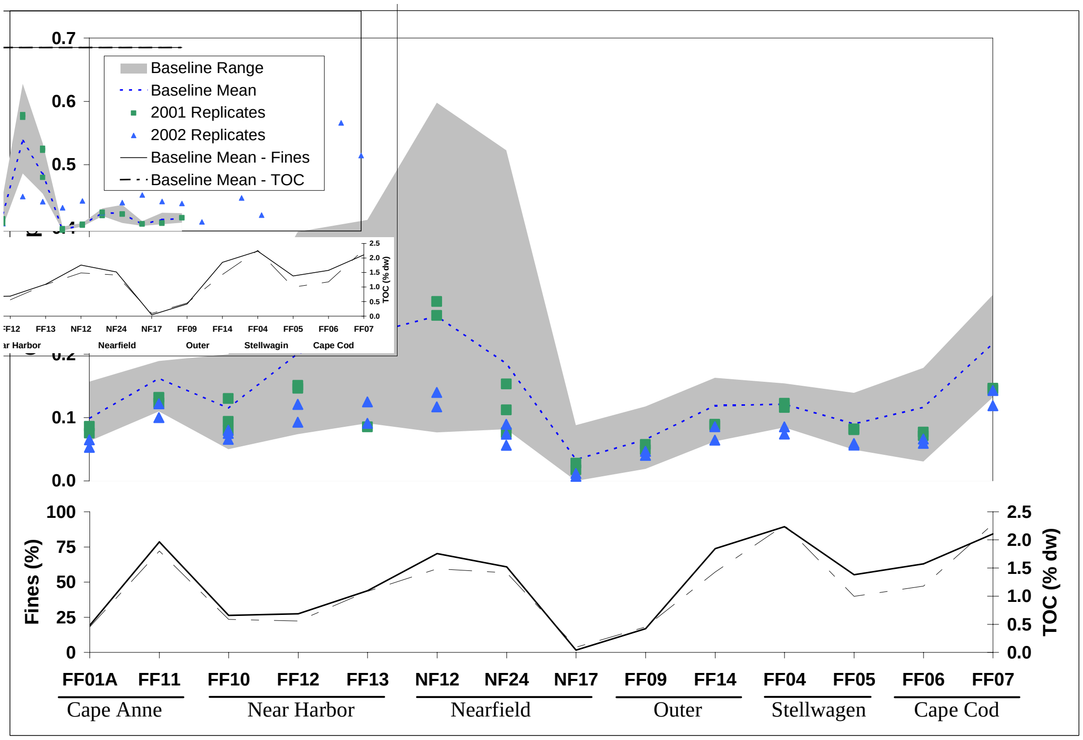


Figure C3-4. Total DDT (top) and cadmium (bottom) for each regional station sampled in 2001 (squares), 2002 (triangles) and the range of values occurring during the baseline period (gray band). The baseline mean values are indicated (dashed line within gray band). Stations are presented in order of location relative to the outfall, from north to south. Baseline station mean values for TOC and percent fines, plotted by station, are shown in the sub-plot.

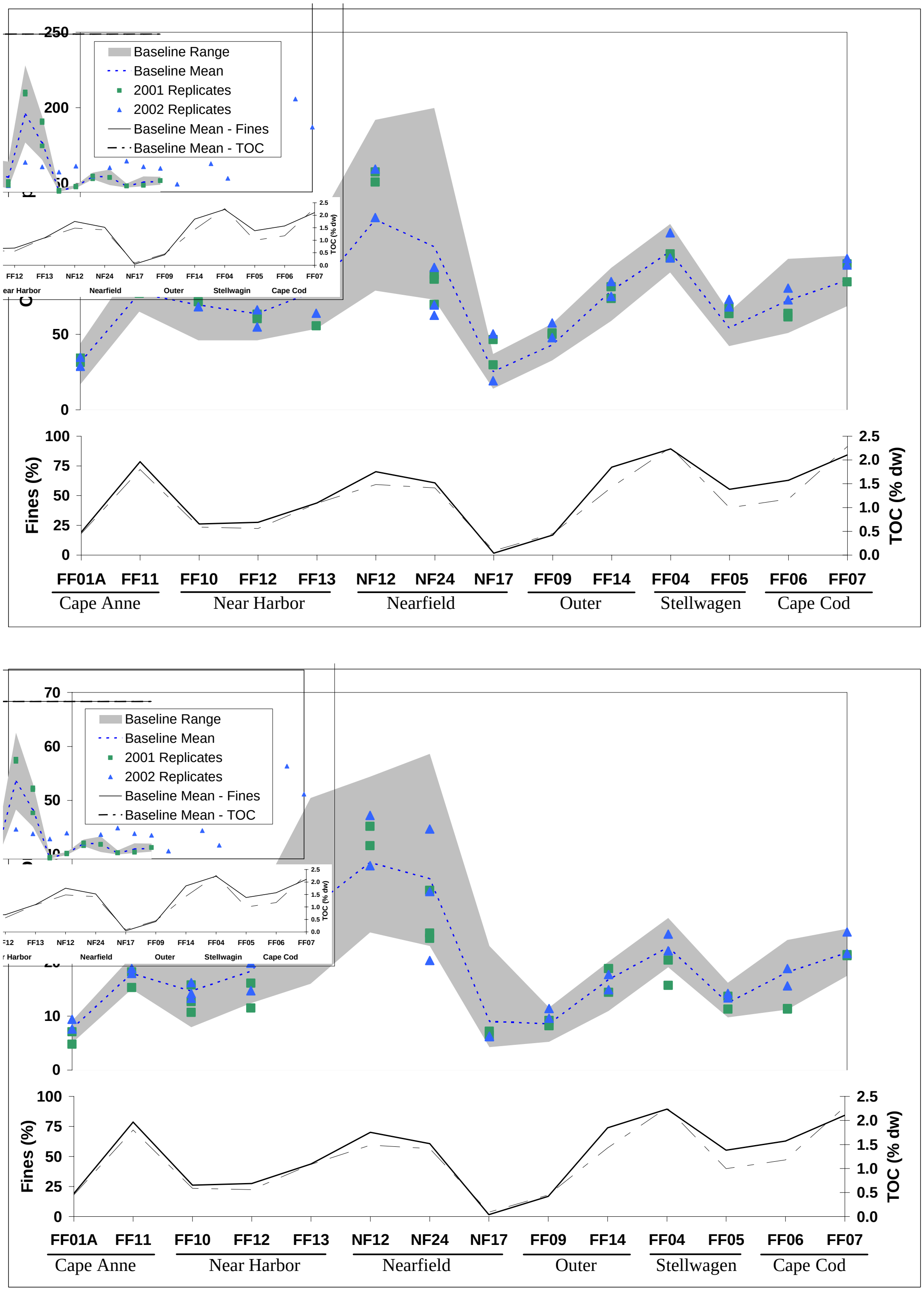


Figure C3-5. Chromium (top) and copper (bottom) for each regional station sampled in 2001 (squares), 2002 (triangles) and the range of values occurring during the baseline period (gray band). The baseline mean values are indicated (dashed line within gray band). Stations are presented in order of location relative to the outfall, from north to south. Baseline station mean values for TOC and percent fines, plotted by station, are shown in the sub-plot.

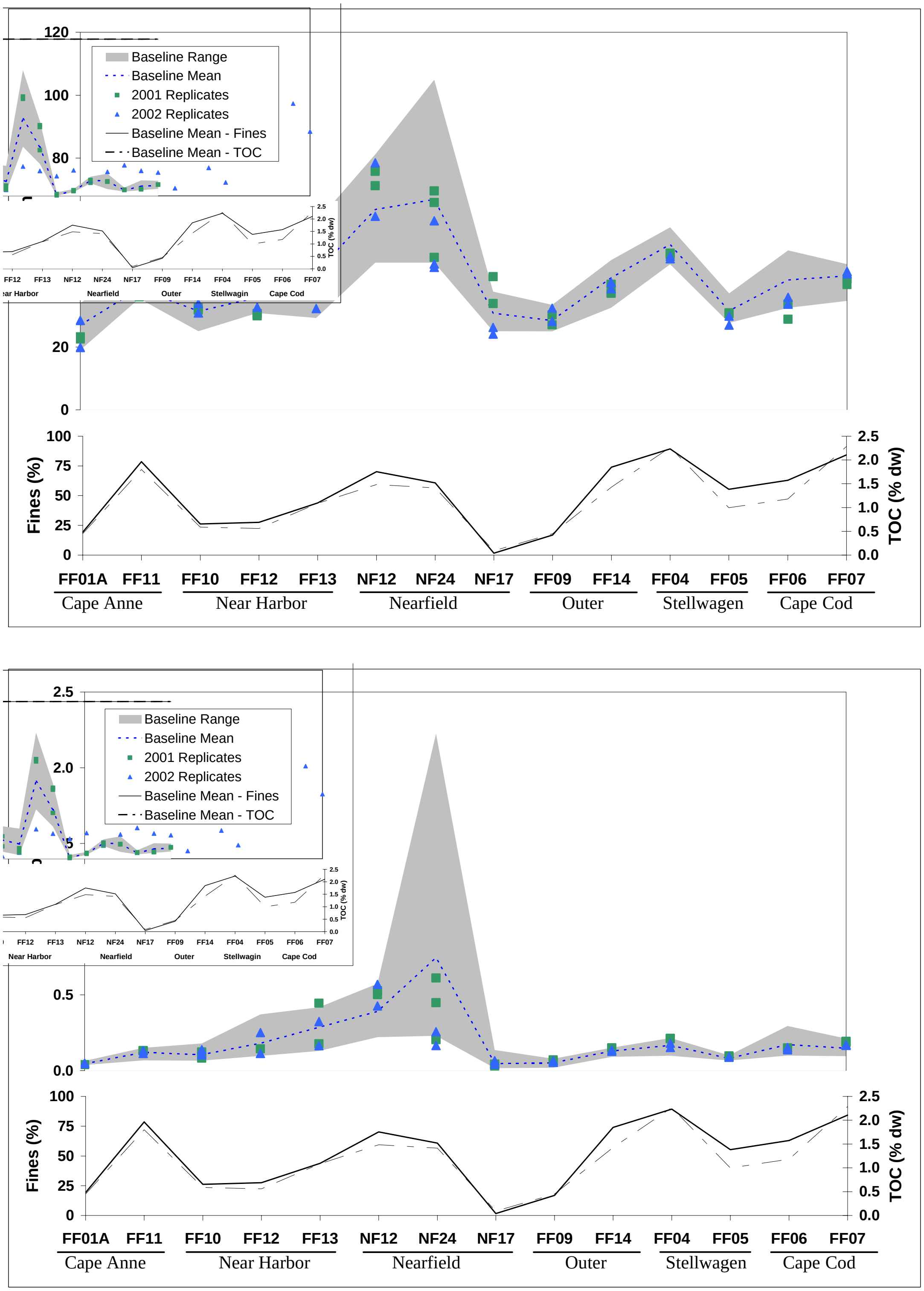


Figure C3-6. Lead (top) and mercury (bottom) for each regional station sampled in 2001 (squares), 2002 (triangles) and the range of values occurring during the baseline period (gray band). The baseline mean values are indicated (dashed line within gray band). Stations are presented in order of location relative to the outfall, from north to south. Baseline station mean values for TOC and percent fines, plotted by station, are shown in the sub-plot.

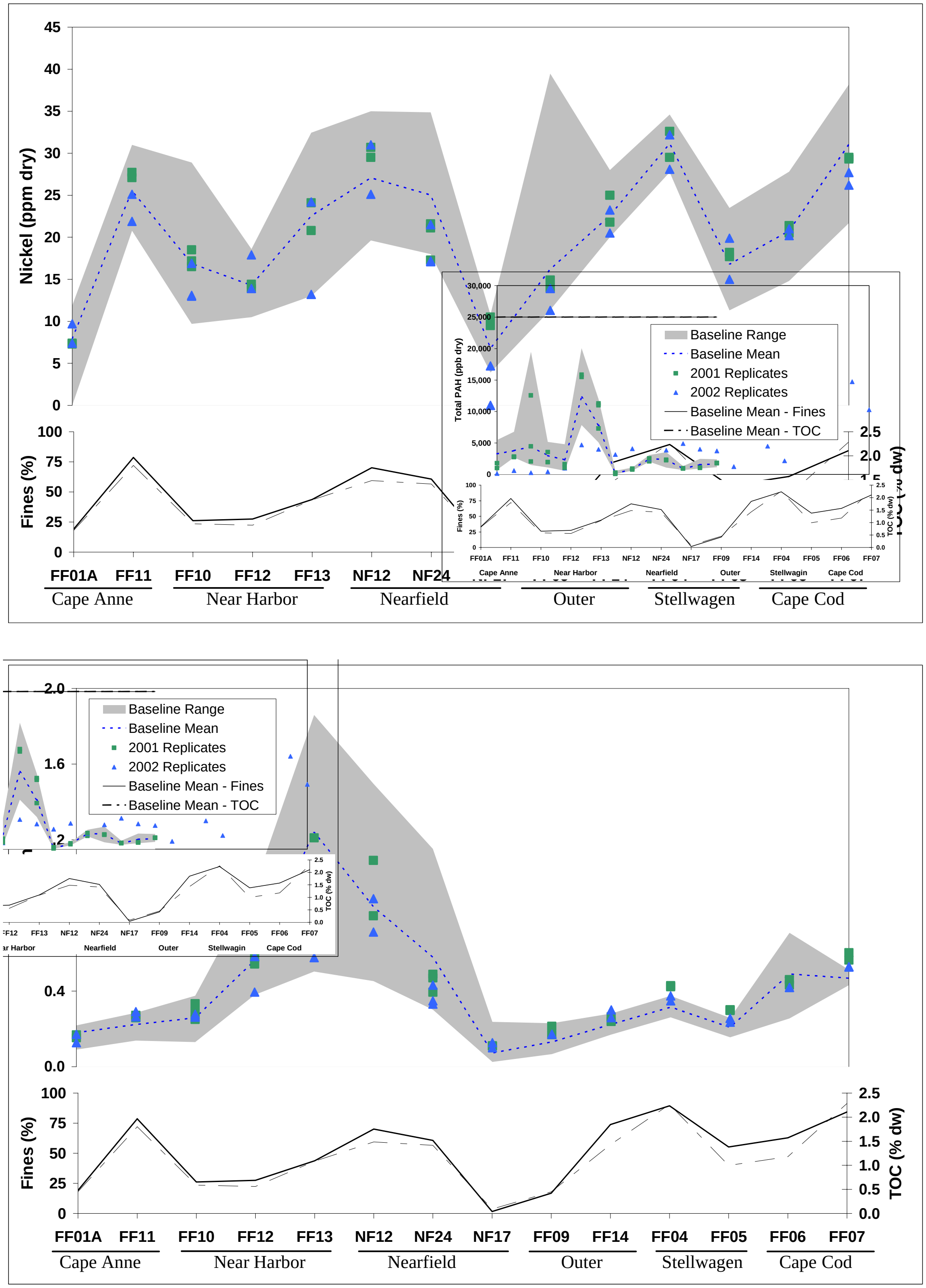


Figure C3-7. Nickel (top) and silver (bottom) for each regional station sampled in 2001 (squares), 2002 (triangles) and the range of values occurring during the baseline period (gray band). The baseline mean values are indicated (dashed line within gray band). Stations are presented in order of location relative to the outfall, from north to south. Baseline station mean values for TOC and percent fines, plotted by station, are shown in the sub-plot.

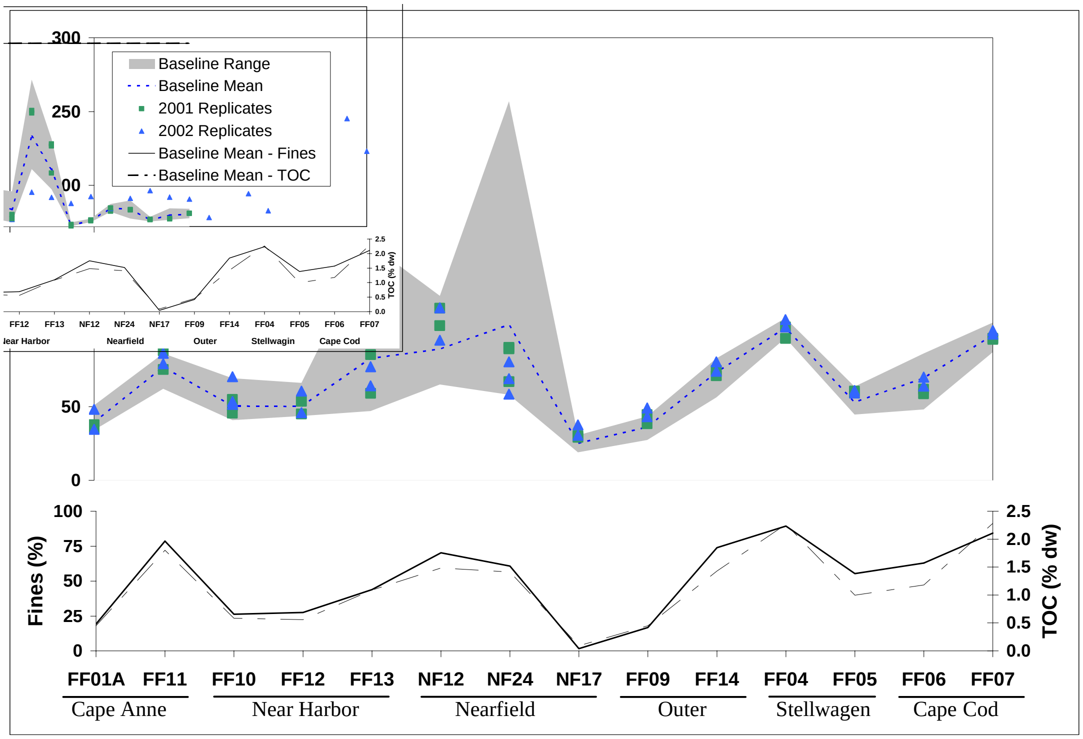


Figure C3-8. Zinc for each regional station sampled in 2001 (squares), 2002 (triangles) and the range of values occurring during the baseline period (gray band). The baseline mean values are indicated (dashed line within gray band). Stations are presented in order of location relative to the outfall, from north to south. Baseline station mean values for TOC and percent fines, plotted by station, are shown in the sub-plot.

APPENDIX C4

Correlation Analysis Results for Nearfield and Regional Stations
1999–2002

and

Correlation Analysis Results for Nearfield Contaminant Special Study (NCSS) Stations
1998–2002

Table C4-1. Correspondence within bulk sediment properties and against contaminants in the nearfield during the two-year period before and after the new outfall came on-line.

Parameter	**Correspondence with Percent Fines**			**Correspondence with TOC** [a]		
	r	***n***	***p***	***r***	***n***	***p***
Pre-Discharge (1999 – 2000)						
Percent Fines	1.000	46	<0.01	0.871	44	<0.01
TOC	0.871	44	<0.01	1.000	44	<0.01
Clostridium perfringens	0.786	46	<0.01	0.659	45	<0.01
Total PAH	0.661	31	<0.01	0.683	32	<0.01
Total PCB	0.831	31	<0.01	0.834	32	<0.01
Total DDT	0.839	31	<0.01	0.797	32	<0.01
Total LAB	0.800	31	<0.01	0.777	32	<0.01
Al	0.779	31	<0.01	0.715	32	<0.01
Cd	0.739	28	<0.01	0.686	28	<0.01
Cr	0.951	31	<0.01	0.859	32	<0.01
Cu	0.859	31	<0.01	0.875	32	<0.01
Fe	0.755	31	<0.01	0.661	32	<0.01
Pb	0.697	31	<0.01	0.835	32	<0.01
Hg	0.908	31	<0.01	0.896	32	<0.01
Ni	0.817	31	<0.01	0.760	32	<0.01
Ag	0.708	31	<0.01	0.690	32	<0.01
Zn	0.826	31	<0.01	0.769	32	<0.01
Post-Discharge (2001 – 2002)						
Percent Fines	1.000	46	<0.01	0.850	45	<0.01
TOC [a]	0.850	45	<0.01	1.000	45	<0.01
Clostridium perfringens	0.767	46	<0.01	0.756	45	<0.01
Total PAH	0.820	46	<0.01	0.762	45	<0.01
Total PCB [b]	0.547	46	<0.01	0.478	45	<0.01
Total DDT [c]	0.403	46	<0.01	0.287	45	>0.05
Total LAB	0.786	46	<0.01	0.740	45	<0.01
Al	0.695	46	<0.01	0.623	45	<0.01
Cd	0.829	46	<0.01	0.655	45	<0.01
Cr	0.952	46	<0.01	0.844	45	<0.01
Cu [d]	0.288	46	>0.05	0.475	45	<0.05
Fe	0.773	46	<0.01	0.712	45	<0.01
Pb [e]	0.082	44	>0.05	0.300	43	>0.05
Hg	0.755	46	<0.01	0.683	45	<0.01
Ni	0.821	46	<0.01	0.802	45	<0.01
Ag	0.819	46	<0.01	0.715	45	<0.01
Zn	0.941	46	<0.01	0.872	45	<0.01

[a] TOC at NF14 in 2002 was unusually high and excluded from the post-discharge correlation analyses.

[b] Total PCB at NF07 in 2002 was unusually high; if excluded from the correlation analysis then r = 0.902 (against Fines) and 0.620 (against TOC).

[c] Total DDT at NF21 in 2001 was unusually high; if excluded from the correlation analysis then r = 0.885 (against Fines) and 0.606 (against TOC).

[d] Copper at NF14 in 2001 was unusually high; if excluded from the correlation analysis then r = 0.786 (against Fines) and 0.809 (against TOC).

[e] Lead at NF15 in 2002 was unusually high; if excluded from the correlation analysis then r = 0.343 (against Fines) and 0.709 (against TOC).

Table C4-2a. Correspondence within bulk sediment properties and against contaminants for regional stations during the two-year period before and after the new outfall came on-line.

Parameter	Correspondence against Percent Fines			Correspondence against TOC		
	r	***n***	***p***	***r***	***n***	***p***
Pre-Discharge (1999 – 2000)						
Percent Fines	1.000	28	<0.01	0.929	28	<0.01
TOC	0.929	28	<0.01	1.000	28	<0.01
Clostridium perfringens	0.282	28	>0.05	0.261	28	>0.05
Total PAH	0.331	20	>0.05	0.343	20	>0.05
Total PCB	0.545	20	<0.05	0.510	20	<0.05
Total DDT	0.832	20	<0.01	0.793	20	<0.01
Total LAB	0.300	20	>0.05	0.352	20	>0.05
Al	0.798	20	<0.01	0.821	20	<0.01
Cd	0.369	19	>0.05	0.498	19	<0.05
Cr	0.817	20	<0.01	0.866	20	<0.01
Cu	0.683	20	<0.01	0.714	20	<0.01
Fe	0.879	20	<0.01	0.939	20	<0.01
Pb	0.662	20	<0.01	0.655	20	<0.01
Hg	0.541	20	<0.05	0.550	20	<0.05
Ni	0.856	20	<0.01	0.923	20	<0.01
Ag	0.362	20	>0.05	0.392	20	>0.05
Zn	0.788	20	<0.01	0.826	20	<0.01
Post-Discharge (2001 – 2002)						
Percent Fines	1.000	28	<0.01	0.961	28	<0.01
TOC	0.961	28	<0.01	1.000	28	<0.01
Clostridium perfringens	0.206	28	>0.05	0.201	28	>0.05
Total PAH	0.346	28	>0.05	0.313	28	>0.05
Total PCB	0.367	28	<0.05	0.342	28	>0.05
Total DDT	0.618	28	<0.01	0.603	28	<0.01
Total LAB	0.111	28	>0.05	0.130	28	>0.05
Al	0.755	28	<0.01	0.723	28	<0.01
Cd	0.534	28	<0.01	0.526	28	<0.01
Cr	0.795	28	<0.01	0.775	28	<0.01
Cu	0.559	28	<0.01	0.560	28	<0.01
Fe	0.894	28	<0.01	0.933	28	<0.01
Pb	0.562	28	<0.01	0.586	28	<0.01
Hg	0.313	28	>0.05	0.285	28	>0.05
Ni	0.926	28	<0.01	0.924	28	<0.01
Ag	0.379	28	<0.05	0.375	28	<0.05
Zn	0.914	28	<0.01	0.929	28	<0.01

Table C4-2b. Correspondence within bulk sediment properties and against contaminants for regional stations, excluding FF10, FF12, FF13, NF12, NF17 and NF24, during the two-year period before and after the new outfall came on-line.

Parameter	**Correspondence against Percent Fines**			**Correspondence against TOC**		
	r	***n***	***p***	***r***	***n***	***p***
Pre-Discharge (1999 – 2000)						
Percent Fines	1.000	16	<0.01	0.907	16	<0.01
TOC	0.907	16	<0.01	1.000	16	<0.01
Clostridium perfringens	0.825	16	<0.01	0.795	16	<0.01
Total PAH	0.544	8	>0.05	0.605	8	>0.05
Total PCB	0.349	8	>0.05	0.229	8	>0.05
Total DDT	0.860	8	<0.01	0.922	8	<0.01
Total LAB	0.879	8	<0.01	0.834	8	<0.01
Al	0.692	8	>0.05	0.765	8	<0.05
Cd	0.573	8	>0.05	0.786	8	<0.05
Cr	0.920	8	<0.01	0.931	8	<0.01
Cu	0.964	8	<0.01	0.973	8	<0.01
Fe	0.937	8	<0.01	0.968	8	<0.01
Pb	0.885	8	<0.01	0.899	8	<0.01
Hg	0.910	8	<0.01	0.873	8	<0.01
Ni	0.917	8	<0.01	0.964	8	<0.01
Ag	0.656	8	>0.05	0.687	8	>0.05
Zn	0.952	8	<0.01	0.956	8	<0.01
Post-Discharge (2001 – 2002)						
Percent Fines	1.000	16	<0.01	0.952	16	<0.01
TOC	0.952	16	<0.01	1.000	16	<0.01
Clostridium perfringens	0.649	16	<0.01	0.661	16	<0.01
Total PAH	0.739	16	<0.01	0.716	16	<0.01
Total PCB	0.706	16	<0.01	0.608	16	<0.05
Total DDT	0.654	16	<0.01	0.658	16	<0.01
Total LAB	0.594	16	<0.05	0.636	16	<0.01
Al	0.697	16	<0.01	0.721	16	<0.01
Cd	0.714	16	<0.01	0.826	16	<0.01
Cr	0.948	16	<0.01	0.933	16	<0.01
Cu	0.919	16	<0.01	0.941	16	<0.01
Fe	0.941	16	<0.01	0.977	16	<0.01
Pb	0.895	16	<0.01	0.900	16	<0.01
Hg	0.899	16	<0.01	0.873	16	<0.01
Ni	0.947	16	<0.01	0.942	16	<0.01
Ag	0.689	16	<0.01	0.731	16	<0.01
Zn	0.954	16	<0.01	0.980	16	<0.01

Table C4-3. Correspondence within bulk sediment properties and against contaminants at Nearfield Contaminant Special Study stations during the two year period before and after the new outfall came on-line.

Parameter	Correspondence against Percent Fines			Correspondence against TOC		
	r	*n*	*p*	*r*	*n*	*p*
	Pre-Discharge (October 1998-August 2000)					
Percent Fines	1.000	35	<0.01	0.681	35	<0.01
TOC	0.681	35	<0.01	1.000	35	<0.01
Clostridium perfringens	0.494	36	<0.01	0.511	35	<0.01
Total PAH [a]	0.070	36	>0.05	0.090	35	>0.05
Total PCB	0.658	36	<0.01	0.826	35	<0.01
Total DDT	0.415	36	<0.05	0.283	35	>0.05
Total LAB	0.445	36	<0.05	0.584	35	<0.05
Al	0.519	36	<0.01	0.469	35	<0.01
Cd	0.520	36	<0.01	0.679	35	<0.01
Cr	0.699	36	<0.01	0.848	35	<0.01
Cu	0.671	36	<0.01	0.792	35	<0.01
Fe	0.496	36	<0.01	0.714	35	<0.01
Pb	0.715	36	<0.01	0.773	35	<0.01
Hg	0.445	36	<0.05	0.468	35	<0.05
Ni	0.223	36	>0.05	0.555	35	<0.05
Ag	0.703	36	<0.01	0.673	35	<0.01
Zn [b]	0.266	36	>0.05	0.459	35	<0.05
	Post-Discharge (October 2001–October 2002)					
Percent Fines	1.000	84	<0.01	0.872	84	<0.01
TOC	0.872	84	<0.01	1.000	84	<0.01
Clostridium perfringens	0.773	84	<0.01	0.771	84	<0.01
Total PAH [c]	0.169	84	>0.05	0.183	84	>0.05
Total PCB	0.652	84	<0.01	0.648	84	<0.01
Total DDT	0.540	84	<0.01	0.498	84	<0.01
Total LAB	0.738	84	<0.01	0.737	84	<0.01
Al	0.407	84	<0.01	0.468	84	<0.01
Cd	0.643	84	<0.01	0.559	84	<0.01
Cr	0.722	84	<0.01	0.744	84	<0.01
Cu [d]	0.596	84	<0.01	0.602	84	<0.01
Fe	0.508	84	<0.01	0.593	84	<0.01
Pb	0.589	84	<0.01	0.629	84	<0.01
Hg	0.584	82	<0.01	0.542	84	<0.01
Ni	0.610	84	<0.01	0.629	82	<0.01
Ag	0.712	84	<0.01	0.693	84	<0.01
Zn	0.727	84	<0.01	0.762	84	<0.01

[a] Unusually high total PAH value for one of the three replicates at NF24 in October 1998; if excluded from correlation analysis then r = 0.449 (against Fines) and 0.840 (against TOC)

[b] Unusually high Zn value for one of the three replicates at NF24 in August 2000; if excluded from correlation analysis then r = 0.632 (against Fines) and 0.859 (against TOC)

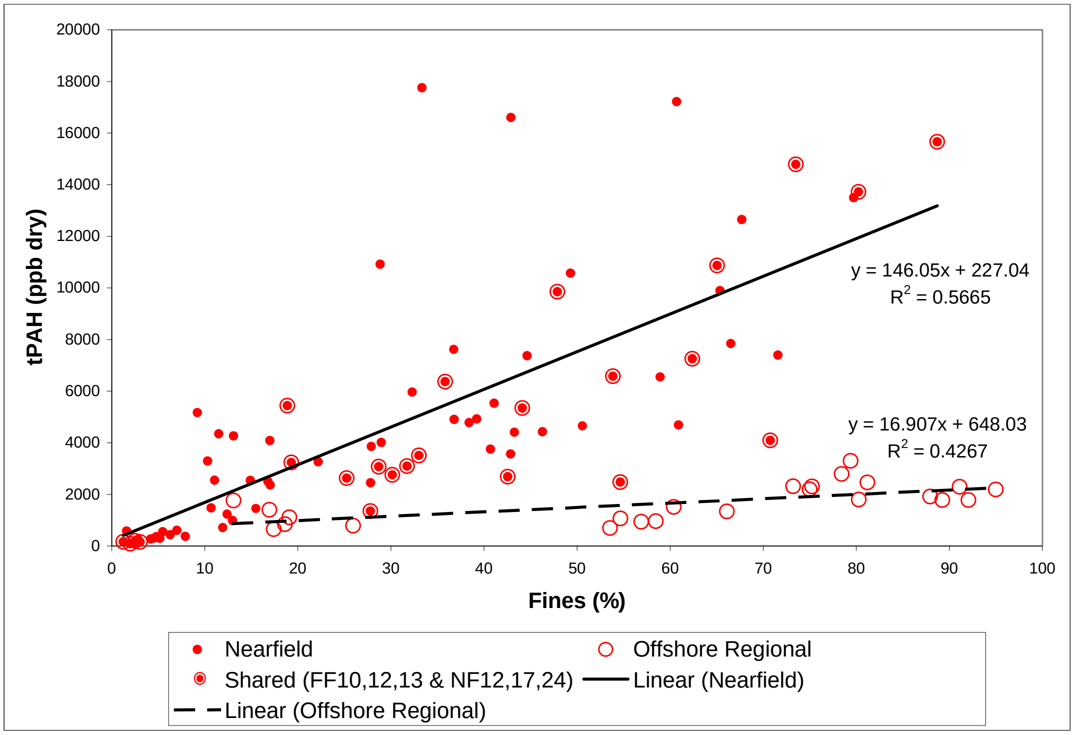
[c] Unusually high total PAH value for one of the three replicates at FF10 in August 2002; if excluded from correlation analysis then r = 0.628 (against Fines) and 0.635 (against TOC)

[d] Unusually high Cu value for one of the three replicates at NF24 in February 2001; if excluded from correlation analysis then r = 0.735 (against Fines) and 0.757 (against TOC)

Supplemental Correlation Plots – Nearfield and Regional Data, 1999 – 2002.

Representative contaminant, Cu, shown in body of report (Figure 4-13). Additional plots provided here also demonstrate that variability among data at regional offshore locations is reduced when near harbor regional stations (FF10, FF12, FF13, NF12, NF17, and NF24) are excluded from the regional correlation analysis. Plots also show that nearfield and near harbor regional stations, with similar grain size as regional offshore stations, have higher contaminant concentrations compared to regional offshore locations.

Data *excluded* from the correlation analyses include NF14 TOC (2002), NF07 total PCB (2002), NF21 total DDT (2001), NF14 Cu (2001), and NF15 Pb (2002) – all data excluded because values unusually high.



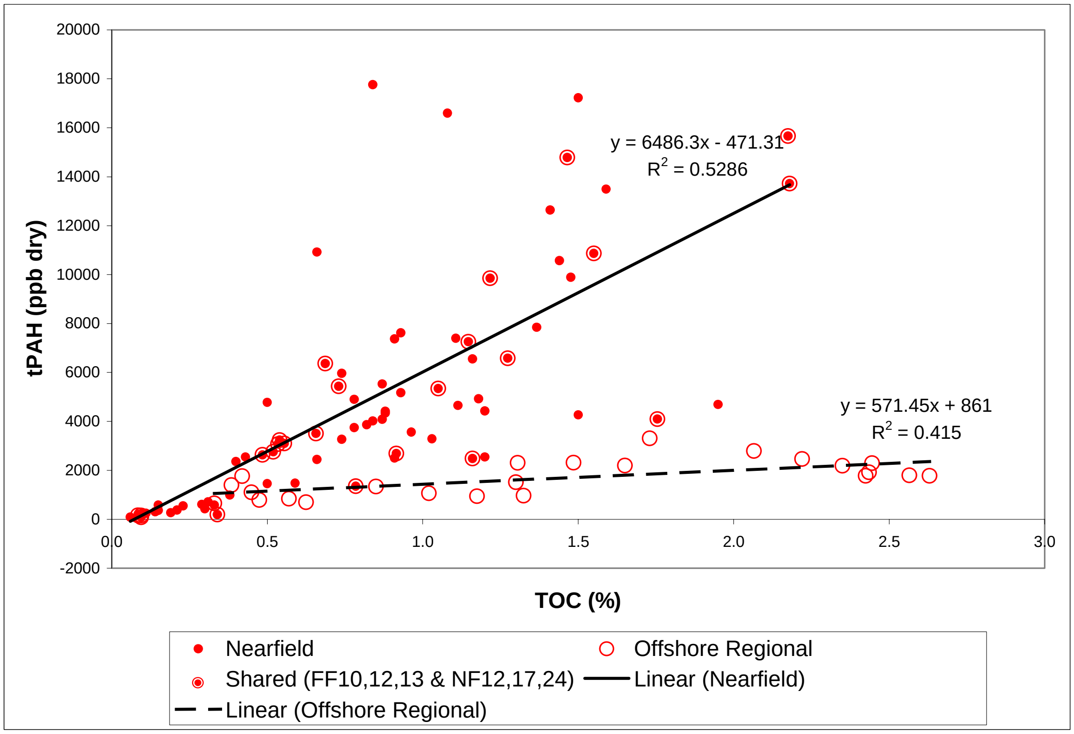
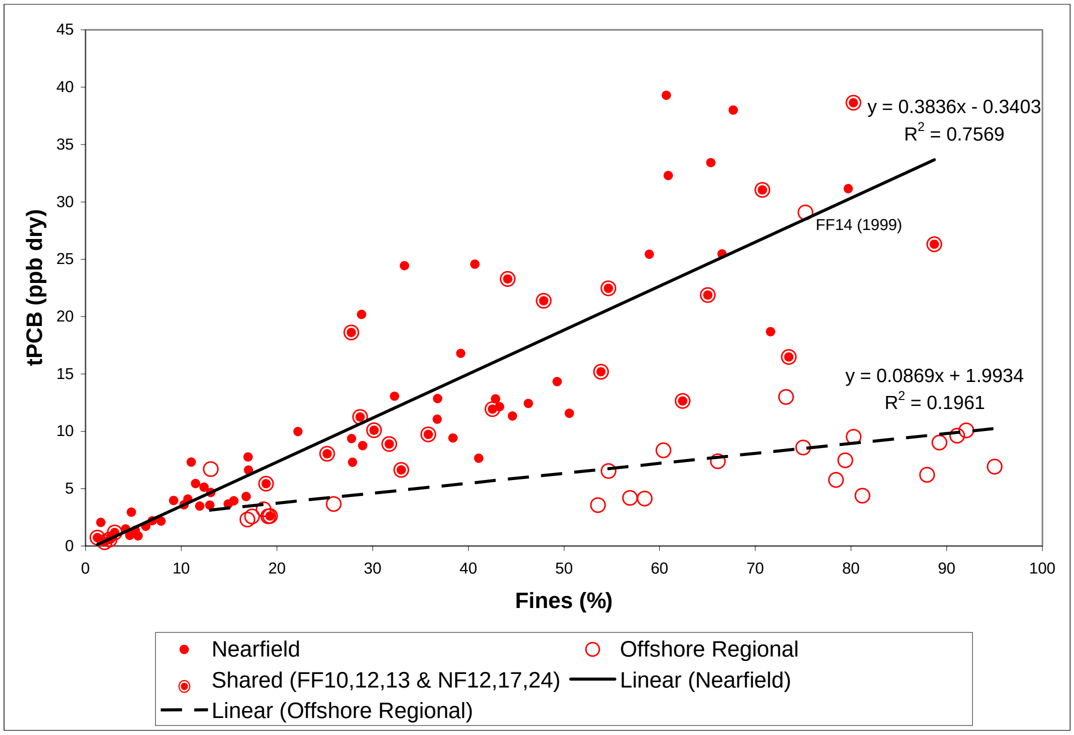


Figure C4-1. Correspondence between total PAH and grain size (top) and TOC (bottom) at nearshore and offshore locations during the two-year period before and after (1999-2002) the new outfall came on-line.



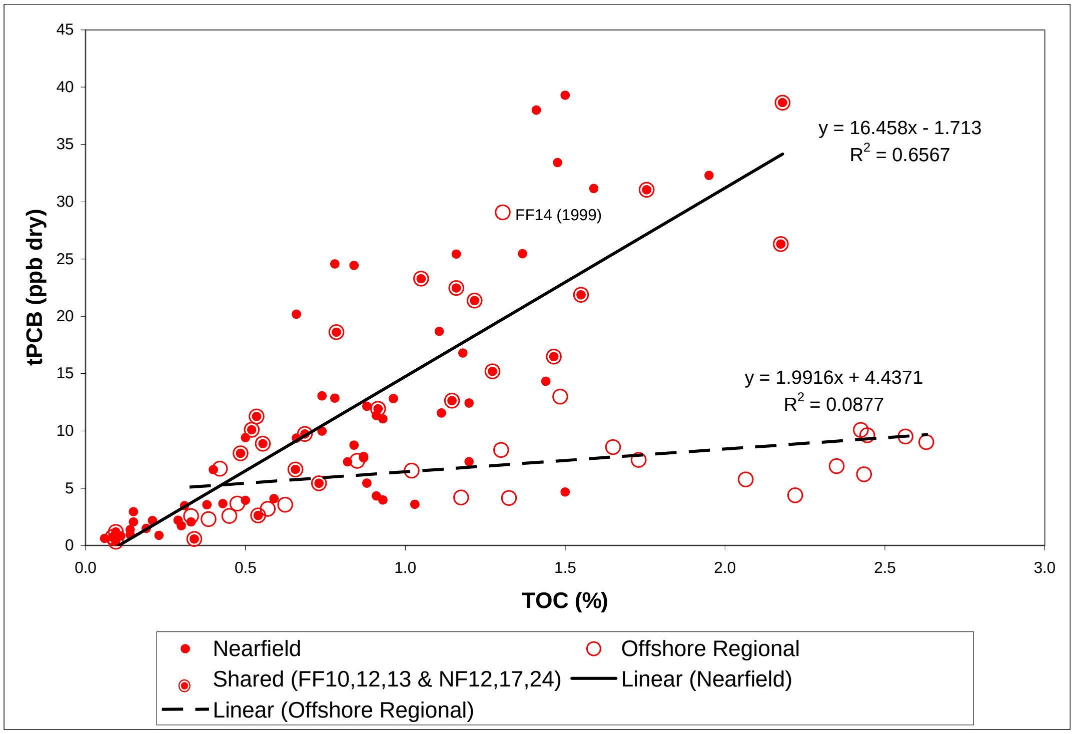
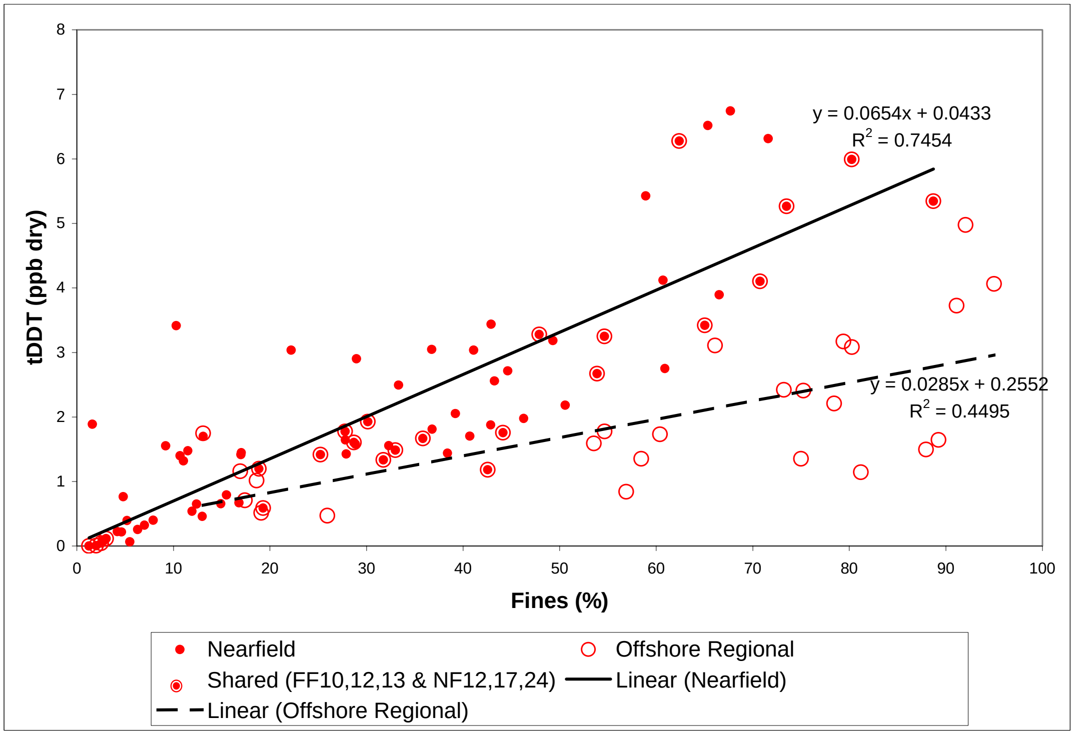


Figure C4-2. Correspondence between total PCB and grain size (top) and TOC (bottom) at nearshore and offshore locations during the two-year period before and after (1999-2002) the new outfall came on-line.



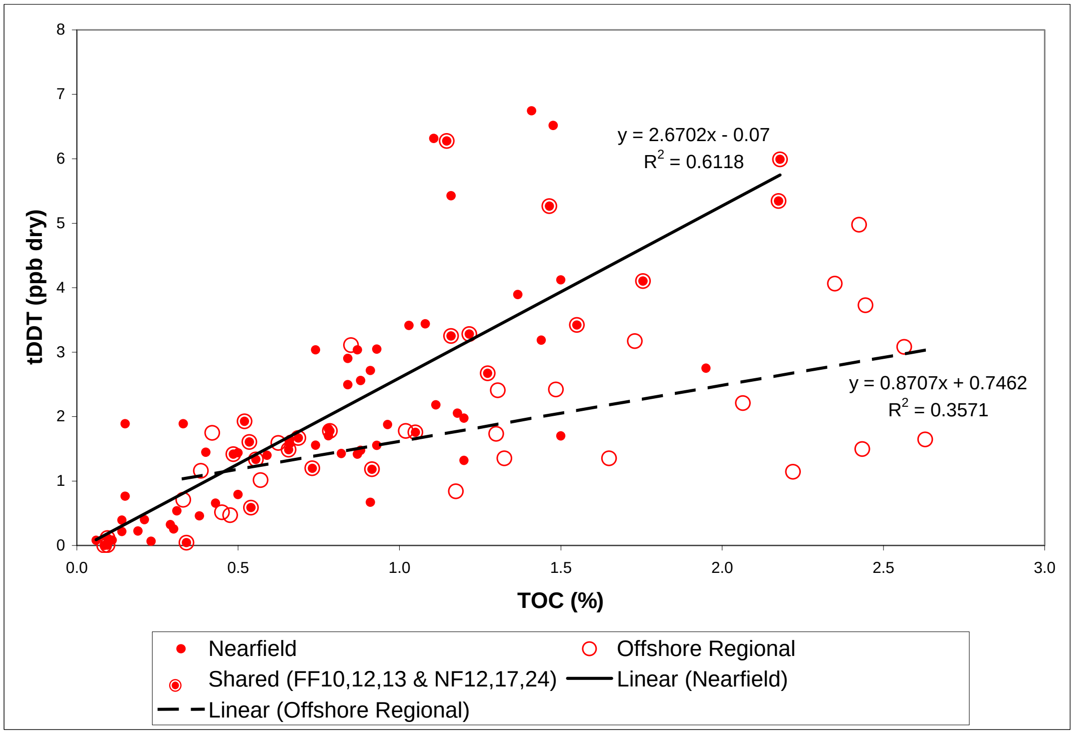
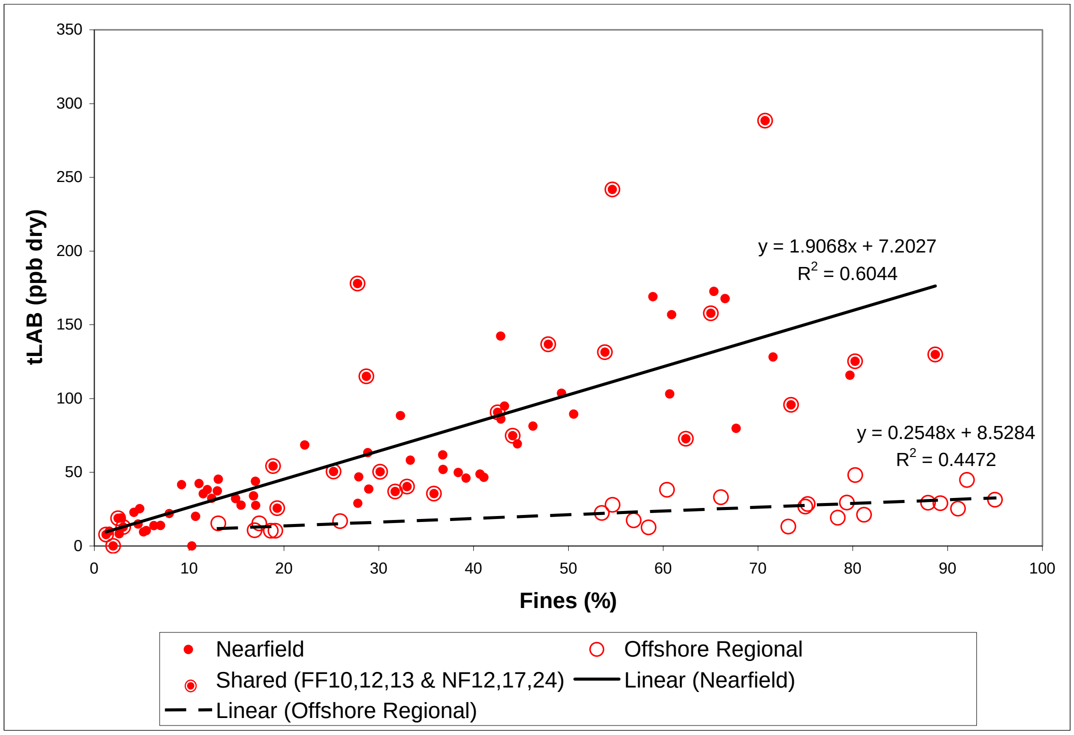


Figure C4-3. Correspondence between total DDT and grain size (top) and TOC (bottom) at nearshore and offshore locations during the two-year period before and after (1999-2002) the new outfall came on-line.



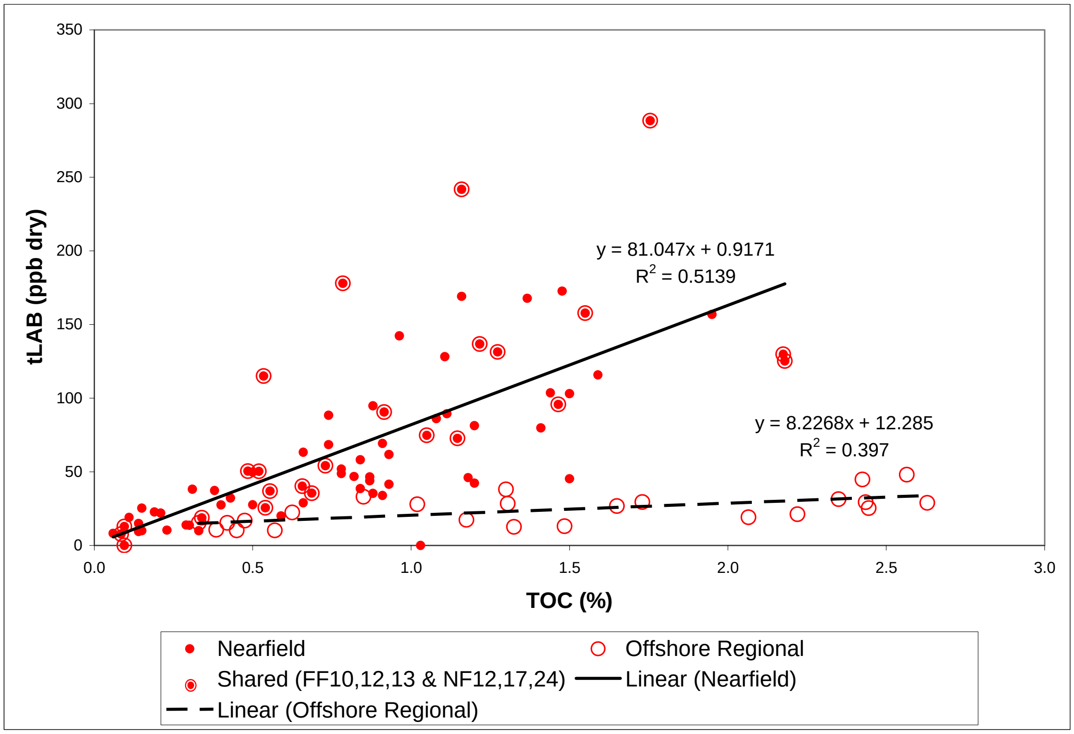
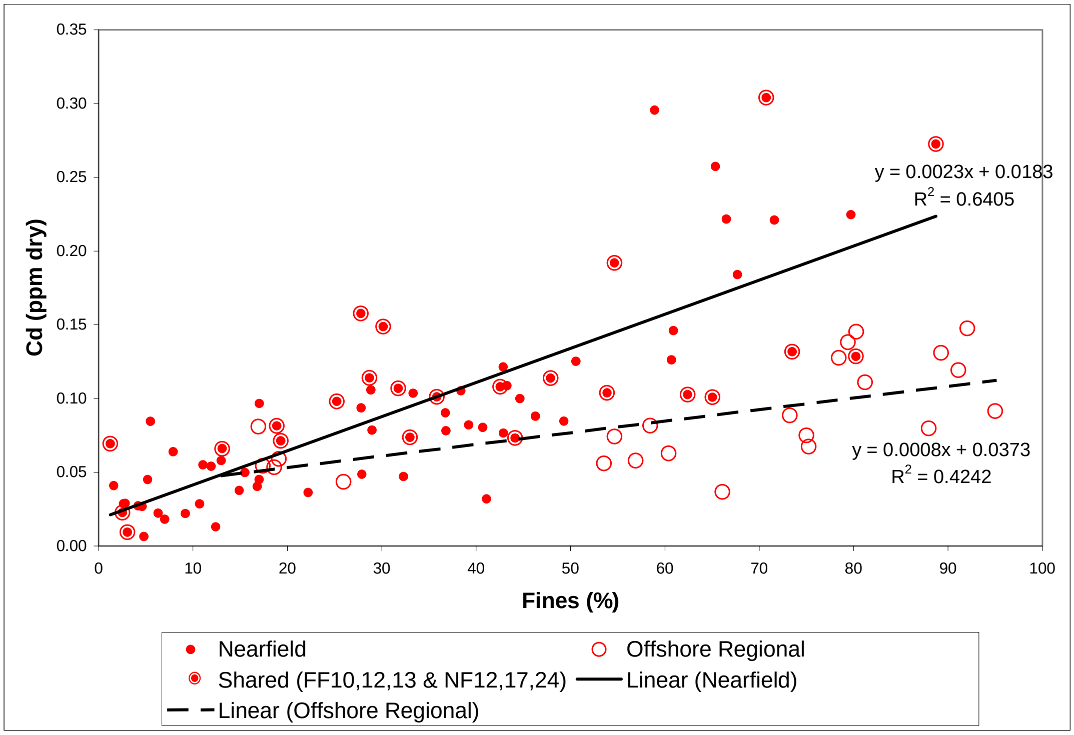


Figure C4-4. Correspondence between total LAB and grain size (top) and TOC (bottom) at nearshore and offshore locations during the two-year period before and after (1999-2002) the new o utfall came on-line.



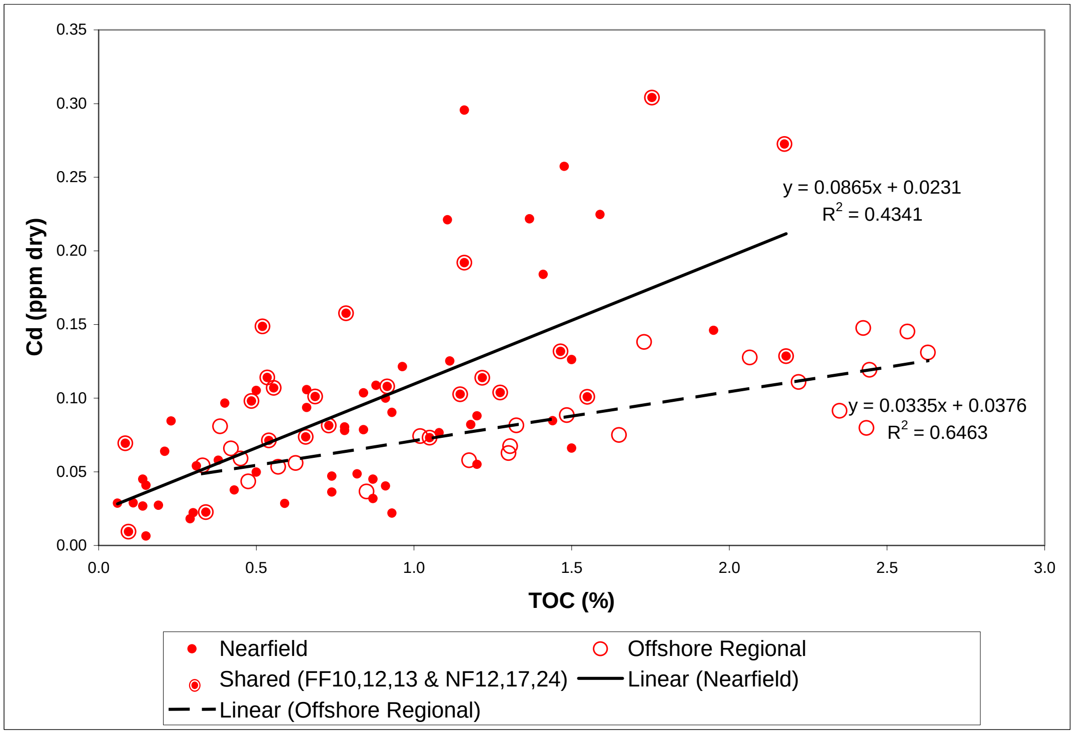


Figure C4-5. Correspondence between Cadmium (Cd) and grain size (top) and TOC (bottom) at nearshore and offshore locations during the two-year period before and after (1999-2002) the new outfall came on-line.

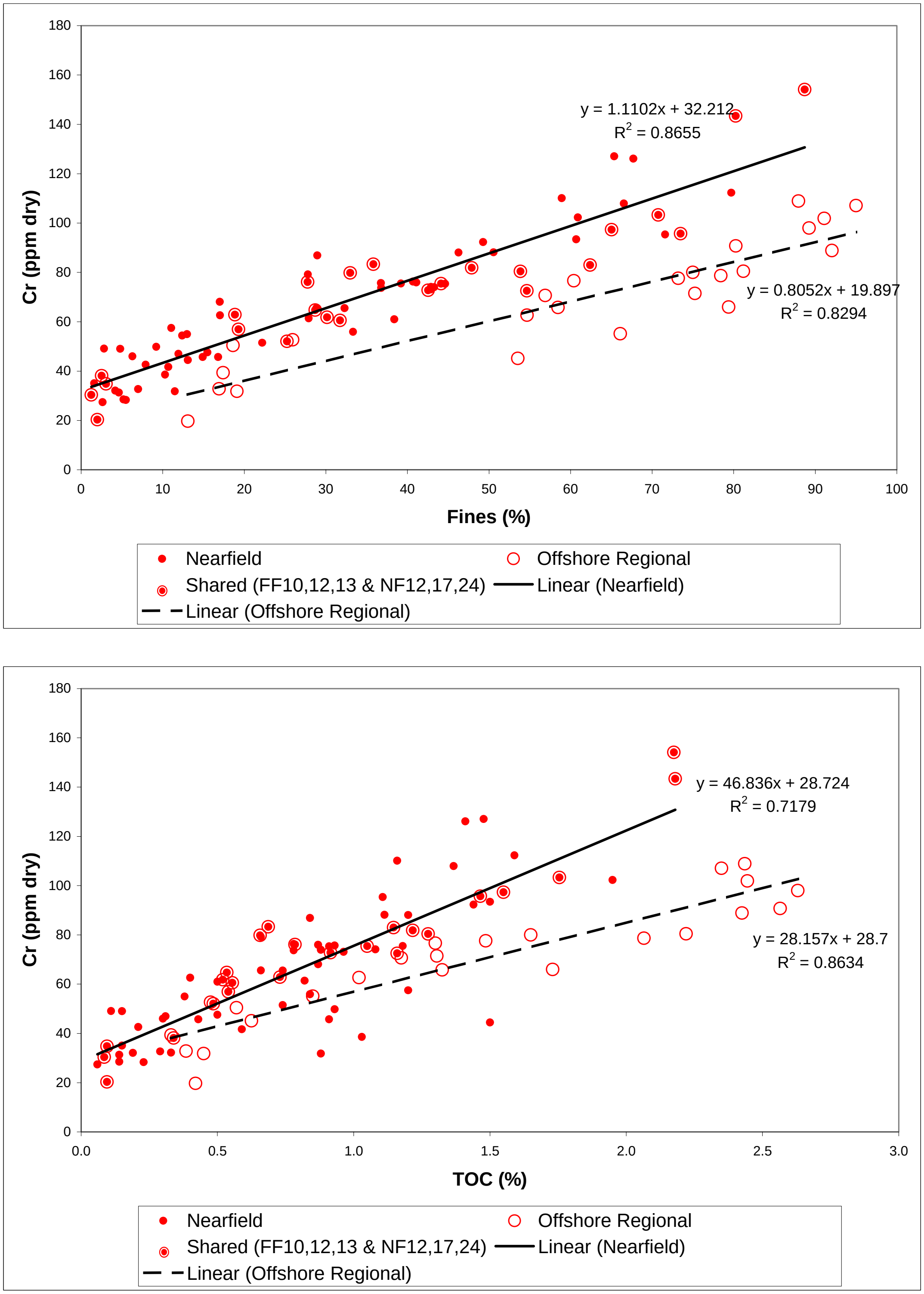
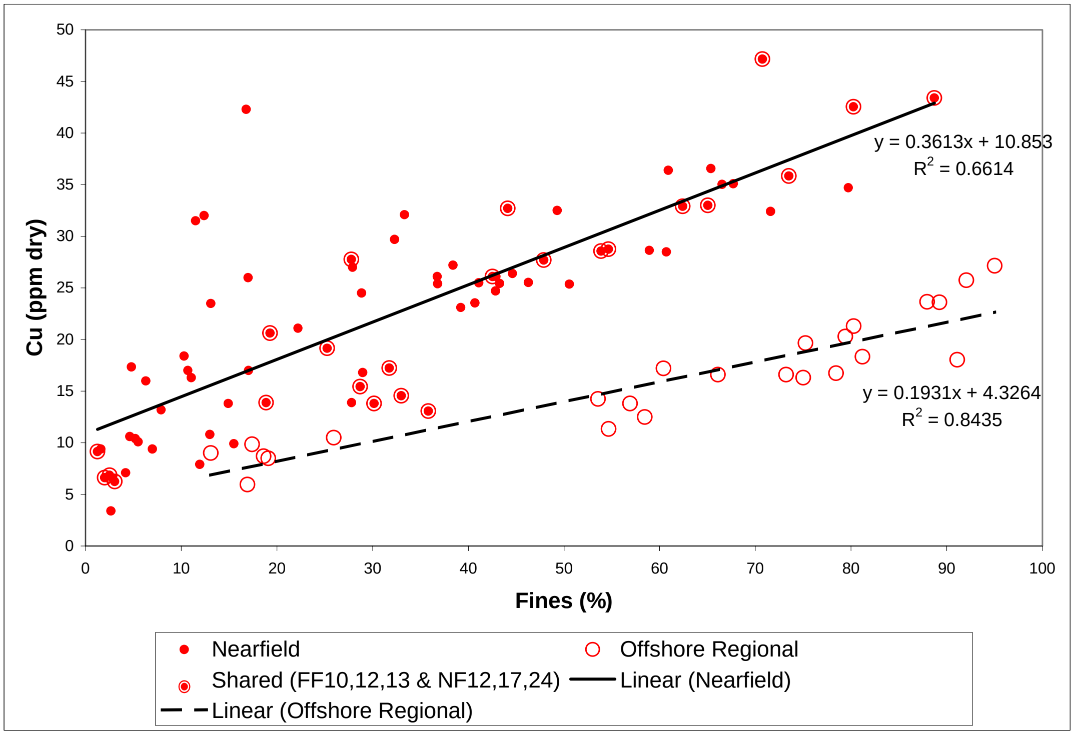


Figure C4-6. Correspondence between Chromium (Cr) and grain size (top) and TOC (bottom) at nearshore and offshore locations during the two-year period before and after (1999-2002) the new outfall came on-line.



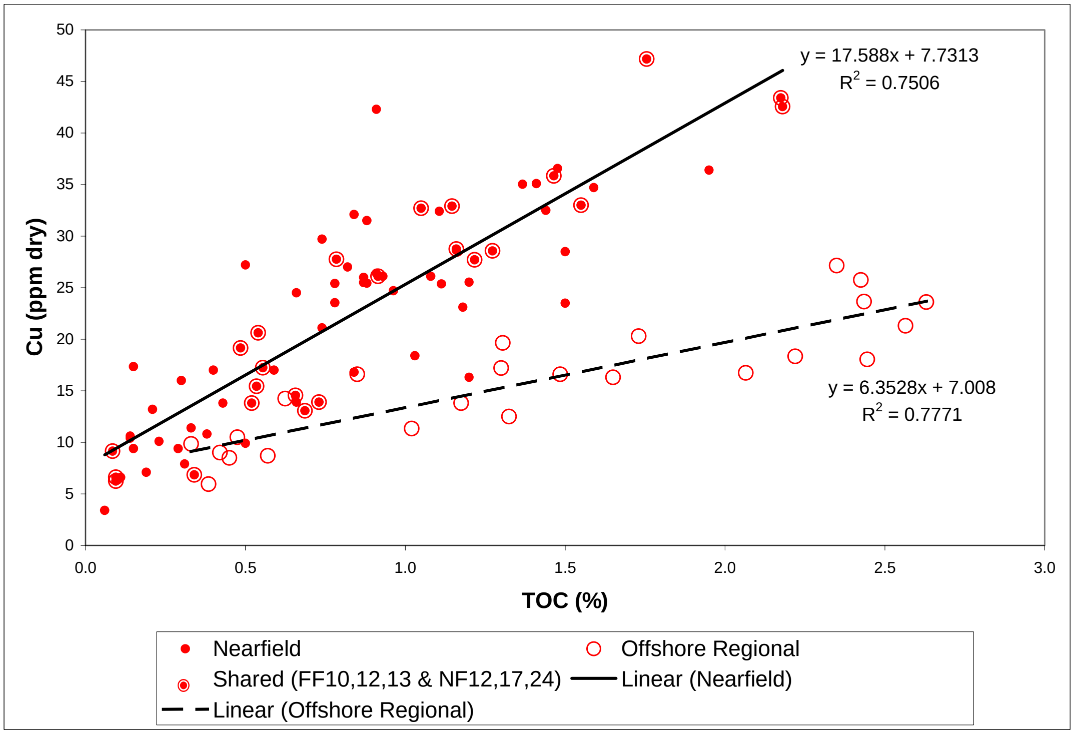
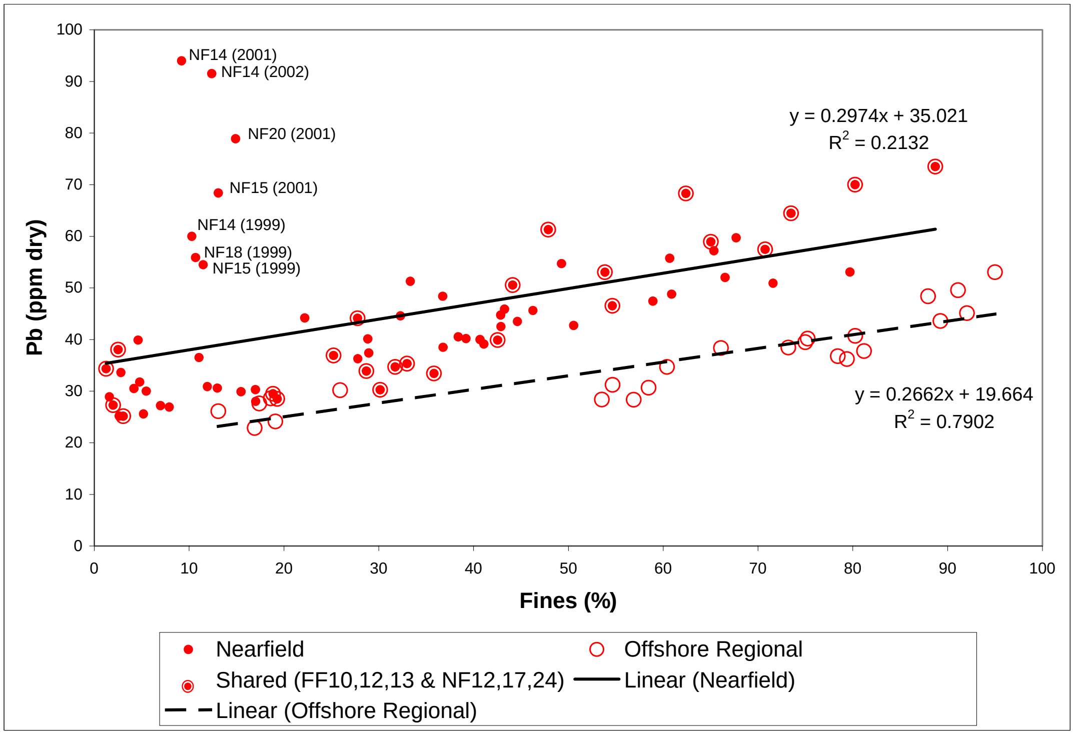


Figure C4-7. Correspondence between Copper (Cu) and grain size (top) and TOC (bottom) at nearshore and offshore locations during the two-year period before and after (1999-2002) the new outfall came on-line.



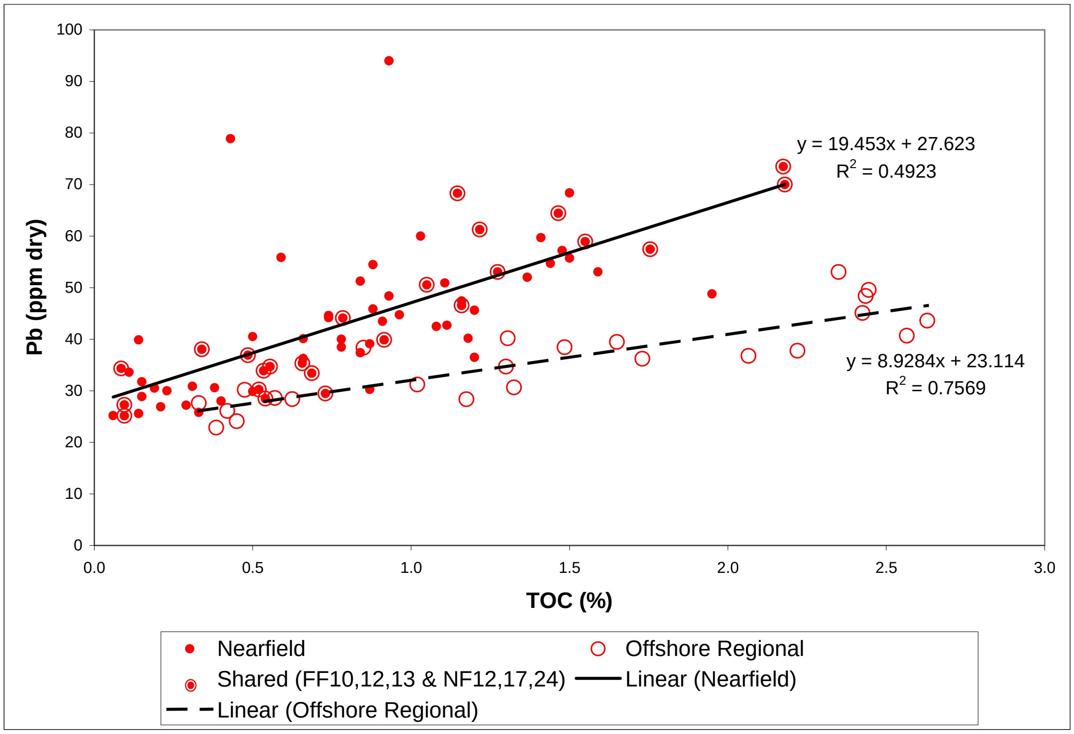
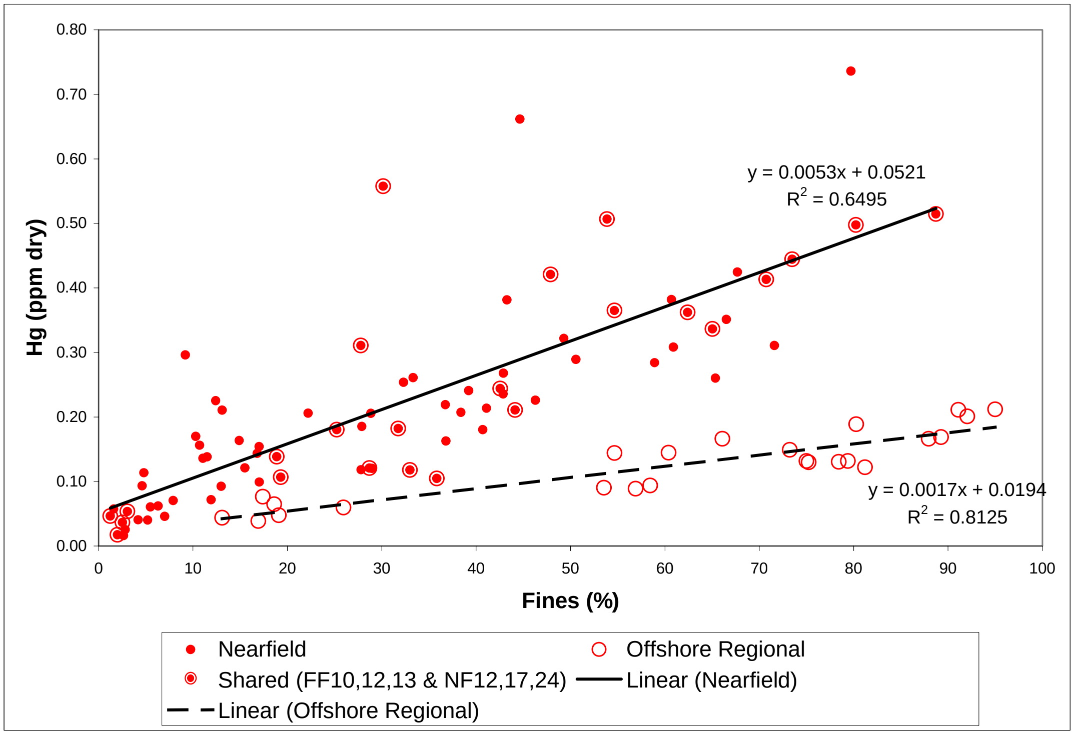


Figure C4-8. Correspondence between Lead (Pb) and grain size (top) and TOC (bottom) at nearshore and offshore locations during the two-year period before and after (1999-2002) the new outfall came on-line.



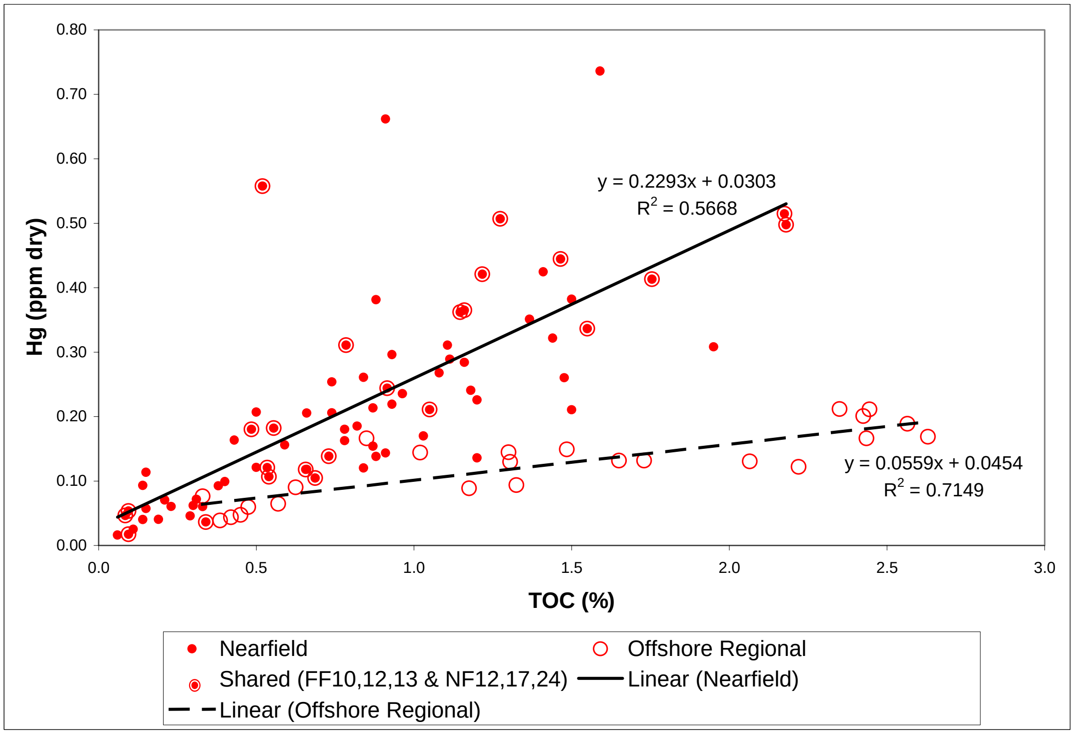
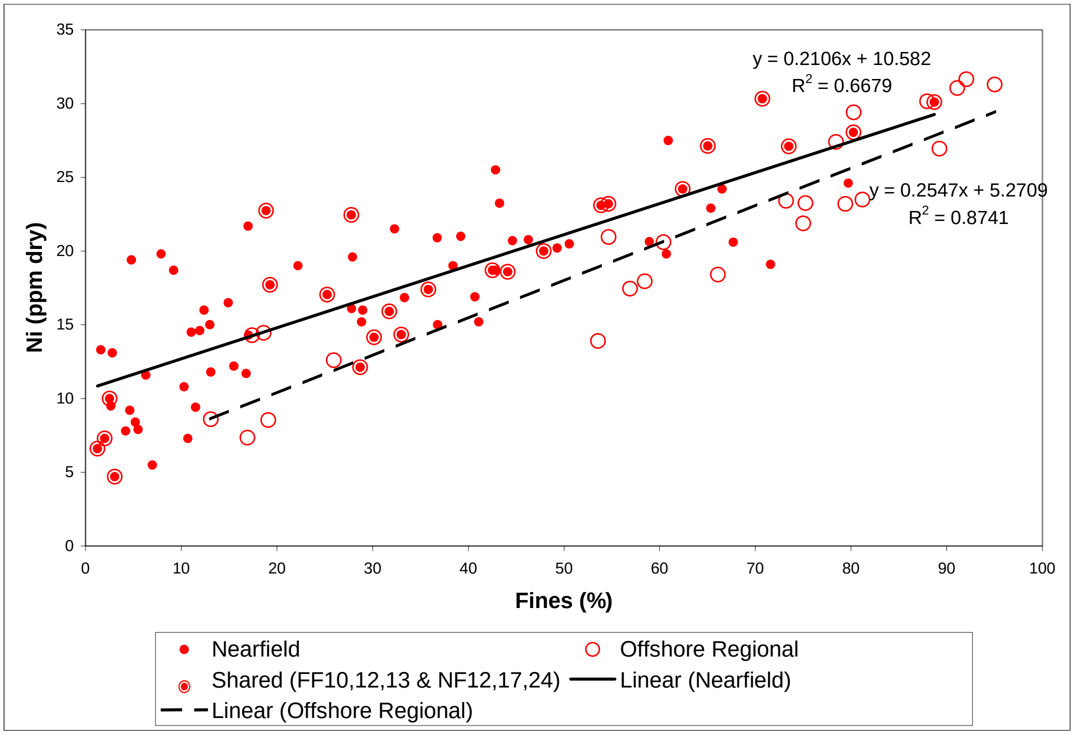


Figure C4-9. Correspondence between Mercury (Hg) and grain size (top) and TOC (bottom) at nearshore and offshore locations during the two-year period before and after (1999-2002) the new outfall came on-line.



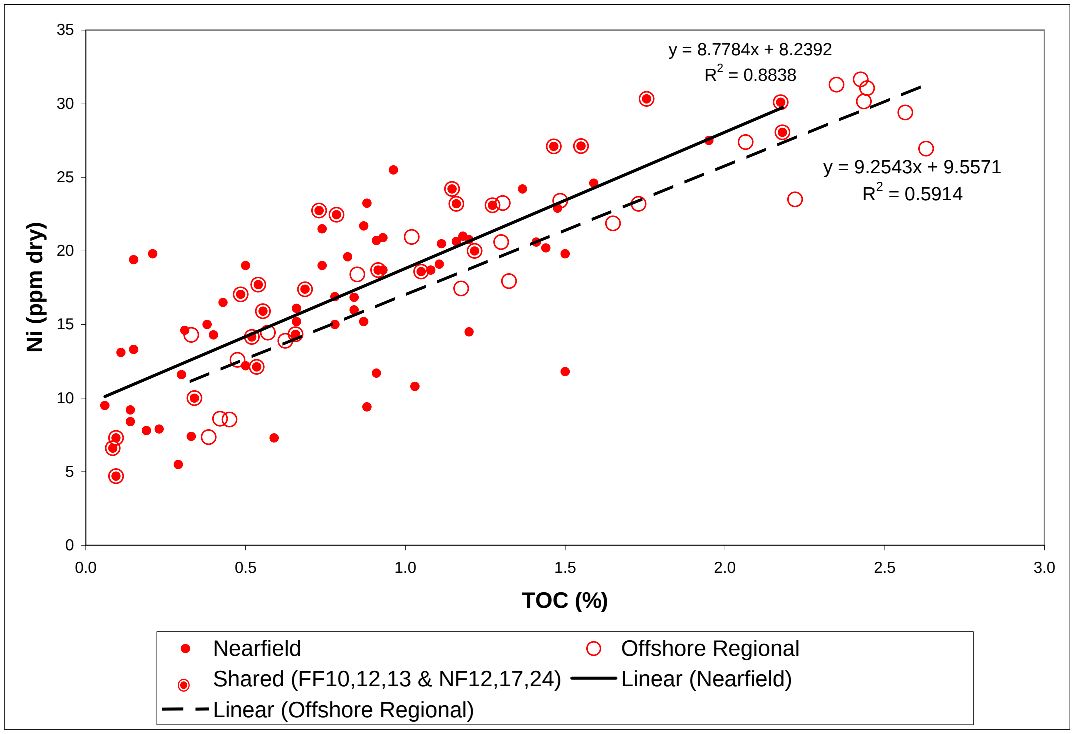
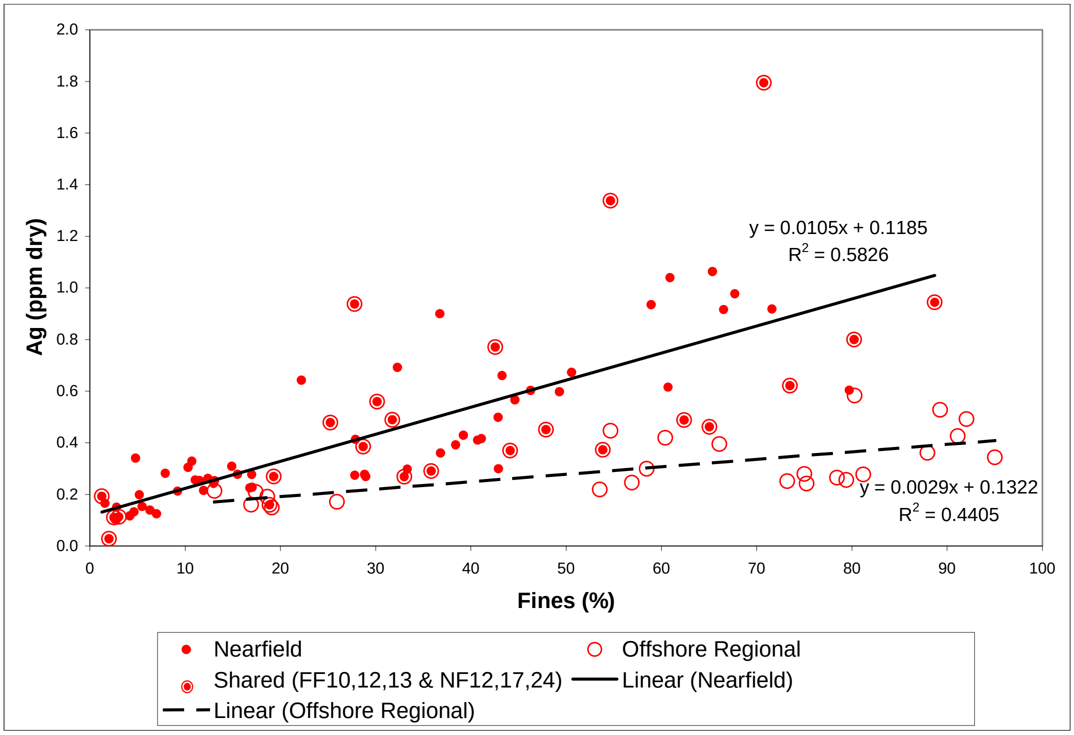


Figure C4-10. Correspondence between Nickel (Ni) and grain size (top) and TOC (bottom) at nearshore and offshore locations during the two-year period before and after (1999-2002) the new outfall came on-line.



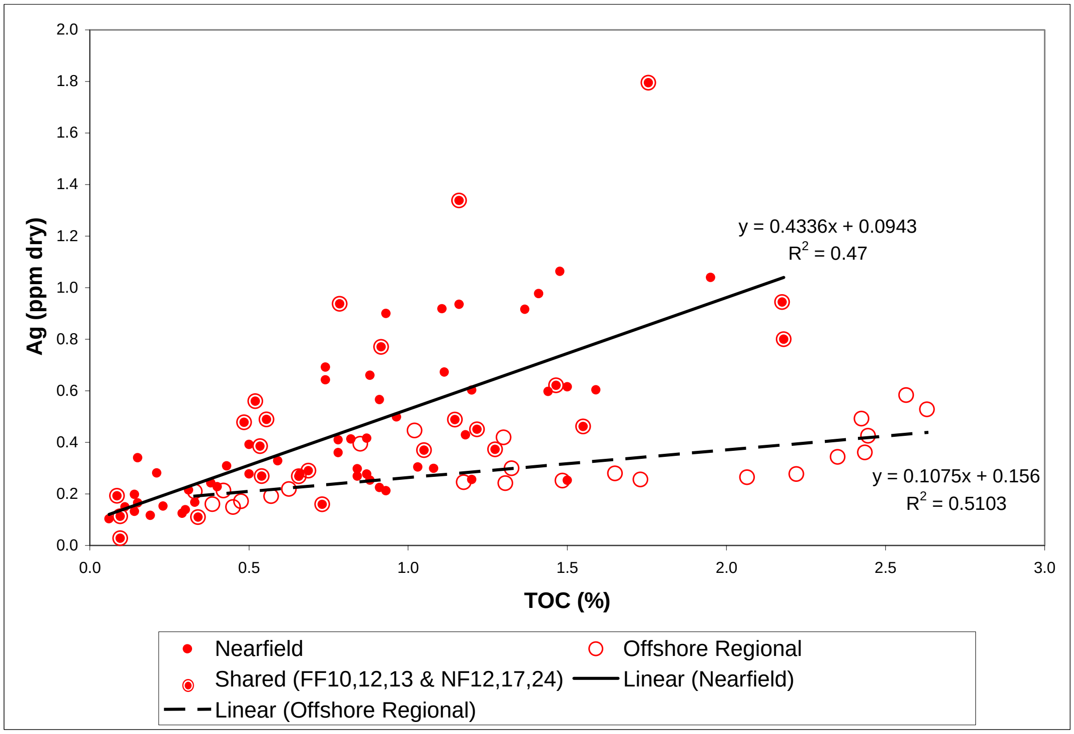
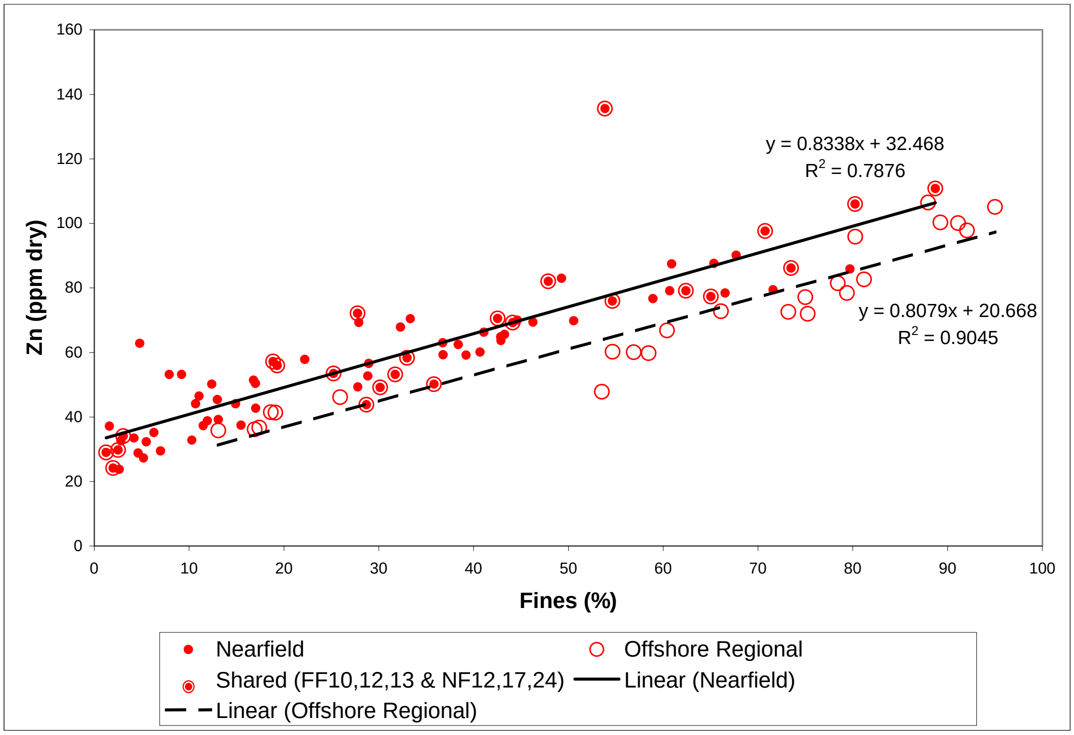


Figure C4-11. Correspondence between Silver (Ag) and grain size (top) and TOC (bottom) at nearshore and offshore locations during the two-year period before and after (1999-2002) the new outfall came on-line.



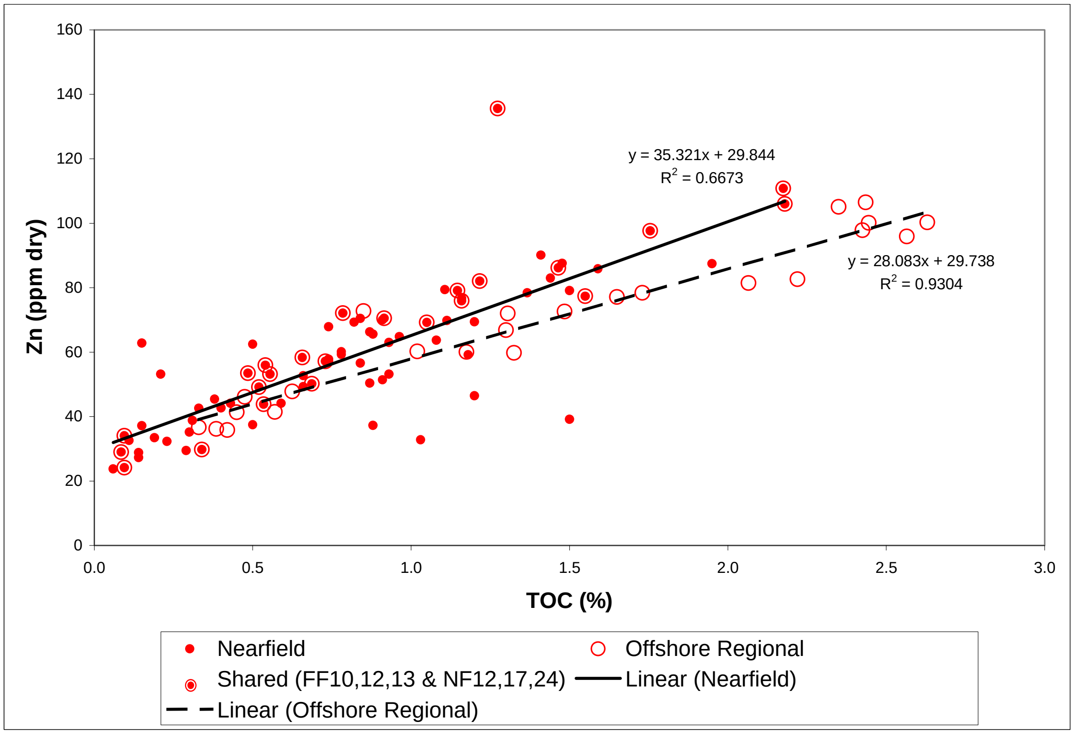


Figure C4-12. Correspondence between Zinc (Zn) and grain size (top) and TOC (bottom) at nearshore and offshore locations during the two-year period before and after (1999-2002) the new outfall came on-line.

APPENDIX C5a

Contaminant Special Study
Bulk Sediment Parameters, 1998–2002

Station	Sampling Event	Units	Gravel pct	Sand pct	Silt pct	Clay pct	Fines[a] pct	TOC pct dry	*Clostridium* cfu/g dry
		ER-M[b]	NR	NR	NR	NR	NR	NR	NR
NF08	Oct-98	Mean	1.7	48.5	38.6	11.1	49.8	1.31	4590
		Stdev	2.94	13.8	13.8	2.85	16.7	0.275	361
	Aug-99	Mean	2.03	26.3	59.6	12	71.6	1.11	3660
		Stdev	3.44	6.53	3.65	2.85	5.19	0.285	1150
	Aug-00	Mean	0.0778	33.4	53.3	13.2	66.5	1.37	2460
		Stdev	0.107	4.05	3.48	2.4	4.15	0.254	267
	Oct-00	Mean	3.13	30.4	51.9	14.5	66.4	1.39	5620
		Stdev	5	4.82	1.99	0.84	2.8	0.124	1290
	Feb-01	Mean	0.031	32.6	50.6	16.7	67.3	1.31	5830
		Stdev	0.0277	5.86	4.34	2.02	5.83	0.142	1290
	Aug-01	Mean	0.166	40.9	45.9	13.1	58.9	1.16	4730
		Stdev	0.144	10.3	6.19	4.5	10.4	0.334	1490
	Oct-01	Mean	0.142	38.9	49.8	11.2	61	1.19	2880
		Stdev	0.235	1.04	1.78	0.84	1.16	0.0624	246
	Feb-02	Mean	0.0222	32.4	53.7	13.9	67.6	1.23	4910
		Stdev	0.0385	5.67	2.95	2.68	5.64	0.372	833
	Aug-02	Mean	0.2	34.4	50.5	14.9	65.4	1.48	6690
		Stdev	0.2	5.53	4.45	3.19	5.44	0.363	2850
	Oct-02	Mean	0	28.5	55.5	16	71.5	1.62	7320
		Stdev	0	4.53	2.71	2.11	4.58	0.245	1600
NF22	Oct-98	Mean	2.5	51.8	34.6	11.1	45.8	0.693	3230
		Stdev	4.07	1.28	5.18	0.78	5.27	0.19	534
	Aug-99	Mean	3.97	52.8	32.2	11.1	43.3	0.88	2660
		Stdev	3.6	3.66	3.76	1.93	5.47	0.171	315
	Aug-00	Mean	2.63	54.5	30.1	12.8	42.9	0.963	1620
		Stdev	1.46	3.35	2.33	0.7	3.02	0.131	269
	Oct-00	Mean	0.833	49.2	37.7	12.2	50	0.957	3730
		Stdev	0.503	2.25	1.4	0.68	1.94	0.0416	87.4
	Feb-01	Mean	0.621	50.4	34.2	14.8	49	0.923	3720
		Stdev	0.44	3.68	2.33	1.33	3.4	0.0569	350
	Aug-01	Mean	0.633	48.8	39.2	11.4	50.6	1.11	3120
		Stdev	0.208	4.7	4.11	0.95	4.83	0.19	106
	Oct-01	Mean	0.114	43.3	44.2	12.4	56.6	1.21	3720
		Stdev	0.102	13	9.77	3.19	12.9	0.465	1020
	Feb-02	Mean	10.6	49.7	29.3	10.4	39.7	0.84	3230
		Stdev	10.1	6.83	6.71	1.36	8.06	0.0889	357
	Aug-02	Mean	1.11	52.54	35.89	10.39	46.28	1.2	3260
		Stdev	0.30	0.89	0.87	0.08	0.93	0.214	967
	Oct-02	Mean	1.27	48.3	38.6	11.9	50.5	1.23	4010
		Stdev	1.76	4.76	5.96	1.32	6.39	0.249	940
NF24	Oct-98	Mean	0.667	38.7	46.1	14.5	60.6	1.07	2610
		Stdev	0.833	34.7	28.9	8.38	35.5	0.51	1760
	Aug-99	Mean	0.167	37.5	47.7	14.7	62.4	1.15	2140
		Stdev	0.289	4.28	5.88	2.72	4.16	0.0577	354
	Aug-00	Mean	0.2	45.9	39.6	14.3	53.9	1.27	1370
		Stdev	0.2	6.97	4.77	2.1	6.86	0.127	25.2
	Oct-00	Mean	0.233	49.4	38	12.4	50.4	1.05	2830
		Stdev	0.252	2.38	1.65	0.87	2.43	0.0306	1020
	Feb-01	Mean	1.17	47.8	35	16.1	51.1	1.23	4510
		Stdev	0.878	8.22	6.91	2.36	8.88	0.211	832
	Aug-01	Mean	0.228	51.9	36.2	11.7	47.9	1.22	5750
		Stdev	0.277	5.49	2.56	3.09	5.29	0.0252	1220

Station	Sampling Event	Units	Gravel	Sand	Silt	Clay	Fines[a]	TOC	*Clostridium*
			pct	pct	pct	pct	pct	pct dry	cfu/g dry
		ER-M[b]	NR	NR	NR	NR	NR	NR	NR
	Oct-01	Mean	0.0879	52.2	40.8	7	47.8	0.723	3360
		Stdev	0.0587	6.16	5.54	0.64	6.17	0.197	901
	Feb-02	Mean	2.17	36.3	46.7	14.8	61.5	1.51	5850
		Stdev	3.58	6.2	5.16	2.93	6.23	0.365	1990
	Aug-02	Mean	0.467	55.5	34.6	9.53	44.1	1.05	4710
		Stdev	0.635	3.2	1.6	2.14	2.73	0.243	1160
	Oct-02	Mean	0.1	47	43.2	9.63	52.9	1.04	4680
		Stdev	0.173	12.4	10	2.66	12.5	0.297	1640
FF10	Oct-98	Mean	1.68	58.6	30.6	9.11	39.7	0.493	1630
		Stdev	1.44	20.8	18.2	4.03	22.2	0.0907	180
	Aug-99	Mean	21.1	59.6	15	4.33	19.3	0.54	1190
		Stdev	17.6	18.7	10.3	1.96	12.3	0.137	72.1
	Aug-00	Mean	22.5	58.7	13.2	5.7	18.9	0.73	1170
		Stdev	23.9	15.9	7.56	4.04	11.6	0.297	450
	Oct-00	Mean	9.17	65.1	19.5	6.32	25.8	0.603	1220
		Stdev	10.6	4.46	4.79	1.42	6.17	0.241	261
	Feb-01	Mean	3.33	70.5	18.8	7.42	26.2	0.597	1120
		Stdev	1.99	3.78	1.46	0.39	1.85	0.115	30.6
	Aug-01	Mean	4.15	60	29.1	6.75	35.8	0.687	1340
		Stdev	0.858	8.71	9.72	0.22	9.5	0.144	162
	Oct-01	Mean	7.29	67.1	20	5.58	25.6	0.593	1370
		Stdev	6.29	3.08	3.19	0.87	4.03	0.0757	354
	Feb-02	Mean	2.13	63.1	27.6	7.23	34.8	0.68	1200
		Stdev	0.723	4.15	3.91	0.57	3.46	0.0917	192
	Aug-02	Mean	3.8	63.2	21.7	11.3	33	0.657	1660
		Stdev	1.93	3.12	1.93	1.21	3	0.0306	348
	Oct-02	Mean	21.3	55.3	17.3	6.04	23.4	0.62	1210
		Stdev	23.9	13.2	8.62	2.12	10.7	0.2	346

[a] Fines = sum of silt and clay.

[b] Based on ER-M sediment quality guidelines from Long et al. (1995).

NR = Not regulated

APPENDIX C5b

Contaminant Special Study
Organic Contaminant Parameters
1998–2002

Station	Sampling Event	Units	Total PAH[a,b]	Total PCB[b]	Total DDT[b]	Total Chlordane[b]	Total Pesticide[b]	Total LAB[b]
			ng/g dry	ng/g dry	ng/g dry	ng/g dry	ng/g dry	ng/g dry
		ER-M[b]	44792	180	46.1	6[d]	NA	NR
NF08	Oct-98	Mean	6760	26.9	11	0.681	0.737	290
		Stdev	2350	7.14	10.7	0.123	0.24	53.3
	Aug-99	Mean	7400	18.7	6.32	0.378	0.0824	128
		Stdev	1480	6.48	7.01	0.0782	0.0736	22.2
	Aug-00	Mean	7850	25.5	3.89	0.497	0.661	168
		Stdev	1460	6.9	1.12	0.201	0.0803	35.1
	Oct-00	Mean	6770	14.5	2.29	0.336	0.443	81.4
		Stdev	6170	16.8	2.39	0.352	0.338	99
	Feb-01	Mean	8480	28.7	3.73	1.03	0.124	170
		Stdev	1830	4.75	0.603	0.15	0.0122	52
	Aug-01	Mean	6550	25.4	5.43	0.78	0.456	169
		Stdev	1540	9.7	1.92	0.225	0.149	59.5
	Oct-01	Mean	8090	24.3	5.94	0.345	0.27	142
		Stdev	1430	4.55	1.67	0.299	0.0397	10.7
	Feb-02	Mean	10500	20.5	5.44	0.558	1.98	126
		Stdev	2350	5.63	2.14	0.0575	2.44	27.4
	Aug-02	Mean	9890	33.4	6.52	0.562	0.504	173
		Stdev	3070	18	3.07	0.401	0.216	100
	Oct-02	Mean	10800	36.2	5.65	0.797	0.839	221
		Stdev	2200	6.94	2.41	0.23	0.22	69
NF22	Oct-98	Mean	3900	11.1	2.51	0.266	0.141	184
		Stdev	705	2.68	0.443	0.0573	0.122	18.9
	Aug-99	Mean	4420	12.1	2.56	0.238	0.176	94.8
		Stdev	578	3	0.389	0.206	0.306	7.61
	Aug-00	Mean	3560	12.8	1.88	0.246	0.429	142
		Stdev	997	2.35	0.396	0.0934	0.124	10.5
	Oct-00	Mean	3860	10.3	1.64	0.212	0.338	80.8
		Stdev	389	0.351	0.61	0.01	0.0424	14.8
	Feb-01	Mean	4070	12.7	1.53	0.551	0.0925	102
		Stdev	167	0.718	0.113	0.0566	0.00408	17.5
	Aug-01	Mean	4660	11.6	2.18	0.337	0.269	89.5
		Stdev	1360	2.49	0.841	0.0779	0.115	15.1
	Oct-01	Mean	6360	15.2	3	0.288	0.224	111
		Stdev	2390	6.84	1.22	0.157	0.103	28
	Feb-02	Mean	3740	8.73	1.86	0.168	0.361	73.3
		Stdev	886	1.44	0.384	0.0732	0.105	17
	Aug-02	Mean	4430	12.4	1.98	0.172	0.0824	81.3
		Stdev	283	0.854	0.081	0.00884	0.0184	5.89
	Oct-02	Mean	4360	12.2	1.61	0.188	0.541	89.2
		Stdev	710	0.561	0.224	0.027	0.0381	24.2
NF24	Oct-98	Mean	17100	20.7	3.96	0.274	0.227	191
		Stdev	20200	9.79	2.01	0.266	0.283	54.8
	Aug-99	Mean	7260	12.6	6.28	0.127	ND	72.7
		Stdev	805	0.694	6.77	0.22	ND	15.4
	Aug-00	Mean	6580	15.2	2.67	0.269	0.316	131
		Stdev	1510	2.03	0.741	0.0473	0.0555	4.83
	Oct-00	Mean	7900	13.6	1.34	0.255	0.295	83.5
		Stdev	1320	0.571	0.386	0.0421	0.204	5.1
	Feb-01	Mean	5930	20.7	2.51	0.611	0.119	113
		Stdev	659	8.38	0.633	0.133	0.0154	4.67
	Aug-01	Mean	9860	21.4	3.28	0.614	0.201	137
		Stdev	2220	14.2	0.441	0.147	0.0643	35.6
	Oct-01	Mean	7030	11.9	1.58	0.292	0.158	88.5

Station	**Sampling Event**	**Units**	**Total PAH[a,b]**	**Total PCB[b]**	**Total DDT[b]**	**Total Chlordane[b]**	**Total Pesticide[b]**	**Total LAB[b]**
			ng/g dry	**ng/g dry**	**ng/g dry**	**ng/g dry**	**ng/g dry**	**ng/g dry**
		ER-M[b]	**44792**	**180**	**46.1**	**6[d]**	**NA**	**NR**
		Stdev	3380	0.907	0.299	0.0615	0.0391	18.9
	Feb-02	Mean	11700	21	8.8	0.302	0.761	155
		Stdev	4320	4.42	6.22	0.0563	0.231	34.3
	Aug-02	Mean	5350	23.3	1.76	0.191	0.108	74.8
		Stdev	1030	18.4	0.144	0.0139	0.0413	5.29
	Oct-02	Mean	10700	13.7	4.13	0.217	0.504	140
		Stdev	8010	6.73	5.17	0.095	0.201	25.6
FF10	Oct-98	Mean	2120	5.88	2.22	0.103	0.00617	79.2
		Stdev	135	1.87	1.9	0.09	0.0107	12.6
	Aug-99	Mean	3230	2.62	0.587	0.0281	ND	25.6
		Stdev	1930	0.448	0.302	0.0487	ND	14.2
	Aug-00	Mean	5440	5.43	1.2	0.185	0.313	54.1
		Stdev	1500	1.69	0.413	0.0569	0.206	23.5
	Oct-00	Mean	5840	19.2	2.97	0.471	0.508	95.7
		Stdev	3430	12.7	2.09	0.337	0.267	66
	Feb-01	Mean	2670	5	0.706	0.224	0.0785	24.5
		Stdev	936	1.09	0.16	0.114	0.0205	4.71
	Aug-01	Mean	6360	9.73	1.67	0.283	0.105	35.6
		Stdev	5500	4.54	0.333	0.0929	0.0186	17.3
	Oct-01	Mean	2980	4.47	1.09	0.0703	0.0777	23.5
		Stdev	1140	0.572	0.223	0.122	0.0268	15.4
	Feb-02	Mean	3220	4.66	4.04	0.135	0.458	28.9
		Stdev	413	0.652	3.8	0.011	0.207	1.31
	Aug-02	Mean	24600	6.63	1.49	0.163	0.685	40.3
		Stdev	36600	1.93	0.767	0.0224	0.566	15.8
	Oct-02	Mean	4350	6.25	0.872	0.19	0.288	54.1
		Stdev	847	1.14	0.417	0.153	0.168	18.8

[a] Total PAH reported was calculated from an extended list of individual PAHs that were not included in the ERM total PAH group (Long 1995)

[b] Contaminant groups defined in Section 4.2.3

[c] ER-M based on sediment quality guidelines from Long *et al.* (1995)

[d] ER-M value is for Total Chlordane; from Long and Morgan (1991)

NA = Not applicable

NR = Not regulated

Comparison to Nearfield – NCSS yearly mean values compared to nearfield baseline.

		Total PAH[a,b]	Total PCB[b]	Total DDT[b]	Total Chlordane[b]
		ng/g dry	**ng/g dry**	**ng/g dry**	**ng/g dry**
NF Baseline (1)		5210	17	3.54	0.38
NCSS Yearly Mean Values (2)					
1998	**Mean**	7480	16.1	4.93	0.331
	stdev	10600	10.1	6.03	0.259
1999	**Mean**	5580	11.5	3.93	0.193
	stdev	2190	6.74	4.89	0.191
2000	**mean**	5970	14.6	2.23	0.309
	stdev	2760	8.7	1.37	0.195
2001	**Mean**	6090	15.9	2.72	0.452
	stdev	2860	9.42	1.77	0.292
2002	**Mean**	8640 (3)	16.6	3.68	0.303
	stdev	10800	12.2	3.41	0.241

(1) From Kropp *et al.*, 2001
(2) NCSS yearly mean calculated as the average of all NCSS stations sampled within a given sampling year.
(3) If exclude FF10 (rep 2) from BF021, then 2002 mean for total PAH is 6,980 ppb dry.

APPENDIX C5c

Contaminant Special Study
Metal Contaminant Parameters
1998–2002

Stn	**Samp-ling Event**	**Units**	**Al**	**Cd**	**Cr**	**Cu**	**Fe**	**Pb**	**Hg**	**Ni**	**Ag**	**Zn**
			pct	**:g/g dry**	**:g/g dry**	**:g/g dry**	**pct**	**:g/g dry**	**:g/g dry**	**:g/g dry**	**:g/g dry**	**:g/g dry**
		ER-M[b]	**NR**	**9.6**	**370**	**270**	**NR**	**218**	**0.71**	**51.6**	**3.7**	**410**
NF08	Oct-98	Mean	5.79	0.244	115	31.7	2.73	49.3	0.344	21.7	0.901	79.6
		Stdev	0.255	0.0599	15.1	3.93	0.164	3.5	0.0485	0.48	0.17	9.22
	Aug-99	Mean	5.52	0.221	95.4	32.4	2.61	50.9	0.311	19.1	0.918	79.4
		Stdev	0.387	0.0363	20.6	7.6	0.166	6.22	0.0849	4.05	0.223	15.2
	Aug-00	Mean	5.47	0.222	108	35	2.64	52	0.351	24.2	0.916	78.4
		Stdev	0.135	0.0696	7.05	2.51	0.0416	5.77	0.119	2.19	0.249	4.3
	Oct-00	Mean	6.57	0.396	124	36.1	2.7	52.3	0.356	25	0.903	88
		Stdev	0.252	0.105	26.4	3.25	0.0569	7.46	0.0597	1.79	0.185	10.6
	Feb-01	Mean	5.96	0.327	118	33.8	2.55	48.8	0.373	20.9	0.763	78.7
		Stdev	0.0814	0.069	13.5	6.4	0.0889	6.81	0.12	3.09	0.172	9.85
	Aug-01	Mean	6.01	0.296	110	28.6	2.58	47.4	0.284	20.6	0.935	76.7
		Stdev	0.0944	0.113	32.9	9.96	0.469	9.17	0.0813	3.84	0.265	19.4
	Oct-01	Mean	5.65	0.257	117	26.5	2.48	44	0.31	22	0.545	76.3
		Stdev	0.397	0.0554	7.27	1.32	0.142	2.73	0.0613	1.93	0.0521	2.67
	Feb-02	Mean	5.63	0.24	102	26.6	2.54	41.6	0.276	23.3	0.812	74.9
		Stdev	0.278	0.0471	22	5.08	0.217	7.55	0.0952	1.68	0.162	12.6
	Aug-02	Mean	6.79	0.257	127	36.6	2.78	57.2	0.26	22.9	1.06	87.6
		Stdev	0.28	0.173	33.7	12.2	0.269	10.1	0.012	4.33	0.546	20
	Oct-02	Mean	7.02	0.399	150	43.5	2.93	57	0.4	23.3	1.24	101
		Stdev	0.222	0.0808	6.95	2.65	0.105	5.16	0.0741	2.64	0.248	7.34
NF22	Oct-98	Mean	5.9	0.107	73.4	21.8	2.57	40	0.351	19.8	0.593	63.4
		Stdev	0.0208	0.0198	8.78	2.68	0.0839	2.9	0.0695	3.1	0.101	3.35
	Aug-99	Mean	6.01	0.109	74	25.4	2.66	45.9	0.381	23.2	0.66	65.6
		Stdev	0.224	0.00613	8.75	2.75	0.0814	1.51	0.112	2.66	0.0961	1.01
	Aug-00	Mean	5.25	0.122	73.1	24.7	2.63	44.7	0.236	25.5	0.498	64.8
		Stdev	0.221	0.0255	5.17	2.29	0.0666	2.64	0.0479	2.09	0.0208	2.72
	Oct-00	Mean	5.69	0.206	73.7	25.8	2.49	46.8	0.29	21.7	0.49	68.2
		Stdev	0.3	0.0299	11.2	3.39	0.04	8.06	0.0207	1.15	0.0137	3.2
	Feb-01	Mean	5.87	0.147	80.8	24.4	2.56	40.7	0.243	18.5	0.525	64.7
		Stdev	0.123	0.0162	2.53	0.764	0.131	0.896	0.119	2.33	0.0824	3.19
	Aug-01	Mean	5.93	0.125	88.1	25.4	2.84	42.7	0.289	20.5	0.673	69.8
		Stdev	0.225	0.0216	9.05	2.32	0.0666	5.1	0.0481	3.37	0.114	4.87
	Oct-01	Mean	5.78	0.13	92.4	21.5	2.4	40.7	0.197	18.8	0.345	68.6
		Stdev	0.168	0.0297	8.3	6.87	0.441	5.73	0.0897	3.96	0.148	10.2
	Feb-02	Mean	5.75	0.128	71.8	20.9	2.83	33.7	0.217	22.8	0.51	60.9
		Stdev	0.095	0.0254	6.92	3.09	0.376	2.12	0.0263	3.25	0.00351	3.78
	Aug-02	Mean	6.47	0.088	88.1	25.5	2.74	45.6	0.226	20.8	0.603	69.4
		Stdev	0.05	0.00206	4.48	0.95	0.0462	3.16	0.00528	1.1	0.00569	2.26
	Oct-02	Mean	6.65	0.142	92.3	25.8	2.8	47	0.298	17.7	0.698	74.7
		Stdev	0.235	0.0103	7.05	2.05	0.0503	6.71	0.0119	2.3	0.105	6.92
NF24	Oct-98	Mean	5.74	0.108	95.1	31.2	2.52	55.4	0.322	19.9	0.698	72.3
		Stdev	1.04	0.0686	56.2	9.58	0.803	23.5	0.179	7.8	0.427	28.4
	Aug-99	Mean	5.74	0.103	83	32.9	2.73	68.3	0.362	24.2	0.488	79.1
		Stdev	0.371	0.0188	9.14	2.42	0.0819	9.76	0.0889	2.7	0.0403	5.77
	Aug-00	Mean	5.72	0.104	80.4	28.6	2.48	53.1	0.507	23.1	0.373	136
		Stdev	0.223	0.00983	9.94	4.46	0.217	9.34	0.44	0.794	0.109	105
	Oct-00	Mean	6.57	0.198	71	27.4	2.35	59.3	0.275	20.4	0.278	70.1
		Stdev	0.739	0.00964	17.3	4.94	0.116	8.52	0.0378	0.702	0.0331	6.89
	Feb-01	Mean	5.4	0.185	93.3	48.9	2.48	56.3	0.301	18.3	0.356	72.1
		Stdev	0.272	0.0451	34	43.2	0.123	7.65	0.091	2.2	0.115	7.18
	Aug-01	Mean	5.87	0.114	81.9	27.7	2.55	61.3	0.421	20	0.451	82
		Stdev	0.397	0.0388	10.5	4.88	0.114	11.3	0.205	2.35	0.0503	13.1

Stn	Samp-ling Event	Units	Al	Cd	Cr	Cu	Fe	Pb	Hg	Ni	Ag	Zn
			pct	:g/g dry	:g/g dry	:g/g dry	pct	:g/g dry	:g/g dry	:g/g dry	:g/g dry	:g/g dry
		ER-M[b]	NR	9.6	370	270	NR	218	0.71	51.6	3.7	410
	Oct-01	Mean	5.28	0.0825	64.5	21	2.03	41	0.146	17.8	0.166	57.3
		Stdev	0.132	0.0238	5.5	3.86	0.115	1.18	0.0601	3.97	0.024	3.85
	Feb-02	Mean	5.45	0.138	95.4	29.7	2.6	64.4	0.365	24.5	0.518	81.2
		Stdev	0.351	0.019	23.7	6.5	0.394	21.4	0.107	6.4	0.0569	3.66
	Aug-02	Mean	6.17	0.0732	75.5	32.7	2.38	50.6	0.211	18.6	0.37	69.2
		Stdev	0.211	0.0166	16.7	12.2	0.223	8.27	0.0639	2.51	0.0535	11
	Oct-02	Mean	6.18	0.0796	70.5	25.1	2.29	46.7	0.197	18.8	0.392	68.3
		Stdev	0.433	0.015	18.8	5.43	0.219	6.68	0.0354	3.61	0.00802	8.1
FF10	Oct-98	Mean	5.32	0.0646	70.1	15.1	1.83	31.4	0.272	15	0.302	43.8
		Stdev	0.0208	0.064	8.33	2.93	0.109	1.51	0.256	1.7	0.0128	1.97
	Aug-99	Mean	5.07	0.0713	56.9	20.6	2.05	28.5	0.107	17.7	0.269	55.9
		Stdev	0.335	0.0104	11.4	10.8	0.311	3.03	0.00673	9.99	0.0554	12.9
	Aug-00	Mean	5.26	0.0814	62.9	13.9	2.53	29.5	0.138	22.7	0.16	57.2
		Stdev	0.264	0.0356	7.98	1.08	0.219	0.346	0.0376	4.17	0.0406	3.95
	Oct-00	Mean	5.09	0.153	58.8	13.6	1.96	31.6	0.113	16	0.128	46.7
		Stdev	0.34	0.00404	19.7	1.46	0.109	1.45	0.00225	1.38	0.0116	4.04
	Feb-01	Mean	4.76	0.116	64.6	14.9	1.83	28.1	0.115	13	0.176	42.4
		Stdev	0.53	0.00953	12.4	3.91	0.135	4.01	0.0278	2	0.00836	2.44
	Aug-01	Mean	5.65	0.101	83.3	13.1	2.14	33.4	0.105	17.4	0.291	50.2
		Stdev	0.122	0.0262	10.2	2.57	0.139	2.42	0.0211	1.01	0.0417	4.7
	Oct-01	Mean	5.25	0.138	88.1	22.6	2.36	44	0.233	19.5	0.316	68.8
		Stdev	0.257	0.0635	43.4	16.1	0.806	17.4	0.181	9.57	0.302	29.2
	Feb-02	Mean	5.09	0.133	78.7	13.5	2	26.7	0.106	16.1	0.328	44.9
		Stdev	0.106	0.00961	5.91	0.551	0.0771	3.54	0.00695	2.17	0.0217	2.03
	Aug-02	Mean	6.19	0.0737	79.8	14.6	2.18	35.3	0.118	14.3	0.268	58.4
		Stdev	0.272	0.00732	10.9	1.48	0.156	5.46	0.0175	2.22	0.00777	10.3
	Oct-02	Mean	6.47	0.116	67	13.1	2.31	31.5	0.218	14.9	0.277	55.2
		Stdev	0.463	0.00709	15.4	3.69	0.517	1.67	0.167	2.58	0.0546	12.4

[a] ER-M based on sediment quality guidelines from Long *et al*. (1995)
NR = Not regulated

Comparison to Nearfield – NCSS yearly mean values compared to nearfield baseline.

		Cd	Cr	Cu	Pb	Hg	Ni	Ag	Zn
		:g/g dry	:g/g dry	:g/g dry	:g/g dry	:g/g dry	:g/g dry	:g/g dry	:g/g dry
NF Baseline (1)		0.167	75.8	23.8	44.2	0.242	17.3	0.56	60.6
NCSS Yearly Mean Values (2)									
1998	**Mean**	0.131	88.5	25	44	0.322	19.1	0.624	64.8
	stdev	0.0856	31.7	8.63	14	0.142	4.48	0.302	19
1999	**Mean**	0.126	77.3	27.8	48.4	0.29	21.1	0.584	70
	stdev	0.062	18.5	7.91	15.7	0.134	5.64	0.271	13.6
2000	**mean**	0.185	81.5	25.6	46.2	0.283	22.3	0.468	76.1
	stdev	0.103	25	8.44	11.4	0.183	3.41	0.307	40.7
2001	**Mean**	0.168	90.2	25.7	44	0.251	18.9	0.462	67.3
	stdev	0.0892	23.9	14.7	10.8	0.13	3.94	0.259	15.3
2002	**Mean**	0.156	91.5	25.6	44.8	0.241	19.8	0.59	70.5
	stdev	0.106	27.9	10.3	13.2	0.105	4.36	0.34	16.7

(1) Kropp *et al.*, 2001

(2) NCSS yearly mean calculated as the average of all NCSS stations sampled within a given sampling year.

APPENDIX C5d

Contaminant Special Study
Comparison of Pre- and Post-Diversion (1998–2002) and Full Baseline (1992–2000) Grand Means

Table C5d-1. Comparison of Nearfield Contaminant Special Study (NCSS) pre-diversion, post-diversion, and full baseline mean values, by parameter. Mean values reported to three significant figures.

Parameter	Units	NCSS Mean Values			NCSS Full Baseline Mean (d)
		Pre-Diversion (a)	Post-Diversion (b)	PD (c)	
Fines	pct	47.9	48.6	1.5%	50.4
TOC	pct dry	0.971	1.04	7.1%	1.15
Clostridium	cfu/g dw	2360	3700	56.7%	3720
Total PAH	ng/g dry	6300	6460	2.5%	7220
Total PCB	ng/g dry	14.1	16	13.2%	23
Total DDT	ng/g dry	3.76	3.04	-19.2%	5.01
Total LAB	ng/g dry	130	100	-23.0%	249
Aluminum	pct	5.57	5.9	6.0%	5.42
Cadmium	:g/g dry	0.13	0.173	33.3%	0.22
Chromium	:g/g dry	82.3	89.6	8.8%	99.6
Copper	:g/g dry	26.1	25.7	-1.7%	29.7
Iron	pct	2.5	2.45	-1.8%	2.5
Lead	:g/g dry	45.8	44.8	-2.0%	50.9
Mercury	:g/g dry	0.307	0.248	-19.1%	0.384
Nickel	:g/g dry	21.4	19.6	-8.3%	22.5
Silver	:g/g dry	0.565	0.515	-8.8%	0.712
Zinc	:g/g dry	72.9	68.8	-5.7%	80.4

(a) NCSS Pre-Diversion Mean – average of all NCSS station replicates (FF10, NF08, NF22, NF24) sampled in October 1998, August 1999 and August 2000 surveys, by parameter.

(b) NCSS Post-Diversion Mean – average of all NCSS station replicates (FF10, NF08, NF22, NF24) sampled in October 2000, 2001, 2002; February 2001 and 2002; and August 2002 and 2002 surveys, by parameter.

(c) Percent Difference = [(NCSS Post-Diversion Mean – NCSS Pre-Diversion Mean)] ÷ NCSS Pre-Diversion Mean

(d) NCSS Full Baseline Mean – average of all NCSS station replicates (FF10, NF08, NF22, NF24) sampled during August surveys only from 1992 to 2000, by parameter.

Table C5d-2. Comparison of NCSS station FF10 pre-diversion, post-diversion, and full baseline mean values, by parameter. Mean values reported to three significant figures.

Parameter	Units	NCSS Mean Values			NCSS Full Baseline Mean (d)
		Pre-Diversion (a)	Post-Diversion (b)	PD (c)	
Fines	pct	26	29.2	12.6%	26.3
TOC	pct dry	0.57	0.634	11.2%	0.588
Clostridium	cfu/g dw	1330	1300	-2.0%	1570
Total PAH	ng/g dry	3600	4160	15.7%	4410
Total PCB	ng/g dry	4.64	7.99	72.0%	6.77
Total DDT	ng/g dry	1.33	1.83	37.5%	1.68
Total LAB	ng/g dry	53	43.2	-18.4%	40.6
Aluminum	pct	5.22	5.5	5.4%	5.2
Cadmium	:g/g dry	0.0724	0.119	63.9%	0.115
Chromium	:g/g dry	63.3	74.3	17.4%	69.5
Copper	:g/g dry	16.6	15	-9.2%	14.7
Iron	pct	2.14	2.11	-1.2%	2.02
Lead	:g/g dry	29.8	33	10.6%	31.3
Mercury	:g/g dry	0.172	0.144	-16.4%	0.104
Nickel	:g/g dry	18.5	15.9	-14.1%	16.9
Silver	:g/g dry	0.244	0.255	4.6%	0.258
Zinc	:g/g dry	52.3	52.4	0.1%	50.3

(a) NCSS Pre-Diversion Mean – average of all NCSS station FF10 replicates sampled in October 1998, August 1999 and August 2000 surveys, by parameter.

(b) NCSS Post-Diversion Mean – average of all NCSS station FF10 replicates sampled in October 2000, 2001, 2002; February 2001 and 2002; and August 2002 and 2002 surveys, by parameter.

(c) Percent Difference = [(NCSS Post-Diversion Mean – NCSS Pre-Diversion Mean)] ÷ NCSS Pre-Diversion Mean

(d) NCSS Full Baseline Mean – average of all station FF10 replicates sampled during August surveys only from 1992 to 2000, by parameter.

Table C5d-3. Comparison of NCSS station NF08 pre-diversion, post-diversion, and full baseline mean values, by parameter. Mean values reported to three significant figures.

Parameter	Units	NCSS Mean Values			NCSS Full Baseline Mean (d)
		Pre-Diversion (a)	Post-Diversion (b)	PD (c)	
Fines	pct	62.6	65.4	4.5%	72.8
TOC	pct dry	1.26	1.34	6.3%	1.73
Clostridium	cfu/g dw	3570	5430	51.9%	5200
Total PAH	ng/g dry	7340	8720	18.9%	12500
Total PCB	ng/g dry	23.7	26.1	10.4%	50.1
Total DDT	ng/g dry	7.08	5	-29.4%	9.23
Total LAB	ng/g dry	195	155	-20.9%	682
Aluminum	pct	5.59	6.23	11.4%	5.73
Cadmium	:g/g dry	0.229	0.31	35.5%	0.443
Chromium	:g/g dry	106	121	14.1%	145
Copper	:g/g dry	33	33.1	0.2%	46.4
Iron	pct	2.66	2.65	-0.3%	2.85
Lead	:g/g dry	50.7	49.8	-1.9%	64.3
Mercury	:g/g dry	0.335	0.326	-2.8%	0.476
Nickel	:g/g dry	21.7	22.6	4.1%	26
Silver	:g/g dry	0.912	0.894	-1.9%	1.44
Zinc	:g/g dry	79.1	83.3	5.2%	105

(a) NCSS Pre-Diversion Mean – average of all NCSS station NF08 replicates sampled in October 1998, August 1999 and August 2000 surveys, by parameter.

(b) NCSS Post-Diversion Mean – average of all NCSS station NF08 replicates sampled in October 2000, 2001, 2002; February 2001 and 2002; and August 2002 and 2002 surveys, by parameter.

(c) Percent Difference = [(NCSS Post-Diversion Mean – NCSS Pre-Diversion Mean)] ÷ NCSS Pre-Diversion Mean

(d) NCSS Full Baseline Mean – average of all station NF08 replicates sampled during August surveys only from 1992 to 2000, by parameter.

Table C5d-4. Comparison of NCSS station NF22 pre-diversion, post-diversion, and full baseline mean values, by parameter. Mean values reported to three significant figures.

Parameter	Units	NCSS Mean Values			NCSS Full Baseline Mean (d)
		Pre-Diversion (a)	Post-Diversion (b)	PD (c)	
Fines	pct	44	48.9	11.3%	49.4
TOC	pct dry	0.846	1.07	26.3%	0.985
Clostridium	cfu/g dw	2500	3540	41.5%	4050
Total PAH	ng/g dry	3960	4500	13.5%	4180
Total PCB	ng/g dry	12	11.9	-1.1%	14.6
Total DDT	ng/g dry	2.31	1.97	-14.8%	3.6
Total LAB	ng/g dry	140	89.5	-36.2%	168
Aluminum	pct	5.72	6.02	5.2%	5.71
Cadmium	:g/g dry	0.112	0.138	23.0%	0.143
Chromium	:g/g dry	73.5	83.9	14.2%	79.9
Copper	:g/g dry	24	24.2	0.8%	25.7
Iron	pct	2.62	2.66	1.8%	2.64
Lead	:g/g dry	43.5	42.5	-2.5%	46.7
Mercury	:g/g dry	0.323	0.251	-22.2%	0.294
Nickel	:g/g dry	22.8	20.1	-12.0%	24.3
Silver	:g/g dry	0.584	0.549	-6.0%	0.67
Zinc	:g/g dry	64.6	68.1	5.3%	67.9

(a) NCSS Pre-Diversion Mean – average of all NCSS station NF22 replicates sampled in October 1998, August 1999 and August 2000 surveys, by parameter.

(b) NCSS Post-Diversion Mean – average of all NCSS station NF22 replicates sampled in October 2000, 2001, 2002; February 2001 and 2002; and August 2002 and 2002 surveys, by parameter.

(c) Percent Difference = [(NCSS Post-Diversion Mean – NCSS Pre-Diversion Mean)] ÷ NCSS Pre-Diversion Mean

(d) NCSS Full Baseline Mean – average of all station NF22 replicates sampled during August surveys only from 1992 to 2000, by parameter.

Table C5d-5. Comparison of NCSS station NF24 pre-diversion, post-diversion, and full baseline mean values, by parameter. Mean values reported to three significant figures.

Parameter	Units	NCSS Mean Values			NCSS Full Baseline Mean (d)
		Pre-Diversion (a)	Post-Diversion (b)	PD (c)	
Fines	pct	59	50.9	-13.7%	60.8
TOC	pct dry	1.16	1.13	-3.0%	1.41
Clostridium	cfu/g dw	2040	4520	121.2%	4890
Total PAH	ng/g dry	10300	8360	-19.0%	7840
Total PCB	ng/g dry	16.2	17.9	11.0%	22.7
Total DDT	ng/g dry	4.3	3.34	-22.3%	6.16
Total LAB	ng/g dry	132	113	-14.2%	131
Aluminum	pct	5.73	5.85	2.0%	5.15
Cadmium	:g/g dry	0.105	0.124	18.4%	0.185
Chromium	:g/g dry	86.2	78.9	-8.5%	108
Copper	:g/g dry	30.9	30.3	-1.8%	35.5
Iron	pct	2.58	2.38	-7.5%	2.66
Lead	:g/g dry	58.9	54.2	-8.0%	66.8
Mercury	:g/g dry	0.397	0.277	-30.2%	0.746
Nickel	:g/g dry	22.4	19.8	-11.7%	25
Silver	:g/g dry	0.52	0.362	-30.4%	0.578
Zinc	:g/g dry	95.7	71.5	-25.3%	105

(a) NCSS Pre-Diversion Mean – average of all NCSS station NF24 replicates sampled in October 1998, August 1999 and August 2000 surveys, by parameter.

(b) NCSS Post-Diversion Mean – average of all NCSS station NF24 replicates sampled in October 2000, 2001, 2002; February 2001 and 2002; and August 2002 and 2002 surveys, by parameter.

(c) Percent Difference = [(NCSS Post-Diversion Mean – NCSS Pre-Diversion Mean)] ÷ NCSS Pre-Diversion Mean

(d) NCSS Full Baseline Mean – average of all station NF24 replicates sampled during August surveys only from 1992 to 2000, by parameter.

APPENDIX C6

Contaminant Special Study
Grain Size Composition (1998–2002)
Ternary Plots

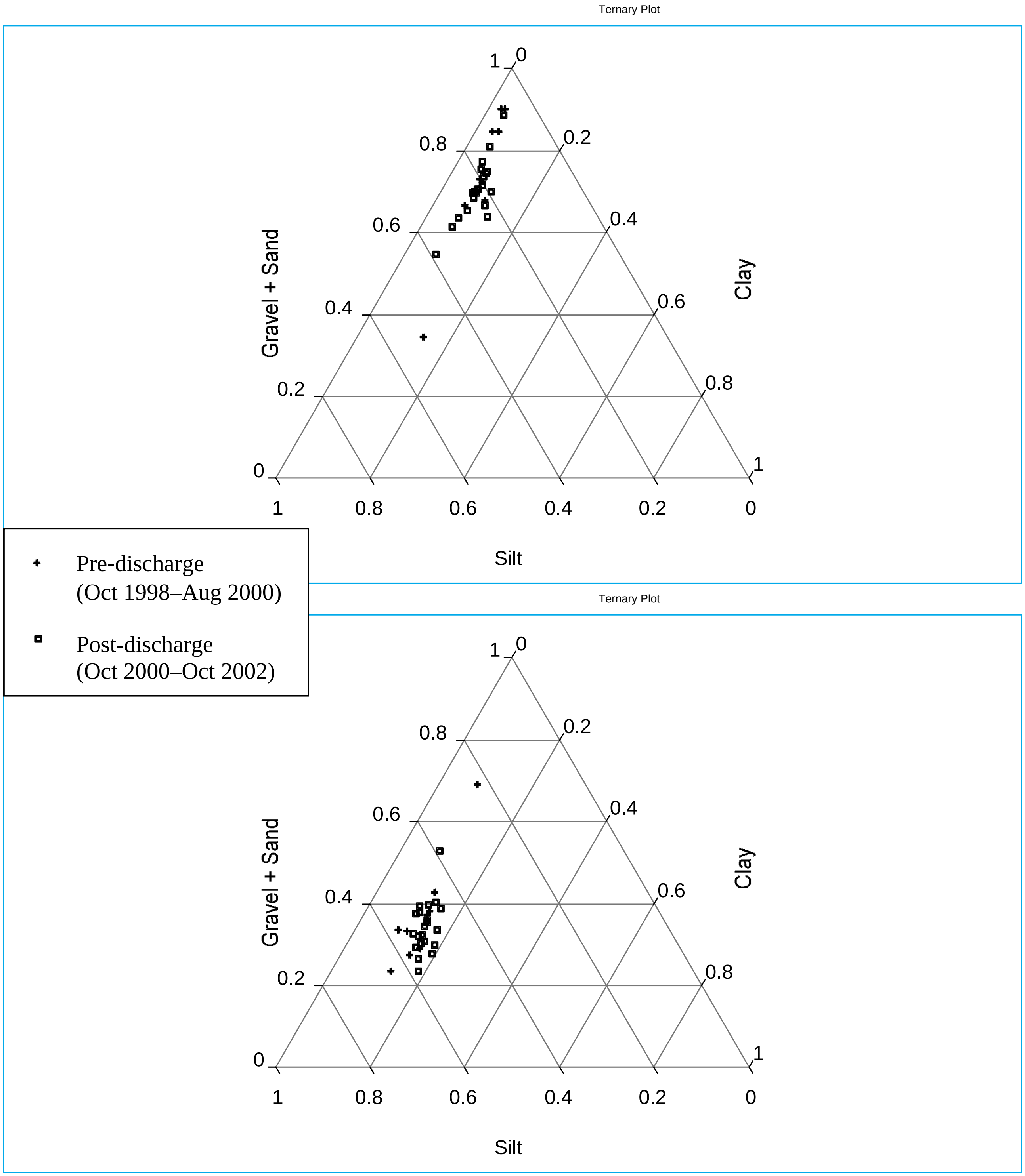


Figure C6-1. Grain size composition at NCSS stations FF10 (top) and NF08 (bottom) from October 1998 to October 2002.

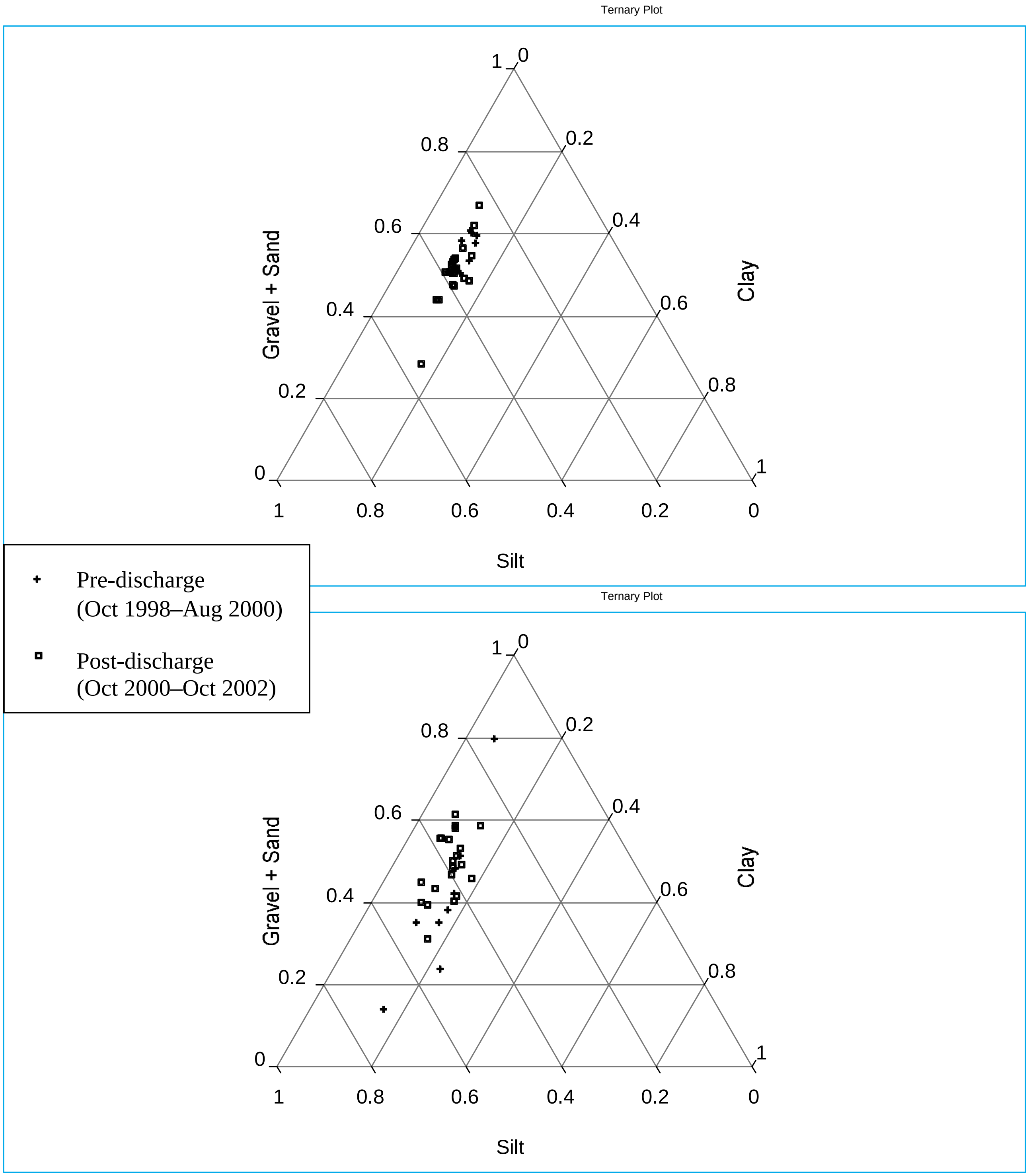


Figure C6-2. Grain size composition at NCSS stations NF22 (top) and NF24 (bottom) from October 1998 to October 2002.

APPENDIX C7

Meeting Minutes from the
1997 OMTF Subcommittee Meeting

UMTFMembcrs,12/18/97 4:34 PM,OMTF Sediment Chemistry Workshop 1

To: 0MTFMembers
From: coniaris@earthlink.net (Cathy Coniaris)
Subject: OMTF Sediment Chemistry Workshop
Cc: OMTFGuests, UMTFMailOnly, mbothner@usgs,gov, jteal@ma.ultranet.corr, fmanheim@nobska.cr.usgs.gov, judith.perry@state.ma.us, steven.lipman@state.ma.us, berry.walter@epamail.epa.gov
Bcc:
X-Attachments:

From Judy Pederson:
I have finally included the minority opinions in the minutes of the Sediment Chemistry Focus Group. I think I have been fair in what is included as minority opinions and additional recommendations (mostly by the regulatory agencies) to prepare short discussion papers or fact sheets describing the agencies' perspectives on several issues before the next focus group meeting (if one is scheduled in the future).

REVISED MINUTES OF THE SEDIMENT CHEMISTRY WORKSHOP
April 17,1997

Attendees:Walter Berry, USEPA, Narragansett, Jim Blake, ENSR, Mike Bothner, USGS, Cathy Coniaris, OMTF assistant, Mike Connor, MWRA, John Farrington, WHOI, OMTF, Gene Gallagher, UMB, OMTF, Maury Hall, MWRA, Carlton Hunt, Battelle, Ken Keay, MWRA, Christian Krahforst, MCZM, OMTF, Matt Liebman, USEPA, OMTF, Frank Manhcim, USGS, Mike Mickelson, MWRA, Judy Pederson, MIT/Sea Grant, OMTF, Judy Perry, DEP, Susan Redlich, WAC, OMTF, Jack Schwartz, OMF, OMTF, Jodi Sugerman, SHSB, OMTF, Windsor Sung, ENSR, John Teal, WHOI, DaveTomey, USEPA, OMTF, Gordon Wallace, UMB

MEETING SUMMARY

1) There is general agreement that the deposition areas are smaller than the entire area. Although the general conceptual models (and some quantitative numerical models) lead to the accumulation of contaminants in fine grained sediments in deposition areas, the Focus Group noted that contaminants could also be incorporated - at least on a temporary basis - in coarser grained areas that are more commonly thought of as sandy sediment, or erosion areas. Therefore, we see no compelling reason at this time to modify the monitoring plan on the basis of some special knowledge about some areas being more likely to accumulate contaminants than others e.g. nearfield, midfield, farfield, Once data have been obtained and assessed for two to three years, there may be evidence that warrants redesign of sampling location and frequency.

2) There was a consensus that the USGS study adequately captures the temporal dynamics likely to be of interest during outfall start-up, and the routine MWRA monitoring adequately captures the spatial resolution desired. However, the group determined that there is merit in sampling more intensely in space (than the 2 USCS stations) and in time (than MWRA's routine annual monitoring) in the nearfield during the first year or two of operation. This may maximize the chances of unanticipated "hot spots" of deposition being recognized if they occur.

There was a minority opinion expressed that frequency of sampling should be increased along with number of stations.

3) We believe there is a high probability that once the outfall is on-line and the initial few years of data are in hand, that an assessment of potential redesign with fewer stations and less frequent sampling will be warranted.

4) The: monitoring design chose the upper 0-2 cm depth interval for sampling the surface sediment. In so doing it is recognized that after at least a year or two (perhaps sooner), the biological and physical mixing of the sediments would more or less evenly distribute contaminants accumulating in the surface sediments over that depth interval or even deeper in the sediments.

However, the group noted that during the initial phases of deposition, many contaminants would be present in highest concentration in the upper 0-2 mm or "fluff" layer of the sediments. These might pose a greater threat to animals with extensive contact with that "fluff" layer than would generally be indicated by sampling and analyzing the upper 0-2 cm (being a larger volume and mass and therefore diluting the concentration).

After recognizing this problem, the group agreed that this concern would be addressed by a continuing sediment trap program of the type currently ongoing as a cooperative effort between USGS and MWRA. The bottom traps in these sediment trap arrays sample resuspended surface floc and analyses of these samples for contaminants of concern will provide an excellent chance of detecting concentration levels of environmental concern should they occur-

5) With respect to sediment quality criteria or standards, the current state-of-knowledge arc such that both the USEPA and the Army Corps of Engineers (among others) at the federal level and the Massachusetts State Agencies at the state level would have to provide interim guidance advisories. Current toxicity testing of the type used for dredging and disposal of dredge spoils in the marine environment are in need of revisions and review. The merit of these tests is that they attempt to measure the net effects of complex mixtures of chemicals on a few target species, or biological functions. Despite the fact that these toxicity tests have merit in and of themselves in some situations, they are best viewed as guides for follow-on more extensive tests. A nationwide comparison of the three common tests - sea urchin fertilization, amphipod (or similar local organisms) survival, and mutagenicity testing using luminescent bacteria - for several hundred estuarine sediment locations (including urban harbors) has provided little concordance and agreement between the tests. (Environmental Science and Technology 30:3585-3592, December, -1996). This presents challenges for setting; absolute criteria.

The Sediment Quality Criteria approach proposed by the USEPA founded in measurement of concentrations of chemicals of environmental concern in sediments, application of relatively simple physical-chemical partitioning models to obtain pore water concentrations, and then comparing these pore water concentrations with Water Quality Criteria have deficiencies caused by the relative simplicity of the physical chemicals functions. In addition, the SQC approach is chemical by chemical and does not assess the net effects of complex mixtures of chemicals.

The group was informed by our USEPA participating scientists that several of the individual PAH SQCs that have been promulgated will soon be withdrawn due to the aforementioned deficiencies and it may be as long as two years before something in the form of "Guidance Advisory" concentrations would be issued.

The merits and limits of the correlative approach of Long, Morgan et al. (various NOAA publications) were discussed. The Effects Range High, Effects Range Medium, and Effects Range Low concentrations of individual chemicals is provided by an overall data base assessment of many unrelated studies with limited overlap of either biological species or biological function tested and individual or mixtures of concentrations measured. We recognize that there is an argument in favor of “in the absence of anything else, this is one of the few guidance approaches we have" might seem like a compelling argument in the sense of "do something".

However, there should be a clear statement to the public and all individual interested parties that the state-of-knowledge is such that there are large uncertainties associated with any "criteria" or "trigger" values. Having stated that, we are comfortable with the current plan for sediment chemistry monitoring and the suggested trigger values because the sediment chemistry monitoring is embedded within a larger program that provides for biological monitoring of benthic ecosystems. If there were an effect that became apparent in the biological monitoring that was determined to be an adverse effect, it is highly likely that it would be possible to institute corrective measures of outfall operation that would reverse the effect within five to ten years.

Furthermore, there has been an acceptance that there will be a small area in the nearfield where there is a high probability of biological effects that will be accepted as a trade-off in a cost-benefit sense for the outfall operation and overall improvement of environmental quality. Given that fact, we believe that there is a fair to good chance that it will be possible to assess the relationship between the level of chemical contamination in sediments in the nearfield and biological effects in the benthic organisms and ecosystems that will provide long term (years to decades) guidance for "trigger" levels of sediment chemical contaminant concentrations in the midfield and farfield.

Given the above, we recognize that there is an opportunity with the outfall monitoring program for the state agencies and the federal agencies to obtain new knowledge of general value in concert with the monitoring efforts. For example, it might be prudent to undertake some testing of the old and newer toxicity testing measures as a research effort within the monitoring effort. It is not clear to us who should pay for this effort, but we believe it is our responsibility to highlight this significant opportunity.

MINORITY OPINION: This topic has a strong, minority opinion expressed particularly by Matt Liebman and Walter Berry of the USEPA and Gene Gallagher, UMass/Boston. All three suggested that MWRA adopt a triad approach, if only to demonstrate there is no impact (G.G.). A tiered approach could be adopted. The concern is that the benthic monitoring alone is not sufficient to indicate outfall effects. Because the different tests reflect different responses is seen as a valuable tool. This was not agreed to by the larger group and should be revisited with the next sediment focus group meeting. One possibility for furthering the discussion is to have EPA and the state define what tests they think are appropriate and why. A comparison of responses to sediment contaminant concentrations and how these relate to expected sediment contaminant concentrations would be useful in assisting the group reach consensus. The group has already recommended that MWRA's data will complement federal agency's research on biological testing.

A second point raised by W. Berry was the importance of SQAL's and that these should be used with ER-Ms. PELs and other values. The majority did not embrace this ***issue*** and therefore it is listed as a minority opinion. In order to further the discussion, there ***needs to*** be a comparison of the SQAL, ER-M, PEL and other potential trigger levels with expected sediment concentrations.

6) There was substantive discussion of the need to phase in assessments of the role of organic carbon in trace metal accumulations in sediments as presented by Professor Cordon Wallace. Similarly, there was substantive discussion about the merits of having an assessment of Acid Volatile Sulfide related metal concentrations carried out as part of the monitoring program. Given the deep oxidation of sediments in the nearfield and throughout Massachusetts Bay, the subcommittee does not currently recommend these analyses be added to the monitoring plan. The role of AVS-SFM as a screening tool to predict sediments within which toxicity might be observed suggests such analyses be considered as a "second tier" screen, carried out if total metals concentrations reach the interim thresholds.

SUMMATION: Only modest modifications of the existing sediment chemistry monitoring plan as stated above arc recommended for full OMTF consideration. Given the minority opinions raised, there should be two short discussion papers or fact sheets prepared for the next focus group meeting to assist with making unformed decisions. The group did not recommend that MWRA undertake a research initiative, but that its monitoring activities should complement EPA and other research into biological effects of contaminants.

APPENDIX D1

Preliminary Data Treatments

Species Code	**Taxon**	**Good/Bad[1]**	**Action (For MERGES, use second name listed).**	**ENSR Comment[2]**
50015402SPP	Flabelligera spp.	B	PERMANENT merge with Flabelligera affinis	Only one species of Flabelligera in the NE US (JAB)
50011308SPP	Paranaitis spp.	B	PERMANENT merge with Paranaitis speciosa	
74SPP	Priapulida spp.	B	PERMANENT merge with Priapulida caudatus	Only one species of Priapulida in the NE US (JAB)
50015003SPP	Tharyx spp.	B	PERMANENT merge with Tharyx acutus	Only species of Tharyx in Mass Bay, per JAB.
5103200108	Alvania castanea	G	PERMANENT merge with Onoba mighelsi	per IW
50015003ASP01	Aphelochaeta sp. 1	G	PERMANENT merge with Aphelochaeta monilaris	per JAB
5001600601	Barantolla americana	G	PERMANENT merge with Heteromastus filiformis	per JAB
55SP02	Bivalvia sp. A	G	PERMANENT merge with Spisula solidissima	per IW
51050503SP01	Colus sp. A	G	PERMANENT merge with Colus pygmaeus	per IW
6154050129	Diastylis abbreviata	G	PERMANENT merge with Diastylis cornuifer	per IW
51SP01	Gastropoda sp. A	G	PERMANENT merge with Moelleria costulata	per IW
6169060402	Microdeutopus anomalus	G	PERMANENT merge with Protomedeia fasciata	per IW
5001210203	Microphthalmus listensis	G	PERMANENT merge with Micropthalmus	per JAB
5001240404	Nereis procera	G	PERMANENT merge with Nereis grayi	Cove and ENSR discussed at length, concluded that there is only one Nereis in Mass Bay
50013614SP01	Parougia sp. 1	G	PERMANENT merge with Parougia caeca	per JAB
5001631001	Rhodine bitorquata	G	PERMANENT merge with R. loveni	per RER
510320SP01	Rissoidae sp. A	G	PERMANENT merge with Onoba mighelsi	per IW
5001400307CF	Scoloplos (leodamas) ?rubra	G	PERMANENT merge with Orbinia swani	per CTM and JAB
500126SP01	Sphaerodoridae sp. 1	G	PERMANENT merge with Amacrodorum	per NJM
50015003KIRK	Tharyx kirkegaardi	G	PERMANENT merge with Tharyx acutus	per JAB
50014502PETT	Trochochaeta pettiboneae	G	PERMANENT merge with Trochocheta carica	per NJM, discussed with CTM
510602SP01	Turridae sp. A	G	PERMANENT merge with Oenopota harpularia	per IW
50012305SP01	Typosyllis sp. 1	G	PERMANENT merge with Typosyllis hyalina	per NJM
50012305SP02	Typosyllis sp. 2	G	PERMANENT merge with Typosyllis hyalina	per NJM
5001260201	Sphaerodoropsis minuta	G	PERMANENT merge with Sphaerodoropsis sp. 1	per NJM
5103760402CF	Polinices cf. pallidus	G	PERMANENT merge with Polinices pallidus	per IW
50090103PAST	Grania pastclitello longiducta	G	PERMANENT merge with G. POSTclitello	per RW (this change may have already been made)
5001230306	Syllis cornuta	G	Change name to Typosyllis cornuta.	per NJM, no voucher available
50016006SP01	Barantolla sp. A	G	Change name to Capitellid n.gen. 1	per JAB, examined voucher 5-03
50016317SPP	Microclymene spp.	B	Change name to Microclymene sp.1; treat as Good	per NJM
50013614SP02	Parougia sp. 2	G	Change all records to Dorvillea sociabilis.	JAB dicussed with CTM.
needs new code	Sphaerosyllis longicauda	G	Change all records to Sphaerosyllis erinaceus	per NJM, see BF021 Nearfield Infaunal Data report
5502040220CF	Nuculana nr. messanensis	G	Change all records to Nuculana pernula	per IW
51080114BISU	Boonea bisuturalis	G	Change all records to Couthouyella striatula	per IW, examined voucher, NF04-1 2001, 5-03

Species Code	**Taxon**	**Good/Bad**[1]	**Action (For MERGES, use second name listed).**	**ENSR Comment**[2]
500163NISPP	Nichomachinae spp.	B	Correct spelling: Nicomachinae	per JAB
5517060102	Crytodaria siliqua	G	Correct spelling: Cyrtodaria	per IW
5001430414	Dipolydora concharum	G	W	This species is found in shells and is not infaunal.
5001330901	Labrorostratus parasiticus	G	W	This species is parasitic and not infaunal.
6001010101	Nymphon grossipes	G	W	This species is epifaunal.
6179220103	Crangon septemspinosa	W	G	
6153012301	Erythrops erythrophthalma	W	G	
6151SPP	Mysidacea spp.	W	B	
6153011401	Mysis mixta	W	G	
6153011508	Neomysis americana	W	G	
6183060226	Pagurus acadianus	W	G	
61830602SPP	Pagurus spp.	W	B	
5001432006	Scolelepis texana	G	NF 10 re p August 1998; orig ID was S. bousfieldi; changed by CTM to S. texana, but orig ID of Scolelepis bousfieldi is correct	per NJM
	Nuculana sp. 1	G	1992 Voucher specimen from FF-08: Identified as Nuculana pernula. Change this record to N. pernula.	per IW

1. "Good" species are those that are iincluded in the analyses for both density and diversity calculations. "Bad" species are included for calculations of total densities (abundances) but not for diverstiy. W= "worst species" are not included for any of the analyses because they are epifaunal, parasitic, or otherwise not members of the infaunal benthos.

2. JAB: James A. Blake, ENSR; NJM: Nancy J. Maciolek, ENSR; CTM: C. Tim Morris, Cove Corporation; RER: R. Eugene Ruff, Ruff Systematics; IW: Isabelle Williams, ENSR.

After the permanent merges and reidentification changes have been done, there should be no data for the following names, and the codes/names should be deleted from the database:

Alvania castanea
Aphelochaeta sp. 1
Barantolla americana
Barantolla sp. A
Bivalvia sp. A
Boonea bisuturalis
Colus sp. A
Diastylis abbreviata
Flabelligera spp.
Gastropoda sp. A
Microdeutopus anomalus
Microphthalmus listensis
Nereis procera
Nuculana nr. messanensis
Nuculana sp. 1 (assuming the FF-8 1992 specimen is the only record)
Paranaitis spp.
Parougia sp. 1
Polinices cf. pallidus
Priapulida spp.
Rhodine bitorquata
Rissoidae sp. A
Scoloplos (leodamas) ?rubra
Sphaerodoropsis minuta
Sphaerodoridae sp. 1
Tharyx kirkegaardi
Tharyx spp.
Trochochaeta pettiboneae
Turridae sp. A
Typosyllis sp. 1
Typosyllis sp. 2

The following taxa were treated as good species for the report:

Turbellaria spp. (Combined with Turbellaria sp. 1 and Turbellaria sp. 2)
Micrura spp.

The following taxa were merged for the report:

Ascidiacea spp.	Combine with Molgula manhattensis for report.	per JAB
Molgula spp.	Combine with Molgula manhattensis for report.	per JAB
Chaetozone spp.	Combine with Chaetozone setosa for report.	per JAB
Chaetozone sp. 4	Combine with Chaetozone setosa for report.	per JAB
Chaetozone sp. 5	Combine with Chaetozone setosa for report.	per JAB
Laonice sp. 1	Combine with Laonice cirrata for report.	per NJM and JAB, possibly permanent merge
Maldane glebifex	Combine with Maldane sarsi for report.	SOP (possibly should be permanent merge).
Scaphopoda spp.	Combine with Dentalium entale for report.	per JAB and RK (2001)
Euclymene cf. collaris	Combine with Euclymene collaris for report	per SOP/Kropp
Aplacophora spp	Combine with Chaetoderma nitidulum canadense for report.	per SOP/Kropp
Clymenura polaris	Combine with Clymenura sp. A for report.	per SOP/Kropp
Proclea sp. 1	Combine with Proclea graffi for report.	per SOP/Kropp
Nereis spp.	Combine with Nereis grayi for report	per CTM
Apistobranchus tullbergi	Combine with Apistobranchus typicus for report	per SOP/Kropp

The 440 valid taxa that were used for diversity and multivariate analysis are listed in Appendix D2. The following 181 categories were included for calculations of total abundances, but were not used for diversity or multivariate analyses:

Actiniaria spp.
Alvania spp.
Ampelisca spp.
Ampeliscidae spp.
Ampharete spp.
Ampharetidae spp.
Amphipoda spp.
Amphiporus spp.
Amphitritinae spp.
Ancistrosyllis spp.
Anomia spp.
Anthozoa spp.
Aphelochaeta spp.
Aphrodita spp.
Apistobranchus spp.
Arabellidae spp.
Arcidae spp.
Aricidea spp.
Astarte spp.
Asteroidea spp.
Autolytinae spp.
Bivalvia spp.
Brada spp.
Buccinidae spp.
Byblis spp.
Bylgides spp.
Campylaspis spp.
Capitellidae spp.
Caprella spp.
Caprellidae spp.
Caulleriella spp.
Cephalaspidea spp.
Cerianthidae spp.
Chone spp.
Cirratulidae spp.
Clymenura spp.
Colus spp.
Corophiidae spp.
Cossuridae spp.
Crenella spp.
Cumacea spp.
Cylichna spp.
Decapoda spp.
Deflexilodes spp.
Diastylidae spp.
Diastylis spp.
Diplocirrus spp.
Dipolydora spp.
Doridella spp.
Dorvilleidae spp.
Drilonereis spp.
Echinoidea spp.
Echiurida spp.
Ensis spp.
Enteropneusta spp.
Eranno spp.
Eteone spp.
Euchone spp.
Euclymeninae spp.
Eudorella spp.
Eulalia spp.
Exogone spp.
Flabelligeridae spp.
Gammarus spp.
Gastropoda spp.
Gastropoda;mollusca
Gattyana spp.
Glycera spp.
Glyceridae spp.
Goniada spp.
Goniadidae spp.
Harmothoe spp.
Harmothoinae spp.
Hippomedon spp.
Holothuroidea spp.
Isopoda spp.
Laonice spp.
Leitoscoloplos spp.
Leptostylis spp.
Leucon spp.
Levinsenia spp.
Lumbrineridae spp.
Lyonsia spp.
Lyonsiidae spp.
Lysianassidae spp.
Lysilla spp.
Maldane spp.
Maldanidae spp.
Melinna spp.
Melitidae spp.
Melphidippa spp.
Microphthalmus spp.
Monoculodes spp.
Monticellina spp.
Munna spp.
Munnidae spp.
Musculus spp.
Myriochele spp.
Mysidacea spp.
Mytilidae spp.
Naticidae spp.
Nemertea spp.
Nephtyidae spp.
Nephtys spp.
Neptunea spp.
Nereididae spp.
Nicomachinae spp.
Notomastus spp.
Nucula spp.
Nuculana spp.
Nuculanidae spp.
Nuculidae spp.
Nudibranchia spp.
Oedicerotidae spp.
Oenopota spp.
Oligochaeta spp.
Onuphidae spp.
Opheliidae spp.
Ophiura spp.
Ophiuroidea spp.
Ophryotrocha spp.
Opisthobranchia spp.
Orbinia spp.
Orbiniidae spp.
Oweniidae spp.
Pagurus spp.
Pandora spp.
Paraonidae spp.
Pectinaria spp.
Pectinidae spp.
Periploma spp.
Pherusa spp.
Pholoe spp.
Phoxocephalidae spp.
Phyllodoce spp.
Phyllodocidae spp.
Pionosyllis spp.
Pleurogonium spp.
Pleustidae spp.
Podoceridae spp.
Polycirrus spp.
Polydora spp.
Polynoidae spp.
Praxillella spp.
Propebela spp.
Protodriloides spp.
Pycnogonida spp.
Sabellidae spp.
Scalibregmatidae spp.
Scoletoma spp.
Scoloplos spp.
Sipuncula spp.
Solariella spp.
Solenidae spp.
Sphaerodoridae spp.
Sphaerosyllis spp.
Spio spp.
Spionidae spp.
Spiophanes spp.
Stenothoidae spp.
Sthenelais spp.
Syllidae spp.
Syllides spp.
Syllis spp.
Tellina spp.
Terebellidae spp.
Terebellides spp.
Tetrastemma spp.
Thraciidae spp.
Thyasira spp.
Thyasiridae spp.
Trichobranchidae spp.
Trochidae spp.
Trochochaeta spp.
Tubificidae spp.
Tubificoides spp.
Turridae spp.
Typosyllis spp.
Unciola spp.
Urosalpinx spp.
Yoldia spp.

APPENDIX D2

Species Identified in Massachusetts Bay Samples 1992–2002

Species identified from Massachusetts Bay Outfall Monitoring Program samples from 1992—2002, excluding May 1992 and FF-08 and used in the 2002 community analysis.

Species collected in August 2002 samples are marked with an asterisk (*).
Species new to the list in 2002 are underlined.

CNIDARIA
- *Ceriantheopsis americanus* (Verrill, 1866) *
- *Ceriantheopsis borealis* Verrill, 1873
- *Edwardsia elegans* Verrill, 1869 *
- *Halcampa duodecimcirrata* (Sars, 1851) *
- Actiniaria sp. 2
- Actiniaria sp. 6

PLATYHELMINTHES
- Turbellaria spp. *

NEMERTEA
- *Amphiporus angulatus* (Fabricius, 1774) *
- *Amphiporus bioculatus* McIntosh, 1873 *
- *Amphiporus cruentatus* Verrill, 1879 *
- *Amphiporus groenlandicus* Oersted, 1844 *
- *Carinomella lactea* Coe, 1905 *
- Cephalothricidae sp. 1 *
- *Cerebratulus lacteus* (Leidy, 1851) *
- *Lineus pallidus* Verrill, 1879
- *Micrura* spp. *
- Nemertea sp. 2 *
- Nemertea sp. 7
- Nemertea sp. 12 *
- Nemertea sp. 13 *
- Nemertea sp. 14
- Nemertea sp. 15 *
- *Tetrastemma vittatum* Verrill, 1874*
- *Tubulanus pellucidus* (Coe, 1895) *

ANNELIDA
- Polychaeta
  - Ampharetidae
    - *Ampharete acutifrons* Grube, 1860 *
    - *Ampharete finmarchica* (Sars, 1865) *
    - *Ampharete lindstroemi* Malmgren, 1867 *
    - *Amphicteis gunneri* (Sars, 1835)
    - *Anobothrus gracilis* (Malmgren, 1866) *
    - *Asabellides oculata* (Webster, 1879) *
    - *Melinna cristata* (Sars, 1851)
    - *Melinna elisabethae* McIntosh, 1914*
  - Amphinomidae
    - *Paramphinome jeffreysii* (McIntosh, 1868)
  - Aphroditidae
    - *Aphrodita hastata* Moore, 1905 *
  - Apistobranchidae
    - *Apistobranchus typicus* (Webster & Benedict, 1887) *
    - *Apistobranchus tullbergi* (Th$^{v}_{s}$el, 1879) *
      - (merged with *A. typicus* for report)
  - Capitellidae
    - *Amastigos caperatus* Ewing & Dauer, 1981
    - *Capitella capitata* complex (Fabricius, 1780) *
    - *Heteromastus filiformis* (Claparède, 1864) *
    - *Mediomastus californiensis* Hartman, 1944 *
  - Chaetopteridae
    - *Spiochaetopterus oculatus* Webster, 1879 *
  - Chrysopetalidae
    - *Dysponetus pygmaeus* Levinsen, 1879 *
  - Cirratulidae
    - *Aphelochaeta marioni* (Saint-Joseph, 1894) *
    - *Aphelochaeta monilaris* (Hartman, 1960) *
    - *Aphelochaeta* sp. 2 *
    - *Aphelochaeta* sp. 3 *
    - *Caulleriella* sp. B *
    - *Caulleriella* sp. C
    - *Chaetozone setosa* mb Malmgren, 1867 *
    - *Chaetozone vivipara* (Christie, 1985) *
    - *Chaetozone* sp. 4
      - (merged with *C. setosa* for report)
    - *Chaetozone* sp. 5
      - (merged with *C. setosa* for report)
    - *Cirratulus cirratus* (O.F. Müller, 1776) *
    - *Monticellina baptisteae* Blake, 1991 *
    - *Monticellina dorsobranchialis* (Kirkegaard, 1959) *
    - *Tharyx acutus* Webster & Benedict, 1887 *
  - Cossuridae
    - *Cossura longocirrata* Webster & Benedict, 1887 *
  - Dorvilleidae
    - *Dorvillea sociabilis* (Webster, 1879) *
    - *Ophryotrocha* cf. *labronica* La Greca & Bacci, 1962
    - *Ophryotrocha* sp. 1 *
    - *Ophryotrocha* sp. 2 *
    - *Parougia caeca* (Webster & Benedict, 1884) *
  - Flabelligeridae
    - *Brada incrustata* St□p Bowitz, 1948
    - *Brada villosa* (Rathke, 1843)*
    - *Diplocirrus hirsutus* (Hansen, 1979) *
    - *Diplocirrus longisetosus* (Marenzeller, 1890)
    - *Flabelligera affinis* Sars, 1829 *
    - *Pherusa affinis* (Leidy, 1855) *
    - *Pherusa plumosa* (O.F. Müller, 1776) *
  - Glyceridae
    - *Glycera americana* Leidy, 1855
    - *Glycera dibranchiata* Ehlers, 1868
  - Goniadidae
    - *Goniada maculata* Oersted, 1843 *
  - Hesionidae
    - *Gyptis* cf. *vittata* Webster & Benedict, 1887
    - *Microphthalmus nahantensis* Westheide & Rieger, 1987*
    - *Microphthalmus pettiboneae* Riser, 2000*
  - Lumbrineridae
    - *Abyssoninoe winsnesae* Frame, 1992*
    - *Lumbrinerides acuta* (Verrill, 1875) *
    - *Lumbrineris tenuis* (Verrill, 1873)
    - *Scoletoma fragilis* (O.F. M□ller, 1776) *

- *Scoletoma hebes* (Verrill, 1880) *
- *Scoletoma impatiens* (Clapar$^{v}_{s}$de, 1868)
- *Ninoe nigripes* Verrill, 1873 *
- *Paraninoe brevipes* (McIntosh, 1903) *

- Maldanidae
  - *Axiothella catenata* (Malmgren, 1865) *
  - *Clymenella torquata* (Leidy, 1855) *
  - *Clymenura polaris* (Th$^{v}_{s}$el, 1879
    (merged with *C.* sp. A for report)
  - *Clymenura* sp. A *
  - *Euclymene collaris* (Clapar$^{D}_{c}$de, 1870) *
  - *Euclymene* cf. *collaris* (Clapar$^{D}_{c}$de, 1870)
    (merged with *E. collaris* for report)
  - Euclymeninae sp. 1 *
  - *Maldane glebifex* Grube, 1860
    (merged with *M. sarsi* for report)
  - *Maldane sarsi* Malmgren, 1865 *
  - *Microclymene* sp. 1
  - *Petaloproctus tenuis* (Th$^{v}_{s}$el
  - *Praxillella affinis* (Sars, 1872)
  - *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
  - *Ceratocephale loveni* Malmgren, 1867
  - *Neanthes virens* Sars, 1835
  - *Nereis grayi* Pettibone, 1956 *
  - *Nereis zonata* Malmgren, 1867
  - *Websterinereis tridentata* Pettibone, 1971
- Oenonidae
  - *Drilonereis filum* (Clapar$^{v}_{s}$de, 1868)
  - *Drilonereis longa* Webster, 1879
  - *Drilonereis magna* Webster * Benedict, 1887
- Opheliidae
  - *Ophelina acuminata* Oersted, 1843 *
  - *Travisia carnea* Verrill, 1873
- Orbiniidae
  - *Leitoscoloplos acutus* (Verrill, 1873) *
  - *Leitoscoloplos* sp. B
  - *Orbinia swani* Pettibone, 1957 *
  - *Scoloplos 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) *
  - *Paradoneis armatus* Gl$^{v}_{s}$marec, 1966 *
  - *Paradoneis lyra* (Southern, 1914)
  - *Paraonis fulgens* (Levinsen, 1883)

- Pectinariidae
  - *Pectinaria gouldii* (Verrill, 1873)
  - *Pectinaria granulata* (Linnaeus, 1767) *
  - *Pectinaria hyperborea* (Malmgren, 1866)
- Pholoidae
  - *Pholoe minuta* (Fabricius, 1780) *
  - *Pholoe tecta* Stimpson, 1854 *
- Phyllodocidae
  - *Eteone flava* (Fabricius, 1780)
  - *Eteone foliosa* Quatrefages, 1865
  - *Eteone heteropoda* Hartman, 1951
  - *Eteone longa* (Fabricius, 1780) *
  - *Eteone spetsbergenesis* Malmgren, 1865
  - *Eulalia bilineata* (Johnston, 1840)
  - *Eulalia viridis* (Linnaeus, 1767)
  - *Eumida sanguinea* (Oersted, 1843)
  - *Mystides borealis* Th$^{v}_{s}$el, 1879 *
  - *Paranaitis speciosa* (Webster, 1870) *
  - *Phyllodoce arenae* Webster, 1879
  - *Phyllodoce groenlandica* Oersted, 1843 *
  - *Phyllodoce maculata* (Linnaeus, 1767) *
  - *Phyllodoce mucosa* Oersted, 1843 *
- Pilargiidae
  - *Ancistrosyllis groenlandica* McIntosh, 1879
- Polygordiidae
  - *Polygordius* sp. A *
- Polynoidae
  - *Arcteobia anticostiensis* (McIntosh, 1874) *
  - *Austrolaenilla mollis* (Sars, 1872)
  - *Bylgides elegans* The$^{v}_{s}$l, 1879
  - *Bylgides groenlandicus* Malmgren, 1867
  - *Bylgides sarsi* (Kinberg, 1865)
  - *Enipo gracilis* Verrill, 1874
  - *Enipo torelli* (Malmgren, 1865) *
  - *Gattyana amondseni* (Malmgren, 1867)*
  - *Gattyana cirrosa* (Pallas, 1766) *
  - *Harmothoe extenuata* (Grube, 1840) *
  - *Harmothoe imbricata* (Linnaeus, 1767) *
  - *Hartmania moorei* Pettibone, 1955 *
  - *Hesperonoe* sp. 1 *
- Psammodrilidae
  - *Psammodrilus balanoglossoides* Swedmark, 1952
- Sabellidae
  - *Chone duneri* (Malmgren, 1867) *
  - *Chone infundibuliformis* Kr□yer, 1856
  - *Chone* cf. *magna* (Moore, 1923) *
  - *Euchone elegans* Verrill, 1873 *
  - *Euchone incolor* Hartman, 1978 *
  - *Euchone papillosa* (Sars, 1851) *
  - *Laonome kroeyeri* Malmgren, 1866 *
  - *Myxicola infundibulum* (Renier, 1804) *
  - *Potamilla neglecta* (Sars, 1851)
  - *Pseudopotamilla reniformis* (Linnaeus, 1788)
- Scalibregmatidae
  - *Scalibregma inflatum* Rathke, 1843 *
- Sigalionidae
  - *Sthenelais limicola* (Ehlers, 1864)
- Sphaerodoridae
  - *Amacrodorum bipapillatum* Kudenov, 1987 *

Sphaerodoridium sp. A *
Sphaerodoridium claparedii Greeff, 1866
Sphaerodoropsis sp. 1 *

Spionidae
Dipolydora caulleryi Mesnil, 1897 *
Dipolydora quadrilobata Jacobi, 1883 *
Dipolydora socialis (Schmarda, 1861) *
Laonice cirrata (Sars, 1851) *
Laonice sp. 1
(merged with *L. cirrata* for report)
Polydora aggregata Blake, 1969
Polydora cornuta Bosc, 1802 *
Prionospio aluta Maciolek, 1985 *
Prionospio cirrifera Wiren, 1883 *
Prionospio steenstrupi Malmgren, 1867 *
Pygospio elegans Calparède, 1863
Scolelepis bousfieldi Pettibone, 1963
Scolelepis foliosa (Auduoin & Milne-Edwards, 1833 *
Scolelepis squamata (O.F. M□ller, 1806)
Scolelepis texana Foster, 1971 *
Spio filicornis (O.F.Müller, 1766) *
Spio limicola Verrill, 1880 *
Spio setosa Verrill, 1873
Spio thulini Maciolek, 1990 *
Spiophanes bombyx Claparède, 1870 *
Spiophanes kroeyeri Grube, 1960 *
Streblospio benedicti Webster, 1879 *
Sternaspidae
Sternaspis scutata (Otto, 1821) *
Syllidae
Exogone hebes (Webster & Benedict, 1884) *
Exogone longicirris (Webster & Benedict, 1887)
*
Exogone verugera (Claparède, 1868) *
Exogone sp. A
Odontosyllis fulgurans Claparᵛₛde, 1864
Parapionosyllis longicirrata (Webster & Benedict, 1884) *
Pionosyllis sp. A *
Proceraea cornuta Agassiz, 1863
Sphaerosyllis erinaceus Claparᵛₛde, 1863 *
Streptosyllis cf. *pettiboneae* Perkins, 1981
Syllides convoluta Webster & Benedict, 1884
Syllides japonica Imajima, 1966 *
Syllides longocirrata Oersted, 1845 *
Typosyllis alternata (Moore, 1908)
Typosyllis cornuta Rathke, 1843
Typosyllis hyalina (Grube, 1863) *
Terebellidae
Amphitrite cirrata O.F. M□ller, 1771
Lanassa venusta venusta (Malm, 1874) *
Nicolea zostericola (Oersted, 1844)
Pista cristata (O.F. Müller, 1776) *
Polycirrus eximus (Leidy, 1855) *
Polycirrus phosphoreus Verrill, 1880 *
Polycirrus medusa Grube, 1850 *
Proclea graffii (Langerhans, 1880)
Proclea sp. 1 *
(merged with *P. graffii* for report)
Trichobranchidae
Terebellides atlantis Williams, 1984
Terebellides stroemii Sars, 1835
Trichobranchus glacialis Malmgren, 1866)
Trichobranchus roseus (Malm, 1874) *

Trochochaetidae
Trochochaeta carica (Birula, 1897) *
Trochochaeta multisetosa (Oersted, 1844) *
Trochochaeta watsoni (Fauvel, 1916)
Oligochaeta
Enchytraiedae
Enchytraiedae sp. 1 *
Enchytraiedae sp. 2
Enchytraiedae sp. 3
Grania postclitellochaeta longiducta *
Tubificidae
Adelodrilus sp. 1 *
Adelodrilus sp. 2 *
Tubificidae sp. 2 *
Tubificidae sp. 4
Tubificoides apectinatus Brinkhurst, 1965 *
Tubificoides nr. *pseudogaster* Dahl, 1960
Tubificoides sp. 1
Tubificoides sp. 2 *
Tubificoides sp. 3

ARTHROPODA

CRUSTACEA
Amphipoda
Ampeliscidae
Ampelisca abdita Mills, 1964 *
Ampelisca macrocephala Lilljeborg, 1852 *
Ampelisca vadorum Mills, 1963
Byblis gaimardi (Krøyer, 1847)
Byblis cf. *gaimardi* (Krøyer, 1847) *
Haploops fundiensis Wildish & Dickinson, 1982 *
Amphilochidae
Gitanopsis arctica Sars, 1895 *
Ampithoidae
Ampithoe rubricata (Montagu, 1808)
Aoridae
Leptocheirus pinguis (Stimpson, 1853) *
Pseudunciola obliquua (Shoemaker, 1949) *
Unciola inermis Shoemaker, 1942 *
Unciola irrorata Say, 1818 *
Argissidae
Argissa hamatipes (Norman, 1869) *
Caprellidae
Aeginina longicornis (Krøyer, 1842-43) *
Caprella linearis (Linnaeus, 1767)
Mayerella limicola Huntsman, 1915 *
Paracaprella tenuis Mayer, 1903
Corophiidae
Crassicorophium crassicorne (Bruzelius, 1859) *
Monocorophium acherusicum (Costa, 1857)
Monocorophium insidiosum (Crawford, 1937)
Monocorophium tuberculatum (Shoemaker, 1934)
Gammaridae
Gammarelluss angulosus (Rathke, 1843)
Haustoriidae

Acanthohaustorius millsi Bousfield, 1965 *
Acanthohaustorius spinosus Bousfield, 1962 *
Pseudohaustorius borealis Bousfield, 1965 *
Isaeidae
Photis pollex Walker, 1895 *
Photis reinhardi Krøyer, 1842
Protomedeia fasciata Krøyer, 1846 *
Ischyroceridae
Erichthonius fasciatus (Stimpson, 1853) *
Ischyrocerus anguipes (Krøyer, 1842)
Jassa marmorata Holmes, 1903
Lysianassidae
Anonyx lilljeborgi Boeck, 1871*
Hippomedon propinquus Sars, 1895 *
Hippomedon serratus Holmes, 1905 *
Orchomenella minuta (Krøyer, 1842)
Melitidae
Casco bigelowi (Blake, 1929) *
Maera loveni (Bruzelius, 1859)
Megamoera dentata (Krøyer, 1842)
Melitidae sp. 1 *
Oedicerotidae
Ameroculodes sp. 1 *
Bathymedon obtusifrons (Hansen, 1887) *
Deflexilodes intermedius (Shoemaker, 1830) *
Deflexilodes tesselatus (Schneider, 1884) *
Deflexilodes tuberculatus (Boeck, 1870) *
Monoculodes packardi Boeck, 1871 *
Westwoodilla brevicalcar Goˢ₂s, 1866 *
Phoxocephalidae
Eobrolgus spinosus (Holmes, 1905)
Harpinia propinqua Sars, 1895 *
Phoxocephalus holbolli (Krøyer, 1842) *
Rhepoxinius hudsoni Barnard & Barnard, 1982 *
Pleustidae
Parapleustes gracilis Buchholz, 1874
Pleustes panoplus (Krøyer, 1838)
Pleusymtes glaber (Boeck, 1861) *
Stenopleustes inermis Shoemaker, 1949 *
Podoceridae
Dulichia tuberculata Boeck, 1870 *
Dyopedos monacanthus (Metzger, 1875) *
Paradulichia typica Boeck, 1870 *
Pontogeniidae
Pontogenia inermis (Krøyer, 1842)
Stenothoidae
Metopella angusta Shoemaker, 1949 *
Proboloides holmesi Bousfield, 1973
Synopiidae
Syrrhoe sp. 1 *
Cumacea
Bodobriidae
Pseudoleptocuma minor (Calman, 1912)
Diastylidae
Diastylis cornuifer (Blake, 1929) *
Diastylis polita (S.I. Smith, 1879)
Diastylis quadrispinosa (Sars, 1871) *
Diastylis sculpta Sars, 1871 *
Leptostylis cf. *ampullacea* (Lilljeborg, 1855)
Leptostylis longimana (Sars, 1865) *
Lampropidae
Lamprops quadriplicata S.I. Smith, 1879
Leuconidae
Eudorella hirsuta Sars, 1869
Eudorella hispida Sars, 1871 *
Eudorella pusilla Sars, 1871 *
Eudorellopsis deformis (Krøyer, 1842) *
Leucon acutirostris Sars, 1865 *
Leucon fulvus Sars, 1865 *
Nannastacidae
Campylaspis rubicunda (Lilljeborg, 1855) *
Campylaspis nr. *sulcata* Sars, 1869) *
Pseudocumatidae
Petalosarsia declivis (Sars, 1865) *

Decapoda
Anomura
Axiidae
Axius serratus Stimpson, 1852 *
Brachyura
Cancridae
Cancer borealis Stimpson, 1859
Caridea
Crangonidae
Crangon septemspinosa Say, 1818 *
Paguridae
Pagurus acadianus Benedict, 1901
Decapoda sp. 1

Isopoda
Anthuriidae
Ptilanthura tenuis Harger, 1879 *
Chaetiiidae
Chiridotea tuftsi (Stimpson, 1883) *
Cirolanidae
Politolana polita (Stimpson, 1853) *
Gnathiidae
Gnathia cerina (Harger,
Idoteidae
Idotea baltica (Pallas, 1772)
Edotia montosa (Stimpson, 1853) *
Edotia triloba (Say, 1818)
Joeropsididae
Joeropsis bifasciatus Kensley, 1984
Munnidae
Munna sp. 1 *
Munnopsidae
Baeonectes muticus (Sars, 1864) *
Paramunnidae
Pleurogonium inerme Sars, 1882 *
Pleurogonium rubicundum (Sars, 1863) *
Pleurogonium spinosissimum (Sars, 1866) *

Mysidacea
Erythrops erythrophthalma (Gᴬ₀es, 1863 *
Mysis mixta Lilljeborg, 1852
Neomysis americana (S.I. Smith, 1873) *

Tanaidacea
Nototanaidae
Tanaissus psammophilus (Wallace, 1919) *

- MOLLUSCA
  - Aplacophora
    - Chaetodermatidae
      - *Chaetoderma nitidulum canadense* (Nierstrasz, 1902) *
  - Bivalvia
    - Anomiidae
      - *Anomia simplex* Orbigny, 1842
      - *Anomia squamula* Linnaeus, 1758
    - Arcidae
      - *Arctica islandica* (Linnaeus, 1767) *
    - Astartidaeᵛₛ
      - *Astarte borealis* (Schumacher, 1817) *
      - *Astarte undata* Gould, 1841 *
    - Cardiidae
      - *Cerastoderma pinnulatum* (Conrad, 1831) *
    - Carditidae
      - *Cyclocardia borealis* (Conrad, 1831) *
    - Hiatellidae
      - *Cyrtodaria siliqua* (Spengler, 1793) *
      - *Hiatella arctica* (Linnaeus, 1767) *
    - Lyonsiidae
      - *Lyonsia arenosa* Möller, 1842 *
    - Mactridae
      - *Mulinia lateralis* (Say, 1822)
      - *Spisula solidissima* (Dillwyn, 1817)
    - Montacutidae
      - *Pythinella cuneata* Dall, 1899 *
    - Myidae
      - *Mya arenaria* Linnaeus, 1758 *
    - Mytilidae
      - *Crenella decussata* (Montagu, 1808) *
      - *Crenella glandula* (Totten, 1834) *
      - *Musculus discors* (Linnaeus, 1767)
      - *Musculus niger* (Gray, 1824) *
    - Nuculanidae
      - *Megayoldia thraciaeformis* (Storer, 1838) *
      - *Nuculana messanensis* (Sequenza, 1877)
      - *Nuculana pernula* (M□ller, 1771) *
      - *Yoldia sapotilla* (Gould, 1841) *
      - *Yoldiella lucida* Lovᵛₛn, 1846
    - Nuculidae
      - *Nucula annulata* Hampson, 1971 *
      - *Nucula delphinodonta* Mighels & Adams, 1842 *
      - *Nuculoma tenuis* (Montagu, 1808) *
    - Pandoridae
      - *Pandora glacialis* Leach, 1819
      - *Pandora gouldiana* Dall, 1886
      - *Pandora* nr. *inflata* Boss * Merrill, 1965 *
    - Pectinidae
      - *Placopectin magellanicus* (Gmelin, 1791) *
    - Periplomatidae
      - *Periploma fragile* (Totten, 1835) *
      - *Periploma papyratium* (Say, 1822) *
    - Solenidae
      - *Ensis directus* Conrad, 1843 *
      - *Siliqua costata* Say, 1822 *
    - Tellinidae
      - *Macoma balthica* (Linnaeus, 1758) *
      - *Tellina agilis* Stimpson, 1857
    - Thraciidae
      - *Asthenothaerus hemphilli* Dall, 1886
      - *Thracia conradi* Couthouy, 1838 *
    - Thyasiridae
      - *Thyasira gouldi* Philippi, 1845 *
      - *Thyasira* nr. *minutus* (Verrill & Bush, 1898)
    - Veneridae
      - *Pitar morrhuanus* Linsley, 1848 *
  - Gastropoda
    - Nudibranchia
      - Corambidae
        - *Doridella obscura* Verrill, 1870
    - Ophisthobranchia
      - Acteocinidae
        - *Acteocina canaliculata* (Say, 1822)
      - Cylichnidae
        - *Cylichana alba* (Brown, 1827) *
        - *Cylichna gouldi* (Couthouy, 1839) *
      - Diaphanidae
        - *Diaphana minuta* (Brown, 1827) *
      - Retusidae
        - *Retusa obtusa* (Montagu, 1807) *
    - Prosobranchia
      - Buccinidae
        - *Colus parvus* (Verrill & Smith, 1882) *
        - *Colus pubescens* (Verrill, 1882)
        - *Colus pygmaeus* (Gould, 1841) *
      - Epitoniidae
        - *Epitonium greenlandicum* (Perry, 1811)
      - Lacunidae
        - *Lacuna vincta* (Montagu, 1803)
      - Melanellidae
        - *Couthouyella striatula* (Couthouy, 1839)
      - Nassariidae
        - *Ilyanassa trivittata* (Say, 1822) *
      - Naticidae
        - *Euspira heros* (Say, 1822) *
        - *Euspira immaculata* (Totten, 1835)
        - *Euspira triseriata* (Say, 1826)
        - *Polinices pallidus* Broderip & Sowerby, 1829
      - Pyramidellidae
        - *Boonea impressa* (Say, 1821)
        - *Fargoa gibbosa* (Bush, 1909)
        - *Odostomia sulcosa* (Miaghels, 1843) *
      - Rissoidae
        - *Onoba mighelsi* (Stimpson, 1851) *
        - *Onoba pelagica* (Stimpson, 1851) *
        - *Pusillina harpa* (Verrill, 1880) *
        - *Pusillina pseudoareeolata* (Warᵛₛn, 1974)
      - Skeneopsidae
        - *Skeneopsis planorbis* (Fabricius, 1780)
      - Trochidae

Moelleria costulata (Mᴬₒller, 1842)
Solariella obscura (Couthouy, 1838) *
Turridae
Oenopota cf. *cancellatus* (Mighels & C.B.
Adams,
1842)
Oenopota harpularia (Couthouy, 1838)
Oenopota incisula Verrill, 1882 *
Oenopota pyramidalis (Strᴬₒm, 1788) *
Propebela exarata (Mᴬₒller, 1842) *
Propeleba turricula (Montagu, 1803) *
Scaphopoda
Dentaliidae
Dentalium entale Linnaeus, 1758 *
SIPUNCULA
Nephasoma diaphanes (Gerould, 1913)
Phascolion strombi (Montagu, 1804)*

ECHIURA
Echiurus echiurus (Pallas, 1767)

PRIAPULA
Priapulus caudata Lamarck, 1816 *

PHORONIDA
Phoronis architecta Andrews, 1890 *

ECHINODERMATA
Asteroidea
Ctenodiscus crispatus (Retzius, 1805) *
Henricia sanguinolenta (O.F. M□ller, 1776) *
<u>*Leptasterias tenera* (Stimpson, 1862) *</u>
Echinoidea
Echinarachnius parma (Lamarck, 1816) *
Holothuroidea
Molpadia oolitica (Pourtalᵛₛs, 1851)
Ophiuroidea
Axiognathus squamatus (Delle Chiaje, 1828)
Ophiocten sericeum (Forbes, 1852)
<u>*Ophiopholis aculeata* (Linnarus, 1788) *</u>
Ophiothrix angulata (Say, 1825
Ophiura robusta (Ayres, 1851)
Ophiura sarsi Lutken, 1855 *
Ophiura sp. 2

HEMICHORDATA
Harrimaniidae
Stereobalanus canadensis (Spengel, 1893) *

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

APPENDIX D3

Benthic Infaunal Community Parameters

Table D3-1. Benthic community parameters for all stations, 2002.

Nearfield Stations							
		Abundance of		**Number of Species**			
Station	**Rep**	**Total Indiv.**	**Good Species**		**H'**	**J'**	**LSA**
FF10	1	747	778	55	3.84	0.66	13.69
FF10	2	2814	2861	83	3.45	0.54	16.05
FF10	3	3160	3228	88	3.56	0.55	16.78
FF12	1	2446	2487	54	3.08	0.54	9.77
FF12	2	3105	3130	52	2.94	0.52	8.87
FF12	3	3083	3113	55	2.98	0.52	9.51
FF13	1	5109	5160	60	3.26	0.55	9.55
FF13	2	5088	5219	65	3.24	0.54	10.51
FF13	3	7083	7371	66	3.16	0.52	10.06
NF02	1	1909	1928	64	3.15	0.53	12.76
NF04	1	3036	3074	97	4.02	0.61	19.12
NF05	1	817	854	84	5.02	0.79	23.48
NF07	1	3685	3764	72	3.32	0.54	12.69
NF08	1	3457	3530	91	4.37	0.67	17.13
NF09	1	2362	2404	77	3.98	0.63	15.25
NF10	1	3833	3887	84	3.77	0.59	15.17
NF12	1	3965	4026	62	3.43	0.58	10.43
NF12	2	2828	2860	67	3.44	0.57	12.31
NF12	3	3255	3293	70	3.51	0.57	12.59
NF13	1	1939	2022	84	4.74	0.74	17.89
NF14	1	3102	3125	84	4.24	0.66	15.92
NF15	1	4831	4869	86	3.52	0.55	14.86
NF16	1	4516	4559	74	3.42	0.55	12.57
NF17	1	715	830	65	4.98	0.83	17.37
NF17	2	1994	2047	61	3.49	0.59	11.90
NF17	3	806	851	68	4.41	0.72	17.71
NF18	1	3409	3441	94	3.09	0.47	17.89
NF19	1	4003	4019	68	3.06	0.50	11.64
NF20	1	3876	3914	79	3.04	0.48	14.05
NF21	1	4228	4273	83	3.34	0.52	14.64
NF22	1	3367	3413	73	3.48	0.56	13.16
NF23	1	1684	1733	77	4.44	0.71	16.64
NF24	1	6081	6299	81	3.30	0.52	13.20
NF24	2	5604	5664	83	2.94	0.46	13.82
NF24	3	7518	7625	81	3.08	0.49	12.68

Table D3-1 continued. Benthic community parameters for all stations, 2002.

Farfield Stations

		Abundance		Number of Species			
Station	**Rep**	**Total**	**Species**		**H'**	**J'**	**LSA**
FF01A	1	3020	2959	85	3.11	0.49	16.33
FF01A	2	1548	1537	64	3.69	0.61	13.49
FF01A	3	2506	2466	75	2.94	0.47	14.61
FF04	1	1349	1301	62	4.36	0.73	13.55
FF04	2	1883	1837	63	4.18	0.70	12.63
FF04	3	1438	1392	62	4.36	0.73	13.31
FF05	1	2248	2217	82	4.53	0.71	16.76
FF05	2	1763	1710	78	4.65	0.74	16.85
FF05	3	1693	1628	74	4.46	0.72	15.97
FF06	1	368	360	50	4.30	0.76	15.77
FF06	2	761	746	62	4.56	0.77	16.06
FF06	3	343	331	54	4.93	0.86	18.32
FF07	1	2470	2430	53	2.77	0.48	9.56
FF07	2	2903	2890	50	2.98	0.53	8.59
FF07	3	3551	3539	48	2.63	0.47	7.85
FF09	1	2325	2231	95	4.07	0.62	20.14
FF09	2	1864	1781	105	4.42	0.66	24.40
FF09	3	1719	1661	90	4.28	0.66	20.40
FF11	1	3744	3672	82	3.53	0.56	14.87
FF11	2	3170	3124	77	3.55	0.57	14.28
FF11	3	1754	1729	69	3.77	0.62	14.38
FF14	1	334	330	52	4.69	0.82	17.35
FF14	2	479	475	53	4.75	0.83	15.28
FF14	3	846	825	65	4.78	0.79	16.54

Table D3-2. Benthic community parameters for all nearfield stations, 1992—2001.

			Abundance of		Number of Species			
Year	Station	Rep	Total	Species		H'	J'	LSA
1992	FF10	1	3961	3642	83	4.19	0.66	15.12
1992	FF10	2	3890	3527	91	4.58	0.70	17.05
1992	FF10	3	4027	3758	82	4.52	0.71	14.80
1992	FF12	1	1594	1559	54	3.70	0.64	10.86
1992	FF12	2	2149	2098	59	3.56	0.61	11.28
1992	FF12	3	2835	2816	56	3.37	0.58	9.91
1992	FF13	1	1172	1149	52	3.57	0.63	11.21
1992	FF13	2	407	405	34	3.63	0.71	8.84
1992	FF13	3	1395	1355	51	3.65	0.64	10.47
1992	NF01	1	1116	1077	59	4.20	0.71	13.42
1992	NF02	1	692	660	47	4.12	0.74	11.57
1992	NF03	1	3240	3100	69	3.95	0.65	12.51
1992	NF04	1	997	755	48	3.66	0.66	11.41
1992	NF05	1	2927	2860	92	3.68	0.56	18.16
1992	NF06	1	3721	3331	66	2.80	0.46	11.67
1992	NF07	1	5800	5644	84	3.40	0.53	14.00
1992	NF08	1	1349	1261	31	2.71	0.55	5.75
1992	NF09	1	2354	2294	81	4.22	0.67	16.36
1992	NF10	1	2113	1827	56	3.74	0.64	10.93
1992	NF11	1	1666	1573	71	3.68	0.60	15.29
1992	NF12	1	1198	1162	54	3.67	0.64	11.72
1992	NF13	1	1587	1272	64	3.87	0.65	14.20
1992	NF14	1	2417	2313	73	4.05	0.65	14.34
1992	NF15	1	2769	2694	64	3.71	0.62	11.77
1992	NF16	1	1321	1261	49	3.53	0.63	10.14
1992	NF17	1	674	624	51	4.36	0.77	13.14
1992	NF18	1	1904	1821	76	4.17	0.67	16.03
1992	NF19	1	4283	3998	77	3.55	0.57	13.53
1992	NF20	1	1306	1273	48	3.32	0.59	9.86
1993	FF10	1	1412	1124	66	4.47	0.74	15.32
1993	FF10	2	1414	1313	63	4.44	0.74	13.80
1993	FF10	3	2181	1988	72	4.62	0.75	14.64
1993	FF12	1	1318	973	41	3.40	0.64	8.67
1993	FF12	2	837	823	35	2.81	0.55	7.42
1993	FF12	3	1442	1428	42	2.59	0.48	8.11
1993	FF13	1	1479	1450	42	3.05	0.57	8.08
1993	FF13	2	943	916	39	3.30	0.62	8.27
1993	FF13	3	1696	1657	43	3.25	0.60	8.07
1993	NF02	1	712	597	45	2.67	0.49	11.29
1993	NF02	2	1775	1628	49	2.19	0.39	9.52
1993	NF02	3	511	492	35	3.00	0.59	8.62
1993	NF04	1	757	706	50	4.06	0.72	12.29
1993	NF04	2	571	546	53	3.80	0.66	14.50
1993	NF04	3	1220	1123	58	3.80	0.65	12.97

			Abundance of		Number of Species			
Year	Station	Rep	Total	Species		H'	J'	LSA
1993	NF08	1	5024	4929	49	2.48	0.44	7.56
1993	NF08	2	3506	3489	43	2.31	0.43	6.91
1993	NF08	3	2881	2855	48	2.75	0.49	8.20
1993	NF09	1	964	935	44	3.94	0.72	9.58
1993	NF09	2	1443	1385	64	4.06	0.68	13.87
1993	NF09	3	1045	988	53	3.98	0.69	11.98
1993	NF10	1	1303	1249	57	3.94	0.68	12.31
1993	NF10	2	904	872	48	3.54	0.63	10.93
1993	NF10	3	1753	1695	57	3.55	0.61	11.38
1993	NF12	1	1354	1319	51	3.74	0.66	10.54
1993	NF12	2	1356	1327	46	3.35	0.61	9.25
1993	NF12	3	2380	2323	50	3.29	0.58	9.00
1993	NF14	1	1133	1070	43	3.79	0.70	8.98
1993	NF14	2	621	572	45	4.24	0.77	11.45
1993	NF14	3	895	846	54	4.13	0.72	12.85
1993	NF16	1	630	593	40	3.72	0.70	9.68
1993	NF16	2	1043	989	52	3.84	0.67	11.69
1993	NF16	3	1217	1169	60	4.21	0.71	13.39
1993	NF17	1	148	135	25	3.61	0.78	9.03
1993	NF17	2	159	132	22	3.83	0.86	7.54
1993	NF17	3	362	327	27	2.33	0.49	6.98
1994	FF10	1	1670	1600	66	4.25	0.70	13.88
1994	FF10	2	3289	3238	79	3.86	0.61	14.62
1994	FF10	3	3363	3311	86	4.07	0.63	16.14
1994	FF12	1	434	361	31	3.87	0.78	8.12
1994	FF12	2	1040	986	37	3.61	0.69	7.59
1994	FF12	3	712	668	39	3.29	0.62	9.03
1994	FF13	1	1648	1614	53	3.72	0.65	10.52
1994	FF13	2	1728	1716	47	3.69	0.66	8.93
1994	FF13	3	1209	1188	42	3.32	0.62	8.49
1994	NF02	1	1860	1816	60	3.61	0.61	11.92
1994	NF04	1	1248	1192	43	3.08	0.57	8.73
1994	NF05	1	771	720	47	3.63	0.65	11.26
1994	NF07	1	1444	1289	52	3.06	0.54	10.87
1994	NF08	1	2202	2153	46	2.96	0.53	8.26
1994	NF09	1	1825	1792	45	3.22	0.59	8.38
1994	NF10	1	2964	2886	62	3.09	0.52	11.15
1994	NF12	1	2664	2619	53	2.97	0.52	9.41
1994	NF12	2	3248	3197	55	3.15	0.54	9.44
1994	NF12	3	3113	3019	55	3.48	0.60	9.55
1994	NF13	1	1903	1818	54	3.40	0.59	10.46
1994	NF14	1	1871	1683	63	3.88	0.65	12.92
1994	NF15	1	1754	1586	65	4.53	0.75	13.64
1994	NF16	1	453	390	38	3.63	0.69	10.41
1994	NF17	1	2286	2159	57	2.96	0.51	10.74

			Abundance of		Number of Species			
Year	Station	Rep	Total	Species		H'	J'	LSA
1994	NF17	2	2281	2219	47	2.12	0.38	8.43
1994	NF17	3	1324	1222	39	2.34	0.44	7.68
1994	NF18	1	1655	1523	73	4.38	0.71	15.98
1994	NF19	1	1289	1163	65	4.58	0.76	14.87
1994	NF20	1	439	372	37	4.18	0.80	10.21
1994	NF21	1	2521	2476	55	3.43	0.59	9.96
1994	NF22	1	4296	4240	72	3.46	0.56	12.32
1994	NF23	1	2068	1777	74	4.42	0.71	15.60
1994	NF24	1	4358	4249	70	3.04	0.50	11.90
1994	NF24	2	3068	2987	68	3.10	0.51	12.39
1994	NF24	3	2066	2003	52	3.22	0.56	9.76
1995	FF10	1	2225	1988	86	4.67	0.73	18.31
1995	FF10	2	1830	1611	75	4.37	0.70	16.29
1995	FF10	3	1811	1578	73	4.20	0.68	15.83
1995	FF12	1	2299	2247	59	3.81	0.65	11.10
1995	FF12	2	2888	2851	67	3.91	0.64	12.29
1995	FF12	3	2408	2327	58	3.63	0.62	10.78
1995	FF13	1	863	769	32	2.79	0.56	6.74
1995	FF13	2	1213	1167	44	2.80	0.51	9.04
1995	FF13	3	1199	1164	48	3.29	0.59	10.09
1995	NF02	1	3492	3365	67	3.64	0.60	11.85
1995	NF04	1	1004	872	59	3.99	0.68	14.30
1995	NF05	1	2219	2070	77	4.19	0.67	15.76
1995	NF07	1	1942	1882	81	4.25	0.67	17.22
1995	NF08	1	2366	2301	50	3.38	0.60	9.02
1995	NF09	1	1810	1698	70	4.14	0.68	14.72
1995	NF10	1	2105	1928	67	3.74	0.62	13.48
1995	NF12	1	2288	2207	67	3.85	0.63	13.04
1995	NF12	2	2026	1893	61	3.56	0.60	12.05
1995	NF12	3	2265	2126	60	3.79	0.64	11.48
1995	NF13	1	1383	1149	48	3.88	0.69	10.13
1995	NF14	1	2248	2091	75	3.49	0.56	15.21
1995	NF15	1	2425	2298	67	4.14	0.68	12.92
1995	NF16	1	1897	1756	71	4.11	0.67	14.85
1995	NF17	1	817	724	41	3.32	0.62	9.41
1995	NF17	2	1061	843	56	4.02	0.69	13.49
1995	NF17	3	759	682	38	3.52	0.67	8.68
1995	NF18	1	1437	1313	84	3.91	0.61	20.00
1995	NF19	1	2609	2427	78	4.10	0.65	15.39
1995	NF20	1	2306	2189	64	3.76	0.63	12.35
1995	NF21	1	1858	1658	70	4.16	0.68	14.81
1995	NF22	1	2034	1887	51	3.82	0.67	9.66
1995	NF23	1	2569	2151	80	4.38	0.69	16.37
1995	NF24	1	734	688	51	3.87	0.68	12.72
1995	NF24	2	1462	1371	62	3.87	0.65	13.36

			Abundance of		Number of Species			
Year	Station	Rep	Total	Species		H'	J'	LSA
1995	NF24	3	1970	1853	63	3.86	0.65	12.61
1996	FF10	1	2716	2591	84	4.51	0.71	16.61
1996	FF10	2	2065	1953	79	4.66	0.74	16.52
1996	FF10	3	1939	1842	83	4.57	0.72	17.87
1996	FF12	1	3295	3193	75	3.97	0.64	13.76
1996	FF12	2	2682	2539	66	3.54	0.59	12.39
1996	FF12	3	3290	3207	63	3.64	0.61	11.11
1996	FF13	1	2474	2421	51	3.84	0.68	9.13
1996	FF13	2	1964	1941	54	3.67	0.64	10.30
1996	FF13	3	2713	2667	57	4.30	0.74	10.24
1996	NF02	1	2544	2467	70	4.06	0.66	13.41
1996	NF04	1	1955	1865	58	2.82	0.48	11.36
1996	NF05	1	1603	1509	92	4.58	0.70	21.59
1996	NF07	1	1476	1408	74	4.40	0.71	16.63
1996	NF08	1	1443	1338	49	3.47	0.62	9.99
1996	NF09	1	1755	1601	76	4.50	0.72	16.60
1996	NF10	1	1680	1599	64	3.77	0.63	13.35
1996	NF12	1	2156	2085	71	4.02	0.65	14.21
1996	NF12	2	2097	2026	68	3.90	0.64	13.56
1996	NF12	3	2751	2600	73	4.14	0.67	13.95
1996	NF13	1	1639	1584	57	3.35	0.57	11.57
1996	NF14	1	2124	2032	75	3.67	0.59	15.32
1996	NF15	1	1660	1601	69	3.72	0.61	14.68
1996	NF16	1	1481	1397	62	4.33	0.73	13.29
1996	NF17	1	1638	1448	69	3.94	0.64	15.08
1996	NF17	2	1381	1188	55	2.91	0.50	11.93
1996	NF17	3	1925	1740	64	4.28	0.71	13.06
1996	NF18	1	1810	1675	81	4.29	0.68	17.78
1996	NF19	1	2458	2349	98	4.48	0.68	20.67
1996	NF20	1	2904	2809	83	4.05	0.64	16.05
1996	NF21	1	1437	1346	67	4.32	0.71	14.82
1996	NF22	1	2944	2766	72	3.96	0.64	13.52
1996	NF23	1	3621	3314	83	4.44	0.70	15.45
1996	NF24	1	1767	1697	67	3.80	0.63	13.93
1996	NF24	2	1561	1461	73	3.92	0.63	16.17
1996	NF24	3	1446	1353	58	3.69	0.63	12.32
1997	FF10	1	1513	1412	78	4.83	0.77	17.78
1997	FF10	2	3213	3110	91	4.28	0.66	17.56
1997	FF10	3	3603	3399	106	4.62	0.69	20.77
1997	FF12	1	3967	3912	76	3.63	0.58	13.38
1997	FF12	2	4089	4023	70	3.55	0.58	12.04
1997	FF12	3	4120	4075	71	3.63	0.59	12.21
1997	FF13	1	4244	4160	60	2.38	0.40	9.93
1997	FF13	2	4820	4719	59	2.47	0.42	9.50
1997	FF13	3	3519	3462	58	2.61	0.45	9.90

			Abundance of		Number of Species			
Year	Station	Rep	Total	Species		H'	J'	LSA
1997	NF02	1	2057	1811	75	4.04	0.65	15.79
1997	NF04	1	3516	3412	92	4.04	0.62	17.41
1997	NF05	1	1712	1598	97	4.92	0.75	22.73
1997	NF07	1	810	785	50	3.95	0.70	11.89
1997	NF08	1	2780	2715	84	3.46	0.54	16.43
1997	NF09	1	3167	3078	78	4.54	0.72	14.56
1997	NF10	1	4029	3741	78	4.05	0.64	13.94
1997	NF12	1	2592	2508	76	4.15	0.66	14.79
1997	NF12	2	3928	3756	87	4.26	0.66	15.91
1997	NF12	3	2928	2695	86	4.28	0.67	16.94
1997	NF13	1	1347	1314	50	2.94	0.52	10.29
1997	NF14	1	3472	3408	79	4.34	0.69	14.45
1997	NF15	1	3845	3648	82	4.16	0.65	14.90
1997	NF16	1	2087	2063	63	3.46	0.58	12.28
1997	NF17	1	455	430	45	3.45	0.63	12.66
1997	NF17	2	736	640	53	4.20	0.73	13.72
1997	NF17	3	985	829	51	3.62	0.64	12.00
1997	NF18	1	3031	2848	114	4.38	0.64	23.78
1997	NF19	1	2831	2742	77	3.87	0.62	14.71
1997	NF20	1	3442	3383	74	3.00	0.48	13.36
1997	NF21	1	1503	1428	76	4.25	0.68	17.14
1997	NF22	1	2357	2295	73	4.11	0.66	14.37
1997	NF23	1	2801	2728	92	3.80	0.58	18.37
1997	NF24	1	2326	2291	71	3.37	0.55	13.89
1997	NF24	2	835	756	55	2.56	0.44	13.64
1997	NF24	3	1174	1137	56	3.35	0.58	12.35
1998	FF10	1	3326	3154	96	4.09	0.62	18.70
1998	FF10	2	2080	1918	88	3.95	0.61	19.04
1998	FF10	3	3115	2995	92	4.24	0.65	17.96
1998	FF12	1	3006	2801	66	3.33	0.55	12.12
1998	FF12	2	2694	2540	61	3.21	0.54	11.25
1998	FF12	3	1823	1743	53	3.17	0.55	10.32
1998	FF13	1	2846	2760	54	2.51	0.44	9.52
1998	FF13	2	4464	4351	54	2.58	0.45	8.68
1998	FF13	3	2487	2418	63	3.11	0.52	11.83
1998	NF02	1	1185	1105	55	3.72	0.64	12.17
1998	NF04	1	2111	1899	90	4.62	0.71	19.64
1998	NF05	1	1306	1223	85	4.86	0.76	20.77
1998	NF07	1	3042	2816	93	3.70	0.57	18.48
1998	NF08	1	2563	2399	69	3.04	0.50	13.26
1998	NF09	1	1686	1563	80	4.29	0.68	17.84
1998	NF10	1	2378	2206	79	4.27	0.68	16.02
1998	NF12	1	3294	3115	91	4.39	0.67	17.55
1998	NF12	2	2683	2424	84	4.20	0.66	16.89
1998	NF12	3	2659	2501	80	4.38	0.69	15.77

			Abundance of		Number of Species			
Year	Station	Rep	Total	Species		H'	J'	LSA
1998	NF13	1	2126	1876	84	4.18	0.65	18.05
1998	NF14	1	4179	3981	98	3.97	0.60	18.17
1998	NF15	1	3323	3216	68	3.41	0.56	12.19
1998	NF16	1	2191	2148	65	3.39	0.56	12.64
1998	NF17	1	917	790	55	3.62	0.63	13.45
1998	NF17	2	942	894	42	3.22	0.60	9.14
1998	NF17	3	961	881	51	3.55	0.63	11.79
1998	NF18	1	3179	2921	92	4.09	0.63	18.07
1998	NF19	1	2550	2431	76	3.55	0.57	14.90
1998	NF20	1	2944	2715	78	3.51	0.56	14.99
1998	NF21	1	2172	2004	80	3.87	0.61	16.68
1998	NF22	1	2179	1966	72	4.14	0.67	14.68
1998	NF23	1	1317	1198	71	4.15	0.67	16.52
1998	NF24	1	3643	3515	71	2.68	0.44	12.60
1998	NF24	2	4939	4787	67	2.59	0.43	11.03
1998	NF24	3	3988	3846	74	2.56	0.41	13.00
1999	FF10	1	3375	2964	98	3.50	0.53	19.48
1999	FF10	2	2663	2472	79	3.31	0.53	15.57
1999	FF10	3	2710	2438	90	4.22	0.65	18.39
1999	FF12	1	2611	2486	62	2.77	0.47	11.53
1999	FF12	2	3197	3009	61	2.81	0.47	10.83
1999	FF12	3	3424	3220	70	3.01	0.49	12.62
1999	FF13	1	1342	1235	48	2.90	0.52	9.94
1999	FF13	2	2986	2817	60	2.74	0.46	10.77
1999	FF13	3	2350	2224	59	3.14	0.53	11.13
1999	NF02	1	4040	3816	79	3.82	0.61	14.09
1999	NF04	1	1795	1538	75	4.25	0.68	16.50
1999	NF05	1	1367	1284	69	4.29	0.70	15.60
1999	NF07	1	2916	2679	84	3.69	0.58	16.48
1999	NF08	1	2223	2067	63	2.90	0.49	12.28
1999	NF09	1	1670	1489	76	4.42	0.71	16.93
1999	NF10	1	3633	3428	82	4.08	0.64	15.10
1999	NF12	1	1969	1821	68	4.15	0.68	13.93
1999	NF12	2	1856	1652	62	4.21	0.71	12.72
1999	NF12	3	2114	1893	66	4.39	0.73	13.29
1999	NF13	1	2703	2165	74	4.24	0.68	14.83
1999	NF14	1	3472	3193	86	3.39	0.53	16.28
1999	NF15	1	2921	2812	62	3.08	0.52	11.21
1999	NF16	1	2500	2404	68	2.99	0.49	13.02
1999	NF17	1	2158	1999	62	3.62	0.61	12.13
1999	NF17	2	2153	2023	58	3.73	0.64	11.14
1999	NF17	3	1674	1600	50	3.63	0.64	9.80
1999	NF18	1	3518	3192	93	3.58	0.55	17.93
1999	NF19	1	5079	4766	88	2.76	0.43	15.32
1999	NF20	1	2938	2776	70	2.77	0.45	13.05

			Abundance of		Number of Species			
Year	Station	Rep	Total	Species		H'	J'	LSA
1999	NF21	1	3111	2888	79	3.06	0.49	15.00
1999	NF22	1	1877	1650	63	3.92	0.66	12.98
1999	NF23	1	2907	2362	78	4.35	0.69	15.50
1999	NF24	1	3474	3311	60	2.60	0.44	10.41
1999	NF24	2	3902	3804	75	2.63	0.42	13.24
1999	NF24	3	3598	3469	70	2.29	0.37	12.42
2000	FF10	1	2078	1625	77	4.39	0.70	16.81
2000	FF10	2	1826	1693	73	2.95	0.48	15.53
2000	FF10	3	2605	2400	73	3.26	0.53	14.22
2000	FF12	1	2882	2557	53	2.88	0.50	9.46
2000	FF12	2	2620	2424	49	2.99	0.53	8.70
2000	FF12	3	2478	2293	50	3.33	0.59	9.02
2000	FF13	1	3572	3340	54	3.23	0.56	9.15
2000	FF13	2	4469	4106	57	2.88	0.49	9.37
2000	FF13	3	4506	4129	57	3.15	0.54	9.36
2000	NF02	1	2792	2469	66	2.99	0.49	12.47
2000	NF04	1	1933	1724	71	4.39	0.71	14.92
2000	NF05	1	1574	1382	87	4.39	0.68	20.62
2000	NF07	1	3294	3184	88	3.37	0.52	16.75
2000	NF08	1	2095	1877	73	3.68	0.59	15.11
2000	NF09	1	2964	2726	86	4.17	0.65	16.90
2000	NF10	1	2504	2297	85	4.31	0.67	17.38
2000	NF12	1	1652	1451	55	4.08	0.71	11.31
2000	NF12	2	3851	3533	78	3.75	0.60	14.11
2000	NF12	3	2568	2334	66	3.92	0.65	12.63
2000	NF13	1	2041	1846	76	4.21	0.67	15.97
2000	NF14	1	4205	3594	73	4.22	0.68	12.97
2000	NF15	1	2810	2591	77	4.02	0.64	14.91
2000	NF16	1	2268	2103	63	2.87	0.48	12.22
2000	NF17	1	1889	1573	57	4.07	0.70	11.59
2000	NF17	2	1663	1459	52	3.82	0.67	10.53
2000	NF17	3	1843	1521	45	4.00	0.73	8.71
2000	NF18	1	2491	2233	88	3.98	0.62	18.28
2000	NF19	1	3430	3341	74	3.48	0.56	13.40
2000	NF20	1	2540	2266	72	3.10	0.50	14.17
2000	NF21	1	2312	2122	57	3.24	0.56	10.78
2000	NF22	1	1434	1207	56	4.10	0.71	12.15
2000	NF23	1	1786	1284	63	4.36	0.73	13.88
2000	NF24	1	4624	4487	71	2.41	0.39	11.98
2000	NF24	2	1827	1721	60	2.99	0.51	12.08
2000	NF24	3	1582	1536	51	2.84	0.50	10.15
2001	FF10	1	1696	1600	67	3.27	0.54	14.14
2001	FF10	2	2679	2051	91	4.51	0.69	19.51
2001	FF10	3	1039	896	77	4.22	0.67	20.18
2001	FF12	1	1683	1602	48	3.22	0.58	9.31

			Abundance of		Number of Species			
Year	Station	Rep	Total	Species		H'	J'	LSA
2001	FF12	2	2467	2349	51	3.43	0.60	9.19
2001	FF12	3	1790	1659	51	3.42	0.60	9.96
2001	FF13	1	4198	4059	55	3.26	0.56	9.00
2001	FF13	2	3798	3563	60	3.31	0.56	10.25
2001	FF13	3	3595	3401	52	3.04	0.53	8.71
2001	NF02	1	1120	940	63	4.55	0.76	15.22
2001	NF04	1	1558	1433	71	4.10	0.67	15.69
2001	NF05	1	994	915	67	4.95	0.82	16.65
2001	NF07	1	1977	1833	65	3.42	0.57	13.15
2001	NF08	1	3387	2986	78	4.01	0.64	14.66
2001	NF09	1	1869	1553	62	4.36	0.73	12.92
2001	NF10	1	2819	2559	69	4.17	0.68	13.06
2001	NF12	1	3752	3358	65	3.84	0.64	11.43
2001	NF12	2	3401	3077	65	3.85	0.64	11.65
2001	NF12	3	2725	2490	64	3.88	0.65	11.98
2001	NF13	1	1797	1470	80	4.58	0.72	18.16
2001	NF14	1	2235	1801	71	4.18	0.68	14.75
2001	NF15	1	2390	2274	65	3.83	0.64	12.47
2001	NF16	1	1166	1096	65	3.77	0.63	15.13
2001	NF17	1	570	461	44	4.10	0.75	11.97
2001	NF17	2	2477	2386	60	2.31	0.39	11.18
2001	NF17	3	999	871	50	3.73	0.66	11.53
2001	NF18	1	2042	1840	81	4.31	0.68	17.33
2001	NF19	1	1708	1660	65	3.33	0.55	13.48
2001	NF20	1	1467	1341	74	4.05	0.65	16.86
2001	NF21	1	1090	961	45	3.68	0.67	9.79
2001	NF22	1	2198	1456	61	3.90	0.66	12.88
2001	NF23	1	1439	1354	69	4.61	0.76	15.37
2001	NF24	1	6055	5499	84	3.32	0.52	14.07
2001	NF24	2	3901	3639	76	3.26	0.52	13.59
2001	NF24	3	3055	2759	65	3.10	0.51	11.93

Table D3-3. Benthic community parameters for all farfield stations, 1992–2001.

			Abundance of		Number of Species			
Year	Station	Rep	Total	Species		H'	J'	LSA
1992	FF01	1	428	404	51	4.61	0.81	15.45
1992	FF01	2	466	442	57	4.65	0.80	17.42
1992	FF01	3	383	356	53	4.67	0.82	17.23
1992	FF04	1	820	808	54	3.05	0.53	13.03
1992	FF04	2	549	539	38	3.03	0.58	9.33
1992	FF04	3	1229	1212	49	3.01	0.54	10.25
1992	FF05	1	1284	1250	50	2.38	0.42	10.43
1992	FF05	2	878	862	41	2.05	0.38	8.96
1992	FF05	3	995	984	54	2.35	0.41	12.28
1992	FF06	1	1484	1468	53	3.61	0.63	10.77
1992	FF06	2	1430	1412	49	3.68	0.66	9.86
1992	FF06	3	1980	1953	61	3.37	0.57	11.96
1992	FF07	1	1260	1259	44	3.27	0.60	8.87
1992	FF07	2	1277	1261	48	3.42	0.61	9.88
1992	FF07	3	3031	2993	49	3.52	0.63	8.32
1992	FF09	1	2746	2661	75	3.14	0.50	14.34
1992	FF09	2	2893	2840	74	3.05	0.49	13.90
1992	FF09	3	2779	2726	65	2.96	0.49	11.96
1992	FF11	1	597	541	39	3.31	0.63	9.64
1992	FF11	2	410	402	30	3.02	0.62	7.50
1992	FF11	3	996	981	39	3.43	0.65	8.12
1992	FF14	1	599	592	39	3.23	0.61	9.37
1992	FF14	2	480	403	44	3.91	0.72	12.58
1992	FF14	3	548	536	47	3.88	0.70	12.40
1993	FF01	1	543	497	54	4.53	0.79	15.41
1993	FF01	2	730	688	55	4.39	0.76	14.07
1993	FF01	3	638	602	56	4.59	0.79	15.09
1993	FF04	1	619	594	39	3.55	0.67	9.36
1993	FF04	2	173	162	32	3.98	0.80	11.95
1993	FF04	3	320	300	37	4.09	0.79	11.10
1993	FF05	1	920	840	49	3.61	0.64	11.35
1993	FF05	2	926	871	58	3.94	0.67	13.98
1993	FF05	3	990	877	51	3.89	0.69	11.80
1993	FF06	1	1233	1125	60	4.29	0.73	13.54
1993	FF06	2	2123	2002	73	4.28	0.69	14.87
1993	FF06	3	1878	1786	68	4.06	0.67	14.00
1993	FF07	1	2487	2443	49	3.45	0.62	8.68
1993	FF07	2	936	857	42	4.00	0.74	9.25
1993	FF07	3	2745	2664	53	3.75	0.66	9.38
1993	FF09	1	1340	1271	61	2.87	0.48	13.36
1993	FF09	2	895	826	59	3.39	0.58	14.54
1993	FF09	3	1197	1144	54	3.07	0.53	11.77

			Abundance of		Number of Species			
Year	**Station**	**Rep**	**Total**	**Species**		**H'**	**J'**	**LSA**
1993	FF11	1	1085	1019	48	3.81	0.68	10.46
1993	FF11	2	1201	1112	55	4.06	0.70	12.15
1993	FF11	3	931	874	54	3.84	0.67	12.72
1993	FF14	1	848	807	45	3.83	0.70	10.28
1993	FF14	2	1172	1121	52	3.93	0.69	11.28
1993	FF14	3	1030	993	46	3.84	0.70	9.98
1994	FF01A	1	464	435	43	4.31	0.79	11.84
1994	FF01A	2	1037	950	68	4.30	0.71	16.77
1994	FF01A	3	1075	978	69	4.57	0.75	16.94
1994	FF04	1	472	447	43	4.10	0.76	11.73
1994	FF04	2	471	446	41	4.33	0.81	11.00
1994	FF04	3	717	701	40	3.74	0.70	9.20
1994	FF05	1	296	277	37	4.38	0.84	11.47
1994	FF05	2	362	332	38	4.27	0.81	11.07
1994	FF05	3	397	324	44	4.63	0.85	13.74
1994	FF06	1	316	288	39	3.93	0.74	12.17
1994	FF06	2	423	394	34	3.44	0.68	8.92
1994	FF06	3	1005	925	58	4.25	0.73	13.73
1994	FF07	1	168	157	27	3.77	0.79	9.39
1994	FF07	2	611	595	35	2.94	0.57	8.13
1994	FF07	3	423	416	31	3.25	0.66	7.75
1994	FF09	1	2416	2373	69	2.97	0.49	13.29
1994	FF09	2	2484	2413	74	3.20	0.52	14.44
1994	FF09	3	2014	1978	66	3.36	0.56	13.15
1994	FF11	1	628	611	48	3.72	0.67	12.20
1994	FF11	2	490	459	54	3.88	0.67	15.90
1994	FF11	3	972	945	42	3.80	0.70	9.01
1994	FF14	1	335	257	41	4.02	0.75	13.76
1994	FF14	2	964	850	47	4.29	0.77	10.72
1994	FF14	3	689	614	46	3.96	0.72	11.51
1995	FF01A	1	2902	2749	75	2.03	0.33	14.24
1995	FF01A	2	3157	2937	70	2.46	0.40	12.88
1995	FF01A	3	2464	2378	74	2.50	0.40	14.49
1995	FF04	1	612	536	38	3.75	0.71	9.34
1995	FF04	2	373	339	42	4.09	0.76	12.62
1995	FF04	3	267	254	30	3.63	0.74	8.85
1995	FF05	1	1024	861	44	3.25	0.59	9.81
1995	FF05	2	822	729	57	3.57	0.61	14.47
1995	FF05	3	920	728	52	3.81	0.67	12.82
1995	FF06	1	1578	1408	48	3.84	0.69	9.61
1995	FF06	2	1301	1066	54	4.30	0.75	12.01
1995	FF06	3	1043	946	57	4.30	0.74	13.33
1995	FF07	1	684	636	49	4.14	0.74	12.38
1995	FF07	2	860	778	51	3.52	0.62	12.24
1995	FF07	3	1307	1168	48	3.70	0.66	10.08

			Abundance of		Number of Species			
Year	**Station**	**Rep**	**Total**	**Species**		**H'**	**J'**	**LSA**
1995	FF09	1	2656	2529	71	2.75	0.45	13.57
1995	FF09	2	3289	3014	65	1.76	0.29	11.70
1995	FF09	3	2524	2429	72	2.36	0.38	13.94
1995	FF11	1	765	721	41	2.49	0.46	9.42
1995	FF11	2	974	951	39	2.71	0.51	8.19
1995	FF11	3	1509	1421	48	2.47	0.44	9.59
1995	FF14	1	699	608	48	4.05	0.72	12.22
1995	FF14	2	1116	931	57	4.34	0.74	13.39
1995	FF14	3	745	643	53	4.25	0.74	13.69
1996	FF01A	1	2088	2009	71	3.02	0.49	14.35
1996	FF01A	2	2421	2316	75	3.15	0.51	14.83
1996	FF01A	3	2187	2112	78	2.94	0.47	15.94
1996	FF04	1	554	518	46	4.23	0.77	12.19
1996	FF04	2	488	445	49	4.29	0.76	14.06
1996	FF04	3	532	502	41	4.11	0.77	10.56
1996	FF05	1	625	568	59	4.54	0.77	16.55
1996	FF05	2	659	617	67	4.54	0.75	19.12
1996	FF05	3	1097	1025	70	4.43	0.72	17.01
1996	FF06	1	1158	1086	72	4.72	0.77	17.34
1996	FF06	2	944	846	57	4.46	0.76	13.79
1996	FF06	3	1181	1062	69	4.66	0.76	16.51
1996	FF07	1	1585	1470	63	4.09	0.68	13.38
1996	FF07	2	1926	1869	61	3.76	0.63	12.08
1996	FF07	3	1374	1309	58	3.75	0.64	12.43
1996	FF09	1	1940	1883	73	3.10	0.50	15.10
1996	FF09	2	3055	2850	81	2.66	0.42	15.52
1996	FF09	3	2577	2440	81	3.08	0.49	16.11
1996	FF11	1	1543	1406	65	3.16	0.52	14.09
1996	FF11	2	1216	1171	47	2.77	0.50	9.81
1996	FF11	3	2433	2397	50	2.62	0.46	8.94
1996	FF14	1	631	557	58	4.70	0.80	16.29
1996	FF14	2	1089	1005	75	4.82	0.77	18.75
1996	FF14	3	1177	1151	61	4.39	0.74	13.74
1997	FF01A	1	1920	1857	87	3.69	0.57	18.93
1997	FF01A	2	2058	1996	86	3.85	0.60	18.29
1997	FF01A	3	2527	2457	87	3.89	0.60	17.59
1997	FF04	1	1463	1382	61	4.20	0.71	13.06
1997	FF04	2	1042	1006	57	4.29	0.74	13.09
1997	FF04	3	962	882	53	4.08	0.71	12.38
1997	FF05	1	1042	960	72	4.47	0.72	18.03
1997	FF05	2	953	918	63	3.81	0.64	15.33
1997	FF05	3	531	508	53	4.52	0.79	14.89
1997	FF06	1	1170	1122	75	4.64	0.74	18.10
1997	FF06	2	1115	1072	67	4.72	0.78	15.84
1997	FF06	3	704	685	48	4.40	0.79	11.76

			Abundance of		Number of Species			
Year	**Station**	**Rep**	**Total**	**Species**		**H'**	**J'**	**LSA**
1997	FF07	1	2162	1994	65	3.84	0.64	12.87
1997	FF07	2	4139	3971	71	3.20	0.52	12.28
1997	FF07	3	2055	1990	56	3.42	0.59	10.71
1997	FF09	1	2624	2431	91	3.61	0.56	18.66
1997	FF09	2	2760	2645	104	3.71	0.55	21.59
1997	FF09	3	2580	2452	97	3.61	0.55	20.17
1997	FF11	1	2024	1984	63	3.11	0.52	12.40
1997	FF11	2	825	766	60	3.56	0.60	15.24
1997	FF11	3	992	965	60	2.67	0.45	14.16
1997	FF14	1	404	353	53	4.59	0.80	17.30
1997	FF14	2	864	822	71	4.63	0.75	18.64
1997	FF14	3	1229	1172	67	4.26	0.70	15.43
1998	FF01A	1	2535	2457	78	2.99	0.48	15.35
1998	FF01A	2	2292	2157	79	3.31	0.52	16.11
1998	FF01A	3	2169	2012	88	3.13	0.49	18.79
1998	FF04	1	2757	2562	62	3.69	0.62	11.45
1998	FF04	2	2982	2755	60	3.72	0.63	10.82
1998	FF04	3	1569	1467	53	3.55	0.62	10.77
1998	FF05	1	1324	1218	62	4.30	0.72	13.80
1998	FF05	2	1092	1045	62	4.18	0.70	14.43
1998	FF05	3	1935	1735	80	4.25	0.67	17.33
1998	FF06	1	1473	1365	67	4.26	0.70	14.77
1998	FF06	2	990	900	59	4.40	0.75	14.16
1998	FF06	3	763	723	61	4.53	0.76	15.89
1998	FF07	1	4534	4280	67	3.36	0.55	11.28
1998	FF07	2	2753	2597	65	3.60	0.60	12.10
1998	FF07	3	4117	3933	66	3.47	0.57	11.27
1998	FF09	1	1871	1695	92	4.18	0.64	20.86
1998	FF09	2	1884	1744	94	3.96	0.60	21.27
1998	FF09	3	2034	1816	93	4.32	0.66	20.74
1998	FF11	1	1746	1674	70	3.31	0.54	14.77
1998	FF11	2	1923	1851	70	3.25	0.53	14.39
1998	FF11	3	1280	1234	60	3.60	0.61	13.19
1998	FF14	1	2193	2044	73	4.64	0.75	14.79
1998	FF14	2	2188	2045	77	4.72	0.75	15.81
1998	FF14	3	1897	1794	70	4.68	0.76	14.51
1999	FF01A	1	4503	4205	86	2.82	0.44	15.30
1999	FF01A	2	3679	3422	82	3.04	0.48	15.11
1999	FF01A	3	4510	4221	96	3.09	0.47	17.48
1999	FF04	1	1041	931	58	4.44	0.76	13.70
1999	FF04	2	1034	891	68	4.48	0.74	17.12
1999	FF04	3	1197	1110	55	4.32	0.75	12.15
1999	FF05	1	2761	2466	74	4.11	0.66	14.37
1999	FF05	2	1933	1783	68	4.28	0.70	14.01
1999	FF05	3	2622	2391	79	4.44	0.70	15.70

			Abundance of		Number of Species			
Year	**Station**	**Rep**	**Total**	**Species**		**H'**	**J'**	**LSA**
1999	FF06	1	1251	1140	53	4.00	0.70	11.51
1999	FF06	2	1275	1160	51	3.98	0.70	10.91
1999	FF06	3	1124	984	49	3.81	0.68	10.84
1999	FF07	1	2608	2523	58	2.95	0.50	10.59
1999	FF07	2	2601	2564	55	3.15	0.54	9.89
1999	FF07	3	1740	1658	51	3.50	0.62	9.96
1999	FF09	1	2340	2081	97	3.93	0.60	21.08
1999	FF09	2	2731	2406	92	3.69	0.57	18.97
1999	FF09	3	1335	1200	67	3.97	0.65	15.32
1999	FF11	1	4831	4535	73	2.29	0.37	12.36
1999	FF11	2	8564	7805	80	3.11	0.49	12.41
1999	FF11	3	3568	3340	71	2.96	0.48	12.74
1999	FF14	1	2945	2515	81	4.40	0.69	15.99
1999	FF14	2	2050	1611	69	4.61	0.75	14.65
1999	FF14	3	1445	1189	63	4.22	0.71	14.19
2000	FF01A	1	2638	2431	71	2.76	0.45	13.69
2000	FF01A	2	3484	3109	79	2.90	0.46	14.75
2000	FF01A	3	3581	3438	79	2.62	0.42	14.42
2000	FF04	1	1364	1242	68	4.34	0.71	15.46
2000	FF04	2	1228	1154	71	4.49	0.73	16.71
2000	FF04	3	1223	1170	53	3.93	0.69	11.43
2000	FF05	1	3053	2676	78	4.32	0.69	15.04
2000	FF05	2	1871	1555	79	4.42	0.70	17.58
2000	FF05	3	2634	2360	73	4.37	0.71	14.27
2000	FF06	1	589	543	41	3.96	0.74	10.29
2000	FF06	2	754	694	45	3.84	0.70	10.76
2000	FF06	3	580	548	40	3.81	0.72	9.93
2000	FF07	1	3610	3502	58	3.53	0.60	9.87
2000	FF07	2	3372	3307	53	3.01	0.53	8.96
2000	FF07	3	4285	4179	56	2.78	0.48	9.14
2000	FF09	1	2497	2271	98	4.30	0.65	20.85
2000	FF09	2	2433	2198	105	4.25	0.63	22.97
2000	FF09	3	1749	1580	92	4.46	0.68	21.30
2000	FF11	1	3037	2907	60	2.76	0.47	10.70
2000	FF11	2	1829	1762	52	2.35	0.41	10.05
2000	FF11	3	1908	1823	56	3.27	0.56	10.93
2000	FF14	1	1498	1331	72	4.49	0.73	16.31
2000	FF14	2	2147	1857	76	4.63	0.74	15.95
2000	FF14	3	1638	1410	72	4.65	0.75	16.05
2001	FF01A	1	1778	1689	62	2.98	0.50	12.65
2001	FF01A	2	2282	2162	72	3.07	0.50	14.33
2001	FF01A	3	2214	2052	72	2.87	0.46	14.52
2001	FF04	1	916	825	51	4.45	0.78	12.02
2001	FF04	2	1620	1461	54	4.04	0.70	11.04
2001	FF04	3	883	831	47	4.03	0.73	10.79

			Abundance of		Number of Species			
Year	Station	Rep	Total	Species		H'	J'	LSA
2001	FF05	1	1635	1276	77	4.79	0.76	18.01
2001	FF05	2	1791	1259	73	4.75	0.77	16.88
2001	FF05	3	2518	1940	76	4.56	0.73	15.77
2001	FF06	1	332	322	30	3.62	0.74	8.09
2001	FF06	2	450	405	37	3.36	0.65	9.91
2001	FF06	3	405	374	40	3.66	0.69	11.35
2001	FF07	1	4608	4346	49	2.99	0.53	7.74
2001	FF07	2	2558	2477	46	2.54	0.46	8.02
2001	FF07	3	1901	1840	41	3.04	0.57	7.43
2001	FF09	1	1645	1418	109	5.05	0.75	27.51
2001	FF09	2	1784	1558	102	5.10	0.76	24.46
2001	FF09	3	1615	1465	95	4.75	0.72	22.72
2001	FF11	1	1990	1903	64	3.71	0.62	12.77
2001	FF11	2	2377	2201	68	3.46	0.57	13.29
2001	FF11	3	4891	4168	74	3.55	0.57	12.78
2001	FF14	1	475	430	51	4.47	0.79	15.06
2001	FF14	2	861	754	61	4.50	0.76	15.66
2001	FF14	3	2883	2468	74	4.52	0.73	14.36
2002	FF01A	1	3020	2959	85	3.11	0.49	16.33
2002	FF01A	2	1548	1537	64	3.69	0.61	13.49
2002	FF01A	3	2506	2466	75	2.94	0.47	14.61
2002	FF04	1	1349	1301	62	4.36	0.73	13.55
2002	FF04	2	1883	1837	63	4.18	0.70	12.63
2002	FF04	3	1438	1392	62	4.36	0.73	13.31
2002	FF05	1	2248	2217	82	4.53	0.71	16.76
2002	FF05	2	1763	1710	78	4.65	0.74	16.85
2002	FF05	3	1693	1628	74	4.46	0.72	15.97
2002	FF06	1	368	360	50	4.30	0.76	15.77
2002	FF06	2	761	746	62	4.56	0.77	16.06
2002	FF06	3	343	331	54	4.93	0.86	18.32
2002	FF07	1	2470	2430	53	2.77	0.48	9.56
2002	FF07	2	2903	2890	50	2.98	0.53	8.59
2002	FF07	3	3551	3539	48	2.63	0.47	7.85
2002	FF09	1	2325	2231	95	4.07	0.62	20.14
2002	FF09	2	1864	1781	105	4.42	0.66	24.40
2002	FF09	3	1719	1661	90	4.28	0.66	20.40
2002	FF11	1	3744	3672	82	3.53	0.56	14.87
2002	FF11	2	3170	3124	77	3.55	0.57	14.28
2002	FF11	3	1754	1729	69	3.77	0.62	14.38
2002	FF14	1	334	330	52	4.69	0.82	17.35
2002	FF14	2	479	475	53	4.75	0.83	15.28
2002	FF14	3	846	825	65	4.78	0.79	16.54

Table D3-4. TOTAL ABUNDANCE at NEARFIELD STATIONS, 1994–2002*

STATION	1994	1995	1996	1997	1998	1999	2000	2001	2002
NF02	1860	3492	2544	2057	1185	4040	2792	1120	1928
NF04	1248	1004	1955	3516	2111	1795	1933	1558	3074
NF05	771	2219	1603	1712	1306	1367	1574	994	854
NF07	1444	1942	1476	810	3042	2916	3294	1977	3764
NF08	2202	2366	1443	2780	2563	2223	2095	3387	3530
NF09	1825	1810	1755	3167	1686	1670	2964	1869	2404
NF10	2964	2105	1680	4029	2378	3633	2504	2819	3887
NF12	3008.3	2193.0	2334.7	3149.3	2878.7	1979.7	2690.3	3292.7	3393.0
NF13	1903	1383	1639	1347	2126	2703	2041	1797	2022
NF14	1871	2248	2124	3472	4179	3472	4205	2235	3125
NF15	1754	2425	1660	3845	3323	2921	2810	2390	4869
NF16	453	1897	1481	2087	2191	2500	2268	1166	4559
NF17	1963.7	879.0	1648.0	725.3	940.0	1995.0	1798.3	1348.7	1242.7
NF18	1655	1437	1810	3031	3179	3518	2491	2042	3441
NF19	1289	2609	2458	2831	2550	5079	3430	1708	4019
NF20	439	2306	2904	3442	2944	2938	2540	1467	3914
NF21	2521	1858	1437	1503	2172	3111	2312	1090	4273
NF22	4296	2034	2944	2357	2179	1877	1434	2198	3413
NF23	2068	2569	3621	2801	1317	2907	1786	1439	1733
NF24	3164.0	1388.7	1591.3	1445.0	4190.0	3658.0	2677.7	4337.0	6529.3
FF10	2774.0	1955.3	2240.0	2776.3	2840.3	2916.0	2169.7	1804.7	2289.0
FF12	728.7	2531.7	3089.0	4058.7	2507.7	3077.3	2660.0	1980.0	2910.0
FF13	1528.3	1091.7	2383.7	4194.3	3265.7	2226.0	4182.3	3863.7	5916.7

* Values to one decimal place are the mean of three replicates; other values are for single samples.

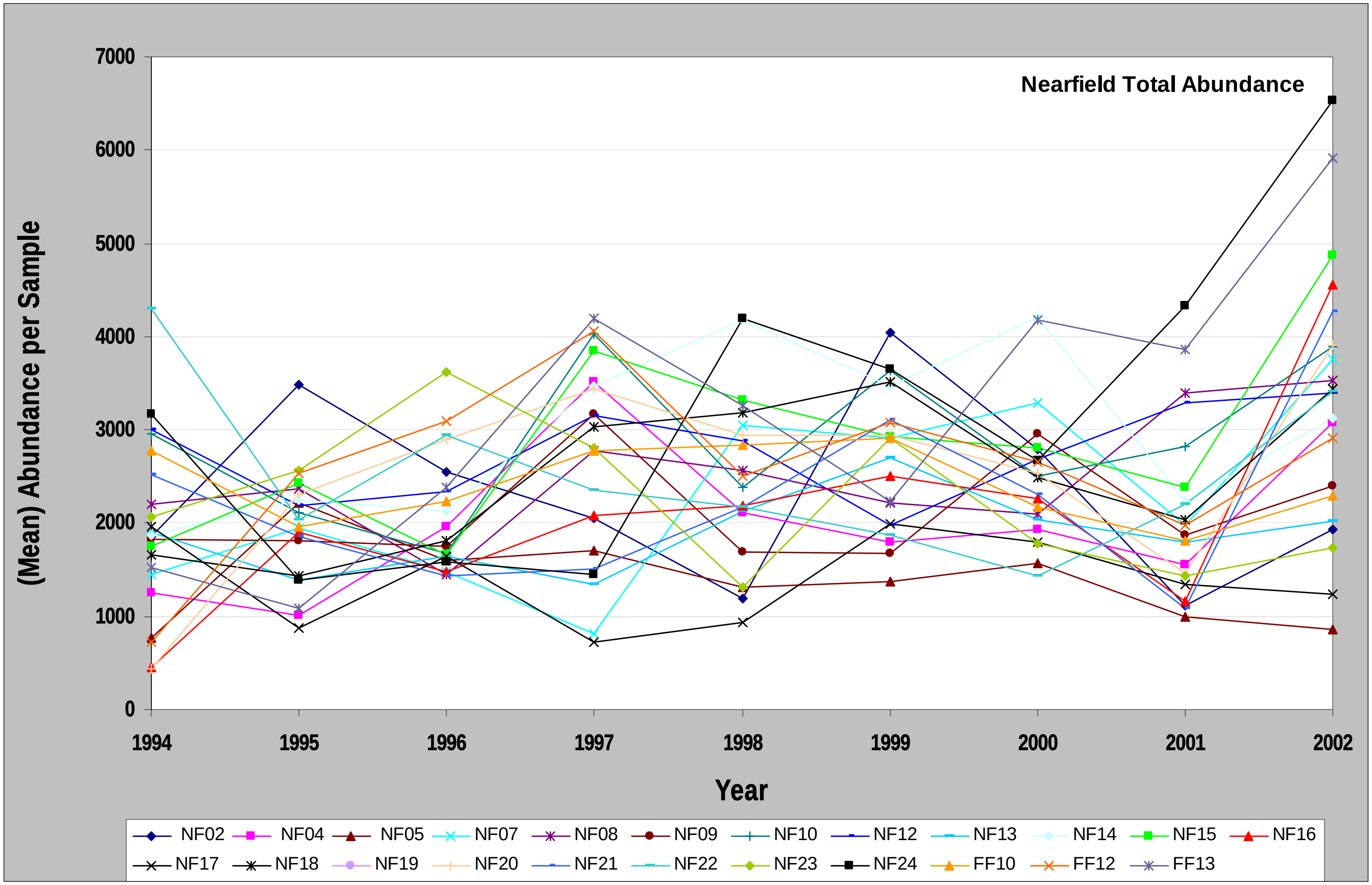


Figure D3-1. Total abundance at nearfield stations from 1994 through 2002. Values are average for three replicates at six of the stations (see Table D3-4) or are for single samples.

Table D3-5. SPECIES RICHNESS at NEARFIELD STATIONS, 1994–2002*

STATION	1994	1995	1996	1997	1998	1999	2000	2001	2002
NF02	60	67	70	75	55	79	66	63	64
NF04	43	59	58	92	90	75	71	71	97
NF05	47	77	92	97	85	69	87	67	84
NF07	52	81	74	50	93	84	88	65	72
NF08	46	50	49	84	69	63	73	78	91
NF09	45	70	76	78	80	76	86	62	77
NF10	62	67	64	78	79	82	85	69	84
NF12*	54.3	62.7	70.7	83.0	85.0	65.3	66.3	64.7	66.3
NF13	54	48	57	50	84	74	76	80	84
NF14	63	75	75	79	98	86	73	71	84
NF15	65	67	69	82	68	62	77	65	86
NF16	38	71	62	63	65	68	63	65	74
NF17*	47.7	45.0	62.7	49.7	49.3	56.7	51.3	51.3	64.7
NF18	73	84	81	114	92	93	88	81	94
NF19	65	78	98	77	76	88	74	65	68
NF20	37	64	83	74	78	70	72	74	79
NF21	55	70	67	76	80	79	57	45	83
NF22	72	51	72	73	72	63	56	61	73
NF23	74	80	83	92	71	78	63	69	77
NF24*	63.3	58.7	66.0	60.7	70.7	68.3	60.7	75.0	81.7
FF10*	77.0	78	82.0	91.7	92.0	89.0	74.3	78.3	75.3
FF12*	77.0	78	82.0	91.7	92.0	89.0	74.3	78.3	75.3
FF13*	47.3	41.3	54.0	59.0	57.0	55.7	56.0	55.7	63.7

* Values to one decimal place are the mean of three replicates; other values are for single samples.

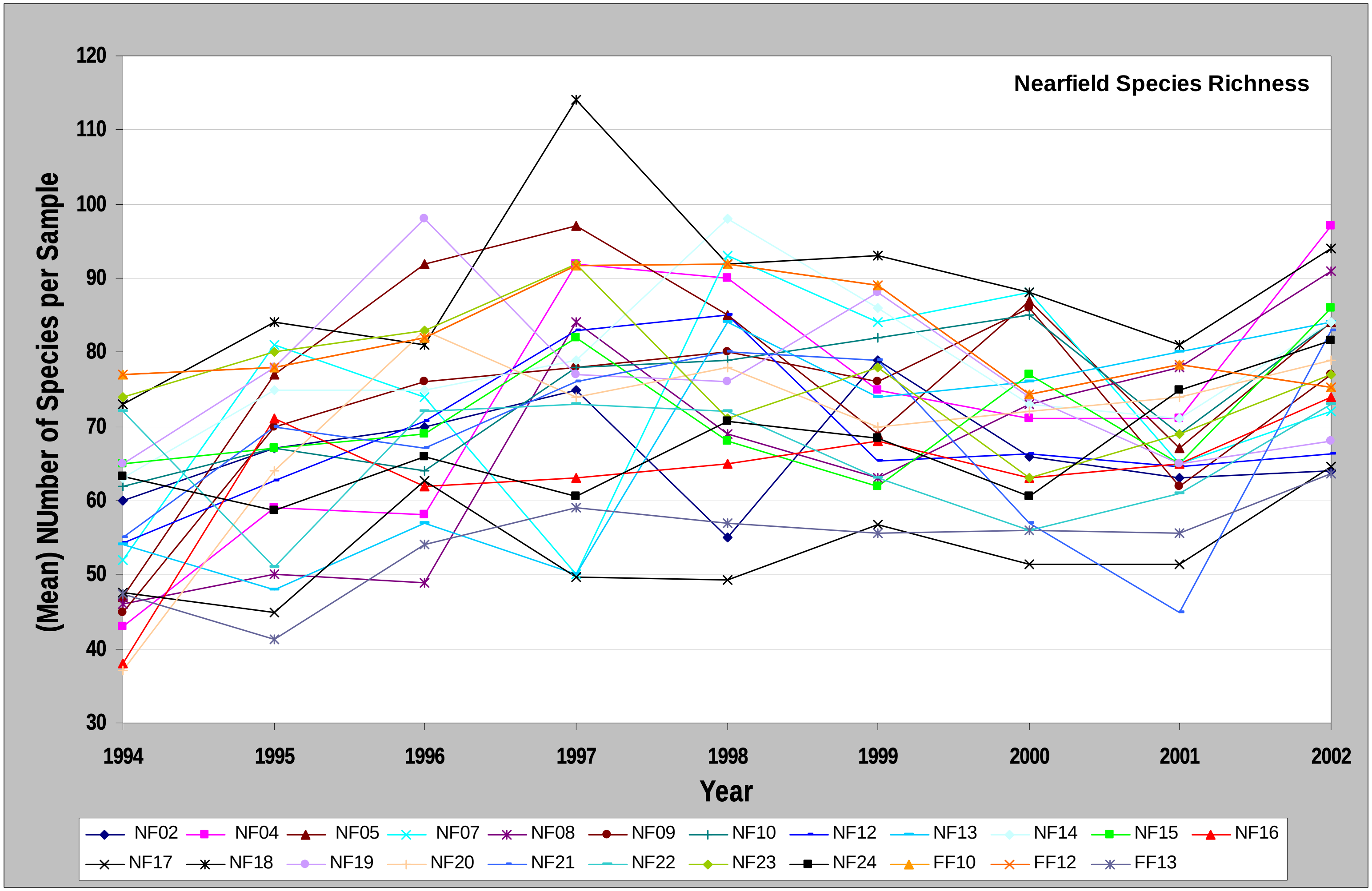


Figure D3-2. Species richness at nearfield stations from 1994 through 2002. Values are average for three replicates at six of the stations (see Table D3-5) or are for single samples.

Table D3-6. SHANNON DIVERSITY at NEARFIELD STATIONS, 1994–2002*

STATION	1994	1995	1996	1997	1998	1999	2000	2001	2002
NF02	3.61	3.64	4.06	4.04	3.72	3.82	2.99	4.55	3.15
NF04	3.08	3.99	2.82	4.04	4.62	4.25	4.39	4.1	4.02
NF05	3.63	4.19	4.58	4.92	4.86	4.29	4.39	4.95	5.02
NF07	3.06	4.25	4.4	3.95	3.7	3.69	3.37	3.42	3.32
NF08	2.96	3.38	3.47	3.46	3.04	2.9	3.68	4.01	4.37
NF09	3.22	4.14	4.5	4.54	4.29	4.42	4.17	4.36	3.98
NF10	3.09	3.74	3.77	4.05	4.27	4.08	4.31	4.17	3.77
NF12*	3.2	3.7	4.0	4.2	4.3	4.3	3.9	3.9	3.5
NF13	3.4	3.88	3.35	2.94	4.18	4.24	4.21	4.58	4.74
NF14	3.88	3.49	3.67	4.34	3.97	3.39	4.22	4.18	4.24
NF15	4.53	4.14	3.72	4.16	3.41	3.08	4.02	3.83	3.52
NF16	3.63	4.11	4.33	3.46	3.39	2.99	2.87	3.77	3.42
NF17*	2.5	3.6	3.7	3.8	3.5	3.7	4.0	3.4	4.3
NF18	4.38	3.91	4.29	4.38	4.09	3.58	3.98	4.31	3.09
NF19	4.58	4.1	4.48	3.87	3.55	2.76	3.48	3.33	3.06
NF20	4.18	3.76	4.05	3	3.51	2.77	3.1	4.05	3.04
NF21	3.43	4.16	4.32	4.25	3.87	3.06	3.24	3.68	3.34
NF22	3.46	3.82	3.96	4.11	4.14	3.92	4.1	3.9	3.48
NF23	4.42	4.38	4.44	3.8	4.15	4.35	4.36	4.61	4.44
NF24*	3.1	3.9	3.8	3.1	2.6	2.5	2.7	3.2	3.1
FF10*	4.1	4.4	4.6	4.6	4.1	3.7	3.5	4.0	3.6
FF12*	3.6	3.8	3.7	3.6	3.2	2.9	3.1	3.4	3.0
FF13*	3.6	3.0	3.9	2.5	2.7	2.9	3.1	3.2	3.2

* Values are the mean of three replicates; other values are for single samples.

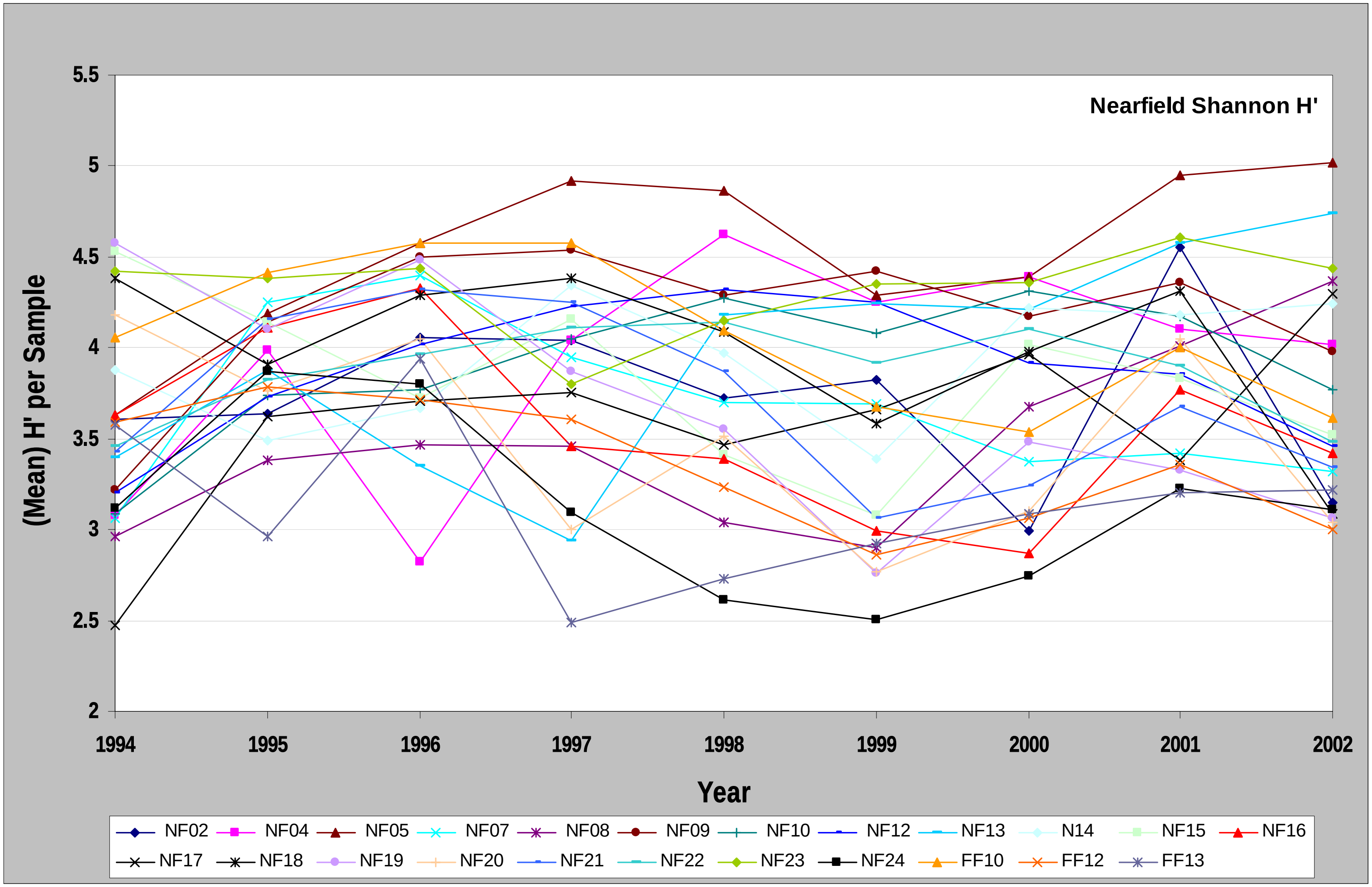


Figure D3-3. Shannon diversity (H′) at nearfield stations from 1994 through 2002. Values are the mean of three replicates at six of the stations (see Table D3-6) or are for single samples.

Table D3-7. EVENNESS at NEARFIELD STATIONS, 1994–2002*

STATION	1994	1995	1996	1997	1998	1999	2000	2001	2002
NF02	0.61	0.60	0.66	0.65	0.64	0.61	0.49	0.76	0.53
NF04	0.57	0.68	0.48	0.62	0.71	0.68	0.71	0.67	0.61
NF05	0.65	0.67	0.70	0.75	0.76	0.70	0.68	0.82	0.79
NF07	0.54	0.67	0.71	0.70	0.57	0.58	0.52	0.57	0.54
NF08	0.53	0.60	0.62	0.54	0.50	0.49	0.59	0.64	0.67
NF09	0.59	0.68	0.72	0.72	0.68	0.71	0.65	0.73	0.63
NF10	0.52	0.62	0.63	0.64	0.68	0.64	0.67	0.68	0.59
NF12*	0.60	0.60	0.70	0.70	0.70	0.70	0.70	0.60	0.60
NF13	0.59	0.69	0.57	0.52	0.65	0.68	0.67	0.72	0.74
NF14	0.65	0.56	0.59	0.69	0.60	0.53	0.68	0.68	0.66
NF15	0.75	0.68	0.61	0.65	0.56	0.52	0.64	0.64	0.55
NF16	0.69	0.67	0.73	0.58	0.56	0.49	0.48	0.63	0.55
NF17*	0.40	0.70	0.60	0.70	0.60	0.60	0.70	0.60	0.70
NF18	0.71	0.61	0.68	0.64	0.63	0.55	0.62	0.68	0.47
NF19	0.76	0.65	0.68	0.62	0.57	0.43	0.56	0.55	0.50
NF20	0.80	0.63	0.64	0.48	0.56	0.45	0.50	0.65	0.48
NF21	0.59	0.68	0.71	0.68	0.61	0.49	0.56	0.67	0.52
NF22	0.56	0.67	0.64	0.66	0.67	0.66	0.71	0.66	0.56
NF23	0.71	0.69	0.70	0.58	0.67	0.69	0.73	0.76	0.71
NF24*	0.50	0.70	0.60	0.50	0.40	0.40	0.50	0.50	0.50
FF10*	0.60	0.70	0.70	0.70	0.60	0.60	0.60	0.60	0.60
FF12*	0.70	0.60	0.60	0.60	0.50	0.50	0.50	0.60	0.50
FF13*	0.60	0.60	0.70	0.40	0.50	0.50	0.50	0.60	0.50

* Values are the mean of three replicates; other values are for single samples.

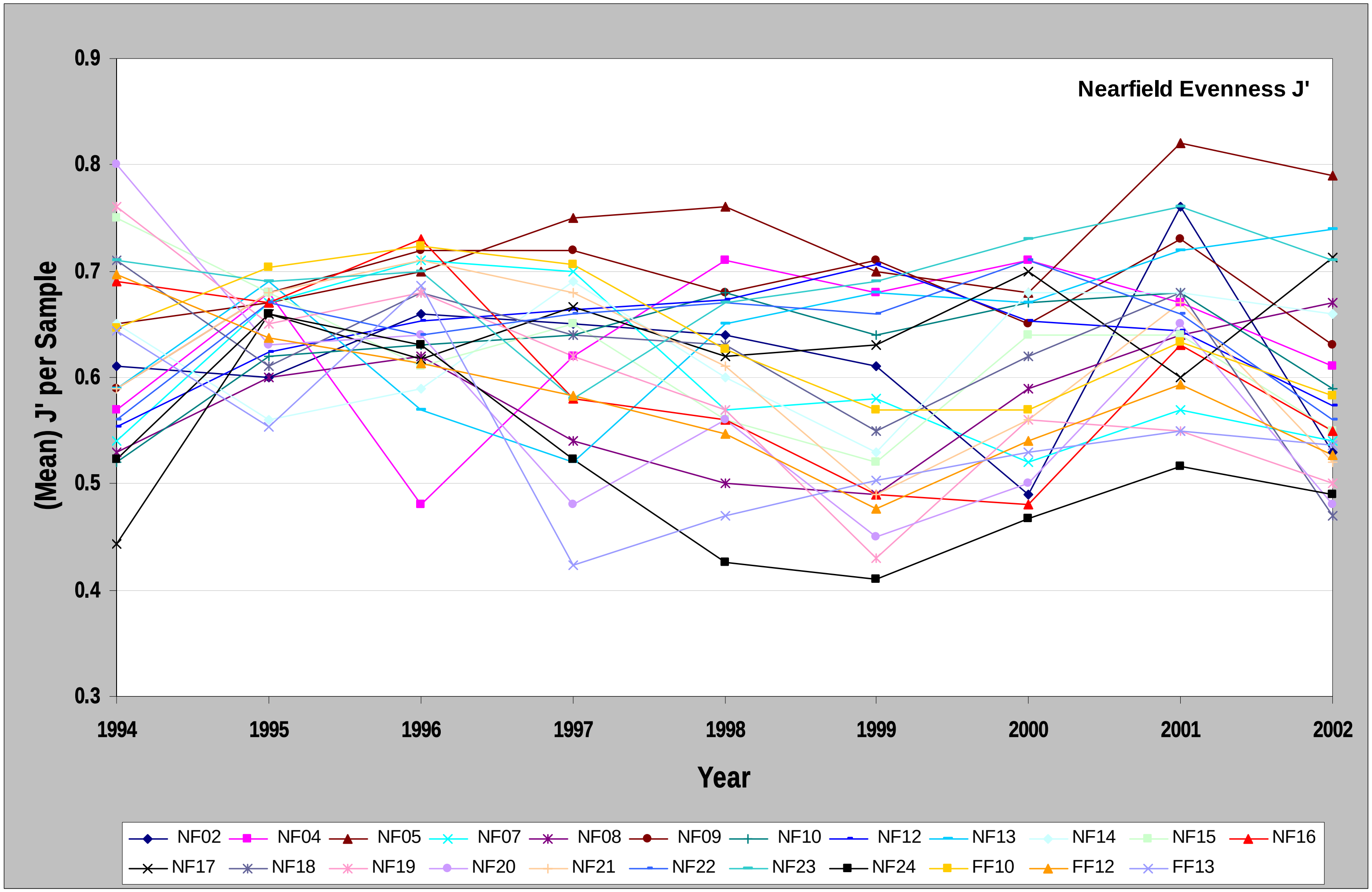


Figure D3-4. Evenness (Pielou's J)′ at nearfield stations from 1994 through 2002. Values are the mean of three replicates at six of the stations (see Table D3-7) or are for single samples.

Table D3-8. LOG-SERIES *ALPHA* at NEARFIELD STATIONS, 1994–2002*

STATION	1994	1995	1996	1997	1998	1999	2000	2001	2002
NF02	11.9	11.9	13.4	15.8	12.2	14.1	12.5	15.2	12.8
NF04	8.7	14.3	11.4	17.4	19.6	16.5	14.9	15.7	19.1
NF05	11.3	15.8	21.6	22.7	20.8	15.6	20.6	16.7	23.5
NF07	10.9	17.2	16.6	11.9	18.5	16.5	16.8	13.2	12.7
NF08	8.3	9.0	10.0	16.4	13.3	12.3	15.1	14.7	17.1
NF09	8.4	14.7	16.6	14.6	17.8	16.9	16.9	12.9	15.3
NF10	11.2	13.5	13.4	13.9	16.0	15.1	17.4	13.1	15.2
NF12*	9.5	12.2	13.9	15.9	16.7	13.3	12.7	11.7	11.8
NF13	10.5	10.1	11.6	10.3	18.1	14.8	16.0	18.2	17.9
NF14	12.9	15.2	15.3	14.5	18.2	16.3	13.0	14.8	15.9
NF15	13.6	12.9	14.7	14.9	12.2	11.2	14.9	12.5	14.9
NF16	10.4	14.9	13.3	12.3	12.6	13.0	12.2	15.1	12.6
NF17*	9.0	10.5	13.4	12.8	11.5	11.0	10.3	11.6	15.7
NF18	16.0	20.0	17.8	23.8	18.1	17.9	18.3	17.3	17.9
NF19	14.9	15.4	20.7	14.7	14.9	15.3	13.4	13.5	11.6
NF20	10.2	12.4	16.1	13.4	15.0	13.1	14.2	16.9	14.1
NF21	10.0	14.8	14.8	17.1	16.7	15.0	10.8	9.8	14.6
NF22	12.3	9.7	13.5	14.4	14.7	13.0	12.2	12.9	13.2
NF23	15.6	16.4	15.5	18.4	16.5	15.5	13.9	15.4	16.6
NF24*	11.4	12.9	14.1	13.3	12.2	12.0	11.4	13.2	13.2
FF10*	14.9	16.8	17.0	18.7	18.6	17.8	15.5	17.9	15.5
FF12*	8.2	11.4	12.4	12.5	11.2	11.7	9.1	9.5	9.4
FF13*	9.3	8.6	9.9	9.8	10.0	10.6	9.3	9.3	10.0

* Values are the mean of three replicates; other values are for single samples.

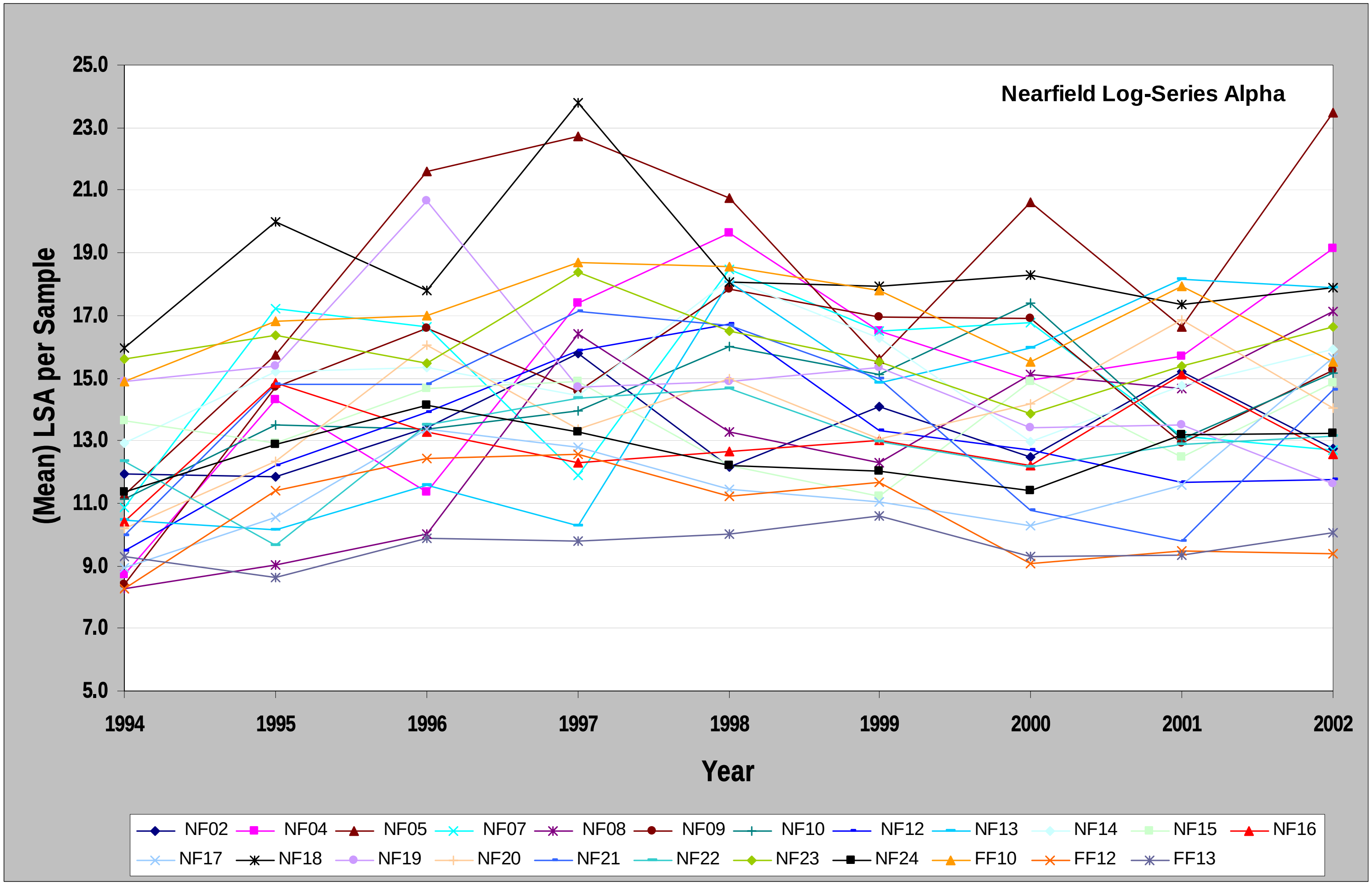


Figure D3-5. Log-series *alpha* at nearfield stations from 1994 through 2002. Values are the mean of three replicates at six of the stations (see Table D3-8) or are for single samples.

Table D3-9. MEAN TOTAL ABUNDANCE at FARFIELD STATIONS, 1992–2002

STATION	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
FF1 or 1A	425.7	637.0	858.7	2841.0	2232.0	2168.3	2332.0	4230.7	3234.3	2091.3	2358.0
FF04	866.0	370.7	553.3	417.3	524.7	1155.7	2436.0	1090.7	1271.7	1139.7	1556.7
FF05	1052.3	945.3	351.7	922.0	793.7	842.0	1450.3	2438.7	2519.3	1981.3	1901.3
FF06	1631.3	1744.7	581.3	1307.3	1094.3	996.3	1075.3	1216.7	641.0	395.7	490.7
FF07	1856.0	2056.0	400.7	950.3	1628.3	2785.3	3801.3	2316.3	3755.7	3022.3	2974.7
FF09	2806.0	1144.0	2304.7	2823.0	2524.0	2654.7	1929.7	2135.3	2226.3	1681.3	1969.3
FF11	667.7	1072.3	696.7	1082.7	1730.7	1280.3	1649.7	5654.3	2258.0	3086.0	2889.3
FF14	542.3	1016.7	662.7	853.3	965.7	832.3	2092.7	2146.7	1761.0	1406.3	553.0

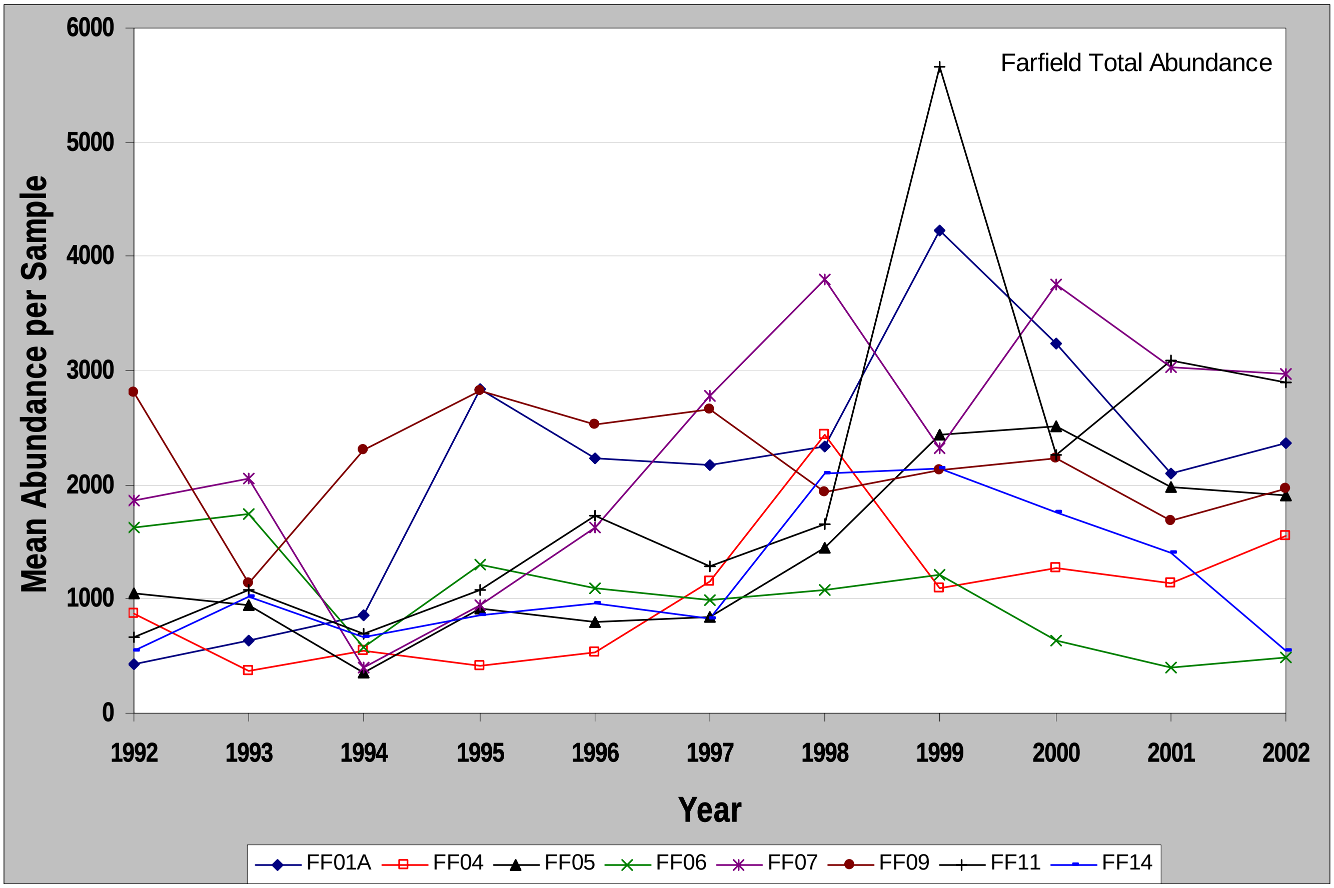


Figure D3-6. Total abundance at farfield stations from 1992 through 2002. Values are the mean of three replicates.

Table D3-10. MEAN SPECIES RICHNESS at FARFIELD STATIONS, 1992–2002											
STATION	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
FF1 or 1A	53.7	55.0	60.0	73.0	74.7	86.7	81.7	88.0	76.3	68.7	74.7
FF04	47.0	36.0	41.3	36.7	45.3	57.0	58.3	60.3	64.0	50.7	62.3
FF05	48.3	52.7	39.7	51.0	65.3	62.7	68.0	73.7	76.7	75.3	78.0
FF06	54.3	67.0	43.7	53.0	66.0	63.3	62.3	51.0	42.0	35.7	55.3
FF07	47.0	48.0	31.0	49.3	60.7	64.0	66.0	54.7	55.7	45.3	50.3
FF09	71.3	58.0	69.7	69.3	78.3	97.3	93.0	85.3	98.3	102.0	96.7
FF11	36.0	52.3	48.0	42.7	54.0	61.0	66.7	74.7	56.0	68.7	76.0
FF14	43.3	47.7	44.7	52.7	64.7	63.7	73.3	71.0	73.3	62.0	56.7

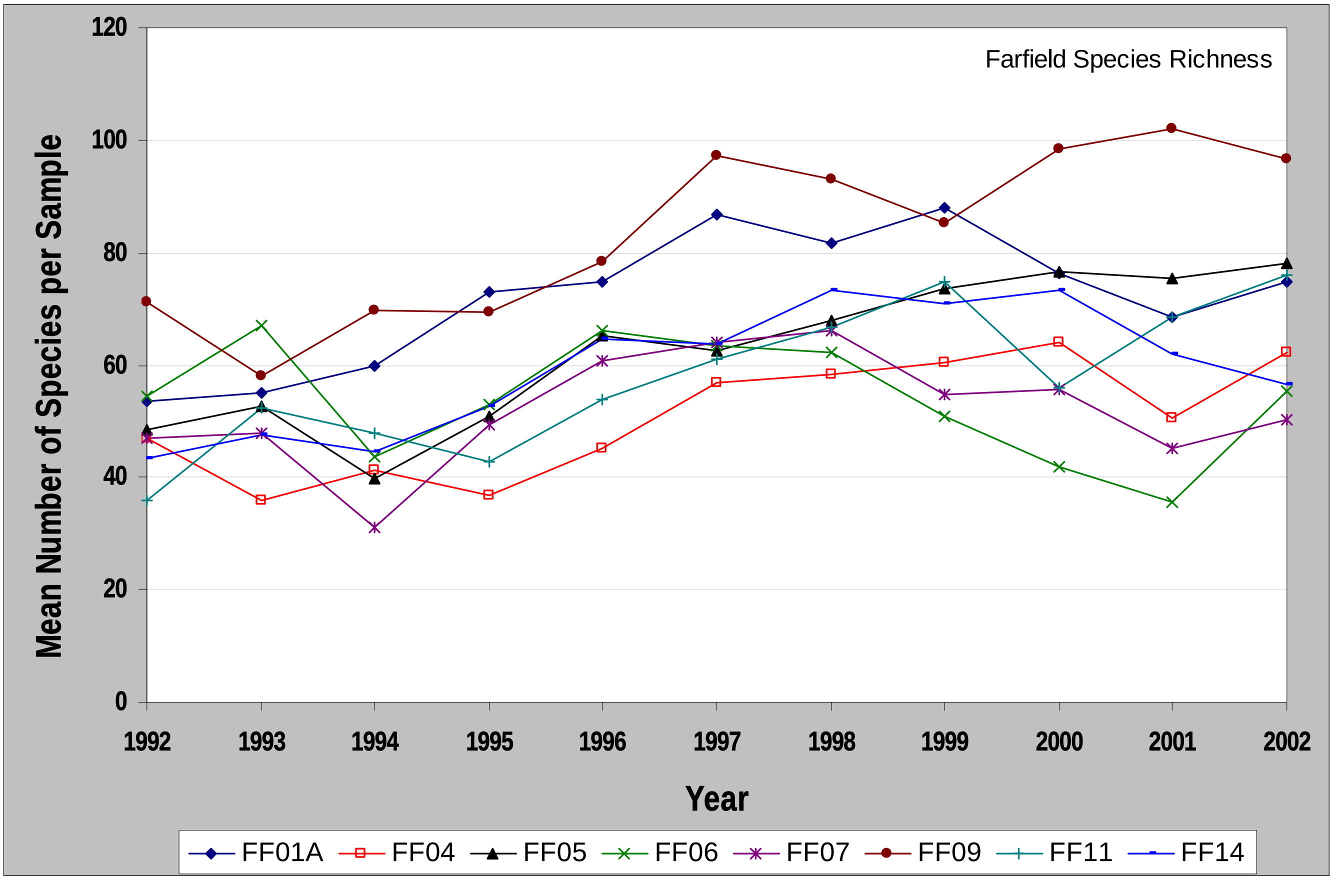


Figure D3-7. Species richness at farfield stations from 1992 through 2002. Values are the mean of three replicates.

Table D3-11. MEAN SHANNON DIVERSITY at FARFIELD STATIONS, 1992–2002

STATION	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
FF1 or 1A	4.64	4.50	4.39	2.33	3.04	3.81	3.15	2.98	2.76	2.97	3.25
FF04	3.03	3.87	4.06	3.82	4.21	4.19	3.65	4.41	4.25	4.17	4.30
FF05	2.26	3.81	4.43	3.54	4.50	4.27	4.24	4.28	4.37	4.70	4.55
FF06	3.55	4.21	3.87	4.15	4.61	4.59	4.39	3.93	3.87	3.55	4.60
FF07	3.40	3.74	3.32	3.79	3.87	3.49	3.47	3.20	3.11	2.86	2.79
FF09	3.05	3.11	3.18	2.29	2.95	3.65	4.15	3.86	4.34	4.97	4.26
FF11	3.25	3.90	3.80	2.56	2.85	3.11	3.39	2.79	2.79	3.57	3.62
FF14	3.67	3.87	4.09	4.21	4.64	4.49	4.68	4.41	4.59	4.50	4.74

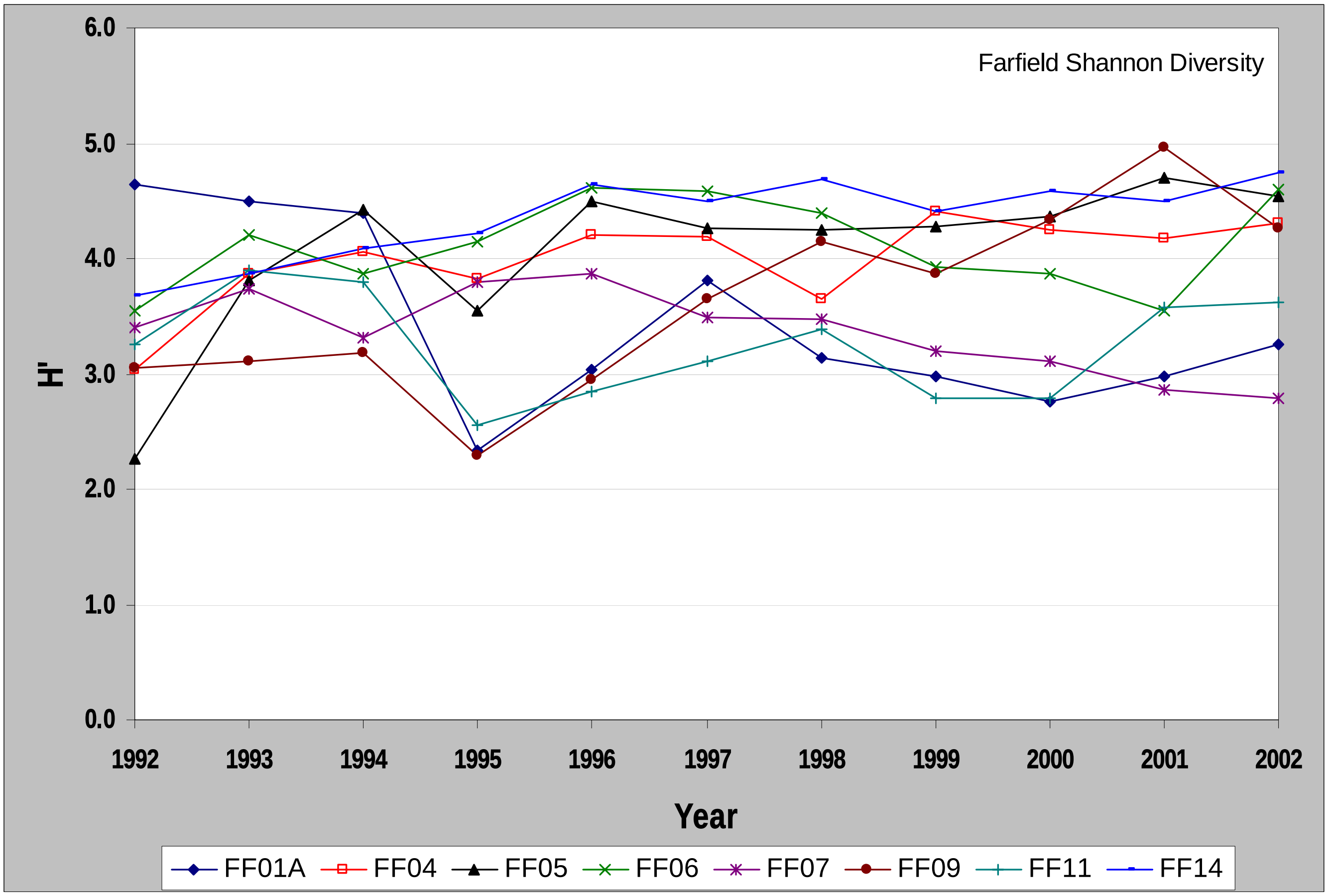


Figure D3-8. Shannon diversity at farfield stations from 1992 through 2002. Values are the mean of three replicates.

Table D3-12. MEAN EVENNESS at FARFIELD STATIONS, 1992–2002											
STATION	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
FF1 or 1A	0.81	0.78	0.75	0.38	0.49	0.59	0.50	0.46	0.44	0.49	0.52
FF04	0.55	0.75	0.76	0.74	0.77	0.72	0.62	0.75	0.71	0.74	0.72
FF05	0.40	0.67	0.83	0.62	0.75	0.72	0.70	0.69	0.70	0.75	0.72
FF06	0.62	0.69	0.71	0.72	0.76	0.77	0.74	0.69	0.72	0.69	0.79
FF07	0.61	0.67	0.67	0.67	0.65	0.58	0.57	0.55	0.54	0.52	0.49
FF09	0.50	0.53	0.52	0.37	0.47	0.55	0.64	0.61	0.66	0.74	0.65
FF11	0.63	0.68	0.68	0.47	0.49	0.52	0.56	0.45	0.48	0.59	0.58
FF14	0.68	0.70	0.75	0.73	0.77	0.75	0.75	0.72	0.74	0.76	0.81

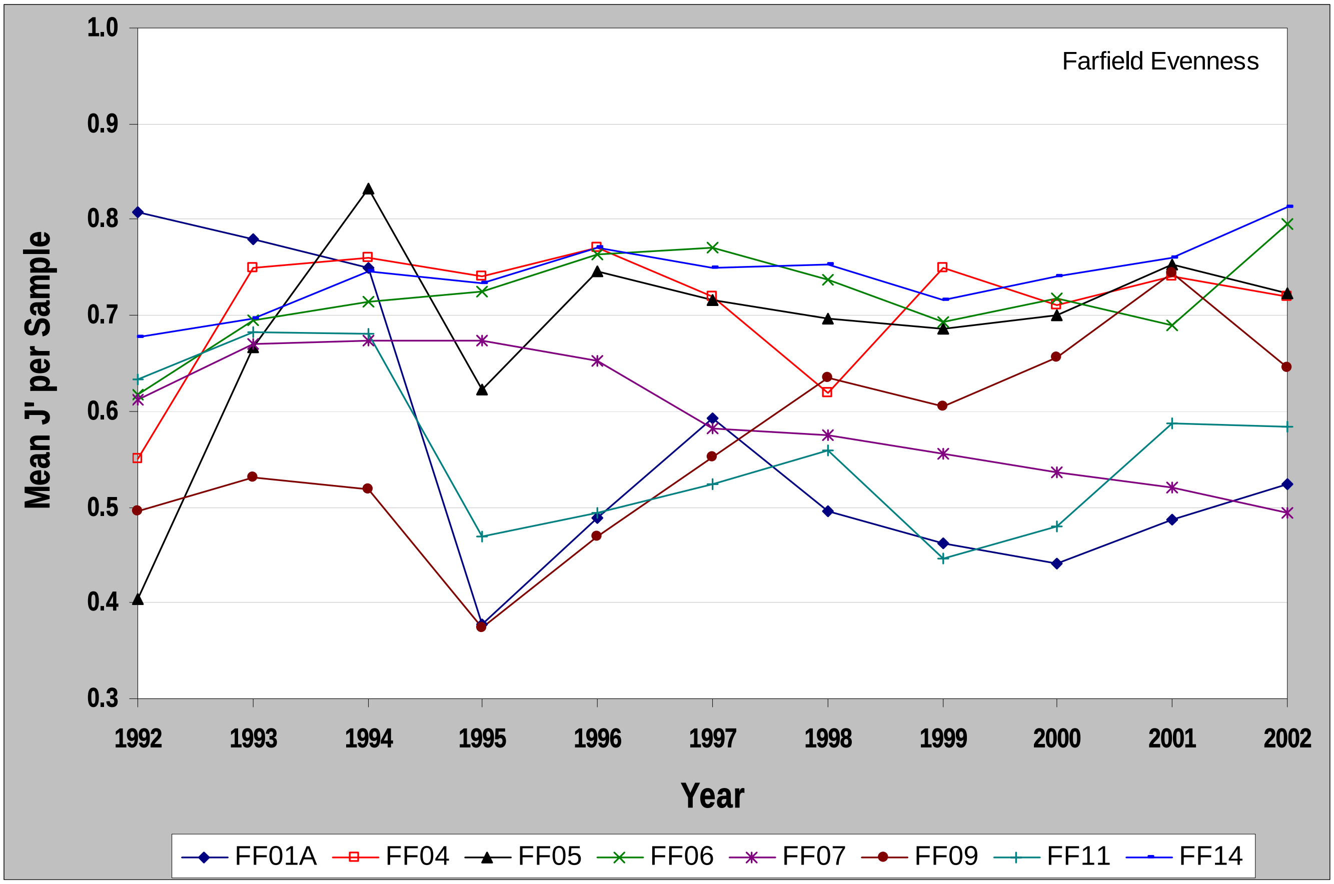


Figure D3-9. Evenness at farfield stations from 1992 through 2002. Values are the mean of three replicates.

Table D3-13. MEAN LOG-SERIES ALPHA at FARFIELD STATIONS, 1992–2002

STATION	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
FF1 or 1A	16.70	14.86	15.19	13.87	15.04	18.27	16.75	15.97	14.29	13.84	14.81
FF04	10.87	10.80	10.64	10.27	12.27	12.84	11.01	14.32	14.53	11.28	13.16
FF05	10.56	12.38	12.09	12.37	17.56	16.08	15.19	14.69	15.63	16.89	16.53
FF06	10.86	14.14	11.61	11.65	15.88	15.24	14.94	11.09	10.33	9.78	16.72
FF07	9.02	9.10	8.42	11.57	12.63	11.95	11.55	10.15	9.33	7.73	8.67
FF09	13.40	13.23	13.63	13.07	15.58	20.14	20.96	18.45	21.71	24.90	21.65
FF11	8.42	11.78	12.37	9.07	10.95	13.93	14.12	12.50	10.56	12.95	14.51
FF14	11.45	10.51	12.00	13.10	16.26	17.12	15.04	14.94	16.10	15.03	16.39

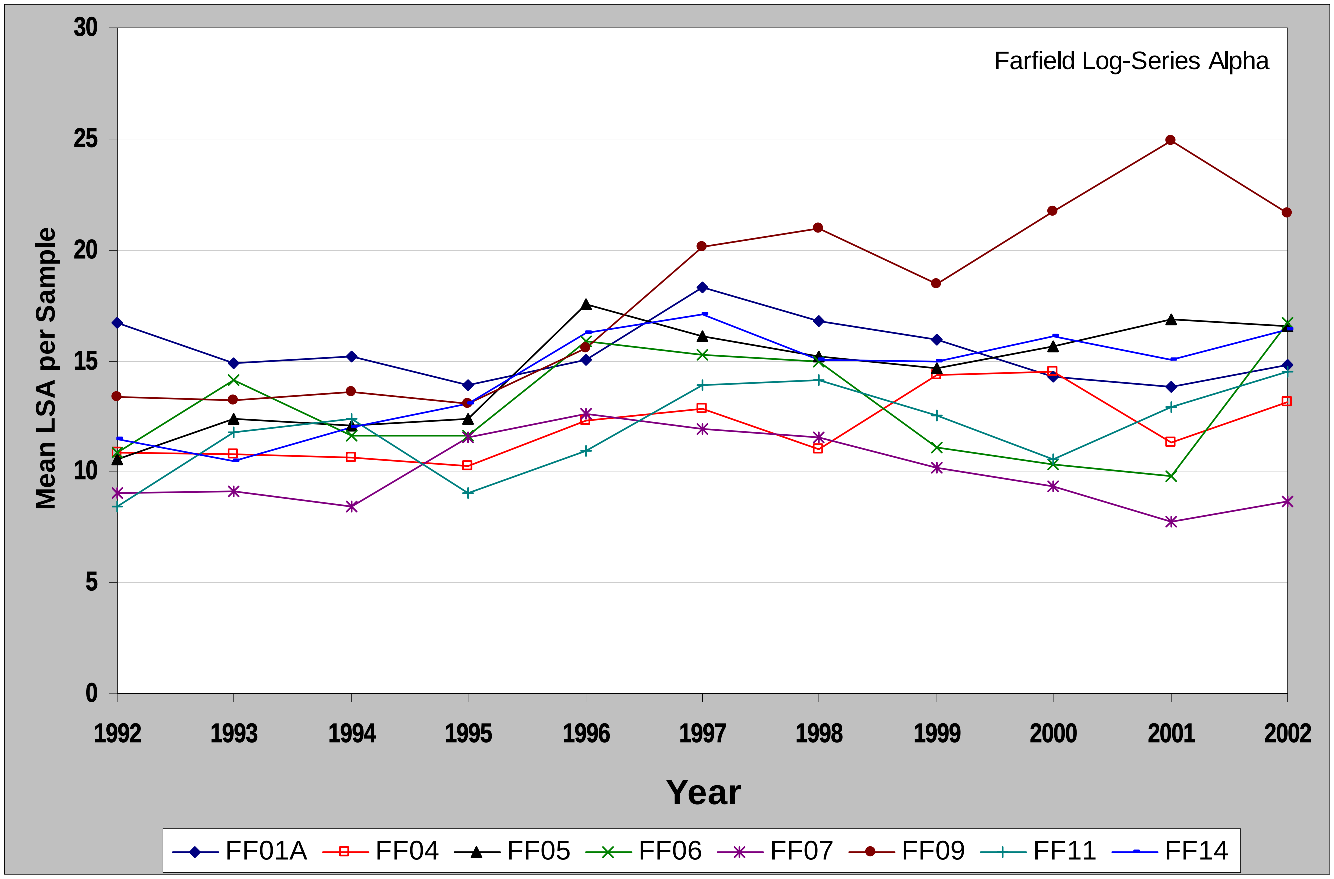


Figure D3-10. Log-series *alpha* at farfield stations from 1992 through 2002. Values are the mean of three replicates.

APPENDIX D4

Dominant Species at
Nearfield NonReplicated Stations
Nearfield Replicated Stations
Farfield Replicated Stations

Station	**Rank**	**Species**	**Count**	**%**	**Cum %**	**2001 Rank**	**2000 Rank**
NF 02	1	*Tharyx acutus*	578	30.3	30.3	5	2
	2	*Prionospio steenstrupi*	518	27.1	57.4	2	1
	3	*Aricidea catherinae*	276	14.5	71.9	3	5
	4	*Mediomastus californiensis*	179	9.4	81.2	11	3
	5	*Leitoscoloplos acutus*	33	1.7	83.0	NP	24
	6	*Spio limicola*	29	1.5	84.5	18	20
	7	*Ninoe nigripes*	22	1.2	85.6	41	15
	8	*Dipolydora socialis*	20	1.0	86.7	1	4
	9	*Levinsenia gracilis*	19	1.0	87.7	53	NP
	10	*Tubificoides apectinatus*	18	0.9	88.6	20	27
	11	*Arctica islandica*	17	0.9	89.5	NP	39
	12	*Euchone incolor*	16	0.8	90.4	33	23
	13	*Polygordius* sp. A	14	0.7	91.1	6	7
	14	*Scoletoma hebes*	14	0.7	91.8	NP	34
	15	*Exogone hebes*	13	0.7	92.5	10	12
(No. Species)	(64)	Station Total Abundance	1909			(63)	(66)
NF 04	1	*Exogone hebes*	857	28.2	28.2	1	2
	2	*Molgula manhattensis*	588	19.4	47.6	15	4
	3	*Exogone verugera*	261	8.6	56.2	2	5
	4	*Dipolydora socialis*	174	5.7	61.9	11	7
	5	*Cerastoderma pinnulatum*	162	5.3	67.2	24	6
	6	*Astarte undata*	117	3.9	71.1	NP	29
	7	Enchytraeidae sp. 1	86	2.8	73.9	4	3
	8	*Aglaophamus circinata*	45	1.5	75.4	23	21
	9	*Prionospio steenstrupi*	45	1.5	76.9	6	15
	10	*Hiatella arctica*	44	1.4	78.3	59	35
	11	*Tharyx acutus*	37	1.2	79.6	10	24
	12	*Asabellides oculata*	36	1.2	80.7	NP	NP
	13	*Owenia fusiformis*	29	1.0	81.7	27	9
	14	*Spiophanes bombyx*	29	1.0	82.6	12	11
	15	*Arctica islandica*	27	0.9	83.5	NP	36
(No. Species)	(97)	Station Total Abundance	3036			(71)	(71)
NF 05	1	*Prionospio steenstrupi*	150	18.4	18.4	7	1
	2	*Mediomastus californiensis*	92	11.3	29.7	1	5
	3	*Haploops fundiensis*	49	6.0	35.7	5	7
	4	*Levinsenia gracilis*	44	5.4	41.0	8	10
	5	*Tharyx acutus*	35	4.3	45.3	4	8
	6	*Astarte undata*	28	3.4	48.8	17	22
	7	*Crenella decussata*	24	2.9	51.7	NP	NP
	8	*Monticellina dorsobranchialis*	23	2.8	54.5	15	57
	9	*Spio limicola*	23	2.8	57.3	23	15
	10	*Asabellides oculata*	21	2.6	59.9	NP	NP
	11	*Aphelochaeta marioni*	19	2.3	62.2	2	3
	12	*Ericthonius fasciatus*	14	1.7	63.9	3	11
	13	*Harpinia propinqua*	14	1.7	65.6	13	9
	14	*Nucula delphinodonta*	14	1.7	67.4	9	16
	15	*Parougia caeca*	12	1.5	68.8	20	24

Station	**Rank**	**Species**	**Count**	**%**	**Cum %**	**2001 Rank**	**2000 Rank**
(No. Species)	(84)	Station Total Abundance	817			(67)	(87)
NF 07	1	*Prionospio steenstrupi*	1614	43.8	43.8	1	1
	2	*Spio limicola*	653	17.7	61.5	2	2
	3	*Mediomastus californiensis*	206	5.6	67.1	3	4
	4	*Aphelochaeta marioni*	122	3.3	70.4	7	10
	5	*Nucula delphinodonta*	121	3.3	73.7	4	6
	6	*Ampharete acutifrons*	97	2.6	76.3	40	NP
	7	*Tharyx acutus*	85	2.3	78.6	5	12
	8	*Euchone incolor*	74	2.0	80.7	9	5
	9	*Aricidea catherinae*	70	1.9	82.6	24	40
	10	*Crenella decussata*	52	1.4	84.0	NP	NP
	11	*Ninoe nigripes*	47	1.3	85.2	11	7
	12	*Dipolydora socialis*	45	1.2	86.5	43	3
	13	*Exogone hebes*	45	1.2	87.7	14	24
	14	*Leitoscoloplos acutus*	43	1.2	88.8	30	25
	15	*Exogone verugera*	39	1.1	89.9	6	8
(No. Species)	(72)	Station Total Abundance	3685			(68)	(88)
NF 08	1	*Tharyx acutus*	613	17.7	17.7	4	11
	2	*Prionospio steenstrupi*	433	12.5	30.2	3	1
	3	*Aphelochaeta marioni*	301	8.7	38.9	1	15
	4	*Phoronis architecta*	274	7.9	46.9	2	62
	5	*Spio limicola*	271	7.8	54.7	5	5
	6	*Ampharete acutifrons*	227	6.6	61.3	48	92
	7	*Mediomastus californiensis*	222	6.4	67.7	6	2
	8	*Ninoe nigripes*	118	3.4	71.1	12	8
	9	*Levinsenia gracilis*	94	2.7	73.8	8	6
	10	*Euchone incolor*	92	2.7	76.5	9	4
	11	*Leitoscoloplos acutus*	79	2.3	78.8	11	10
	12	*Nucula delphinodonta*	68	2.0	80.7	14	13
	13	*Dipolydora socialis*	63	1.8	82.6	7	3
	14	*Aricidea catherinae*	56	1.6	84.2	18	50
	15	*Metopella angusta*	36	1.0	85.2	53	25
(No. Species)	(91)	Station Total Abundance	3457			(78)	(73)
NF 09	1	*Prionospio steenstrupi*	816	34.5	34.5	1	1
	2	*Spio limicola*	228	9.7	44.2	2	3
	3	*Ampharete acutifrons*	198	8.4	52.5	19	56
	4	*Mediomastus californiensis*	165	7.0	59.5	3	4
	5	*Nucula delphinodonta*	103	4.4	63.9	10	6
	6	*Tharyx acutus*	95	4.0	67.9	14	15
	7	*Ninoe nigripes*	65	2.8	70.7	9	8
	8	*Levinsenia gracilis*	55	2.3	73.0	6	9
	9	*Leitoscoloplos acutus*	52	2.2	75.2	40	21
	10	*Aricidea catherinae*	46	1.9	77.1	5	11
	11	*Phoronis architecta*	44	1.9	79.0	4	35
	12	*Aphelochaeta marioni*	42	1.8	80.8	12	20
	13	*Monticellina baptisteae*	35	1.5	82.3	7	5
	14	*Dipolydora socialis*	32	1.4	83.6	16	2
	15	*Onoba pelagica*	26	1.1	84.7	13	17

Station	**Rank**	**Species**	**Count**	**%**	**Cum %**	**2001 Rank**	**2000 Rank**
(No. Species)	(77)	Station Total Abundance	2362			(62)	(89)
NF 10	1	*Prionospio steenstrupi*	1270	33.1	33.1	2	1
	2	*Spio limicola*	481	12.5	45.6	1	4
	3	*Tharyx acutus*	324	8.5	54.1	5	14
	4	*Aricidea catherinae*	321	8.4	62.5	4	3
	5	*Mediomastus californiensis*	301	7.9	70.3	3	2
	6	*Ampharete acutifrons*	218	5.7	76.0	25	45
	7	*Levinsenia gracilis*	63	1.6	77.7	8	12
	8	*Dipolydora socialis*	59	1.5	79.2	11	5
	9	*Aphelochaeta marioni*	58	1.5	80.7	7	8
	10	*Leitoscoloplos acutus*	57	1.5	82.2	22	24
	11	*Nucula delphinodonta*	57	1.5	83.7	9	13
	12	*Ninoe nigripes*	56	1.5	85.1	12	6
	13	*Euchone incolor*	46	1.2	86.3	14	11
	14	*Monticellina baptisteae*	42	1.1	87.4	6	7
	15	*Phyllodoce mucosa*	34	0.9	88.3	18	42
(No. Species)	(84)	Station Total Abundance	3833			(69)	(85)
NF 13	1	*Tharyx acutus*	198	10.2	10.2	30	19
	2	*Exogone hebes*	185	9.5	19.7	3	4
	3	*Exogone verugera*	182	9.4	29.1	4	3
	4	*Enchytraeidae* sp. 1	176	9.1	38.2	2	2
	5	*Molgula manhattensis*	159	8.2	46.4	17	16
	6	*Prionospio steenstrupi*	152	7.8	54.2	8	7
	7	*Crenella decussata*	79	4.1	58.3	NP	NP
	8	*Euclymene collaris*	75	3.9	62.2	NP	25
	9	*Aglaophamus circinata*	68	3.5	65.7	51	20
	10	*Dipolydora socialis*	66	3.4	69.1	6	8
	11	*Adelodrilus* sp. 1	47	2.4	71.5	20	11
	12	*Crenella glandula*	47	2.4	73.9	1	27
	13	*Grania postcl. longiducta*	44	2.3	76.2	NP	52
	14	*Mediomastus californiensis*	31	1.6	77.8	33	28
	15	*Asabellides oculata*	26	1.3	79.2	NP	NP
(No. Species)	(84)	Station Total Abundance	1939			(80)	(76)
NF 14	1	*Prionospio steenstrupi*	700	22.6	22.6	2	9
	2	*Aricidea catherinae*	385	12.4	35.0	12	18
	3	*Exogone verugera*	269	8.7	43.7	1	1
	4	Tubificidae sp. 2	263	8.5	52.2	71	22
	5	*Protomedeia fasciata*	232	7.5	59.6	9	10
	6	*Exogone hebes*	194	6.3	65.9	3	2
	7	*Mediomastus californiensis*	139	4.5	70.4	5	12
	8	*Unciola inermis*	108	3.5	73.9	7	3
	9	*Crenella decussata*	97	3.1	77.0	NP	NP
	10	*Ericthonius fasciatus*	52	1.7	78.7	18	7
	11	*Crenella glandula*	50	1.6	80.3	8	9
	12	*Ninoe nigripes*	46	1.5	81.8	NP	63
	13	*Ampharete acutifrons*	40	1.3	83.0	NP	NP
	14	*Nemertea* sp. 12	33	1.1	84.1	13	17
	15	*Astarte undata*	31	1.0	85.1	21	16

Station	**Rank**	**Species**	**Count**	**%**	**Cum %**	**2001 Rank**	**2000 Rank**
(No. Species)	(84)	Station Total Abundance	3102			(71)	(73)
NF 15	1	*Prionospio steenstrupi*	2081	43.1	43.1	1	1
	2	*Aricidea catherinae*	543	11.2	54.3	2	3
	3	*Owenia fusiformis*	268	5.5	59.9	3	4
	4	*Spio limicola*	230	4.8	64.6	6	8
	5	*Mediomastus californiensis*	212	4.4	69.0	4	2
	6	*Spiophanes bombyx*	186	3.9	72.9	7	9
	7	*Exogone hebes*	172	3.6	76.4	5	6
	8	*Nucula delphinodonta*	152	3.1	79.6	8	11
	9	*Tharyx acutus*	116	2.4	82.0	12	28
	10	*Dipolydora socialis*	100	2.1	84.1	15	5
	11	*Phyllodoce mucosa*	86	1.8	85.8	10	30
	12	*Euchone incolor*	78	1.6	87.5	11	7
	13	*Edotia montosa*	58	1.2	88.7	13	10
	14	*Phoronis architecta*	37	0.8	89.4	9	31
	15	*Capitella capitata complex*	34	0.7	90.1	25	35
(No. Species)	(86)	Station Total Abundance	4831			(65)	(77)
NF 16	1	*Prionospio steenstrupi*	1660	36.8	36.8	1	1
	2	*Tharyx acutus*	837	18.5	55.3	3	6
	3	*Mediomastus californiensis*	454	10.1	65.4	2	2
	4	*Euchone incolor*	181	4.0	69.4	13	5
	5	*Spio limicola*	160	3.5	72.9	10	20
	6	*Ampharete acutifrons*	159	3.5	76.5	47	NP
	7	*Leitoscoloplos acutus*	130	2.9	79.3	6	17
	8	*Levinsenia gracilis*	128	2.8	82.2	5	3
	9	*Ninoe nigripes*	122	2.7	84.9	4	4
	10	Tubificidae sp. 2	85	1.9	86.8	18	16
	11	Nemertea sp. 12	74	1.6	88.4	42	7
	12	*Aphelochaeta marioni*	69	1.5	89.9	48	NP
	13	*Exogone verugera*	43	1.0	90.9	54	35
	14	*Nucula delphinodonta*	42	0.9	91.8	25	12
	15	*Parougia caeca*	27	0.6	92.4	9	11
(No. Species)	(74)	Station Total Abundance	4516			(65)	(63)
NF 18	1	*Prionospio steenstrupi*	1977	58.0	58.0	2	1
	2	*Aricidea catherinae*	168	4.9	62.9	4	6
	3	*Spio limicola*	159	4.7	67.6	26	26
	4	*Mediomastus californiensis*	130	3.8	71.4	3	4
	5	*Asabellides oculata*	121	3.5	75.0	NP	NP
	6	*Tharyx acutus*	95	2.8	77.7	20	13
	7	*Ampharete acutifrons*	75	2.2	79.9	59	NP
	8	*Nucula delphinodonta*	39	1.1	81.1	14	23
	9	*Euchone incolor*	35	1.0	82.1	65	22
	10	*Arctica islandica*	32	0.9	83.1	61	NP
	11	*Crenella decussata*	32	0.9	84.0	NP	NP
	12	*Ninoe nigripes*	32	0.9	84.9	22	9
	13	*Levinsenia gracilis*	27	0.8	85.7	15	12
	14	*Pholoe tecta*	25	0.7	86.5	NP	49
	15	*Astarte undata*	24	0.7	87.2	5	7

Station	**Rank**	**Species**	**Count**	**%**	**Cum %**	**2001 Rank**	**2000 Rank**
(No. Species)	(94)	Station Total Abundance	3409			(81)	(88)
NF 19	1	*Prionospio steenstrupi*	2038	50.9	50.9	1	1
	2	*Tharyx acutus*	405	10.1	61.0	11	35
	3	*Spio limicola*	234	5.8	66.9	62	13
	4	*Mediomastus californiensis*	233	5.8	72.7	2	4
	5	*Aricidea catherinae*	212	5.3	78.0	6	15
	6	*Nucula delphinodonta*	119	3.0	81.0	3	3
	7	*Molgula manhattensis*	79	2.0	82.9	23	28
	8	*Euchone incolor*	76	1.9	84.8	7	5
	9	*Exogone hebes*	76	1.9	86.7	8	8
	10	*Phyllodoce mucosa*	53	1.3	88.0	16	14
	11	*Spiophanes bombyx*	46	1.1	89.2	10	34
	12	*Aphelochaeta marioni*	35	0.9	90.1	5	6
	13	*Dipolydora socialis*	33	0.8	90.9	15	2
	14	*Ninoe nigripes*	32	0.8	91.7	14	9
	15	*Arctica islandica*	29	0.7	92.4	37	45
(No. Species)	(68)	Station Total Abundance	4003			(65)	(74)
NF 20	1	*Prionospio steenstrupi*	2002	51.7	51.7	1	1
	2	*Tharyx acutus*	477	12.3	64.0	2	6
	3	*Mediomastus californiensis*	297	7.7	71.7	3	3
	4	*Scoletoma hebes*	131	3.4	75.0	11	11
	5	*Euchone incolor*	118	3.0	78.1	15	15
	6	*Ninoe nigripes*	96	2.5	80.6	5	4
	7	Tubificidae sp. 2	81	2.1	82.7	9	36
	8	*Levinsenia gracilis*	73	1.9	84.5	4	5
	9	*Monticellina dorsobranchialis*	62	1.6	86.1	8	14
	10	*Nucula delphinodonta*	47	1.2	87.4	6	37
	11	*Monticellina baptisteae*	44	1.1	88.5	7	7
	12	*Spio limicola*	33	0.9	89.3	18	29
	13	*Argissa hamatipes*	29	0.7	90.1	19	33
	14	*Ampharete acutifrons*	23	0.6	90.7	NP	NP
	15	*Arctica islandica*	23	0.6	91.3	29	40
(No. Species)	(79)	Station Total Abundance	3876			(74)	(72)
NF 21	1	*Prionospio steenstrupi*	1876	44.4	44.4	1	1
	2	*Spio limicola*	692	16.4	60.8	3	3
	3	*Mediomastus californiensis*	245	5.8	66.6	2	2
	4	*Tharyx acutus*	165	3.9	70.5	6	10
	5	*Leitoscoloplos acutus*	164	3.9	74.3	7	9
	6	*Ampharete acutifrons*	109	2.6	76.9	20	NP
	7	*Ninoe nigripes*	90	2.1	79.0	5	5
	8	*Aphelochaeta marioni*	81	1.9	81.0	12	25
	9	*Levinsenia gracilis*	71	1.7	82.6	4	6
	10	*Aricidea quadrilobata*	63	1.5	84.1	13	12
	11	*Parougia caeca*	58	1.4	85.5	15	18
	12	*Nucula delphinodonta*	52	1.2	86.7	10	8
	13	*Monticellina baptisteae*	51	1.2	87.9	9	7
	14	*Anobothrus gracilis*	48	1.1	89.1	8	43
	15	*Aricidea catherinae*	45	1.1	90.1	22	22

Station	**Rank**	**Species**	**Count**	**%**	**Cum %**	**2001 Rank**	**2000 Rank**
(No. Species)	(83)	Station Total Abundance	4228			(45)*	(57)
NF 22	1	*Prionospio steenstrupi*	1058	31.4	31.4	3	6
	2	*Tharyx acutus*	697	16.5	47.9	2	7
	3	*Mediomastus californiensis*	409	9.7	57.6	1	1
	4	*Spio limicola*	235	5.6	63.1	4	3
	5	*Levinsenia gracilis*	141	3.3	66.5	6	4
	6	*Leitoscoloplos acutus*	115	2.7	69.2	9	13
	7	Tubificidae sp. 2	64	1.5	70.7	31	17
	8	*Euchone incolor*	59	1.4	72.1	5	2
	9	*Ninoe nigripes*	57	1.3	73.4	7	5
	10	*Anobothrus gracilis*	56	1.3	74.8	NP	NP
	11	*Parougia caeca*	55	1.3	76.1	10	21
	12	*Aricidea quadrilobata*	43	1.0	77.1	11	9
	13	*Aphelochaeta marioni*	37	0.9	77.9	20	12
	14	*Eteone longa*	36	0.9	78.8	34	15
	15	*Ampharete acutifrons*	34	0.8	79.6	36	NP
(No. Species)	(73)	Station Total Abundance	3367			(61)	(56)
NF 23	1	*Exogone hebes*	358	21.3	21.3	2	1
	2	*Molgula manhattensis*	281	16.7	38.0	4	6
	3	*Dipolydora socialis*	120	7.1	45.1	22	9
	4	*Arctica islandica*	94	5.6	50.7	48	50
	5	*Aglaophamus circinata*	93	5.5	56.2	35	26
	6	Enchytraeidae sp. 1	63	3.7	60.0	3	8
	7	*Spiophanes bombyx*	59	3.5	63.5	1	2
	8	*Astarte borealis*	54	3.2	66.7	NP	NP
	9	*Exogone verugera*	44	2.6	69.3	7	11
	10	*Monticellina baptisteae*	43	2.6	71.8	34	32
	11	*Hiatella arctica*	35	2.1	73.9	53	17
	12	*Tanaissus psammophilus*	34	2.0	75.9	27	13
	13	*Pythinella cuneata*	26	1.5	77.5	NP	NP
	14	*Euclymene collaris*	25	1.5	79.0	13	31
	15	*Prionospio steenstrupi*	25	1.5	80.4	10	12
(No. Species)	(77)	Station Total Abundance	1684			(69)	(63)

NP = Not present in sample.

Station	**Rank**	**Species**	**Mean**	**Std. Dev.**	**%**	**Cum %**	**2001 Rank**	**2000 Rank**
NF 12	1	*Prionospio steenstrupi*	973.7	139.2	29.1	29.1	5	1
	2	*Tharyx acutus*	470.0	131.7	14.0	43.1	3	9
	3	*Mediomastus californiensis*	435.7	109.7	13.0	56.1	1	3
	4	*Spio limicola*	430.0	59.1	12.8	69.0	2	4
	5	*Aricidea catherinae*	309.0	92.8	9.2	78.2	4	7
	6	*Levinsenia gracilis*	95.0	19.5	2.8	81.0	7	8
	7	*Leitoscoloplos acutus*	89.0	38.2	2.7	83.7	12	15
	8	*Aphelochaeta marioni*	72.3	25.9	2.2	85.9	6	10
	9	*Ninoe nigripes*	55.0	19.1	1.6	87.5	9	11
	10	*Exogone verugera*	46.3	23.6	1.4	88.9	10	14
	11	*Parougia caeca*	45.3	14.4	1.4	90.2	8	18
	12	*Monticellina baptisteae*	39.3	28.4	1.2	91.4	13	6
	13	*Aricidea quadrilobata*	30.3	6.1	0.9	92.3	18	19
	14	*Micrura* spp.	23.0	12.5	0.7	93.0	15	21
	15	*Nucula delphinodonta*	19.7	7.2	0.6	93.6	14	13
(No. Species)	(98)	Station Mean Abundance	3349.3				(89)	(94)
NF 17	1	*Molgula manhattensis*	328.3	386.6	28.0	28.0	1	2
	2	*Crassicorophium crassicorne*	117.3	118.0	10.0	38.0	5	1
	3	*Spiophanes bombyx*	114.7	89.5	9.8	47.8	3	8
	4	*Dipolydora socialis*	71.0	61.0	6.1	53.9	35	5
	5	*Grania postcli. longiducta*	51.3	45.5	4.4	58.2	7	NP
	6	*Exogone hebes*	46.7	41.1	4.0	62.2	2	4
	7	*Cerastoderma pinnulatum*	29.0	21.4	2.5	64.7	15	6
	8	*Polygordius* sp. A	25.0	8.9	2.1	66.8	4	7
	9	*Aglaophamus circinata*	24.3	16.6	2.1	68.9	45	23
	10	*Phyllodoce mucosa*	20.3	13.6	1.7	70.6	11	18
	11	*Tharyx acutus*	19.7	31.5	1.7	72.3	44	71
	12	*Prionospio steenstrupi*	17.0	18.5	1.5	73.8	10	32
	13	*Pythinella cuneata*	17.0	8.5	1.5	75.2	NP	NP
	14	*Paradoneis armatus*	16.7	25.5	1.4	76.6	NP	67
	15	*Tanaissus psammophilus*	15.3	12.2	1.3	78.0	12	14
(No. Species)	(104)	Station Mean Abundance	1171.7				(85)	(72)
NF 24	1	*Prionospio steenstrupi*	3155.0	640.0	49.3	49.3	1	1
	2	*Tharyx acutus*	764.7	112.5	11.9	61.2	5	7
	3	*Mediomastus californiensis*	385.0	103.9	6.0	67.3	2	2
	4	*Aricidea catherinae*	343.7	106.2	5.4	72.6	4	3
	5	*Aphelochaeta marioni*	239.3	103.6	3.7	76.4	3	18
	6	*Spio limicola*	225.0	63.3	3.5	79.9	6	6
	7	*Dipolydora socialis*	191.3	85.3	3.0	82.9	20	29
	8	*Leitoscoloplos acutus*	119.3	20.3	1.9	84.7	12	13
	9	*Euchone incolor*	109.0	35.6	1.7	86.4	8	5
	10	*Levinsenia gracilis*	76.0	50.1	1.2	87.6	7	4
	11	*Phyllodoce mucosa*	74.0	32.5	1.2	88.8	10	25
	12	*Arctica islandica*	59.3	14.0	0.9	89.7	46	44
	13	*Eteone longa*	55.0	14.9	0.9	90.6	19	10
	14	*Phoronis architecta*	38.3	29.3	0.6	91.2	11	85
	15	*Ampharete acutifrons*	36.7	11.5	0.6	91.7	60	NP

Station	Rank	Species	Mean	Std. Dev.	%	Cum %	2001 Rank	2000 Rank
(No. Species)	(111)	Station Mean Abundance	6401.0				(104)	(90)
FF 10	1	*Prionospio steenstrupi*	981.3	626.4	43.8	43.8	1	1
	2	*Aricidea catherinae*	243.7	139.7	10.9	54.7	2	3
	3	*Nucula delphinodonta*	161.3	90.4	7.2	61.9	7	5
	4	*Mediomastus californiensis*	129.7	72.2	5.8	67.7	3	2
	5	*Spio limicola*	74.7	58.5	3.3	71.0	4	24
	6	*Scoletoma hebes*	51.3	30.9	2.3	73.3	14	15
	7	*Ampharete acutifrons*	44.7	54.0	2.0	75.3	46	NP
	8	*Ninoe nigripes*	42.0	28.6	1.9	77.2	8	6
	9	*Tharyx acutus*	36.3	36.6	1.6	78.8	13	21
	10	*Astarte undata*	33.7	23.0	1.5	80.3	24	10
	11	*Euchone incolor*	31.7	16.0	1.4	81.7	37	35
	12	*Asabellides oculata*	28.0	6.2	1.2	82.9	97	NP
	13	*Levinsenia gracilis*	27.3	19.7	1.2	84.2	10	14
	14	*Monticellina baptisteae*	25.3	21.5	1.1	85.3	5	7
	15	*Exogone hebes*	18.3	7.2	0.8	86.1	18	12
(No. Species)	(109)	Station Mean Abundance	2240.3				(120)	(124)
FF 12	1	*Prionospio steenstrupi*	1212.7	218.9	42.1	42.1	1	1
	2	*Owenia fusiformis*	481.7	160.1	16.7	58.8	2	3
	3	*Mediomastus californiensis*	333.0	62.9	11.6	70.4	3	2
	4	*Tharyx acutus*	216.3	59.6	7.5	77.9	4	4
	5	*Scoletoma hebes*	110.7	15.2	3.8	81.8	5	7
	6	*Ninoe nigripes*	66.7	12.0	2.3	84.1	9	5
	7	*Monticellina baptisteae*	60.3	7.6	2.1	86.2	7	6
	8	*Spiophanes bombyx*	58.7	20.5	2.0	88.2	8	12
	9	*Euchone incolor*	47.3	11.9	1.6	89.9	19	14
	10	*Levinsenia gracilis*	39.3	9.3	1.4	91.2	12	9
	11	*Aricidea catherinae*	34.0	25.2	1.2	92.4	6	8
	12	*Monticellina dorsobranchialis*	32.0	7.0	1.1	93.5	10	10
	13	*Spio limicola*	25.0	16.5	0.9	94.4	22	26
	14	*Phyllodoce mucosa*	17.3	11.5	0.6	95.0	11	32
	15	*Leitoscoloplos acutus*	14.7	6.5	0.5	95.5	13	28
(No. Species)	(74)	Station Mean Abundance	2878.0				(68)	(71)
FF 13	1	*Prionospio steenstrupi*	1702.0	372.7	29.5	29.5	5	1
	2	*Tharyx acutus*	1205.0	258.3	20.9	50.4	1	3
	3	*Aricidea catherinae*	885.7	237.7	15.4	65.8	3	5
	4	*Mediomastus californiensis*	663.3	210.0	11.5	77.3	4	2
	5	*Dipolydora socialis*	274.0	28.7	4.8	82.1	9	10
	6	*Leitoscoloplos acutus*	132.7	31.5	2.3	84.4	17	26
	7	*Eteone longa*	120.3	35.3	2.1	86.5	21	21
	8	*Phoronis architecta*	99.3	25.4	1.7	88.2	6	15
	9	*Phyllodoce mucosa*	86.3	42.4	1.5	89.7	7	11
	10	*Scoletoma hebes*	85.3	28.7	1.5	91.2	12	13
	11	*Tubificoides apectinatus*	66.7	30.6	1.2	92.3	8	18
	12	*Metopella angusta*	42.0	13.0	0.7	93.1	33	22
	13	*Monticellina baptisteae*	41.3	4.0	0.7	93.8	11	12
	14	*Photis pollex*	35.7	29.8	0.6	94.4	2	4
	15	*Euchone incolor*	34.7	13.9	0.6	95.0	10	8

Station	Rank	Species	Mean	Std. Dev.	%	Cum %	2001 Rank	2000 Rank
(No. Species)	(88)	Station Mean Abundance	5760.0				(75)	(75)
FF01A	1	*Prionospio steenstrupi*	1254.3	520.8	54.05	54.05	1	1
	2	*Nucula delphinodonta*	131.3	26.0	5.66	59.71	2	3
	3	*Aricidea catherinae*	117.0	72.8	5.04	64.75	8	10
	4	*Levinsenia gracilis*	90.7	14.4	3.91	68.66	5	5
	5	*Tharyx acutus*	72.7	23.5	3.13	71.79	3	9
	6	*Asabellides oculata*	62.7	42.6	2.70	74.49	NP	NP
	7	*Mediomastus californiensis*	51.7	25.5	2.23	76.72	12	7
	8	*Spiophanes bombyx*	47.3	17.6	2.04	78.76	4	2
	9	*Thyasira gouldi*	41.7	12.6	1.80	80.55	7	11
	10	*Euchone incolor*	36.7	23.8	1.58	82.13	6	6
	11	*Monticellina baptisteae*	32.7	2.5	1.41	83.54	20	33
	12	*Spio limicola*	31.7	1.5	1.36	84.90	11	17
	13	*Aricidea quadrilobata*	29.3	13.7	1.26	86.17	29	38
	14	*Ninoe nigripes*	27.3	1.5	1.18	87.35	9	8
	15	*Dipolydora socialis*	21.0	24.8	0.90	88.25	NP	21
(No. Species)	(107)	Station Mean Abundance	2320.7				(96)	(102)
FF04	1	*Cossura longocirrata*	270.3	82.9	17.90	17.90	1	1
	2	*Aricidea quadrilobata*	195.3	53.6	12.94	30.84	6	4
	3	*Chaetozone setosa mb*	177.3	54.1	11.74	42.58	2	2
	4	*Anobothrus gracilis*	122.7	36.7	8.12	50.70	3	9
	5	*Tubificoides apectinatus*	101.7	41.5	6.73	57.44	7	8
	6	*Levinsenia gracilis*	84.7	13.6	5.61	63.04	4	3
	7	*Syllides longocirrata*	53.0	32.0	3.51	66.55	8	16
	8	*Spio limicola*	44.0	18.4	2.91	69.47	25	15
	9	*Prionospio steenstrupi*	40.0	10.0	2.65	72.12	17	10
	10	*Aphelochaeta marioni*	39.0	2.6	2.58	74.70	9	14
	11	*Leitoscoloplos acutus*	38.7	26.7	2.56	77.26	27	24
	12	*Paramphinome jeffreysii*	24.7	30.6	1.63	78.89	5	7
	13	*Thyasira gouldi*	24.3	5.7	1.61	80.50	16	12
	14	*Mediomastus californiensis*	19.7	4.5	1.30	81.81	10	5
	15	*Dentalium entale*	19.3	2.5	1.28	83.09	11	18
(No. Species)	(86)	Station Mean Abundance	1510.0				(71)	(87)
FF05	1	*Anobothrus gracilis*	219.7	68.9	11.86	11.86	3	3
	2	*Prionospio steenstrupi*	218.0	38.6	11.77	23.63	7	4
	3	*Spio limicola*	218.0	73.5	11.77	35.41	4	2
	4	*Chaetozone setosa mb*	161.3	25.3	8.71	44.12	9	6
	5	*Aricidea quadrilobata*	147.7	14.6	7.97	52.09	1	5
	6	*Levinsenia gracilis*	147.3	27.1	7.96	60.05	5	9
	7	*Cossura longocirrata*	79.3	19.1	4.28	64.34	10	11
	8	*Mediomastus californiensis*	78.3	5.5	4.23	68.57	6	7
	9	*Thyasira gouldi*	64.0	3.6	3.46	72.02	11	10
	10	*Parougia caeca*	31.3	3.1	1.69	73.71	16	25
	11	*Galathowenia oculata*	26.7	14.0	1.44	75.15	14	13
	12	*Nucula delphinodonta*	25.0	16.1	1.35	76.50	13	14
	13	*Periploma papyratium*	23.3	6.8	1.26	77.76	NP	NP
	14	*Leitoscoloplos acutus*	22.3	3.2	1.21	78.97	34	35
	15	Nemertea sp. 12	21.0	7.5	1.13	80.10	19	15

Station	Rank	Species	Mean	Std. Dev.	%	Cum %	2001 Rank	2000 Rank
(No. Species)	(108)	Station Mean Abundance	1851.7				(98)	(106)
FF06	1	*Cossura longocirrata*	83.7	32.3	17.47	17.47	1	1
	2	*Aricidea quadrilobata*	52.0	50.2	10.86	28.32	22	51
	3	*Euchone incolor*	42.3	60.4	8.84	37.16	NP	35
	4	*Harpinia propinqua*	22.0	7.5	4.59	41.75	2	2
	5	*Levinsenia gracilis*	21.0	4.4	4.38	46.14	4	5
	6	*Aricidea catherinae*	17.7	22.5	3.69	49.83	6	12
	7	*Mediomastus californiensis*	17.3	4.6	3.62	53.44	3	4
	8	Tubificidae sp. 2	17.0	9.5	3.55	56.99	10	13
	9	*Ninoe nigripes*	15.3	5.0	3.20	60.19	8	9
	10	*Nucula annulata*	13.3	6.7	2.78	62.98	11	7
	11	*Prionospio steenstrupi*	13.0	8.9	2.71	65.69	39	11
	12	*Aricidea minuta*	12.7	3.8	2.64	68.34	9	14
	13	*Nucula delphinodonta*	12.0	1.0	2.51	70.84	7	10
	14	*Eudorella pusilla*	9.3	8.4	1.95	72.79	24	36
	15	*Sternaspis scutata*	8.7	8.3	1.81	74.60	40	67
(No. Species)	(78)	Station Mean Abundance	479.0				(55)	(69)
FF07	1	*Cossura longocirrata*	1492.0	339.2	50.52	50.52	1	1
	2	*Euchone incolor*	454.3	253.0	15.39	65.91	2	2
	3	*Aricidea catherinae*	143.7	17.0	4.87	70.77	3	9
	4	*Mediomastus californiensis*	128.7	17.6	4.36	75.13	4	4
	5	Tubificidae sp. 2	113.0	49.5	3.83	78.95	7	3
	6	*Prionospio steenstrupi*	110.7	19.9	3.75	82.70	10	10
	7	*Ninoe nigripes*	100.3	2.5	3.40	86.10	9	8
	8	*Aricidea quadrilobata*	99.3	38.2	3.36	89.46	6	6
	9	*Tharyx acutus*	47.7	6.8	1.61	91.08	8	5
	10	*Parougia caeca*	39.7	14.7	1.34	92.42	11	11
	11	*Eudorella pusilla*	26.0	27.7	0.88	93.30	20	39
	12	*Levinsenia gracilis*	20.7	6.0	0.70	94.00	14	13
	13	*Nephtys incisa*	18.3	17.9	0.62	94.62	37	35
	14	*Yoldia sapotilla*	14.3	7.1	0.49	95.11	30	48
	15	*Nucula delphinodonta*	11.3	5.0	0.38	95.49	15	12
(No. Species)	(69)	Station Mean Abundance	2953.0				(64)	(66)
FF09	1	*Prionospio steenstrupi*	591.0	124.9	31.25	31.25	1	1
	2	*Dipolydora socialis*	246.3	110.6	13.03	44.28	2	2
	3	*Anobothrus gracilis*	129.3	31.0	6.84	51.12	3	6
	4	*Levinsenia gracilis*	99.0	19.7	5.24	56.35	5	4
	5	*Nucula delphinodonta*	69.3	15.5	3.67	60.02	4	5
	6	*Thyasira gouldi*	67.7	14.5	3.58	63.60	6	7
	7	*Aricidea quadrilobata*	59.0	10.4	3.12	66.72	7	12
	8	*Mediomastus californiensis*	56.7	6.5	3.00	69.72	8	8
	9	*Microclymene* sp.1	42.0	10.8	2.22	71.94	9	9
	10	*Apistobranchus typicus*	26.7	3.5	1.41	73.35	61	105
	11	*Harpinia propinqua*	25.3	5.5	1.34	74.69	14	10
	12	*Exogone verugera*	24.3	17.0	1.29	75.97	27	17
	13	*Parougia caeca*	24.3	4.9	1.29	77.26	15	20
	14	*Periploma papyratium*	23.0	9.5	1.22	78.48	NP	NP
	15	*Exogone hebes*	21.3	16.3	1.13	79.61	20	15

Station	**Rank**	**Species**	**Mean**	**Std. Dev.**	**%**	**Cum %**	**2001 Rank**	**2000 Rank**
(No. Species)	(136)	Station Mean Abundance	1891.0				(134)	(133)
FF 11	1	*Prionospio steenstrupi*	982.3	374.0	34.57	34.57	1	1
	2	*Aricidea quadrilobata*	409.7	215.8	14.42	48.99	2	3
	3	*Euchone incolor*	221.7	106.0	7.80	56.79	4	4
	4	*Levinsenia gracilis*	197.3	61.0	6.94	63.73	5	2
	5	*Anobothrus gracilis*	168.0	68.1	5.91	69.64	3	9
	6	*Cossura longocirrata*	149.7	13.9	5.27	74.91	6	5
	7	*Spio limicola*	121.7	40.5	4.28	79.19	8	12
	8	*Tubificoides apectinatus*	111.3	66.3	3.92	83.11	7	6
	9	*Chaetozone setosa mb*	92.0	25.5	3.24	86.35	9	7
	10	Nemertea sp. 12	31.0	18.5	1.09	87.44	10	13
	11	*Mediomastus californiensis*	28.3	17.0	1.00	88.43	13	11
	12	*Eteone longa*	17.3	4.0	0.61	89.04	23	25
	13	*Galathowenia oculata*	17.0	5.0	0.60	89.64	12	8
	14	*Microclymene* sp.1	16.3	11.4	0.57	90.22	21	51
	15	*Onoba pelagica*	16.3	10.4	0.57	90.79	15	17
(No. Species)	(106)	Station Mean Abundance	2841.7				(94)	(74)
FF 14	1	*Spio limicola*	52.0	35.0	9.57	9.57	5	1
	2	*Aricidea quadrilobata*	50.0	41.8	9.20	18.77	2	4
	3	*Prionospio steenstrupi*	49.3	7.5	9.08	27.85	8	3
	4	*Chaetozone setosa mb*	43.7	12.1	8.04	35.89	3	2
	5	*Levinsenia gracilis*	43.7	25.7	8.04	43.93	6	7
	6	*Cossura longocirrata*	33.3	5.5	6.13	50.06	11	12
	7	*Anobothrus gracilis*	21.0	18.7	3.87	53.93	1	8
	8	*Galathowenia oculata*	21.0	8.0	3.87	57.79	4	5
	9	*Tubificoides apectinatus*	20.0	4.0	3.68	61.47	7	6
	10	*Aphelochaeta monilaris*	12.3	5.5	2.27	63.74	49	21
	11	*Crenella decussata*	12.3	7.8	2.27	66.01	NP	NP
	12	*Mediomastus californiensis*	12.3	8.4	2.27	68.28	16	11
	13	*Onoba pelagica*	12.0	6.6	2.21	70.49	22	13
	14	*Sternaspis scutata*	11.7	12.5	2.15	72.64	12	9
	15	*Aphelochaeta marioni*	10.7	2.1	1.96	74.60	9	21
(No. Species)	(81)	Station Mean Abundance	543.3				(96)	(101)

NP = Not present in sample.

APPENDIX E1

2002 Hard-Bottom
Still Photographs

Table Appendix E1. Summary of data recorded from still photographs taken on hard-bottom survey, 2002.

Transect	1	1	1	1	1	2	2	2	2	2	4	4	4	4/6	4/6	6	6	7	7	8	8	9	10	Diff	Total
Waypoint	1	2	3	4	5	1	2	3	4	5	1	2	3	1(1)	1(2)	1	2	1	2	1	2	1	1	44	
# frames	34	32	32	33	31	32	33	33	32	26	31	33	29	33	32	31	33	32	28	20	27	32	26	28	733
Depth (m)	25.4	26.1	22.5	23	29.8	25.9	24.5	24.8	28.1	33.1	32.3	29.3	30	26.3	23.8	32.7	27.8	24.9	26.5	25.2	23.7	25.4	23.3	32.32	
Substrate	b+mx	b+c	b+c	b+c	cp+mx	mx+c	b+mx	b+mx	b+mx	d+rr	cp+g	mx	mx+c	b+mx	b+mx	cp+g	mx+b	b+mx	b+mx	mx	mx	b+mx	b	d+rr	
Sediment drape	m	lm	lm	l-lm	m	m	m-mh	m-mh	m-mh	m	lm	lm	lm	l-lm	l	m	lm	m	m-mh	lm	l-lm	m	mh	m	
Coralline algae (formerly *Lithothamnion* sp.)	34	61	69	71	35	39	28	23	12		2	28	41	50	80	3	56	36	28	59	56	36	1	0	
Ptilota serrata (formerly *A. hamifera*)	r-c	r	f-c	r		r	r	r-f							r			c-a	f-c			r-a	r		
Hydroid	c-a	c	f-a	f-c	f-c	c	c-a	c	c-a	c	r	f-c	f-c	f	f	c	f-c	c	c-a	f-c	f-c	c	c-a	c	
spirorbids	f-c	r-f	r-f	r-f	f	c	f-c	f-c	f-c	r-f	r-c	f-c	f-c	f-a	f	r-f	f-c	c	c	r-f	f	c	c	r-f	
Rhodymenia palmata	198	6	26			94	324	316	31				1	14			12	284	268	5		229	76		1884
Agarum cribrosum							1											24	4			1			30
Sponge	2	2		1		4	4	10	6	28	3	1	8	7	2	1	7	2	4	1		1	3	3	100
Aplysilla sulfurea	1	8	6	1		15	13	38	25				69	35	9		91		30			27	15		383
Halichondria panicea	12	4		2		4	16	19	14			2	11	31		1	16	4	6	2	2	12	27		185
Haliclona spp. (upright)										3															3
Suberites spp.	6				2	12	2	16	17				13	16		2	25		1		2	1	1		116
white divided							144	161	83					34					19			67			508
orange/tan encrusting	66	55	26	48	34	77	79	109	115	6		36	76	86	62	60	101	42	39	52	52	70	47		1338
orange encrusting	20	26	16	17	45	38	45	41	42	1		4	38	54	48	5	59	39	46	3	5	58	12		662
pink fuzzy encrusting	8	1	18	29	5	15	2	12	18	1		4	62	10	23	26	31	34	7	18	24	2	1		351
white translucent	76	23	19	18	20	75	109	126	82	5		14	5	83	9	5	64	54	41	28	22	46	42	4	970
cream encrusting		6	5	6		4	11	22	13									1	2	2		3			75
filamentous white encrusting	1						11	6	3					1			2				3				27
Melonanchora elliptica								1						1	1		2								5
Haliclona spp. (encrusting)		2				2		2	2	2						1							1		12
general encrusting	14	7	4	3	6	9	26	10	53	2	13	13	9	12	19	15	19	18	48	13	5	62	17		397
Obelia geniculata																		20				1			21
anemone	2					1			2				1	2			1		3		1	1			14
Metridium senile	29	27	45	47			184	122	252	1560		1		23	21				8		7	6	1	531	2864
Urticina felina				3					2			1	2	1	1	2	2	1	1				2	2	20
Cerianthus borealis											7	1													8
Gersemia rubiformis																							16		16
Tubularia sp. (formerly *Campanularia* sp.)										116															116
Alcyonium digitatum									2																2
gastropod			1																						1

Table Appendix E1. Summary of data recorded from still photographs taken on hard-bottom survey, 2002. continued.

Transect	1	1	1	1	1	2	2	2	2	2	4	4	4	4/6	4/6	6	6	7	7	8	8	9	10	Diff	Total
Waypoint	1	2	3	4	5	1	2	3	4	5	1	2	3	1(1)	1(2)	1	2	1	2	1	2	1	1	44	
# frames	34	32	32	33	31	32	33	33	32	26	31	33	29	33	32	31	33	32	28	20	27	32	26	28	733
Depth (m)	25.35	26.13	22.5	22.97	29.81	25.88	24.52	24.85	28.13	33.08	32.26	29.33	29.97	26.3	23.77	32.68	27.79	24.91	26.46	25.2	23.7	25.38	23.31	32.32	
Substrate	b+mx	b+c	b+c	b+c	cp+mx	mx+c	b+mx	b+mx	b+mx	d+rr	cp+g	mx	mx+c	b+mx	b+mx	cp+g	mx+b	b+mx	b+mx	mx	mx	b+mx	b	d+rr	
Sediment drape	m	lm	lm	l-lm	m	m	m-mh	m-mh	m-mh	m	lm	lm	lm	l-lm	l	m	lm	m	m-mh	lm	l-lm	m	mh	m	
Tonicella marmorea		1		2											5										8
Crepidula plana	7					20								1	10		4		10						52
Buccinum undatum								1							2									2	5
nudibranch																				3					3
Modiolus modiolus	26	32	120	90	4	42	121	60	24		2	8	23	76	161	26	92	84	97	42	54	22	35		1241
Placopecten magellanicus						1					3	4	1		1	2					2			1	15
Arctica islandica		1			3							4	1			5	3								17
Balanus spp.	3	8	1	3		5		3	1				3	28	16		12		2	5	4				94
Homarus americanus	1		2			2	1	1	1			1		1	2		1								13
Cancer spp.	3	1	4	2	1	5	2	6	7	2	10	4	6	3	5	5	1	2	2	2	1	1	3	1	79
hermit crab											2														2
general crab														1											1
Strongylocentrotus droebachiensis	4	21	22	54		2	5	5		8		1	5	25	45		14	3	1	8	19	3		9	254
small white starfish	179	165	275	183	40	80	115	103	111	36	10	67	38	267	255	71	170	88	68	48	84	116	54	23	2646
Asterias vulgaris	2	8	5	5	11	3	6	16	43	14	4	7	19	10	3	18	13	9		2	1	3	2	7	211
Henricia sanguinolenta	63	42	73	33	18	31	98	87	60	12	5	6	7	103	72	19	52	49	60	5	10	79	37	10	1031
Porania insignis									1																1
Crossaster papposus											2	3													5
Pteraster militaria	1							4							1		1		2			1			10
Psolus fabricii	1	6	10	51		3	1	13	4				4	26	16		8		1	6	61		3		214
Aplidium spp.	91	61	6	22	102	56	39	19	17	1	1	117	112	90	133	38	139	23		80	117	25		71	1360
Dendrodoa carnea	47	52	28	36	1	21	62	58	22	2	1	46	73	75	80	3	61	48	48	24	25	75	4	14	906
Didemnum albidum	133	108	25	28	55	120	153	174	216	60	1	11	20	74			94	82	86	9	13	132	81		1675
Halocynthia pyriformis	5	5	10	2		2	13	17	8	127				69			3	1	1		3	6		109	381
Boltenia ovifera	2																					2		2	6
white *Halocynthia pyriformis*	1	14	9				23	5	3	138		1	7	27			1	1	1		6	5		111	353
bryozoan		13	2			1	48	17	39	78		5	4	53	3	1	49	14	27	1	2	49	70	64	540
Membranipora sp.																		2							2
red crust bryozoan		3	1					1		3				1			2				2	1	18		32
Myxicola infundibulum	26	17	4	10	1	12	37	47	51		1	7	8	13	13	4	14	16	19		2		8	10	320
sabellid								6																	6
Terebratulina septentrionalis			3				275	370	187			3		239			4		53			216			1350
fish						1			1			1	1			1									5
Tautogolabrus adspersus	76	102	130	165	1	52	76	68	92	82	1	21	34	95	105	8	53	172	105	6	33	133	127	48	1785
Myoxocephalus spp.		1		2	1	2	1				3	1	1	1		2			1					1	17
Macrozoarces americanus													1								1		1		3
Hemitripterus americanus																							1		1
Pseudopleuronectes americanus	1	1			1		1		1				1							1					7
Gadus morhua			1	1			2							6								1		1	12

APPENDIX E2

2002 Hard-Bottom Video Summary

Table Appendix E2. Summary of data recorded from video photographs taken on hard-bottom survey, 2002.

Station	T1-1	T1-2	T1-3	T1-4	T1-5	T2-1	T2-2	T2-3	T2-4	T2-5	T4-1	T4-2	T4-3	T4/ T6-1	T4/ T6-1	T6-1	T6-2	T7-1	T7-2	T8-1	T8-2	T9-1	T10-1	DIFFUSER 44	Total
Start time	12:37	12:58	14:14	15:10	15:59	17:05	17:46	18:30	9:24	11:20	16:55	17:42	13:24	9:41	14:21	10:57	11:41	12:47	15:48	13:09	14:55	14:47	15:57	16:56	
End time	12:57	13:22	14:41	15:32	16:20	17:28	18:06	18:51	9:47	11:47	17:16	18:03	13:44	10:12	14:43	11:18	12:02	13:07	16:08	13:33	15:18	15:11	16:19	17:16	
Usable minutes	20	24	27	22	21	23	20	21	23	27	21	21	20	31	22	21	21	20	20	24	23	24	22	18	536
Begin depth (meters)	26	26	24	24	30	27	27	26	29	34	34	31	31	25	25	33	29	25	27	26	24	26	26	34	
End depth (meters)	26	26	23	22	30	26	24	25	28	36	32	27	30	27	24	33	29	25	27	25	24	25	23	31	
Substrate	mx	b+c	b+c	b+c	mx	mx	b+c	b+c	b+c	d+rr	cp+g	cp	c+b	b+c	b+c	cp	mix	c+b	b+c	mix	mix	b+c	b	d+rr	
Habitat relief	m	m	mh	m	lm	lm	m	m	m		l	l	lm	m	m	l	m	m	m	lm	lm	mh	h		
Sediment drape	m	lm	lm	l	m	m	mh	m	mh	m-mh	lm	m	lm	l	lm	m	lm	m	m	lm	lm	m	mh-h	m	
Coralline algae (formerly *Lithothamnion* sp.)	f-c	c	a	a	f-c	c	r-f	f-c	f		r	f-c	c	a	c		c	f-c	c	c-a	c	c			
Ptilota serrata (formerly *A. hamifera*)	f							r-f										c-a	c			f-c			
Hydroid	c	f	f-c	f	f	r-c	a	c	c	f-a	r-f	f	f	f	f	f	f	c-a	c	f-c	f	c-a	a	f-a	
spirorbids								f-c	c		r	c	f	f	f	r		f-c	c	r	f	f-c	c	r	
Rhodymenia palmata	f		f				f	f						r				c-a	c			f-c	f-c		
Agarum cribrosum			2				1	1										c	c			5	1		10
Halichondria panicea	6	7	3	2		4	9	2	5				4	c	3		3	6	11		1	12	c		78
Haliclona spp. (upright)									1	1															2
Haliclona spp. (encrusting)							2	2	1				1		1						1		3		11
Melonanchora elliptica									1																1
Polymastia?											1														1
Suberites spp.	5				3	c	5	c	c		1	2	f	f		5	f-c	f	6		2	4			33
white divided sponge							f-c	a	c					c					f			c	1		1
Sponge	2						1	1	8	3				1		1	1		6			1	4	1	30
Obelia geniculata																		c	f						
Tubularia sp. (formerly *Campanularia* sp.)										a															
anemone					3				1																4
Metridium senile	c	9	c	c		2	c-a	a	a	a		1	4	f	c	2	4	1	4		4	5	3	c	
Urticina felina		2		1			1	2	1				1	3		3	2					3	1	2	22
Cerianthus borealis											11	1				1									13
Alcyonium digitatum						2																			2
Gersemia rubiformis																							c		
Buccinum undatum			1			1																		1	3
Neptunea decemcostata						1																			1
Modiolus modiolus	c	c	a	a	f	f	c	c	f		c	f	f	c-a	a	f	f	a	c	f	f	c-a	c-a		
Placopecten magellanicus	3				3	1			1		22	2	2		1	7				1	5			1	49
Balanus spp.		1										1		c			1						1		4

Table Appendix E2. Summary of data recorded from still photographs taken on hard-bottom survey, 2002. continued.

Station	T1-1	T1-2	T1-3	T1-4	T1-5	T2-1	T2-2	T2-3	T2-4	T2-5	T4-1	T4-2	T4-3	T4/ T6-1	T4/ T6-1	T6-1	T6-2	T7-1	T7-2	T8-1	T8-2	T9-1	T10-1	DIFFUSER 44	Total
Start time	12:37	12:58	14:14	15:10	15:59	17:05	17:46	18:30	9:24	11:20	16:55	17:42	13:24	9:41	14:21	10:57	11:41	12:47	15:48	13:09	14:55	14:47	15:57	16:56	
End time	12:57	13:22	14:41	15:32	16:20	17:28	18:06	18:51	9:47	11:47	17:16	18:03	13:44	10:12	14:43	11:18	12:02	13:07	16:08	13:33	15:18	15:11	16:19	17:16	
Usable minutes	20	24	27	22	21	23	20	21	23	27	21	21	20	31	22	21	21	20	20	24	23	24	22	18	536
Begin depth (meters)	26	26	24	24	30	27	27	26	29	34	34	31	31	25	25	33	29	25	27	26	24	26	26	34	
End depth (meters)	26	26	23	22	30	26	24	25	28	36	32	27	30	27	24	33	29	25	27	25	24	25	23	31	
Substrate	mx	b+c	b+c	b+c	mx	mx	b+c	b+c	b+c	d+rr	cp+g	cp	c+b	b+c	b+c	cp	mix	c+b	b+c	mix	mix	b+c	b	d+rr	
Habitat relief	m	m	mh	m	lm	lm	m	m	m		l	l	lm	m	m	l	m	m	m	lm	lm	mh	h		
Sediment drape	m	lm	lm	l	m	m	mh	m	mh	m-mh	lm	m	lm	l	lm	m	lm	m	m	lm	lm	m	mh-h	m	
Homarus americanus	4	1	3			3		1	1	1				2	3		4	1	1		1		3		29
Cancer spp.	8	6	7	5	8	13	5	11	19	1	18	9	19	9	19	10	9	3	3	5	3	4	8	3	205
Strongylocentrotus droebachiensis	r	c	c	c		f-c	1	f		f			f	a	a		c	c	f	f	c	f			1
small white starfish	f-c	c	a	c	r	f	a	c	c	c	r	f	c	c-a	c-a	f	f	c	c	f	c	f	a	f-c	
Asterias vulgaris	f		2		c	2	f	f	f	f	c	c	c	f	r	c	r	f		r	r	f	c	c	4
Henricia sanguinolenta	f	c	c	c	f	f	c	c	c	f	r	r	r	c	c	r	f	c	c	f	r	f-c	c		
Porania insignis									1																1
Crossaster papposus											1	1				1									3
Solaster endeca																				1					1
Psolus fabricii		r		c				f	1				f	f-c	c			r		f	c		r		
Aplidium spp.	c	c	f	f-c	c	f	c	f-c	f			f	c	c	f	f	c	f	f	c	c	c		r	
Halocynthia pyriformis	6		13				c	7	3	a				c			4	1	2		5	3	2	c	
Boltenia ovifera	2											1		1								2		1	7
bryozoan										c													c		
Myxicola infundibulum	6	c	c				c	c	c			r	f	f	c	r	r		c	r			c	c	
Terebratulina septentrionalis							f-c	a	c					c					f			c	1		
fish					2						1	1	1					1						1	7
Tautogolabrus adspersus	c	c	a	c	f	r-c	c-a	c-a	c	f-a	1	f	f-c	c-a	a	r	c	c-a	c	f-c	f-c	c-a	a	c	
Myoxocephalus spp.		1		3	6	6	2		1	1	4	1	3	1	1	4		1	1			1		1	38
Macrozoarces americanus				1												2					1	1	1		6
Hemitripterus americanus			1												1							1	1		4
Pseudopleuronectes americanus	2	1			1		1		2	1			1	1	1					9					20
Gadus morhua		1	6	6			5	1	2	12				13					1			2	1	3	53
Prionotus spp.	1																								1

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