2004 outfall benthic monitoring report

Massachusetts Water Resources Authority

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2004 Outfall Benthic Monitoring Report

Submitted to

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EXECUTIVE SUMMARY

The benthic surveys discussed in this report began in 1992 as part of the Benthic (Sea-Floor) Monitoring component of the MWRA Harbor and Outfall Monitoring (HOM) program. The benthic program has four major components, including the annual late-summer measurement of

- geochemical properties, contaminants, and sewage tracers in sediments
- the apparent redox potential layer in sediment profile images (SPI) taken in the nearfield
- benthic infaunal (soft-bottom) community structure
- hard-bottom community structure

Sampling in August 2003 reflected modifications of the monitoring program, *i.e.*, discontinuation of a special study of chemical contaminants in sediments and a reduction in the frequency of sediment chemistry measurements at all stations. In late 2003, the MWRA received permission from the USEPA to further modify the benthic sampling, including reduction in the number of stations sampled each year, as well as reduction in the sediment chemistry parameters measured at each station. In August 2004, all of the SPI and hard-bottom stations were visited, but the soft-bottom benthos was sampled at roughly half the number of stations that had been previously been evaluated annually. Sediment geochemical parameters, including grain size and total organic carbon, and the sewage tracer *Clostridium perfringens* were measured at each of the infaunal stations; however, the full suite of metal and organic measurements (PAHs, PCBs, and pesticides) were made at only two of the nearfield stations (NF17 and NF23).

Contingency Plan Thresholds

The offshore outfall is regulated under a permit issued to MWRA by the United States Environmental Protection Agency (USEPA) and Massachusetts Department of Environmental Protection (DEP), under the National Pollutant Discharge Elimination System (NPDES). The permit stipulates that MWRA must monitor the outfall effluent and the ambient receiving waters to test for compliance with NPDES permit requirements; specifically, whether the impact of the discharge on the environment is within the bounds predicted by the SEIS (USEPA 1988), and whether any changes within the system exceed any of the Contingency Plan thresholds, including those for sediment redox depth, toxic contaminant concentrations, community structure, or abundance of opportunistic species (MWRA 2001).

The Contingency Plan (MWRA 2001) is an attachment to the Memorandum of Agreement among the National Marine Fisheries Service, USEPA, and MWRA. Warning level thresholds listed in the plan are based on effluent limits, observations from baseline monitoring, national water quality criteria, state standards, and, in some cases, best professional judgment. Contingency plan threshold values (Table 1) for benthic monitoring were originally based on averages calculated for the period 1992 through 2000, *i.e.*, from the beginning of the monitoring program through September 2000, when diversion of highly treated effluent to the new outfall was initiated. Because a different subset of stations will be sampled in even-numbered and odd-numbered years, starting in 2004, the benthic community thresholds were adjusted to reflect the stations actually sampled in alternate years (Williams *et al.* 2005). No thresholds were exceeded in 2004.

Monitoring Questions

The benthic monitoring program was designed to address a series of questions (MWRA 2001) regarding sediment contamination and tracers, and the benthic communities:

- *What is the level of sewage contamination and its spatial distribution in Massachusetts and Cape Cod Bays sediments before discharge through the new outfall?*
- *Has the level of sewage contamination or its spatial distribution in Massachusetts and Cape Cod Bays sediments changed after discharge through the new outfall?*

- *Have the concentrations of contaminants in sediments changed?*
- *Have the sediments become more anoxic; that is, has the thickness of the sediment oxic layer decreased?*
- *Has the soft-bottom community changed?*
- *Are any benthic community changes correlated with changes in levels of toxic contaminants (or sewage tracers) in sediments?*
- *Has the hard-bottom community changed?*

Table 1. Contingency plan thresholds established by MWRA for monitoring potential impacts of the offshore outfall. Benthic thresholds adjusted for stations collected in even- and odd-numbered years (Williams *et al.* 2005)

Location	Parameter	Caution Level	Warning Level
Sediment toxic contaminants, nearfield	Acenaphthene	None	500 ppb dry
	Acenaphylene	None	640 ppb dry
	Anthracene	None	1100 ppb dry
	Benz(a)pyrene	None	1600 ppb dry
	Benzo(a)pyrene	None	1600 ppb dry
	Cadmium	None	9.6 ppm dry
	Chromium	None	370 ppm dry
	Chrysene	None	2800 ppb dry
	Copper	None	270 ppm dry
	Dibenzo(a,h)anthracene	None	260 ppb dry
	Fluoranthene	None	5100 ppb dry
	Fluorene	None	540 ppb dry
	Lead	None	218 ppm dry
	Mercury	None	0.71 ppm dry
	Naphthalene	None	2100 ppb dry
	Nickel	None	51.6 ppb dry
	p,p'-DDE	None	27 ppm dry
	Phenanthrene	None	1500 ppb dry
	Pyrene	None	2600 ppb dry
	Silver	None	3.7 ppm dry
	Total DDTs	None	46.1 ppb dry
	Total HMWPAH	None	9600 ppb dry
	Total LMWPAH	None	3160 ppb dry
	Total PAH	None	44792 ppb dry
	Total PCBs	None	180 ppb dry
	Zinc	None	410 ppm dry
Sediments, nearfield	RPD depth	1.18 cm	None
Even Years Benthic diversity, nearfield	Species per sample	<48.41 or >82.00	None
	Fisher's log-series *alpha*	<9.99 or >16.47	None
	Shannon diversity	<3.37 or >4.14	None
	Pielou's evenness	<0.58 or >0.68	None
Odd Years Benthic diversity, nearfield	Species per sample	<46.52 or >79.95	None
	Fisher's log-series *alpha*	<9.95 or >15.17	None
	Shannon diversity	<3.30 or >3.91	None
	Pielou's evenness	<0.56 or >0.66	None
All Years Species composition, nearfield	Percent opportunists	10%	25%

Sediment Geochemistry and Sewage Tracer

- ♦ *What is the level of sewage contamination and its spatial distribution in Massachusetts and Cape Cod Bays sediments before discharge through the new outfall?*
- ♦ *Has the level of sewage contamination or its spatial distribution in Massachusetts and Cape Cod Bays sediments changed after discharge through the new outfall?*

Abundances of the sewage tracer *Clostridium perfringens* measured in regional sediments prior to diversion of effluent discharge (1992–2000) ranged from undetected to 24,100 cfu/g dry weight (Figure 1). In general, *C. perfringens* abundances were low throughout Massachusetts and Cape Cod Bays, with higher levels observed closer to Boston Harbor. Abundances generally decreased with distance from the harbor, with regional sediments located far way from Boston Harbor (>20 km) having the lowest *C. perfringens* abundances.

Following diversion of effluent discharge to the new outfall in September 2000, *C. perfringens* abundances were within the general distribution of samples collected during the baseline period (Figure 1), although abundances decreased between 1992 and 2000 while treatment upgrades were implemented. In 2001–2002, abundances of *C. perfringens* increased above 1999–2000 (*i.e.*, immediate pre-diversion) average values at most nearfield locations. At the same time, a modest decrease in *C. perfringens* was observed at near-harbor stations and no substantial changes were observed at farfield stations.

Modest increases in the percentages of fine-grained material (primarily silt) were also observed at selected nearfield stations following outfall activation. At nearfield stations located more than 2 km from the outfall, normalization to grain size reduced the post-diversion abundances of *C. perfringens* closer to baseline values. Stations located within 2 km of the outfall, however, still showed elevated abundances of *C. perfringens,* even after normalization to grain size, indicating an effluent signal near the outfall. Abundances of *C. perfringens* (normalized to grain size) decreased in 2003–2004 compared with 2001–2002 values, possibly due to sediment transport, bioturbation and mixing down in the sediments, or deposition of less-contaminated material over the surface sediments. Alternatively, the decrease could reflect the natural variability within the system.

Sediment Contaminants

- ♦ *Have the concentrations of contaminants in sediments changed?*

Nearfield stations comprise a series of heterogeneous sediments located west of the Massachusetts Bay outfall and within nine miles of Boston Harbor, which is the historic primary source of contaminants to these stations. In addition, distributed sources such as atmospheric input and input from distant rivers contribute to the contaminant load. Factors that influence contaminant variability in the nearfield include proximity to sources of contamination and two of the bulk sediment properties (grain size and TOC) characteristic of sediment depositional environments. The primary factor among those measured associated with the variance in nearfield data is sand content.

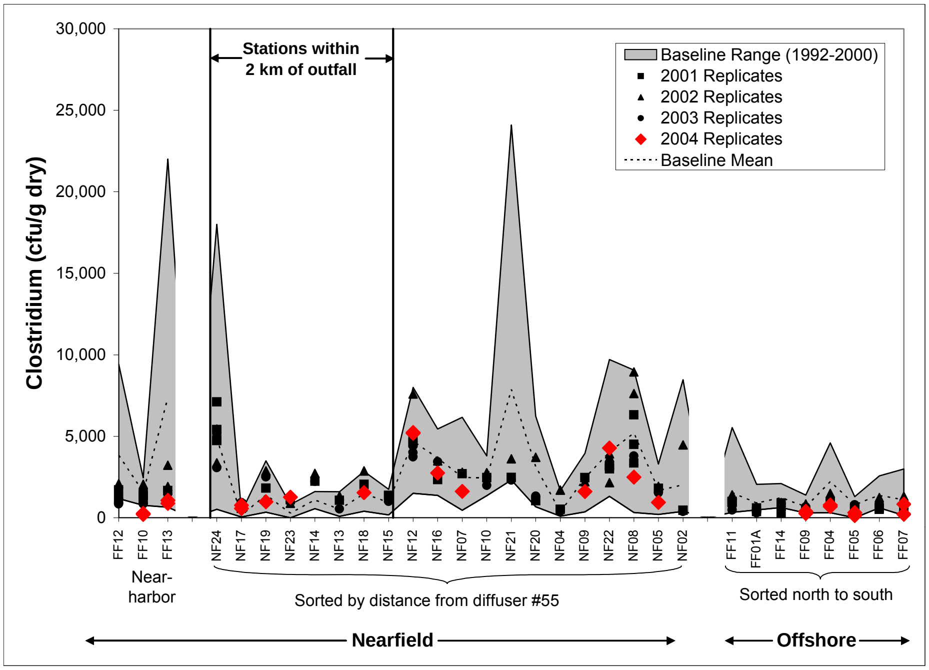

Figure 1. Post-diversion abundances of *Clostridium perfringens* in regional sediments during the baseline (1992–2000 range of values, gray band) and post-diversion (2001–2004, symbols) periods. The baseline mean values are indicated by a dashed line within the gray band.

Farfield stations include a series of locations having heterogeneous sediments and located farther away from the harbor compared with nearfield stations. These sediments generally have lower concentrations of contaminants and sewage tracers compared with nearfield sediments. The composition of sediments at farfield locations is influenced by the analytes associated with fines and may reflect regional sediment inputs distinct from Boston Harbor. As in the nearfield, the variance in the farfield sediment data is primarily associated with sand content.

Concentrations of contaminants in sediment in 2001 and 2002 have not changed (*i.e.*, systematic or widespread change) compared to baseline following effluent discharge from the new outfall. Similarly, contaminant data in 2003 and 2004 for nearfield stations NF12 and NF17 showed no evidence of an increase in contaminants of environmental concern (*e.g.*, PCBs, Figure 2).

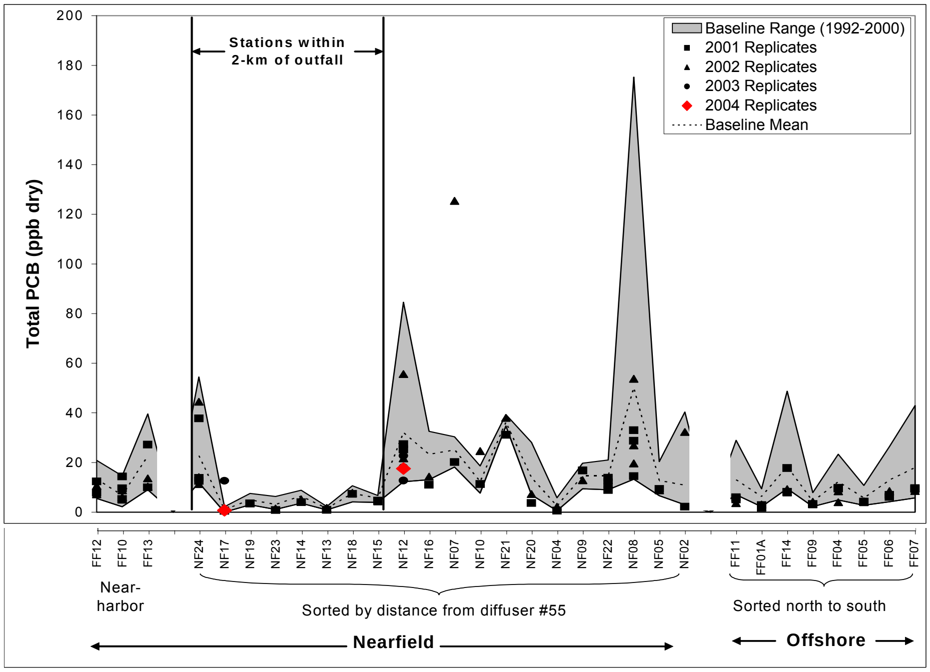

Figure 2. Concentrations of total PCB in regional sediments during the baseline (1992–2000 range of values, gray band) and post-diversion (2001–2004, symbols) periods. The baseline mean values are indicated by a dashed line within the gray band.

Sediment Redox Potential Layer

♦ *Have the sediments become more anoxic; that is, has the thickness of the sediment oxic layer decreased?*

In 2004, there was little change in the sedimentary environment relative to baseline or other post-diversion years (Figure 3). Within a station, there did not appear to be any change in the sediment color or fabric, indicating that there has not been an accumulation of organic matter in surface sediments of the nearfield stations. There also did not appear to be 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. The average apparent color RPD for 2004 of 2.4 cm (SE = 0.11) was not significantly different from the baseline RPD of 2.3 cm. A 50% change in RPD layer depth would require the mean RPD for a year to be at least <1.2 or >3.4 cm. The average RPD for 2004 was well within the range of annual RPDs, with 1998 being the shallowest year at 1.6 cm and 1995 the deepest year at 3.0 cm.

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, *e.g.*, 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. When the RPD layers in fine sediments are >1 cm, bioturbation by infauna or major resuspension/deposition events are responsible for oxygenating the sediments. At all 15 fine-sediment stations, those with fine-sand-silt-clay and fine-sandy-silt, the RPD layer depth was >1.3 cm and SPI images confirmed the importance of bioturbation in deepening RPD layers at these stations.

The prominence of biogenic structures on the sediment surface and organism activity in 2004 appeared to be similar relative to 2003, but less than the last three years of the baseline period. In 2004, stations NF05, NF16, and NF22 appeared to have ampeliscid tubes. Station NF05 has had ampeliscid tubes every year since 1999, the first year tubes were observed in the nearfield SPI images. Overall, in 2004 it appeared that physical (Figure 4) and biological (Figure 5) processes were about equally responsible in structuring surface sediments.

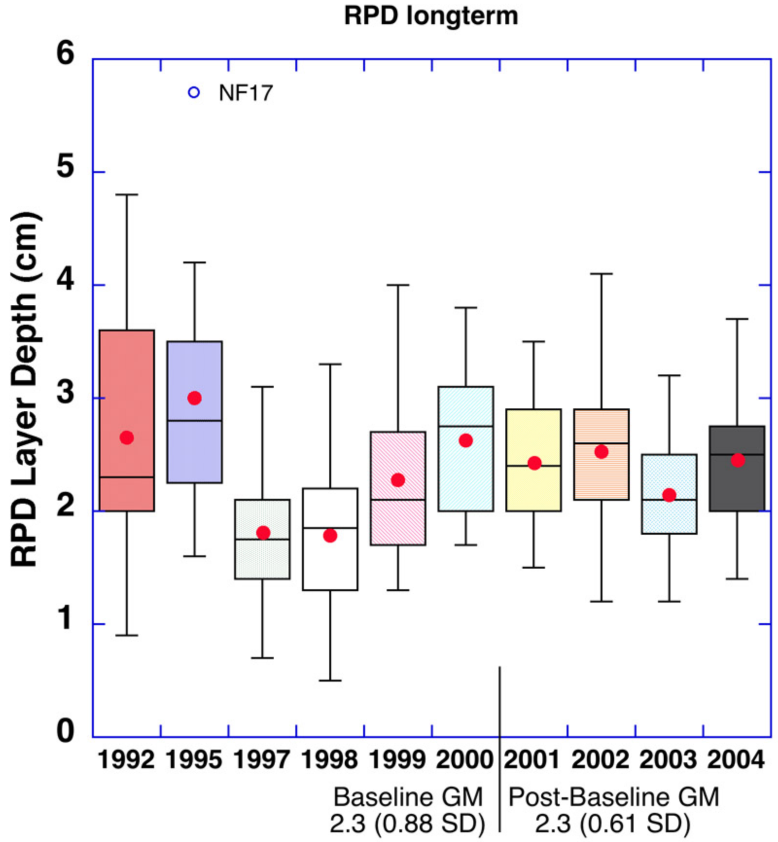

Figure 3. Apparent color RPD layer depth (cm) summarized by year for all data from nearfield stations. Box is interquartile range, short bar is median, dot is mean, and whiskers are data range. Station NF17 was an outlier in 1995.

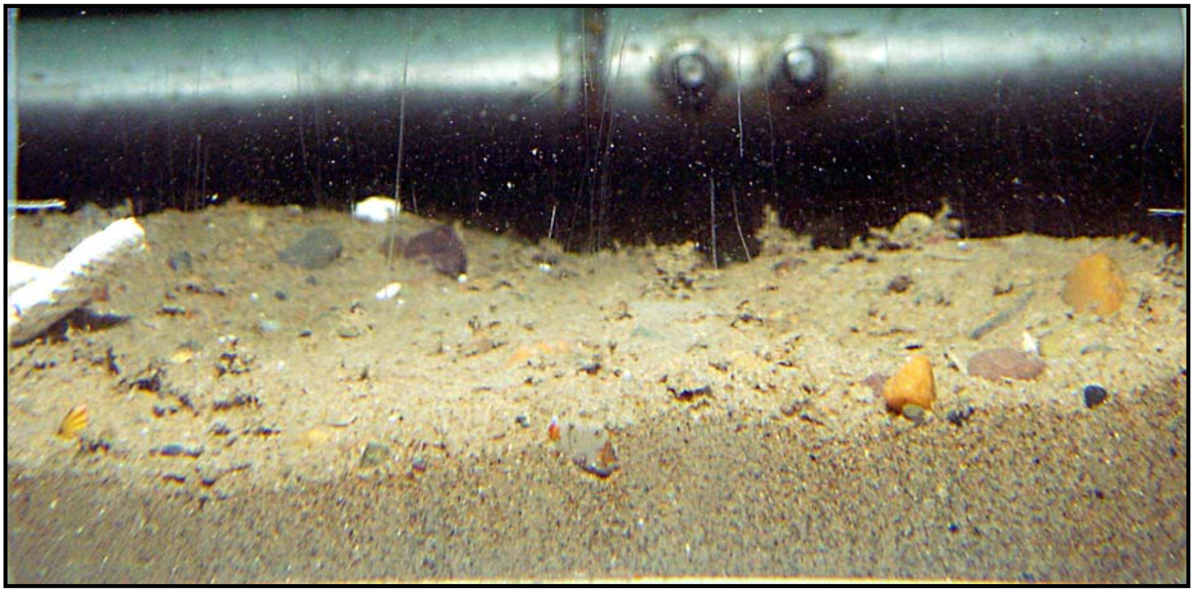

Figure 4. Sediment profile image of NF23, 2004, showing physically structured sediment surface.

Figure 5. Sediment profile image of NF08 , 2004, showing biologically structured sediment surface.

Soft-Bottom Benthic Infaunal Communities

- *Has the soft-bottom community changed?*

There have been clear temporal changes in the soft-bottom benthic infaunal community over the time period of the monitoring program, including changes in terms of total infaunal density, species composition and richness, and, to a lesser extent, diversity. Through 2003, infaunal abundance (per sample) increased roughly 60% over abundances recorded in the early years of the program. Populations of the numerically dominant species have fluctuated over time and some species (*e.g*., *Spio limicola*) have been replaced by others (*e.g*., *Prionospio steenstrupi*). In 2003, the population levels of *P. steenstrupi* reached the highest levels recorded in the monitoring program, but crashed in 2004 to levels similar to those seen in the early 1990s. Species richness also increased, in 2003 reaching the highest mean values in both the nearfield and farfield areas. This high level has been maintained into 2004, although a reduced subset of stations were sampled.

- *Are any benthic community changes correlated with changes in levels of toxic contaminants (or sewage tracers) in sediments?*

The design of the monitoring program is such that a variety of habitats have been sampled in areas both near the outfall and at a distance from it, and in time periods both before and after the discharge was diverted to the outfall. Throughout the baseline period, there were differences in the mean values of community parameters between the nearfield and farfield, often with similar annual increases and decreases in both areas resulting in a nearly parallel sine-wave-like pattern (Figure 5-12). If the outfall discharge (and any associated contaminants) were having an effect on the benthos, such an effect would be expected to be seen at the nearfield stations closest to the outfall, with decreased diversity and species richness, and an increase in organic-tolerant opportunistic species. The same values at the farfield stations would depart increasingly from those at the nearfield stations. Such patterns have not been seen, either in 2001–2003 when all of the stations were sampled, or in 2004 when a subset of stations were sampled.

In 2003, nearfield and farfield stations actually converged in terms of abundance, diversity, and evenness. In 2004, mean total abundance fell in both the nearfield and farfield, primarily because of a major decline in the abundance of one species, *Prionospio steenstrupi*. Shannon diversity (H′) and evenness (J′) increased in both areas. Species richness, whether measured by the number of species per sample or log-series *alpha*, declined in the farfield and increased in the nearfield. Such patterns do not indicate any impact of the outfall, rather appear to be part of a natural cycle. Detailed investigation of individual stations also did not suggest any localized outfall impact, even at stations where levels of the sewage tracer *Clostridium perfringens* suggested a modest impact from the outfall.

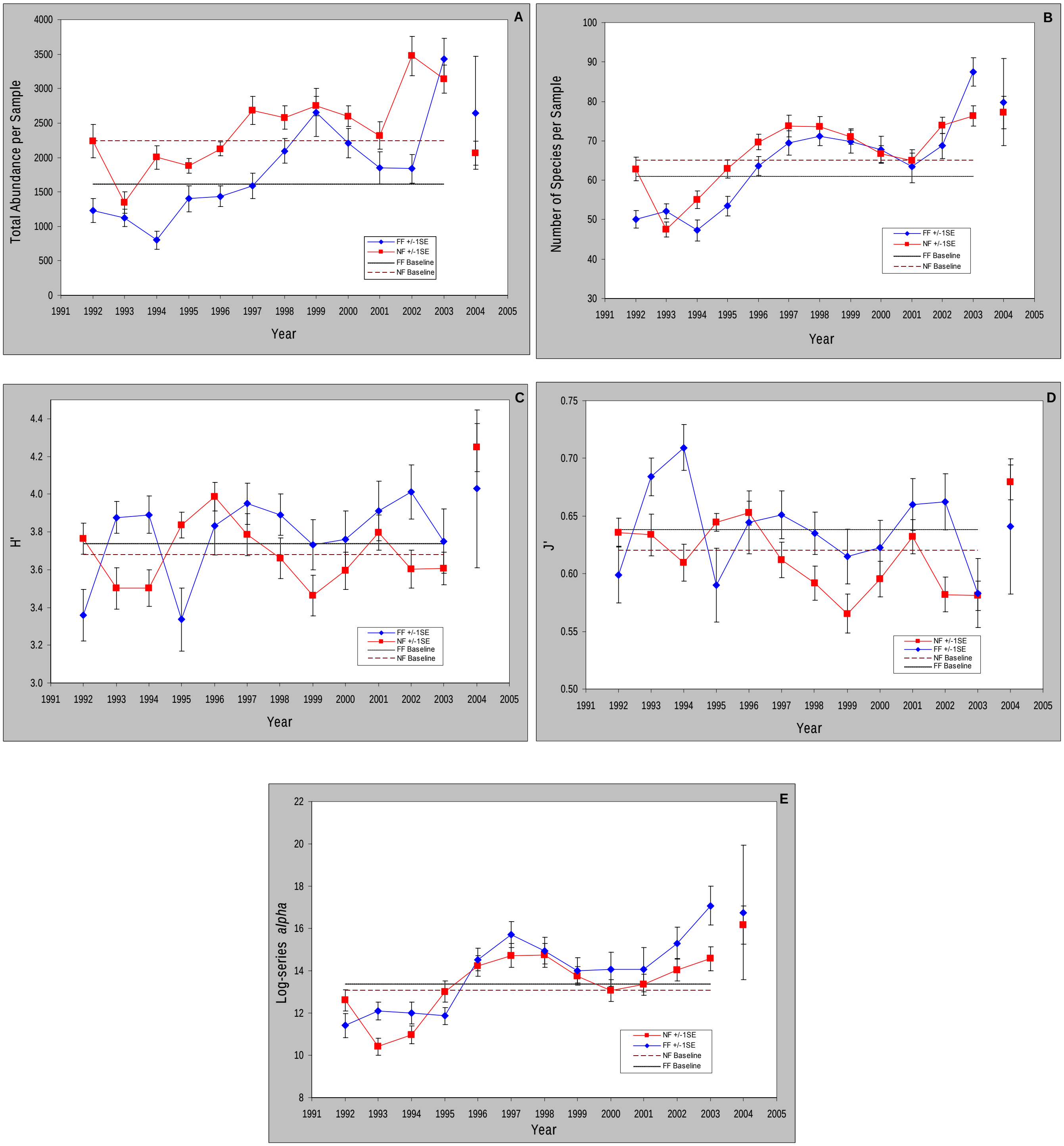

Figure 6. Mean benthic community parameters for nearfield and farfield stations sampled 1992–2004. (A) abundance per sample, (B) number of species per sample, (C) Shannon diversity H′, (D) Pielou's evenness J′, and (E) log-series *alpha*. Fewer stations were sampled in 2004 than in previous years.

Hard-Bottom Benthic Communities

- *Has the hard-bottom community changed?*

The hard-bottom benthic communities near the outfall remained relatively stable over the 1995–2000 baseline time period, and have not substantially changed since the activation of the outfall. Major departures from baseline conditions have not occurred during the post-diversion years; however some subtle changes have been observed. A general decrease in the number of upright algae observed in 2003 resulted in a change in the benthic community at four of the sites. In 2004, two of these four sites reverted back to communities dominated by upright algae. It is unlikely that the decrease in upright algae was attributable to the activation of the outfall, since the general decline had started in the late 1990s and the number of upright algae had increased again by 2004. The abundance of upright algae was found to be quite variable throughout the baseline period, reflecting year-to-year differences in abundance as well as extreme spatial variability. This variability has continued into the baseline period and appears to reflect inherent cyclical changes.

Another post-discharge change that has been observed in the hard-bottom communities has been an increase in sediment drape (*i.e.*, the sediment, detritus, and associated small animals found on rocks and boulders) and a concurrent decrease in percent cover of coralline algae at several sites on the top of the drumlin north of the outfall and at the two northernmost reference sites. The decrease in coralline algae has been noticeable in all four post-diversion years, though it was less pronounced in 2003. In 2004, an additional station south of the outfall also had reduced percent cover of coralline algae. Whether this decrease is related to the outfall discharge is presently not known. The baseline data indicated 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. Changes might also be expected in the depth distribution of coralline algae and upright 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 both coralline and upright algae would be reduced. Conversely, if water clarity is increased, then it is expected that high coralline algal coverage or upright algae could extend into some of the deeper areas. No noticeable changes in the depth distribution of coralline algae have been observed since discharge began. Additionally, the decline observed in the numbers of upright algae in recent years appears to be reversing.

The first four years of discharge monitoring have shown only modest changes suggestive of outfall impact at a subset of five stations, and additional changes that do not appear to be related to outfall impact at an additional two stations. Lush epifaunal growth continues to thrive on the diffuser heads surveyed for this study (Figure 7) 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.

**Figure 7. Head of the active diffuser at T2-5 (Diffuser #2).
Note the numerous frilly anemones *Metridium senile* surrounding the discharge port.
A large blood star *Henricia sanguinolenta* is also visible.**

1. INTRODUCTION

by Nancy J. Maciolek

1.1 Background

Since 1985, the Massachusetts Water Resources Authority (MWRA) has been responsible for the development and maintenance of greater Boston's municipal wastewater system. 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 was achieved in phases, with the final phase completed in 2000 and becoming fully operational in 2001. In September 2000, the effluent from Deer Island was diverted to a new outfall approximately 15 km offshore, in 32 m water depth in Massachusetts Bay. All of these improvements—the improved effluent treatment, the complete cessation of sludge discharge to the harbor in 1991, and the transfer of wastewater discharge offshore—were implemented to improve the water quality in Boston Harbor and to increase effluent dilution with minimal impact on the environment of Massachusetts and Cape Cod Bays.

The offshore outfall is regulated under a permit issued to MWRA by the United States Environmental Protection Agency (USEPA) and Massachusetts Department of Environmental Protection (DEP), under the National Pollutant Discharge Elimination System (NPDES). The permit stipulates that MWRA must monitor the outfall effluent and the ambient receiving waters to test for compliance with NPDES permit requirements; specifically, whether the impact of the discharge on the environment is within the bounds predicted by the SEIS (USEPA 1988), and whether any changes within the system exceed any of the Contingency Plan thresholds, including those for sediment redox depth, toxic contaminant concentrations, community structure, or abundance of opportunistic species (MWRA 2001).

The Contingency Plan (MWRA 2001) is an attachment to the Memorandum of Agreement among the National Marine Fisheries Service, USEPA, and MWRA. Warning level thresholds listed in the plan are based on effluent limits, observations from baseline monitoring, national water quality criteria, state standards, and, in some cases, best professional judgment (Table 1-1). The Contingency Plan also details the process of how the MWRA would respond to any exceedances of the threshold values. Threshold values for benthic monitoring were originally based on averages calculated for the period 1992 through 2000, *i.e.*, from the beginning of the monitoring program through September 2000, when diversion of highly treated effluent to the new outfall was initiated. Beginning in 2004, a different subset of stations will be sampled in even-numbered and odd-numbered years (see Section 1.3 below); therefore, the benthic community thresholds were adjusted to reflect the stations actually sampled in alternate years (Williams *et al.* 2005).

The studies included in the monitoring plan (MWRA 1991, 1997) are more extensive than necessary to calculate the Contingency Plan threshold values or to meet the NPDES permit requirements (MWRA 2004). Relocating the outfall raised concerns about potential effects of the discharge on the offshore benthic (bottom) environment. These concerns focused on three issues: eutrophication and related low levels of dissolved oxygen; accumulation of toxic contaminants in depositional areas; and smothering of animals by particulate matter. Extensive information collected over a nine-year baseline period and a four-year post-diversion period has allowed a more complete understanding of the bay system and has provided data to explain any changes in the parameters of interest and to address the question of whether MWRA's discharge has contributed to any such changes.

Table 1-1. Contingency plan thresholds established by MWRA for monitoring potential impacts of the offshore outfall. Benthic thresholds adjusted for stations collected in even- and odd-numbered years (Williams *et al.* 2005).

Location	Parameter	Caution Level	Warning Level
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	Pielou's evenness	<0.56 or >0.66	None
All Years Species composition, nearfield	Percent opportunists	10%	25%

1.2 Design of the Benthic Monitoring Program

The benthic surveys discussed in this report began in 1992 as part of the Benthic (Sea-Floor) Monitoring component of the MWRA Harbor and Outfall Monitoring (HOM) program (MWRA 1991). The benthic program has four major components, including the measurement of

- the apparent redox potential layer in sediment profile images (SPI)
- geochemical properties, contaminants, and sewage tracers in sediments
- benthic infaunal (soft-bottom) community structure
- hard-bottom community structure

Although SPI are taken only in the nearfield, the other three technical components are carried out at both nearfield (defined as being within 8 km of the outfall) and farfield locations.

The benthic monitoring program was designed to address a series of questions (MWRA 2001) regarding sediment contamination and tracers:

> *Have the concentrations of contaminants in sediments changed?*
>
> *What is the level of sewage contamination and its spatial distribution in Massachusetts and Cape Cod Bays sediments before discharge through the new outfall?*
>
> *Has the level of sewage contamination or its spatial distribution in Massachusetts and Cape Cod Bays sediments changed after discharge through the new outfall?*

and benthic communities:

> *Have the sediments become more anoxic; that is, has the thickness of the sediment oxic layer decreased?*
>
> *Has the soft-bottom community changed?*
>
> *Are any benthic community changes correlated with changes in levels of toxic contaminants (or sewage tracers) in sediments?*
>
> *Has the hard-bottom community changed?*

Achieving a good monitoring design for the nearfield was difficult because of the heterogeneity of habitats in the vicinity of the outfall. As a result, the sampling protocol has been modified several times to find the best approach. Shifts in station design have presented some problems in comparing year-to-year trends because the 1993 nearfield design departed significantly from that of 1992 and 1994−2003. Nevertheless, the baseline data accrued from 1992−2000 are considered to be sufficient to assess long-term regional trends and to establish thresholds against which potential impacts from the effluent discharge can be measured.

Until 2003, 23 nearfield and 8 farfield stations were sampled (either replicated or as single-sample stations) for benthic infauna and chemical contaminants; SPI was taken at 23 locations in the nearfield, and the hard-bottom communities photographed using ROV-mounted cameras at 23 waypoints in both nearfield and farfield areas. Although the SPI and hard-bottom sampling have remained essentially unchanged, beginning in 2004, a reduced number of stations are now sampled for soft-bottom infauna and chemical contaminants (see section 1.3 below).

1.3 Revision of the Benthic Monitoring Program

In 2003, the MWRA began an intensive review of all elements of the monitoring program and the results to date, including the four components of the benthic monitoring. The concentrations of contaminants and of sewage tracers in sediments has changed only modestly and only in the immediate vicinity of the outfall in the first two years since the outfall came online, and no changes in any of the benthic community parameters that could be related to the outfall were detected (Maciolek *et al*. 2004). MWRA therefore proposed to reduce sampling effort in several program areas, and the proposed changes were reviewed and ultimately approved by the USEPA and the MADEP. A revised sampling plan was released in March 2004 by the MWRA (2004).

Several major and minor revisions to the monitoring program have therefore been implemented, with additional changes planned for the 2005 field season. Sampling in August 2003 reflected the discontinuation of the Nearfield Special Study (sediments around the outfall were sampled three times per year before and after outfall start-up to see if there would be rapid accumulation of contaminants there) and a reduction in the frequency of sediment chemistry measurements at all stations.

Additional modifications to the benthic sampling include a reduction in the number of stations sampled each year, as well as a reduction in the sediment chemistry parameters measured at each station. In August 2004, all of the SPI and hard-bottom stations were visited, but the soft-bottom benthos was sampled at roughly half the number of stations that had been previously been evaluated annually. Sediment geochemical parameters, including grain size and total organic carbon, and the sewage tracer *Clostridium perfringens* were measured at each of the infaunal stations; however, the full suite of metal and organic measurements (PAHs, PCBs, and pesticides) were made at only two of the nearfield stations (NF17 and NF23).

For the past several years, both SPI and grab sampling for benthos and chemistry have been carried out annually at 23 nearfield stations. Under the revised plan, the frequency of sampling for infaunal benthos and chemical constituents has been reduced by at least 50 percent (Table 1-2). The revised plan includes the following adjustments:

- SPI will be taken at all 23 nearfield stations.
- Infaunal stations were randomly split into two subsets that will be sampled in alternate years, with the result that all stations will be sampled every two years. Stations were binned by region and level of replication before the random selection (MWRA, 2003 briefing package).
- Sediment characteristics/tracers, including total organic carbon (TOC), sediment grain size, and *Clostridium perfringens* spore counts in the 0–2-cm depth fraction will be sampled annually at each of the stations sampled for infauna (Table 1-2).
- Chemical constituents, *i.e*., PAHs, PCBs, pesticides, and metals, will be sampled at a variable number of stations, depending on the year (Table 1-2).
    - Stations NF12 and NF17 will be sampled annually for all parameters.

  - Every three years, all stations sampled for infauna will be sampled for all chemical constituents, with the next sampling scheduled for 2005.

- The only modification to the hard-bottom sampling was to drop two locations and add two new ones. The details of this station placement are discussed in Chapters 2 and 6 of this report.

The sewage tracer and organic carbon data, and sediment trap data from a companion US Geological Survey (USGS) study, will be evaluated to ensure that there continue to be no sudden changes in sediment chemistry over the next few years. If the sediments are still not accumulating contaminants, and effluent toxic contaminant concentrations remain low, the MWRA might propose to further reduce chemistry sampling.

Table 1-2. Revised benthic station sampling and replication (from MWRA 2004).

Station Group	Stations	Year sampled	Replication: biology	Replication: metals and organic contaminants	Replication: TOC/grain size
Core (2 stations to be sampled every year)	NF12, NF17	2004, 2005	3	2	2
2004 replicated nearfield (2 stations)	FF10, FF13	2004	3	0	2
2004 unreplicated nearfield (9 stations)	NF05, NF07, NF08, NF09, NF16, NF18, NF19, NF22, NF23	2004	1	0	1
2004 farfield (4 stations)	FF04, FF05, FF07, FF09	2004	3	0	2
2005 replicated nearfield (2 stations)	FF12, NF24	2005	3	2	2
2005 unreplicated nearfield (8 stations)	NF02, NF04, NF10, NF13, NF14, NF15, NF20, NF21	2005	1	1	1
2005 farfield (4 stations)	FF01A, FF06, FF11, FF14	2005	3	2	2

2. FIELD OPERATIONS

by Isabelle P. Williams

2.1 Sampling Design

2.1.1 Soft Bottom

Sediment Samples—Benthic monitoring surveys are conducted each year in August. The nearfield station array was designed to provide detailed spatial coverage of the infaunal communities inhabiting depositional sediments within about 8 km of the diffuser (Figure 2-1). Farfield stations, located more than 8 km from the diffuser, 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 (Station FF04 and FF05) was conducted under sampling permit SBNMS-2002-007. Target locations for all soft-sediment stations are given in Table 2-1, and the actual station data for each biology and chemistry grab sample, along with a brief description of each, are in Appendix A1. In 2004, sediment grab samples were collected at 13 nearfield and 4 farfield stations.

Sediment Profile Images—The Sediment Profile Image (SPI) surveys are conducted in August of each year at the 23 nearfield stations (Figure 2-1). The SPI survey allows a rapid comparison of benthic conditions to the triggering threshold for depth of the apparent color RPD layer. SPI can also be integrated with the quantitative results from the infaunal and sediment chemistry analyses to aid in assessing outfall effects. Sediment profile imagery, using digital technology first implemented 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). In 2004, sediment profile images were taken at all 23 nearfield stations. Specific locations of all sediment profile images collected in 2004 are listed in Appendix A2.

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 18 waypoints/stations along six transects and five additional waypoints (T9-1, T10-1, T11-1, T12-1, and Diffuser #44) (Figure 2-3). Target locations for hard-bottom survey waypoints are listed in Table 2-2. Station data taken at the arrival of each station is given in Appendix A-3.

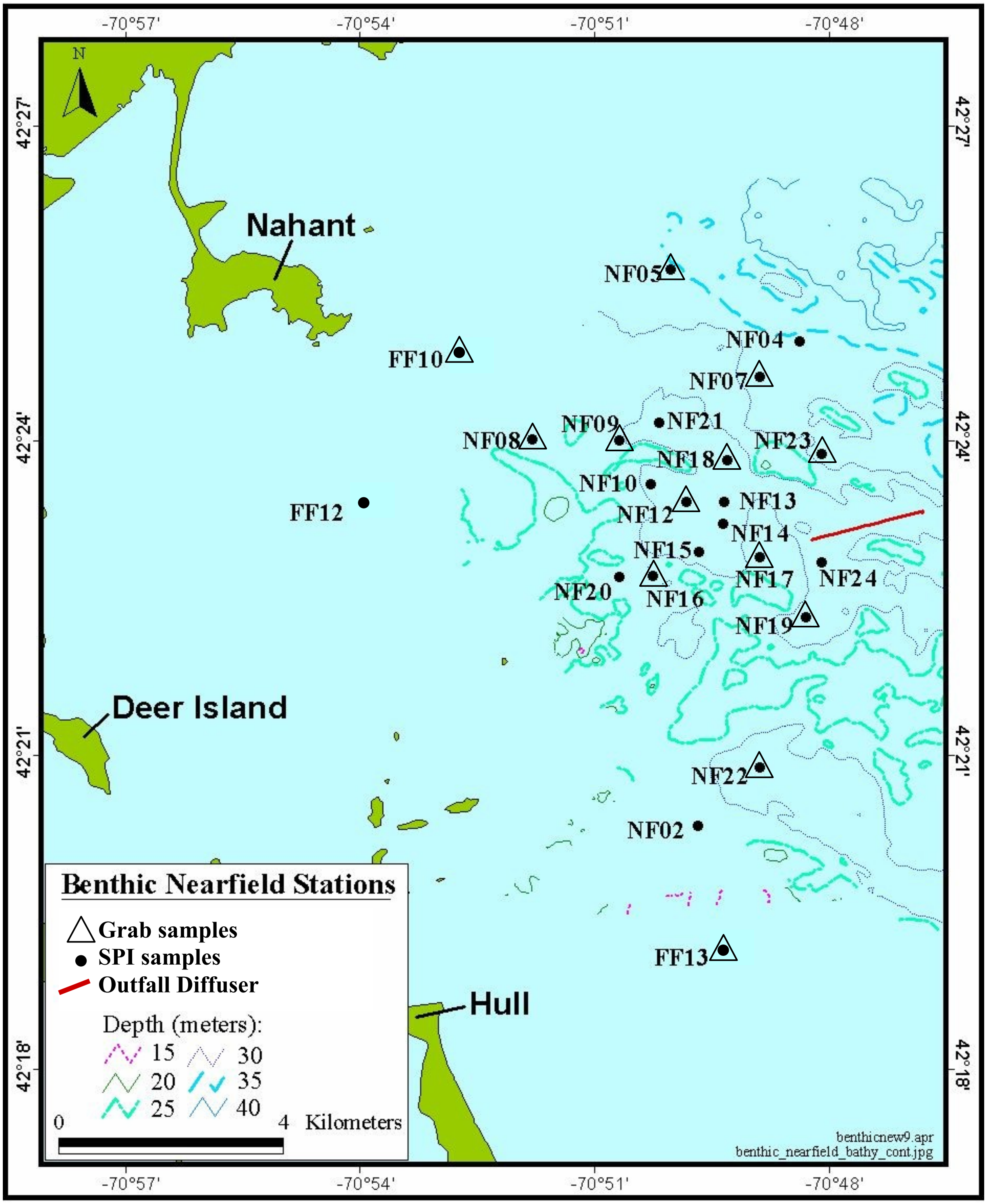

Figure 2-1. Locations of nearfield stations sampled in August 2004.

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

Station	Latitude	Longitude	Depth (m)
Nearfield Stations			
FF10 [1,2]	42°24.84′N	70°52.72′W	28.7
FF12 [1]	42°23.40′N	70°53.98′W	23.5
FF13 [1,2]	42°19.19′N	70°49.38′W	20.7
NF02 [1]	42°20.31′N	70°49.69′W	26
NF04 [1]	42°24.93′N	70°48.39′W	34
NF05 [1,2]	42°25.62′N	70°50.03′W	36
NF07 [1,2]	42°24.60′N	70°48.89′W	32
NF08 [1,2]	42°24.00′N	70°51.81′W	28
NF09 [1,2]	42°23.99′N	70°50.69′W	29
NF10 [1]	42°23.57′N	70°50.29′W	32.9
NF12 [1,2]	42°23.40′N	70°49.83′W	34.9
NF13 [1]	42°23.40′N	70°49.35′W	33.8
NF14 [1]	42°23.20′N	70°49.36′W	34.1
NF15 [1]	42°22.93′N	70°49.67′W	32.7
NF16 [1,2]	42°22.70′N	70°50.26′W	31.1
NF17 [1,2]	42°22.88′N	70°48.89′W	30.6
NF18 [1,2]	42°23.80′N	70°49.31′W	33.3
NF19 [1,2]	42°22.30′N	70°48.30′W	33.2
NF20 [1]	42°22.69′N	70°50.69′W	28.9
NF21 [1]	42°24.16′N	70°50.19′W	30
NF22 [1,2]	42°20.87′N	70°48.90′W	30
NF23 [1,2]	42°23.86′N	70°48.10′W	36
NF24 [1]	42°22.83′N	70°48.10′W	37
Farfield Stations			
FF01A [3]	42°33.84′N	70°40.55′W	35
FF04 [2]	42°17.30′N	70°25.50′W	90
FF05 [2]	42°08.00′N	70°25.35′W	65
FF06 [3]	41°53.90′N	70°24.20′W	35
FF07 [2]	41°57.50′N	70°16.00′W	39
FF09 [2]	42°18.75′N	70°39.40′W	50
FF11 [3]	42°39.50′N	70°30.00′W	88.4
FF14 [3]	42°25.00′N	70°39.29′W	73.3

[1] Stations sampled by SPI in 2004 (all NF stations)
[2] Stations sampled by grab in 2004 (13 NF and 4 FF stations)
[3] Farfield stations not sampled in 2004

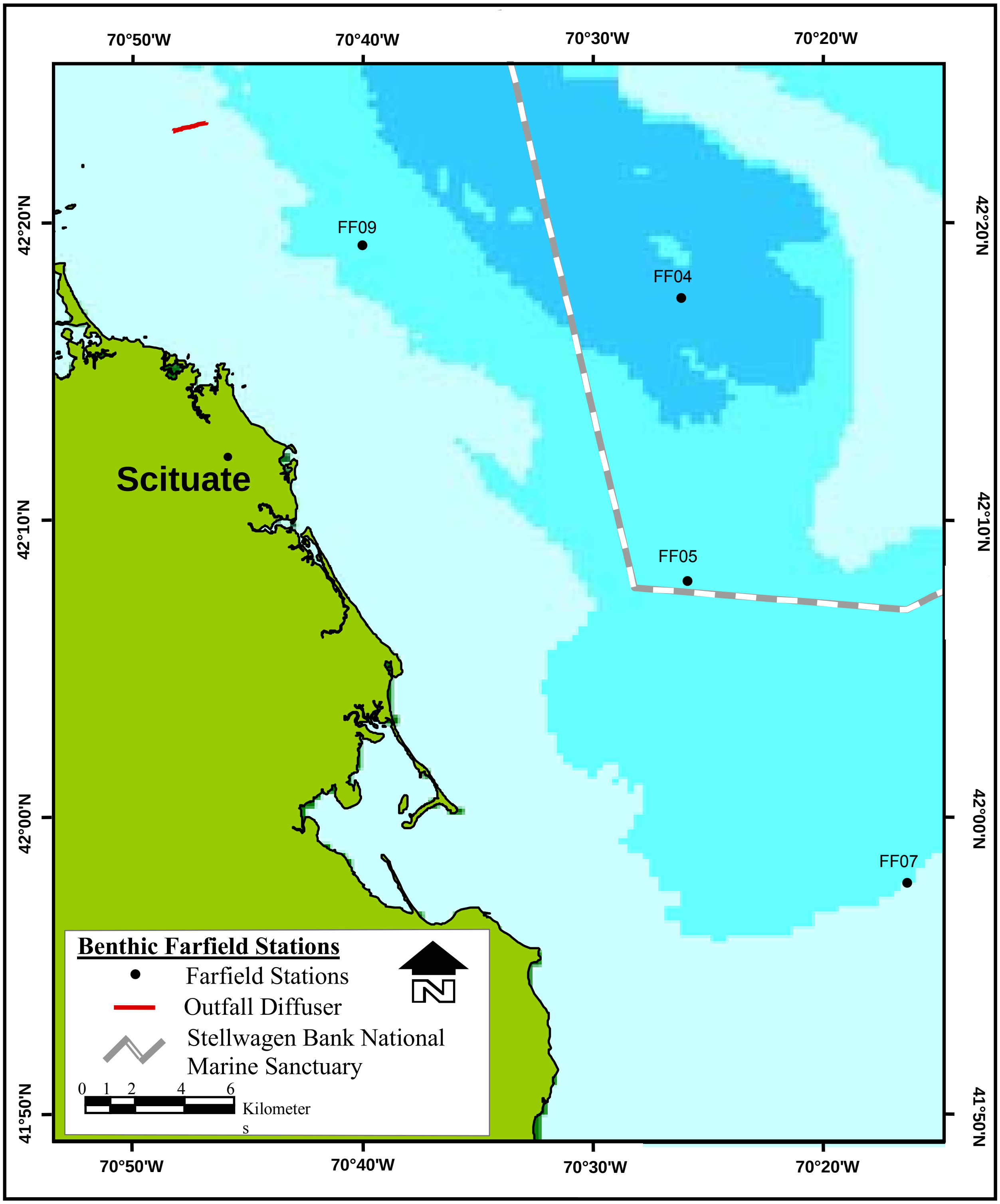

Figure 2-2. Locations of farfield grab stations sampled in August 2004.

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

Transect	Waypoint/ Station	Latitude	Longitude	Depth (m)
T1	1	42°23.606'N	70°48.201'W	25
T1	2	42°23.625'N	70°48.324'W	24
T1	3	42°23.741'N	70°48.532'W	22
T1	4	42°23.815'N	70°48.743'W	20
T1	5	42°23.869'N	70°48.978'W	27
T2	1	42°23.634'N	70°47.833'W	26
T2	2	42°23.570'N	70°47.688'W	27
T2	3	42°23.525'N	70°47.410'W	26
T2	4	42°23.457'N	70°47.265'W	32
T2	5 (Diffuser #2)	42°23.331'N	70°46.807'W	34
T4	2	42°23.012'N	70°46.960'W	29
T4/6	1	42°22.948'N	70°47.220'W	23
T6	1	42°22.993'N	70°47.712'W	30
T6	2	42°22.855'N	70°47.082'W	27
T7	1	42°24.565'N	70°47.015'W	23
T7	2	42°24.570'N	70°46.920'W	24
T8	1	42°21.602'N	70°48.920'W	23
T8	2	42°21.823'N	70°48.465'W	23
T9	1	42°24.170'N	70°47.768'W	24
T10	1	42°22.680'N	70°48.852'W	26
T11	1	42°14.405'N	70°34.373'W	36
T12	1	42°21.477'N	70°45.688'W	29
	Diffuser # 44	42°23.116'N	70°47.931'W	33

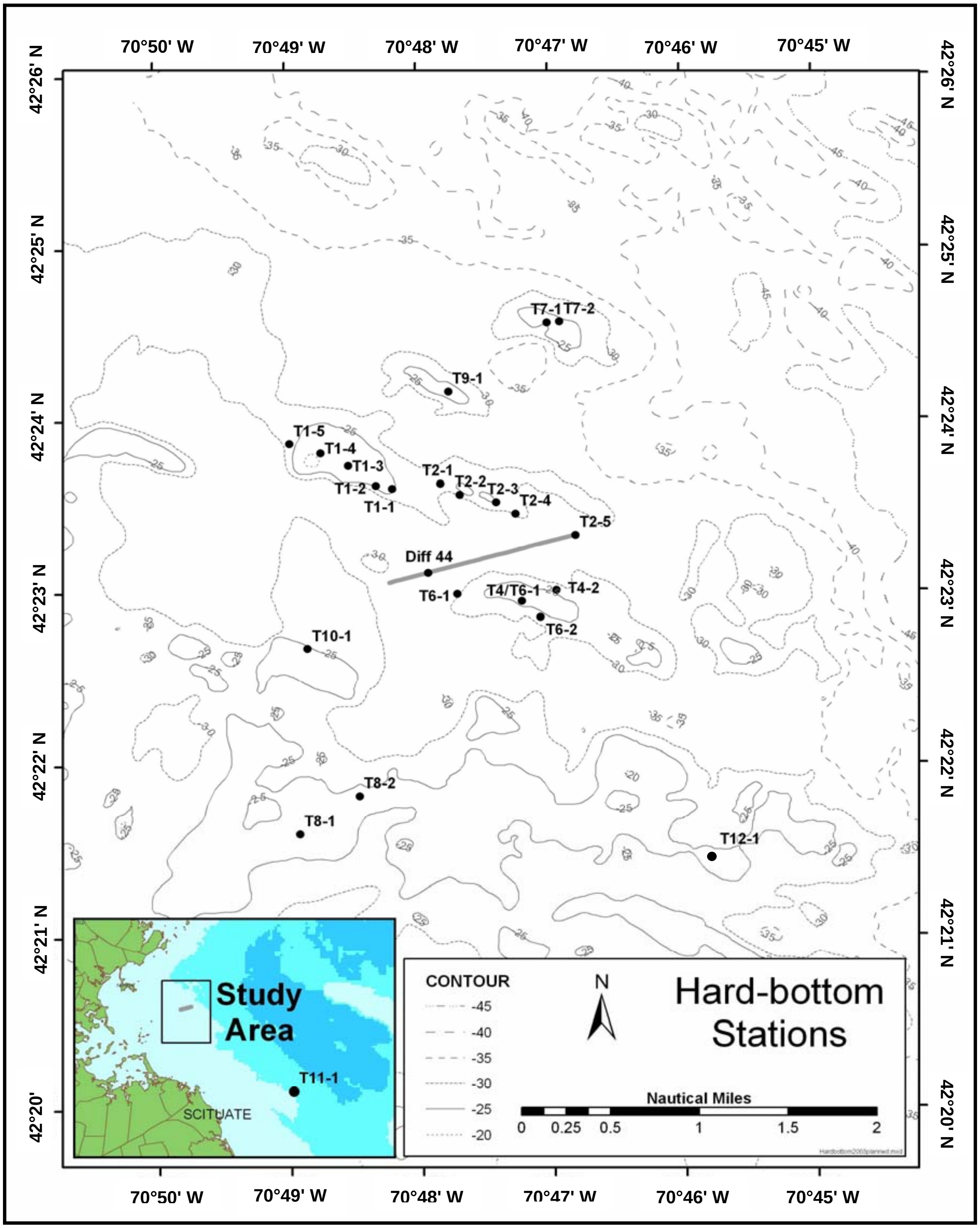

Figure 2-3. Hard-bottom stations sampled in June 2004.

2.2 Field Program Results

2.2.1 Vessel and Navigation

All benthic surveys in 2004 were conducted on Battelle's research vessel, 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.

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 for this program.

2.2.2 Grab Sampling

Ms. Isabelle Williams was the Chief Scientist for collection of soft-sediment grab samples. In 2004, two sampling protocols were used for Nearfield/Farfield Benthic Survey BN041/BF041.

- At four nearfield stations, FF10, FF13, NF12 and NF17, and four farfield stations, FF04, FF05, FF07, and FF09, three replicate samples for infaunal analysis and two replicate samples for chemical analyses were collected.
- At nine nearfield stations, NF05, NF07, NF08, NF09, NF16, NF18, NF19, NF22, and NF23, one faunal and one chemistry grab sample were collected.

Samples for organic and metal contaminants were collected only at Stations NF12 and NF17. At all remaining stations chemical analyses were limited to total organic carbon, sediment grain-size, and *Clostridium perfringens*. Numbers of samples collected are summarized in Table 2-3. At all stations, samples were collected with modified van Veen grabs; specifically, a 0.04-m^2 grab for infaunal samples and either a 0.04-m^2 or 0.1-m^2 Kynar-coated grab for chemistry samples. The larger 0.1-m^2 grab was used at stations NF12 and NF17 where additional sediment was needed for metals and organics analyses and at a few stations with very soft sediments where the smaller grab was more prone to overpenetrate the sediments, disturbing the sediment surface.

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.

Table 2-3. Benthic samples collected in 2004.

Survey Type	Survey ID	2004 Date(s)	Samples Collected									
			Inf	TOC	GS	Cp	Org	TM	SPI	35	V	DVD
Nearfield Benthic	BN041	2 Aug	21	17	17	17	4	4				
Farfield Benthic	BF041	4 Aug	12	8	8	8						
SPI	BR041	23 Aug							93			
Hard-bottom	BH041	21–26 June								739	~500	6

Key: Inf: Infauna; TOC: total organic carbon; GS: grain size; Cp: *Clostridium perfringens*; Org: organic contaminants; TM: trace metals; SPI: individual sediment profile images; 35: 35-mm slides; V: minutes of video; DVD: digital video discs.

2.2.3 Sediment Profile Imagery (SPI)

The SPI specialists for the 2004 SPI Survey (BR041) were Randy Cutter, Wrenn Diaz, and Derek Kibler. The digital camera used for this survey captured a 5.2-megapixel image that produced a 14.1-megabyte RGB image that was then recorded to an IBM 1-gigabyte microdrive. The digital camera was also equipped with a video-feed used to send images to the surface via cable so that prism penetration could be monitored in real-time. In addition, the camera frame supported a video-plan camera mounted to view the surface of the seabed. These images were also relayed to the surface via the video cable and permitted the camera operator to see the seafloor and know exactly when the camera had reached the bottom. The camera operator then switched to the digital still camera and, while viewing the camera penetration, chose exactly when to record sediment profile images. A series of 2–4 photographs was taken each time the camera was on the bottom, generally taken within the first 12 seconds after bottom contact. This sampling protocol helped ensure that at least one usable photograph was produced during each lowering of the camera.

At each station, the camera was lowered to the seafloor at least four times to ensure that at least three replicate images, suitable for analysis, were obtained. Thus, at least four replicate samples were collected at each station (Table 2-3; Appendix A2-2). At several stations, where difficulties were recognized immediately, additional camera drops were made. The video signal showing the surface of the seafloor was recorded on 8-mm videotape for later review. 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©.

The microdrive was capable of recording more images than could be collected during a day of sampling. However, during this survey, the camera housing had to be opened four times to replace the battery and once to check camera function. Generally, images were downloaded from the microdrive to the laptop computer whenever the camera housing was opened. It was not necessary to take test shots on deck because loss of battery power to the strobe or camera would have been noticed immediately when the video cable failed to relay any images. This digital capability allowed a review of the collected images within 20 min of downloading the microdrive to a computer and then to a compact disc (CD) for long-term storage.

2.2.4 Hard-Bottom Sampling

Dr. Barbara Hecker was Senior Scientist for the 2004 Hard-bottom Nearfield Survey (BH041) during which 23 waypoints were visited (Table 2-2; Appendix A-3). 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, DVD, 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 20-30 minutes of video footage per waypoint were recorded along a randomly selected heading (Table 2-3). Along this route, still photographs were taken as selected by Dr. 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 Dr. Hecker) were recorded on the videotape. The NAVSAM© produced barcode labels for the videotapes (attached directly to the videotape cartridge) and photographic film (attached to the Battelle survey logbook). 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. Digital Video Discs (DVD) also were produced as the ROV was filming the hard-bottom stations.

3. 2004 CHEMISTRY

by Deirdre T. Dahlen and Carlton D. Hunt

3.1 Status of the Bay

Sediments from Massachusetts and Cape Cod Bays have been collected since 1992 to support the harbor and outfall monitoring program. Baseline data from 1992 to 2000 showed multiple regions defined by physical and chemical composition. Nearfield stations (Figure 2-1) include a series of locations having heterogeneous sediments located west of the Massachusetts Bay outfall and within nine miles of Boston Harbor. Sources of contaminants to the nearfield sediments include the primary historic source of contaminants, Boston Harbor, and distributed sources such as atmospheric input and inputs from distant rivers. Factors that influence contaminant variability in the nearfield include proximity to sources of contamination and two of the bulk sediment properties (grain size and TOC) characteristic of sediment depositional environments. The primary factor among those measured associated with the variance in the nearfield sediment data is sand content.

Farfield stations (Figure 2-2) include a series of locations having heterogeneous sediments located farther away from the harbor compared with nearfield stations. Farfield sediments generally have lower concentrations of contaminants and sewage tracers compared with nearfield sediments. Principal components analysis (PCA) showed that the composition of sediments at farfield sampling locations was influenced by the analytes associated with fines and may reflect regional sediment inputs distinct from Boston Harbor (Maciolek *et al.* 2003). As in the nearfield, the variance in the farfield sediment data was primarily associated with sand content.

Concentrations of contaminants on average have remained relatively constant over time and were well below the Massachusetts Water Resources Authority (MWRA 2001) thresholds. More importantly, post-diversion sediment data (*i.e.,* 2001–2002) suggested that the effluent discharged from the Massachusetts Bay outfall has not caused an increase in contaminants of environmental concern to the Massachusetts and Cape Cod Bay systems. Notably, concentrations of the sewage tracers, *Clostridium perfringens* and total linear alkyl benzenes (LABs), have decreased in recent years for stations located closest to the harbor. This suggests that the documented reductions in effluent solids loading during the 1990s (Werme and Hunt, 2000) also reflect a reduction in *Clostridium* spore loads. In contrast, there has been a localized, yet modest, increase in post-diversion *C. perfringens* abundance at nearfield stations located close to the outfall. Given that the post-diversion *C. perfringens* data suggested that there was an effluent signal near the outfall, discussions presented here will focus on a more detailed analysis of tracer responses.

2004 represents the first sampling year in which revisions to the monitoring plan affected all parameters measured in the sediments (grain size, TOC, *Clostridium*, organic contaminants and metals). In the *Briefing for OMSAP workshop on ambient monitoring revisions* (July 24, 2003), the MWRA proposed to sample nearfield stations NF12 and NF17 in duplicate in 2004 and 2005 for all parameters. The remaining stations were divided into 'alternating subsets' to be sampled in 2004 and 2005 for grain size, TOC, and *Clostridium*. This was agreed to by the Outfall Monitoring Science Advisory Panel (OMSAP) and approved by the United States Environmental Protection Agency and the Massachusetts Department of Environmental Protection in 2003. Stations sampled for grain size, TOC, and *Clostridium* in 2004 included nearfield stations NF05, NF07, NF08, NF09, NF16, NF18, NF19, NF22, NF23, F10, and F13, and farfield stations FF04, FF05, FF07, and FF09. Nearfield stations FF10 and FF13 and all farfield stations were sampled in duplicate.

3.2 Methods

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

Laboratory procedures in 2004 followed those outlined in the Benthic Monitoring CW/QAPP (Williams *et al.* 2005), except that the polycyclic aromatic hydrocarbon (PAH) data used in this report were prepared by Battelle. 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 particle size and standard deviation were calculated. Grain-size analyses were performed by GeoPlan Associates.

Total Organic Carbon (TOC)—Samples were analyzed for TOC by using a DC-190 analyzer following Prasse *et al.* (2004). Data were presented as percent dry weight. TOC analyses were performed by the Department of Laboratory Services (DLS), MWRA.

***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.

3.2.2 Organic Contaminants and Metals

Chemical testing procedures were performed following methods outlined in Table 3-1. Samples were analyzed for organic contaminants and metals, including PAH, polychlorinated biphenyls (PCBs), chlorinated pesticides, and major and trace metals. More detailed information regarding methods and target analytes (organics, metals) is provided in the CW/QAPP (Williams *et al.* 2005). Chemical analyses were performed by DLS, and the extracts were also analyzed for PAH by Battelle. Results from the PAH analyses conducted by Battelle are used in this report.

Table 3-1. Parameters and methods of analysis for organic constituents and metals.

Parameter	Unit of Measurement	Method[a]
Polycyclic Aromatic Compounds	ng/g	Gas chromatography/mass spectrometry (GC/MS)
Polychlorinated Biphenyls/ Pesticides	ng/g	GC/MS
Major Metals (Al, Fe)	% Dry Weight	Flame atomic absorption (FAA)
Trace Metals (Cd, Pb, and Ag)	µg/g	Graphite furnace atomic absorption (GFAA)
Trace Metals (Cr, Cu, Ni, and Zn)	µg/g	Inductively coupled plasma/mass spectrometry (ICP/MS)
Trace Metals (Hg)	µg/g	Cold vapor atomic absorption (CVAA)

[a] See CW/QAPP (Williams *et al.* 2005) for complete details regarding analytical methods.

3.2.3 Data Terms and Analyses

Key terms used to describe the sediment data are summarized below; a complete list of data terms is presented in Appendix B1.

- *Regional* – refers to all nearfield and farfield stations sampled throughout Massachusetts and Cape Cod Bays.
- *Nearfield* – refers to all regional stations located west of the Massachusetts Bay outfall and in close proximity to Boston Harbor, including NF02, NF04, NF05, NF07, NF08, NF09, NF10, NF12, NF13, NF14, NF15, NF16, NF17, NF18, NF19, NF20, NF21, NF22, NF23, NF24, FF10, FF12, and FF13.
- *Farfield* – refers to regional stations located far away from the outfall and Boston Harbor, *i.e.,* stations FF01A, FF04, FF05, FF06, FF07, FF09, FF11, and FF14.
- *Near-harbor*– refers to nearfield stations located close to Boston Harbor, *i.e.,* FF10, FF12, and FF13.
- *Outfall* – refers to the Massachusetts Bay outfall.

Key data analyses conducted to assess spatial and temporal trends in the sediment data from 1992 to 2004 are summarized below; complete details, including documentation of data that were excluded from the data analyses, are discussed Appendix B1.

- Box plots were used to visualize the data distribution, and identify points with extreme values (*i.e.,* outliers). The ends of the box represent the 25th and 75th quartiles, and the line across the middle represents the median value. The lines are "whiskers" that extend from the ends of the box to the outermost data point that falls within the distances computed (a distance of 1.5 times the interquartile range, difference between 25th and 75th quartiles). Data points above or below the whiskers represent possible outliers. Box plots were prepared using JMP (The Statistical Discovery Software).
- Ternary plots were used to visualize the grain size data, as percentages of gravel + sand, silt, and clay. Ternary plots were also prepared using JMP.
- Range plots were used to visualize baseline (1992–2000) and post-diversion (2001–2004) data on a station-by-station basis. Nearfield stations were presented as a function of distance from the western end of diffuser #55. Farfield stations were sorted as a function of their north to south location relative to the new outfall. Range plots were prepared using Microsoft® Excel 2002.

The relationship between variables (grain size, TOC, organic contaminants and metals) was determined using two types of correlation coefficients: Pearson correlations (parametric) and Kendall correlations (nonparametric). The Pearson correlation coefficient measures the degree to which two variables have a linear relationship if the variables have normal distributions. The Kendall correlation, on the other hand, measures the degree to which high concentrations of one variable are associated with high concentrations of the second variable. Kendall's *tau* is a nonparametric correlation coefficient, which is preferable to Pearson if the data are not normally distributed, which is the case with most of the sediment data. For both Pearson and Kendall correlations, values near 1 indicate that the two variables have a strong positive correlation, values near -1 indicate that the two variables have a strong negative correlation, and values near 0 indicate that the two variables are unrelated. Sediment data used in the correlation analyses included baseline (1999–2000) and post-diversion (2001–2004) station mean values.

3.3 Results and Discussion

Discussions of the 2004 data focus on how these data compare to historical data (pre- and post-diversion). In addition, discussions focus on the *Clostridium* data, and whether 2004 results continue to suggest an effluent signal near the outfall. All sediment results are discussed in terms of dry weight using the baseline range, baseline station mean, and station mean values (see Appendix B1 for data term definitions).

3.3.1 Sediment Properties 1992–2004

Surface sediments collected from nearfield and farfield locations have varying grain-size compositions, ranging from sandy to silty sediments (Appendix B2). Most surface sediments, especially nearfield sediments, contained higher percentages of sand, followed by silt and clay. Near-harbor stations FF10 and FF13 demonstrated variable grain-size composition (measured as percentages of gravel + sand, silt, and clay) over time, ranging from sandy to silty sediments (Appendix B2). Grain-size composition was less variable over time at near-harbor station FF12, and was generally comprised of coarse-grained sediments (Appendix B2). Nearfield stations located near the outfall were comprised of coarse-grained (NF02, NF04, NF05, NF13, NF14, NF15, NF17, NF18, NF19, NF20, and NF23) and fine-grained (NF08, NF12, NF21, and NF24) sediments. Nearfield stations NF07, NF09, NF10, NF16, and NF22 had more intermediate grain-size composition, with roughly equal percentages of coarse- and fine-grained sediments (Appendix B2). Farfield stations were generally comprised of fine-grained sediments, except FF01A and FF09 which were comprised of coarse-grained sediments (Appendix B2). Higher TOC was typically measured in fine-grained (higher amounts of silt+clay) sediments and lower TOC was typically measured in coarse-grained sediments.

A statistical summary of grain size and TOC data from nearfield and farfield surface sediments is shown graphically as side-by-side boxplots in Figure 3-1. Grain-size and TOC data from the three major regions in the nearfield—near-harbor, <2 km from the outfall, and >2 km from the outfall—were also evaluated and are presented in Appendix B2. Each boxplot shows the data distribution. In general, the data indicate that grain-size composition (percentages silt, sand, and clay) and TOC are not substantially different in regional sediments over time, although farfield surface sediments generally contained less sand and more silt and clay compared with nearfield sediments (representative data shown in Figure 3-1; all data in Appendix B2). Further, variability among the data decreased at near-harbor locations following outfall activation (Appendix B2, Figures B2-6 – B2-9 and Table B2-1). The statistical summary also shows that clay content and TOC were unusually high (>20%, possible outliers are circled on Figure 3-1) at selected stations[1] periodically during the program (1992 to 2004), especially in the nearfield sediments. Notably, samples with unusually high TOC occurred with similar frequencies, before and after outfall activation (Figure 3-1, Appendix B2), albeit at different stations. Station NF24, located adjacent to the western end of diffuser #55, consistently had the highest percentages of silt and clay, before and after outfall activation, compared with other sediments located within 2 km of the outfall (Appendix B2, Figures B2-8 and B2-9).

Baseline (1992–2000) and post-diversion (2001–2004) data were also evaluated by using range plots, and the results were consistent with the statistical evaluations (box plots). Specifically, most of the post-diversion grain-size and TOC data were within the variability of the baseline samples, although percentage clay and TOC increased above baseline at some regional stations (representative data shown in Figure 3-2, all data in Appendix B2). Even so, the increases were small and isolated. The post-diversion data suggest that diversion of treated effluent discharge to the outfall has not caused widespread or systematic changes to grain-size composition and TOC in regional surface sediments.

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[1] Clay content was unusually high at NF24 (1995, 1997), NF02 (1992), NF12 (2001, 2002, 2004), NF22 (2004) and FF07 (2002). TOC was unusually high at NF08 (1992, 1993), NF24 (1995), NF14 (2002), and NF12 (2001, 2002).

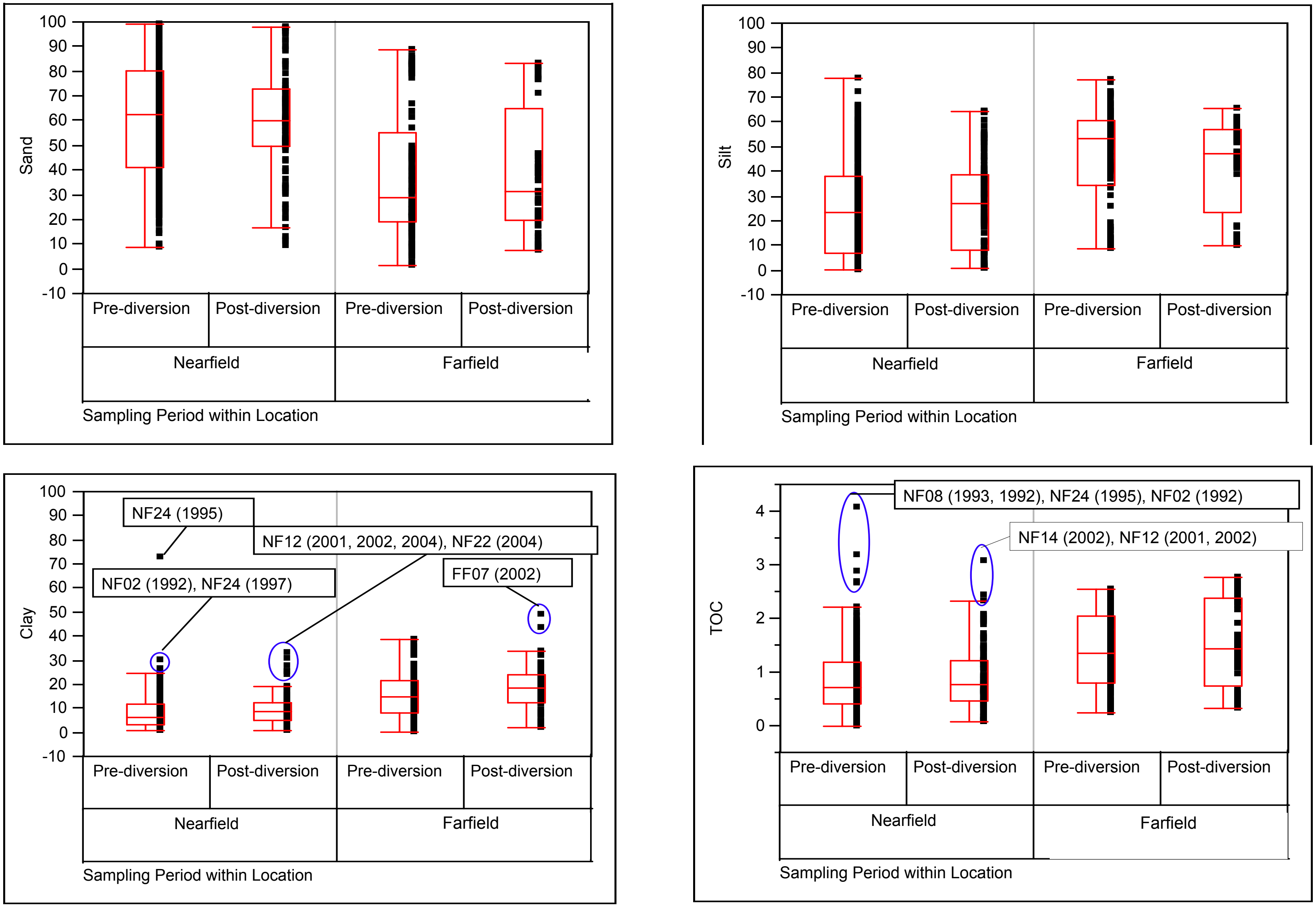

Figure 3-1. Distribution of percentages sand, silt, clay, and TOC in regional surface (top 2 cm) sediments; pre- and post-diversion periods.

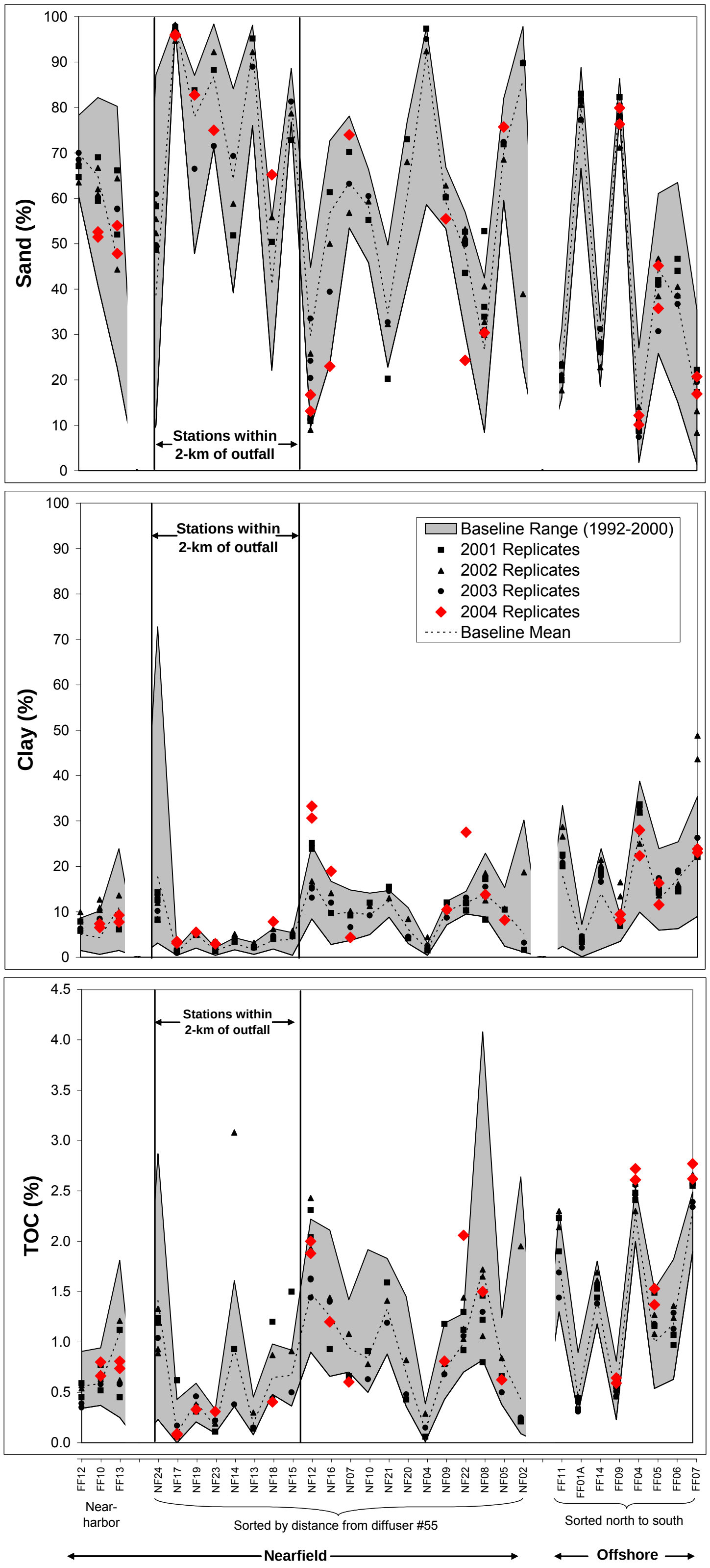

Figure 3-2. Percentages sand, clay, and TOC in regional surface (top 2 cm) sediments during the baseline (1992–2000 range of values, gray band) and post-diversion (2001–2004, symbols) periods. The baseline mean values are indicated by a dashed line within the gray band.

3.3.2 Organic Contaminants and Metals 1992–2004

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, Boston Harbor. Relative to the nearfield sediments, regional sediments located further away from the harbor (*i.e.,* farfield) exhibited greater local compositional character that was attributed to the greater spatial separation and local characteristics of the regional sampling locations (*e.g*., Cape Cod, Cape Ann) (Maciolek *et al.* 2003).

An evaluation of baseline (1992–2000) and post-diversion (2001 and 2002) data using PCA showed that the post-diversion samples typically were within the overall variability of the baseline samples. Further, the PCA results showed that the primary factor among those measured associated with the variance in the data was sand content, followed by secondary factors associated with anthropogenic analytes and fine particles (Maciolek *et al.* 2003). More specifically, the PCA results revealed four general trends among the sediment data. First, percent sand was inversely correlated with organic and inorganic analyte concentrations. Presumably, this reflected the lack of association of organic and inorganic analytes with coarse-grained, low organic carbon content material, *i.e.,* sand. Stations NF02, NF04, NF17, NF13, NF19, NF23, FF01A, and FF09 were naturally sandy sediments. Second, anthropogenic analytes were measured at relatively high levels in the early years of the baseline study (*e.g.,* 1992–1994) for one or more samples from stations FF10, FF12, FF13, NF05, NF07, NF08, NF09, NF10, NF12, NF16, NF20, NF21, NF22, and NF24. This suggests that these sample locations received higher pollutant loadings, especially during the early 1990s, from Boston Harbor. The PCA results suggest, however, that since the mid- to late 1990s, concentrations of anthropogenic analytes generally decreased over time at numerous sampling stations. 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, NF02, NF08, NF12, NF16, NF21, NF22, NF24, FF01A, FF04, FF05, FF06, FF07, FF11, and FF14. This grouping was consistent with naturally occurring mineral matter (*e.g.,* fines, clay, silt, Al, and Fe). At farfield locations, these samples generally contained high percentages of silt and clay without large anthropogenic chemical content. Fourth, the samples that were largely undifferentiated into the first three groups constituted the fourth sample grouping, and included one or more samples from FF10, FF12, NF05, NF07, NF10, NF14, NF15, NF18, NF20, FF05, FF06, and FF09. Samples in the fourth group contained intermediate amounts of sand, fines, and anthropogenic analytes during most of the baseline and post-diversion periods.

Baseline (1992–2000) and post-diversion (2001–2002 all stations; 2003–2004 NF12 and NF17 only) data were also evaluated by using range plots. Results were consistent with the PCA results in that most of the post-diversion data were within the general distribution of samples collected during the baseline period. Concentrations of aluminum in 2001 were within the baseline at most stations, but increased above baseline in 2002, especially at nearfield stations (Figure 3-3). Concentrations of aluminum returned to baseline in 2003 at NF12 and NF17, but increased above baseline again in 2004 at NF12 (one replicate only) and NF17 (both replicates). There were also some localized increases in post-diversion contaminant concentrations at one or more stations; however, the largest increases (total DDT at NF21 in 2001, Figure 3-4; total PAH at FF10 in 2002,Appendix B3, Figure B3-1; Pb at NF15 in 2002, Figure 3-4) did not appear to be related to the outfall. Instead, the post-diversion increases appear be due to analytical interferences (total DDT), random spikes (total PAH), or unknown contamination (Pb), as contaminant values generally returned to baseline in subsequent sampling surveys (Figures 3-3 and 3-4)[2]. Thus, the localized increases in contaminant concentrations do not persuasively suggest an effluent signal. Rather, post-diversion sediment data suggest that diversion of treated effluent discharge to the outfall has not caused widespread or systematic increases in contaminants of environmental concern to Massachusetts and Cape Cod Bay systems.

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[2] Pb has not been sampled at NF15 since 2002, however, triplicate sediment grabs were collected at NF20 in October 2002 and results showed that Pb concentrations returned to baseline from the suspiciously high value measured in August 2002.

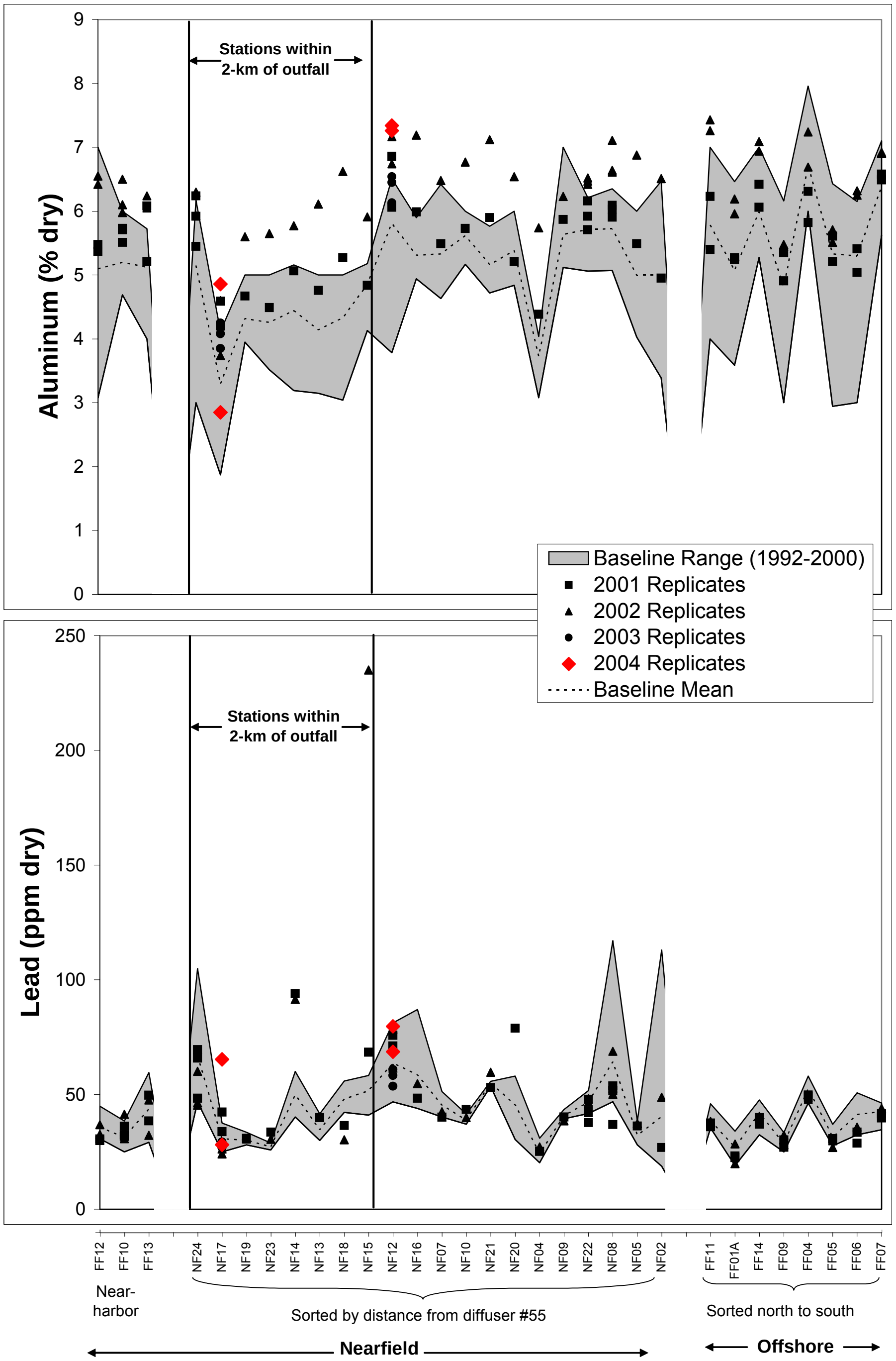

Figure 3-3. Concentrations of aluminum (top) and lead (bottom) in regional surface (top 2 cm) sediments during the baseline (1992–2000 range of values, gray band) and post-diversion (2001–2004, symbols) periods. The baseline mean values are indicated by a dashed line within the gray band.

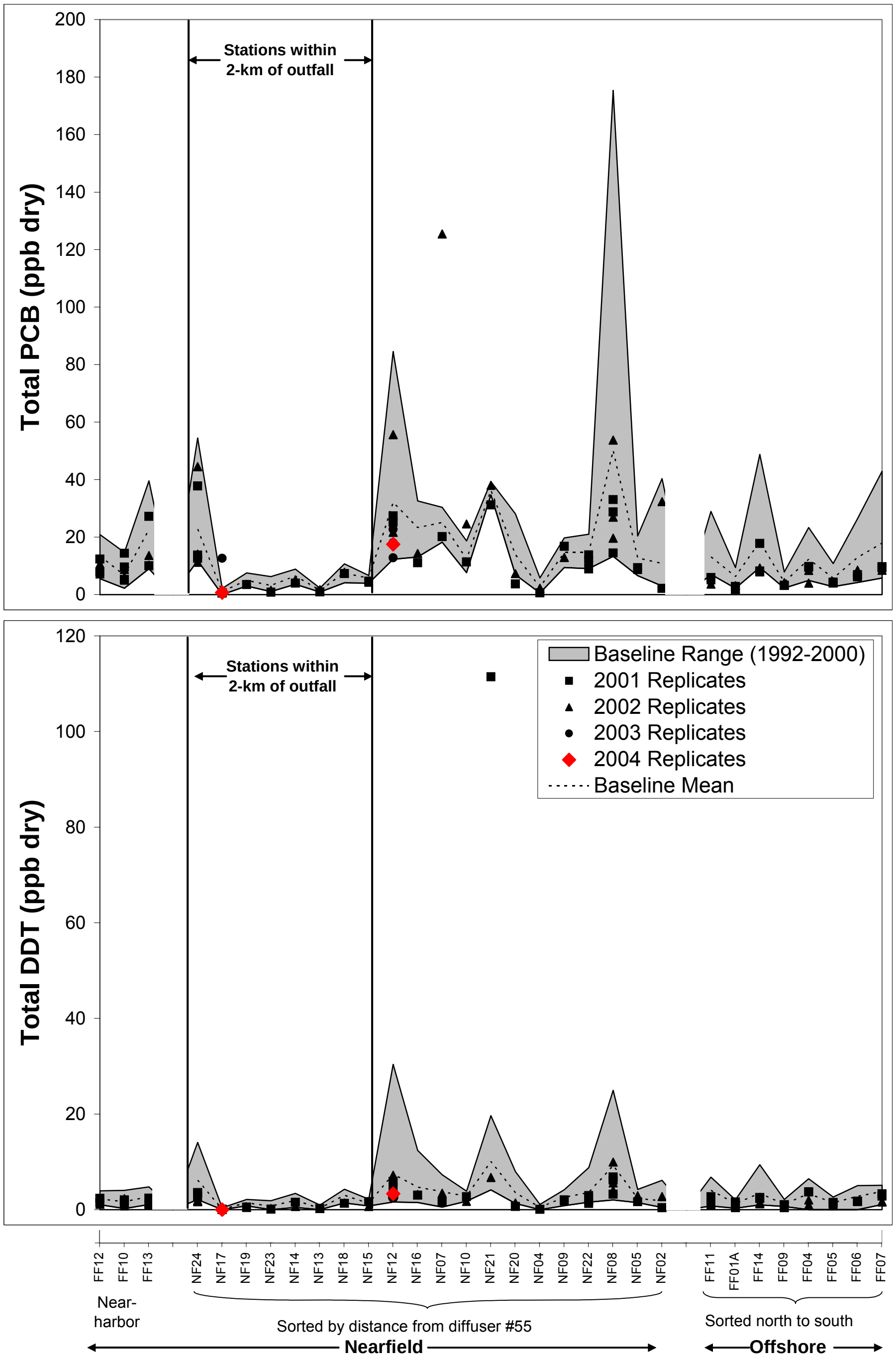

Figure 3-4. Concentrations of total PCB (top) and total DDT (bottom) in regional surface (top 2 cm) sediments during the baseline (1992–2000 range of values, gray band) and post-diversion (2001–2004, symbols) periods. The baseline mean values are indicated by a dashed line within the gray band.

3.3.3 Sewage Tracer *Clostridium perfringens* 1992–2004

Cessation of sludge disposal to the harbor in 1991 and subsequent improvements in sewage treatment,[3] including diversion of treated effluent discharge to the outfall in 2000, have had a positive influence on Boston Harbor sediments. Notably, a statistically significant decrease in *C. perfringens* abundances (log-transformed) has been observed in the harbor over time (Maciolek *et al.* 2004).

Clostridium data were also evaluated to assess the impacts, if any, that the diversion of treated effluent discharge to the outfall may have had on regional sediments located throughout Massachusetts and Cape Cod Bays. *Clostridium* data from two sampling periods were used for the evaluations, *i.e.,* 2000 and 1999–2000. Data from 2000 were used for comparison because it represented the system after improvements to sewage treatment and just prior to outfall activation. Data from 1999–2000 were also used because this sampling period shows the most representative conditions after improvements to sewage treatment and two years before diversion of effluent discharge to the new outfall.

Post-diversion *C. perfringens* abundances decreased or were within the baseline range (1999–2000) at near-harbor and farfield stations (Figures 3-5 and 3-6). A localized increase was observed in post-diversion *C. perfringens* abundances at most nearfield stations (Figures 3-5 and 3-6). Notably, *C. perfringens* abundances decreased at many nearfield stations in 2003 and 2004 compared with 2001–2002 values. The decrease was unexpected had the system remained in a steady state. The observed decrease may suggest that the spores are being consumed or, more likely, that *Clostridium* is being lost as a result of physical processes[4], and that it is not being replenished by a strong source (*i.e.,* less input from the outfall). Alternatively, the decrease could reflect the natural variability within the system (coefficient of variation in the nearfield data is >50% for all monitoring years; see Appendix B4).

C. perfringens abundances, normalized to percent silt, clay, fines and TOC, were evaluated to assess the influence of grain size and TOC on *Clostridium*, and to assess whether the *Clostridium* response can be explained. Normalized post-diversion data were compared to baseline data from the two years prior to outfall activation, *i.e.,* 1999–2000. Normalization of the *C. perfringens* abundances to grain size, and to a lesser extent TOC, reduced the variability among the regional data (silt and TOC normalized data shown in Figure 3-7; all data in Appendix B4). Further, the observed decrease in post-diversion *C. perfringens* abundances at near-harbor locations was more evident after normalization to grain size. More importantly, normalized, post-diversion *C. perfringens* abundances approached baseline at all nearfield stations (except NF04) located further away (>2 km) from the western end of diffuser #55 (Figure 3-7 and Appendix B4); whereas, stations located within 2 km of the western end of diffuser #55 still showed elevated, post-diversion abundances of *C. perfringens,* even after normalization. These findings suggest that changes in *C. perfringens* abundances in the nearfield are primarily associated with changes in sediment grain size, except at stations located within 2 km of the outfall and NF04 where the increase in *C. perfringens* abundances were higher than expected given the corresponding grain-size composition. This suggests an effluent signal near the outfall. Stations located within 2 km of the outfall (excluding NF24) and NF04 are comprised of very sandy sediments, with small amounts of fine-grained material (generally <10% silt). The sandy nature of these sediments suggests a high-energy environment, where only coarse-grained sediments would deposit or remain over time. A higher-energy environment may explain in part why the abundances of *C. perfringens* decreased in 2003 and 2004. For example, physical processes such as sediment transport (storm driven) or burial under cleaner, more coarse-grained material (biological reworking) would contribute to a reduced *Clostridium* response. Insufficient data, however, are available to completely understand why the abundances of *C. perfringens* decreased in 2003 and 2004.

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[3] Primary treatment in 1995, secondary treatment in 1997, and diversion of Nut Island influent to Deer Island in 1998.

[4] Sediment processes such as sediment transport or bioturbation and mixing down in the sediments.

Closer examination of the sediment data indicates that the post-diversion increase in the nearfield *C. perfringens* abundances (non-normalized) corresponds in many cases to stations where percentages of fine-grained material (primarily silt) and, to a lesser extent, TOC increased compared to 2000[5] values (silt and TOC data shown in Figure 3-8; all data in Appendix B4). For example, post-diversion increases in percent silt were observed at stations NF12, NF21, NF22, NF16, FF10, and NF20 (Figure 3-8). Percent silt also increased at NF02 and NF07 in 2002 and at NF09 in 2003 and 2004 (Figure 3-8). Increases in percent clay were also observed at many of these same stations, especially in 2002 (NF02, NF12, NF16, FF10, NF20) and 2004 (NF12, NF22, NF18 and NF17) (Appendix B4, Figure B4-9). The observed changes in grain-size composition (compared to 2000 data) at selected nearfield stations may be associated with natural variability in the system. More important, these changes do not correspond with increases in normalized *C. perfringens* abundances observed at nearfield stations located within 2 km of the western end of diffuser #55. Rather, this observed increase continues to be indicative of an effluent signal near the outfall.

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[5] While grain-size composition can vary from year to year, post-diversion grain-size data were compared only to 2000 values because this sampling period represents the system just prior to outfall activation.

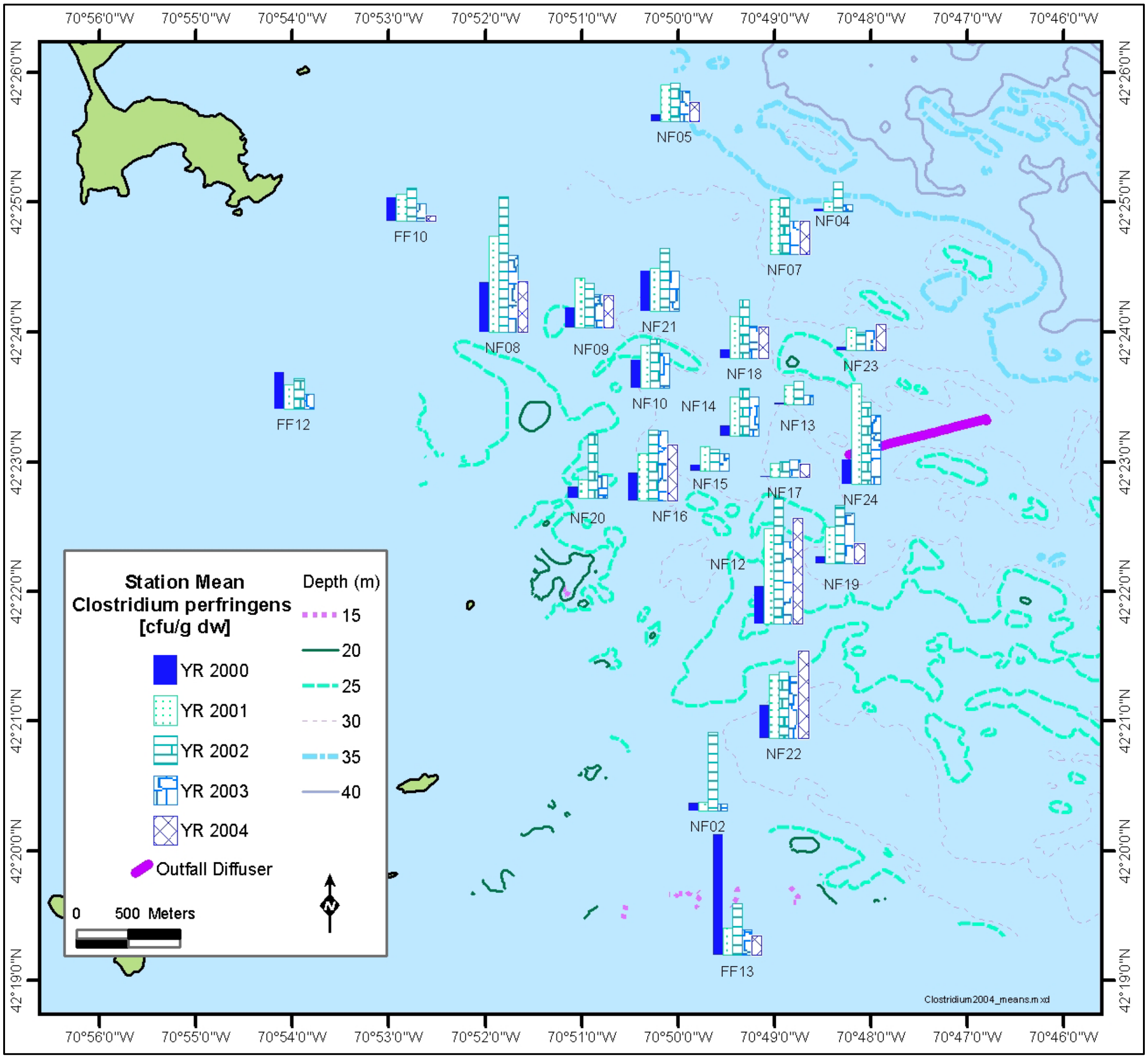


Figure 3-5. Station mean concentrations of *Clostridium perfringens* in nearfield surface (top 2 cm) sediments prior to (August 2000) and after (August 2001–2004) outfall activation.

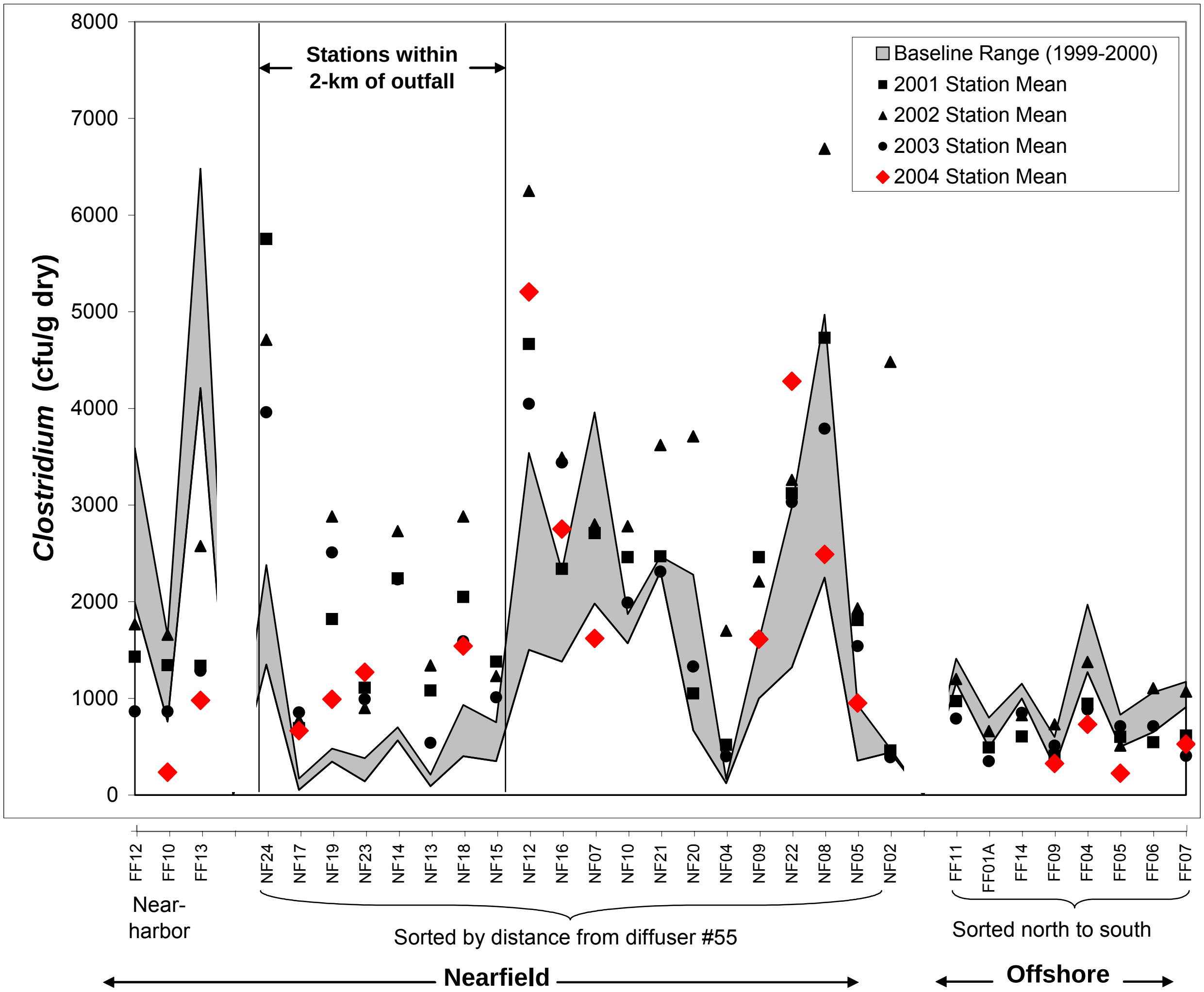


Figure 3-6. ***Clostridium perfringens*** **abundances (non-normalized) in regional surface (top 2 cm) sediments during the baseline (1999–2000 range of values, gray band) and post-diversion (2001–2004, symbols) periods.**

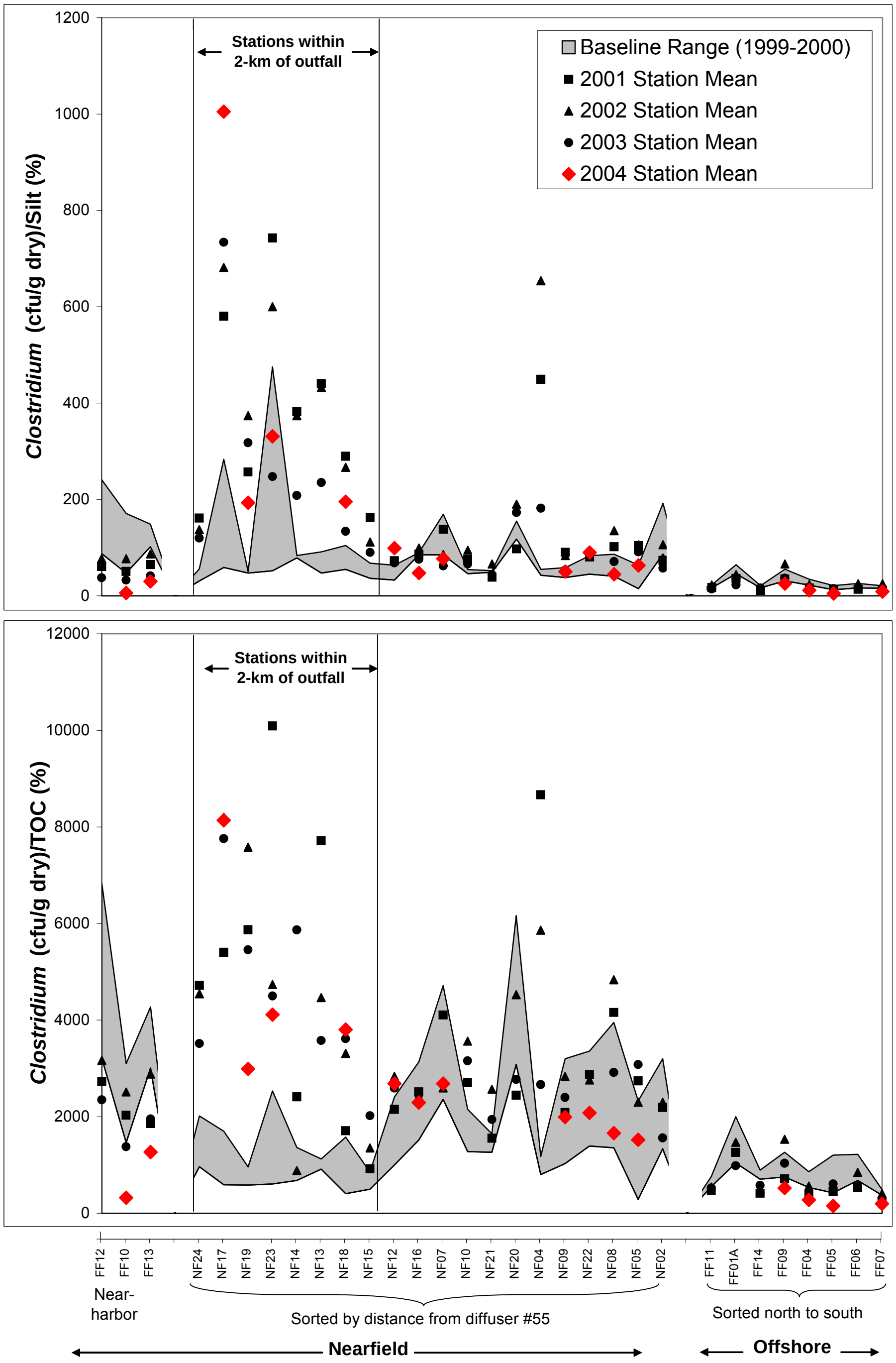


Figure 3-7. ***Clostridium perfringens*** **abundances, normalized to percent silt (top) and TOC (bottom), in regional surface (top 2 cm) sediments during the baseline (1999–2000 range of values, gray band) and post-diversion (2001–2004, symbols) periods.**

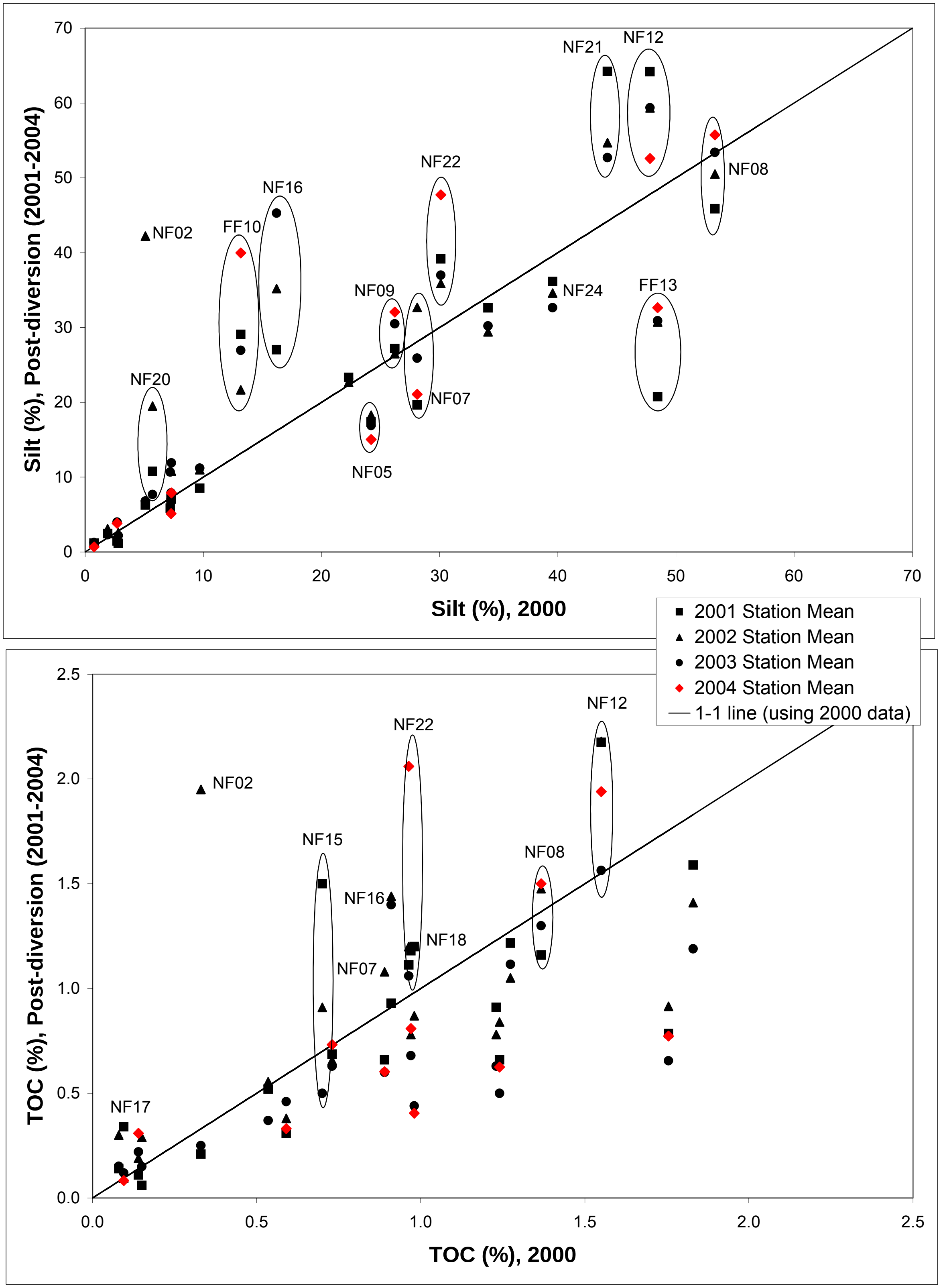


Figure 3-8. Correspondence between percent silt (top) and TOC (bottom) in nearfield surface (top 2 cm) sediments in 2000 and post-diversion periods.

3.3.4 Chemistry Interrelationships

Pearson (parametric) and Kendall (nonparametric) correlation results and regression plots are presented in Appendix B5. Sediment data from 1999–2000 were used as the baseline because this sampling period shows the most representative conditions after improvements to sewage treatment and before diversion of effluent discharge to the new outfall. Post-diversion sediment data are available for all stations and all testing parameters in 2001–2002; however, organic contaminant and metals data are available only for nearfield stations NF12 and NF17 in 2003 (sampled in triplicate) and 2004 (sampled in duplicate). As a result, chemical data from 2003–2004 have limited utility with regard to assessing chemistry interrelationships.

Data evaluations showed that proximity to the primary historic source of contaminants, Boston Harbor, was positively correlated with the chemical concentrations in regional sediments. Nearfield sediments, with grain size similar to farfield sediments, generally had higher chemical concentrations compared with farfield values, especially for organic contaminants (total PAH data shown in Figure 3-9; all data in Appendix B5). Chemical concentrations present at levels above the underlying farfield signature are indicative of a local source (Boston Harbor), as evidenced by a higher slope value from the regression analysis for nearfield data compared with farfield data (Figure 3-9). Chemical concentrations at farfield locations are primarily influenced by widely distributed sources (*e.g.,* atmospheric input, distant rivers). PCA supported this and showed that the composition of sediments at farfield sampling locations is influenced by the analytes associated with fines and may reflect regional sediment inputs distinct from Boston Harbor (Maciolek *et al.* 2003).

Sediment grain size and TOC were positively correlated with organic contaminants and metals in regional sediments. For example, fine-grained sediments characteristic of depositional environments generally contained higher contaminant concentrations. In contrast, coarse-grained sediments typically contained lower contaminant concentrations. There was a strong, positive correlation (Pearson r = 0.86; Kendall r = 0.75) between TOC and percent fines at all regional stations from 1999–2004, although TOC concentrations were higher than expected given the corresponding grain size at nearfield stations NF14 (1999, 2001, and 2002), NF15 (1999 and 2001) and NF18 (2000 and 2001) (Figure 3-10). The elevated TOC levels at these coarse-grained stations may be associated with incomplete carbonate digestion (Battelle, 2002). *Clostridium perfringens*, organic contaminants, and metals were also positively correlated with percent fines and TOC (Appendix B5); correlations were moderate to strong (Pearson and Kendall r typically > 0.5; (Appendix B5). Correlations (Kendall) between organic contaminants and bulk sediment data (percent fines and TOC) were typically stronger (higher r values) in nearfield sediments, primarily because sample concentrations in farfield sediments were relatively low and the variability among the data was higher. Correlations (Kendall) between most metals and bulk sediment data (percent fines and TOC) were similar (<30% relative percent difference) between nearfield and farfield sediments. The correlation between silver and percent fines was stronger in the nearfield compared to farfield sediments, indicating that silver concentrations were lower than expected (un-impacted) in farfield sediments given the corresponding grain-size composition.

The strength in the correlations (Kendall) between most of the sediment data did not change substantially following outfall activation, especially at nearfield locations (Appendix B5). The correlation between the sewage tracer *C. perfringens* and bulk sediment data (percent fines and TOC) did degrade in farfield sediments following outfall activation. However, the weaker correlation (Kendall r decreased from 0.72 to 0.47 for *C. perfringens* against percent fines and from 0.62 to 0.36 for *C. perfringens* against TOC) appears to be associated with an observed decrease (approximately 25% on average) in *C. perfringens* abundances with no corresponding change in grain size. Overall, results from the correlation analyses show no clear evidence of an outfall impact resulting in contaminant contributions to regional sediments.

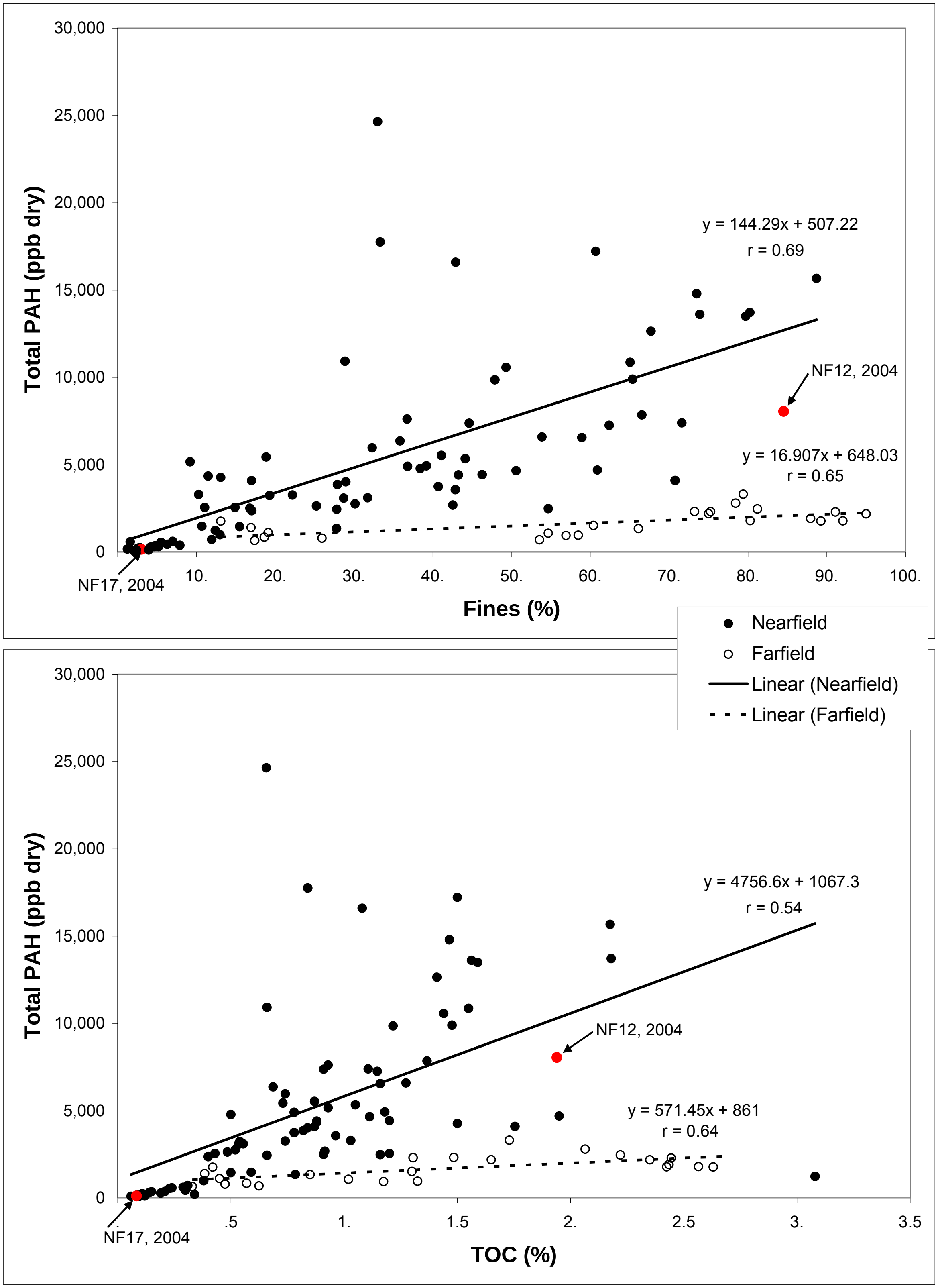


Figure 3-9. Correlation between total PAH and fines (top) and TOC (bottom) in regional surface (top 2 cm) sediments from 1999–2004.

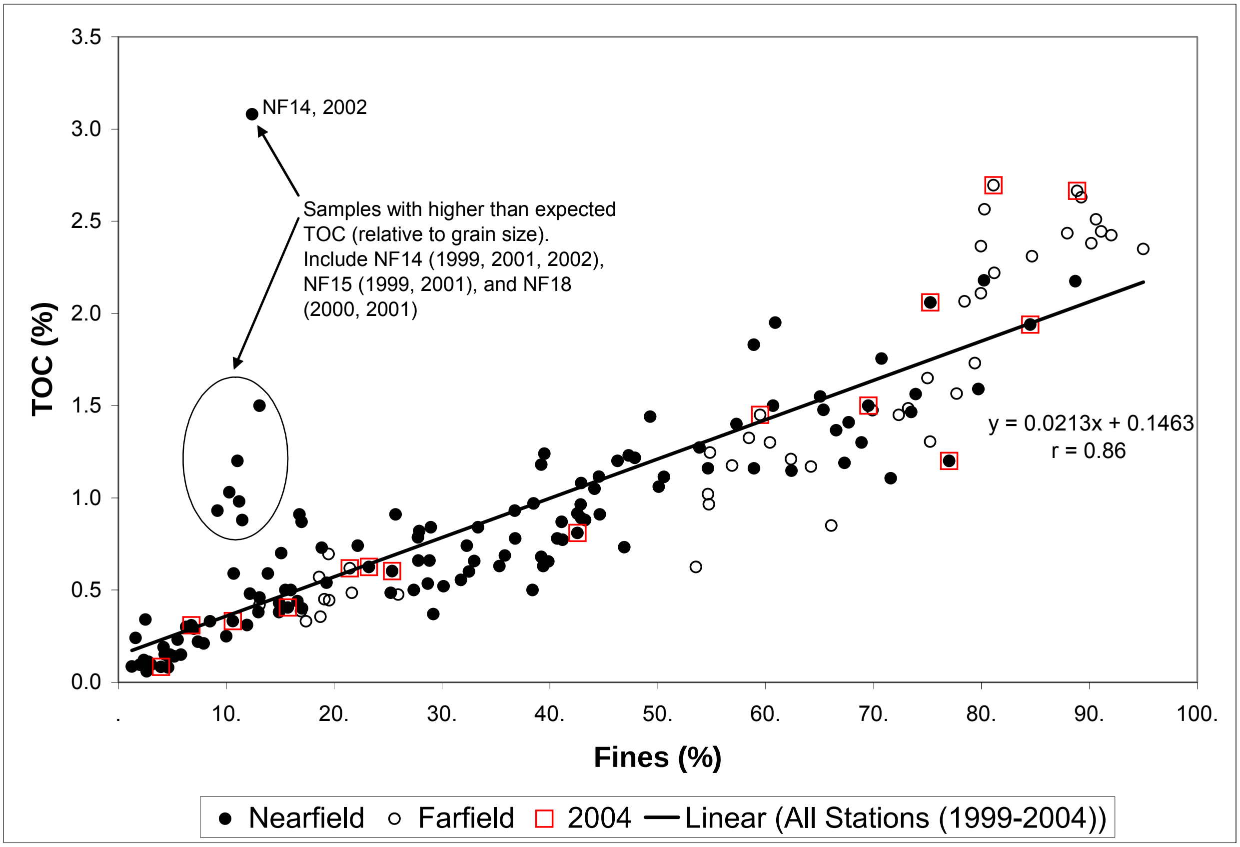


Figure 3-10. Correlation between TOC and fines in regional surface (top 2 cm) sediments from 1999–2004.

3.4 Monitoring Questions and Conclusions

3.4.1 Monitoring Questions

Relocation of the outfall to Massachusetts Bay raised environmental concerns regarding potential effects of the diverted discharge on the sea floor. These concerns focused on three issues: eutrophication and related low levels of dissolved oxygen, accumulation of toxic contaminants in depositional areas, and smothering of animals by particulate matter (MWRA 1991, 1997). This section focuses on the second issue, accumulation of potentially toxic contaminants. Sediment monitoring conducted under the Benthic (Sea Floor) Monitoring component of the MWRA HOM program was designed to address specific monitoring questions.

- ♦ *Have the concentrations of contaminants in sediment changed?*

While small increases in some metals and organic contaminant concentrations were observed at one or more individual stations, most of the post-diversion contaminant data (2001–2004) were consistent with concentration ranges and distribution patterns of samples collected during the baseline period (1992–2000). Thus, concentrations of contaminants in sediment in 2001 and 2002 have not changed (*i.e.,* systematic or widespread change) compared to baseline following effluent discharge from the new outfall.

Similarly, contaminant data in 2003 and 2004 for nearfield stations NF12 and NF17 showed no evidence of an increase in contaminants of environmental concern.

- ♦ *What is the level of sewage contamination and its spatial distribution in Massachusetts and Cape Cod Bays sediments before discharge through the new outfall?*

Clostridium perfringens abundances measured in surface sediments throughout Massachusetts and Cape Cod Bays have ranged from undetected (NF23 in 1995; FF05 and FF08 in 1992) to 24,100 cfu/g dry weight (NF21 in 1997). In general, *Clostridium* abundances were low throughout the bay, with slightly higher levels observed closer to Boston Harbor. Abundances generally decreased with distance from the harbor, with regional sediments located far way from Boston Harbor (>20 km) having the lowest *C. perfringens* abundances.

- ♦ *Has the level of sewage contamination or its spatial distribution in Massachusetts and Cape Cod Bays sediments changed after discharge through the new outfall?*

Post-diversion abundances (normalized to grain size) of the sewage tracer, *C. perfringens,* have not changed substantially at regional stations located far way from the offshore outfall. Normalized abundances have decreased slightly, however, at regional stations located near Boston Harbor (*i.e.,* FF10, FF12, and FF13) compared to 2000 levels. This suggests that diversion of the effluent discharge to the outfall may be having a positive influence on the near-harbor sediments, and not contributing measurably to the *C. perfringens* abundances in regions further from the harbor.

In contrast, there is a clear, localized post-diversion increase in *C. perfringens* abundances at most nearfield stations. Post-diversion increases in *C. perfringens* abundances correspond in many cases to stations where the percentage of fine-grained material (primarily silt) increased since 2000. Normalization to grain size brought the post-diversion *Clostridium* response more in line with baseline values (1999–2000), especially for nearfield stations located more than 2 km from the outfall. Notably, the *Clostridium* response (normalized to grain size) decreased in 2003–2004 compared with 2001–2002 values, possibly due to sediment transport or deposition of less contaminated material over the surface sediments. However, stations located within 2 km of the outfall still showed an elevated post-diversion *Clostridium* response. The consistency in the areas of apparent effluent signal near the outfall, described by *C. perfringens,* indicate the primary area of influence the outfall has on the sediments.

3.4.2 Conclusions

Sediment data available to date indicate that diversion of the effluent discharge to the outfall has not caused widespread or systematic increases in contaminants of environmental concern to the Massachusetts and Cape Cod Bay systems, even though there is a clear signature of the effluent discharge in the sediments near the diffuser. This area (near the diffuser) is primarily identified by substantial changes to the abundances of the sewage tracer, *C. perfringens*. Small decreases in *C. perfringens* abundances (normalized to grain size), however, have been observed at regional stations located closer to Boston Harbor.

4. 2004 SEDIMENT PROFILE IMAGING

by Robert J. Diaz

4.1 Status of the Bay

The nearfield baseline years for Sediment Profile Images (SPI) were the six years between 1992 and 2000 during which collections were made. These collections provided the baseline for assessing change in the depth of the apparent color redox potential discontinuity (RPD) layer as described in the MWRA's Contingency Plan (MWRA 2001). During the baseline period, the yearly mean RPD layer depth varied from a low of 1.8 cm (SE = 0.13 to 0.14) in 1997 and 1998 to a high of 3.0 cm (SE = 0.22) in 1995. In 1997, due to technical problems, sampling occurred in both August and October, which may have contributed to the variation because the RPD layer becomes seasonally shallower in the fall. In 1998 all sampling was done in August. The largest deepening of the RPD layer between successive samplings was 0.5 cm from 1998 to 1999 and was associated with an increase in the levels of biogenic activity. The increased occurrence of Stage II communities in 1998 and 1999, and Stage III in 1999 (Figure 4-1), 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 to small tube-building worms. Factors responsible for the depth of the RPD layer in the nearfield appeared to be acting at regional scales with yearly patterns in RPD depth reasonably consistent across stations. Figure 4-2 shows patterns for the six stations that had measured RPD layer depths for all sampled dates. The dynamics of the RPD layer were related principally to the interaction of physical and biological processes that structured surface sediments and infaunal communities. It appeared that successional Stage I pioneering communities dominated the nearfield stations from the start of SPI sampling in 1992 to 1997. Starting in 1998, it appeared that intermediate successional Stage II communities dominated to the end of the baseline period in 2000 and into 2003.

The Organism Sediment Index (OSI), a measure of benthic habitat condition, indicated that infaunal communities at 30% of the nearfield stations might have been stressed for three or more years during the baseline period. This assessment is based on applying the interpretation of OSI developed by Rhoads and Germano (1986) for inshore estuarine habitats, where an OSI <6 would be indicative of stressed conditions. The likely stressors in the nearfield were the physical processes shaping the dynamic sedimentary environment and not water or sediment quality, since these were consistently found to be good (see Chapter 3 this report, Libby *et al*. 2003). In the long term, the annual OSI oscillated around a grand mean of 6.4 (SD = 1.68), with the greatest departure in 1997 likely due to the shift in sampling dates from August to October. There was little difference in the OSI between the baseline mean and post-diversion mean (Figure 4-3). The variation in OSI from year to year is not statistically significant and likely represents a shifting balance between biological and physical processes. The peak year for biological processes in the SPI images was 2000. Based on the paradigm used in estimating successional stage from the SPI images, it is not likely that the variation in OSI is related to the operation of the outfall since successional stage remained relatively constant. A decline in successional stage would be expected if organic enrichment was occurring (Pearson and Rosenberg 1978).

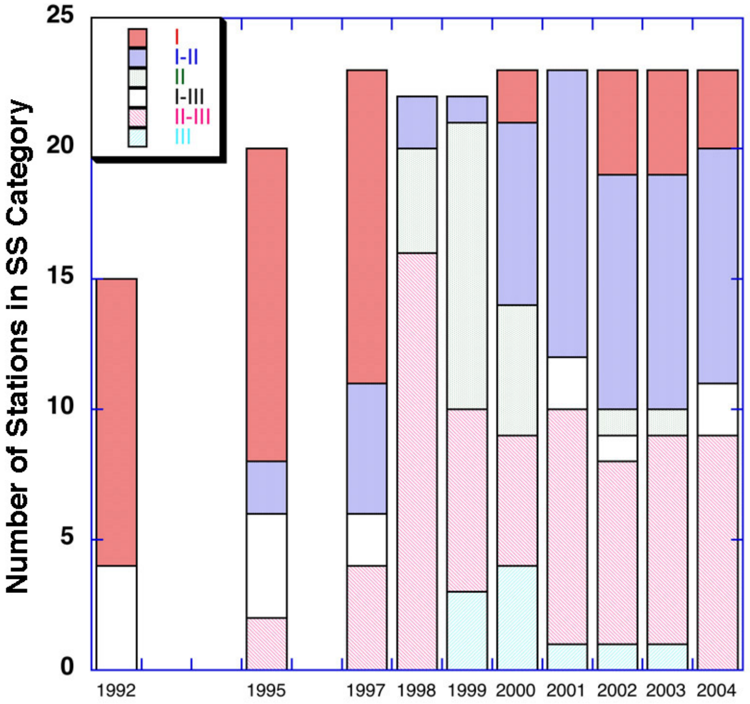


Figure 4-1. Long-term patterns in estimated successional stage from nearfield SPI images.

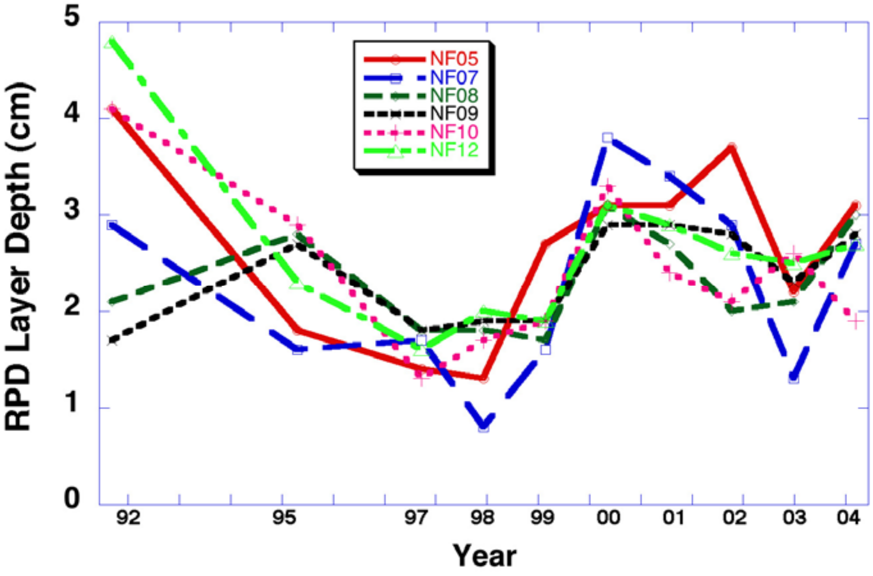


Figure 4-2. Patterns in RPD layer depth at the six stations that had measured RPD layers for all sampled years.

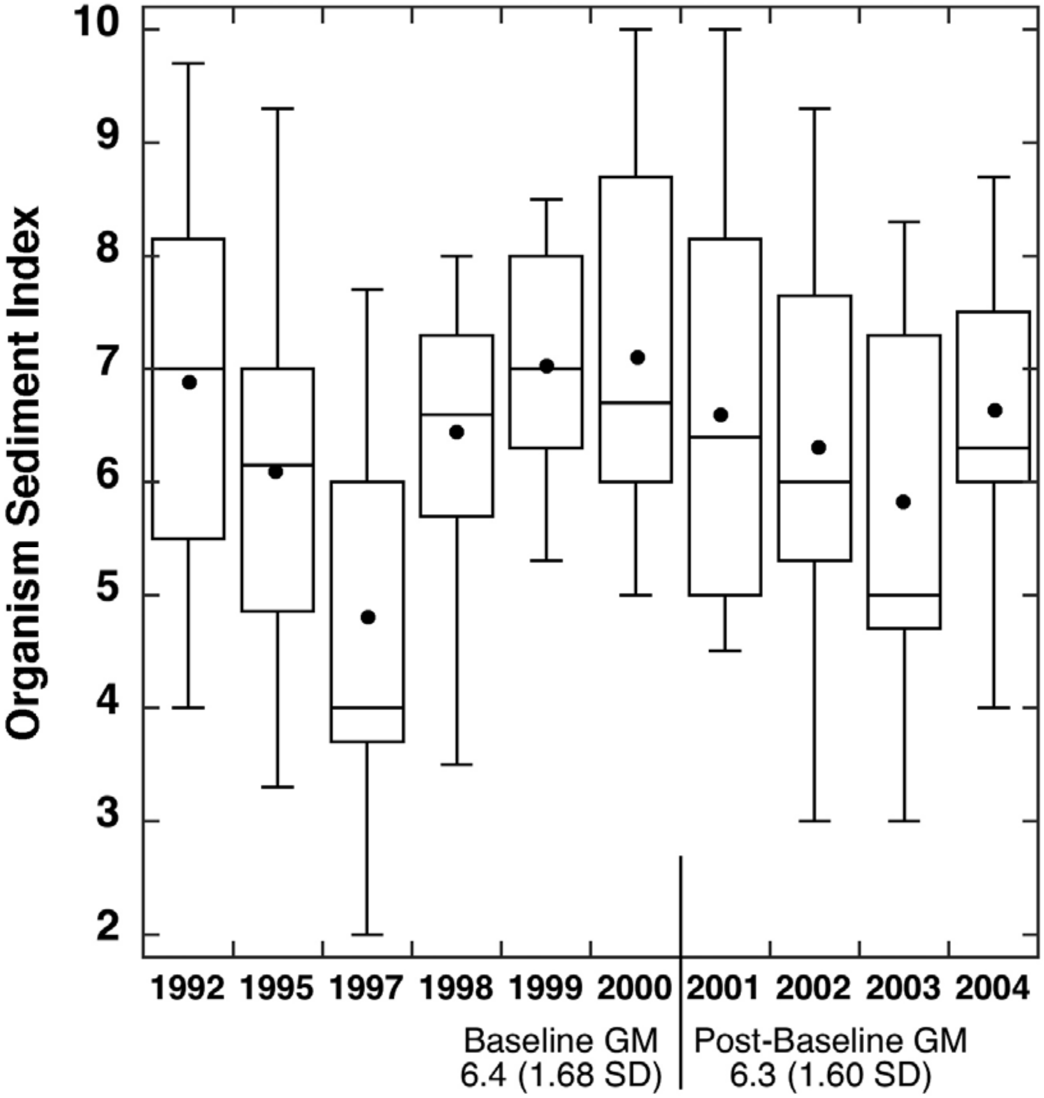


Figure 4-3. Organism Sediment Index (OSI) summarized by year for all data from nearfield stations. Box is interquartile range, bar is median, dot is mean, and whiskers are data range.

4.2 Methods

4.2.1 Quick-Look Analysis

The Quick Look analysis was developed in 1998 to meet the need for rapid data turn-around for assessment of benthic triggers, one of which is an area-wide 50% reduction in the average depth of the RPD layer (MWRA 1997). Basically, the RPD layer depth is evaluated visually from unprocessed images and categorized at 0.5-cm intervals. While still in the field, the 2004 digital SPI images were compared to the 2003 images for gross changes. The Quick Look analysis was completed 28 August 2004. See Williams *et al.* (2002) for more details on the Quick Look analysis.

4.2.2 Image Analysis

The digital SPI images were analyzed by using the program Adobe PhotoShop®. 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 4-1 summarizes the parameters measured.

4.3 Results and Discussion

4.3.1 Quick-Look versus Detailed Analysis

Based on the Quick Look analysis, the mean apparent color RPD layer depth in 2004 did not exceed the threshold of a 50% decrease from the baseline conditions. To exceed the threshold RPD value, the departure from the baseline mean (2.3 cm, SD = 0.88 cm) would at a minimum have to be <1.2 cm and given the variability of the baseline data (CV = 37%) a significant change would have to be closer to <1.0 cm. The quick look mean for 2004 was 2.5 cm (0.50 SD) and was not significantly different than the baseline period mean of 2.3 cm (based on a t-test weighted to adjust for different variances in the two groups, $t = 0.80$, $p = 0.426$).

For 2004, as with previous years, there was a high degree of correspondence between the depths of the apparent color RPD layer, one of the benthic trigger parameters (MWRA 1997), from the Quick Look and detailed image analyses. The mean RPD from the Quick Look analysis was 0.1 cm deeper than the mean from the computer analysis results. The correlation between the two analyses was 0.85 (Stations FF12, NF04, NF13, and NF17 with >RPD layers excluded, $n = 19$, $p = 0.0002$).

Table 4-1. 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 appear to be oxidized. Area of aerobic sediment divided by width of digitized image
Thickness of Sediment Layers	cm	CA	Measure thickness above original sediment surface
Methane/Nitrogen Gas Voids	Number	V	Count
Epifaunal Occurrence	Number	V	Count, identify
Tube Density	Number /cm^2	V	Count
Tube Type			
Burrow Structures	—	V	Identify
Pelletal Layer	cm	V	Measure thickness, area
Bacterial Mats	—	V	Determine presence and color
Infaunal Occurrence	Number	V	Count, identify
Feeding Voids	Number	V	Count, measure thickness, area
Apparent Successional Stage	—	V,CA	Estimated based on all of the above parameters
Organism Sediment Index	—	CA	Derived from RPD, successional stage, gas voids (Rhoads and Germano 1986)

V: Visual measurement or estimate

CA: Computer analysis

4.3.2 Physical Processes and Sediments

Sediment grain size in 2004 was similar to previous years and ranged from pebble (PB) to fine-sand-silt-clay (FSSICL), with 11 stations having a mixture of coarse (fine-sand and larger grain size) and fine (silt and clay) sediments, and 12 stations being primarily fine sediments. Station NF16 was the most heterogeneous with replicate images ranging from fine-sand-silt-clay to fine-sand-silt-gravel-pebble (Figure 4-4). Sandy sediments that ranged from very-fine-sand (VFS) to fine-medium-sand (FSMS) occurred at three stations. The modal grain size descriptor was fine-sand-silt-clay (5.5 to 4.5 phi) and occurred at 11 stations. Prism penetration and grain size were related, with lowest penetration occurring at sand-to-pebble stations and the highest at mixed muddy stations. Penetration was shallowest (1.8 cm) at Station NF13, which had fine-medium-sand-gravel sediments and deepest (19.9 cm) at Station NF02, which had fine-sand-silt-clay (Figure 4-4 and Table 4-2).

Relative to the baseline, sediment grain sizes in 2004 were most similar to the 1998 to 2000 baseline years. For baseline years 1992, 1995, and 1997, sediments coarser than gravel were not recorded from the SPI images. Starting in 1998 pebble and cobble were observed in some SPI images (Table 4-3). Two possible hypotheses that explain this pattern are sampling/dispersion and change in grain size. For the sampling/dispersion hypothesis, spatial heterogeneity of the largest sediment grain sizes, combined with cumulative sampling at the same stations, eventually sampled the broadly dispersed pebble- and cobble-sized grains. The change in grain size hypothesis would support a coarsening of sediments between the 1997 and 1998 samplings. From 1999 on, there has been little variation in modal grain size, which would be most consistent with the change in grain size hypothesis. If dispersion of larger grains was responsible for the observed patterns, it would not be expected that they would consistently occur in the long-term.

4.3.3 Apparent Color RPD Depth

At four porous, coarse-sediment stations (FF12, NF04, NF13, and NF17), 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 2004. At stations NF15 and NF23, two of the three replicate images had RPD layers that were deeper than the prism penetration and at station NF14 one of the three replicate images. The general pattern in RPD layer depths in 2004 was similar to both the baseline and first three post-diversion years (Figure 4-5). In 2004, the station average apparent color RPD layer depth ranged from 1.4 cm (NF02) to >3.7 cm (NF04), with a grand mean of 2.4 cm (SD = 0.53 cm). A Welch ANOVA, which tests for equality of mean while allowing the standard deviations to be unequal (a problem when sample sizes are unequal, 123 for baseline years vs. 23 for 2004), found that there was no significant difference in the depth of the apparent color RPD layer depth between baseline years and 2004 ($F = 0.83$, $p = 0.366$). The fact that there was no statistical difference between 2004 and the baseline would also indicate that the RPD threshold was not exceeded. The difference between 2004 and the baseline was a deepening of the RPD by 5%.

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 FF10 and NF08. The deepest RPD layers were associated with mixed fine-sand-silt-clay sediments that had higher levels of biogenic activity (for example, compare NF08 to NF02, Figure 4-4).

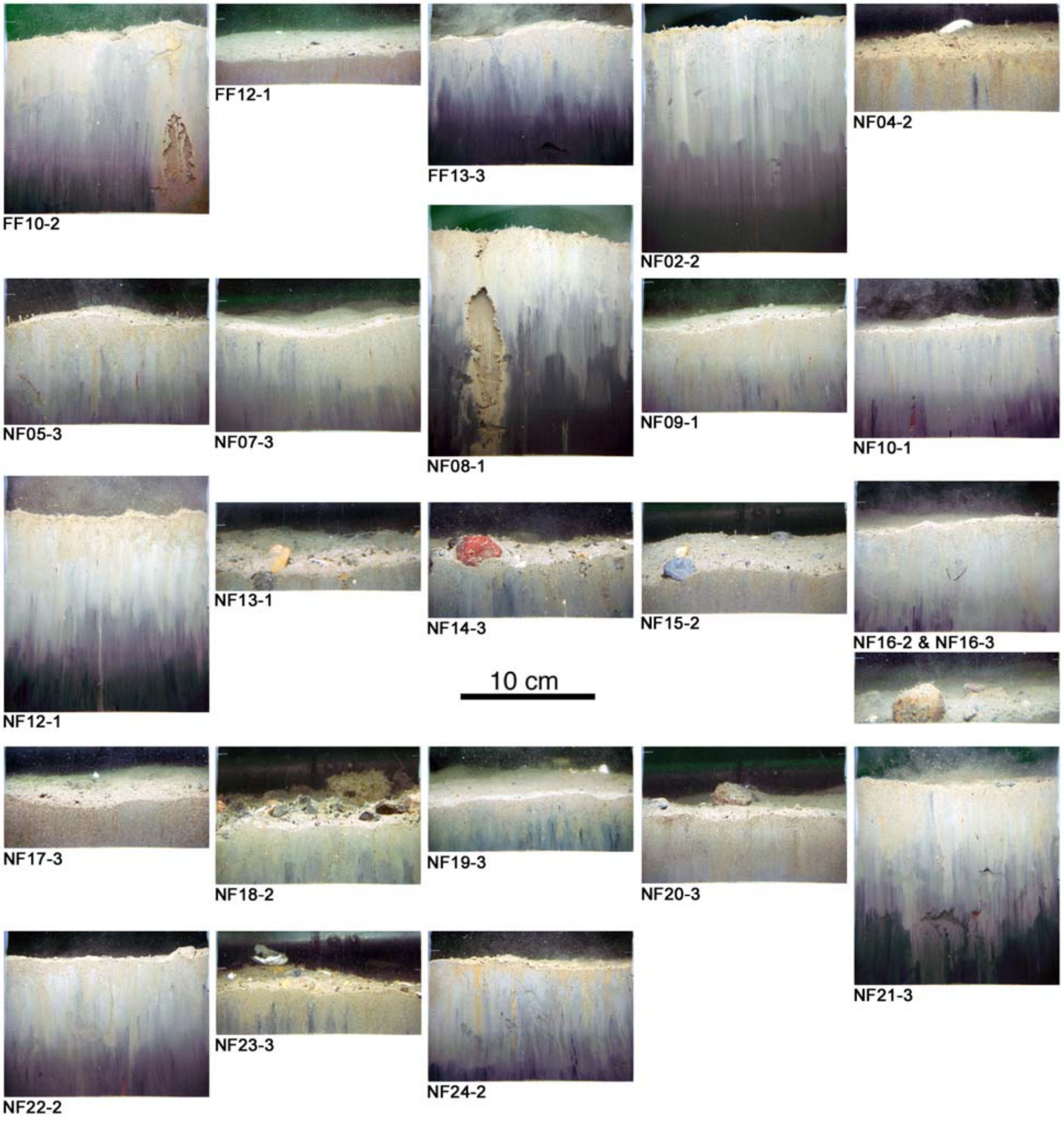


Figure 4-4. Sample SPI images from 2004 nearfield stations.

Table 4-2. Summary of SPI parameters for nearfield stations, August 2004. Data from all replicates were averaged for quantitative parameters and the median was used for categorical parameters.

STA	PEN[1] (cm)	SR[2] (cm)	RPD[3] (cm)	Modal Grain Size	Surface Process	Amphi. Tubes	Worm Tubes	INF[4]	BUR[5]	Oxic Voids	SS[6]	OSI[7]	Fish Eggs	Stick Amphi
FF10	10.5	1.1	1.6	FSSICL	BIO/PHY	NONE	MANY	4.3	2.3	1.3	I-III	6.3	+	-
FF12	2.0	0.9	>1.9	VFS	PHY	NONE	SOME	1.0	2.5	0.0	I-II	>5.5	-	+
FF13	8.4	1.0	2.1	FSSI	BIO/PHY	NONE	FEW	7.3	3.3	0.3	I-II	6.0	-	-
NF02	19.9	1.1	1.4	FSSICL	PHY	NONE	SOME	1.7	5.7	3.7	I-III	7.3	-	-
NF04	3.7	1.3	>3.7	FS	BIO/PHY	NONE	MANY	0.7	1.7	0.0	I	7.0	-	-
NF05	7.6	0.8	3.1	FSSICL	BIO	SOME	MANY	4.7	6.0	0.0	II-III	8.7	-	+
NF07	8.0	1.5	2.7	FSSICL	BIO/PHY	NONE	SOME	13.7	4.7	0.0	I-II	6.0	-	-
NF08	15.8	1.1	3.0	FSSICL	BIO	NONE	MANY	5.0	4.0	1.3	II-III	8.3	-	-
NF09	7.1	1.4	2.8	FSSICL	BIO/PHY	NONE	MANY	11.0	7.3	1.0	II-III	7.3	+	-
NF10	8.8	1.1	1.9	FSSICL	BIO/PHY	NONE	MANY	10.3	5.7	0.3	II-III	6.7	-	-
NF12	17.9	1.0	2.7	FSSICL	BIO/PHY	NONE	SOME	12.0	5.3	2.0	II-III	8.3	+	-
NF13	1.8	1.2	>1.8	FSMSGR	PHY	NONE	MANY	0.0	0.7	0.0	I-II	>4.7	-	+
NF14	4.0	1.2	2.5	FSMSSIGR	PHY	NONE	SOME	1.7	1.7	0.0	I-II	6.0	+	-
NF15	3.2	1.9	2.3	FSMSSIGR	PHY	NONE	SOME	1.3	0.3	0.0	I-II	6.0	+	-
NF16	2.9	0.7	2.9	FSSICL to PB	PHY	FEW	MANY	6.0	3.0	1.0	II-III	8.0	-	-
NF17	2.9	0.7	>2.9	FSMS	BIO/PHY	NONE	MANY	0.0	0.0	0.0	I-II	>6.3	-	-
NF18	4.5	0.9	2.4	FSMS to FSSIGRPB	PHY	NONE	SOME	2.0	1.7	0.0	I-II	5.7	+	-
NF19	2.8	1.5	1.9	FSSIGR	PHY	NONE	SOME	1.3	2.0	0.0	I	4.0	-	-
NF20	4.4	1.0	2.7	FSSIGR	PHY	NONE	SOME	1.3	2.0	0.0	I	5.0	-	-
NF21	12.9	0.7	2.6	FSSICL	BIO/PHY	NONE	SOME	9.3	8.0	2.3	II-III	8.3	-	-
NF22	10.5	1.3	2.3	FSSICL	BIO/PHY	FEW	SOME	8.0	4.7	1.0	II-III	7.0	-	-
NF23	2.5	1.1	2.3	FSMSGR	PHY	NONE	MANY	0.3	0.0	0.0	I-II	6.0	-	-
NF24	11.0	1.1	2.6	FSSICL	BIO/PHY	NONE	SOME	8.3	4.7	2.7	II-III	7.7	+	-

[1] Penetration depth; [2] SR = Surface roughness; [3] ">" indicates the RPD was deeper than the prism penetration depth; [4]INF=Infauna; [5] BUR= burrows; [6] Successional Stage; [7] Organism-Sediment Index.

Table 4-3. Modal sediment grain size at nearfield SPI stations for all sampled years.

	Baseline						Post-Diversion			
Station	**1992**	**1995**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
FF10	VFS	.	VFS	VFS	CB to SIFS	PB to GR	CB to FS	PB to FSSICL	VFS	FSSICL
FF12	.	.	VFS	FS	FS	VFS	VFS	VFS	VFS	VFS
FF13	.	.	SIFS	SIFS	CB to FSSI	CB to SI	FSSI	CB to FSGR	CB to FSSI	FSSI
NF02	VFS	CS	SIFS	PB to GR	CB to FSSI	CB to MSCS	FSSI	FSSI	FSMS/FSSI	FSSICL
NF04	FS	FS	VFS	FS	GR to FS	FS	PB to FSMS	PB to FS	FS	FS
NF05	FS	VFS	VFS	VFS	FS/SICL	FS/SICL	FSSICL	FSSICL	FSSICL	FSSICL
NF07	VFS	VFS	VFS	VFS	SIFS	SIFS/CL	FSSICL	FSSICL	FSSICL	FSSICL
NF08	VFS	SIFS	VFS	VFS	SIFS	SIFS	SIFS	FSSICL	SIFS	FSSICL
NF09	VFS	VFS	VFS	VFS	FSSI	FSSI	FSSICL	FSSI	FSSICL	FSSICL
NF10	VFS	VFS	VFS	VFS	FSSICL	FSSICL	FSSICL	FSSICL	FSSICL	FSSICL
NF12	VFS	SI	SIFS	SIFS	FSSICL	FSSICL	FSSICL	FSSI	FSSICL	FSSICL
NF13	FS	FS to VFS	FS	PB to SIFS	FSMS	PB to FSMS	GR to FSMS	PB to FSMS	PB to FSMS	FSMSGR
NF14	FS	VFS	VFS	PB to VFS	PB to SIFS	PB to FSSICL	PB to FSSI	PB to FSSI	PB to FSSIGR	FSMSSIGR
NF15	FS	VFS	VFS	GR to FS	PB to FSSI	PB to FSSI	PB to FSSI	GR to VFS	PB to FSSIGR	FSMSSIGR
NF16	VFS	SIFS	VFS	SIFS	FSSICL	PB to FSSI	CB to FSSICL	FSSICL	CBPB	PB to FSSICL
NF17	FS	FS	FS	FS	GR to FSMS	PB to FSMS	FSMS	FSMS	FSMS	FSMS
NF18	VFS	VFS	VFS	GR to VFS	PB to SIFS	FSSICL	PB to FSSICL	PB to FSSICL	PB to FSSIGR	FSSIGRPB to FSMS
NF19	.	CS to VFS	VFS	FSSICL	FSSICL	CB to FSSICL	GR to FSSI	VFS	CB to FSSI	FSSIGR
NF20	VFS	CS to VFS	GR to FSMS	GR to SICL	PB to SIFS	PB to SIFS	PB to FSSI	FSSI	CB to FSSIGR	FSSIGR
NF21	.	SIFS	VFS	SIFS	SIFS	SIFS	SIFS	FSSICL	FSSICL	FSSICL
NF22	.	SIFS	SIFS	SIFS	SIFS	SIFS	FSSICL	FSSICL	FSSICL	FSSICL
NF23	.	CS to VFS	FS	FS	PB to FSSICL	GR to FSMS	PB to FSMS	GR to FSMS	PB to FSMS	FSMSGR
NF24	.	SI	SIFS	FSSICL	PB to FSSICL	FSSICL	FSSICL	FSSICL	FSSICL	FSSICL

CB = Cobble   FS = Fine-sand   PB = Pebble   VFS = Very-fine-sand   GR = Gravel   SI = Silt   CS = Coarse-sand   CL = Clay   MS = Medium-sand   / = Layered

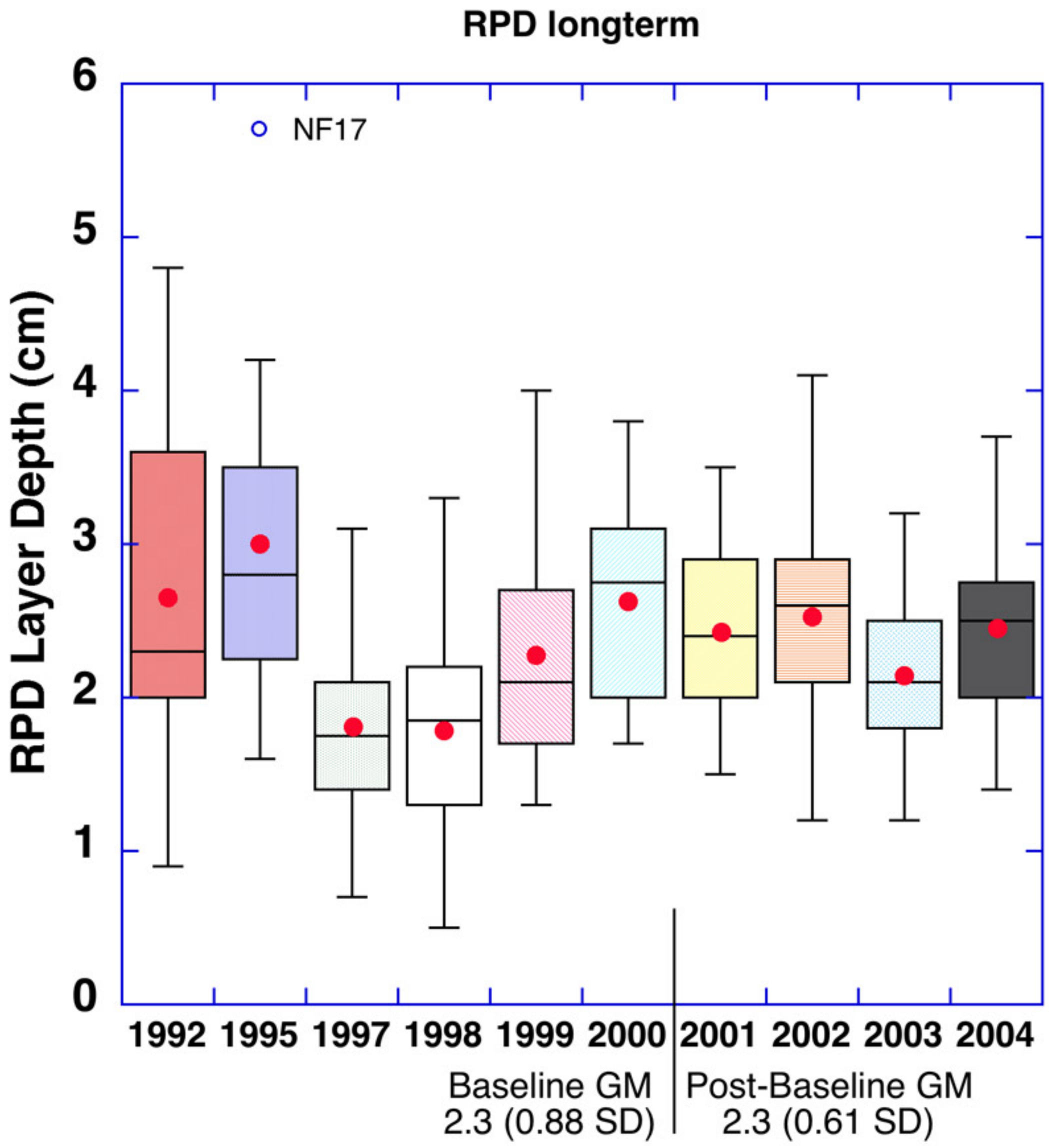


Figure 4-5. Apparent color RPD layer depth (cm) summarized by year for all data from nearfield stations. Box is interquartile range, short bar is median, dot is mean, and whiskers are data range. Station NF17 was an outlier in 1995.

4.3.4 Biogenic Activity

Sediment surfaces in 2004 continued to appear structured by a combination of biological and physical processes, with 11 of the 23 stations (*e.g.*, NF09) having biogenic structures in combination with physical features such as bedforms. At 10 stations (*e.g.*, FF13), physical processes dominated. Stations NF05 and NF08 were classified as having a biologically structured sediment surface (Table 4-2). The proportion of physically structured stations in 2004 relative to baseline years 1998, 1999, and 2000 (this variable was not reported in 1992, 1995, or 1997) when biological processes dominated sediment surfaces was significant (stations that were both physically and biologically dominated were excluded; Fisher's Exact Test, p = <0.0001). The odds of encountering a station with a biologically dominated sediment surface from 1998 to 2000 was 7 to 1. In 2004, the odds were reversed and favored encountering physically dominated surface sediments by 5 to 1.

Bed roughness or surface relief at physically dominated stations was either large sediment grains or bedforms. At biologically dominated stations, bed roughness was due to feeding mounds or pits. Most of the sediment grains larger than gravel were not covered with thin layers of fine sediment, but some did have tubes covering much of their surfaces, for example NF16 (Figure 4-4). Biogenic structures associated with activities of successional stage II and III fauna dominated biological processes in 2004 and were similar to those found during the baseline period. Included were what appeared to be ampeliscid tubes (NF05), biogenic whips or sticks of *Dyopedos* spp. (FF12), large worm tubes (NF05), biogenic mounds (NF07), and possibly fish eggs (NF14). Subsurface biogenic structures associated with infaunal organisms included active oxic burrows (NF08) and water-filled oxic voids (NF21).

Free-burrowing infaunal worms occurred at 21 stations in 2004, with a grand average of 4.8 (SE = 0.90) worms per image per station, which was not significantly different from the 3.9 (SE = 0.40) worms per image average for the last three years of the baseline period (ANOVA, F = 1.04, p = 0.311). At Station NF07, the average number of worms was 13.7 per image, with a maximum of 19 worms at NF07-1.

All stations in 2004, except FF13, had high densities (>1 tube per cm^2) of small polychaete tubes; based on tubes that were within 1 cm of the 15-cm-wide prism faceplate, this density would scale to >10,000 tubes per m^2. The majority of the tubes were small, <1 mm in diameter, and straight, but at ten stations a medium size, 1–2-mm diameter tube occurred. Twisted tubes projecting 1–2 cm above the sediment surface, which first appeared in nearfield SPI images in 2000, did not occur in 2004. Other than this, tubes in 2004 were similar in appearance and density to those observed during the baseline period.

4.3.5 Successional Stage and Organism Sediment Index

The distribution of estimated successional stages of the infaunal communities in 2004 was bimodal, with a mode at pioneering/intermediate (Stage I-II) and another mode at intermediate/equilibrium (Stage II-III) (Figure 4-1). About half of the stations (11 of 23) appeared to be a mixture of successional stages (Table 4-2). Stage I appeared to dominate at three stations (NF04, NF19, and NF20) while Stage II and III communities dominated nine stations.

Over the 13-year period of sampling the nearfield, the largest shift in successional stage occurred during the baseline period between 1997 and 1998 (Figure 4-1). Compared with the first three baseline sampling periods (1992, 1995, and 1997), the 2004 SPI images had a higher proportion of intermediate and advanced successional stage stations (Fisher's Exact Test, p = <0.0001). For this period of the baseline, the odds, at 1.5 to 1, were slightly in favor of encountering a station with a Stage I designation. For the last three years of the baseline period the odds were 32.5 to 1 against encountering a station with a Stage I designation. In 2004, the odds were still 6.7 to 1 against encountering a station with a Stage I designation. The high degree of biogenic sediment reworking observed in many of the 2004 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 4-2).

In 2004, the mean Organism Sediment Index (OSI) was 6.6 (SE = 0.34), which was statistically the same as the baseline grand mean of 6.4 (SE = 0.15) (ANOVA, F = 0.45, p = 0.502). Rhoads and Germano (1986) developed the OSI for assessing benthic conditions of inshore estuarine and coastal embayments in the northeast and found that 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. Based on this interpretation of the OSI, on average the nearfield SPI stations would tend toward stressed conditions. However, caution must be applied when the OSI is used in a different environment as a means of assessing benthic conditions. Diaz *et al.* (2003) found that for Chesapeake Bay an OSI value of <3 was associated with stressed benthic communities. In 2004, five stations had OSI values <6. At these stations the stressor appeared to be physical processes with no sign of stress from organic loading. Two of these stations (FF12 and NF13) had RPD layer depths deeper than prism penetration, which leads to possible underestimation of the OSI. The other three stations had unqualified OSI values <6 (Table 4-2) with the lowest value of 4.0 at station NF19, which had coarse heterogeneous sediments with little evidence of biological activity. The highest OSI was 8.7 at station NF05, which had finer sediments and a well-developed infaunal community.

4.3.6 Summary of 2004 SPI Data

The mean apparent color RPD layer depth in 2004 of 2.4 cm (SE = 0.11) was statistically the same as the baseline period mean RPD of 2.3 cm (SE = 0.08). There did not appear to be any relationship between RPD layer depth and outfall operation, which started in September 2000. Even at NF24, the muddy station closest to the outfall where negative effects (a shallowing of the RPD layer depth) would likely first appear, there was no difference in RPD between baseline and 2004 data. Mean baseline RPD layer depth at NF24 was 1.9 cm (SE = 0.29) and in 2004 it was 2.6 cm (SE = 0.69) (ANOVA, F = 0.85, p = 0.409).

There was little change in the sedimentary environment in 2004 relative to baseline or other post-diversion years. Within a station, there did not appear to be any change in the sediment color or fabric, which would indicate there has not been an accumulation of organic matter in surface sediments of the nearfield stations.

The prominence of biogenic structures on the sediment surface and organism activity in 2004 appeared to be similar relative to 2003, but less than the last three years of the baseline period. In 2004, stations NF05, NF16, and NF22 appeared to have ampeliscid tubes. Station NF05 has had ampeliscid tubes every year since 1999, the first year tubes were observed in the nearfield SPI images. Overall, in 2004 it appeared that physical and biological processes were about equally responsible in structuring surface sediments.

Monitoring Question

- ♦ *Have the sediments become more or less anoxic; that is, has the thickness of the sediment oxic layer decreased or increased?*

There did not appear to be 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. The average apparent color RPD for 2004 of 2.4 cm was not significantly different from the baseline RPD of 2.3 cm. A 50% change in RPD layer depth would require the mean RPD for a year to be at least <1.2 or >3.4 cm. The average RPD for 2004 was well within the range of annual RPDs, with 1998 being the shallowest year at 1.6 cm and 1995 the deepest year at 3.0 cm.

Based on the color and texture of sediments in the 2004 SPI images, it did not appear that the amount of deposited organic matter had changed relative to the startup of the outfall in 2000. Baseline images for the nearfield SPI stations also appeared to have the same color and texture as the 2004 images.

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, *e.g.*, 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), bioturbation by infauna (Rhoads 1974) or major resuspension/deposition events (Dr. Don Rhoads, personal communication) are responsible for oxygenating the sediments. At all 15 fine-sediment stations, those with fine-sand-silt-clay and fine-sandy-silt, the RPD layer depth was >1.3 cm and SPI images confirmed the importance of bioturbation in deepening RPD layers at these stations.

4.4 Conclusions

The sediments at many stations in 2004 continued to be heterogeneous, with a mixture of grain sizes ranging from sandy-silts-clays to pebbles. This sediment heterogeneity was consistent from 1998 to the present (Table 4-3). Prior to 1998, sediments at the nearfield SPI stations appeared to be more homogeneous and finer. 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. Tubes were the most numerous surface biogenic structures and occurred at all stations in 2004.

While the general appearance of the sediments and benthic habitat conditions at the nearfield stations in 2004 was similar to that of the other post-diversion and baseline years, the overall dominance of surface sediments by biogenic structures and organism activity in 2004 appeared to be less relative to the last three years of the baseline period. For example, in 1999 nine stations and in 2001 four stations had dense tube mats (>50,000 tubes per m^2), but since 2002 tube mats were not observed. Also, the medium-size twisted tube that was widespread at nearfield stations in 2001 did not occur in 2004. The number of stations with ampeliscid tubes did increase from one to three stations between 2003 and 2004, but tube densities were low. Ampeliscid tubes were first observed in the nearfield SPI images in 1999 and have consistently been observed at only station NF05. While biogenic activity at the sediment surface appeared to be reduced in 2004 relative to the last portion of the baseline period, the level of subsurface biogenic activity appeared similar.

While not significantly different than the grand mean baseline OSI of 6.4, the average OSI of 6.6 for 2004 was at least heading up (Figure 4-3). 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. In 2004, it appeared that biological processes were still important in structuring surface sediments with signs that physical processes has slightly diminished. For example, bedforms, typically associated with higher energy bottoms, were observed at five stations in 2004 and eight in 2003. 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 during the baseline years of 1998 and 1999 when biogenic activity at the sediment surface increased and bedforms occurred at four and two stations, respectively. Overall, the benthic habitat conditions during the post-baseline years of 2001 to 2004 were similar to the baseline years of 1992 to 2000 (Table 4-4).

Table 4-4. Summary of sediment profile image data for baseline and post-baseline years.

	Baseline Years 1992-2000	**Post-Baseline Years 2001-2004**
Successional Stage	Advanced from I to II-III	Bimodal: I-II and II-III
OSI - Low	4.8 (1997)	5.8 (2003)
OSI - High	7.2 (2000)	6.6 (2001 and 2004)
OSI -Grand Mean	6.4 (1.68 SD)	6.3 (1.64 SD)
RPD - Low	1.8 cm (1997 and 1998)	2.1 cm (2003)
RPD -High	3.0 cm (1995)	2.5 cm (2002)
RPD - Grand Mean	2.3 (0.88 SD) cm	2.3 (0.67 SD)
Bioturbation	Increased in 1995, High since 1998	High at most stations

5. 2004 SOFT-BOTTOM BENTHIC INFAUNAL COMMUNITIES

by Nancy J. Maciolek

5.1 Status of the Bay

5.1.1 Monitoring Program

The MWRA has studied the soft-bottom benthos of Massachusetts Bay for several years as part of the program to locate an outfall system 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 (see 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 in a wide geographical area, 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.

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 designations 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). In 2003, the MWRA reviewed and revised the monitoring program, and with the concurrence of the EPA, has rescaled the sampling effort. In 2004, only half the stations were sampled for benthos and sediment parameters TOC and grain size, *i.e.*, four of the eight farfield and 13 of the 23 nearfield stations (See Chapter 1 Introduction and Chapter 2 Field, this report).

5.1.2 Benthic Communities

During the baseline period (1992–2000), multivariate analyses of the infauna data suggested 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 syllid 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 potentially 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) as well as being geographically widespread, and sediment types 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, although *P. steenstrupi* is common at some of the stations. A different species of polychaete, *Cossura longocirrata*, is dominant at station FF06 in Cape Cod Bay, along with *Euchone incolor*, which typically indicates the presence of the deep-burrowing holothurian *Molpadia oolitica* (Rhoads and Young, 1971).

Kropp *et al.* (2002) discussed the idea that a significant storm in 1992, which was followed by additional storms that disturbed the sea floor, 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 the diversity measure log-series *alpha*. Recently, Kropp (pers. comm.) suggested that if only those stations that had been sampled in both 1992 and 1993 were included in the calculation of the annual means, rather than including stations were either sampled in 1992 but not 1993 or were not added to the program until 1994, the decline between those two years would not appear as severe. Maciolek *et al.* (2004) presented an analysis of mean density of stations sampled both before and after 1992, and indeed those means do not appear to be significantly different before and after the storm.

Samples collected in August 2001, the first year of sampling after the outfall went online, did not indicate any discernable impact of the discharge on the infauna (Kropp *et al.* 2002). Samples collected in August 2002 and 2003, which represented data for two and three years of discharge into the bay, similarly did not indicate any changes related to operation of the outfall. The few statistical differences detected in the benthic community parameters, such as increased numbers of certain species and increased dominance by certain species at one or two of the nearfield stations were considered to be natural fluctuations in the populations and not related to the outfall discharge (Maciolek *et al.* 2003, 2004).

5.2 Methods

5.2.1 Laboratory Analyses

Samples were rinsed with filtered seawater 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. Organisms were then identified to the lowest practical taxonomic category, usually species. Voucher specimens of each species were kept as part of the MWRA reference collection.

5.2.2 Data Analyses

Preliminary Data Treatment—Appendix C1 contains detailed information on how various taxa were treated prior to statistical analysis. For example, some taxa were merged before the analyses were performed so that the data are consistent throughout the several years of the program. Another 173 taxa are juvenile or categories that represent more than one species, and are therefore not included in calculations of diversity. These modifications were generally similar to those performed in previous years.

Calculations of abundance included all infaunal taxa occurring in each sample, whether identified to species level or not, but did not include epifaunal or colonial organisms. Calculations based on species (number of species, dominance, diversity, evenness, similarity, 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 (1992–2004) is contained in Appendix C2.

Statistical Analysis—Initial inspection of the benthic data included production of summaries of species densities by sample, tables of species dominance, and tabulation 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. Any 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 similarity and clustering programs are included in COMPAH96, originally written by Dr. Donald Boesch and now available from Dr. Eugene Gallagher at the University of Massachusetts, Boston (http://www.es.umb.edu/edgwebp.htm). Patterns in benthic communities were analyzed by similarity analysis using CNESS (chord-normalized expected species shared), which was developed by Gallagher (Trueblood *et al.* 1994) and is related to Grassle and Smith's (1976) NESS (normalized expected species shared). CNESS and NESS can be made more or less sensitive to rare species in the community; these algorithms were developed primarily for use with deep-sea data, in which no single species usually accounts for more than 4–10% of the individuals. CNESS is 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 determined to be 15. For comparison, the Bray-Curtis similarity measure was also used, based on a fourth-root transformation of the data (performed in order to diminish the impact of numerically dominant species). Both similarity matrices were clustered using group average sorting and dendrograms were plotted. Results of these analyses were inspected for patterns among and between the different seasons. In evaluating long-term trends, because of the limitations of COMPAH in handling more than 400 samples, the data set was sometimes reduced in size by excluding data from 1992 and 1993.

PRIMER v.5 (Clarke and Gorley 2001) was used to calculate several diversity indices, including Shannon's H′ (base 2), Pielou's evenness value J′, Sanders-Hurlbert rarefaction, and Fisher's log-series *alpha*. Magurran (1988) classifies diversity indices into three categories: (1) species richness indices (*e.g.*, rarefaction); (2) species abundance indices (*e*.g., log-series *alpha*), and (3) indices based on the proportional abundances of species (*e*.g., Shannon index). The Shannon index, which is based on information theory, has been popular with marine ecologists for many years, but this index assumes that individuals are randomly sampled from an infinitely large population and that all species are present in the sample (Pielou 1975, Magurran 1988): neither assumption correctly describes the environmental samples collected in most marine benthic programs. Fisher's log-series model of species abundance (Fisher *et al.* 1943) has been widely used, particularly by entomologists and botanists (Magurran 1988). Taylor's (1978) studies of the properties of this index found that it was the best index for discriminating among subtly different sites, and 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 and promoted the use of this index for studies of diversity in all environments.

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, whereas species that have discordant distributions plot with angles approaching 180°. PCA-H was performed using MATLAB as an operating platform and additional programs written by Dr. E.D. Gallagher.

5.3 Results and Discussion

5.3.1 Species Composition of 2004 Samples

Species Composition—A list of all species collected as part of the Outfall Monitoring Program is included in Appendix C2. Two taxa were newly reported from the 2004 samples, which comprised 265 valid species. The newly added taxa were polychaetes, *Nothria* sp. A and *Streblosoma spiralis* Verrill, 1874. The number of valid taxa in the Massachusetts Bay database, which includes both nearfield and farfield samples, and also includes all of the stations sampled in the program, now stands at 465 species.

5.3.2 Benthic Community Analysis for 2004: Nearfield

Several benthic community parameters have been tracked since the inception of the monitoring program in 1992, including the number of organisms and species in each sample, and the calculated measures of diversity (Shannon H′) and evenness (Pielou's J′). Fisher's log-series *alpha*, another measure of diversity, was added in 1998 (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. Baseline values and the mean value for each parameter for each year from 1992–2003 are plotted below, with the means for 2004 indicated with a different symbol since these represent a reduced number of stations. Results by sample are given in Appendix C3, Table C3-1, and community parameters for individual stations are plotted in the figures in Appendix C3.

***Density*—**The highest mean infaunal density per sample was recorded in 2002 (3475 organisms per sample), and was only slightly lower in 2003 (3138 organisms per sample). In 2004, the mean density for the reduced station set was 2062 ± 641 SD organisms per sample (Figure 5-1A). This value is lower than the baseline mean for the nearfield stations, but within the range of values recorded during the pre-operational years. Maciolek *et al.* (2003) considered the high variability at some stations, which contrasted with the stability of other stations over time, and suggested that several processes, biological as well as physical, were operating in this system: annual fluctuations in the population densities of several species as well as occasional scouring of the bottom by strong storms both contribute to the overall invertebrate densities recorded in the benthic grab samples.

Inspection of the abundance data for individual nearfield stations (Figure 5-1B; Appendix C3, Table C3-2, Figure C3-1) indicated that, in 2004, the total densities declined at 11 of the 13 nearfield stations. At NF05, NF07, NF09, NF12, and FF10, densities declined from 21.1 to 30.3 % between 2003 and 2004, whereas the remaining six stations had larger decreases ranging from 39.9 to 59.5 %. The greatest decline in abundance was at NF18, where the 2004 total abundance of 4,272 organisms per sample dropped to 1,729 organisms and at NF22, where the 2004 total abundance of 4,073 organisms per sample dropped to 1,530 organisms The lower densities at these stations can be attributed primarily to the collapse of the *Prionospio steenstrupi* population, which in the preceding two years had reached extremely high levels (Maciolek *et al.* 2004). The two exceptions were NF17 and FF13, where densities were essentially the same in 2004 as in 2003. *Prionospio steenstrupi* has not been one of the dominant species at NF17; and although it was an important species at FF13 in previous years, the decrease in 2004 was offset by an increase in the population levels of other species such as *Aricidea catherinae*.

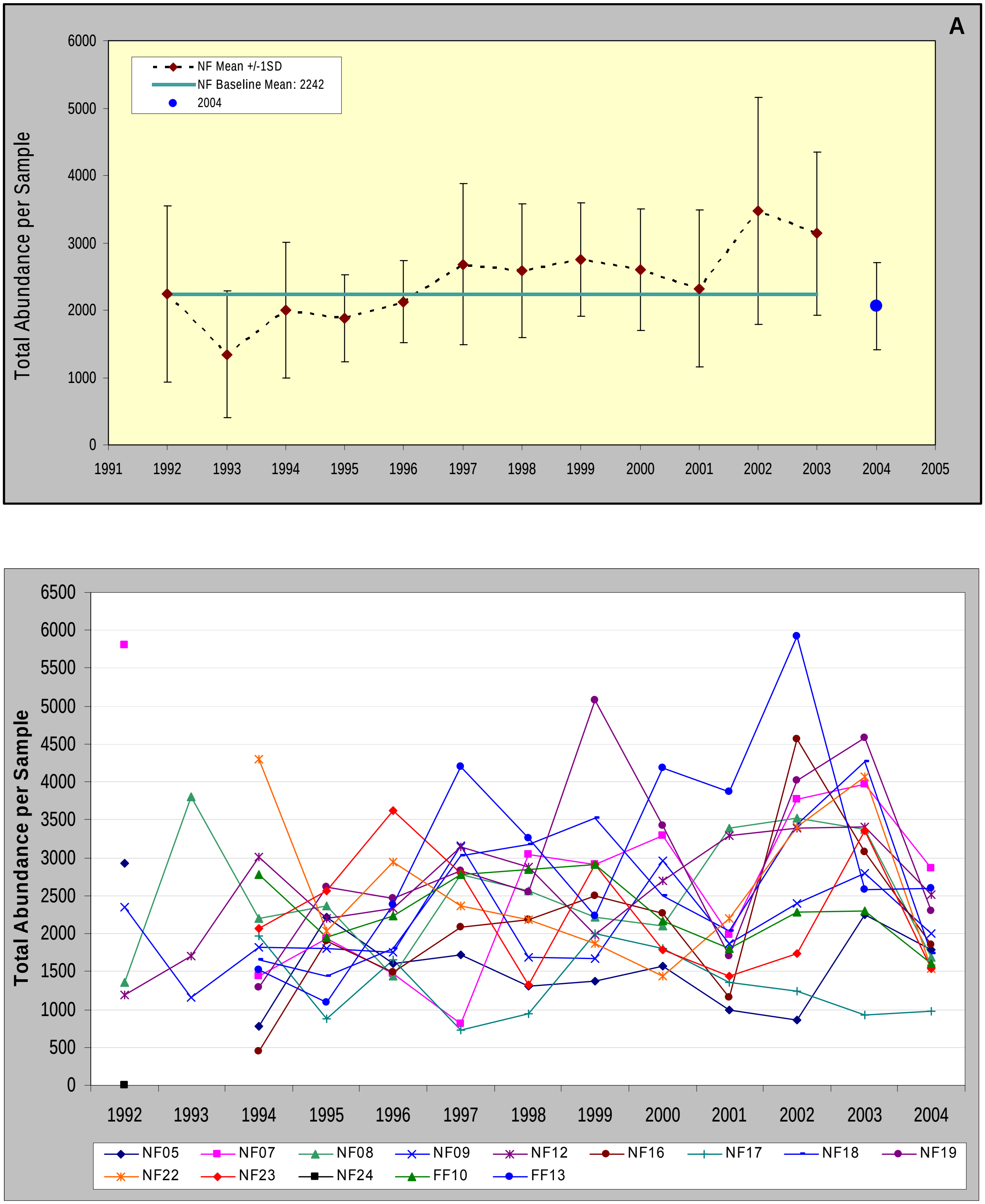


Figure 5-1. (A). Mean abundance per sample for nearfield stations. The value for 2004 represents fewer stations than sampled in previous years. (B). Abundance each year for individual nearfield stations. Only station NF 17 and FF13 had similar values in 2003 and 2004.

***Species Richness*—**In 2004, 219 species occurred in the 21 nearfield samples. The average number of species per nearfield sample increased to 76 species in 2003 (Maciolek *et al*. 2004), which was only slightly higher than the 2002 mean of 74 species. In 2004, the average number of species per sample was 77.2 (Figure 5-2A), well above the baseline average of 65 species per sample. The apparent increase in species richness in 2004 might be an artifact of the reduced number of stations sampled in 2004 compared with 2003.

In 2004, the number of species per sample increased at only two of the 13 nearfield stations: FF10 (a 4.9% increase from 74.7 to 78.3 species) and NF07 (an 11.7% increase from 94 to 105 species). At the remaining stations, the species richness values were 73 to 99 % of the 2003 values. The largest decreases were at NF05 (a 19.3% decrease from 114 to 92 species), NF 17 (a 15.3% decrease from 61 to 51.7 species), and NF22 (a 27.4% decrease from 84 to 61 species per sample) (Appendix C3, Figure C3-2). The number of species at NF05 was particularly high in 2003, and the richness exhibited in 2004 was still higher than recorded at that station for most years of the monitoring program. At NF17 and NF22, the species richness values were similar to those recorded in 2000. Species richness at NF17 (51.7 species/sample) was similar to the station average of 51.8 (baseline years) and 53.9 (1994–2003), but at NF22 the 61 species/sample was below the average for that station (67.2 for baseline years and 67.7 for 1994–2003).

***Diversity and Evenness*—**In 2004, all three measures indicated an increase in diversity over previous years. Both Shannon diversity (H′) and Pielou's evenness (J′) were much higher in 2004 than in previous years, and well above the baseline means of 3.68 (H′) and 0.62 (J′) (Figure 5-2B,C; Appendix C3, Figures C3-3 and C3-4). Mean Shannon diversity for nearfield stations sampled in 2004 was 4.2, and was the same or slightly higher at 10 of the 13 stations, declining only at NF05, NF12, and NF17. Similarly, mean evenness in 2004 was 0.67, and declined only at NF12 and NF17 and was similar or somewhat higher at the remaining stations. The changes in these two indices most likely reflect the decrease in abundance of a single species, *Prionospio steenstrupi,* while numbers of species in the samples remained fairly constant.

The diversity measure log-series *alpha* continued the trend of a higher mean value compared with the two years immediately previous (Figure 5-2B, Appendix C3, Figure C3-5). *Alpha* declined at stations NF05, NF09, NF12, and NF22, but increased at the remaining stations; the average value of 16.2 was well above the baseline mean of 13.06. Compared with the Shannon index, which is based on information theory and makes assumptions that are not met by the present samples (see Methods section 5.2.2 above), log-series *alpha*, which is based on species abundances, appears to provide a better discrimination among subtly different sites and thus is more reliable in reflecting the actual environmental trend.

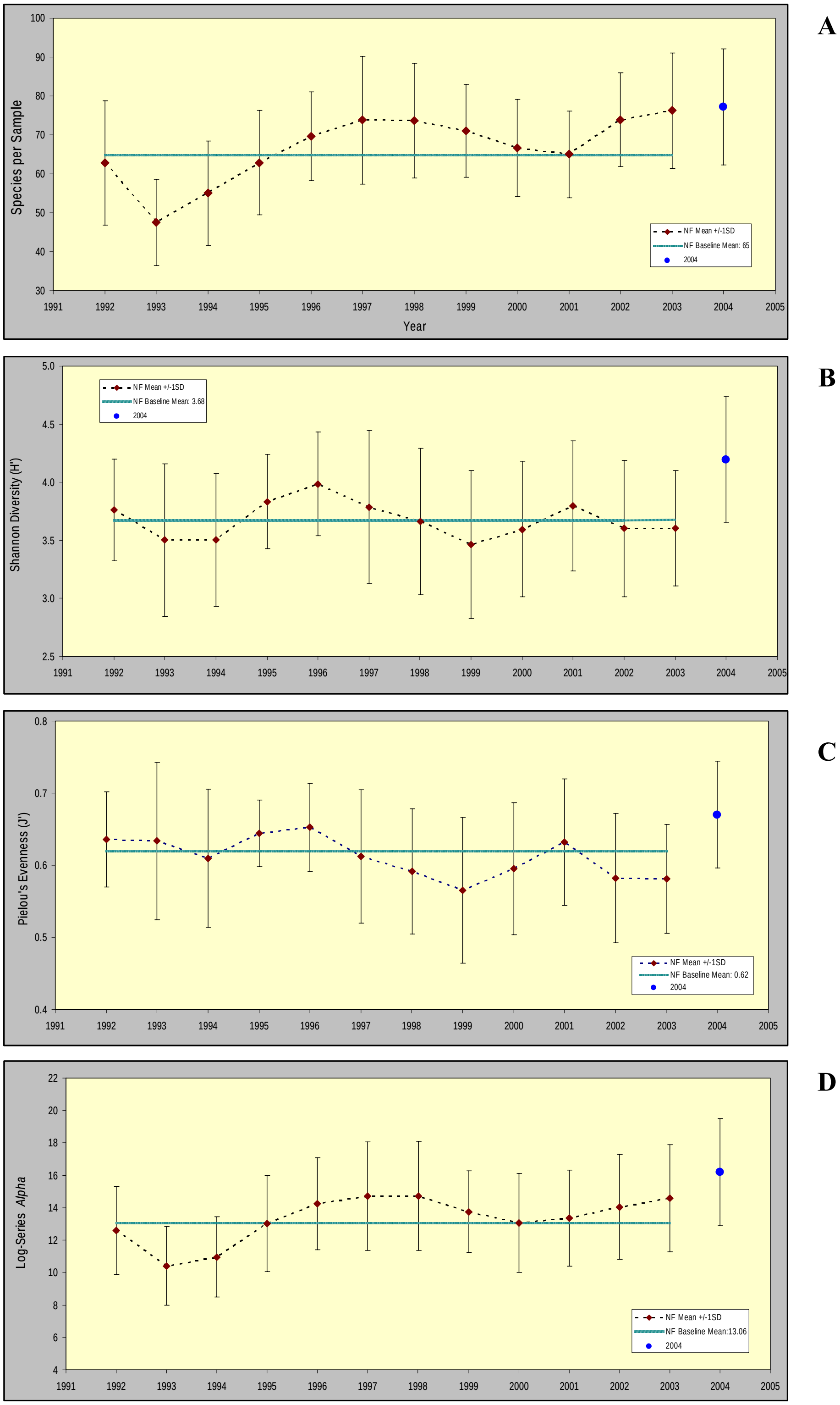


Figure 5-2. (A) Mean number of species per sample, (B) Mean Shannon diversity, (C) Mean evenness, and (D) Mean log-series *alpha* at nearfield stations from 1992–2004. The mean for the reduced number of stations sampled in 2004 is indicated as a separate point.

***Dominant Species*—**Dominant species at each nearfield station are listed in Appendix C4, along with the percent contribution of each to the total community, based on total individuals in the sample and those that were identified to species. In the latter case, the percentage is usually just a few tenths of a point less than when calculated for total individuals. A detailed analysis and discussion of the species dominant at each nearfield station is presented in Appendix C5 and summarized here.

Between 1992 and 2004, 38 species have been among the three most abundant taxa at least once at one or more of the 13 nearfield stations sampled in 2004 (Table 5-1). Some species were found to be abundant at a given station only once or twice, with the result that their overall rank at that station was as low as twelfth. For example, the oligochaete Enchytraeidae sp.1 was the numerical dominant at NF23 in 1995, but was only the seventh most abundant species at that station over all 13 years of the monitoring program.

To explore how those species that ranked first, second, or third at least once during the program compared to all nearfield species, station mean totals for each species were ordered by decreasing abundance and ranked as given in Table 5-2 (table was truncated after all top 38 species were included). The resultant overall nearfield ranks show that the 14 most abundant species found in the nearfield were among the 38 top dominant species. Conversely, the isopod *Chiridotea tuftsi*, which was the second most abundant animal found at Station NF17 in 1993 and which ranked twelfth in numbers at Station NF17, only ranked seventy-fourth among all nearfield species combined. As another example, the polychaete *Spio limicola*, the third most abundant species when numbers from all 13 stations were totaled, ranked from second to seventh at ten stations but was not among the 12 most abundant species at three stations. These differences can be most likely be attributed to differences in community composition at stations with coarse sediments (*e.g.*, NF17 and NF23) compared with those with fine sediments (*e.g.*, NF05).

The spionid polychaete *Prionospio steenstrupi* has been the numerical dominant in Massachusetts Bay for the past several years; in 2003 it was the most numerous species recorded and was the numerical dominant at 18 of the 23 nearfield stations, while ranking second at another two stations. However, in 2004, the population level of this species had crashed at all except one of the stations that were sampled, with the result that total abundances were much lower at many stations (Figure 5-3). In spite of the reduced densities, *P. steenstrupi* remained the numerical dominant at six of the 13 nearfield stations, including NF07, NF09, NF12, NF18, NF19, and FF10. At those stations where it was the numerical dominant, it accounted for about 18% of the sample (NF09 and FF10) to as much about 43% (NF12). NF12 was the only nearfield station where the density of this species was equal to or slightly higher in 2004 compared with 2003 (Figure 5-3).

At NF23, where *Exogone hebes* had been the numerical dominant in 2002, a large population of *Phoronis architecta* accounted for nearly 30% of the infaunal abundance in 2003 (see Appendix C5). In 2004, the phoronids were reduced in number to about 2.6% of the community abundance and were the tenth most numerous species. *Exogone hebes*, whose population levels had remained fairly constant, was again the numerical dominant, with about 12% of the community abundance, followed by *Polygordius* sp. A, with 10.8% of the abundance.

Table 5-1. Species that occurred as one of the three most abundant taxa at one or more stations from the 2004 nearfield station set. At these stations, 38 taxa ranked first, second, or third at least once between 1992 and 2004.

Numerically Dominant Taxa (NF stations, 1992–2004)	Stations where species ranked 1, 2, or 3													Total Number Stations
	FF10	FF13	NF05	NF07	NF08	NF09	NF12	NF16	NF17	NF18	NF19	NF22	NF23	
Prionospio steenstrupi	●	●	●	●	●	●	●	●		●	●	●	●	12
Mediomastus californiensis	●	●	●	●	●	●	●	●		●	●	●		11
Spio limicola	●		●	●	●	●	●	●		●	●	●		10
Dipolydora socialis	●		●	●		●	●		●		●	●	●	9
Tharyx acutus		●	●		●		●	●			●	●		7
Aricidea catherinae	●	●			●	●	●	●		●				7
Ninoe nigripes					●	●		●		●		●		5
Aphelochaeta marioni			●	●	●		●				●			5
Exogone hebes				●					●	●	●		●	5
Euchone incolor					●		●	●				●		4
Exogone verugera			●	●						●			●	4
Phoronis architecta		●			●	●							●	4
Levinsenia gracilis					●			●				●		3
Nucula delphinodonta	●		●								●			3
Monticellina baptisteae						●		●						2
Crassicorophium crassicorne									●				●	2
Molgula manhattensis									●				●	2
Unciola inermis									●				●	2
Spiophanes bombyx									●				●	2
Polygordius sp. A									●				●	2
Hiatella arctica										●			●	2
Photis pollex		●												1
Protomedeia fasciata										●				1
Enchytraeidae sp. 1													●	1
Pseudunciola obliquua									●					1
Dipolydora quadrilobata			●											1
Nephtys cornuta		●												1
Polydora sp. 1											●			1
Asabellides oculata										●				1
Nephtys incisa								●						1
Ampharete acutifrons						●								1
Pholoe minuta				●										1
Haploops fundiensis			●											1
Crenella decussata			●											1
Tubificidae sp. 2								●						1
Cerastoderma pinnulatum									●					1
Echinarachnius parma									●					1
Chiridotea tuftsi									●					1

Table 5-2. Nearfield species ranked by station mean total to include all 38 species (in bold font below) ranking first, second, or third during at least one of the 13 sampling years at nearfield stations sampled in 2004.

Taxon	Number of Individuals	Overall	Taxon	Number of Individuals	Overall
	Station Mean Totals[a]	NF Rank		Station Mean Totals	NF Rank
Prionospio steenstrupi	6773	1	*Micrura* spp.	122	38
Mediomastus californiensis	2735	2	*Astarte undata*	122	39
Spio limicola	2211	3	*Scoletoma hebes*	122	40
Tharyx acutus	1711	4	**Enchytraeidae sp. 1**	114	41
Aricidea catherinae	1567	5	*Capitella capitata* complex	103	42
Dipolydora socialis	1091	6	Nemertea sp. 12	98	43
Ninoe nigripes	757	7	*Edotia montosa*	89	44
Aphelochaeta marioni	680	8	*Arctica islandica*	87	45
Exogone hebes	657	9	***Nephtys cornuta***	86	46
Levinsenia gracilis	558	10	*Owenia fusiformis*	85	47
Nucula delphinodonta	540	11	*Maldane sarsi*	84	48
Euchone incolor	535	12	***Pseudunciola obliquua***	83	49
Exogone verugera	521	13	*Metopella angusta*	77	50
Monticellina baptisteae	468	14	***Polydora* sp. 1**	71	51
Leitoscoloplos acutus	413	15	*Tubificoides apectinatus*	69	52
Phoronis architecta	406	16	*Ericthonius fasciatus*	69	53
Crassicorophium crassicorne	378	17	*Thyasira gouldi*	68	54
Phyllodoce mucosa	260	18	*Crenella glandula*	66	55
Spiophanes bombyx	240	19	*Amphiporus caecus*	56	56
Molgula manhattensis	237	20	*Aglaophamus circinata*	55	57
Parougia caeca	229	21	*Aricidea quadrilobata*	54	58
***Polygordius* sp. A**	212	22	***Haploops fundiensis***	51	59
Hiatella arctica	212	23	*Dyopedos monacanthus*	51	60
Unciola inermis	201	24	*Nereis grayi*	49	61
Photis pollex	194	25	*Harpinia propinqua*	48	62
Crenella decussata	179	26	*Chaetozone setosa mb*	48	63
Protomedeia fasciata	173	27	*Euclymene collaris*	47	64
Ampharete acutifrons	168	28	***Echinarachnius parma***	46	65
Pholoe minuta	164	29	*Anobothrus gracilis*	46	66
Cerastoderma pinnulatum	160	30	*Pleurogonium rubicundum*	44	67
Nephtys incisa	155	31	*Stenopleustes inermis*	42	68
Asabellides oculata	146	32	*Trochochaeta multisetosa*	40	69
Eteone longa	146	33	*Ceriantheopsis americanus*	37	70
Monticellina dorsobranchialis	132	34	*Argissa hamatipes*	35	71
Tubificidae sp. 2	130	35	*Ampelisca abdita*	31	72
Dipolydora quadrilobata	126	36	*Clymenella torquata*	24	73
Ampharete baltica	123	37	***Chiridotea tuftsi***	19	74

[a] For each species, the station mean is the total number of animals collected at each station over all years of sampling divided by the total number of samples collected at that station, and the station mean total is the sum of this number for all NF stations sampled in 2004.

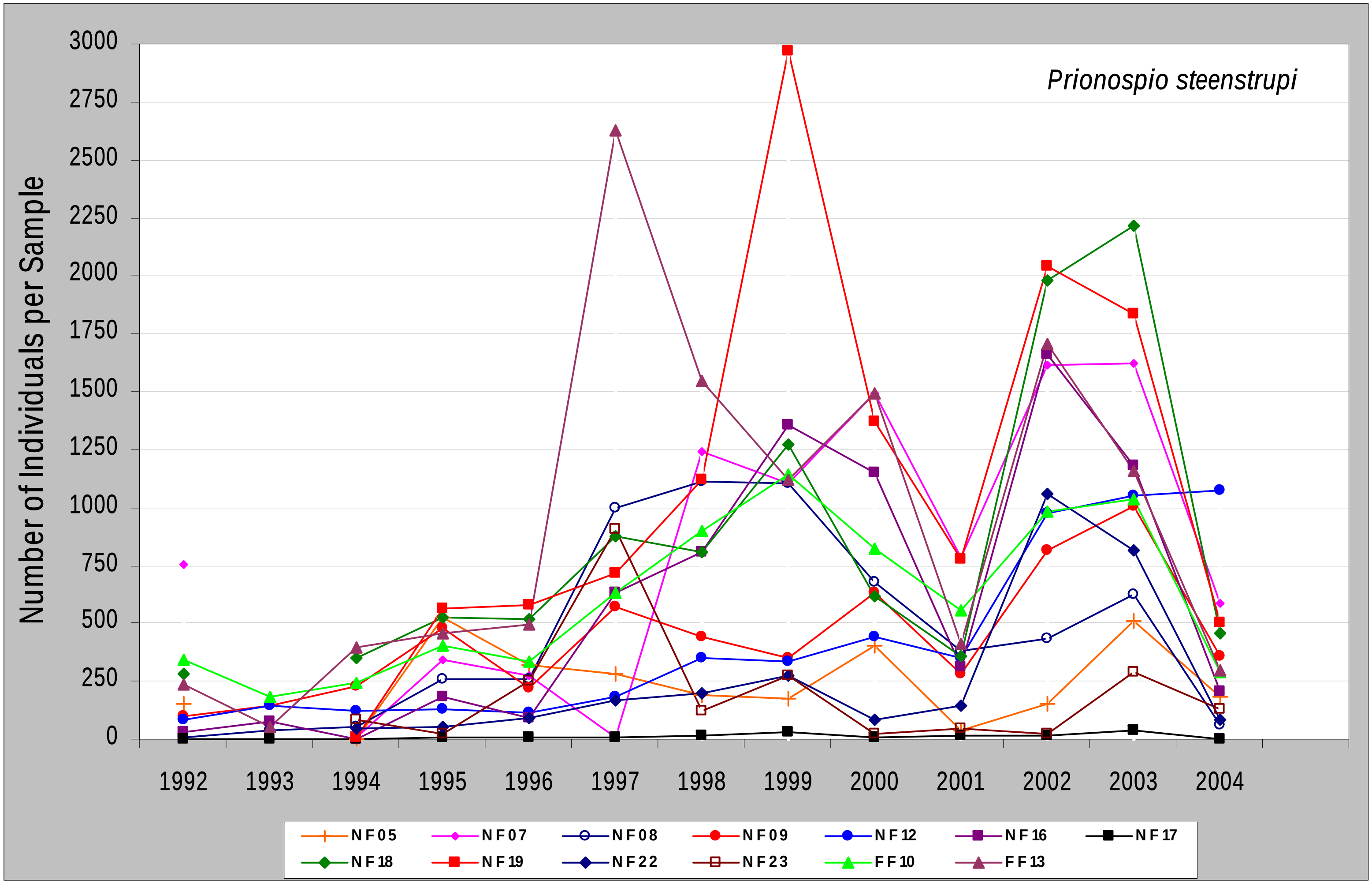


Figure 5-3. Abundance (or mean abundance) of *Prionospio steenstrupi* at nearfield stations sampled in 2004.

5.3.3 Benthic Community Analysis for 2004: Farfield

Several benthic community parameters have been tracked since the inception of the monitoring program in 1992, including the number of organisms and species in each sample, and the calculated measures of diversity (Shannon H′) and evenness (Pielou's J′). Fisher's log-series *alpha*, another measure of diversity, was added in 1998 (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. Baseline values and the mean value for each parameter for each year from 1992–2004 are plotted below, with the means for 2004 indicated with a different symbol since these represent a reduced number of stations (only half of the farfield stations were sampled in 2004: FF04, FF05 , FF07, and FF09).

Results by sample are given in Appendix C3, Table C3-1, and community parameters for individual stations are plotted in the figures in Appendix C3.

Density— In 2003, the mean density of infaunal organisms in the farfield increased to 3249 organisms per sample, nearly twice that of the mean densities recorded in 2002 and more than twice the baseline average of 1615 organisms per sample (Figure 5-4A). In 2004, mean densities had declined at each of the four farfield stations sampled (Figure 5-4B, Appendix C3, Figure C3-1), thus contributing to a lower mean density in the farfield overall. However, the mean density at farfield stations was well above the baseline mean of 1615 organisms per sample; albeit with a large standard deviation around the mean (Figure 5-4A).

The farfield stations are located within a large geographic area, and consequently occupy a variety of habitats. FF04 and FF05 are in relatively deep water (90 and 65 m, respectively, in the Stellwagen Basin National Marine Sanctuary, while FF09 is in about 50 m of water, intermediate between the nearfield stations and the Stellwagen Basin stations. FF07 is in Cape Cod Bay in about 39 m (see Table 2-1).

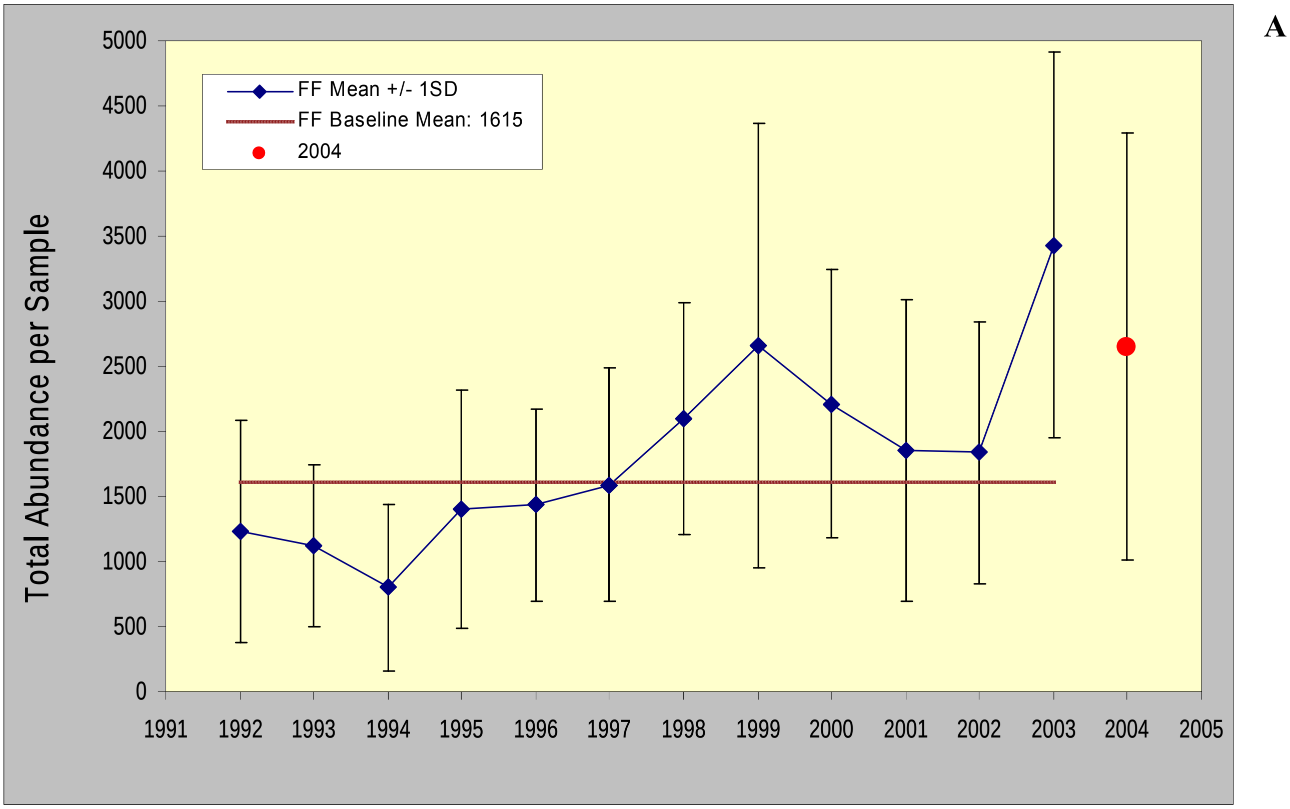
The change in abundance at each farfield station was due to different species at each location

- At FF04, *Spio limicola* increased in density and other species (e.g., *Cossura longocirrata, Chaetozone setosa* mb, *Euchone incolor,* and *Aricidea quadrilobata*) declined, resulting in a mean density only slightly lower in 2004 (1281.3 organisms per sample) than in 2003 (1413.3 organisms per sample).

- At FF05, mean density declined from 2610.3 organisms per sample in 2003 to 2437.0 organisms per sample in 2004. Increases in abundance of *Spio limicola* and *Anobothrus gracilis* were offset by decreases in *Prionospio steenstrupi* and *Aricidea quadrilobata.*

- At FF07, the Cape Cod Bay station, the increased infaunal abundances in 2003 were due primarily to both *Euchone incolor,* a surface feeder associated with the fecal mounds produced by the deep-dwelling holothurian *Molpadia oolitica* (Rhoads and Young, 1971), and *Cossura longocirrata,* a subsurface deposit feeder. In 2004, the numbers of both declined, *C. longocirrata* more so than *E. incolor.*

- At FF09, mean density declined from 2281.7 organisms per sample in 2003 to 1875.3 organisms per sample in 2004, primarily because of the decline in abundance of *Prionospio steenstrupi*.



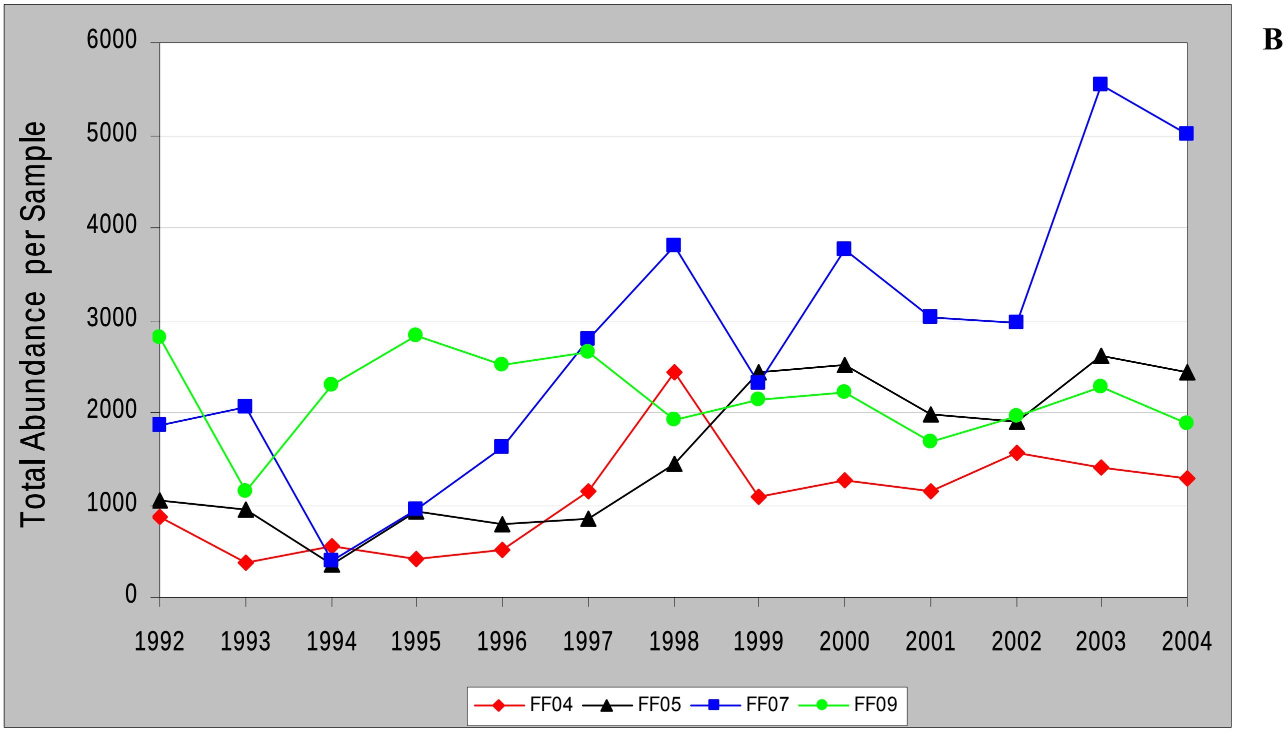


Figure 5-4. (A) Mean abundance per sample for farfield stations. The value for 2004 represents fewer stations than sampled in previous years. (B) Mean abundance by year for farfield stations sampled in 2004.

Species Richness—In 2004, 192 species were identified from the 12 farfield samples taken at four locations. In 2003, the average number of species per farfield sample was 87.5 species (Maciolek *et al.* 2004). In 2004, the average for four stations was 79.8 species per sample (Figure 5-5A), with a range from 57.7 at FF07 to 104.3 at FF09. Although the mean number of species per sample declined at each of the four farfield stations (Figure 5-6A, Appendix C3, Figure C3-2), the mean value was still above the baseline value of 61 species.

***Diversity and Evenness*—**In 2004, mean Shannon diversity (H′) at the farfield stations was 4.03, higher than the baseline value of 3.74, and the highest mean value recorded to date during the monitoring program (Figure 5-5B). The mean value for 2004 appears to be higher than that recorded in 2003; however, if only the four stations sampled in 2004 had been used to calculated the mean for 2003, this value would have declined from 4.18 (2003) to 4.03 (2004). Each station had a different pattern of change compared with H′ values recorded in 2003 (Figure 5-6B): FF04 declined from 4.6 to 4.5; FF05 declined from 4.7 to 3.9; FF07 remained the same at 2.9; and FF09 increased from 4.5 to 4.8. The overall change was therefore a decline in H′, influenced most by the change at FF05.

Mean Pielou's evenness (J′) (0.64) was also higher in 2004 compared with the 2003 mean value of 0.58, and was the same as the baseline value of 0.64 (Figure 5-5C). As demonstrated for the Shannon values, if only these four stations were used to calculate the mean value for 2003, there would have been no change at all in 2004: the mean value for these stations in both years was 0.64. Each farfield station exhibited a slightly different pattern of change (Figure 5-6C), with FF05 declining in evenness from 0.71 in 2003 to 0.59 in 2004 and the other three stations either increasing slightly (FF07, from 0.45 in 2003 to 0.50 in 2004; FF09, from 0.66 in 2003 to 0.71 in 2004) or remaining essentially the same (FF04, 0.75 in 2003 and 0.76 in 2004).

Although mean log-series *alpha* declined slightly at each station in 2004 compared with 2003 (Figure 5-6D), the overall mean value in 2004 (16.75) was still well above the baseline mean of 13.40 (Figure 5-5D). The four stations sampled in 2004 had a mean *alpha* value of 17.63 in 2003, therefore there was a real decline in this measure. *Alpha* tracks the decline in species richness at each of the farfield stations in 2004, whereas Shannon diversity and evenness show the opposite trend.

***Dominant Species*—**Dominant species at each farfield station are listed in Appendix C4, along with the percent contribution of each to the total community based on both total individuals in the sample and those that were identified to species. In the latter case, the percentage is usually just a few tenths of a point less than when calculated for total individuals. A detailed analysis and discussion of the species dominant at each farfield station over the duration of the monitoring program is presented in Appendix C5. The population fluctuations of five of the dominant species are shown in Figure 5-7.

- At FF04, *Spio limicola* was the numerical dominant for the first time since 1994, *Cossura longocirrata* was second most numerous, and *Chaetozone setosa* mb, which had been one of the two most numerous species in 2003, placed third. *Aricidea quadrilobata*, which was the other most numerous species at FF04 in 2003, was not among the top three in 2004.

- The numerically dominant species at FF05 in 2004 were similar to those reported in 2003, with S. *limicola*, *Prionospio steenstrupi*, and *A. quadrilobata* as the most numerous species.

- Dominants at FF07 and FF09 in 2004 were also the same as those recorded in 2003: *C. longocirrata*, *Euchone incolor*, and *Aricidea catherinae* at FF07; and *P. steenstrupi*, *Anobothrus gracilis*, and *Levinsenia gracilis* at FF09.

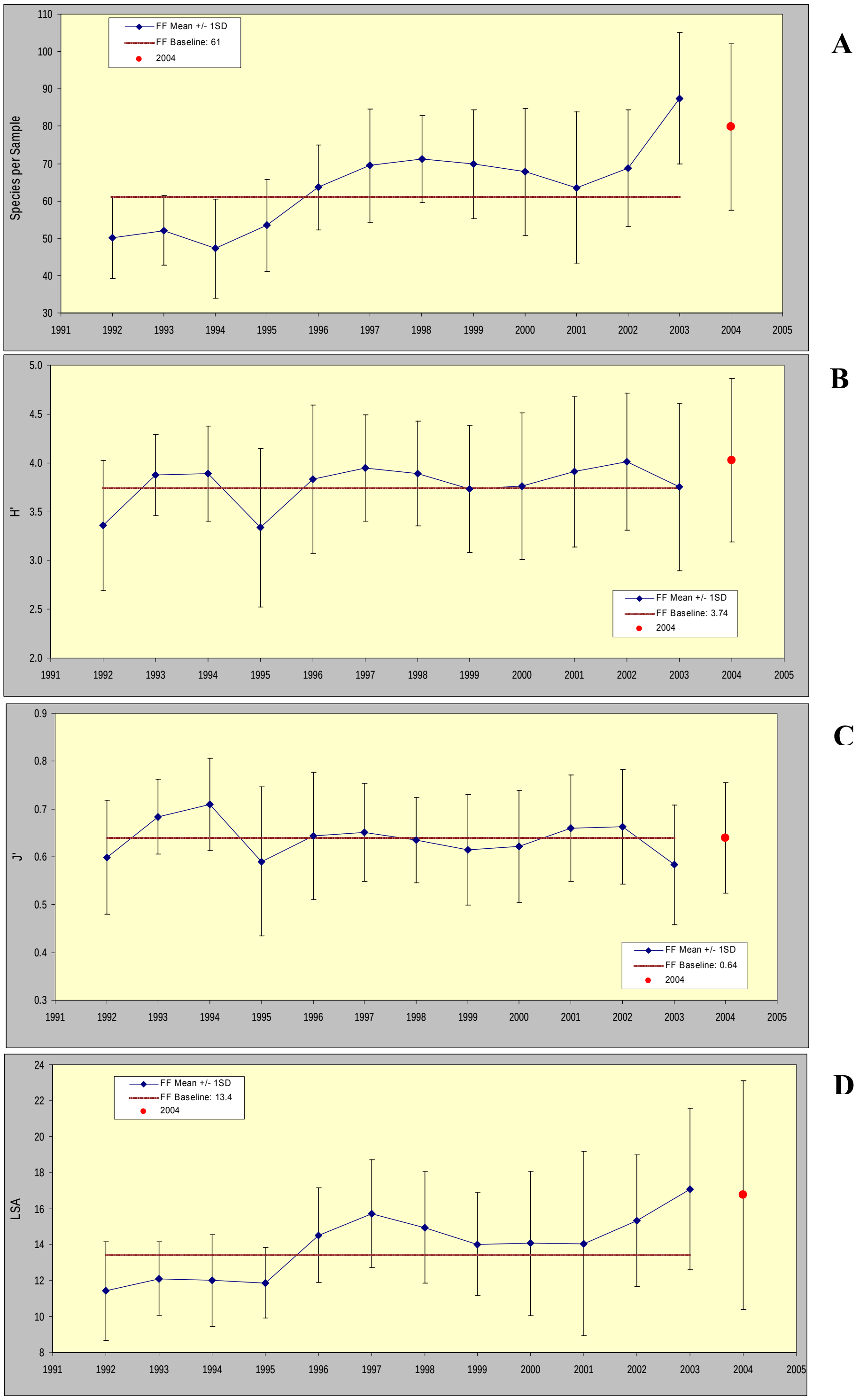


Figure 5-5. Annual mean parameters for farfield benthic infaunal stations. (A) Mean number of species per sample, (B) Mean Shannon diversity, (C) Mean evenness, and (D) Mean log-series *alpha* at farfield stations from 1992–2004. The mean for the reduced number of stations sampled in 2004 is indicated as a separate point.

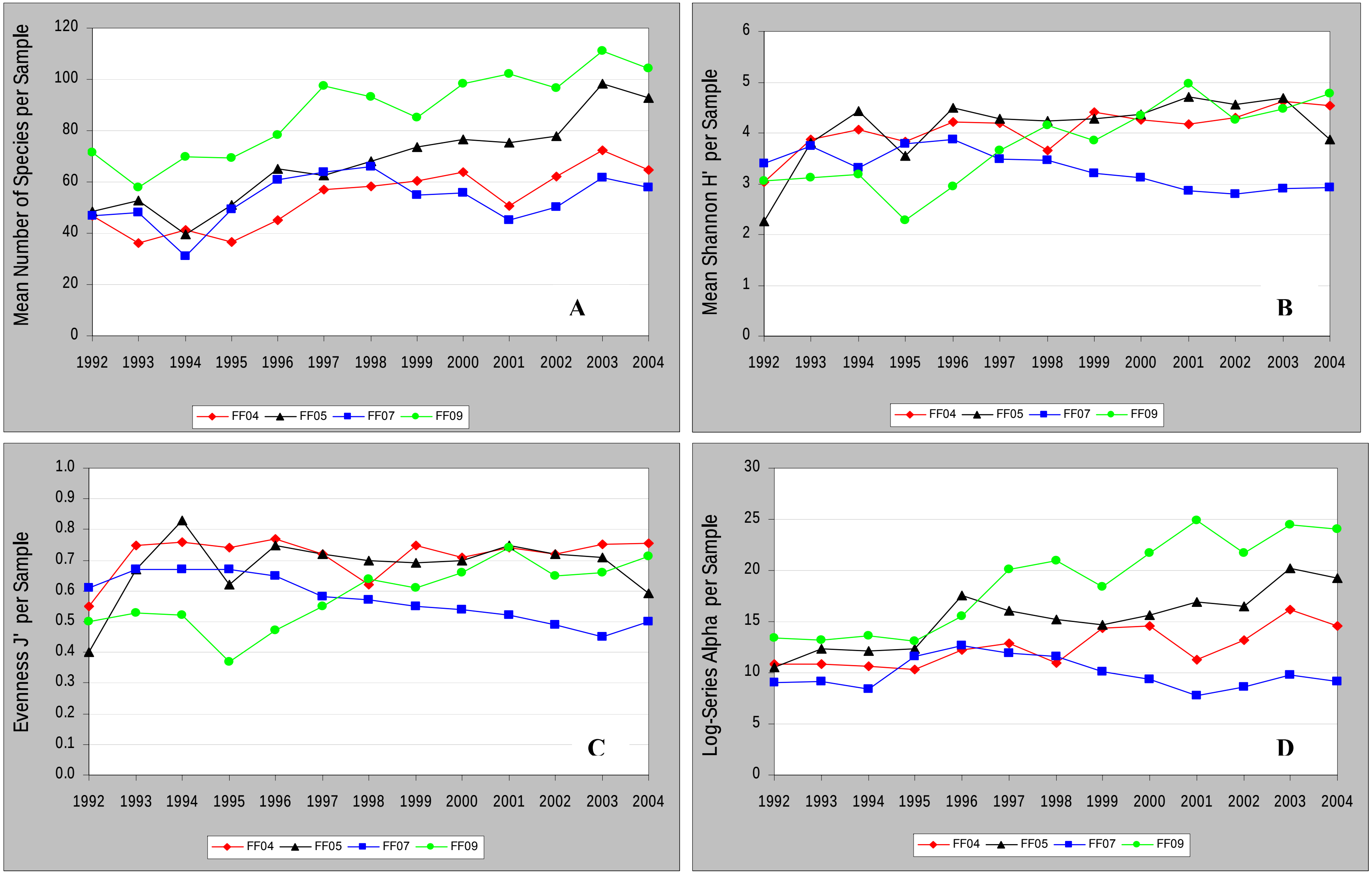


Figure 5-6. Annual parameters for individual farfield benthic infaunal stations sampled in 2004. (A) Mean number of species per sample, (B) Mean Shannon diversity, (C) Mean evenness, and (D) Mean log-series *alpha*.

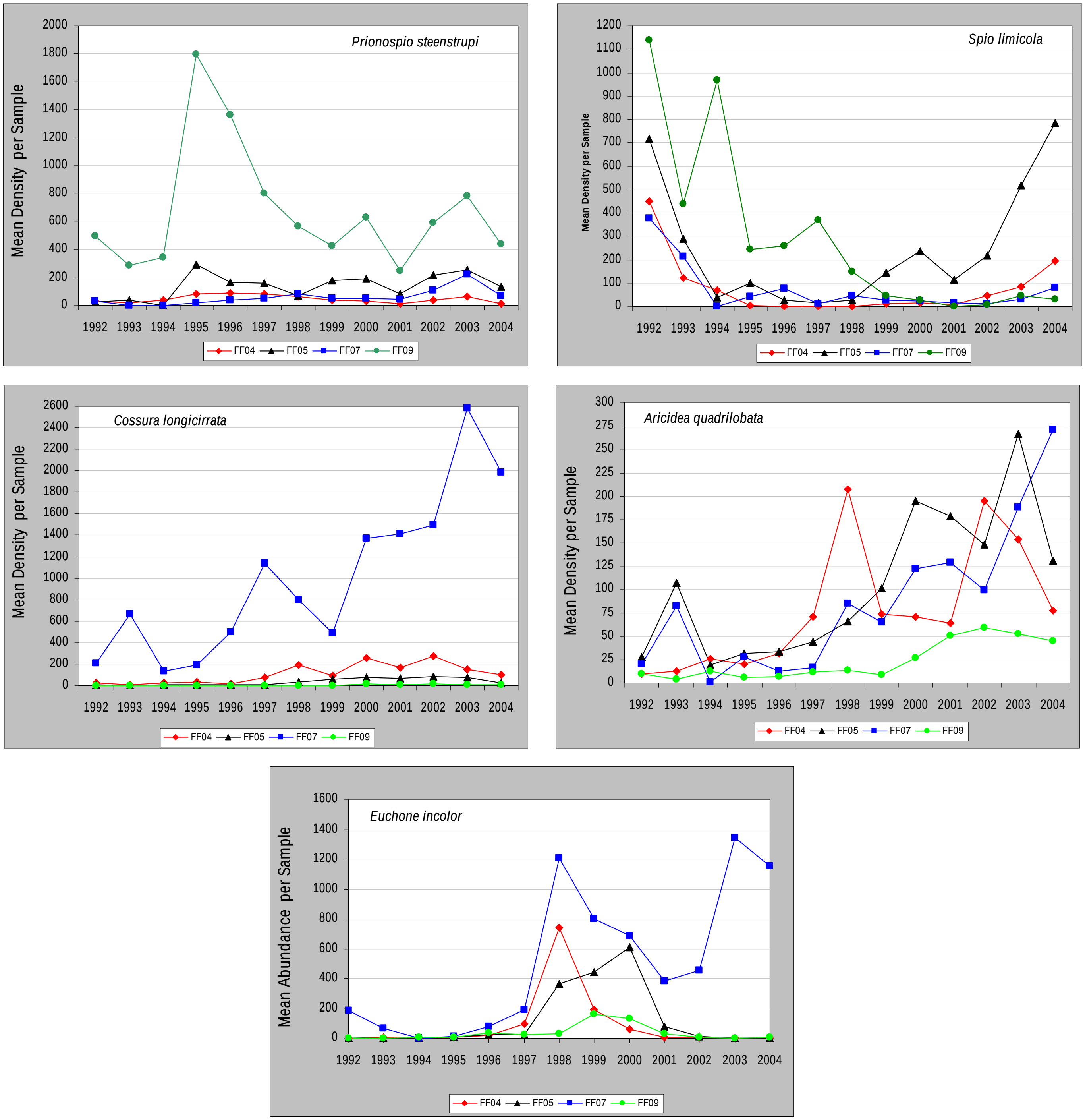


Figure 5-7. Mean density per 0.04-m^2 samples of five species common at farfield stations.

5.3.4 Multivariate Analysis of 2004 Samples

***Similarity Analysis*—**The CNESS (*m* =15) similarities of the 33 samples taken in 2004 were clustered using group average sorting (Figure 5-8). The samples form four major groups or clusters, essentially identical to those obtained in previous years (Maciolek *et al*. 2003, 2004), although now with fewer stations. The four groups comprise (1) sandy stations near the outfall, (2) finer-grained nearfield stations, (3) farfield stations FF04, FF05, and FF09, and (4) Cape Cod Bay station FF07. Where replicates were taken at a station, those replicates are always more similar to samples from within the station than to samples from another station. Cluster 1, consisting of NF17 and NF23, is highly dissimilar to the other groups, at a CNESS level of 1.32 (highest dissimilarity with CNESS is 1.41).

The Bray-Curtis analysis of these data (after a fourth-root transformation to decrease the influence of species with high abundances) resulted in a similar overall pattern, with the sandy nearfield station NF17 again forming the most dissimilar group and the Cape Cod Bay station forming a distinct unit within a large cluster (Figure 5-9). Specific similarities among the nearfield stations differ to a small degree between the two analyses, but replicates from single stations always cluster together, as in previous years (Maciolek *et al.* 2004). With Bray-Curtis, NF23 groups with the finer-grained nearfield samples (group 2), whereas with CNESS it was more similar to NF17 (group 1), the other sandy nearfield station. NF 17 and NF23 share many species that are not found at the other nearfield stations, e.g., *Spiophanes bombyx*, *Echinarachnius parma*, *Polygordius* sp. A. However, some species that are common a the finer-grained stations, e.g., *Prionospio steenstrupi* and *Eteone longa*, are also found at NF 23, but not NF17. The amphipod *Crassicorophium crassicorne*, which is not present at NF23, is common at NF17.

With CNESS, the Cape Cod Bay station FF07 was essentially an outlier to the majority of nearfield and farfield stations; it clustered with them only at a CNESS level of 1.15. With Bray-Curtis, FF07 clusters with the large group of finer-grained nearfield stations before that groups joins the other three farfield stations. The species composition of FF07, with its large numbers of *Cossura longicirrata*, *Euchone incolor*, and Tubificidae sp. 2 appears on an intuitive level to differ more from the other stations than the Bray-Curtis result would indicate; it is possible that the square-root transformation of the data prior to analysis resulted in a greater smoothing of the data than might be warranted.

The way in which the two algorithms handle the species abundance and composition determines the placement of the samples within the cluster dendrogram. CNESS appears to emphasize the differences among samples, whereas Bray-Curtis emphasizes the similarities.

***PCA-H analysis*—**The PCA-H analysis based on the CNESS similarities separated the cluster groups discussed above along several multidimensional axes, with axis 1 and axis 2 together accounting for 49% of the total variation (Figure 5-10A). These two axes are most likely represent a combined sediment grain size vs. depth (or region) gradient; however, these factors are not clearly assignable to either axis. Cluster 1 (NF17 and NF23) again appear most separated from the other samples in this two-dimensional presentation, and the farfield stations also clearly separate from the nearfield samples.

The species accounting for more than 2% of the CNESS variation, and therefore the ones responsible for the separation of the samples, are indicated for Axes 1 and 2 in the Gabriel Euclidean distance biplot (Figure 5-10B) and detailed for Axes 1–3 in Table 5-3. The majority of nearfield stations are structured by the surface-deposit- (and sometimes filter-) feeder *Prionospio steenstrupi*, and the subsurface deposit feeders *Aricidea catherinae*, *Mediomastus californiensis*, and *Tharyx acutus*. The sandy nearfield stations (NF17 and NF23) are characterized by the syllid polychaete *Exogone hebes* (an omnivore), the filter-feeding polychaete *Spiophanes bombyx,* the ascidian *Molgula manhattensis*, and two bivalves, *Ensis directus and Hiatella arctica.* As seen in previous years, the Cape Cod Bay station FF07 is structured by the filter-feeding sabellid polychaete *Euchone incolor* and the thin-bodied burrowing polychaete *Cossura longocirrata*. At the remaining farfield stations, the important species comprise a suite of polychaetes in the essentially the same families (and sometimes genera) as those seen at the nearfield stations. *Anobothrus gracilis* has increased in importance in recent years, although its numbers are not large in comparison with some of the other species.

With CNESS (*m*=15), 42 of the 265 species recorded in 2004 accounted for 92% of the variation in the community structure, and contributed at least 1% to the PCA-H axes (Table 5-4). The covariance analysis from the PCA-H analysis indicates the relationships among the 265 species that comprise the 2004 samples, *i.e.,* whether they co-occur or are found in different samples. The axes loadings for each species are included in Appendix C6, and selected species are indicated in Figure 5-11.

Three major groupings of species can be discerned, corresponding roughly to sediment types:

- Negative loadings on axis 1and axis 2 appear to be characteristic for species found in coarser-grained sediments, such as *Echinarachnius parma*, *Spiophanes bombyx*, *Exogone hebes, and Polygordius* sp. A.

- Species that prefer finer-grained sandy sediments, such as *Exogone verugera*, *Nuculoma tenuis*, and *Dentalium entale* have positive loadings on axis 1 and negative loadings on axis 2.

- The third group, which includes *Aricidea catherinae*, *Mediomastus californiensis*, and *Prionospio steenstrupi*, has mixed loadings on axis 1 and positive loadings on axis 2. These species are common in a range of fine-sand or muddy sediments at the nearfield stations.

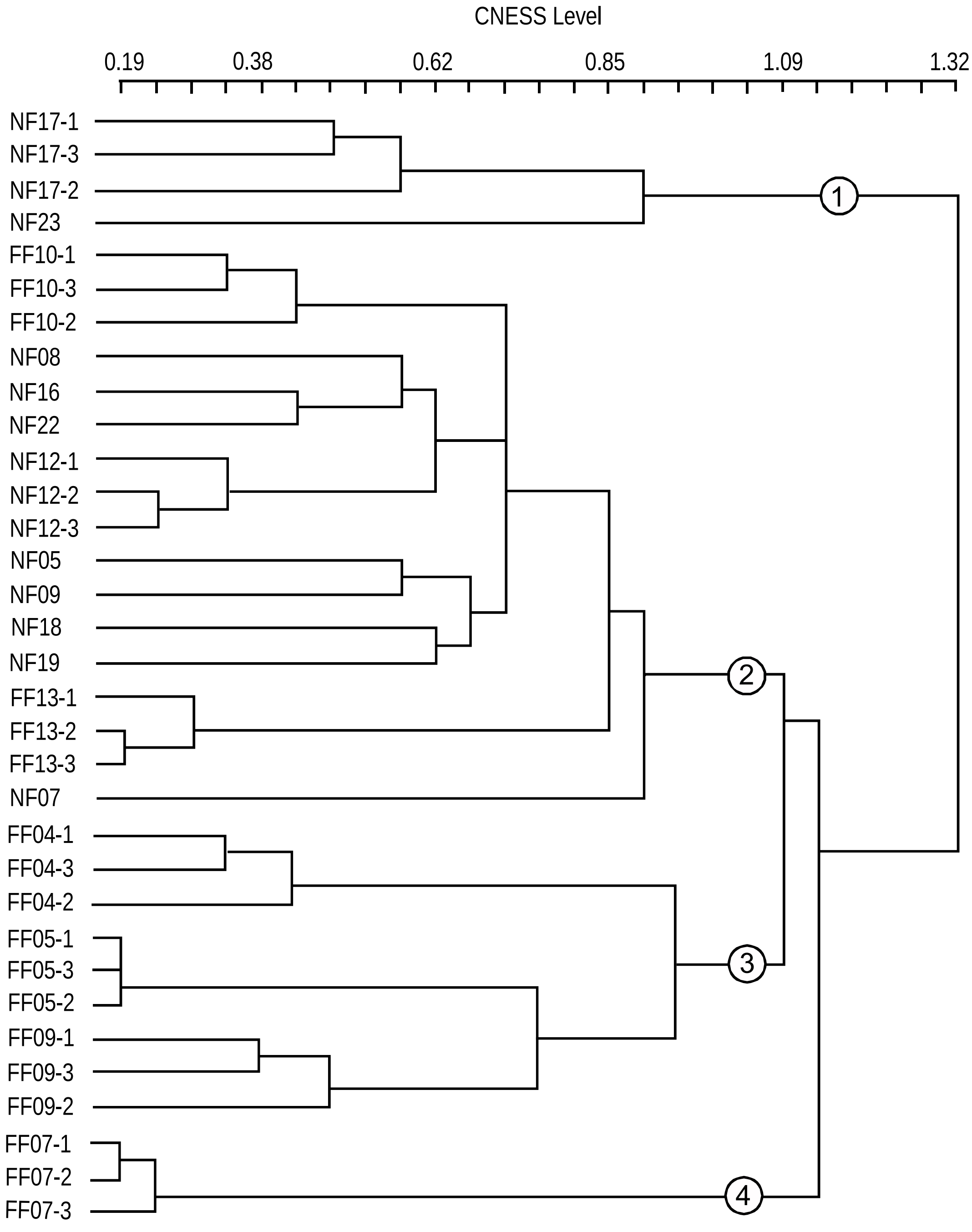


Figure 5-8. Relationship of 2004 samples based on CNESS similarity (*m*=15) and group average clustering.

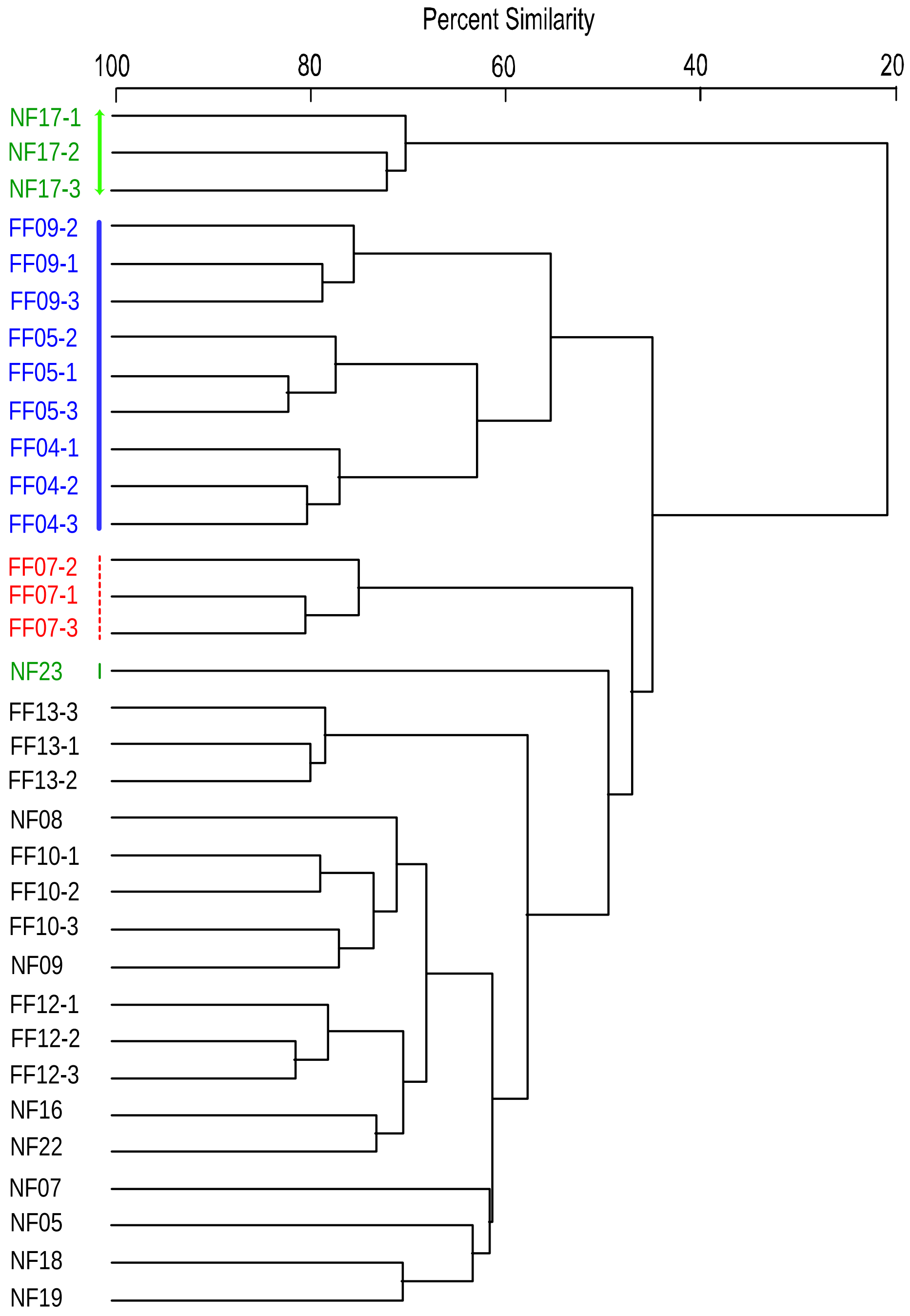


Figure 5-9. Relationship of 2004 samples based on Bray-Curtis similarity after fourth-root transformation of the data and group average clustering. Samples corresponding to CNESS groups are identified by green arrows (group 1), no line (group 2), solid blue line (group 3), and dashed red line (group 4).

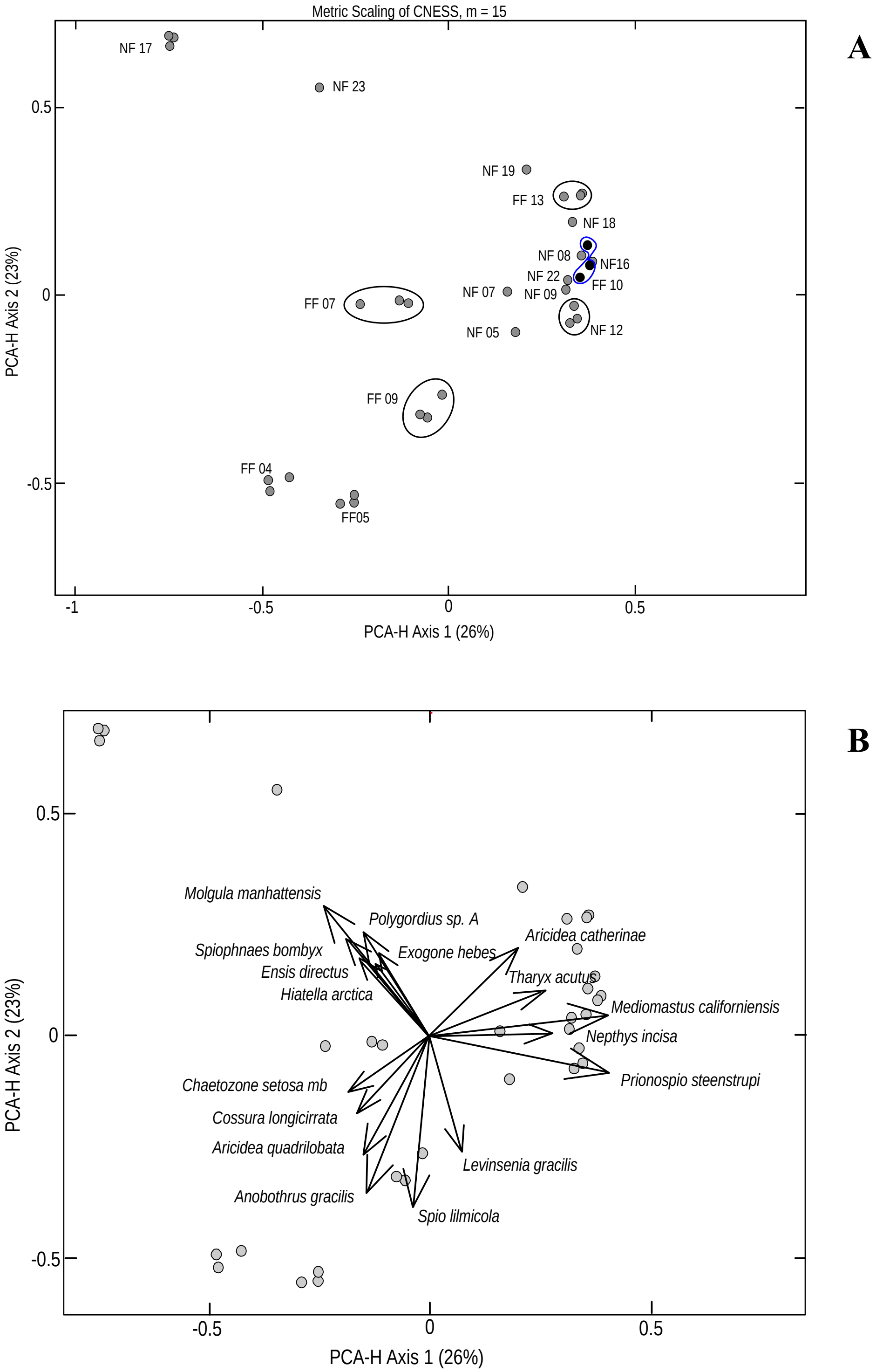


Figure 5-10. Metric scaling on PCA-H axes 1 and 2 of the 2004 benthic infaunal samples (A) and the Euclidean distance biplot showing the species responsible for >2% of the variation (B).

Table 5-3. Contributions to PCA-H axes by species accounting for >2% of the CNESS variation among the infaunal samples collected in 2004 (see Figure 5-9B).

Important species: Axis 1 vs. 2

PCA-H Rank	Species	Contr.	Total Contr.	Axis1	Axis2
1	*Prionospio steenstrupi*	8	8	15	1
2	*Mediomastus californiensis*	8	16	15	0
3	*Spio limicola*	7	24	0	15
4	*Anobothrus gracilis*	7	31	2	12
5	*Molgula manhattensis*	7	37	6	8
6	*Aricidea quadrilobata*	5	42	2	7
7	*Spiophanes bombyx*	4	46	3	5
8	*Aricidea catherinae*	4	50	4	4
9	*Nephtys incisa*	4	54	7	0
10	*Tharyx acutus*	4	57	6	1
11	*Polygordius* sp. A	4	61	2	5
12	*Levinsenia gracilis*	3	64	0	7
13	*Cossura longocirrata*	3	67	3	3
14	*Ensis directus*	3	70	2	3
15	*Chaetozone setosa mb*	2	72	3	2
16	*Exogone hebes*	2	74	1	3
17	*Hiatella arctica*	2	76	2	3

Important species: Axis 1 vs. 3

PCA-H Rank	Species	Contr.	Total Contr.	Axis 1	Axis 3
1	*Prionospio steenstrupi*	12	12	15	7
2	*Cossura longocirrata*	10	22	3	23
3	*Mediomastus californiensis*	10	32	15	0
4	*Aricidea catherinae*	8	40	4	15
5	*Euchone incolor*	6	47	0	17
6	*Nephtys incisa*	5	51	7	0
7	*Tharyx acutus*	4	55	6	1
8	*Molgula manhattensis*	4	60	6	2
9	*Anobothrus gracilis*	3	63	2	4
10	*Ninoe nigripes*	3	65	4	1
11	*Aricidea quadrilobata*	2	68	2	3
12	*Spiophanes bombyx*	2	70	3	1
13	*Nucula delphinodonta*	2	72	1	3
14	*Chaetozone setosa mb*	2	74	3	0
15	*Scoletoma hebes*	2	76	3	0

Important species: Axis 2 vs. 3

PCA-H Rank	Species	Contr.	Total Contr.	Axis 2	Axis 3
1	*Cossura longocirrata*	11	11	3	23
2	*Anobothrus gracilis*	9	20	12	4
3	*Spio limicola*	9	29	15	1
4	*Aricidea catherinae*	9	38	4	15
5	*Euchone incolor*	7	45	0	17
6	*Molgula manhattensis*	6	50	8	2
7	*Aricidea quadrilobata*	5	56	7	3
8	*Levinsenia gracilis*	5	61	7	3
9	*Polygordius sp. A*	3	64	5	1
10	*Spiophanes bombyx*	3	67	5	1
11	*Prionospio steenstrupi*	3	70	1	7
12	*Exogone hebes*	3	73	3	2
13	*Thyasira gouldi*	2	75	3	1

Table 5-4. Contribution of the 42 species in the 2004 Massachusetts and Cape Cod Bay samples identified by PCA-H analysis as important in structuring the infaunal communities, and their loadings on each of the seven PCA-H axes.

PCA-H Rank	Species	Contr.	Total Contr.	Ax.1	Ax.2	Ax.3	Ax.4	Ax.5	Ax.6	Ax.7
1	*Prionospio steenstrupi*	6	6	15	1	7	7	0	3	3
2	*Spio limicola*	6	12	0	15	1	8	5	5	1
3	*Anobothrus gracilis*	6	17	2	12	4	10	1	0	4
4	*Aricidea catherinae*	5	23	4	4	15	2	4	13	0
5	*Cossura longocirrata*	5	28	3	3	23	0	2	0	2
6	*Mediomastus californiensis*	5	33	15	0	0	1	0	0	8
7	*Tharyx acutus*	4	37	6	1	1	9	15	2	1
8	*Molgula manhattensis*	4	40	6	8	2	0	0	0	0
9	*Nephtys incisa*	4	44	7	0	0	1	0	30	2
10	*Euchone incolor*	4	48	0	0	17	5	11	1	0
11	*Aricidea quadrilobata*	3	51	2	7	3	1	0	0	0
12	*Scoletoma hebes*	3	53	3	1	0	0	25	0	0
13	*Nucula delphinodonta*	3	56	1	0	3	9	0	0	29
14	*Levinsenia gracilis*	3	59	0	7	3	0	0	4	1
15	*Polygordius* sp. A	2	61	2	5	1	0	1	1	0
16	*Spiophanes bombyx*	2	63	3	5	1	0	0	0	0
17	*Ampharete baltica*	2	65	1	0	0	1	3	6	15
18	*Tubificoides apectinatus*	2	67	0	1	1	6	12	2	0
19	*Ensis directus*	2	69	2	3	0	0	0	2	1
20	*Hiatella arctica*	2	71	2	3	1	0	0	1	0
21	*Exogone hebes*	2	72	1	3	2	0	1	1	1
22	*Chaetozone setosa mb*	2	74	3	2	0	4	2	0	0
23	Tubificidae sp. 2	1	76	1	0	4	1	0	3	2
24	*Crassicorophium crassicorne*	1	77	2	2	0	0	0	2	0
25	*Ninoe nigripes*	1	78	4	0	1	0	0	1	0
26	*Thyasira gouldi*	1	79	0	3	1	1	1	0	2
27	*Cerastoderma pinnulatum*	1	81	1	2	1	0	0	1	0
28	*Monticellina baptisteae*	1	82	2	0	0	2	0	1	1
29	*Syllides longocirrata*	1	83	1	1	0	4	1	0	1
30	*Dentalium entale*	1	84	0	1	0	3	1	0	2
31	*Paramphinome jeffreysii*	1	85	0	1	0	3	1	0	1
32	*Exogone verugera*	1	86	0	0	0	0	1	1	1
33	*Pholoe minuta/tecta/spp.*	1	86	0	0	0	0	1	0	3
34	*Aphelochaeta marioni*	1	87	0	1	0	2	0	0	1
35	*Arctica islandica*	1	88	0	0	0	0	0	0	3
36	*Parougia caeca*	1	89	1	0	0	0	3	3	2
37	*Leitoscoloplos acutus*	1	89	1	0	0	2	0	0	1
38	*Crenella decussata*	1	90	0	0	1	3	0	0	1
39	*Phyllodoce mucosa*	1	91	0	2	0	0	1	1	0
40	*Eteone longa*	1	91	1	0	0	0	0	2	1
41	Nemertea sp. 12	1	92	0	1	0	0	2	0	0
42	*Phoronis architecta*	1	92	0	0	1	2	0	1	1

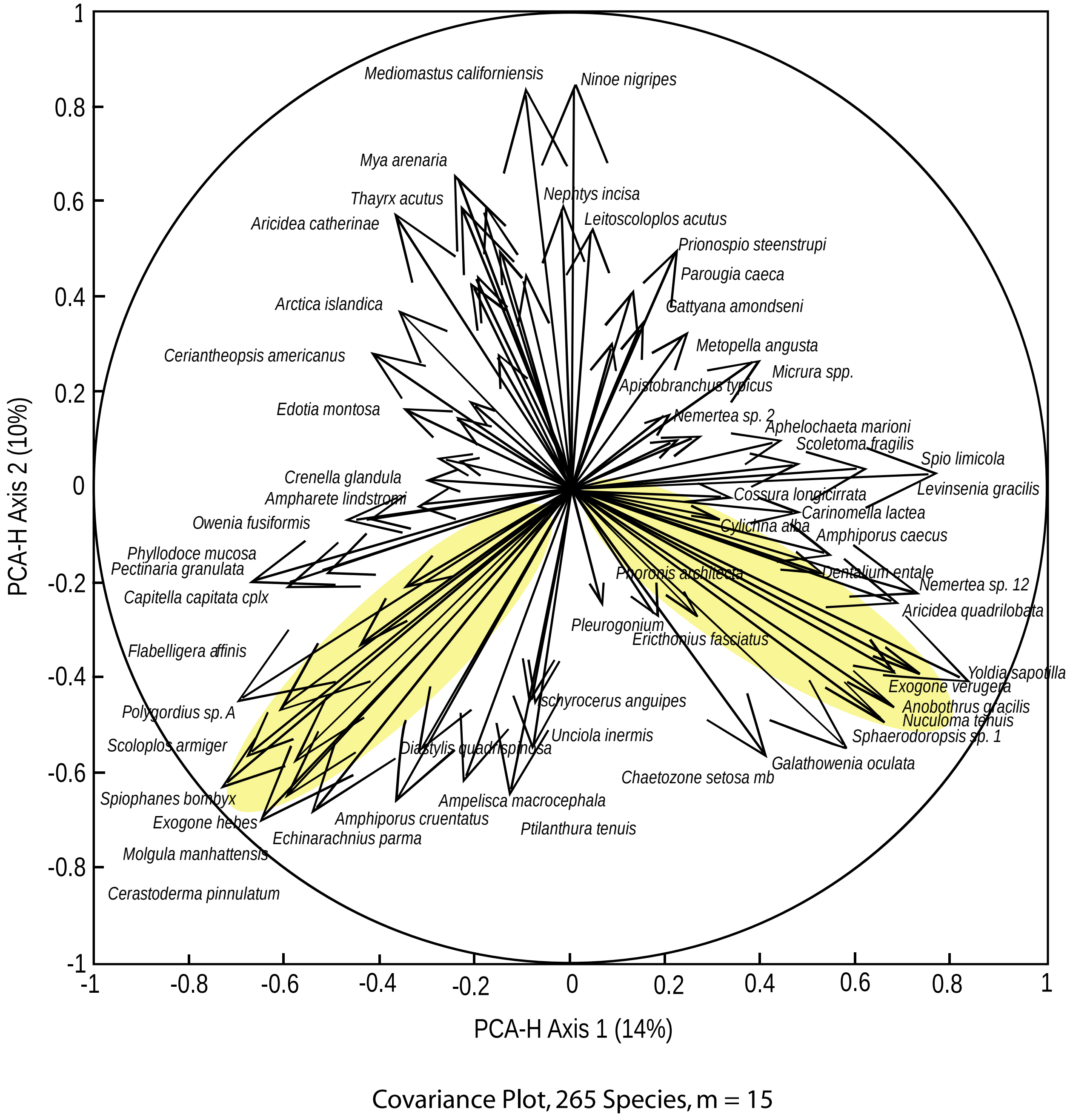


Figure 5-11. Covariance plot of 265 species found in the samples collected in 2004. Selected species are shown on axes 1 and 2. Shaded areas indicate numerous species with similar axis loadings.

5.3.5 Multivariate Analysis of 1994–2004 Nearfield Samples

As in previous years (Maciolek *et al*. 2004), the farfield stations continued to have low similarity to the nearfield stations; therefore, only the nearfield samples were examined in greater detail for any evidence of an impact from the outfall.

CNESS Analysis— A multivariate analysis of stations sampled 1994–2004 (CNESS, *m* =15) indicated two major groups of samples, with one group comprising primarily NF17 and the second group comprising the majority of the remaining samples. The size of the dendrogram allows only a summary, rather than detailed, diagram to be presented here (Figure 5-12).

The major division into two groups separates the sandy stations from the finer-grained ones. The large cluster containing the 33 NF17 samples, plus seven NF23 and one NF07 sample, was similar to the remaining stations/samples only at a level of 1.29 (with 1.41 being the lowest similarity by the CNESS measure). At NF17, five replicates from 1995, 1996, 2001, and 2002 had lower within-group similarity than did the other 28 replicates, but there was no there was no clear separation of earlier monitoring years from later ones: although the three replicates from a particular year often were most similar to other replicates from that years, groupings of years such as 1994 and 1996 with 2003 were also seen.

Also within this major group of sandy station samples, NF23 from 1995, 2000–2002, and 2003 formed a subgroup within the large cluster of NF17 samples, being most similar to NF17 samples from the years 2001, 2002, and 2004. NF23 1998 and 2003 had a lower similarity to the large cluster of NF17 samples. The remaining NF23 samples (1994, 1996, 1997, and 1999) were in the second major cluster, and these two groups were similar only at CNESS level 1.29. The separation of NF23 samples into the two major clusters possibly reflects a difference in sediment composition and the resulting differences in species present n the samples. Sediment composition at NF 17 has been >95% sand each year (see Chapter 3, this report) whereas at NF23, &sand has ranged from 71% in 1994 (and 2003) to 98% in 1995, with years 1996, 19997, 1998, and 2002 also having >90% sand (Chapter 3, this report). The single sample from NF07 in this major cluster is from 1997, when abundances at that station were roughly half of that found in other years, and several species usually found at NF07 were absent or scarce, e.g., *P. steenstrupi, M. californiensis, Pholoe minuta, and Phyllodoce mucosa*.

In the second major cluster (Figure 5-12), there was high within-station similarity, with all samples from a station clustering together before joining samples from other stations. Stations at which replicate samples were taken include FF10, FF13, NF12. The 33 samples from NF12 grouped into four clusters, with 1994/1995, 1999/2000, and 1996–1998 similar to each other at 0.61, and to samples from years 2001–2004 at 0.78.

Samples from FF10 were split into two large clusters plus two outliers: the first cluster contained samples from 1994–1997 and grouped at 0.60; the second contained all but two samples from 1998–2004, and grouped internally at 0.81 and with the earlier years at 0.84; the most dissimilar two samples were from 1999 and 2000 and joined the others at a level of 1.0.

Thirty-two of the 33 samples from FF13 were contained within one cluster that grouped internally at the 0.78 level (the last sample was in a very dissimilar group). Within this group, however, samples from years 1994, 1995, 1996, and 1998 clustered separately from samples collected in 1999–2004. The single sample that was not in this group was from 1999; the reason for this dissimilarity is not entirely clear from inspection of the raw data, but that sample did have large numbers of the polychaete *Asabellides oculata* and the bivalve *Cerastoderma pinnulatum*, species that were rare in all other samples from FF13.

Among the nonreplicated nearfield stations, samples from NF05 and NF23 (discussed above) were at opposite ends of the spectrum in terms of within-station similarity. NF05 formed the tightest grouping, with 8 of 11 samples (1995–2002) combining at CNESS level 0.67. Samples from 2003 and 2004 were similar to each other, and to samples from NF08 and NF09 collected in 2003 and 2004.; these joined the first group at CNESS 0.84. At many stations, samples from the years 1994 through 1999 were dissimilar to those from later years, but the overall within-station similarity levels were such that no before- and after-discharge effects could be identified.

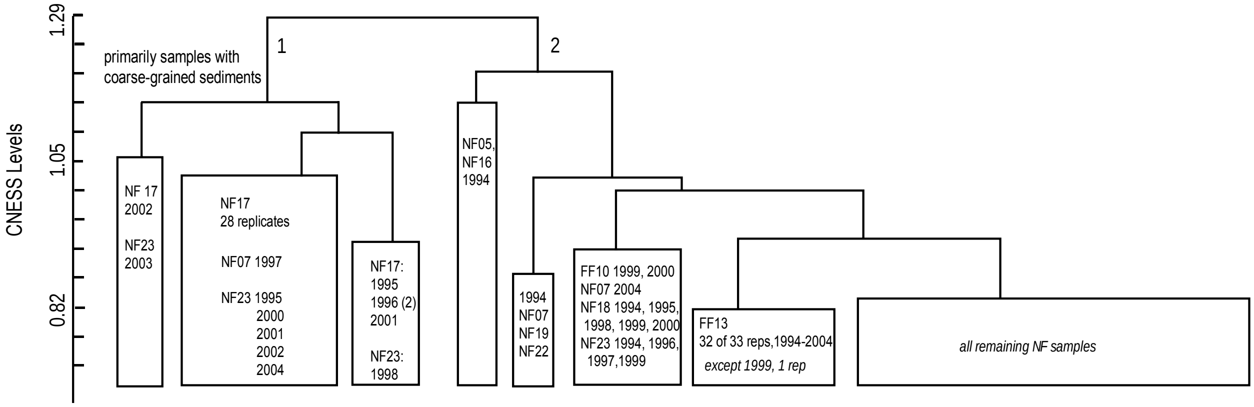


Figure 5-12. Summary CNESS dendrogram of nearfield replicates collected 1994–2004.

***PCA-H Analysis*—**Two PCA-H analyses, one based on the 267 samples taken at the nearfield stations between 1992 and 2004, and a second analysis based on the 231 samples collected 1994–2004, yielded essentially identical results. Results from the second analysis, which corresponds to the data used for the CNESS analysis, are presented here.

With CNESS (*m*=15), 40 of the 361 species recorded in the 267 nearfield samples in 1992–2004 accounted for 87% of the variation in the community structure, and contributed at least 1% to the PCA-H axes (Table 5-5). This result corresponds closely with the results from 2003, in which samples from all of the nearfield stations were analyzed, rather than only the subset of stations sampled in 2004. In 2003, 39 of the 392 species recorded in the 414 nearfield samples in 1992–2003 accounted for 88% of the variation in the community structure (Maciolek *et al*. 2004). Of these 39 species, 34 correspond to the important species identified by this analysis in 2004, suggesting that the subset of stations sampled in 2004was a good representation of the full station set sampled in previous years.

The samples separated along several multidimensional axes, with axes 1 and 2 accounting for 40% of the total CNESS variation. The sandier nearfield stations NF17 and NF23 separated from the finer-grained stations primarily along Axis 1 (Figure 5-13A). FF10 and FF13 separate along axis 2 from the remainder of the nearfield samples, which are mostly in a dense cloud as they were in the 2003 analysis (Maciolek *et al*. 2004). Axis 2 possibly also indicates a temporal component, with samples from the mid-1990s, (e.g., 1994, which was dominated by *Spio limicola*) having negative loadings and those from the late 1990s and early 2000s, which were dominated by *Prionospio steenstrupi*, *Aricidea catherinae*, and *Tharyx acutus*, having positive loadings (Figure 5-13B). In the absence of detailed information on station loadings in these plots, the majority of samples collected in 2004 could not be distinguished within the dense cloud of points representing all of the finer-grained nearfield stations.

The species accounting for more than 2% of the CNESS variation of this dataset are indicated in the Gabriel Euclidean distance biplot (Figure 5-12B) and detailed in Table 5-6. As seen for the 2004 samples, the majority of nearfield stations are structured by the spionid polychaetes *Prionospio steenstrupi* and *Spio limicola,* as well as *Aricidea catherinae*, *Mediomastus californiensis*, and *Tharyx acutus*. The sandy nearfield stations (NF17 and NF23) are influenced by the polychaetes *Exogone hebes*, *Spiophanes bombyx*, *Polygordius* sp. A, and the amphipod *Crassicorophium crassicorne*. The influence of particular species also carries a temporal component, with, for example, *S. limicola* and *C. crassicorne* being strongly influential in some years but not in others.

Table 5-5. Contribution of the 40 species in the 1994–2004 Massachusetts Bay nearfield samples identified by PCA-H analysis as important in structuring the infaunal communities, and their loadings on each of the six PCA-H axes.

PCA-H Rank	Species	Contr.	Total Contr.	Ax.1	Ax.2	Ax.3	Ax.4	Ax.5	Ax.6	Ax.7
1	*Prionospio steenstrupi*	6	6	11	8	15	0	4	9	1
2	*Spio limicola*	6	13	7	25	1	0	11	2	2
3	*Mediomastus californiensis*	5	18	14	0	1	0	0	1	8
4	*Aricidea catherinae*	5	23	3	11	1	20	25	7	5
5	*Crassicorophium crassicorne*	5	27	12	1	1	0	1	4	1
6	*Tharyx acutus*	4	32	4	2	7	24	0	15	1
7	*Dipolydora socialis*	4	36	0	11	12	11	15	5	9
8	*Exogone hebes*	3	39	6	1	7	0	0	1	3
9	*Aphelochaeta marioni*	3	42	2	9	0	1	0	1	0
10	*Spiophanes bombyx*	3	45	6	0	1	1	1	2	1
11	*Polygordius* sp. A	3	48	6	0	2	0	1	1	1
12	*Molgula manhattensis*	3	50	3	0	0	0	0	4	0
13	*Nucula delphinodonta*	3	53	1	3	7	5	0	0	25
14	*Pseudunciola obliquua*	2	55	4	0	4	1	0	6	2
15	*Ninoe nigripes*	2	58	3	1	1	5	6	2	0
16	*Levinsenia gracilis*	2	60	2	3	6	0	4	0	1
17	*Euchone incolor*	2	62	2	4	0	0	3	7	4
18	*Monticellina baptisteae*	2	64	2	1	1	11	0	0	1
19	*Phoronis architecta*	2	66	0	1	0	3	5	0	8
20	*Unciola inermis*	2	68	1	0	2	0	4	8	2
21	*Cerastoderma pinnulatum*	2	69	2	0	0	1	1	0	1
22	*Exogone verugera*	2	71	0	2	9	0	2	4	0
23	*Photis pollex*	2	73	0	3	0	4	1	1	0
24	*Nephtys cornuta*	1	74	0	3	0	2	0	1	0
25	*Phyllodoce mucosa*	1	75	1	2	0	1	1	1	1
26	*Leitoscoloplos acutus*	1	76	1	0	2	0	0	1	1
27	*Scoletoma hebes*	1	78	0	3	0	2	1	0	0
28	*Nephtys incisa*	1	79	0	0	1	0	1	0	1
29	*Echinarachnius parma*	1	80	1	0	1	0	0	1	0
30	*Hiatella arctica*	1	81	0	0	1	0	1	1	1
31	*Protomedeia fasciata*	1	81	0	0	2	0	2	1	2
32	Enchytraeidae sp. 1	1	82	0	0	0	0	0	2	0
33	*Asabellides oculata*	1	83	0	0	1	0	0	0	0
34	*Crassicorophium crassicorne*	1	84	0	0	2	0	0	0	1
35	*Ampharete baltica*	1	84	0	0	0	0	0	0	2
36	Tubificidae sp. 2	1	85	0	0	0	0	1	0	0
37	*Parougia caeca*	1	85	0	0	1	0	2	1	0
38	*Ampharete acutifrons*	1	86	0	0	0	0	0	0	2
39	*Dipolydora quadrilobata*	1	87	0	0	0	0	0	0	2
40	*Owenia fusiformis*	1	87	0	0	0	0	0	0	0

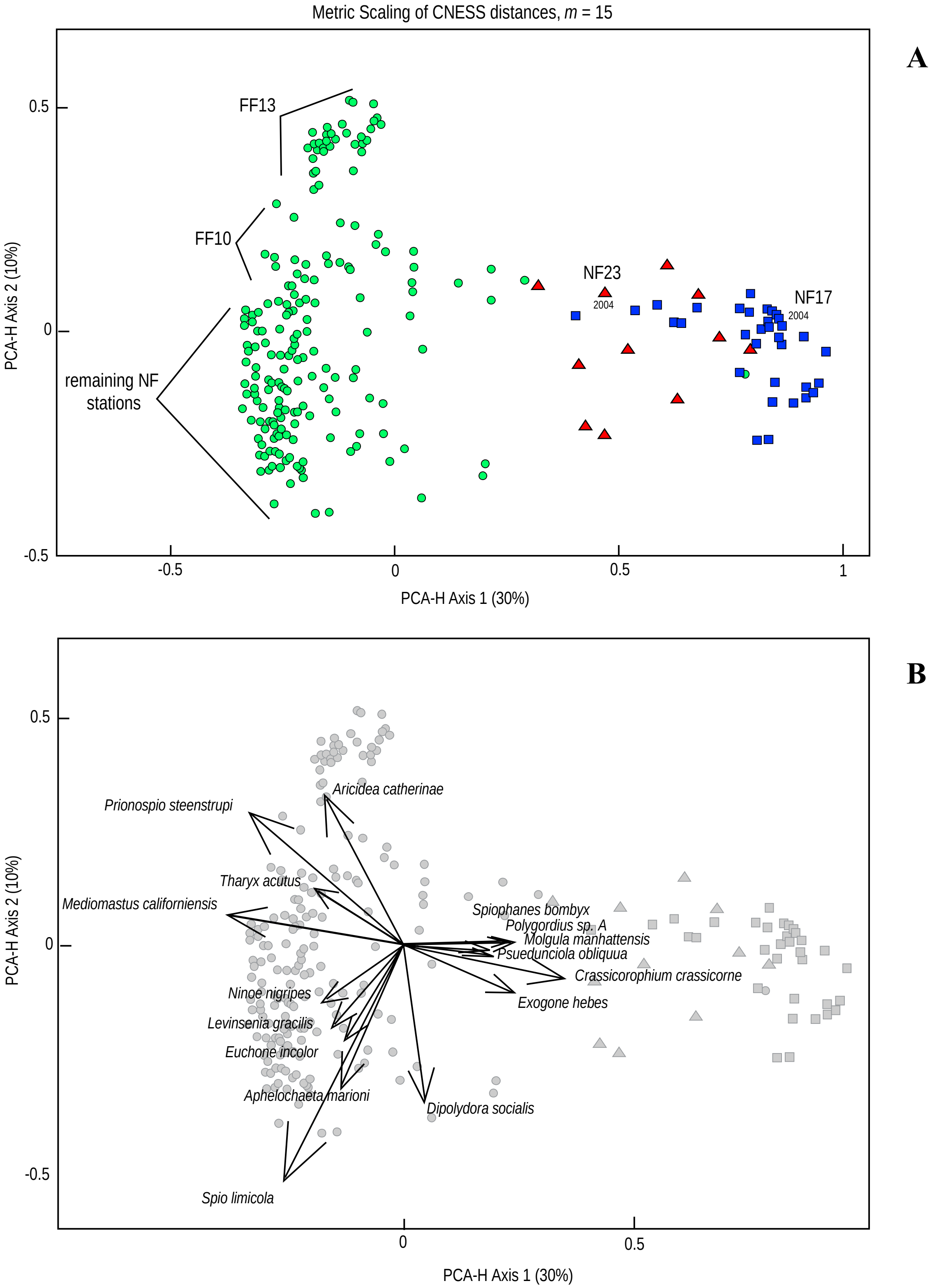


Figure 5-13. Metric scaling on PCA-H axes 1 and 2 of 231 nearfield benthic infaunal samples collected 1994–2004 (A) and the Euclidean distance biplot showing the species responsible for >2% of the CNESS (m = 15) variation (B).

Table 5-6. Contributions to PCA-H axes by species accounting for >2% of the CNESS variation among the infaunal samples collected from nearfield stations 1994-2004 (see Figure 5-11B for plot of axis 1 vs. axis 2).

Important species: Axis 1 vs. Axis 2

PCA-H Rank	Species	Contr.	Total Contr.	Axis 1	Axis 2
1	*Spio limicola*	11	11	7	25
2	*Mediomastus californiensis*	11	22	14	0
3	*Prionospio steenstrupi*	10	32	11	8
4	*Crassicorophium crassicorne*	9	41	12	1
5	*Aricidea catherinae*	5	46	3	11
6	*Exogone hebes*	4	50	6	1
7	*Spiophanes bombyx*	4	55	6	0
8	*Polygordius sp. A*	4	59	6	0
9	*Aphelochaeta marioni*	4	63	2	9
10	*Tharyx acutus*	3	66	4	2
11	*Dipolydora socialis*	3	69	0	11
12	*Ninoe nigripes*	3	72	3	1
13	*Pseudunciola obliquua*	3	74	4	0
14	*Levinsenia gracilis*	3	77	2	3
15	*Molgula manhattensis*	2	79	3	0
16	*Euchone incolor*	2	81	2	4

Important species: Axis 1 vs. Axis 3

PCA-H Rank	Species	Contr.	Total Contr.	Axis 1	Axis 3
1	*Mediomastus californiensis*	12	12	14	1
2	*Prionospio steenstrupi*	12	23	11	15
3	*Crassicorophium crassicorne*	10	33	12	1
4	*Spio limicola*	6	39	7	1
5	*Exogone hebes*	6	45	6	7
6	*Polygordius* sp. A	5	50	6	2
7	*Spiophanes bombyx*	5	55	6	1
8	*Tharyx acutus*	4	59	4	7
9	*Pseudunciola obliquua*	4	63	4	4
10	*Levinsenia gracilis*	3	66	2	6
11	*Ninoe nigripes*	3	69	3	1
12	*Molgula manhattensis*	3	71	3	0
13	*Aricidea catherinae*	3	74	3	1
14	*Dipolydora socialis*	2	76	0	12
15	*Nucula delphinodonta*	2	79	1	7

Table 5-6. Continued.

Important species: Axis 2 vs. Axis 3					
PCA-H Rank	**Species**	**Contr.**	**Total Contr.**	**Axis 2**	**Axis 3**
1	*Spio limicola*	16	16	25	1
2	*Dipolydora socialis*	12	28	11	12
3	*Prionospio steenstrupi*	11	38	8	15
4	*Aricidea catherinae*	7	45	11	1
5	*Aphelochaeta marioni*	6	51	9	0
6	*Exogone verugera*	5	56	2	9
7	*Nucula delphinodonta*	5	61	3	7
8	*Levinsenia gracilis*	4	65	3	6
9	*Tharyx acutus*	4	68	2	7
10	*Exogone hebes*	3	72	1	7
11	*Euchone incolor*	3	74	4	0
12	*Photis pollex*	2	77	3	0
13	*Scoletoma hebes*	2	79	3	0

5.3.6 Threshold Assessment

Monitoring thresholds for several parameters were established for comparison of post-discharge data with the baseline values. These parameters include species richness, log-series *alpha*, Shannon diversity (H'), Pielou's evenness (J'), and density. When the monitoring program was modified in 2003, the threshold values were adjusted to reflect the subset of stations to be sampled in even and odd years (Williams *et al.* 2005).

None of the 2004 annual means for these parameters exceeded or were lower than any of the threshold values (Table 5-7). Of the 21 nearfield sample, four had parameters that fell below the lower threshold values: FF13 replicate 1 (H' = 3.24 and J' = 0.54); NF12 replicate 2 (J' =0.57) and replicate 3 (H' = 3.14 and J' = 0.54) ; and NF17 replicate 3 (number of species = 43). Several individual values exceeded the upper threshold limit, but such exceedances are not considered problematical. Values for each replicate samples are in Appendix C3, Table C3-1.

Table 5-7. Threshold values and post-diversion annual means of benthic infaunal community parameters.

	Threshold Value Even Years		Baseline	Post-Dispersion Annual Means			
Parameter	**lower**	**upper**	**Average[1]**	**2001[2]**	**2002[2]**	**2003[2]**	**2004[3]**
Total Abundance	na	na	2242	2318	3476	3138	2062
Abundance of Valid Species	na	na	2106	2091	3413	3085	2003
Species/Grab	48.41	82.00	65	65	74	76	77
H'	3.37	4.14	3.68	3.80	3.60	3.61	4.07
J'	0.58	0.68	0.62	0.63	0.58	0.58	0.66
alpha	9.99	16.37	13.06	13.35	14.05	14.57	14.87
Percent Opportunists	10	25					0.23

na= Not applicable.

[1] Calculated June 2003 as the average of all pre-diversion (1992–2000) nearfield samples.

[2] Based on 23 nearfield stations.

[3] Based on subset of 13 nearfield stations.

5.4 Monitoring Questions

♦ *Has the soft-bottom community changed?*

There have been clear temporal changes in the soft-bottom benthic infaunal community over the time period of the monitoring program, including changes in terms of total infaunal density, species composition and richness, and, to a lesser extent, diversity. By 2003, infaunal abundance (per sample) had increased roughly 60% over abundances recorded in the early years of the program. Populations of the numerically dominant species have fluctuated over time and some species (*e.g.*, *Spio limicola*) have been replaced by others (*e.g.*, *Prionospio steenstrupi*). In 2003, the population levels of *P. steenstrupi* reached the highest levels recorded in the monitoring program, but crashed in 2004 to levels similar to those seen in the early 1990s. Species richness also increased, in 2003 reaching the highest mean values in both the nearfield and farfield areas. This high level has been maintained into 2004, although a reduced subset of stations were sampled.

♦ *Are any benthic community changes correlated with changes in levels of toxic contaminants (or sewage tracers) in sediments?*

The design of the monitoring program is such that a variety of habitats have been sampled in areas both near the outfall and at a distance from it, and in time periods both before and after the discharge was diverted to the outfall. Throughout the baseline period, there were differences in the mean values of community parameters between the nearfield and farfield, often with similar annual increases and decreases in both areas resulting in a nearly parallel sine-wave-like pattern (Figure 5-14). If the outfall discharge (and any associated contaminants) were having an effect on the benthos, such an effect would be expected to be seen at the nearfield stations closest to the outfall, with decreased diversity and species richness, and an increase in organic-tolerant opportunistic species. The same values at the farfield stations would depart increasingly from those at the nearfield stations. Such patterns have not been seen, either in 2001–2003 when all of the stations were sampled, or in 2004 when a subset of stations were sampled.

In 2003, nearfield and farfield stations actually converged in terms of abundance, diversity, and evenness. In 2004, mean total abundance fell in both the nearfield and farfield, primarily because of a major decline in the abundance of one species, *Prionospio steenstrupi*. Shannon diversity (H′) and evenness (J′) increased in both areas. Species richness, whether measured by the number of species per sample or log-series *alpha*, declined in the farfield and increased in the nearfield. Such patterns do not indicate any impact of the outfall, rather appear to be part of a natural cycle. Detailed investigation of individual stations also did not suggest any localized outfall impact, even at stations within 2 km of the outfall (*e.g.*, NF17) where elevated levels of the sewage tracer *Clostridium perfringens* suggested a modest impact of the discharge (see Chapter 3).

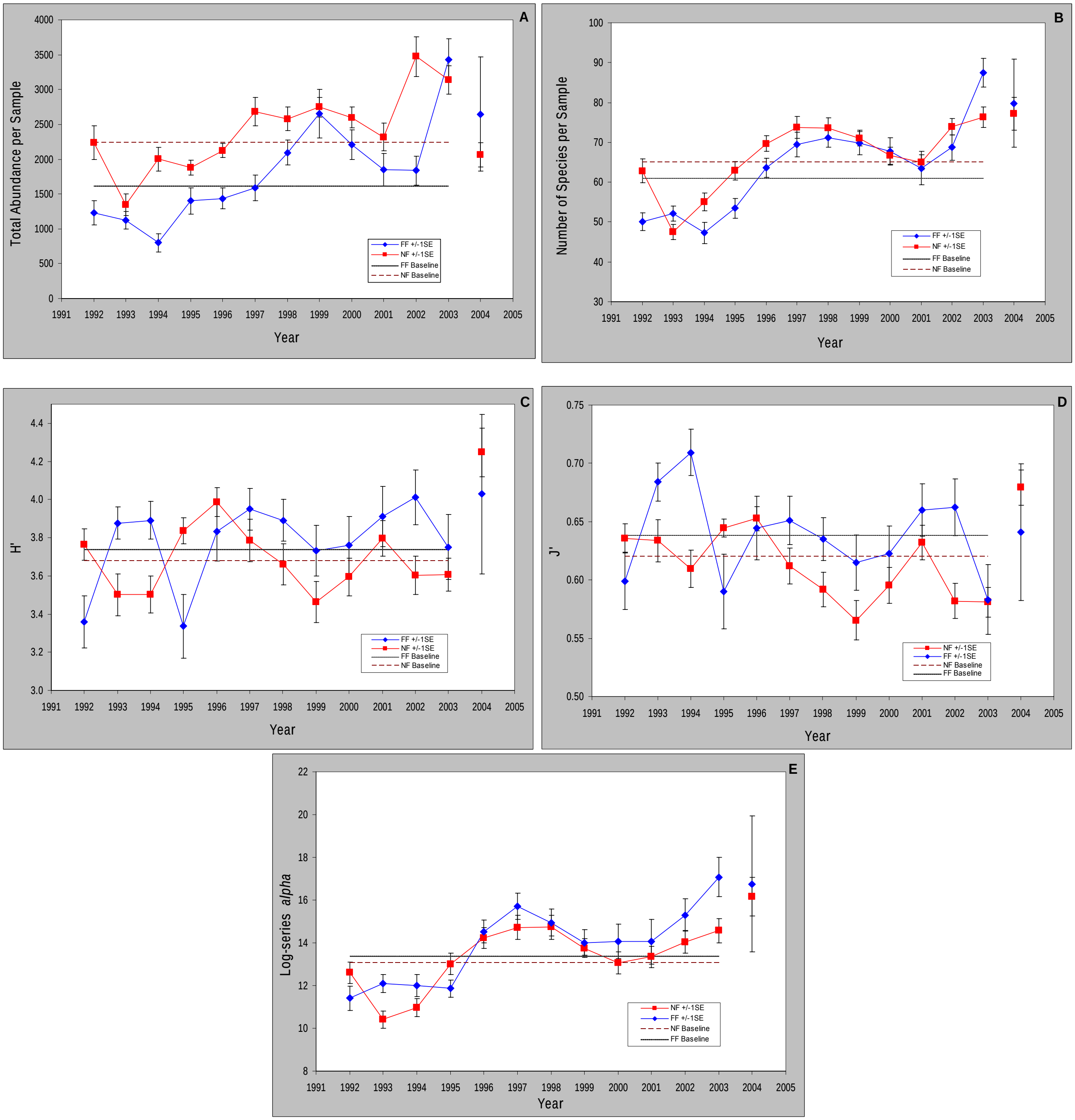


Figure 5-14. Mean benthic community parameters for nearfield and farfield stations sampled 1992–2004. (A) abundance per sample, (B) number of species per sample, (C) Shannon diversity H′, (D) Pielou's evenness J′, and (E) log-series *alpha*. Fewer stations were sampled in 2004 than in previous years.

6. 2004 HARD-BOTTOM BENTHIC HABITATS AND FAUNA

by Barbara Hecker

6.1 Status of the Bay

The nearfield hard-bottom communities inhabiting drumlins in the vicinity of the outfall have been surveyed annually for the last eleven 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 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.

Images collected during the baseline period indicate that the nearfield 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 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. Coralline algae usually dominate in areas with 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 the hard-bottom areas. Its areal coverage and distribution remained quite stable during the entire baseline period. The percent cover of coralline algae appears to be related to the 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 related to habitat relief. These algae are patchily distributed and are found in appreciable abundances only in areas of moderate to high relief. Areas supporting numerous upright algae also tend to have moderate to heavy sediment drape, with the holdfasts of the algae appearing to trap sediment.

The benthic communities inhabiting the hard-bottom areas were quite stable during the baseline period, with the structure of the benthic communities remaining relatively unchanged between 1995 and 2000. Occasional year-to-year shifts in cluster designation of specific sites usually appeared to reflect spatial habitat heterogeneity rather than temporal changes in the biotic communities. Upright algae dominated the communities inhabiting the northern reference sites, and several other sites on the top of drumlins on either side of the outfall. In contrast, coralline algae dominated the communities at the two southernmost reference sites, as well as at some drumlin top and flank sites on either side of the outfall. One of the southern reference sites, located southwest of the outfall, represents a relatively extreme habitat characterized by very large boulders with heavy sediment drape. This area is frequently inhabited by numerous invertebrates including a red soft coral *Gersemia rubiformis*, which is not found at any of the other sites. Several sites on the flanks of a drumlin located just south of the outfall are relatively depauperate when compared with the other sites. The diffuser heads of the outfall have been colonized by a luxuriant community of frilled sea anemones, *Metridium senile*, sea-peach tunicates, *Halocynthia pyriformis*, and northern sea stars, *Asterias vulgaris*.

The nearfield hard-bottom communities observed during the first three post-discharge surveys were remarkably similar to those observed pre-discharge (Maciolek *et al*. 2003, 2004). Several modest differences have been noted between the pre- and post discharge periods. The most consistent difference was a slight increase in sediment drape and a concurrent decrease in percent cover of coralline algae at five stations north of the outfall during the first two post-discharge years. Decreased percent cover of coralline algae was also observed at an additional northern reference site during the third post-discharge year, but this was not accompanied by a concurrent increase in sediment drape. A trend of decreased abundances of upright algae was also noted during the post discharge years, and was particularly pronounced in 2003.

The data discussed in this chapter were collected during the fourth post-discharge survey of the hard-bottom communities conducted during late June 2004. This chapter presents the results of the 2004 survey and compares these results to pre-discharge baseline conditions and to the previous post discharge conditions. All of the waypoints were successfully surveyed during 2004, including an actively discharging diffuser head at the eastern end of the outfall.

6.2 Methods

A Benthos MiniRover MK II ROV equipped with video and still cameras was deployed at each station. The ROV was operated at slow speeds close to the seafloor to optimize visual clarity of the images. Video images were collected to provide broad large-scale coverage, while still photographs (slides) were collected to provide high-resolution images used for semi-quantitative assessment of habitat characteristics and biota.

Both video footage and still photographs were obtained at each of 23 waypoints (Table 6-1, see Figure 2-3). Photographic coverage ranged from 16 to 28 minutes of video footage and 29 to 34 still photographs (35-mm slides) at each waypoint. A total of 739 still photographs was taken and used in the following data analysis.

Table 6-1. Photographic coverage at locations surveyed during the 2004 nearfield hard-bottom survey.

Transect	Waypoint	Location on drumlin	Depth (m)	Video (min)	Stills (# frames)
1	1	Top	26	24	31
1	2	Top	24	20	32
1	3	Top	23	20	34
1	4	Top	25	20	32
1	5	Flank	29	23	33
2	1	Top	26	21	33
2	2	Flank	30	21	34
2	3	Top	26	20	33
2	4	Flank	32	20	32
2	5	Diffuser #2	32	16	32
4	2	Flank	32	23	31
4/6	1	Top	24	23	33
6	1	Flank	34	21	32
6	2	Flank	32	20	33
7	1	Top	25	20	32
7	2	Top	24	21	32
8	1	Top	24	28	31
8	2	Top	25	18	33
9	1	Top	24	30	32
10	1	Top	23	23	31
11	1		34	22	32
12	1	Top	24	20	32
Diffuser	#44		36	21	29

6.2.1 Visual Analysis

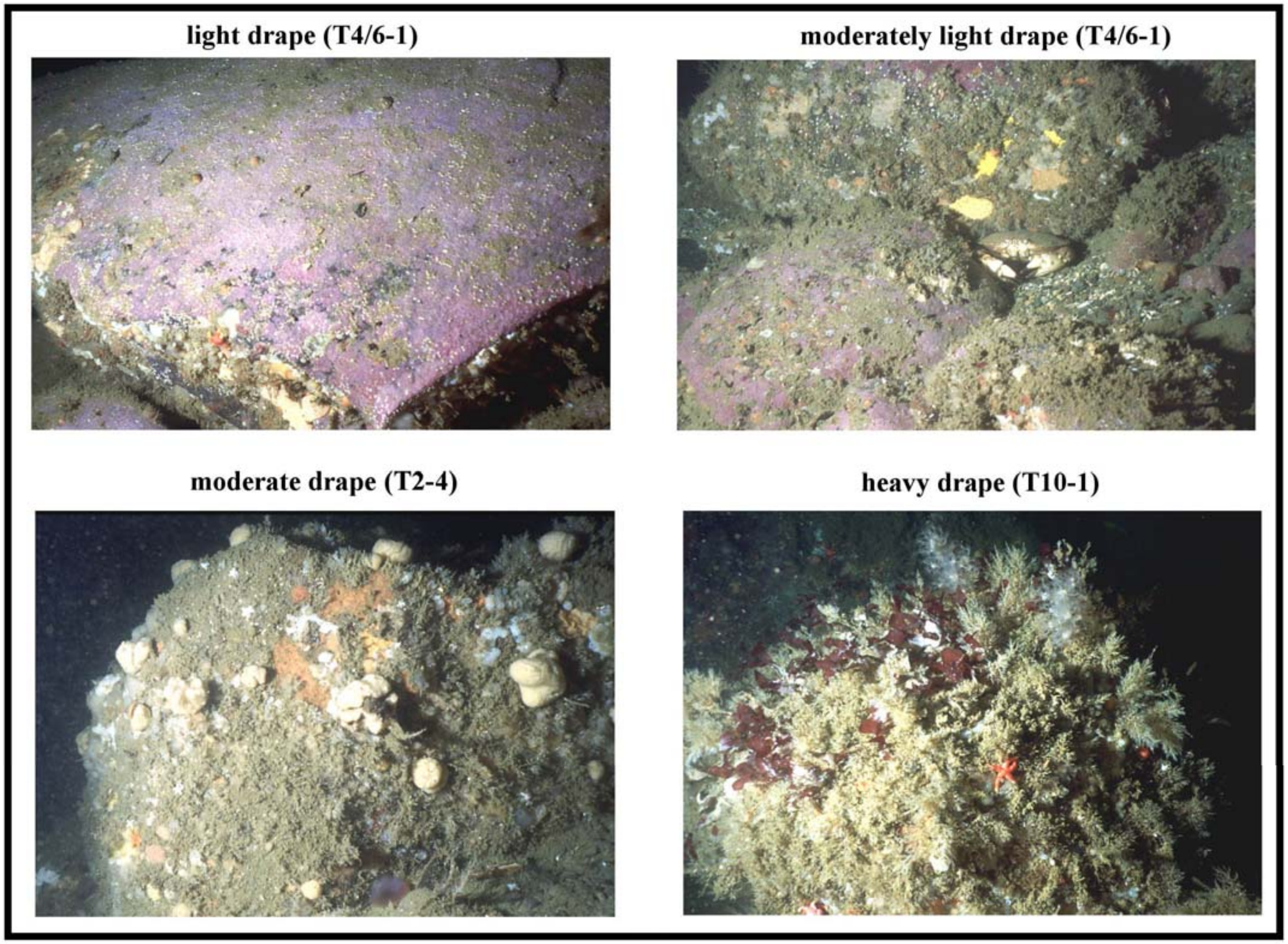
Each 35-mm slide was projected and analyzed for sea-floor characteristics (*i.e.*, substratum type and size class, and amount of sediment drape) and biota. Sediment drape refers to the visible layer of detrital material that drapes many of the rock surfaces in the hard-bottom areas. This material likely consists of a combination of phytodetritus, zooplankton fecal material, fine-grained resuspended sediments, biogenic tubes, and possibly effluent particles. The amount of sediment draped on the rock surfaces was assessed in terms of relative thickness and amount of surface area covered, ranging from clean when the entire rock surface was visible to heavy when none of the rock surface was visible. Examples of several of the sediment drape categories can be seen in Figure 6-1. 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 practical 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 have not been identified to species. Most of these have been 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 morphological variability or differences in viewing angles and lighting. Because of high relief in many of the habitats surveyed, all reported abundances are extremely conservative. In many areas, only a portion of available surface area is visible; thus, actual faunal abundances in these areas are undoubtedly much higher than the counts indicate. A summary of the 2004 slide analysis is included in Appendix E1.



light drape (T4/6-1)

moderately light drape (T4/6-1)

moderate drape (T2-4)

heavy drape (T10-1)

Figure 6-1. Photographs representative of sediment drape categories. Light drape is the presence of a dusting or small patches of sediment leaving the rock surfaces clearly visible. Moderately light drape is the presence of larger patches of sediment, yet still leaving most of the rock surfaces visible. Moderate drape is the presence of drape on most rock surfaces with only small patches showing through. Heavy drape is the entire rock surface covered by a substantial amount of drape.

Several changes in taxonomic designations have occurred during the years of this survey. Coralline algae, which were originally referred to as *Lithothamnion* spp., were found to belong to at least 5 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 algae were lumped into one taxon. Additionally, an abundant red filamentous alga that had previously been designated as *Asparagopsis hamifera*, was subsequently 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 2004 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, 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 the community analysis. Only taxa with an abundance of ten or more individuals in the entire data set were retained for the community analysis. Of the original 79 taxa, nine were dropped on the basis of belonging to a general taxonomic category, and 27 were dropped on the basis of fewer than ten individuals being present in the data set. This process resulted in 43 taxa being retained for community analysis.

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 and Discussion

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 photograph.

6.3.1 Distribution of Habitat Types

The sea floor on the tops of the drumlins consisted of a mix of glacial erratics in the boulder and cobble size categories. The sea floor on the drumlin immediately north of the outfall (T1 and T2) ranged from areas of moderate to moderately high relief characterized by numerous boulders interspersed with cobbles, to areas of moderately low relief characterized by a mix of cobbles, occasional boulders, and gravel in the slightly deeper areas. The sea floor on the top of the drumlin located south of the outfall (T4/6-1) also had a moderate relief mix of boulders and cobbles. The sea floor at the three northern reference sites ranged from moderate to moderately high and consisted primarily of boulders interspersed with cobbles. The sea floor at the southern reference sites ranged from moderately low to moderately high relief. The two southern reference sites that consisted mainly of cobbles with occasional boulders (T8-1 and T8-2) had moderately low relief. Another southern reference site T12-1 that consisted mainly of boulders with occasional cobbles had moderate relief, while the remaining southern reference site T10-1 consisted mainly of large boulders and had moderately high relief. The sea floor of the drumlin flank sites usually consisted of a low to moderate relief mix of cobbles, boulders, and gravel. The sea floor at the new reference site near Scituate (T11-1) consisted of a cobble pavement overlain with occasional large boulders, which resulted in a moderate relief habitat.

The tops of drumlins had varying amounts of sediment drape, ranging from a light drape at T4/6-1 to a moderately heavy drape at T10-1. Of the remaining 12 drumlin top areas, nine had moderately low sediment drape, while four had moderate drape. Three of the four southern reference sites had moderately light drape (T8-1, T8-2, and T12-1), while the remaining one had moderately heavy drape (T10-1). Two of the three northern reference sites had moderate drape (T7-1 and T7-2), while the remaining site (T9-1) had moderately light drape. Sediment drape was moderate at all six flank sites, as well as at the site near Scituate.

Habitat relief and sediment drape frequently were quite variable within many of the sites surveyed. Most moderate to high relief areas also contained numerous small patches of lower relief cobbles and gravel, and some of the low relief areas contained occasional islands 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 also visited during the 2004 survey, one that was actively discharging effluent (T2-5, Diffuser #2) and one that had not been 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 the active diffuser head and moderately high at the inactive head.

6.3.2 Distribution and Abundance of Epibenthic Biota

Eighty-three taxa were seen during the visual analyses of the 2004 nearfield hard-bottom survey still photographs and videotapes (Table 6-2). Seventy-nine of these taxa were seen on the still photographs and fifty-three were seen on the video footage. Taxonomic counts or estimates of abundances from the still photographs included 6,212 algae, 27,627 invertebrates, and 921 fish (Table 6-3). Coralline algae was the most abundant alga taxon observed during the survey, with an estimated abundance of 4,405 individuals. Two other algae commonly seen were dulse (*Rhodymenia palmata*) and a red filamentous alga *Ptilota serrata*, with abundances of 931 and 847 individuals, respectively. The least abundant alga encountered was the shotgun kelp, *Agarum cribosum*.

The three most abundant invertebrates observed on the slides were the northern white-crust tunicate *Didemnum albidum* (3,521 individuals), the northern sea star *Asterias vulgaris* (3,171 juveniles and 572 adults), and an unidentified whitish translucent sponge (3,151 individuals). Other abundant invertebrates observed on the still photographs were the horse mussel *Modiolus modiolus* (1,930 individuals), the brachiopod *Terebratulina septentrionalis* (1,720 individuals), the sea-pork tunicate *Aplidium* spp. (1,539 individuals), an unidentified orange/tan sponge (1,530 individuals), and the frilled anemone *Metridium senile* (1,455 individuals). Other common invertebrate inhabitants of the drumlins included: unidentified bryozoans (1,169 individuals), sea peach tunicates *Halocynthia pyriformis* (1,082 individuals), the blood sea star *Henricia sanguinolenta* (1,031 individuals), and numerous sponges and encrusting organisms. The most abundant fish observed in the still photographs were the cunner *Tautogolabrus adspersus* (881 individuals), sculpin *Myoxocephalus* spp. (13 individuals), winter flounder (12 individuals), cod *Gadus morhua* (4 individuals), and rock gunnel *Pholis gunnellus* (4 individuals).

Coralline algae was one of the most widely distributed taxa 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 3.3% at T6-1 to 70% at T1-3. Figure 6-2 shows the relationships between depth, sediment drape, percent cover of coralline algae, and topography. The strongest relationship was observed 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. Amount of sediment drape did not show a strong relationship with either depth or topography. Additionally, percent cover of coralline algae was quite variable and showed a weak general trend of higher cover at shallower depths. In contrast to the wide distribution of coralline algae, the two most abundant upright algae, *Ptilota serrata* and *Rhodymenia palmata*, had much more restricted distributions, with *P. serrata* being common at only four of the sites and *R. palmata* being common at only eight of the sites. These upright algae were common in areas characterized by moderate to moderately high relief and moderate to heavy sediment drape. The reduced percent cover of coralline algae in areas supporting high abundances of upright algae may 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.

Table 6-2. Taxa observed during the 2004 nearfield hard-bottom survey.

Name	Common Name
Algae	
Coralline algae	pink encrusting algae
Ptilota serrata	filamentous red algae
Rhodymenia palmata	dulse
Agarum cribosum	shotgun kelp
Invertebrates	
Sponges	
general sponge	
* *Aplysilla sulfurea*	sponge (yellow encrust)
Halichondria panicea	crumb-of-bread sponge
Haliclona oculata	finger sponge
Haliclona spp.	encrusting sponge
Melonanchora elliptica	warty sponge
Polymastia?	siphon sponge
** *Phakellia* spp.	chalice sponge
Suberites spp.	fig sponge
white divided	sponge on brachiopod
* orange/tan encrusting	sponge
* orange encrusting	sponge
* gold encrusting	sponge
* pink fuzzy encrusting	sponge
* dark red/brown encrusting	sponge
* white translucent	sponge
* cream encrusting	sponge
* filamentous white encrusting	sponge
frilly white sponge	sponge?
* general encrusting organism	
* red/orange crust	encrusting organism
* dark grey translucent material	*Diplosoma listerianum*?
Cnidarians	
general hydroid	
** *Corymorpha pendula*	stalked hydroid
Obelia geniculata	hydroid
* *Tubularia* sp.	hydroid
general anemone	
Metridium senile	frilly anemone
Urticina felina	northern red anemone
Cerianthus borealis	northern cerianthid
Gersemia rubiformis	red soft coral
* *Alcyonium digitatum*	dead man's fingers
Mollusks	
* gastropod	
* *Tonicella marmorea*	mottled red chiton
* *Crepidula plana*	flat slipper limpet
* *Notoacmaea testudinalis*	tortoiseshell limpet
Buccinum undatum	waved whelk
* *Busicotypus canaliculatus*	channeled whelk
Neptunea decemcostata	ten-ridged whelk
nudibranch	
* *Coryphella* sp.	red-gilled nudibranch
* *Arctica islandica*	ocean quahog
Modiolus modiolus	horse mussel
Placopecten magellanicus	sea scallop
Crustaceans	
* *Balanus* spp.	acorn barnacle
Homarus americanus	lobster
Cancer spp.	Jonah or rock crab
*general crab	
** hermit crab	
Echinoderms	
Strongylocentrotus droebachiensis	green sea urchin
juvenile *Asterias*	small white sea star
Asterias vulgaris	northern sea star
Crossaster papposus	spiny sunstar
Henricia sanguinolenta	blood star
* *Porania insignis*	badge star
Pteraster militaria	winged sea star
***Solaster endeca*	
** Cucumaria frondosa*	orange-footed holothurian
Psolus fabricii	scarlet holothurian
Tunicates	
Aplidium spp.	sea pork tunicate
* *Boltenia echinata*	cactus tunicate
Boltenia ovifera	stalked tunicate
* *Dendrodoa carnea*	drop of blood tunicate
* *Didemnum albidum*	northern white crust
Halocynthia pyriformis	sea peach tunicate
* clear globular tunicate	
Bryozoans	
general bryozoan	
* red crust bryozoan	
Miscellaneous	
Myxicola infundibulum	slime worm
spirorbids	
Terebratulina septentrionalis	northern lamp shell
Fish	
general fish	
Gadus morhua	cod
Hemitripterus americanus	sea raven
Macrozoarces americanus	ocean pout
Myoxocephalus spp.	sculpin
Pholis gunnellus	rock gunnel
Pseudopleuronectes americanus	winter flounder
Tautogolabrus adspersus	cunner

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

Table 6-3. Taxa seen in still photographs taken during the 2004 nearfield hard-bottom survey, arranged in order of abundance.

Taxon	Count	Taxon	Count
Algae			
Coralline algae	4405*	*Tubularia* sp.	27
Rhodymenia palmata	931	*Haliclona* spp. (encrusting)	24
Ptilota serrata	847*	*Arctica islandica*	22
Agarum cribosum	29	*Tonicella marmorea*	21
Total algae	**6212**	general anemone	18
		Cancer spp.	16
Invertebrates		nudibranch	13
Didemnum albidum	3521	*Haliclona* spp. (upright)	9
juvenile *Asterias* spp.	3171	*Crossaster papposus*	8
white translucent sponge	3151	*Alcyonium digitatum*	7
Modiolus modiolus	1930	*Melonanchora elliptica*	6
Terebratulina septentrionalis	1720	*Polymastia?*	5
Aplidium spp.	1539	*Homarus americanus*	5
orange/tan encrusting sponge	1530	filamentous white encrusting sponge	4
Metridium senile	1455	*Obelia geniculata*	4
general bryozoan	1169	*Buccinum undatum*	4
Halocynthia pyriformis	1082	*Placopecten magellanicus*	4
Henricia sanguinolenta	1031	*Boltenia ovifera*	4
Dendrodoa carnea	961	*Cerianthus borealis*	3
white divided sponge	752	general gastropod	3
orange encrusting sponge	721	*Notoacmaea testudinalis*	3
Asterias vulgaris	572	red crust bryozoan	3
Myxicola infundibulum	503	*Neptunea decemcostata*	2
general encrusting organism	477	*Porania insignis*	2
Boltenia echinata	364	*Coryphella* sp.	1
pink fuzzy encrusting sponge	341	*Busicotypus canaliculatus*	1
Halichondria panicea	202	general crab	1
gold encrusting sponge	142	*Pteraster militaria*	1
Balanus spp.	133	*Cucumaria frondosa*	1
Aplysilla sulfurea	123	hydroids	**
general sponge	122	spirorbids	**
cream encrusting sponge	119	**Total invertebrates**	**27,627**
Gersemia rubiformis	119		
Strongylocentrotus droebachiensis	114	**Fish**	
red/orange encrusting organism	113	*Tautogolabrus adspersus*	881
Psolus fabricii	110	*Myoxocephalus* spp.	13
Suberites spp.	84	*Pseudopleuronectes americanus*	12
frilly white sponge	68	*Pholis gunnellus*	4
dark red/brown encrusting sponge	45	*Gadus morhua*	4
Crepidula plana	42	general fish	3
dark grey translucent organism	41	*Macrozoarces americanus*	2
clear globular tunicate	33	*Hemitripterus americanus*	2
Urticina felina	27	**Total fish**	**921**

*Estimated

**Not counted

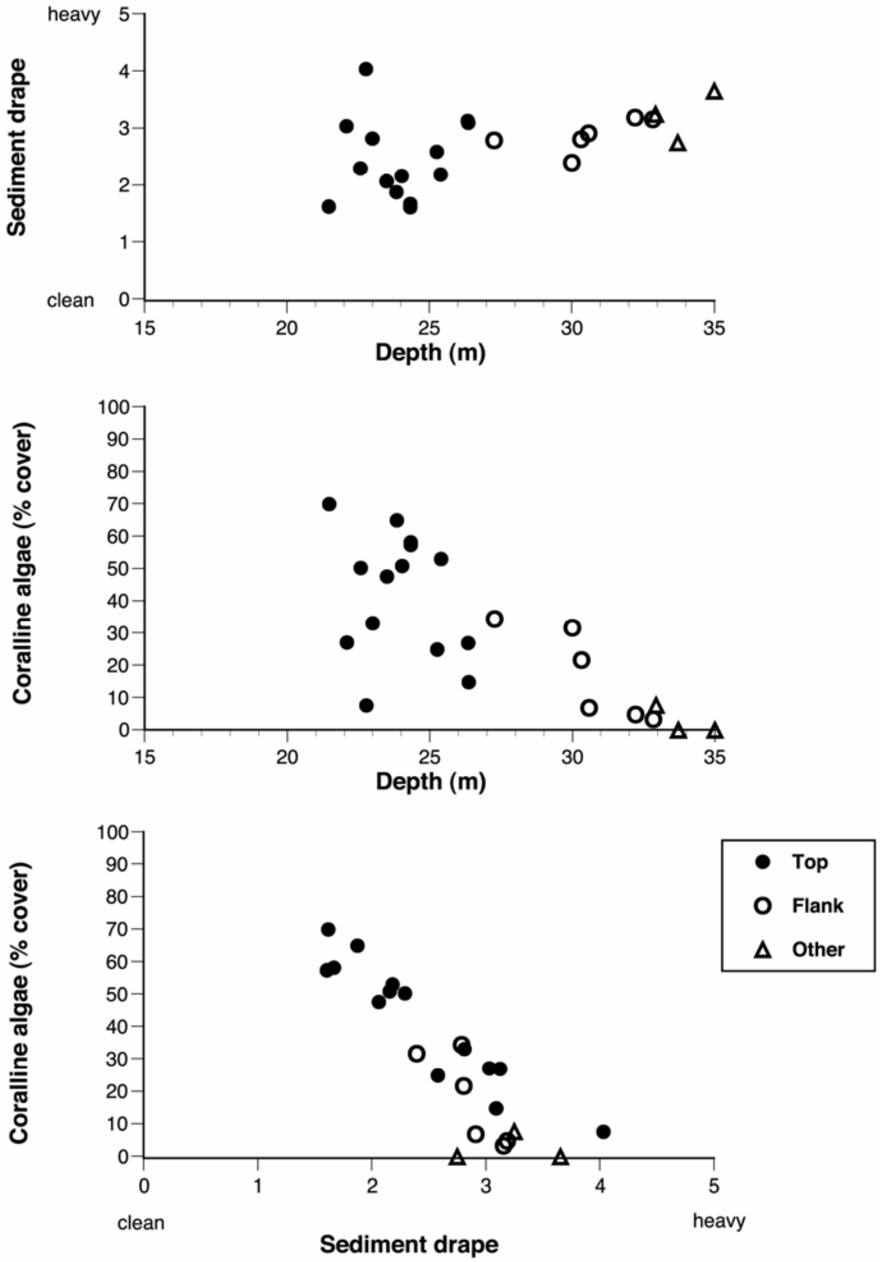


Figure 6-2. Depth, sediment drape, and percent cover of coralline algae of the sites from the 2004 nearfield hard-bottom survey.

Several of the commonly seen invertebrates also exhibited wide distributional patterns. Juvenile and adult northern sea stars *Asterias vulgaris* were found at all sites. Juvenile *Asterias* were usually much more abundant than adults and were most abundant on the top of drumlins, while adults appeared to have less of a habitat preference. Another sea star, the blood sea star *Henricia sanguinolenta*, was also observed at all sites. This species was most abundant on boulders in areas of high relief. The horse mussel *Modiolus modiolus* was also very widely distributed, being found at all sites except the inactive diffuser. This mussel was most abundant on the top of drumlins, where large numbers were observed nestled among cobbles and at the bases of boulders. Because of the mussel's cryptic nature of being nestled in among rocks and frequently being almost totally buried, the observed abundances are very conservative. The number of mussels definitely would be underestimated in areas of high relief, because the bases of larger boulders were rarely visible in the images. Thirteen individuals of this mussel were observed near one of the ports of the head of Diffuser #2.

Several other abundant invertebrates exhibited more restricted distributions. Four of these species appear to be primarily restricted to large boulders. The brachiopod *Terebratulina septentrionalis* was found at 16 of the sites, but was seen in high abundances at only eight of them (T2-3, T2-4, T4-2, T7-1, T7-2, T9-1, T11-1, and T12-1). This species appeared to be restricted to the sides of large boulders, where it is partially protected from sediment loading, which could clog the brachiopod's filtering apparatus. Another species that was markedly more abundant on large boulders was the frilled anemone *Metridium senile*. This anemone was found at 15 sites, but was common to abundant at only five of them. *Metridium senile* was exceptionally abundant on the head of the active diffuser (Diffuser #2) and somewhat less abundant on the head of the inactive diffuser (Diffuser #44). It was also commonly observed on the larger boulders found at sites T1-3, T9-1, and T11-1. This anemone was usually seen on the tops and upper sides of boulders. The sea peach tunicate *Halocynthia pyriformis* was found at 22 sites but was found in high abundances at only three sites: the head of the inactive diffuser (Diffuser #44), the site off Scituate (T11-1), and the southernmost nearfield reference site (T12-1). This species was also usually seen on the sides of larger boulders. One species with a very restricted distribution was the soft red coral *Gersemia rubiformis*, which was seen at only two of the sites. All of the *G. rubiformis*, except for one individual, were seen at T10-1, where they inhabited the tops of large boulders characteristic of this site.

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 green sea urchin *Strongylocentrotus droebachiensis* was relatively widely distributed, being found at 17 sites. This urchin was common only in regions that had a high percent cover of coralline algae (T1-3, T4/6-1, T8-2, and T9-1), on which it grazes (Sebens 1986). The red holothurian *Psolus fabricii* also was widely distributed. This holothurian was found at 19 sites, but was abundant at only three of them (T1-4, T8-2, and T12-1). Reasons for its high abundance in some areas, and not in others, were not readily apparent.

Four invertebrates were newly encountered this year. Two of these species are unidentified and were seen only on boulders that had die-offs of the barnacle settlement that was observed in 2003 (Figure 6-3). One of these species was a frilly white encrusting material that may be a sponge. Several of these were seen at T9-1 last year, but this year 68 individuals were seen at six sites. The other species was a dark grey translucent organism that only occurred on boulders that had barnacle die-off and the frilly white sponge.

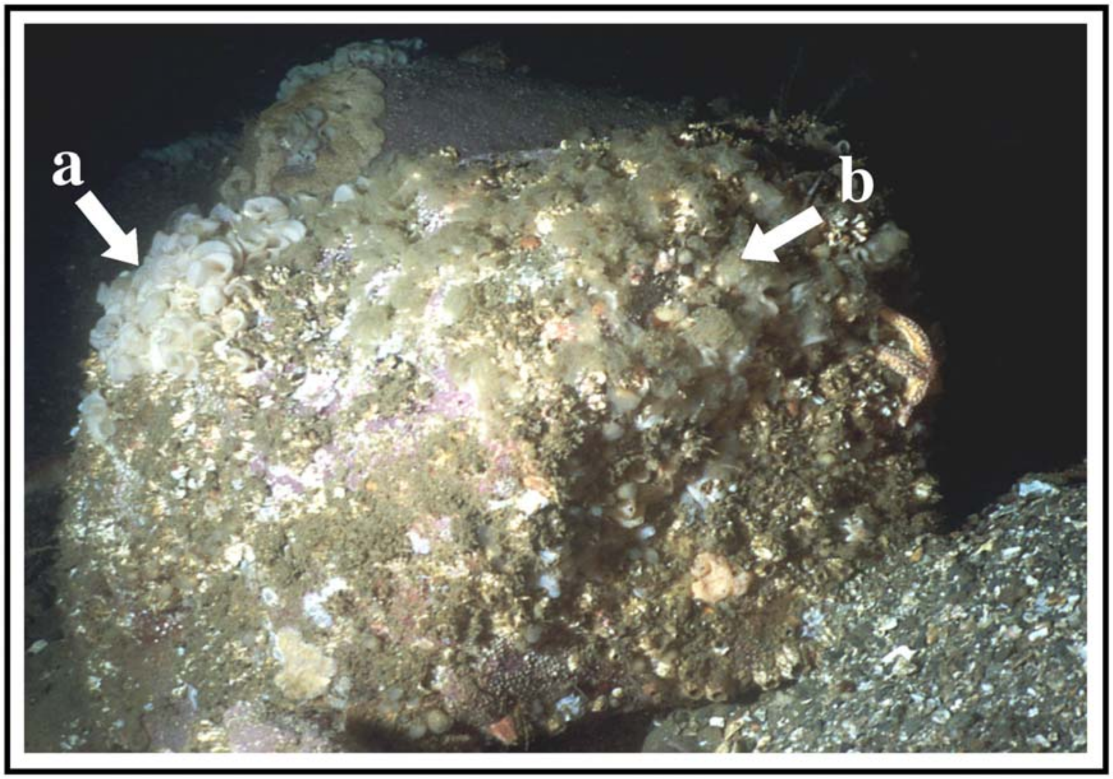


Figure 6-3. Photograph of two encrusting species newly observed in 2004. (a) A frilly white organism, possibly a sponge. (b) A grey translucent organism that appears to be overgrowing other taxa including the frilly white sponge (possibly *Diplosoma listerianum*, an invasive tunicate). Both species were seen only on boulders that had previously been colonized by barnacles.

This grey material appeared as though it might be encasing and overgrowing other organisms on the rocks. Forty-one of these translucent gray organisms were seen at three sites. A potential identification for this gray organism is the invasive colonial tunicate *Diplosoma listerianum*, which has been seen overgrowing organisms at another hard-bottom site in Massachusetts Bay this year (B. Hecker, unpublished data). Both of these species were most abundant at a drumlin top site located just south of the outfall (T4/6-1). One of the other newly recorded species was the cactus tunicate *Boltenia echinata*. This species has been seen in the past, but had not previously been identified and enumerated. It is extremely cryptic, basically two small red dots (siphon openings) on a spiny sediment colored bump. Three hundred sixty-four individuals were seen at 17 stations. The other newly occurring species was one orange-footed holothurian *Cucumaria frondosa* that was seen on a large boulder at T9-1.

The fish fauna was dominated by the cunner *Tautogolabrus adspersus*, which was observed at all 23 waypoints. This fish was most abundant in moderate to high relief areas, where it tended to congregate among large boulders (T10-1, T9-1, T1-3, and T2-3). In areas of heterogeneous relief, *T. adspersus* frequently was seen only in the immediate vicinity of boulders. Six other fish species, sculpin (*Myoxocephalus* spp.), winter flounder (*Pseudopleuronectes americanus*), cod (*Gadus morhua*), rock gunnel *Pholis gunnellus*, ocean pout (*Macrozoarces americanus*), and sea raven (*Hemitripterus americanus*) also were seen on the still photographs. The sculpin and flounder were usually seen in flat low-relief areas, while cod and ocean pout were seen only around boulders in high-relief areas.

6.3.3 Community Structure

Classification analysis of the 23 waypoints and 43 taxa defined two large clusters of stations, two small clusters of two stations each, and two outliers loosely attached to the two larger clusters (Figure 6-4). The two large clusters of stations further subdivided into slightly more cohesive groups. The first cluster consisted of six drumlin top sites that had boulders as their primary substrate and had moderate to moderately high relief. Sediment drape varied among the sites in cluster 1: three of the sites had moderate sediment drape (1a), while the remaining three sites had light to moderately light drape (1b). All three northern reference sites (T7-1, T7-2, and T9-1), one southern reference site (T12-1), and two sites located just north of the outfall (T1-3 and T2-3) were in cluster 1. The second cluster consisted of 11 stations, including seven drumlin top areas and four flank areas. Habitat relief at these sites ranged from moderately low at eight of the sites to moderate at three of the drumlin top sites. Sediment drape ranged from light to moderate, with less drape present in the sites in the first subgroup (2a) and more drape present in the areas in the second subgroup (2b). Two of the southern reference sites (T8-1 and T8-2), as well as stations located on drumlins adjacent to the outfall, were in cluster 2. The two outlier areas that loosely attach to these two clusters consist of one drumlin top area and one flank area. The drumlin top outlier was a southern reference site (T10-1) that consisted of numerous large boulders. This site had moderately high relief and moderately heavy sediment drape. In contrast, the flank outlier area (T6-1) consisted of a low relief cobble pavement with moderate sediment drape. The remaining two clusters (3 and 4) were quite distinct from the other stations, separating out from the main group at faunal similarities of 41% and 28%, respectively. The two stations in cluster 3, a flank station (T2-4) and the site off Scituate (T11-1), had moderate relief and moderate to moderately heavy sediment drape. The remaining cluster (4) consisted of the two diffuser stations, which included the diffuser head and its immediate surroundings. Sediment drape was moderate at the active diffuser (T2-5, Diffuser #2) and moderately heavy at the inactive diffuser (#44). The clustering structure appeared to reflect a combination of topography, habitat characteristics, and geographic proximity. Neighboring waypoints with similar habitat characteristics tended to cluster together (T7-1 and T7-2; T8-1 and T8-2). Habitat characteristics and the range of abundance of dominant taxa for each of the cluster groups are presented in Table 6-4.

Coralline algae were commonly found in all but one of the areas in the first two clusters. Major differences between the two clusters were related to the relative proportion of upright algae in each of the areas. The sites in cluster 1 generally supported more upright algae than the sites in cluster 2. Within each of these clusters, areas further divided into subgroups of stations that were inhabited by slightly different biota. The three stations in subgroup 1a supported more upright algae, while the three areas in subgroup 1b supported more coralline algae. The three sites in subgroup 1a included the two northernmost reference sites (T7-1 and T7-2) and a site just north of the outfall (T2-3). Dulse, *Rhodymenia palmata*, was common at all three sites in subgroup 1a, while a filamentous red alga, *Ptilota serrata*, was commonly found at the two northern reference sites, but not at T2-3. The three stations in subgroup 1b consisted of the remaining northern reference station (T9-1), a southern reference station (T12-1), and a site north of the outfall (T1-3). These sites supported a moderate number of upright algae and high percent cover of coralline algae. All of the sites in cluster 1 also supported numerous encrusting and mobile invertebrates.

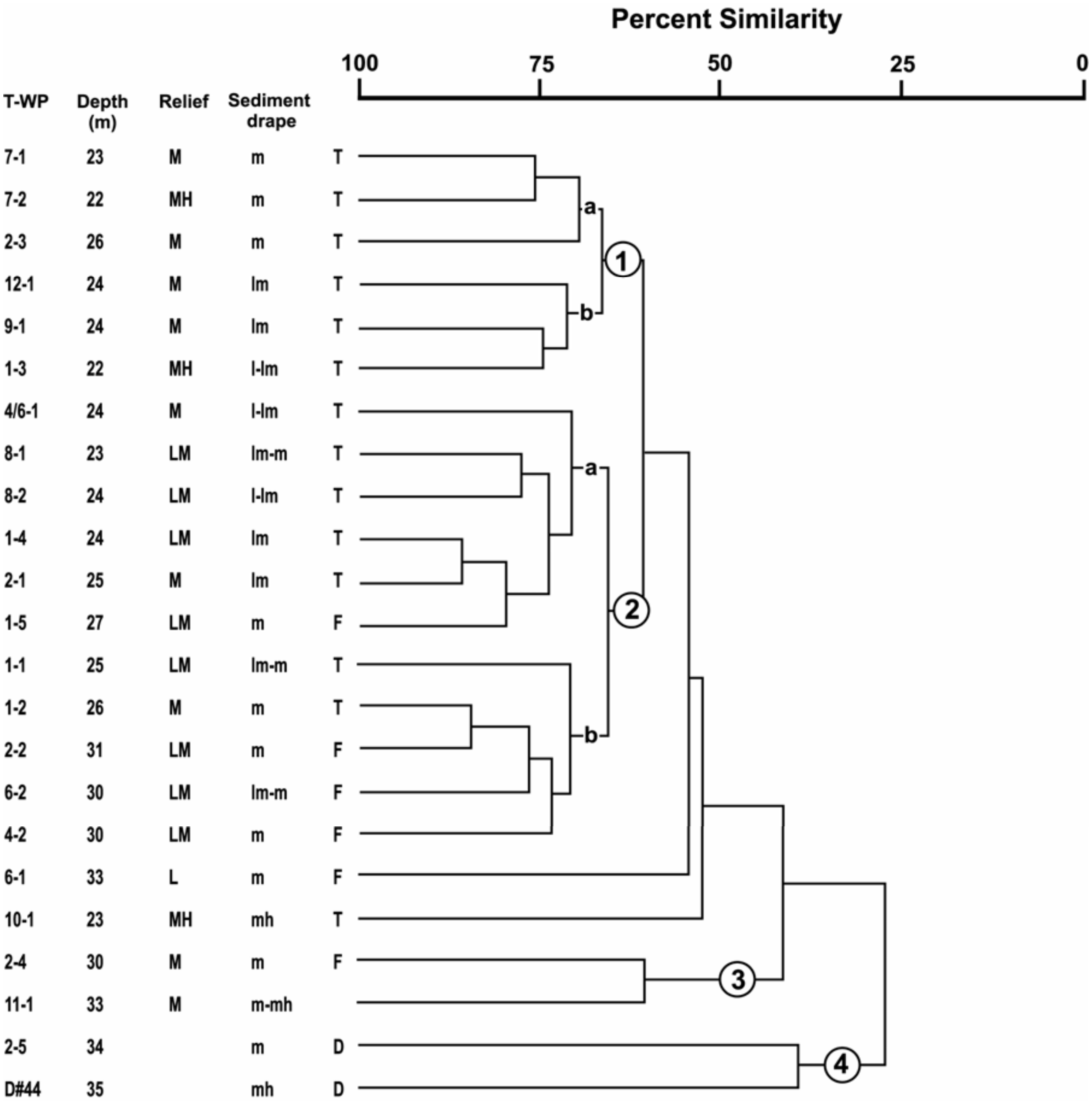


Figure 6-4. Cluster analysis of data collected from still photographs taken during the 2004 nearfield hard-bottom survey.

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

Cluster	**1**		**2**				**3**	**4**
	a	**b**	**a**	**b**	**T6-1**	**T10-1**		
Depth (m)	22-26	21-24	23-27	25-31	33	23	32-33	34-35
Habitat relief[1]	M-MH	M-MH	LM-M	LM-M	L	MH	M	H
Sediment drape[2]	m	l-lm	l-m	m	m	mh-h	m-mh	m-mh
Coralline algae (% cover)	14.7-32.97	**47.50-69.85**	**34.39-64.84**	6.82-31.67	3.28	7.48	4.75-7.69	-
Rhodymenia palmata	**3.27-5.75**	1.50-1.94	0.00-1.15	0.00-2.58	-	2.03	0-0.22	-
Ptilota serrata (estimated)	**0.00-10.06**	**1.31-4.82**	0.00-0.38	-	-	0.13	-	-
Coralline algae (estimated)	3.03-6.03	**9.44-14.12**	**4.91-13.75**	1.74-5.15	1.41	1.81	1.28-2.03	-
Didemnum albidum	3.53-7.44	3.69-4.63	1.12-6.42	4.42-8.50	4.31	3.61	1.22-5.53	1.21-5.25
Aplidium spp.	0-1.64	1.15-3.94	1.82-6.16	1.71-4.07	0.69	0.06	0-1.66	0.13-0.76
Modiolus modiolus	2.94-4.81	1.75-7.38	1.16-4.52	0.67-2.56	0.53	3.52	0.81-3.19	0-0.41
juvenile *Asterias*	4.39-6.34	5.84-9.97	1.88-6.03	2.74-6.48	2.94	4.03	0.50-2.53	1.48-2.50
Terebratulina septentrionalis	2.22-8.09	0.59-7.22	0-0.03	0-2.48	-	0.03	**8.75-16.34**	0.03-0.07
Metridium senile	0-0.13	0.06-0.97	0-0.18	0-0.15	-	0.03	0-1.09	**8.00-34.38**
Halocynthia pyriformis	0.41-0.97	1.06-1.53	0.03-0.18	0.22-2.45	-	0.29	0.25-1.91	**0.19-21.66**
Gersemia rubiformis	-	-	-	-	-	**3.81**	0-0.03	-
Tautogolabrus adspersus	1.19-2.76	0.88-3.94	0.30-0.85	0.32-0.78	0.03	**4.32**	0.22-0.34	0.31-1.69
Total algae	**6.30-20.81**	**12.34-20.88**	**5.03-15.13**	1.74-7.09	1.41	3.97	1.28-2.25	-
Total invertebrates	**35.47-45.31**	**36.24-55.59**	16.39-37.70	30.16-40.19	16.56	**35.13**	**46.16-58.22**	**43.38-56.81**
Total fish	1.19-2.82	0.94-4.03	0.33-0.94	0.39-1.12	0.13	**4.35**	0.22-0.44	0.35-1.84

[1] L = low; LM = moderately low; M = moderate; MH = moderately high; H = high.

[2] l = light; lm = moderately light; m = moderate; mh = moderately heavy.

The stations in cluster 2 mostly supported moderate to high percent cover of coralline algae and few if any upright algae. Cluster 2 further divided into two slightly more cohesive subgroups. The first of these groups (2a) consisted mostly of drumlin top areas that had moderately low to moderate relief and moderately light sediment drape. These sites included two of the southern reference sites and four sites located on the drumlins immediately north and south of the outfall. The second group (2b) consisted of two drumlin top sites and three flank sites. These sites were characterized by having mostly moderately low relief and moderately light to moderate sediment drape. The drumlin top sites comprising group 2a had much higher percent cover of coralline algae (>50%) than any of the sites in group 2b (<32%). The areas in cluster 2 also supported numerous invertebrates.

The two areas that were outliers to the group formed by clusters 1 and 2 consisted of one drumlin flank station that was located immediately south of the outfall (T6-1) and one drumlin top reference station that was immediately southwest of the outfall (T10-1). Station T10-1 consisted of mainly of large boulders covered with a moderately heavy sediment drape. This station had the lowest percent cover of coralline algae (7.48%) of any of the drumlin top stations. Additionally, this station supported relatively few upright algae. However, the large boulders at this site provided suitable attachment sites for numerous red soft corals, *Gersemia rubiformis*, and other invertebrates. The cunner *Tautogolabrus adspersus* was also quite common at this site. In contrast, the other outlier site (T6-1) consisted mainly of a low relief cobble pavement with moderate sediment drape. This station supported a moderate number of invertebrates, few algae, and very few fish.

The remaining four sites supported few if any algae. One of these sites was located on the flank of the drumlin north of the outfall, while the other site was the southern reference site located east-northeast of Scituate. The seafloor at both of these sites had numerous large boulders that supported numerous brachiopods (*Terebratulina septentrionalis*) and other invertebrates. The two sites in cluster 4 were the diffuser sites, which consisted of the diffuser heads and their immediate surroundings. The head of the active diffuser (#2 at T2-5) was colonized by numerous frilled anemones *Metridium senile*, where dense aggregations of this anemone covered most of the exposed surfaces of the dome, as well as the indentations of the discharge ports. In contrast, the head of the inactive diffuser (#44) was much more sparsely populated and was colonized primarily by the sea peach tunicate *Halocynthia pyriformis*. The diffuser heads and their immediate surroundings also supported a fairly high number of invertebrates.

6.3.4 Comparison of Pre- and Post-Diversion Communities

The nearfield hard-bottom communities in the vicinity of the outfall have been surveyed annually for eleven years. Seven of the surveys occurred under pre-discharge baseline conditions, while the last four 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 has evolved to maximize the probability of detecting potential impacts of outfall operations. The present design includes 13 sites near the outfall, 7 nearfield reference sites (3 north and 4 south of the outfall), one farfield reference site off Scituate, and an inactive and an active diffuser head. Additionally, the emphasis on data products also has evolved. Still photographs and video footage are both utilized to provide a detailed characterization of the sea floor and of the biota inhabiting the hard-bottom sites. The still photographs provide the high resolution required 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. In contrast, the much broader areal coverage provided by the video images has allowed assessment of habitat relief, spatial heterogeneity, and the occurrence of large, rare biota.

The hard-bottom habitats though spatially quite variable, have shown consistent trends over time. At many of the waypoints, year-to-year variations in habitat characteristics tended to be relatively small. Habitat relief does not vary over time, but slightly different areas of the sites were surveyed each year, so varying relief at a site indicates habitat heterogeneity. Figure 6-5 shows the habitat relief observed during the 1995 to 2004 surveys. Location on the drumlins appeared to be a primary factor in determining habitat relief. The sea floor on the tops of drumlins usually consisted of a mix of boulders and cobbles. Habitat relief varied from moderate to high on drumlin tops dominated by boulders (T1-2, T1-3, T2-2, T2-3, T4/6-1, T7, T9, T10, and T12) to moderate to low on drumlins that consisted of a mix of cobbles and boulders (T1-4, T2-1, 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 to moderately low on the drumlin south of the outfall (T4-1, T4-2, T4-3, T6-1, and T6-2) to moderately low to moderate on the drumlin north of the outfall (T1-5 and T2-4).

Figure 6-6 shows the relative amount of sediment drape seen on the rock surfaces during the 1995 to 2004 surveys. Sediment drape was lightest on the shallowest part of the drumlins adjacent to the outfall (T1-2, T1-3, T1-4 and T4/6-1), slightly more at the southernmost reference sites (T8-1, T8-2 and T12-1), and moderate to moderately heavy at the northern reference sites (T7-1, T7-2, and T9-1). Drape was also heavier on the deeper part of the drumlin north of the outfall (T1-1, T2-2, and T2-3), as well as on the flanks (T2-4, T4-1, and T6-1). Drape was heaviest at T10-1, the southern reference site west-southwest of the outfall. The tops of the drumlins were relatively homogeneous, so that lateral shifts in position usually 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 of the stations north of the outfall (T1-2, T1-3, T1-4, T7-1, and T7-2) continue to have slightly more sediment drape since the outfall went on line.

Encrusting coralline algae has historically been the most abundant and widely distributed taxon encountered during the hard-bottom surveys. Figure 6-7 shows the percent cover of coralline algae estimated from the slides taken during the 1996 to 2004 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 and T6-1). The percent cover of coralline algae was most variable near the edges of the tops of drumlins or on the flanks, where small lateral shifts in location frequently resulted large differences in coralline algal cover. Percent cover of coralline algae was quite stable during the “baseline” period and has remained so at most stations during the post-discharge period. However, several stations located north of the outfall have shown decreases in percent cover of coralline algae during the post discharge period. Table 6-5 shows the estimated percent cover of coralline algae for the 1996 to 2004 time period. Five stations have consistently had lower percent cover of coralline algae since diversion of the outfall, these include 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). The decrease in percent cover of coralline algae at these stations was less pronounced in 2003, but was more pronounced again in 2004.

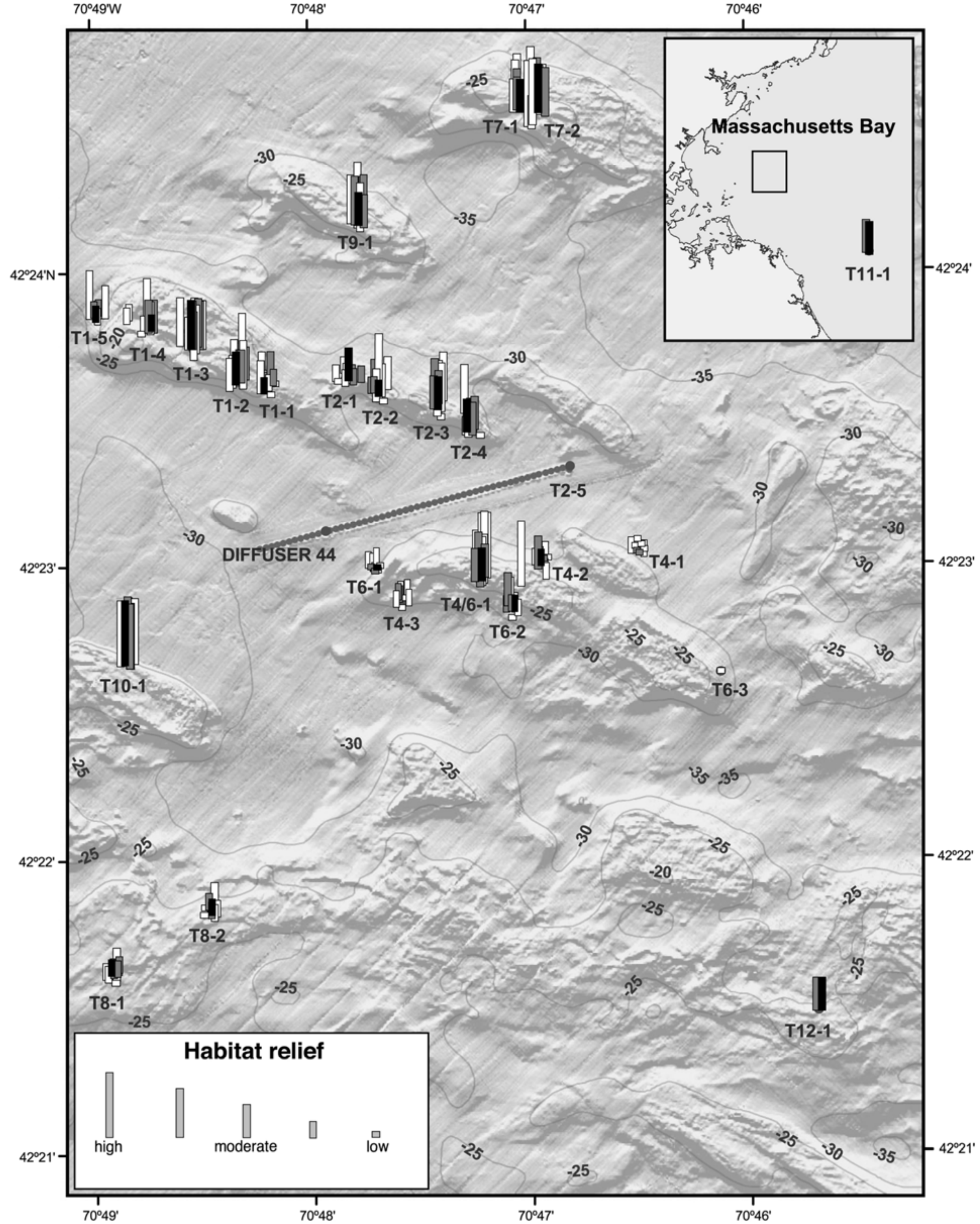


Figure 6-5. Habitat relief determined from the 1995–2004 nearfield hard-bottom surveys. White bars are pre-diversion values, gray bars are values from the first three post-diversion years (2001 to 2003), and black bars are 2004 values.

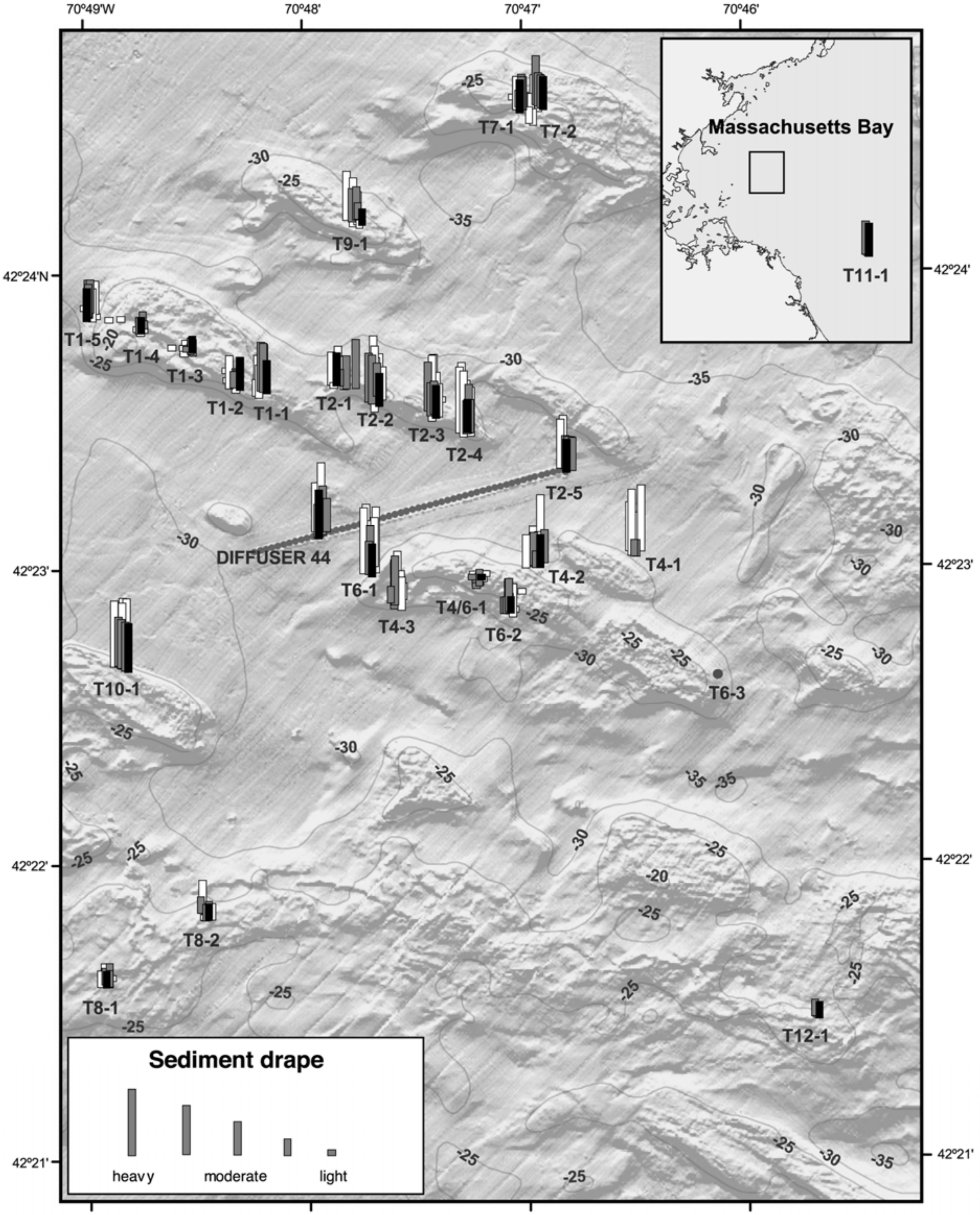


Figure 6-6. Sediment drape determined from the 1995–2004 nearfield hard-bottom surveys. White bars are pre-diversion values, gray bars are values from the first three post-diversion years (2001 to 2003), and black bars are 2004 values.

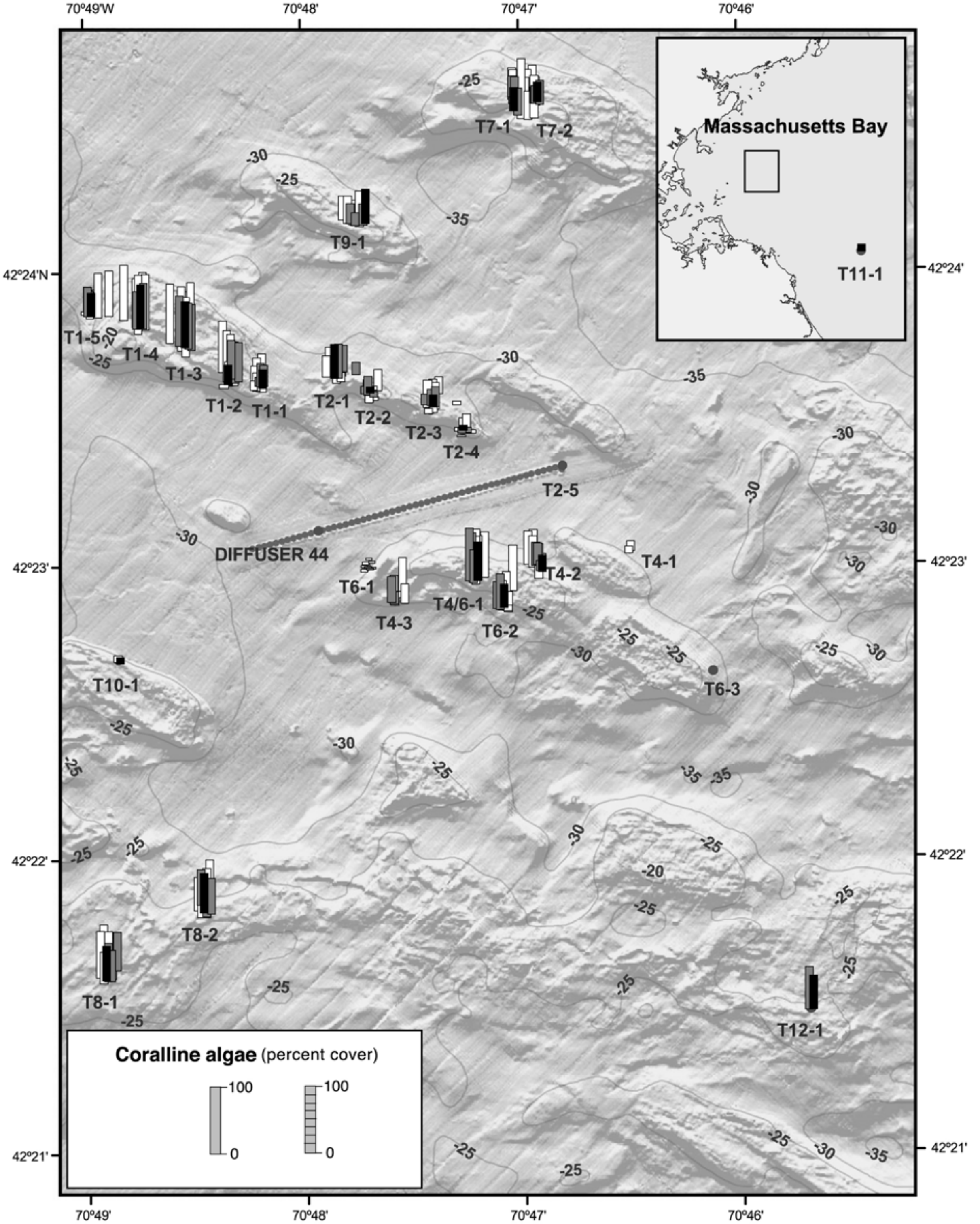


Figure 6-7. Percent cover of coralline algae determined from the 1995–2004 nearfield hard-bottom surveys. White bars are pre-diversion values, gray bars are values from the first three post-diversion years (2001 to 2003), and black bars are 2004 values.

Table 6-5. Estimated percent cover of coralline algae from 1996 to 2004. Noticeable differences between pre- and post-diversion are highlighted by shading. Asterisks mark differences that appear to be related to shifts in position of the areas surveyed.

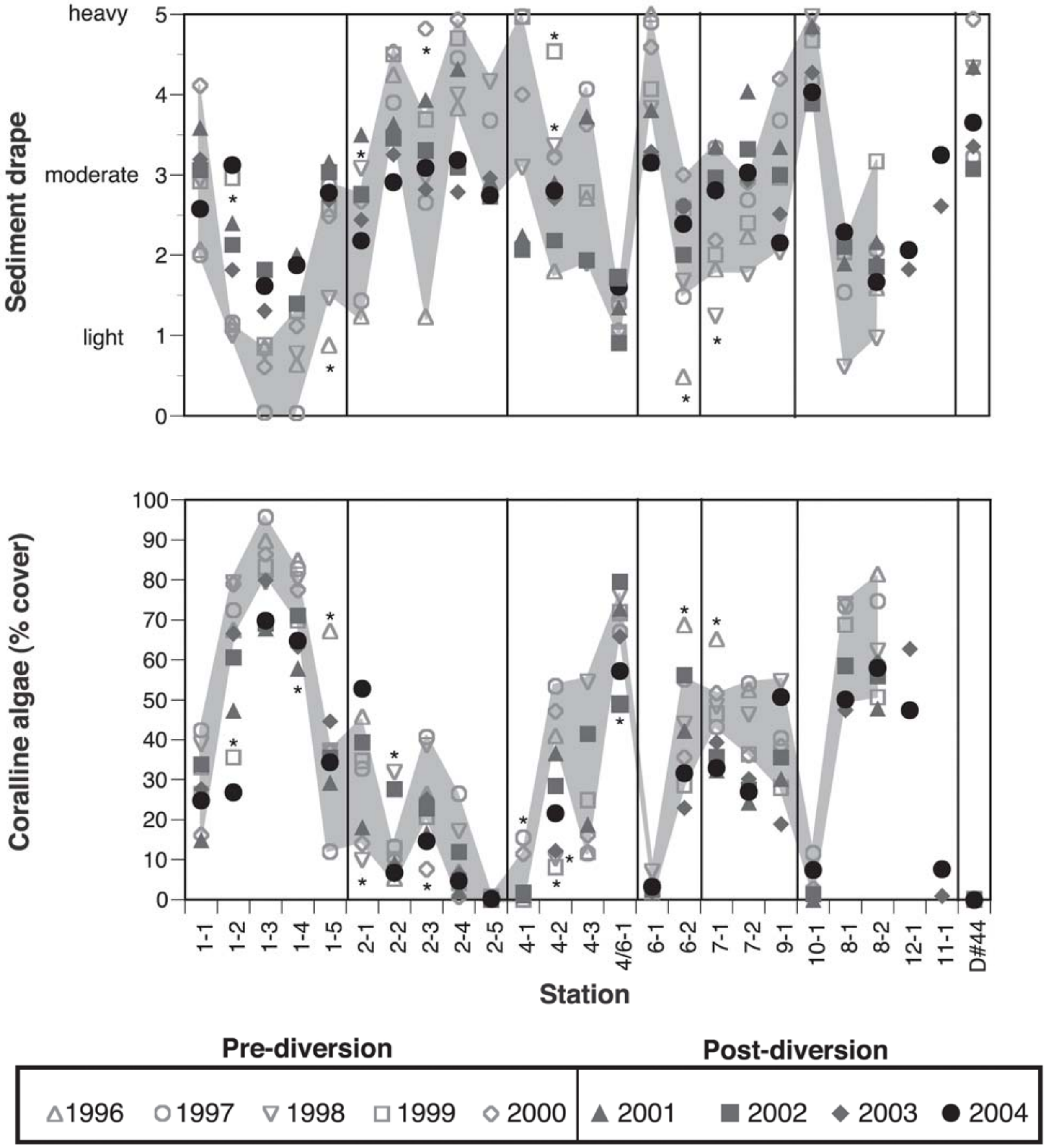
		Pre-diversion					Post-diversion			
Transect	**Waypoint**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
1	1	34	42	39	26	16	15	34	28	25
	2	67	72	79	36*	79	47	61	67	27
	3	90	96	80	83	86	68	69	80	70
	4	85	83	81	70*	77	58	71	63	65
	5	68*	12	37	37	37	29	35	45	34
2	1	46	33	10*	35	14	18	39	53	53
	2	5	13	33*	13	10	9	28	8	7
	3	26	41	39	21	8*	17	23	25	15
	4	7	26	17	4	1	2	12	6	5
	5	<1	<1	<1			0	0	0	0
4	1		15*	1	0	11	1	2		
	2	41	53	10*	8*	47	37	28	12	22
	3	12	12	54*	25	16	19	41		
4/6	1	72	67	76	72	71	73	80 (50)*	66	57
6	1	2	4	7	2	2	3	3	2	3
	2	69*	55	44	29	36	42	56	23	32
7	1	65*	43	48	47	52	32	36	39	33
	2	52	54	46	36	36	24	28	30	27
8	1		73	74	69	49	58	59	47	50
	2	81	75	62	51	58	48	56	59	58
9	1		40	55	28	38	30	36	19	51
10	1		12	<1	2	3	0	1	<1	7
11	1								1	8
12	1								63	48
Diffuser	44		0	<1		<1	<1	<1	0	0

Several other stations have also had lower percent cover post-diversion than during the baseline period, but these changes have not been as consistent. The other northern reference station (T9-1) had a marked decrease in percent cover of coralline algae in 2003, and a marked increase (19% to 51%) in 2004. A flank station T4-2 also had less percent cover of coralline algae during three of the four post-diversion years. One additional station (T4/6-1) showed a decrease in coralline algae in 2004, but this may reflect variability within the site (note the variability observed at two different locations within this station in 2002). In contrast, one station located north of the outfall (T2-1) has had higher percent cover of coralline algae in 2003 and 2004.

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, Sears and Cooper 1978). However, in previous years of this study, percent cover of coralline algae has been found to be inversely related to sediment drape (Kropp *et al*. 2002, Maciolek *et al.* 2004). Percent cover is usually highest in areas that have little drape and lowest in areas that have moderate to heavy drape. This is not surprising, because the encrusting growth form of coralline algae would make them quite susceptible to smothering by fine particles.

Changes in percent cover of coralline algae and sediment drape at each of the stations over time can be seen on Figure 6-8. The post-diversion decrease in percent cover of coralline algae can be seen at several stations on transect 1, and at the two northernmost reference stations. These stations frequently also had 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 between 2001 and 2004, while on transect 7 it increased from moderately light to moderate at T7-1 and moderately light to moderately heavy at T7-2. Percent cover of coralline algae was also lower post-diversion at T4-2, a flank site located south of the outfall. In contrast, percent cover of coralline algae was not reduced, and sediment drape was not elevated, at most of the other waypoints. Reasons for the increase in sediment drape and decrease in coralline cover at some locations and not at others are not readily apparent, but may be related to the discharge.

In contrast to the wide distribution of coralline algae, the distributions of the three upright algae commonly inhabiting the drumlins, the filamentous red alga *Ptilota serrata,* the dulse *Rhodymenia palmata*, and the shotgun kelp *Agarum cribosum*, were quite restricted. Additionally, their abundances varied quite widely during both the pre- and post-diversion periods (Figure 6-9). Some of this variability appears to reflect patchiness in the small-scale (within station) spatial distributions of the upright algae. Dense stands of upright algae were frequently seen neighboring areas totally devoid of them. This spatial patchiness may reflect the fact that upright algae were most abundant on the top of larger boulders in areas of moderate to high relief. However, most of the variability observed appears to reflect yearly changes in the abundance of upright algae, rather than changes related to outfall diversion. Both *P. serrata* and *R. palmata* were commonly observed in the middle of transect 2, at Station T1-1, and at the three northern reference sites (T7 and T9). *Ptilota serrata* was most abundant in 1996 and 1998, and least abundant in 1997. Additionally, the density of this filamentous red alga declined from 1998 to 2003, and increased slightly in 2004. In contrast, the density of *R. palmata*, followed a different trend. Dulse was most abundant in 1997, decreased in 1998, slowly increased until 2001 or 2002, and then decreased again. *Agarum cribosum* had the most restrictive distribution of the upright algae, and was abundant only at the northernmost reference sites. This alga was most abundant at T7-2, where peak numbers were observed in 2000 and then rapidly declined until 2002. The peak density of shotgun kelp in 2000 coincided with the appearance of lacy bryozoans *Membranipora* sp. encrusting many of the kelp fronds. The dramatic decline in shotgun kelp after 2000 may be related to the appearance of the invasive bryozoan, rather than the start of outfall discharge. There does appear to be a general trend of decreased abundances of upright algae over time. In contrast, the abundance of *P. serrata* increased at T1-3 in 2004.



* denotes changes related to shifts in position

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 1996–2004 surveys. Shaded area shows the range baseline values.

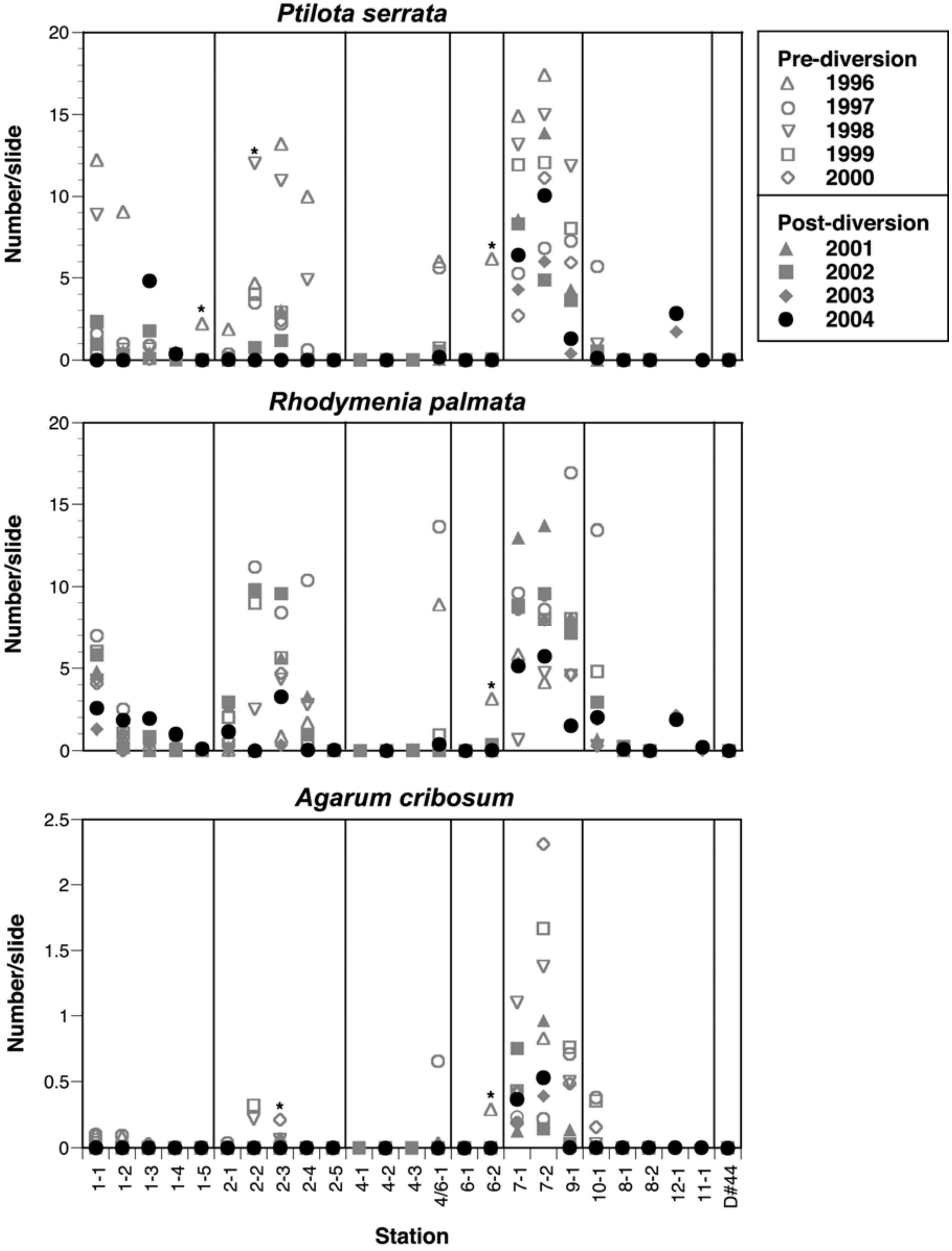


Figure 6-9. Abundance of three species of upright algae, (a) *Ptilota serrata*, (b) *Rhodymenia palmata*, and (c) *Agarum cribosum* at the nearfield hard-bottom sites, as determined from 35-mm slides taken during the 1996–2004 surveys.

One pronounced biotic change was noted in 2003, when dense aggregations of adult barnacles were observed at 13 of the 23 stations. This massive influx of barnacles appeared to reflect a large recruitment event that occurred in the fall of 2002 (Maciolek *et al*. 2004). By 2004, most of these barnacles had died off due to overcrowding, leaving large surfaces of rocks covered with barnacle bases and valves. Rocks covered with barnacle debris were observed at 11 stations. Two of the new species observed in 2004, a frilly white encrusting organism (sponge?) and a grey translucent encrusting organism, were seen only on boulders that had previously been colonized by the barnacles.

The benthic communities inhabiting the hard-bottom areas were remarkably stable between 1996 and 2002 (Maciolek *et al*. 2003), with many of the sites remaining relatively unchanged from year to year. During this time period, differences in cluster designation were usually attributable to slight geographic shifts in the area being surveyed (Figure 6-10). Upright algae historically dominated benthic communities at the northern reference sites (T7-1, T7-2, and T9-1) and at several sites located on the deeper drumlin top north of the outfall (T1-1, T2-2, and T2-3). In contrast, coralline algae historically dominated communities at two of the southern reference sites (T8-1 and T8-2) and on the shallower drumlin top north of the outfall (T1-2, T1-3, and T1-4). Only one or two weak departures from the baseline pattern were observed in 2001 and 2002, while four stations showed shifts in community structure in 2003, and three stations showed shifts in 2004 (Table 6-6). The shifts observed in 2003 mainly reflected decreases in the number of upright algae (cluster 1) at T1-1, T2-2, T2-3, and T9-1 resulting in communities dominated by coralline algae (cluster 2). The increase in the number of upright algae observed in 2004 resulted in a reversal of this trend at two of the stations, T2-3 and T9-1. However, the appearance of upright algae at another station, T1-3, resulted in its shift from cluster 2 to cluster 1. The positioning of site T6-1 as an outlier to clusters 1 and 2 in 2003 and 2004 merely reflects the relatively depauperate nature of the fauna inhabiting the sediment-covered cobble pavement characteristic of this site, rather than a shift in the benthic community. Community structure at the remaining sites stayed relatively constant through 2004. Stations that had historically been dominated by coralline algae remained in cluster 2, and diffuser heads and some of the flank stations clustered separately. The benthic community at the new nearfield southern reference site (T12-1) added in 2003 resembled the communities found at T8-1 and T8-2 in being dominated by coralline algae, but differed in that it also supported some upright algae (dulse and *Ptilota serata*). The community at the new farfield reference site nearer to Scituate (T11-1) differs from all of the other reference sites in that it supports very few algae.

The diffuser heads of the outfall continue to be colonized by *Metridium senile* and *Halocynthia pyriformis*. The barnacle settlement observed on the head of the inactive diffuser (Diffuser #44) in 2003 has died off, leaving large areas of uncolonized hard substrate. Diffuser #44 has historically been colonized mainly by *H. pyriformis* and this trend continued into 2004. In contrast, the head of the active diffuser (Diffuser #2 at T2-5) has historically been colonized by dense aggregations of *M. senile* on most of its exposed surfaces, and this trend also continued in 2004. Additionally, the riprap surrounding the immediate vicinity of the diffuser heads continues to be colonized by a variety of encrusting organisms.

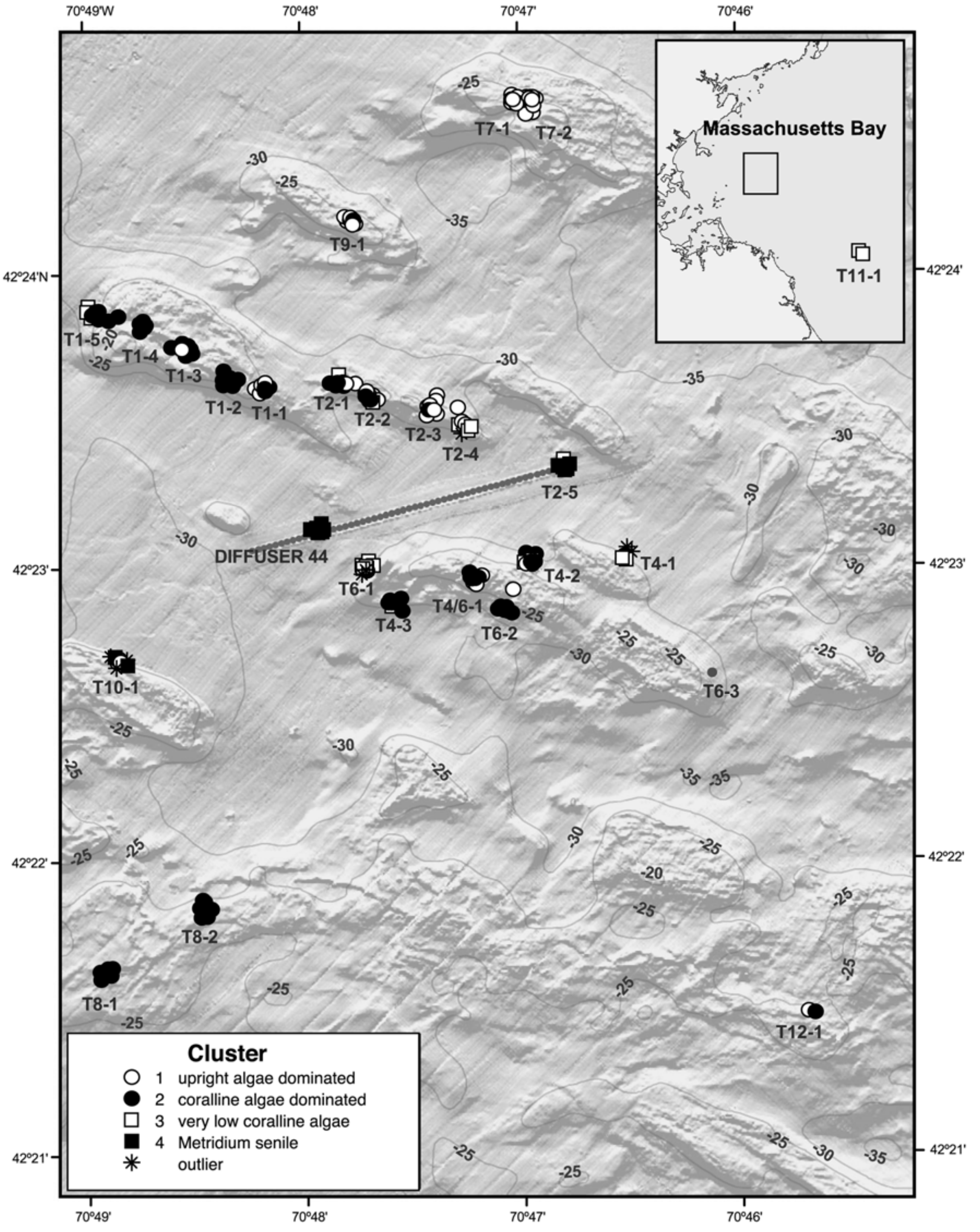


Figure 6-10. Benthic communities defined from classification of the 35-mm images taken during the 1995 to 2004 nearfield hard-bottom surveys.

Table 6-6. Cluster group designations defined by classification analysis of the waypoints surveyed from 1996 to 2004. Differences between pre- and post-diversion are highlighted by shading. Asterisks show differences explained by shifts in location.

		Pre-diversion					Post-diversion			
Transect	**Waypoint**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
1	1	1	1	1	1	2	1	1	2	2
	2	1*	2	2	2	2	2	2	2	2
	3	2	2	2	2	2	2	2	2	1
	4	2	2	2	2	2	2	2	2	2
	5	2*	3	3	2*	3	2	2	2	2
2	1	2	2	3*	2	2	1*	1	2	2
	2	1	1	1	1	3*	1	1	2	2*
	3	1	1	1	1	1	1	1	2	1
	4	1	1	1	3	outlier	1	1	3	3
	5	4	4	3*			4	4	4	4
4	1		2	outlier	outlier	2	3	3		
	2	2	2	3*	3*	2	1	2	2	2
	3	3	3	2	2	2	2	2		
4/6	1	1	1	2	2	2	2	2 (1)	2	2
6	1	3	3	3	3	2	3	3	outlier	outlier
	2	1*	2	2	2	2	2	2	2	2
7	1	1	1	1	1	1	1	1	1	1
	2	1	1	1	1	1	1	1	1	1
8	1		2	2	2	2	2	2	2	2
	2	2	2	2	2	2	2	2	2	2
9	1		1	1	1	1	1	1	2	1
10	1		1	outlier	outlier	1	outlier	1	4	outlier
11	1								3	3
12	1								2	1
Diffuser	44		4	4		4	4	4	4	4

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 on line and have continued post discharge. When only sites that were surveyed in each of the years are taken into account, several patterns become apparent. Abundances of the green sea urchin *Strongylocentrotus droebachiensis* appear to follow a cyclical pattern, declining from 0.88 individuals per photograph in 1996 to 0.28 individuals per photograph in 2000, then increasing slightly in 2001 and 2002 (0.33 and 0.39 individuals per photograph, respectively), and again decreasing in 2003 and 2004 (0.16 and 0.13 individuals per photograph, respectively). Two other species, the crab *Cancer* sp. and the lobster *Homarus americanus*, increased until 2002 and then started decreasing. In the still photographs, *Cancer* crabs increased from one to six individuals seen annually between 1996 and 1999, to 53 individuals seen in 2002, and decreased in 2003 and 2004. This pattern was also reflected in the video data, with 3 to 14 *Cancer* crabs observed annually between 1996 and 1999, increasing to 143 individuals in 2002, and decreasing again in 2003 and 2004. The video data for lobsters showed a similar trend, with the highest numbers of lobsters being seen in 2002 and 2003. With the exception of 2003, the number of cod observed during these surveys has also increased over time. Prior to the outfall going on line, no cod had been seen at the diffuser stations, yet in all post-diversion years cod have been seen in the vicinity of 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. The presence of numerous cod in the vicinity of the outfall was particularly noticeable during a visual structural survey of the diffuser heads that was conducted in June 2003, when the presence of codfish was frequently used as an indicator of proximity to an actively discharging diffuser head.

Table 6-7. Number of individuals of selected species observed during the nearfield hard-bottom surveys, adjusted to include only stations that were surveyed in all nine years.

	Pre-diversion					**Post-diversion**			
	1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Video									
Minutes of video	401	448	317	374	380	354	373	386	364
Cancer spp. (rock crab)	6	3	3	14	70	112	143	135	111
Gadus morhua (cod)	-	6	12	17	11	22	22	6	30
Homarus americanus (lobster)	6	2	9	3	17	14	23	29	12
Still Photographs									
Number of photographs	501	504	514	491	542	483	528	538	551
Strongylocentrotus droebachiensis	441	329	279	285	150	159	204	85	70
Cancer spp. (rock crab)	3	1	2	6	12	43	53	44	14
Gadus morhua (cod)	-	-	2	3	-	7	4	-	-
Homarus americanus (lobster)	1	-	3	3	5	4	12	4	5

6.4 Monitoring Question

- *Has the hard-bottom community changed? (Question #30)*

The hard-bottom benthic communities near the outfall remained relatively stable over the 1995–2000 baseline time period, and have not substantially changed with activation of the outfall. Major departures from baseline conditions have not occurred during the post-diversion years, however some subtler changes have been observed (Figure 6-11). A general decrease in the number of upright algae observed in 2003 resulted in a change in the benthic community at four of the sites. In 2004, two of these four sites reverted back to communities dominated by upright algae. It is unlikely that the decrease in upright algae was attributable to the activation of the outfall, since the general decline had started in the late 1990s and the number of upright algae had increased again by 2004. The abundance of upright algae was found to be quite variable throughout the baseline period, reflecting year-to-year differences in abundance as well as extreme spatial variability. This variability has continued into the baseline period and appears to reflect inherent cyclical changes.

Another post-discharge change that has been observed in the hard-bottom communities has been an increase in sediment drape and a concurrent decrease in percent cover of coralline algae at several sites on the top of the drumlin north of the outfall and at the two northernmost reference sites. The decrease in coralline algae has been noticeable in all four post-diversion years, though it was less pronounced in 2003. In 2004, an additional station south of the outfall also had reduced percent cover of coralline algae. Whether this decrease is related to the outfall discharge is presently not known. The baseline data indicated 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. Changes might also be expected in the depth distribution of coralline algae and upright 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 both coralline and upright algae would be reduced. Conversely, if water clarity were increased, then it is expected that high coralline algal coverage or upright algae could extend into some of the deeper areas. No noticeable changes in the depth distribution of coralline algae have been observed since discharge began. Additionally, the decline observed in the numbers of upright algae in recent years appears to be reversing.

The first four years of discharge monitoring, have shown only modest changes suggestive of outfall impact at a subset of five stations, and additional changes that do not appear to be related to outfall impact at an additional two stations. Lush epifaunal growth continues to thrive on the diffuser heads surveyed for this study (Figure 6-12), 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.

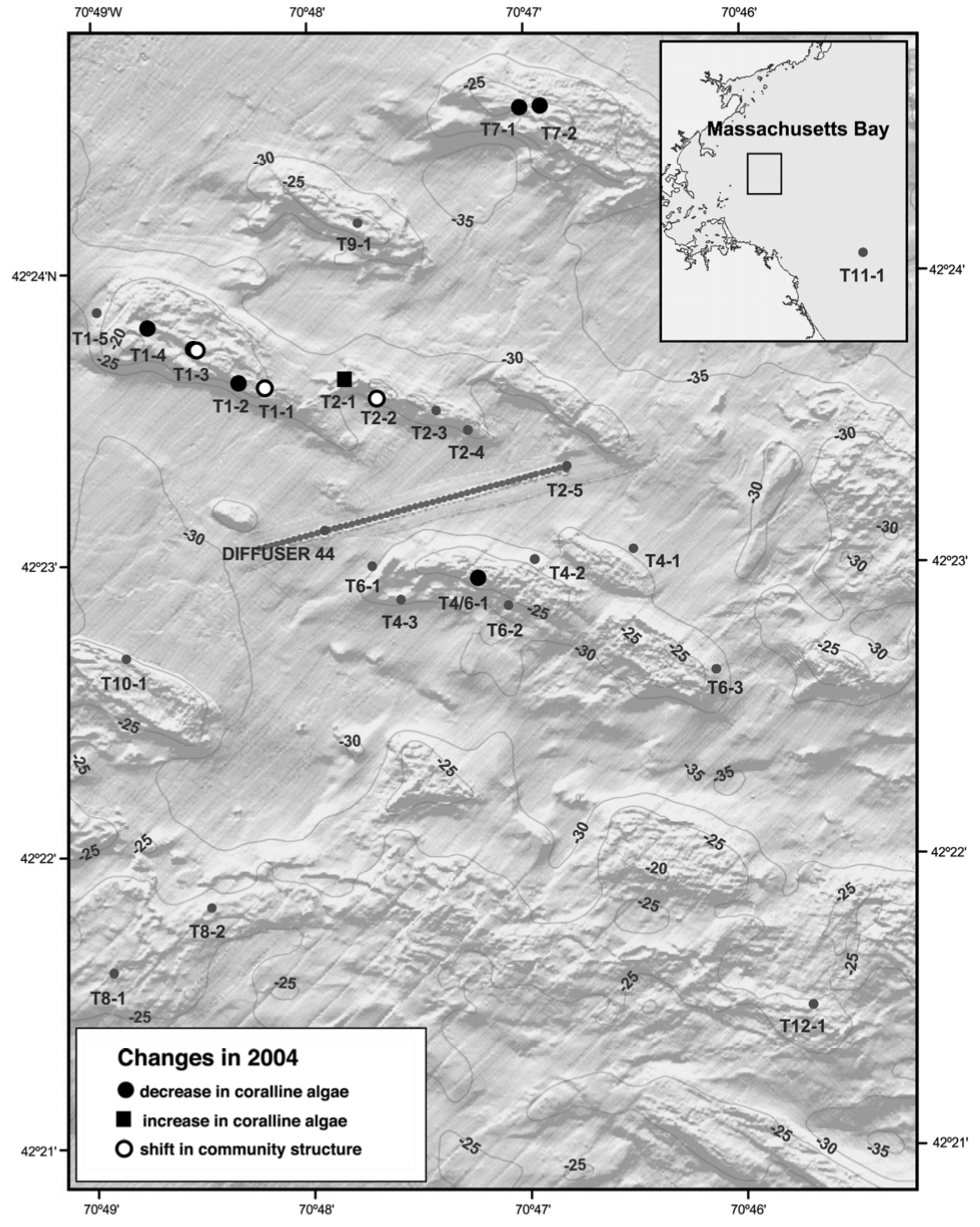


Figure 6-11. Map of changes observed in the hard-bottom communities in 2004.

Figure 6-12. Photograph of the head of the active diffuser at T2-5 (Diffuser #2). Note the numerous frilly anemones *Metridium senile* surrounding the discharge port. A large blood star *Henricia sanguinolenta* is also visible.

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APPENDIX A1

Station Data:
Benthic Grab Samples (BN041/BF041)

Table A1-1. Field Data from Nearfield/Farfield Benthic Surveys BN041/BF041.

(Times are reported as Eastern Standard Time)

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_TOP	DEPTH_UNIT_CODE	SAMPLE_ID	SAMP_VOL	SAMP_VOL_UNIT_CODE	DEPTH_CLASS_CODE
BMBSOFT	BF041	FF04	08/04/2004 08:49:10	42.2885017	-70.4249191	87.9	m	DGPS	+/- 10m	SED	VV04	9.5	0	cm	BF0410D5	3.25	L	E
BMBSOFT	BF041	FF04	08/04/2004 08:49:10	42.2885017	-70.4249191	87.9	m	DGPS	+/- 10m	SED	VV04	10	0	cm	BF0410D3	3.25	L	E
BMBSOFT	BF041	FF04	08/04/2004 08:49:10	42.2885017	-70.4249191	87.9	m	DGPS	+/- 10m	SED	VV04	10	0	cm	BF0410D1	3.25	L	E
BMBSOFT	BF041	FF04	08/04/2004 08:49:10	42.2885017	-70.4249191	87.9	m	DGPS	+/- 10m	SED	VV04	9.5	0	cm	BF0410D0	3.25	L	E
BMBSOFT	BF041	FF04	08/04/2004 08:49:10	42.2885017	-70.4249191	87.9	m	DGPS	+/- 10m	SED	VV04	10	0	cm	BF0410CD	3.25	L	E
BMBSOFT	BF041	FF05	08/04/2004 10:22:36	42.1333008	-70.4226303	62.8	m	DGPS	+/- 10m	SED	VV04	9.5	0	cm	BF041201	3.25	L	E
BMBSOFT	BF041	FF05	08/04/2004 10:22:36	42.1333008	-70.4226303	62.8	m	DGPS	+/- 10m	SED	VV04	10	0	cm	BF041200	3.25	L	E
BMBSOFT	BF041	FF05	08/04/2004 10:22:36	42.1333008	-70.4226303	62.8	m	DGPS	+/- 10m	SED	VV04	10	0	cm	BF0411FF	3.25	L	E
BMBSOFT	BF041	FF05	08/04/2004 10:22:36	42.1333008	-70.4226303	62.8	m	DGPS	+/- 10m	SED	VV04	9.5	0	cm	BF0411FE	3.25	L	E
BMBSOFT	BF041	FF05	08/04/2004 10:22:36	42.1333008	-70.4226303	62.8	m	DGPS	+/- 10m	SED	VV04	9.5	0	cm	BF0411FC	3.25	L	E
BMBSOFT	BF041	FF07	08/04/2004 12:09:53	41.9582481	-70.2666702	39.9	m	DGPS	+/- 10m	SED	VV01	14	0	cm	BF04121B	11	L	E
BMBSOFT	BF041	FF07	08/04/2004 12:09:53	41.9582481	-70.2666702	39.9	m	DGPS	+/- 10m	SED	VV04	10	0	cm	BF041217	3.25	L	E
BMBSOFT	BF041	FF07	08/04/2004 12:09:53	41.9582481	-70.2666702	39.9	m	DGPS	+/- 10m	SED	VV04	9.5	0	cm	BF041210	3.25	L	E
BMBSOFT	BF041	FF07	08/04/2004 12:09:53	41.9582481	-70.2666702	39.9	m	DGPS	+/- 10m	SED	VV04	10	0	cm	BF04120C	3.25	L	E
BMBSOFT	BF041	FF07	08/04/2004 12:09:53	41.9582481	-70.2666702	39.9	m	DGPS	+/- 10m	SED	VV04	10	0	cm	BF04120A	3.25	L	E
BMBSOFT	BF041	FF09	08/04/2004 07:20:07	42.3125	-70.656868	48.2	m	DGPS	+/- 10m	SED	VV04	9.5	0	cm	BF0410BF	3.25	L	E
BMBSOFT	BF041	FF09	08/04/2004 07:20:07	42.3125	-70.656868	48.2	m	DGPS	+/- 10m	SED	VV04	9.5	0	cm	BF0410BD	3.25	L	E
BMBSOFT	BF041	FF09	08/04/2004 07:20:07	42.3125	-70.656868	48.2	m	DGPS	+/- 10m	SED	VV04	9	0	cm	BF0410B9	3	L	E
BMBSOFT	BF041	FF09	08/04/2004 07:20:07	42.3125	-70.656868	48.2	m	DGPS	+/- 10m	SED	VV04	9.5	0	cm	BF0410BA	3.25	L	E
BMBSOFT	BF041	FF09	08/04/2004 07:20:07	42.3125	-70.656868	48.2	m	DGPS	+/- 10m	SED	VV04	9.5	0	cm	BF0410BE	3.25	L	E
BMBSOFT	BF041	FF10	08/02/2004 07:24:52	42.4141655	-70.8788986	28.4	m	DGPS	+/- 10m	SED	VV04	8	0	cm	BF041016	2.75	L	E
BMBSOFT	BF041	FF10	08/02/2004 07:24:52	42.4141655	-70.8788986	28.4	m	DGPS	+/- 10m	SED	VV04	8	0	cm	BF041015	2.75	L	E
BMBSOFT	BF041	FF10	08/02/2004 07:24:52	42.4141655	-70.8788986	28.4	m	DGPS	+/- 10m	SED	VV04	7.5	0	cm	BF041013	2.5	L	E
BMBSOFT	BF041	FF10	08/02/2004 07:24:52	42.4141655	-70.8788986	28.4	m	DGPS	+/- 10m	SED	VV04	10	0	cm	BF041010	3.25	L	E
BMBSOFT	BF041	FF10	08/02/2004 07:24:52	42.4141655	-70.8788986	28.4	m	DGPS	+/- 10m	SED	VV04	10	0	cm	BF04100D	3.25	L	E
BMBSOFT	BF041	FF13	08/02/2004 15:52:04	42.3200836	-70.823082	21.2	m	DGPS	+/- 10m	SED	VV04	9	0	cm	BF0410A5	3	L	E
BMBSOFT	BF041	FF13	08/02/2004 15:52:04	42.3200836	-70.823082	21.2	m	DGPS	+/- 10m	SED	VV04	9.5	0	cm	BF0410A4	3.25	L	E
BMBSOFT	BF041	FF13	08/02/2004 15:52:04	42.3200836	-70.823082	21.2	m	DGPS	+/- 10m	SED	VV04	9.5	0	cm	BF0410A0	3.25	L	E
BMBSOFT	BF041	FF13	08/02/2004 15:52:04	42.3200836	-70.823082	21.2	m	DGPS	+/- 10m	SED	VV04	9	0	cm	BF04109D	3	L	E
BMBSOFT	BF041	FF13	08/02/2004 15:52:04	42.3200836	-70.823082	21.2	m	DGPS	+/- 10m	SED	VV04	9.5	0	cm	BF0410A1	3.25	L	E
BMBSOFT	BF041	NF05	08/02/2004 10:00:48	42.4271011	-70.8339462	37.4	m	DGPS	+/- 10m	SED	VV04	8.5	0	cm	BF04103A	3	L	E
BMBSOFT	BF041	NF05	08/02/2004 10:00:48	42.4271011	-70.8339462	37.4	m	DGPS	+/- 10m	SED	VV04	9	0	cm	BF041039	3	L	E
BMBSOFT	BF041	NF07	08/02/2004 10:28:09	42.4100838	-70.8148346	35.5	m	DGPS	+/- 10m	SED	VV04	7	0	cm	BF041043	2.25	L	E
BMBSOFT	BF041	NF07	08/02/2004 10:28:09	42.4100838	-70.8148346	35.5	m	DGPS	+/- 10m	SED	VV04	9.5	0	cm	BF041042	3.25	L	E
BMBSOFT	BF041	NF08	08/02/2004 09:02:04	42.4000511	-70.8633499	30	m	DGPS	+/- 10m	SED	VV04	9.5	0	cm	BF041024	3.25	L	E
BMBSOFT	BF041	NF08	08/02/2004 09:02:04	42.4000511	-70.8633499	30	m	DGPS	+/- 10m	SED	VV04	10	0	cm	BF04101F	3.25	L	E
BMBSOFT	BF041	NF09	08/02/2004 09:38:58	42.399765	-70.844902	31.5	m	DGPS	+/- 10m	SED	VV04	9	0	cm	BF04102F	3	L	E
BMBSOFT	BF041	NF09	08/02/2004 09:38:58	42.399765	-70.844902	31.5	m	DGPS	+/- 10m	SED	VV04	9	0	cm	BF04102E	3	L	E
BMBSOFT	BF041	NF12	08/02/2004 12:17:30	42.3899345	-70.8305969	36.1	m	DGPS	+/- 10m	SED	VV01	13	0	cm	BF041067	11	L	E
BMBSOFT	BF041	NF12	08/02/2004 12:17:30	42.3899345	-70.8305969	36.1	m	DGPS	+/- 10m	SED	VV04	9.5	0	cm	BF041064	3.25	L	E
BMBSOFT	BF041	NF12	08/02/2004 12:17:30	42.3899345	-70.8305969	36.1	m	DGPS	+/- 10m	SED	VV04	9	0	cm	BF041063	3	L	E
BMBSOFT	BF041	NF12	08/02/2004 12:17:30	42.3899345	-70.8305969	36.1	m	DGPS	+/- 10m	SED	VV04	10	0	cm	BF041065	3.25	L	E
BMBSOFT	BF041	NF12	08/02/2004 12:17:30	42.3899345	-70.8305969	36.1	m	DGPS	+/- 10m	SED	VV01	14	0	cm	BF041066	11	L	E
BMBSOFT	BF041	NF16	08/02/2004 14:11:04	42.3782845	-70.8376465	32.4	m	DGPS	+/- 10m	SED	VV04	10	0	cm	BF04107B	3.25	L	E
BMBSOFT	BF041	NF16	08/02/2004 14:11:04	42.3782845	-70.8376465	32.4	m	DGPS	+/- 10m	SED	VV04	9.5	0	cm	BF04107A	3.25	L	E
BMBSOFT	BF041	NF17	08/02/2004 13:15:34	42.3814011	-70.8147659	31.4	m	DGPS	+/- 10m	SED	VV04	7.5	0	cm	BF041073	2.5	L	E
BMBSOFT	BF041	NF17	08/02/2004 13:15:34	42.3814011	-70.8147659	31.4	m	DGPS	+/- 10m	SED	VV04	7.5	0	cm	BF041072	2.5	L	E
BMBSOFT	BF041	NF17	08/02/2004 13:15:34	42.3814011	-70.8147659	31.4	m	DGPS	+/- 10m	SED	VV04	7	0	cm	BF041071	2.25	L	E
BMBSOFT	BF041	NF17	08/02/2004 13:15:34	42.3814011	-70.8147659	31.4	m	DGPS	+/- 10m	SED	VV01	10	0	cm	BF04106E	9	L	E
BMBSOFT	BF041	NF17	08/02/2004 13:15:34	42.3814011	-70.8147659	31.4	m	DGPS	+/- 10m	SED	VV01	8	0	cm	BF04106F	6.5	L	E
BMBSOFT	BF041	NF18	08/02/2004 11:46:07	42.3967018	-70.8218307	36.1	m	DGPS	+/- 10m	SED	VV04	8	0	cm	BF04105D	2.75	L	E
BMBSOFT	BF041	NF18	08/02/2004 11:46:07	42.3967018	-70.8218307	36.1	m	DGPS	+/- 10m	SED	VV04	8.5	0	cm	BF04105B	3	L	E
BMBSOFT	BF041	NF19	08/02/2004 14:37:52	42.371685	-70.8050842	35.2	m	DGPS	+/- 10m	SED	VV04	8	0	cm	BF041088	2.75	L	E
BMBSOFT	BF041	NF19	08/02/2004 14:37:52	42.371685	-70.8050842	35.2	m	DGPS	+/- 10m	SED	VV04	8	0	cm	BF041083	2.75	L	E
BMBSOFT	BF041	NF22	08/02/2004 15:21:51	42.3478317	-70.8150024	34.5	m	DGPS	+/- 10m	SED	VV04	10	0	cm	BF041092	3.25	L	E
BMBSOFT	BF041	NF22	08/02/2004 15:21:51	42.3478317	-70.8150024	34.5	m	DGPS	+/- 10m	SED	VV04	9.5	0	cm	BF041094	3.25	L	E
BMBSOFT	BF041	NF23	08/02/2004 10:54:22	42.3977318	-70.8017502	35.1	m	DGPS	+/- 10m	SED	VV04	8	0	cm	BF041050	2.75	L	E
BMBSOFT	BF041	NF23	08/02/2004 10:54:22	42.3977318	-70.8017502	35.1	m	DGPS	+/- 10m	SED	VV04	8.5	0	cm	BF04104E	3	L	E

Table A1-2. Station data and field observations for individual soft-bottom infauna and chemistry grab samples collected August 2004 (BN041/BF041).

Station ID	Sample ID	Date/Time (EDT)	Latitude (N)	Longitude (W)	Sample Type	RPD Depth (cm)	Sediment Texture	Fauna and Miscellaneous Observations
FF10	BF04100D	8/2/04 09:04	42.41417	-70.87890	Chem	0.5	silty sand	No fauna on surface
	BF041010	8/2/04 09:18	42.41410	-70.87895	Chem	0.5	silty sand	Some amphipod tubes
	BF041013	8/2/04 09:32	42.41420	-70.87898	Biol	0.5	silty sand	No fauna on surface
	BF041015	8/2/04 09:41	42.41422	-70.87897	Biol	0.5	silty sand	Amphipod, tubes
	BF041016	8/2/04 09:48	42.41417	-70.87894	Chem	0.4	silty sand	Tubes
NF08	BF04101F	8/2/04 10:05	42.40005	-70.86335	Biol	0.5	silt	Amphipod
	BF041024	8/2/04 10:28	42.39990	-70.86359	Chem	0.3	silt	Many tubes
NF09	BF04102E	8/2/04 10:42	42.39977	-70.84490	Chem	0.4	v. fine sandy silt	Worm tubes
	BF04102F	8/2/04 10:47	42.39985	-70.84496	Biol	1.0		Worm tubes
NF05	BF041039	8/2/04 11:09	42.42710	-70.83395	Chem	0.5	silty sand	Amphipods, many tubes
	BF04103A	8/2/04 11:16	42.42705	-70.83395	Biol	1.0	silty sand	Amphipods, many tubes, fecal pellets
FF07	BF041042	8/2/04 11:35	42.41008	-70.81483	Biol	0.3	sandy silt	Many tubes
	BF041043	8/2/04 11:40	42.41007	-70.81492	Chem	0.6	silty sand	Tubes
NF23	BF04104E	8/2/04 12:03	42.39773	-70.80175	Chem	0.3	sandy	No fauna on surface, shells
	BF041050	8/2/04 12:15	42.39780	-70.80193	Biol	0.6	sandy	Tubes
NF18	BF04105B	8/2/04 12:54	42.39670	-70.82183	Chem	0.8	sandy with pebbles	Tubes
	BF04105D	8/2/04 13:07	42.39667	-70.82188	Biol	0.7		Tubes, shells, rocks
NF12	BF041063	8/2/04 13:19	42.38993	-70.83060	Biol	1.2	silt	Nothing noted
	BF041064	8/2/04 13:26	42.39027	-70.83057	Biol	0.5	silt	Tubes
	BF041065	8/2/04 13:32	42.39010	-70.83058	Biol	0.8	silt	Tubes
	BF041066	8/2/04 13:48	42.38995	-70.83050	Chem	0.5	silt	Tubes
	BF041067	8/2/04 14:01	42.39002	-70.83041	Chem	1.2	silt	Tubes
NF17	BF04106E	8/2/04 14:17	42.38140	-70.81477	Chem	>10.0	medium sand	Amphipod, worm, sand dollar, shrimp
	BF04106F	8/2/04 14:28	42.38135	-70.81483	Chem	>8.0	medium sand	Amphipods, shrimp, tubes
	BF041071	8/2/04 14:44	42.38142	-70.81485	Biol	>7.0	sandy	Amphipods, tubes
	BF041072	8/2/04 14:50	42.38132	-70.81490	Biol	>7.5	sandy	Tubes
	BF041073	8/2/04 14:56	42.38148	-70.81483	Biol	>7.5	sandy	Tubes
NF16	BF04107A	8/2/04 15:15	42.37828	-70.83765	Biol	0.5	sandy silt	No fauna on surface
	BF04107B	8/2/04 15:23	42.37831	-70.83772	Chem	1.0	v. fine sandy silt	Amphipods, tubes
NF19	BF041083	8/2/04 15:39	42.37169	-70.80508	Chem	1.0	silty sand	Tubes, rocks, shell
	BF041088	8/2/04 16:08	42.37187	-70.80524	Biol	1.0	sandy	Amphipod, pebbles, shell, gelatinous egg sac
NF22	BF041092	8/2/04 16:27	42.34783	-70.81500	Biol	1.0	sandy silt	Tubes
	BF041094	8/2/04 16:36	42.34782	-70.81495	Chem	0.5	v. fine sandy silt	Many tubes
FF13	BF04109D	8/2/04 16:57	42.32008	-70.82308	Biol	0.6	sandy silt	Tubes
	BF0410A0	8/2/04 17:03	42.32005	-70.82270	Chem	0.3	v. fine sandy silt	Nothing noted
	BF0410A1	8/2/04 17:10	42.31995	-70.82273	Biol	0.4		Tubes
	BF0410A4	8/2/04 17:15	42.32000	-70.82283	Chem	0.4		Tubes
	BF0410A5	8/2/04 17:21	42.31987	-70.82273	Biol	1.0		Tubes
FF09	BF0410B9	8/4/04 08:26	42.31250	-70.65687	Chem	1.0	sandy silt	Snail, tubes
	BF0410BA	8/4/04 08:31	42.31258	-70.65665	Biol	1.0	sandy silt	Amphipod, starfish, tubes
	BF0410BD	8/4/04 08:41	42.31255	-70.65663	Chem	1.0	sandy silt	Tubes
	BF0410BE	8/4/04 08:49	42.31258	-70.65660	Biol	1.2	sandy silt	Tubes, no fauna seen
	BF0410BF	8/4/04 08:55	42.31258	-70.65667	Biol	1.0	sandy silt	Tubes, no fauna seen

Station ID	Sample ID	Date/Time (EDT)	Latitude (N)	Longitude (W)	Sample Type	RPD Depth (cm)	Sediment Texture	Fauna and Miscellaneous Observations
FF04	BF0410CD	8/4/04 09:59	42.28850	-70.42492	Biol	0.6	silt	Tubes, no fauna seen
	BF0410D0	8/4/04 10:07	42.28830	-70.42490	Chem	0.7	silt	Worms, brittle star, tubes
	BF0410D1	8/4/04 10:18	42.28833	-70.42493	Biol	1.0	silt	Amphipods, tubes
	BF0410D3	8/4/04 10:27	42.28845	-70.42493	Biol	0.8	silt	Starfish, tubes
	BF0410D5	8/4/04 10:35	42.28828	-70.42492	Chem	0.6	silt	Tubes
FF05	BF0411FC	8/4/04 11:35	42.13330	-70.42263	Chem	1.2	silt	Tubes, no fauna seen
	BF0411FE	8/4/04 11:45	42.13332	-70.42265	Chem	1.0	silt	Tubes
	BF0411FF	8/4/04 11:54	42.13330	-70.42252	Biol	0.9	v. fine sandy silt	Tubes, no fauna seen
	BF041200	8/4/04 12:03	42.13334	-70.42271	Biol	1.0		Tubes, no fauna seen
	BF041201	8/4/04 12:10	42.13328	-70.42278	Biol	1.0		Amphipod
FF07	BF04120A	8/4/04 13:14	41.95825	-70.26667	Biol	0.8	silt	Brittle stars, tubes
	BF04120C	8/4/04 13:20	41.95818	-70.26645	Biol	1.0	silt	Brittle star, tubes
	BF041210	8/4/04 13:30	41.95832	-70.26670	Chem	0.5	silt	Tubes, no fauna seen
	BF041217	8/4/04 13:46	41.95827	-70.26691	Biol	1.0	silt	Many brittle stars
	BF04121B	8/4/04 14:06	41.95837	-70.26653	Chem	1.0	silt	Amphipod, brittle stars, tubes

APPENDIX A2

Station Data:
Sediment Profile Images (BR041)

Table A2-1. Field data for sediment profile image survey BR041.
(Times are reported in Eastern Standard Time)

STUDY_ID	EVENT_ID	STAT_ID	LOC_DESC	STAT_ARRIV (EST)	BEG_LATITUDE	BEG_LONGITUDE	DEPTH_TO_BOTTOM	DEPTH_UNIT_CODE	NAVIGATION_CODE	NAV_QUAL
BMBSOFT	BR041	FF10	MASSACHUSETTS BAY NEAR NAHANT	8/23/04 13:12	42.4140816	-70.8787155	29.3	m	DGPS	+/- 10m
BMBSOFT	BR041	FF12	MASSACHUSETTS BAY NEAR NAHANT	8/23/04 13:26	42.3900337	-70.8996964	24.3	m	DGPS	+/- 10m
BMBSOFT	BR041	FF13	MASSACHUSETTS BAY NEAR THIEVES LEDGE	8/23/04 7:03	42.3197517	-70.82267	21.9	m	DGPS	+/- 10m
BMBSOFT	BR041	NF02	SOUTHWEST OF OUTFALL SITE	8/23/04 7:20	42.3386497	-70.8279037	28.2	m	DGPS	+/- 10m
BMBSOFT	BR041	NF04	NORTH OF OUTFALL SITE	8/23/04 12:26	42.4154816	-70.8067322	35.5	m	DGPS	+/- 10m
BMBSOFT	BR041	NF05	NORTHWEST OF OUTFALL SITE	8/23/04 9:43	42.4268684	-70.8340302	35.5	m	DGPS	+/- 10m
BMBSOFT	BR041	NF07	NORTH OF OUTFALL SITE	8/23/04 12:17	42.4099503	-70.8149643	34.2	m	DGPS	+/- 10m
BMBSOFT	BR041	NF08	NORTHWEST OF OUTFALL SITE	8/23/04 12:59	42.400135	-70.8634796	30.3	m	DGPS	+/- 10m
BMBSOFT	BR041	NF09	NORTHWEST OF OUTFALL SITE	8/23/04 10:11	42.3998489	-70.8450012	30	m	DGPS	+/- 10m
BMBSOFT	BR041	NF10	WEST OF OUTFALL SITE	8/23/04 10:20	42.3928986	-70.8380203	31.9	m	DGPS	+/- 10m
BMBSOFT	BR041	NF12	WEST OF OUTFALL SITE	8/23/04 11:04	42.3899498	-70.8302689	33.6	m	DGPS	+/- 10m
BMBSOFT	BR041	NF13	WEST OF OUTFALL SITE	8/23/04 8:53	42.3898163	-70.8226166	32.4	m	DGPS	+/- 10m
BMBSOFT	BR041	NF14	WEST OF OUTFALL SITE	8/23/04 8:45	42.3866005	-70.8227692	32.9	m	DGPS	+/- 10m
BMBSOFT	BR041	NF15	WEST OF OUTFALL SITE	8/23/04 11:13	42.3821487	-70.8277664	32	m	DGPS	+/- 10m
BMBSOFT	BR041	NF16	WEST OF OUTFALL SITE	8/23/04 11:23	42.3783493	-70.8375168	30.6	m	DGPS	+/- 10m
BMBSOFT	BR041	NF17	WEST OF OUTFALL SITE	8/23/04 8:32	42.3813515	-70.8146973	29.5	m	DGPS	+/- 10m
BMBSOFT	BR041	NF18	NORTHWEST OF OUTFALL SITE	8/23/04 9:04	42.3966331	-70.8218002	33.5	m	DGPS	+/- 10m
BMBSOFT	BR041	NF19	SOUTH OF OUTFALL SITE	8/23/04 8:05	42.3713989	-70.8047867	34.3	m	DGPS	+/- 10m
BMBSOFT	BR041	NF20	WEST OF OUTFALL SITE	8/23/04 11:41	42.3781319	-70.8445969	29.3	m	DGPS	+/- 10m
BMBSOFT	BR041	NF21	NORTHWEST OF OUTFALL SITE	8/23/04 9:57	42.4026337	-70.83638	32.1	m	DGPS	+/- 10m
BMBSOFT	BR041	NF22	SOUTH OF OUTFALL SITE	8/23/04 7:47	42.3479996	-70.8147964	34.4	m	DGPS	+/- 10m
BMBSOFT	BR041	NF23	NORTH OF OUTFALL SITE	8/23/04 9:16	42.3977165	-70.8014679	32.9	m	DGPS	+/- 10m
BMBSOFT	BR041	NF24	SOUTH OF OUTFALL SITE	8/23/04 8:21	42.3804169	-70.8019638	35.3	m	DGPS	+/- 10m

Table A2-2. Station data from SPI survey conducted in August 2004.

SurveyID	SampleID	Sample Date	Sample Time	StationID	Replicate *analyzed	Longitude	Latitude
HR041	HR041016	08/23/04	8:09:06 AM	FF13	1*	-70.8227	42.3198
HR041	HR041017	08/23/04	8:09:24 AM	FF13	2*	-70.8226	42.3198
HR041	HR041018	08/23/04	8:10:11 AM	FF13	3*	-70.8225	42.3198
HR041	HR041019	08/23/04	8:10:40 AM	FF13	4	-70.8225	42.3199
HR041	HR041026	08/23/04	8:22:27 AM	NF02	1*	-70.8279	42.3386
HR041	HR041027	08/23/04	8:28:21 AM	NF02	2*	-70.8280	42.3383
HR041	HR041029	08/23/04	8:35:23 AM	NF02	3*	-70.8280	42.3384
HR041	HR04102B	08/23/04	8:41:37 AM	NF02	4	-70.8278	42.3384
HR041	HR041033	08/23/04	8:49:28 AM	NF22	1*	-70.8148	42.3480
HR041	HR041034	08/23/04	8:50:20 AM	NF22	2*	-70.8147	42.3480
HR041	HR041035	08/23/04	8:54:11 AM	NF22	3*	-70.8151	42.3477
HR041	HR041036	08/23/04	8:54:52 AM	NF22	4	-70.8151	42.3476
HR041	HR04103C	08/23/04	9:09:16 AM	NF19	1*	-70.8048	42.3714
HR041	HR04103D	08/23/04	9:13:05 AM	NF19	2*	-70.8052	42.3716
HR041	HR04103E	08/23/04	9:13:42 AM	NF19	3*	-70.8052	42.3716
HR041	HR04103F	08/23/04	9:14:26 AM	NF19	4	-70.8051	42.3715
HR041	HR041045	08/23/04	9:23:13 AM	NF24	1*	-70.8020	42.3804
HR041	HR041046	08/23/04	9:24:04 AM	NF24	2*	-70.8019	42.3804
HR041	HR041047	08/23/04	9:24:55 AM	NF24	3*	-70.8019	42.3803
HR041	HR041048	08/23/04	9:25:47 AM	NF24	4	-70.8018	42.3803
HR041	HR04104E	08/23/04	9:36:08 AM	NF17	1*	-70.8147	42.3814
HR041	HR04104F	08/23/04	9:37:08 AM	NF17	2*	-70.8148	42.3813
HR041	HR041050	08/23/04	9:37:51 AM	NF17	3*	-70.8148	42.3813
HR041	HR041051	08/23/04	9:38:52 AM	NF17	4	-70.8147	42.3813
HR041	HR041057	08/23/04	9:46:42 AM	NF14	1*	-70.8228	42.3866
HR041	HR041058	08/23/04	9:47:39 AM	NF14	2*	-70.8227	42.3866
HR041	HR041059	08/23/04	9:48:37 AM	NF14	3*	-70.8227	42.3866
HR041	HR04105A	08/23/04	9:49:14 AM	NF14	4	-70.8227	42.3866
HR041	HR041062	08/23/04	9:55:34 AM	NF13	1*	-70.8226	42.3898
HR041	HR041063	08/23/04	9:56:22 AM	NF13	2*	-70.8226	42.3898
HR041	HR041064	08/23/04	9:57:01 AM	NF13	3*	-70.8225	42.3898
HR041	HR041065	08/23/04	9:57:39 AM	NF13	4	-70.8225	42.3899
HR041	HR04106B	08/23/04	10:06:03 AM	NF18	1*	-70.8218	42.3966
HR041	HR04106C	08/23/04	10:06:51 AM	NF18	2*	-70.8218	42.3966
HR041	HR04106D	08/23/04	10:08:06 AM	NF18	3*	-70.8219	42.3966
HR041	HR04106E	08/23/04	10:08:17 AM	NF18	4	-70.8219	42.3966
HR041	HR041074	08/23/04	10:19:30 AM	NF23	1*	-70.8015	42.3977
HR041	HR041075	08/23/04	10:20:10 AM	NF23	2*	-70.8016	42.3978
HR041	HR041076	08/23/04	10:21:15 AM	NF23	3*	-70.8017	42.3978
HR041	HR041078	08/23/04	10:27:23 AM	NF23	4	-70.8018	42.3977
HR041	HR04107E	08/23/04	10:46:36 AM	NF05	1*	-70.8340	42.4269
HR041	HR041080	08/23/04	10:47:20 AM	NF05	2*	-70.8340	42.4269

SurveyID	SampleID	Sample Date	Sample Time	StationID	Replicate *analyzed	Longitude	Latitude
HR041	HR041083	08/23/04	10:47:45 AM	NF05	3*	-70.8340	42.4269
HR041	HR041085	08/23/04	10:48:20 AM	NF05	4	-70.8339	42.4270
HR041	HR04108B	08/23/04	10:59:44 AM	NF21	1*	-70.8364	42.4026
HR041	HR04108D	08/23/04	11:00:28 AM	NF21	2*	-70.8364	42.4026
HR041	HR04108F	08/23/04	11:01:08 AM	NF21	3*	-70.8365	42.4027
HR041	HR041091	08/23/04	11:01:56 AM	NF21	4	-70.8365	42.4027
HR041	HR041098	08/23/04	11:13:48 AM	NF09	1*	-70.8450	42.3998
HR041	HR04109A	08/23/04	11:14:27 AM	NF09	2*	-70.8451	42.3999
HR041	HR04109C	08/23/04	11:15:04 AM	NF09	3*	-70.8452	42.3998
HR041	HR04109E	08/23/04	11:15:35 AM	NF09	4	-70.8452	42.3997
HR041	HR0410A9	08/23/04	11:57:42 AM	NF10	1*	-70.8380	42.3929
HR041	HR0410AB	08/23/04	11:58:24 AM	NF10	2*	-70.8380	42.3929
HR041	HR0410AD	08/23/04	11:59:13 AM	NF10	3*	-70.8382	42.3928
HR041	HR0410AF	08/23/04	11:59:38 AM	NF10	4	-70.8382	42.3928
HR041	HR0410B5	08/23/04	12:06:09 PM	NF12	1*	-70.8303	42.3899
HR041	HR0410B7	08/23/04	12:06:47 PM	NF12	2*	-70.8303	42.3900
HR041	HR0410B9	08/23/04	12:07:24 PM	NF12	3*	-70.8304	42.3900
HR041	HR0410BB	08/23/04	12:08:08 PM	NF12	4	-70.8305	42.3900
HR041	HR0410C3	08/23/04	12:15:53 PM	NF15	1*	-70.8278	42.3821
HR041	HR0410C5	08/23/04	12:16:36 PM	NF15	2*	-70.8278	42.3821
HR041	HR0410C7	08/23/04	12:17:13 PM	NF15	3*	-70.8278	42.3821
HR041	HR0410C9	08/23/04	12:17:51 PM	NF15	4	-70.8279	42.3821
HR041	HR0410D0	08/23/04	12:25:33 PM	NF16	1*	-70.8375	42.3783
HR041	HR0410D2	08/23/04	12:26:33 PM	NF16	2*	-70.8376	42.3784
HR041	HR0410D3	08/23/04	12:27:00 PM	NF16	3*	-70.8376	42.3783
HR041	HR0410D5	08/23/04	12:27:35 PM	NF16	4	-70.8376	42.3783
HR041	HR0410DF	08/23/04	12:59:37 PM	NF20	1*	-70.8446	42.3781
HR041	HR0410E1	08/23/04	1:00:22 PM	NF20	2*	-70.8447	42.3782
HR041	HR0410E5	08/23/04	1:02:03 PM	NF20	3*	-70.8446	42.3780
HR041	HR0410EC	08/23/04	1:19:12 PM	NF07	1*	-70.8150	42.4100
HR041	HR0410EE	08/23/04	1:19:54 PM	NF07	2*	-70.8149	42.4100
HR041	HR0410F0	08/23/04	1:20:34 PM	NF07	3*	-70.8149	42.4100
HR041	HR0410F2	08/23/04	1:21:03 PM	NF07	4	-70.8150	42.4100
HR041	HR0410F8	08/23/04	1:28:29 PM	NF04	1*	-70.8067	42.4155
HR041	HR0410F9	08/23/04	1:29:17 PM	NF04	2*	-70.8067	42.4155
HR041	HR0410FB	08/23/04	1:30:00 PM	NF04	3*	-70.8068	42.4155
HR041	HR0410FD	08/23/04	1:30:33 PM	NF04	4	-70.8068	42.4155
HR041	HR041105	08/23/04	1:48:00 PM	NF20	4	-70.8448	42.3779
HR041	HR041106	08/23/04	1:49:50 PM	NF20	5	-70.8447	42.3783
HR041	HR04110D	08/23/04	2:01:20 PM	NF08	1*	-70.8635	42.4001
HR041	HR04110F	08/23/04	2:03:02 PM	NF08	2*	-70.8635	42.4000
HR041	HR041111	08/23/04	2:03:41 PM	NF08	3*	-70.8635	42.4000
HR041	HR041113	08/23/04	2:04:28 PM	NF08	4	-70.8635	42.3999

SurveyID	SampleID	Sample Date	Sample Time	StationID	Replicate *analyzed	Longitude	Latitude
HR041	HR04111D	08/23/04	2:14:02 PM	FF10	1*	-70.8787	42.4141
HR041	HR04111F	08/23/04	2:14:39 PM	FF10	2*	-70.8787	42.4140
HR041	HR041121	08/23/04	2:15:06 PM	FF10	3*	-70.8787	42.4140
HR041	HR041123	08/23/04	2:15:44 PM	FF10	4	-70.8787	42.4139
HR041	HR04112A	08/23/04	2:27:45 PM	FF12	1*	-70.8997	42.3900
HR041	HR04112E	08/23/04	2:28:54 PM	FF12	2*	-70.8999	42.3899
HR041	HR041130	08/23/04	2:29:33 PM	FF12	3*	-70.8999	42.3898
HR041	HR041132	08/23/04	2:30:22 PM	FF12	4	-70.8999	42.3898

APPENDIX A3

Station Data:
Hard-bottom Survey (BH041)

Table A3-1. Field data from hard-bottom survey BH041.

(Times are reported as Eastern Standard Time)

STUDY_ID	EVENT_ID	STAT_ID	STAT_ARRIV (EST)	BEG_LATITUDE	BEG_LONGITUDE	DEPTH_TO_BOTTOM	DEPTH_UNIT_CODE	NAVIGATION_CODE	NAV_QUAL
HBBS	BH041	DIFFUSER44	6/25/2004 13:54:10	42.3852158	-70.7989197	35.7	m	DGPS	+/- 10m
HBBS	BH041	T1-1	6/23/2004 11:46:33	42.3935318	-70.8035965	25.6	m	DGPS	+/- 10m
HBBS	BH041	T1-2	6/23/2004 12:51:52	42.3938675	-70.8054657	24.2	m	DGPS	+/- 10m
HBBS	BH041	T1-3	6/23/2004 16:48:57	42.3956985	-70.8087006	22.5	m	DGPS	+/- 10m
HBBS	BH041	T1-4	6/23/2004 17:37:46	42.396965	-70.8124008	24.5	m	DGPS	+/- 10m
HBBS	BH041	T1-5	6/24/2004 07:44:47	42.3978348	-70.8162003	28.6	m	DGPS	+/- 10m
HBBS	BH041	T10-1	6/25/2004 11:40:08	42.3779831	-70.8142471	23.3	m	DGPS	+/- 10m
HBBS	BH041	T11-1	6/25/2004 08:11:50	42.2400169	-70.5727463	33.5	m	DGPS	+/- 10m
HBBS	BH041	T12-C1	6/25/2004 10:20:41	42.3581161	-70.7612839	24.1	m	DGPS	+/- 10m
HBBS	BH041	T2-1	6/24/2004 10:26:46	42.39287	-70.79507	26.0	m	DGPS	+/- 10m
HBBS	BH041	T2-2	6/24/2004 11:31:02	42.3927841	-70.7949524	30.4	m	DGPS	+/- 10m
HBBS	BH041	T2-3	6/24/2004 12:15:00	42.392067	-70.7902298	26.2	m	DGPS	+/- 10m
HBBS	BH041	T2-4	6/24/2004 13:23:16	42.3908157	-70.7879181	31.7	m	DGPS	+/- 10m
HBBS	BH041	T2-5	6/25/2004 14:58:52	42.38420	-70.78397	32.1	m	DGPS	+/- 10m
HBBS	BH041	T4-2	6/24/2004 15:57:59	42.3835831	-70.7826004	31.5	m	DGPS	+/- 10m
HBBS	BH041	T4/T6-1	6/25/2004 12:38:47	42.3824844	-70.7870636	24.4	m	DGPS	+/- 10m
HBBS	BH041	T6-1	6/24/2004 14:14:48	42.3832321	-70.7952805	34	m	DGPS	+/- 10m
HBBS	BH041	T6-2	6/24/2004 15:11:51	42.3807487	-70.7845688	31.8	m	DGPS	+/- 10m
HBBS	BH041	T7-1	6/24/2004 08:46:27	42.4093323	-70.7834473	24.6	m	DGPS	+/- 10m
HBBS	BH041	T7-2	6/24/2004 09:39:30	42.4093513	-70.7819519	23.5	m	DGPS	+/- 10m
HBBS	BH041	T8-1	6/22/2004 10:29:24	42.3600159	-70.8153992	23.9	m	DGPS	+/- 10m
HBBS	BH041	T8-2	6/22/2004 11:56:58	42.3636665	-70.8078995	24	m	DGPS	+/- 10m
HBBS	BH041	T8-2	6/25/2004 16:29:00	42.3635483	-70.807785	24.5	m	DGPS	+/- 10m
HBBS	BH041	T9-1	6/23/2004 07:32:53	42.4026985	-70.7963638	24.4	m	DGPS	+/- 10m

APPENDIX B1

Data Terms and Analyses
Bulk Sediment, *Clostridium perfringens*, and Contaminant Data
1992–2004

Data Terms

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

- *Regional* – refers to all nearfield and farfield stations sampled throughout Massachusetts and Cape Cod Bays.
- *Nearfield* – refers to all regional stations located west of the Massachusetts Bay outfall and in close proximity to Boston Harbor, including NF02, NF04, NF05, NF07, NF08, NF09, NF10, NF12, NF13, NF14, NF15, NF16, NF17, NF18, NF19, NF20, NF21, NF22, NF23, NF24, FF10, FF12, and FF13.
- *Farfield* – refers to regional stations located far away from the outfall and Boston Harbor, *i.e.,* FF01A, FF04, FF05, FF06, FF07, FF09, FF11, and FF14.
- *Near-harbor*– refers to all nearfield stations located close to Boston Harbor, *i.e.,* FF10, FF12, and FF13.
- *Outfall* – refers to the Massachusetts Bay outfall.
- Anthropogenic – refers to analytes that are generated or enriched in the environment by human activity. They are functionally defined for PCA as TPAH, TPCB, TDDT, TCHLOR, TLAB, and CPERF. In addition, they include metals such as 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.
- 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 9 of the benthic monitoring CW/QAPP (Williams *et al.,* 2002), excluding Benzothiozole
- Total PCB (also referred to as TPCB) – sum of concentrations of all PCB congeners listed in Table 9 of the benthic monitoring CW/QAPP (Williams *et al.,* 2002)
- 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 9 of the benthic monitoring CW/QAPP (Williams *et al.,* 2002)
- 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 9 of the benthic monitoring CW/QAPP (Williams *et al.,* 2002)
- CPERF – refers to the sewage tracer *Clostridium perfringens*.
- 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).

For total contaminant calculations (*e.g.,* Total PAH), a value of 0.0 was assigned to individual analytes that were not detected.

Data Analyses

Data analyses (*e.g.,* correlations) were performed on regional data from 1992 to 2004, Note that data from 2000 represented a reduced sampling year, and that 2003 represented the first year of reduced monitoring following revisions to the monitoring plan (MWRA, 2003). The following data were excluded from the data analyses:

- FF08 data were 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 to1993 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;
- FF10 (rep1), NF14, and NF20 TOC data for 2000 were omitted because of suspected anomalies with the high TOC results (5.05% dry, 2.35 % dry, and 3.32% dry, respectively);
- FF01A (rep2) mercury data were omitted from 2001 because of a unusually high value (0.715 µg/g dry) that was attributed to isolated laboratory contamination; and
- NF13 and NF20 for 2002 (August survey BN021) were omitted because of suspiciously high Pb values (631 µg/g dry and 7,690 µg/g dry respectively).[1]

Sediment data were evaluated using box plots, ternary plots, range plots, XY scatter plots, and correlation analyses to assess spatial and temporal trends over time and to examine the correspondence between these parameters.

- Box plots were used to visualize the data distribution, and identify points with extreme values (*i.e.,* outliers). The ends of the box represent the 25th and 75th quartiles, and the line across the middle represents the median value. The lines are “whiskers” that extend from the ends of the box to the outermost data point that falls within the distances computed (a distance of 1.5 times the interquartile range, difference between 25th and 75th quartiles. Box plots were prepared using JMP (The Statistical Discovery Software).
- Ternary plots were used to visualize the grain size data, as percentages of gravel + sand, silt, and clay. Ternary plots were also prepared using JMP.

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[1] Replicate grab samples were collected in November 2002 at NF20 to confirm Pb values determined from the BN021 survey conducted in August 2002. Results from the November 2002 sampling from NF20 showed that Pb concentrations were comparable to background levels and significantly below the value previously determined, *i.e.* 7,690 µg/g dry (BN021). As a result, the original data value was deemed suspicious. Further, these data suggest that the unusually high Pb values determined during event BN021 at stations NF20 (approx. 170 times above baseline mean value) and NF13 (approx. 15 times above baseline mean value) may be high due to, or in part from, field and/or laboratory contamination. Pb data for NF13 in 2002 were also deemed suspicious.

- Range plots were used to evaluate spatial and temporal trends between baseline and post-diversion data. 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. Post-diversion (2001–2004) data were then compared to the baseline range and mean values for each regional station to evaluate how the post-diversion data fit in with our understanding of the baseline system. Nearfield stations were presented as a function of distance from the western end of diffuser #55. Offshore stations were sorted as a function of their north to south location relative to the new outfall. Range plots were prepared using Microsoft® Excel 2002.
- XY scatter plots were used to visualize the correspondence between the sediment data. Scatter plots were prepared using Microsoft® Excel 2002.
- Pearson (parametric) and Kendall (nonparametric) correlation analyses were performed to assess the relationship between variables (grain size, TOC, organic contaminants and metals). The Pearson correlation coefficient measures the degree to which two variables have a linear relationship if the variables have normal distributions. The Kendall correlation, on the other hand, measures the degree to which high concentrations of one variable are associated with high concentrations of the second variable. The Kendall's *tau* is a nonparametric correlation coefficients, which is preferable to Pearson if the data are not normally distributed, which is the case with most of the sediment data. For both Pearson and Kendall correlations, values near 1 indicate that the two variables have a strong positive correlation, values near -1 indicate that the two variables have a strong negative correlation, and values near 0 indicate that the two variables are unrelated. Sediment data used in the correlation analyses included baseline (1999–2000) and post-diversion (2001–2004), station mean values.

APPENDIX B2

Grain Size and TOC
Box Plots, Ternary Plots, and Range Plots
Regional Sediments 1992–2004

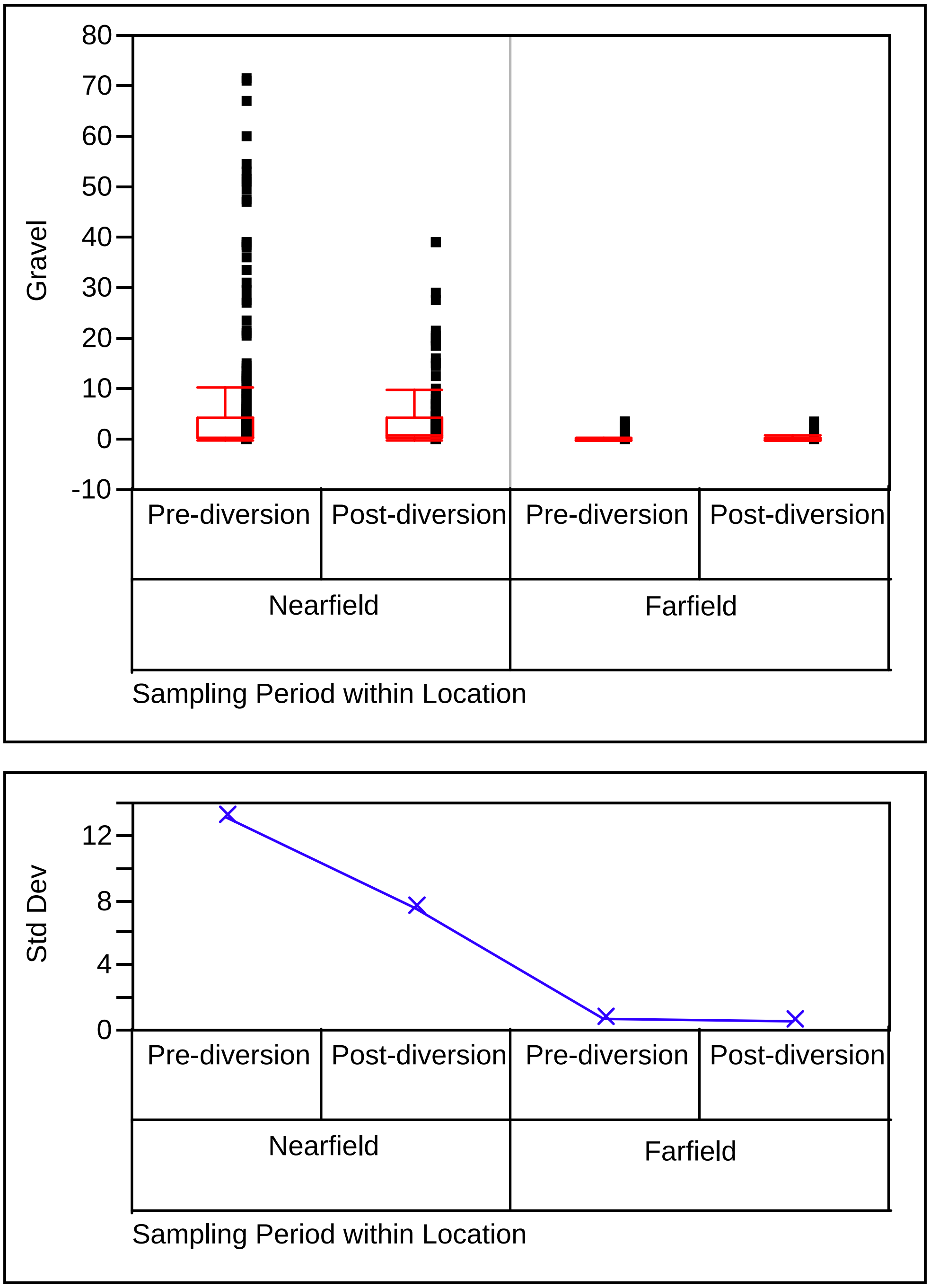


Figure B2-1. Distribution of percentage gravel in regional surface (top 2 cm) sediments, pre-diversion (1992–2000) and post-diversion (2001–2004) periods. ***(Sample distributions for nearfield sediments shown in greater detail in Figure B2-6).***

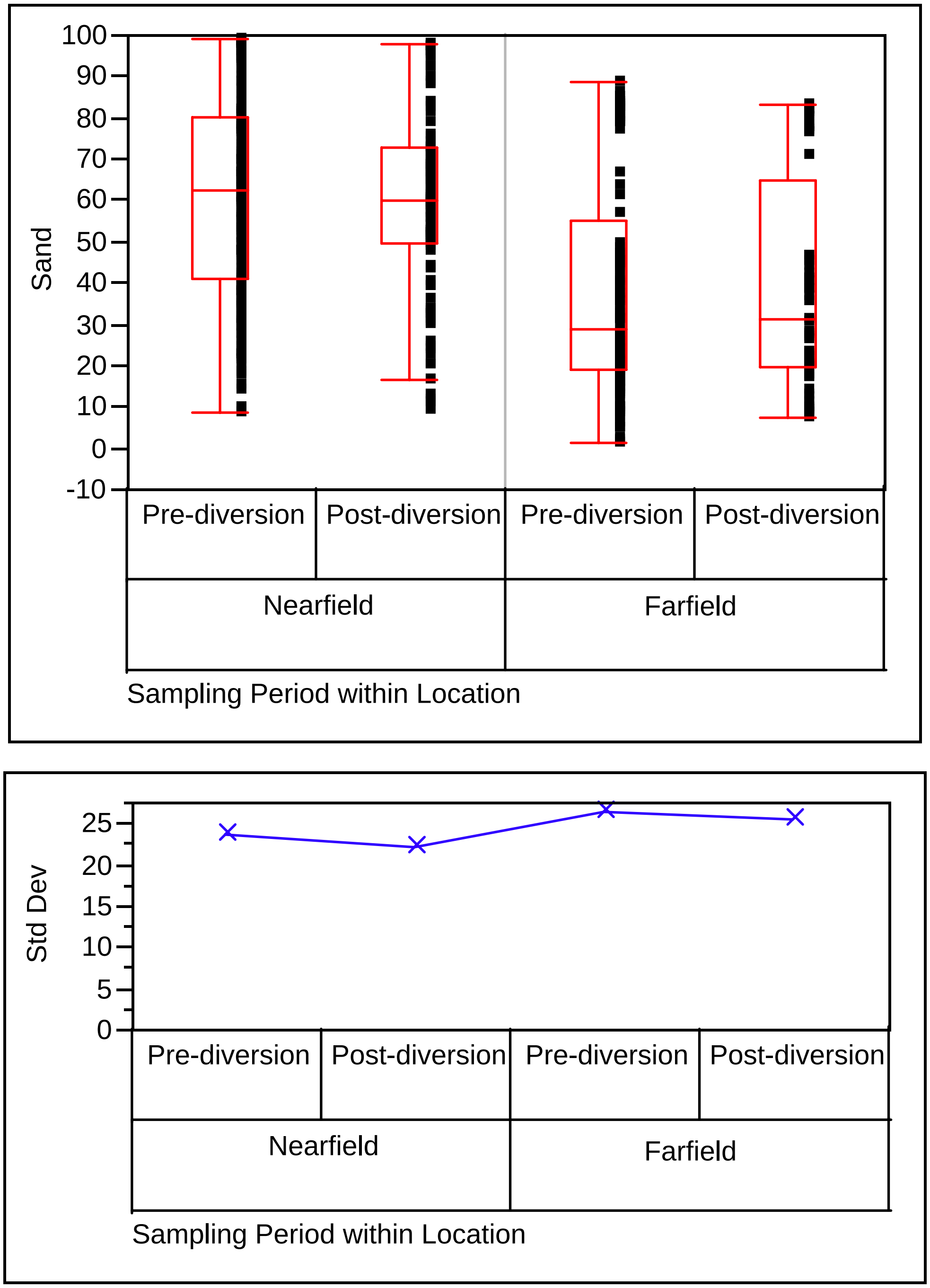
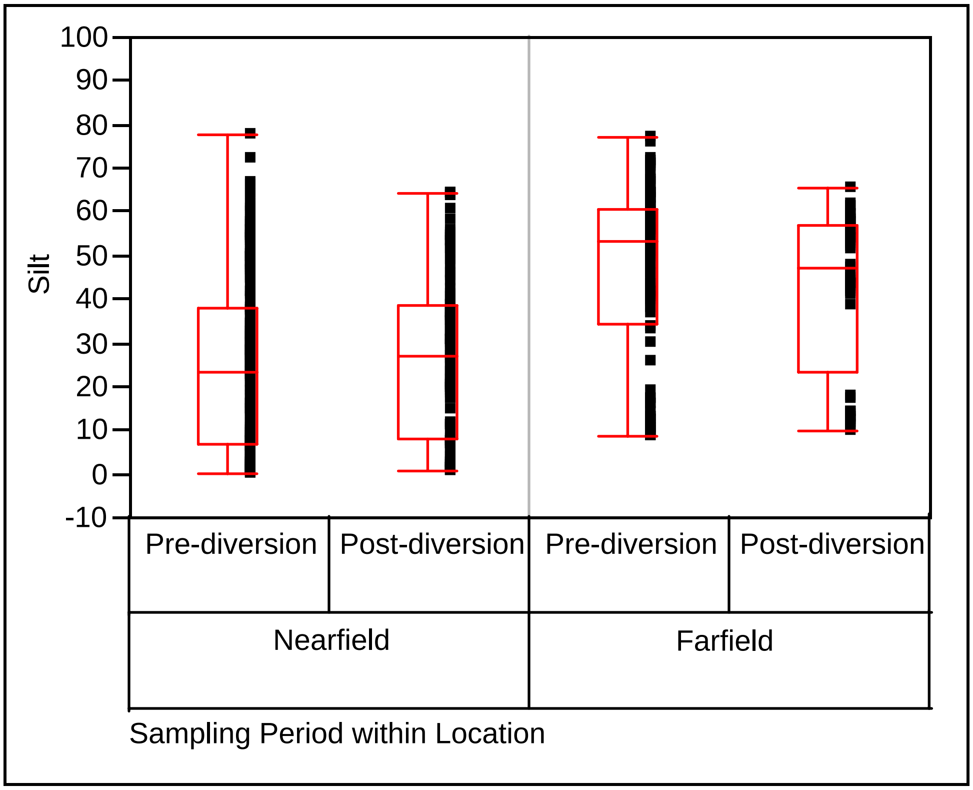


Figure B2-2. Distribution of percentage sand in regional surface (top 2 cm) sediments, pre-diversion (1992–2000) and post-diversion (2001–2004) periods. ***(Sample distributions for nearfield sediments shown in greater detail in Figure B2-7).***



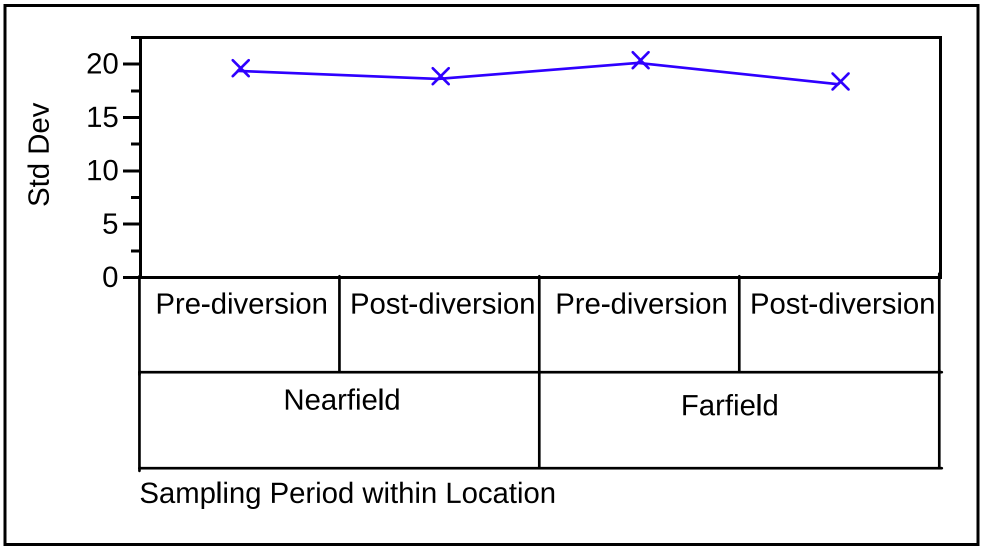
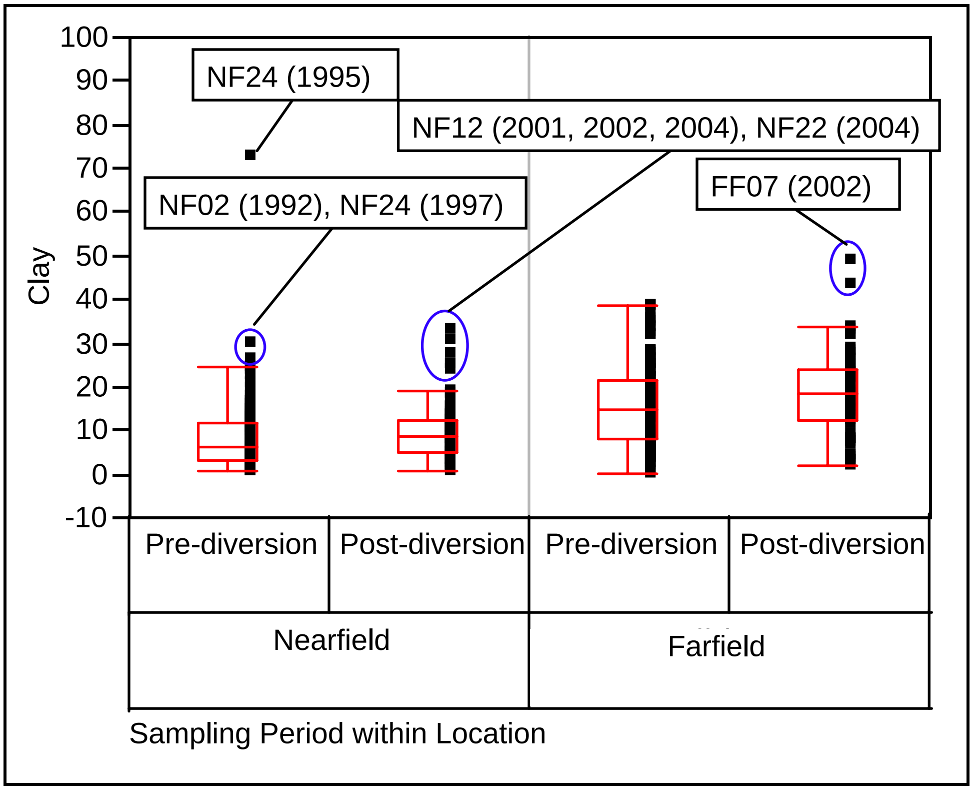


Figure B2-3. Distribution of percentage silt in regional surface (top 2 cm) sediments, pre-diversion (1992–2000) and post-diversion (2001–2004) periods. ***(Sample distributions for nearfield sediments shown in greater detail in Figure B2-8).***



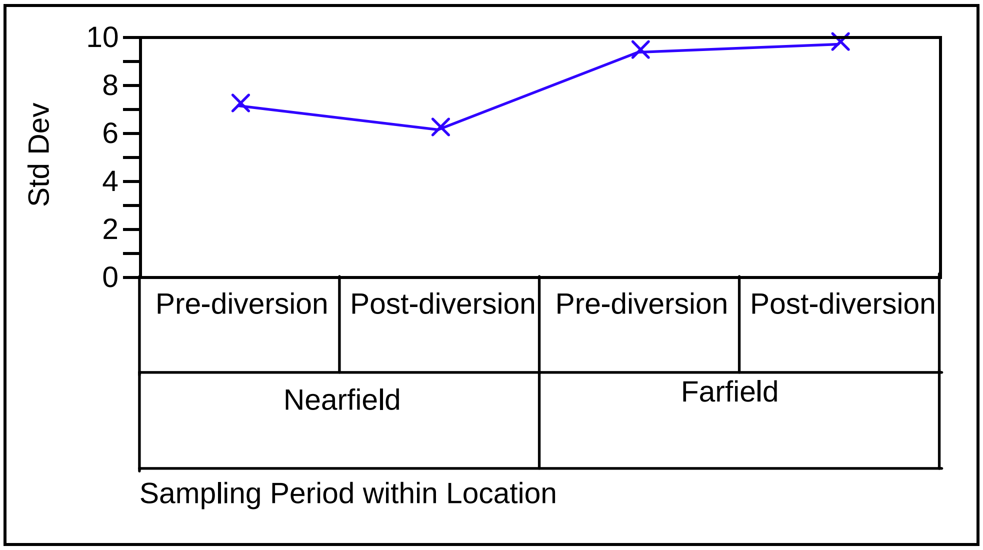
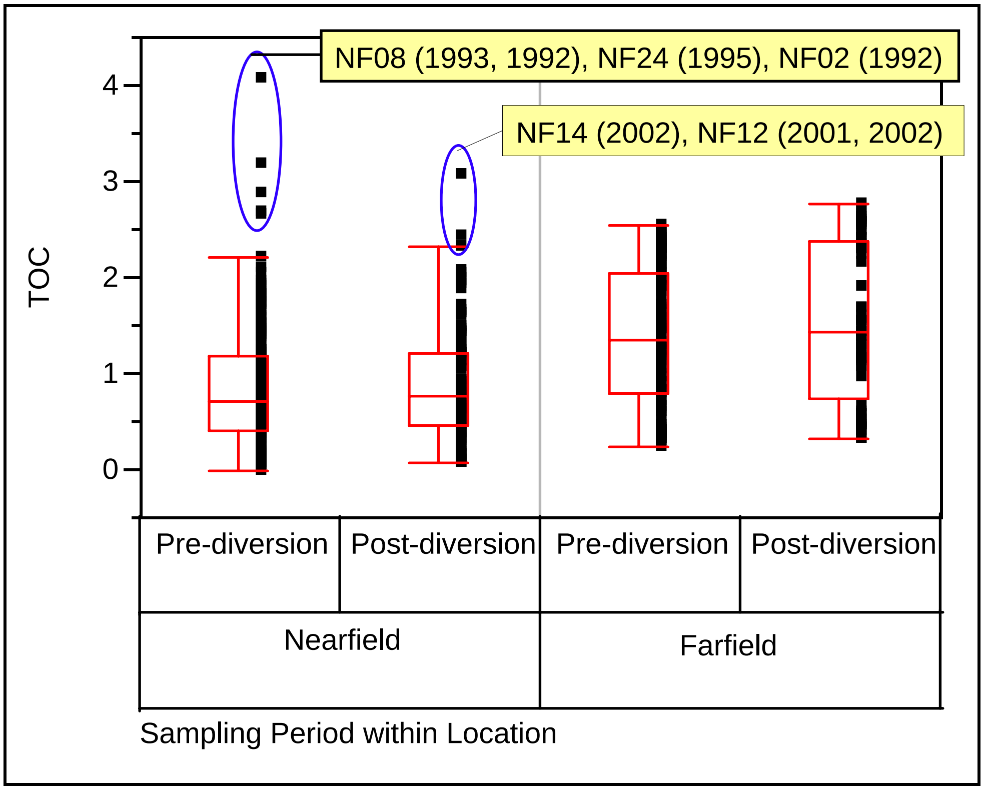


Figure B2-4. Distribution of percentage clay in regional surface (top 2 cm) sediments, pre-diversion (1992–2000) and post-diversion (2001–2004) periods. ***(Sample distributions for nearfield sediments shown in greater detail in Figure B2-9).***



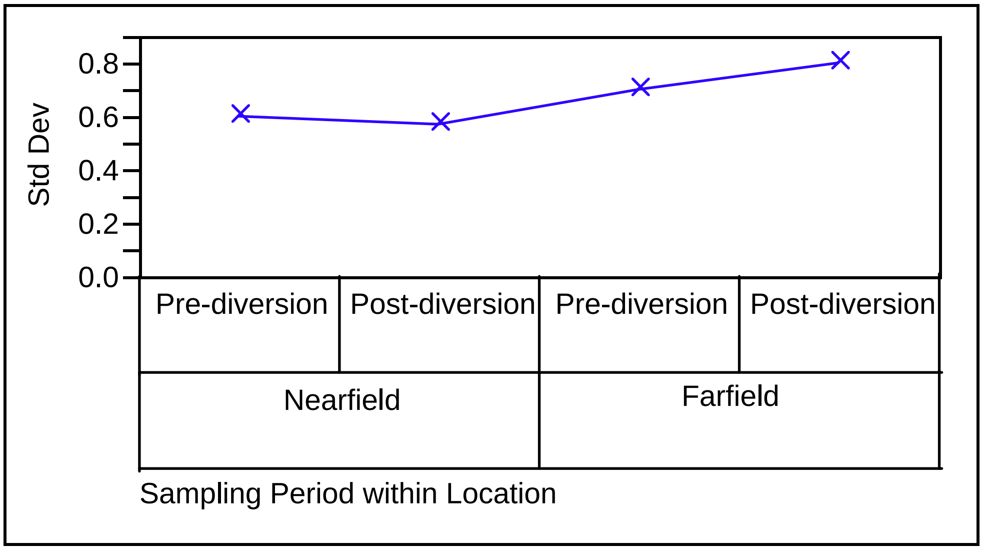
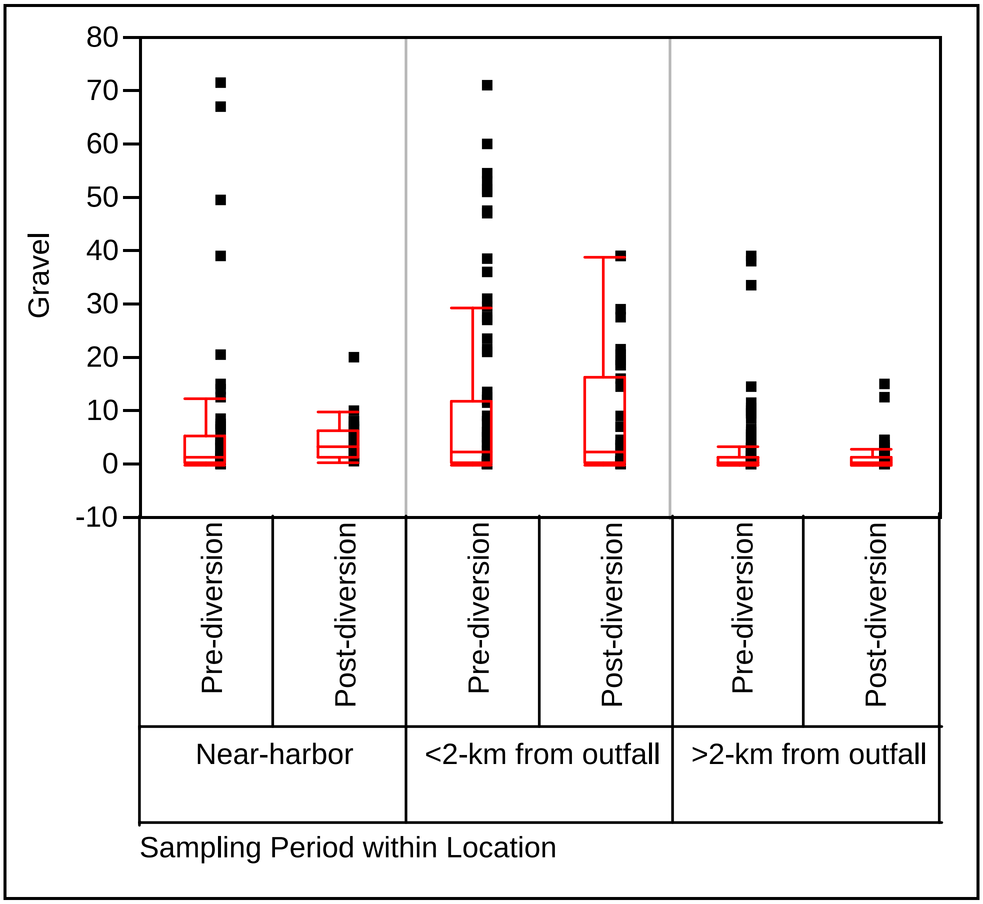


Figure B2-5. Distribution of TOC in regional surface (top 2 cm) sediments, pre-diversion (1992–2000) and post-diversion (2001–2004) periods. ***(Sample distributions for nearfield sediments shown in greater detail in Figure B2-10).***



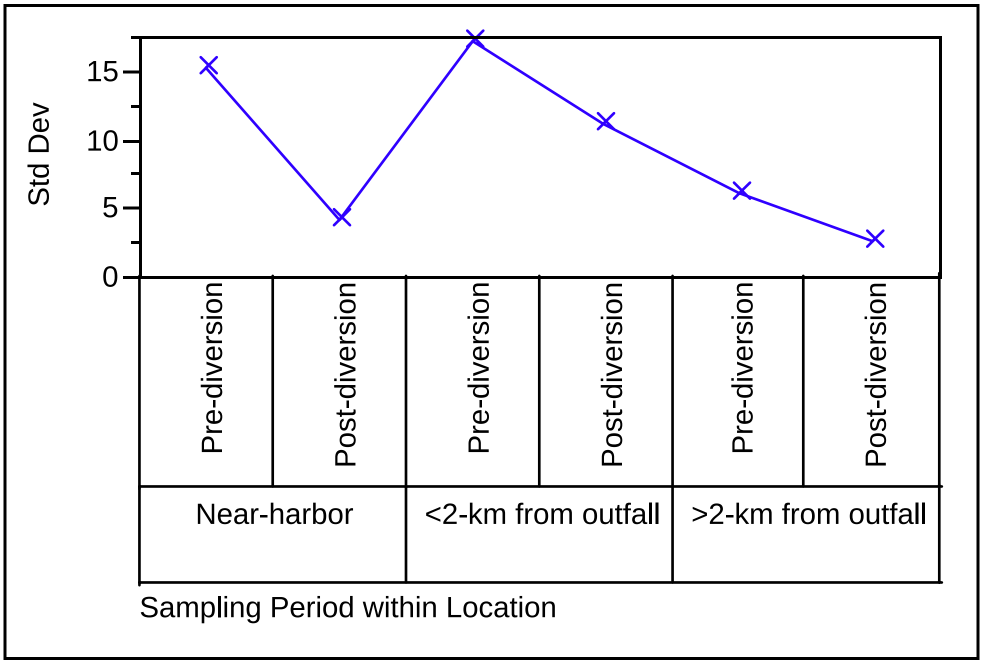
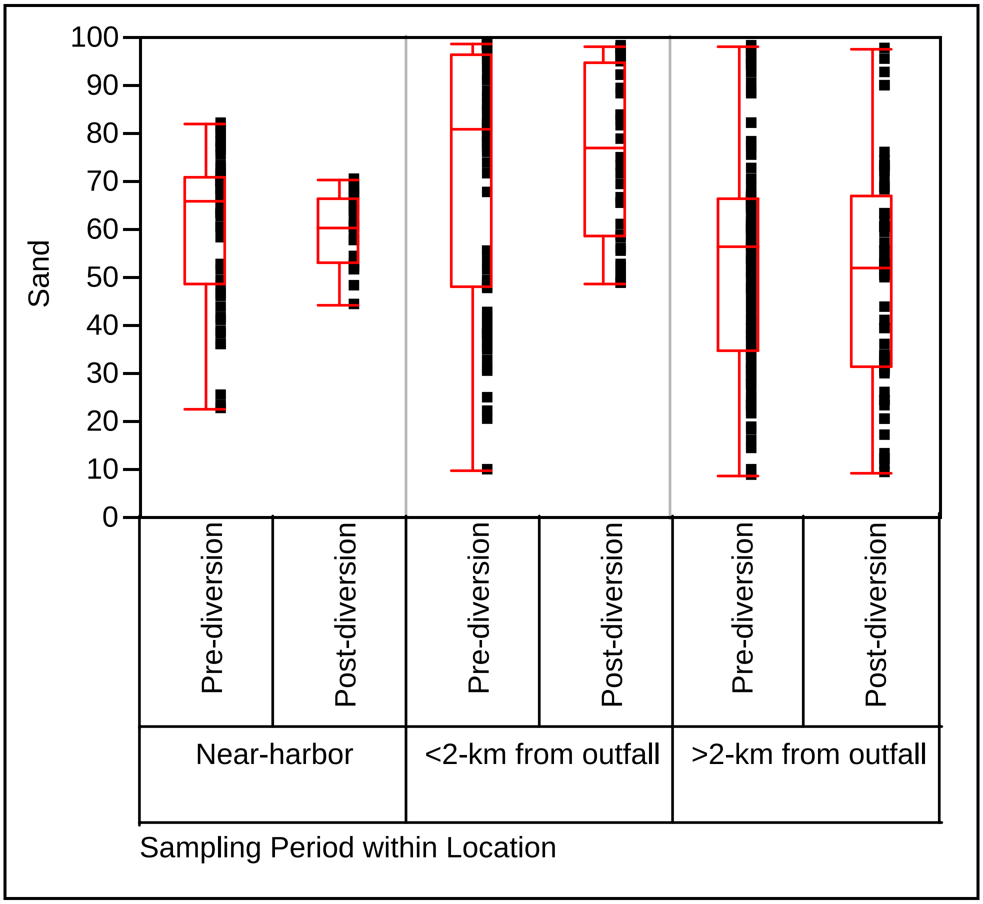


Figure B2-6. Distribution of percentage gravel in nearfield surface (top 2 cm) sediments during pre-diversion (1992–2000) and post-diversion (2001–2004) periods. Nearfield stations grouped as near-harbor (FF10, FF12, FF13), <2 km from outfall, and >2 km from outfall.



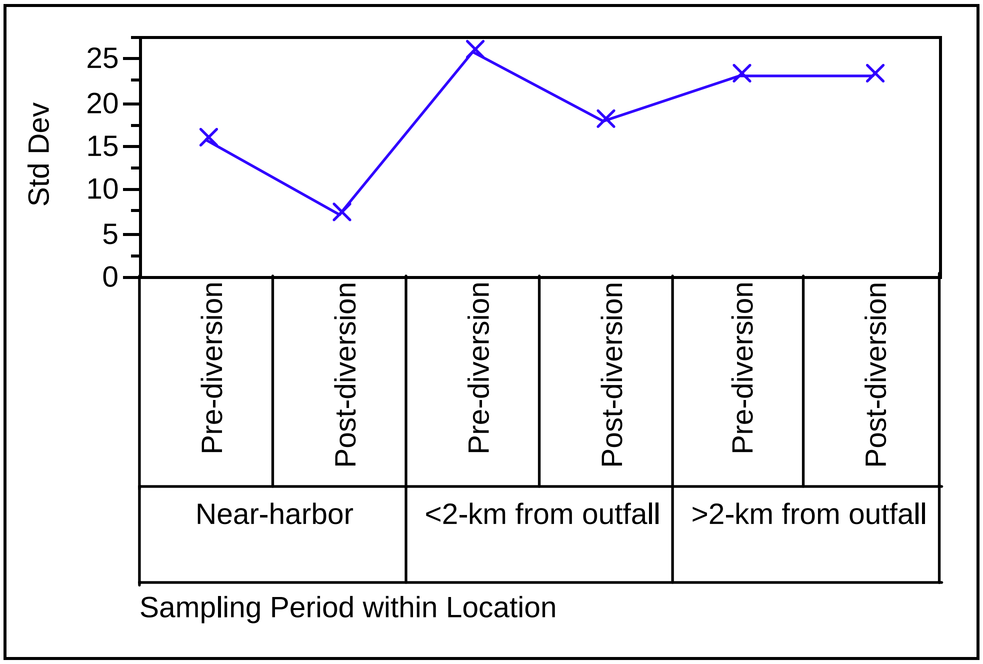


Figure B2-7. Distribution of percentage sand in nearfield surface (top 2 cm) sediments during pre-diversion (1992–2000) and post-diversion (2001–2004) periods. Nearfield stations grouped as near-harbor (FF10, FF12, FF13), <2 km from outfall, and >2 km from outfall.

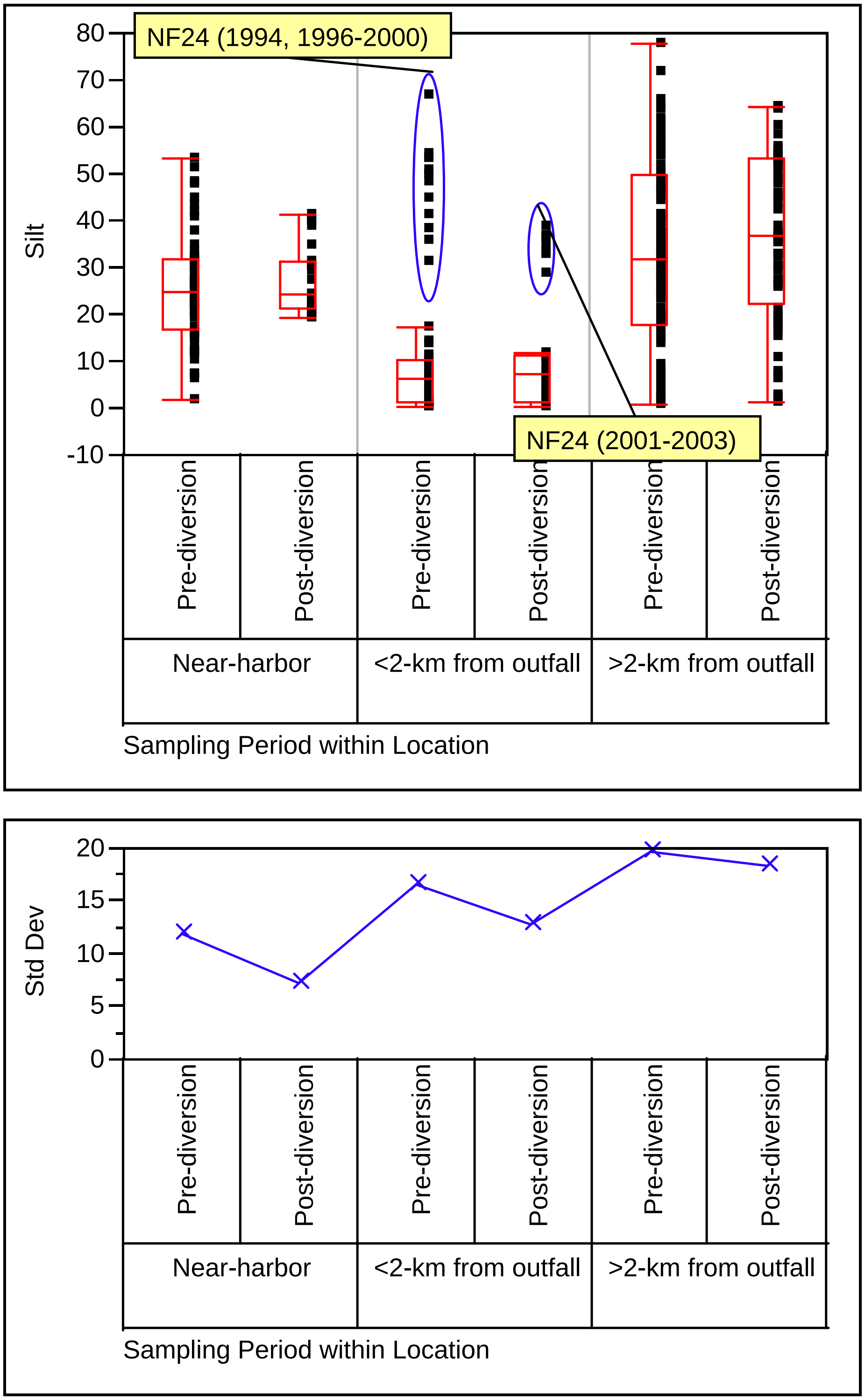
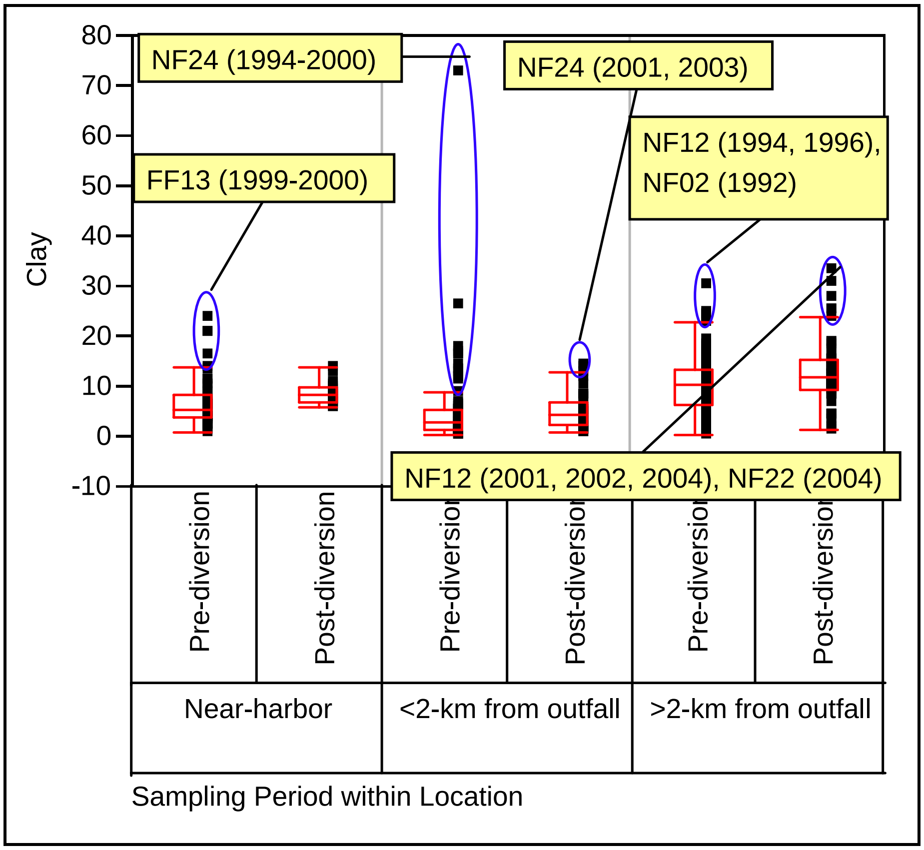


Figure B2-8. Distribution of percentage silt in nearfield surface (top 2 cm) sediments during pre-diversion (1992–2000) and post-diversion (2001–2004) periods. Nearfield stations grouped as near-harbor (FF10, FF12, FF13), <2 km from outfall, and >2 km from outfall.



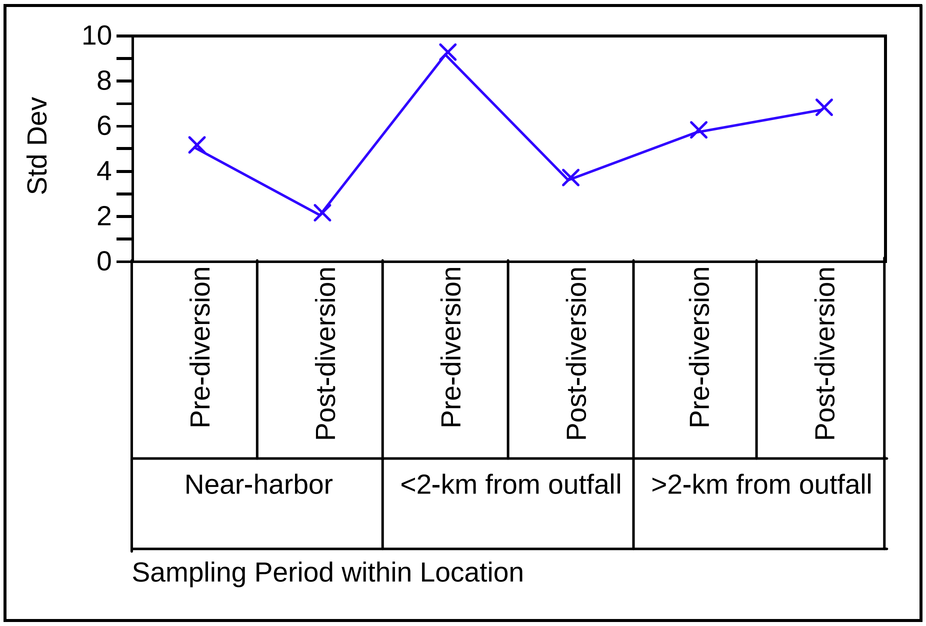


Figure B2-9. Distribution of percentage clay in nearfield surface (top 2 cm) sediments during pre-diversion (1992–2000) and post-diversion (2001–2004) periods. Nearfield stations grouped as near-harbor (FF10, FF12, FF13), <2 km from outfall, and >2 km from outfall.

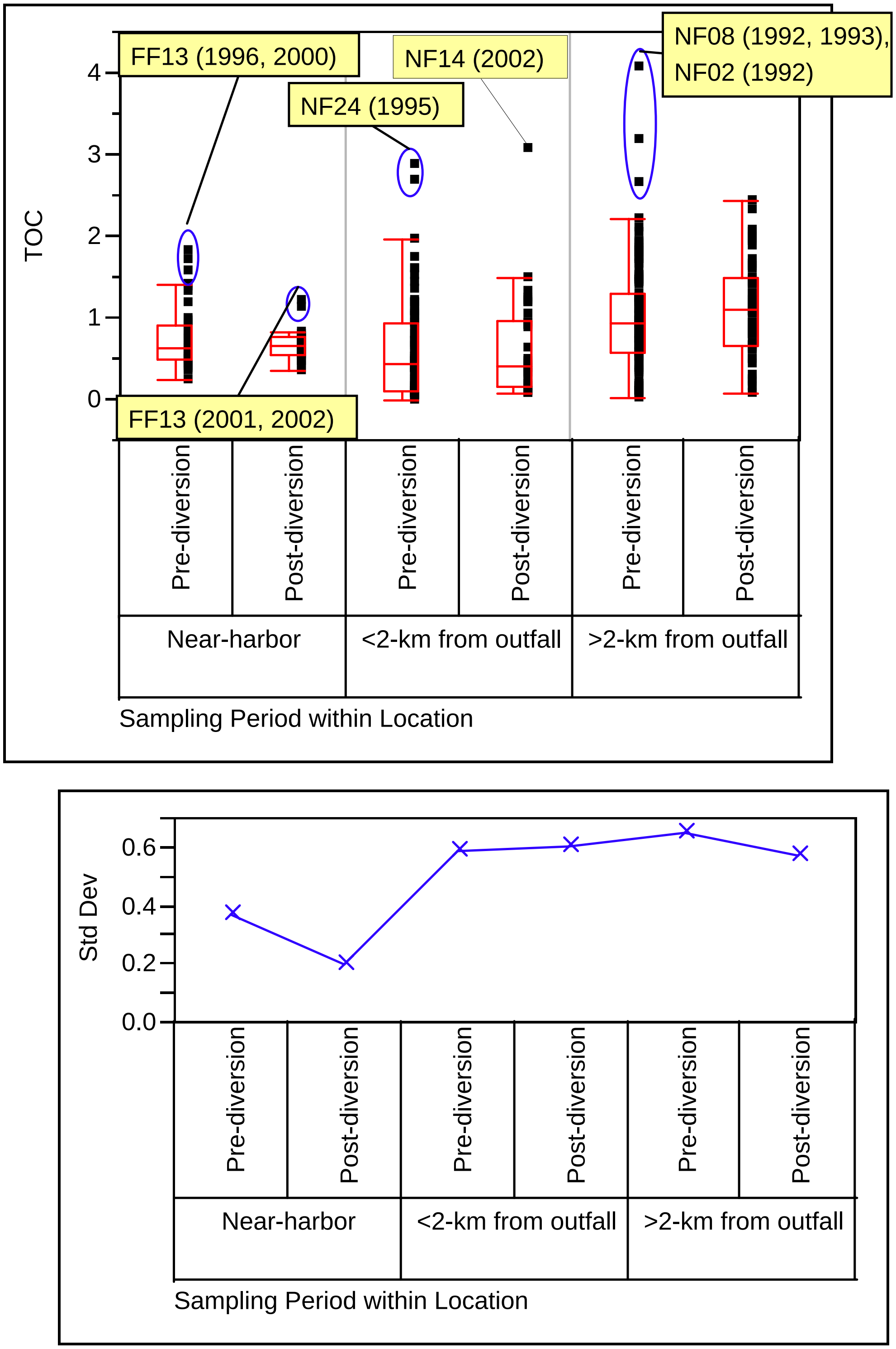


Figure B2-10. Distribution of TOC in nearfield surface (top 2 cm) sediments during pre-diversion (1992–2000) and post-diversion (2001–2004) periods. Nearfield stations grouped as near-harbor (FF10, FF12, FF13), <2 km from outfall, and >2 km from outfall.

Table B2-1. Variability among percent gravel, sand, silt, and clay in regional sediments, pre- (1992–2000) and post-diversion (2001–2004) periods.

Location	Sampling Period	Number of observations	CV(Gravel)	CV(Sand)	CV(Silt)	CV(Clay)
Near-harbor	Pre-diversion	53	218	26	46	75
Near-harbor	Post-diversion	24	96	12	27	25
<2 km from outfall	Pre-diversion	80	161	36	140	166
<2 km from outfall	Post-diversion	38	139	23	114	71
>2 km from outfall	Pre-diversion	123	271	42	60	55
>2 km from outfall	Post-diversion	56	218	47	50	53
Farfield	Pre-diversion	132	211	69	44	60
Farfield	Post-diversion	56	229	66	43	53

CV, Coefficient of variation.

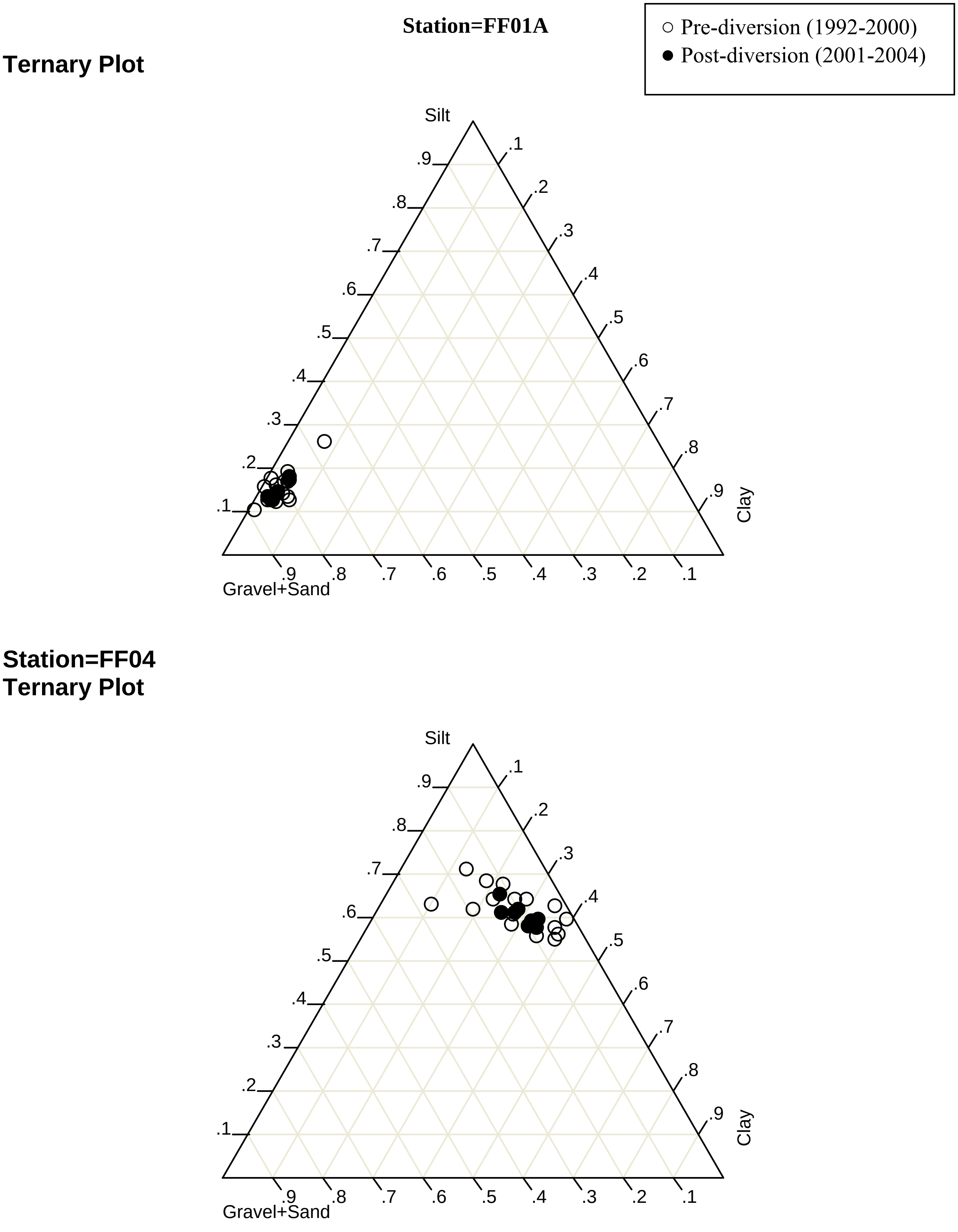
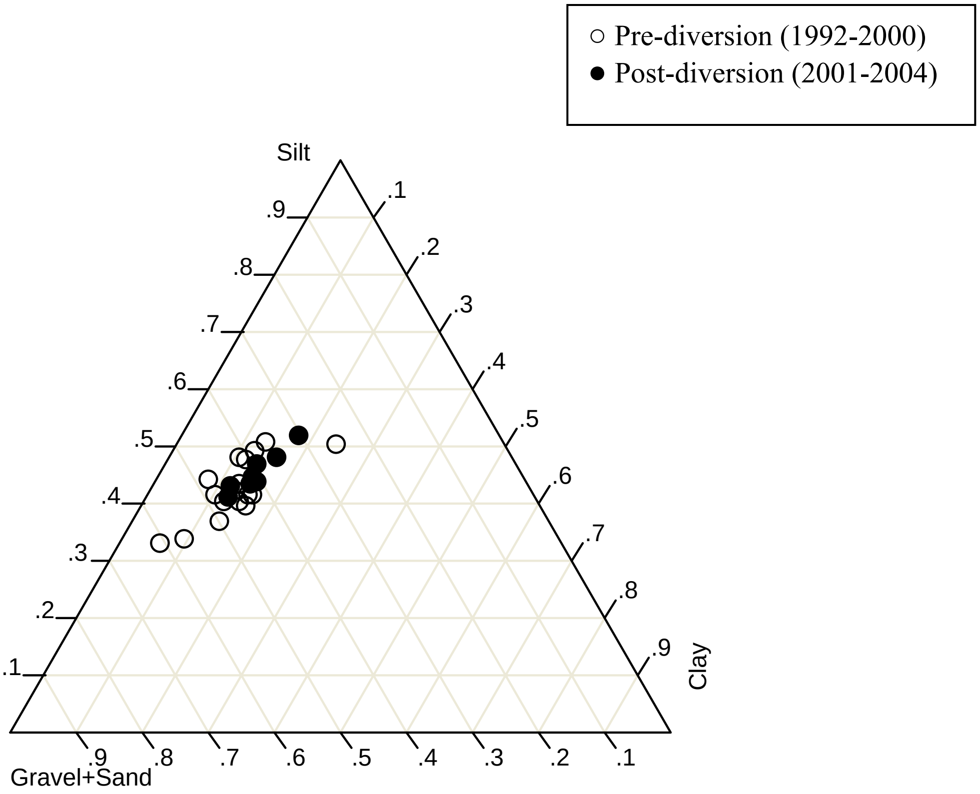


Figure B2-11. Distribution of percentages gravel + sand, silt, and clay in FF01A (top) and FF04 (bottom) surface (top 2 cm) sediments, pre- and post-diversion sampling periods.

Station=FF05
Ternary Plot



Station=FF06
Ternary Plot

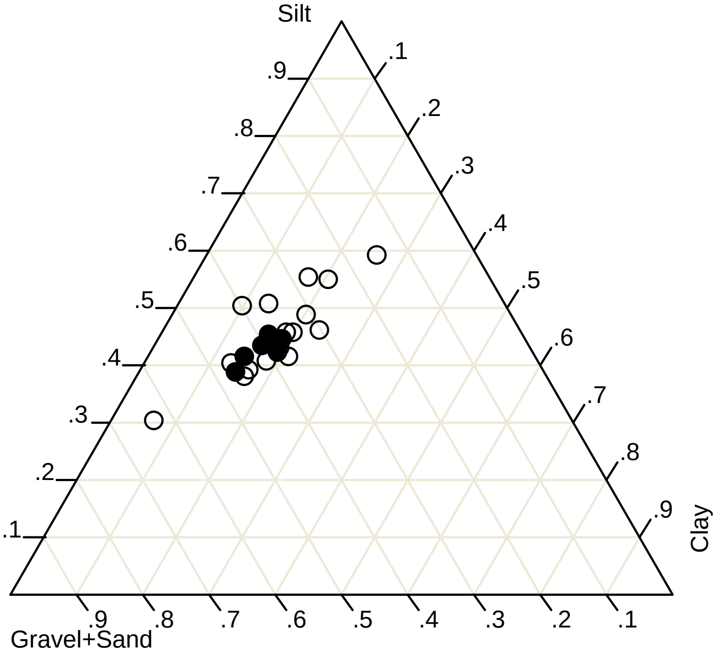
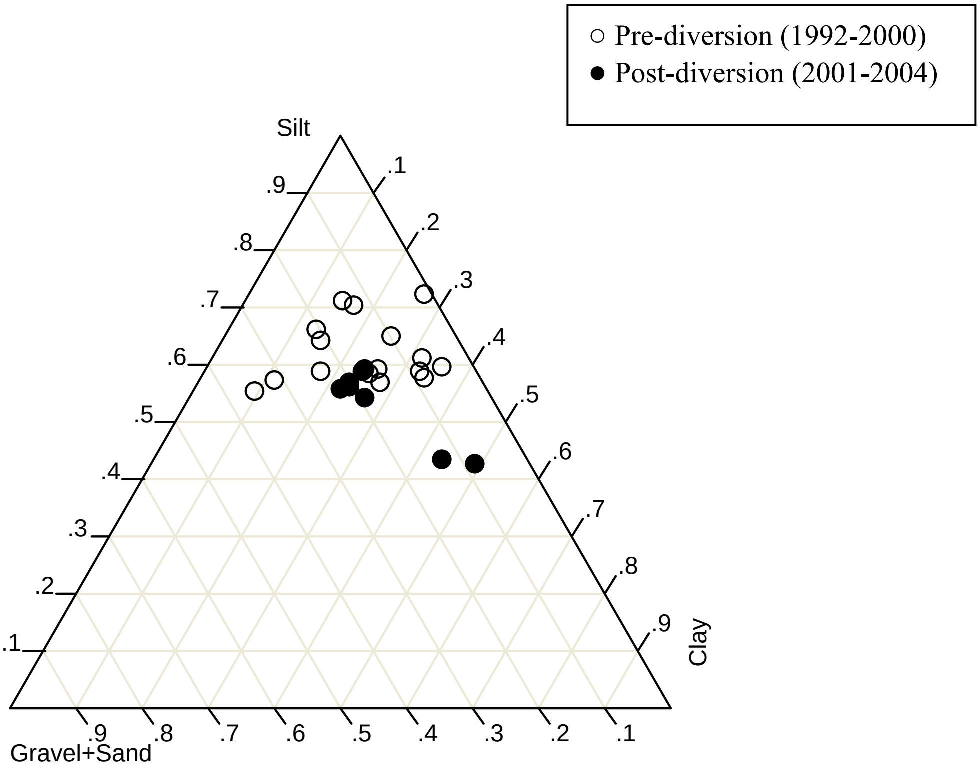


Figure B2-12. Distribution of percentages gravel + sand, silt, and clay in FF05 (top) and FF06 (bottom) surface (top 2 cm) sediments, pre- and post-diversion sampling periods.

Station=FF07
Ternary Plot



Station=FF09
Ternary Plot

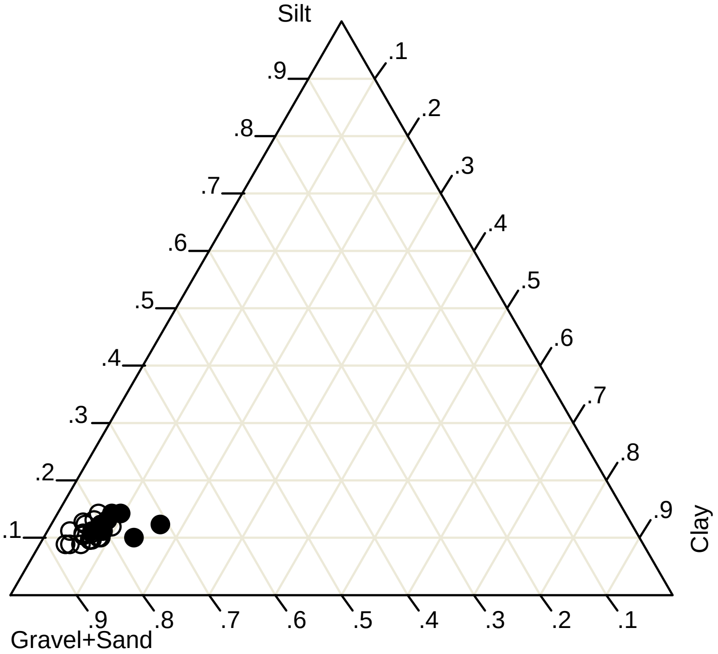
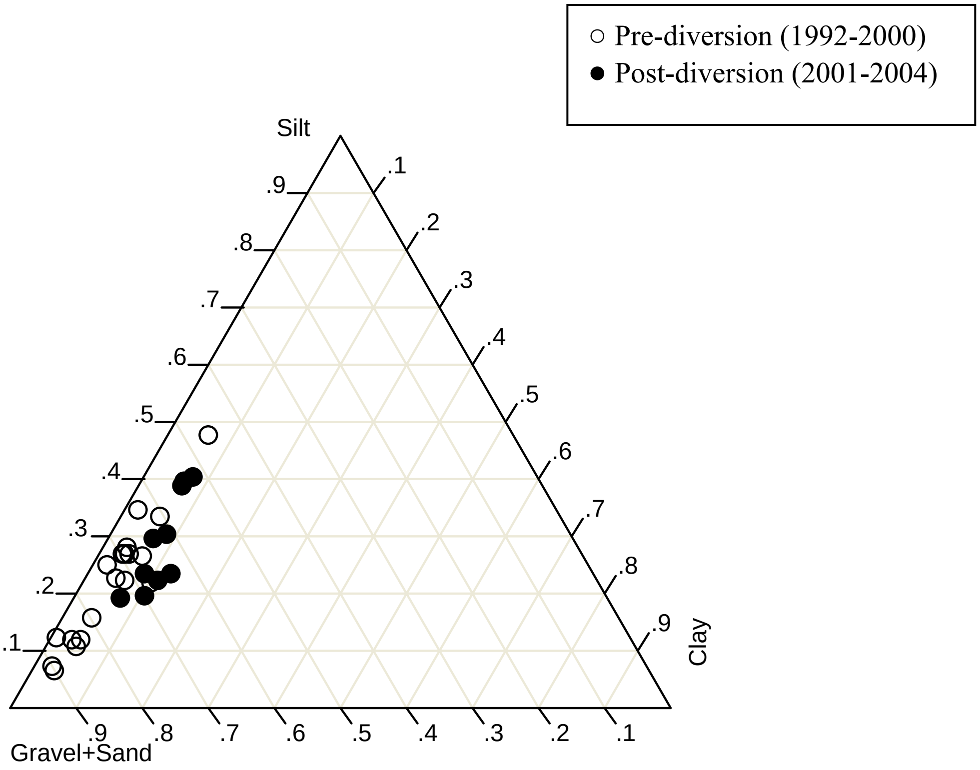


Figure B2-13. Distribution of percentages gravel + sand, silt, and clay in FF07 (top) and FF09 (bottom) surface (top 2 cm) sediments, pre- and post-diversion sampling periods.

Station=FF10
Ternary Plot



Station=FF11
Ternary Plot

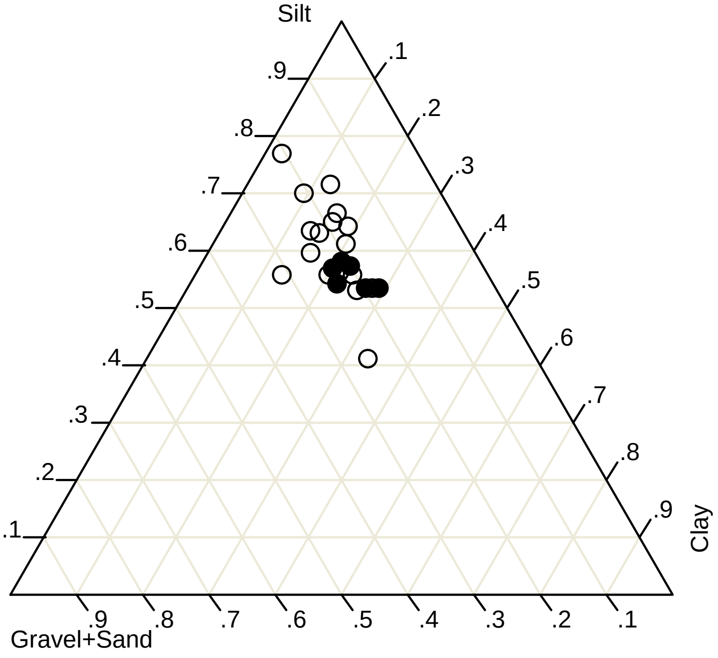
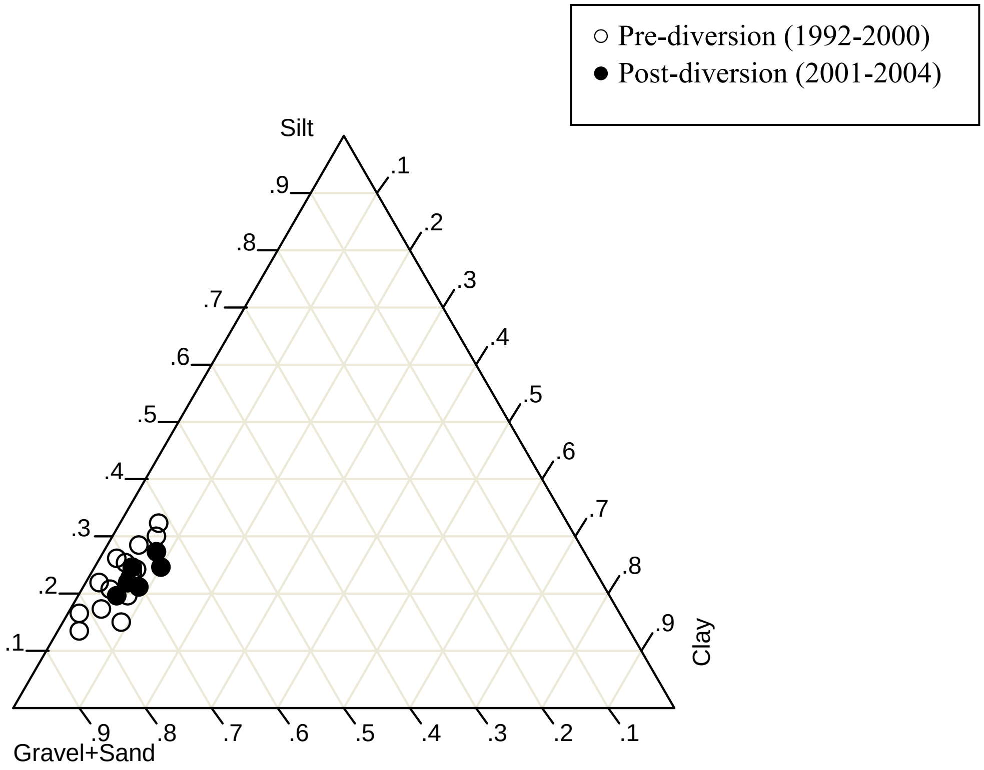


Figure B2-14. Distribution of percentages gravel + sand, silt, and clay in FF10 (top) and FF11 (bottom) surface (top 2 cm) sediments, pre- and post-diversion sampling periods.

Station=FF12
Ternary Plot



Station=FF13
Ternary Plot

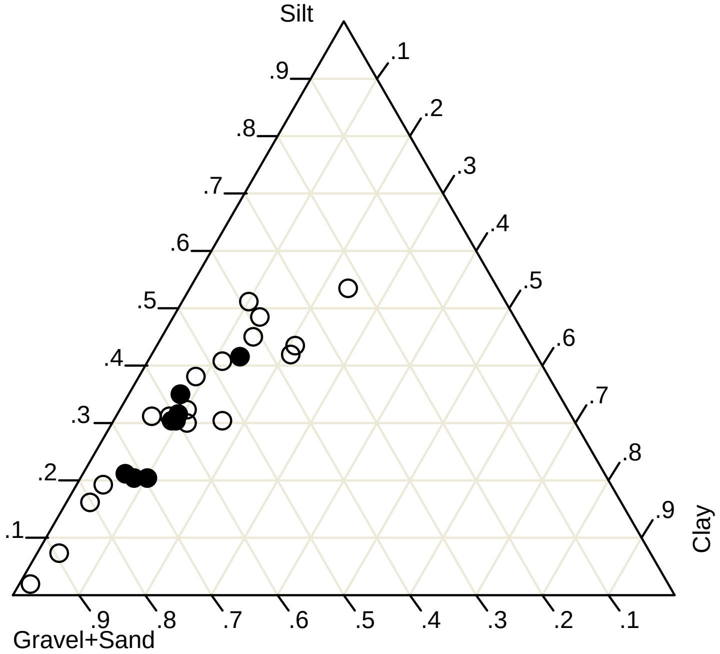
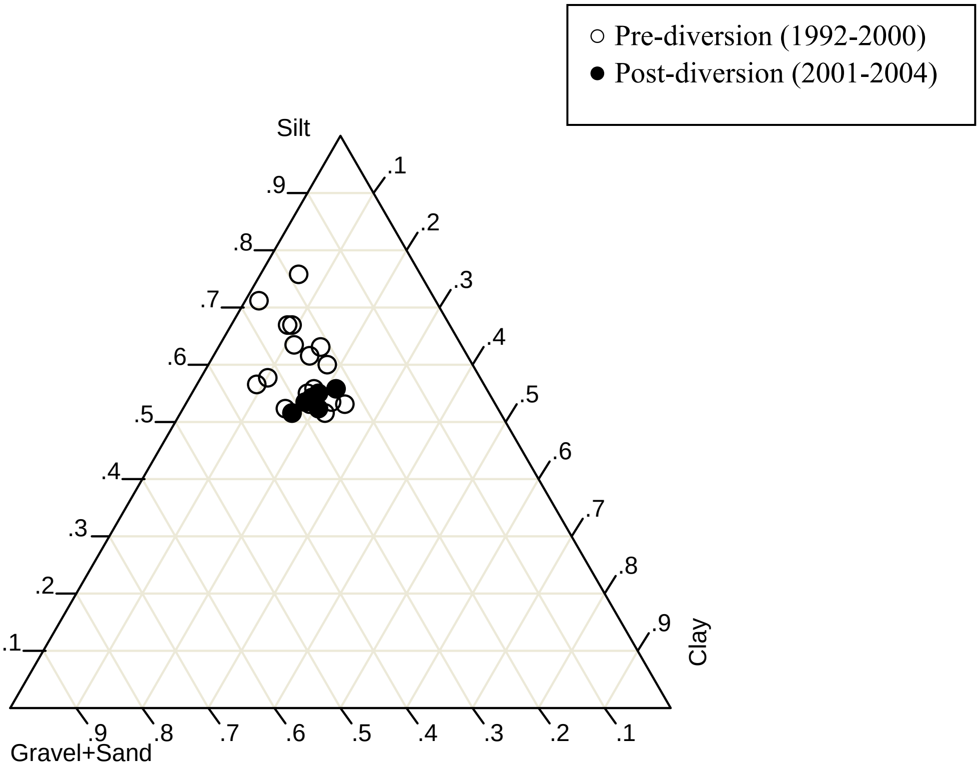


Figure B2-15. Distribution of percentages gravel + sand, silt, and clay in FF12 (top) and FF13 (bottom) surface (top 2 cm) sediments, pre- and post-diversion sampling periods.

Station=FF14
Ternary Plot



Station=NF02
Ternary Plot

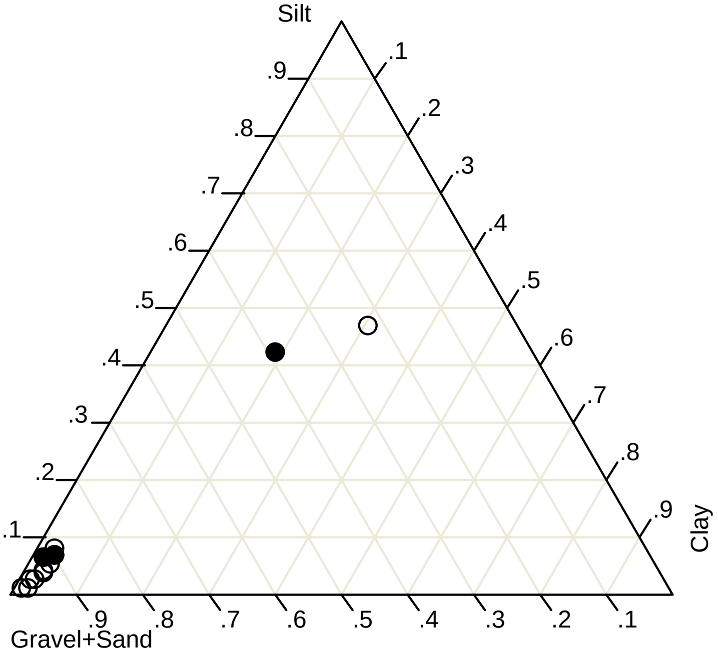
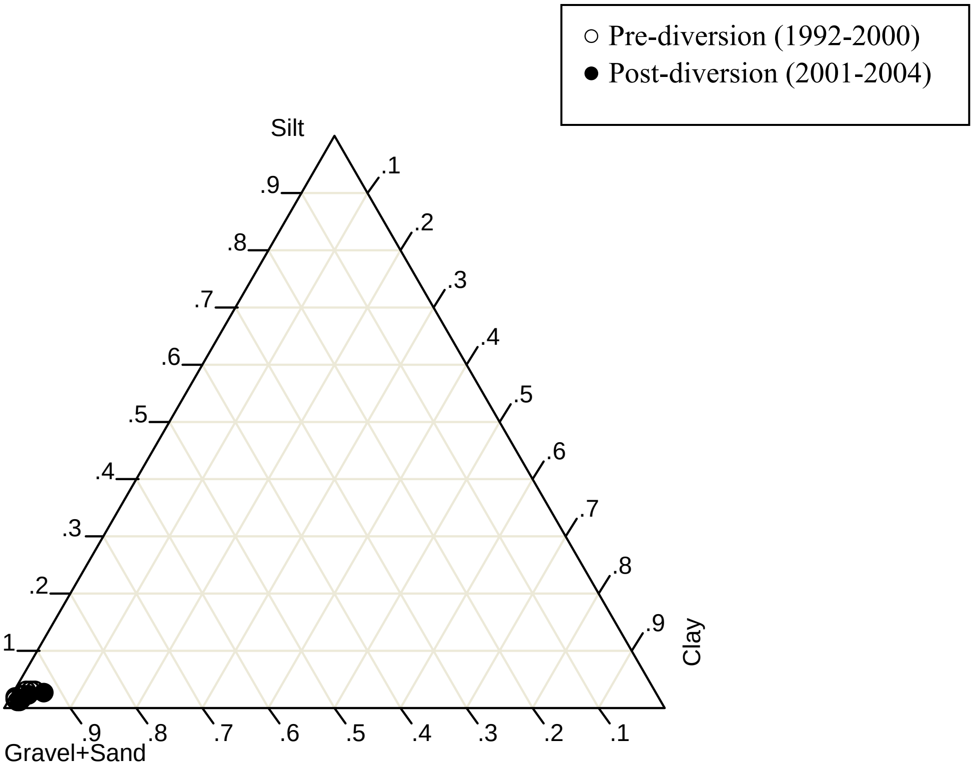


Figure B2-16. Distribution of percentages gravel + sand, silt, and clay in FF14 (top) and NF02 (bottom) surface (top 2 cm) sediments, pre- and post-diversion sampling periods.

Station=NF04
Ternary Plot



Station=NF05
Ternary Plot

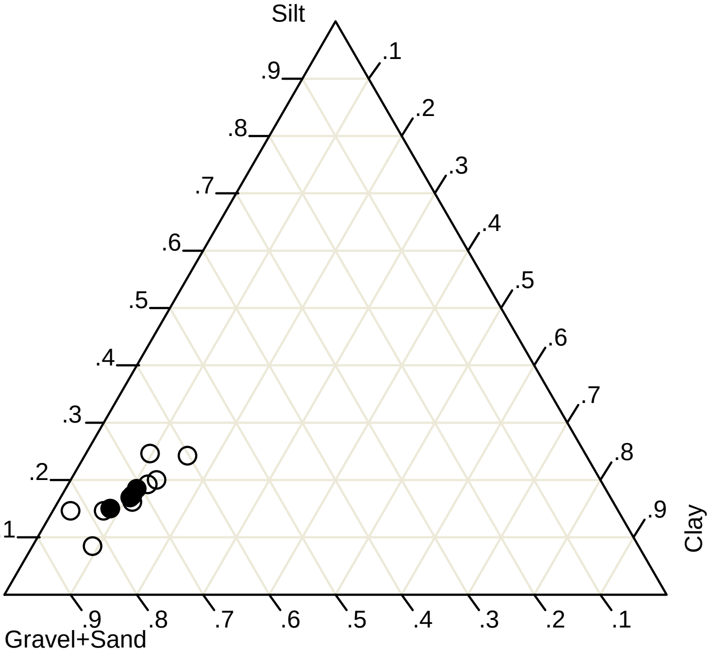
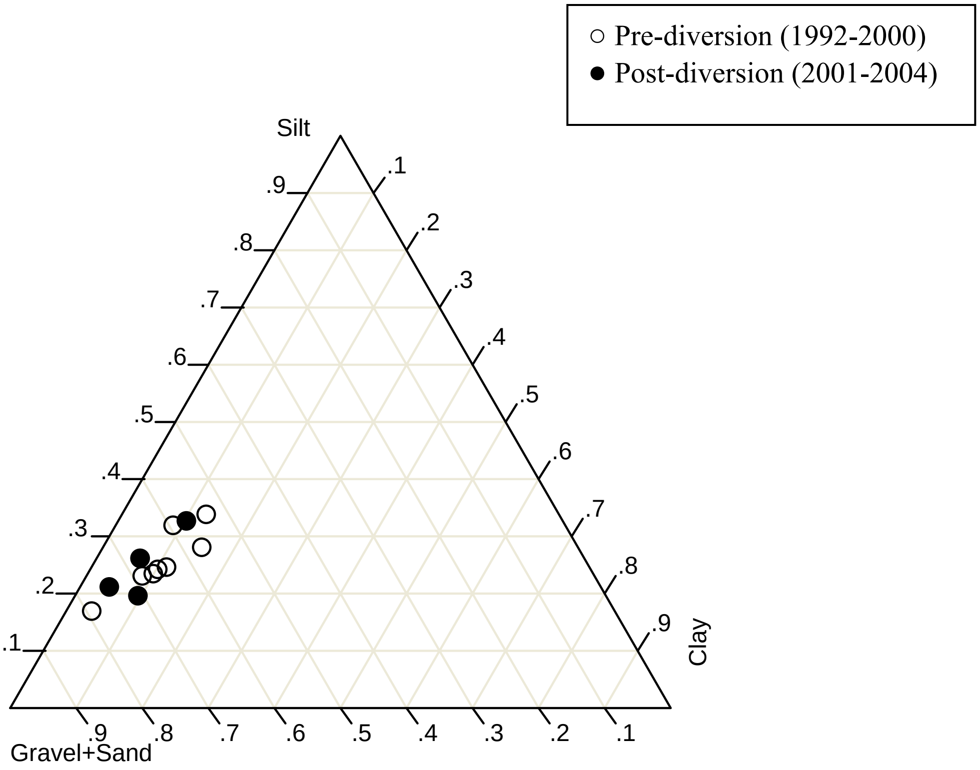
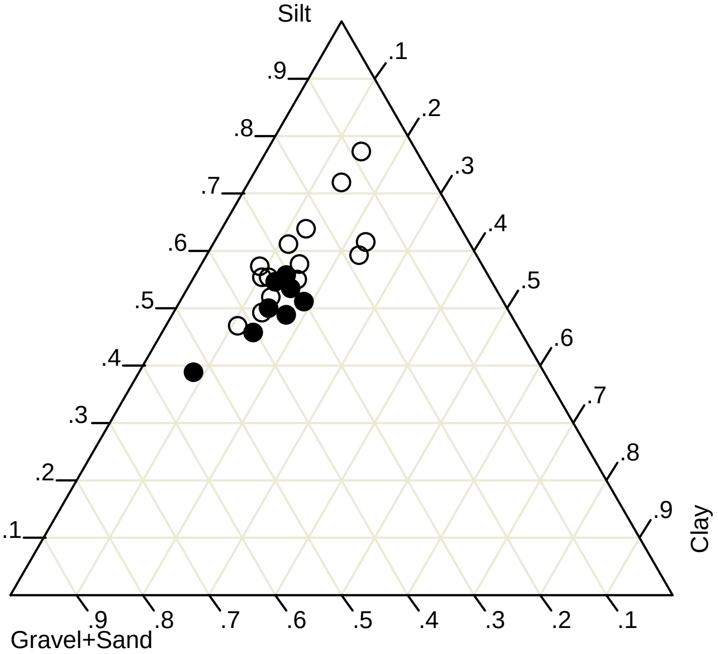


Figure B2-17. Distribution of percentages gravel + sand, silt, and clay in NF04 (top) and NF05 (bottom) surface (top 2 cm) sediments, pre- and post-diversion sampling periods.



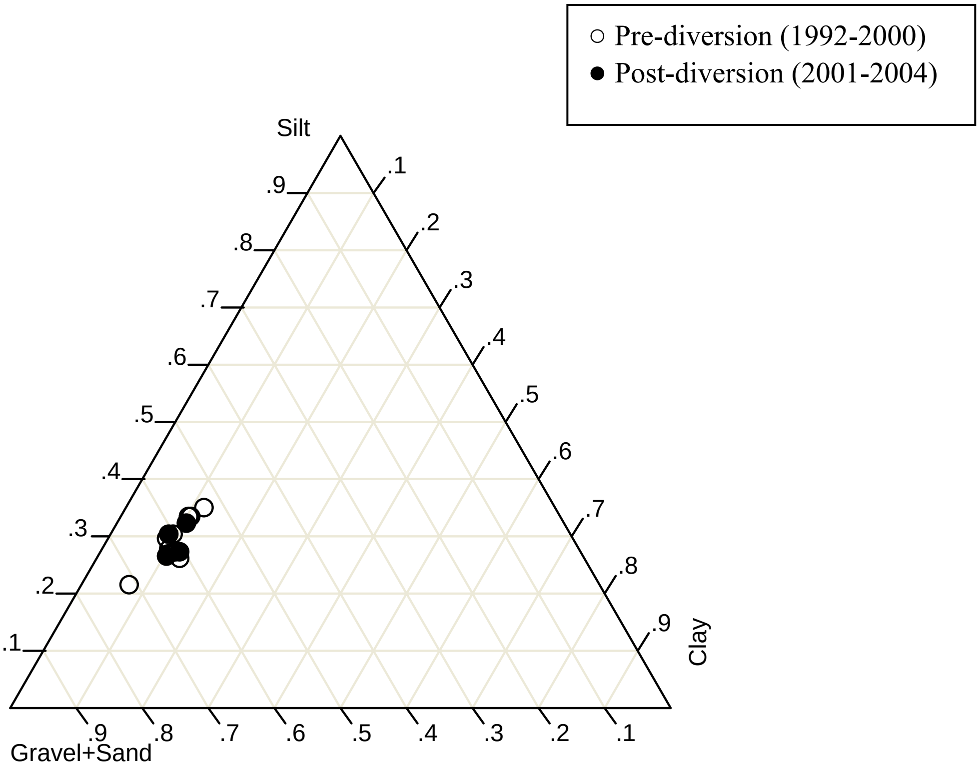
Station=NF07
Ternary Plot



Station=NF08
Ternary Plot

Figure B2-18. Distribution of percentages gravel + sand, silt, and clay in NF07 (top) and NF08 (bottom) surface (top 2 cm) sediments, pre- and post-diversion sampling periods.

Station=NF09
Ternary Plot



Station=NF10
Ternary Plot

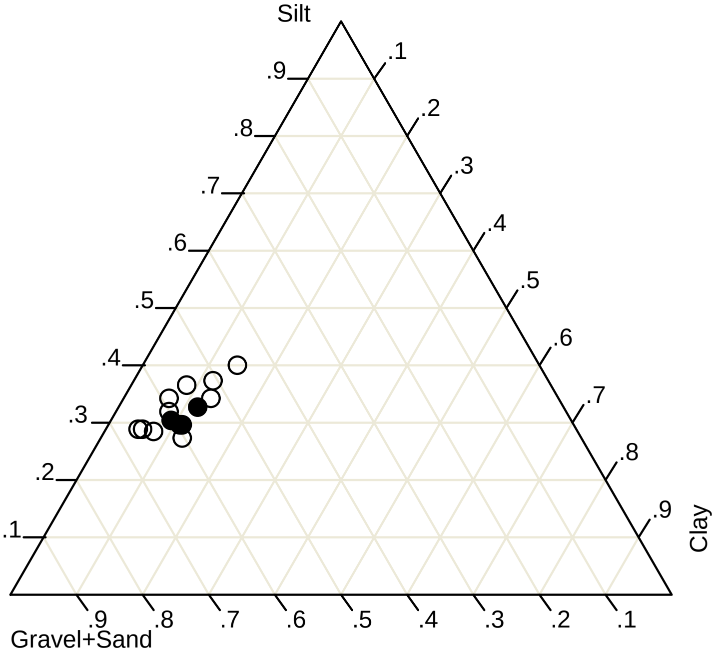
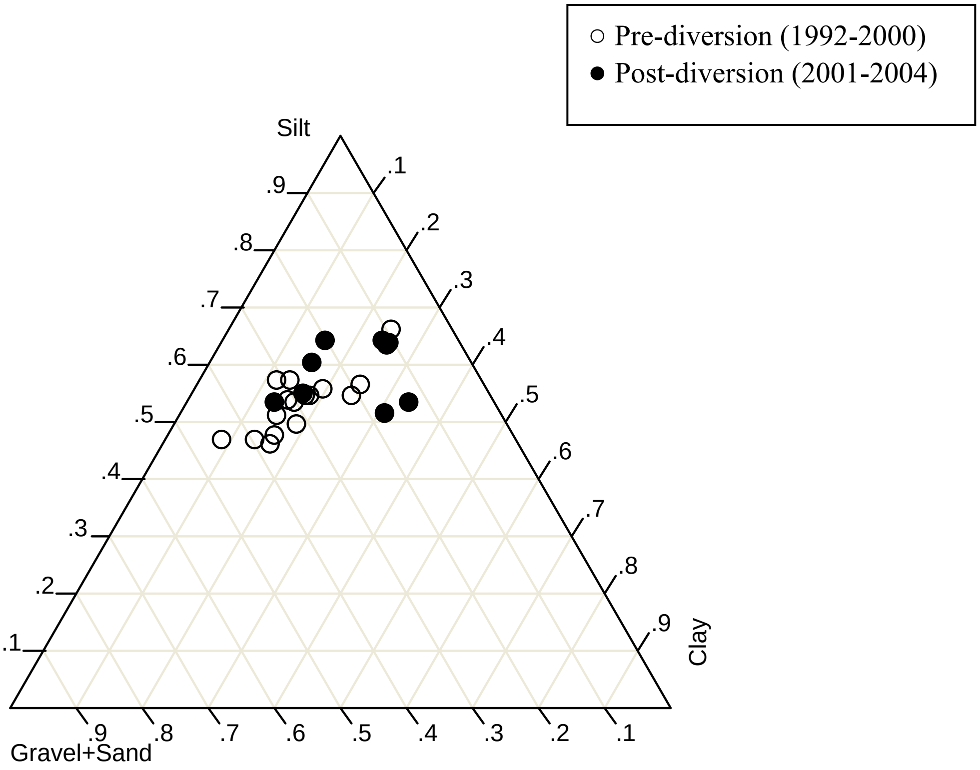


Figure B2-19. Distribution of percentages gravel + sand, silt, and clay in NF09 (top) and NF10 (bottom) surface (top 2 cm) sediments, pre- and post-diversion sampling periods.

Station=NF12
Ternary Plot



Station=NF13
Ternary Plot

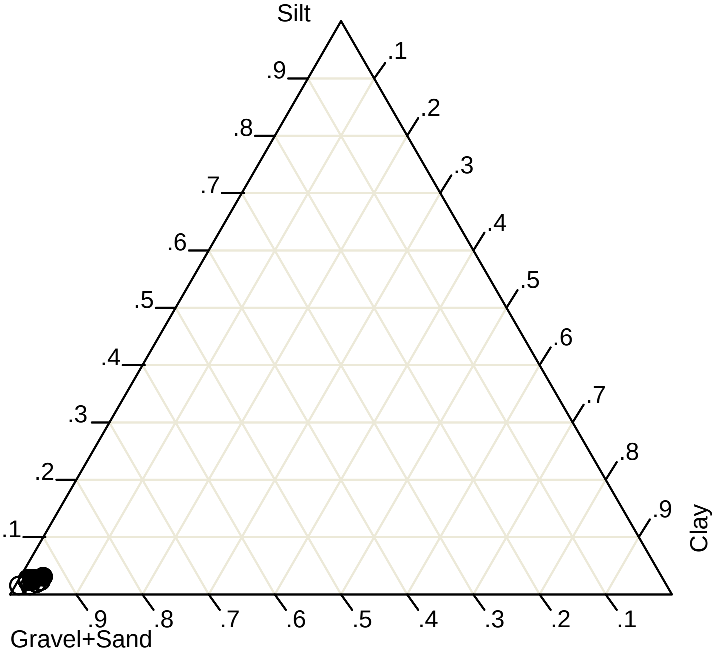
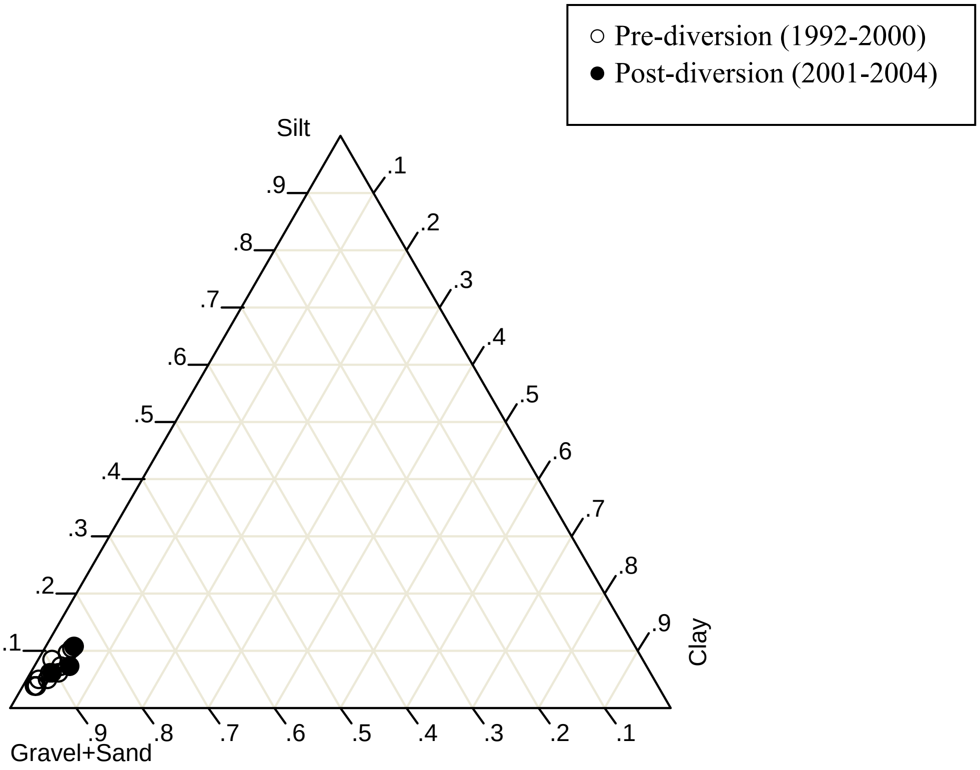


Figure B2-20. Distribution of percentages gravel + sand, silt, and clay in NF12 (top) and NF13 (bottom) surface (top 2 cm) sediments, pre- and post-diversion sampling periods.

Station=NF14
Ternary Plot



Station=NF15
Ternary Plot

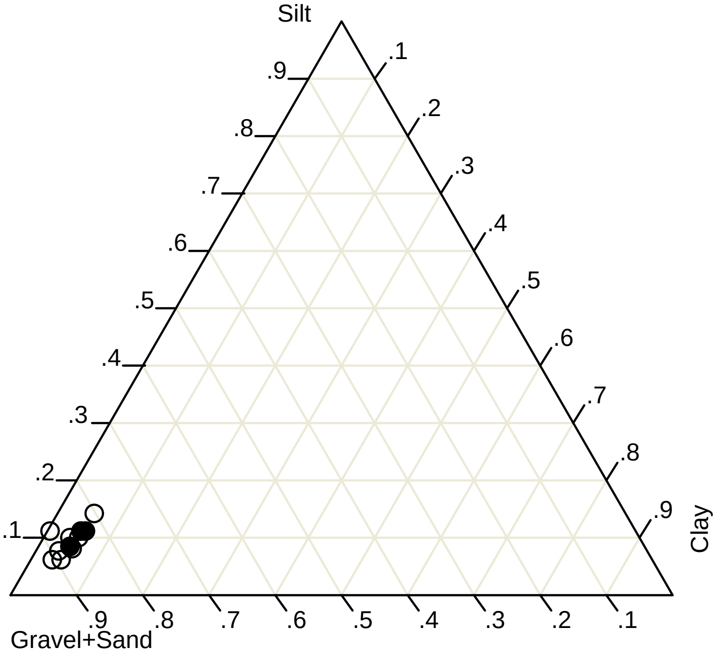
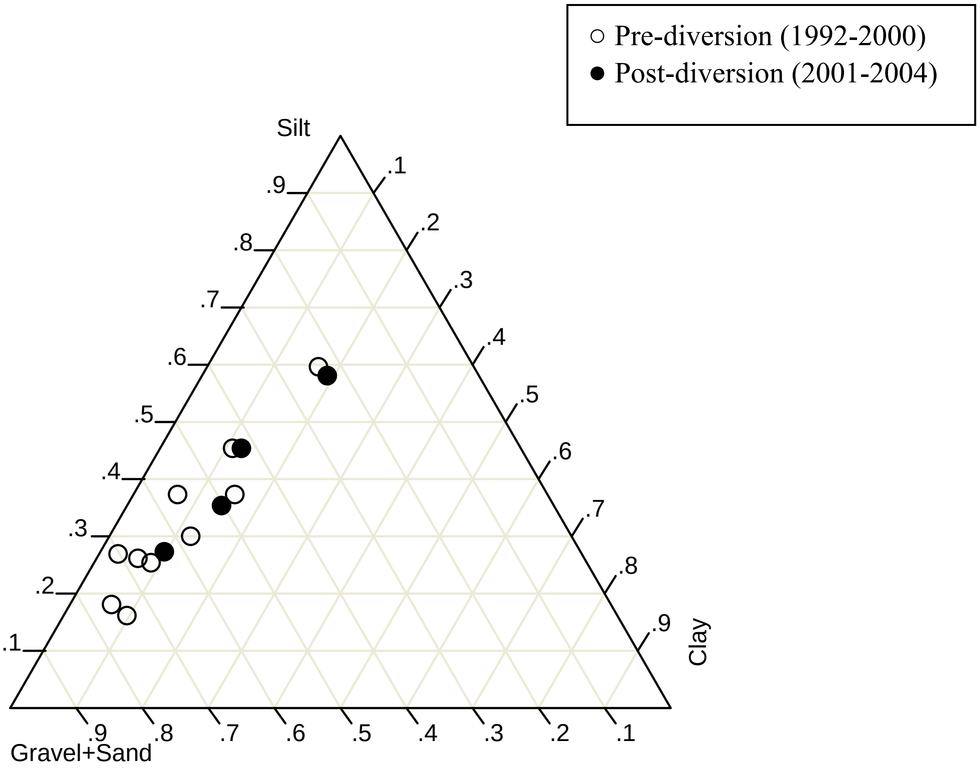


Figure B2-21. Distribution of percentages gravel + sand, silt, and clay in NF14 (top) and NF15 (bottom) surface (top 2 cm) sediments, pre- and post-diversion sampling periods.

Station=NF16
Ternary Plot



Station=NF17
Ternary Plot

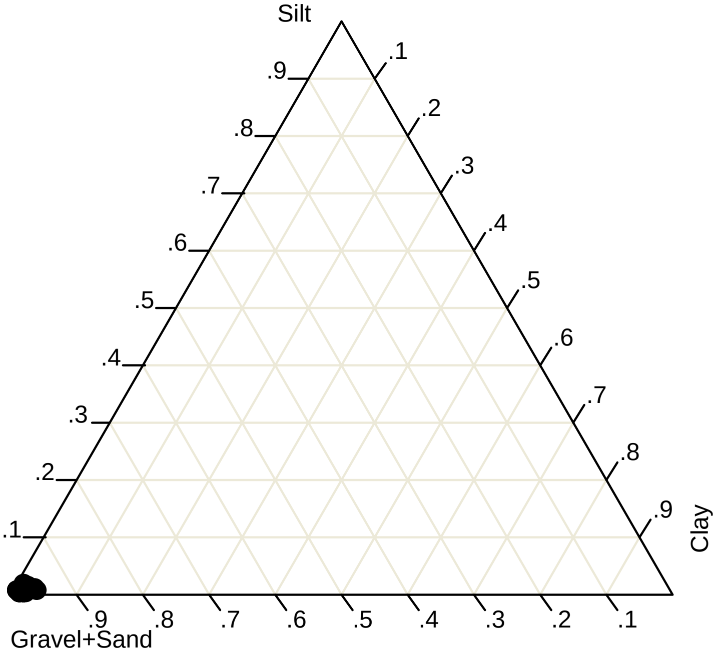
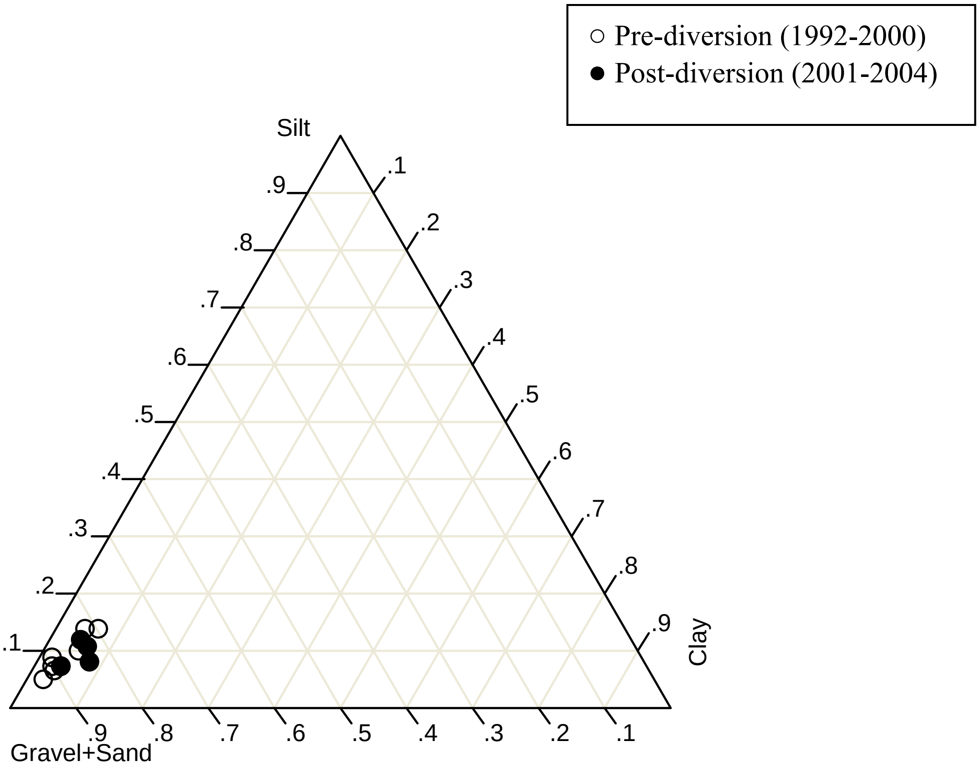


Figure B2-22. Distribution of percentages gravel + sand, silt, and clay in NF16 (top) and NF17 (bottom) surface (top 2 cm) sediments, pre- and post-diversion sampling periods.

Station=NF18
Ternary Plot



Station=NF19
Ternary Plot

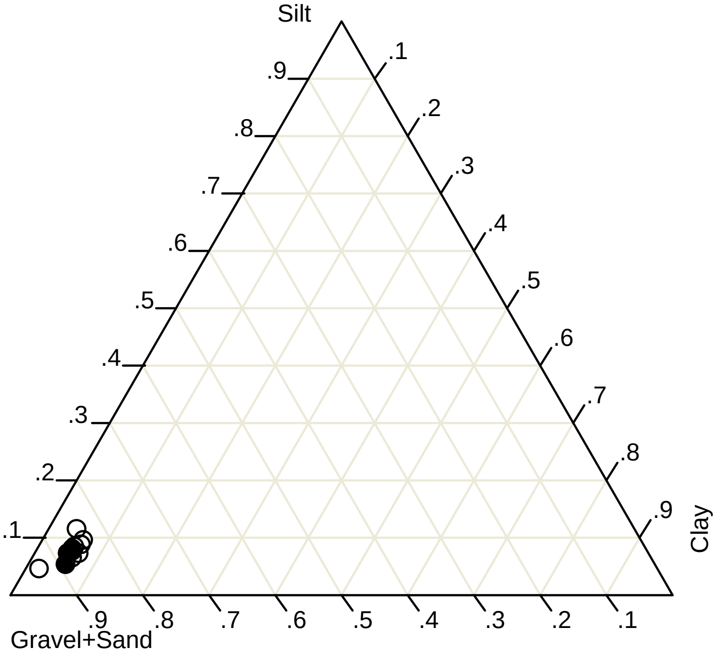
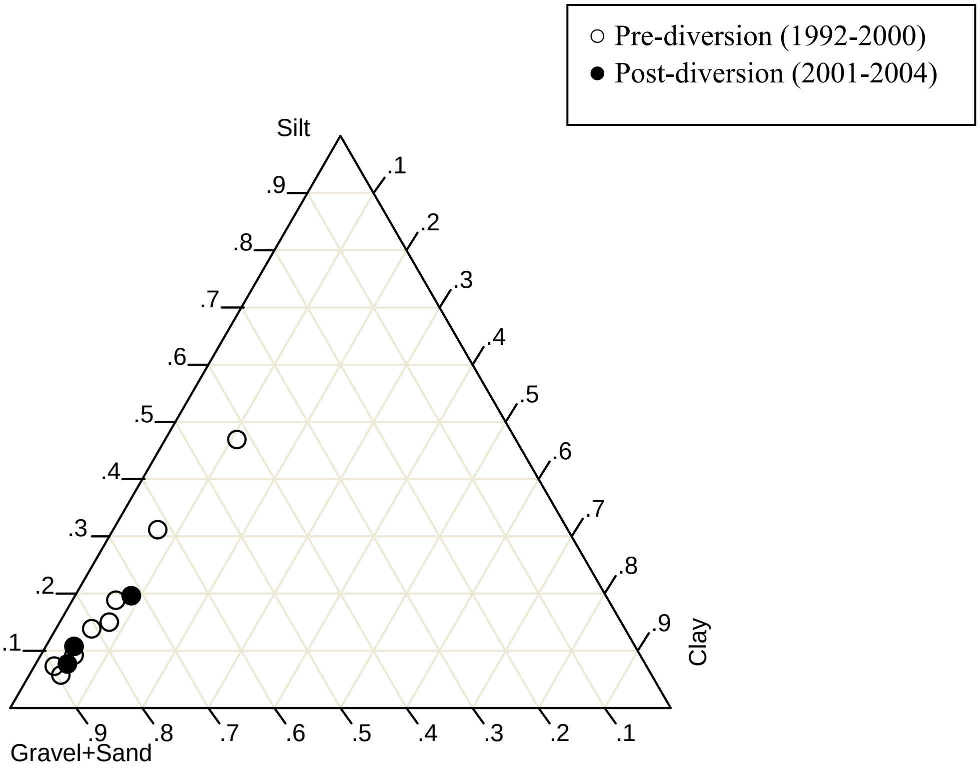


Figure B2-23. Distribution of percentages gravel + sand, silt, and clay in NF18 (top) and NF19 (bottom) surface (top 2 cm) sediments, pre- and post-diversion sampling periods.

Station=NF20
Ternary Plot



Station=NF21
Ternary Plot

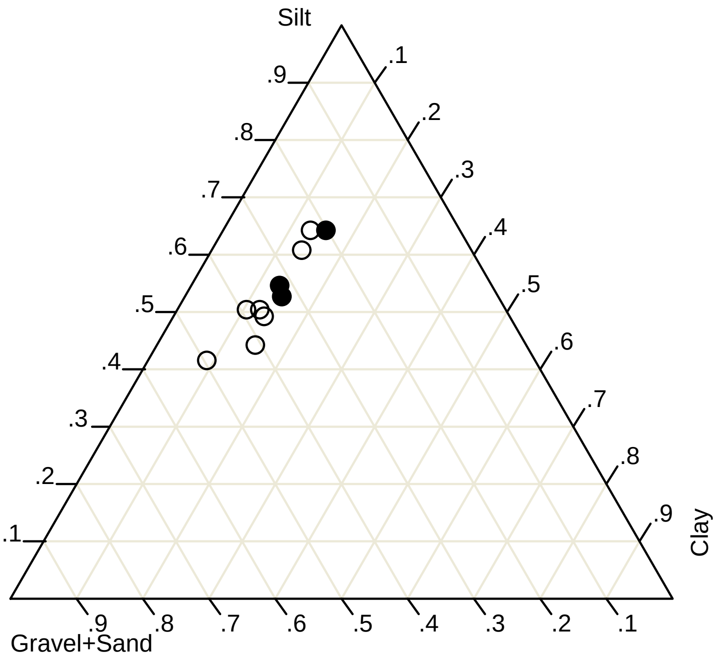
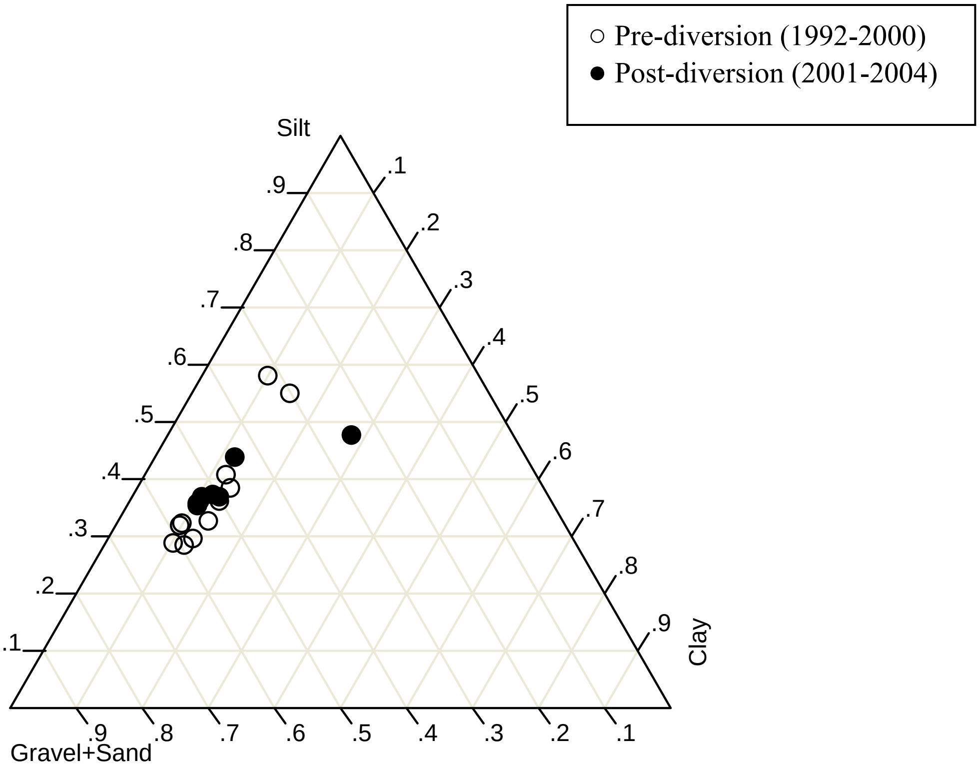


Figure B2-24. Distribution of percentages gravel + sand, silt, and clay in NF20 (top) and NF21 (bottom) surface (top 2 cm) sediments, pre- and post-diversion sampling periods.

Station=NF22
Ternary Plot



Station=NF23
Ternary Plot

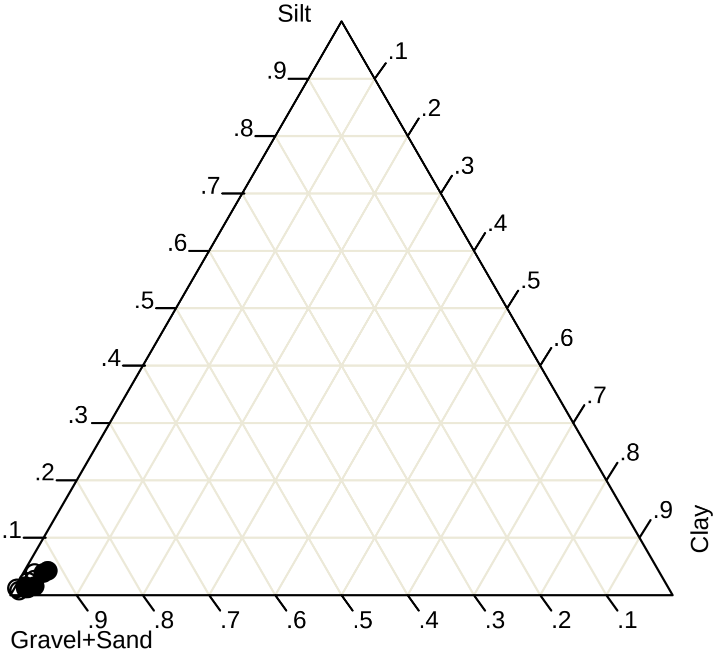


Figure B2-25. Distribution of percentages gravel + sand, silt, and clay in NF22 (top) and NF23 (bottom) surface (top 2 cm) sediments, pre- and post-diversion sampling periods.

Station=NF24
Ternary Plot

○ Pre-diversion (1992-2000)
● Post-diversion (2001-2004)

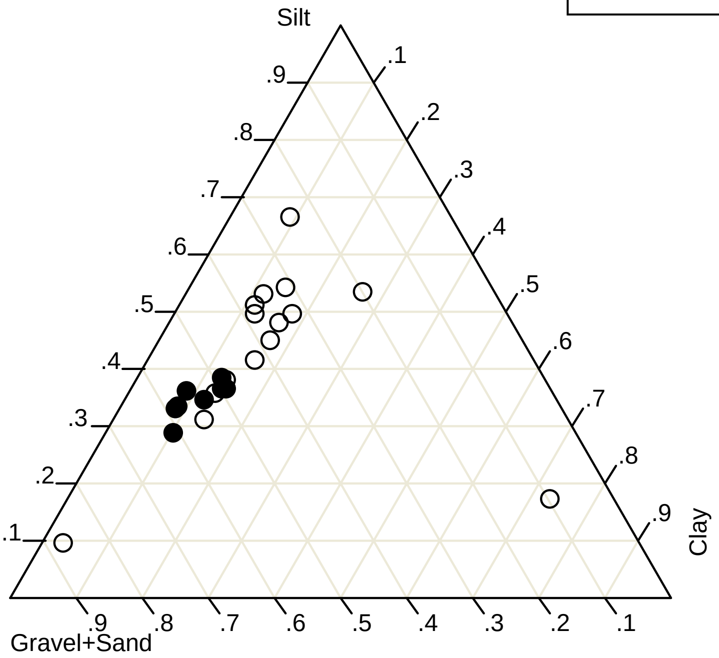


Figure B2-26. Distribution of percentages gravel + sand, silt, and clay in NF24 surface (top 2 cm) sediments, pre- and post-diversion sampling periods.

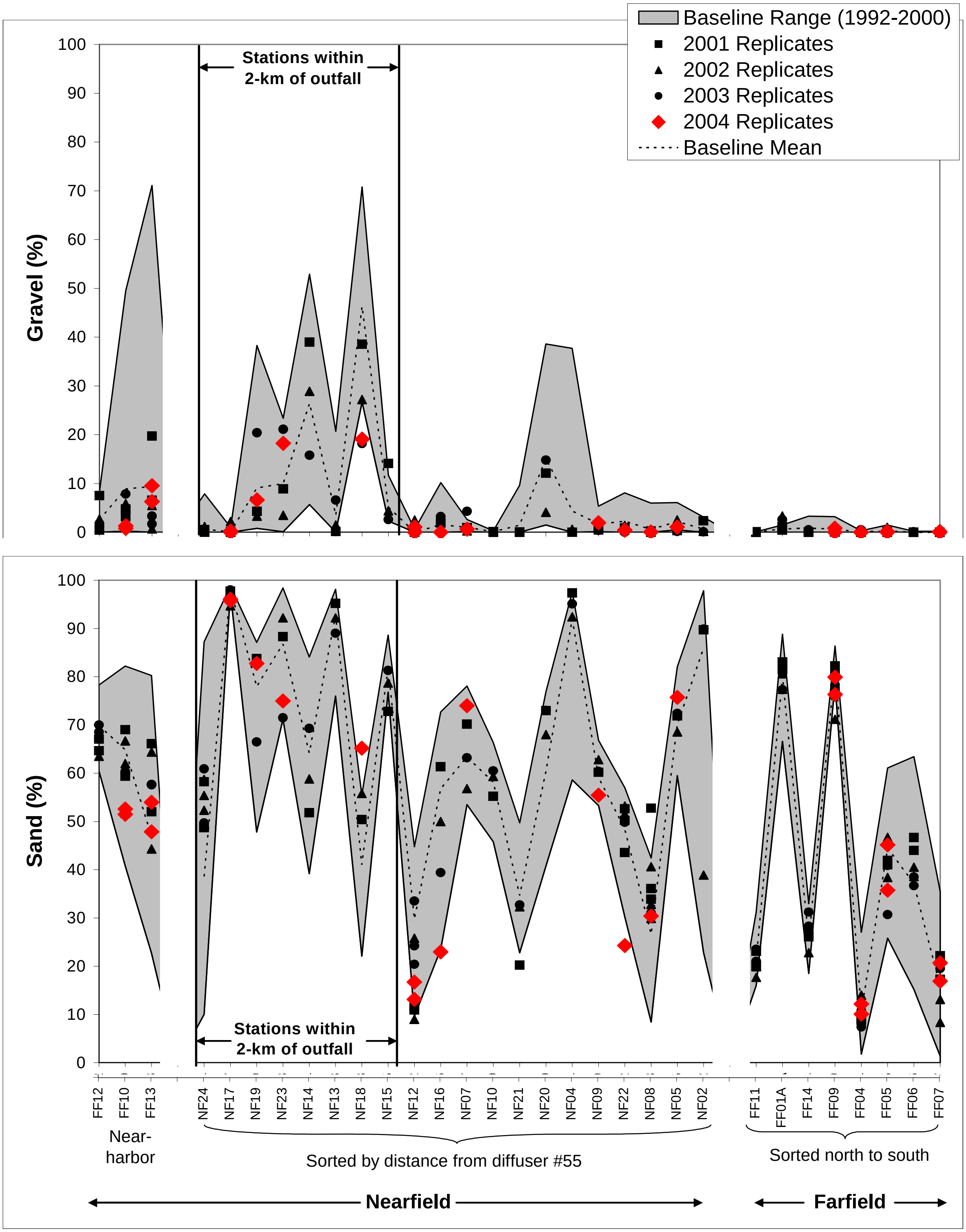


Figure B2-27. Percentages gravel (top) and sand (bottom) in regional surface (top 2 cm) sediments during the baseline (1992–2000 range of values, gray band) and post-diversion (2001–2004, symbols) periods. The baseline mean values are indicated by a dashed line within the gray band.

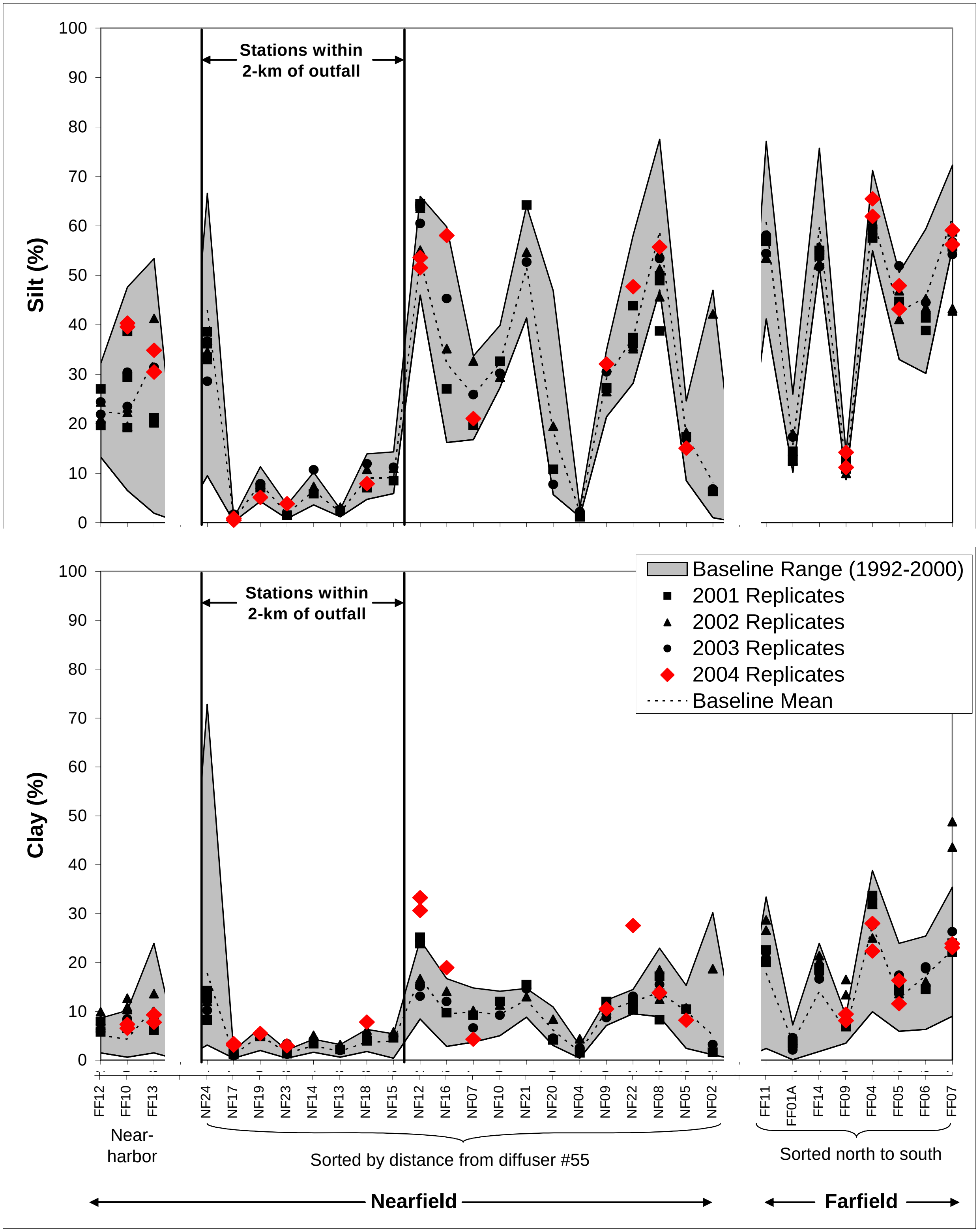


Figure B2-28. Percentages silt (top) and clay (bottom) in regional surface (top 2 cm) sediments during the baseline (1992–2000 range of values, gray band) and post-diversion (2001–2004, symbols) periods. The baseline mean values are indicated by a dashed line within the gray band.

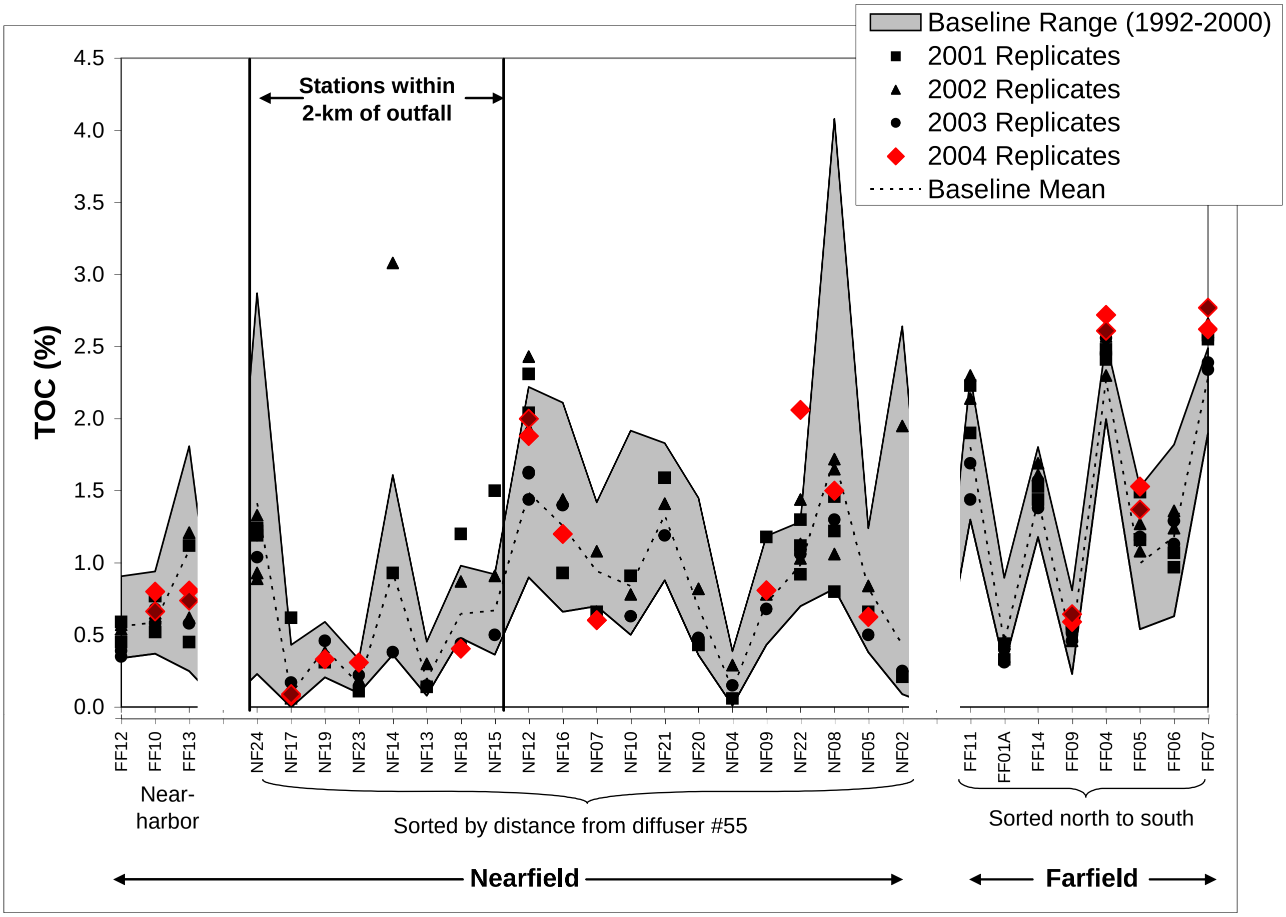


Figure B2-29. TOC in regional surface (top 2 cm) sediments during the baseline (1992–2000 range of values, gray band) and post-diversion (2001–2004, symbols) periods. The baseline mean values are indicated by a dashed line within the gray band.

APPENDIX B3

Organic Contaminants and Metals Range Plots
Regional Sediments 1992–2004

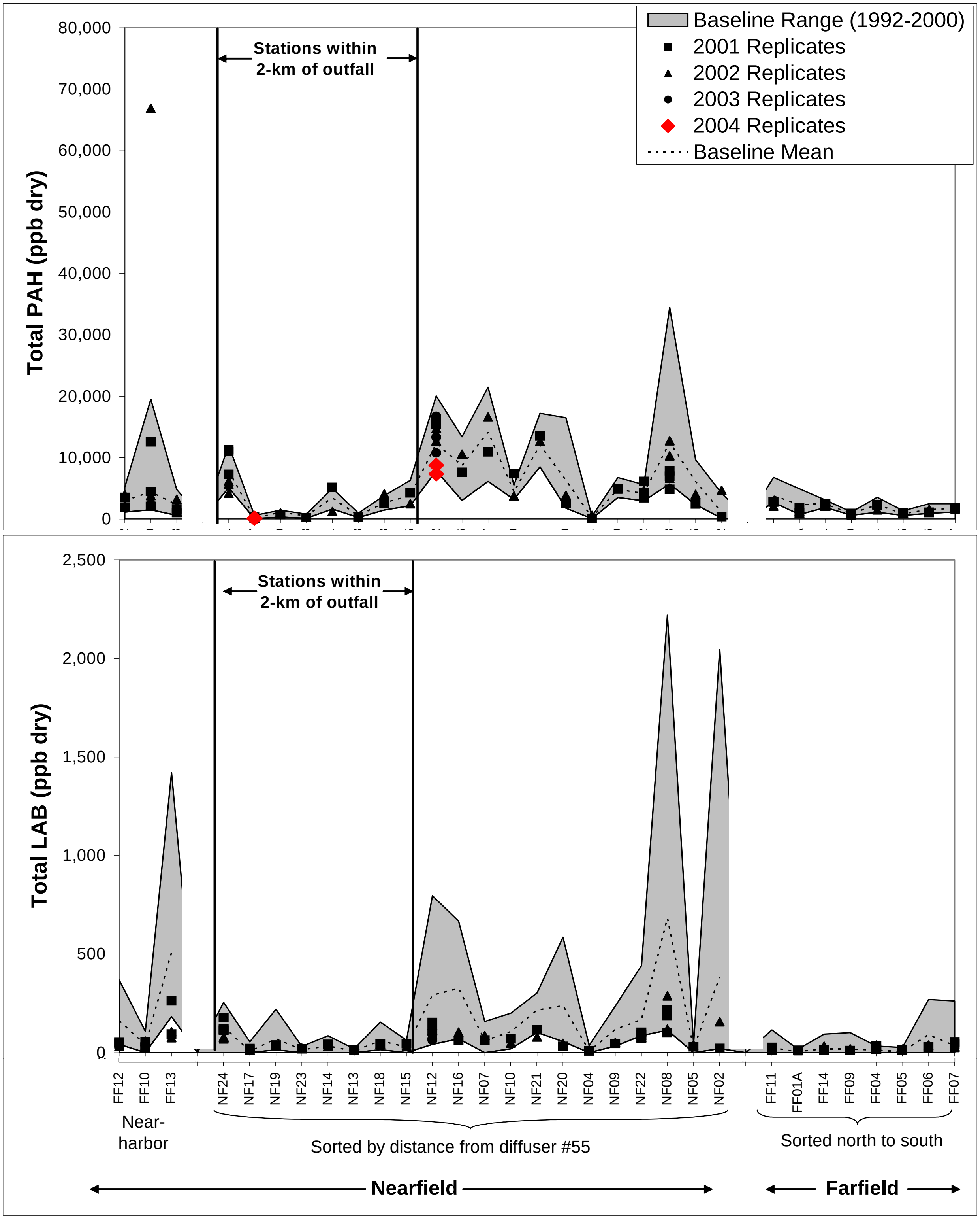


Figure B3-1. Total PAH (top) and total LAB (bottom) for regional stations over the baseline (1992–2000 range of values, grey band) and post-diversion (2001–2004, symbols). The baseline mean values are indicated by a dashed line within gray band. No LAB data for 2004.

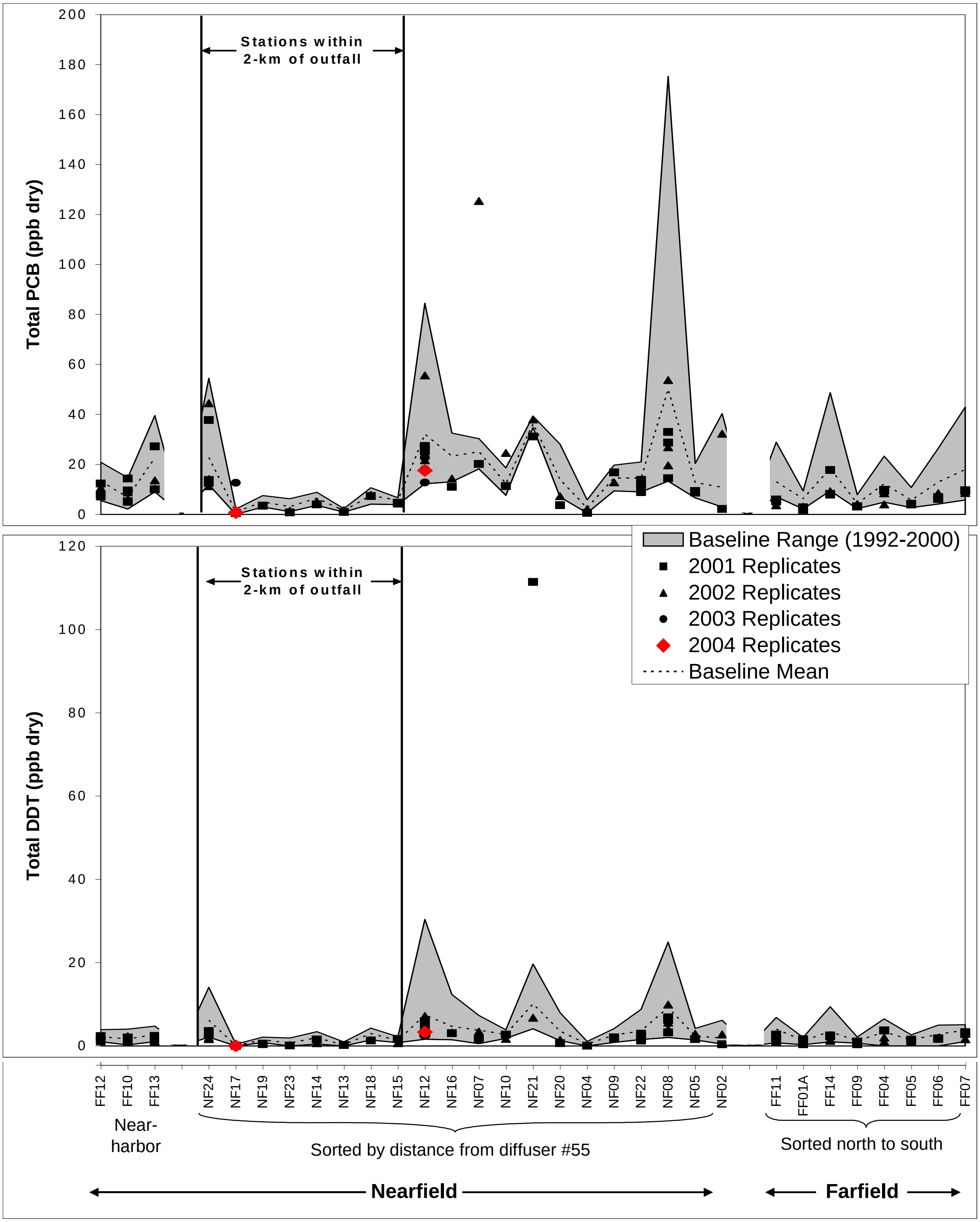


Figure B3-2. Total PCB (top) and total DDT (bottom) for regional stations over the baseline (1992–2000 range of values, grey band) and post-diversion (2001–2004, symbols). The baseline mean values are indicated by a dashed line within gray band.

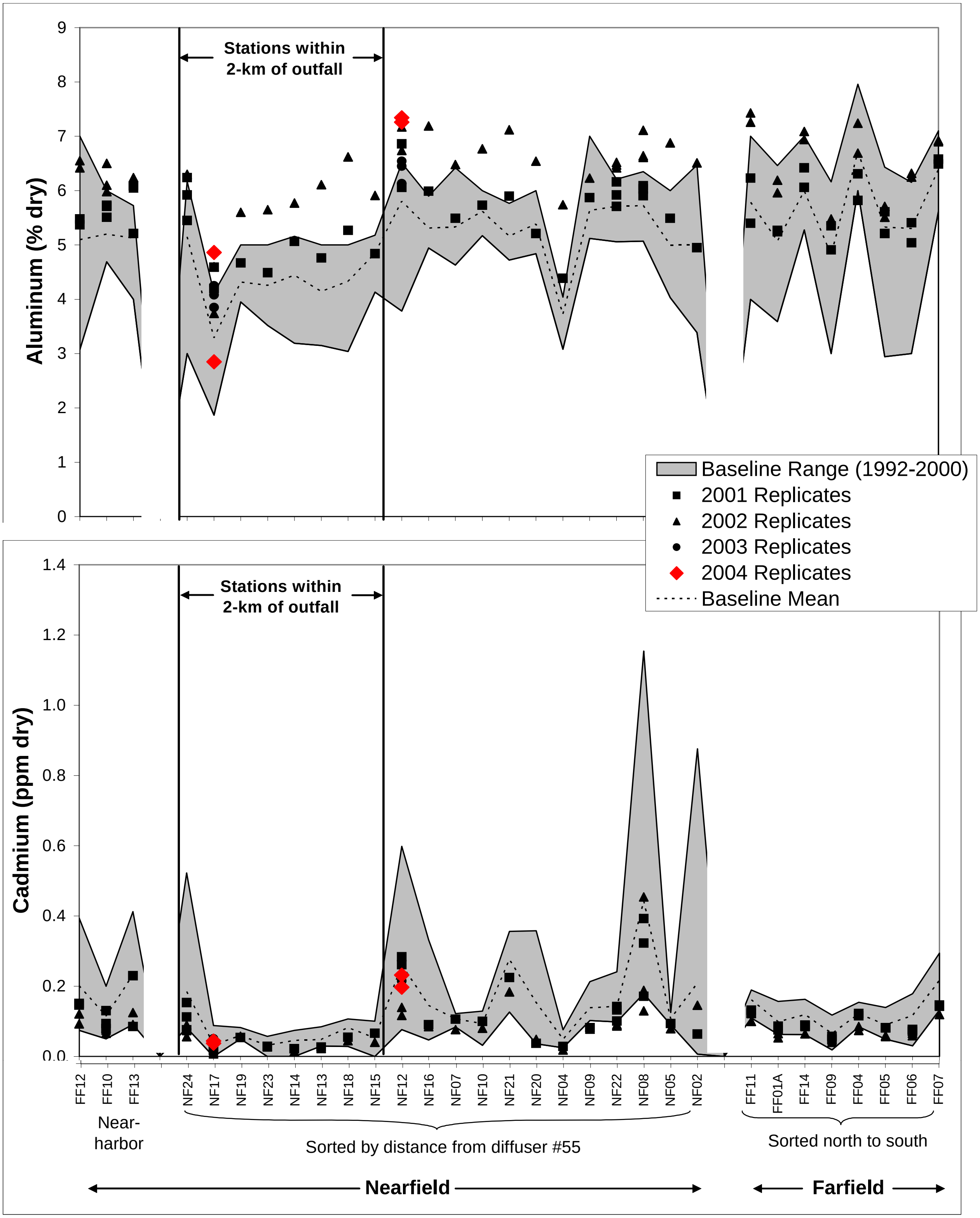


Figure B3-3. Aluminum (top) and cadmium (bottom) for regional stations over the baseline (1992–2000 range of values, grey band) and post-diversion (2001–2004, symbols). The baseline mean values are indicated by a dashed line within gray band.

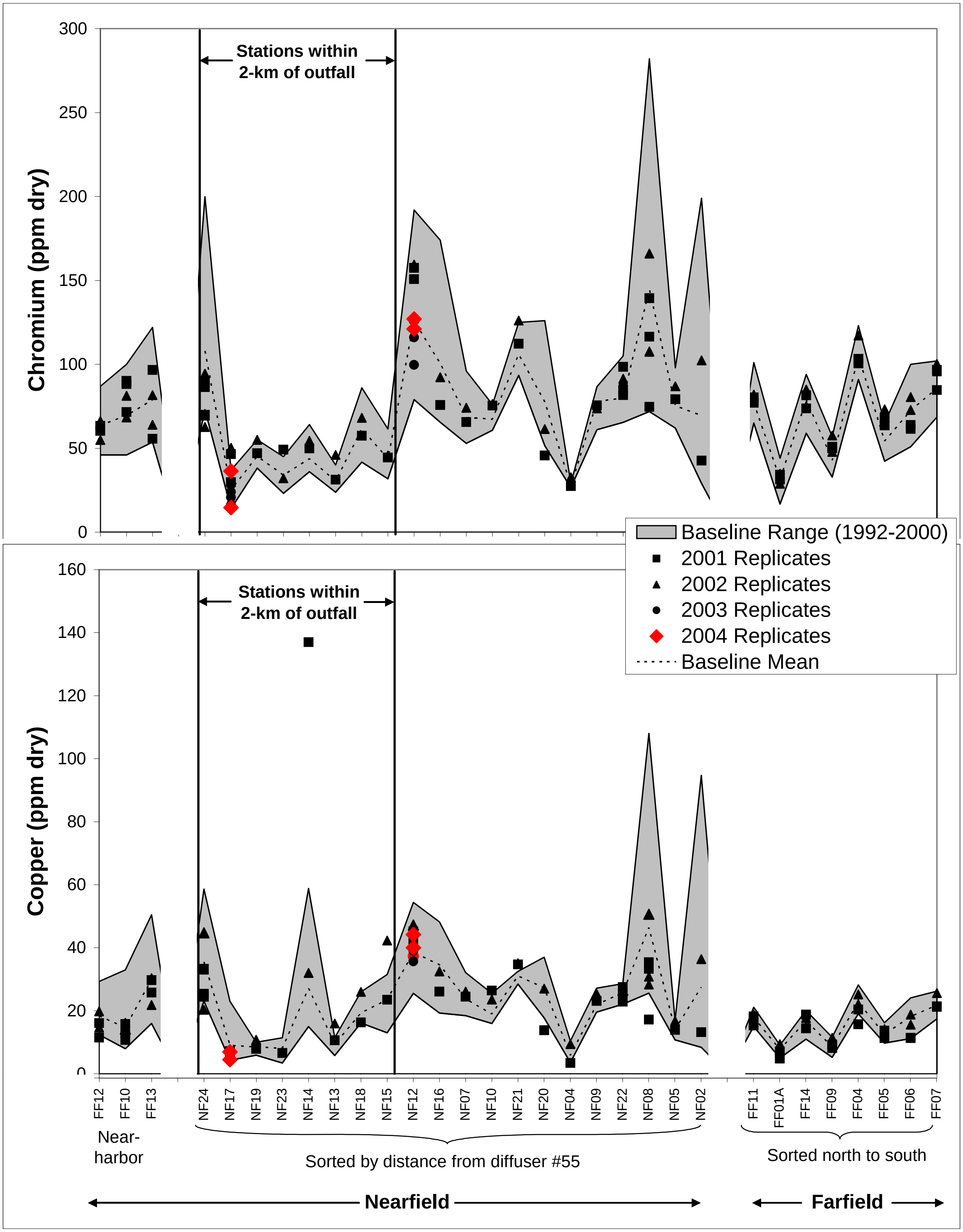


Figure B3-4. Chromium (top) and copper (bottom) for regional stations over the baseline (1992–2000 range of values, grey band) and post-diversion (2001–2004, symbols). The baseline mean values are indicated by a dashed line within gray band.

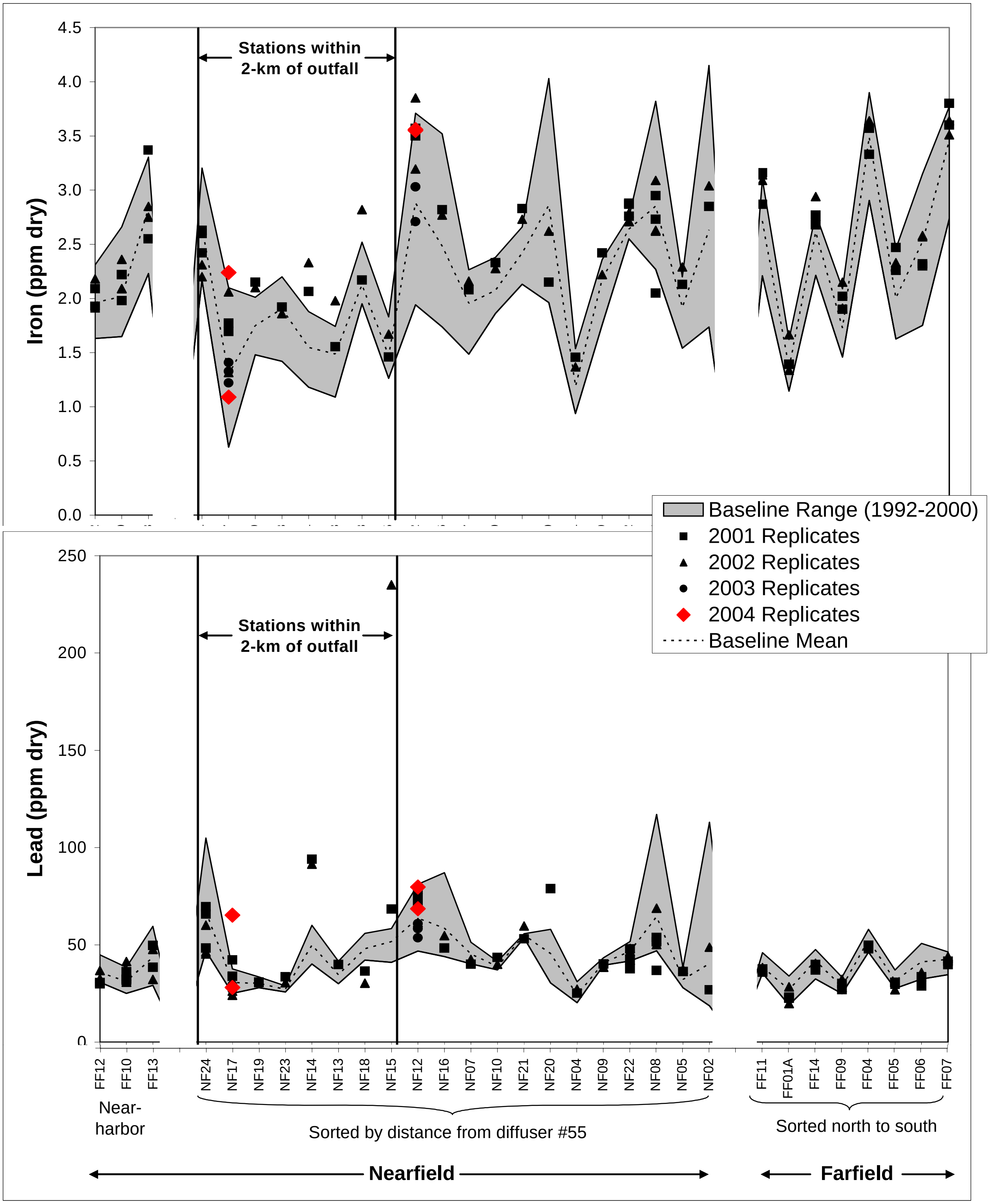


Figure B3-5. Iron (top) and lead (bottom) for regional stations over the baseline (1992–2000 range of values, grey band) and post-diversion (2001–2004, symbols). The baseline mean values are indicated by a dashed line within gray band.

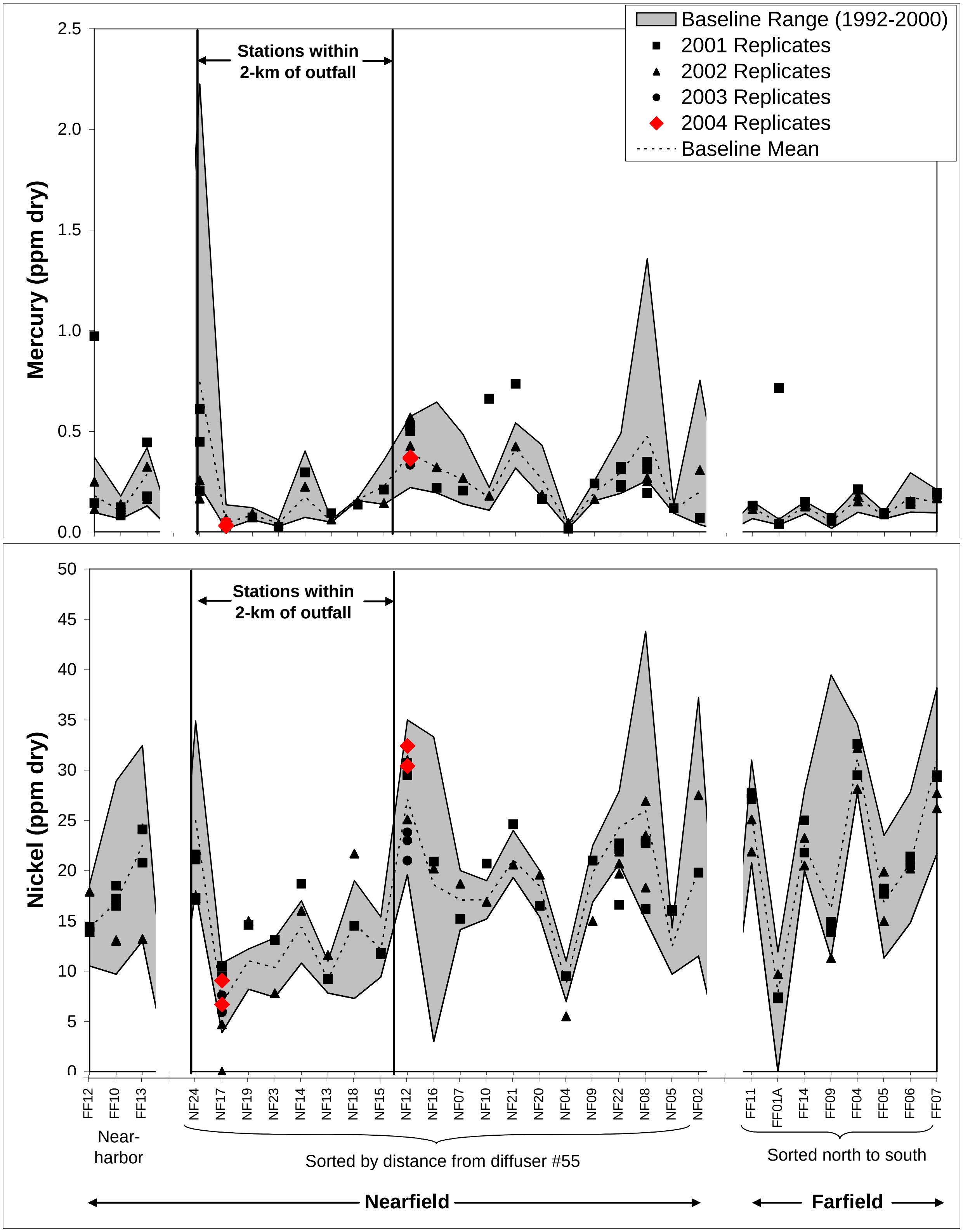


Figure B3-6. Mercury (top) and nickel (bottom) for regional stations over the baseline (1992–2000 range of values, grey band) and post-diversion (2001–2004, symbols). The baseline mean values are indicated by a dashed line within gray band.

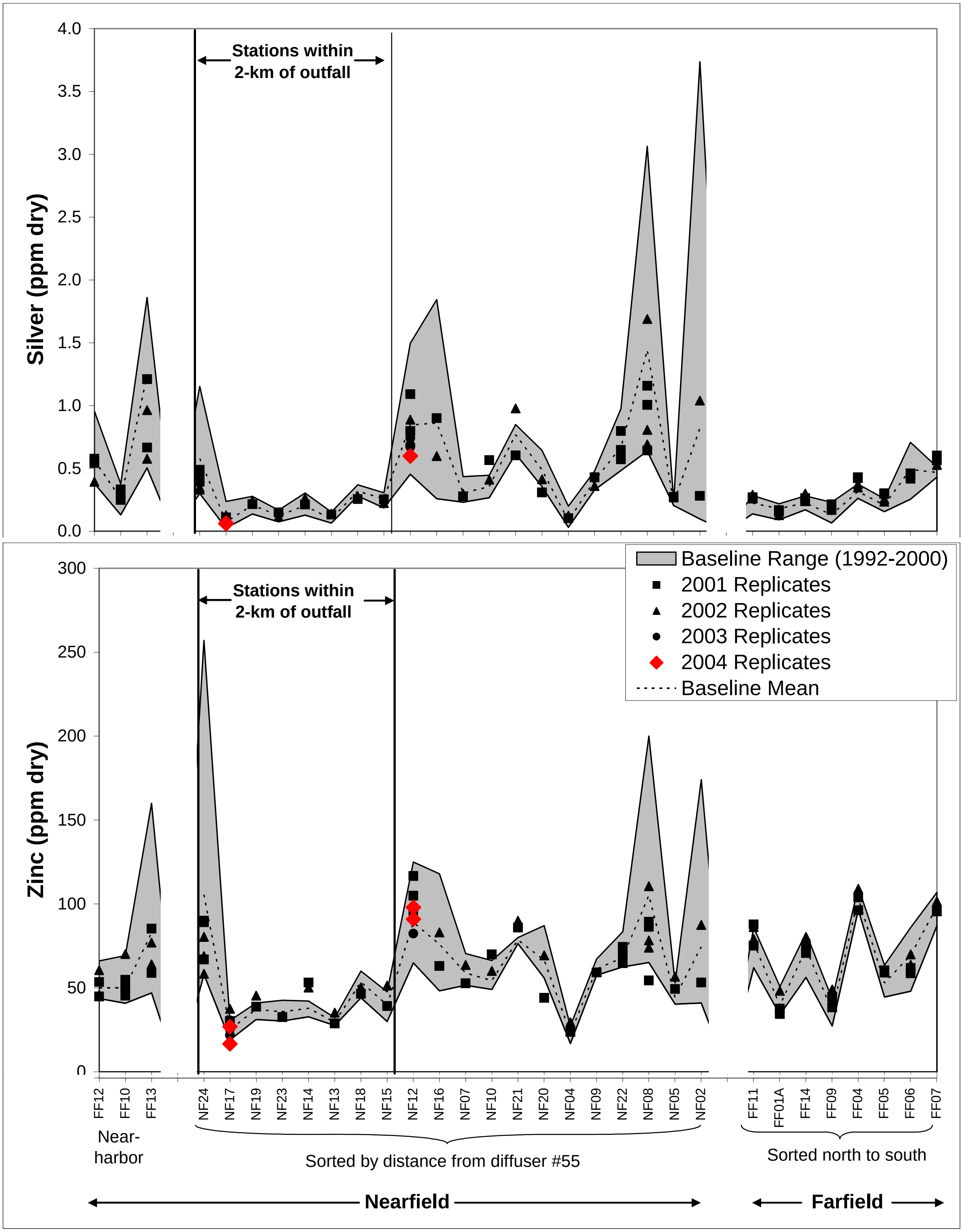


Figure B3-7. Silver (top) and zinc (bottom) for regional stations over the baseline (1992–2000 range of values, grey band) and post-diversion (2001–2004, symbols). The baseline mean values are indicated by a dashed line within gray band.

APPENDIX B4

Clostridium Maps and Range Plots, 1999–2004
Grain Size and TOC Scatter Plots, 2000–2004

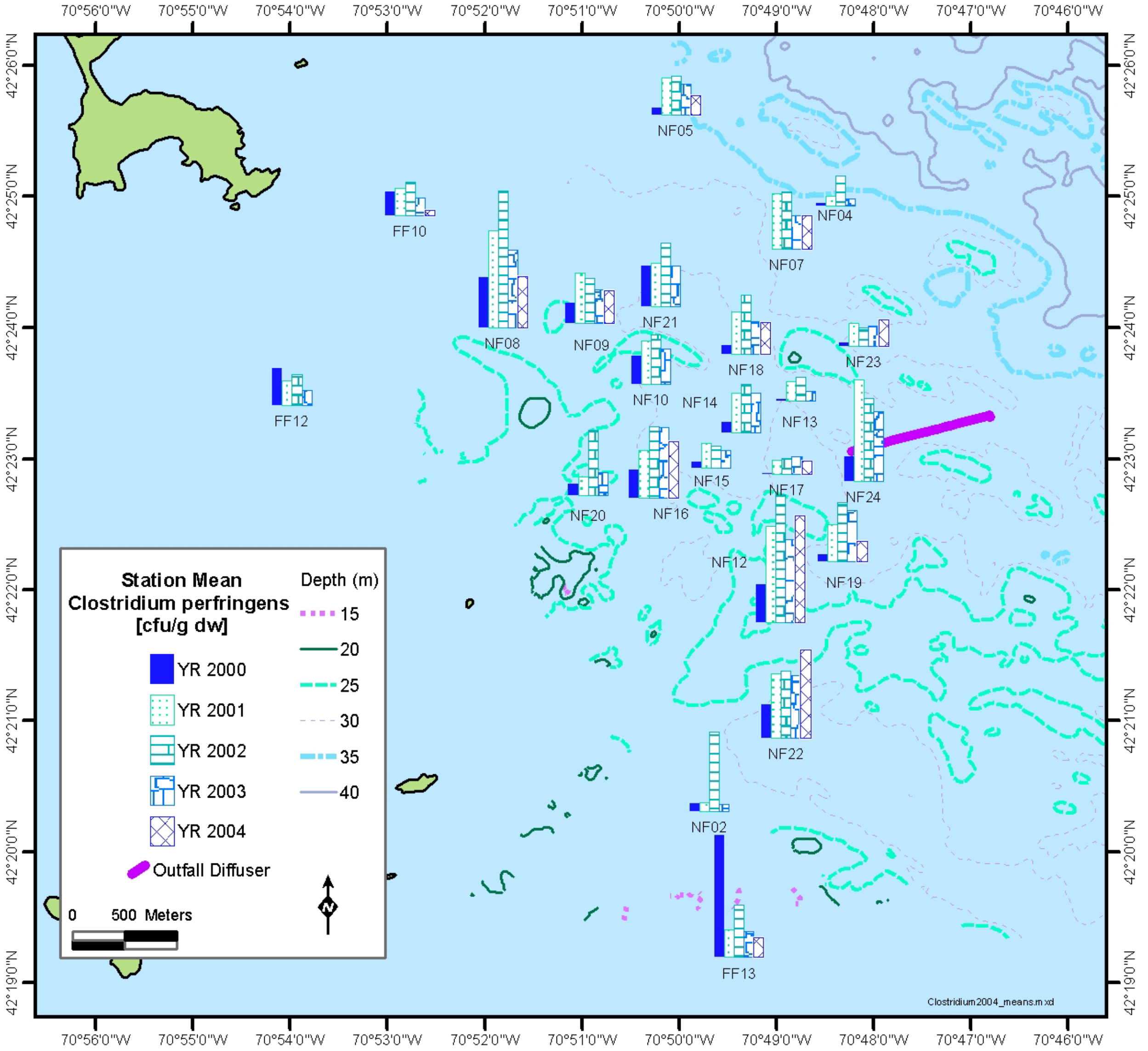


Figure B4-1. Station mean concentrations of *C. perfringens* (non-normalized) in nearfield sediments prior to (August 2000) and after (August 2001–2004) outfall activation.

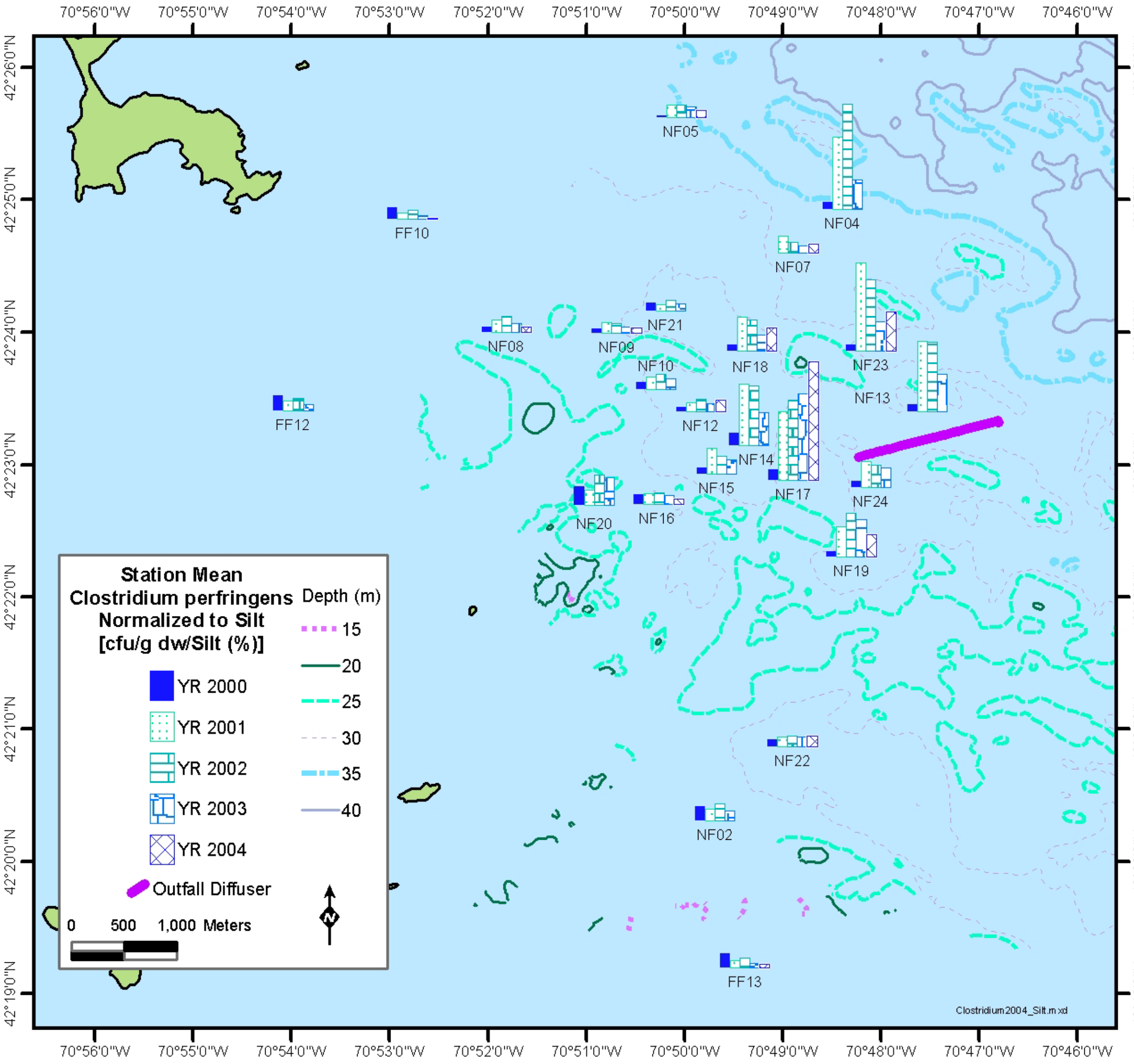


Figure B4-2. Station mean concentrations of *C. perfringens* (normalized to percent silt) in nearfield sediments prior to (August 2000) and after (August 2001–2004) outfall activation.

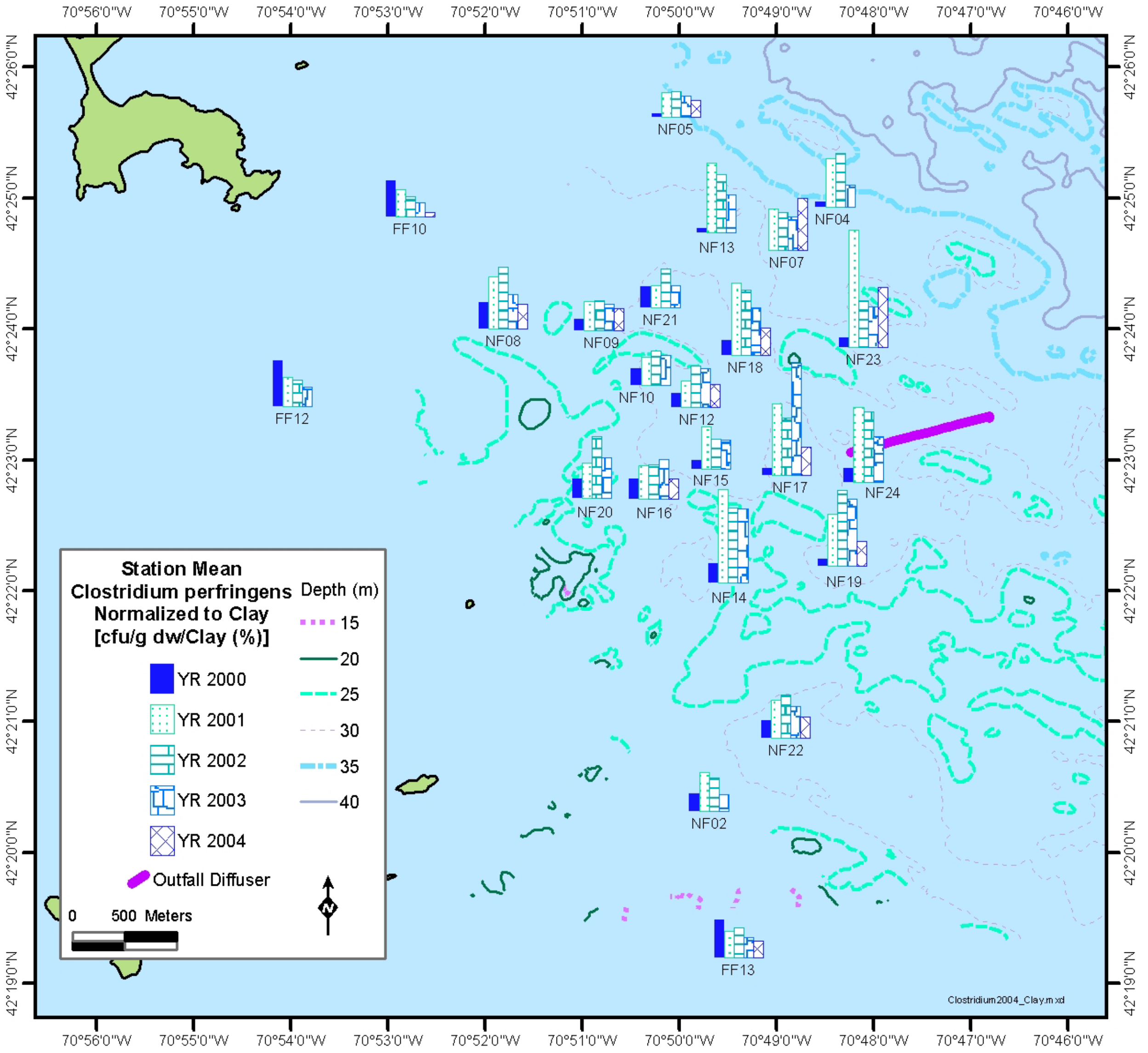


Figure B4-3. Station mean concentrations of *C. perfringens* (normalized to percent clay) in nearfield sediments prior to (August 2000) and after (August 2001–2004) outfall activation.

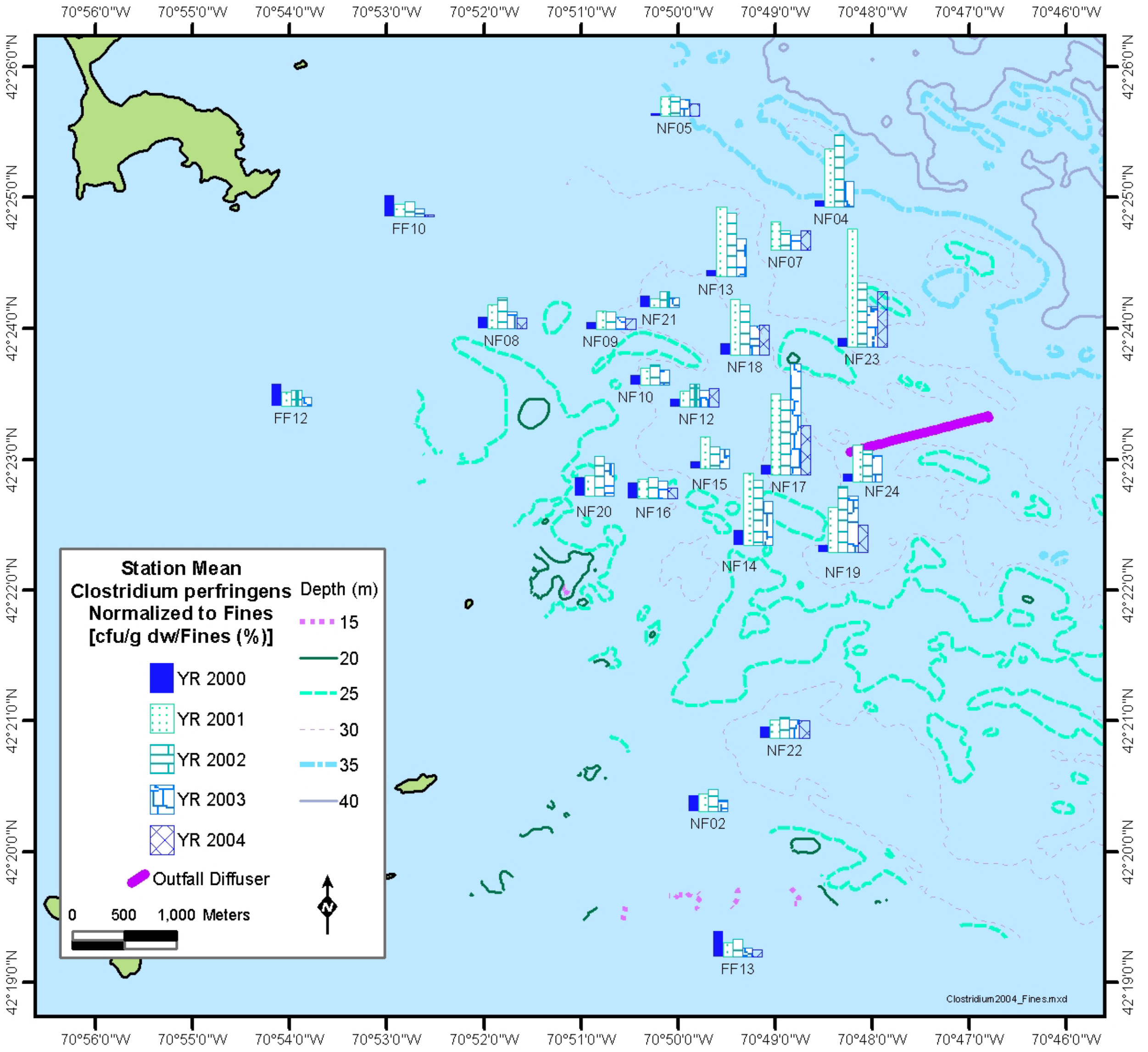


Figure B4-4. Station mean concentrations of *C. perfringens* (normalized to percent fines) in nearfield sediments prior to (August 2000) and after (August 2001–2004) outfall activation.

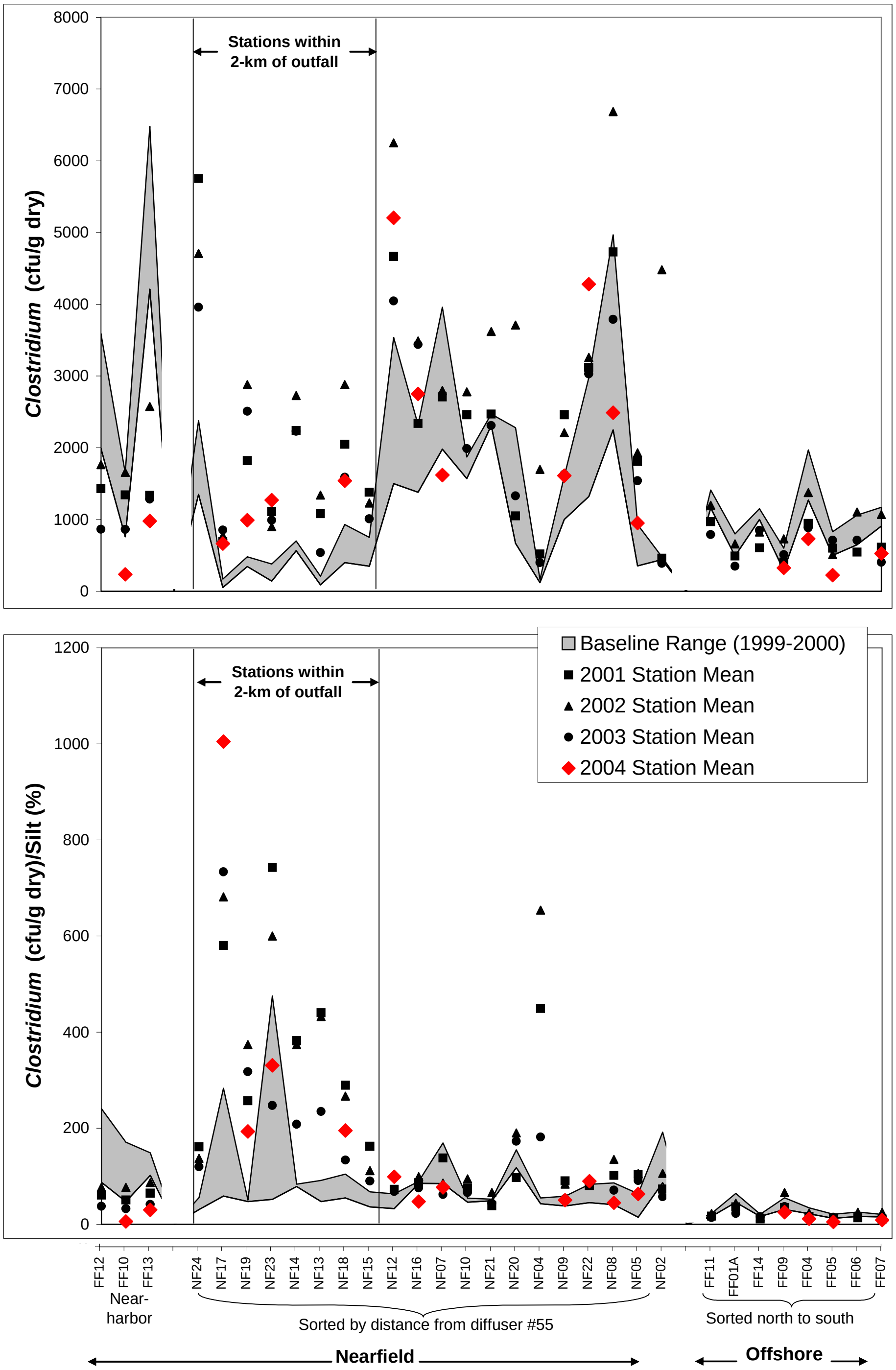


Figure B4-5. ***C. perfringens*** **response non-normalized (top) and normalized to percent silt (bottom) for regional stations sampled during the baseline (1999–2000 range of values, grey band) and post-diversion (2001–2004, symbols) periods.**

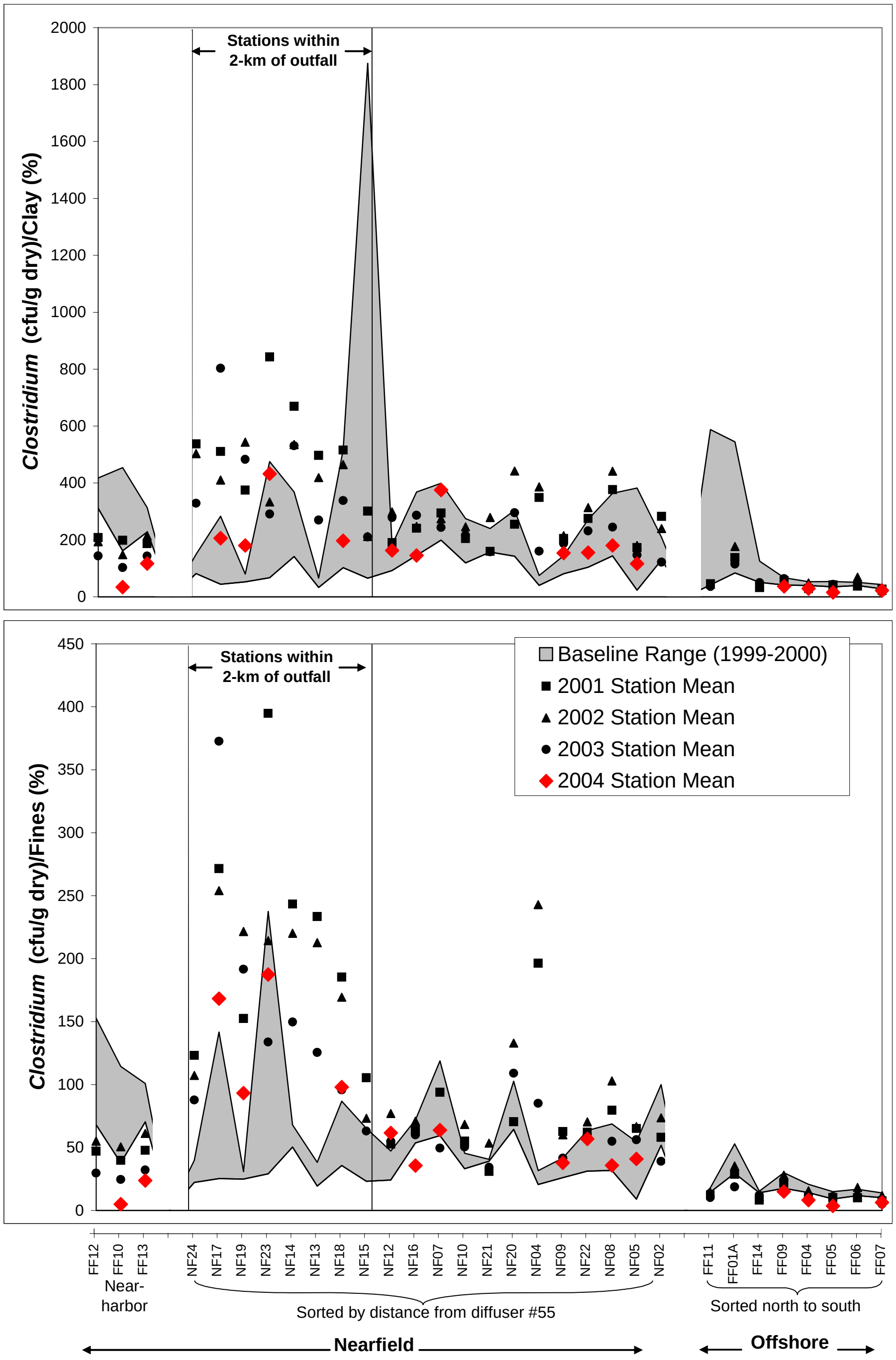


Figure B4-6. *C. perfringens* response normalized to percent clay (top) and normalized to percent fines (bottom) for regional stations sampled during the baseline (1999–2000 range of values, grey band) and post-diversion (2001–2004, symbols) periods.

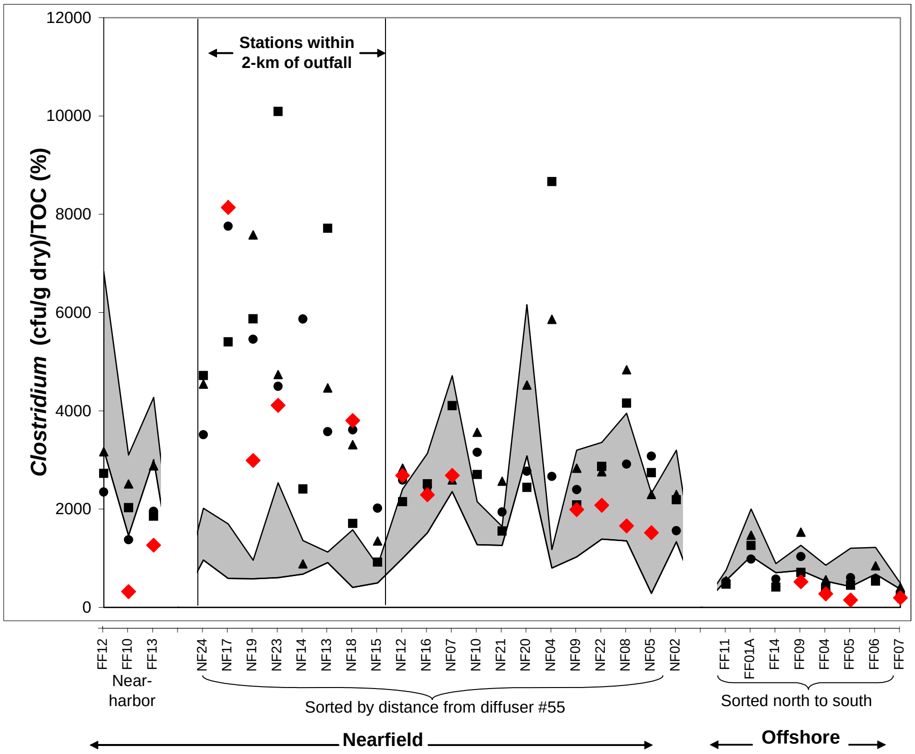


Figure B4-7. *C. perfringens* response normalized to TOC for regional stations sampled during the baseline (1999–2000 range of values, grey band) and post-diversion (2001–2004, symbols) periods.

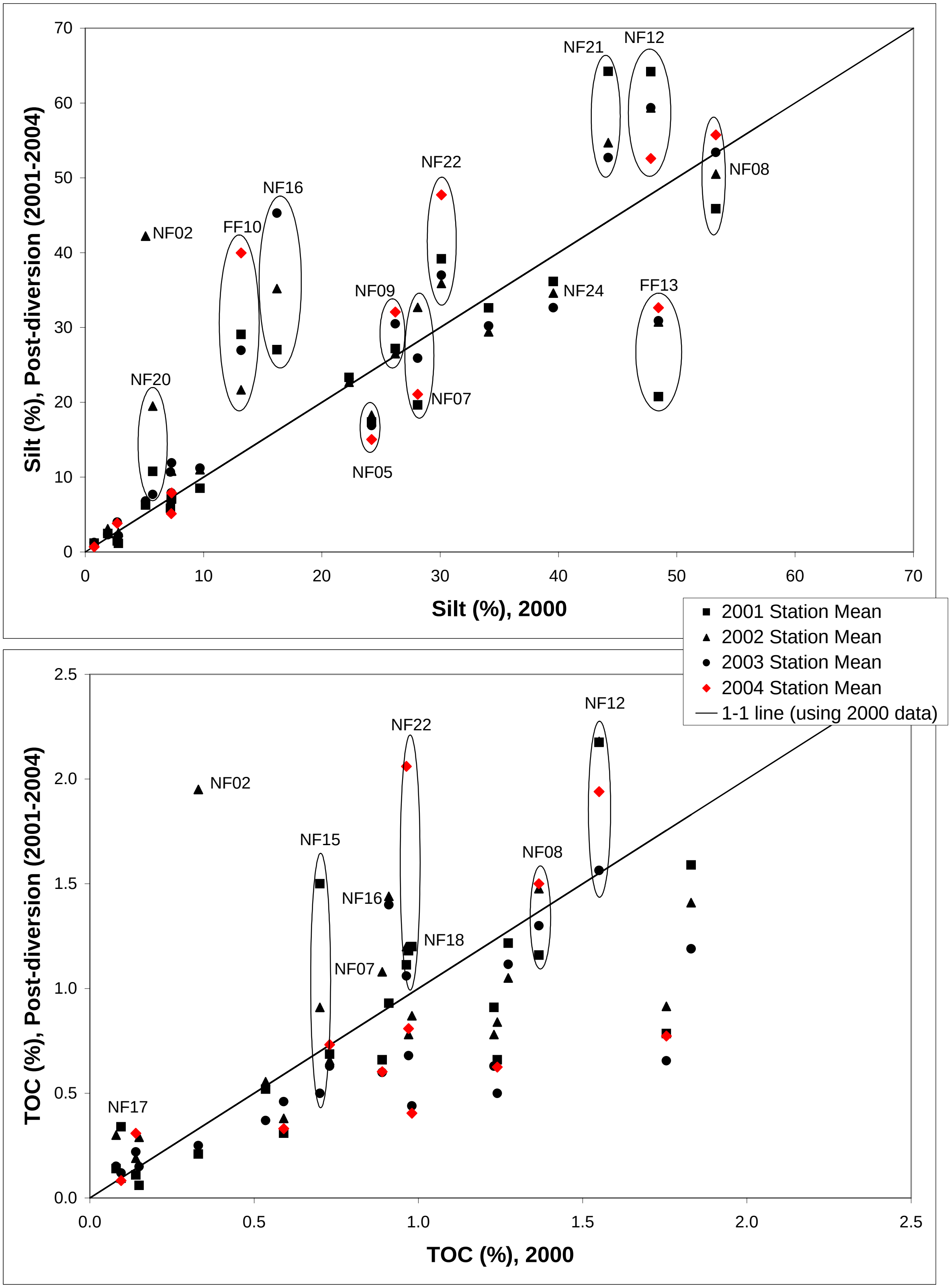


Figure B4-8. Correspondence between percent silt (top) and TOC (bottom) in nearfield surface (top 2 cm) sediments in 2000 and post-diversion periods.

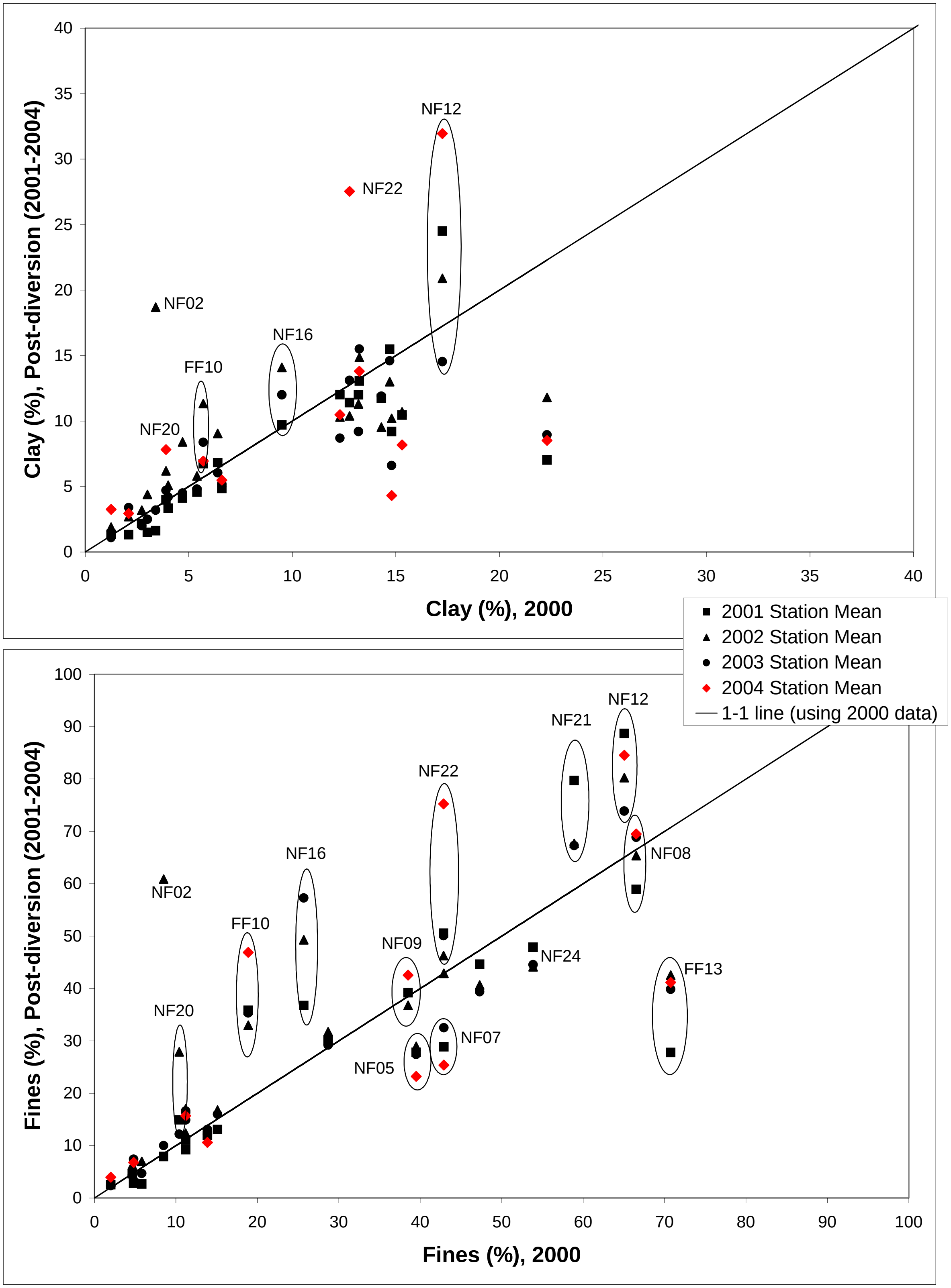


Figure B4-9. Correspondence between percent clay (top) and fines (bottom) in nearfield surface (top 2 cm) sediments in 2000 and post-diversion periods.

Table B4-1. Coefficient of variation (CV) in *Clostridium perfringens* data in nearfield and farfield sediments collected from 1991 to 2004.

Year	Nearfield		Farfield	
	N	CV	N	CV
1992	22	104	14	148
1993	24	84	14	55
1994	29	71	16	38
1995	52	115	24	55
1996	29	87	16	59
1997	29	122	16	58
1998	30	72	16	57
1999	36	73	16	46
2000	35	96	16	33
2001	35	68	16	36
2002	35	62	16	36
2003	31	67	16	37
2004	17	86	8	60

N, number of observations.

CV, Coefficient of variation (CV) is a measure of the variability among the data:

(standard deviation of all nearfield stations, by year ÷ average of all nearfield stations, by year) × 100

APPENDIX B5

Correlation Analysis Results and XY Scatter Plots Regional Sediments 1999–2004

Table B5-1. Pearson product-moment correlation coefficients for nearfield sediment data, pre-diversion (1999–2000) and post-diversion (2001–2004) sampling periods.

Variable	by Variable	Pre-diversion (1999-2000)			Post-diversion (2001-2004)			Post-diversion[a] (2001-2004)	
		Correlation	Count	Signif Prob	Correlation	Count	Signif Prob	Correlation	Signif Prob
TOC	Fines	0.869	44	1.92E-14	0.743	82	1.32E-15	0.876	1.08E-26
Clostridium	Fines	0.788	45	1.33E-10	0.727	82	1.05E-14		
Aluminum	Fines	0.775	31	3.10E-07	0.733	50	1.41E-09		
Cadmium	Fines	0.794	31	9.94E-08	0.856	50	2.20E-15		
Chromium	Fines	0.951	31	2.30E-16	0.956	50	2.94E-27		
Copper	Fines	0.859	31	6.33E-10	0.354	50	1.17E-02	0.824	3.37E-13
Iron	Fines	0.759	31	7.44E-07	0.813	50	7.06E-13		
Lead	Fines	0.699	31	1.23E-05	0.135	48	3.615E-01	0.416	0.0036
Mercury	Fines	0.909	31	1.44E-12	0.767	50	8.06E-11		
Nickel	Fines	0.826	31	1.06E-08	0.844	50	1.38E-14		
Silver	Fines	0.708	31	8.30E-06	0.814	50	6.98E-13		
Zinc	Fines	0.824	31	1.28E-08	0.946	50	4.01E-25		
Total DDT	Fines	0.839	31	3.78E-09	0.365	50	9.10E-03	0.859	3.09E-15
Total LAB	Fines	0.800	31	6.65E-08	0.769	48	1.65E-10		
Total PAH	Fines	0.661	31	5.19E-05	0.709	50	8.03E-09		
Total PCB	Fines	0.831	31	7.13E-09	0.525	50	1.00E-04	0.867	7.49E-16
Clostridium	TOC	0.651	43	2.27E-06	0.736	82	3.25E-15	0.799	4.08E-19
Aluminum	TOC	0.708	31	8.50E-06	0.600	50	4.07E-06	0.690	4.26E-08
Cadmium	TOC	0.655	31	6.32E-05	0.522	50	1.03E-04	0.700	2.21E-08
Chromium	TOC	0.854	31	1.03E-09	0.720	50	3.70E-09	0.871	3.86E-16
Copper	TOC	0.869	31	2.31E-10	0.480	50	4.24E-04	0.896	7.43E-18
Iron	TOC	0.667	31	4.12E-05	0.668	50	1.14E-07	0.766	1.47E-10
Lead	TOC	0.830	31	7.85E-09	0.374	48	8.80E-03	0.659	6.42E-07
Mercury	TOC	0.892	31	1.59E-11	0.621	50	1.48E-06	0.710	1.10E-08
Nickel	TOC	0.762	31	6.27E-07	0.716	50	5.24E-09	0.834	9.72E-14
Silver	TOC	0.681	31	2.45E-05	0.597	50	4.79E-06	0.733	2.07E-09
Zinc	TOC	0.763	31	5.89E-07	0.753	50	2.89E-10	0.894	5.16E-18
Total DDT	TOC	0.807	31	4.30E-08	0.220	50	1.25E-01	0.798	1.12E-11
Total LAB	TOC	0.770	31	4.09E-07	0.581	48	1.49E-05	0.736	3.62E-09
Total PAH	TOC	0.674	31	3.28E-05	0.495	50	2.59E-04	0.633	1.07E-06
Total PCB	TOC	0.830	31	7.97E-09	0.378	50	6.76E-03	0.786	3.56E-11

[a] Correlation and Signif Prob values are based on excluding selected data where the post-diversion value was unusually high. Specifically, TOC at NF14 in 2002, total PCB at NF07 in 2002, total DDT at NF21 in 2001, at NF14 in 2001, and lead at NF15 in 2002. Count is -1 from reported value for Post-diversion data; grey filled cell indicates no change from Post-diversion data.

Table B5-2. Kendall Tau correlation coefficients for nearfield sediment data, pre-diversion (1999–2000) and post-diversion (2001–2004) sampling periods. (see Table B5-1 for number of observations)

Variable	**by Variable**	**Pre-diversion (1999-2000)**		**Post-diversion (2001-2004)**		**Post-diversion [a] (2001-2004)**	
		Kendall Tau b	**Prob>|Tau b|**	**Kendall Tau b**	**Prob>|Tau b|**	**Kendall Tau b**	**Prob>|Tau b|**
TOC	Fines	0.689	5.15E-11	0.711	0	0.741	0.00E+00
Clostridium	Fines	0.682	4.55E-11	0.544	4.75E-13		
Aluminum	Fines	0.617	1.07E-06	0.579	3.16E-09		
Cadmium	Fines	0.639	4.81E-07	0.654	2.08E-11		
Chromium	Fines	0.798	2.87E-10	0.777	1.67E-15		
Copper	Fines	0.696	3.99E-08	0.630	1.12E-10	0.680	5.99E-12
Iron	Fines	0.616	1.16E-06	0.620	2.28E-10		
Lead	Fines	0.510	5.62E-05	0.450	6.59E-06	0.481	1.85E-06
Mercury	Fines	0.716	1.52E-08	0.678	3.62E-12		
Nickel	Fines	0.660	1.96E-07	0.658	1.74E-11		
Silver	Fines	0.617	1.07E-06	0.736	4.82E-14		
Zinc	Fines	0.753	2.69E-09	0.804	2.22E-16		
Total DDT	Fines	0.673	1.04E-07	0.781	1.33E-15	0.777	3.55E-15
Total LAB	Fines	0.706	2.47E-08	0.704	1.70E-12		
Total PAH	Fines	0.634	5.33E-07	0.706	4.63E-13		
Total PCB	Fines	0.742	4.52E-09	0.758	7.77E-15	0.774	4.44E-15
Clostridium	TOC	0.519	1.06E-06	0.610	5.55E-16	0.615	4.44E-16
Aluminum	TOC	0.557	1.15E-05	0.465	2.01E-06	0.489	7.79E-07
Cadmium	TOC	0.435	6.27E-04	0.443	5.77E-06	0.502	3.81E-07
Chromium	TOC	0.652	2.82E-07	0.611	4.11E-10	0.651	4.49E-11
Copper	TOC	0.675	1.12E-07	0.705	6.19E-13	0.733	2.37E-13
Iron	TOC	0.549	1.56E-05	0.579	3.31E-09	0.598	1.50E-09
Lead	TOC	0.652	2.82E-07	0.590	3.57E-09	0.599	4.84E-09
Mercury	TOC	0.734	7.41E-09	0.646	3.86E-11	0.666	1.66E-11
Nickel	TOC	0.587	4.03E-06	0.612	4.08E-10	0.644	7.50E-11
Silver	TOC	0.522	3.87E-05	0.551	1.71E-08	0.589	2.56E-09
Zinc	TOC	0.646	3.68E-07	0.677	4.54E-12	0.716	4.41E-13
Total DDT	TOC	0.686	6.40E-08	0.647	3.64E-11	0.688	5.94E-12
Total LAB	TOC	0.637	5.25E-07	0.603	1.58E-09	0.651	1.20E-10
Total PAH	TOC	0.652	2.82E-07	0.605	5.98E-10	0.650	4.76E-11
Total PCB	TOC	0.690	5.29E-08	0.591	1.54E-09	0.641	1.46E-10

[a] Correlation and Signif Prob values are based on excluding selected data where the post-diversion value was unusually high. Specifically, TOC at NF14 in 2002, total PCB at NF07 in 2002, total DDT at NF21 in 2001, at NF14 in 2001, and lead at NF15 in 2002. Grey filled cell indicates no change from Post-diversion data.

Table B5-3. Pearson product-moment correlation coefficients for farfield sediment data, pre-diversion (1999–2000) and post-diversion (2001–2004) sampling periods.

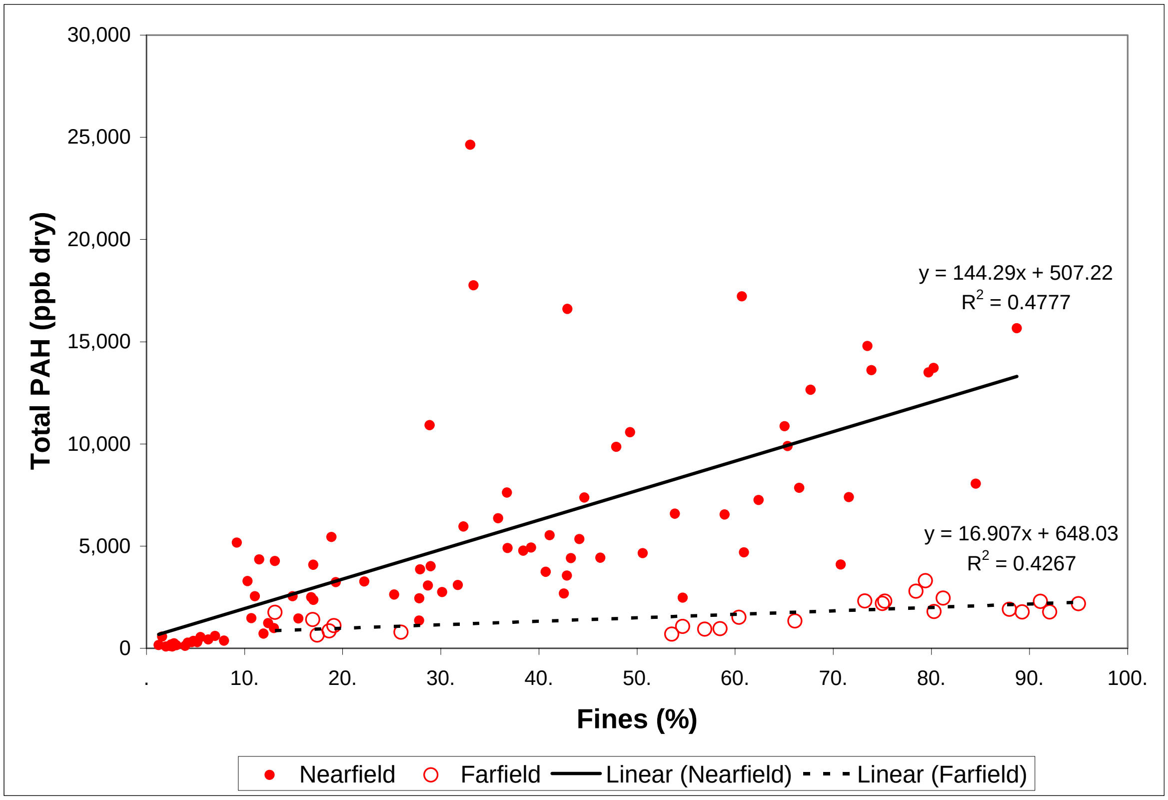
Variable	by Variable	Pre-diversion (1999-2000)			Post-diversion (2001-2004)		
		Pearson r	Count	Signif Prob	Pearson r	Count	Signif Prob
TOC	Fines	0.907	16	1.27E-06	0.937	28	2.33E-13
Clostridium	Fines	0.825	16	8.50E-05	0.572	28	1.46E-03
Aluminum	Fines	0.692	8	5.72E-02	0.697	16	2.69E-03
Cadmium	Fines	0.573	8	1.38E-01	0.715	16	1.85E-03
Chromium	Fines	0.920	8	1.20E-03	0.948	16	2.39E-08
Copper	Fines	0.964	8	1.10E-04	0.919	16	4.94E-07
Iron	Fines	0.937	8	6.01E-04	0.941	16	5.75E-08
Lead	Fines	0.885	8	3.45E-03	0.895	16	2.88E-06
Mercury	Fines	0.910	8	1.68E-03	0.122 (0.899[a])	16 (15[a])	0.65199091 (2.13E-06[a])
Nickel	Fines	0.917	8	1.32E-03	0.947	16	2.66E-08
Silver	Fines	0.656	8	7.74E-02	0.689	16	3.14E-03
Zinc	Fines	0.952	8	2.62E-04	0.954	16	1.10E-08
Total DDT	Fines	0.860	8	6.16E-03	0.654	16	5.96E-03
Total LAB	Fines	0.879	8	4.01E-03	0.594	16	1.52E-02
Total PAH	Fines	0.544	8	1.64E-01	0.739	16	1.07E-03
Total PCB	Fines	0.349	8	3.97E-01	0.706	16	2.24E-03
Clostridium	TOC	0.795	16	2.30E-04	0.498	28	6.93E-03
Aluminum	TOC	0.765	8	2.71E-02	0.721	16	1.63E-03
Cadmium	TOC	0.785	8	2.11E-02	0.827	16	7.90E-05
Chromium	TOC	0.931	8	7.87E-04	0.933	16	1.41E-07
Copper	TOC	0.973	8	5.09E-05	0.941	16	5.91E-08
Iron	TOC	0.968	8	8.07E-05	0.977	16	8.03E-11
Lead	TOC	0.899	8	2.36E-03	0.900	16	2.06E-06
Mercury	TOC	0.875	8	4.47E-03	0.173 (0.874[a])	16 (15[a])	0.52222664 (9.69E-06[a])
Nickel	TOC	0.964	8	1.16E-04	0.942	16	5.29E-08
Silver	TOC	0.686	8	6.02E-02	0.731	16	1.29E-03
Zinc	TOC	0.956	8	2.07E-04	0.980	16	3.60E-11
Total DDT	TOC	0.922	8	1.14E-03	0.658	16	5.59E-03
Total LAB	TOC	0.834	8	9.99E-03	0.636	16	8.11E-03
Total PAH	TOC	0.605	8	1.12E-01	0.716	16	1.81E-03
Total PCB	TOC	0.229	8	5.86E-01	0.608	16	1.25E-02

[a] Correlation, Count, and Signif Prob values are based on excluding mercury data for FF01A (replicate 1) in 2001. Mercury concentration was unusually high (0.715 ppm dry weight) in FF01A (replicate 1, 2001) compared to historical data and data for replicate 2 from the same station.

Table B5-4. Kendall Tau correlation coefficients for farfield sediment data, pre-diversion (1999–2000) and post-diversion (2001–2004) sampling periods. (see Table B5-3 for number of observations)

Variable	by Variable	Pre-diversion (1999-2000)		Post-diversion (2001-2004)	
		Kendall r	Prob>|Tau b|	Kendall r	Prob>|Tau b|
TOC	Fines	0.867	2.84E-06	0.810	1.49E-09
Clostridium	Fines	0.717	1.08E-04	0.468	5.02E-04
Aluminum	Fines	0.500	8.33E-02	0.533	3.96E-03
Cadmium	Fines	0.500	8.33E-02	0.550	2.96E-03
Chromium	Fines	0.929	1.30E-03	0.883	1.82E-06
Copper	Fines	1.000	5.32E-04	0.800	1.55E-05
Iron	Fines	1.000	5.32E-04	0.850	4.38E-06
Lead	Fines	0.857	2.99E-03	0.817	1.02E-05
Mercury	Fines	0.857	2.99E-03	0.433 (0.683 [a])	1.92E-02 (2.23E-04 [a])
Nickel	Fines	0.786	6.49E-03	0.817	1.02E-05
Silver	Fines	0.643	2.60E-02	0.533	3.96E-03
Zinc	Fines	0.929	1.30E-03	0.867	2.84E-06
Total DDT	Fines	0.714	1.33E-02	0.450	1.50E-02
Total LAB	Fines	0.643	2.60E-02	0.483	9.02E-03
Total PAH	Fines	0.500	8.33E-02	0.483	9.02E-03
Total PCB	Fines	0.429	1.38E-01	0.600	1.19E-03
Clostridium	TOC	0.617	8.63E-04	0.356	8.06E-03
Aluminum	TOC	0.357	2.16E-01	0.483	9.02E-03
Cadmium	TOC	0.643	2.60E-02	0.633	6.22E-04
Chromium	TOC	0.786	6.49E-03	0.833	6.72E-06
Copper	TOC	0.857	2.99E-03	0.817	1.02E-05
Iron	TOC	0.857	2.99E-03	0.900	1.16E-06
Lead	TOC	0.714	1.33E-02	0.767	3.44E-05
Mercury	TOC	0.714	1.33E-02	0.450 (0.700 [a])	1.50E--02 (1.56E-04 [a])
Nickel	TOC	0.786	6.49E-03	0.800	1.55E-05
Silver	TOC	0.786	6.49E-03	0.617	8.63E-04
Zinc	TOC	0.786	6.49E-03	0.850	4.38E-06
Total DDT	TOC	0.857	2.99E-03	0.467	1.17E-02
Total LAB	TOC	0.786	6.49E-03	0.533	3.96E-03
Total PAH	TOC	0.500	8.33E-02	0.400	3.07E-02
Total PCB	TOC	0.571	4.78E-02	0.583	1.62E-03

[a] Correlation and Signif Prob values are based on excluding mercury data for FF01A (replicate 1) in 2001. Mercury concentration was unusually high (0.715 ppm dry weight) in FF01A (replicate 1, 2001) compared to historical data and data for replicate 2 from the same station.



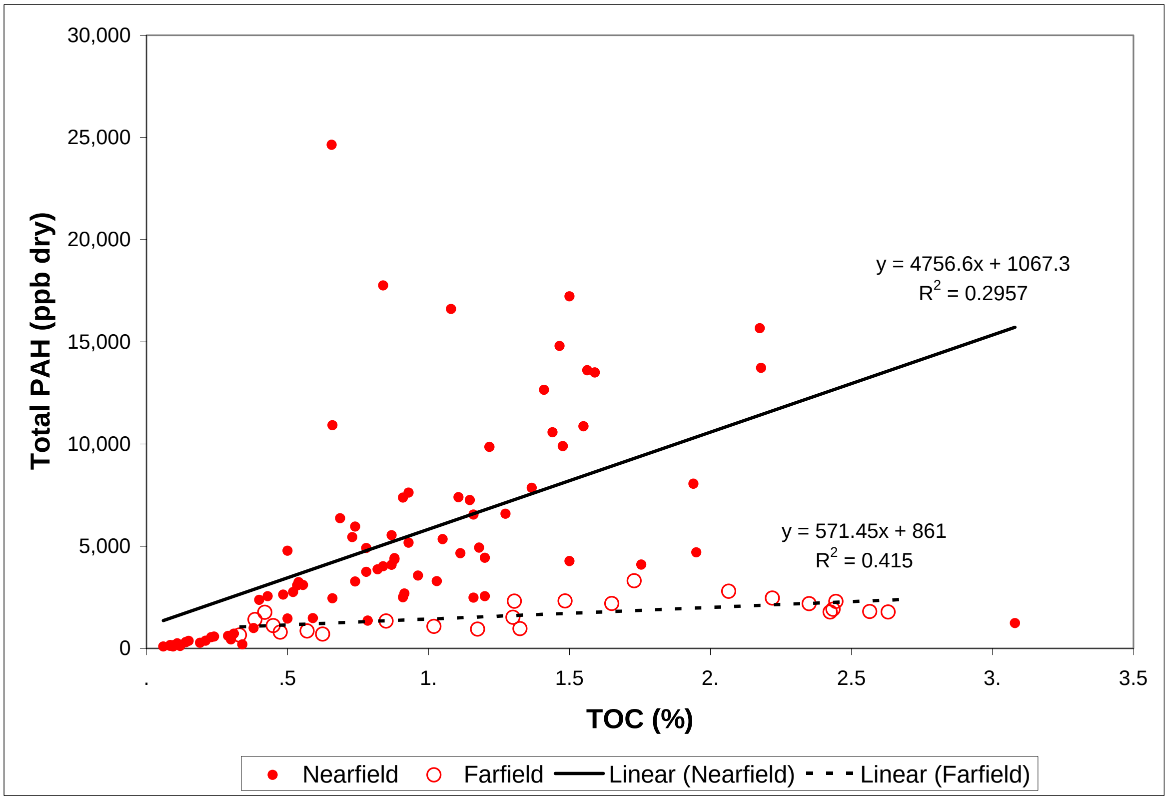
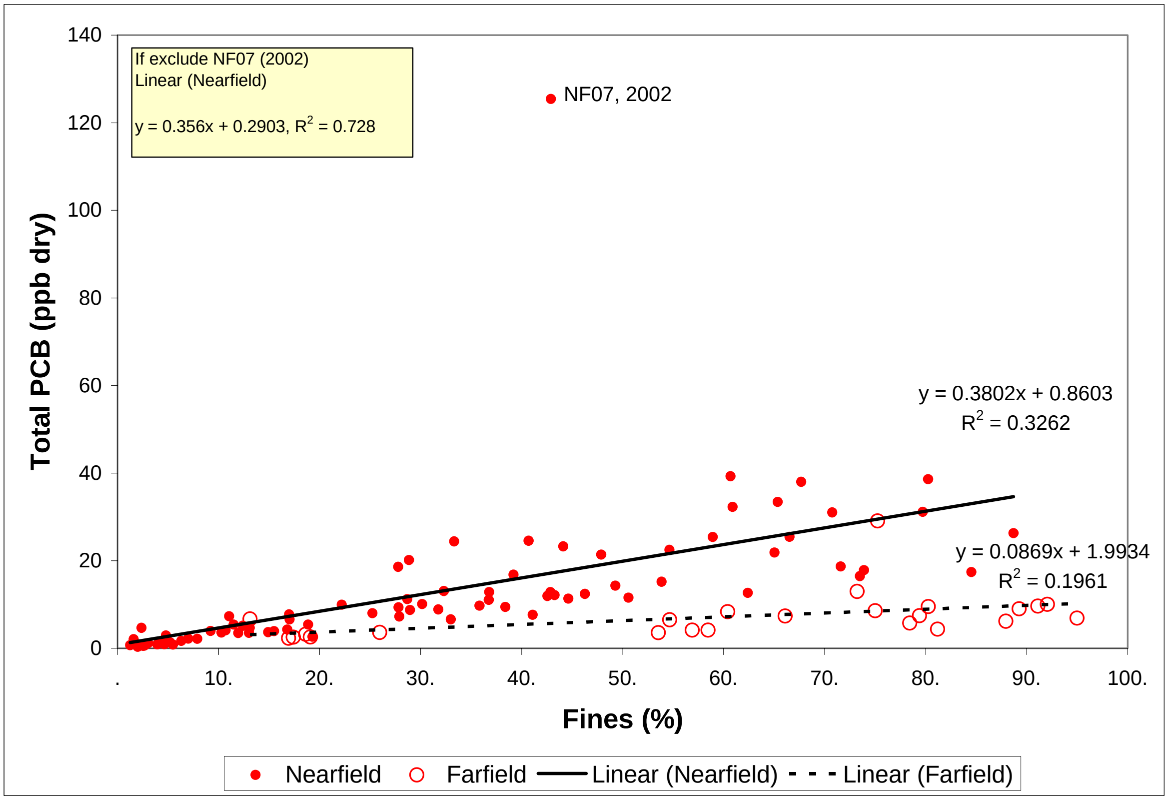


Figure B5-1. Correspondence between total PAH and percent fines (top) and TOC (bottom) at nearfield and farfield locations (using 1999–2004 station mean values).



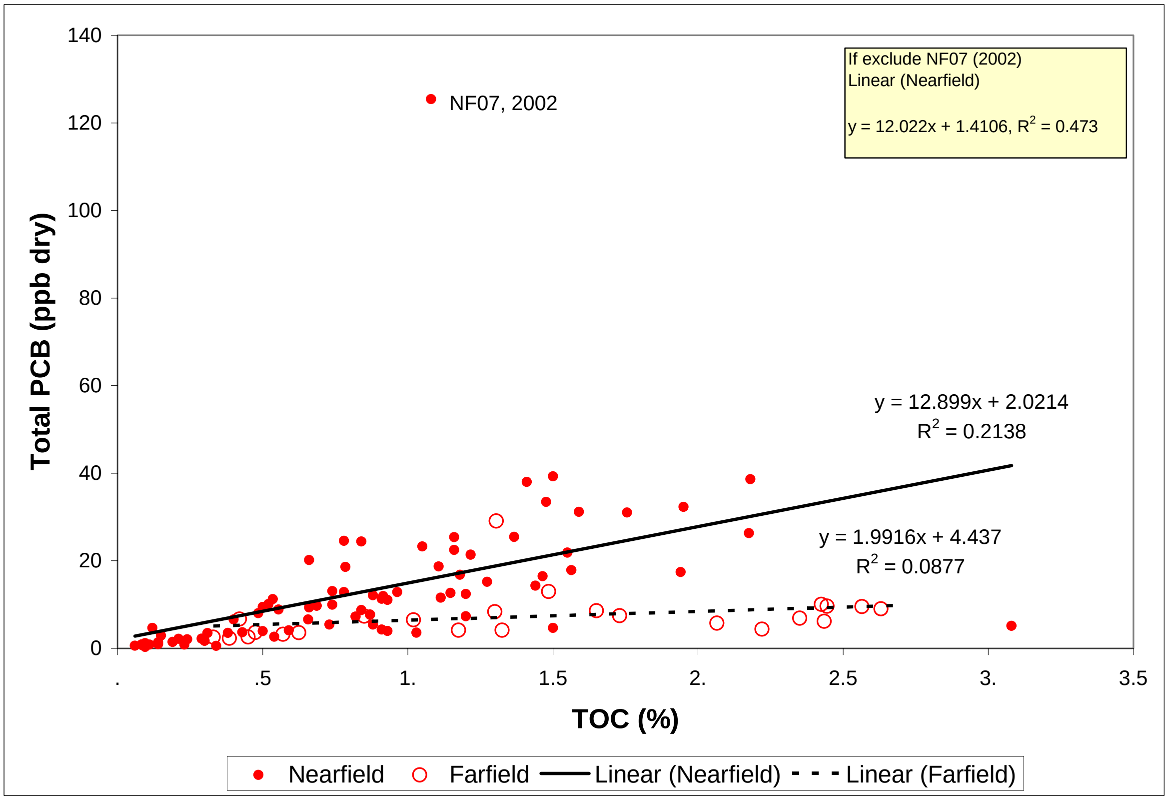


Figure B5-2. Correspondence between total PCB and percent fines (top) and TOC (bottom) at nearfield and farfield locations (using 1999–2004 station mean values).

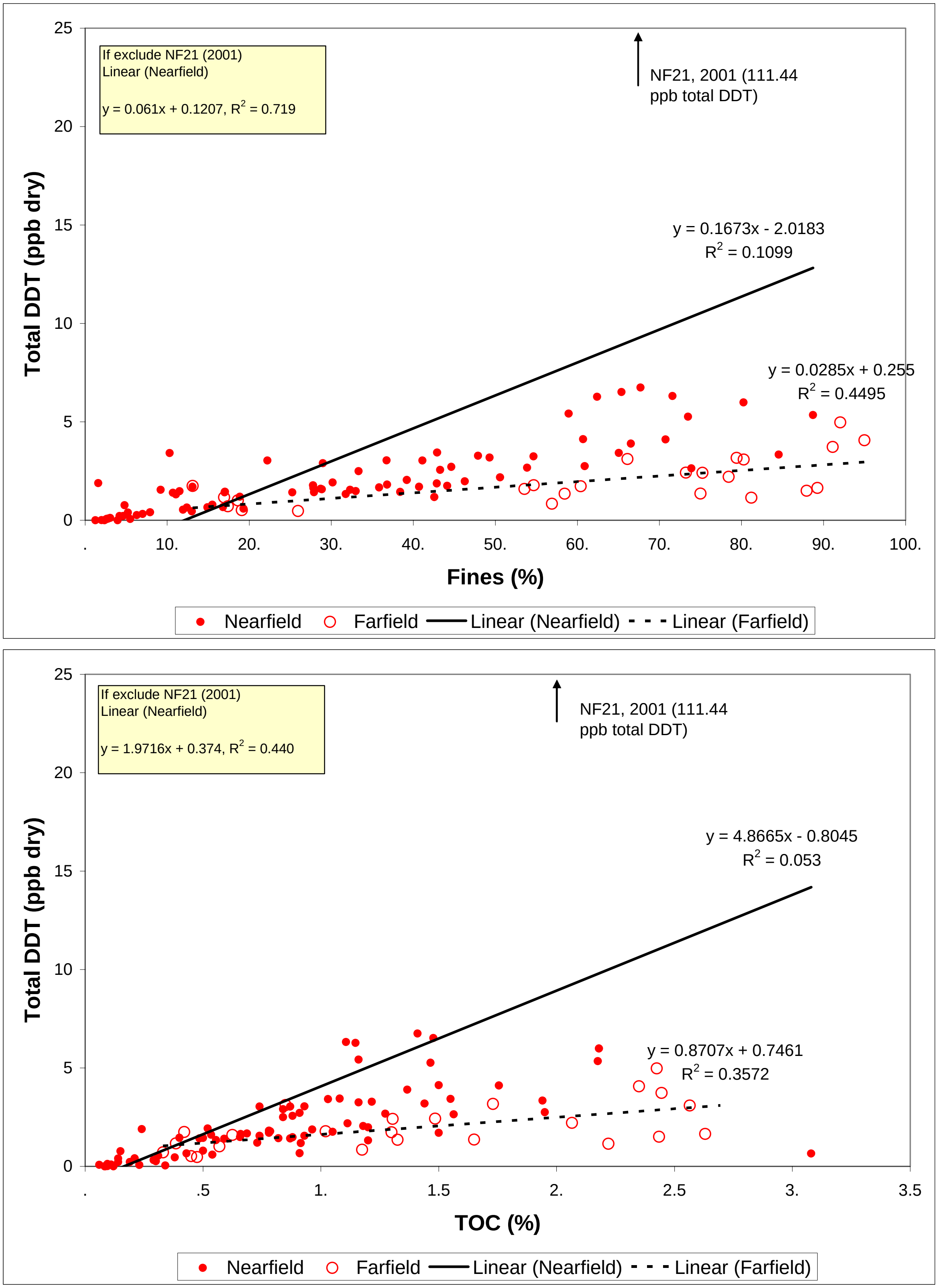


Figure B5-3. Correspondence between total DDT and percent fines (top) and TOC (bottom) at nearfield and farfield locations (using 1999–2004 station mean values).

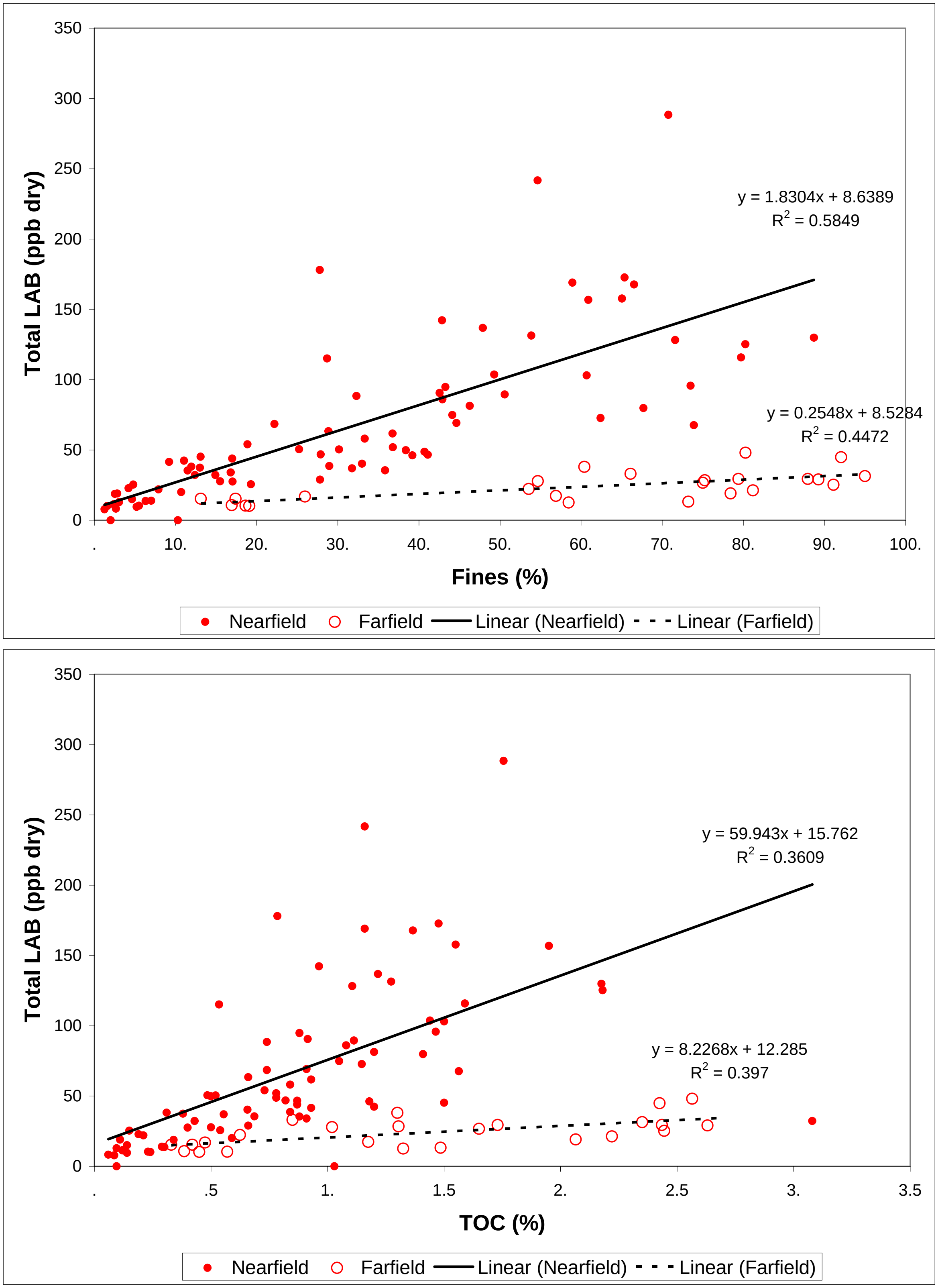
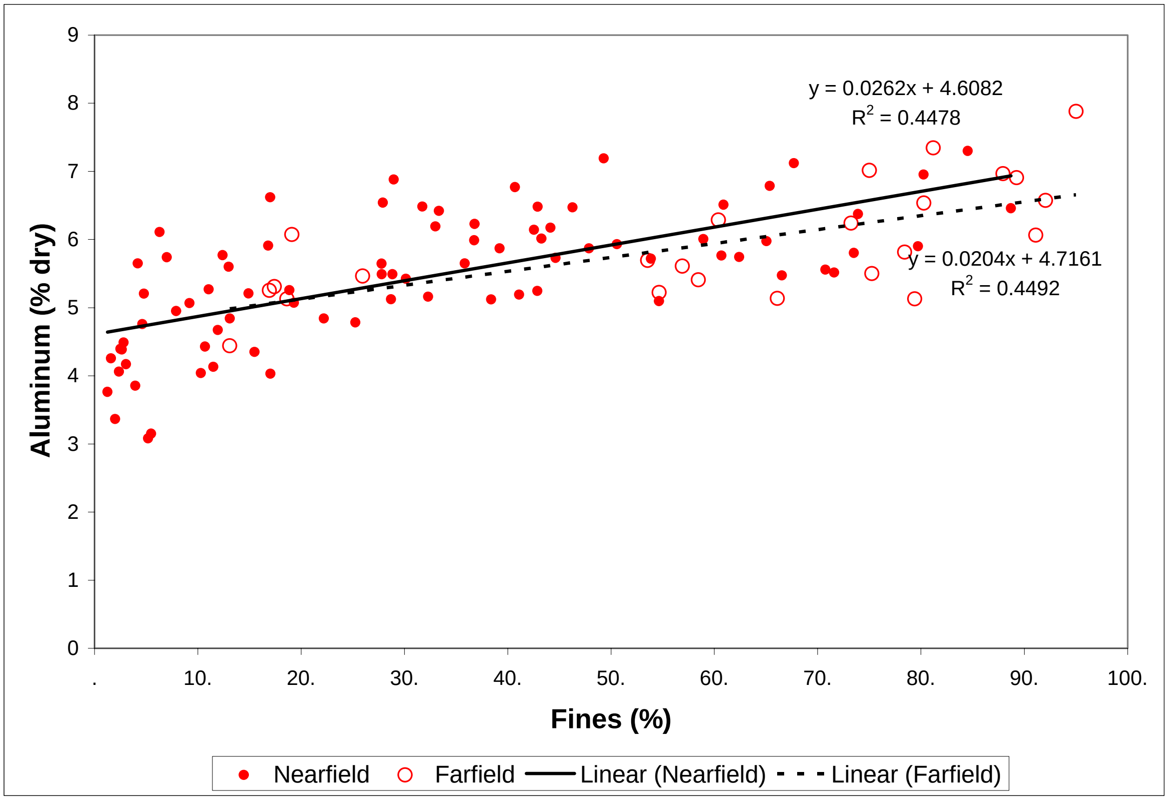


Figure B5-4. Correspondence between total LAB and percent fines (top) and TOC (bottom) at nearfield and farfield locations (using 1999–2004 station mean values).



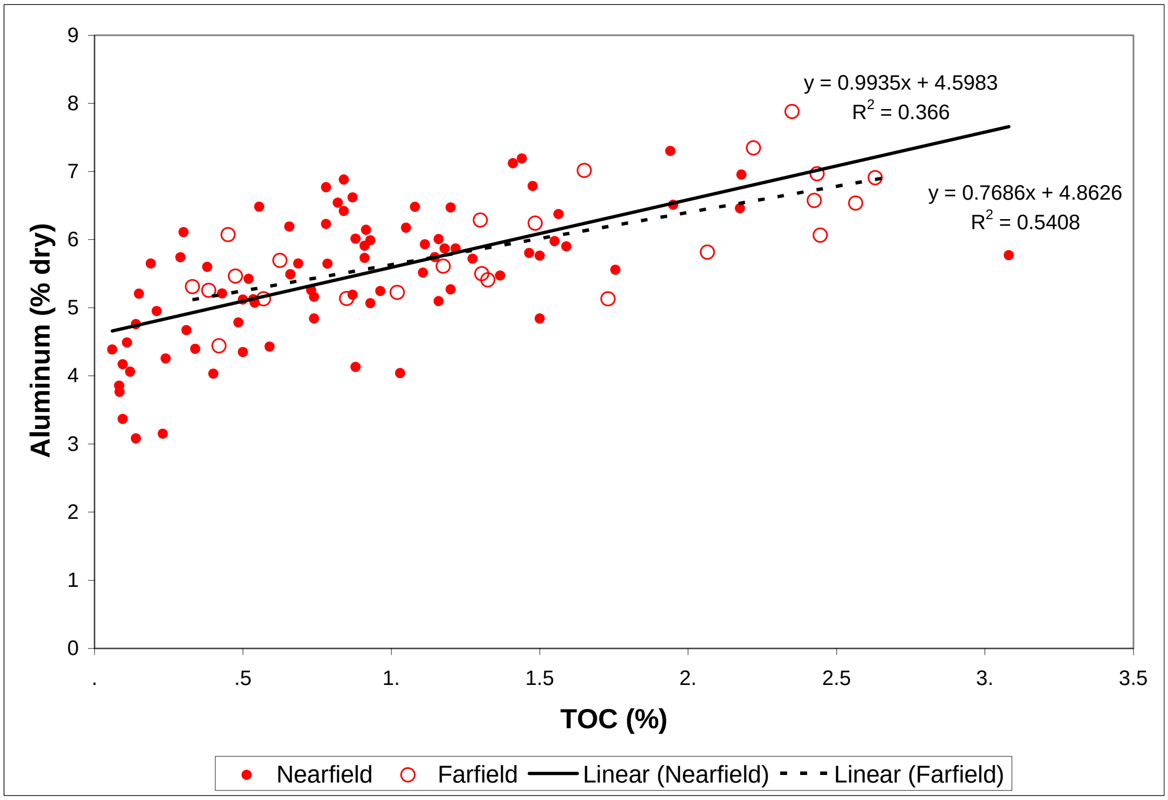
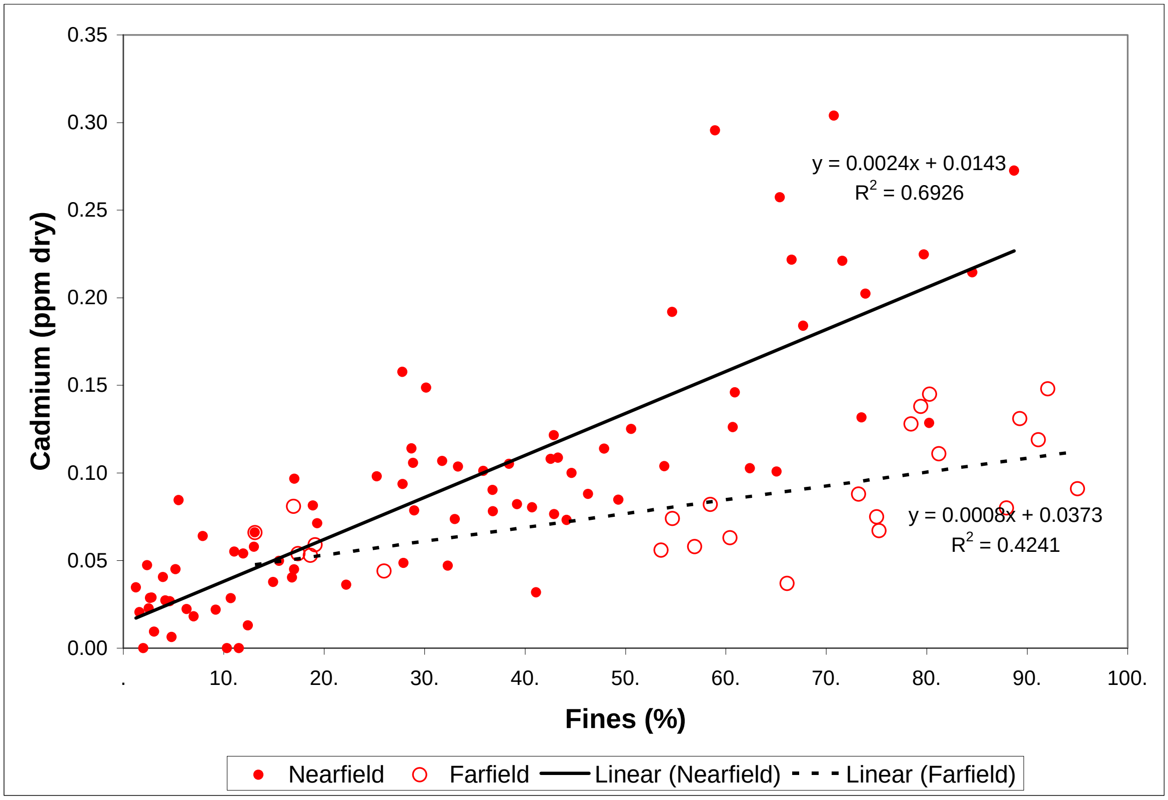


Figure B5-5. Correspondence between aluminum (Al) and percent fines (top) and TOC (bottom) at nearfield and farfield locations (using 1999–2004 station mean values).



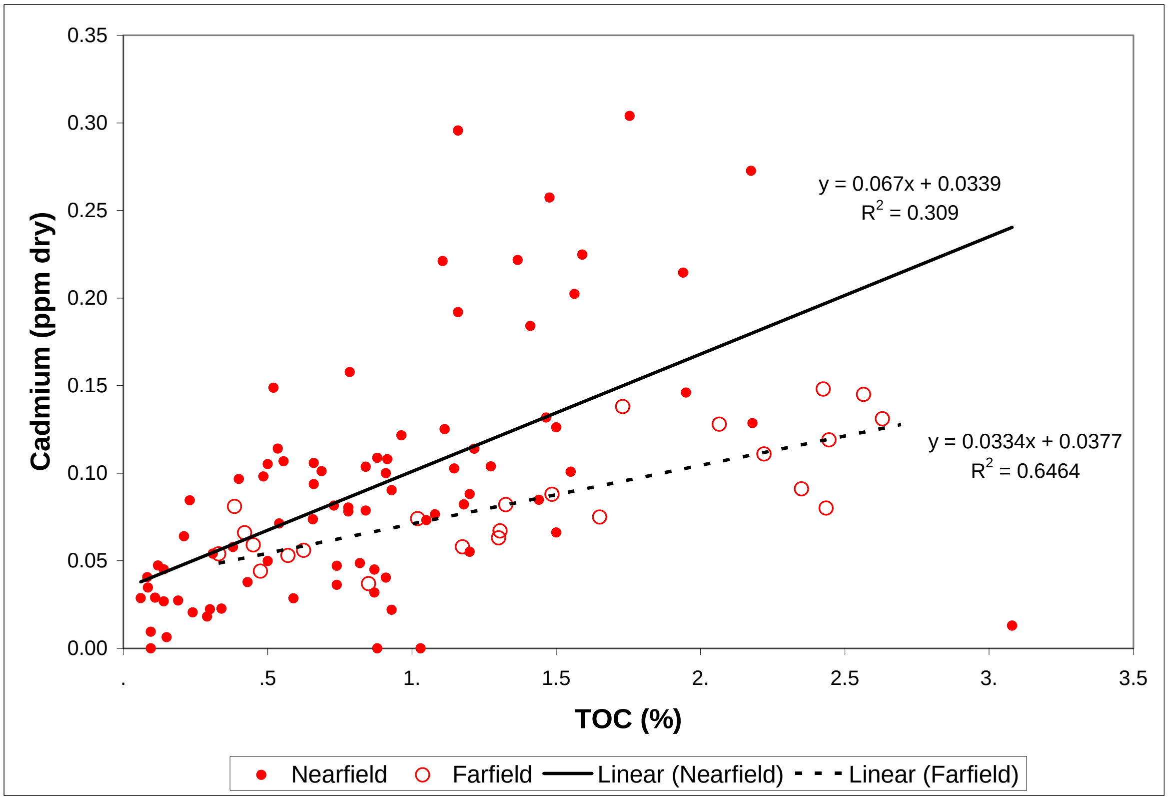
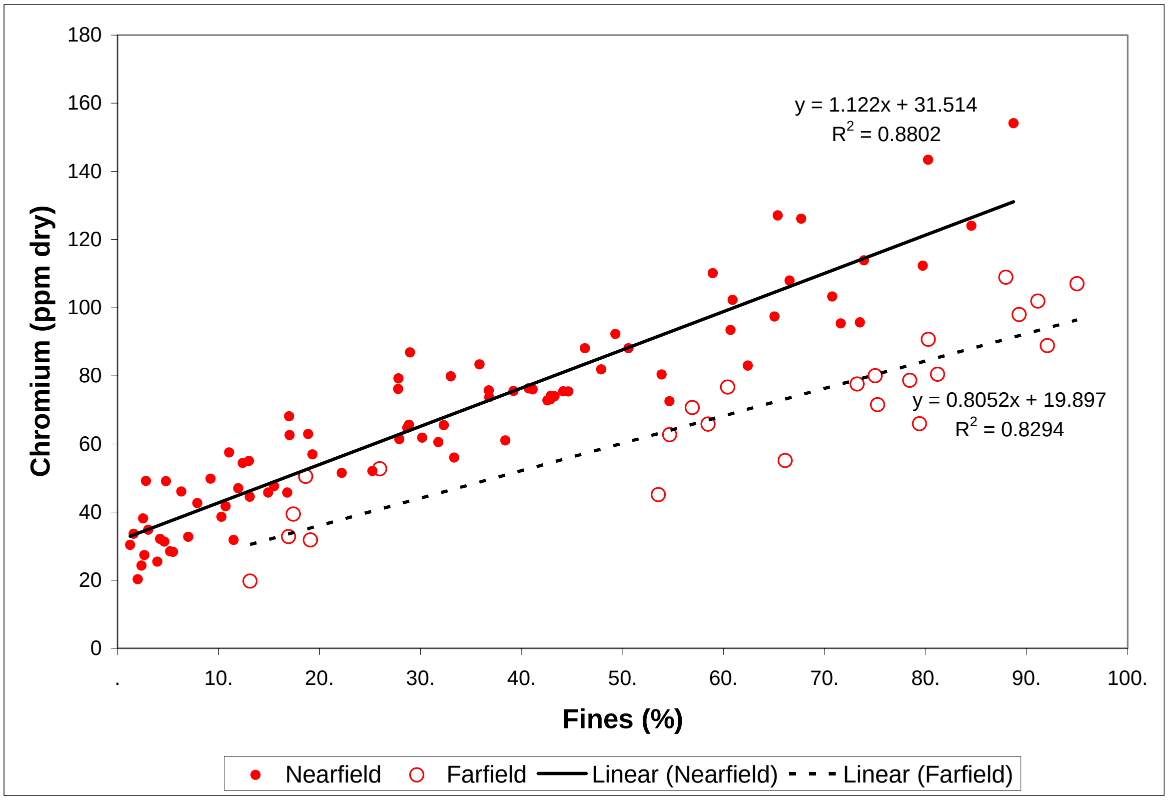


Figure B5-6. Correspondence between cadmium (Cd) and percent fines (top) and TOC (bottom) at nearfield and farfield locations (using 1999–2004 station mean values).



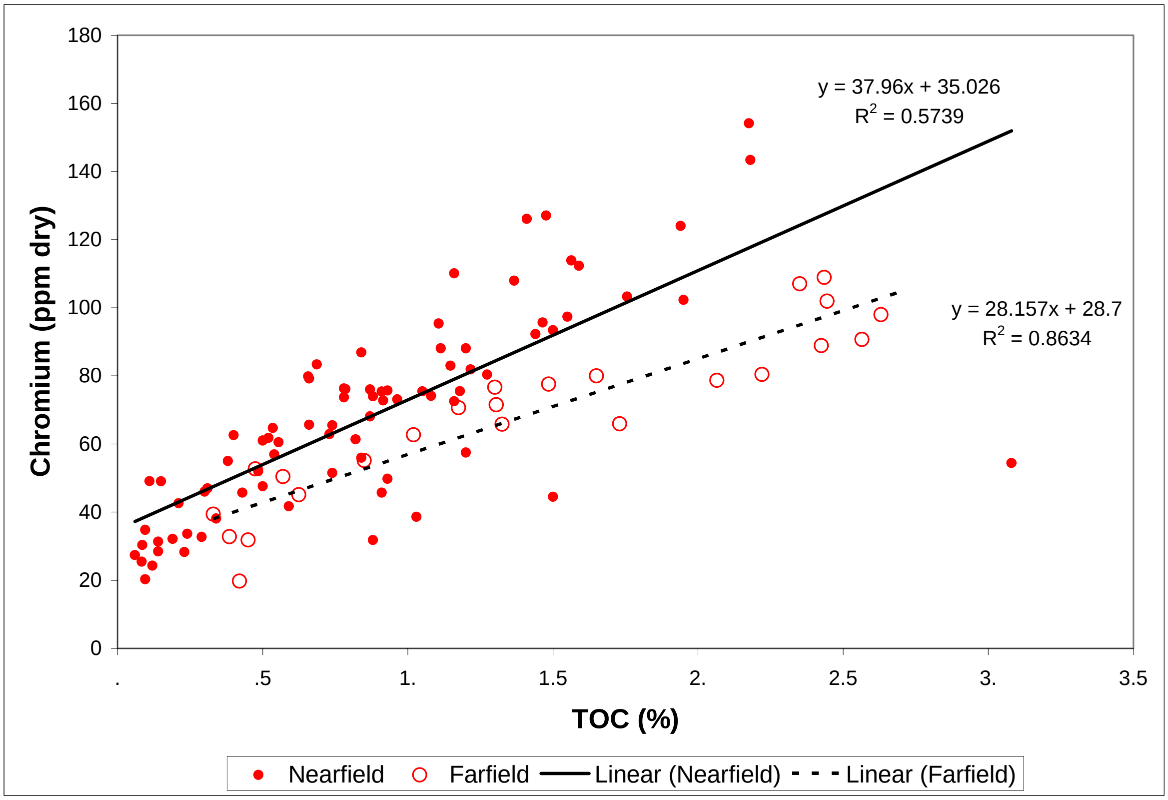


Figure B5-7. Correspondence between chromium (Cr) and percent fines (top) and TOC (bottom) at nearfield and farfield locations (using 1999–2004 station mean values).

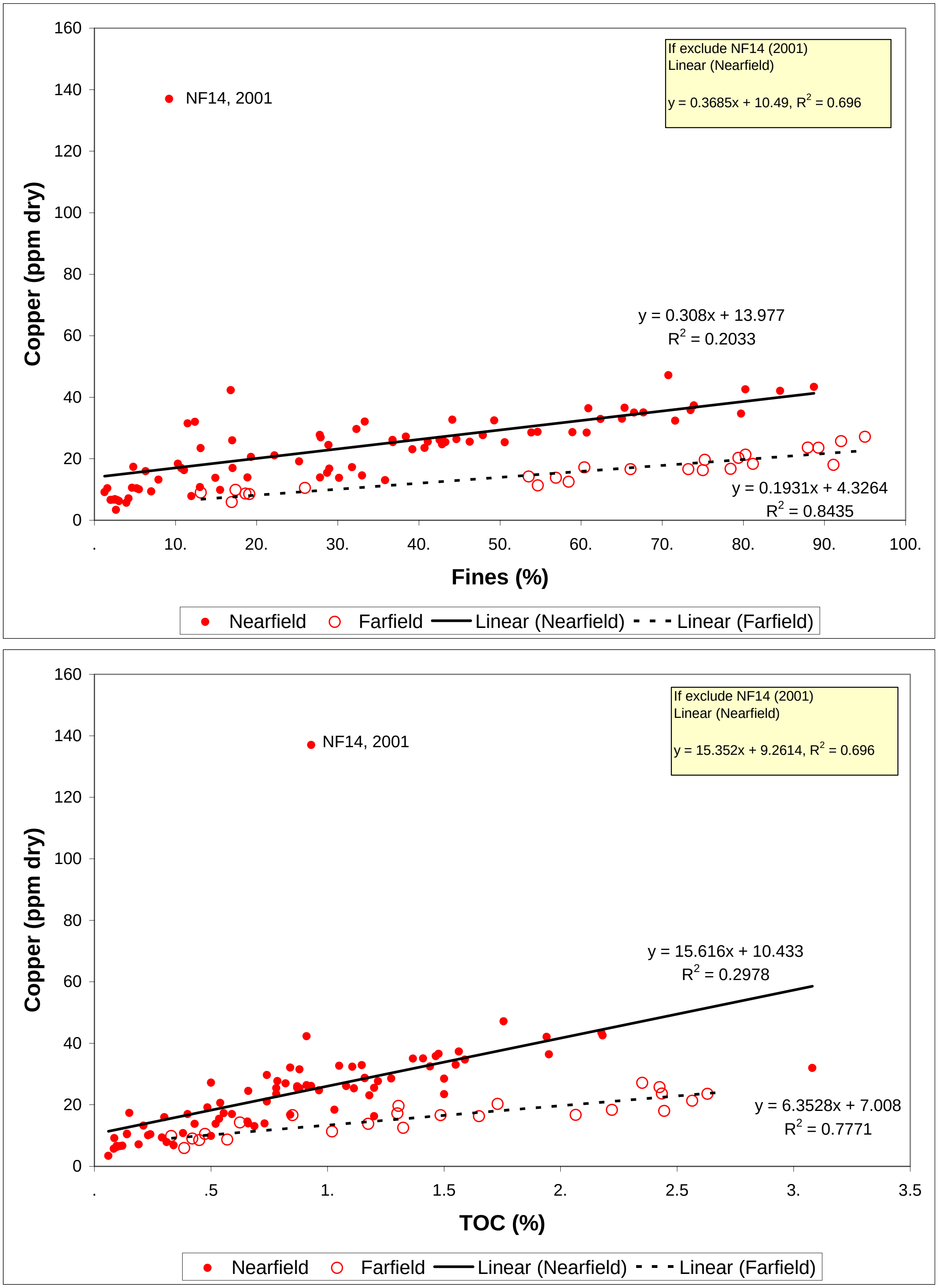


Figure B5-8. Correspondence between copper (Cu) and percent fines (top) and TOC (bottom) at nearfield and farfield locations (using 1999–2004 station mean values).

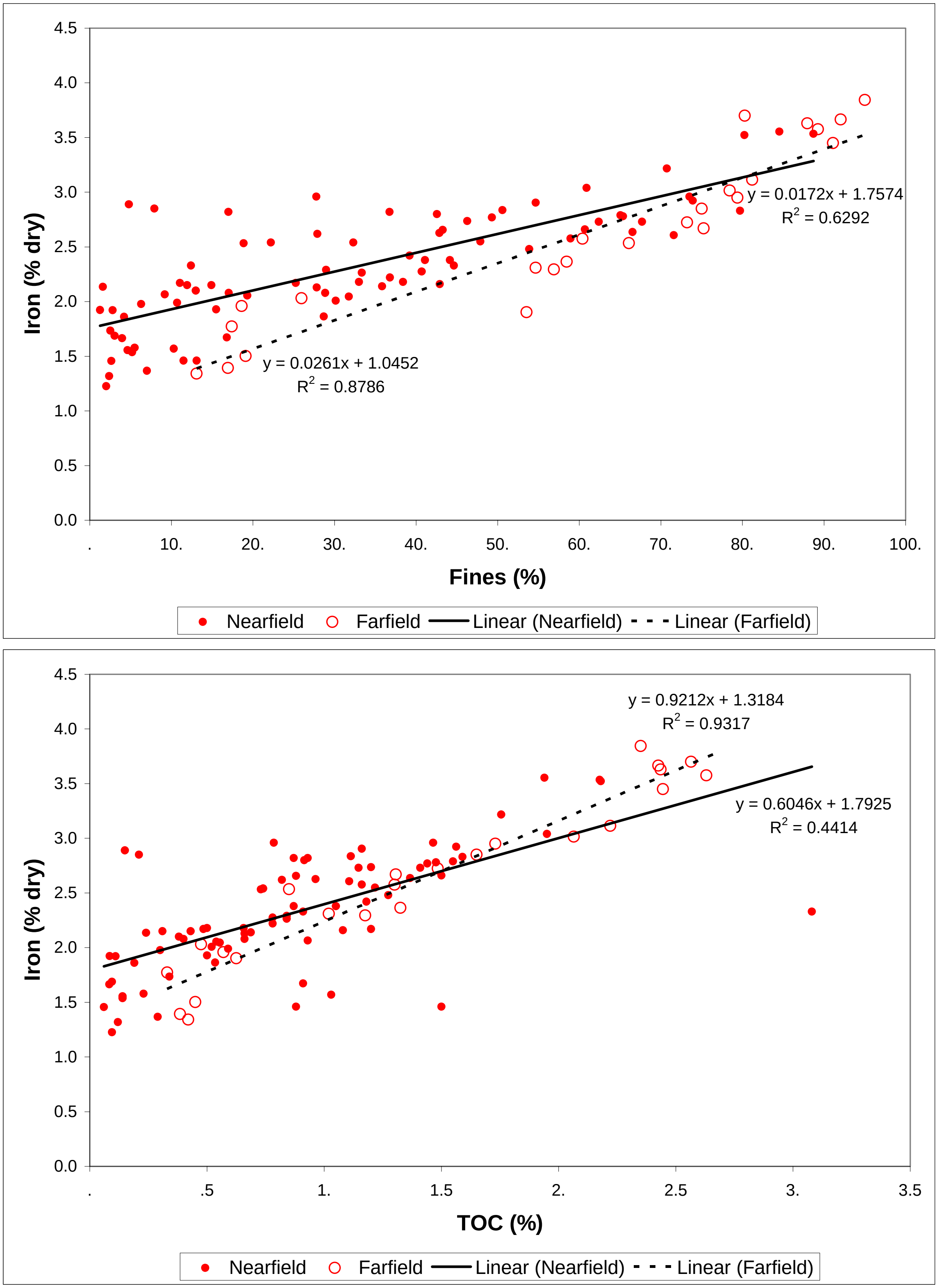
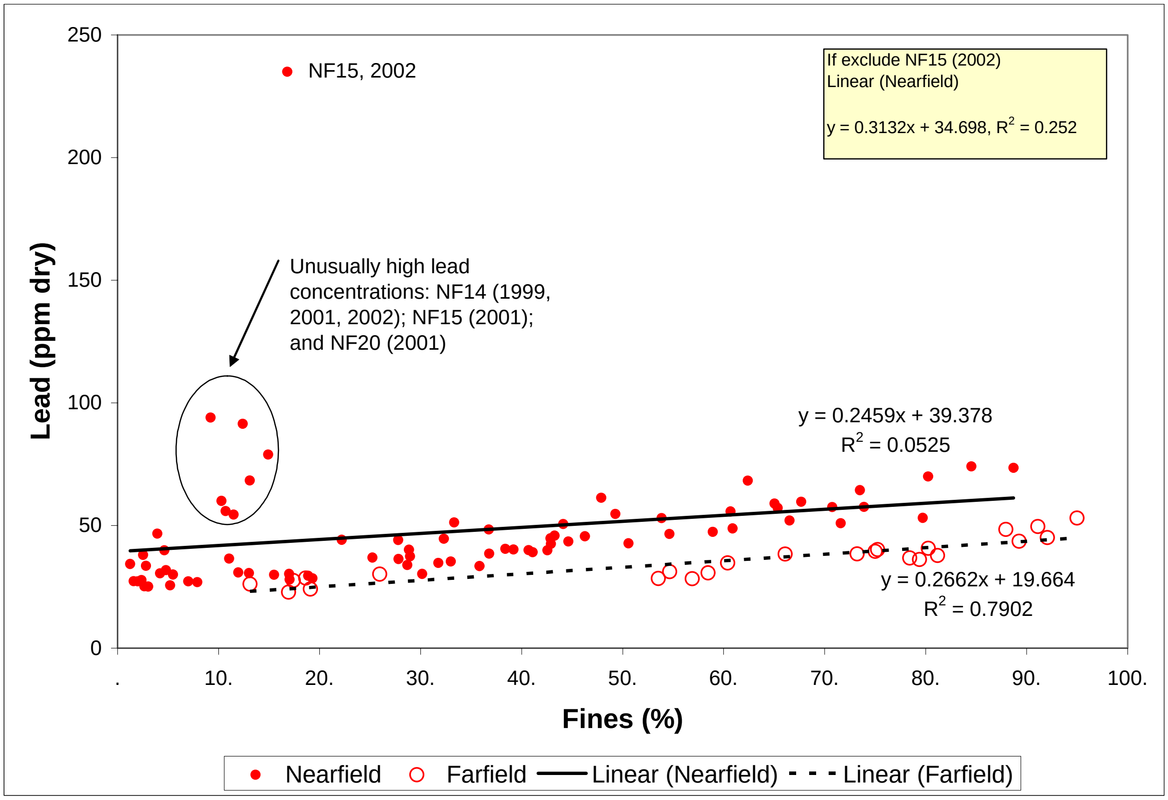


Figure B5-9. Correspondence between iron (Fe) and percent fines (top) and TOC (bottom) at nearfield and farfield locations (using 1999–2004 station mean values).



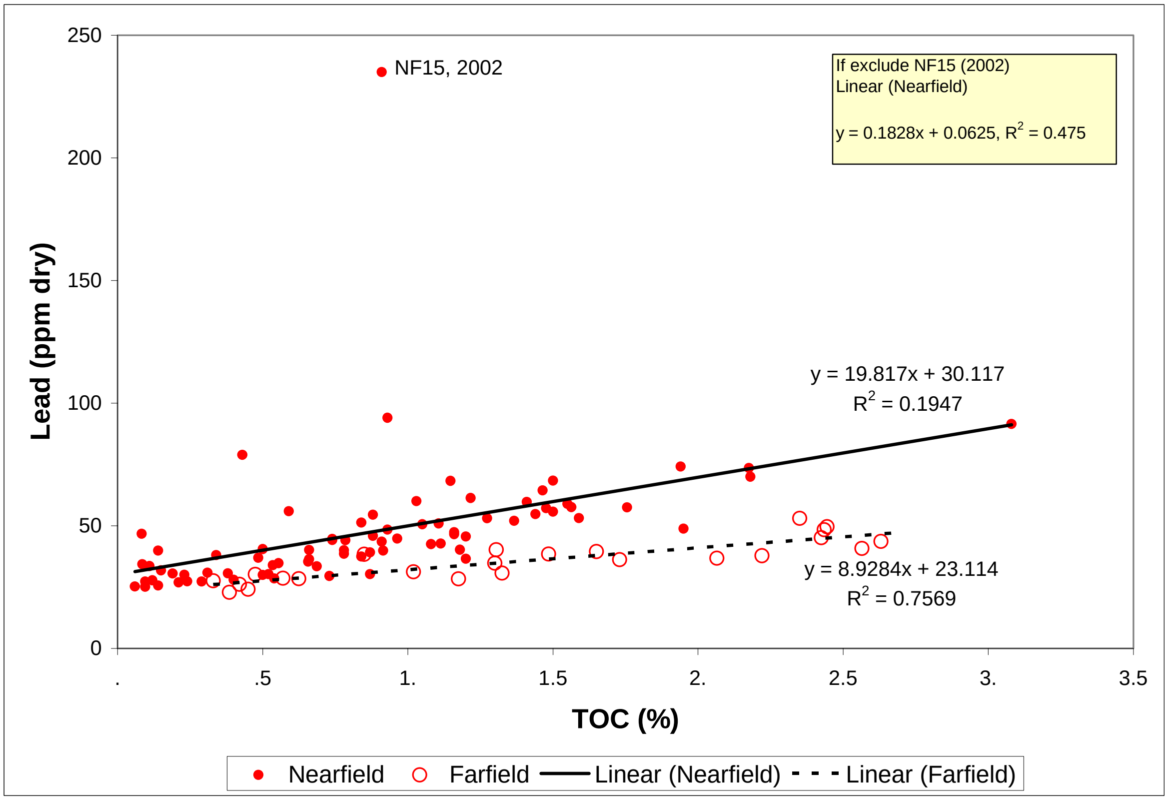


Figure B5-10. Correspondence between lead (Pb) and percent fines (top) and TOC (bottom) at nearfield and farfield locations (using 1999–2004 station mean values).

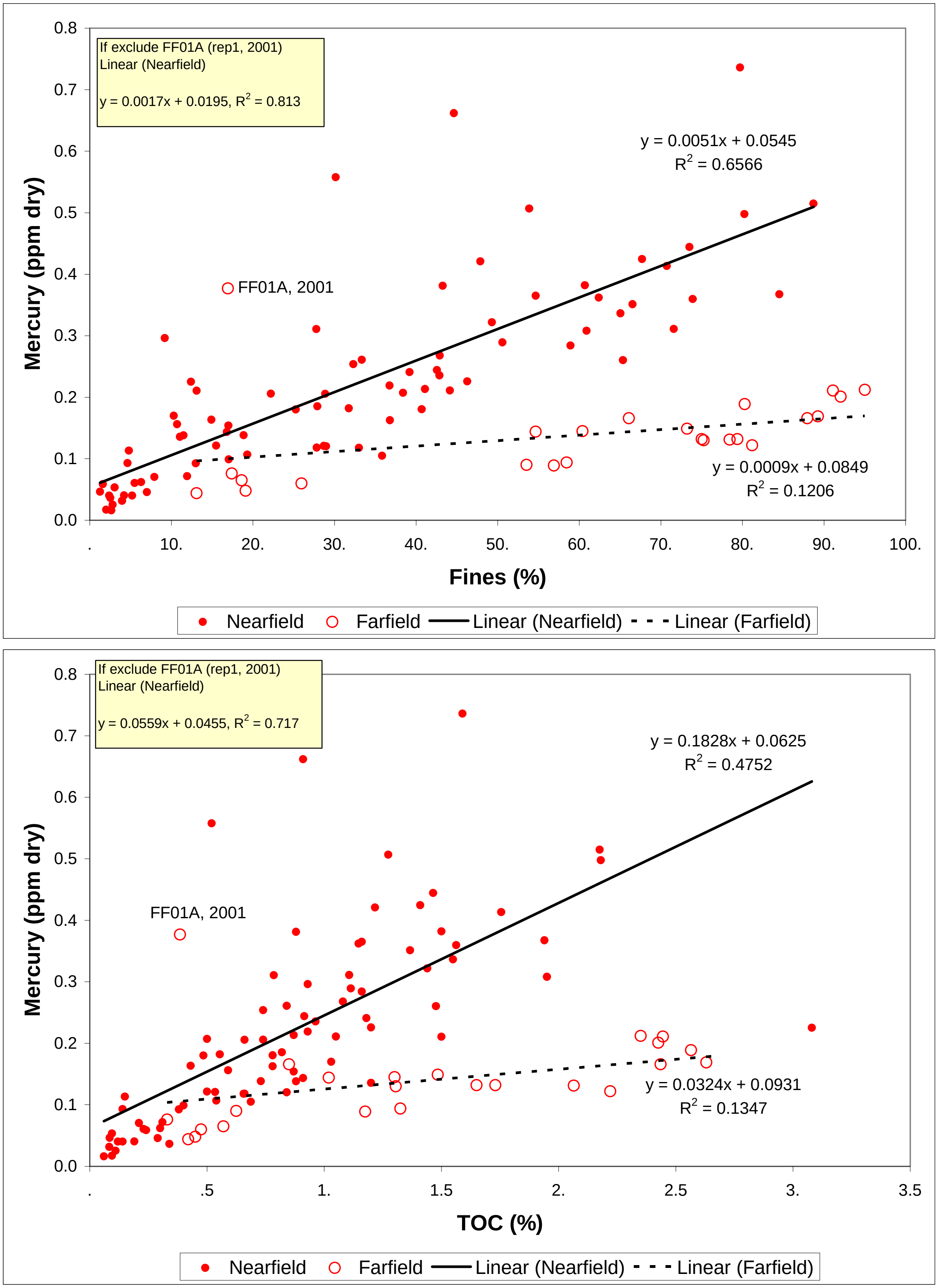


Figure B5-11. Correspondence between Mercury (Hg) and percent fines (top) and TOC (bottom) at nearfield and farfield locations (using 1999–2004 station mean values).

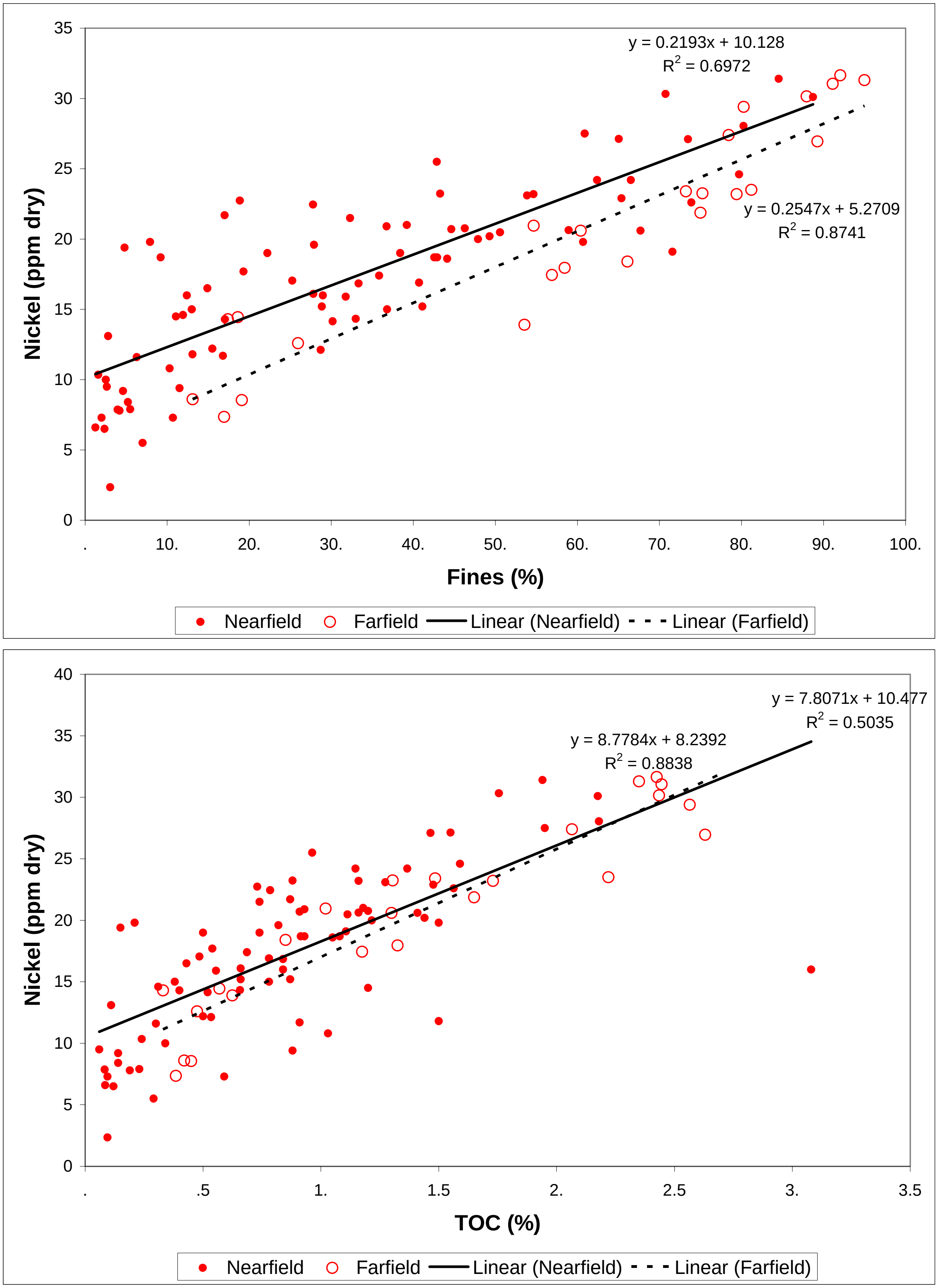


Figure B5-12. Correspondence between nickel (Ni) and percent fines (top) and TOC (bottom) at nearfield and farfield locations (using 1999–2004 station mean values).

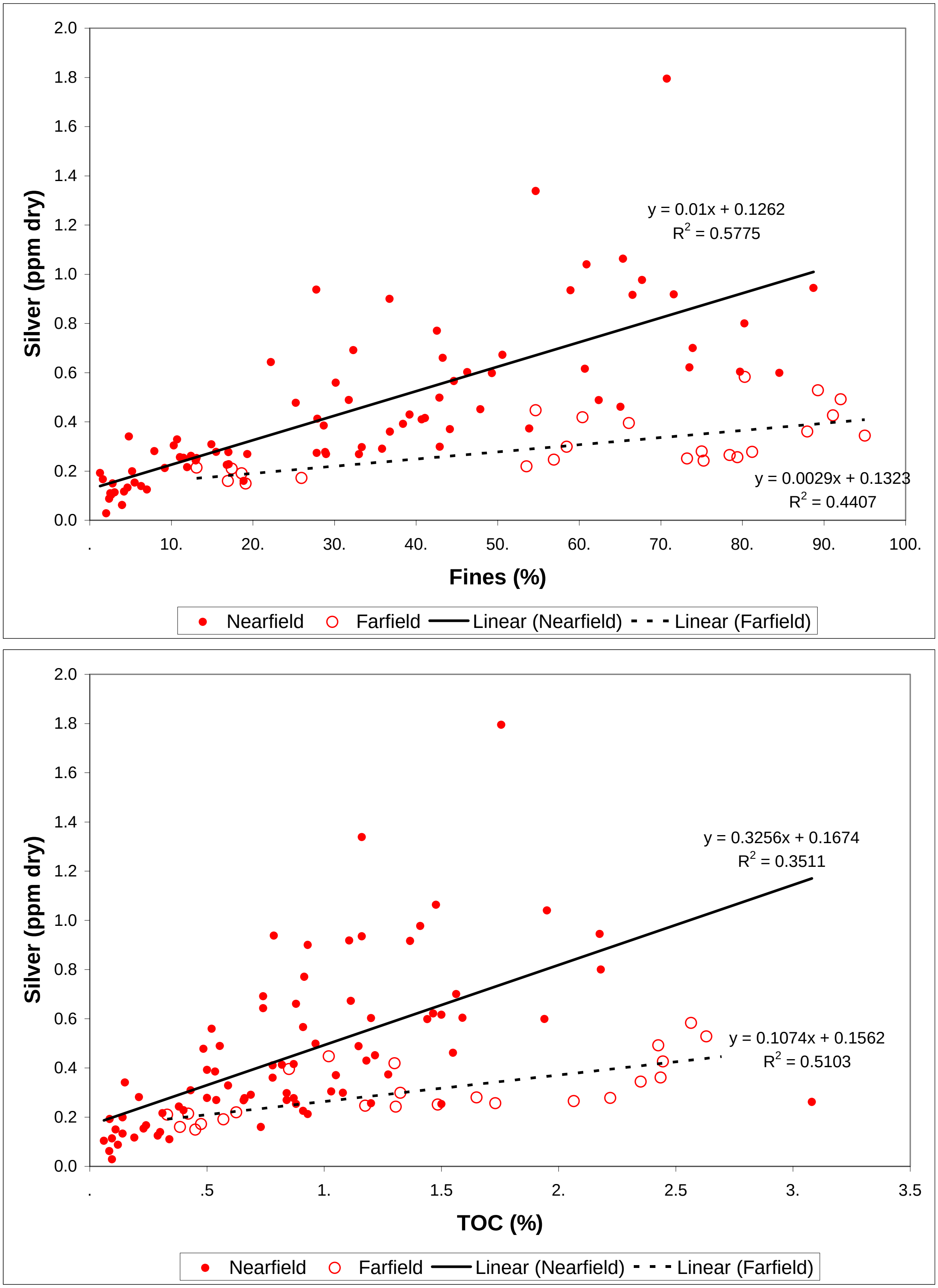
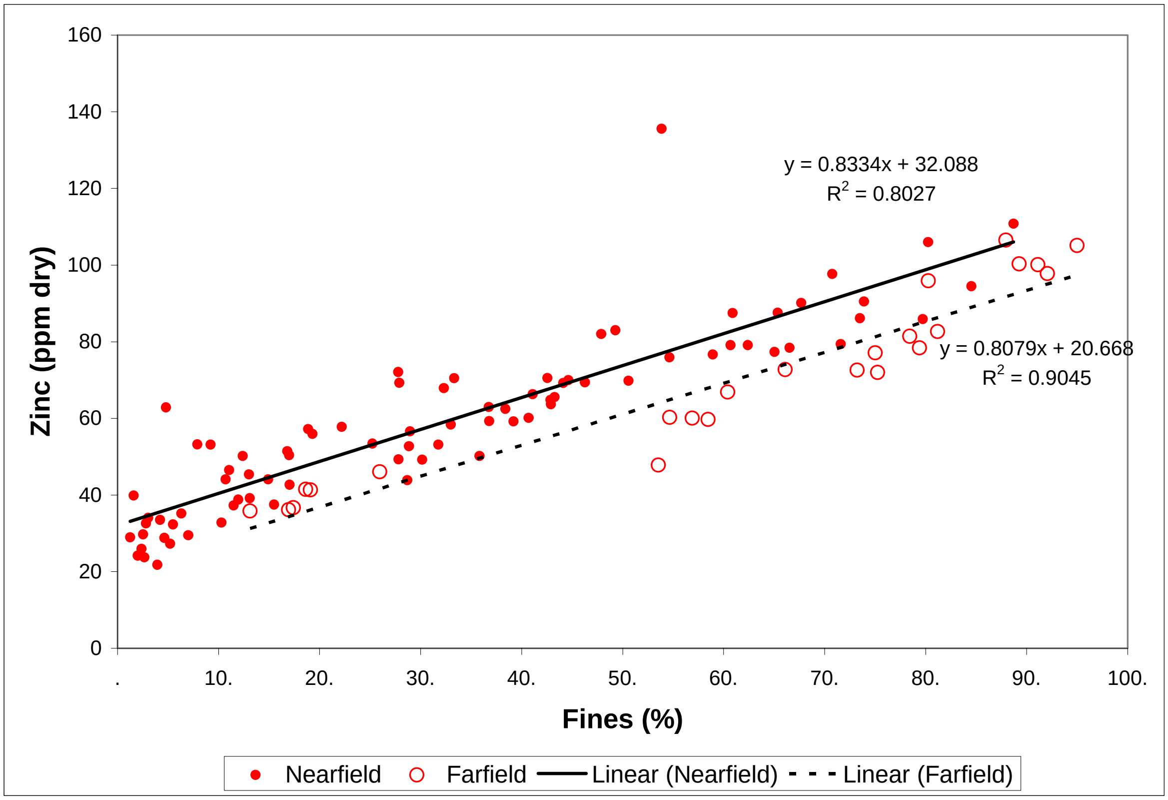


Figure B5-13. Correspondence between silver (Ag) and percent fines (top) and TOC (bottom) at nearfield and farfield locations (using 1999–2004 station mean values).



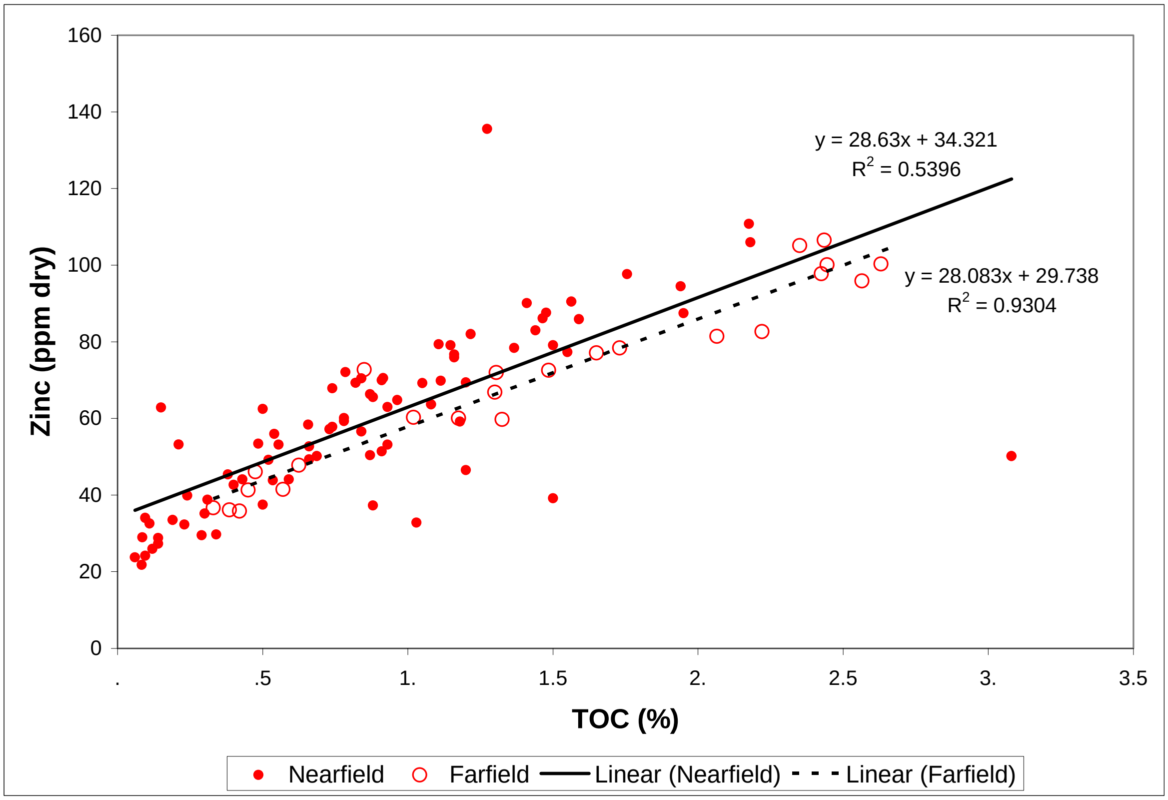


Figure B5-14. Correspondence between zinc (Zn) and percent fines (top) and TOC (bottom) at nearfield and farfield locations (using 1999–2004 station mean values).

APPENDIX C1

2004 Preliminary Treatment of Infaunal Data

Species Code	Description	Status Code	Change Code	Action (For MERGES, use second name listed).	VALID CODE	ENSR Comment
Code: 1. Permanent merge of two species. 2. Name change, Identification change, or spelling correction. 3. Merge for analyses only. 4. G/B/W designation change.						
6169370817	*Deflexilodes intermedius**		2	*Deflexilodes tesselatus*	6169370821	per IPW
6169060304	*Lembos websteri**		2	*Microdeutopus anomalous*	6169060402	per IPW
8127010401	*Ophiocten sericeum*		2	*Ophiura sarsi*	8127010610	1998 data, 98 specimens; per IPW and Cove Corp
8127010401	*Ophiocten sericeum*		2	*Ophiura sarsi*	8127010610	2000 data, 62 specimens; per IPW and Cove Corp
	(One specimen of Ophocten sericeum identified in 1995 is retained in the database)					
	*D. intermedius and L. websteri are still valid species, just not present in the MWRA database as of now. - per IPW					
MERGE ONLY FOR ANALYSES FOR REPORT:						
3901SP01	*Turbellaria* sp. 1		3	Combine with *Turbellaria* spp.	3901SPP	per SOP/Kropp
3901SP02	*Turbellaria* sp. 2		3	Combine with *Turbellaria* spp.	3901SPP	per SOP/Kropp
3901SPP	*Turbellaria spp.*		3	Treat as Good species	3901SPP	SOP
43030205SPP	*Micrura* spp.		3	Treat as Good species	43030205SPP	SOP
5001630302	*Maldane glebifex* and *Maldane* spp.		3	Combine with *Maldane sarsi*	5001630301	SOP
5001631102CF	*Euclymene cf. collaris*		3	Combine with *Euclymene collaris*	5001631102	SOP
5402010102	*Aplacophora* spp		3	Combine with *Chaetoderma nitidulum canadense*	5402010102	per SOP/Kropp
5001631202	*Clymenura polaris*		3	Combine with *Clymenura* sp. A	50016312SP01	per SOP/Kropp
50016817SP01	*Proclea* sp. 1		3	Combine with *Proclea graffi*	5001681702	per SOP/Kropp
5001420101	*Apistobranchus tullbergi* and *Apistobranchus* spp.		3	Combine with *Apistobranchus typicus*	5001420103	per SOP/Kropp/NJM
50020601TECT	*Pholoe tecta* and *Pholoe* spp.		3	Combine with *Pholoe minuta*	5001060101	per SOP
8401SPP	*Ascidiacea* spp.		3	Combine with *Molgula manhattensis*	8406030108	per JAB

84060301SPP	*Molgula* spp.		3	Combine with *Molgula manhattensis*	8406030108	per JAB
50015004SPP	*Chaetozone* spp.		3	Combine with *Chaetozone setosa*	50015004MB	per JAB
500150043SP04	*Chaetozone* sp. 4		3	Combine with *Chaetozone setosa*	50015004MB	per JAB
50015004SP05	*Chaetozone* sp. 5		3	Combine with *Chaetozone setosa*	50015004MB	per JAB
50012404SPP	*Nereis* spp.		3	Combine with *Nereis grayi*	5001240409	per CTM
56SPP	*Scaphopoda* spp.		3	Combine with *Dentalium entale*	5601010201	per JAB and RK (2001)
3743010102	*Cerianthus borealis*		3	Combine with *Ceriantheopsis americanus*	3743010201	per IPW, who identified this species originally
374301SPP	*Cerianthidae* spp.		3	Combine with *Ceriantheopsis americanus*	3743010201	per IPW
3758SP02	*Actiniaria* sp. 2		3	Combine with *Ceriantheopsis americanus*	3743010201	per IPW
5001260401	*Sphaerodoridium claparedii*		3	Combine with *Sphaerodoridium* sp. A	50012604SP01	per NJM
616312SPP	*Munnidae* spp.		3	Combine with *Munna* sp. 1	61631201SP01	per IPW
61631201SPP	*Munna* spp.		3	Combine with *Munna* sp.1	61631201SP01	per IPW
50014016SP01	*Leitoscoloplos* sp. B		3	Combine with *Leitoscoloplos acutus*	5001400305	per JAB (*L*. sp.B apparently not used by Cove)
50014016SPP	*Leitoscoloplos* spp.		3	Combine with *Leitoscoloplos acutus*	5001400305	per JAB
	Ampharete baltica		3	Combine with *Ampharete acutifrons*		for consistency/NJM

The taxa that were used for diversity and multivariate analysis are listed in Appendix C2. The following categories are included for calculations of total abundances, if they occur in the datasbase, but are not used for diversity or multivariate analysis:

Actiniaria spp.
Alvania spp.
Ampelisca spp.
Ampeliscidae spp.
Ampharete spp.
Ampharetidae spp.
Amphipoda spp.
Amphiporus spp.
Amphitritinae spp.
Ancistrosyllis 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.
Caulleriella spp.
Cephalaspidea spp.
Chone spp.
Cirratulidae spp.
Cirratulus 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.
Leptostylis spp.
Leucon spp.
Levinsenia spp.
Lumbrineridae spp.
Lyonsia spp.
Lyonsiidae spp.
Lysianassidae spp.
Lysilla spp.
Maldane spp.
Maldanidae spp.
Melinna spp.
Melitidae spp.
Microphthalmus spp.
Monoculodes spp.
Monticellina spp.
Musculus spp.
Myriochele spp.
Mysidacea 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.

Taxa that are recorded as samples are processed, but are not included in any summations are:

Aeginina longicornis
Anomia simplex
Anomia spp.
Anomia squamula
Balanus crenatus
Balanus spp.
Caprella linearis
Caprella spp.
Caprellidae spp.
Caridea spp.
Corymorpha pendula
Crepidula fornicata
Crepidula spp.
Dichelopandalus leptocerus
Dipolydora concharum
Eualus pusiolus
Hydrozoa spp.
Labrorostratus parasiticus
Limnoria lignorum
Modiolus modiolus
Mytilidae spp.
Mytilus edulis
Mytilus spp.
Nymphon grossipes
Paracaprella tenuis
Polydora websteri
Polyplacophora spp.
Porifera spp.

APPENDIX C2

Species Identified in Massachusetts Bay Samples
1992–2004

Table C2-1. Species identified from Massachusetts Bay Outfall Monitoring Program samples from 1992–2004 (May 1992 and FF-08 samples are excluded) and used in the 2004 OBR community analysis. Species collected in August 2004 samples are marked with an asterisk (*). Species new to the list in 2004 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 bioculatus* McIntosh, 1873 *
  - *Amphiporus caecus* Verrill, 1892 *
    (inc. former *A. angulatus* and *A. groenlandicus*)
  - *Amphiporus cruentatus* Verrill, 1879 *
    - *Carinomella lactea* Coe, 1905 *
  - Cephalothricidae sp. 1 *
  - *Cerebratulus lacteus* (Leidy, 1851) *
  - *Cyanophthalmus cordiceps* (Friedrich, 1933)
    (name corrected from *Tetrastemma vittatum*)
  - *Lineus pallidus* Verrill, 1879
  - Micrura spp. *
  - Nemertea sp. 2 *
  - Nemertea sp. 7
  - Nemertea sp. 12 *
  - Nemertea sp. 13
  - Nemertea sp. 14
  - Nemertea sp. 15 *
  - Nemertea sp. 16
  - *Tetrastemma elegans* (Girard, 1825) *
  - *Tubulanus pellucidus* (Coe, 1895) *

- ANNELIDA
  - Polychaeta
    - Ampharetidae
      - *Ampharete acutifrons* Grube, 1860 *
      - *Ampharete baltica* Eliason, 1955 *
      - *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* (Théel, 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 *
      - Capitellidae sp. 2
    - 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* Støp 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)
      - *Ninoe nigripes* Verrill, 1873 *
      - *Paraninoe brevipes* (McIntosh, 1903)
      - *Scoletoma fragilis* (O.F. Möller, 1776) *
      - *Scoletoma hebes* (Verrill, 1880) *
      - *Scoletoma impatiens* (Claparéde, 1868)

- Maldanidae
  - *Axiothella catenata* (Malmgren, 1865)
  - *Clymenella torquata* (Leidy, 1855) *
  - *Clymenura polaris* (Théel, 1879) (merged with *C.* sp. A for report)
  - *Clymenura* sp. A
  - *Euclymene collaris* (Claparéde, 1870) *
  - *Euclymene* cf. *collaris* (Claparéde, 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* (Théel, 1879)
  - *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* (Claparéde, 1868)
  - *Drilonereis longa* Webster, 1879
  - *Drilonereis magna* Webster & Benedict, 1887
- Onuphidae
  - *Nothria* sp. A *
- 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* Glémarec, 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
  - *Eteone trilineata* (de Saint Joseph, 1888) *
  - *Eulalia bilineata* (Johnston, 1840)
  - *Eulalia viridis* (Linnaeus, 1767)
  - *Eumida sanguinea* (Oersted, 1843) *
  - *Microphthalmus pettiboneae* *
  - *Mystides borealis* Théel, 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* Théel, 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* Kröyer, 1856
  - *Chone* cf. *magna* (Moore, 1923)
  - Chone spp. * $^+$
  - *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* cf. *longipalpa* Hartman & Fauchald, 1971

  - *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)
  - *Microspio* sp.1 *
  - *Polydora aggregata* Blake, 1969
  - *Polydora cornuta* Bosc, 1802 *
  - *Polydora* sp. 1
  - *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. Müller, 1806)
  - *Scolelepis texana* Foster, 1971
  - *Scolelepis* cf. *tridentata* (Southern, 1914)
  - *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* Claparède, 1864
  - *Parapionosyllis longicirrata* (Webster & Benedict, 1884) *
  - *Pionosyllis* sp. A *
  - *Proceraea cornuta* Agassiz, 1863
  - *Sphaerosyllis brevifrons* Webster & Benedict, 1884*
  - *Sphaerosyllis erinaceus* Claparède, 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. Müller, 1771
  - *Lanassa venusta venusta* (Malm, 1874) *
  - *Nicolea zostericola* (Oersted, 1844) *
  - *Pista cristata* (O.F. Müller, 1776)
  - *Polycirrus eximus* (Leidy, 1855)
  - *Polycirrus medusa* Grube, 1850
  - *Polycirrus phosphoreus* Verrill, 1880 *
  - *Proclea graffii* (Langerhans, 1880)
  - *Proclea* sp. 1 *
    (merged with *P. graffii* for report)
  - *Streblosoma spiralis* Verrill, 1874
- 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
    - Enchytraeidae
        - Enchytraeidae sp. 1 *
        - Enchytraeidae sp. 2
        - Enchytraeidae sp. 3
        - *Grania postclitellochaeta longiducta* Erséus & Lasserre, 1976 *
    - 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
            - *Gammarellus 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
Melphidippidae
Melphidippa cf. *borealis* Boeck, 1871
Melphidippa cf. goesi Stebbing, 1899
Oedicerotidae
Ameroculodes sp. 1 *
Bathymedon obtusifrons (Hansen, 1887) *
Deflexilodes tesselatus (Schneider, 1884) *
(includes former *D. intermedius*)
Deflexilodes tuberculatus (Boeck, 1870) *
Monoculodes packardi Boeck, 1871 *
Westwoodilla megalops (Sars, 1883)*
(includes former *W. brevicalcar*)
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
Pagurus spp.*$^{+}$
Decapoda sp. 1
Isopoda
Anthuriidae
Ptilanthura tenuis Harger, 1879 *
Chaetiiidae
Chiridotea tuftsi (Stimpson, 1883) *
Cirolanidae
Politolana polita (Stimpson, 1853) *
Gnathiidae
Gnathia cerina (Stimpson, 1833)
Idoteidae
Edotia montosa (Stimpson, 1853) *
Edotia triloba (Say, 1818)
Idotea baltica (Pallas, 1772)
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 (Göes, 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) *
Astartidae
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 (Möller, 1771) *
Yoldia limatula (Say, 1831)
Yoldia sapotilla (Gould, 1841) *
Yoldiella lucida Lovén, 1846
Nuculidae
Nucula annulata Hampson, 1971 *
Nucula delphinodonta Mighels & Adams, 1842 *
Nuculoma tenuis (Montagu, 1808) *
Pectinidae
Placopectin magellanicus (Gmelin, 1791) *
Periplomatidae
Periploma leanum (Conrad, 1831) *
(inc. *P. fragile* & *Asthenothaerus hemphilli*)
Periploma papyratium (Say, 1822) *
Petricolidae
Petricola pholadiformis (Lamarck, 1818)
Solenidae
Ensis directus Conrad, 1843 *
Siliqua costata Say, 1822 *
Tellinidae
Macoma balthica (Linnaeus, 1758) *
Tellina agilis Stimpson, 1857
Thraciidae
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)
Neptunea spp. * $^+$
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 (Warén, 1974)
Skeneopsidae
Skeneopsis planorbis (Fabricius, 1780) *
Trochidae
Moelleria costulata (Möller, 1842)
Solariella obscura (Couthouy, 1838)
Turridae
Oenopota cf. *cancellatus* (Mighels & C.B. Adams, 1842)
Oenopota harpularia (Couthouy, 1838)
Oenopota incisula Verrill, 1882 *
Oenopota pyramidalis (Ström, 1788)
Propebela exarata (Möller, 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. Möller, 1776) *
  - *Leptasterias tenera* (Stimpson, 1862)
- Echinoidea
  - *Echinarachnius parma* (Lamarck, 1816) *
- Holothuroidea
  - *Molpadia oolitica* (Pourtalés, 1851)
  - *Pentamera calcigera* (Stimpson, 1851)*
- Ophiuroidea
  - *Axiognathus squamatus* (Delle Chiaje, 1828) *
  - *Ophiocten sericeum* (Forbes, 1852)
  - *Ophiopholis aculeata* (Linnarus, 1788)
  - *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) *

$^+$ *Chone* spp., *Neptunea* spp, and *Pagurus* spp. are considered good species for 2004 analyses based on absence of other identified individuals belonging to these genera.

APPENDIX C3

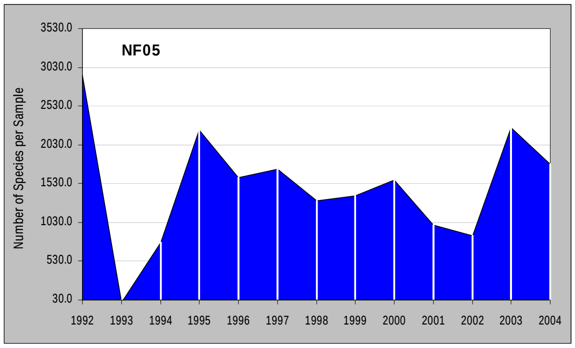
Benthic Infaunal Community Parameters

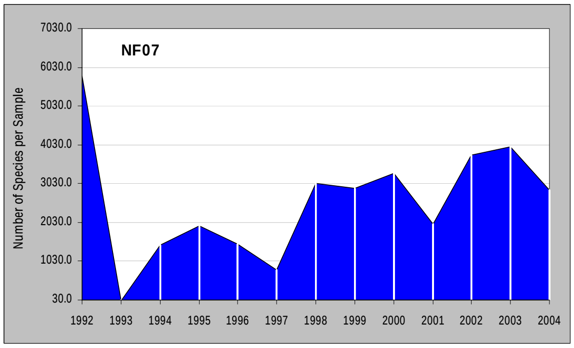
Table C3-1. Benthic community parameters for all samples, 2004.

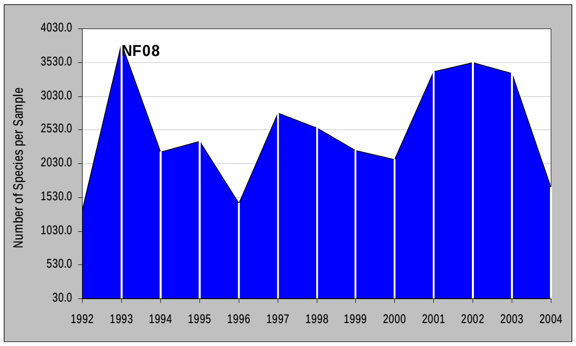
Nearfield Stations							
		Abundance of		Number of Species			
Station	Rep	Total Indiv.	Good Species		H'	J'	LSA
FF10	1	1107	987	74	4.81	0.77	18.53
FF10	2	1265	1262	71	4.60	0.75	16.27
FF10	3	2433	2082	90	4.63	0.71	19.16
FF13	1	2891	2826	63	3.24	0.54	11.42
FF13	2	2399	2384	59	3.53	0.60	10.95
FF13	3	2509	2366	68	3.67	0.60	13.07
NF05	1	1780	1736	92	4.63	0.71	20.72
NF07	1	2865	2802	105	4.70	0.70	21.53
NF08	1	1680	1670	72	4.41	0.71	15.32
NF09	1	2007	1987	80	4.63	0.73	16.71
NF12	1	2446	2320	74	3.66	0.59	14.58
NF12	2	2511	2490	66	3.44	0.57	12.44
NF12	3	2606	2514	58	3.14	0.54	10.60
NF16	1	1854	1840	73	3.87	0.63	15.19
NF17	1	1118	1082	62	4.18	0.70	14.28
NF17	2	1205	1177	50	3.85	0.68	10.59
NF17	3	607	588	43	3.73	0.69	10.68
NF18	1	1729	1671	83	4.52	0.71	18.35
NF19	1	2304	2278	83	4.32	0.68	16.90
NF22	1	1530	1522	61	4.01	0.68	12.73
NF23	1	3355	3178	95	4.63	0.70	18.42

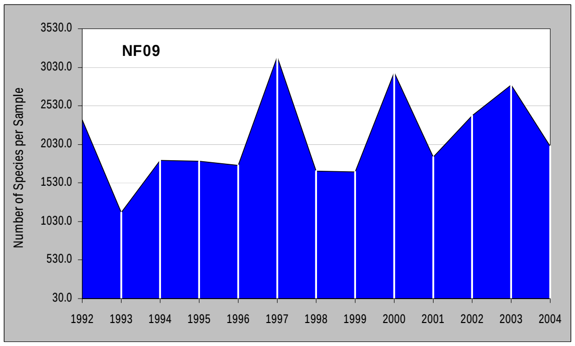
Farfield Stations							
		Abundance		Number of Species			
Station	Rep	Total Indiv.	Good Species		H'	J'	LSA
FF04	1	989	982	63	4.56	0.76	15.02
FF04	2	1496	1488	58	4.35	0.74	12.02
FF04	3	1359	1344	73	4.73	0.76	16.56
FF05	1	2461	2379	83	3.91	0.61	16.72
FF05	2	2593	2543	103	3.87	0.58	21.55
FF05	3	2257	2221	92	3.85	0.59	19.36
FF07	1	4005	3969	58	3.03	0.52	9.63
FF07	2	3896	3870	45	2.89	0.53	7.15
FF07	3	7104	7047	70	2.83	0.46	10.80
FF09	1	1980	1923	103	4.63	0.69	23.27
FF09	2	1825	1799	105	4.86	0.72	24.32
FF09	3	1821	1730	105	4.85	0.72	24.61

Figure C3-1
Abundance Charts for each NF and FF Massachusetts Bay Station
1992–2004


NF05
Number of Species per Sample
3530.0
3030.0
2530.0
2030.0
1530.0
1030.0
530.0
30.0
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004


NF07
Number of Species per Sample
7030.0
6030.0
5030.0
4030.0
3030.0
2030.0
1030.0
30.0
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004


NF08
Number of Species per Sample
4030.0
3530.0
3030.0
2530.0
2030.0
1530.0
1030.0
530.0
30.0
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004


NF09
Number of Species per Sample
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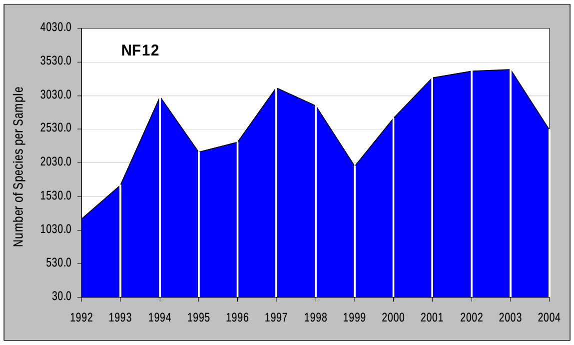
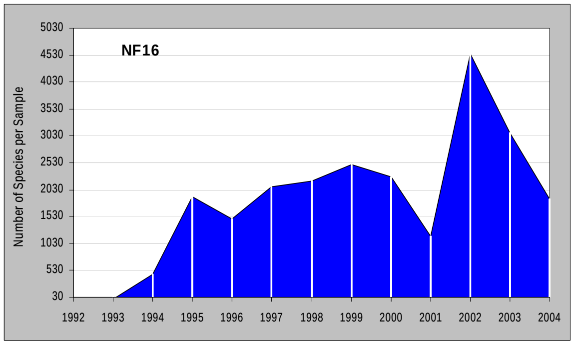
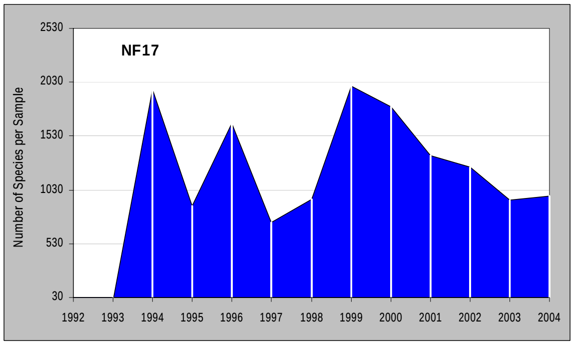
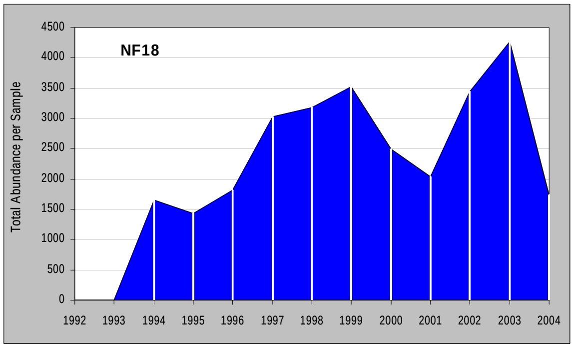
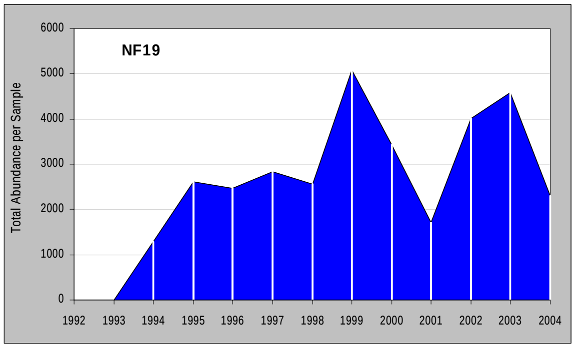
3030.0
2530.0
2030.0
1530.0
1030.0
530.0
30.0
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004

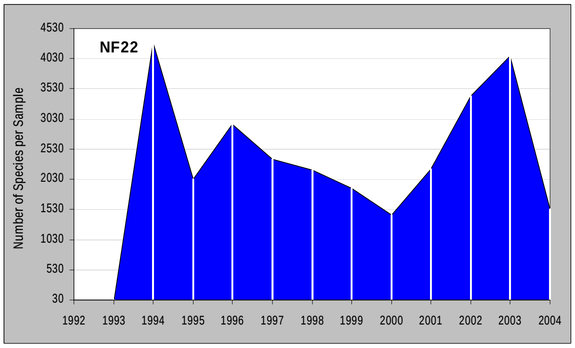

NF12
Number of Species per Sample
4030.0
3530.0
3030.0
2530.0
2030.0
1530.0
1030.0
530.0
30.0
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004

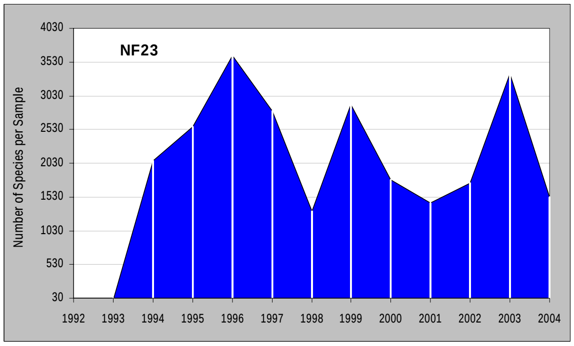

NF16
Number of Species per Sample
5030
4530
4030
3530
3030
2530
2030
1530
1030
530
30
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004

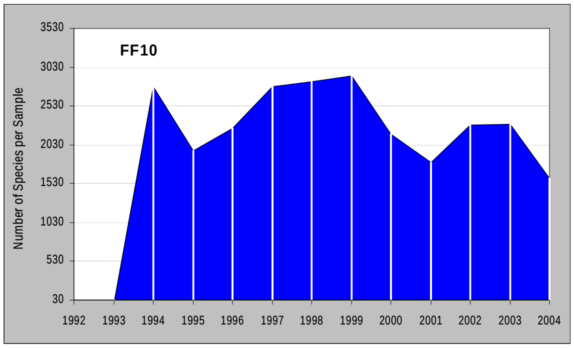

NF17
Number of Species per Sample
2530
2030
1530
1030
530
30
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004

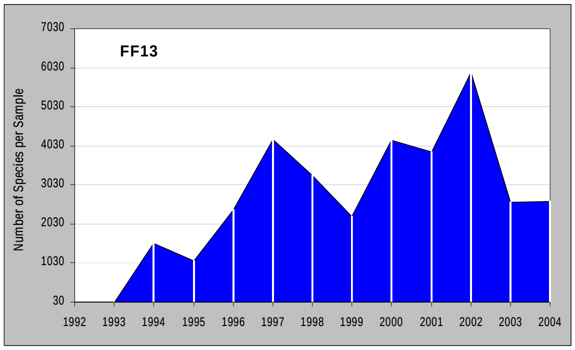

NF18
Total Abundance per Sample
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004

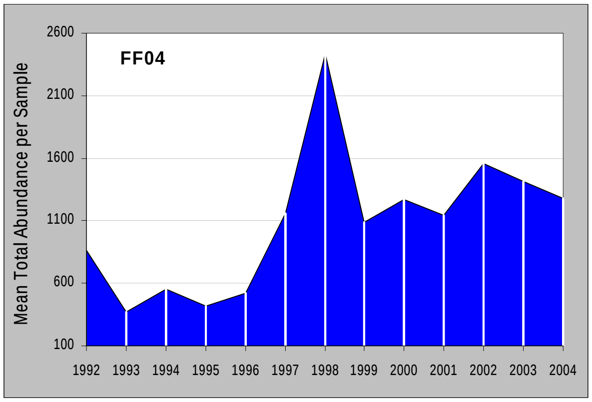

NF19
Total Abundance per Sample
6000
5000
4000
3000
2000
1000
0
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004

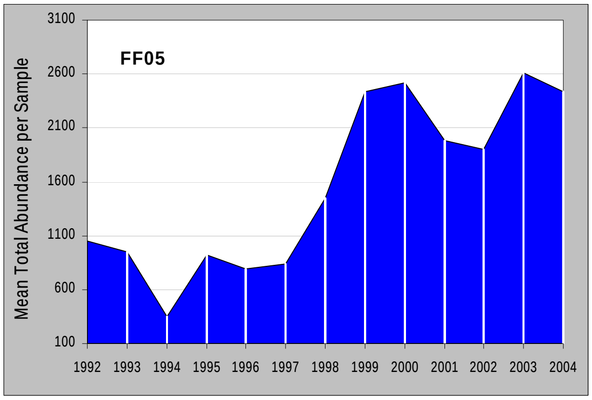

NF22
Number of Species per Sample
4530
4030
3530
3030
2530
2030
1530
1030
530
30
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004

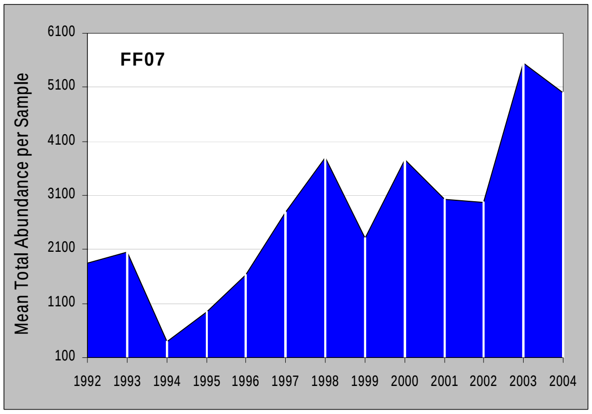

NF23
Number of Species per Sample
4030
3530
3030
2530
2030
1530
1030
530
30
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004


FF10
Number of Species per Sample
3530
3030
2530
2030
1530
1030
530
30
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004


FF13
Number of Species per Sample
7030
6030
5030
4030
3030
2030
1030
30
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004


FF04
Mean Total Abundance per Sample
2600
2100
1600
1100
600
100
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004


FF05
Mean Total Abundance per Sample
3100
2600
2100
1600
1100
600
100
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004


FF07
Mean Total Abundance per Sample
6100
5100
4100
3100
2100
1100
100
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004

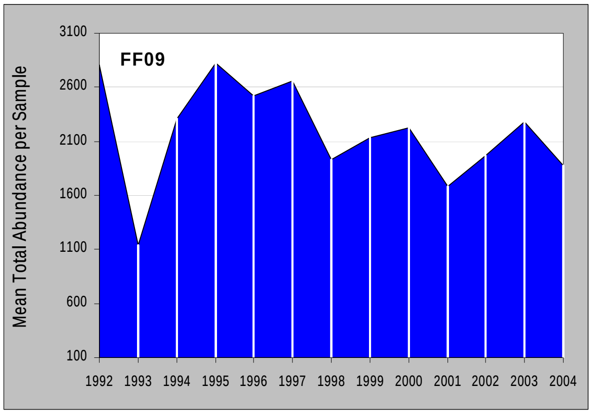
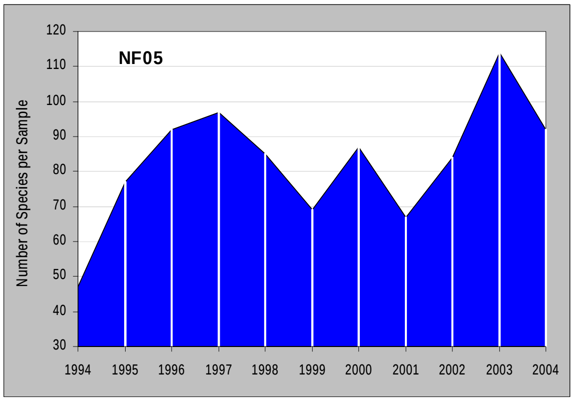

FF09
Mean Total Abundance per Sample
3100
2600
2100
1600
1100
600
100
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004

Figure C3-2

Species Richness Charts for each NF and FF Massachusetts Bay Station
1992–2004


NF05
Number of Species per Sample
120
110
100
90
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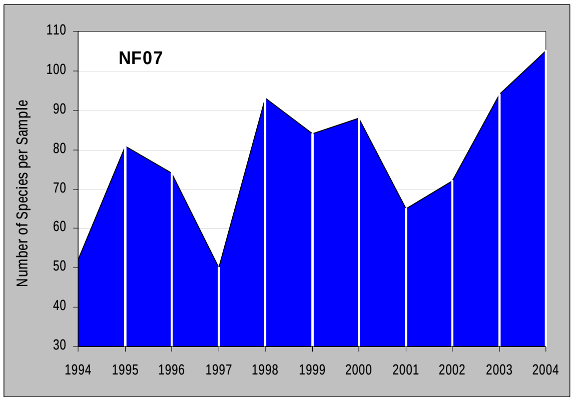
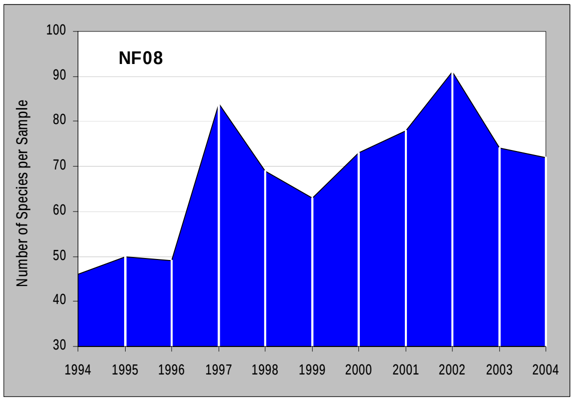
70
60
50
40
30
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004


NF07
Number of Species per Sample
110
100
90
80
70
60
50
40
30
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004


NF08
Number of Species per Sample
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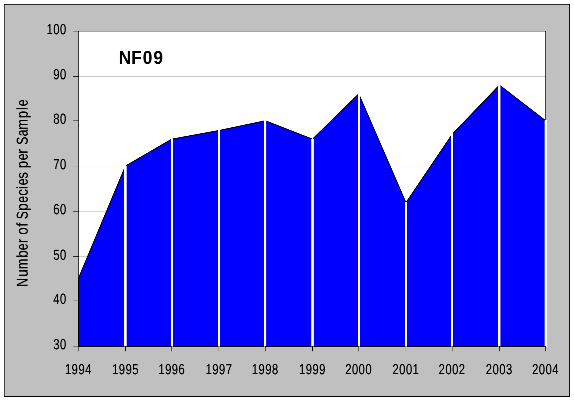
80
70
60
50
40
30
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004


NF09
Number of Species per Sample
100
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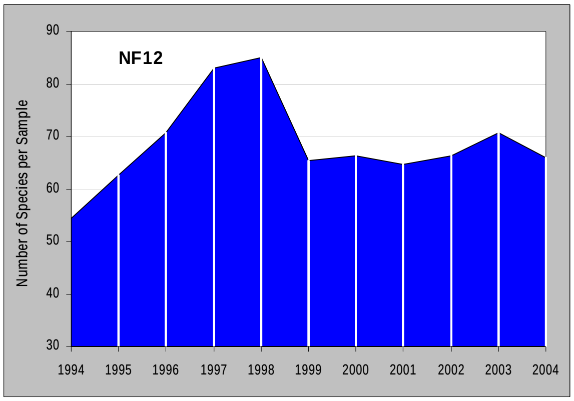
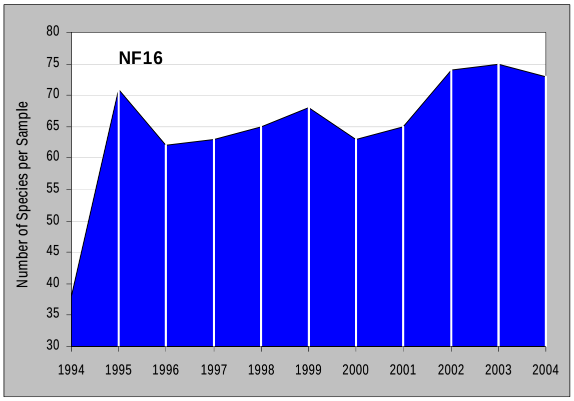
80
70
60
50
40
30
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004


NF12
Number of Species per Sample
90
80
70
60
50
40
30
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004


NF16
Number of Species per Sample
80
75
70
65
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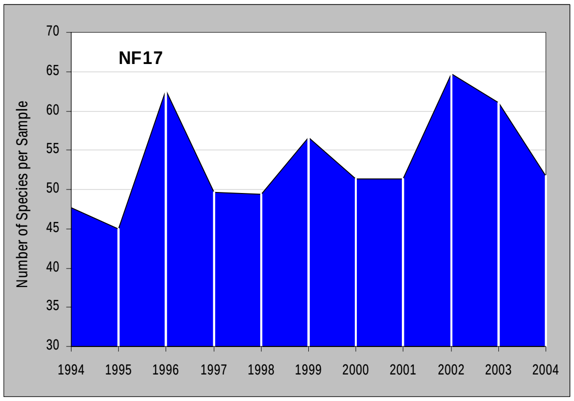
55
50
45
40
35
30
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004


NF17
Number of Species per Sample
70
65
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50
45
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35
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1994
1995
1996
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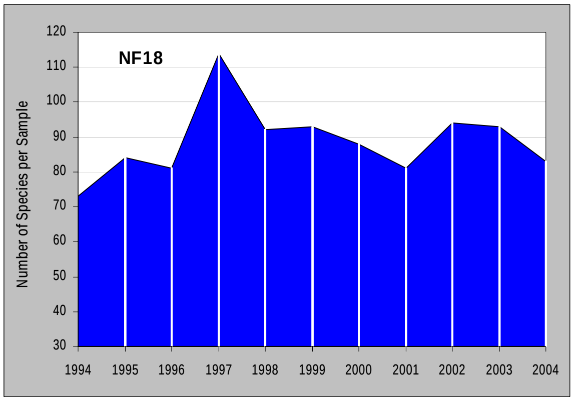
2000
2001
2002
2003
2004


NF18
Number of Species per Sample
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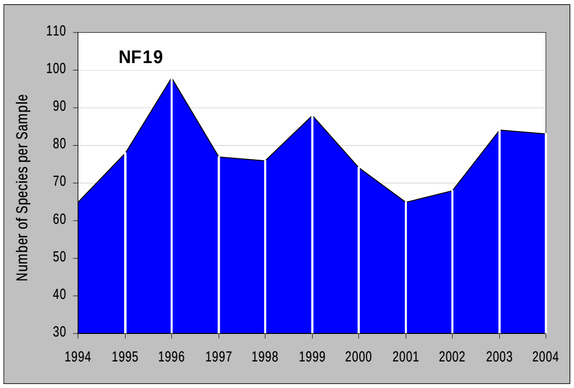
1996
1997
1998
1999
2000
2001
2002
2003
2004


NF19
Number of Species per Sample
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100
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60
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40
30
1994
1995
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1997
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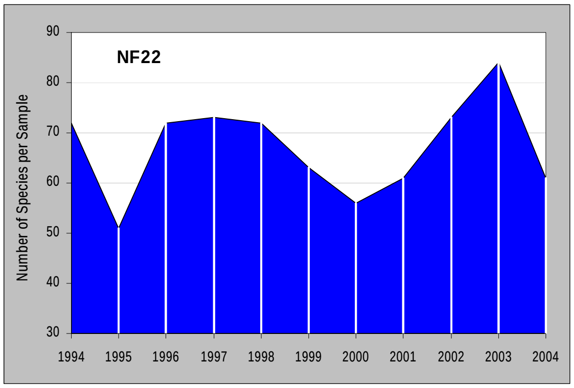
2000
2001
2002
2003
2004


NF22
Number of Species per Sample
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60
50
40
30
1994
1995
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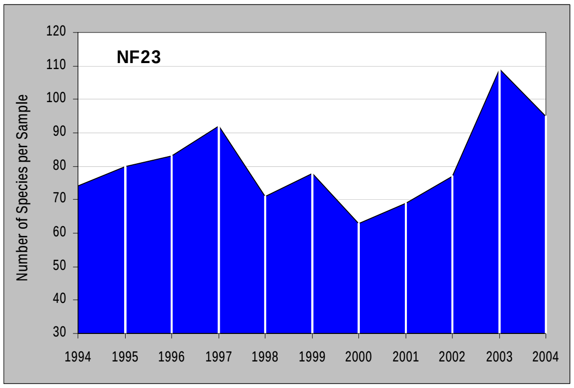
1999
2000
2001
2002
2003
2004


NF23
Number of Species per Sample
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100
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70
60
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1994
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1997
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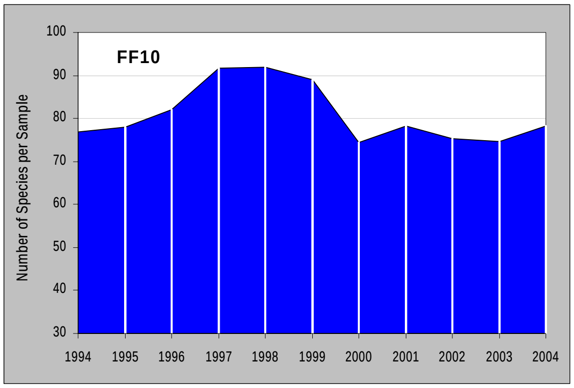
2001
2002
2003
2004


FF10
Number of Species per Sample
100
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70
60
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40
30
1994
1995
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1997
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2001
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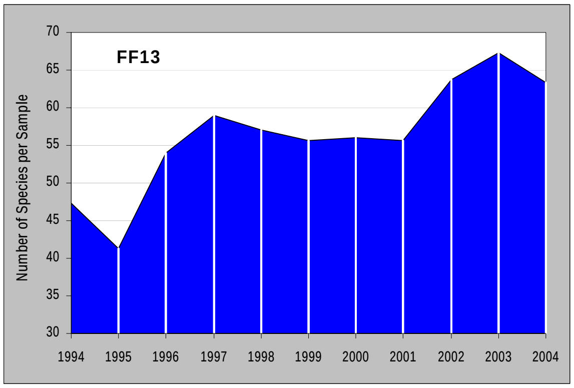
2003
2004


FF13
Number of Species per Sample
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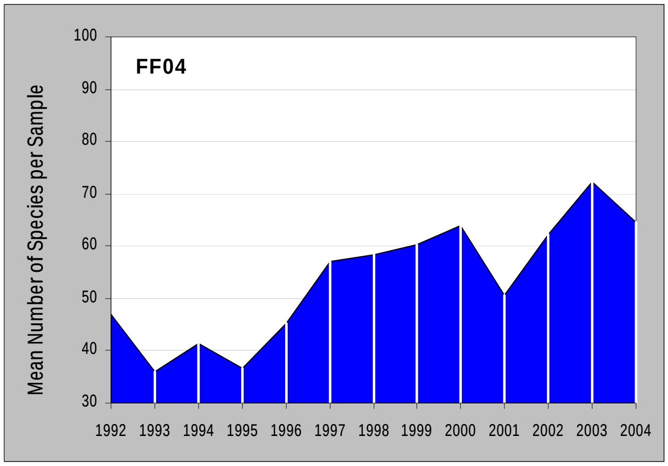
60
55
50
45
40
35
30
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004


FF04
Mean Number of Species per Sample
100
90
80
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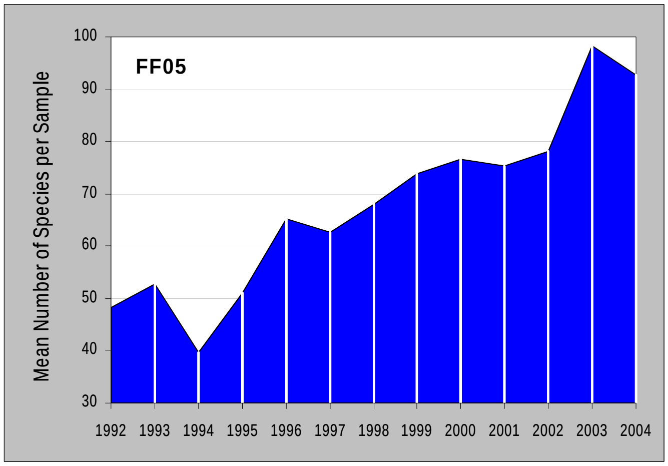
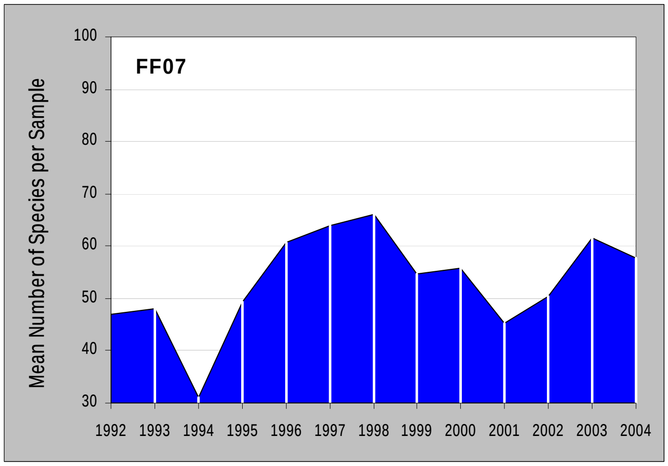
50
40
30
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004


FF05
Mean Number of Species per Sample
100
90
80
70
60
50
40
30
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004


FF07
Mean Number of Species per Sample
100
90
80
70
60
50
40
30
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004

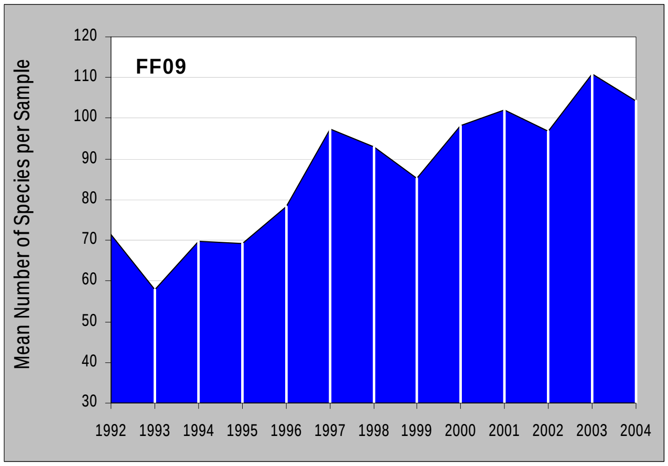
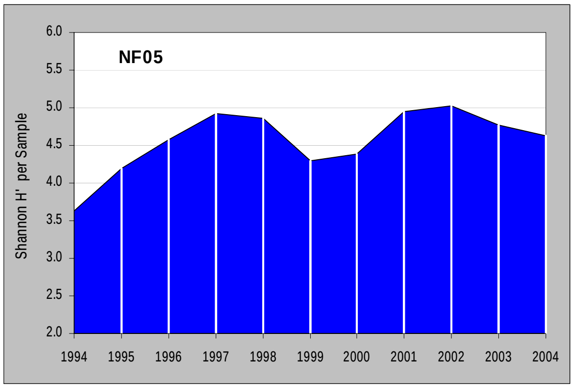
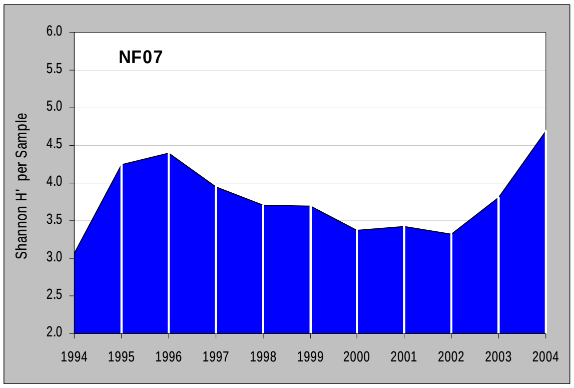
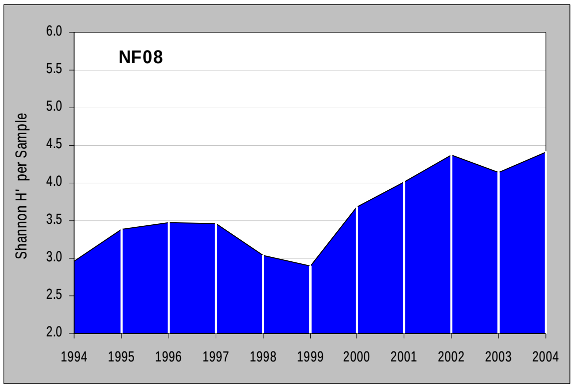

FF09
Mean Number of Species per Sample
120
110
100
90
80
70
60
50
40
30
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004

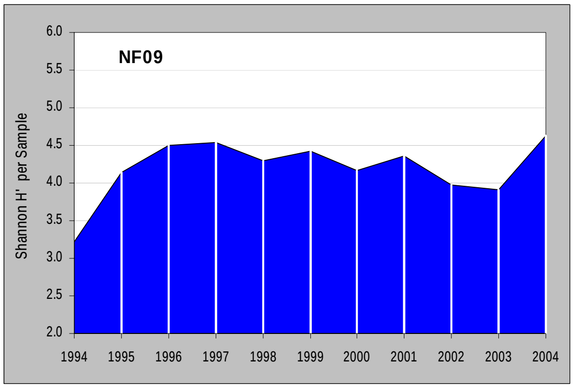
Figure C3-3

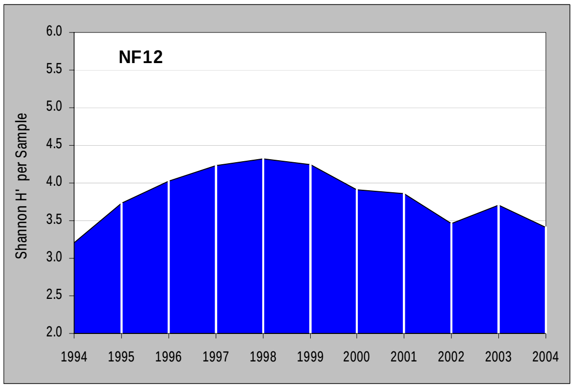
Shannon Diversity (H′)
Charts for each NF and FF
Massachusetts Bay Station
1992–2004

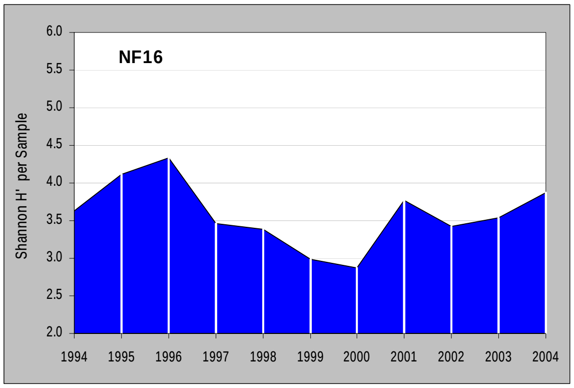

NF05
Shannon H' per Sample
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004

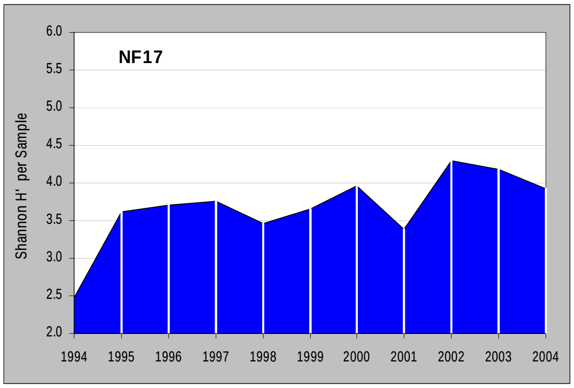

NF07
Shannon H' per Sample
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004

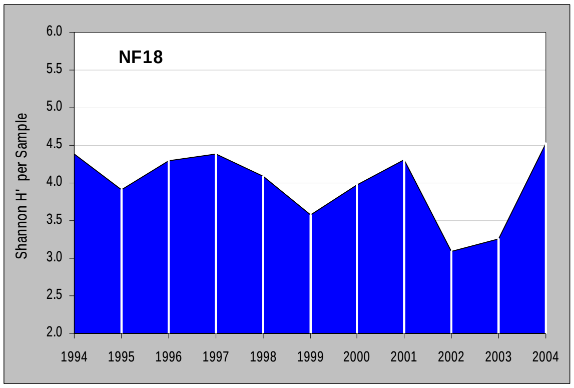

NF08
Shannon H' per Sample
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004

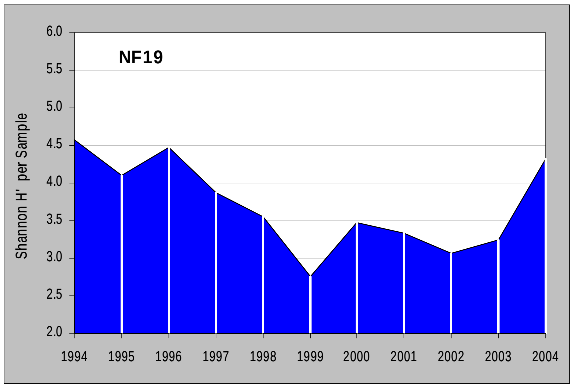

NF09
Shannon H' per Sample
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004

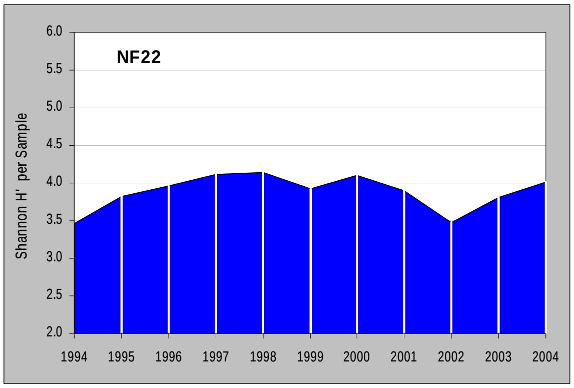

NF12
Shannon H' per Sample
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004

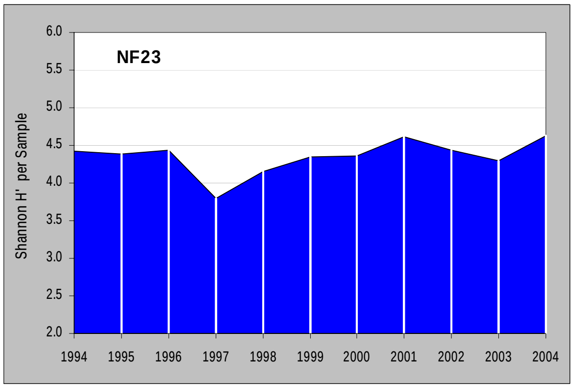

NF16
Shannon H' per Sample
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004

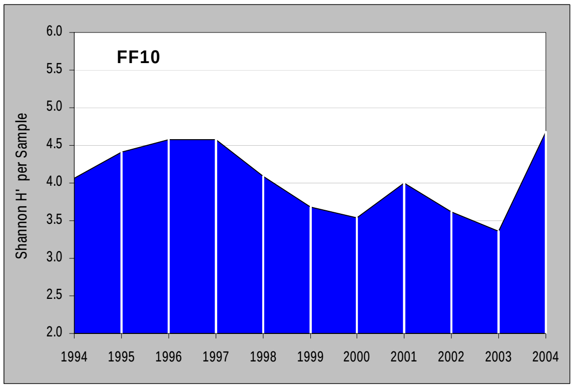

NF17
Shannon H' per Sample
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004

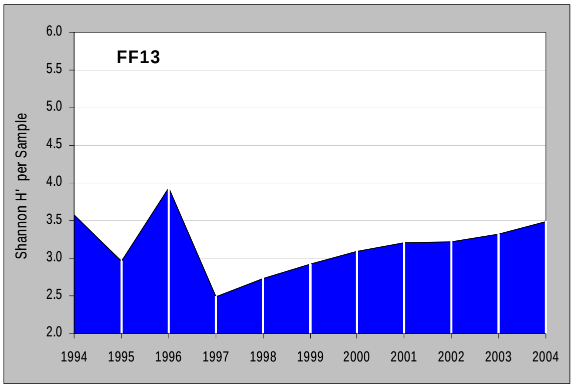

NF18
Shannon H' per Sample
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004

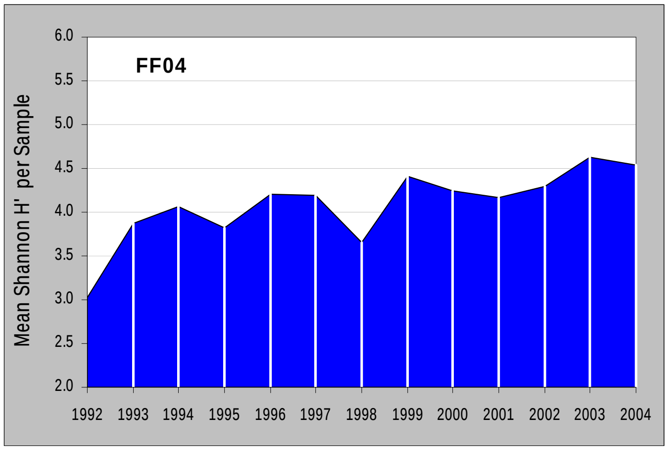

NF19
Shannon H' per Sample
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004

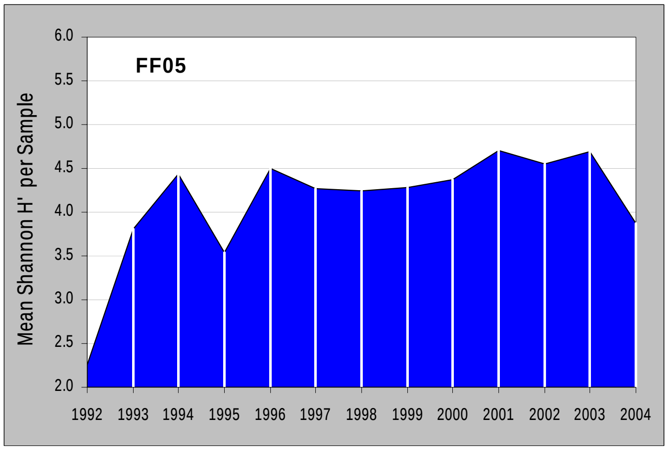

NF22
Shannon H' per Sample
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004

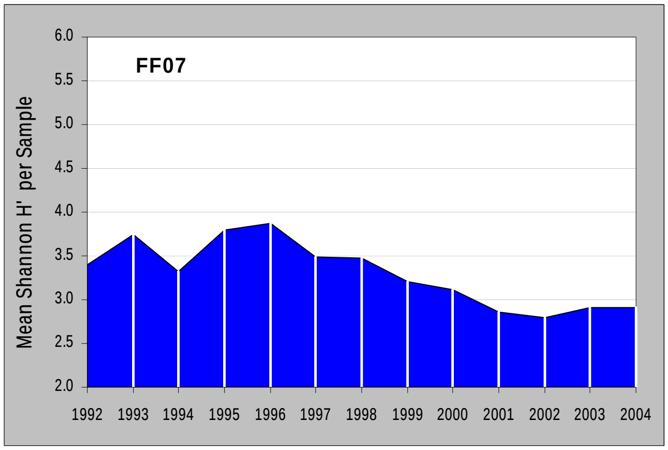

NF23
Shannon H' per Sample
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004


FF10
Shannon H' per Sample
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004


FF13
Shannon H' per Sample
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004


FF04
Mean Shannon H' per Sample
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004


FF05
Mean Shannon H' per Sample
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004


FF07
Mean Shannon H' per Sample
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004

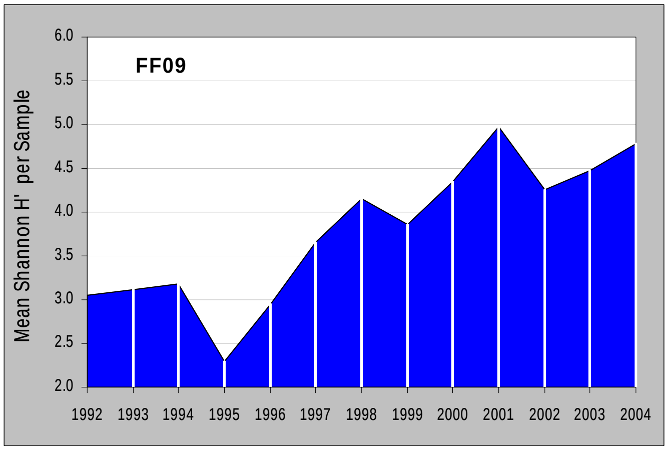
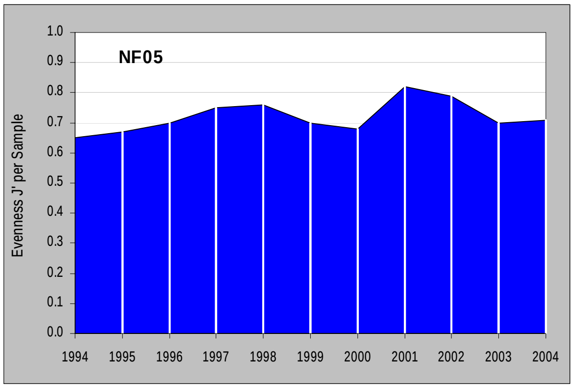
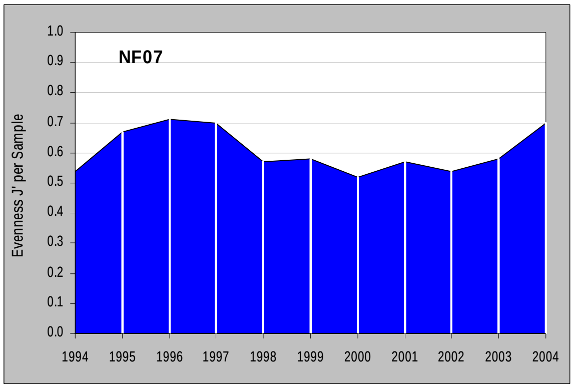
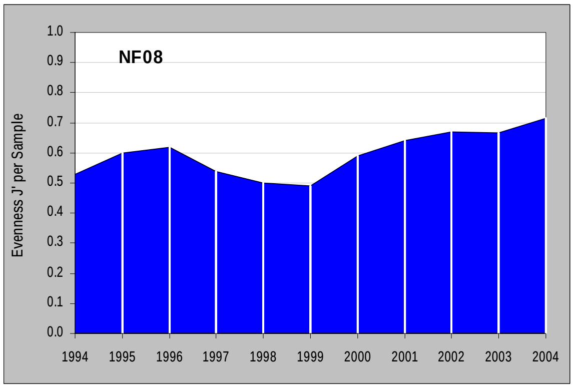

FF09
Mean Shannon H' per Sample
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004

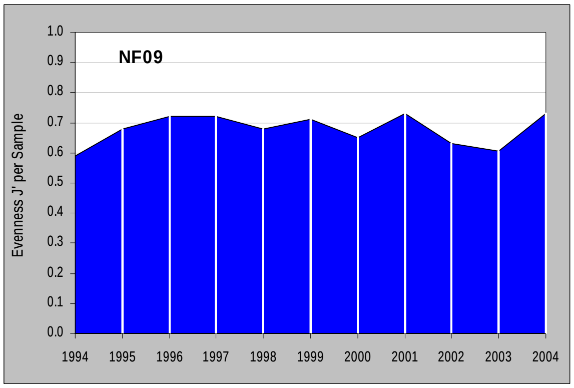
Figure C3-4

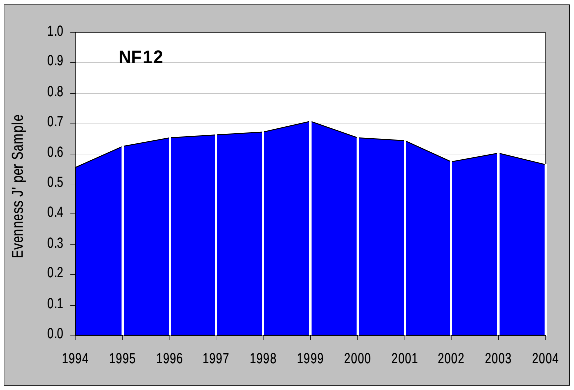
Pielou's Evenness (J′)
Charts for each NF and FF
Massachusetts Bay Station
1992–2004

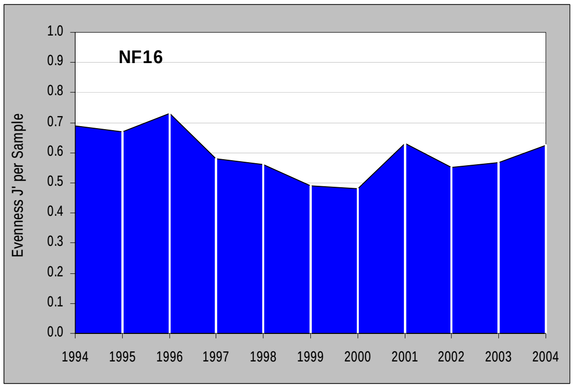

NF05
Evenness J' per Sample
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004

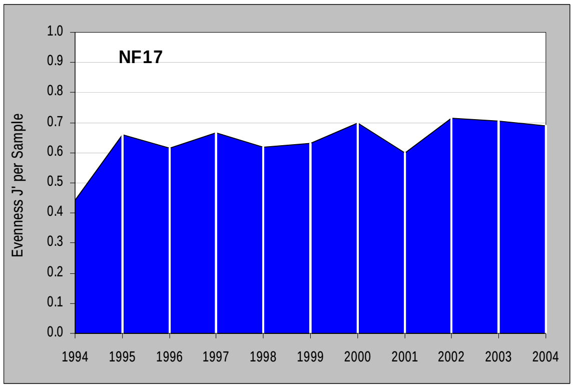

NF07
Evenness J' per Sample
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004

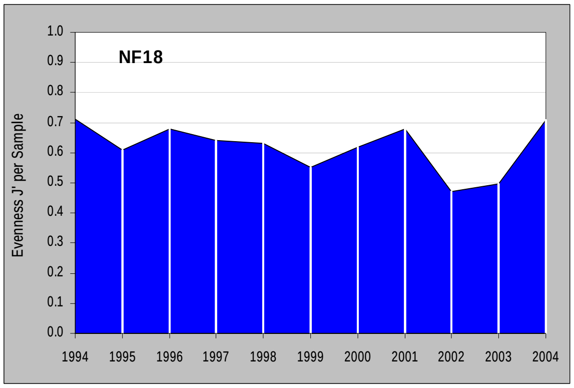

NF08
Evenness J' per Sample
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004

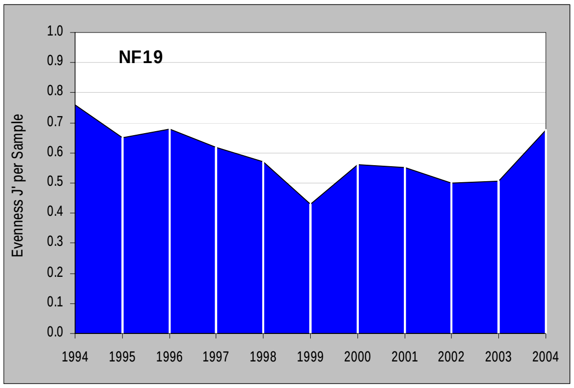

NF09
Evenness J' per Sample
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004

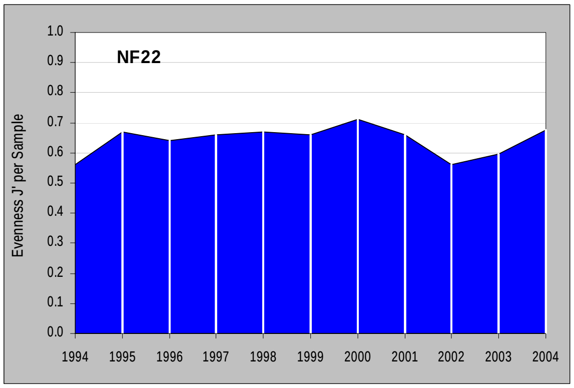

NF12
Evenness J' per Sample
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004

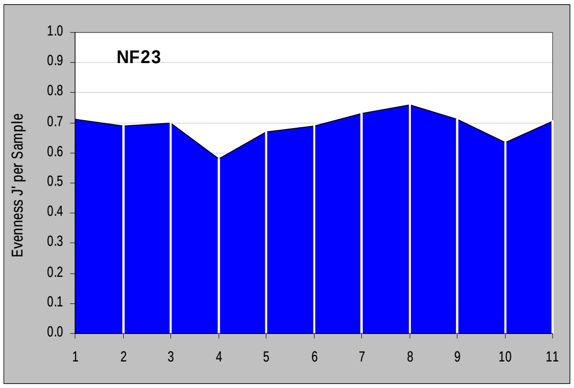

NF16
Evenness J' per Sample
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004

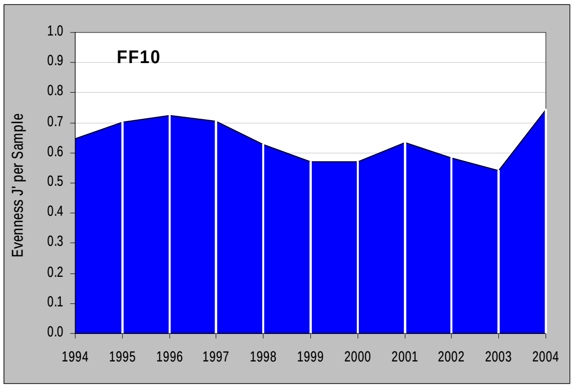

NF17
Evenness J' per Sample
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004

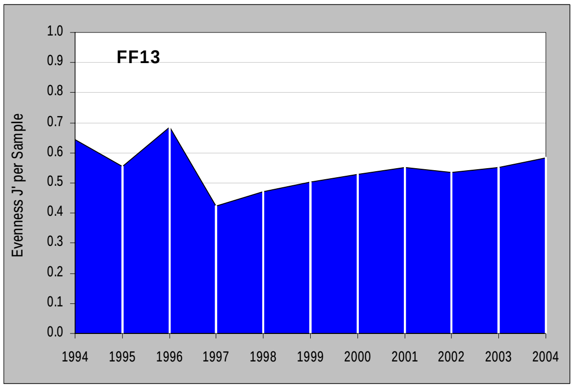

NF18
Evenness J' per Sample
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004

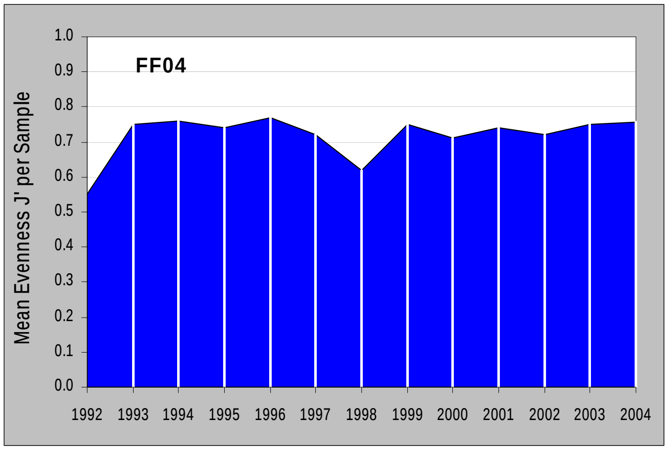

NF19
Evenness J' per Sample
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004

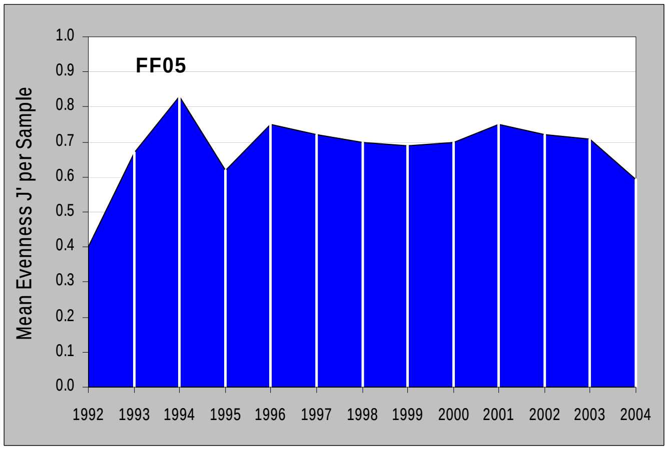

NF22
Evenness J' per Sample
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004

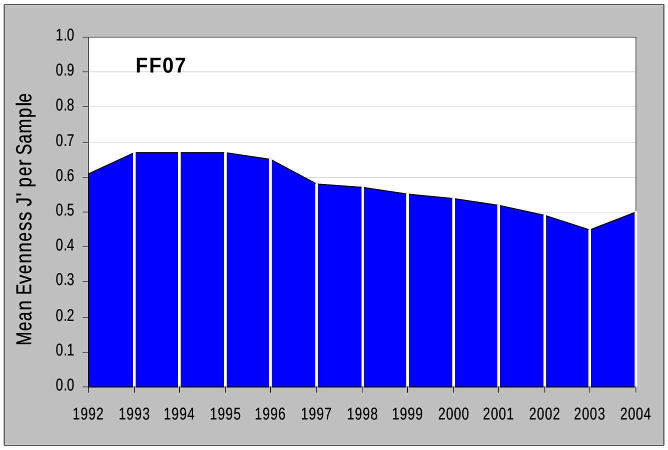

NF23
Evenness J' per Sample
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1
2
3
4
5
6
7
8
9
10
11


FF10
Evenness J' per Sample
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004


FF13
Evenness J' per Sample
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004


FF04
Mean Evenness J' per Sample
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004


FF05
Mean Evenness J' per Sample
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004


FF07
Mean Evenness J' per Sample
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004

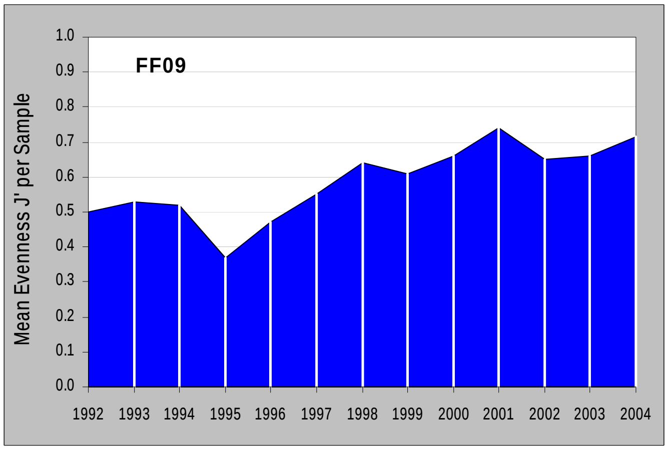
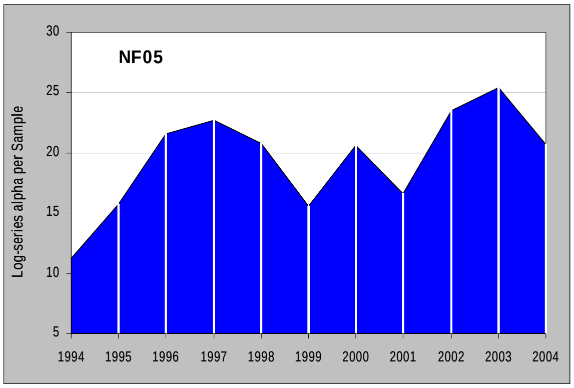
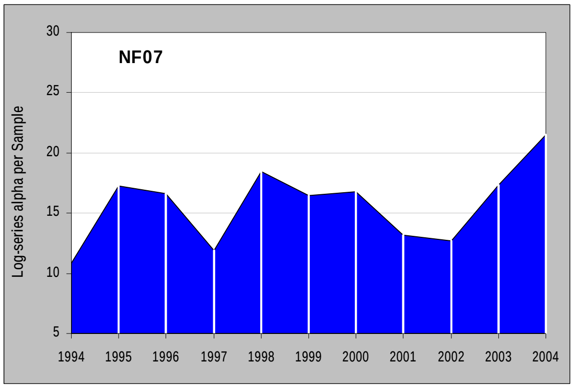
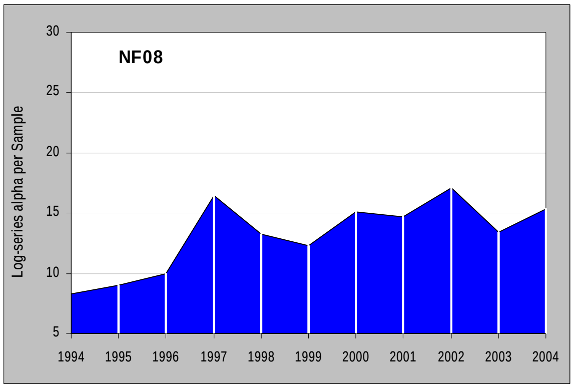

FF09
Mean Evenness J' per Sample
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004

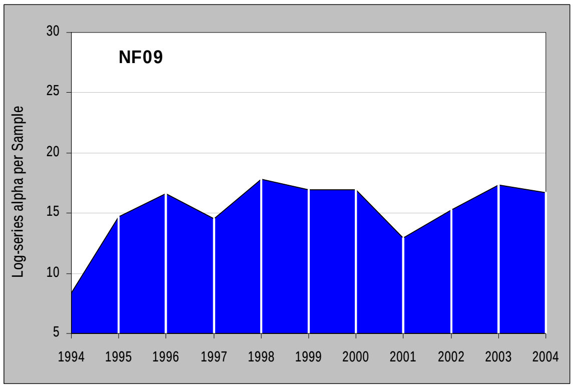
Figure C3-5

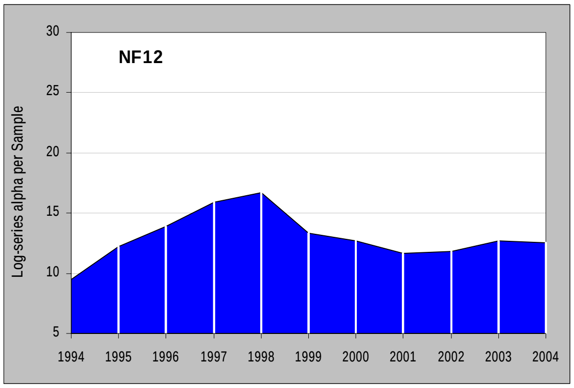
Log-series *Alpha* Charts for each NF and FF Massachusetts Bay Station 1992–2004

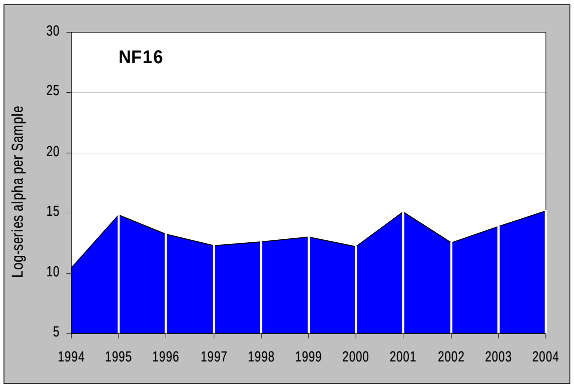

NF05
Log-series alpha per Sample
30
25
20
15
10
5
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004

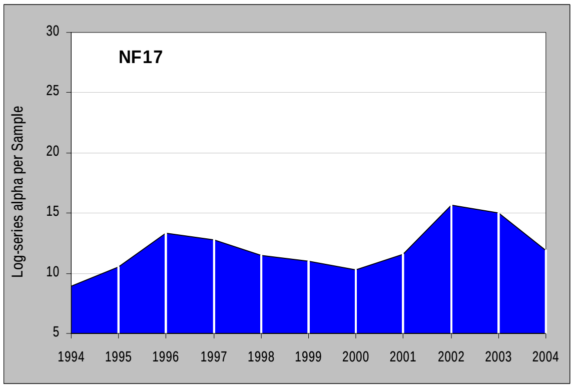

NF07
Log-series alpha per Sample
30
25
20
15
10
5
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004

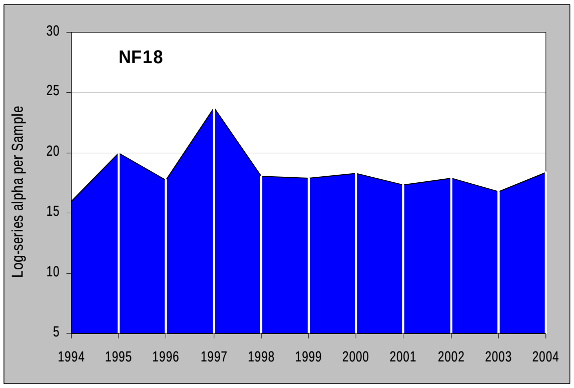

NF08
Log-series alpha per Sample
30
25
20
15
10
5
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004

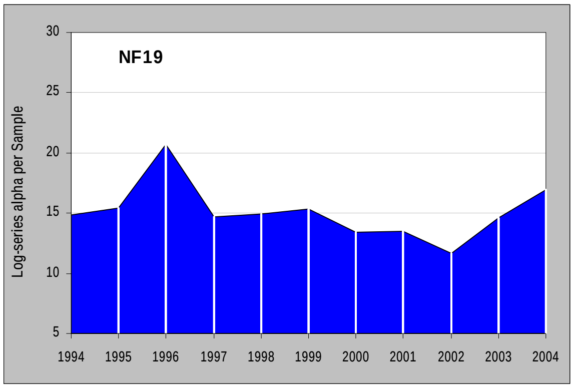

NF09
Log-series alpha per Sample
30
25
20
15
10
5
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004


NF12
Log-series alpha per Sample
30
25
20
15
10
5
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004


NF16
Log-series alpha per Sample
30
25
20
15
10
5
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004


NF17
Log-series alpha per Sample
30
25
20
15
10
5
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004


NF18
Log-series alpha per Sample
30
25
20
15
10
5
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004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Log-series alpha per Sample
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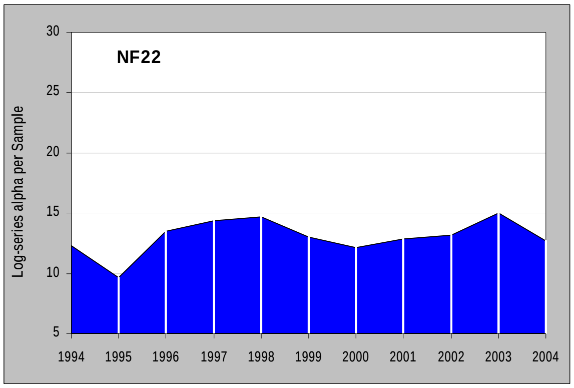
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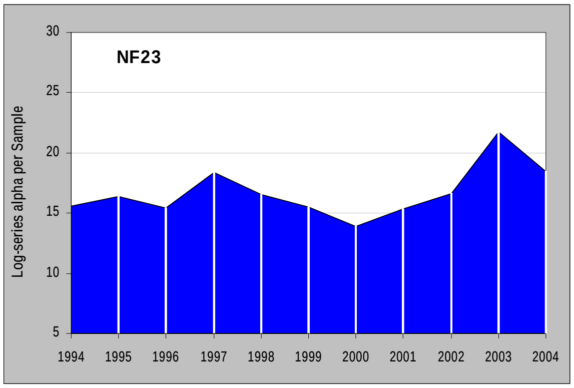
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Log-series alpha per Sample
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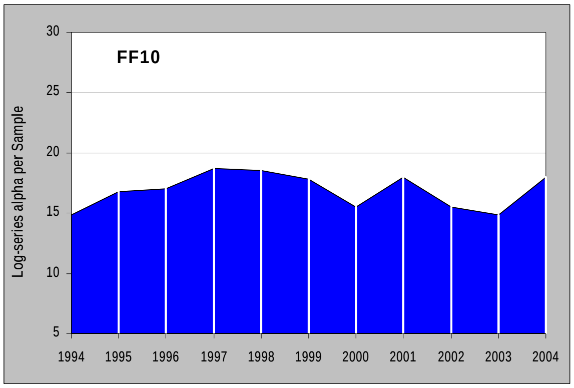
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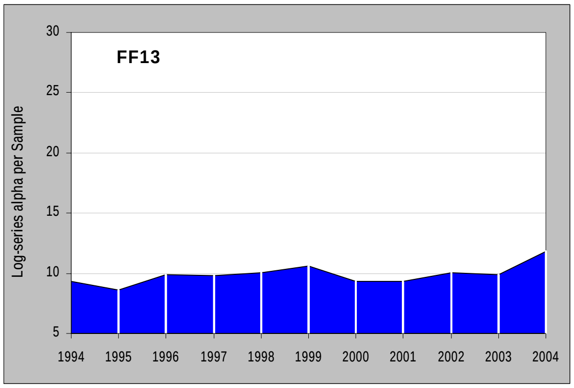
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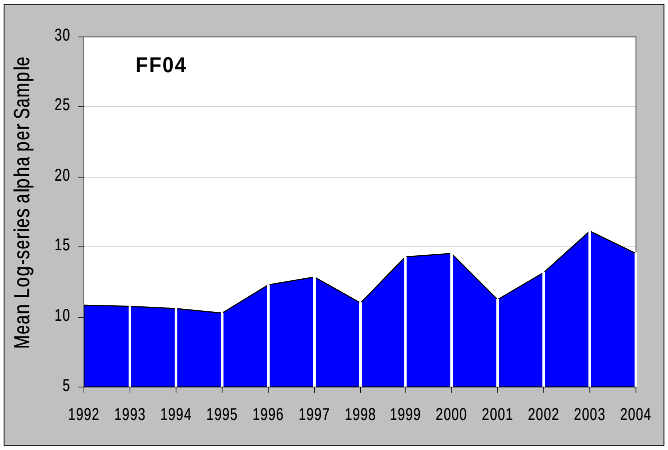
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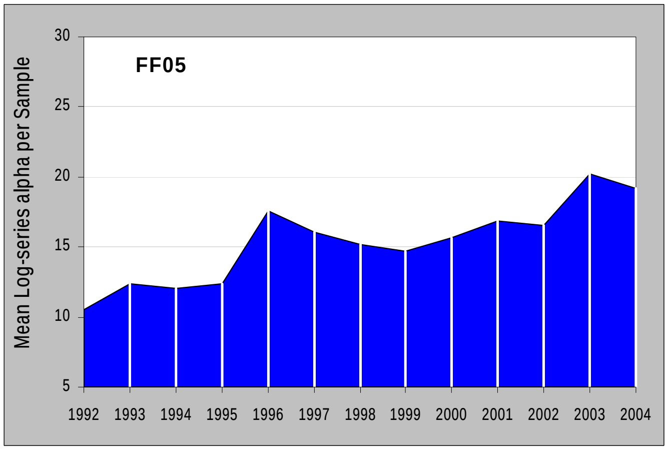
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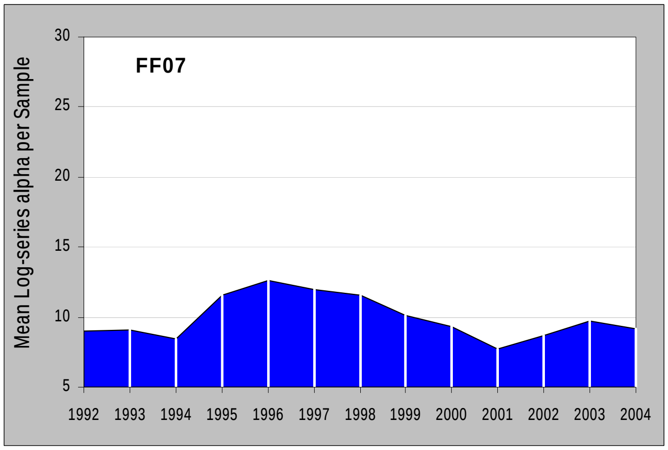
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Mean Log-series alpha per Sample
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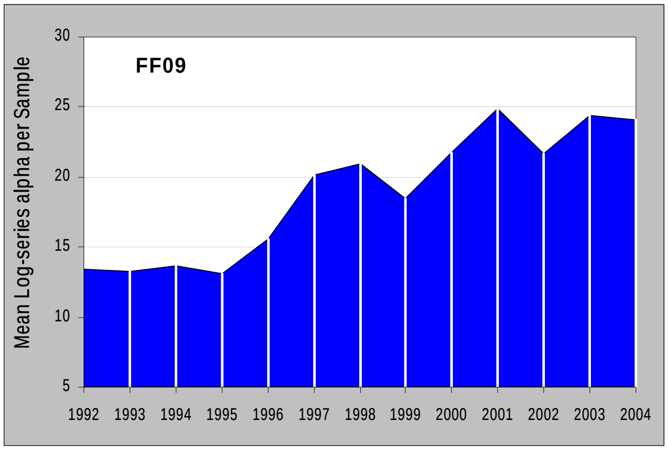
FF09
Mean Log-series alpha per Sample
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APPENDIX C4

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

Station	Rank	Species	Count	% Total	% Ident.	Cum % (Total)	Cum % (Ident.)	2003 Rank	2002 Rank	2001 Rank
NF 05	1	*Spio limicola*	416	23.4	24.0	23.4	24.0	2	8	20
	2	*Tharyx acutus*	199	11.2	11.5	34.6	35.5	5	5	4
	3	*Prionospio steenstrupi*	183	10.3	10.5	44.9	46.0	1	1	6
	4	*Levinsenia gracilis*	81	4.5	4.7	49.4	50.7	4	4	7
	5	*Mediomastus californiensis*	78	4.4	4.5	53.8	55.2	3	2	1
	6	*Ampharete baltica*	54	3.0	3.1	56.8	58.3	17	NP	NP
	7	*Nucula delphinodonta*	51	2.9	2.9	59.7	61.2	6	11	8
	8	*Aricidea catherinae*	45	2.5	2.6	62.2	63.8	11	14	17
	9	*Phoronis architecta*	41	2.3	2.4	64.5	66.2	8	23	23
	10	*Ninoe nigripes*	32	1.8	1.8	66.3	68.0	21	18	9
	11	*Monticellina dorsobranchialis*	29	1.6	1.7	67.9	69.7	27	8	13
	12	*Onoba pelagica*	28	1.6	1.6	69.5	71.3	15	13	24
	13	*Crenella decussata*	26	1.4	1.5	70.9	72.8	13	7	NP
	14	*Ampharete acutifrons*	25	1.4	1.4	72.3	74.2	29	13	27
	15	*Rhodine loveni*	23	1.3	1.3	73.6	75.5	NP	15	23
(No. Species)	(92)	Station Total Abundance	1781 (all) 1736 (ident)					(128)	(77)	(67)
NF 07	1	*Prionospio steenstrupi*	585	20.4	20.9	20.4	20.9	1	1	1
	2	*Pholoe minuta*	274	9.5	9.8	29.9	30.7	14	24	27
	3	*Exogone verugera*	257	8.9	9.2	38.8	39.9	23	14	6
	4	*Mediomastus californiensis*	244	8.5	8.7	47.3	48.6	3	3	3
	5	*Spio limicola*	125	4.3	4.5	51.6	53.1	2	2	2
	6	*Nereis grayi*	116	4.0	4.1	55.6	57.2	34	29	25
	7	*Tharyx acutus*	84	2.9	3.0	58.5	60.2	5	7	5
	8	*Parougia caeca*	78	2.7	2.8	61.2	63.0	13	19	19
	9	*Sphaerosyllis erinaceus*	65	2.3	2.3	63.5	65.3	30	NP	25
	10	*Ninoe nigripes*	63	2.2	2.3	65.7	67.6	11	11	12
	10	*Aphelochaeta marioni*	63	2.2	2.3	67.9	69.9	10	4	7
	11	*Eteone longa*	57	2.0	2.0	69.9	71.9	9	20	26
	12	*Levinsenia gracilis*	52	1.8	1.9	71.7	73.8	18	16	8
	13	*Euchone incolor*	42	1.5	1.5	73.2	75.3	31	8	9
	14	Micrura spp.	36	1.3	1.3	74.5	76.6	34	17	21
	15	*Ampharete baltica*	34	1.2	1.2	75.7	77.8	19	NP	NP
(No. Species)	(107)	Station Total Abundance	2872 (all) 2797 (ident.)					(109)	(72)	(68)

NP = Not present in sample.

NP = Not present in sample.

Station	**Rank**	**Species**	**Count**	**% Total**	**% Ident.**	**Cum % (Total)**	**Cum % (Ident.)**	**2003 Rank**	**2002 Rank**	**2001 Rank**
NF 08	1	*Mediomastus californiensis*	243	14.5	14.6	14.5	14.6	6	7	6
	2	*Ampharete baltica*	193	11.5	11.6	26.0	26.2	2	NP	NP
	3	*Tharyx acutus*	172	10.2	10.3	36.2	36.5	4	1	4
	4	*Levinsenia gracilis*	126	7.5	7.5	43.7	44.0	10	9	9
	5	*Monticellina baptisteae*	123	7.3	7.3	51.0	51.3	7	17	11
	6	*Nephtys incisa*	106	6.3	6.3	57.3	57.6	14	26	26
	6	*Ninoe nigripes*	106	6.3	6.3	63.6	63.9	8	8	13
	7	*Aricidea catherinae*	62	3.7	3.7	67.3	67.6	20	14	21
	8	*Prionospio steenstrupi*	61	3.6	3.7	70.9	71.3	1	2	3
	9	*Scoletoma hebes*	59	3.5	3.5	74.4	74.8	12	17	28
	10	*Spio limicola*	56	3.3	3.4	77.7	78.2	5	5	5
	11	*Trochochaeta multisetosa*	38	2.3	2.3	80.0	80.5	22	35	32
	12	*Leitoscoloplos acutus*	34	2.0	2.0	82.0	82.5	13	11	7
	13	*Nucula delphinodonta*	31	1.8	1.9	83.8	84.4	9	12	15
	14	*Aphelochaeta marioni*	30	1.8	1.8	85.6	86.2	17	3	1
	15	*Eteone longa*	26	1.6	1.6	87.2	87.8	19	23	29
(No. Species)	(72)	Station Total Abundance	1681 (all) 1670 (ident.)					(85)	(91)	(78)
NF 09	1	*Prionospio steenstrupi*	361	18.0	18.2	18.0	18.2	1	1	1
	2	*Ampharete baltica*	271	13.5	13.6	31.5	31.8	6	NP	NP
	3	*Mediomastus californiensis*	157	7.8	7.9	39.3	39.7	4	4	3
	4	*Spio limicola*	140	7.0	7.1	46.3	46.8	3	2	2
	5	*Nucula delphinodonta*	132	6.6	6.6	52.9	53.4	5	5	10
	6	*Tharyx acutus*	97	4.8	4.9	57.7	58.3	8	6	14
	7	*Ninoe nigripes*	74	3.7	3.7	61.4	62.0	10	7	9
	8	*Aricidea catherinae*	52	2.6	2.6	64.0	64.6	11	10	5
	9	*Leitoscoloplos acutus*	50	2.5	2.5	66.5	67.1	11	9	15
	10	*Levinsenia gracilis*	44	2.2	2.2	68.7	69.3	12	8	6
	11	*Monticellina baptisteae*	41	2.0	2.1	70.7	71.4	9	13	7
	12	*Scoletoma hebes*	36	1.8	1.8	72.5	73.2	19	18	32
	13	*Aphelochaeta marioni*	30	1.5	1.5	74.0	74.7	13	12	12
	14	*Onoba pelagica*	27	1.3	1.4	75.3	76.1	18	15	13
	15	*Nephtys incisa*	26	1.3	1.3	76.6	77.4	15	32	28
(No. Species)	(80)	Station Total Abundance	2009 (all) 1987 (ident.)					(108)	(77)	(62)

Station	Rank	Species	Count	% Total	% Ident.	Cum % (Total)	Cum % (Ident.)	2003Rank	2002 Rank	2001 Rank
NF 16	1	*Nephtys incisa*	526	28.3	28.6	28.3	28.6	12	27	22
	2	*Mediomastus californiensis*	266	14.3	14.4	42.6	43.0	3	3	2
	3	*Tharyx acutus*	214	11.5	11.6	54.1	54.6	2	2	3
	4	*Prionospio steenstrupi*	205	11.0	11.1	65.1	65.7	1	1	1
	5	*Levinsenia gracilis*	95	5.1	5.2	70.2	70.9	4	8	5
	6	*Ninoe nigripes*	69	3.7	3.8	73.9	74.7	5	9	4
	7	*Trochochaeta multisetosa*	35	1.9	1.9	75.8	76.6	20	31	NP
	8	*Parougia caeca*	34	1.8	1.8	77.6	78.4	6	15	9
	9	Tubificidae sp. 2	31	1.7	1.7	79.3	80.1	13	10	14
	10	*Eteone longa*	28	1.5	1.5	80.8	81.6	17	16	22
	11	*Arctica islandica*	20	1.1	1.1	81.9	82.7	27	29	21
	11	*Spio limicola*	20	1.1	1.1	83.0	83.8	8	5	10
	12	*Monticellina baptisteae*	18	1.0	1.0	84.0	84.8	10	16	14
	13	*Leitoscoloplos acutus*	16	0.9	0.9	84.9	85.7	9	7	6
	13	*Phyllodoce mucosa*	16	0.9	0.9	85.8	86.6	14	30	16
	13	*Scoletoma hebes*	16	0.9	0.9	86.7	87.5	19	20	20
	14	*Orchomenella minuta*	15	0.8	0.8	87.5	88.3	28	NP	21
	15	*Amphiporus caecus*	13	0.7	0.7	88.2	89.0	23	26	20
(No. Species)	(73)	Station Total Abundance	1855 (all) 1840 (ident.)					(84)	(74)	(65)
NF 18	1	*Prionospio steenstrupi*	459	26.5	27.5	26.5	27.4	1	1	2
	2	*Mediomastus californiensis*	152	8.8	9.1	35.3	36.5	4	4	3
	3	*Aricidea catherinae*	98	5.7	5.9	41.0	42.4	2	2	4
	4	*Nephtys incisa*	73	4.2	4.4	45.2	46.8	33	NP	NP
	4	*Tharyx acutus*	73	4.2	4.4	49.4	51.2	20	6	17
	5	*Ninoe nigripes*	53	3.1	3.2	52.5	54.4	6	10	18
	6	*Eteone longa*	52	3.0	3.1	55.5	57.5	13	21	29
	6	*Monticellina dorsobranchialis*	52	3.0	3.1	58.5	60.6	12	15	9
	7	*Ampharete baltica*	49	2.8	2.9	61.3	63.5	7	NP	NP
	8	*Levinsenia gracilis*	42	2.4	2.5	63.7	66.	14	11	15
	9	*Nucula delphinodonta*	40	2.3	2.4	66.0	68.4	8	8	14
	10	*Exogone hebes*	38	2.2	2.3	68.2	70.7	15	23	1
	10	*Ophelina acuminata*	38	2.2	2.3	70.4	73.0	26	26	30
	11	*Monticellina baptisteae*	37	2.1	2.2	72.5	75.2	NP	15	17
	12	*Molgula manhattensis*	34	2.0	2.0	74.5	77.2	NP	13	20
	13	*Spio limicola*	33	1.9	2.0	76.4	79.2	5	3	19
	14	Tubificidae sp. 2	28	1.6	1.7	78.0	80.9	19	21	28
	15	*Astarte undata*	24	1.4	1.4	79.4	82.3	16	12	5
	15	*Crenella decussata*	24	1.4	1.4	80.8	83.7	18	10	NP
(No. Species)	(83)	Station Total Abundance	1731 (all) 1671 (ident.)					(102)	(94)	(81)

NF 19	1	*Prionospio steenstrupi*	499	21.7	21.9	21.7	21.9	1	1	1
	2	*Tharyx acutus*	351	15.2	15.4	36.9	37.3	3	2	11
	3	*Mediomastus californiensis*	169	7.3	7.4	44.2	44.7	5	4	2
	4	*Aricidea catherinae*	161	7.0	7.1	51.2	51.8	4	5	6
	5	*Ampharete baltica*	119	5.2	5.2	56.4	57.0	27	NP	NP
	6	*Polygordius* sp. A	114	4.9	5.0	61.3	62.0	29	24	9
	7	*Arctica islandica*	95	4.1	4.2	65.4	66.2	12	14	25
	8	*Eteone longa*	71	3.1	3.1	68.5	69.3	11	18	20
	9	*Phyllodoce mucosa*	68	3.0	3.0	71.5	72.3	6	9	16
	10	*Nucula delphinodonta*	64	2.8	2.8	74.3	75.1	7	6	3
	11	*Exogone hebes*	48	2.1	2.1	76.4	77.2	10	8	8
	12	*Ninoe nigripes*	47	2.0	2.1	78.4	79.3	9	13	14
	13	*Molgula manhattensis*	46	2.0	2.0	80.4	81.3	32	7	21
	14	*Ampharete acutifrons*	37	1.6	1.6	82.0	82.9	30	20	26
	15	*Levinsenia gracilis*	27	1.2	1.2	83.2	84.1	24	17	24
(No. Species)	(83)	Station Total Abundance	2304 (all) 2278 (ident.)					(93)	(68)	(65)
NF 22	1	*Tharyx acutus*	318	20.8	20.9	20.8	20.9	1	2	2
	2	*Mediomastus californiensis*	305	19.9	20.0	40.7	40.9	3	3	1
	3	*Levinsenia gracilis*	134	8.8	8.8	49.5	49.7	5	5	7
	4	*Nephtys incisa*	105	6.8	6.9	56.3	56.6	18	25	18
	5	*Prionospio steenstrupi*	81	5.3	5.3	61.6	61.9	2	1	3
	6	*Monticellina baptisteae*	71	4.6	4.7	66.2	66.6	14	16	12
	7	*Ninoe nigripes*	69	4.5	4.5	70.7	71.1	8	9	8
	8	*Trochochaeta multisetosa*	58	3.8	3.8	74.5	74.9	26	NP	25
	9	*Parougia caeca*	57	3.7	3.8	78.2	78.7	6	11	10
	10	*Leitoscoloplos acutus*	30	2.0	2.0	80.2	80.7	11	6	5
	11	*Euchone incolor*	26	1.7	1.7	81.9	82.4	12	8	6
	12	*Spio limicola*	25	1.6	1.6	83.5	84.0	23	7	23
	12	Tubificidae sp. 2	25	1.6	1.6	85.1	85.6	4	4	4
	13	*Aricidea quadrilobata*	20	1.3	1.3	86.4	86.9	9	12	11
	14	*Monticellina dorsobranchialis*	19	1.2	1.2	87.6	88.1	19	17	25
	15	*Aphelochaeta marioni*	13	0.9	0.9	88.5	89.0	30	NP	NP
	15	*Apistobranchus typicus*	13	0.9	0.9	89.4	89.9	17	13	20
	15	*Eteone longa*	13	0.9	0.9	90.3	90.8	13	14	24
(No. Species)	(61)	Station Total Abundance	1530 (all) 1522 (ident.)					(98)	(73)	(61)

NP = Not present in sample.

Station	**Rank**	**Species**	**Count**	**% Total**	**% Ident.**	**Cum % (Total)**	**Cum % (Ident.)**	**2003 Rank**	**2002 Rank**	**2001 Rank**
NF 23	1	*Exogone hebes*	415	12.4	13.1	12.4	13.1	3	1	2
	2	*Polygordius* sp. A	364	10.8	11.4	23.2	24.5	15	22	8
	3	*Hiatella arctica*	320	9.5	10.1	32.7	34.6	21	11	27
	4	*Tharyx acutus*	291	8.7	9.2	41.4	43.8	14	23	18
	5	*Aricidea catherinae*	206	6.1	6.5	47.5	50.3	7	15	5
	6	*Enchytraeidae* sp. 1	193	5.8	6.1	53.3	56.4	8	6	3
	7	*Molgula manhattensis*	152	4.5	4.8	57.8	61.2	5	2	4
	8	*Spiophanes bombyx*	144	4.3	4.5	62.1	65.7	17	7	1
	9	*Prionospio steenstrupi*	130	3.9	4.1	66.0	69.8	2	14	10
	10	*Phoronis architecta*	87	2.6	2.7	68.6	72.5	1	NP	11
	11	*Cerastoderma pinnulatum*	79	2.4	2.5	71.0	75.0	31	22	18
	12	*Phyllodoce mucosa*	57	1.7	1.8	72.7	76.8	9	18	12
	13	*Chaetozone setosa* mb	54	1.6	1.7	74.3	78.5	12	20	9
	14	*Aphelochaeta marioni*	52	1.5	1.6	75.8	80.1	16	27	NP
	15	*Dipolydora socialis*	51	1.5	1.6	77.3	81.7	6	3	19
(No. Species)	(95)	Station Total Abundance	3358 (all) 3178 (ident.)					(121)	(77)	(69)

NP = Not present in sample.

NP = Not present in sample.

Station	Rank	Species	Mean	Std. Dev.	% Total	% Ident.	Cum % (Total)	Cum % (Ident.)	2003 Rank	2002 Rank	2001 Rank
NF 12	1	*Prionospio steenstrupi*	1071.0	199.5	42.5	43.9	42.5	43.9	1	1	1
	2	*Mediomastus californiensis*	262.7	110.2	10.4	10.8	52.9	54.7	2	3	2
	3	*Spio limicola*	153.7	8.6	6.1	6.3	59.0	61.0	6	4	3
	4	*Tharyx acutus*	118.3	42.2	4.7	4.8	63.7	65.8	3	2	4
	5	*Parougia caeca*	81.7	30.7	3.2	3.3	66.9	69.1	8	11	8
	6	*Leitoscoloplos acutus*	81.0	28.8	3.2	3.3	70.1	72.4	11	7	8
	7	*Levinsenia gracilis*	78.0	7.9	3.1	3.2	73.2	75.6	7	6	7
	8	*Ninoe nigripes*	72.0	29.8	2.9	3.0	76.1	78.6	10	9	10
	9	*Aphelochaeta marioni*	54.3	12.1	2.2	2.2	78.3	80.8	9	8	6
	10	*Aricidea catherinae*	51.7	15.4	2.0	2.1	80.3	82.9	4	5	5
	11	*Nephtys incisa*	41.0	59.8	1.6	1.7	81.9	84.6	21	38	24
	12	*Monticellina baptisteae*	35.7	9.3	1.4	1.5	83.3	86.1	12	12	15
	13	*Apistobranchus typicus*	32.3	9.3	1.3	1.3	84.6	87.4	22	21	22
	14	*Micrura* spp.	29.7	14.2	1.2	1.2	85.8	88.6	17	14	17
	14	*Nereis grayi*	29.7	7.5	1.2	1.2	87.0	89.8	44	44	38
	15	*Eteone longa*	28.3	5.1	1.1	1.2	88.1	91.0	13	18	26
(No. Species)	(92)	Station Mean Abundance	2522.0 (all) 2441.3 (ident.)						(118)	(98)	(89)
NF 17	1	*Molgula manhattensis*	260.3	96.7	26.6	27.4	26.6	27.4	21	1	1
	2	*Spiophanes bombyx*	81.3	16.0	8.3	8.6	34.9	36.0	6	2	3
	3	*C. crassicorne*	73.0	84.4	7.5	7.7	42.4	43.7	1	3	5
	4	*Ensis directus*	65.7	15.0	6.7	6.9	49.1	50.6	NP	39	NP
	5	*Hiatella arctica*	59.0	74.5	6.0	6.2	55.1	56.8	23	34	17
	6	*Polygordius* sp. A	58.7	29.5	6.0	6.2	61.1	63.0	16	8	4
	7	*Cerastoderma pinnulatum*	54.3	39.8	5.5	5.7	66.6	68.7	35	9	14
	8	*Exogone hebes*	44.7	18.5	4.6	4.7	71.2	73.4	3	6	2
	9	*Echinarachnius parma*	29.3	25.4	3.0	3.1	74.2	76.5	2	32	24
	10	*Phyllodoce mucosa*	20.3	3.5	2.1	2.1	76.3	78.6	4	14	11
	11	*Aglaophamus circinata*	14.7	3.5	1.5	1.6	77.8	80.2	13	23	24
	11	*Chaetozone setosa mb*	14.7	6.5	1.5	1.6	79.3	81.8	10	12	31
	12	*Phyllodoce maculata*	11.7	19.3	1.2	1.2	80.5	83.0	35	44	33
	13	*Cnemidocarpa mollis*	10.3	10.0	1.1	1.1	81.6	84.1	NP	NP	NP
	14	*Rhepoxynius hudsoni*	9.7	3.2	1.0	1.0	82.6	85.1	17	36	24
	15	*Hippomedon serratus*	8.7	9.9	0.9	0.9	83.5	86.0	29	36	28
(No. Species)	(76)	Station Mean Abundance	978.3 (all) 949.0 (ident.)						(112)	(104)	(85)

Station	Rank	Species	Mean	Std. Dev.	% Total	% Ident.	Cum % (Total)	Cum % (Ident.)	2003 Rank	2002 Rank	2001 Rank
FF 10	1	*Prionospio steenstrupi*	286.3	184.3	17.9	19.8	17.9	19.8	1	1	1
	2	*Nucula delphinodonta*	131.7	117.8	8.2	9.1	26.1	28.9	5	3	6
	3	*Mediomastus californiensis*	104.3	20.8	6.5	7.2	32.6	36.1	3	4	2
	4	*Aricidea catherinae*	81.7	3.2	5.1	5.7	37.7	41.8	2	2	2
	5	*Ninoe nigripes*	64.3	20.8	4.0	4.5	41.7	46.3	5	8	7
	5	*Scoletoma hebes*	64.3	44.7	4.0	4.5	45.7	50.8	4	6	13
	6	Tubificidae sp. 2	56.3	55.3	3.5	3.9	49.2	54.7	14	17	24
	7	*Spio limicola*	45.7	36.1	2.8	3.2	52.0	57.9	6	5	3
	8	*Arctica islandica*	45.3	14.4	2.8	3.1	54.8	61.0	26	21	45
	9	*Nephtys incisa*	44.7	73.0	2.8	3.1	57.6	64.1	24	44	41
	10	*Levinsenia gracilis*	43.0	4.4	2.7	3.0	60.3	67.1	11	13	9
	11	*Monticellina baptisteae*	42.3	26.1	2.6	2.9	62.9	70.0	8	14	4
	12	*Tharyx acutus*	34.7	15.1	2.2	2.4	65.1	72.4	10	9	12
	13	*Parougia caeca*	25.0	2.6	1.6	1.7	66.7	74.1	20	32	23
	14	*Thyasira gouldi*	21.7	9.9	1.4	1.5	68.1	75.6	18	27	31
	15	*Ampharete baltica*	19.3	24.6	1.2	1.3	69.3	76.9	9	NP	NP
(No. Species)	(109)	Station Mean Abundance	1601.7 (all) 1443.7 (ident.)						(125)	(109)	(124)
FF 13	1	*Aricidea catherinae*	754.7	210.9	28.9	29.9	28.9	29.9	3	3	3
	2	*Mediomastus californiensis*	497.3	6.8	19.1	19.7	48.0	49.6	2	4	4
	3	*Prionospio steenstrupi*	300.0	74.0	11.5	11.9	59.5	61.5	1	1	5
	4	*Scoletoma hebes*	255.3	18.4	9.8	10.1	69.3	71.6	4	10	12
	5	*Ninoe nigripes*	95.3	35.3	3.7	3.8	73.0	75.4	12	16	21
	6	*Tubificoides apectinatus*	81.0	36.9	3.1	3.2	76.1	78.6	10	11	8
	7	*Eteone longa*	67.7	19.9	2.6	2.6	78.7	81.2	13	7	20
	8	*Phyllodoce mucosa*	46.0	12.2	1.8	1.8	80.5	83.0	8	9	7
	9	*Tharyx acutus*	45.3	15.3	1.7	1.8	82.2	84.8	11	2	1
	10	*Monticellina baptisteae*	45.0	11.8	1.7	1.8	83.9	86.6	5	13	12
	11	Nemertea sp. 12	34.7	8.4	1.3	1.4	85.2	88.0	6	17	14
	12	*Leitoscoloplos acutus*	31.7	7.2	1.2	1.2	86.4	89.2	9	6	9
	13	*Levinsenia gracilis*	26.7	4.9	1.0	1.1	87.4	90.3	29	33	32
	14	Tubificidae sp. 2	26.0	21.8	1.0	1.0	88.4	91.3	19	19	17
	15	*Phoronis architecta*	24.7	16.3	0.9	1.0	89.3	92.3	7	8	6
(No. Species)	(89)	Station Mean Abundance	2610.3 (all) 2525.3 (ident.)						(95)	(88)	(75)

NP = Not present in sample.

NP = Not present in sample.

Station	Rank	Species	Mean	Std. Dev.	% Total	% Ident.	Cum % (Total)	Cum % (Ident.)	2003 Rank	2002 Rank	2001 Rank
FF04	1	*Spio limicola*	196.3	68.6	15.3	15.4	15.3	15.4	6	8	24
	2	*Cossura longocirrata*	99.3	8.7	7.8	7.8	23.1	23.2	3	1	1
	3	*Tubificoides apectinatus*	95.0	31.6	7.4	7.4	30.5	30.6	5	5	7
	4	*Chaetozone setosa mb*	94.0	25.1	7.3	7.4	37.8	38.0	1	3	2
	5	*Aricidea quadrilobata*	77.3	34.3	6.0	6.1	43.8	44.1	2	2	6
	6	*Levinsenia gracilis*	76.0	17.5	5.9	6.0	49.7	50.1	4	6	4
	7	*Paramphinome jeffreysii*	72.3	85.2	5.6	5.7	55.3	55.8	11	12	5
	8	*Dentalium entale*	67.0	22.9	5.2	5.3	60.5	61.1	12	15	12
	9	*Syllides longocirrata*	66.0	9.0	5.2	5.2	65.7	66.3	10	7	8
	10	*Aphelochaeta marioni*	44.3	3.5	3.5	3.5	69.2	69.8	9	10	9
	11	*Thyasira gouldi*	40.3	19.4	3.1	3.2	72.3	73.0	13	13	16
	12	Nemertea sp. 12	38.0	14.4	3.0	3.0	75.3	76.0	14	19	14
	13	*Anobothrus gracilis*	35.7	19.7	2.8	2.8	78.1	78.8	8	4	3
	14	*Tubulanus pellucidus*	26.7	0.6	2.1	2.1	80.2	80.9	17	16	15
	15	*Mediomastus californiensis*	15.0	2.0	1.2	1.2	81.4	82.1	15	14	10
(No. Species)	(88)	Station Mean Abundance	2181.7 (all) 1271.3 (ident.)						(121)	(86)	(71)
FF05	1	*Spio limicola*	786.0	113.6	32.2	33.0	32.2	33.0	1	3	4
	2	*Anobothrus gracilis*	473.7	59.8	19.4	19.9	51.6	52.9	4	1	3
	3	*Prionospio steenstrupi*	132.3	26.8	5.4	5.6	57.0	58.5	3	2	7
	4	*Aricidea quadrilobata*	131.0	18.7	5.4	5.5	62.4	64.0	2	5	1
	5	*Levinsenia gracilis*	120.3	13.8	4.9	5.1	67.3	69.1	5	6	5
	6	*Thyasira gouldi*	70.0	16.1	2.9	2.9	70.2	72.0	8	9	11
	7	*Chaetozone setosa* mb	52.7	10.5	2.2	2.2	72.4	74.2	6	4	9
	8	*Mediomastus californiensis*	47.7	11.2	1.9	2.0	74.3	76.2	9	8	6
	9	*Proclea* sp. 1	31.7	13.8	1.3	1.3	75.6	77.5	NP	NP	NP
	10	*Cossura longocirrata*	29.3	4.7	1.2	1.2	76.8	78.7	7	7	10
	11	Nemertea sp. 12	27.3	5.7	1.1	1.1	77.9	79.8	14	15	20
	12	*Ninoe nigripes*	26.0	2.6	1.1	1.1	79.0	80.9	23	26	24
	13	*Terebellides atlantis*	23.0	4.6	1.0	1.0	80.0	81.9	12	17	37
	14	*Galathowenia oculata*	21.7	9.0	0.9	0.9	80.9	82.8	20	11	14
	15	*Nephtys incisa*	21.3	6.4	0.9	0.9	81.8	83.7	43	35	40
(No. Species)	(126)	Station Mean Abundance	2437.0 (all) 2376.3 (ident.)						(159)	(108)	(98)

Station	Rank	Species	Mean	Std. Dev.	% Total	% Ident.	Cum % (Total)	Cum % (Ident.)	2003 Rank	2002 Rank	2001 Rank
FF07	1	*Cossura longocirrata*	1982.7	646.8	39.6	40.0	39.6	40.0	1	1	1
	2	*Euchone incolor*	1155.0	830.1	23.1	23.2	62.7	63.2	2	2	2
	3	*Aricidea catherinae*	505.0	105.7	10.1	10.2	72.8	73.4	3	3	3
	4	*Aricidea quadrilobata*	271.0	122.1	5.4	5.4	78.2	78.8	5	8	6
	5	Tubificidae sp. 2	175.0	42.0	3.5	3.5	81.7	82.3	9	5	7
	6	*Ninoe nigripes*	152.7	13.6	3.1	3.1	84.8	85.4	6	7	9
	7	*Mediomastus californiensis*	145.3	25.8	2.9	2.9	87.7	88.3	7	4	4
	8	*Spio limicola*	78.7	14.3	1.6	1.6	89.3	89.9	13	15	16
	9	*Prionospio steenstrupi*	70.0	20.1	1.4	1.4	90.7	91.3	4	6	10
	10	*Parougia caeca*	67.7	26.0	1.4	1.4	92.1	92.7	10	10	11
	11	*Metopella angusta*	55.0	13.9	1.1	1.1	93.2	93.8	15	16	33
	12	*Levinsenia gracilis*	28.3	4.7	0.6	0.6	93.8	94.4	18	11	14
	13	*Sphaerodoridium* sp. A	24.0	26.1	0.5	0.5	94.3	94.9	21	28	23
	14	*Tharyx acutus*	22.7	6.7	0.4	0.4	94.7	95.4	8	9	8
	15	*Nephtys incisa*	21.7	7.2	0.4	0.4	95.1	95.8	16	12	28
(No. Species)	(82)	Station Mean Abundance	5001.7 (all) 4962.0 (ident.)						(96)	(69)	(64)
FF09	1	*Prionospio steenstrupi*	441.7	41.0	23.5	24.3	23.5	24.3	1	1	1
	2	*Anobothrus gracilis*	174.3	87.0	9.3	9.6	32.8	33.9	2	3	3
	3	*Levinsenia gracilis*	128.3	25.4	6.8	7.1	39.6	41.0	3	4	5
	4	*Nucula delphinodonta*	112.0	18.7	6.0	6.2	45.6	47.2	5	5	4
	5	*Thyasira gouldi*	61.7	0.6	3.3	3.4	48.9	50.6	6	6	6
	6	*Crenella decussata*	55.0	44.8	3.0	3.0	51.9	53.6	11	16	NP
	7	*Aricidea quadrilobata*	45.0	5.2	2.4	2.5	54.3	56.1	8	7	7
	8	*Phoronis architecta*	42.0	25.5	2.2	2.3	56.5	58.4	7	15	13
	9	*Mediomastus californiensis*	40.7	8.3	2.2	2.2	58.7	60.6	10	8	8
	10	*Periploma papyratium*	34.7	6.8	1.8	1.9	60.5	62.5	14	13	NP
	11	Nemertea sp. 12	33.0	15.7	1.7	1.8	62.2	64.3	16	22	14
	12	*Spio limicola*	29.7	12.7	1.6	1.6	63.8	65.9	12	25	47
	13	*Microclymene* sp.1	27.0	10.0	1.4	1.5	65.2	67.4	9	9	10
	14	*Nephtys incisa*	26.7	17.6	1.4	1.5	66.6	68.9	20	31	48
	15	*Parougia caeca*	23.0	6.6	1.2	1.2	67.8	70.1	17	12	16
(No. Species)	(145)	Station Mean Abundance	1880.3 (all) 1817.3 (ident.)						(185)	(134)	(133)

NP = Not present in sample.

APPENDIX C5

Analysis of Dominant Infaunal Species

Analysis of Numerically Dominant Species 1992–2004

by Isabelle P. Williams

An analysis of the dominant infauna at the 13 nearfield and four farfield stations sampled in 2004 over the 13-year (1992–2004) monitoring period is presented in this appendix. This discussion focuses on those species that were the numerical dominants (*i.e.*, ranking first, second, or third) at each station during at least one year of the survey.

Nearfield Stations

A tally of the mean numbers of individuals belonging to the most abundant species at each station revealed that a great number of species (38) filled these top-ranking positions. Some species were found to be abundant at a given station only once or twice, with the result that their overall rank at that station was as low as twelfth. Such an extreme example was the oligochaete Enchytraeidae sp.1 at Station NF23, where it was the numerical dominant in 1995 but was only the twelfth most abundant species at that station over all 13 years of the monitoring program. Data and graphs are therefore provided for the 12 most abundant species at all stations. In addition, the rank order of those species ranking first, second, or third in terms of abundance by station and by year are tabulated and discussed.

Summary Table C5-1 lists all of the 12 most abundant species from the 13 nearfield stations discussed here and the stations where they were numerically dominant. To explore how those species that ranked first, second, or third at least once during the program compared to all nearfield species, station mean totals for each species were ordered by decreasing abundance and ranked as given in Table C5-2 (table was truncated after all top 38 species were included). The resultant overall nearfield ranks showed, for example, that the 14 most abundant species found in the nearfield were among the 38 top dominant species, but that, conversely, the least abundant species to hold high rank, the isopod *Chiridotea tuftsi*, which was the second most abundant animal found at Station NF17 in 1993 and which ranked twelfth in numbers at Station NF17, was only seventy-fourth among all nearfield species combined. As another example, the polychaete *Spio limicola*, the third most abundant species when numbers from all 13 stations were totaled, ranked from second to seventh at ten stations but was absent from the top 12 dominant species list at three stations.

Table C5-1. Taxa that comprise the top 12 dominant taxa occurring at the 13 nearfield stations sampled in 2004 during the sampling program from 1992 through 2004. A total of 38 nearfield taxa had mean counts ranking first, second, or third at least once; six taxa appeared on the top 12 dominants list at one or more stations but were never among the top three most abundant species.

Top 12 Taxa (all stations, all years)	Stations where species ranked 1, 2, or 3													Total Number Stations
	FF10	FF13	NF05	NF07	NF08	NF09	NF12	NF16	NF17	NF18	NF19	NF22	NF23	
Prionospio steenstrupi														12
Mediomastus californiensis														11
Spio limicola														10
Dipolydora socialis														9
Tharyx acutus														7
Aricidea catherinae														7
Ninoe nigripes														5
Aphelochaeta marioni														5
Exogone hebes														5
Euchone incolor														4
Exogone verugera														4
Phoronis architecta														4
Levinsenia gracilis														3
Nucula delphinodonta														3
Monticellina baptisteae														2
Crassicorophium crassicorne														2
Molgula manhattensis														2
Unciola inermis														2
Spiophanes bombyx														2
Polygordius sp. A														2
Hiatella arctica														2
Photis pollex														1
Protomedeia fasciata														1
Enchytraeidae sp. 1														1
Pseudunciola obliquua														1
Dipolydora quadrilobata														1
Nephtys cornuta														1
Polydora sp. 1														1
Asabellides oculata														1
Nephtys incisa														1
Ampharete acutifrons														1
Pholoe minuta														1
Haploops fundiensis														1
Crenella decussata														1
Tubificidae sp. 2														1
Cerastoderma pinnulatum														1
Echinarachnius parma														1
Chiridotea tuftsi														1
Leitoscoloplos acutus														0
Phyllodoce mucosa														0
Scoletoma hebes														0
Maldane sarsi														0
Parougia caeca														0
Ampelisca abdita														0

Table C5-2. Nearfield species ranked by station mean total to include all 38 species (in bold font below) ranking first, second, or third during at least one of the 13 sampling years at all 13 nearfield stations sampled in 2004. For each species, the station mean total is the sum for all 13 stations, of the total number or animals collected at each station over all years of sampling divided by the total number of samples collected at each station.

Taxon	Number of Individuals	Overall	Taxon	Number of Individuals	Overall
	Station Mean Totals	NF Rank		Station Mean Totals	NF Rank
Prionospio steenstrupi	6773	1	*Micrura* spp.	122	38
Mediomastus californiensis	2735	2	*Astarte undata*	122	39
Spio limicola	2211	3	*Scoletoma hebes*	122	40
Tharyx acutus	1711	4	**Enchytraeidae sp. 1**	114	41
Aricidea catherinae	1567	5	*Capitella capitata* complex	103	42
Dipolydora socialis	1091	6	Nemertea sp. 12	98	43
Ninoe nigripes	757	7	*Edotia montosa*	89	44
Aphelochaeta marioni	680	8	*Arctica islandica*	87	45
Exogone hebes	657	9	***Nephtys cornuta***	86	46
Levinsenia gracilis	558	10	*Owenia fusiformis*	85	47
Nucula delphinodonta	540	11	*Maldane sarsi*	84	48
Euchone incolor	535	12	***Pseudunciola obliquua***	83	49
Exogone verugera	521	13	*Metopella angusta*	77	50
Monticellina baptisteae	468	14	**_Polydora_ sp. 1**	71	51
Leitoscoloplos acutus	413	15	*Tubificoides apectinatus*	69	52
Phoronis architecta	406	16	*Ericthonius fasciatus*	69	53
Crassicorophium crassicorne	378	17	*Thyasira gouldi*	68	54
Phyllodoce mucosa	260	18	*Crenella glandula*	66	55
Spiophanes bombyx	240	19	*Amphiporus caecus*	56	56
Molgula manhattensis	237	20	*Aglaophamus circinata*	55	57
Parougia caeca	229	21	*Aricidea quadrilobata*	54	58
Polygordius sp. A	212	22	***Haploops fundiensis***	51	59
Hiatella arctica	212	23	*Dyopedos monacanthus*	51	60
Unciola inermis	201	24	*Nereis grayi*	49	61
Photis pollex	194	25	*Harpinia propinqua*	48	62
Crenella decussata	179	26	*Chaetozone setosa mb*	48	63
Protomedeia fasciata	173	27	*Euclymene collaris*	47	64
Ampharete acutifrons	168	28	***Echinarachnius parma***	46	65
Pholoe minuta	164	29	*Anobothrus gracilis*	46	66
Cerastoderma pinnulatum	160	30	*Pleurogonium rubicundum*	44	67
Nephtys incisa	155	31	*Stenopleustes inermis*	42	68
Asabellides oculata	146	32	*Trochochaeta multisetosa*	40	69
Eteone longa	146	33	*Ceriantheopsis americanus*	37	70
Monticellina dorsobranchialis	132	34	*Argissa hamatipes*	35	71
Tubificidae sp. 2	130	35	*Ampelisca abdita*	31	72
Dipolydora quadrilobata	126	36	*Clymenella torquata*	24	73
Ampharete baltica	123	37	***Chiridotea tuftsi***	19	74

FF10

Station FF10 has been sampled in triplicate every August since 1992, for a total of 39 samples. The numerically dominant species at Station FF10 were the most consistent of any nearfield or farfield station sampled in 2004, with only six species (Table C5-3) ranking first (only two species), second, or third over the 13-year sampling period. The 12 most abundant taxa (more than 1400 specimens each) included 11 polychaetes and one bivalve. The mean abundance of these species are tabulated and plotted for each year (Table C5-4, Figure C5-1).

Prionospio steenstrupi was the most numerically abundant species with three times as many individuals found than for the second most common species. *P. steenstrupi* consistently ranked second (1992–1994) or first (1995–2004), while the second most abundant spionid polychaete, *Spio limicola*, ranked first during the three years that *P. steenstrupi* ranked second and ranked second or third during three additional years. *Mediomastus californiensis,* which was the third most abundant species at Station FF10, was the second top dominant in the nearfield overall and, indeed, at 4 of the 13 stations examined here. At Station FF10, *M. californiensis* ranked second (tying with *P. steenstrupi* in 1994) or third in 10 of the 13 years of monitoring. *Aricidea catherinae* ranked second for six years (tying with *M. californiensis* in 2001) and a third spionid polychaete, *Dipolydora socialis,* ranked third in 1992 only. The small protobranch bivalve, *Nucula delphinodonta*, ranked third three times and second once, in 2004.

Table C5-3. Annual rank of numerically dominant species at FF10. For overall NF rank, species were ordered by the means of all 13 stations totaled for all years.

Taxon	Annual Numerical Rank													
	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	Overall NF Rank
Prionospio steenstrupi	2	2	2	1	1	1	1	1	1	1	1	1	1	1
Mediomastus californiensis		3	2	2	3		3	3	2	2		3	3	2
Spio limicola	1	1	1	3	2					3				3
Aricidea catherinae						2	2	2	3	2	2	2		5
Dipolydora socialis	3													6
Nucula delphinodonta			3			3					3		2	11

Table C5-4. Mean number of individuals (n=3 for all years) belonging to the 12 most abundant species found in samples collected from FF10 from 1992 through 2004. Taxa are listed in order of decreasing mean abundance.

Taxon	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Prionospio steenstrupi	342	186	243	405	335	630	901	1142	825	553	981	1037	286
Spio limicola	687	271	912	141	251	127	21	15	9	71	75	53	46
Mediomastus californiensis	305	88	242	199	152	161	167	125	132	132	130	147	104
Aricidea catherinae	74	48	71	52	118	206	245	168	119	132	244	318	82
Nucula delphinodonta	278	59	152	117	127	186	156	44	69	30	161	57	132
Monticellina baptisteae	111	74	87	120	106	92	106	39	53	39	25	46	42
Ninoe nigripes	97	77	63	64	106	127	87	48	53	28	42	57	64
Tharyx acutus	108	50	55	10	83	124	67	30	12	19	36	39	35
Dipolydora socialis	313	41	98	5	39	79	9	12	3	14	7	1	1
Exogone verugera	112	32	52	63	29	26	41	98	77	17	6	5	1
Aphelochaeta marioni	86	42	77	19	127	37	41	22	7	10	4	6	18
Dipolydora quadrilobata	291	43	76	35	15	16	0	1	0	6	0	0	0

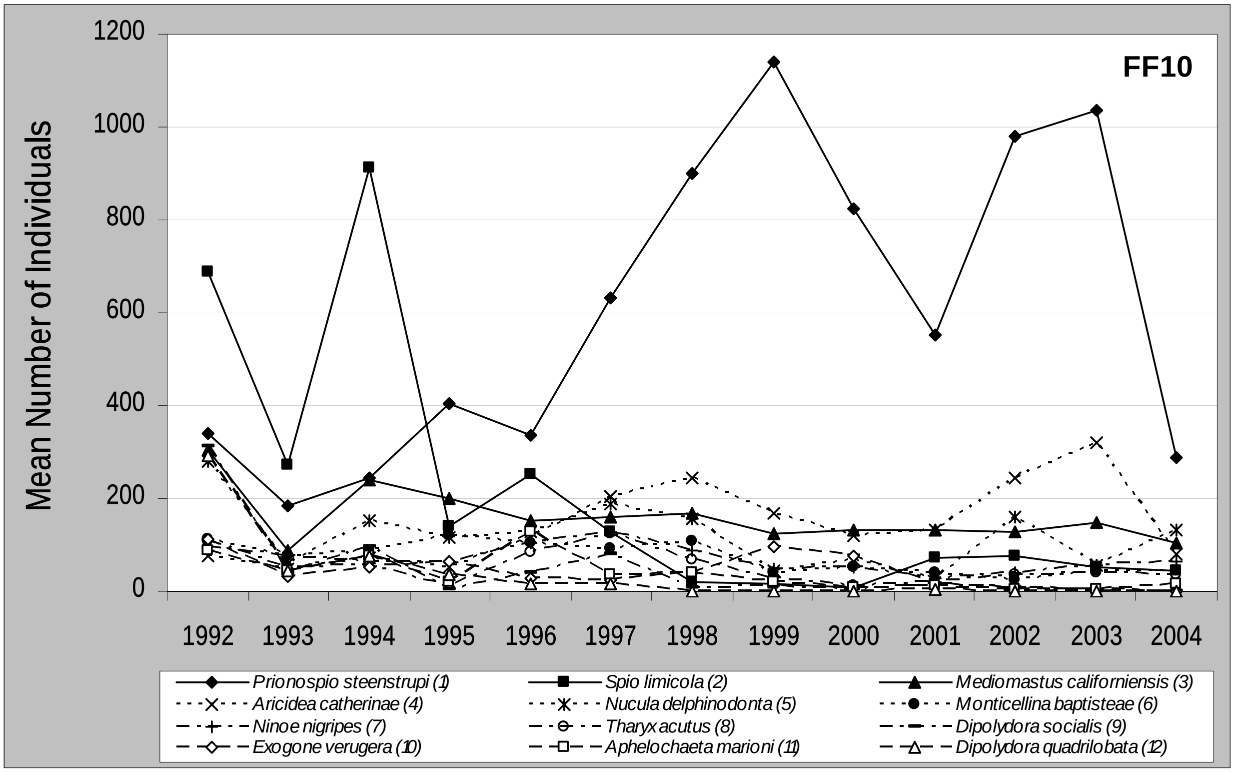

Figure C5-1. Mean number of individuals (n=3 for all years) belonging to the 12 most abundant species at FF10 from 1992 through 2004. The station rank order of each species follows the species name.

FF13

Station FF13 has been sampled in triplicate every August since 1992, for a total of 39 samples. Station FF13 was nearly as consistent as Station FF10 in species composition of numerically dominant species, with only seven species (including three that ranked high at FF10) achieving high relative abundance over the 13-year sampling period (Table C5-5). The 12 most abundant taxa (more than 1100 specimens each) included nine polychaetes, two amphipods, and one phoronid. The mean abundance of these species are tabulated and plotted for each year (Table C5-6, Figure C5-2.)

As at Station FF10, *Prionospio steenstrupi* and *Mediomastus californiensis* ranked first and third, respectively; at both stations, *P. steenstrupi* abundance was nearly triple that of the second most abundant species, *Spio limicola* at Station FF10 and the paraonid polychaete *Aricidea catherinae* at Station FF13. *P. steenstrupi* was the most abundant species for 10 of the 13 years of monitoring, and the paraonid polychaete *Aricidea catherinae* ranked first in 2004 as well as second or third for an additional seven years of monitoring. *M. californiensis* never was the most abundant species, but ranked second or third for nine years evenly spread throughout the monitoring period. The fourth most abundant species was the cirratulid polychaete *Tharyx acutus*, which ranked first in 1993 and 2001 and second or third during an additional three years. The three remaining species included the phoronid *Phoronis architecta*, which ranked third in 1996; the polychaete *Nephtys cornuta*, which ranked second in 1996 and third for an additional three years (tying with *M. californiensis* in 1993); and the amphipod *Photis pollex*, which ranked second in 1997 and 2001. Although *P. pollex* only ranked twenty-fifth overall in the nearfield, this small amphipod ranked sixth in abundance at Station FF13, the only station where it was a numerically dominant species.

Table C5-5. Annual rank of numerically dominant species at FF13. For overall NF rank, species were ordered by the means of all 13 stations totaled for all years.

	Annual Numerical Rank													
Taxon	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**Overall NF Rank**
Prionospio steenstrupi	1		1	1	1	1	1	1	1		1	1	3	1
Mediomastus californiensis	2	3	2	2		3		3	2			2	2	2
Tharyx acutus	3	1							3	1	2			4
Aricidea catherinae		2	3				2	2		3	3	3	1	5
Phoronis architecta					3									16
Photis pollex						2				2				25
Nephtys cornuta		3		3	2		3							46

Table C5-6. Mean number of individuals (n=3 for all years) belonging to the 12 most abundant species found in samples collected from FF13 from 1992 through 2004. Taxa are listed in order of decreasing total mean abundance at this station.

Taxon	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Prionospio steenstrupi	233	57	395	459	492	2630	1544	1120	1492	410	1702	1160	300
Aricidea catherinae	21	236	150	26	92	57	477	160	358	504	886	345	755
Mediomastus californiensis	140	125	319	152	150	149	141	151	507	456	663	582	497
Tharyx acutus	109	452	72	36	127	125	227	50	462	851	1205	45	45
Photis pollex	37	6	9	4	190	229	33	93	394	583	36	1	2
Nephtys cornuta	44	126	83	114	315	0	279	6	2	0	9	2	2
Phoronis architecta	7	1	13	12	222	75	7	7	19	382	99	72	25
Scoletoma hebes	2	20	19	9	51	17	54	55	26	16	85	201	255
Phyllodoce mucosa	36	99	57	17	52	53	58	18	33	145	86	71	46
Leitoscoloplos acutus	14	66	101	28	86	46	25	15	64	40	133	50	32
Ampelisca abdita	17	11	10	20	147	68	18	14	82	12	0	3	1
Dipolydora socialis	0	0	1	1	8	10	1	5	34	28	274	4	4

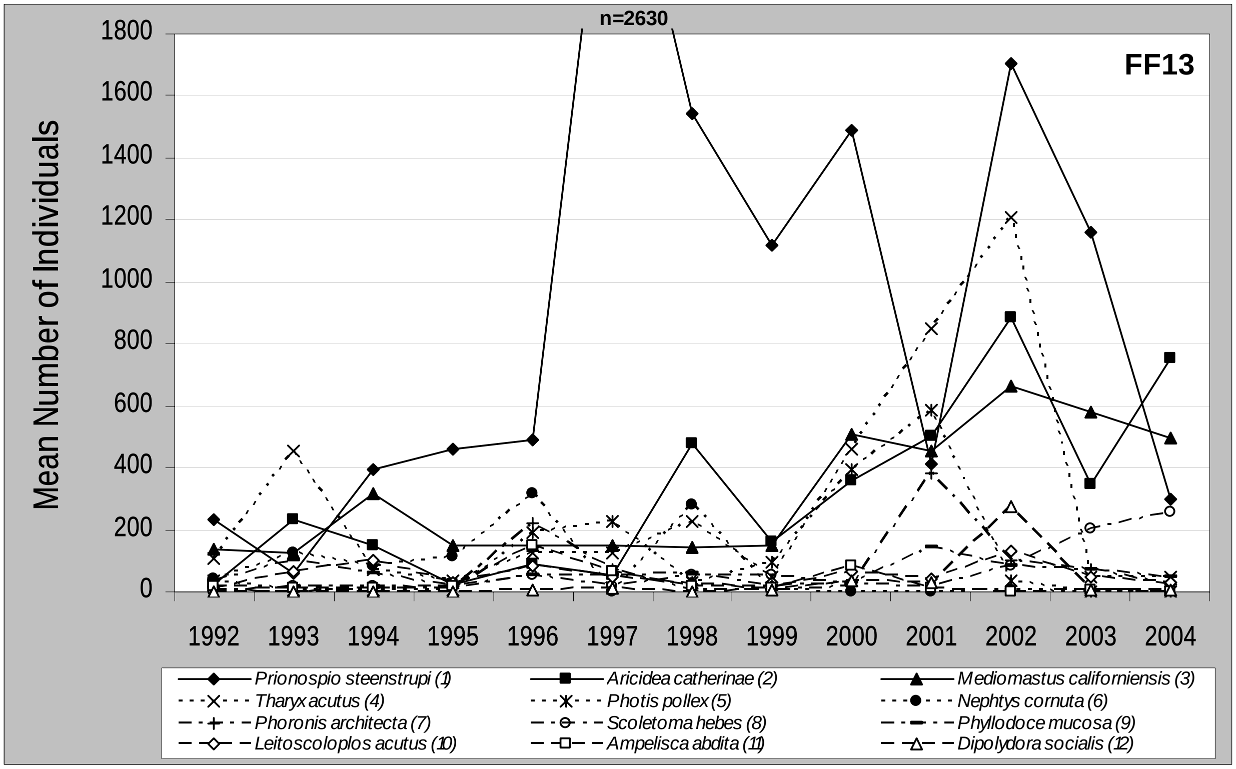

Figure C5-2. Mean number of individuals (n=3 for all years) belonging to the 12 most abundant species found in samples collected from FF13 from 1992 through 2004. The station rank order of each species follows the species name.

NF05

Station NF05 has been sampled every August since 1992, with the exception of 1993, for a total of 12 samples, one each year. In contrast to Stations FF10 and FF13, the species composition of top dominant species at Station NF05 was diverse, with eleven different species ranking first through third for at least one year during the monitoring period (Figure C5-7). The 12 most abundant taxa (more than 500 specimens each) included nine polychaetes, two bivalves, and one ampeliscid amphipod. The mean abundance of these species are tabulated and plotted for each year in Table C5-8, Figure C5-3.

Spionid polychaetes were the most abundant animals found. The three top dominant species at NF05 overall were all spionids, *Prionospio steenstrupi*, *Spio limicola*, and *Dipolydora socialis* while a fourth species, *Dipolydora quadrilobata* was also among the top 12 dominant species. *S. limicola* was the top dominant in 1992 and 2004 with a much greater number found in 1992 than for any other top dominant found in any other year sampled. *P. steenstrupi* was the top dominant for seven years (1994-1998, 2000, 2002-2003) and ranked second in 1999. *D. socialis* was the top dominant in 1999 and ranked second in 1992 and 2000. The capitellid polychaete, *Mediomastus californiensis*, was the most common animal in 2001, one of three years with less than 1000 animals found all together, and ranked second (1998, 2002) or third (1996, 1997, 2003) in five additional years. In contrast, bivalve molluscs dominated in 1994, the year with the least infaunal density seen. A very small (less than 3 mm in length) member of the Mytilidae, *Crenella decussata*, was the most abundant animal in 1994, followed by the common Massachusetts Bay protobranch bivalve, *Nucula delphinodonta*. Three additional polychaetes wee among the top 12 dominant species, *Exogone verugera*, *Tharyx acutus*, and *Levinsenia gracilis*. One ampeliscid amphipod, *Haploops fundiensis*, was among the top 12 dominant species in every year except 1995 when it was either absent or not identified, and even ranked third in 1999. Most of these top 12 species were present in all years sampled, with the exception of the *H. fundiensis* mentioned above, *P. steenstrupi* and *S. limicola* in 1994 only, *D. quadrilobata* from 1997 through 2004, and *C. decussata* absent or not identified in 1995 and 2000-2001.

Table C5-7. Annual rank of numerically dominant species at NF05. For overall NF rank, species were ordered by the means of all 13 stations totaled for all years.

Taxon	**Annual Numerical Rank**												
	1992	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**Overall NF Rank**
Prionospio steenstrupi			1	1	1	1	2	1		1	1	3	1
Mediomastus californiensis					3	2			1	2	3		2
Spio limicola	1										2	1	3
Tharyx acutus			3						3			2	4
Dipolydora socialis	2						1	2					6
Aphelochaeta marioni			2	2	2	3		3	2				8
Nucula delphinodonta		2											11
Exogone verugera		3		3									13
Crenella decussata		1											26
Dipolydora quadrilobata	3												36
Haploops fundiensis							3			3			59

Table C5-8. Mean number of individuals (n=1 for all years) belonging to the 12 most abundant species found in samples collected from NF05 in 1992 and 1994 through 2004. Taxa are listed in order of decreasing total mean abundance at this station.

Taxon	1992	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Prionospio steenstrupi	152	0	526	322	278	193	174	404	39	150	512	183
Spio limicola	791	0	55	20	30	11	19	18	10	23	275	416
Dipolydora socialis	608	5	22	21	83	25	274	186	8	10	38	0
Mediomastus californiensis	120	11	171	123	109	136	78	63	93	92	119	78
Aphelochaeta marioni	34	43	231	201	115	97	70	78	75	19	3	16
Tharyx acutus	31	3	190	35	99	52	40	38	62	35	88	199
Nucula delphinodonta	30	122	65	86	69	63	49	16	35	14	85	51
Exogone verugera	62	57	184	111	54	26	9	63	24	2	20	11
Dipolydora quadrilobata	488	52	4	2	0	0	0	0	0	0	0	8
Haploops fundiensis	31	41	0	54	21	51	131	43	52	49	60	8
Crenella decussata	53	226	0	80	33	21	20	0	0	24	39	26
Levinsenia gracilis	23	6	26	26	36	51	55	24	38	44	96	81

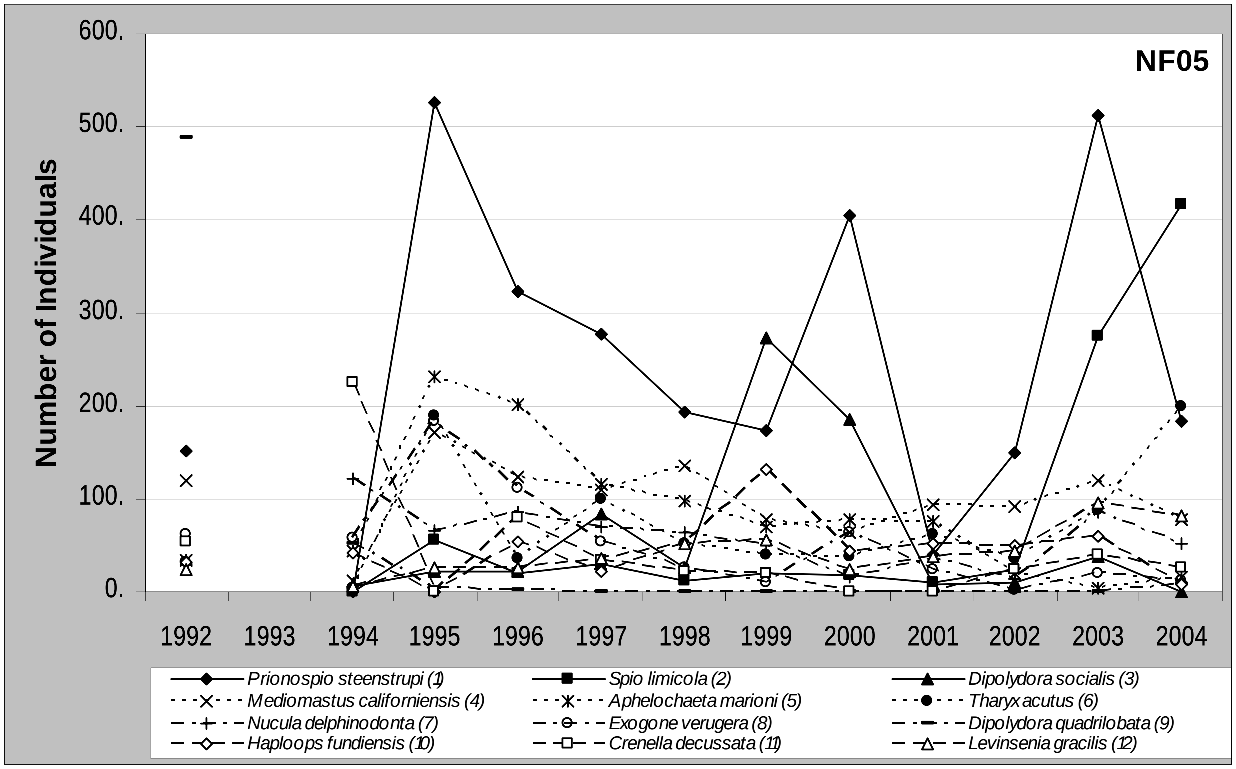

Figure C5-3. Mean number of individuals (n=1 for all years) belonging to the 12 most abundant species at NF05 from 1992 through 2004. The station rank order of each species follows the species name.

NF07

Station NF07 has been sampled every August since 1992, with the exception of 1993, for a total of 12 samples, one each year. Eight species, all polychaetes, ranked first, second, or third over the 13-year sampling period (Table C5-9). The 12 most abundant taxa (more than 500 specimens each) included eleven polychaetes and one bivalve. The mean abundance of these species are tabulated and plotted for each year (Table C5-10, Figure C5-4).

Spionid polychaetes were the most abundant animals and were the highest ranking animals for all but one year of sampling; *Prionospio steenstrupi* for nine years (1995-1996, 1998-2004); *Spio limicola* once (1992); and *Dipolydora socialis* once (1994). *Mediomastus californiensis* was important and while ranking third overall at Station NF07, was the second dominant in 1998 and third dominant for five years (1994-1995, 2001-2003). The syllid polychaete, *Exogone hebes*, was unusual in achieving high rank only once as the most abundant species in 1997, while ranking only eleventh overall at this station. Three other polychaetes, which ranked second or third at least once, included *Aphelochaeta marioni* (tying with *D. socialis* for third place in 1996), *Exogone verugera*, and *Pholoe minuta*. The majority of the 12 most abundant species found at Station NF07 were present during each year of sampling with the exceptions that *A. marioni* was not identified in 1994 or 1997 and another four species were not identified in the 1997 sample, a year when unusually low numbers of animals were found at this station. The eight most abundant species at Station NF07 were the same as those at Station NF05 with just some slight differences in rank order. One of these, the bivalve *Nucula delphinodonta*, was the eighth most common animal at Station NF07 overall but was never a top dominant.

Table C5-9. Annual rank of numerically dominant species at NF07. For overall NF rank, species were ordered by the means of all 13 stations totaled for all years.

Taxon	Annual Numerical Rank												
	1992	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	Overall NF Rank
Prionospio steenstrupi	3		1	1	3	1	1	1	1	1	1	1	1
Mediomastus californiensis		3	3			2			3	3	3		2
Spio limicola	1	2	2	2		3	3	2	2	2	2		3
Dipolydora socialis		1		3	2		2	3					6
Aphelochaeta marioni				3									8
Exogone hebes					1								9
Exogone verugera	2											3	13
Pholoe minuta												2	29

Table C5-10. Mean number of individuals (n=1 for all years) belonging to the 12 most abundant species found in samples collected from NF07 from 1992 and 1994 through 2004. Taxa are listed in order of decreasing total mean abundance at this station.

Taxon	1992	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Prionospio steenstrupi	755	7	343	276	11	1240	1101	1494	787	1614	1621	585
Spio limicola	1917	78	317	198	4	189	253	277	247	653	454	125
Mediomastus californiensis	401	74	206	111	1	318	133	183	173	206	204	244
Dipolydora socialis	545	708	49	131	28	108	319	191	2	45	97	12
Exogone verugera	894	38	37	30	7	27	36	61	42	39	18	257
Aphelochaeta marioni	125	0	175	133	0	46	27	52	37	122	67	63
Tharyx acutus	136	47	122	23	5	19	20	32	55	85	134	84
Nucula delphinodonta	13	12	19	39	0	45	40	159	101	121	45	24
Euchone incolor	30	1	45	36	0	85	89	161	28	74	9	42
Pholoe minuta	39	40	39	20	0	41	21	32	1	9	48	286
Exogone hebes	95	31	30	23	151	54	26	10	19	45	22	30
Ninoe nigripes	58	11	53	41	0	57	28	94	23	47	61	63

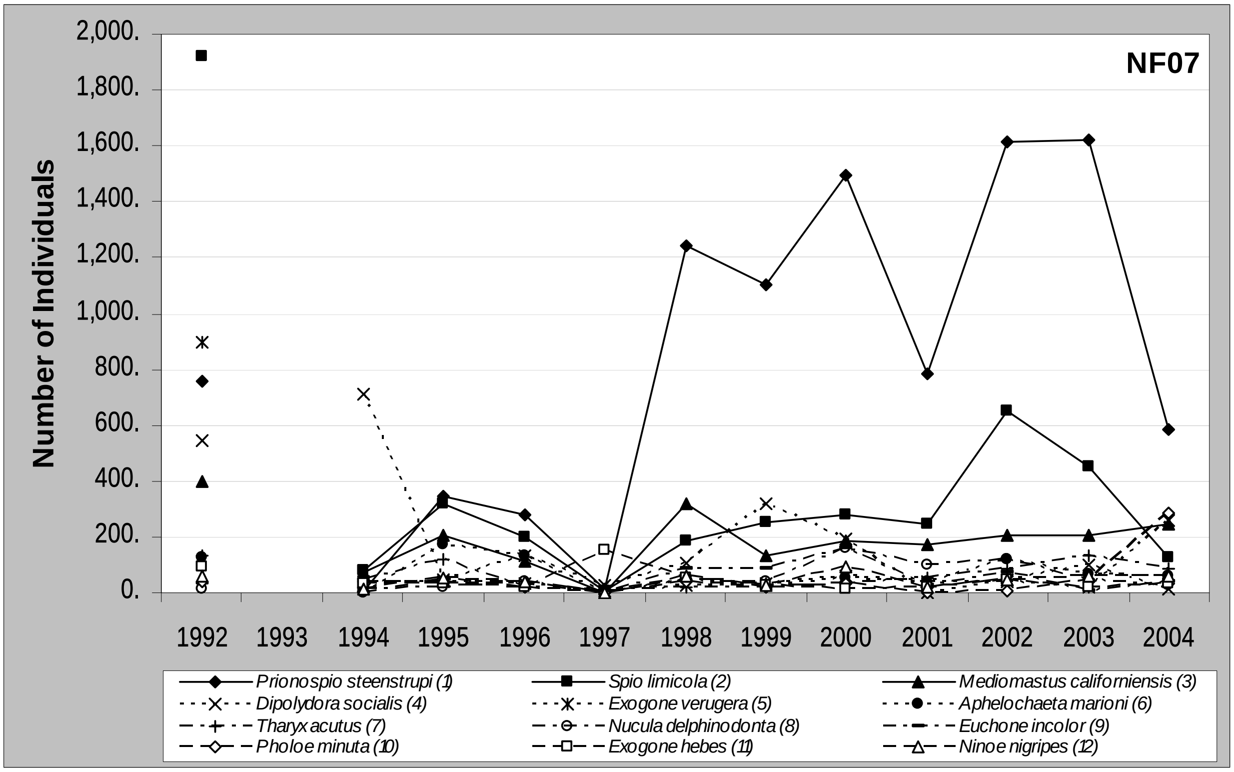

Figure C5-4. Mean number of individuals (n=1 for all years) belonging to the 12 most abundant species at NF07 from 1992 through 2004. The station rank order of each species follows the species name.

NF08

Station NF08 has been sampled every August since 1992 (n=1 except in 1993 when n=3) for a total of 15 samples. At this fairly diverse station, ten species, nine polychaetes and the phoronid were top dominants, ranking first, second, or third at least once during the 13-year sampling period (Table C5-11). The 12 most abundant taxa (more than 700 specimens each) included eleven polychaetes and one species belonging to the lophophorate phylum Phoronida. The mean abundance of these species are tabulated and plotted for each year (Table C5-12, Figure C5-5).

Prionospio steenstrupi, ranking first five times (1997-2000, 2003), and *Mediomastus californiensis*, ranking first three times (1995-1996, 2004), were the first and second most abundant species, respectively, overall at Station NF08. The third most abundant species was the paraonid polychaete *Aricidea catherinae*, a species that ranked fifth over all nearfield stations combined. *A. catherinae* was most common at Station NF08 during the early years of the program, ranking first in 1992-1993 and second in 1994-1995, years during which *Spio limicola* was the most abundant species at a number of other nearfield stations. Numbers of *A. catherinae* were extremely high in 1993 when the mean number of individuals for the three replicate samples was 1862, by far the highest number found for any species for any sampling period at this station. *S. limicola* was a top dominant only in one year, 1994, and although ranking fifth at Station NF08 over all years, more than 40% of the individuals collected were from just the 1994 sample. Two other polychaetes, *Tharyx acutus* and *Aphelochaeta marioni*, each ranked first for one year. Although only ranking eighth overall at this station, *Phoronis architecta* was the second most abundant species twice, in 2001 and 2003.

Table C5-11. Annual rank of numerically dominant species at NF08. For overall NF rank, species were ordered by the means of all 13 stations totaled for all years.

	Annual Numerical Rank													
Taxon	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**Overall NF Rank**
Prionospio steenstrupi				3	2	1	1	1	1	3	2	1		1
Mediomastus californiensis	2	3	3	1	1	2	2	2	2				1	2
Spio limicola			1											3
Tharyx acutus	3	2									1	3	2	4
Aricidea catherinae	1	1	2	2										5
Ninoe nigripes					3	3	3							7
Aphelochaeta marioni										1	3			8
Levinsenia gracilis													3	10
Euchone incolor								3	3					12
Phoronis architecta										2		2		16

Table C5-12. Mean number of individuals (n=1 except in 1993 when n=3) belonging to the 12 most abundant species found in samples collected from NF08 from 1992 through 2004. Taxa are listed in order of decreasing total mean abundance at this station.

Taxon	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Prionospio steenstrupi	7	40	52	258	261	998	1113	1106	681	382	433	628	61
Mediomastus californiensis	197	376	271	655	397	546	501	250	237	229	222	208	243
Aricidea catherinae	583	1862	426	552	21	94	0	0	1	17	56	24	62
Tharyx acutus	179	826	18	0	3	11	3	29	35	350	613	284	172
Spio limicola	43	35	920	170	19	16	9	14	101	246	271	237	56
Monticellina baptisteae	53	128	64	138	107	115	79	31	44	62	31	132	123
Ninoe nigripes	19	16	16	39	197	171	107	83	51	32	118	111	106
Phoronis architecta	5	10	1	4	2	0	2	0	1	444	274	302	6
Leitoscoloplos acutus	6	74	87	84	41	163	81	64	93	152	79	63	34
Aphelochaeta marioni	41	14	0	0	0	7	5	0	12	529	301	37	30
Levinsenia gracilis	45	60	59	68	25	64	82	48	71	86	94	75	126
Euchone incolor	0	2	5	42	40	112	51	174	109	72	92	73	8

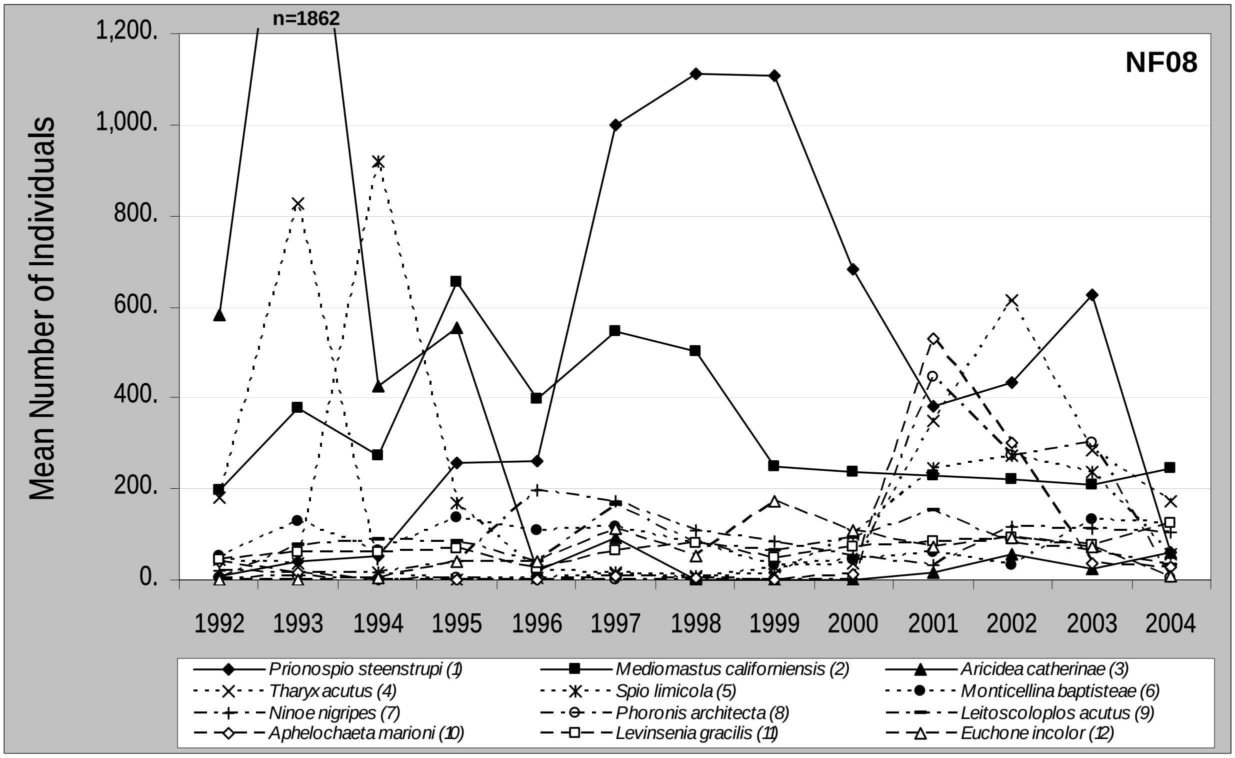

Figure C5-5. Mean number of individuals (n=1 except in 1993 when n=3) belonging to the 12 most abundant species at NF08 from 1992 through 2004. The station rank order of each species follows the species name.

NF09

Station NF09 has been sampled every August since 1992 (n=1 except in 1993 when n=3) for a total of 15 samples. Nine species, eight polychaetes and one phoronid, were top dominants, ranking first, second, or third at least once during the 13-year sampling period (Table C5-13). The 12 most abundant taxa (more than 600 specimens each) included ten polychaetes, one bivalve, and one phoronid. The mean abundance of these species are tabulated and plotted for each year (Table C5-14, Figure C5-6).

The three most abundant species found overall were *Prionospio steenstrupi*, *Spio limicola*, and *Mediomastus californiensis* ranking first, second, and third, respectively. Only the two spionids ever held the top ranking spot, *S. limicola* early in the program (1992-1994), and *P. steenstrupi* for the remainder of the monitoring (1995-2004), while *M. californiensis* ranked second or third for 10 years. An additional six polychaete species ranked second or third overall once or twice during the program. *Phoronis architecta*, while only ranking tenth overall at Station NF09, did rank second one time, in 2003, one of the same years that it ranked second at Station NF08. Although the bivalve, *Nucula delphinodonta*, was the sixth most common animal found at Station NF09, it never ranked among the top three numerically dominant species.

Table C5-13. Annual rank of numerically dominant species at NF09. For overall NF rank, species were ordered by the means of all 13 stations totaled for all years.

	Annual Numerical Rank													
Taxon	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**Overall NF Rank**
Prionospio steenstrupi		2		1	1	1	1	1	1	1	1	1	1	1
Mediomastus californiensis	2	3	2	2	2	3	2	2		3			2	2
Spio limicola	1	1	1	3		2			3	2	2	3	3	3
Aricidea catherinae							3							5
Dipolydora socialis	3								2					6
Ninoe nigripes					3			3						7
Monticellina baptisteae			3											14
Phoronis architecta												2		16
Ampharete acutifrons											3			28

Table C5-14. Mean number of individuals (n=1 except in 1993 when n=3) belonging to the 12 most abundant species found in samples collected from NF09 from 1992 through 2004. Taxa are listed in order of decreasing total mean abundance at this station.

Taxon	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Prionospio steenstrupi	97	146	230	479	224	571	445	347	633	278	816	1008	361
Spio limicola	585	296	733	124	142	300	94	99	339	191	228	281	140
Mediomastus californiensis	278	75	255	238	209	227	160	120	201	181	165	131	157
Ninoe nigripes	71	37	39	45	184	204	84	107	91	52	65	55	74
Dipolydora socialis	259	14	0	26	8	212	10	55	377	20	32	21	10
Nucula delphinodonta	35	57	46	81	60	107	66	85	103	51	103	103	132
Aricidea catherinae	32	28	56	30	110	188	96	85	58	92	46	38	52
Monticellina baptisteae	101	32	81	94	87	67	65	37	112	61	35	63	41
Aphelochaeta marioni	83	32	20	99	90	131	54	57	24	33	42	32	30
Phoronis architecta	22	8	12	17	9	73	22	5	6	123	44	294	19
Maldane sarsi	52	39	51	50	27	61	49	56	97	58	23	38	25
Ampharete acutifrons	124	4	34	10	23	169	14	8	1	17	198	3	10

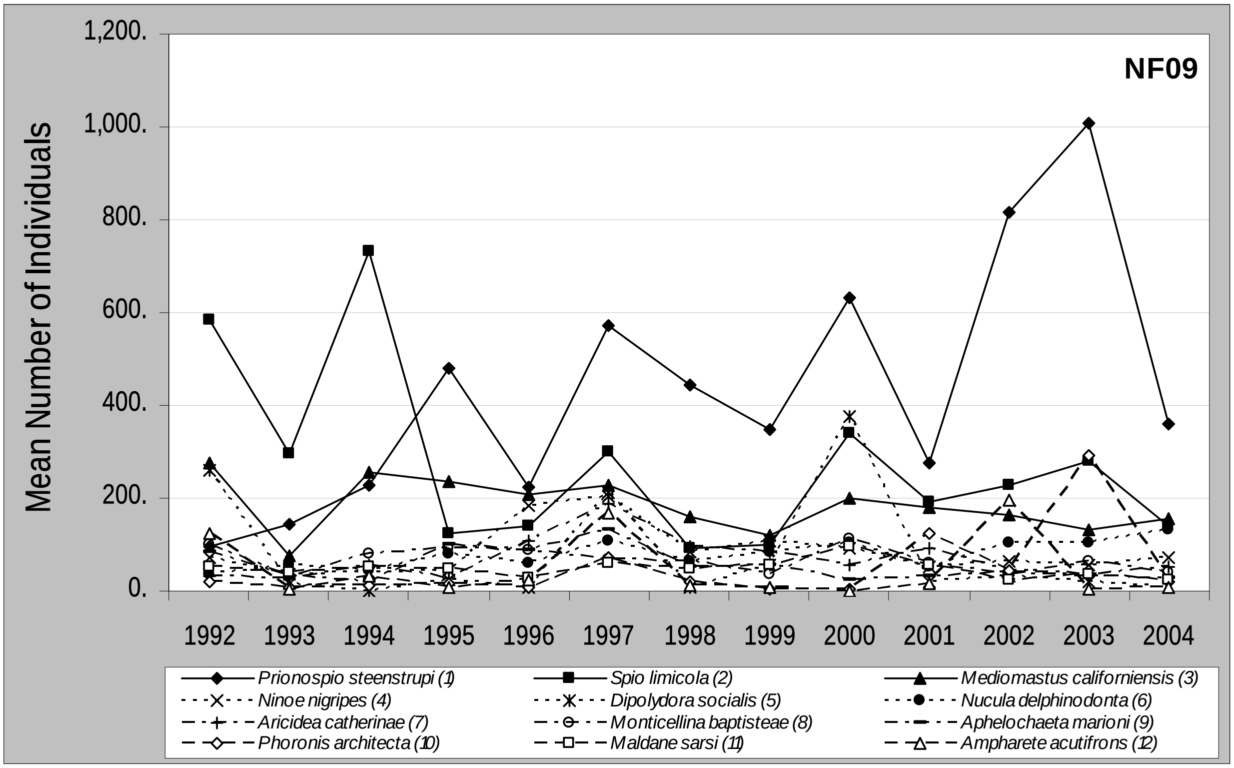

Figure C5-6. Mean number of individuals (n=1 except in 1993 when n=3) belonging to the 12 most abundant species at NF09 from 1992 through 2004. The station rank order of each species follows the species name.

NF12

Station NF12 has been sampled every August since 1992, in triplicate for all years except 1992 when only one sample was collected, for a total of 37 samples. Eight polychaete species were top dominants, ranking first, second, or third at least once during the 13-year sampling period (Table C5-15). The 12 most abundant species also were all polychaetes, (more than 2300 specimens each). The mean abundance of these species are tabulated and plotted for each year (Table C5-16, Figure C5-7).

The three most abundant species found overall at Station NF12 were *Prionospio steenstrupi*, *Mediomastus californiensis*, and *Spio limicola* ranking first, second, and third, respectively, making this the only nearfield station where the station order of abundance of the three dominant species was the same as that for the overall nearfield abundance. During the course of the last 13 years, four species have been the numerically most abundant species, *P. steenstrupi* (1999-2000, 2003-2004), *M. californiensis* (1992-1993, 1995-1998, 2001), *S. limicola* (1994,1997), and *Dipolydora socialis* (in 2000 this species virtually tied in abundance with *P. steenstrupi*). *Aricidea catherinae* ranked second or third five times during the first half of the program while *Tharyx acutus* became important after the year 2000. *Aphelochaeta marioni* and *Euchone incolor*, ranking sixth and eleventh, respectively, for the station overall, each ranked third for only one year of sampling.

Table C5-15. Annual rank of numerically dominant species at NF12. For overall NF rank, species were ordered by the means of all 13 stations totaled for all years.

	Annual Numerical Rank													
Taxon	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**Overall NF Rank**
Prionospio steenstrupi							2	1	1		1	1	1	1
Mediomastus californiensis	1	1	2	1	1	1	1	2	2	1	3	2	2	2
Spio limicola	2	3	1	2	2	1			3	2			3	3
Tharyx acutus										3	2	3		4
Aricidea catherinae	3	2	3	3		3								5
Dipolydora socialis						2		3	1					6
Aphelochaeta marioni					3									8
Euchone incolor							3							12

Table C5-16. Mean number of individuals (n=3 except in 1992 when n=1) belonging to the 12 most abundant species found in samples collected from NF12 from 1992 through 2004. Taxa are listed in order of decreasing total mean abundance at this station.

Taxon	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Prionospio steenstrupi	84	143	125	130	112	180	351	538	698	347	974	1048	1071
Mediomastus californiensis	249	520	530	508	446	436	496	418	470	467	436	464	263
Spio limicola	198	190	1138	367	382	434	183	180	378	423	430	177	154
Aricidea catherinae	179	247	238	228	209	274	155	136	136	351	309	227	52
Tharyx acutus	13	50	107	22	38	169	78	71	92	375	470	284	118
Aphelochaeta marioni	6	19	36	129	220	232	213	114	88	281	72	105	54
Dipolydora socialis	2	0	53	23	22	279	80	344	697	1	1	0	0
Levinsenia gracilis	86	47	95	102	108	76	105	97	131	120	95	127	78
Ninoe nigripes	126	98	68	39	152	163	131	129	77	58	55	98	72
Monticellina baptisteae	22	84	211	193	36	66	109	105	149	37	39	67	36
Euchone incolor	9	5	14	40	94	156	225	204	158	49	11	0	17
Leitoscoloplos acutus	34	73	58	38	40	41	40	48	88	112	89	70	81

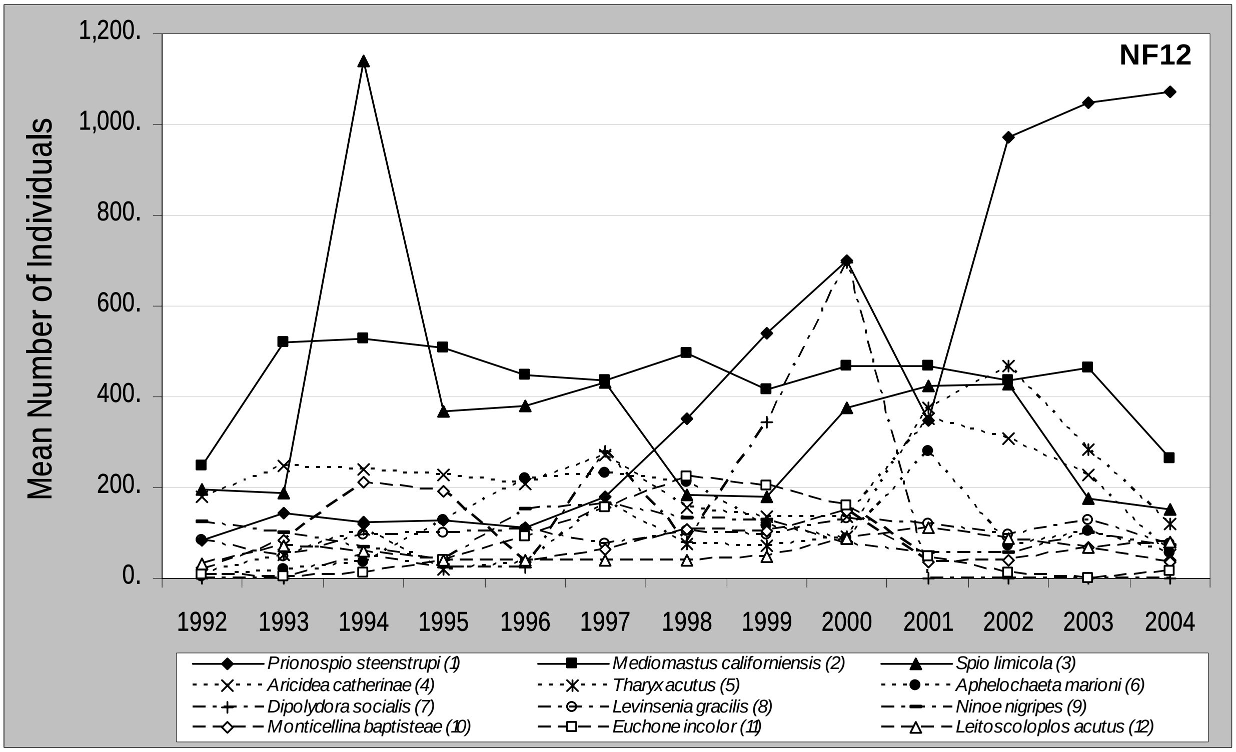

Figure C5-7. Mean number of individuals (n=3 except in 1992 when n=1) belonging to the 12 most abundant species at NF12 from 1992 through 2004. The station rank order of each species follows the species name.

NF16

Station NF16 has been sampled every August since 1992 (n=1 except in 1993 when n=3) for a total of 15 samples. The species composition of top dominant species at Station NF16 was very diverse, with eleven different species ranking first through third for at least one year during the monitoring period (Table C5-17). The 12 most abundant taxa (more than 400 specimens each) included eleven polychaetes and one oligochaete. The mean abundance of these species are tabulated and plotted for each year (Table C5-18, Figure C5-8).

Prionospio steenstrupi was the numerical overall dominant at Station NF16 and for each year from 1997 through 2003. The next most abundant species overall were *Mediomastus californiensis* and *Tharyx acutus*. *M. californiensis* was the most abundant species early in the program, ranking first in four of the first five years (1992-1993,1995-1996) and second or third from 1998 through 2004. *T. acutus* ranked second or third for five years and consistently from 2001 through 2004. *Aricidea catherinae* was common from 1992-1994 and ranked first in 1994. Unusually, three species shared the top dominant rank in 1996 when *M. californiensis, Spio limicola,* and *Ninoe nigripes* were nearly equally represented with152, 151, and 151 individuals, respectively, present (counts only one or two numbers different were treated as a tie). *Nephtys incisa,* while ranking eighth overall at Station NF16 was the most common species found in 2004, with more than twice as many animals present as the next most abundant species. The oligochaete, Tubificidae sp. 2, which ranked twelfth overall at Station NF16, shared third place with *Levinsenia gracilis* in 1992.

Table C5-17. Annual rank of numerically dominant species at NF16. For overall NF rank, species were ordered by the means of all 13 stations totaled for all years.

	Annual Numerical Rank													
Taxon	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**Overall NF Rank**
Prionospio steenstrupi					3	1	1	1	1	1	1	1		1
Mediomastus californiensis	1	1		1	1		2	2	2	2	3	3	2	2
Spio limicola		2		3	1									3
Tharyx acutus						3				3	2	2	3	4
Aricidea catherinae	2	3	1											5
Ninoe nigripes			3		1	2		3	3					7
Levinsenia gracilis	3		2		3		3		3					10
Euchone incolor					2									12
Monticellina baptisteae				2										14
Nephtys incisa													1	31
Tubificidae sp. 2	3													35

Table C5-18. Mean number of individuals (n=1 except in 1993 when n=3) belonging to the 12 most abundant species found in samples collected from NF16 from 1992 through 2004. Taxa are listed in order of decreasing total mean abundance at this station.

Taxon	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Prionospio steenstrupi	28	74	0	185	94	632	806	1356	1152	314	1660	1178	205
Mediomastus californiensis	427	246	1	305	152	221	413	149	217	180	454	296	266
Tharyx acutus	65	45	4	25	91	250	45	21	57	174	837	447	214
Ninoe nigripes	59	60	33	56	151	270	166	137	103	75	122	124	69
Levinsenia gracilis	81	41	69	137	94	144	198	115	105	54	128	154	95
Euchone incolor	40	2	0	93	102	181	34	132	102	10	181	76	10
Spio limicola	61	88	1	227	151	30	45	15	7	15	160	66	20
Nephtys incisa	3	7	0	5	8	13	5	4	1	1	6	39	526
Monticellina baptisteae	47	23	12	234	55	57	48	10	31	9	23	46	18
Aricidea catherinae	209	75	119	14	2	0	3	50	10	20	21	17	6
Leitoscoloplos acutus	37	36	0	67	34	37	31	25	38	35	130	50	16
Tubificidae sp. 2	79	11	0	105	68	0	26	14	13	9	85	35	31

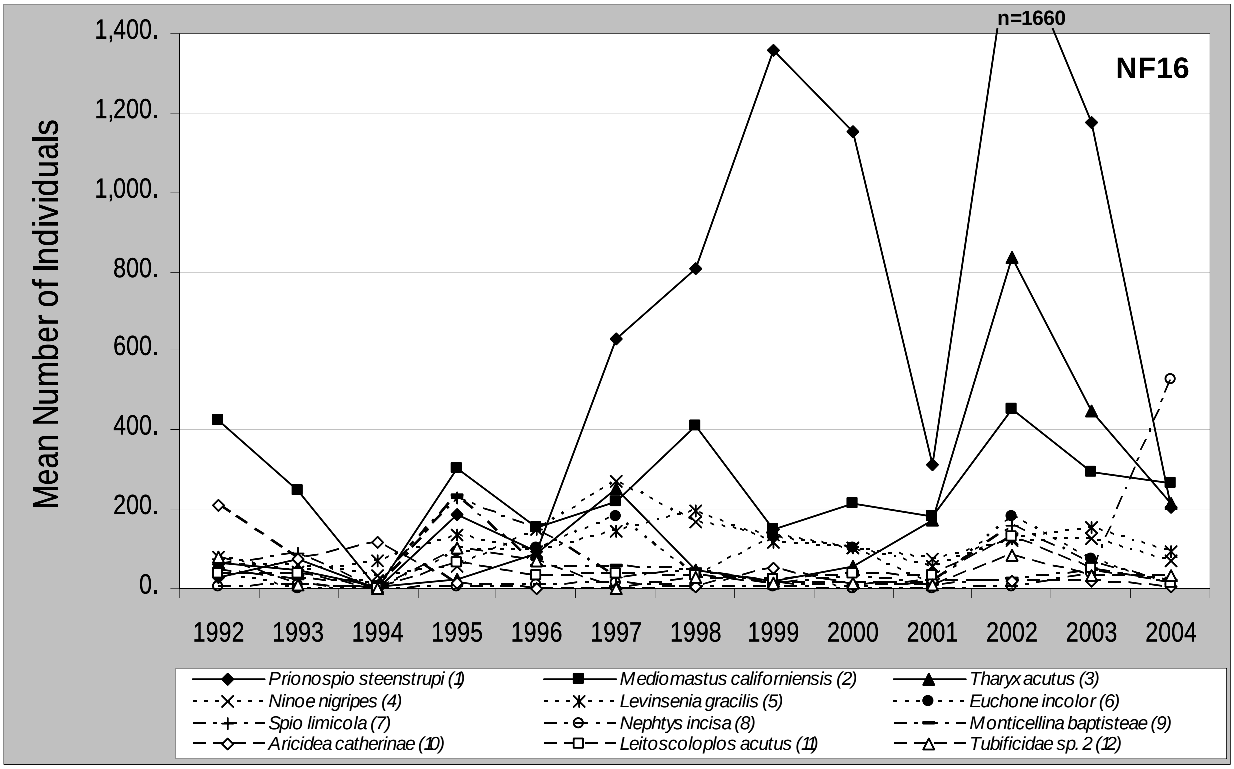

Figure C5-8. Mean number of individuals (n=1 except in 1993 when n=3) belonging to the 12 most abundant species at NF16 from 1992 through 2004. The station rank order of each species follows the species name.

NF17

Station NF17 has been sampled every August since 1992, in triplicate for all years except 1992 when only one sample was collected, for a total of 37 samples. At this very diverse station, eleven species were top dominants, ranking first, second, or third at least once (Table C5-19). The12 most abundant species (more than 600 specimens each) included four polychaetes, three amphipods, one isopod, one tunicate, one bivalve, and one sand dollar. The mean abundance of these species are tabulated and plotted for each year (Table C5-20, Figure C5-9).

In contrast to all other nearfield stations, polychaetes were not the most abundant animals found here. Two species of amphipods, *Crassicorophium crassicorne* and *Pseudunciola obliquua*, were among the top three most abundant animals overall at Station NF17, whereas for the 13 nearfield stations discussed in this section combined, they only ranked seventeenth and forty-ninth, respectively. *C. crassicorne*, an inhabitant of muddy sand bottoms, was the most common animal found in six of the 13 years of the monitoring program (1992-1994, 1999-2000, 2003) and ranked second or third for an additional five years. It was particularly abundant in 1994 with more than five times as many individuals collected as for the next most common species. Sand-encrusted juvenile forms of the ascidiacean, *Molgula manhattensis*, were quite abundant and ranked first three times (2001-2002, 2004), although this is possibly an artifact of naming forms that earlier in the program were categorized as Ascidiacea spp., a worse species not included in these data sets. One or the other aorid amphipod, *P. obliquua* or its close relative, *Unciola inermis*, ranked second or third for most years from 1992 through 2000. Two polychaetes were the top dominant species for the middle portion of the monitoring period, *Polygordius* sp. A (1995-1996) and *Spiophanes bombyx* (1997-1998) and another two species, *Dipolydora. socialis* and *Exogone hebes* each ranked second or third at least once. Three non-polychaetes each ranked second or third once, the bivalve, *Cerastoderma pinnulatum* (1997), the sand-dollar, *Echinarachnius parma* (2003), and an isopod, *Chiridotea tuftsi* (1993). *C. tuftsi*, ranking twelfth overall at Station NF17, actually was the second most abundant animal found, with only 16 individuals, in 1993, a year when very low numbers of animals were collected at this station.

Table C5-19. Annual rank of numerically dominant species at NF17. For overall NF rank, species were ordered by the means of all 13 stations totaled for all years.

Taxon	Annual Numerical Rank													
	1992	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**Overall NF Rank**
Dipolydora socialis	c		2										c	6
Exogone hebes	2		3							2		3	2	9
Crassicorophium crassicorne	1	1	1	3	2		3	1	1		3	1	1	17
Spiophanes bombyx						1	1			3	2			19
Molgula manhattensis									2	1	1			20
Polygordius sp. A				1	1		2	3						22
Unciola inermis	3				3								3	24
Cerastoderma pinnulatum						3								30
Pseudunciola obliquua		3		2		2		2	3					49
Echinarachnius parma												2		65
Chiridotea tuftsi		2												74

Table C5-20. Mean number of individuals (n=3 except in 1992 when n=1) belonging to the 12 most abundant species found in samples collected from NF17 from 1992 through 2004. Taxa are listed in order of decreasing total mean abundance at this station.

Taxon	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Crassicorophium crassicorne	116	93	1134	115	231	46	42	509	298	55	117	157	73
Molgula manhattensis	3	0	0	27	3	1	34	11	218	629	356	8	260
Pseudunciola obliquua	27	14	56	122	17	136	102	346	200	6	10	0	2
Polygordius sp. A	15	0	45	155	235	10	123	184	70	57	36	12	59
Spiophanes bombyx	17	7	60	20	15	142	307	27	61	63	123	38	81
Exogone hebes	70	5	69	22	31	36	27	25	96	101	47	129	45
Cerastoderma pinnulatum	6	6	1	29	48	64	0	111	81	9	33	1	54
Unciola inermis	55	1	14	35	207	2	7	56	13	38	0	0	0
Dipolydora socialis	13	0	197	1	6	2	1	0	85	3	81	25	1
Echinarachnius parma	9	2	44	16	24	11	14	61	32	4	4	136	29
Phyllodoce mucosa	3	1	9	21	1	2	39	152	13	14	22	43	20
Chiridotea tuftsi	23	16	13	19	6	25	9	16	49	7	11	17	7

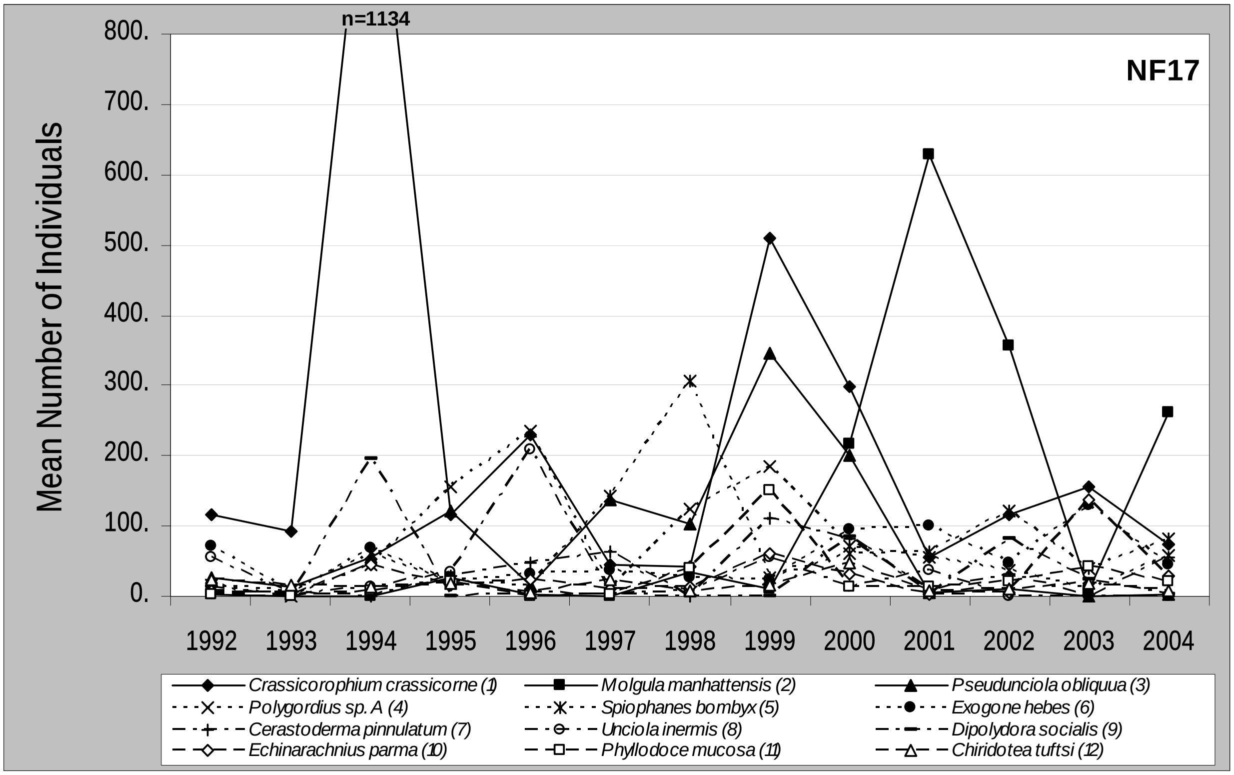

Figure C5-9. Mean number of individuals (n=3 except in 1992 when n=1) belonging to the 12 most abundant species at NF17 from 1992 through 2004. The station rank order of each species follows the species name.

NF18

Station NF18 has been sampled every August since 1992, with the exception of 1993, for a total of 12 samples, one each year. At this fairly diverse station, ten species were top dominants, ranking first, second, or third at least once during the 13-year sampling period (Table C5-21). The 12 most abundant taxa (more than 300 specimens each) included nine polychaetes, two amphipods, and one bivalve. The mean abundance of these species are tabulated and plotted for each year (Table C5-22, Figure C5-10).

Prionospio steenstrupi was the top dominant species overall at Station NF18 with more than 5 times as many individuals collected than the second ranking species, *Mediomastus californiensis*. *P. steenstrupi* ranked first (10 times) or second (twice) for every year that this station was sampled while *M. californiensis* ranked second in 2004 only and ranked third half the time. The only other species that ranked first in abundance were the polychaetes *Spio limicola* in 1992 and *Exogone hebes* in 2001. The amphipod, *Protomedeia fasciata,* ranked third overall at this station mostly due to the large numbers collected in only two years (1999-2000) when it was the second top dominant. Four additional polychaetes and one bivalve ranked second at least once during the monitoring period, *Aricidea catherinae* (2002-2003), *Ninoe nigripes* (1996), *Exogone verugera* (1998), *Hiatella arctica* (1997), and *Asabellides oculata* (1994).

Table C5-21. Annual rank of numerically dominant species at NF18. For overall NF rank, species were ordered by the means of all 13 stations totaled for all years.

	Annual Numerical Rank												
Taxon	**1992**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**Overall NF Rank**
Prionospio steenstrupi	2	1	1	1	1	1	1	1	2	1	1	1	1
Mediomastus californiensis	3		3		3		3	3	3			2	2
Spio limicola	1									3			3
Aricidea catherinae										2	2	3	5
Ninoe nigripes				2									7
Exogone hebes			2			3			1				9
Exogone verugera		3				2							13
Hiatella arctica				3	2								23
Protomedeia fasciata							2	2					27
Asabellides oculata		2									3		32

Table C5-22. Mean number of individuals (n=1) belonging to the 12 most abundant species found in samples collected from NF18 from 1992 and 1994 through 2004. Taxa are listed in order of decreasing total mean abundance at this station.

Taxon	1992	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Prionospio steenstrupi	279	351	526	518	877	805	1271	617	358	1977	2215	459
Mediomastus californiensis	211	138	98	71	202	212	218	101	164	130	161	152
Protomedeia fasciata	0	0	1	9	92	125	634	511	54	2	2	3
Exogone hebes	65	65	119	64	93	294	77	54	419	10	39	38
Aricidea catherinae	55	30	24	22	79	26	112	76	89	168	352	98
Spio limicola	433	5	10	47	20	0	1	11	16	159	118	33
Exogone verugera	79	141	93	29	40	311	49	44	22	8	16	14
Asabellides oculata	8	159	2	14	70	0	35	0	0	121	317	12
Ninoe nigripes	61	40	25	147	120	35	82	52	17	32	61	53
Hiatella arctica	1	53	3	95	313	51	23	5	21	8	7	5
Tharyx acutus	92	29	6	61	37	18	33	33	21	95	18	73
Unciola inermis	0	0	1	0	16	287	26	15	42	0	0	0

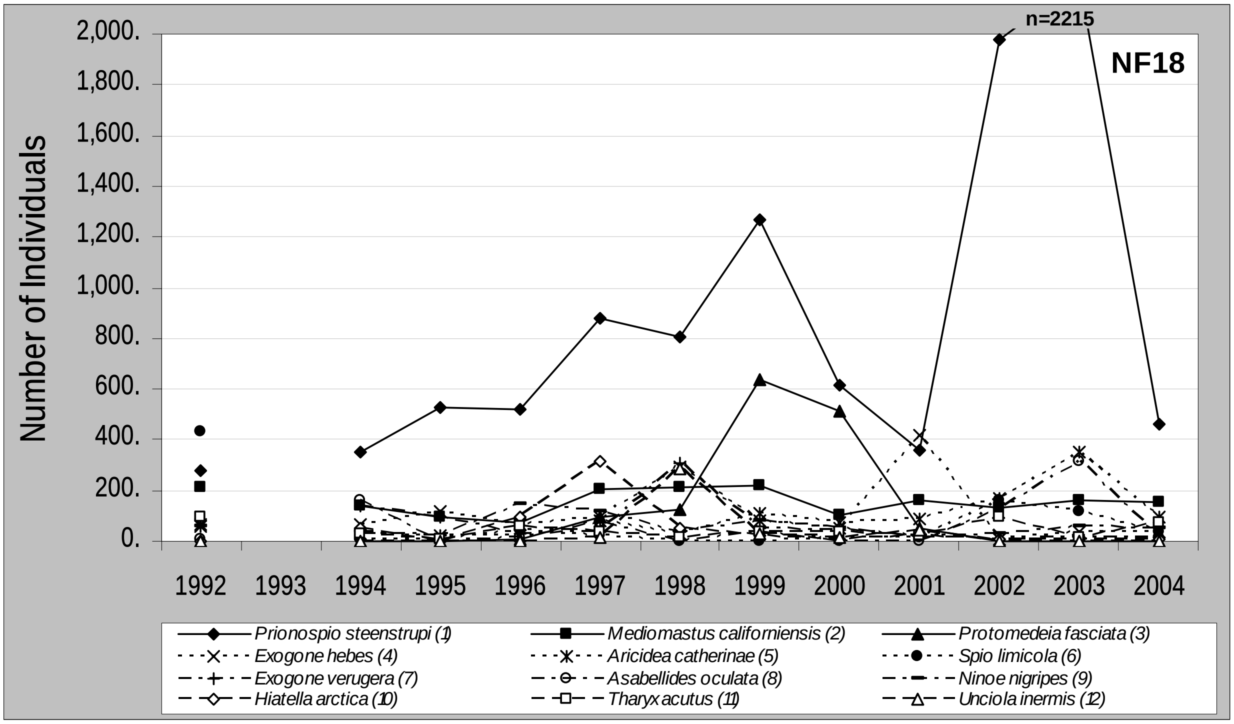

Figure C5-10. Mean number of individuals (n=1) belonging to the 12 most abundant species at NF18 from 1992 through 2004. The station rank order of each species follows the species name.

NF19

Station NF19 has been sampled every August since 1992, with the exception of 1993, for a total of 12 samples, one each year. Nine species were top dominants, ranking first, second, or third at least once during the 13-year sampling period (Table C5-23). The 12 most abundant taxa (more than 500 specimens each) included eleven polychaetes and one bivalve. Mean abundance of these species are tabulated and plotted for each year (Table C5-24, Figure C5-11).

Spionid polychaetes were the most abundant animals found at Station NF 19. *Prionospio steenstrupi*, *Dipolydora socialis*, and *Spio limicola* ranked first, second, and third, respectively, overall at this station and were the only species to rank first during the monitoring period, *S. limicola* once in 1992, *D. socialis* once in 1994, and *P. steenstrupi* for all remaining 10 years (1995-2004). *S. limicola* ranked third for five years, most of these during the first half of the monitoring period (1994-1997), but in 1994 tying for third place with *Exogone hebes*. *Mediomastus californiensis*, which ranked second and third, three times each, ranked fourth overall at Station NF19. *Tharyx acutus* ranked fifth overall but with large numbers present only from 2002 through 2004. *Aphelochaeta marioni*, *Nucula delphinodonta*, and *Polydora* sp. 1 each ranked in second place once. *Polydora* sp. 1, totally absent every year except for 2003, was the second most numerically dominant species in 2003 with more than 800 individuals collected.

Table C5-23. Annual rank of numerically dominant species at NF19. For overall NF rank, species were ordered by the means of all 13 stations totaled for all years.

	Annual Numerical Rank												
Taxon	**1992**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**Overall NF Rank**
Prionospio steenstrupi			1	1	1	1	1	1	1	1	1	1	1
Mediomastus californiensis	3					2	2		2	3		3	2
Spio limicola	1	3	3	3	3					3			3
Tharyx acutus										2	3	2	4
Dipolydora socialis	2	1			2		3	2					6
Aphelochaeta marioni			2			3							8
Exogone hebes		3		2									9
Nucula delphinodonta		2						3	3				11
Polydora sp. 1											2		51

Table C5-24. Mean number of individuals (n=1) belonging to the 12 most abundant species found in samples collected from NF19 from 1992 and 1994 through 2004. Taxa are listed in order of decreasing total mean abundance at this station.

Taxon	1992	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Prionospio steenstrupi	49	6	567	579	713	1118	2973	1373	780	2038	1833	499
Dipolydora socialis	1081	249	148	169	633	49	197	414	15	33	12	19
Spio limicola	1338	55	295	194	259	66	46	38	1	234	81	23
Mediomastus californiensis	186	20	166	121	81	222	266	174	177	233	220	169
Tharyx acutus	74	25	79	17	37	21	19	7	26	405	517	351
Aphelochaeta marioni	19	1	419	157	56	166	53	110	64	35	16	23
Nucula delphinodonta	17	65	21	54	101	69	85	330	95	119	85	64
Aricidea catherinae	9	7	20	54	67	45	38	23	61	212	262	161
Exogone hebes	19	53	79	214	131	55	76	70	39	76	42	48
Polydora sp. 1	0	0	0	0	0	0	0	0	0	0	829	0
Euchone incolor	5	2	39	56	67	63	164	158	47	76	29	11
Phyllodoce mucosa	19	2	43	23	16	41	109	35	13	53	103	68

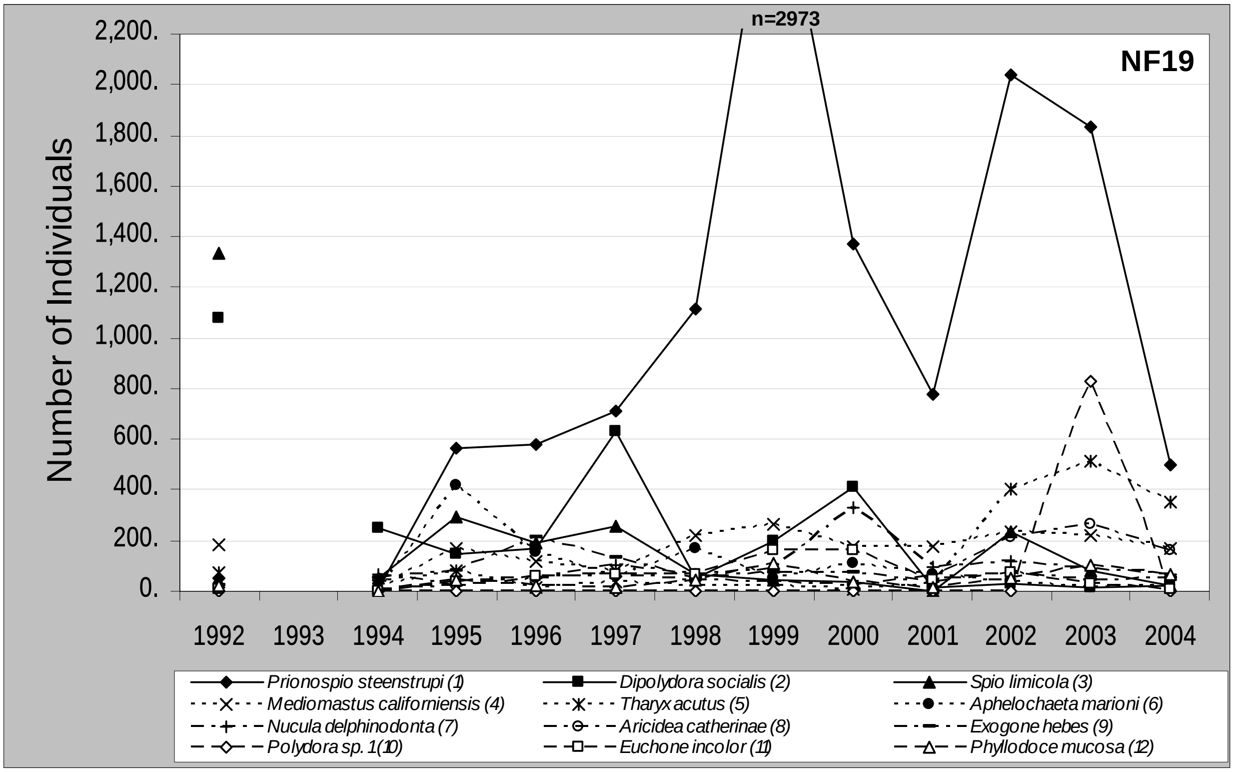

Figure C5-11. Mean number of individuals (n=1) belonging to the 12 most abundant species at NF19 from 1992 through 2004. The station rank order of each species follows the species name.

NF22

Station NF22 has been sampled every August since 1994 for a total of 11 samples, one each year. Eight species were top dominants, ranking first, second, or third at least once during the 11-year sampling period (Table C5-25). The 12 most abundant taxa (more than 500 specimens each) were all polychaetes. Mean abundance of these species are tabulated and plotted for each year (Table C5-26, Figure C5-12).

The top dominant species found at Station NF22 was *Mediomastus californiensis*, which ranked first, second, or third for 10 years (1995-2004), during five of which it was the most common species found. The next most abundant species was *Tharyx acutus* (a large number of unidentified Cirratulidae not included in this analysis are possibly also *T. acutus*). *T. acutus* was a consistent presence at Station NF22 and ranked second six times and first twice, both times during the last two years of the current monitoring program (2003-2004). The spionids, *Spio limicola* and *Prionospio steenstrupi*, were next in abundance, ranking third and fourth overall, respectively. Both species ranked first and second once and third three times with *S. limicola* concentrated towards the earlier years of sampling and *P. steenstrupi* towards the later years; these spionids actually tied for third place in 2001. Two additional species were first in numbers during one year of sampling only, *Ninoe nigripes* (1996) and *Euchone incolor* (1999), and ranked fifth and sixth overall, respectively, at this station.

Table C5-25. Annual rank of numerically dominant species at NF22. For overall NF rank, species were ordered by the means of all 13 stations totaled for all years.

	Annual Numerical Rank											
Taxon	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**Overall NF Rank**
Prionospio steenstrupi					3	3		3	1	2		1
Mediomastus californiensis		1	3	1	1	2	1	1	3	3	2	2
Spio limicola	1	3	2				3	3				3
Tharyx acutus	2	2		2	2			2	2	1	1	4
Dipolydora socialis	3											6
Ninoe nigripes			1	3								7
Levinsenia gracilis											3	10
Euchone incolor						1	2					12

Table C5-26. Mean number of individuals (n=1) belonging to the 12 most abundant species found in samples collected from NF22 from 1994 through 2004. Taxa are listed in order of decreasing total mean abundance at this station.

Taxon	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Mediomastus californiensis	480	439	379	342	486	312	470	379	409	627	305
Tharyx acutus	742	289	166	305	209	51	156	192	697	927	318
Spio limicola	1193	280	499	134	51	75	254	141	235	308	25
Prionospio steenstrupi	42	54	90	169	197	271	172	143	1058	814	81
Ninoe nigripes	56	79	534	270	149	77	186	54	57	90	69
Euchone incolor	30	51	219	225	171	328	274	99	59	50	26
Levinsenia gracilis	75	141	114	102	109	103	218	86	141	187	134
Aphelochaeta marioni	288	129	169	189	91	59	40	7	37	31	13
Dipolydora socialis	668	0	7	4	0	2	92	0	2	4	0
Leitoscoloplos acutus	29	32	47	38	35	49	128	108	115	55	30
Monticellina baptisteae	81	21	36	101	55	27	76	23	25	37	71
Parougia caeca	15	59	76	64	32	23	12	33	55	121	57

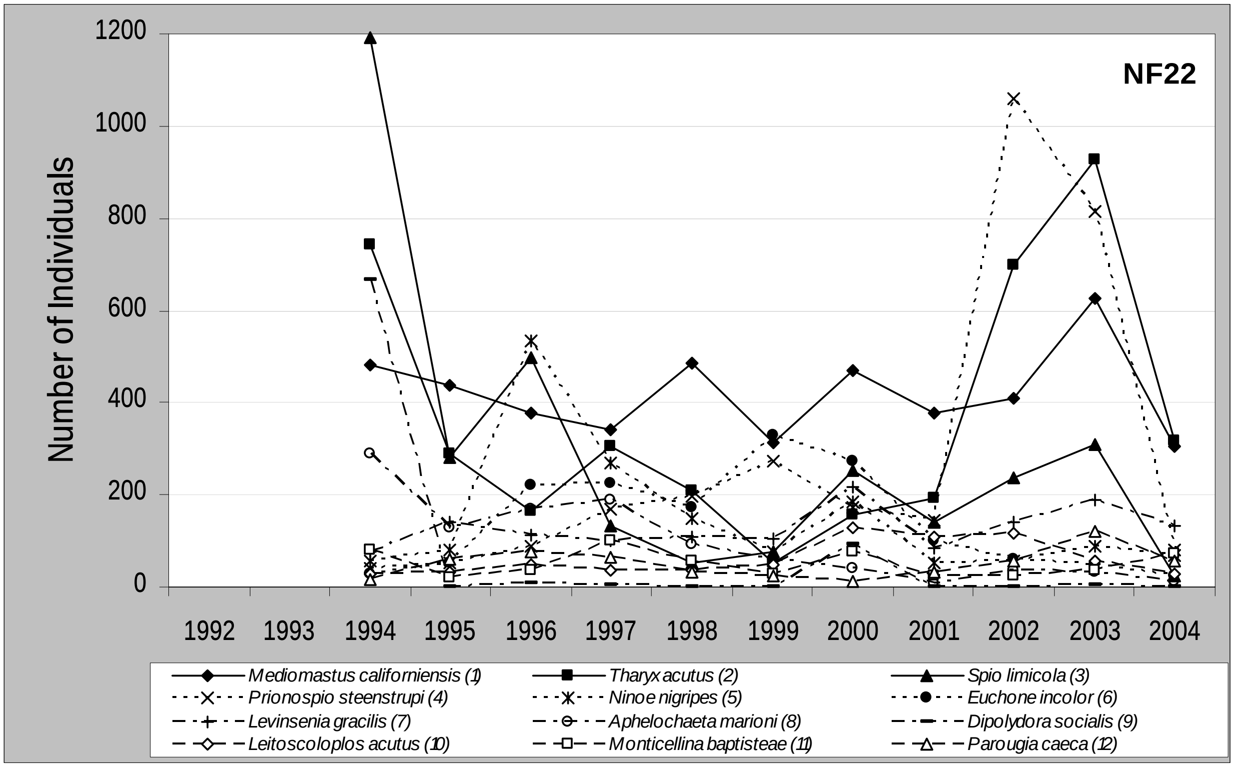

Figure C5-12. Mean number of individuals (n=1) belonging to the 12 most abundant species at NF22 from 1992 through 2004. The station rank order of each species follows the species name.

NF23

Station NF23 has been sampled every August since 1994 for a total of 11 samples, one each year. Twelve species were top dominants at this very diverse station, ranking first, second, or third at least once during the 11-year sampling period and seven species ranked first at least once (Table C5-27). The 12 most abundant taxa (more than 600 specimens each) included six polychaetes, one oligochaete, one phoronid, two amphipods, one bivalve, and one tunicate. The mean abundance of these species are tabulated and plotted for each year (Table C5-28, Figure C5-13.

The syllid polychaete, *Exogone hebes*, was the top dominant and was the most abundant animal for four sampling years spread throughout the sampling period (1994, 2000, 2002, 2004). *Prionospio steenstrupi* was the next most abundant species found over all the years of sampling but only ranked first once, in 1997. A second spionid, *Spiophanes bombyx*, held the top ranking spot two times, in 1998 and 2001, while a third spionid *Dipolydora socialis*, although more abundant than *S. bombyx* overall, only ranked second one time and third twice. The two amphipods, *Crassicorophium crassicorne* and *Unciola inermis*, each ranked first, second, or third once while *Phoronis architecta* and the oligochaete Enchytraeidae sp. 1 each were the numerically dominant species one time. The polychaetes, *Exogone hebes* and *Polygordius* sp. A, each ranked second and third one time, while the tunicate, *Molgula manhattensis*, and bivalve, *Hiatella arctica*, ranked second and third, respectively, once.

Table C5-27. Annual rank of numerically dominant species at NF23. For overall NF rank, species were ordered by the means of all 13 stations totaled for all years.

	Annual Numerical Rank											
Taxon	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**Overall NF Rank**
Prionospio steenstrupi			3	1		3				2		1
Dipolydora socialis				3		2			3			6
Exogone hebes	1	2		2			1	2	1	3	1	9
Exogone verugera	3		2									13
Phoronis architecta										1		16
Crassicorophium crassicorne	2		1				3					17
Spiophanes bombyx					1		2	1				19
Molgula manhattensis									2			20
Polygordius sp. A					3						2	22
Hiatella arctica											3	23
Unciola inermis		3			2	1						24
Enchytraeidae sp. 1		1						3				41

Table C5-28. Mean number of individuals (n=1) belonging to the 12 most abundant species found in samples collected from NF23 from 1994 through 2004. Taxa are listed in order of decreasing total mean abundance at this station.

Taxon	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Exogone hebes	382	383	250	401	61	215	209	177	358	234	415
Prionospio steenstrupi	85	26	253	909	124	272	23	44	25	291	130
Unciola inermis	34	171	203	230	194	438	118	11	4	4	0
Dipolydora socialis	210	0	157	295	2	285	49	10	120	157	51
Crassicorophium crassicorne	214	157	546	66	1	67	126	65	18	1	0
Phoronis architecta	4	3	0	1	0	0	1	40	0	989	87
Enchytraeidae sp. 1	0	393	0	47	0	166	50	102	63	96	193
Exogone verugera	88	166	418	115	7	123	33	63	44	11	20
Spiophanes bombyx	11	12	0	36	260	46	137	220	59	33	144
Polygordius sp. A	67	78	3	4	156	41	107	50	10	40	364
Molgula manhattensis	0	48	0	6	12	27	85	97	281	169	152
Hiatella arctica	18	68	49	38	21	58	11	2	35	21	320

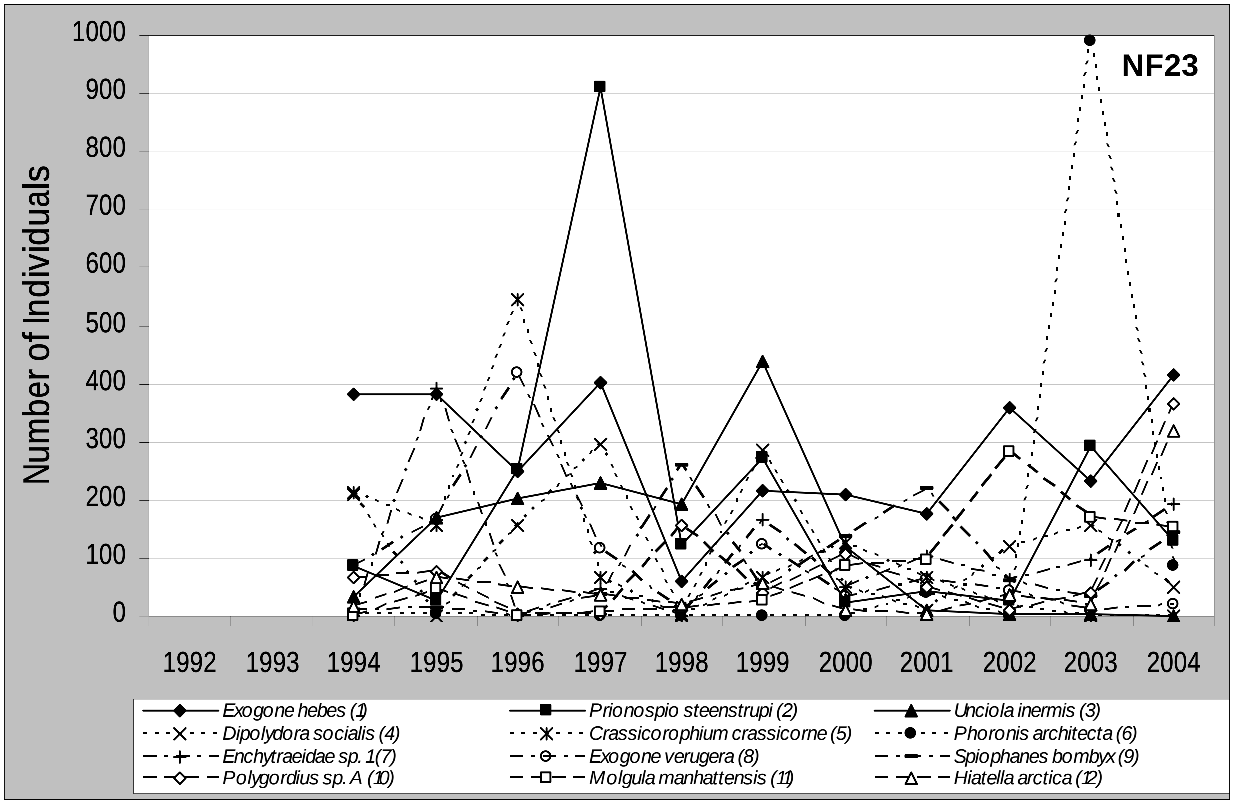

Figure C5-13. Mean number of individuals (n=1) belonging to the 12 most abundant species at NF23 from 1992 through 2004. The station rank order of each species follows the species name.

Nearfield Summary

Examining data from all sampling years (a total of 264 samples) for the 13 nearfield stations sampled in 2004 showed that a large diversity of animals were consistently or sporadically important components of the benthic community. A total of 44 species occurred at one time or another among the top 12 most abundant species found when all 13 stations were tabulated together (Table C5-1). Of these, 38 species ranked first, second, or third at least once during the 13 years of this monitoring program. While the 14 most abundant species (ordered by station mean totals) found in the nearfield were dominant at least at some time during the monitoring program, there were other species that were important at some point but were generally much less commonly found. For an extreme example, the isopod *Chiridotea tuftsi* was the second most abundant animal found at Station NF17 in 1993. This species ranked twelfth in numbers at Station NF17 but only seventy-fourth among all nearfield species combined (Table C5-1).

Three polychaete species were top dominants at most stations during at least some years of sampling. *Prionospio steenstrupi* was a top dominant at all stations except for sandy Station NF17; *Mediomastus californiensis* ranked highly at all stations except for NF 17 and NF23, while *Spio limicola* was predominant at all stations except for NF17, NF23, and FF13 (Table C5-1). Three additional polychaete species, *Dipolydora socialis*, *Tharyx acutus*, and *Aricidea catherinae* held top-ranking positions at more than half of the stations. Fifteen species dominated at from two to five stations. Of these, five species were top ranking species only at sandy stations NF17 and NF23; *Crassicorophium crassicorne*, *Molgula manhattensis*, *Unciola inermis*, *Spiophanes bombyx*, and *Polygordius* sp. A. Seventeen species, including seven polychaetes, two oligochaetes, four amphipods, one isopod, two bivalves, and a sand dollar ranked first, second, or third at only one station (Table C5-1) but many of these held such a top rank for several years of the program. A few species only ranked highly at one station for only one year. For example, the amphipod, *Haploops fundiensis*, ranking only fifty-ninth overall (Table C5-2) one year only (1999) held the third-ranking spot.

Many species were found consistently at many stations over most of the last 13 years of the monitoring program. These include *Prionospio steenstrupi*, *Mediomastus californiensis*, *Tharyx acutus*, and *Dipolydora socialis*. Others were very prominent for only some years. For example, *Spio limicola* was very commonly found at many stations in the early years of sampling, from 1992 through about 1996, after which its numbers fell off dramatically. However, since 2002, *S. limicola* has increased in numbers and this species has again become a high-ranking species at a few stations (NF05, NF07 and NF09). Conversely, numbers of *Euchone incolor* increased in numbers in the nearfield starting in 1996 when it ranked second at NF16, then appeared at NF12, ranking third in 1998, and finally in 1999 and 2000 ranked first and second, respectively, at Station NF22 and third at NF08 in both years. However, *E. incolor* has not been a top-ranking species at any station since 2000. Some species have been consistently present at some stations but at other stations have been dominant species for only a few years. For example, *Aricidea catherinae* has been a fairly consistent member of the community at Station FF13 (high-ranking for 8 years spread throughout the monitoring program), but was common only early in the program at NF08 (1992-1995), NF12 (1992-1995 and 1997), and NF16 (1992-1994) while later in the program it gained prominence at FF10 starting in 1997 (through 2003) and NF19 starting in 2002 (through 2004).

A compilation of the numerically dominant species by year in presented in (Tables C5-29 – C5-35). The numerically dominant species seen in any given year range in number from nine species in 1993 (21 samples collected) to 17 species in 2000 (21 samples collected). Considering only the last ten years of monitoring (1994-2004) when all of the same stations were sampled the same number of times each year, the range is only slightly smaller, from 11 species in 2003 to the17 species seen in 2000. Of these species, the top five numerically dominant species for the nearfield as a whole are those most consistently present. *Prionospio steenstrupi*, *Mediomastus californiensis*, and *Spio limicola*, ranking first, second, and third, respectively, overall in the nearfield have been present as top dominants every year. The fourth ranking species, *Tharyx acutus* was numerically dominant during all years except 1996 and 1999 and the fifth ranking species, *Aricidea catherinae*, was a top dominant every year except for 1996. The remaining species occurred as top dominants on a more sporadic basis.

The diversity of species that have been found to contribute to the most abundant members of the benthic community and the wide fluctuations seen in species composition of dominant species from year-to-year at the 13 nearfield stations examined here contribute to the evidence of the dynamic nature of this fairly restricted geographic area of Massachusetts Bay.

Table C5-29. Annual rank of numerically dominant species in 1992 and 1993 for nearfield stations sampled in 2004. A total of 38 taxa had mean counts ranking first, second, or third at least once; only those with high ranks for each year are listed here. For overall NF rank, species were ordered by the station means totaled for all years.

	1992											
Taxon	**FF10**	**FF13**	**NF05**	**NF07**	**NF08**	**NF09**	**NF12**	**NF16**	**NF17**	**NF18**	**NF19**	**Overall NF Rank**
Prionospio steenstrupi	2	1		3						2		1
Mediomastus californiensis		2			2	2	1	1		3	3	2
Spio limicola	1		1	1		1	2			1	1	3
Tharyx acutus		3			3							4
Aricidea catherinae					1		3	2				5
Dipolydora socialis	3		2			3					2	6
Exogone hebes									2			9
Levinsenia gracilis								3				10
Exogone verugera				2								13
Crassicorophium crassicorne									1			17
Unciola inermis									3			24
Tubificidae sp. 2								3				35
Dipolydora quadrilobata			3									36

	1993							
Taxon	**FF10**	**FF13**	**NF08**	**NF09**	**NF12**	**NF16**	**NF17**	**Overall NF Rank**
Prionospio steenstrupi	2			2				1
Mediomastus californiensis	3	3	3	3	1	1		2
Spio limicola	1			1	3	2		3
Tharyx acutus		1	2					4
Aricidea catherinae		2	1		2	3		5
Crassicorophium crassicorne							1	17
Nephtys cornuta		3						46
Pseudunciola obliquua							3	49
Chiridotea tuftsi							2	74

Table C5-30. Annual rank of numerically dominant species in 1994 and 1995 for nearfield stations sampled in 2004. A total of 38 taxa had mean counts ranking first, second, or third at least once; only those with high ranks for each year are listed here. For overall NF rank, species were ordered by the station means totaled for all years.

Taxon	1994													
	FF10	**FF13**	**NF05**	**NF07**	**NF08**	**NF09**	**NF12**	**NF16**	**NF17**	**NF18**	**NF19**	**NF22**	**NF23**	**Overall NF Rank**
Prionospio steenstrupi	2	1								1				1
Mediomastus californiensis	2	2		3	3	2	2							2
Spio limicola	1			2	1	1	1				3	1		3
Tharyx acutus												2		4
Aricidea catherinae		3			2		3	1						5
Dipolydora socialis				1					2		1	3		6
Ninoe nigripes								3						7
Exogone hebes									3		3		1	9
Levinsenia gracilis								2						10
Nucula delphinodonta	3		2								2			11
Exogone verugera			3							3			3	13
Monticellina baptisteae						3								14
Crassicorophium crassicorne									1				2	17
Crenella decussata			1											26
Asabellides oculata										2				32

Taxon	1995													
	FF10	**FF13**	**NF05**	**NF07**	**NF08**	**NF09**	**NF12**	**NF16**	**NF17**	**NF18**	**NF19**	**NF22**	**NF23**	**Overall NF Rank**
Prionospio steenstrupi	1	1	1	1	3	1				1	1			1
Mediomastus californiensis	2	2		3	1	2	1	1		3		1		2
Spio limicola	3			2		3	2	3			3	3		3
Tharyx acutus			3									2		4
Aricidea catherinae					2		3							5
Aphelochaeta marioni			2								2			8
Exogone hebes										2			2	9
Monticellina baptisteae								2						14
Crassicorophium crassicorne									3					17
Polygordius sp. A									1					22
Unciola inermis													3	24
Enchytraeidae sp. 1													1	41
Nephtys cornuta		3												46
Pseudunciola obliquua									2					49

Table C5-31. Annual rank of numerically dominant species in 1996 and 1997 for nearfield stations sampled in 2004. A total of 38 taxa had mean counts ranking first, second, or third at least once; only those with high ranks for each year are listed here. For overall NF rank, species were ordered by the station means totaled for all years.

	1996													
Taxon	**FF10**	**FF13**	**NF05**	**NF07**	**NF08**	**NF09**	**NF12**	**NF16**	**NF17**	**NF18**	**NF19**	**NF22**	**NF23**	**Overall NF Rank**
Prionospio steenstrupi	1	1	1	1	2	1		3		1	1		3	1
Mediomastus californiensis	3				1	2	1	1				3		2
Spio limicola	2			2			2	1			3	2		3
Dipolydora socialis				3										6
Ninoe nigripes					3	3		1		2		1		7
Aphelochaeta marioni			2	3			3							8
Exogone hebes											2			9
Levinsenia gracilis								3						10
Euchone incolor								2						12
Exogone verugera			3										2	13
Phoronis architecta		3												16
Crassicorophium crassicorne									2				1	17
Polygordius sp. A									1					22
Hiatella arctica										3				23
Unciola inermis									3					24
Nephtys cornuta		2												46

	1997													
Taxon	**FF10**	**FF13**	**NF05**	**NF07**	**NF08**	**NF09**	**NF12**	**NF16**	**NF17**	**NF18**	**NF19**	**NF22**	**NF23**	**Overall NF Rank**
Prionospio steenstrupi	1	1	1	3	1	1		1		1	1		1	1
Mediomastus californiensis		3	3		2	3	1			3		1		2
Spio limicola						2	1				3			3
Tharyx acutus								3				2		4
Aricidea catherinae	2						3							5
Dipolydora socialis				2			2				2		3	6
Ninoe nigripes					3			2				3		7
Aphelochaeta marioni			2											8
Exogone hebes				1									2	9
Nucula delphinodonta	3													11
Spiophanes bombyx									1					19
Hiatella arctica										2				23
Photis pollex		2												25
Cerastoderma pinnulatum									3					30
Pseudunciola obliquua									2					49

Table C5-32. Annual rank of numerically dominant species in 1998 and 1999 for nearfield stations sampled in 2004. A total of 38 taxa had mean counts ranking first, second, or third at least once; only those with high ranks for each year are listed here. For overall NF rank, species were ordered by the station means totaled for all years.

	1998													
Taxon	**FF10**	**FF13**	**NF05**	**NF07**	**NF08**	**NF09**	**NF12**	**NF16**	**NF17**	**NF18**	**NF19**	**NF22**	**NF23**	**Overall NF Rank**
Prionospio steenstrupi	1	1	1	1	1	1	2	1		1	1	3		1
Mediomastus californiensis	3		2	2	2	2	1	2			2	1		2
Spio limicola				3										3
Tharyx acutus												2		4
Aricidea catherinae	2	2				3								5
Ninoe nigripes					3									7
Aphelochaeta marioni			3								3			8
Exogone hebes										3				9
Levinsenia gracilis								3						10
Euchone incolor							3							12
Exogone verugera										2				13
Crassicorophium crassicorne									3					17
Spiophanes bombyx									1				1	19
Polygordius sp. A									2				3	22
Unciola inermis													2	24
Nephtys cornuta		3												46

	1999													
Taxon	**FF10**	**FF13**	**NF05**	**NF07**	**NF08**	**NF09**	**NF12**	**NF16**	**NF17**	**NF18**	**NF19**	**NF22**	**NF23**	**Overall NF Rank**
Prionospio steenstrupi	1	1	2	1	1	1	1	1		1	1	3	3	1
Mediomastus californiensis	3	3			2	2	2	2		3	2	2		2
Spio limicola				3										3
Aricidea catherinae	2	2												5
Dipolydora socialis			1	2			3				3		2	6
Ninoe nigripes						3		3						7
Euchone incolor					3							1		12
Crassicorophium crassicorne									1					17
Polygordius sp. A									3					22
Unciola inermis													1	24
Protomedeia fasciata										2				27
Pseudunciola obliquua									2					49
Haploops fundiensis			3											59

Table C5-33. Annual rank of numerically dominant species in 2000 and 2001 for nearfield stations sampled in 2004. A total of 38 taxa had mean counts ranking first, second, or third at least once; only those with high ranks for each year are listed here. For overall NF rank, species were ordered by the station means totaled for all years.

Taxon	**2000**													
	FF10	**FF13**	**NF05**	**NF07**	**NF08**	**NF09**	**NF12**	**NF16**	**NF17**	**NF18**	**NF19**	**NF22**	**NF23**	**Overall NF Rank**
Prionospio steenstrupi	1	1	1	1	1	1	1	1		1	1			1
Mediomastus californiensis	2	2			2		2	2		3		1		2
Spio limicola				2		3	3					3		3
Tharyx acutus		3												4
Aricidea catherinae	3													5
Dipolydora socialis			2	3		2	1				2			6
Ninoe nigripes								3						7
Aphelochaeta marioni			3											8
Exogone hebes													1	9
Levinsenia gracilis								3						10
Nucula delphinodonta											3			11
Euchone incolor					3							2		12
Crassicorophium crassicorne									1				3	17
Spiophanes bombyx													2	19
Molgula manhattensis									2					20
Protomedeia fasciata										2				27
Pseudunciola obliquua									3					49

Taxon	**2001**													
	FF10	**FF13**	**NF05**	**NF07**	**NF08**	**NF09**	**NF12**	**NF16**	**NF17**	**NF18**	**NF19**	**NF22**	**NF23**	**Overall NF Rank**
Prionospio steenstrupi	1			1	3	1		1		2	1	3		1
Mediomastus californiensis	2		1	3		3	1	2		3	2	1		2
Spio limicola	3			2		2	2					3		3
Tharyx acutus		1	3				3	3				2		4
Aricidea catherinae	2	3												5
Aphelochaeta marioni			2		1									8
Exogone hebes									2	1			2	9
Nucula delphinodonta											3			11
Phoronis architecta					2									16
Spiophanes bombyx									3				1	19
Molgula manhattensis									1					20
Photis pollex		2												25
Enchytraeidae sp. 1													3	41

Table C5-34. Annual rank of numerically dominant species in 2002 and 2003 for nearfield stations sampled in 2004. A total of 38 taxa had mean counts ranking first, second, or third at least once; only those with high ranks for each year are listed here. For overall NF rank, species were ordered by the station means totaled for all years.

	2002													
Taxon	**FF10**	**FF13**	**NF05**	**NF07**	**NF08**	**NF09**	**NF12**	**NF16**	**NF17**	**NF18**	**NF19**	**NF22**	**NF23**	**Overall NF Rank**
Prionospio steenstrupi	1	1	1	1	2	1	1	1		1	1	1		1
Mediomastus californiensis			2	3			3	3			3	3		2
Spio limicola				2		2				3	3			3
Tharyx acutus		2			1		2	2			2	2		4
Aricidea catherinae	2	3								2				5
Dipolydora socialis													3	6
Aphelochaeta marioni					3									8
Exogone hebes													1	9
Nucula delphinodonta	3													11
Crassicorophium crassicorne									3					17
Spiophanes bombyx									2					19
Molgula manhattensis									1				2	20
Ampharete acutifrons						3								28
Haploops fundiensis			3											59

	2003													
Taxon	**FF10**	**FF13**	**NF05**	**NF07**	**NF08**	**NF09**	**NF12**	**NF16**	**NF17**	**NF18**	**NF19**	**NF22**	**NF23**	**Overall NF Rank**
Prionospio steenstrupi	1	1	1	1	1	1	1	1		1	1	2	2	1
Mediomastus californiensis	3	2	3	3			2	3				3		2
Spio limicola			2	2		3								3
Tharyx acutus					3		3	2			3	1		4
Aricidea catherinae	2	3								2				5
Exogone hebes									3				3	9
Phoronis architecta					2	2							1	16
Crassicorophium crassicorne									1					17
Asabellides oculata										3				32
Polydora sp. 1											2			51
Echinarachnius parma									2					65

Table C5-35. Annual rank of numerically dominant species in 2004 for nearfield stations sampled in 2004. A total of 38 taxa had mean counts ranking first, second, or third at least once; only those with high ranks for each year are listed here. For overall NF rank, species were ordered by the station means totaled for all years.

	2004													
Taxon	**FF10**	**FF13**	**NF05**	**NF07**	**NF08**	**NF09**	**NF12**	**NF16**	**NF17**	**NF18**	**NF19**	**NF22**	**NF23**	**Overall NF Rank**
Prionospio steenstrupi	1	3	3	1		1	1			1	1			1
Mediomastus californiensis	3	2			1	2	2	2		2	3	2		2
Spio limicola			1			3	3							3
Tharyx acutus			2		2			3			2	1		4
Aricidea catherinae		1								3				5
Exogone hebes													1	9
Levinsenia gracilis					3							3		10
Nucula delphinodonta	2													11
Exogone verugera				3										13
Crassicorophium crassicorne									3					17
Spiophanes bombyx									2					19
Molgula manhattensis									1					20
Polygordius sp. A													2	22
Hiatella arctica													3	23
Pholoe minuta				2										29
Haploops fundiensis								1						31

Farfield Stations

All four of the farfield stations sampled in 2004 (FF04, FF05, FF07, and FF09) have been sampled in triplicate every August for the last 13 years (1992-2004) for a total of 39 samples each. However, only 38 samples are analyzed for FF07 as one of the 1993 samples has been excluded from analysis due to suspect data.

FF04

At Station FF04, nine species, all polychaetes, ranked first, second, or third over the 13-year sampling period (Table C5-36). The 12 most abundant species (more than 900 specimens each) included ten polychaetes, one oligochaete, and one scaphopod mollusc. The mean abundance of these species are tabulated and plotted for each year (Table C5-37, Figure C5-14). The spionid polychaete, S*pio limicola*, ranking fifth overall, was the most abundant animal present in samples in 1992 and 1993, declined to second place in 1994, and was present only in low numbers through 2001. From 2002 until 2004, the density of *S. limicola* increased until, in 2004, this species again was the top dominant species. The next most abundant spionid, *Prionospio steenstrupi*, ranking eighth overall, ranked third in 1992-1993 and was the most abundant species in 1995-1996, but has decreased in relative abundance since then. *Mediomastus californiensis* was an important component of the infauna for the first six years of sampling (1992-1997), ranking first (two times), second (three times), or third (once); since then it also has declined in relative abundance. The cirratulid polychaete, *Chaetozone setosa* mb and the ampharetid polychaete, *Anobothrus gracilis*, were also important during the first half of the program, each ranking second one time during those six years. Starting in 1998, and only for 1998-1999, the filter-feeding sabellid polychaete, *Euchone incolor*, gained prominence, ranking first and, as well, being, in 1998, the most abundant animal at this station in all years of sampling. *C. setosa* mb continued to be important, ranking second for four years in a row (1998-2001) and attaining the topmost dominant rank in 2003 (closely tied with the paraonid polychaete, *Aricidea quadrilobata*). *Cossura longocirrata*, an important component of muddy sediments, and the top dominant species, overall, at Station FF04, has ranked first or second (three years each) for the last six years of the program.

In summary, the dominant infauna at Station FF04 has been variable with eight different polychaete species ranking either first (7 species) or second (1 species) at least once during the thirteen years of the program and can be loosely organized into three major groups by years sampled (1992-1997, 1998-1999, and 2000-2004). The period 1992-1997 was characterized by three principal species, of which the most consistent was *Mediomastus californiensis* which was among the top three most abundant species every year from 1992 through 1997, twice ranking first (1994 and 1997). Two other species that each attained the highest rank twice were *Spio limicola* (1992-1993) and *Prionospio steenstrupi* (1995-1996). The benthic fauna during 1998-1999 was dominated by *Euchone incolor*, followed by *Chaetozone setosa* mb and *Aricidea quadrilobata*. *Cossura longocirrata* also increased in numbers during this time period and by 1999 was loosely tied with *C. setosa* mb for second place. The year 2000 was marked by a sharp increase in numbers of *C. longocirrata* and a sharp decline in the numbers of *E. incolor*. For the years 2000-2004, *C. longocirrata* always ranked first (2000-2002) or second (2003-2004) and *C. setosa* mb was the second most consistent species present, ranking second or third every year except in 2003 when it shared first place with *A. quadrilobata*. Present in low numbers during most of this time period, *S. limicola* became, in 2004, the most abundant species for the first time in ten years.

Table C5-36. Annual rank of numerically dominant species at FF04. Taxa are listed in order of decreasing total mean abundance at this station.

	Annual Numerical Rank												
Taxon	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Cossura longocirrata								2	1	1	1	2	2
Chaetozone setosa mb			3		2	3	2	2	2	2	3	1	3
Euchone incolor							1	1					
Aricidea quadrilobata							3	3	3		2	1	
Spio limicola	1	1	2										1
Anobothrus gracilis						2				3			
Levinsenia gracilis	3	3		3								3	
Mediomastus californiensis	2	2	1	2	3	1							
Prionospio steenstrupi	3	3		1	1								

Table C5-37. Mean number of individuals (n=3) belonging to the 12 most abundant species found in samples collected from FF04 from 1992 through 2004. Taxa are listed in order of decreasing total mean abundance at this station.

Taxon	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Cossura longocirrata	21	10	29	30	20	73	187	90	255	164	270	147	99
Chaetozone setosa mb	19	14	45	25	59	112	231	89	167	144	177	155	94
Euchone incolor	2	4	1	4	19	98	738	189	59	7	6	0	2
Aricidea quadrilobata	10	12	26	20	32	71	207	74	71	64	195	154	77
Spio limicola	451	123	68	4	0	1	1	10	15	7	44	85	196
Anobothrus gracilis	14	4	2	5	10	143	158	50	48	111	123	60	36
Levinsenia gracilis	30	22	27	48	34	49	51	50	85	105	85	95	76
Mediomastus californiensis	44	27	83	52	55	162	140	47	62	23	20	23	15
Prionospio steenstrupi	31	21	41	83	87	82	64	37	29	11	40	62	14
Tubificoides apectinatus	8	4	5	11	21	12	55	22	56	64	102	91	95
Paramphinome jeffreysii	3	3	1	0	2	1	6	44	57	74	25	45	72
Dentalium entale	18	6	0	14	11	15	67	32	12	21	19	42	67

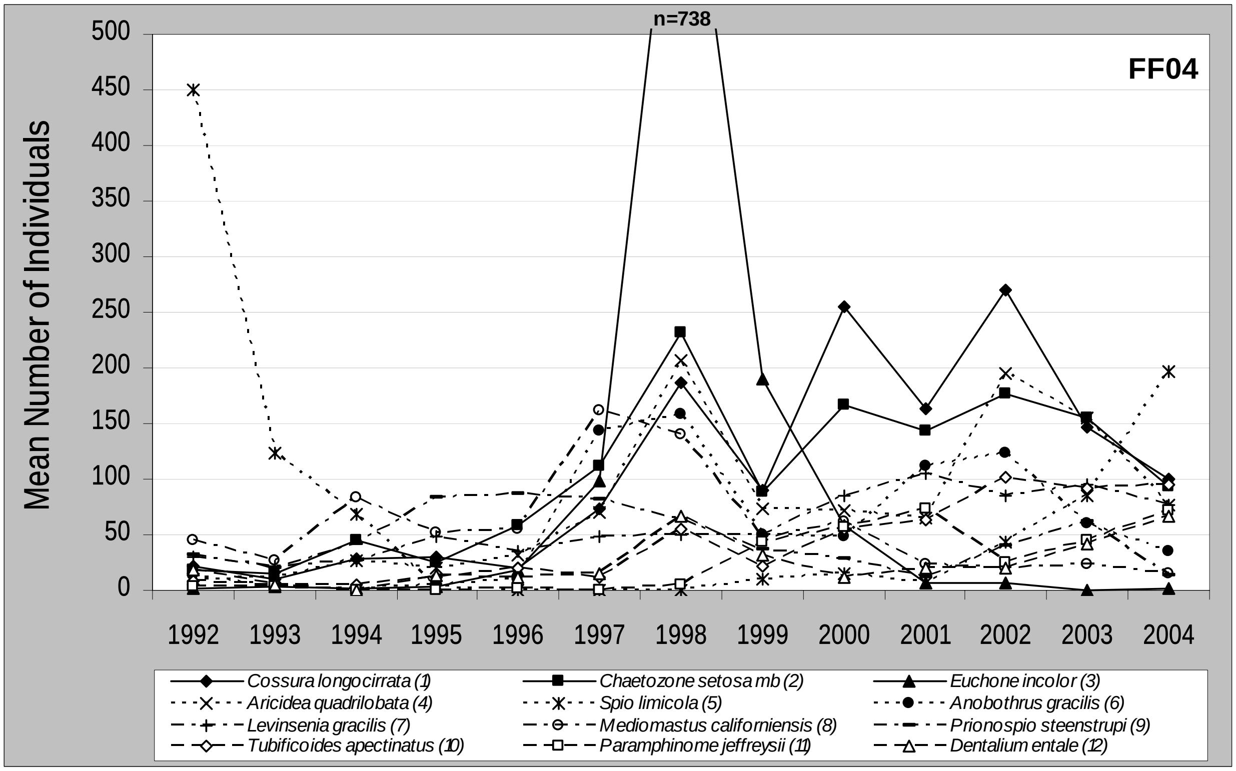

Figure C5-14. Mean number of individuals (n=3) belonging to the 12 most abundant species at FF04 from 1992 through 2004. The station rank order of each species follows the species name.

FF05

At Station FF05, ten species, nine polychaetes and one bivalve, ranked first, second, or third over the 13-year sampling period (Table C5-38). The 12 most abundant species at Station FF05 (more than 800 specimens each) included ten polychaetes and two bivalves. The mean abundance of the analyzed species are tabulated and plotted for each year (Table C5-39, Figure C5-15).

Spio limicola, the most abundant species found at Station FF05, overall, was the top dominant for the first three (1992-1994) and last three (2002-2004) years; from 1995-2000 this species was always present but in lower numbers. *Prionospio steenstrupi*, which ranked second overall, gained prominence in 1995 when it ranked first. *P. steenstrupi* remained a top dominant during most of the remainder of the program, ranking first for three years and second or third for five years. In 1997, *Mediomastus californiensis*, for the only time at this station, became the most abundant species. As at FF04, *Euchone incolor* became the top dominant in 1998 and remained so for three years (1998-2000), one year longer than at FF04. Spionid polychaetes were relatively rare in 1998 but regained prominence starting in 1999 (*Dipolydora socialis* in 1999, *S. limicola* in 2000, and *P. steenstrupi* in both years). *Aricidea quadrilobata*, which ranked second (1993) or third (1992) initially, again ranked third in 2000 and then first in 2001 (with the exception that their number was exceeded by an assemblage of unidentified ampharetid polychaetes). In 2002, the infauna was unusually even in distribution with three species, *S. limicola, P. steenstrupi*, and *Anobothrus gracilis,* sharing the top ranking spot. All three of these species as well as *A. quadrilobata* remained important for the remainder of the program.

In summary, the dominant infauna at FF05 was nearly as variable as that at FF04 with nine different polychaete species ranking either first (6 species) or second (3 species) at least once. The only non-polychaete present in enough numbers to be a dominant species was the bivalve, *Thyasira gouldi*, which ranked third in both 1992 and1993. As at FF04, the infauna can be loosely organized into three groups by year; however, at FF05, the fauna found in the year 2000 was more closely associated with that found in 1998-1999 than with 2001-2004 fauna. From 1992 through 1997, the spionids, *Spio limicola* and *Prionospio steenstrupi*, paraonids, *Aricidea quadrilobata* and *Levinsenia gracilis,* and the capitellid *Mediomastus californiensis* were the most commonly encountered species. From 1998 through 2000, *Euchone incolor* was overwhelmingly abundant, followed by *M. californiensis*, *Dipolydora socialis,* and *S. limicola,* each ranking second one time, in 1998, 1999, and 2000, respectively. *Anobothrus gracilis*, *P. steenstrupi,* and *A. quadrilobata* each ranked third at least once during these three years. From 2001-2004, *S. limicola* and *A. quadrilobata* were among the top three dominant species every year followed by *P. steenstrupi* and *A. gracilis* each of which were top dominants for three of the four years.

Table C5-38. Annual rank of numerically dominant species at FF05. Taxa are listed in order of decreasing total mean abundance at this station.

Taxon	Annual Numerical Rank												
	1992	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Spio limicola	1	1	1	2					2	3	1	1	1
Prionospio steenstrupi				1	1	2		3	3		1	3	3
Anobothrus gracilis							3			2	1		2
Euchone incolor							1	1	1				
Aricidea quadrilobata	3	2							3	1	3	2	3
Mediomastus californiensis			3		2	1	2						
Levinsenia gracilis	2		2	3	3	3					3		
Chaetozone setosa mb											2		
Thyasira gouldi	3	3											
Dipolydora socialis								2		2			

Table C5-39. Mean number of individuals (n=3) belonging to the 12 most abundant species found in samples collected from FF05 from 1992 through 2004. Taxa are listed in order of decreasing total mean abundance at this station.

Taxon	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Spio limicola	718	290	40	98	28	14	25	146	237	116	218	518	786
Prionospio steenstrupi	23	36	0	295	167	159	72	179	193	80	218	257	132
Anobothrus gracilis	9	19	4	9	39	16	98	127	212	126	220	251	474
Euchone incolor	0	1	0	3	22	26	363	441	607	79	14	0	0
Aricidea quadrilobata	28	107	19	32	33	44	66	101	195	179	148	267	131
Mediomastus californiensis	24	52	23	41	75	175	134	100	140	87	78	63	48
Levinsenia gracilis	40	37	35	77	43	66	67	65	93	96	147	123	120
Chaetozone setosa mb	14	27	0	15	22	18	68	160	165	69	161	105	53
Thyasira gouldi	27	63	17	24	21	17	34	83	79	66	64	70	70
Dipolydora socialis	23	2	11	5	20	1	1	279	92	127	12	46	4
Cossura longocirrata	8	4	5	10	12	9	35	59	77	68	79	77	29
Nucula delphinodonta	9	31	11	9	14	9	20	28	45	29	25	40	20

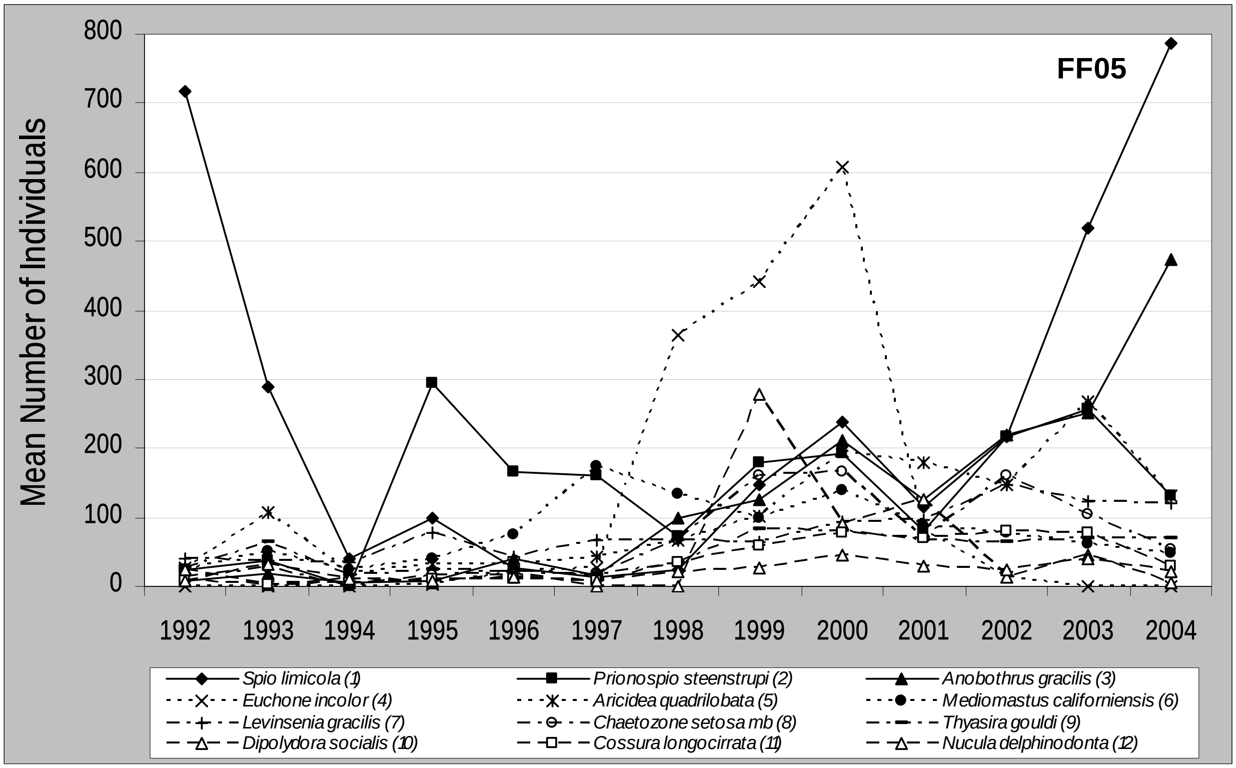

Figure C5-15. Mean number of individuals (n=3) belonging to the 12 most abundant species at FF05 from 1992 through 2004. The station rank order of each species follows the species name.

FF07

Of the four farfield stations sampled in 2004, Station FF07 had the fewest number of species (six polychaetes and one oligochaete) ranking first, second, or third over the 13-year sampling period (Table C5-40). The 12 most abundant species at Station FF07 (more than 700 specimens each) included eleven polychaetes and one oligochaete. The mean abundance of these species are tabulated and plotted for each year (Table C5-41, Figure C5-16).

The top dominant species in 1992 was *Spio limicola*. But, in contrast to the other three farfield stations treated here, *S. limicola* decreased in rank to third place in 1993 and has continued to be present only in relatively low numbers since then. *Cossura longocirrata*, the highest ranking species overall at Station FF07, has ranked first during 10 years of sampling, and second during the remaining three years (outranked only by *S. limicola* in 1992 and *Euchone incolor* in 1998-1999). Starting in 1997, *E. incolor* increased in importance to second place, ranked first in 1998 and 1999, and has continued in second place for the last five years (2000-2004). Other common species were *Aricidea catherinae*, ranking second in 1993-1994 and third in 2000-2004, as well as the oligochaete, Tubificidae sp. 2, ranking second in 1995 and third in 1992 and 1996-2000. *Tharyx acutus* ranked second or third three times (1995-1997) and *Ninoe nigripes* once (1994). At Station FF07, *Prionospio steenstrupi* was conspicuously absent from the list of the top 12 dominant species, the only one of the farfield stations where this occurred.

In contrast to Stations FF04 and FF05, dominant infaunal species at Station FF07 were much more uniformly distributed with only three species, *S. limicola*, *C. longocirrata*, and *E. incolor*, attaining top dominant status during the last 13 years. The infauna at Station FF07 can be loosely organized into four groups by year. For Station FF07, 1992 stands alone, with *S. limicola* the most abundant species, as at all four farfield stations discussed here. From 1993 through 1997, with *C. longocirrata* the highest ranking species, the next most important species included *A. catherinae* (1993-1994), Tubificidae sp. 2 and *T. acutus* (1995-1997), and *E. incolor* (1997). For 1998-2000, *E. incolor* dominated in 1998-1999, followed by *C. longocirrata* and this order was reversed in 2000 while Tubificidae sp. 2 held third place throughout. Fourthly, from 2001 through 2004, the rank order was unchanged with *C. longocirrata*, *E. incolor*, and *A. catherinae*, ranking first, second, and third, respectively.

Table C5-40. Annual rank of numerically dominant species at FF07. Taxa are listed in order of decreasing total mean abundance at this station.

Taxon	Annual Numerical Rank												
	1992	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Cossura longocirrata	2	1	1	1	1	1	2	2	1	1	1	1	1
Euchone incolor						2	1	1	2	2	2	2	2
Aricidea catherinae		2	2							3	3	3	3
Tubificidae sp. 2	3			2	3	3	3	3	3				
Tharyx acutus				3	2	2							
Spio limicola	1	3											
Ninoe nigripes			3										

Table C5-41. Mean number of individuals (n=3 except for 1993 when n=2) belonging to the 12 most abundant species found in samples collected from FF07 from 1992 through 2004. Taxa are listed in order of decreasing total mean abundance at this station.

Taxon	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Cossura longocirrata	209	668	134	187	499	1140	795	491	1368	1409	1492	2584	1983
Euchone incolor	184	68	0	10	76	191	1203	802	687	385	454	1346	1155
Aricidea catherinae	139	357	112	36	70	69	56	61	60	164	144	335	505
Tubificidae sp. 2	204	56	2	181	102	144	138	166	440	96	113	78	175
Aricidea quadrilobata	20	82	1	28	12	16	85	65	122	129	99	188	271
Tharyx acutus	41	129	0	56	111	190	120	40	146	68	48	83	23
Spio limicola	378	214	0	41	77	13	46	28	22	15	11	31	79
Ninoe nigripes	20	64	15	27	72	59	52	52	84	64	100	139	153
Prionospio steenstrupi	35	1	0	19	37	54	85	50	51	43	111	221	70
Apistobranchus typicus	31	27	0	35	25	97	105	10	109	132	1	51	14
Parougia caeca	6	2	0	1	8	8	39	18	49	41	40	64	68
Terebellides atlantis	9	28	0	2	57	8	87	4	12	6	7	41	2

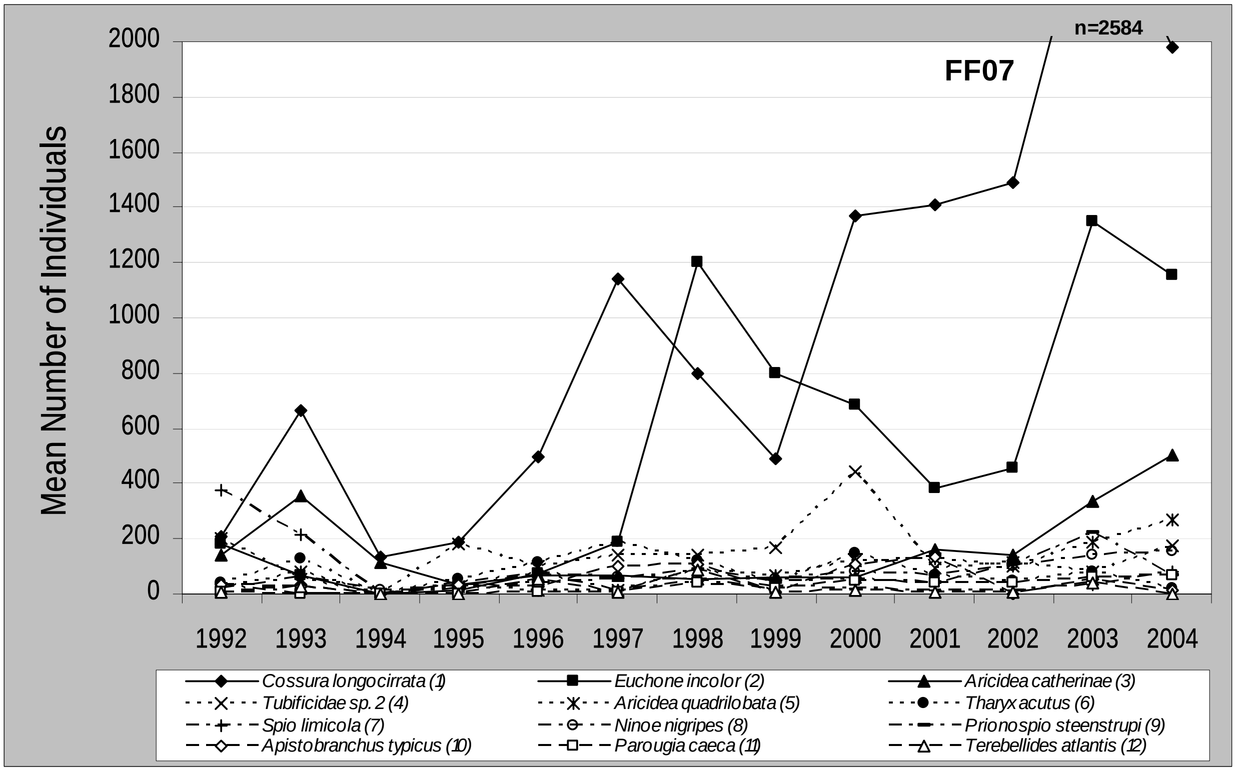

Figure C5-16. Mean number of individuals (n=3 except in 1993 when n=2) belonging to the 12 most abundant species at FF07 from 1992 through 2004. The station rank order of each species follows the species name.

FF09

At Station FF09, eight species, seven polychaetes and one bivalve, ranked first, second, or third over the 13-year sampling period (Table C5-42). The 12 most abundant species at Station FF09 (more than 900 specimens each) included ten polychaetes and two bivalves. The mean abundance of these species are tabulated and plotted for each year (Table C5-43, Figure C5-17).

Spio limicola, the second most abundant species found at Station FF09, overall, was the top dominant for the first three years (1992-1994) of the program, second for the next two years (1995-1996), and third for the following two years (1997-1998) and has been present in only low numbers since then. *Prionospio steenstrupi* was the most abundant species, overall, at FF09, ranking first nine times (1995-1998 and 2000-2004) and second for the remaining four years (1992-1994 and 1999). *Dipolydora socialis*, the third most abundant species found at FF09, was the top dominant species only once, in 1999, but ranked second five times and third three times. *Anobothrus gracilis* has increased in relative numbers since 2001, ranking second three times and third one time since then. *Mediomastus californiensis*, *Levinsenia gracilis*, and *Euchone incolor* have each ranked third two times over the monitoring period. The years that numbers of *E. incolor* were high (1999-2000) correspond to years that this species was high-ranking at other farfield stations.

As at Station FF07, the composition of the dominant infaunal species was fairly uniformly distributed. Only three species, and all spionid polychaetes, *P. steenstrupi*, *S. limicola*, and *D. socialis*, held the top ranking position at Station FF09 during the 13 years of monitoring. The only non-polychaete present in enough numbers to be a top dominant species (seventh overall) was the bivalve, *Nucula delphinodonta*, which ranked third in 2001 only. At Station FF09, infaunal associations can be placed into three groups by year. This station showed more consistency during the first half of the program than the other three farfield stations treated here. From 1992 through 1998 the three spionids, *P. steenstrupi*, *S. limicola*, and *D. socialis* along with the capitellid, *M. californiensis*, were most important. For 1999-2000, *E. incolor* replaced *S. limicola* in importance. From 2001-2004, *P. steenstrupi*, *D. socialis*, *A. gracilis*, and *L. gracilis* were the dominant

Table C5-42. Annual rank of numerically dominant species at FF09. Taxa are listed in order of decreasing total mean abundance at this station.

Taxon	**Annual Numerical Rank**												
	1992	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Prionospio steenstrupi	2	2	2	1	1	1	1	2	1	1	1	1	1
Spio limicola	1	1	1	2	2	3	3						
Euchone incolor								3	3				
Levinsenia gracilis												3	3
Mediomastus californiensis		3		3									
Dipolydora socialis	3		3		3	2	2	1	2	2	2		
Anobothrus gracilis										2	3	2	2
Nucula delphinodonta										3			

Table C5-43. Mean number of individuals (n=3) belonging to the 12 most abundant species found in samples collected from FF09 from 1992 through 2004. Taxa are listed in order of decreasing total mean abundance at this station.

Taxon	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Prionospio steenstrupi	498	288	344	1798	1364	805	565	428	628	249	591	786	442
Spio limicola	1140	438	967	243	260	370	147	47	25	1	9	44	30
Dipolydora socialis	309	14	319	54	107	556	219	578	248	120	246	93	10
Levinsenia gracilis	89	32	40	68	47	46	55	69	84	75	99	102	128
Mediomastus californiensis	105	49	78	75	73	82	60	45	49	45	57	46	41
Anobothrus gracilis	0	0	15	4	3	11	42	44	73	118	129	142	174
Nucula delphinodonta	6	5	10	6	21	43	108	43	81	112	69	92	112
Thyasira gouldi	8	3	15	12	19	31	33	48	64	63	68	80	62
Euchone incolor	2	1	3	8	34	23	30	160	133	32	4	2	3
Exogone verugera	35	35	46	53	30	16	14	28	21	10	24	28	20
Scalibregma inflatum	162	8	107	15	43	3	2	0	0	0	0	1	3
Aridicea quadrilobata	10	4	12	6	7	11	13	9	27	51	59	53	45

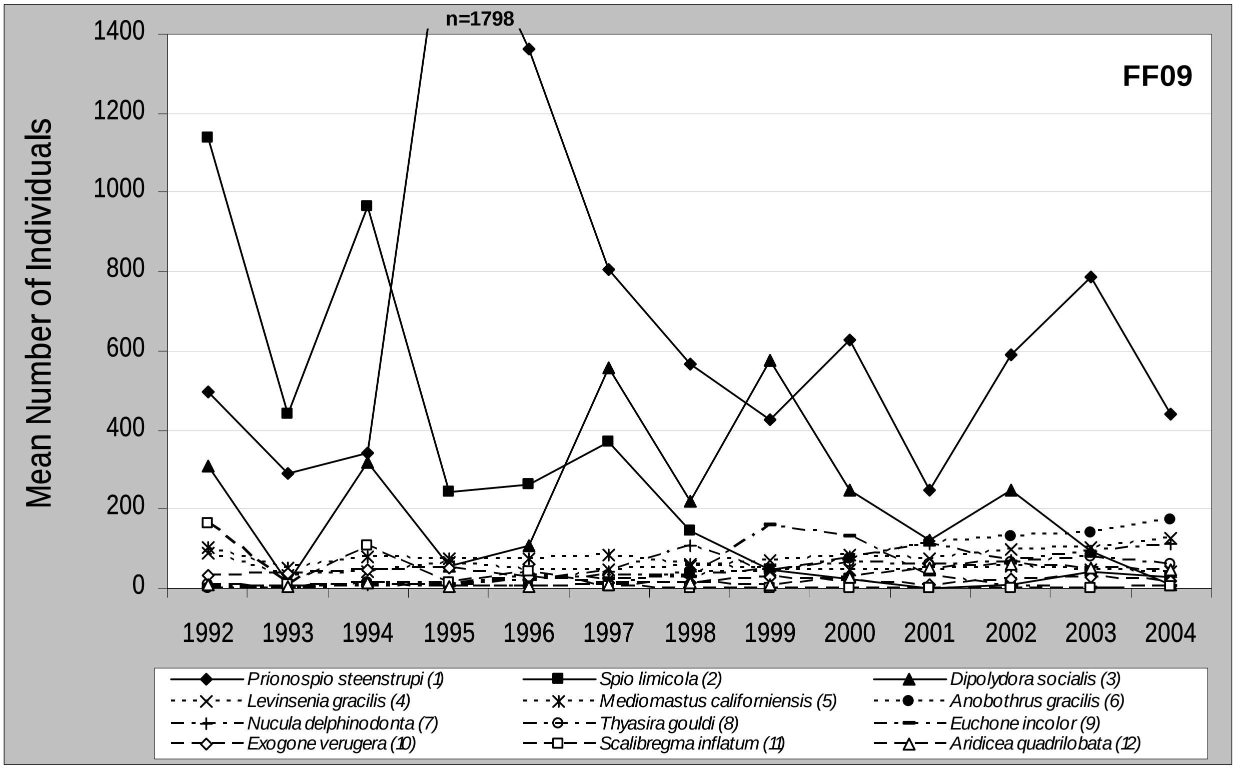

Figure C5-17. Mean number of individuals (n=3) belonging to the 12 most abundant species at FF09 from 1992 through 2004. The station rank order of each species follows the species name.

APPENDIX C6

2004 Species Covariance Loadings

	Positive Loadings on Axis 1 and Axis 2					
Species	**Axis 1**	**Axis 2**	**Axis 3**	**Axis 4**	**Axis 5**	**Axis 6**
Pusillina harpa	0.0021	0.1082	0.2029	0.0557	-0.2491	0.1913
Nucula annulata	0.0026	0.1110	0.2079	0.0587	-0.2540	0.1940
Ninoe nigripes	0.0064	0.8428	-0.0297	0.3460	0.0350	0.0151
Parapionosyllis longicirrata	0.0082	0.0789	0.1455	0.0610	-0.1612	0.1112
Dipolydora caulleryi	0.0082	0.0789	0.1455	0.0610	-0.1612	0.1112
Bostrichobranchus pilularis	0.0100	0.0735	-0.2801	-0.2325	0.0900	-0.4959
Pleurogonium rubicundum	0.0183	0.2298	-0.1024	-0.0292	0.0016	-0.2118
*Pholoe minuta/tecta/*spp.	0.0237	0.0419	-0.2883	-0.1400	0.1280	-0.2028
Dipolydora quadrilobata	0.0241	0.0649	-0.3070	-0.2111	0.0793	-0.4493
Ophelina acuminata	0.0332	0.0306	-0.4578	-0.1394	0.2993	-0.0960
Edwardsia elegans	0.0346	0.1627	-0.1989	0.2140	-0.0350	0.2313
Pentamera calcigera	0.0419	0.0097	-0.2627	-0.0846	0.1310	-0.1227
Leitoscoloplos acutus	0.0475	0.5380	0.0654	0.2489	0.1230	-0.1140
Ophiura sarsi	0.0616	0.1029	0.2672	0.0743	-0.3461	0.1759
Nereis grayi	0.0645	0.2201	-0.4708	-0.0282	0.2152	-0.0449
Byblis gaimardi	0.0764	0.1078	-0.1839	-0.1732	-0.0580	-0.5757
*Apistobranchus typicus/*spp.	0.0923	0.2986	-0.2195	0.2454	0.0717	0.0660
Enipo torelli	0.0932	0.1582	-0.1230	-0.1370	-0.1384	-0.5693
Deflexilodes tesselatus	0.1003	0.2712	-0.0909	0.1881	-0.0533	-0.2909
Polycirrus phosphoreus	0.1044	0.0620	-0.1274	-0.2138	-0.0863	-0.3789
Stenopleustes inermis	0.1246	0.1374	0.1128	0.0664	-0.0884	0.1287
Casco bigelowi	0.1319	0.0678	-0.3449	0.2692	0.1533	0.0592
Parougia caeca	0.1334	0.4093	-0.1486	0.2035	0.0368	0.0532
Gattyana amondseni	0.1478	0.3355	-0.3647	-0.0563	0.0780	-0.3942
Nemertea sp. 2	0.1981	0.1472	0.3908	-0.1697	0.2780	0.1196
Onoba pelagica	0.2016	0.0976	0.0337	-0.2368	0.3341	-0.4699
Prionospio steenstrupi	0.2177	0.4909	-0.6698	0.1267	0.0715	-0.0505
Praxillella gracilis	0.2281	0.0969	0.2504	0.0769	0.0605	0.0701
Metopella angusta	0.2350	0.3146	0.3158	0.0037	0.0938	0.0273
Pleurogonium inerme	0.2356	0.0132	-0.1146	0.0828	-0.3981	0.1021
Goniada maculata	0.2357	0.1035	-0.3916	0.2775	0.0327	0.1084
Nucula delphinodonta	0.2612	0.1022	-0.6718	0.1653	0.1418	-0.0006
Micrura spp.	0.3854	0.2657	-0.0283	0.1526	0.3619	-0.0224
Aphelochaeta marioni	0.4329	0.0926	0.1272	-0.2840	0.5353	0.0357
Scoletoma fragilis	0.4670	0.0468	-0.1580	0.0041	0.1577	-0.2341
Spio limicola	0.6165	0.0292	0.2222	-0.2380	0.0265	-0.5291
Levinsenia gracilis	0.7641	0.0286	-0.1661	0.1117	0.1296	-0.1490

	Positive Loading on Axis 1 and Negative Loading on Axis 2					
Species	**Axis 1**	**Axis 2**	**Axis 3**	**Axis 4**	**Axis 5**	**Axis 6**
Nicolea zostericola	0.0465	-0.1669	-0.3083	-0.2474	-0.0735	0.4500
Henricia sanguinolenta	0.0558	-0.0326	-0.2871	-0.0738	0.0102	0.2996
Pleurogonium spinosissimum	0.0663	-0.2449	-0.3829	-0.4533	-0.1738	0.4099
Exogone verugera	0.0727	-0.0345	-0.4702	-0.1704	0.1916	-0.1129
Sphaerosyllis erinaceus	0.0887	-0.0777	-0.4035	-0.1689	0.1001	-0.0868
Euclymene collaris	0.0914	-0.1965	-0.0436	-0.4627	-0.3548	-0.3329
Asabellides oculata	0.1286	-0.0413	-0.5127	-0.2207	0.3359	-0.4213
Hippomedon propinquus	0.1611	-0.0800	-0.3159	0.1300	-0.0167	0.2717
Siliqua costata	0.1742	-0.1384	-0.2730	0.1123	-0.0521	0.3112
Nothria sp. 1	0.1742	-0.1384	-0.2730	0.1123	-0.0521	0.3112
Aricidea minuta	0.1742	-0.1384	-0.2730	0.1123	-0.0521	0.3112
Gitanopsis arctica	0.1794	-0.1117	-0.4186	-0.3552	-0.1352	-0.4104
Ericthonius fasciatus	0.1835	-0.2658	-0.4185	-0.2448	-0.1921	0.3530
Nephtys ciliata	0.1893	-0.0940	0.0559	-0.0019	-0.2275	-0.0757
Phyllodoce groenlandica	0.2015	-0.0955	0.0950	-0.0137	-0.2238	-0.1315
Cancer borealis	0.2015	-0.0955	0.0950	-0.0137	-0.2238	-0.1315
Eumida sanguinea	0.2059	-0.0896	-0.0731	-0.1709	-0.2060	-0.5157
Phoronis architecta	0.2185	-0.1610	-0.6638	-0.1610	0.0651	0.1468
Ophiura sp. 2	0.2323	-0.2044	-0.4346	0.1083	0.3162	-0.0155
Dyopedos monacanthus	0.2326	-0.1041	0.0571	-0.1337	-0.3608	-0.4748
Cancer borealis	0.2329	-0.1265	-0.4847	-0.1048	-0.0683	-0.2007
Nephasoma diaphanes	0.2428	-0.0958	0.3271	-0.2041	0.3528	-0.0967
Turbellaria spp.	0.2550	-0.1064	0.4380	-0.1615	0.2981	-0.0076
Laonice sp. 1	0.2634	-0.1512	0.0689	-0.1227	-0.3822	-0.4866
Lanassa venusta venusta	0.2634	-0.1512	0.0689	-0.1227	-0.3822	-0.4866
Polydora cornuta	0.2654	-0.1224	0.3262	-0.1093	0.3445	0.1075
Nuculana pernula	0.2654	-0.1224	0.3262	-0.1093	0.3445	0.1075
Ancistrosyllis groenlandica	0.2654	-0.1224	0.3262	-0.1093	0.3445	0.1075
Spio setosa	0.2684	-0.2625	-0.3807	0.1940	0.2749	0.1061
Macoma balthica	0.2684	-0.2625	-0.3807	0.1940	0.2749	0.1061
Ampharete finmarchica	0.2684	-0.2625	-0.3807	0.1940	0.2749	0.1061
Brada villosa	0.2818	-0.1511	-0.5429	0.1940	0.2190	0.0656
Oenopota incisula	0.2837	-0.0559	0.1829	-0.3179	-0.0444	-0.4641
Myriochele heeri	0.2926	-0.1848	-0.1594	0.0836	-0.2261	0.1699
Maldane sarsi/spp.	0.2958	-0.0621	-0.5951	0.2098	0.0176	0.1245
Paradulichia typica	0.2989	-0.1629	-0.5637	-0.0761	0.0623	-0.2288
Paramphinome jeffreysii	0.3048	-0.1545	0.4457	-0.1372	0.3389	0.1030
Prionospio aluta	0.3112	-0.1731	0.0931	-0.1227	-0.4326	-0.5083
Westwoodilla megalops	0.3126	-0.2479	-0.3939	0.0849	-0.1836	0.2128
Streblosoma spiralis	0.3126	-0.2479	-0.3939	0.0849	-0.1836	0.2128
Aphrodita hastata	0.3126	-0.2479	-0.3939	0.0849	-0.1836	0.2128
Cossura longocirrata	0.3141	-0.0180	0.5637	-0.0366	-0.0571	0.2033
Paranaitis speciosa	0.3227	-0.0252	-0.4409	-0.0325	-0.2053	-0.2949

	Positive Loading on Axis 1 and Negative Loading on Axis 2					
Species	**Axis 1**	**Axis 2**	**Axis 3**	**Axis 4**	**Axis 5**	**Axis 6**
Rhodine loveni	0.3323	-0.2010	-0.6439	0.0184	0.0240	-0.0797
Cephalothricidae sp. 1	0.3325	-0.2411	0.4419	-0.1477	0.2538	0.0952
Tubificoides apectinatus	0.3355	-0.0828	0.6039	-0.1046	0.3424	0.1328
Diastylis cornuifer	0.3369	-0.1353	0.4611	-0.1826	0.0617	-0.1723
Crenella decussata	0.3370	-0.2189	-0.7442	0.0705	0.2841	0.0577
Dysponetus pygmaeus	0.3381	-0.1706	0.1183	-0.0414	-0.4125	-0.2641
Cylichna alba	0.3466	-0.2936	-0.5892	0.1604	0.2368	0.1465
Praxillella praetermissa	0.3634	-0.2546	-0.4561	0.1084	-0.1516	0.3403
Proclea graffii	0.3666	-0.1796	0.0374	-0.1335	-0.4261	-0.4838
Propebela exarata	0.3705	-0.2834	-0.5112	0.0686	0.1273	-0.1472
Sternaspis scutata	0.3785	-0.1193	0.1417	-0.0343	-0.3393	-0.2972
Phascolion strombi	0.3791	-0.2703	-0.6810	0.0420	0.1317	0.0085
Campylaspis nr. *sulcata*	0.3812	-0.2603	-0.3005	0.1159	-0.2623	0.2580
Scalibregma inflatum	0.3845	-0.1966	-0.5877	-0.0142	-0.1263	-0.1407
Mystides borealis	0.4003	-0.2694	-0.1700	-0.0533	-0.4250	-0.2833
Chaetozone setosa mb	0.4049	-0.5560	0.5604	-0.2972	0.1585	-0.0256
Praxillura ornata	0.4093	-0.3147	-0.5404	0.1128	-0.1690	0.2482
Leucon acutirostris	0.4153	-0.2016	0.6076	-0.2104	0.4956	0.0947
Melinna cristata	0.4169	-0.2014	0.5582	-0.2121	0.2929	-0.0591
Trochochaeta carica	0.4277	-0.1983	0.5439	-0.1979	0.3451	-0.0102
Monoculodes packardi	0.4283	-0.2158	0.3503	-0.1795	-0.1659	-0.3687
Eudorella hispida	0.4309	-0.2236	0.4695	-0.1577	0.3500	0.0808
Pythinella cuneata	0.4312	-0.2899	-0.0286	-0.1002	0.3037	0.0192
Syllides japonica	0.4491	-0.2633	0.1279	-0.1399	0.0418	-0.3513
Tetrastemma elegans	0.4497	-0.1997	0.4471	-0.1557	0.1642	0.0399
Tubulanus pellucidus	0.4642	-0.2256	0.6380	-0.2338	0.4496	0.0241
Carinomella lactea	0.4712	-0.0596	0.6279	-0.1109	0.4389	-0.0467
Campylaspis rubicunda	0.4764	-0.2561	-0.3038	0.1048	0.1864	0.0032
Leptostylis longimana	0.4806	-0.3057	-0.1893	0.0951	-0.3037	-0.0663
Terebellides stroemii	0.4902	-0.2404	0.6235	-0.2515	0.3376	-0.0974
Syllides longocirrata	0.4947	-0.2369	0.6533	-0.2295	0.3890	0.0102
Microclymene sp.1	0.5115	-0.4050	-0.5082	0.1721	-0.0055	0.3898
Dentalium entale	0.5225	-0.1785	0.5723	-0.1579	0.4586	0.0348
Harpinia propinqua	0.5248	-0.3506	-0.6128	0.2038	-0.0734	0.2594
Amphiporus caecus	0.5327	-0.1372	-0.3231	0.0229	0.1714	0.3130
Ctenodiscus crispatus	0.5335	-0.3760	-0.0623	0.0651	0.3299	0.1290
Prionospio cirrifera	0.5373	-0.4303	-0.4783	0.1883	0.0445	0.3057
Haploops fundiensis	0.5432	-0.3514	-0.5654	0.0227	-0.1755	-0.1497
Aphelochaeta monilaris	0.5521	-0.3032	0.2732	-0.1393	-0.2986	-0.2963
Bathymedon obtusifrons	0.5541	-0.2778	0.5463	-0.1838	0.3283	-0.0240
Dorvillea sociabilis	0.5678	-0.2920	0.4225	-0.1489	0.2618	0.0128
Stereobalanus canadensis	0.5682	-0.2759	0.1520	0.0231	0.3452	0.2453
Galathowenia oculata	0.5724	-0.5416	-0.1988	0.0070	-0.3583	-0.2305
Terebellides atlantis	0.5736	-0.2597	0.0033	0.0034	-0.4275	-0.2808

	Positive Loading on Axis 1 and Negative Loading on Axis 2					
Species	**Axis 1**	**Axis 2**	**Axis 3**	**Axis 4**	**Axis 5**	**Axis 6**
Trichobranchus roseus	0.5912	-0.3228	0.3548	-0.1365	-0.1013	-0.1147
Spiophanes kroeyeri	0.6032	-0.4506	-0.4109	0.1071	-0.0948	0.1245
Photis pollex	0.6054	-0.3089	0.0167	0.0655	-0.4035	-0.1035
Diplocirrus hirsutus	0.6069	-0.4451	-0.4149	0.1016	-0.1838	-0.0491
Heteromastus filiformis	0.6071	-0.2946	0.5400	-0.1522	0.3081	-0.0057
Mayerella limicola	0.6298	-0.3870	-0.0447	0.0187	-0.0243	0.0535
Periploma papyratium	0.6478	-0.3894	-0.5675	0.1645	-0.0573	0.0456
Sphaerodoropsis sp. 1	0.6533	-0.4824	-0.4258	0.1555	-0.0760	0.1196
Chaetoderma nitidulum canadense	0.6546	-0.4250	0.0284	-0.0477	-0.0305	-0.1227
Nuculoma tenuis	0.6865	-0.4561	-0.1185	0.0240	0.2005	0.1900
Aricidea quadrilobata	0.6870	-0.2386	0.3948	-0.0084	-0.2308	0.0672
Anobothrus gracilis	0.7205	-0.4362	-0.1412	0.0009	-0.3093	-0.1007
Nemertea sp. 12	0.7215	-0.2243	0.2037	0.0222	0.1929	0.2286
Eudorella pusilla	0.7394	-0.3960	-0.0281	-0.0282	-0.1381	-0.0695
Thyasira gouldi	0.7966	-0.3956	-0.1180	0.0386	0.0277	-0.0377
Yoldia sapotilla	0.8294	-0.4077	0.0117	0.0520	-0.0202	0.1212

	Negative Loading on Axis 1 and Positive Loading on Axis 2					
Species	**Axis 1**	**Axis 2**	**Axis 3**	**Axis 4**	**Axis 5**	**Axis 6**
Ameroculodes sp. 1	-0.0012	0.0830	0.1566	0.0342	-0.1996	0.1585
Cirratulus cirratus	-0.0023	0.0458	-0.1984	-0.1159	0.1479	-0.2066
Syllides convoluta	-0.0106	0.1542	0.0119	0.0886	0.0156	0.0103
Priapulus caudatus	-0.0143	0.1531	0.0364	0.0556	0.0321	0.0149
Euchone incolor	-0.0150	0.2441	0.2146	0.0992	-0.2505	0.2137
Nephtys incisa	-0.0169	0.5833	-0.1303	0.3717	0.0967	0.0081
Laonice cirrata	-0.0338	0.2277	-0.0563	0.1989	0.0350	0.0689
Sphaerosyllis brevifrons	-0.0362	0.2179	-0.0533	0.0405	0.0429	-0.1447
Astarte undata	-0.0394	0.2640	-0.5833	-0.1464	0.3736	-0.1980
Spiochaetopterus oculatus	-0.0422	0.1961	-0.0396	0.1687	0.0310	0.0423
Thracia conradi	-0.0426	0.3650	-0.3291	0.1930	0.2444	-0.2168
Sphaerodoridium sp. A	-0.0450	0.4277	0.0901	0.1816	-0.1483	0.0151
Placopecten magellanicus	-0.0457	0.0565	-0.3341	-0.4187	0.0957	-0.4261
Chone spp.	-0.0497	0.1903	0.0516	0.1091	0.0077	0.0719
Trochochaeta multisetosa	-0.0616	0.3063	-0.0480	0.1625	0.0237	-0.0582
Podoceridae spp.	-0.0656	0.1498	-0.3119	-0.2860	0.2099	-0.4125
Lyonsia arenosa	-0.0675	0.2821	-0.2212	-0.0141	0.1518	-0.4341
Clymenella torquata	-0.0716	0.2150	-0.0334	0.1438	0.1041	-0.1138
Pherusa affinis	-0.0740	0.3021	-0.1017	0.1383	0.1658	-0.1461
Eteone heteropoda	-0.0775	0.2561	-0.0181	0.0921	0.0043	-0.0672
Axiognathus squamatus	-0.0812	0.1011	0.0550	0.0939	-0.0537	0.1046

	Negative Loading on Axis 1 and Positive Loading on Axis 2					
Species	**Axis 1**	**Axis 2**	**Axis 3**	**Axis 4**	**Axis 5**	**Axis 6**
Lamprops quadriplicata	-0.0812	0.1011	0.0550	0.0939	-0.0537	0.1046
Orchomenella minuta	-0.0823	0.1144	-0.0347	0.0903	-0.0167	0.0002
Bylgides sarsi	-0.0875	0.1177	0.0430	0.1383	-0.0523	0.1392
Leptocheirus pinguis	-0.0875	0.1177	0.0430	0.1383	-0.0523	0.1392
Microspio sp. 1	-0.0875	0.1177	0.0430	0.1383	-0.0523	0.1392
Petalosarsia declivis	-0.0878	0.1928	-0.0417	-0.0953	0.0267	0.0523
Mediomastus californiensis	-0.0918	0.8274	-0.1775	0.2549	0.0637	-0.0484
Dulichia tuberculata	-0.0962	0.1426	-0.3047	-0.3022	0.1984	-0.1062
Cerebratulus lacteus	-0.0988	0.4189	0.0527	0.3198	-0.0765	0.1889
Oligochaeta spp.	-0.0990	0.1337	-0.1567	-0.1671	0.1999	-0.0870
Syrrhoe sp. 1	-0.0991	0.2051	-0.2077	-0.2725	0.0924	-0.1882
Hartmania moorei	-0.1000	0.4319	-0.0490	0.2982	0.1155	-0.0215
Propebela turricula	-0.1008	0.2544	0.0024	0.2359	-0.0130	0.1297
Ampharete acutifrons	-0.1055	0.1912	-0.3388	-0.4233	0.1564	-0.3541
Ampelisca abdita	-0.1103	0.1567	0.0681	0.1336	-0.0758	0.1369
Pitar morrhuanus	-0.1203	0.2545	-0.1284	0.0027	0.2116	-0.1453
*Pionosyllis sp. A/*spp.	-0.1305	0.0392	-0.4871	-0.6274	0.1524	0.1577
Deflexilodes tuberculatus	-0.1340	0.1251	-0.1098	-0.2621	0.0831	0.0807
Eteone trilineata	-0.1340	0.1251	-0.1098	-0.2621	0.0831	0.0807
Spisula solidissima	-0.1340	0.1251	-0.1098	-0.2621	0.0831	0.0807
Ampharete baltica	-0.1363	0.3643	-0.2782	-0.1654	0.1743	-0.2947
Harmothoe imbricata	-0.1420	0.0775	-0.0458	-0.3668	-0.0049	0.2168
Tubificidae sp. 2	-0.1432	0.4955	0.1200	0.2646	-0.0892	0.0950
Nephtys cornuta	-0.1512	0.2771	0.0569	0.2544	-0.0708	0.1965
Microphthalmus pettiboneae	-0.1555	0.0235	-0.2657	-0.5448	0.1167	0.0339
Ophiura spp.	-0.1577	0.1210	-0.3547	-0.5351	0.1599	-0.2031
Eteone longa	-0.1806	0.5748	-0.3069	-0.0699	0.1747	0.0368
Musculus niger	-0.1893	0.0836	-0.2016	-0.4671	0.1589	0.0754
Monticellina dorsobranchialis	-0.1947	0.4395	-0.3020	-0.1627	0.2511	-0.3002
Scoletoma hebes	-0.2009	0.4240	0.0354	0.3273	-0.0345	0.1422
Laonome kroeyeri	-0.2069	0.1766	-0.2717	-0.4021	0.0781	0.2168
Euclymeninae sp. 1	-0.2090	0.0896	-0.0932	0.2285	0.2336	-0.1632
Mya arenaria	-0.2259	0.6507	-0.2300	-0.0028	0.1792	-0.1767
Tharyx acutus	-0.2299	0.5859	-0.2815	-0.3483	0.1873	-0.1479
Monticellina baptisteae	-0.2355	0.6453	-0.1197	0.1679	0.1165	-0.0583
Cyclocardia borealis	-0.2361	0.1401	-0.2336	-0.5453	0.1823	0.1089
Munna sp. 1	-0.2435	0.0530	-0.1692	-0.6374	0.0374	0.2740
Spio filicornis	-0.2645	0.0583	-0.1747	-0.6231	-0.0014	0.3168
Crenella glandula	-0.2944	0.0193	-0.1729	-0.2965	0.0742	-0.1039
Edotia montosa	-0.3415	0.1642	-0.2254	0.0964	0.1588	-0.1800
Arctica islandica	-0.3618	0.3684	-0.2190	0.0590	0.2554	-0.1459
Aricidea catherinae	-0.3637	0.5699	0.0497	0.0034	-0.1228	0.2770
Ceriantheopsis americanus	-0.4147	0.2775	-0.1677	0.1245	0.1288	-0.0935

	Negative Loading on Axis 1 and Negative Loading on Axis 2					
Species	**Axis 1**	**Axis 2**	**Axis 3**	**Axis 4**	**Axis 5**	**Axis 6**
Ischyrocerus anguipes	-0.0743	-0.4455	-0.4529	0.1199	0.1737	-0.0531
Unciola inermis	-0.0771	-0.5390	-0.2900	0.3258	0.4257	-0.0198
Dipolydora socialis	-0.0802	-0.2291	-0.4870	-0.4469	0.1560	0.2922
Ptilanthura tenuis	-0.1248	-0.6336	-0.4136	0.2330	0.1491	0.1285
Nemertea sp. 15	-0.1745	-0.0454	-0.1839	-0.8687	-0.0379	0.1673
Amphiporus bioculatus	-0.2044	-0.0401	-0.0438	-0.6320	-0.1470	0.3974
Euchone elegans	-0.2080	-0.0387	-0.1991	-0.7549	-0.0584	0.1764
Ampelisca macrocephala	-0.2184	-0.6032	-0.2890	0.3273	0.4095	-0.0388
Amacrodorum bipapillatum	-0.2291	-0.0905	-0.1348	-0.7294	-0.0563	0.3603
Grania postclitellochaeta longiducta	-0.2291	-0.0905	-0.1348	-0.7294	-0.0563	0.3603
Pleusymtes glaber	-0.2291	-0.0905	-0.1348	-0.7294	-0.0563	0.3603
Skeneopsis planorbis	-0.2291	-0.0905	-0.1348	-0.7294	-0.0563	0.3603
Diaphana minuta	-0.2899	-0.2387	-0.0475	-0.1863	-0.2675	-0.3466
Protomedeia fasciata	-0.3010	-0.1172	-0.1315	-0.0278	0.3301	-0.1546
Diastylis quadrispinosa	-0.3087	-0.5467	-0.2031	0.3353	0.3970	-0.0735
Ampharete lindstroemi	-0.3150	-0.0415	-0.3856	-0.2342	0.1565	-0.5042
Nephtys caeca	-0.3261	-0.3185	0.1114	-0.0182	-0.3244	-0.0266
Periploma leanum	-0.3261	-0.3185	0.1114	-0.0182	-0.3244	-0.0266
Pseudunciola obliquua	-0.3261	-0.3185	0.1114	-0.0182	-0.3244	-0.0266
Phyllodoce maculata	-0.3306	-0.2920	-0.0084	-0.1254	-0.2583	-0.2061
Acanthohaustorius millsi	-0.3350	-0.3053	0.0964	-0.0340	-0.3049	-0.0348
Enchytraeidae sp. 1	-0.3463	-0.2104	-0.1021	-0.7001	-0.1070	0.3372
Amphiporus cruentatus	-0.3582	-0.6510	-0.1930	0.3530	0.2917	-0.0838
Owenia fusiformis	-0.4302	-0.0690	-0.1289	-0.3314	-0.1762	0.0472
Sthenelais limicola	-0.4407	-0.4794	-0.0502	0.2152	0.3638	-0.2327
Flabelligera affinis	-0.4446	-0.3316	0.0409	0.2991	0.2511	-0.1083
Pectinaria granulata	-0.4486	-0.0716	-0.2437	-0.4387	0.2727	0.1201
Acanthohaustorius spinosus	-0.4664	-0.5259	0.0231	0.2727	0.3288	-0.1672
Diastylis polita	-0.4664	-0.5259	0.0231	0.2727	0.3288	-0.1672
Euspira immaculata	-0.4664	-0.5259	0.0231	0.2727	0.3288	-0.1672
Paradoneis armatus	-0.4664	-0.5259	0.0231	0.2727	0.3288	-0.1672
Chiridotea tuftsi	-0.4669	-0.4467	0.1494	0.0335	-0.3320	-0.0392
Naticidae spp.	-0.4688	-0.4573	0.0421	0.2913	0.2895	-0.1186
Pontogeneia inermis	-0.4765	-0.4880	0.0338	0.2908	0.3096	-0.1412
Rhepoxynius hudsoni	-0.5084	-0.5108	0.1446	0.1017	-0.1806	-0.0686
Anonyx liljeborgi	-0.5126	-0.5182	-0.0546	0.1631	0.2251	-0.0959
Caulleriella sp. B	-0.5184	-0.5335	-0.0187	0.0409	0.2993	-0.0515
Capitella capitata complex	-0.5237	-0.1767	-0.3036	-0.2848	0.2245	-0.3075
Cnemidocarpa mollis	-0.5312	-0.5567	0.1083	0.1310	-0.1022	-0.1128
Echinarachnius parma	-0.5320	-0.6734	-0.0119	0.0523	-0.1544	0.0036
Spio thulini	-0.5370	-0.4457	0.1271	0.2064	0.1333	-0.0018
Orbinia swani	-0.5399	-0.5698	0.0803	0.2341	0.1431	-0.1360

	Negative Loading on Axis 1 and Negative Loading on Axis 2					
Species	**Axis 1**	**Axis 2**	**Axis 3**	**Axis 4**	**Axis 5**	**Axis 6**
Crassicorophium crassicorne	-0.5568	-0.5631	0.1382	0.0968	-0.2192	-0.0899
Politolana polita	-0.5701	-0.5715	0.1412	0.1269	-0.1703	-0.0895
Hippomedon serratus	-0.5737	-0.6208	0.0669	0.2706	0.2209	-0.1655
Eudorellopsis deformis	-0.5773	-0.5972	0.1078	0.2043	0.0294	-0.1242
Unciola irrorata	-0.5842	-0.5888	0.1344	0.1072	-0.2016	-0.1056
Phoxocephalus holbolli	-0.5887	-0.6434	0.0882	0.1149	0.1180	-0.1007
Argissa hamatipes	-0.5922	-0.1997	-0.0675	0.4671	0.1251	0.0344
Aglaophamus circinata	-0.5938	-0.5062	0.0662	-0.0230	-0.1196	-0.0453
Scoloplos armiger	-0.6190	-0.4670	0.0135	-0.3038	-0.1763	0.0803
Exogone hebes	-0.6331	-0.5205	-0.2687	-0.4039	0.0649	0.1848
Ensis directus	-0.6416	-0.6177	0.1336	0.1927	-0.0616	-0.0928
Tanaissus psammophilus	-0.6429	-0.6423	0.1085	0.0381	-0.1278	-0.0637
Hiatella arctica	-0.6437	-0.5527	-0.1108	-0.2933	0.1458	0.0532
Cerastoderma pinnulatum	-0.6463	-0.6902	-0.1322	0.0766	0.0850	-0.0138
Phyllodoce mucosa	-0.6675	-0.1997	0.0054	-0.1255	-0.0959	0.1641
Spiophanes bombyx	-0.6802	-0.5947	0.0723	-0.1083	-0.1313	0.0296
Polygordius sp. A	-0.6904	-0.4461	-0.0381	-0.4307	-0.1043	0.1347
Diastylis sculpta	-0.6951	-0.5755	0.1068	0.2430	0.0069	-0.1163
Molgula manhattensis	-0.7159	-0.6213	0.0421	-0.1090	-0.0623	-0.0346

APPENDIX D

D1. Summary of Hard-Bottom Still Photographs 2004

D2. Summary of Video Footage 2004

Appendix D1. Summary of data recorded from still photographs taken on 2004 hard-bottom survey.

Station	T1-1	T1-2	T1-3	T1-4	T1-5	T2-1	T2-2	T2-3	T2-4	T2-5	T4-2	T4/6-1	T6-1	T6-2	T7-1	T7-2	T8-1	T8-2	T9-1	T10-1	T11-1	T12-1	Diff 44	Total
Number of frames	31	32	34	32	33	33	34	33	32	32	31	33	32	33	32	32	31	33	32	31	32	32	29	739
Depth (m)	25.3	26.3	21.5	23.8	27.3	25.4	30.6	26.4	32.2	33.7	30.3	24.3	32.8	30.0	23.0	22.1	22.6	24.3	24.0	22.8	32.9	23.5	35.0	
Substrate [1]	b+c	b+mx	b+c	b+mx	mx	b+mx	b+mx	b+mx	mx	d+rr	mx	b+mx	cp+g	mx+b	b+c	b+c	c+b	mx+b	b+mx	b+mx	b+mx	b+c	d+rr	
Sediment drape	2.6	3.1	1.6	1.9	2.8	2.2	2.9	3.1	3.2	2.8	2.8	1.6	3.2	2.4	2.8	3.0	2.3	1.7	2.2	4	3.3	2.1	3.7	
Coralline algae	24.8	26.9	69.9	64.8	34.4	52.9	6.8	14.7	4.8	0.0	21.6	57.3	3.3	31.7	33.0	27.0	50.2	58.0	50.8	7.5	7.7	47.5	0.0	
Ptilota serrata[2]			f-a	r		r						r			c-a	c-a			f	r		f-c		
Hydroid[2]	f-a	c	f-c	f	c	f-c	c-a	c-a	c	f-a	f-c	f-c	f-c	f-c	c	c	f-c	f-c	f-c	c	c-a	f-c	f-c	
spirorbids[2]	f	f	f	f-c	f	r-f	f	f	f	r-f	f	c-a	r-f	f-c	f-c	f	f	f-c	f-c	f	f	f	r-f	
Rhodymenia palmata	80	59	66	32	4	38		108				13		1	165	184	3		48	63	7	60		931
Agarum cribosum															12	17								29
Sponge	4		5			3	9	3	11	4	6	3	1	6	3	2	3	2	13	2	35	2	5	122
Aplysilla sulfurea	7	14			3	9	1	1	9		9		6	22	5	7	4		3	14	9			123
Halichondria panicea	6	9			7	2	9	11	8		11	5	3	18	2	28	3		22	20	32	6		202
Haliclona spp. (upright)										1											8			9
Suberites spp.	4	9			10	1	12		3	1	15		9	13			1				5	1		84
white divided							1	87	174		23				5	97			100		243	22		752
orange/tan encrusting	28	97	34	45	100	74	133	58	94	85	94	31	68	114	38	24	86	54	20	39	116	57	41	1530
orange encrusting	26	53	15	14	58	34	33	36	31	29	33	24	9	29	36	55	6	23	42	42	62	31		721
gold encrusting			4	2				5	8		1	8		2	33	13			25	11	20	10		142
pink fuzzy encrusting		4	26	31	43	20	2	2	4	3	6	4	6	4	37	29	21	26	10		9	53	1	341
dark red/brown encrusting			3	1					31		10													45
white translucent	138	175	79	94	103	252	228	182	268	104	131	175	45	171	98	71	30	48	89	127	332	158	53	3151
cream encrusting		3		1	1	1	1		2		1			10	15		5	1	10		56	12		119
filamentous white encrusting								3	1															4
Melonanchora elliptica							1	1	2										2					6
Haliclona spp. (encrusting)	1					1		1	2	8				1		1					1	1	7	24
frilly white organism (sponge?)				3				19			1	30		4					11					68
Polymastia?	5																							5
general encrusting	3	9	10	8	17	18	12	33	41	2	4	3	24	19	62	78	13	11	15	11	43	28	13	477
red/orange crust		3			4	3	18	10	8		3	1		20		2				13	22	6		113

Station	**T1-1**	**T1-2**	**T1-3**	**T1-4**	**T1-5**	**T2-1**	**T2-2**	**T2-3**	**T2-4**	**T2-5**	**T4-2**	**T4/6-1**	**T6-1**	**T6-2**	**T7-1**	**T7-2**	**T8-1**	**T8-2**	**T9-1**	**T10-1**	**T11-1**	**T12-1**	**Diff 44**	**Total**
dark grey translucent organism				7								33							1					41
Obelia geniculata															2	2								4
anemone	1		2			3	3	2					1	1	1				1	1	1	1		18
Metridium senile			33	3			2	1		1100	1	6		5		4		1	29	1	35	2	232	1455
Urticina felina	1	5				1	1	1	1	1		3		2			1			4	2	3	1	27
Cerianthus borealis					1				1				1											3
Gersemia rubiformis									1											118				119
Tubularia sp.										25									1		1			27
Alcyonium digitatum									4		1							2						7
gastropod	1									1													1	3
Tonicella marmorea		1	5	2		1		1				4		1				1	1		2	2		21
Crepidula plana																			42					42
Notoacmaea testudinalis												2				1								3
Coryphella sp.								1																1
Buccinum undatum											1			2	1									4
Neptunea decemcostata											1								1					2
nudibranch						1		2	1			1		8										13
Busicotypus canaliculatus											1													1
Modiolus modiolus	37	82	197	126	55	85	40	97	26	13	43	137	17	22	154	111	36	149	236	109	102	56		1930
Placopecten magellanicus											1								1				2	4
Arctica islandica	1						4		5		6		4								1	1		22
Balanus spp.		1	1	1	1		4					109						1	2	3	9		1	133
Homarus americanus	1		2								1			1										5
Cancer spp.		1					1				2	2	4	3	1								2	16
general crab										1														1
Strongylocentrotus droebachiensis	2	1	22	1	1	5	2	1		1	1	17		4				13	34	6		1	2	114
small white starfish	128	135	294	193	174	145	93	145	81	80	201	94	94	95	203	189	75	62	319	125	16	187	43	3171
Asterias vulgaris	17	48	14	13	14	9	29	29	6	3	26	111	35	71	18	20	20	2	9	9	28	4	37	572
Henricia sanguinolenta	46	53	97	49	30	29	30	64	15	14	27	74	13	50	62	51	21	21	68	118	17	52	30	1031
Porania insignis						1																1		2
Crossaster papposus		1									3				1						3			8
Pteraster militaria	1																							1
Psolus fabricii	1	4	3	11	1	1	1		2	1	9	3	1	7	1	1		22	2	3		29		103
Cucumaria frondosa																			1					1

Station	T1-1	T1-2	T1-3	T1-4	T1-5	T2-1	T2-2	T2-3	T2-4	T2-5	T4-2	T4/6-1	T6-1	T6-2	T7-1	T7-2	T8-1	T8-2	T9-1	T10-1	T11-1	T12-1	Diff 44	Total
Aplidium spp.	126	110	39	197	120	114	62	54	53	4	53	60	22	70		2	87	100	116	2		126	22	1539
Dendrodoa carnea	31	48	42	38	69	41	27	58	23	7	30	109	8	108	63	73	25	42	54	23		42		961
Didemnum albidum	137	272	154	180	197	212	175	234	177	168	238	128	138	204	113	238	67	37	118	112	39	148	35	3521
Halocynthia pyriformis	10	7	19	7	3	2	3	17	3	4	67	3		42	26	10		3	34	9	10	36	523	838
Boltenia echinata	84	20	23	2	27	10	18	38	7		10	9		26	8	3			14	60		5		364
Boltenia ovifera	1	1																			1		1	4
clear globular tunicate					17	2		1	3	5				5										33
white *Halocynthia pyriformis*	6		17	1	1	1	6	15	5	2	9	3				3	1		5		51	13	105	244
bryozoan	28	63	23	25	66	29	95	70	64	148	53	32	16	69	49	45	2	10	26	103	25	36	92	1169
red crust bryozoan								2								1								3
Myxicola infundibulum	52	57	45	23	24	18	21	43	22	2	12	19	5	7	27	30	1	9	71	3	4	1	7	503
Terebratulina septentrionalis	1		20				7	142	280	1	77	1		4	71	259			231	1	523	100	2	1720
fish						1				1						1								3
Tautogolabrus adspersus	16	25	118	24	10	22	25	91	7	54	10	28	1	36	38	38	19	11	126	134	11	28	9	881
Myoxocephalus spp.			1	1			3	1		1							3				2	1		13
Macrozoarces americanus												1		1										2
Hemitripterus americanus		1									1													2
Pseudopleuronectes americanus					1			1		3		2	3						2					12
Pholis gunnellus				1	1						1										1			4
Gadus morhua																			1	1		1	1	4

[1] b=boulder, c=cobble,cp=cobble pavement, mx=mix, g=gravel, d=diffuser head, rr=riprap

[2] a=abundant, c=common, f= few, r = rare.

Appendix D2. Summary of data recorded from video footage taken on 2004 hard-bottom survey.

Station	**T1-1**	**T1-2**	**T1-3**	**T1-4**	**T1-5**	**T2-1**	**T2-2**	**T2-3**	**T2-4**	**T2-5**	**T4/6-1**	**T4-2**	**T6-1**	**T6-2**	**T7-1**	**T7-2**	**T8-1**	**T8-2**	**T9-1**	**T10-1**	**T11-1**	**T12-1**	**Diff 44**	**Total**
Minutes	24	20	20	20	23	21	21	20	21	16	23	23	21	20	20	21	28	18	30	23	22	20	21	496
Depth (m)	25.6	24.2	22.5	24.5	28.6	26	30.4	26.2	31.7	32.1	31.5	24.4	34	31.8	24.6	23.5	23.9	24.5	24.4	23.3	33.5	24.1	35.7	
Relief[1]	LM	M	MH	LM	LM	M	LM	M	M	M	LM	M	L	LM	M	MH	LM	LM	M	MH	M	M	M	
Substrate[2]	c+b	b+c	b+c	c+b	cp+o b	b+c	b+c	b+c	b+c	d+rr	cp+ob	b+c	cp+o b	c+b	b+c	b+c	cp+o b	b+c	b+c	b+c	cp+o b	b+c	d+rr	
Sediment drape[3]	lm	m	lm	lm	m	lm	m	m	m	m	m	l	m	m	m	m	lm	lm	lm	mh	m	lm	mh	
Suspended material[4]		h			h	h	h	h	h		h	h			h	h		h	h	h	h	h	h	
Coralline algae[5]	c	f-c	a	c-a	c	c	f	f	r		f-c	a		f-c	c	c	c-a	a	c	r-c	f	c-a		
Ptilota serrata[5]			c-a	r-f											f-a	a			f			f-c		
hydroids[5]	f-c	c	f-c	f	c	c	c-a	c-a	c	r-a	f-c	f	f-c	c	c-a	a	f-c	f	c	a	c	f	r-a	
spirorbids[5]	f	f	f	f	f	f	f	f	f	f	f	c-a	r	c	f-c	f-c	f	f	f	f	f	f	f	
Rhodymenia palmata[5]	f	r	r	r				f							f-c	a	r		f	f-c		f		
Agarum cribosum[5]															c	c-a			r	r		r		
Sponge									4	2						1					1			8
Halichondria panicea[5]	r		r		f	f	c	r	f		f	f	r	f	r	c			f	f-c	f	r		
Haliclona spp. (upright)										1											8		3	12
Suberites spp.[5]	c	f			f	f-c	f-c	f	f-c		f		f	f	r	r					c	r		
white divided[5]	f	r					r	c	a						f	c			c		a	c		
Phakellia spp.																					1			1
Melonanchora elliptica							1	1	2												1	1		6
Haliclona spp. (encrusting)	4	3				2	1	8	13	2	2	1		2	1	3			1	3	2			48
white frilly sponge[5]								c				a							c					
Polymastia?	10																							10
Obelia geniculata[5]																c								
Corymorpha pendula										2														2
anemone		1				3	4		1					1										10
Metridium senile[5]			f-c			r	r			c-a	r	r		r	r	r			f	f	c	r	f-c	
Urticina felina		2		1			2	3			1	5	4	1	2		2			6	4		2	35
Cerianthus borealis									2		1		1											4
Gersemia rubiformis[5]																				a				
Buccinum undatum							1				3			1										5
Neptunea decemcostata									1		1													2
nudibranch								1																1

Station	**T1-1**	**T1-2**	**T1-3**	**T1-4**	**T1-5**	**T2-1**	**T2-2**	**T2-3**	**T2-4**	**T2-5**	**T4/6-1**	**T4-2**	**T6-1**	**T6-2**	**T7-1**	**T7-2**	**T8-1**	**T8-2**	**T9-1**	**T10-1**	**T11-1**	**T12-1**	**Diff 44**	**Total**
Modiolus modiolus[5]	f-c	a	a	a	f	c-a	c-a	c-a	c		c	c-a	f	f-c	c-a	a	c	a	a	c-a	c	c-a		
Placopecten magellanicus						1	2			1	7		2						1					14
Homarus americanus	1	3	2			1	1		1					2		1								12
Cancer spp.		6		2	4	5	13	3	2		15	13	26	14	2		3	3	1		1	1	3	117
hermit crab					1						1		1											3
Strongylocentrotus droebachiensis[5]	f	r	c-a	r		f-c	r	f			r	c		r-f		f	r	c	c	c	r	r	r-c	
small white starfish[5]	c	c	c-a	c	c	c	c	c-a	c	f	f	a	f	c	c-a	a	f	f	a	a	c	a	f-c	
Asterias vulgaris[5]	f-c	c	r	f	c	f	f-c	c	f-c	f-c	f-c	c-a	c	c	f-c	r	f	f	f	c	c	c	f-c	
Henricia sanguinolenta[5]	f	c	c	f	f-c	c	f	c	f	f	f	c	f	f-c	c	c	f	f	c	c	f-c	c	r-f	
Crossaster papposus																					1			1
Pteraster militaria	1																							1
Solaster endeca																					1			1
Psolus fabricii[5]			r	f			r					f						f				c		
Aplidium spp.[5]	a	c	f	f-c	c	c-a	f-c	c	c-a		f-c	f-c	f	c	c	c	f-c	f	c	f	f	c	r	
Halocynthia pyriformis[5]	f	r	c	r		r	f	f-c	c	f	f	r		r	f-c	f			c	f	c	f-c	f-c	
Boltenia ovifera	1							1							2						9	2	1	16
bryozoan										1														1
Myxicola infundibulum[5]	f	c	f	f-c		f	f	c-a	c		f	c	r	r	c	c		c	c-a		f			
Terebratulina septentrionalis[5]	f	r					r	c	a						f	c			c		a	c		
fish																					1	1		2
Tautogolabrus adspersus[5]	r-f	f-c	a	f-c	f	c	f	c-a	c	f-c	f	c	r	f-c	c-a	a	r-f	f	a	a	f	f-c	r-f	
Myoxocephalus spp.	1	3	1	3	1	2	3	2	3	1	5	1	4	1	1	1	4		1		2	2		42
Macrozoarces americanus		1	1							1		2		1										6
Hemitripterus americanus		1								1	1	1												4
Pseudopleuronectes americanus			1		3	1		2		3		2	6	1				4	1					24
Pholis gunnellus		1							2				1	1			1		1					7
Gadus morhua	1		4					1		1					9	13		2	5	4	12	10	12	74

1 L=low, ML=moderately low, M=moderate, MH=moderately high
2 b=boulder, ob=occassional boulders, c=cobble, cp=cobble pavement, d=diffuser head, rr=riprap
3 l=light, ml=moderately light, m=moderate, mh=moderately heavy
4 h=high
5 a=abundant, c=common, f=few, r=rare

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