2003 outfall benthic monitoring report

Massachusetts Water Resources Authority

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2003 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

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

Sampling in August 2003 reflected some modification of the monitoring program, *i.e*., discontinuation of a special study of chemical contaminants in sediments. 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.

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 part of a 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 are 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.

Monitoring Questions

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

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?

and benthic communities:

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?

Each of these monitoring questions is addressed in this section and in the following report.

Table 1. Contingency plan thresholds established by MWRA for monitoring potential impacts of the offshore outfall.

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
Benthic diversity, nearfield	Species per sample	<47.97 or >81.09	None
	Fisher's log-series alpha	<10.13 or >15.58	None
	Shannon diversity	<3.32 or >4.02	None
	Pielou's evenness	<0.56 or >0.67	None
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?*

Following diversion of treated effluent discharge to the offshore outfall in September 2000, the spatial distribution and temporal response of two sediment properties, grain size and total organic carbon (TOC), did not depart substantially from baseline values. Post-diversion abundances of the sewage tracer *Clostridium perfringens* were also 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 prediversion) 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 offshore regional stations.

Modest increases in the percentages of silt and clay (and fines) 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, suggesting an effluent signal near the outfall. Abundances of *C. perfringens* (normalized to grain size) decreased in 2003 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.

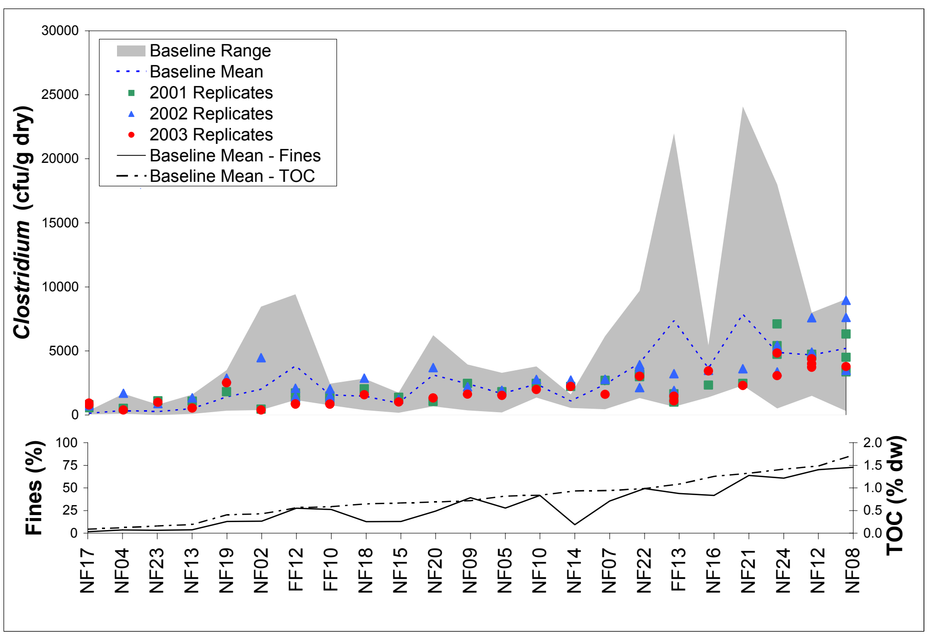


Figure 1. Post-diversion abundances of *Clostridium perfringens* at each nearfield station sampled in 2001 (squares), 2002 (triangles), and 2003 (circles) and the range of values occurring during the baseline period (gray band). Stations are presented in order of increasing mean TOC concentration.

Sediment Contaminants

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

Nearfield stations comprise a series of heterogeneous sediments located in close proximity to 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. Two factors that influence contaminant variability in the nearfield include the bulk sediment properties, grain-size distribution and TOC. The primary factor among those measured associated with the variance in nearfield data is sand content.

Regional stations are distributed throughout Massachusetts and Cape Cod Bays, and proximity to Boston Harbor also influences the chemical composition of these sediments. Regional stations located farther away from the harbor generally have lower concentrations of contaminants and sewage tracers compared with near-harbor stations. The composition of sediments at offshore regional sampling locations is influenced by the analytes associated with fines and may reflect regional inputs distinct from Boston Harbor. As in the nearfield, sand content strongly influences the variance in the regional data.

Sediment data from 2001 and 2002 suggest that diversion of the treated effluent discharge to the offshore outfall has not caused widespread or systematic increases in contaminants of environmental concern to the Massachusetts and Cape Cod Bay systems. Similarly, contaminant data from 2003 for nearfield stations NF12 and NF17 showed no evidence of an increase in contaminants of environmental concern (*e.g.,* PCBs, Figure 2).

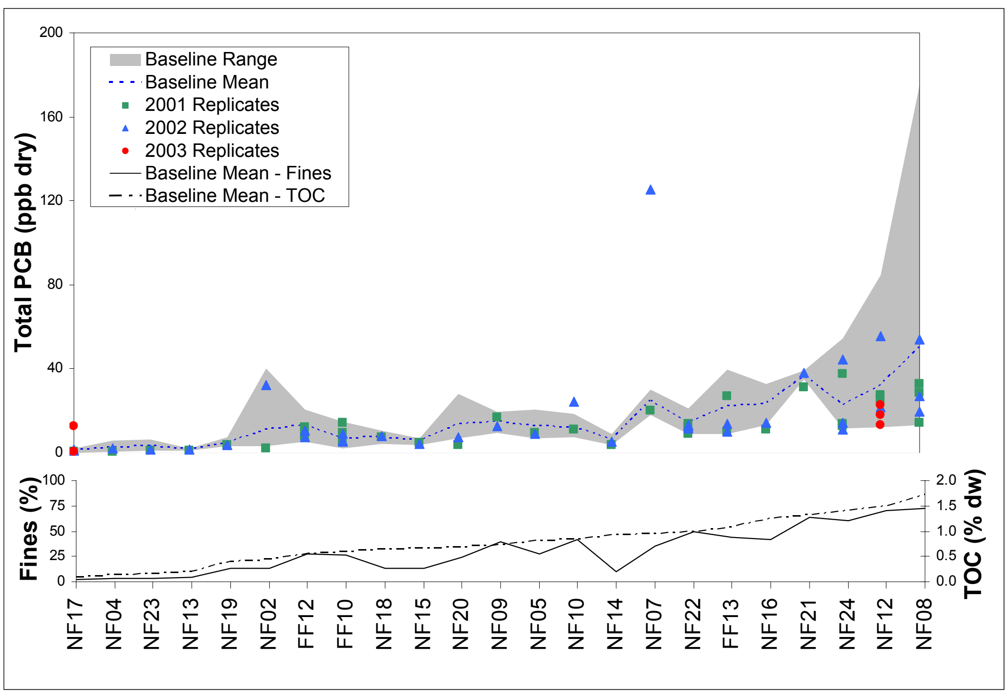


Figure 2. Total PCB (A) and lead (B) for each nearfield station sampled in 2001 (squares), 2002 (triangles), and 2003 (circles) and the range of values occurring during the baseline period (gray band). Stations are presented in order of increasing mean TOC concentration.

Sediment Redox Potential Layer

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

There does not appear to be a relationship between the depth of the redox potential discontinuity (RPD) layer and the operation of the offshore outfall. The general pattern in 2003, when the apparent color RPD depth at a station ranged from 1.3 cm (NF07) to >3.2 cm (NF17), with a grand mean of 2.1 cm (SD ±0.54 cm), was similar to that seen in both baseline and post-diversion years (Figure 3).

For assessing outfall effects, the MWRA set a 50% reduction (or increase) in the apparent color RPD layer depth as a critical level. 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 2003 (2.1 cm) was well within the range of annual values, with 1998 having the shallowest depth (1.6 cm) and 1995 the deepest (3.0 cm). The difference between the 2003 and baseline values was a shallowing of the RPD by 11%, but the MWRA threshold was not exceeded.

The depth of the apparent color RPD layer at nearfield stations reflected the combination of biological and physical processes that appear to be structuring surface sediments. In sandy porous sediments (*e.g.*, NF17, Figure 4), deep RPD layers were primarily a function of pore water circulation, during which oxygenated water is pumped into the sediment. In fine sediments, physical diffusion limits oxygen penetration to <1 cm, therefore when the RPD layers in those sediments are >1 cm (*e.g.,* NF05), biological processes such as bioturbation by infauna or major resuspension/deposition events are responsible for oxygenation. At all 15 fine-sediment stations, the RPD layer depth was >1.5 cm and SPI images confirmed the importance of bioturbation in deepening the RPD layers at these stations.

At many stations, biogenic activity, represented by burrow structures increased the depth to which oxic sediments occurred (Figure 5). Sediments that appeared to be oxic and light-brown to reddish in color extended >10 cm below the sediment-water interface at Stations NF21 and NF24, and extended deeper than prism penetration in at least one replicate image at 17 stations. The deepest RPD layers were associated with mixed fine-sand-silt-clay sediments that had higher levels of biogenic activity. Based on the color and texture of sediments in the 2003 SPI images, it did not appear that the amount of sedimented organic matter had changed relative to the baseline images for the nearfield SPI stations due to operation of the outfall.

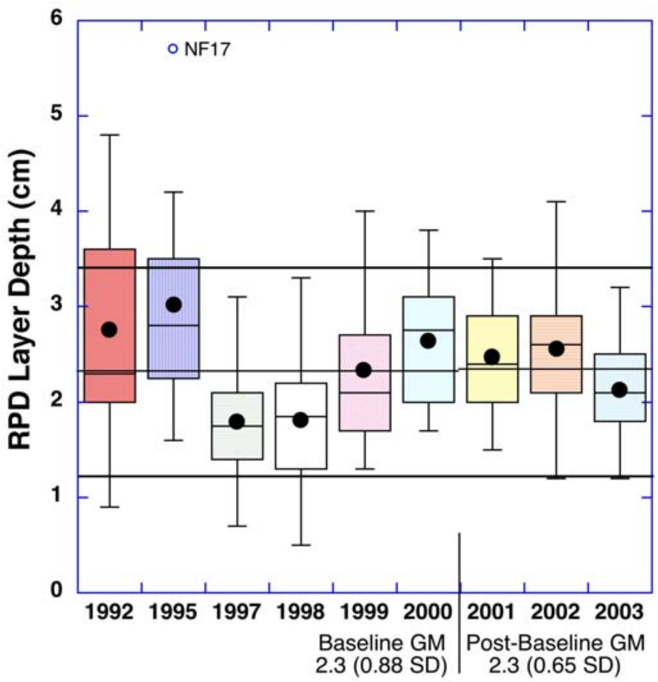


Figure 3. Apparent color RPD layer depth (cm) summarized by year for all data from nearfield stations. Box is interquartile range, short bar is median, dot is mean, and whiskers are data range. Horizontal line is grand mean for baseline years, with upper and lower boundaries indicating the trigger thresholds for exceeding a 50% change in RPD layer depth. Station NF17 was an outlier in 1995.

Figure 4. Sediment profile image of NF20, 2003, showing physically structured sediment surface.

Figure 5. Sediment profile image of NF21, 2003, showing deep RDP layer and evidence of biological structures (feeding void, burrows).

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. Infaunal abundance (per sample) has 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*). Species richness has also increased, in 2003 reaching the highest mean values in both the nearfield and farfield areas.

♦ *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 6). 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. These patterns have not been seen: species richness and log-series alpha have increased at nearfield stations, while diversity (H′) and evenness(J′) have been stable since the outfall came online. Nearfield and farfield stations have not diverged but in 2003 actually converged in terms of abundance, diversity, and evenness. Although the number of species per sample and log-series alpha appear to have increased more in the farfield than in the nearfield, the fact that they also increased in the nearfield precludes the conclusion that this is indicative of an outfall effect. None of the 2003 annual means exceeded any of the threshold parameters set by the MWRA. Preliminary statistical evaluation of the differences (before and after diversion; nearfield versus farfield) indicate no significant differences and therefore no evidence of impact from the outfall.

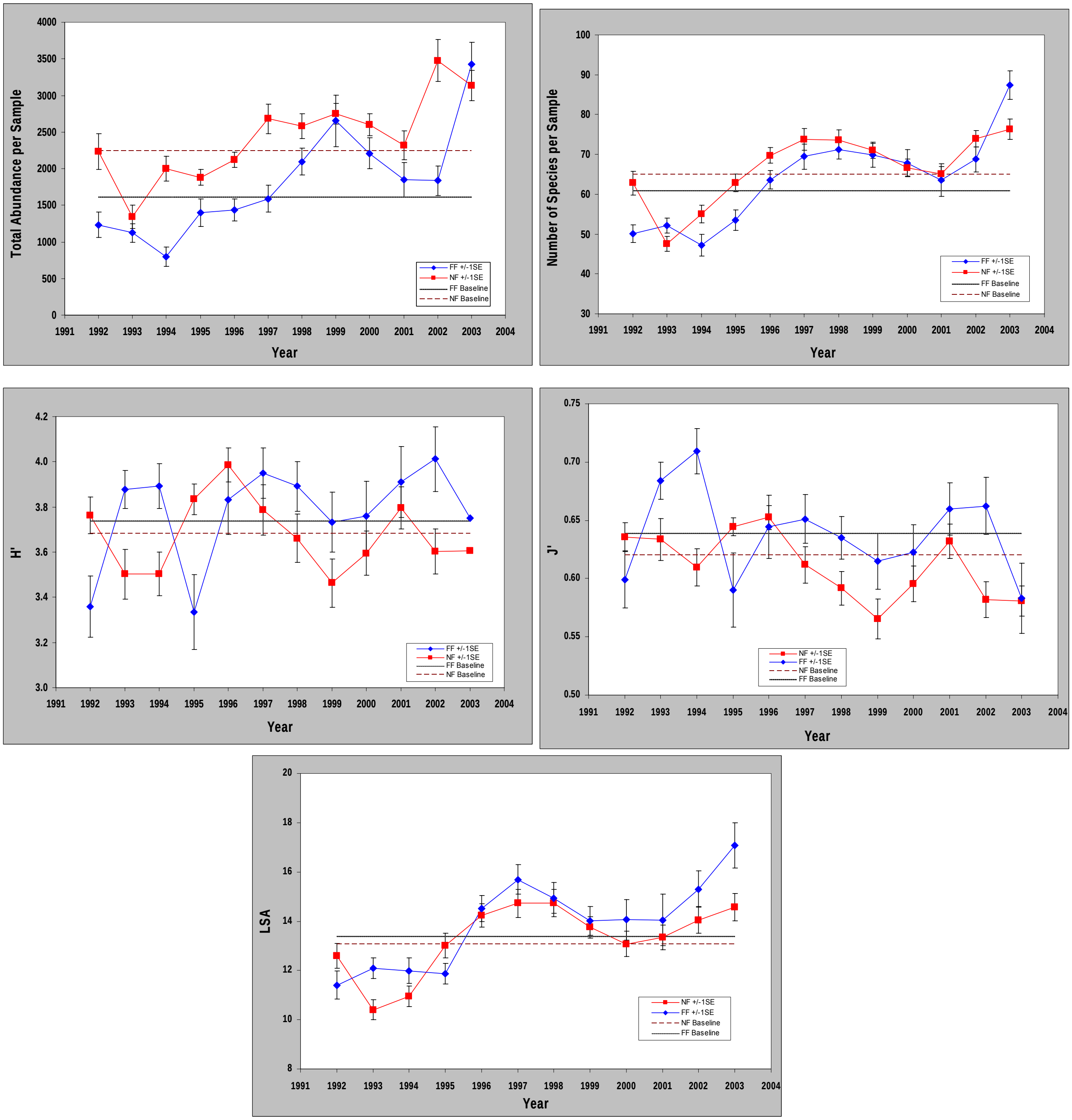


Figure 6. Mean benthic community parameters for nearfield and farfield stations sampled 1992–2003. (A) abundance per sample, (B) number of species per sample, (C) Shannon diversity H′, (D) Pielou's evenness J′, and (E) log-series *alpha*.

Hard-Bottom Benthic Communities

- *Has the hard-bottom community changed?*

The hard-bottom benthic communities near the outfall remained relatively stable over the baseline period (1995–2000) and have not changed substantially since the activation of the outfall. Major departures from baseline conditions have not occurred during the first three years of discharge; however, some subtle changes have been observed. For example, a noticeable decrease in the abundance of upright algae was observed in 2003. The abundance of upright algae was found to be quite variable throughout the baseline period, reflecting exceptionally patchy distributions. Additionally, year-to-year differences in abundance have also been observed. Whether the pattern seen in 2003 is the start of an outfall-related downward trend in upright algal populations, or merely reflects inherent cyclical changes, is presently not understood.

Another post-diversion change that has been observed is 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. Such changes were seen 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 was most noticeable in 2001 and 2002 and slightly less so in 2003. 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 for detecting degradation of the hard-bottom habitat 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 resulted in materials accumulating 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 altered 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.

The first three 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 four stations. Lush epifaunal growth continues to thrive on both diffuser heads surveyed for this study (Figure 7), and throughout many of the other stations visited. However, changes in the hard-bottom communities could be chronic and/or cumulative, and may take a longer time to manifest themselves.

Figure 7. The diffusers of the MWRA Massachusetts Bay outfall provide attachment substrate for a lush growth of epifaunal organisms, including the anemones seen here attached to Diffuser 2.

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 part of a 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. The Contingency Plan also details the process of how the MWRA would respond to any exceedances of the threshold values.

The studies included in the monitoring plan 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 three-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.

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. 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.

Most recently, 23 nearfield and 8 farfield stations have been sampled (either replicated or as single-sample stations) for benthic infauna and chemical contaminants; SPI have been taken at 23 locations in the nearfield, and the hard-bottom communities have been photographed using ROV-mounted cameras at 23 waypoints in both nearfield and farfield areas.

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 have been detected (Maciolek *et al*. 2003). 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 already been implemented, or will be in the 2004 and 2005 field seasons. Major changes include the termination 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); a reduction in the number of stations sampled for chemical analyses; and a reduction in the number of soft-bottom stations sampled each year for benthic community structure and associated sediment characteristics (Table 1-1). 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. 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 1-1).
- Chemical constituents including PAHs, PCBs, pesticides, metals, will be sampled at 12 or 13 stations in the nearfield, and four stations in the farfield (depending on year, see Table 1-1).
    - 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 has been 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 1-1. Revised benthic station sampling and replication.

(from MWRA 2004)

Station Group	Stations	Year sampled	Replication: biology	Replication: chemistry	Replication: TOC/grain size
Core (2 stations)	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 (Stations 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.

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 data 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 the 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). Specific locations of all sediment profile images collected in 2003 are 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 survey of hard-bottom habitats is conducted each June. The hard-bottom ROV (remotely operated vehicle) survey is designed to provide semiquantitative data about the hard-bottom community and its response to the operation of the outfall. In 2003, video and 35-mm photographic images were collected at each of 23 waypoints (Table 2-2, Figure 2-3).

For the 2003 survey, two stations (T4-1 and T4-3) were discontinued and two stations (T11-1 and T12-1) were added to expand the geographic coverage of the study. The two stations that were dropped added little information: T4-1 was relatively depauperate and T4-3 was redundant with a station (T6-1) located closer to the outfall. In lieu of these stations, two new reference stations were established: T11-1, located approximately 10 miles east of Scituate, MA, and T12-1, located southeast of the outfall. T12-1 was visited by the USGS in 1999.

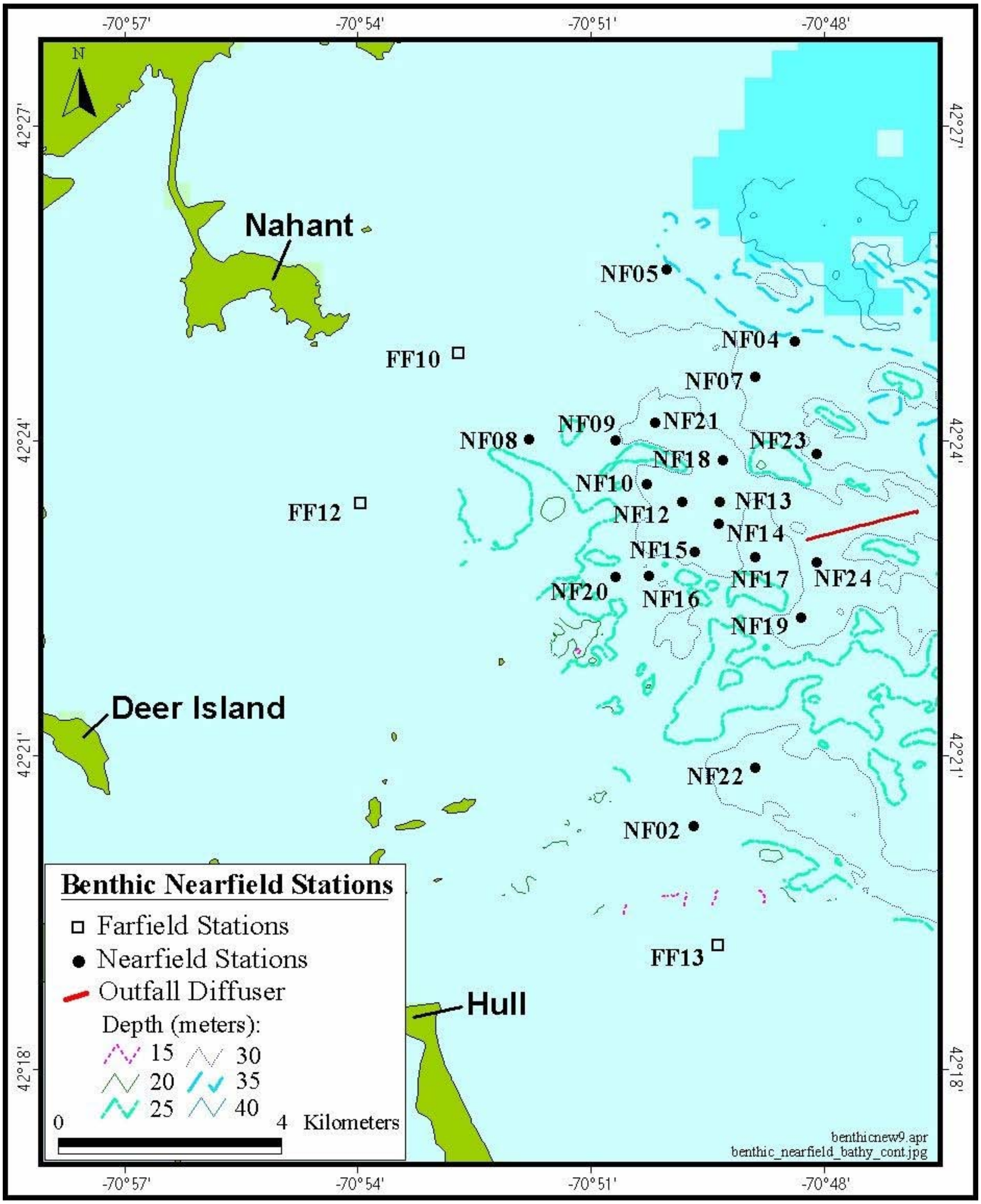


Figure 2-1. Massachusetts Bay nearfield grab stations sampled in August 2003.

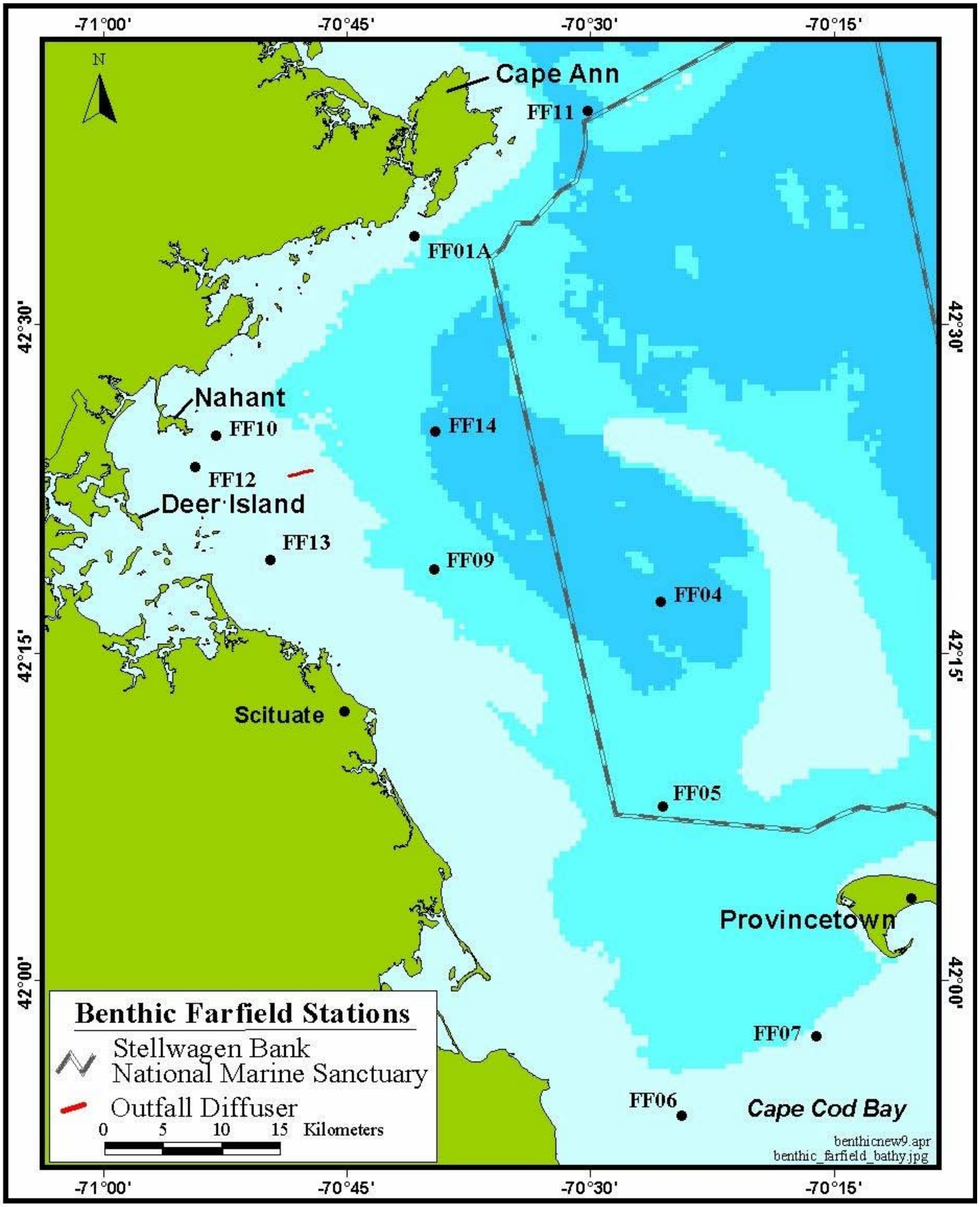


Figure 2-2. Farfield grab stations sampled in August 2003.

Table 2-1. Target locations for benthic grab and SPI stations at the MWRA outfall.

Station	Latitude	Longitude	Depth (m)
Nearfield Stations			
NF02	42°20.31´N	70º49.69´W	26
NF04	42º24.93´N	70º48.39´W	34
NF05	42º25.62´N	70º50.03´W	36
NF07	42º24.60´N	70º48.89´W	32
NF08	42º24.00´N	70º51.81´W	28
NF09	42º23.99´N	70º50.69´W	29
NF10	42º23.57´N	70º50.29´W	33
NF12	42º23.40´N	70º49.83´W	35
NF13	42º23.40´N	70º49.35´W	34
NF14	42º23.20´N	70º49.36´W	34
NF15	42º22.93´N	70º49.67´W	33
NF16	42º22.70´N	70º50.26´W	31
NF17	42º22.88´N	70º48.89´W	31
NF18	42º23.80´N	70º49.31´W	33
NF19	42º22.30´N	70º48.30´W	33
NF20	42º22.69´N	70º50.69´W	29
NF21	42º24.16´N	70º50.19´W	30
NF22	42º20.87´N	70º48.90´W	30
NF23	42º23.86´N	70º48.10´W	36
NF24	42º22.83´N	70º48.10´W	37
FF10	42º24.84´N	70º52.72´W	29
FF12	42º23.40´N	70º53.98´W	24
FF13	42º19.19´N	70º49.38´W	21
Farfield Stations			
FF01A	42º33.84´N	70º40.55´W	35
FF04	42º17.30´N	70º25.50´W	90
FF05	42º08.00´N	70º25.35´W	65
FF06	41º53.90´N	70º24.20´W	35
FF07	41º57.50´N	70º16.00´W	39
FF09	42º18.75´N	70º39.40´W	50
FF11	42º39.50´N	70º30.00´W	88
FF14	42º25.00´N	70º39.29´W	73

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

Transect	Waypoint/ Station	Latitude	Longitude	Depth (m)
T1	1	42º23.606'N	70º48.201'W	25
T1	2	42º23.625'N	70º48.324'W	24
T1	3	42º23.741'N	70º48.532'W	22
T1	4	42º23.815'N	70º48.743'W	20
T1	5	42º23.869'N	70º48.978'W	27
T2	1	42º23.634'N	70º47.833'W	26
T2	2	42º23.570'N	70º47.688'W	27
T2	3	42º23.525'N	70º47.410'W	26
T2	4	42º23.457'N	70º47.265'W	32
T2	5 (Diffuser #2)	42º23.331'N	70º46.807'W	34
T4	2	42º23.012'N	70º46.960'W	29
T4/6	1	42º22.948'N	70º47.220'W	23
T6	1	42º22.993'N	70º47.712'W	30
T6	2	42º22.855'N	70º47.082'W	27
T7	1	42º24.565'N	70º47.015'W	23
T7	2	42º24.570'N	70º46.920'W	24
T8	1	42º21.602'N	70º48.920'W	23
T8	2	42º21.823'N	70º48.465'W	23
T9	1	42º24.170'N	70º47.768'W	24
T10	1	42º22.680'N	70º48.852'W	26
T11	1	42º14.405'N	70º34.373'W	36
T12	C1	42º21.477'N	70º45.688'W	29
	Diffuser # 44	42º23.116'N	70º47.931'W	33

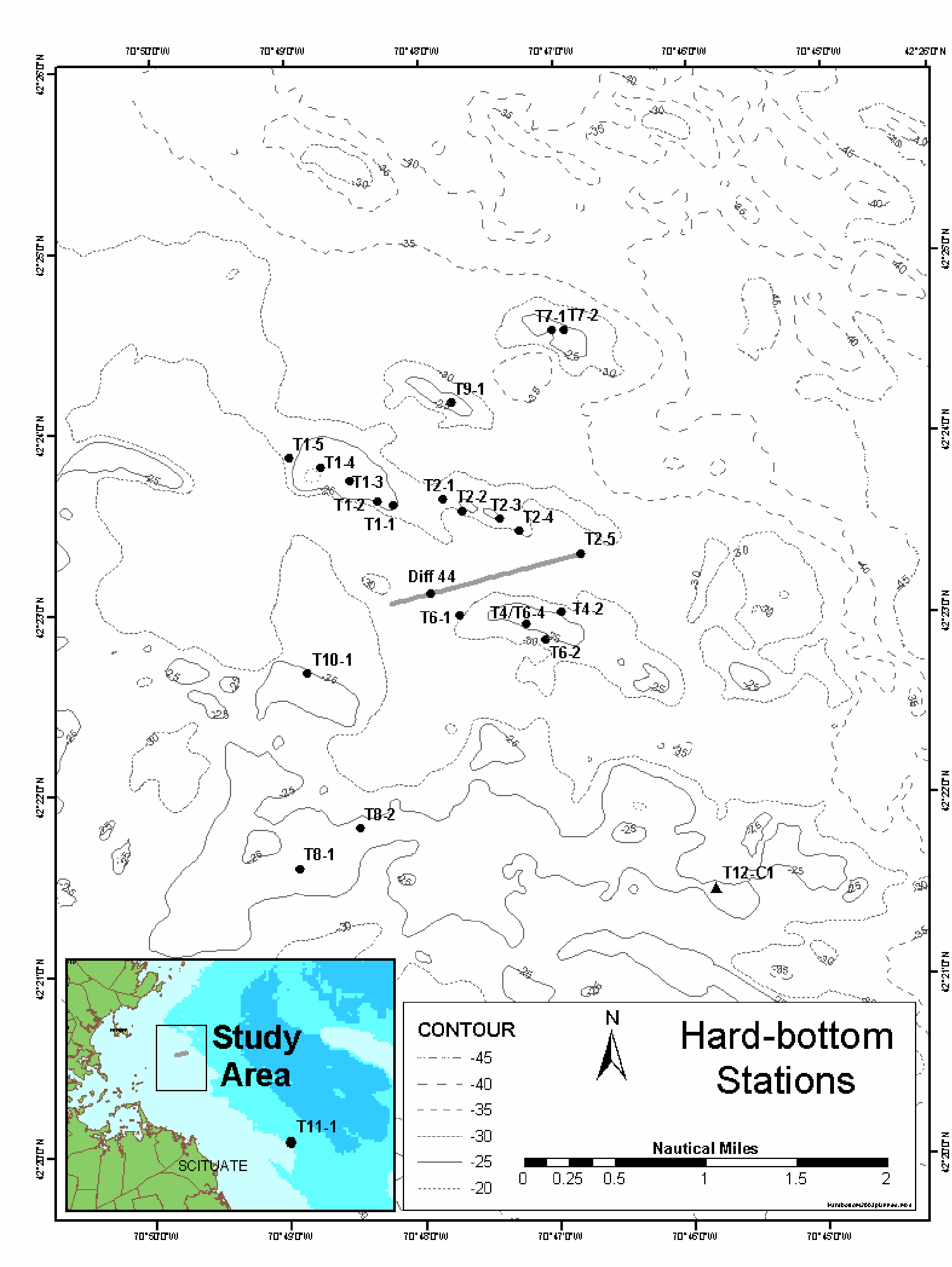


Figure 2-3. Hard-bottom stations sampled in June 2003.

2.2 Field Program Results

2.2.1 Vessel and Navigation

The 2003 grab sampling and SPI survey were conducted from 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 sec 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.

The hard-bottom survey was completed on board the F/V *Christopher Andrew*. A DGPS and ORE International LXT Underwater positioning system were used for positioning the vessel and the ROV. The Windows-based software, HYPACK, was used to integrate these positioning data and provide real-time navigation, including position and heading of the vessel and position of the ROV relative to the vessel.

2.2.2 Grab Sampling

Ms. Isabelle Williams was the Chief Scientist for collection of soft-sediment grab samples. In 2003, three sampling protocols were used for Nearfield/Farfield Benthic Survey BN031/BF031.

- At Stations NF12 and NF17, three replicate samples for infaunal analysis and three replicate samples for chemical analyses were collected.
- At Stations NF24, FF10, FF12, FF13, and at each of the eight farfield stations, three infaunal and two chemistry grabs were collected.
- At each of the 17 remaining nearfield stations, 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. Extra subsamples were removed from the nearfield chemistry samples to provide sediment for analysis of organics, metals, and TOC by MWRA's Department of Laboratory Services. At all stations, samples were collected with modified van Veen grab samplers; specifically, a 0.04-m^2 grab for infaunal samples and a 0.1-m^2 Kynar-coated grab for chemistry samples.

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 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 2003.

Survey Type	Survey ID	Sampling Dates (2003)	Number of Samples Collected									
			Inf	TOC	GS	Cp	Org	TM	SPI	35	V	DVD
Nearfield Benthic	BN031	5–6, 8 Aug	35	62	31	31	6	6				
Farfield Benthic	BF031	6–8 Aug	24	16	16	16						
SPI	BR031	25 Aug							69			
Hard-bottom	BH031	23–26 June								725	54	27

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: video segments, DVD: digital video disc segments.

2.2.3 Sediment Profile Imagery (SPI)

Dr. Robert Diaz was the Senior Scientist for the 2003 SPI Survey (BR031). Three replicate samples were collected at each station (Table 2-3). A series of 2–4 photographs was taken on each camera deployment. For this survey, a digital camera recording to an IBM 1-gigabyte microdrive was used in place of the 35-mm film camera that was described in the CWQAPP for this project (Williams *et al.* 2002). The digital camera captured a 5.2-megapixel image that produced a 14.1-megabyte RBG image; the camera was also equipped with a video-feed that was used to send images to the surface 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 Dr. Diaz to see the seafloor and know exactly when the camera had reached the bottom. Dr. Diaz then switched to the digital still camera and, while viewing the camera penetration, chose exactly when to record sediment profile images. Images were usually taken at about 1 and 15 sec after bottom contact.

This sampling protocol helped ensure that at least one usable photograph was produced during each lowering of the camera. The video signal showing the surface of the seafloor was recorded on 8-mm videotape for later review. Because the images were viewed in real time on the video monitor, it was rarely necessary to lower the camera to the seafloor more than three times at each station. The date, time, station, water depth, photo number, and estimated camera penetration were recorded in the field log, with each touchdown 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. For this survey, the batteries provided enough energy for each day of sampling and the camera housing had to be opened only at the end of each survey day to replace the microdrive and batteries. 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 new digital capability allowed a review of the collected images within 20 min of downloading the microdrive. While still in the field, images were transferred from 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 2003 Hard-bottom Nearfield Survey (BH031), during which 23 waypoints were visited (Table 2-3). 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 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 20–35 min of video footage per waypoint were recorded along a randomly selected heading. 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 CD for archival. Digital Video Discs (DVD) also were produced as the ROV was filming the hard-bottom stations. Details of the photographic coverage at each waypoint are discussed in Chapter 6 of this report.

3. 2003 CHEMISTRY

by Deirdre T. Dahlen and Carlton D. Hunt

3.1 Status of the Bay

Baseline data collected in Massachusetts and Cape Cod Bays from 1992 to 2000 show multiple regions defined by physical and chemical composition. Nearfield stations (Figure 2-1) include a series of locations having heterogeneous sediments located in close proximity to 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 two of the bulk sediment properties (grain-size distribution and TOC) characteristic of sediment depositional environments. The primary factor among those measured associated with the variance in the data is sand content.

Regional stations are spatially distributed throughout Massachusetts and Cape Cod Bays (Figure 2-2), and proximity to Boston Harbor influenced the chemical composition of the regional sediments. Regional sediments located farther away from the harbor, *i.e.,* offshore regional sediments, generally have lower concentrations of contaminants and sewage tracers compared with near-harbor regional (and nearfield) sediments. Principal components analysis (PCA) showed that the composition of sediments at offshore regional 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, sand content strongly influenced the variance in the regional data.

Concentrations of contaminants on average have remained relatively constant over time and were well below MWRA (2001) thresholds. More importantly, post-diversion sediment data (*i.e.,* 2001–2003) suggested that the treated effluent discharged from the offshore 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, 2001) 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 offshore 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.

3.2 Methods

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

Laboratory procedures in 2003 followed those outlined in the Benthic Monitoring CW/QAPP (Williams *et al.* 2002) and are consistent with the methods previously used under the MWRA HOM Program. Summaries of the procedures are provided below.

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

Total Organic Carbon (TOC)—Samples were analyzed for TOC using a coulometric carbon analyzer following SOP AMS-2201 (formerly AMS-TOC94).[1] Data were presented on a percent dry weight basis. TOC determinations were performed by Applied Marine Sciences, Inc.

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

3.2.2 Contaminants

Revisions to the monitoring plan, approved by the United States Environmental Protection Agency (USEPA) and Massachusetts Department of Environmental Protection (DEP), were implemented in 2003. These revisions resulted in reduced monitoring for contaminants, *i.e.,* only nearfield stations NF12 and NF17 were sampled for contaminants (stations were sampled in triplicate). Prior to 2003, all nearfield and regional stations were sampled for contaminants. Sediment contaminant data are available for 1992–1995 and 1998–2003, however, 2000 and 2003 represent reduced sampling years.

Analyses of sediments for organic constituents and metals were performed following methods outlined in Table 3-1. Samples were analyzed for organic and metal contaminants, including linear alkyl benzenes (LABs), polycyclic aromatic hydrocarbon compounds (PAHs), polychlorinated biphenyls (PCBs), chlorinated pesticides, and major and trace metals. Analytical methods followed general National Status and Trends (NS&T) methodologies (Peven *et al.* 1993a, b). More detailed information regarding methods and target analytes (organics, metals) is provided in the CW/QAPP (Williams *et al.* 2002).

3.2.3 Statistical Analysis, Data Terms, and Data Treatments

Statistical Analysis—Sediment data (grain size, TOC, and *C. perfringens*) were evaluated using correlation analyses to examine the correspondence between these parameters. Probability values were taken from Rohlf and Sokal (1969).

Data Treatments—In the discussion of bulk sediment and contaminant data, many terms are used to describe the data (Appendix B1). Appendix B1 also presents summaries of the data analyses (*e.g.*, correlations) and evaluations (*e.g.*, histogram plots) performed on the data to assess temporal and spatial trends over time. Data that were excluded from the evaluations are also documented in Appendix B1.

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

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

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

[1] SOPs AMS-2201 and AMS-TOC94 are comparable to USEPA Method 9060, as modified by the National Institute of Standards and Technology (NIST) Benthic Surveillance Program. The change in SOP numbers from AMS-TOC94 to AMS-2201 simply represents a change in the numbering system, not a change in procedure.

3.3 Results and Discussion

Given that there are limited contaminant data available for 2003, and that *C. perfringens* data suggest an effluent signal near the outfall, discussions presented here will focus on the *Clostridium* response. Discussions presented here regarding nearfield and regional chemistry (Sections 3.3.1 and 3.3.2) and chemistry interrelationships (Section 3.3.4) are summaries of the findings presented in Maciolek *et al.* (2003), updated as appropriate to include the 2003 data.

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

3.3.1 Nearfield Chemistry 1992–2003

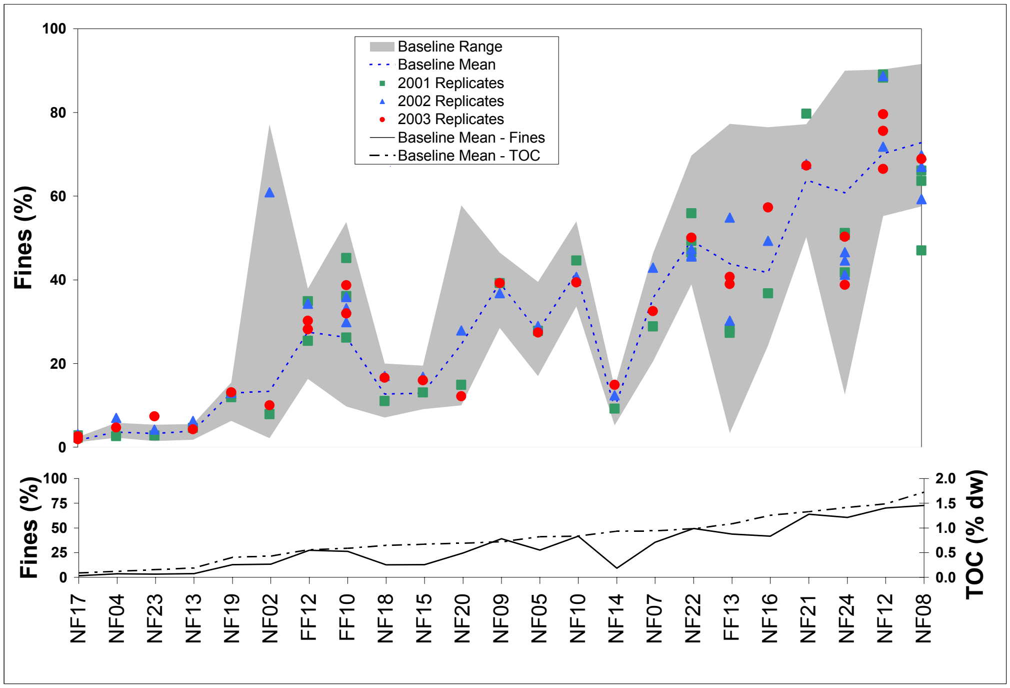
Baseline data for the nearfield showed a system that is highly variable with heterogeneous sediments in relatively close proximity to the historic leading source of contaminants, Boston Harbor. Maciolek *et al.* (2003, Chapter 4) evaluated baseline and post-diversion (2001 and 2002) data using PCA to visualize the intersample and intervariable relationships among the sediment chemical data. 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 (selected pesticides and metals) and fine particles (selected metals). More specifically, the PCA results revealed four general trends among the data collected from the nearfield sediment samples. 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. Nearfield stations NF02, NF04, NF17, NF13, NF19, and NF23 were naturally sandy sediments. Second, anthropogenic analytes (*e.g.,* TPEST, TCHLOR, TDDT, and Cd) were measured at relatively high levels in the early years of the baseline study (*e.g.,* 1992–1994) 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 loading during the baseline years. Since the mid- to late 1990s, however, there was a consistent trend away from the anthropogenic analytes among numerous sampling stations, suggesting that concentrations of anthropogenic analytes generally decreased over time. 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, and NF24. This grouping was consistent with naturally occurring mineral matter (*e.g.,* fines, clay, silt, Al, and Fe). 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, and NF20. Samples in the fourth group contained intermediate amounts of sand and fines during most of the baseline and post-diversion periods.

In addition to providing an understanding of the key factors that influence contaminant variability in the nearfield, the PCA results also showed that the post-diversion samples (2001 and 2002) typically fell within the overall variability of the baseline samples. These findings were consistent with the range plot analyses, which showed that while there were some localized increases in contaminant concentrations at one or more stations, most of the post-diversion data (2001 and 2002) were within the general distribution of samples collected during the baseline period (Maciolek *et al.* 2003). Further, where localized increases were observed, the largest increases in post-diversion concentrations (total DDT at NF21 in 2002; total PAH at FF10 in 2002; Pb at NF15 in 2002) did not appear to be related to the outfall. Instead, the increases appear be due to analytical interferences (total DDT), random spikes (total PAH), and/or unknown contamination (Pb), as contaminant values generally returned to baseline in subsequent sampling surveys (Maciolek *et al.* 2003). Thus, the localized increases in contaminant concentrations do not persuasively suggest an effluent signal.

Bulk sediment and sewage-tracer data from 2003 continued to support findings presented in Maciolek *et al.* (2003). For example, bulk sediment and sewage-tracer data fell within the baseline range at nearly all nearfield stations (Figure 3-1). Contaminant data for the two stations (NF12, NF17) sampled in 2003 were also within the baseline range, except for one replicate at NF17 that had slightly elevated total PCB concentrations (representative contaminants shown in Figure 3-2; all data in Appendix B2). The somewhat high total PCB value was not found in the sample split analyzed by MWRA's laboratory; in those analyses all three samples from NF17 had equally low levels of PCBs. The high result is reported in Figure 3-2a in the interest of completeness, but it should be viewed with caution.

Sediment data from 2001 and 2002 indicated that diversion of treated effluent discharge to the offshore outfall has not caused widespread or systematic increases in contaminants of environmental concern to the Massachusetts and Cape Cod Bay systems. Contaminant data from 2003 also showed no substantial changes at nearfield stations NF12 and NF17 following outfall activation.

A



B

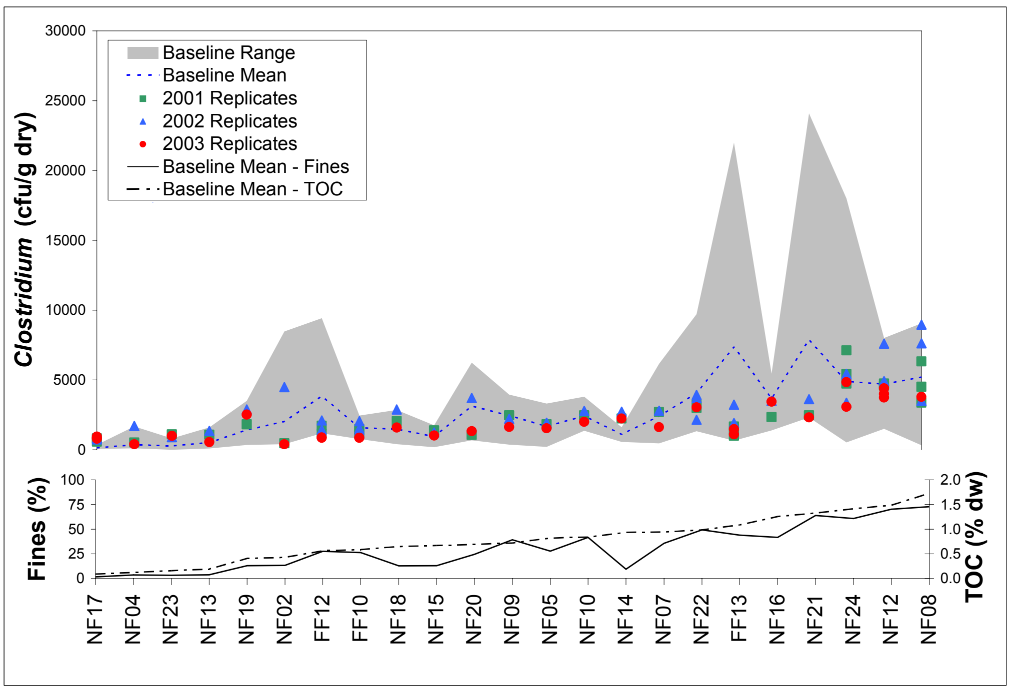
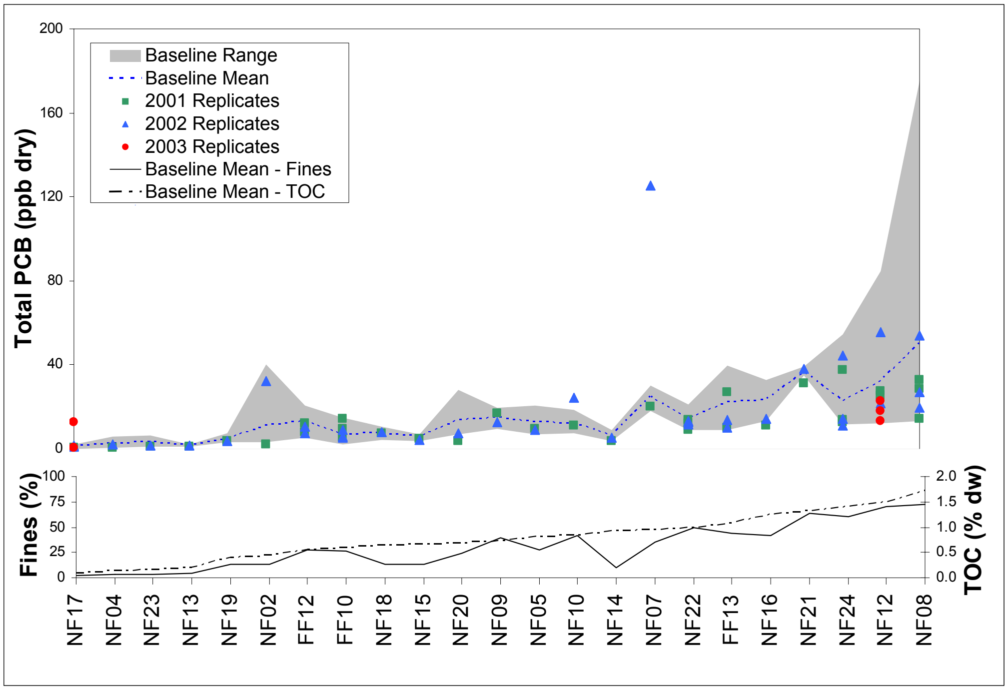


Figure 3-1. Percent fines (A) and *Clostridium perfringens* (B) for each nearfield station sampled in 2001 (squares), 2002 (triangles), and 2003 (circles) and the range of values occurring during the baseline period (gray band). The baseline mean values are indicated by a dashed line within the gray band. Stations are presented in order of increasing mean TOC concentration. Baseline station mean values for TOC (dashed line in subplot) and percent fines (solid line in subplot), plotted by station, are shown in the subplot.

A



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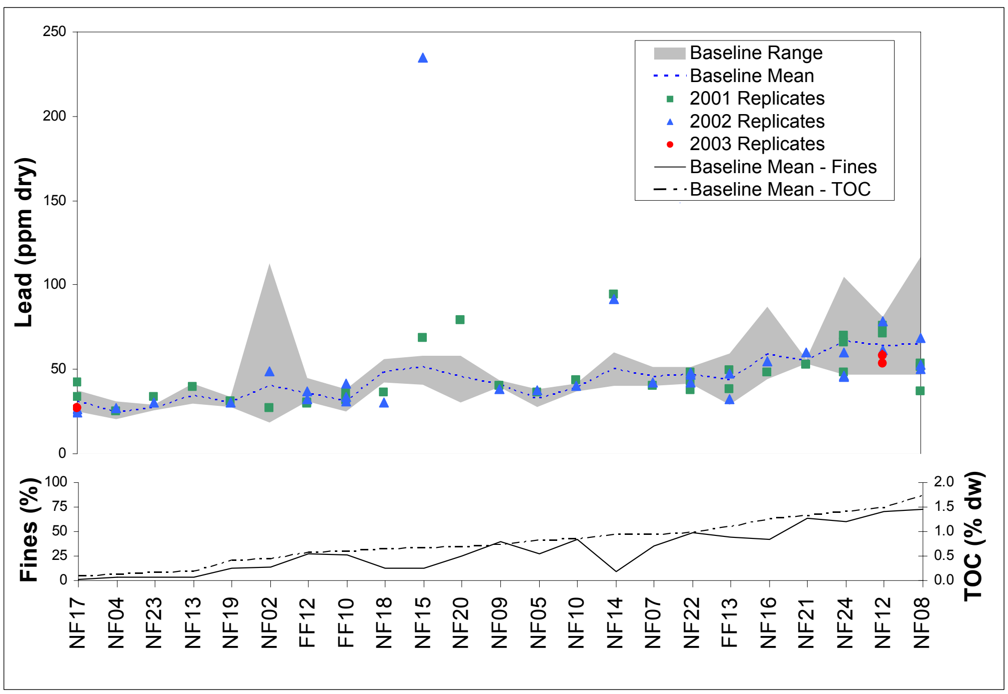


Figure 3-2. Total PCB (A) and lead (B) for each nearfield station sampled in 2001 (squares), 2002 (triangles), and 2003 (circles) and the range of values occurring during the baseline period (gray band). The baseline mean values are indicated by a dashed line within the gray band. Stations are presented in order of increasing mean TOC concentration. Baseline station mean values for TOC (dashed line in subplot) and percent fines (solid line in subplot), plotted by station, are shown in the subplot.

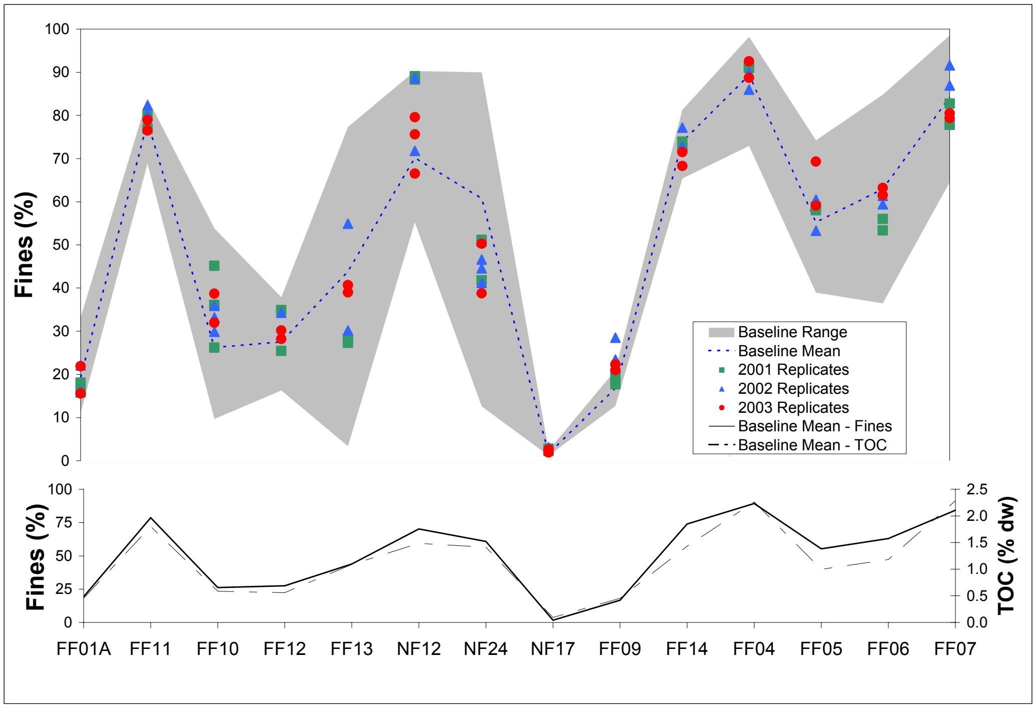
3.3.2 Regional Chemistry 1992–2003

Relative to the nearfield sediments, the regional sample groupings exhibited greater compositional definition from one another. The increased definition was attributed to the greater spatial separation and local characteristics of the regional sampling locations. PCA performed on baseline and post-diversion (2001 and 2002) regional data showed that the more distant the sampling location from Boston Harbor, the more tightly samples from that location tended to cluster, *i.e.*, the more reproducible its local compositional character (Maciolek *et al.* 2003). As was observed with the nearfield data, the PCA results showed that the primary factor among those measured associated with the variance in the regional data was sand content, followed by secondary factors associated with anthropogenic analytes and fine particles. More specifically, the PCA results revealed four general trends among the regional data. First, percent sand was inversely correlated with organic and inorganic analyte concentrations. Stations NF17, FF09, and FF01 (post-1993) contained the highest levels of sand. Second, anthropogenic analytes (*e.g.,* TLAB, Ag, CPERF, Hg, Cd, and TCHLOR) were measured at relatively consistently high levels in the baseline period at the following locations: FF12, FF13, NF12, and NF24. These samples may have received higher pollutant loadings, especially during the early 1990s, from Boston Harbor. Third, for most of the baseline and post-diversion (2001 and 2002) periods, relatively high concentrations of fines and associated parameters (TOC, Ni, Zn, Al, and Fe) were enriched in one or more samples from FF01 (sampled in 1992 and 1993 only), FF04, FF05, FF06, FF07, FF11, and FF14. These samples 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 comprised the fourth sample grouping, and included multiple samples from FF05, FF06, FF09, and FF10. These samples generally contained intermediate amounts of sand, fines, and anthropogenic analytes during most of the baseline and post-diversion periods.

In addition to providing an understanding of the key factors that influence contaminant variability at regional locations, the PCA results also showed that the post-diversion regional samples (2001 and 2002) fell within the overall variability of the baseline samples. These findings were consistent with the range plot analyses, which showed that while there were some localized increases in contaminant concentrations at one or more stations, most of the post-diversion data (2001 and 2002) fell within the general distribution of regional samples collected during the baseline period (Maciolek *et al.* 2003). Bulk sediment and sewage tracer data from 2003 continued to support findings presented in Maciolek *et al.* (2003). For example, bulk sediment and *C. perfringens* data fell within the baseline range at nearly all regional stations (Figure 3-3). In addition, *C. perfringens* abundances frequently fell below the baseline mean (Figure 3-3).

The regional sediment data available from 2001 and 2002 suggest that the treated effluent discharged from the offshore outfall has not caused widespread or systematic increases in contaminants of environmental concern to the Massachusetts and Cape Cod Bay systems.

A



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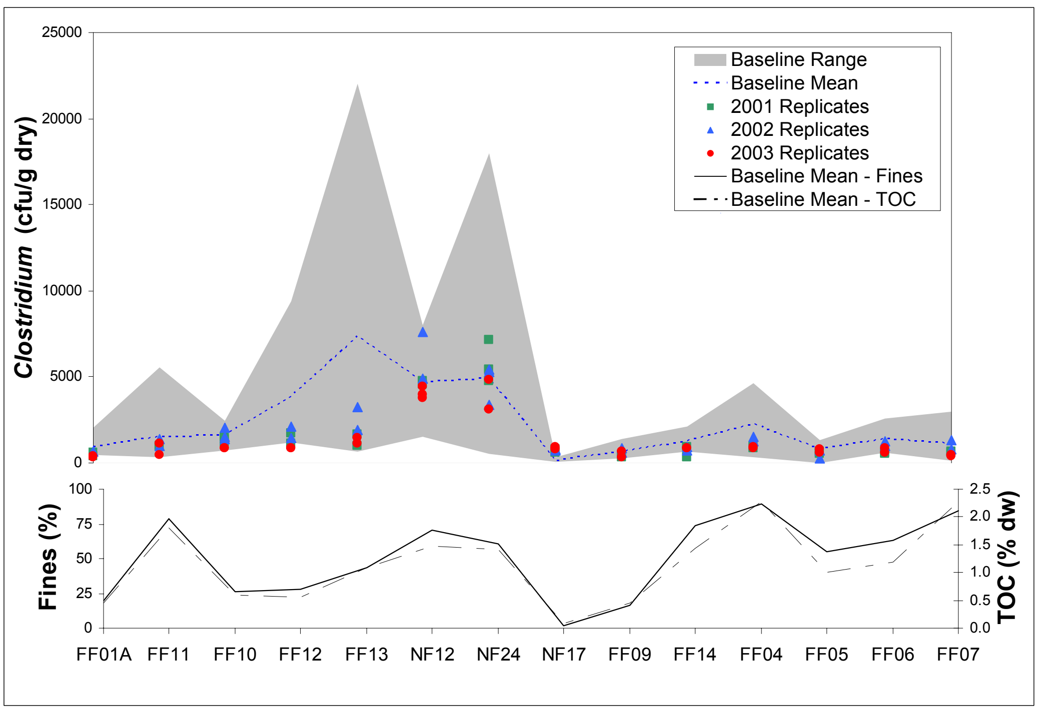


Figure 3-3. Percent fines (A) and *Clostridium perfringens* (B) for each regional station sampled in 2001 (squares), 2002 (triangles), 2003 (circles) and the range of values occurring during the baseline period (gray band). The baseline mean values are indicated by a dashed line within the gray band. Stations are presented in order of location relative to the outfall, from north to south. Baseline station mean values for TOC (dashed line in subplot) and percent fines (solid line in subplot), plotted by station, are shown in the subplot.

3.3.3 Spatio/Temporal Response of Sewage Tracers 1992–2003

Cessation of sludge disposal to the harbor in 1991 and subsequent improvements in sewage treatment,[2] including diversion of treated effluent discharge to the offshore outfall in 2000, have had a positive influence on harbor sediments. Specifically, *C. perfringens* abundances (normalized to percent fines) showed sustained decreases since 1998 at near-harbor locations compared with 1992–1997 values (Maciolek *et al.* 2003). Further, abundances of *C. perfringens* have also decreased in Boston Harbor sediments since 1999 (Maciolek *et al.* 2004).

Diversion of treated effluent discharge to the offshore outfall has also had a localized, but modest, influence on sediments near the outfall. *C. perfringens* abundances (normalized to percent fines) increased in 2001–2003 at most nearfield stations compared with 2000 values (Figure 3-4). Data from 2000 was used (for comparison) because it represented the system after improvements to sewage treatment and shows the system just prior to outfall activation (although the baseline was extended to also include 1999 data for additional evaluations presented below, as this shows the most representative conditions before diversion of effluent discharge to the new outfall). Notably, normalized abundances decreased at many nearfield stations in 2003 compared with 2001–2002 values. The decrease was unexpected had the system remained in a steady state, and may suggest that:

- the source has changed (*e.g.,* cleaner effluent with less particulate matter) resulting in reduced *Clostridium* spore loads. This does not appear likely, as flows, TSS loadings, and effluent treated only with primary treatment were approximately 10–15% higher in 2003 than in 2001–2002 (M. Hall, MWRA, personal communication, 2004).

- the spores have changed form, *i.e.,* sporalated. Again, this is also unlikely as spores are persistent in the environment (Dr. Robert Duncanson, MTH Environmental, personal communication, 2004).

- the sample collection methods varied, resulting in deeper sediments being collected. This too is doubtful as the field methodologies have not changed.

- the spores are being consumed, and

- *Clostridium* is being lost as a result of physical processes such as sediment transport or bioturbation and mixing down in sediments.

Clostridium abundances, non-normalized and normalized to percent silt, clay, fines and TOC, were evaluated to assess the influence of grain size and TOC on *Clostridium* abundance in the nearfield, and to assess whether the *Clostridium* response can be explained. Evaluations were performed against baseline *Clostridium* data from the two years prior to outfall activation, *i.e.,* 1999–2000.

Evaluation of the non-normalized *Clostridium* response confirmed previous findings. Specifically, post-diversion *C. perfringens* abundances increased above baseline (*i.e.,* 1999–2000) at most nearfield locations, while a modest decrease was observed at near-harbor stations (*i.e.,* FF12 and FF13) and no substantial changes were observed at offshore regional stations (Figure 3-5). The 2003 non-normalized *Clostridium* response also decreased at most nearfield stations compared with 2001–2002 values (Figure 3-5). The post-diversion increase in the nearfield *Clostridium* response (non-normalized) corresponds in

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

many cases to stations where percentage of fine-grained material (primarily silt) and TOC increased since 2000 (Figure 3-6). For example, increases in percent silt (and fines) were observed in 2001 at stations NF12, NF21, NF22**,** FF10**,** NF16**,** and NF20 (Figure 3-6). Percent silt increased yet again at stations NF02 and NF07 in 2002, and at station NF09 in 2003 (Figure 3-6). Percent TOC also increased in 2001 and 2002 at many of these stations (Appendix B3). Increases in percent clay in 2001 occurred less frequently compared with silt; however, by 2002 many of the same stations (NF02, NF16, FF10, NF20) showed increases in percent clay compared with 2000 values (Appendix B3). In 2003, however, percent clay decreased at most stations that had exhibited increases in 2002 (excluding NF08, NF16 and FF10).

Normalization of the *C. perfringens* abundances to grain size (percent silt, clay, and fines), but less so to TOC, reduced the variability among the nearfield and regional data (silt and TOC normalized data shown in Figure 3-7; all data in Appendix B3). More importantly, the normalized, post-diversion *Clostridium* abundance approached baseline at all nearfield stations, except NF04, located further away (>2-km) from the western end of diffuser #55 (Figure 3-7); 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 near 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. These nearby stations (excluding NF24) and NF04 are comprised of very sandy sediments, with small amounts of fine-grained material (generally <10% silt). The sandy nature of the nearby sediments (excluding NF24) and NF04 suggests a high-energy environment, one where only coarser-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. 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. Supplemental testing such as analysis of sediment cores and/or treated effluent for *C. perfringens* would provide additional insight into the *Clostridium* response.

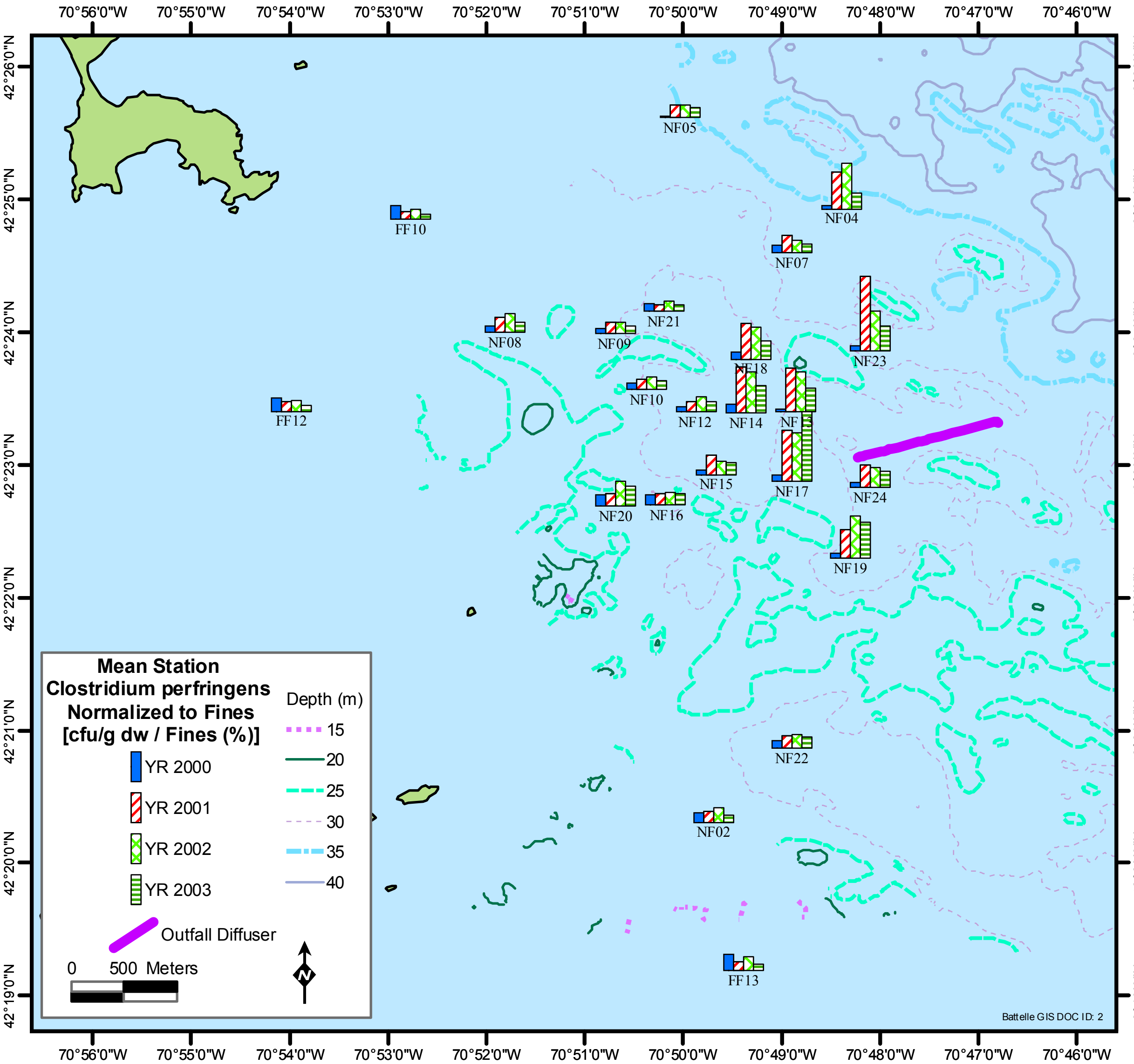


Figure 3-4. Station mean concentrations of *C. perfringens* (normalized to percent fines) in nearfield sediments prior to (August 2000) and after (August 2001-2003) outfall activation.

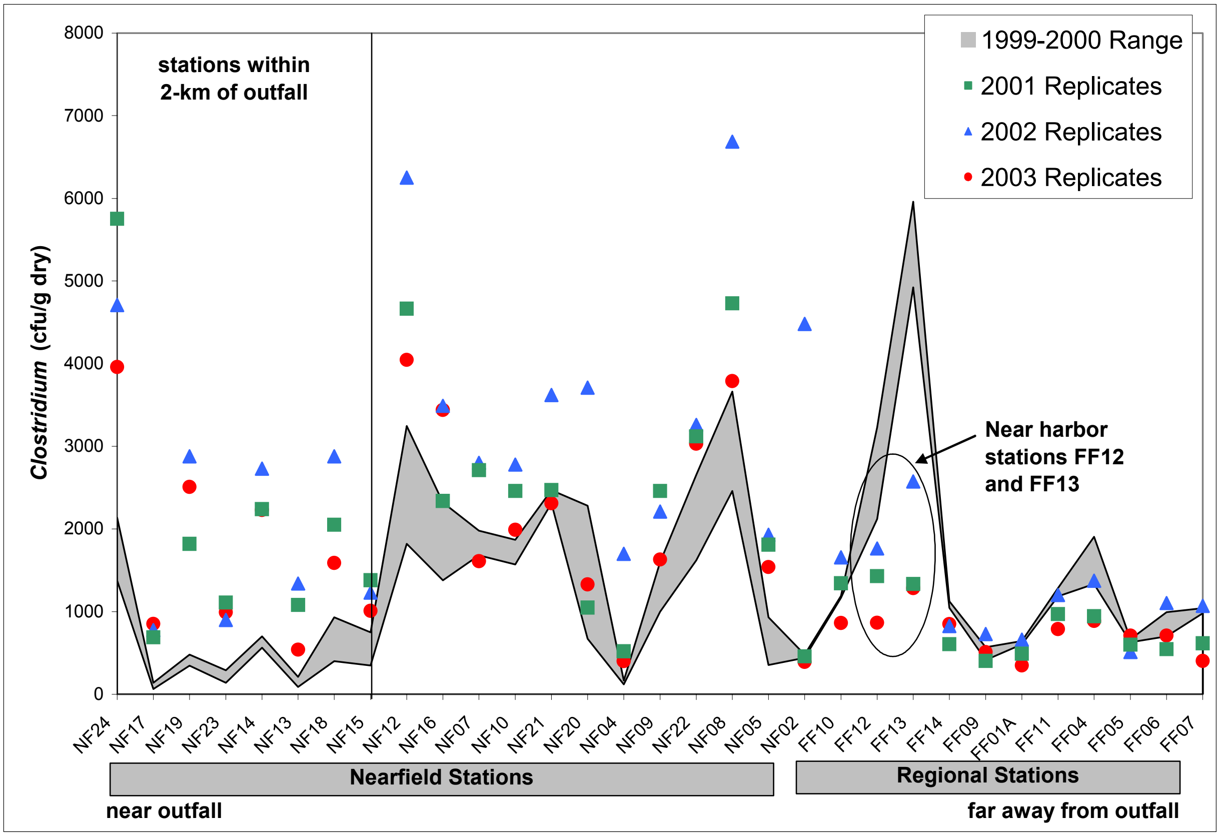


Figure 3-5. ***C. perfringens*** **response (non-normalized, station mean values) for each nearfield and regional station sampled in 2001 (squares), 2002 (triangles), and 2003 (circles) and the range of values occurring during the 1999-2000 baseline period (gray band). Stations are presented in order of location relative to the outfall, from close (*e.g.*, NF24) to more distant (*e.g.*, NF02).**

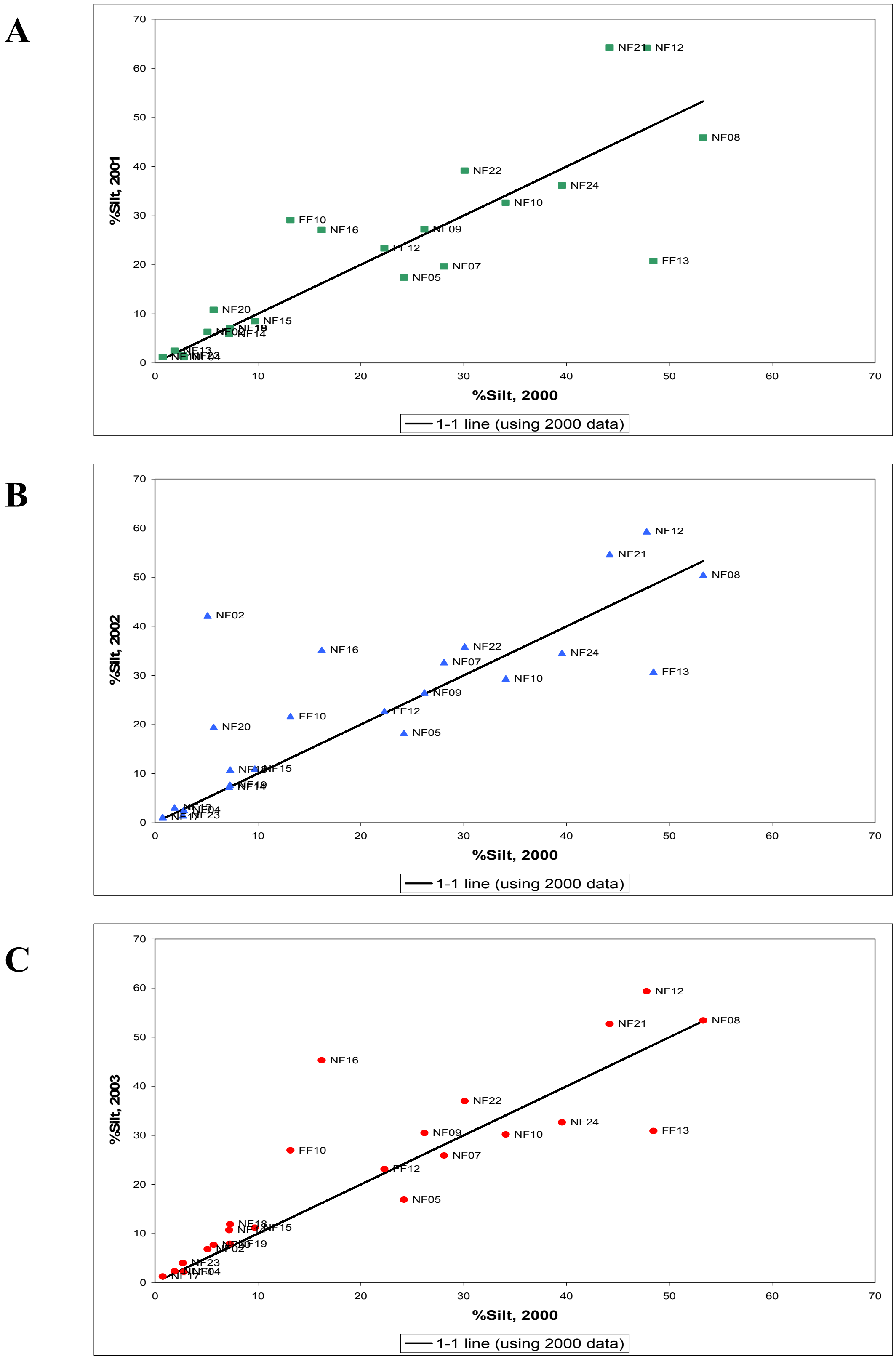


Figure 3-6. Correspondence between percent silt in 2000 and post-diversion periods: 2001 (A), 2002 (B), and 2003 (C).

A

B

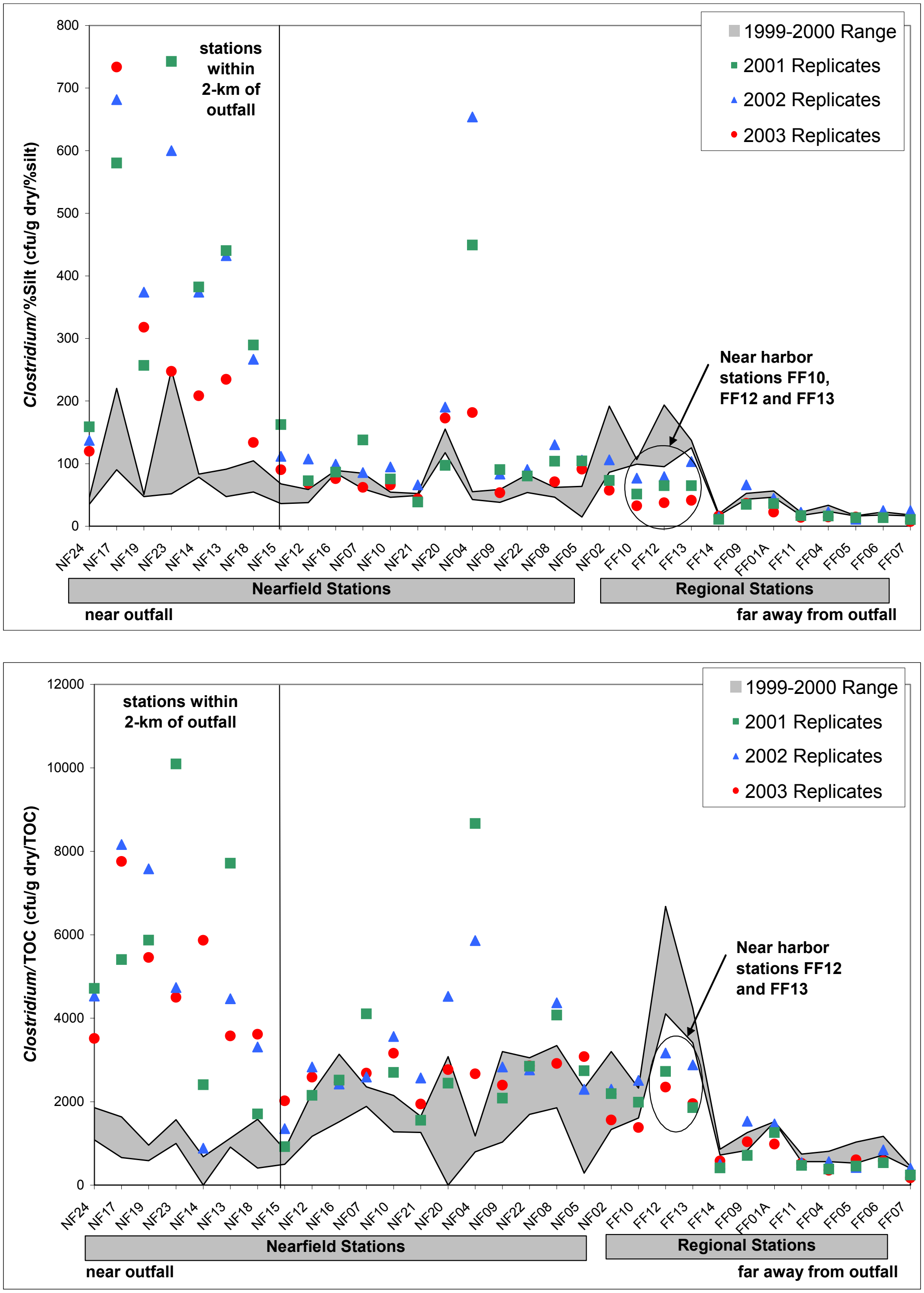


Figure 3-7. ***C. perfringens*** **response normalized to percent silt (A) and TOC (B) (station mean values) at nearfield and regional stations before and after outfall activation. Pre-diversion levels (1999-2000) are represented by the gray band; post-diversion levels are represented by symbols: August 2001 (squares), 2002 (triangles), 2003 (circles). Stations are presented in order of location relative to the outfall, from close (*e.g.*, NF24) to more distant (*e.g.*, NF02).**

3.3.4 Chemistry Interrelationships

Proximity to the primary historic source of contaminants, Boston Harbor, influenced the concentration of contaminants in nearfield and regional sediments (Maciolek *et al.* 2003). Nearfield and near-harbor regional sediments, which are located closer to Boston Harbor, generally have higher concentrations of contaminants compared with offshore regional sediments. Contaminant concentrations at offshore regional locations are primarily influenced by distributed sources (*e.g.,* atmospheric input, distant rivers). PCA supported this and showed that the composition of sediments at offshore regional sampling locations is influenced by the analytes associated with fines and may reflect regional sediment inputs distinct from Boston Harbor. Factors that influence contaminant variability at nearfield and regional locations include the two bulk sediment properties (grain size and TOC) characteristic of different sediment depositional environments.

For 2003, grain-size, TOC and *C. perfringens* data are available for all nearfield and regional sediments. Contaminant data, however, are only available for nearfield sediments from NF12 and NF17 (sampled in triplicate), and have extremely limited utility with regard to confirming previous findings (Maciolek *et al.* 2003). As a result, discussions presented here regarding relationships between bulk sediment properties and contaminants are in effect summaries of findings presented in Maciolek *et al.* (2003).

Nearfield—Tabular results (*i.e.*, *r* values) and regression plots from the correlation analysis are presented in Appendix B4. Contaminant variability in the nearfield is associated primarily with grain size and TOC. Moreover, the relationships between bulk sediment properties and contaminants did not change substantially following outfall activation. Results from 2003 continued to support these findings. For example, grain size continued to be strongly correlated ($r^2 > 0.7$; or $r \geq 0.8$) with TOC before and after treated effluent diversion (Appendix B4, Figure B4-13a). The sewage tracer, *C. perfringens*, also remained moderately correlated (r^2 generally 0.5 or higher; or $r \geq 0.7$) to grain size and TOC, although a modest increase in post-diversion *C. perfringens* abundances are evident (Appendix B4, Figure B4-13b,c; discussed in greater detail in Section 3.3.3). Most contaminants were moderately to strongly correlated with grain size and TOC before and after treated effluent diversion, although the correlation with total PCB, total DDT, and Pb did degrade after activation of the offshore outfall. The degraded correlation is primarily due to unusually high post-diversion values of these contaminants at selected stations[3] (Appendix B4, Figures B4-14 and B4-15). The unusually high contaminant values appear to be due to analytical artifacts, random spikes, and/or an unknown source, as most values returned to baseline in subsequent sampling surveys (Maciolek *et al.* 2003). The unusually high contaminant values, therefore, do not definitively suggest an effluent signal.

Regional—Tabular results and regression plots are presented in Appendix B4. The wide spatial distribution of regional sediments contributed to the higher variability among the regional data compared with that among nearfield sediments (Maciolek *et al.* 2003). Regional stations located far away from Boston Harbor generally had lower contaminant concentrations compared with regional stations located closer to the harbor (Appendix B4). The variability among contaminants decreased when near-harbor regional stations (*i.e.,* FF10, FF12, FF13, NF12, NF17, and NF24) were excluded from the correlation analysis, suggesting that the factors that influence contaminant variability at offshore regional locations include distributed sources.

Near-harbor regional and nearfield stations, with similar grain size to offshore regional stations, generally had higher contaminant concentrations compared with offshore regional values (Maciolek *et al.* 2003; regression plots provided in Appendix B4). Contaminant concentrations present at levels above the

[3] Total PCB unusually high at NF07 in 2002 and NF17 in 2003; total DDT unusually high at NF21 in 2001; and Pb unusually high at NF14 and NF15 in 2001 and 2002, and NF20 in 2001.

underlying offshore regional signature are indicative of a local source (Boston Harbor), as evidenced by a higher slope value from the regression analysis for nearfield data compared with offshore regional data (Appendix B4).

Last, Maciolek *et al.* (2003) showed that there were no substantial changes to the strength of the correlation within bulk sediment properties and metals at offshore regional stations after the offshore outfall came on-line (Appendix B4, Table B4-2b). In contrast, the correlation between some organic contaminants (total DDT, total LAB) and bulk sediment properties degraded slightly (smaller *r* value) after the offshore outfall came on-line, whereas others (total PAH, total PCB) improved (higher *r* value) (Appendix B4, Table B4-2b). Thus, there was no clear evidence of an outfall impact at stations distant from the offshore outfall.

3.4 Monitoring Questions

Relocation of the outfall to Massachusetts Bay raised environmental concerns regarding potential effects of the diverted discharge on the offshore 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. 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 localized increases in some metals and organic contaminants were observed at one or more stations, most of the post-diversion contaminant data (2001–2003) were within the general distribution of samples collected during the baseline period (1992–2000). These findings suggest that the treated effluent discharged from the offshore outfall has not caused a general increase in contaminants of environmental concern to the Massachusetts and Cape Cod Bay systems in 2001 and 2002.

- ♦ *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 (normalized to grain size) were higher in sediments located closer to Boston Harbor, and decreased with distance from the harbor. Regional sediments located far way from Boston Harbor generally have among the lowest *C. perfringens* abundances (frequently less than 1,000 cfu/g dry weight). Since 1998, *C. perfringens* abundances (normalized to grain size) have shown sustained decreases in nearfield sediments located within 10-km of Boston Harbor. Abundances of *C. perfringens* have also decreased in Boston Harbor sediments since 1999 (Maciolek *et al.* 2004). These findings suggest that the cessation of sludge disposal to the harbor in 1991 and subsequent improvements to sewage treatment have had a positive influence on harbor sediments.

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

The abundance of the sewage tracer, *C. perfringens,* did not change substantially at regional stations located far way from the offshore outfall. This suggests that the effluent discharged from the offshore outfall is not influencing the offshore regional sediments. The post-diversion *Clostridium* response (normalized to grain size) has decreased slightly at regional stations located near Boston Harbor (*i.e.,* FF10, FF12, and FF13) compared to 2000 levels. This suggests that diversion of the treated effluent discharge from the harbor to the offshore outfall may be having a positive influence on the near harbor sediments.

Diversion of the treated effluent discharge to the offshore outfall has also had a localized, but modest, influence on sediments near the outfall. Post-diversion *C. perfringens* abundances have increased at most nearfield stations, suggesting an effluent signal near the outfall. 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, especially for nearfield stations located more than 2 km from the outfall. Stations located within 2 km of the outfall still showed an elevated post-diversion *Clostridium* response, even after normalization to grain size. This continues to show an effluent signal near the outfall. Notably, the *Clostridium* response (normalized to grain size) decreased in 2003 compared to 2001–2002 values, possibly due to sediment transport or deposition of less contaminated material over the surface sediments.

3.5 Conclusions

Sediment data available to date suggests that diversion of the treated effluent discharge to the offshore outfall has not caused widespread or systematic increases in contaminants of environmental concern to the Massachusetts and Cape Cod Bay systems. Nor has activation of the offshore outfall resulted in substantial changes to the abundances of the sewage tracer, *C. perfringens,* in regional sediments located far away from the outfall. Small decreases in *C. perfringens* abundances (normalized to grain size), however, have been observed at regional stations located closer to Boston Harbor. This suggests that diversion of treated effluent discharge, from the harbor to the offshore outfall, is having a positive influence on harbor sediments.

Diversion of treated effluent discharge to the offshore outfall has also had a localized, but modest, influence on sediments near the outfall. *Clostridium perfringens* abundances increased at most nearfield stations in 2001–2003 compared to pre-diversion (1999–2000) values. Normalization to grain size reduced the post-diversion *Clostridium* response to pre-diversion values for stations located more than 2 km from the outfall. However, nearfield stations located with 2 km of the outfall still showed an elevated, post-diversion *Clostridium* response even after normalization to grain size. This suggests that there is an effluent signal near the outfall, thereby indicating that *C. perfringens* spores are excellent indicators of the response in the sediments to diversion of the effluent discharge. The *Clostridium* response (normalized to grain size) decreased in 2003 compared to 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. Supplemental testing, such as analysis of sediment cores and/or treated effluent discharged from the outfall, would allow for a more comprehensive understanding of the decreased *Clostridium* response observed in 2003.

4. 2003 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 monitoring 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 change 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 may 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 6.3 (SD = 0.72), with the greatest departure in 1997 likely due to shifting sampling dates from August to October. There was little difference in the OSI between the baseline mean and post-diversion mean. For the last three years of the baseline period (1998 to 2000), there was an increasing trend in the annual average OSI that reflected the increased importance of biological processes in structuring surface sediments (Figure 4-3). With the start of the post-diversion period in 2001, the annual average OSI trended down, which may represent a shifting balance between biological and physical processes at the nearfield stations. The peak year for biological processes was 2000. Based on the paradigm used in estimating successional stage from the SPI images, it is not likely that the decline 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). The marked decline in OSI in 2003 was due to shallowing of the RPD layer depth, which accounts for a third of the OSI score.

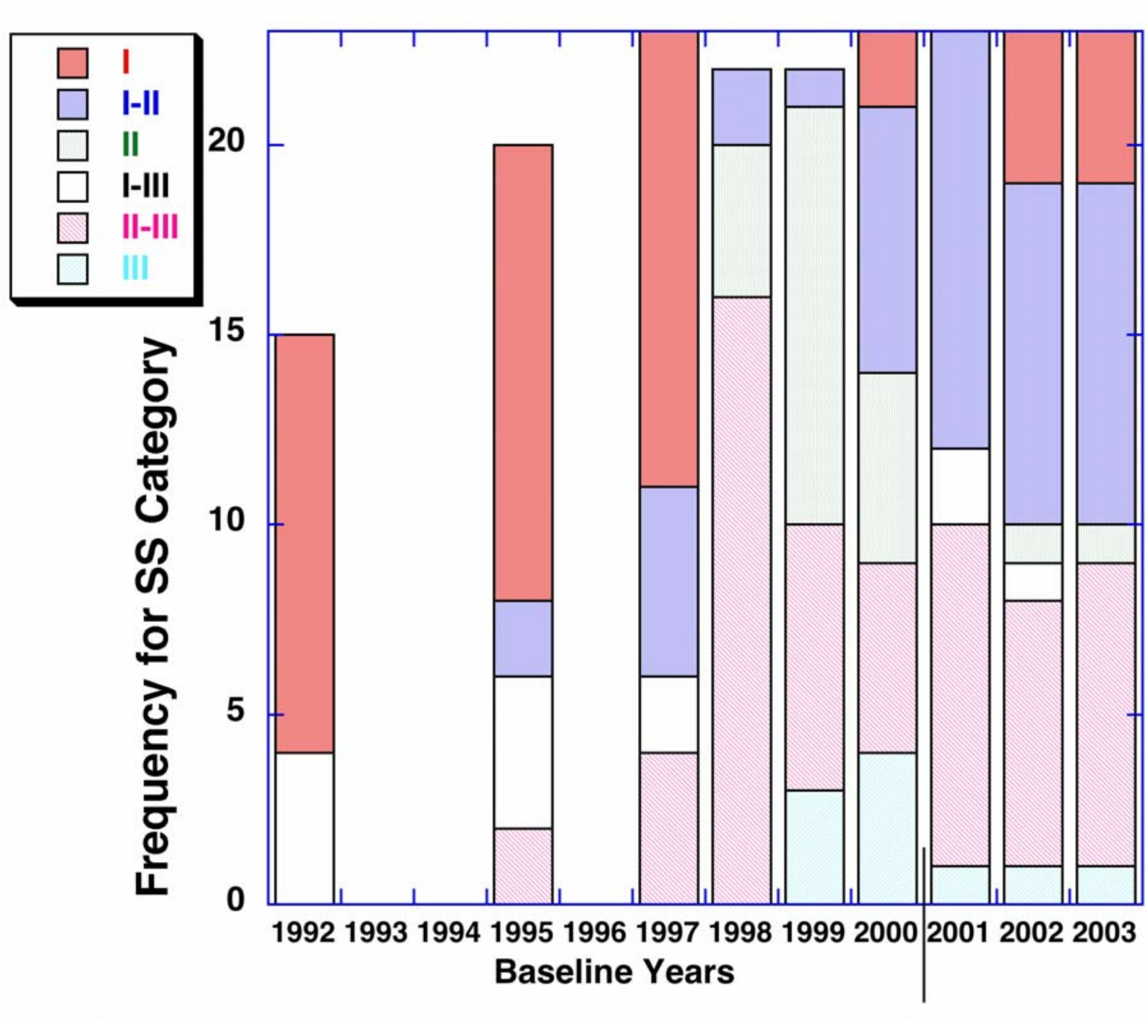


Figure 4-1. Long-term patterns in estimated successional stage from nearfield SPI images.

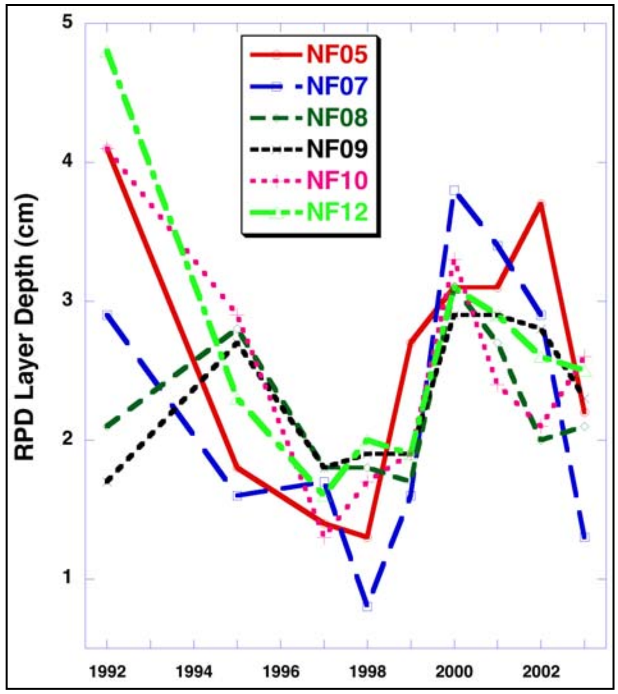


Figure 4-2. Patterns in RPD layer depth at the six stations that had measured RPD layers for all sampled years.

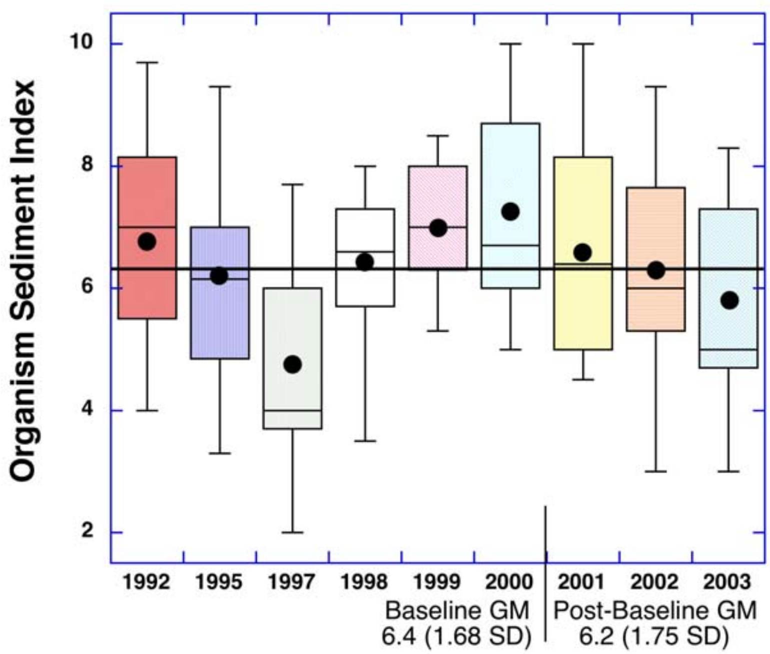


Figure 4-3. Organism Sediment Index (OSI) summarized by year for all data from nearfield stations. Box is interquartile range, bar is median, dot is mean, and whiskers are data range. Horizontal line is grand mean for all years.

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 2003 digital SPI images were compared to the 2002 images for gross changes and the Quick Look analysis was completed 28 August 2003. 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 Adobe PhotoShop and National Institute of Health Image programs. Data from each image were sequentially saved to a spreadsheet file for later analysis. Details of how these data were obtained can be found in Diaz and Schaffner (1988) and Rhoads and Germano (1986). Table 4-1 summarizes the parameters measured.

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 Feeding Voids	Number	V	Count, identify 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 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 2003 did not exceed the threshold of a 50% change 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 >3.4 cm or <1.2 cm and given the variability of the baseline data (CV = 37%) a significant change would have to be closer to >3.6 cm or <1.0 cm. The quick look mean for 2003 was 2.0 cm (Table 4-2).

For 2003, 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 shallower than the mean from the computer analysis results (Table 4-2). The correlation between the two analyses was 0.87 ($n = 21$, $p = <0.0001$) with no significant difference between the mean RPD from two analyses (paired t-test, $df = 20$, $p = 0.384$).

4.3.2 Physical Processes and Sediments

Sediment grain size in 2003 was similar to previous years and ranged from cobble (CB) and pebble (PB) to fine-sand-silt-clay (FSSICL), with 14 stations having a mixture of coarse (fine-sand and larger grain size) and fine (silt and clay) sediments, and nine stations being primarily fine sediments. Sandy sediments that ranged from very-fine-sand (VFS) to fine-medium-sand (FSMS) occurred at four stations. The modal grain size descriptor was fine-sand-silt-clay (5.5 to 4.5 phi) and occurred at eight stations (Table 4-3). 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 0 cm at Station NF16, which had pebble to cobble sediments and deepest at Stations NF21 and NF08, which had fine-sand-silt-clay and silty-fine-sand sediments, respectively (Table 4-3).

Relative to the baseline, sediment grain sizes in 2003 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 SPI images (Table 4-4). Two possible hypotheses that explain this pattern are sampling/dispersion and change in grain size. For the sampling/dispersion hypothesis, spatial heterogeneity of 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.

Table 4-2. Summary comparisons of 2003 Quick Look (QL) analysis with computer analysis and baseline apparent color RPD layer depth.

Station	QL RPD (cm)	Computer RPD (cm)	Computer-Quick Look
FF10	2.2	2.7	0.5
FF12	1.5	>1.7	>0.2
FF13	1.0	1.4	0.4
NF02	2.2	2.1	-0.1
NF04	>1.7	>1.4	-0.3
NF05	2.2	2.2	0.0
NF07	2.0	1.3	-0.7
NF08	2.3	2.1	-0.2
NF09	2.3	2.3	0.0
NF10	2.5	2.6	0.1
NF12	2.5	2.5	0.0
NF13	>1.0	ND	-
NF14	1.5	1.9	0.4
NF15	1.5	1.8	0.3
NF16	ND	ND	-
NF17	>3.2	>3.2	0.0
NF18	1.8	1.9	0.1
NF19	2.5	2.8	0.3
NF20	2.0	1.9	-0.1
NF21	2.3	2.2	-0.1
NF22	2.5	2.6	0.1
NF23	>1.2	>1.2	0.0
NF24	1.8	2.0	0.2

ND=No Data

	Baseline*	2003 QuickLook	2003 Computer	Post Diversion**
Mean (cm)	2.3	2.0	2.1	2.3
SD (cm)	0.88	0.55	0.54	0.65
N	123	23	23	67

* 1992, 1995, 1997, 1998, 1999, 2000
** 2001, 2002, 2003

Table 4-3. Summary of SPI parameters for nearfield stations, August 2003. Data from all replicates were averaged for quantitative parameters and summed for qualitative parameters (*e.g.*, the presence of tubes in one replicate resulted in a + for the station).

Station	PEN[1] (cm)	SR[2] (cm)	RPD[3] (cm)	Modal Grain Size	Surface Process	Amphi. Tubes	Worm Tubes	INF[4]	BUR[5]	Oxic Voids	SS[6]	OSI[7]	Fish Eggs	Twisted Tubes	Stick Amphi
FF10	4.1	1.1	2.7	VFS	BIO/PHY	0	>24	2.7	3.7	1.0	I-II	6.0	+	+	-
FF12	1.7	1.3	> 1.7	VFS	PHY	0	6-24	0.0	0.7	0.0	I-II	>4.3	-	-	+
FF13	0.9	1.9	1.4	FSSIGRPBCB	PHY	0	6-24	0.0	0.0	0.0	I	3.0	-	-	-
NF02	4.0	0.9	2.1	FSMS/FSSI	PHY	0	6-24	0.7	3.0	0.3	I-II	5.0	+	+	-
NF04	1.1	0.9	> 1.4	FS	BIO/PHY	0	>24	0.0	0.0	0.0	I	>3.0	-	+	-
NF05	6.4	0.8	2.2	FSSICL	BIO	3	>24	4.0	11.3	1.7	II-III	7.3	-	+	-
NF07	7.9	3.0	1.3	FSSICL	BIO/PHY	0	>24	5.3	6.7	0.0	II	5.0	-	-	-
NF08	12.5	0.4	2.1	SIFS	BIO/PHY	0	>24	3.0	7.3	3.3	II-III	7.3	-	+	-
NF09	6.7	1.2	2.3	FSSICL	BIO/PHY	0	6-24	7.7	10.0	1.0	II-III	7.7	-	-	-
NF10	6.9	0.6	2.6	FSSICL	BIO/PHY	0	6-24	6.7	9.3	1.7	II-III	8.3	+	-	+
NF12	9.3	1.0	2.5	FSSICL	BIO/PHY	0	6-24	6.0	9.3	1.7	II-III	7.7	+	-	-
NF13	0.5	0.6	IND	FSMSGRPB	PHY	0	>24				I-II		-	+	-
NF14	3.8	0.9	1.9	FSSIGRPB	PHY	0	6-24	2.7	2.3	0.0	I-II	5.0	+	+	+
NF15	1.9	2.2	1.8	FSSIGRPB	PHY	0	6-24	0.7	0.7	0.0	I-II	5.0	-	+	-
NF16	0.0	IND	IND	PBCB	PHY	0	>24				II-III		-	-	-
NF17	3.2	1.0	>3.2	FSMS	PHY	0	6-24	0.0	0.0	0.0	I-II	8.0	-	-	-
NF18	3.8	0.9	1.9	FSSIGR	BIO/PHY	0	>24	1.0	2.3	0.0	I-II	5.0	-	+	-
NF19	2.1	1.5	2.8	FSSIPBCB	PHY	0	0	0.7	0.0	0.0	I	5.0	-	-	-
NF20	1.4	1.3	1.9	FSSIGRPBCB	PHY	0	>24	0.0	0.0	0.0	I	4.0	+	-	-
NF21	12.6	1.1	2.2	FSSICL	BIO	0	>24	2.7	7.3	2.7	III	8.0	-	-	-
NF22	8.8	0.8	2.6	FSSICL	BIO/PHY	0	6-24	5.7	9.3	0.7	II-III	8.0	-	-	-
NF23	0.9	1.0	>1.2	FSMSGRPB	PHY	0	>24	0.0	0.0	0.0	I-II	>4.0	-	+	-
NF24	10.4	1.4	2.0	FSSICL	BIO/PHY	0	>24	6.3	9.7	0.7	II-III	7.0	+	-	+

[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. IND: Indeterminate

Table 4-4. 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**
FF10	VFS	.	VFS	VFS	CB to SIFS	PB to GR	CB to FS	PB to FSSICL	VFS
FF12	.	.	VFS	FS	FS	VFS	VFS	VFS	VFS
FF13	.	.	SIFS	SIFS	CB to FSSI	CB to SI	FSSI	CB to FSGR	CB to FSSI
NF02	VFS	CS	SIFS	PB to GR	CB to FSSI	CB to MSCS	FSSI	FSSI	FSMS/FSSI
NF04	FS	FS	VFS	FS	GR to FS	FS	PB to FSMS	PB to FS	FS
NF05	FS	VFS	VFS	VFS	FS/SICL	FS/SICL	FSSICL	FSSICL	FSSICL
NF07	VFS	VFS	VFS	VFS	SIFS	SIFS/CL	FSSICL	FSSICL	FSSICL
NF08	VFS	SIFS	VFS	VFS	SIFS	SIFS	SIFS	FSSICL	SIFS
NF09	VFS	VFS	VFS	VFS	FSSI	FSSI	FSSICL	FSSI	FSSICL
NF10	VFS	VFS	VFS	VFS	FSSICL	FSSICL	FSSICL	FSSICL	FSSICL
NF12	VFS	SI	SIFS	SIFS	FSSICL	FSSICL	FSSICL	FSSI	FSSICL
NF13	FS	FS to VFS	FS	PB to SIFS	FSMS	PB to FSMS	GR to FSMS	PB to FSMS	PB to FSMS
NF14	FS	VFS	VFS	PB to VFS	PB to SIFS	PB to FSSICL	PB to FSSI	PB to FSSI	PB to FSSIGR
NF15	FS	VFS	VFS	GR to FS	PB to FSSI	PB to FSSI	PB to FSSI	GR to VFS	PB to FSSIGR
NF16	VFS	SIFS	VFS	SIFS	FSSICL	PB to FSSI	CB to FSSICL	FSSICL	CBPB
NF17	FS	FS	FS	FS	GR to FSMS	PB to FSMS	FSMS	FSMS	FSMS
NF18	VFS	VFS	VFS	GR to VFS	PB to SIFS	FSSICL	PB to FSSICL	PB to FSSICL	PB to FSSIGR
NF19	.	CS to VFS	VFS	FSSICL	FSSICL	CB to FSSICL	GR to FSSI	VFS	CB to FSSI
NF20	VFS	CS to VFS	GR to FSMS	GR to SICL	PB to SIFS	PB to SIFS	PB to FSSI	FSSI	CB to FSSIGR
NF21	.	SIFS	VFS	SIFS	SIFS	SIFS	SIFS	FSSICL	FSSICL
NF22	.	SIFS	SIFS	SIFS	SIFS	SIFS	FSSICL	FSSICL	FSSICL
NF23	.	CS to VFS	FS	FS	PB to FSSICL	GR to FSMS	PB to FSMS	GR to FSMS	PB to FSMS
NF24	.	SI	SIFS	FSSICL	PB to 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

4.3.3 Apparent color RPD Depth

At four porous, coarse-sediment stations (FF12, NF04, NF17, and NF23), the apparent color RPD layer depths were deeper than the prism penetration for all replicates. For these stations, prism penetration was then assumed to be a conservative minimum estimate of the RPD layer depth and was included in the calculation of the average RPD layer depth for 2003. At station NF15, two of the three replicate images had RPD layers that were deeper than the prism penetration.

The general pattern in RPD layer depths in 2003 was similar to both the baseline and post-diversion years (Figure 4-4). In 2003, the apparent color RPD layer depth averaged for the three replicate images at a station ranged from 1.3 cm (NF07) to >3.2 cm (NF17), with a grand mean of 2.1 cm (SD = 0.54 cm). A Welch ANOVA, which tests for equality of mean while allowing the standard deviations to be unequal (a problem when sample sizes are so different, see Table 4-2), found that there was no significant difference in the depth of the apparent color RPD layer depth between baseline years and 2003 ($F = 2.75$, $df = 1$, $p = 0.105$). The fact that there was no statistical difference between 2003 and the baseline would also indicate that the RPD threshold was not exceeded. The difference between 2003 and the baseline was a shallowing of the RPD by 11%.

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 NF21 and NF24, and extended deeper than prism penetration in at least one replicate image at 17 stations. 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 NF21, Figure 4-5).

4.3.4 Biogenic Activity

Sediment surfaces in 2003 appeared to be structured by a combination of biological and physical processes, with 10 of the 23 stations (*e.g.*, NF09) having biogenic structures in combination with physical features such as bedforms. At 11 stations (*e.g.*, FF13), physical processes dominated. Stations NF05 and NF21 were classified as having a biologically structured sediment surface (Table 4-3). The increase in the proportion of physically structured stations relative to the last three years of the baseline period when biological processes dominated sediment surfaces was significant (stations that were both physically and biologically dominated were not included; 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. By 2003, the odds were 5.5 to 1 in favor of encountering physically dominated surface sediments.

Surface relief or bed roughness averaged 1.2 cm (SD = 0.58 cm) with no significant differences based on the processes structuring sediment surfaces (ANOVA, $df = 2$, $p = 0.353$). Roughness 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 FF13 (Figure 4-5).

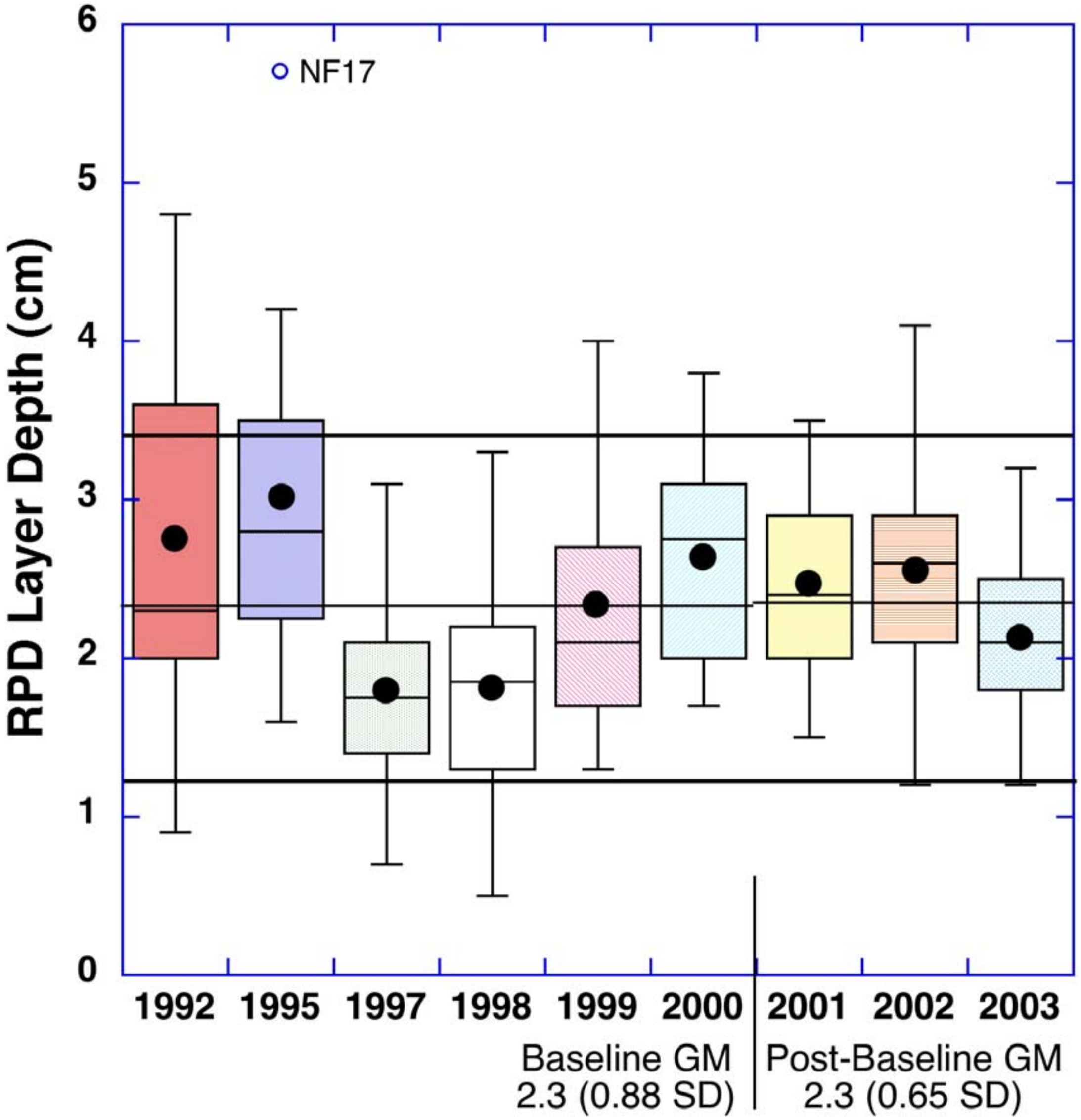


Figure 4-4. Apparent color RPD layer depth (cm) summarized by year for all data from nearfield stations. Box is interquartile range, short bar is median, dot is mean, and whiskers are data range. Horizontal line is grand mean for baseline years, with upper and lower boundaries indicating the trigger thresholds for exceeding a 50% change in RPD layer depth. Station NF17 was an outlier in 1995.

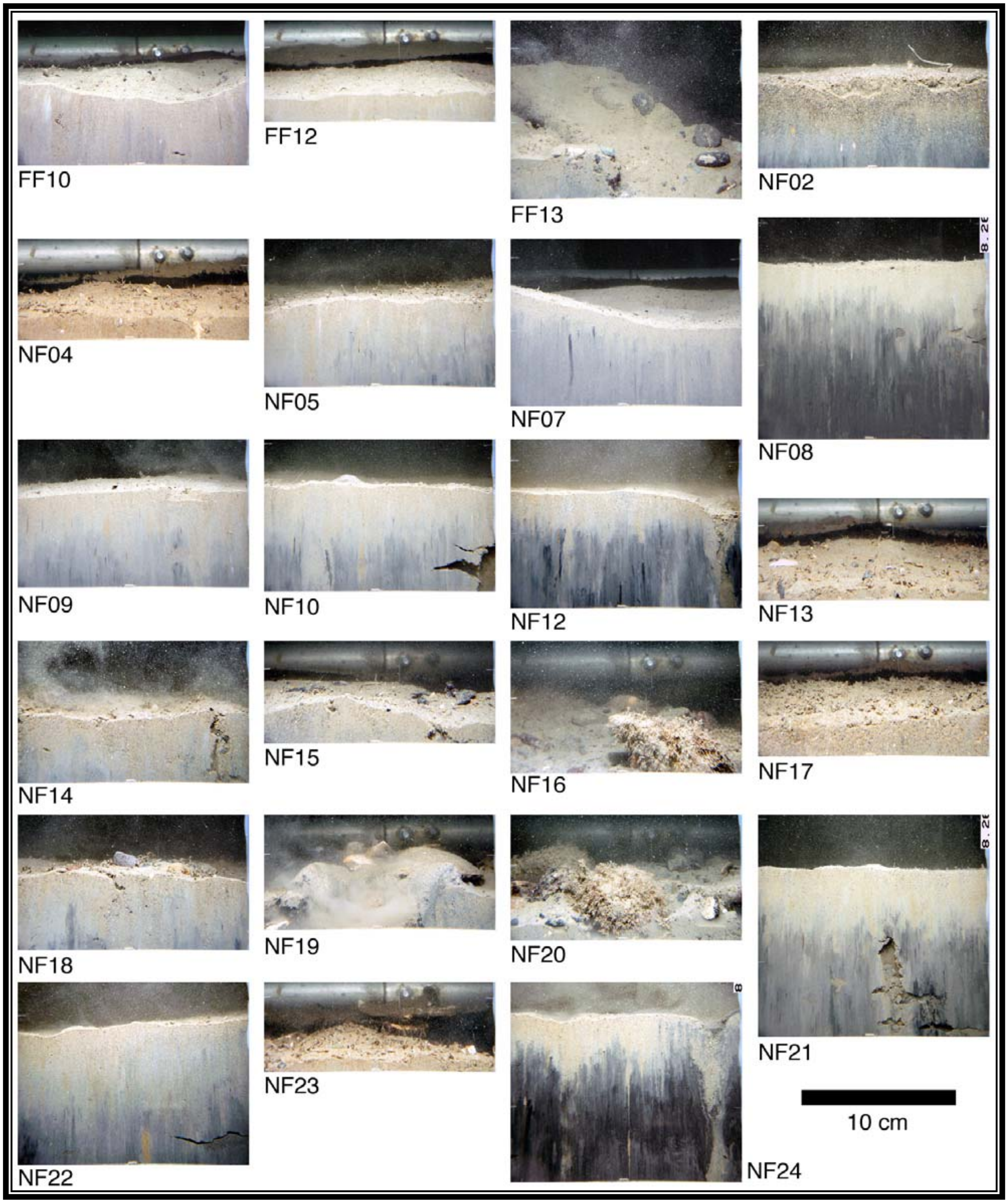


Figure 4-5. Sample SPI images from 2003 nearfield stations.

Biogenic structures associated with activities of successional stage II and III fauna dominated biological processes in 2003 and were similar to those found during the baseline period. Included in 2003 were *Ampelisca* spp. tubes (NF05), biogenic whips or sticks of *Dyopedos* spp. (NF10), large worm tubes (NF04), biogenic mounds (NF10), and possibly fish eggs (NF14). Subsurface biogenic structures associated with infaunal organisms included active oxic burrows (NF12) and water-filled oxic voids (NF21).

Free-burrowing infaunal worms occurred at 15 stations in 2003, with a grand average of 2.6 (SE = 0.70) worms per image, 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 = 2.54, p = 0.115). At Station NF09 the average number of worms was 7.7 per image, with a maximum of 9 worms at NF09-1. The maximum number of worms in any one replicate image was 14 at NF12-1.

All stations in 2003, except NF19, 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, twisted tube projecting 1–2 cm above the sediment surface occurred (NF04). These tubes possibly belonged to oweniid polychaetes (Maciolek, personal communication) and first appeared in nearfield SPI images in 2000. Tubes in 2003 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 2003 was bimodal, with a peak between pioneering (Stage I) and intermediate (Stage II) and another peak between intermediate and equilibrium (Stage III) (Figure 4-1). Most of the stations (17 of 23) appeared to be a mixture of successional stages (Table 4-3). Stage I appeared to dominate four of the stations while Stage II and Stage III communities dominated at one station each. Compared with the first three baseline sampling periods (1992, 1995, and 1997), the 2003 SPI images had a higher proportion of intermediate and advanced successional stage stations (Fisher's Exact Test, p = <0.0001). For the first portion of the baseline the odds of encountering a station with a Stage I designation were 1.5 to 1. For the last three years of the baseline period the odds were 32.5 to 1 against a Stage I designation. In 2003 the odds were still against a Stage I designation at 4.75 to 1. The high degree of biogenic sediment reworking observed in many of the 2003 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 4-3). Over the 12-year period of sampling the nearfield, the major shift in successional stage occurred during the baseline period between 1997 and 1998 (Figure 4-1).

In 2003, the mean Organism Sediment Index (OSI) was 5.9 (SE = 0.37), which was statistically the same as the baseline grand mean of 6.4 (SE = 0.15) based on Welch ANOVA (F = 1.91, p = 0.18). 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 2003, 11 stations had OSI values <6. At these stations the stressor appeared to be physical processes with no sign of stress from organic loading. Three of these stations had RPD layer depths deeper than prism penetration, which leads to possible underestimation of the OSI. The other eight stations had unqualified OSI values <6 (Table 4-3) with the lowest value of 3.0 at station FF13, which had coarse heterogeneous sediments with little evidence of biological activity. The highest OSI was 8.3 at station NF10, which had finer sediments and a well-developed infaunal community.

4.3.6 Summary of 2003 SPI Data

The mean apparent color RPD layer depth in 2003 of 2.1 cm (SE = 0.18) was statistically the same as the baseline period 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 would likely first appear, there was no difference in RPD between baseline and 2003 data. Mean baseline RPD layer depth at NF24 was 1.9 cm (SE = 0.29) and in 2003 it was 2.1 cm (SE = 0.38).

There was little change in the sedimentary environment in 2003 relative to baseline and 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 2003 appeared to be less relative to 2002 and the last three years of the baseline period, but subsurface biogenic activity was similar to that noted in 2002. Stations with *Ampelisca* spp. tubes decreased from five to one between 2002 and 2003. *Ampelisca* spp. tubes were first observed in the nearfield SPI images during the baseline period in 1999. Overall, in 2003 it appeared that physical and biological processes were about equally responsible in structuring surface sediments. The declining trend in OSI that started in 2001 is likely a representation of the shifting balance between biological and physical processes. Similarly, the increasing trend in OSI that started in 1998 was a representation of the increasing importance of biological processes in structuring surface sediments.

4.4 Monitoring Questions

- *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 2003 of 2.1 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 2003 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 2003 SPI images, it did not appear that the amount of sedimented organic matter had changed relative to the operation of the outfall or the baseline images for the nearfield SPI stations. Mean annual TOC for the same years that the SPI images were collected were also not different and ranged from 0.6% to 1.2% (see Chapter 3, this report).

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 sediments. At all 15 fine-sediment stations, those with fine-sand-silt-clay and fine-sandy-silt, the RPD layer depth was >1.5 cm and SPI images confirmed the importance of bioturbation in deepening RPD layers at these stations.

4.5 Conclusions

The sediments at many stations in 2003 continued to be heterogeneous, with a mixture of grain sizes ranging from sandy-silts-clays to cobbles. This sediment heterogeneity was consistent from 1998 to the present (Table 4-4). 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 and cobbles. Tubes were the most numerous surface biogenic structures and occurred at all but one station in 2003.

While the general appearance of the sediments and benthic habitat conditions at the nearfield stations in 2003 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 2003 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 in 2003 tube mats were not observed. Also, the medium-size twisted tube that was widespread at nearfield stations in 2001 occurred in lower densities in 2003. The number of stations with *Ampelisca* spp. tubes also decreased from five to two stations between 2002 and 2003. *Ampelisca* spp. tubes were first observed in the nearfield SPI images in 1999. While biogenic activity at the sediment surface appeared to be reduced in 2003 relative to the last portion of the baseline period, the level of subsurface biogenic activity appeared similar.

Another indication that biogenic activity may have declined in 2003 was that while not significantly lower than the grand mean baseline OSI, the average OSI for 2003 was below the baseline mean of 6.4 (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. The declining trend in the mean OSI, from a high in 2000 of 7.2 to 5.9 in 2003, may represent a shifting balance between biological and physical processes at the nearfield stations, with 2000 being the peak year for biological processes for the 12-year period that SPI data were collected at the nearfield stations.

Overall, it appeared that biological processes were still important in structuring surface sediments, but signs of physical processes increased in 2003 relative to other years. Bedforms, typically associated with higher energy bottoms, were observed at eight stations in 2003, five stations in 2002, eight in 2001, and six in 2000. In the absence of storm-induced bottom currents, benthic organisms tend to eradicate physical structures such as bedforms during quiescent periods such as those experienced 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.

5. 2003 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 2003, the station array was sampled as it had been in previous years, but starting in 2004, only half the stations will be sampled each year (see Introduction, this report).

5.1.2 Benthic Communities

During the baseline period (1992–2000), multivariate analyses of the infauna data indicated that sediment grain size was the dominant factor in structuring the benthic communities. The nearfield stations fall into one of two major sediment regimes: fine sediments characterized by the polychaete annelids *Prionospio steenstrupi*, *Spio limicola*, *Mediomastus californiensis*, and *Aricidea catherinae*; and sandy sediments (primarily NF13, NF17, and NF23) characterized by the 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 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).

In the 2001 Outfall Benthic Report, 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*. Two other descriptive community parameters, Shannon diversity (H′) and Pielou's evenness (J′), did not show the same temporal pattern, but were highly variable within each year and showed little absolute change during the 1992–2001 period. Kropp *et al.* (2002) speculated that, because of the storm's effects, "the high variability in this baseline may make it difficult to recognize potentially important changes in the benthos resulting from effluent discharges through the outfall."

Samples collected in August 2001, the first year of 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, which represented data for two years of discharge into the bay, similarly did not indicate any changes related to operation of the outfall. Through analysis of the 1991–2002 dataset (Maciolek *et al.* 2003), some statistical differences were 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, but these were considered to be natural fluctuations in the populations, and not related to the outfall discharge.

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. 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 (1992–2003) 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. 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 include several indices that 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, and dendrograms were plotted. Results of these analyses were inspected for patterns among and between the different seasons.

Using MATLAB as an operating platform and additional programs written by Dr. Gallagher, several indices were calculated, including Shannon's H′ (base 2), Pielou's evenness value J′, rarefaction (ESn) values at 25 points (Sanders 1968, as modified by Hurlbert 1971), and Fisher's log-series *alpha*. May (1975) demonstrated that Sanders-Hurlbert rarefaction curves are often identical to those produced under the assumption that the distribution of individuals among species follows a log-series distribution. Hubble (2001) considers *alpha* the fundamental biodiversity parameter. The results of these computations were verified by running the same calculations in PRIMER v.5 (Clarke and Gorley 2001).

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°.

5.3 Results and Discussion

5.3.1 Species Composition of 2003 Samples

Laboratory Analyses—A portion of the 2003 sample collected at station NF14 was lost when the mollusc, crustacean, and miscellaneous fractions were misplaced. The remainder of the sample was processed, but the data were not used for the evaluation of 2003 results. This year's report is therefore based on 34 (rather than 35) samples taken at 22 (rather than 23) nearfield stations. This incident was reported by ENSR to the MWRA in the Nearfield Faunal Data Report (dated December 11, 2003), and the sample is flagged in the database.

Species Composition—A list of all species collected as part of the Outfall Monitoring Program is included in Appendix C2. A total of 15 new taxa were reported from the 2003 samples, which comprised 297 valid species. The number of valid taxa in the Massachusetts Bay database, which includes both nearfield and farfield samples, now stands at 462 species (456 taxa were used in the present analyses).

The newly added taxa included three nemerteans (*Amphiporus caecus*, Nemertea sp. 16, and *Tetrastemma elegans*), seven polychaetes (*Ampharete baltica*, *Eteone trilineata*, Capitellidae sp.2, *Sphaerodoropsis* cf. *longipalpa*, *Polydora* sp. 1, *Microspio* sp.1, and *Scolelepis* cf. *tridentata*), two amphipods (*Melphidippa* cf. *borealis* and *Westwoodilla megalops*), two bivalves (*Periploma leanum* and *Yoldia limatula*), and one holothurian (*Pentamera calcigera*).

Several of the polychaetes (Capitellidae sp.2, *Polydora* sp. 1, *Microspio* sp.1, and possibly *Sphaerodoropsis* cf. *longipalpa*) are undescribed, *i.e*., they are new to science and have not yet been named. *Ampharete baltica* was present previously, but this small species was incorrectly identified until this past year. For report purposes, it is merged with *A. acutifrons* to ensure consistency between years. *Eteone trilineata* and *Scolelepis* cf. *tridentata*, as well as the majority of other species, are found elsewhere in the northern Atlantic Ocean but are newly identified from Massachusetts Bay.

5.3.2 Benthic Community Analysis for 2003: 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. Results by sample are given in Appendix C3, Table C3-1, and individual station means 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) (Figure 5-1A). The precipitous decline in abundance (and species richness) recorded between 1992 and 1993 was discussed in Kropp *et al.* (2002) *inter alia*, as possibly related to major storms that disturbed the sea floor and associated benthic communities prior to sampling. 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.

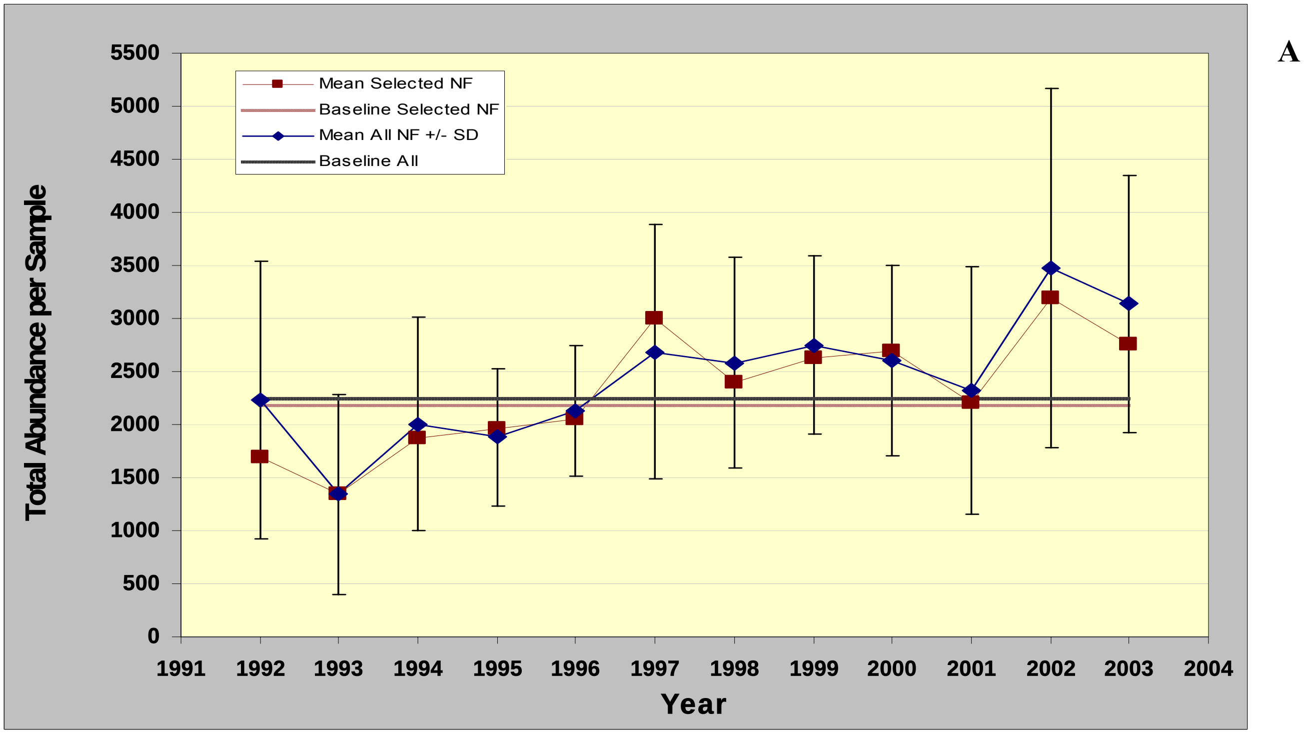
Recently, Kropp (pers. comm.) suggested that if only those stations that had been sampled in both 1992 and 1993 were included in the calculation of the annual means, the decline between those two years would not appear as severe. Stations sampled both before (1992) and after (1993) the 1992 storm include

NF02, NF04, NF08, NF09, NF10, NF12, NF14, NF16, NF 17, FF10, FF12, and FF13. The remaining stations were either sampled in 1992 but not 1993 (NF05, NF07, NF13, NF15, NF18, NF19, and NF20) or were not added to the program until 1994 (NF 21, NF22, NF23, and NF24). The mean for all nearfield stations can be compared with the mean for stations sampled both before and after 1992 in Figure 5-1A, and indeed the means for stations sampled both before and after the 1992 storm do not appear to be significantly different between years.

Inspection of the abundance data for individual nearfield stations (Figures 5-1B, 5-2; Appendix C3, Table C3-2, Figure C3-1) indicated that, as seen in previous years, the change in infaunal densities between 2002 and 2003 was not uniform at all stations. Of the 22 NF stations analyzed in 2003, total abundance increased at six stations, declined at nine, and remained essentially the same at seven. The largest increase was at NF05, where 2003 densities were 264% of the 2002 values. The increased total abundance at NF05 was due to increases in several species common at this station, notably the polychaetes *Spio limicola* and *Prionospio steenstrupi*; also *Parougia caeca,* several terebellid and ampharetid species, several molluscs including *Nucula delphinodonta* and *Thyasira gouldi*, the phoronid *Phoronis architecta*, and the ascidian *Molgula manhattensis*. In 2002, NF05 was one of only two stations where densities declined relative to 2001, and while the decline from 2001 to 2002 was only 14%, the increase in 2003 resulted in the highest density ever recorded at that station.

Conversely, the greatest decreases were seen at FF13 and NF15, where densities were 43.6 and 51.5 % of the 2002 values. Densities at FF13 were especially high in 2002 (Figure 5-1B), due to several polychaete species including *Aricidea catherinae*, *Tharyx acutus*, and *Dipolydora socialis* that had reached very high abundances. In 2003, these species were present in reduced numbers. Other species, such as *Mediomastus californiensis* and *Prionospio steenstrupi*, had densities in 2003 similar to those in 2002.

At NF 15, total abundances have varied widely from year to year. In 2001, total abundances in the single sample collected at this station were roughly half that recorded in 2000, and in 2003 the densities were again roughly half that recorded in 2002. Fluctuations in the population levels of several common species such as *Prionospio steenstrupi*, *Spio limicola*, *Exogone hebes*, *Aricidea catherinae*, *Spiophanes bombyx*, *Dipolydora socialis*, *Mediomastus californiensis*, *Owenia fusiformis*, and *Nucula delphinodonta* accounted for these increases and decreases in total abundances. Conversely, *Phoronis architecta* and *Capitella capitata* complex increased in 2003 compared with the several previous years.



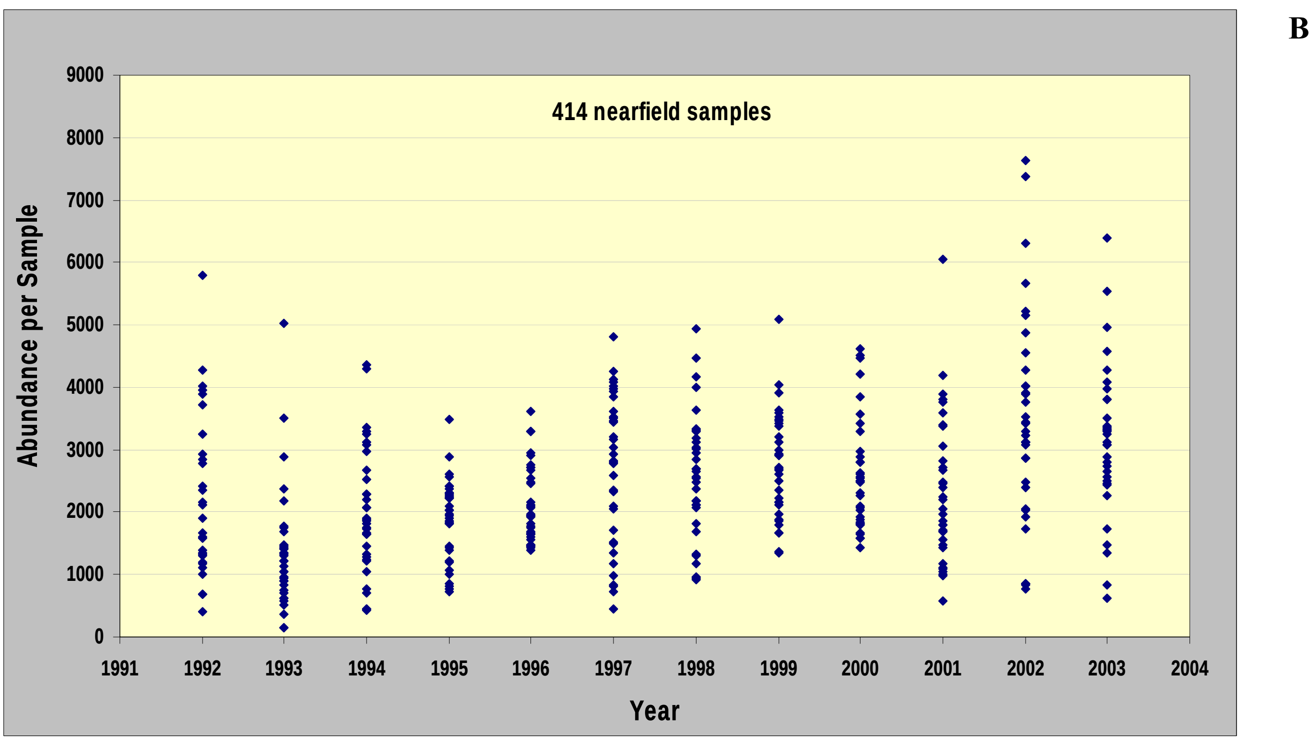
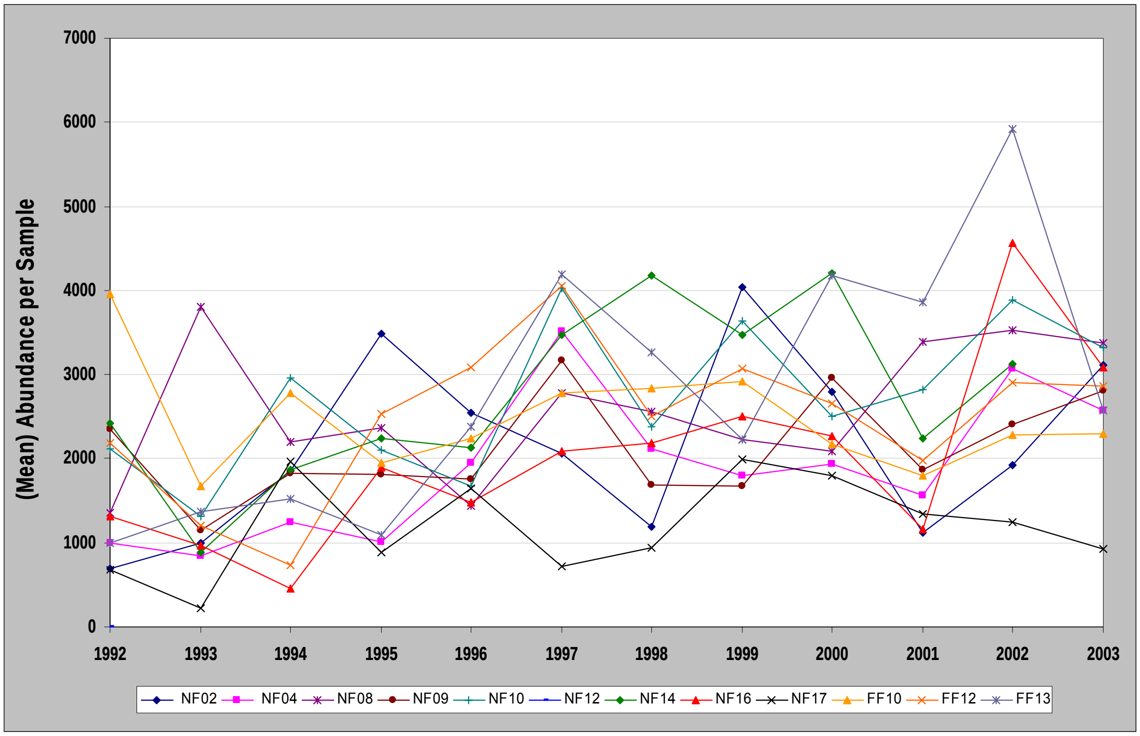


Figure 5-1. Abundance per sample for nearfield stations. (A) Mean abundance per sample, (B) Abundance per sample at individual stations.

A



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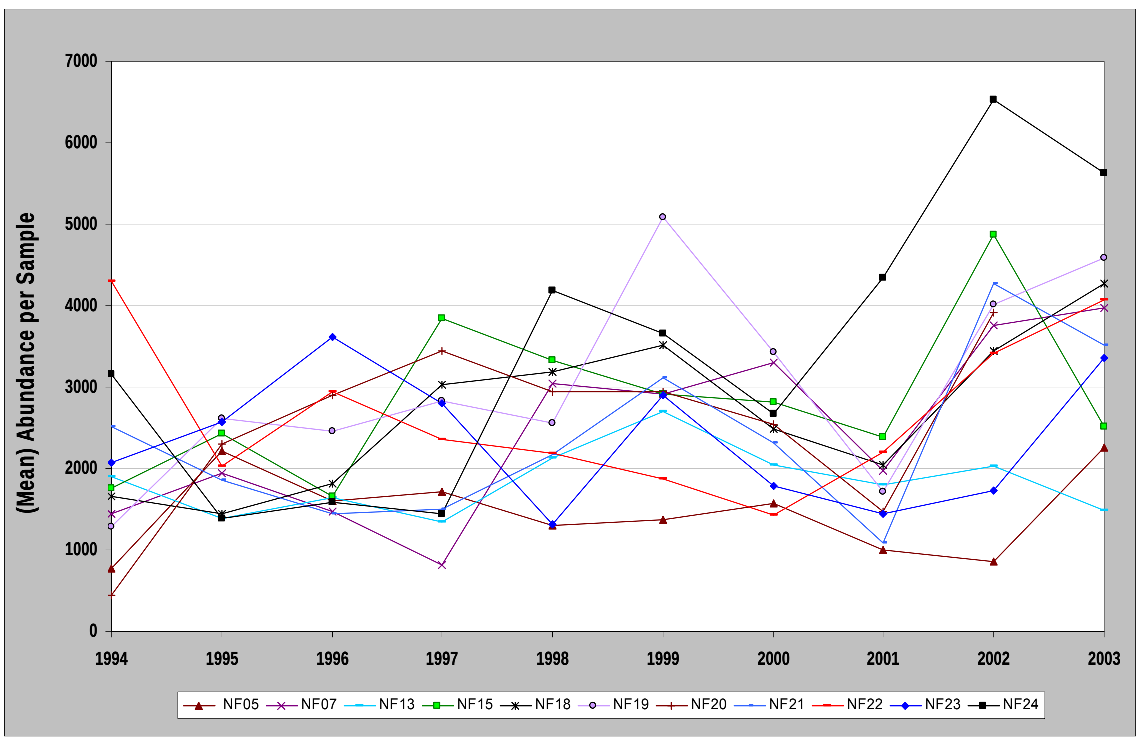


Figure 5-2. Abundance each year for individual nearfield stations. (A) Stations sampled each year since 1992, (B) Stations added in 1994, or sampled in 1992 but not 1993.

Species Richness—A total of 392 valid taxa have been recorded from the nearfield stations since the initiation of the monitoring program (this number reflects the few merges made for report purposes). In 2003, the average number of species per sample increased to 76 species (Figure 5-3A), only slightly higher than the 2002 mean of 74 species. These values are roughly equivalent to those recorded in 1997 and 1998. The number of species per sample increased at 11 of the 22 nearfield stations, especially at

NF05: 114 species in 2003 vs. 87, 67, and 84 in 2000, 2001, and 2002, respectively
NF07: 94 species in 2003 vs. 88, 65, and 72 in 2000, 2001, and 2002, respectively
NF23: 109 species in 2003 vs. 63, 69, and 77 in 2000, 2001, and 2002, respectively

At NF05, the "additional" 20 species recorded in 2003 included a variety of nemerteans. polychaetes, amphipods, and molluscs, and were primarily species that are often recorded at nearby stations. Only the amphipod *Westwoodilla megalops*, which was represented by one specimen at this station, was new to the monitoring program species list this year.

At NF 07, 28 species, or approximately 30% of the species present in 2003, were not found at this station in 2000, when nearly the same number of species were present. Of these 28, four were recorded in 2001, and nine in 2002. The remaining 15 are new to this station in 2003, and include the nemertean *Amphiporus caecus* and the polychaete Polydora sp. 1, both new additions to the monitoring program species list.

Unlike the other two stations discussed above, the number of species at NF23 appears to have steadily increased over the past four years. Thirty-three species present in 2003 were not recorded in the prior three years. One of the species found in 2003 was *Cerianthiopsis americanus*, a deep-dwelling anemone; this species often has a number of small organisms associated with the thick tube that it constructs, and the presence of two individuals might account for some of the additional species recorded this past year. Two species, the nemertean *Amphiporus caecus* and the holothurian *Pentamera calcigera*, were new additions to the overall species list in 2003.

At the remaining stations, the number of species per sample was generally within a few percentage points of last year's values (Appendix C3, Table C3-3 and Figure C3-2).

Diversity and Evenness— The diversity measure log-series *alpha* continued the trend of higher values compared with the two years immediately previous (Figure 5-3B). This measure increased at 14 of the 22 stations, with the largest increases at NF07, NF19, and NF23 (Appendix C3, Table C3-4, Figure C3-5).

Both Shannon diversity (H′) and Pielou's evenness (J′) were essentially the same in 2003 as in 2002, and both were lower than in 2001 (Figure 5-3C,D). Shannon diversity increased (slightly) at 14 of the 22 stations, and decreased (slightly) at eight (Appendix C3, Table C3-4, Figure C3-3). Diversity was lowest at NF24 (H′ = 2.8) and highest at NF05 (although lower than in 2002; H′ at this station was 4.76). The greatest change in H′ was at NF13, where this measure decreased from 4.74 in 2002 to 3.95 in 2003. Pielou's evenness, which is based on H′, followed the same trend of increasing at the same stations at which H′ had increased, and vice versa. The highest evenness value, 0.70, was at NF05 and NF17, and the lowest value, 0.40, was at station NF24 (Appendix C3, Table C3-5, Figure C3-4).

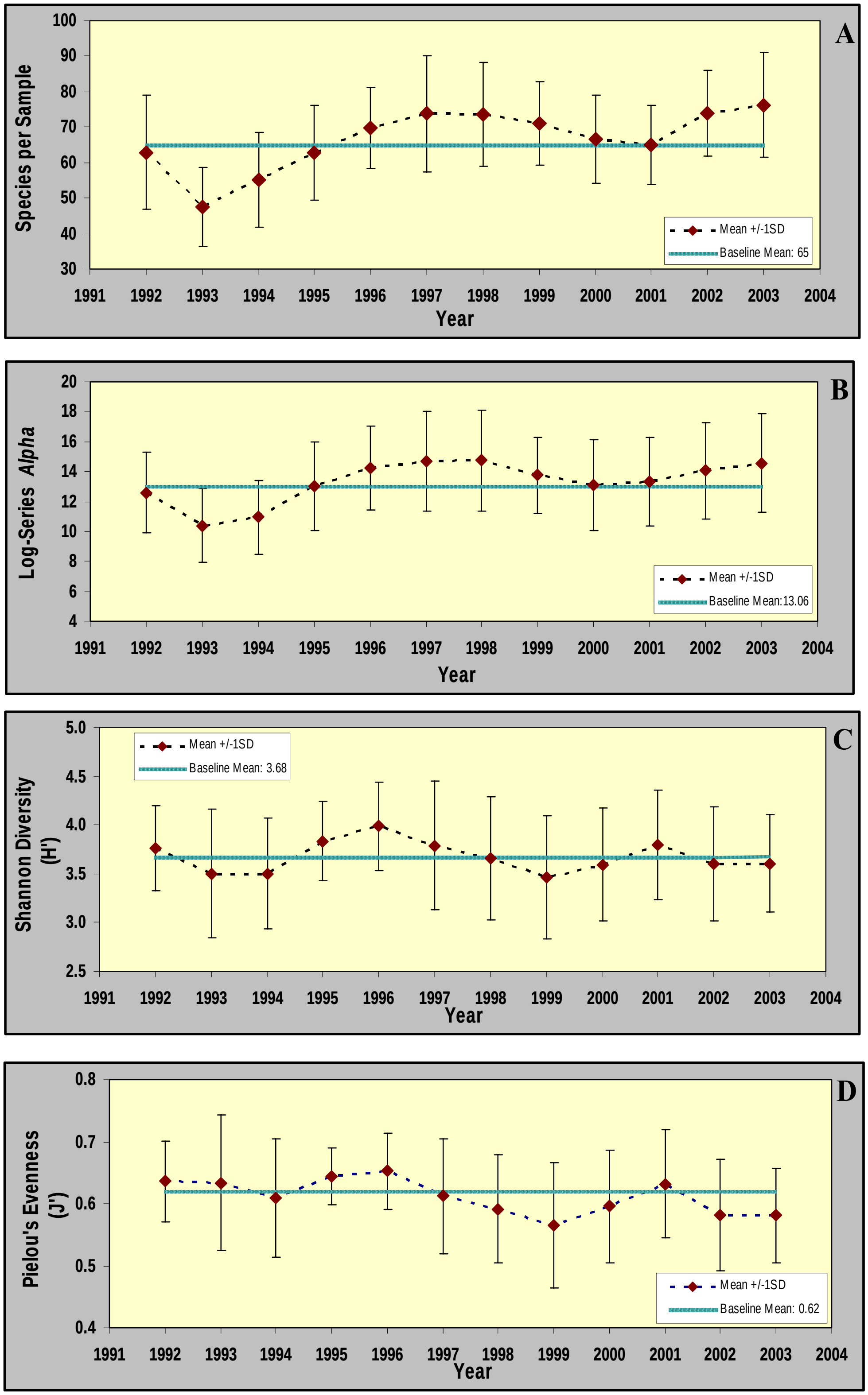


Figure 5-3. (A) Mean number of species per sample, (B) Mean log-series *alpha*, (C) Mean Shannon diversity, and (D) Mean evenness at nearfield stations from 1992–2003.

Dominant Species—Dominant species at each nearfield station are listed in Appendix C4, along with the percent contribution of each to the total community. The spionid polychaete *Prionospio steenstrupi* (Figures 5-4 and 5-5) has been the numerical dominant in Massachusetts Bay for the past several years, and in 2003 continued to be the most numerous species recorded. The highest densities were recorded at NF24, where the mean population density was equal to that recorded in 2002 (Figure 5-4). At other stations, the density of *P. steenstrupi* declined relative to 2002, but it was the numerical dominant at 18 of the 22 nearfield stations and ranked second at anther two stations.

The sylllid polychaete *Exogone hebes* was the numerical dominant at NF04, and the cirratulid polychaete *Tharyx acutus* was dominant at NF22, as they had been in 2002. At NF23, where *E. hebes* was the numerical dominant in 2002, a large population of *Phoronis architecta* accounted for nearly 30% of the infaunal abundance in each sample, with *P. steenstrupi*, *E. hebes*, and other species each accounting for less than 9%.

The ascidian *Molgula manhattensis*, which in 2002 accounted for more than 25% of the infauna in the samples from NF17, was represented by only 24 individuals in three replicates in 2003, contributing less than 1% of the organisms collected at that station. Other stations where *Molgula* was numerous in 2002 were NF13 and NF19; it was also recorded at NF14 and NF18. In 2003, this species was found at NF05 and NF07, and was a numerical dominant at NF04 and NF23 (results are not available for NF14). The amphipod *Crassicorophium crassicorne*, the sand dollar *Echinarachnius parma*, and the syllid polychaete *E. hebes* were the numerical dominants at NF17, accounting for 16.8, 14.6, and 13.8 percent of the infaunal abundance in each of the three samples, respectively.

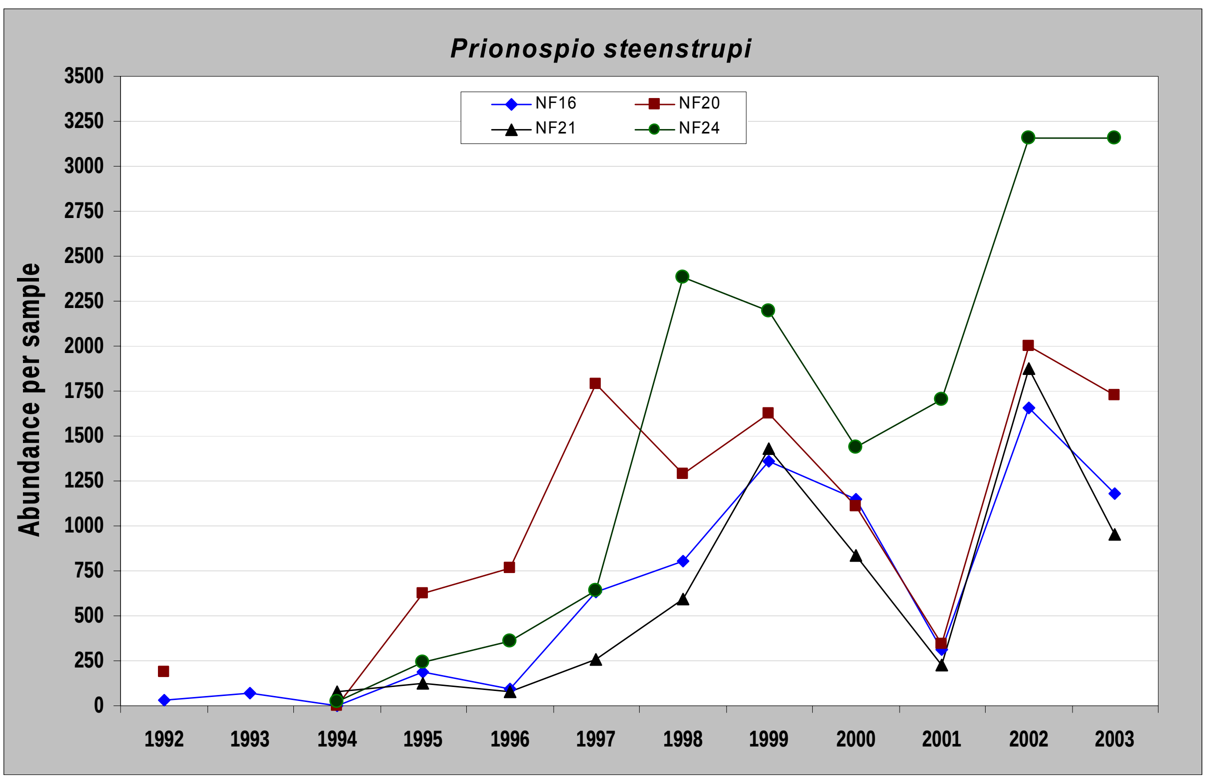


Figure 5-4. Abundance (or mean abundance) of *Prionospio steenstrupi* at four nearfield stations.

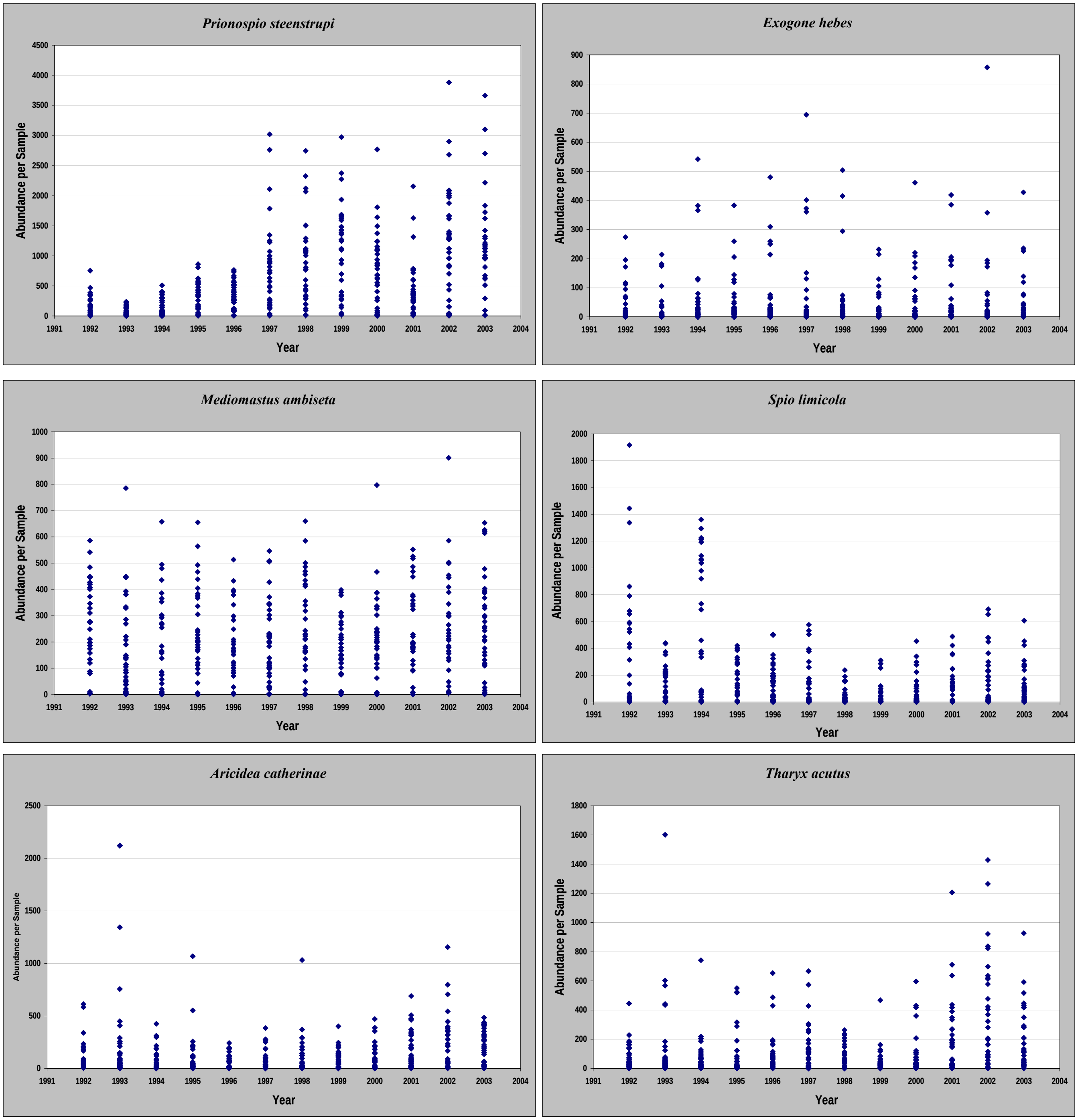


Figure 5-5. Density per 0.04-m^2 sample of six species common at nearfield stations.

5.3.3 Benthic Community Analysis for 2003: 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. This baseline value and the mean value for each parameter for each year from 1992–2003 are plotted below. Results by sample are given in Appendix C3, Table C3-1, and individual station means are plotted in the figures in Appendix C3.

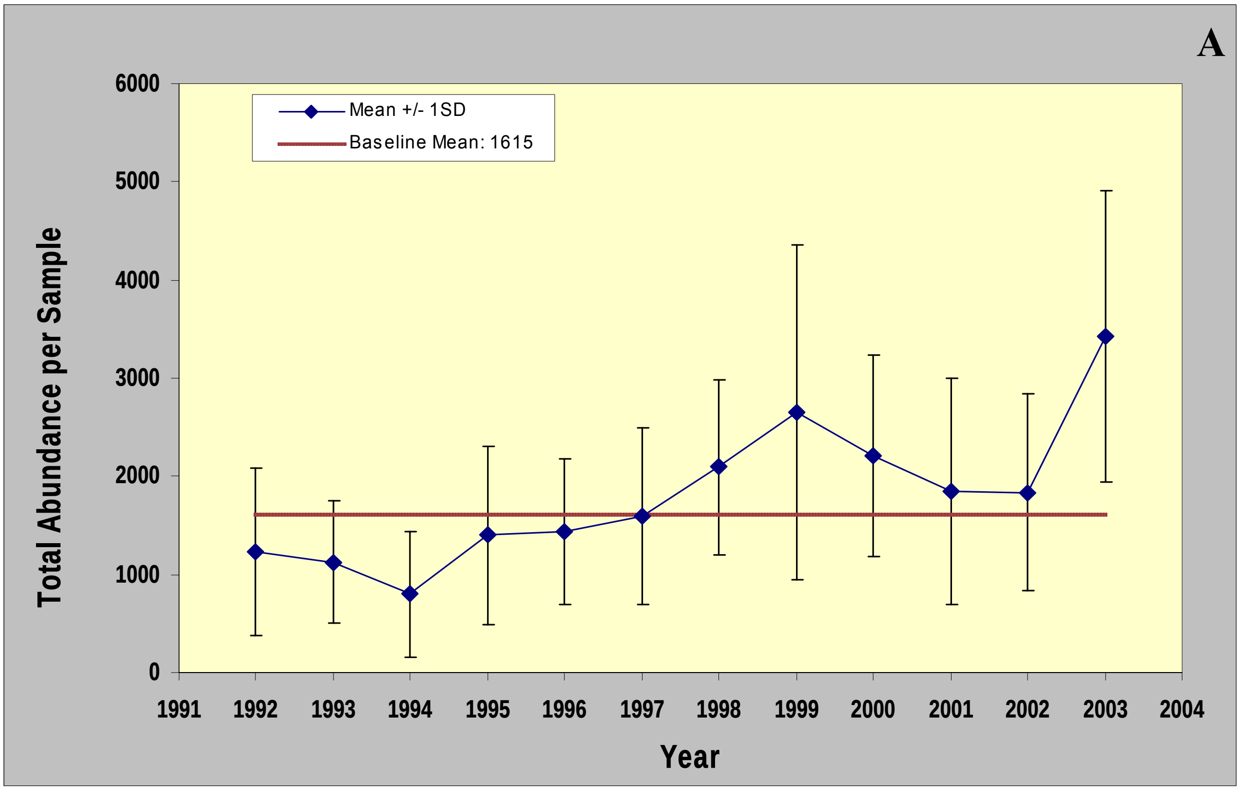
Density— In 2003, the mean density of infaunal organisms in the farfield increased to 3249 organisms per sample, nearly twice that of the mean densities recorded in 2002 and more than twice the baseline average of 1615 organisms pre sample (Figure 5-6A). Abundances were elevated at five of the eight farfield stations: FF01A, FF06, FF07, FF11, and FF14, and essentially equivalent to those recorded in 2002 at the remaining three farfield stations FF04, FF05, and FF09 (Figure 5-6B, Appendix C3).

The farfield stations are located within a large geographic area, and consequently occupy a variety of habitats. The increased abundances at farfield stations were due to different species:

- At FF01A and FF11, off Cape Ann, the increase was due to *Prionospio steenstrupi*, which doubled in average densities from 1254 individuals per sample in 2002 to 2179 individuals in 2003 (FF01A) and from 982 individuals per sample in 2002 to 1963 individuals in 2003 (FF11).

- At FF06 and FF07, the Cape Cod Bay stations, the increased infaunal abundances were due primarily to both *Euchone incolor* and *Cossura longocirrata*. The surface feeder *E. incolor* is associated with the fecal mounds produced by the deep-dwelling *Molpadia oolitica* (Rhoads and Young, 1971), whereas the thin-bodied *Cossura* is a subsurface deposit feeder. Other species increased as well, but none to the extent of these two species.

- At FF14, east of the diffuser array, *Spio limicola* increased from an average of 55 individuals per sample in 2002 to an average of 655 individuals in 2003. Other species, including *Anothrobus gracilis*, *Aricidea quadrilobata*, *Chaetozone setosa* mb, and *Prionospio steenstrupi* also contributed to the overall higher density at this station.



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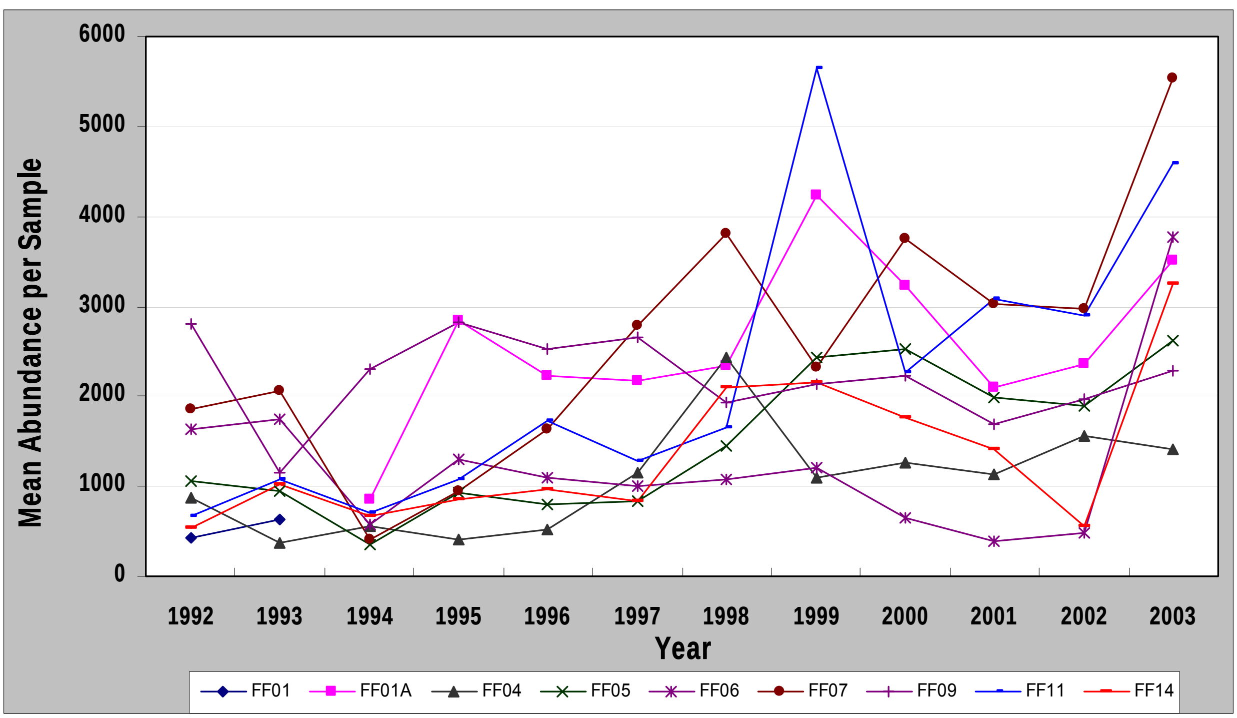


Figure 5-6. Mean abundance for the farfield stations sampled 1992–2003. (A) Annual mean plotted against baseline mean. (B) Annual mean abundance at each farfield station.

Species Richness—A total of 342 valid taxa have been recorded from the farfield stations since the initiation of the monitoring program (this number reflects the few merges made for report purposes). In 2003, the average number of species per sample increased by 18.7 (27%) to 87.5 species (Figure 5-7A). The number of species per sample increased at all farfield stations except FF09, where this parameter was equivalent to that recorded in 2002 (Appendix C3).

For example, a total of 81 species were recorded at FF14 in 2002, and 125 species in 2003. There was an increase in the number of singletons and rare species at this station, but none were considered to be invasive or inappropriate to the area. As at the other farfield stations, the dominant species remained similar from year to year (see below).

Diversity and Evenness—Although the diversity measure log-series *alpha* continued the trend, as seen in the nearfield, of higher values compared with the immediately previous years, both Shannon diversity (H′) and Pielou's evenness (J′) were lower in 2003 compared with 2001 and 2002 (Figure 5-7B-D). Shannon diversity was 3.75, essentially the same as the baseline value of 3.74, and evenness was 0.58, well below the baseline value of 0.64. Individual farfield stations showed similar declines in H′ and J′ (Appendix C).

Dominant Species— Dominant species at each farfield station are listed in Appendix C4, along with the percent contribution of each to the total community. In general, the numerically dominant species at each of the farfield stations in 2003 were the same as those recorded in 2000–2002, with the exception of FF06. At that Cape Cod Bay station, the abundance of *Euchone incolor* has increased significantly since 2001, when it was not present, to a mean density of 2216.3 per 0.04-m^2 sample. This small sabellid polychaete, which is also a numerical dominant at the other Cape Cod Bay station (FF07) is associated with fecal mounds made by *Molpadia*, a large burrowing holothurian. Rhoads and Young (1971) found *Molpadia* in densities of 2–6 per m^2 in the fine-grained muds of Cape Cod Bay and described the impact on the surrounding area:

> *This species ingests only fine-grained particles at depth in the sediment, and deposits uncompacted feces at the surface, producing a fecal mound around the anal opening. This reworking produces vertical sediment sorting, high sediment-water content, and topographic relief of the sea floor. The fecal cones of M. oolitica provide a relatively stable surface for settlement and growth of the suspension feeders Euchone incolor (polychaete), Aeginina longicornis (amphipod), and Thyasira gouldi (bivalve). Uncompacted feces. accumulated in depressions between the mounds, form an unstable substratum frequently resuspended by tidal flow. Suspension feeders are absent from intercone areas.*

Molpadia is not adequately sampled with the gear used in the monitoring program, and is rarely collected in samples from FF06 or FF07. Individuals of *Molpadia* are occasionally retrieved by the larger grabs used to obtain sediment contaminant samples, both at the Cape Cod Bay stations and at stations FF04 and FF05 in Stellwagen Basin (K. Keay, MWRA, personal communication). However, the presence of *Euchone incolor* in the samples can be used as an indication of the presence at depth of this species.

Aeginina longicornis is a caprellid and therefore is not included in these analyses. *Thyasira gouldi* is common at all farfield stations, and has not increased in abundance in the past year. Densities of *Cossura longocirrata* and *Spio limicola* have also increased at some stations, while those of *Prionospio steenstrupi* have varied over time, with some increase in 2003 (Figure 5-8).

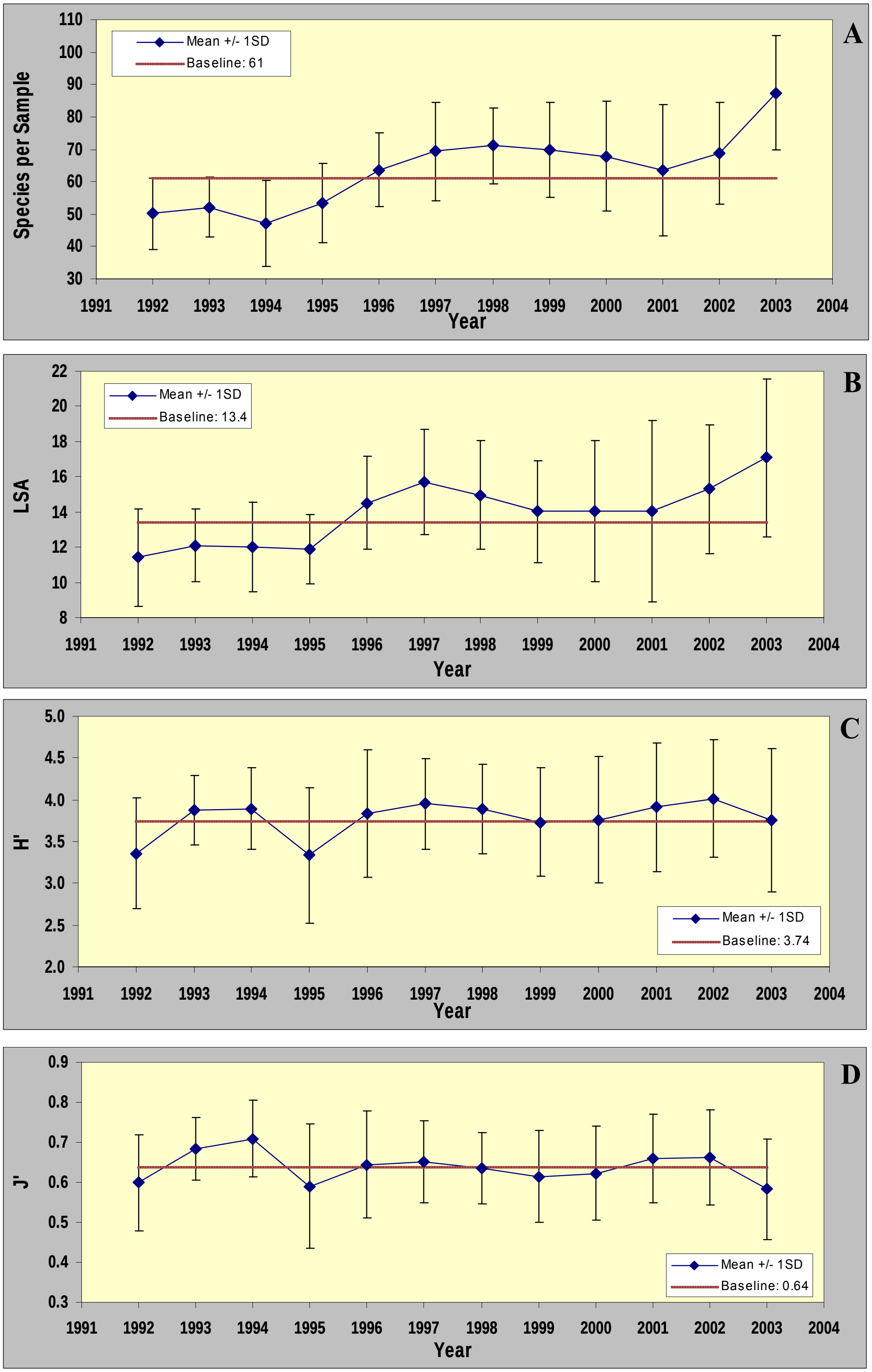


Figure 5-7. Annual mean parameters for farfield benthic infaunal stations.

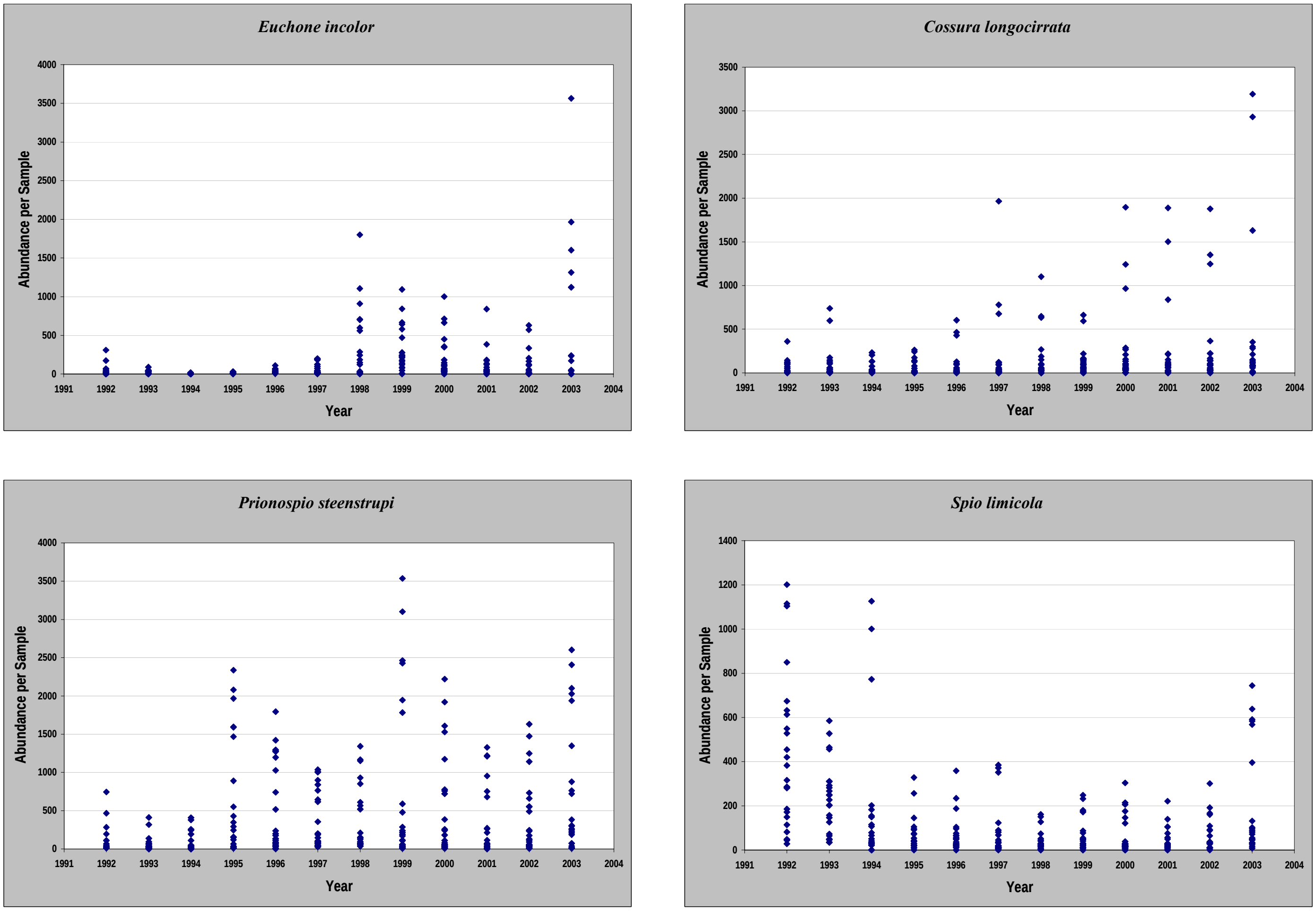


Figure 5-8. Density per 0.04-m² samples of four species common at farfield stations.

5.3.4 Multivariate Analysis of 2003 Samples

The CNESS (*m* =15) similarities of the 58 samples taken in 2003 were clustered using group average sorting (Figure 5-9). The samples form four major groups or clusters, essentially identical to those obtained for the 2002 samples (not shown, see Maciolek *et al*. 2003). The four groups comprise (1) sandy stations near the outfall, (2) finer-grained nearfield stations plus FF01A, (3) farfield stations FF04, FF05, FF09, FF11, and FF14, and (4) Cape Cod Bay stations FF06 and 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. Station FF01A south of Gloucester was added to the program in 1994 to represent sediments of a similar texture and depth to much of the nearfield, but well outside any possible impact from the outfall. As in 2003, the infaunal communities sampled there often show strong similarities to those sampled in the nearfield.

The Bray-Curtis analysis of these data resulted in a similar overall pattern, with the sandy nearfield stations again forming the most dissimilar group and the Cape Cod Bay stations forming a distinct unit within a large cluster (Figure 5-10). In this analysis, FF09 groups with FF01A, whereas with CNESS it was more similar to the other, deepwater farfield stations. The infaunal communities at FF09 thus appear to have strong similarities to both nearfield and deepwater stations, consistent with its intermediate depth. Specific similarities among the nearfield stations differ to a small degree between the two analyses, but replicates from single stations always cluster together.

The PCA-H analysis based on the CNESS similarities separated these cluster groups along several multidimensional axes, with axes 1 and 2 accounting for 45% of the total variation. Cluster groups 1 and 3 separated along Axis 1 (probably depth), and groups 2 and 4 separated along axis 2 (probably sediment grain size) (Figure 5-11A).

The species accounting for more than 2% of the CNESS variation, and therefore the ones responsible for the separation of the samples, are indicated in the Gabriel Euclidean distance biplot (Figure 5-11B) and detailed in Table 5-1. 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 (NF13, NF17, and NF23) are influenced by the syllid polychaete *Exogone hebes* (an omnivore) and the filter-feeder sand dollar *Echinarachnius parma*. As seen in previous years, the Cape Cod Bay stations FF06 and FF07 are 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), 32 of the 279 species recorded in 2003 accounted for 89% of the variation in the community structure, and contributed at least 1% to the PCA-H axes (Table 5-2).

The covariance biplot (Figure 5-12) from the PCA-H analysis shows the relationships among the 297 species that comprise the 2003 samples. The axes loadings for each of these species are included in Appendix C5. Species with positive loadings on both axes correspond to those found in the sandy nearfield sediments: *e.g*., *Echinarachnius parma*, *Spiophanes bombyx*, and *Exogone hebes*. A second major group of species, which characterizes the finer-grained nearfield stations, are those with positive loadings on axis 1 and negative loadings on axis 2. These species include *Ninoe nigripes*, *Mediomastus californiensis*, and *Aricidea catherinae*. Species with negative loadings on axis 1 and positive loadings on axis 2 characterize the farfield stations.

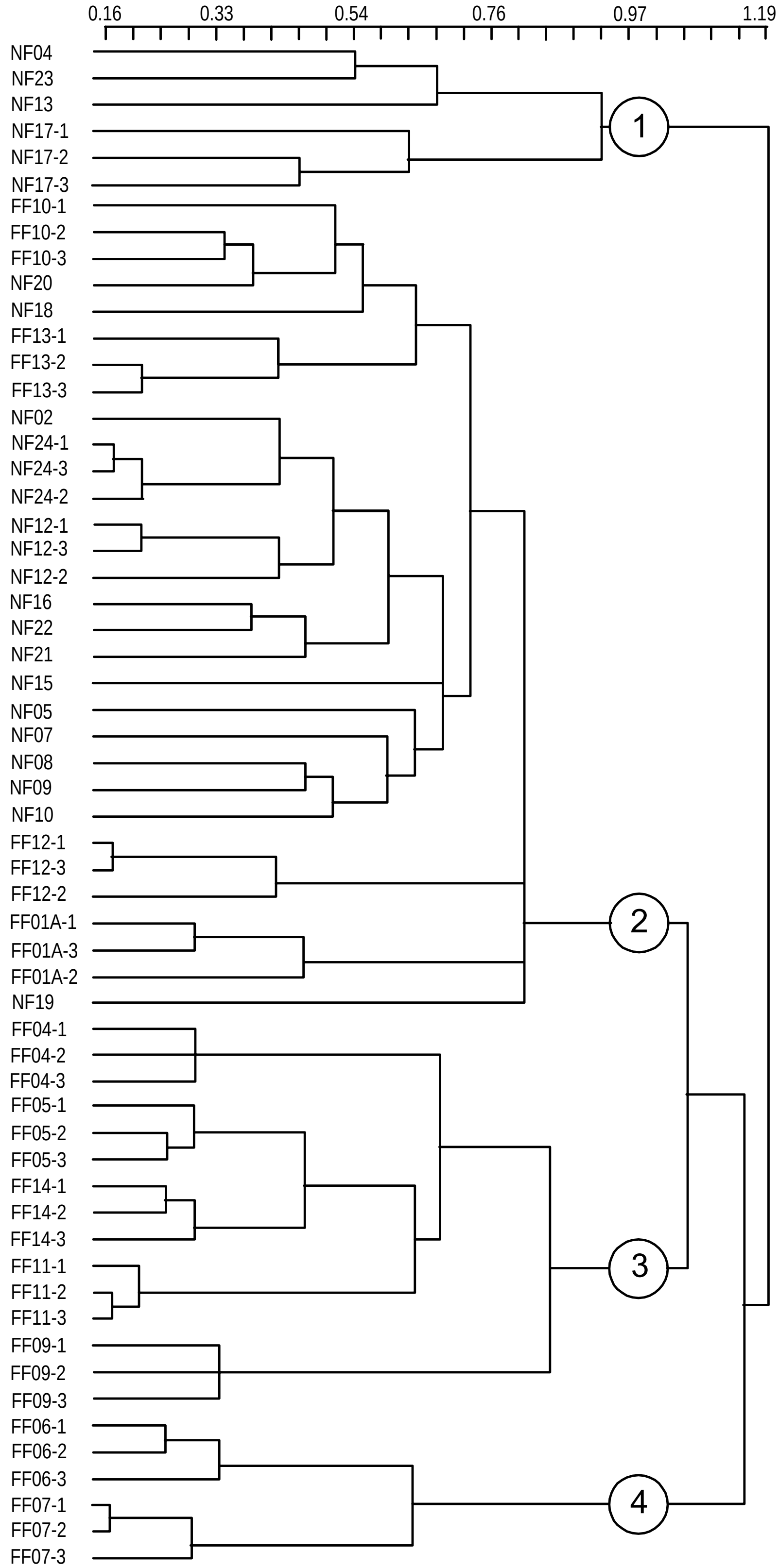


Figure 5-9. Relationship of 2003 samples based on CNESS similarity (*m*=15) and group average clustering.

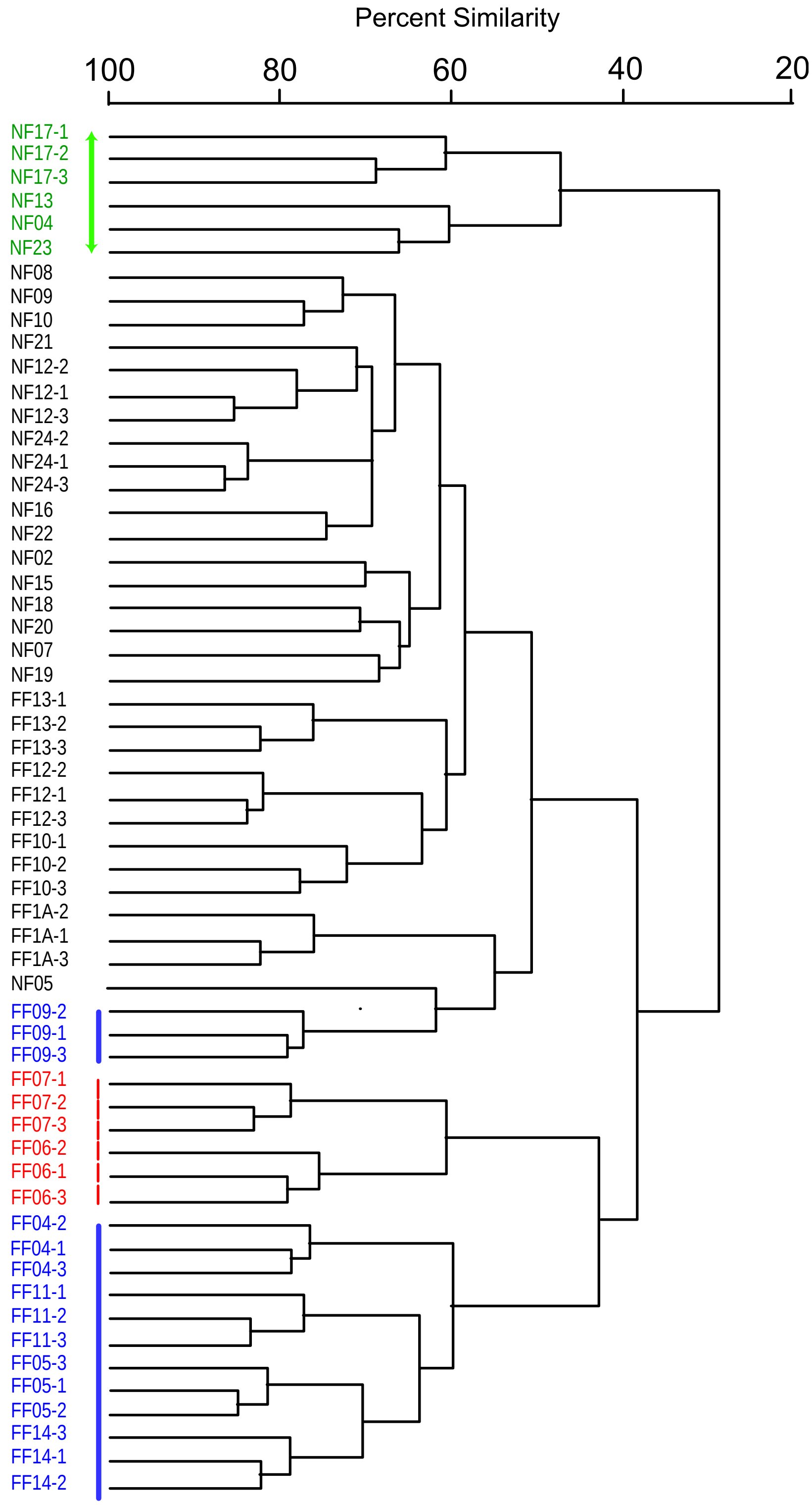


Figure 5-10. Relationship of 2003 samples based on Bray-Curtis similarity after fourth-root transformation of the data and group average clustering. Samples corresponding to CNESS groups identified by green arrows (group 1), no line (group 2), solid blue line (group 3), and dashed red line (group 4).

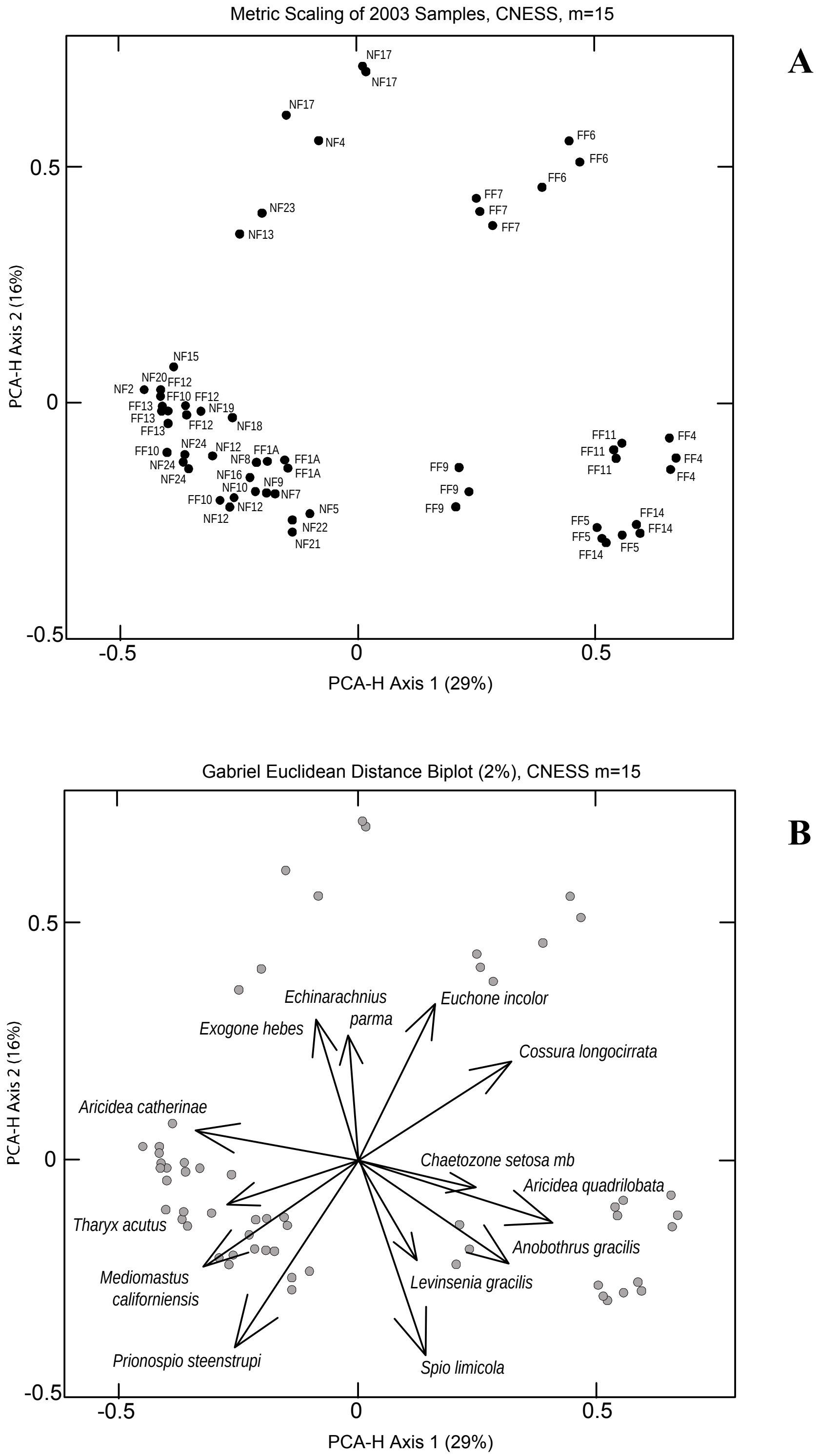


Figure 5-11. Metric scaling on PCA-H axes 1 and 2 of 2003 benthic infaunal samples (A) and the Euclidean distance biplot showing the species responsible for >2% of the variation (B).

Table 5-1. Contributions to PCA-H axes by species accounting for >2% of the CNESS variation among the infaunal samples collected in 2003 (see Figure 5-13, bottom).

Important species: Axis 1 vs. 2					
PCA-H Rank	**Species**	**Contr.**	**Total Contr.**	**Axis1**	**Axis2**
1	*Aricidea quadrilobata*	11	11	16	2
2	*Prionospio steenstrupi*	9	20	6	15
3	*Mediomastus californiensis*	8	28	10	5
4	*Cossura longocirrata*	8	36	10	4
5	*Anobothrus gracilis*	8	44	10	4
6	*Aricidea catherinae*	7	51	11	0
7	*Spio limicola*	7	58	2	16
8	*Euchone incolor*	5	64	3	10
9	*Tharyx acutus*	5	68	7	1
10	*Chaetozone setosa mb*	4	72	6	0
11	*Exogone hebes*	3	76	1	8
12	*Levinsenia gracilis*	2	78	1	4
13	*Echinarachnius parma*	2	80	0	6

Important species: Axis 1 vs. 3					
PCA-H Rank	**Species**	**Contr.**	**Total Contr.**	**Axis 1**	**Axis 3**
1	*Cossura longocirrata*	11	11	10	13
2	*Aricidea quadrilobata*	11	22	16	0
3	*Aricidea catherinae*	10	32	11	8
4	*Euchone incolor*	9	41	3	23
5	*Mediomastus californiensis*	8	49	10	3
6	*Anobothrus gracilis*	7	56	10	2
7	*Tharyx acutus*	6	61	7	3
8	*Chaetozone setosa mb*	4	66	6	2
9	*Prionospio steenstrupi*	4	70	6	0
10	*Exogone hebes*	4	74	1	9
11	*Echinarachnius parma*	2	76	0	7

Important species: Axis 2 vs. 3					
PCA-H Rank	**Species**	**Contr.**	**Total Contr.**	**Axis 2**	**Axis 3**
1	*Euchone incolor*	16	16	10	23
2	*Spio limicola*	9	25	16	1
3	*Exogone hebes*	8	34	8	9
4	*Cossura longocirrata*	8	42	4	13
5	*Prionospio steenstrupi*	8	50	15	0
6	*Echinarachnius parma*	6	56	6	7
7	*Aricidea catherinae*	4	60	0	8
8	*Mediomastus californiensis*	4	64	5	3
9	*Crassicorophium crassicorne*	4	68	4	4
10	*Anobothrus gracilis*	3	71	4	2
11	*Levinsenia gracilis*	2	74	4	0

Table 5-2. Contribution of the 32 species in the 2003 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 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	*Euchone incolor*	7	7	3	10	23	0	8	2	0
2	*Aricidea catherinae*	7	13	11	0	8	12	1	20	5
3	*Cossura longocirrata*	6	19	10	4	13	0	0	1	0
4	*Prionospio steenstrupi*	6	25	6	15	0	14	2	3	2
5	*Aricidea quadrilobata*	6	31	16	2	0	2	2	0	0
6	*Spio limicola*	5	36	2	16	1	16	1	5	4
7	*Tharyx acutus*	5	41	7	1	3	14	0	12	4
8	*Mediomastus californiensis*	5	46	10	5	3	2	4	0	1
9	*Anobothrus gracilis*	5	50	10	4	2	5	0	1	0
10	*Phoronis architecta*	4	54	1	1	3	5	10	14	12
11	*Exogone hebes*	3	57	1	8	9	0	0	1	2
12	*Owenia fusiformis*	3	60	1	0	0	0	1	14	25
13	*Chaetozone setosa mb*	3	63	6	0	2	0	6	1	0
14	*Echinarachnius parma*	2	65	0	6	7	0	0	1	2
15	*Nucula delphinodonta*	2	67	0	2	0	2	15	1	0
16	*Crassicorophium crassicorne*	2	69	0	4	4	0	2	3	3
17	*Levinsenia gracilis*	2	71	1	4	0	0	1	2	0
18	*Asabellides oculata*	2	73	0	0	1	4	5	5	0
19	*Scoletoma hebes*	2	75	1	0	0	1	4	0	17
20	*Phyllodoce mucosa*	1	76	2	1	1	1	1	0	1
21	*Tubificoides apectinatus*	1	77	2	1	0	1	7	1	0
22	*Dipolydora socialis*	1	79	0	1	3	0	6	0	1
23	*Terebellides atlantis*	1	80	1	1	2	1	1	0	1
24	*Ampharete acutifrons*	1	81	1	1	0	2	1	0	2
25	*Monticellina baptisteae*	1	82	2	1	0	0	0	0	5
26	*Molgula manhattensis*	1	83	0	1	2	0	1	1	0
27	*Aphelochaeta marioni*	1	84	1	1	0	5	0	2	0
28	*Thyasira gouldi*	1	85	1	1	1	1	2	0	0
29	*Parougia caeca*	1	86	0	0	1	5	2	0	0
30	*Polydora* sp. 1	1	87	0	0	0	0	0	0	3
31	*Ninoe nigripes*	1	88	0	0	2	1	0	0	0
32	*Spiophanes bombyx*	1	89	0	2	1	0	1	2	0

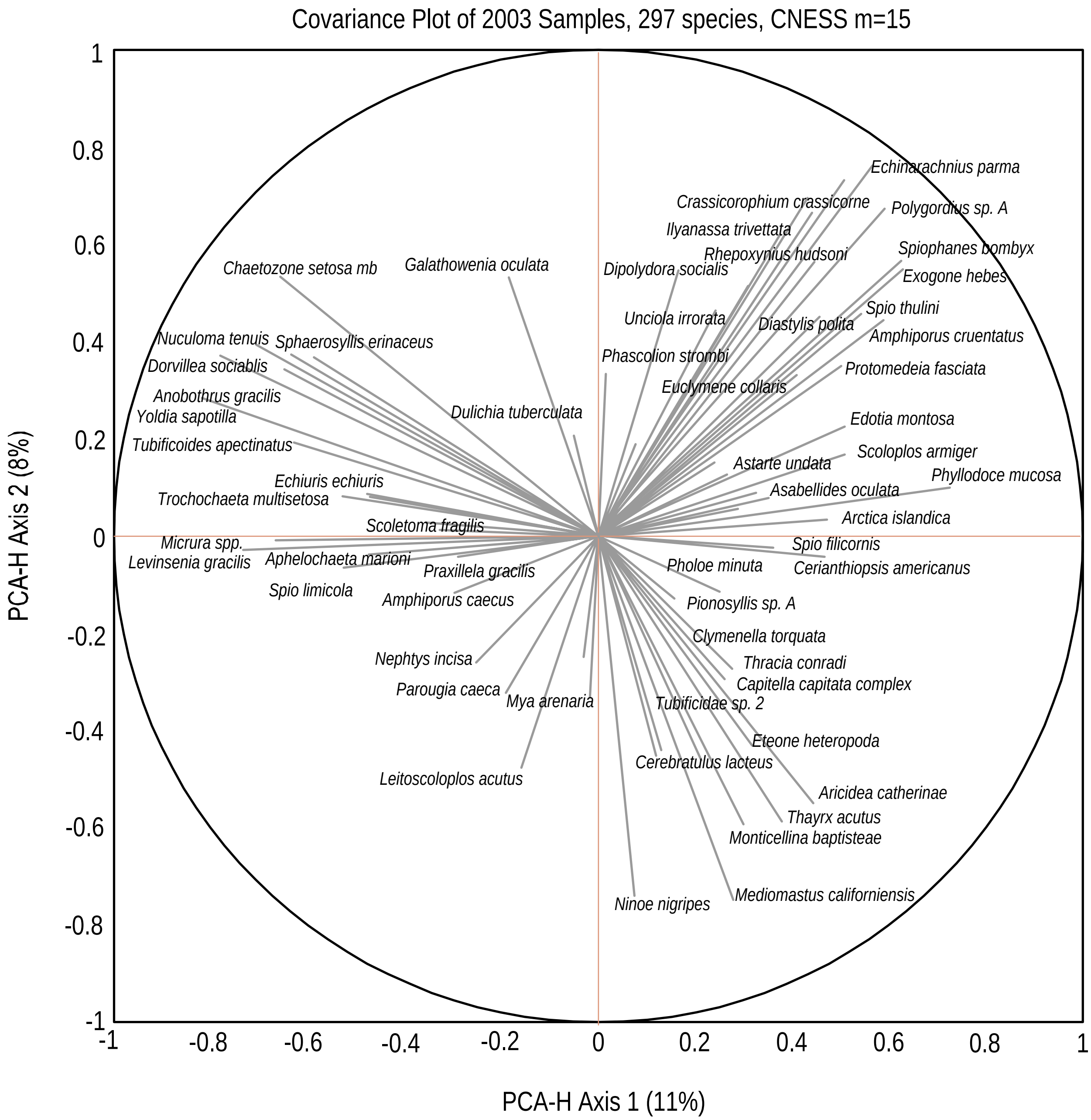


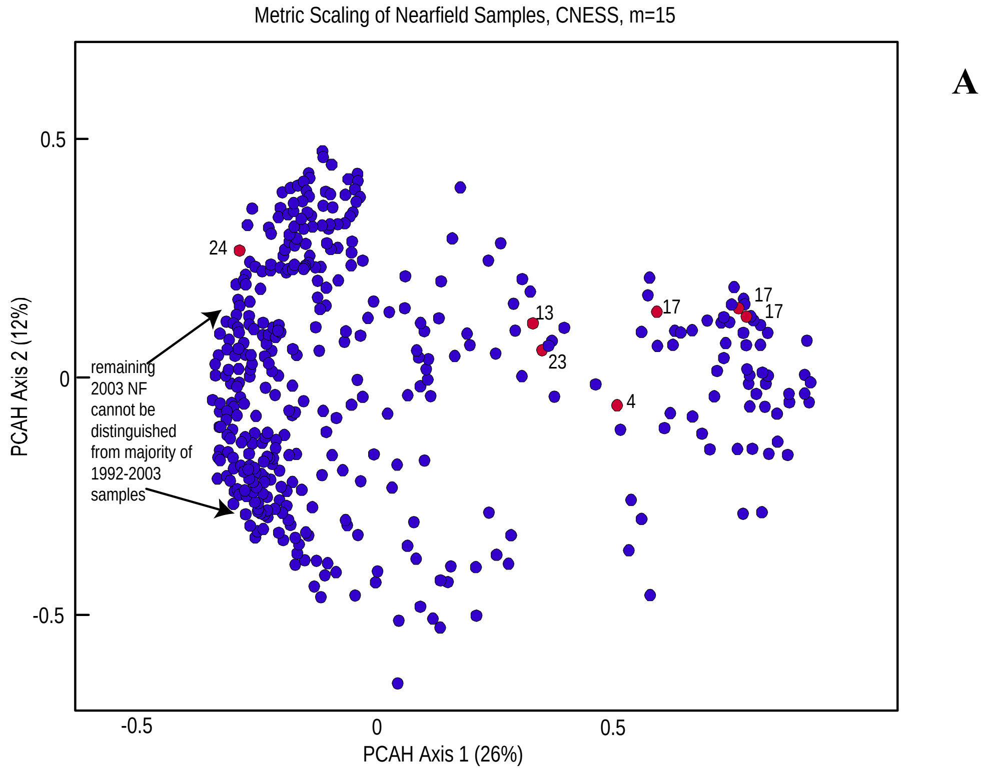
Figure 5-12. Covariance plot of the 297 species found in the samples collected in 2003.

5.3.5 Multivariate Analysis of 1992–2003 Nearfield Samples

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. The PCA-H analysis based on the CNESS (*m* =15) similarities of the 414 samples taken in the nearfield between 1992 and 2003 separated the samples along several multidimensional axes, with axes 1 and 2 accounting for 38% of the total variation. The sandier nearfield stations separated from the finer-grained stations primarily along Axis 1 (Figure 5-13A). Axis 2 probably represents a time component, with samples from the early 1990s, which were 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 2003 could not be distinguished within the dense cloud of points representing all of the finer-grained nearfield stations. Further analysis of only the finer-grained samples (*i.e.*, 345 samples, stations NF 4, NF13, NF17 and NF23 excluded) did not yield any additional resolution. This evidence points toward the absence of any detectable recent impact on the soft-bottom infauna.

The species accounting for more than 2% of the CNESS variation of the full suite of nearfield samples are indicated in the Gabriel Euclidean distance biplot (Figure 5-13B) and detailed in Table 5-3. As seen for the 2003 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 (NF13, NF17, and NF23) are influenced by the syllid polychaetes *Exogone hebes* and *E. verugera*, *Spiophanes bombyx*, *Polygordius* sp. A, and the amphipod *Crassicorophium crassicorne*.

With CNESS (*m*=15), 39 of the 392 species recorded in the 414 nearfield samples in 1992–2003 accounted for 88% of the variation in the community structure, and contributed at least 1% to the PCA-H axes (Table 5-4).



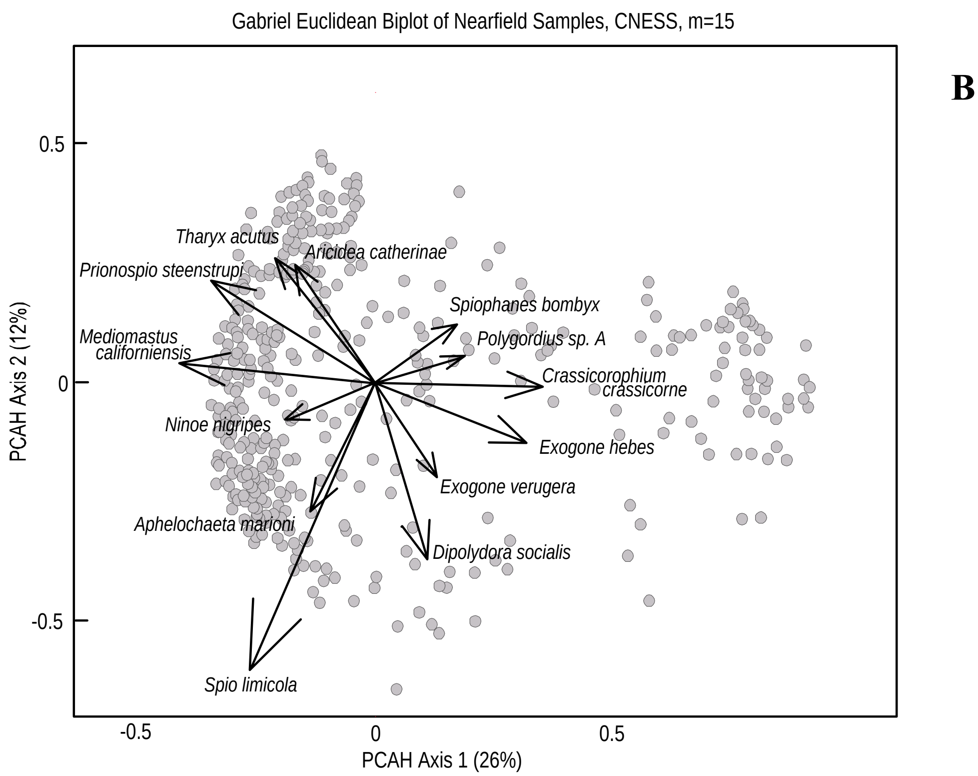


Figure 5-13. Metric scaling on PCA-H axes 1 and 2 of 414 nearfield benthic infaunal samples (A) and the Euclidean distance biplot showing the species responsible for >2% of the variation (B).

Table 5-3. Contributions to PCA-H axes by species accounting for >2% of the CNESS variation among the infaunal samples collected from nearfield stations 1992-2003 (see Figure 5-16B 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*	16	16	7	36
2	*Mediomastus californiensis*	11	26	15	0
3	*Prionospio steenstrupi*	9	35	11	5
4	*Crassicorophium crassicorne*	8	44	12	0
5	*Exogone hebes*	7	51	10	2
6	*Dipolydora socialis*	5	56	1	14
7	*Tharyx acutus*	5	61	4	7
8	*Aricidea catherinae*	4	65	3	6
9	*Aphelochaeta marioni*	3	68	2	7
10	*Ninoe nigripes*	3	70	4	1
11	*Exogone verugera*	2	73	2	4
12	*Spiophanes bombyx*	2	75	3	1
13	*Polygordius* sp. A	2	77	3	0
Important species: Axis 1 vs. Axis 3					
PCA-H Rank	**Species**	**Contr.**	**Total Contr.**	**Axis 1**	**Axis 3**
1	*Prionospio steenstrupi*	17	17	11	41
2	*Mediomastus californiensis*	12	29	15	0
3	*Crassicorophium crassicorne*	10	39	12	1
4	*Exogone hebes*	9	48	10	4
5	*Aricidea catherinae*	6	54	3	22
6	*Spio limicola*	6	60	7	4
7	*Tharyx acutus*	4	64	4	3
8	*Ninoe nigripes*	3	67	4	0
9	*Polygordius sp. A*	3	70	3	0
10	*Levinsenia gracilis*	2	72	3	0
11	*Spiophanes bombyx*	2	74	3	0
12	*Euchone incolor*	2	76	2	4
Important species: Axis 2 vs. Axis 3					
PCA-H Rank	**Species**	**Contr.**	**Total Contr.**	**Axis 2**	**Axis 3**
1	*Spio limicola*	25	25	36	4
2	*Prionospio steenstrupi*	17	42	5	41
3	*Aricidea catherinae*	11	53	6	22
4	*Dipolydora socialis*	9	62	14	0
5	*Tharyx acutus*	5	68	7	3
6	*Aphelochaeta marioni*	5	72	7	0
7	*Exogone verugera*	4	76	4	3
8	*Owenia fusiformis*	3	79	3	4
9	*Nucula delphinodonta*	3	82	3	2
10	*Exogone hebes*	2	84	2	4

Table 5-4. Contribution of the 39 species in the 1992–2003 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	*Spio limicola*	7	7	7	36	4	0	0	0	3
2	*Prionospio steenstrupi*	7	14	11	5	41	1	1	0	11
3	*Aricidea catherinae*	5	19	3	6	22	23	8	7	1
4	*Mediomastus californiensis*	5	24	15	0	0	0	0	0	0
5	*Tharyx acutus*	5	29	4	7	3	0	24	18	9
6	*Dipolydora socialis*	5	34	1	14	0	5	27	4	2
7	*Exogone hebes*	4	38	10	2	4	6	1	0	3
8	*Crassicorophium crassicorne*	4	42	12	0	1	3	1	0	0
9	*Owenia fusiformis*	3	45	0	3	4	6	11	21	8
10	*Aphelochaeta marioni*	3	48	2	7	0	1	0	8	0
11	*Ninoe nigripes*	2	50	4	1	0	3	4	3	5
12	*Exogone verugera*	2	53	2	4	3	8	1	1	8
13	*Monticellina baptistae*	2	55	2	0	2	2	1	12	7
14	*Spiophanes bombyx*	2	57	3	1	0	6	0	3	2
15	*Euchone incolor*	2	59	2	1	4	4	1	1	0
16	*Levinsenia gracilis*	2	61	3	1	0	4	3	1	3
17	*Polygordius sp. A*	2	63	3	0	0	3	0	0	2
18	*Nuculana delphinodonta*	2	65	1	3	2	0	1	3	1
19	*Hiatella arctica*	2	67	1	0	0	2	0	0	0
20	*Unciola inermis*	2	69	2	0	1	1	1	2	4
21	*Molgula manhattensis*	2	70	2	0	0	0	0	0	0
22	*Pseudunciola obliquua*	2	72	2	0	1	6	1	0	5
23	*Cerastoderma pinnulatum*	2	73	2	0	0	0	1	0	0
24	*Phoronis architecta*	1	75	0	0	0	0	2	1	2
25	*Enchytraeidae* sp. 1	1	76	1	0	0	0	0	0	3
26	*Leitoscoloplos acutus*	1	77	2	0	1	0	0	0	0
27	*Scoletoma hebes*	1	78	0	2	0	0	1	6	1
28	*Phyllodoce mucosa*	1	80	0	2	0	0	1	1	7
29	*Photis pollex*	1	81	0	1	0	1	1	0	2
30	*Nephtys cornuta*	1	82	0	1	0	0	0	1	2
31	*Crenella decussata*	1	83	0	1	0	2	0	0	1
32	*Dipolydora quadrilobata*	1	84	0	1	0	0	1	1	0
33	*Protomedeia fasciata*	1	84	0	0	1	2	1	1	1
34	*Asabellides oculata*	1	85	0	0	0	1	0	1	0
35	*Ampharete acutifrons*	1	86	0	1	0	0	0	0	0
36	*Echinarachnius parma*	1	86	1	0	0	1	0	0	1
37	*Tubificidae* sp. 2	1	87	0	0	0	0	1	0	0
38	*Maldane sarsi*	1	88	0	1	0	0	0	1	0
39	*Chiridotea tuftsi*	1	88	1	0	0	1	0	0	1

5.3.6 Correlation with Sediment Data and SPI results

Canonical analysis of both nearfield and farfield data was used last year to investigate which environmental variables might be associated with changes in species composition (Maciolek *et al*. 2003). Six key environmental variables—depth, % fines, % gravel, % TOC, *Clostridium perfringens*, and year—were tested. For nearfield samples, Axes 1 and 2 accounted for only 14% of the variation in community structure, whereas for farfield stations these two axes accounted for 38% of the variation. TOC and percent fines were only weakly related to community structure and *Clostridium* was a poor predictor of community structure (Maciolek *et al*. 2003).

In both the nearfield and farfield, depth was the most important predictor of community structure (Maciolek *et al*. 2003). Depth might be indicative of food resources reaching the bottom communities or how the sediments are impacted by physical forces such as currents and storms that operate in the Massachusetts and Cape Cod Bay system; however, the winter storms of 1992 changed the grain-size composition at the majority of nearfield and all farfield stations, irrespective of depth (Appendix B2, Figures B2-11 and B2-12). This change toward coarser sediments was most noticeable at NF02, where fine sediments were reduced from 77% to 10%. The species composition of the infaunal community was not absolutely determined by grain size, as exemplified by NF02: the dominant species at that station were similar whether fines were 3–10% or 62–77% of the sediment composition.

Similarly, the sandy nearfield stations, NF04, NF13, NF17, and NF23, where fine sediments comprise 10% or less of the substrate, are each characterized by different numerically dominant species. In 2003, the dominants (and the percent of the sample represented by this species) at these stations were: NF04, *Exogone hebes* (16.7%); NF13, *Prionospio steenstrupi* (35%); NF17, *Crassicorophium crassicorne* (17%); and NF23, *Phoronis architecta* (30%). Clearly, other factors in addition to sediment grain size are impacting the communities. Stations NF13, NF17, and NF23 are among those where sediment profile images indicate that physical processes dominate the structuring of the community; NF04 is characterized by both biological and physical processes (see Chapter 4, this report).

The similarity of dominant species at NF02 in spite of drastic changes in sediment composition may be related to the timing of the event(s) that brought (or removed) the fine material at this station; likewise, differences in species composition at coarse-sediment stations may be related to the timing of larval settlement. The affinity of certain species for an area may not be correlated as tightly to sediment grain-size composition as previously supposed.

5.3.7 Threshold Assessment

Monitoring thresholds for several parameters have been 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. None of the 2003 annual means for these parameters exceeded any of the threshold values Table 5-5); however, 11 of 34 nearfield samples had an evenness value of 0.56 or lower.

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

Parameter	Threshold Value lower	Threshold Value upper	Baseline Average[1]	Post-Dispersion Annual Means 2001	2002	2003
Total Abundance	na	na	2242	2318	3476	3138
Abundance of Valid Species	na	na	2106	2091	3413	3085
Species/Grab	47.97	81.09	65	65	74	76
H'	3.32	4.02	3.68	3.80	3.60	3.61
J'	0.56	0.67	0.62	0.63	0.58	0.58
alpha	10.13	15.58	13.06	13.35	14.05	14.57

[1]Calculated June 2003 as average of all nearfield samples 1992–2000. na= Not applicable.

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. Infaunal abundance (per sample) has 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*). Species richness has also increased, in 2003 reaching the highest mean values in both the nearfield and farfield areas.

♦ *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. These patterns have not been seen: species richness and log-series *alpha* have increased at nearfield stations, while diversity (H′) and evenness(J′) have been stable since the outfall came online. Nearfield and farfield stations have not diverged but in 2003 actually converged in terms of abundance, diversity, and evenness. Although the number of species per sample and log-series *alpha* appear to have increased more in the farfield than in the nearfield, the fact that they also increased in the nearfield precludes the conclusion that this is indicative of an outfall effect. Preliminary statistical evaluation of the differences (before and after diversion; nearfield versus farfield) indicate no significant differences and therefore no evidence of impact from the outfall (Dr. E. Gallagher, personal communication, June 2004).

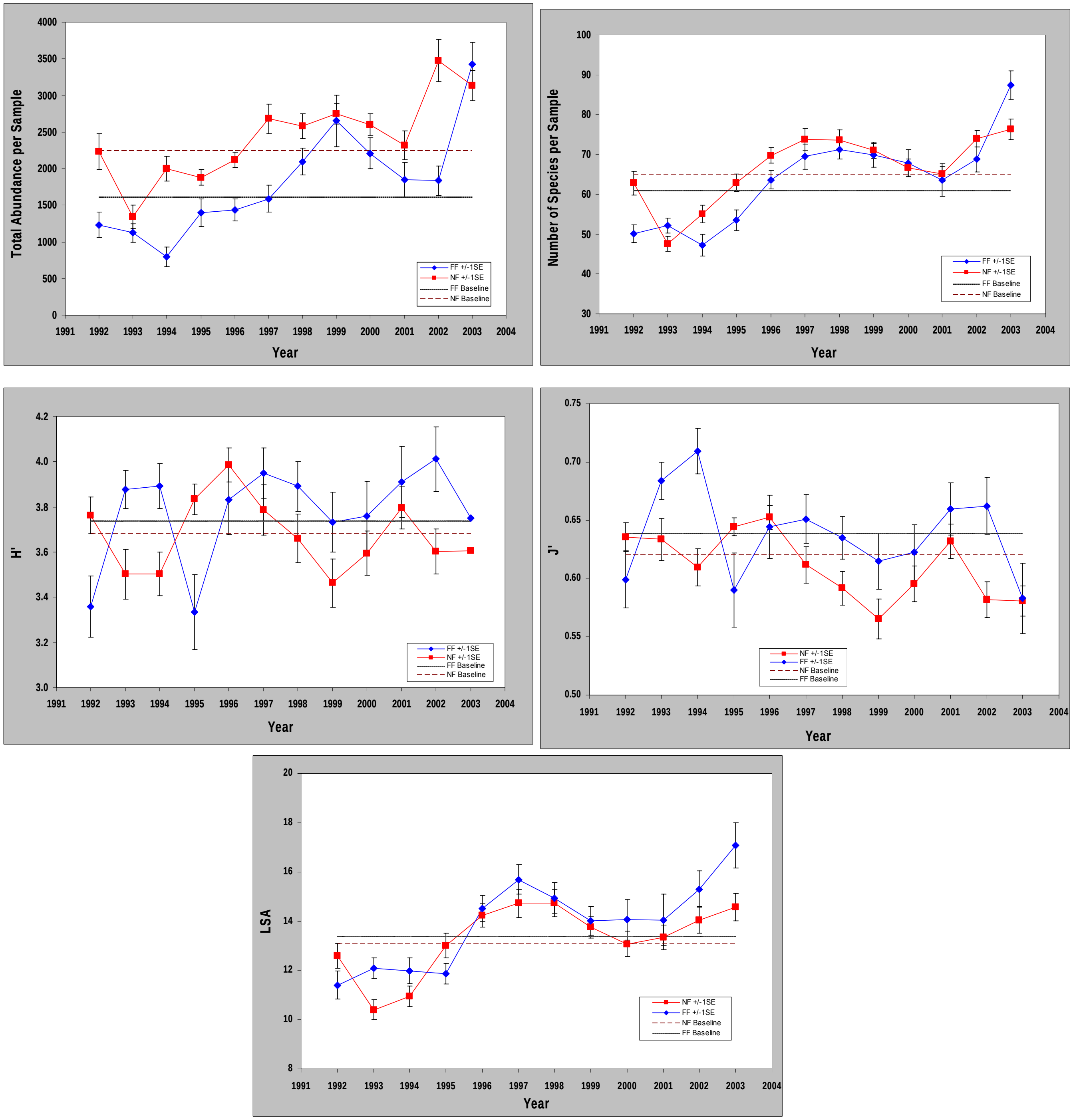


Figure 5-14. Mean benthic community parameters for nearfield and farfield stations sampled 1992–2003. (A) abundance per sample, (B) number of species per sample, (C) Shannon diversity H′, (D) Pielou's evenness J′, and (E) log-series *alpha*.

6. 2003 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 ten 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*. 2002 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 indicated 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 quite variable, and usually consists of a cobble pavement interspersed to varying degrees with patches of sand, gravel, and boulders. Habitat relief on the flanks ranges from low to moderate, depending on how many boulders are present. Sediment drape in the flank areas usually ranges from moderate to heavy. The tops of the drumlins generally tend to be more spatially homogeneous than either the edges of the tops or the flanks of the drumlins, which tend to be spatially heterogeneous. As a result, small lateral shifts in position near the edges of the drumlin tops or on the flanks frequently result in substantially different habitat characteristics, and hence different communities.

Algae usually dominate benthic communities on the tops of drumlins, while invertebrates (mostly encrusting or attached forms) become increasingly dominant on the flanks of the drumlins. Both encrusting coralline algae and several species of upright algae are quite common throughout the hard-bottom areas near the outfall. 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 stable during the baseline period. The structure of the benthic communities remained relatively unchanged between 1995 and 2000. Occasional year-to-year differences 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 to 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 two post-discharge surveys were remarkably similar to those observed pre-discharge (Maciolek *et al.* 2003). Only one consistent difference was noted between the pre- and post-discharge periods. A slight increase in sediment drape and a concurrent decrease in percent cover of coralline algae was observed at five stations north of the outfall during the first two post discharge years.

The data discussed in this chapter were collected during the third post-discharge survey of the hard-bottom communities. This survey was conducted during late June 2003. This chapter presents the results of the 2003 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 2003, including an actively discharging diffuser head at the eastern end of the outfall.

6.2 Methods

Both video footage and still photographs were obtained at each of 23 waypoints (Table 6-1, see Figure 2-3). For the 2003 survey, two stations were discontinued (T4-1 and T4-3) and two stations were added (T11-1 and T12-1) to expand the geographic coverage of the study. The two stations that were dropped added little to the data set, one was relatively depauperate (T4-1) and the other one was redundant (T4-3) with a station located closer to the outfall (T6-1). In lieu of these stations, two new reference stations were established (T11-1 and T12-1). Criteria for choosing the new stations included a high probability of encountering hard substrate that had minimal sediment drape and some information available about pre-discharge conditions. One of the new stations (T12-1) is located approximately 2 mi (3.2 km) southeast of the outfall and had been visited by the USGS in 1999; the other (T11-1) is located approximately 10 miles (16 km) east of Scituate, MA , and had been visited in 2000. Photographic coverage ranged from 20 to 35 minutes of video footage and 26 to 33 still photographs (35-mm slides) at each waypoint. A total of 725 still photographs was taken and used in the following data analysis.

Table 6-1. Photographic coverage at locations surveyed during the 2003 nearfield hard-bottom survey.

Transect	Waypoint	Location on drumlin	Depth (m)	Video (min)	Stills (# frames)
1	1	Top	23	23	31
1	2	Top	20	21	32
1	3	Top	18	22	33
1	4	Top	21	21	33
1	5	Flank	25	22	32
2	1	Top	23	22	32
2	2	Top	27	35	32
2	3	Top	22	21	33
2	4	Flank	25	23	33
2	5	Diffuser #2	29	20	26
4	2	Flank	27	21	27
4/6	1	Top	20	23	32
6	1	Flank	31	21	28
6	2	Flank	28	21	31
7	1	Top	22	23	32
7	2	Top	23	23	33
8	1	Top	21	21	33
8	2	Top	20	23	31
9	1	Top	23	21	33
10	1	Top	22	21	33
11	1		33	22	31
12	1	Top	22	21	33
Diffuser	#44		31	21	31

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

Additionally, individual adult barnacles were counted individually unless they occurred in aggregations too dense to count accurately, in which case they were estimated in groups of 10, 20, or 50 at a time.

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 2003 slide analysis is included in Appendix D1.

Some changes in taxonomic designations have occurred during the years of this survey. Coralline algae originally referred to as *Lithothamnion* spp. were found to belong to at least five species: *Leptophytum laevae*, *Leptophytum foecundum*, *Phymatolithon lamii*, *Phymatolithon laevigatum*, and *Lithothamnion glaciale*. Differences between these species can not be discerned on the basis of photographs, so all pink encrusting coralline 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 2003 video analyses is included in Appendix D2.

6.2.2 Data analysis

Data for all slides taken at each waypoint were pooled. 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. This process resulted in 40 of the original 69 taxa being retained for community analysis. Exceptionally heavy settlements of barnacles (*Balanus* sp.) were encountered at a number of sites in 2003. Their abundances were high enough that they tended to overwhelm the community analysis, so classification analysis was run with and without the inclusion of barnacles.

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.

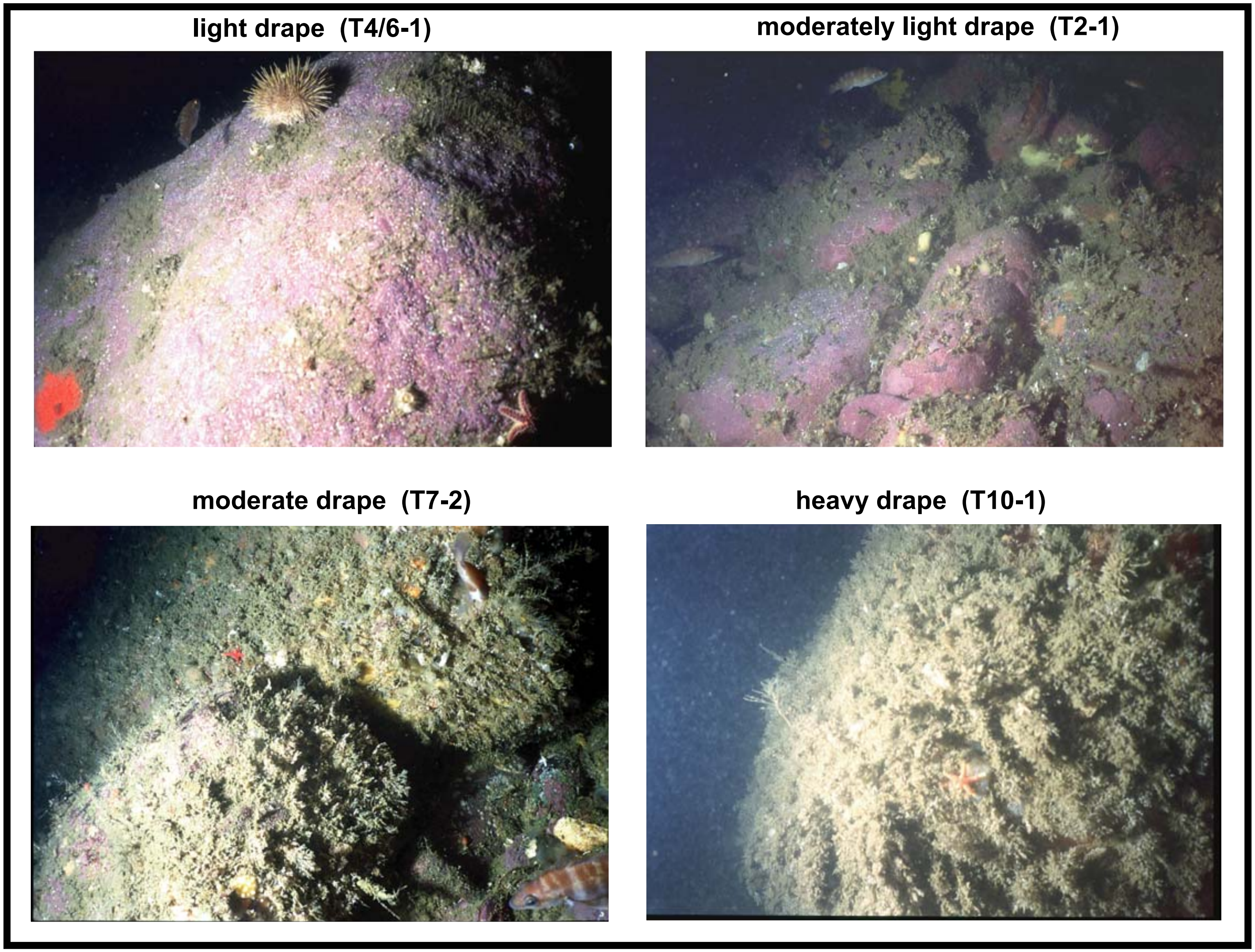


Figure 6-1. Photographs representative of sediment drape categories. Light drape is the presence of a dusting or small patches of sediment leaving the rock surfaces clearly visible. Moderately light drape is the presence of larger patches of sediment, yet still leaving most of the rock surfaces visible.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

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 photographs.

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 ranged from areas of moderate to moderately high relief characterized by numerous boulders interspersed with cobbles in the shallowest areas, 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. In contrast, the sea floor at two of the southern reference sites (T8-1 and T8-2) consisted of a moderately low relief of cobbles with occasional boulders. The highest relief encountered during the survey was large boulders on the sea floor at the southern reference site located just southwest of the outfall (T10-1). The new southern reference site (T12-1) had a moderate relief sea floor, which consisted of cobbles and boulders. The sea floor of the five drumlin flank sites usually consisted of a low to moderate relief mix of cobbles, boulders, and gravel. At the new reference site near Scituate the sea floor 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 T1-3 to a moderately heavy drape at T10-1. Of the remaining 13 drumlin top areas, seven had moderately low sediment drape, while six 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). All three of the northern reference sites had moderate drape (T7-1, T7-2, and T9-1). Sediment drape was moderate at all five flank sites, as well as 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 2003 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 both diffusers.

6.3.2 Distribution and Abundance of Epibenthic Biota

Seventy-seven taxa were seen during the visual analyses of the 2003 nearfield hard-bottom survey still photographs and videotapes (Table 6-2). Seventy-three of these taxa were seen on the still photographs and fifty-two were seen on the video footage. Taxonomic counts or estimates of abundances from the still photographs included 5,792 algae, 33,098 invertebrates, and 1,668 fish (Table 6-3). Coralline algae was the most abundant alga taxon observed during the survey, with an estimated abundance of 4,659 individuals. Two other algae commonly seen were dulse (*Rhodymenia palmata*) and a red filamentous alga *Ptilota serrata*, with abundances of 698 and 416 individuals, respectively. The least abundant alga encountered was the shotgun kelp, *Agarum cribosum*.

The most abundant invertebrate encountered during the 2003 survey was the barnacle, *Balanus* spp., with an abundance of 10,911 individuals. Massive settlements of barnacles that had grown past the initial settlement stage were found at a number of sites, including the inactive diffuser head. Comparable densities of adult barnacles have not been observed in previous baseline or post-discharge surveys. Other abundant invertebrates observed on the still photographs were the brachiopod *Terebratulina septentrionalis* (2654 individuals), the frilled anemone *Metridium senile* (2,464 individuals), the northern sea star *Asterias vulgaris* (2,072 juveniles and 516 adults), an unidentified whitish translucent sponge (2,350 individuals), an unidentified orange/tan sponge (1,598 individuals), the horse mussel *Modiolus modiolus* (1,320 individuals), an unidentified sponge encrusting the brachiopods (1,105 individuals), the sea-pork tunicate *Aplidium* spp. (1,048 individuals), the northern white-crust tunicate *Didemnum albidum* (981 individuals), and the blood sea star *Henricia sanguinolenta* (779 individuals). Other common invertebrate inhabitants of the drumlins included numerous sponges and encrusting organisms. The most abundant fish observed in the still photographs were the cunner *Tautogolabrus adspersus* (1,634 individuals), cod *Gadus morhua* (11 individuals), rock gunnel *Pholis gunnellus* (7 individuals), sculpin *Myoxocephalus* spp. (6 individuals), and winter flounder (5 individuals).

Coralline algae was one of the most widely distributed taxa encountered during the survey. This encrusting alga was seen at 20 of the 23 waypoints, being absent from T10-1 and the two diffuser sites. Mean areal coverage of coralline algae ranged from 1% at T11-1 to 80% at T1-3. Figure 6-2 shows the relationships between depth, sediment drape, percent cover of coralline algae, and topography. Amount of sediment drape did not show a strong relationship with either depth or topography. Percent cover of coralline algae was quite variable and showed a weak general trend of higher cover at shallower depths. However, the strongest relationship was between percent cover of coralline algae and degree of sediment drape. Corallines were most abundant in areas that had minimal sediment drape on the rock surfaces and least abundant in areas that had heavy sediment cover. In contrast, the two most abundant upright algae, *Ptilota serrata* and *Rhodymenia palmata* had much more restricted distributions, with *P. serrata* being common at only three of the sites and *R. palmata* being common at only four of the sites. These upright algae frequently dominated in areas characterized by moderate to high relief and a 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.

The new southern reference site, T12-1, is similar to the other two southernmost reference sites in that it supports a high percent cover of coralline algae, but it differs in that it also supports modest numbers of upright algae. In contrast, the new farfield site, T11-1, located near Scituate, supported very few algae. However, this site was quite spectacular in that it supported high numbers of brachiopods and cod.

Table 6-2. Taxa observed during the 2003 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*	yellow sponge
Halichondria panicea	crumb-of-bread sponge
Haliclona oculata	finger sponge
Haliclona spp.	encrusting sponge
Melonanchora elliptica	warty sponge
Suberites spp.	fig sponge
white divided	sponge on brachiopod
* orange/tan encrusting	sponge
* orange encrusting	sponge
* gold encrusting	sponge
* tan encrusting	sponge
* pink fuzzy encrusting	sponge
* dark red/brown encrusting	sponge
* white translucent	sponge
* cream encrusting	sponge
* rust-cream encrusting	sponge
* filamentous white encrusting	sponge
* general encrusting organism	
* red crust	encrusting organism
* red/orange crust	encrusting organism
Cnidarians	
general hydroid	
Obelia geniculata	zig-zag hydroid
Tubularia sp.	hydroid
general anemone	
Metridium senile	frilly anemone
Urticina felina	northern red anemone
Gersemia rubiformis	red soft coral
** *Alcyonium digitatum*	dead-mans-fingers coral
Mollusks	
* gastropod	
* *Tonicella marmorea*	mottled red chiton
* *Crepidula plana*	flat slipper limpet
* nudibranch	
* *Coryphella* sp.	red-gilled nudibranch
Buccinum undatum	waved whelk
** bivalve	
Arctica islandica	ocean quahog
Modiolus modiolus	horse mussel
Placopecten magellanicus	sea scallop
Crustaceans	
Balanus spp.	acorn barnacle
Cancer spp.	Jonah or rock crab
Homarus americanus	lobster
Echinoderms	
Strongylocentrotus	green sea urchin
general starfish	
juvenile *Asterias*	small white starfish
Asterias vulgaris	northern sea star
Crossaster papposus	spiny sunstar
Henricia sanguinolenta	blood star
* *Porania insignis*	badge star
Pteraster militaria	winged sea star
Solaster endeca	smooth sunstar
Psolus fabricii	scarlet holothurian
Tunicates	
Aplidium spp.	sea pork tunicate
Boltenia ovifera	stalked tunicate
* *Dendrodoa carnea*	drop-of-blood tunicate
* *Didemnum albidum*	northern white crust
Halocynthia pyriformis	sea peach tunicate
* white globular tunicate	
Bryozoans	
General bryozoan	
** *Membranipora* spp.	sea lace bryozoan
* red crust bryozoan	
Miscellaneous	
Myxicola infundibulum	slime worm
spirorbids	
Terebratulina septentrionalis	northern lamp shell
Fish	
general fish	
** dogfish	
Gadus morhua	cod
Hemitripterus americanus	sea raven
Macrozoarces americanus	ocean pout
Myoxocephalus spp.	sculpin
Pseudopleuronectes	winter flounder
* *Pholis gunnellus*	rock gunnel
Tautogolabrus adspersus	cunner

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

Table 6-3. Taxa seen in still photographs taken during the 2003 nearfield hard-bottom survey, arranged in order of abundance.

Taxon	Count	Taxon	Count
Algae		*Gersemia rubiformis*	39
Coralline algae	4659[1]	*Tonicella marmorea*	21
Rhodymenia palmata	698	*Arctica islandica*	18
Ptilota serrata	416[1]	*Urticina felina*	17
Agarum cribosum	19	*Obelia geniculata*	13
Total algae	**5792**	dark red/brown encrusting sponge	10
		anemone	10
Invertebrates		*Haliclona* spp. (upright)	9
Balanus spp.	10911	*Boltenia ovifera*	8
Terebratulina septentrionalis	2654	filamentous white encrusting sponge	6
Metridium senile	2464	*Haliclona* spp. (encrusting)	6
white translucent sponge	2350	nudibranch	6
Juvenile *Asterias*	2072	*Homarus americanus*	6
orange/tan encrusting sponge	1598	tan encrusting sponge	5
Modiolus modiolus	1320	*Placopecten magellanicus*	5
white divided sponge	1105	*Crossaster papposus*	5
Aplidium spp.	1048	*Melonanchora elliptica*	4
Didemnum albidum	981	*Buccinum undatum*	4
Henricia sanguinolenta	779	red/orange encrusting organism	3
white globular tunicate	648	*Pteraster militaria*	3
bryozoan	618	*Solaster endeca*	3
Dendrodoa carnea	564	rust-cream encrusting sponge	2
orange encrusting sponge	548	gastropod	1
Asterias vulgaris	516	*Coryphella* sp.	1
Halocynthia pyriformis	497	starfish	1
pink fuzzy encrusting sponge	321	*Porania insignis*	1
Myxicola infundibulum	277	hydroids	*
general encrusting organism	261	spirorbids	*
Crepidula plana	244	**Total invertebrates**	**33098**
Halichondria panicea	145		
Aplysilla sulfurea	131		
sponge	129	**Fish**	
Suberites spp.	122	*Tautogolabrus adspersus*	1634
Strongylocentrotus droebachiensis	97	*Gadus morhua*	11
Psolus fabricii	84	*Pholis gunnellus*	7
red crust bryozoan	84	*Myoxocephalus* spp.	6
Tubularia sp.	82	*Pseudopleuronectes americanus*	5
gold encrusting sponge	68	fish	2
red encrusting organism	65	*Macrozoarces americanus*	2
cream encrusting sponge	60	*Hemitripterus americanus*	1
Cancer spp.	48	**Total fish**	**1668**

*Not counted
[1]Estimated

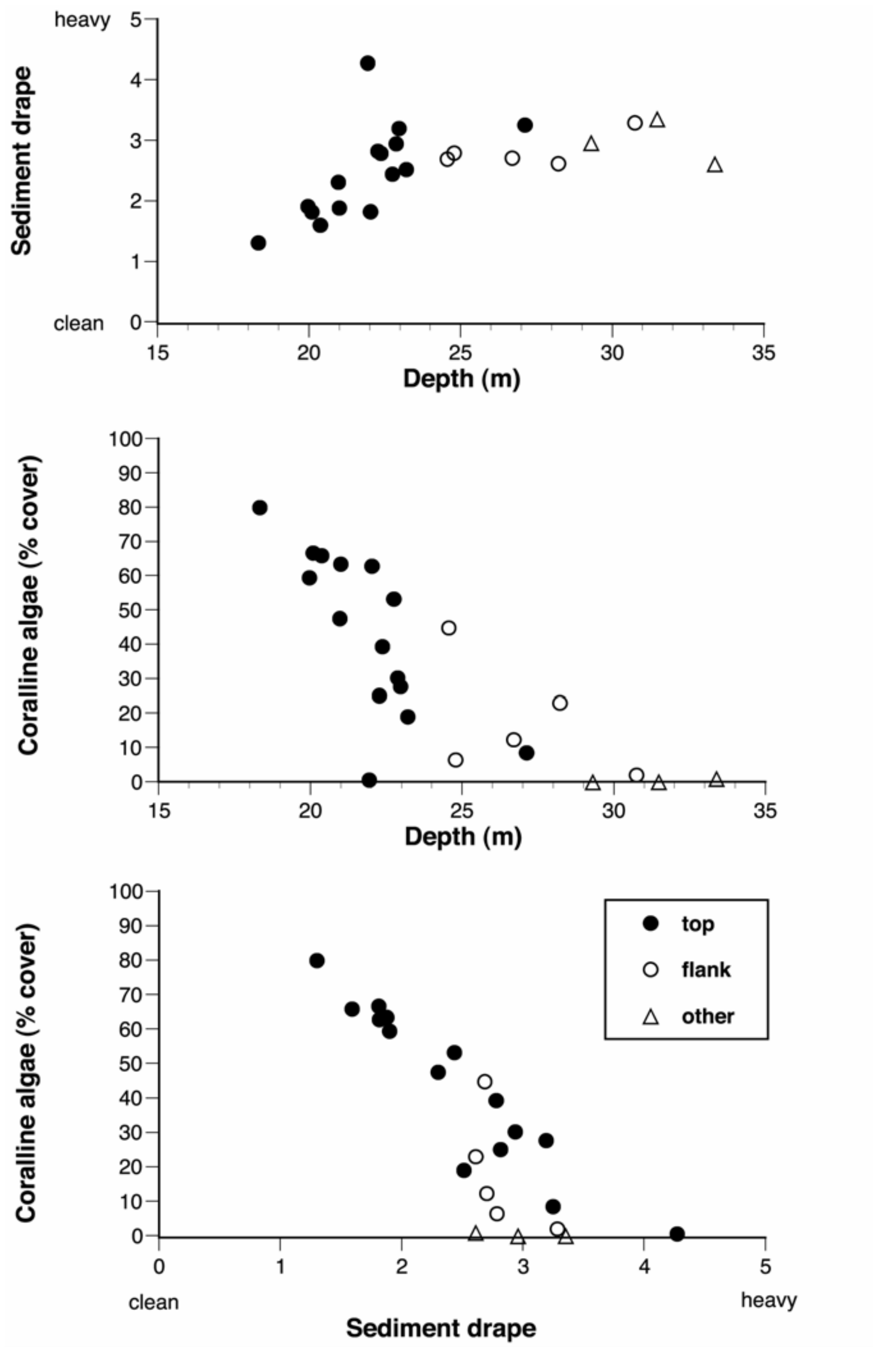


Figure 6-2. Depth, sediment drape, and percent cover of coralline algae of the sites from the 2003 nearfield hard-bottom survey.

Several of the commonly seen invertebrates also exhibited wide distributional patterns. Juvenile and adult northern sea stars *Asterias vulgaris* were found at all of the sites. Juvenile *Asterias* were usually much more abundant than adults and were most abundant on the top of drumlins, while adults were more abundant on the flanks and near the diffuser heads. Additionally, adult *A. vulgaris* were frequently seen on dense aggregations of barnacle. Another sea star, the blood sea star *Henricia sanguinolenta*, was also observed at all of the 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 two diffusers. 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.

The most abundant organism encountered, the barnacle *Balanus* spp., was found at all but six of the sites surveyed. Unusually dense aggregations of adult *Balanus* were observed at 11 of the 23 sites, and were spread throughout the study area (Figure 6-3). Massive widespread settlements of barnacles were found at seven of the sites: one on the drumlin north of the diffuser (T1-4), two on the drumlin south of the diffuser (T4-2 and T4/6-1), at one of each of the northern (T9-1) and southern reference (T10-1) sites, at the site off Scituate (T11-1), and on the head of Diffuser #44. Less dramatic, yet heavy, settlements were observed at an additional four sites, both near the outfall and at the reference sites. The barnacles were frequently so crowded that they formed tall, twisted colonies that were dying off. Overcrowding leading to mass mortality was very evident at Diffuser #44. The only surfaces on the top and upper sides of the diffuser head that were not covered by barnacles were those already occupied by larger *Metridium senile* and *Halocynthia pyriformis*. Many of these barnacles were very elongated, showing the typical form of barnacles growing under very crowded conditions. Numerous areas of exposed bases and piles of plates from dead barnacles were observed within crowded barnacle colonies, indicating heavy mortality (Figure 6-4). Barnacles had not been present on the diffuser in June of 2002. Similar dense settlements of adult *Balanus* have not been observed previously at the hard-bottom sites. Additional instances of massive die-offs of *Balanus* were also observed at several other stations, particularly T8-1.

Several other abundant invertebrates exhibited more restricted distributions. Four of these species appeared to be primarily restricted to large boulders. The brachiopod *Terebratulina septentrionalis* was found at ten of the sites, but was seen in high abundances only at six of them (T2-4, T4-2, 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 17 sites, but was abundant at only seven of them. It was abundant on the larger boulders found at sites T4/6-1, T7-2, T10-1, T11-1, and T12-1. This anemone was usually seen on the tops and upper sides of boulders. Additionally, this anemone was abundant on the head of the inactive diffuser (Diffuser #44) and was exceptionally abundant on head of the active diffuser (Diffuser #2). The sea peach tunicate *Halocynthia pyriformis* was found at 19 sites, but was found in high abundances only at two sites: the new site off Scituate (T11-1) and the head of the inactive diffuser (Diffuser #44). This species was also usually seen on the sides of larger boulders. One species with a more restricted distribution was the soft coral *Gersemia rubiformis*, which was seen only at T10-1 where it commonly inhabited the tops of large boulders characteristic of this site.

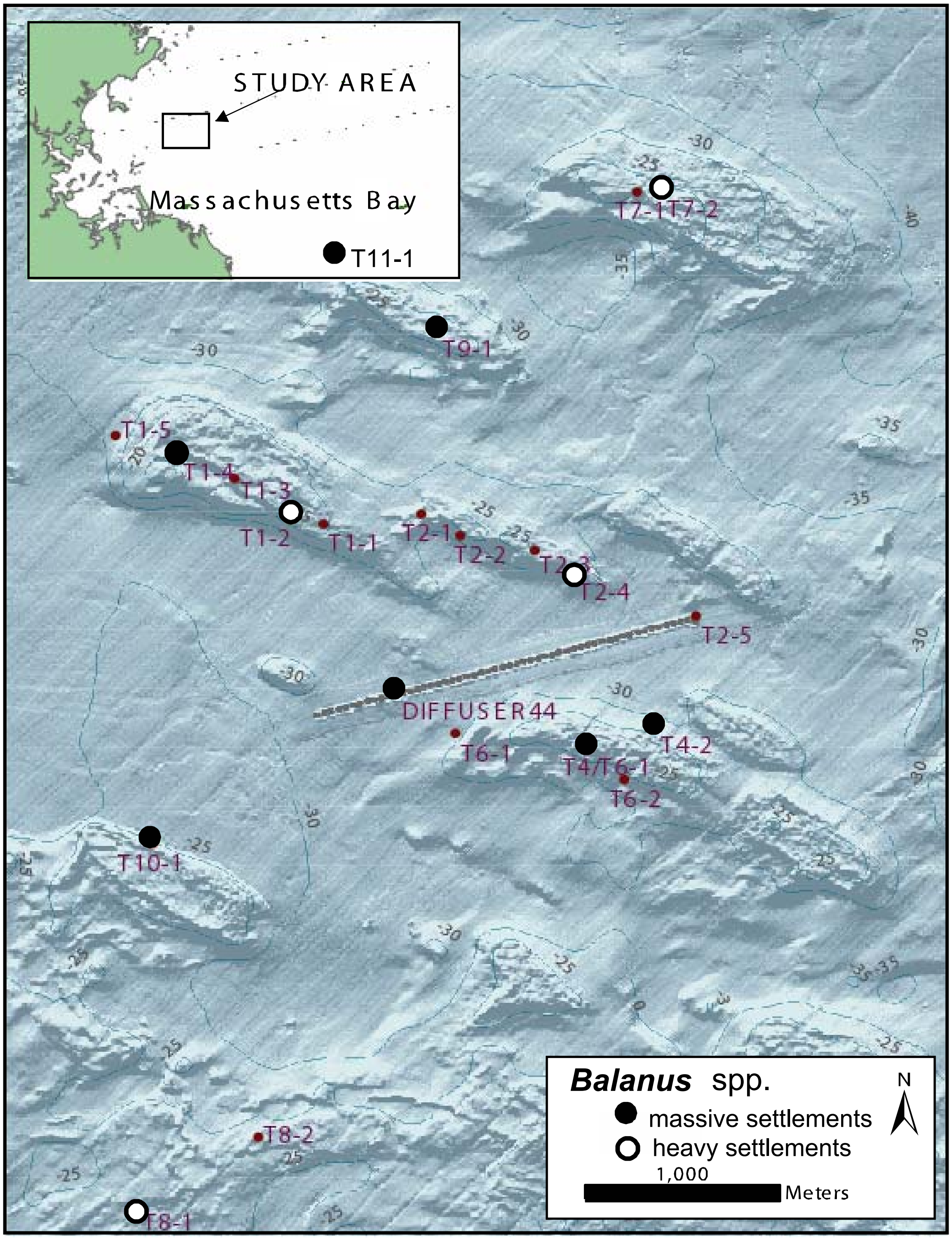


Figure 6-3. Locations of massive barnacle settlements observed during the 2003 survey.

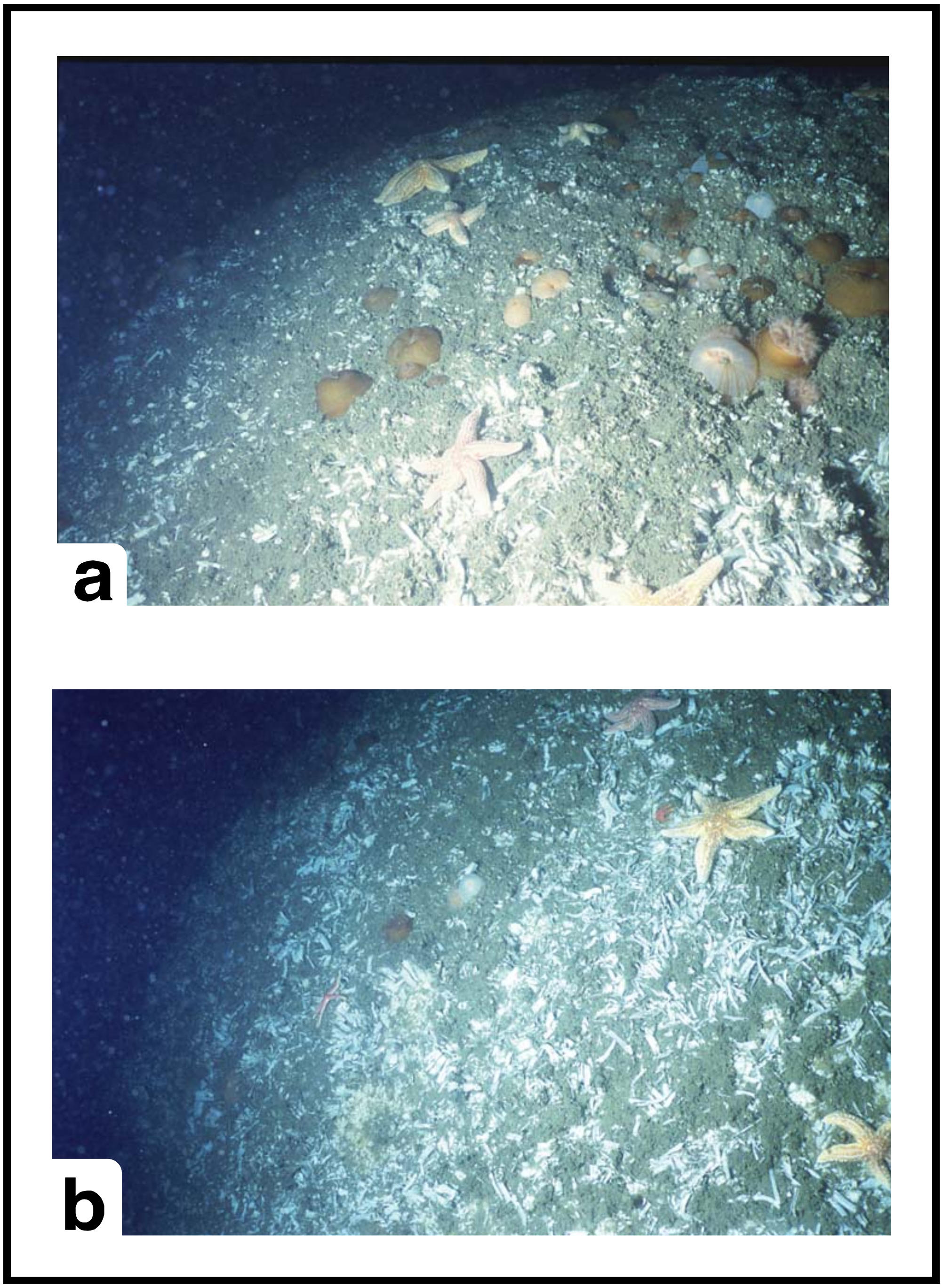


Figure 6-4. Photographs showing massive settlement of barnacles on Diffuser #44. (a) The entire surface of the top of the diffuser head is covered with barnacles, with the exception of space occupied by adult *Metridium senile*. (b) Numerous plates of dead barnacles were seen on the sides of the diffuser head, attesting to a massive die-off of barnacles. The starfish *Asterias vulgaris* may be preying on the barnacles.

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 distribution of the green sea urchin *Strongylocentrotus droebachiensis* mirrored that of coralline algae. This urchin was found at 16 sites, but was commonly seen only in regions that had a high percent cover of coralline algae (T1-3, T4/6-1, and T8-2), on which it grazes (Sebens, 1986). The red holothurian *Psolus fabricii* also was widely distributed. This holothurian was found at 14 sites, but was abundant at only three of them (T1-3, T8-2, and T12-1). Reasons for its high abundance in some areas, and not in others, were not readily apparent.

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 (T7-1, T1-2, T1-3, T2-3, and T4/6-1). In areas of heterogeneous relief, *T. adspersus* frequently was seen only in the immediate vicinity of boulders. Six other fish species, cod (*Gadus morhua*), rock gunnel (*Pholis gunnellus*), sculpin (*Myoxocephalus* spp.), winter flounder (*Pseudopleuronectes americanus*), ocean pout (*Macrozoarces americanus*), and a sea raven (*Hemitripterus americanus*) also were seen on the still photographs. The sculpin and flounder were usually seen in areas of lower relief, while cod and ocean pout were observed only in areas of higher relief.

6.3.3 Community Structure

Community structure was examined with and without the inclusion of *Balanus* in the data set. The initial analysis of 23 waypoints and 40 taxa (including *Balanus*) defined two large clusters of stations and one outlier (Figure 6-5). The two clusters basically separate on the presence or absence of high numbers of Balanus (Table 6-4). The first cluster consisted of areas that supported few barnacles, while the second cluster consisted of areas that supported dense settlements of barnacles. Site T2-5, which included the head of an active diffuser (Diffuser #2) and its immediate surroundings, was an outlier. This site differed from all of the other sites in that the diffuser head was colonized by very dense aggregations of *Metridium senile*. A bushy hydroid, *Tubularia* sp., was also commonly seen on the diffuser and on the rocks around its base. Further subdivisions within the two main clusters often reflected geographic location and habitat characteristics. Neighboring waypoints with similar habitat characteristics tended to cluster together (T7-1 and T7-2; T1-2 and T1-3; T8-1 and T8-2). Stations that historically had clustered together based on the presence of upright algae (shown by the shaded lines) were scattered throughout both clusters.

Because of the overwhelming dominance of barnacles at a number of the sites, the data set was also analyzed with *Balanus* spp. omitted and the results are shown on Figure 6-6. The classification identified one large cluster (cluster 2) that contained 15 of the 23 sites, and several smaller clusters of two or three sites. The overall community structure was similar to the previous analysis in that stations that had historically clustered together into cluster 1 no longer formed a cohesive group. The majority of these sites shifted into cluster 2, which historically had been characterized by a dominance of coralline algae and few if any upright algae. The only sites that remained in cluster 1 were the two northernmost reference sites, which still supported sizable populations of dulse and filamentous red algae (Table 6-5). Again, the clustering structure reflected habitat characteristics and geographic location, with neighboring stations frequently clustering together.

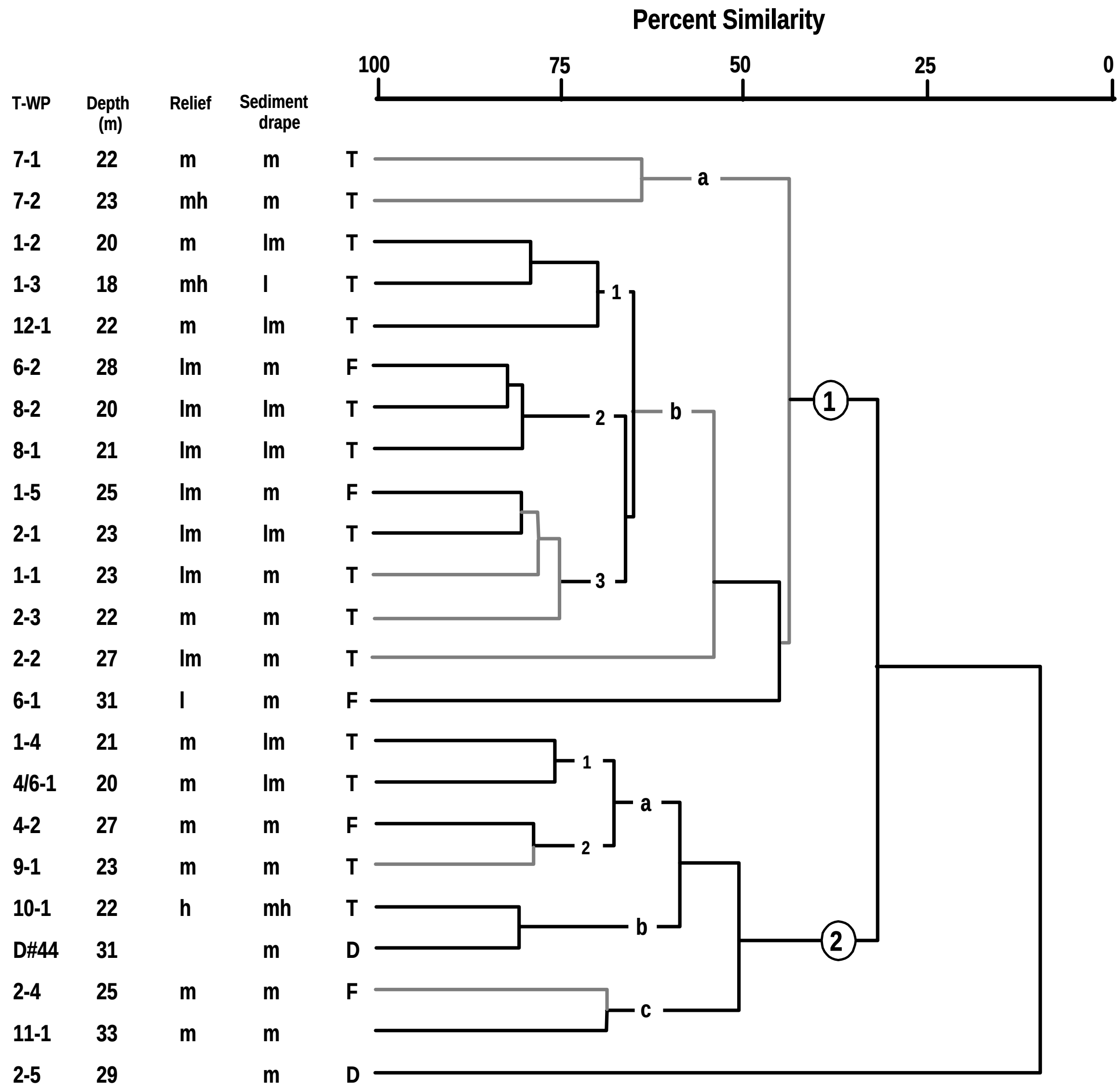


Figure 6-5. Cluster analysis of data collected from still photographs taken during the 2003 nearfield hard-bottom survey. Shaded lines show stations that had historically clustered together with T7-1 and T7-2 into Cluster 1.

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

Cluster	1						2				outlier
	a	b_1	b_2	b_3	T2-2	T6-1	a_1	a_2	b	c	T2-5
Depth (m)	22-23	18-22	20-28	22-25	27	31	20-21	23-27	22-31	25-33	29
Habitat relief [1]	M-MH	M-MH	LM	LM-M	LM	M	M	M	H	M	H
Sediment drape [2]	m	l-lm	lm-m	lm-m	m	m	lm	m	m-mh	m	m
Coralline algae (percent cover)	30-39	**63-80**	23-59	25-53	8	2	**63-66**	12-19	-	1-6	-
Ptilota serrata	**4.28-6.00**	0.00-1.73	-	-	-	-	0.00-0.06	0.00-0.39	-	-	-
Rhodymenia palmata	**5.34-7.94**	0.45-2.12	0.00-0.15	0.00-1.29	-	-	0.00-0.73	0.00-1.58	0.00-0.27	-	-
Agarum cribrosum	**0.19-0.39**	-	-	-	-	-	-	-	-	-	-
Coralline algae	4.73-7.34	**12.97-14.88**	4.26-13.06	4.27-10.31	2.06	0.64	**13.18-13.75**	2.74-3.55	0.00-0.03	0.26-1.58	-
Balanus spp.	**4.53-13.64**	1.85-6.13	0.00-0.70	0.00-0.31	1.66	-	**29.21-49.44**	**20.81-22.88**	**25.55-80.00**	**12.12-73.55**	-
juvenile *Asterias*	**2.81-4.15**	**3.15-6.00**	0.94-3.58	**2.66-4.38**	1.06	2.82	**2.56-6.82**	2.26-2.76	1.52-1.65	0.06-1.70	0.73
Aplidium spp.	0.00-0.09	0.48-2.61	**1.13-2.90**	**1.61-3.85**	1.50	0.71	1.34-3.88	0.89-1.52	0.00-0.03	0.06-0.58	-
Didemnum albidum	0.22-0.61	1.18-2.28	0.32-0.76	**2.36-2.84**	**2.50**	1.00	0.91-1.97	0.55-1.37	0.27-0.55	0.19-2.18	1.27
Modiolus modiolus	1.09-3.48	**1.91-7.61**	0.19-2.39	1.25-2.71	0.53	0.29	**2.91-4.03**	0.48-1.55	0.00-0.33	0.16-0.76	-
Terebratulina septentrionalis	0.00-6.58	0.00-2.73	-	0.00-0.55	-	-	0.00-0.34	**5.12-6.48**	0.00-0.06	**19.45-42.87**	-
Metridium senile	0.00-2.18	0.42-1.39	0.00-0.36	0.00-0.19	-	-	0.21-1.56	0.00-0.33	2.36-10.06	0.88-4.00	**64.42**
Tubularia sp.	0.00-0.27	-	-	-	-	-	-	-	-	-	**2.81**
Tautogolabrus adspersus	**1.39-8.44**	**2.06-5.70**	0.6-1.76	0.75-3.42	0.59	0.07	2.03-3.47	1.45-3.44	1.00-1.58	0.81-1.64	1.81
Total algae	**17.16-19.06**	**15.09-16.82**	4.26-13.06	4.61-10.50	2.06	0.64	**13.75-13.97**	2.74-5.52	0.03-0.27	0.26-1.58	-
Total Invertebrates	19.28-51.58	28.12-40.53	8.42-19.68	23.16-31.70	22.63	9.50	**60.67-72.47**	**51.42-54.74**	**40.76-110.16**	**70.15-163.71**	**78.12**
Total fish	1.39-8.44	**2.06-5.73**	0.26-1.82	0.84-3.42	0.69	0.11	2.09-3.47	1.52-3.44	1.03-1.58	1.16-1.67	1.81

[1] L =low; LM = moderately low; M= moderate; MH = moderately high; H = high. [2] l = light; lm = moderately light; m=moderate; mh = moderately heavy; h = heavy.

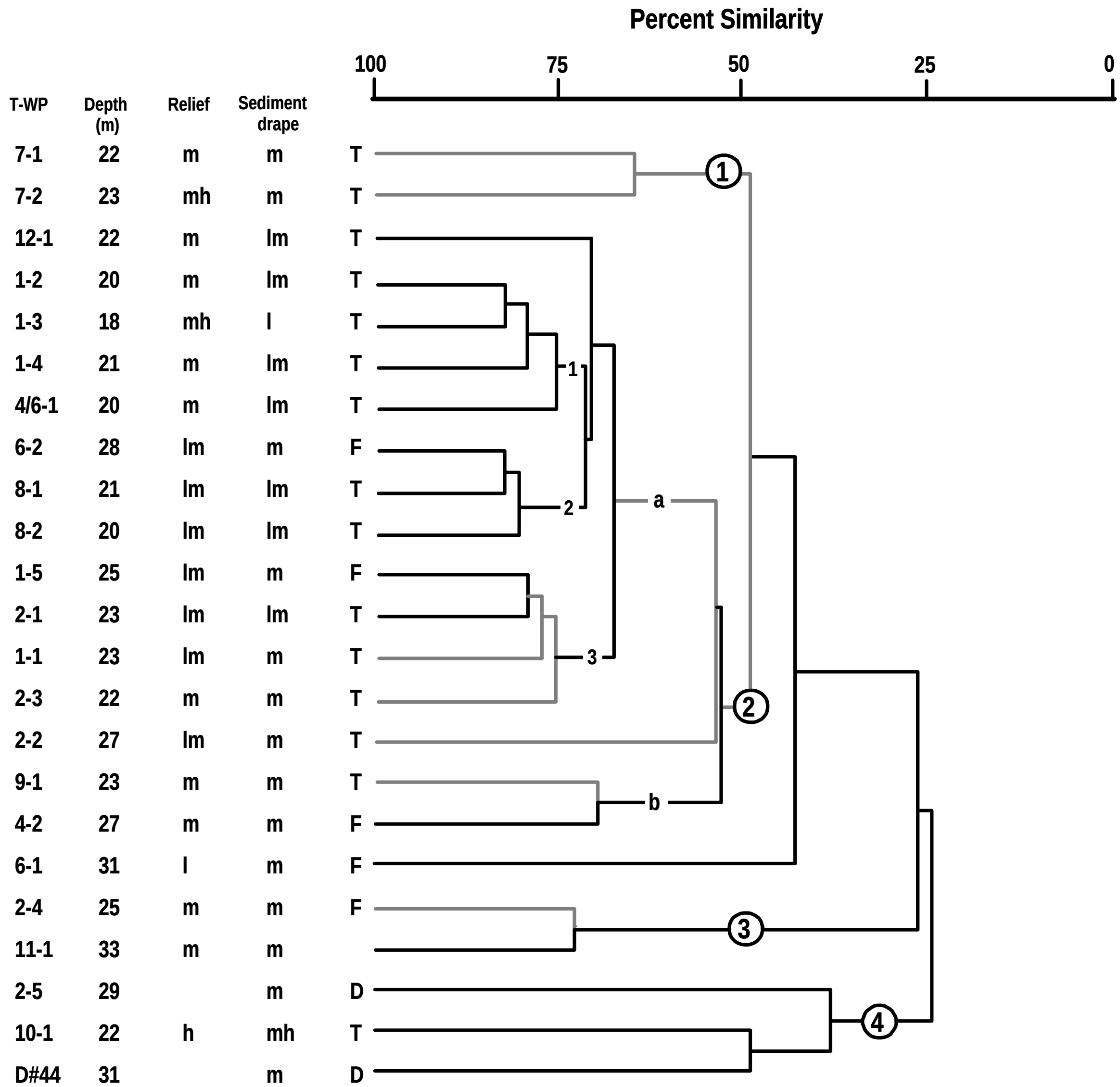


Figure 6-6. Cluster analysis of data collected from still photographs taken during the 2003 nearfield hard-bottom survey with *Balanus* spp. omitted. Shaded lines show stations that had historically clustered together with T7-1 and T7-2 into Cluster 1.

Table 6-5. Habitat characteristics and range of abundance (number per picture) of selected taxa in clusters defined by classification analysis with *Balanus* spp. omitted. Numbers in bold highlight major differences among clusters and subgroups.

Cluster	**1**	**2**							**3**	**4**
		T12-1	**a_1**	**a_2**	**a_3**	**T2-2**	**b**	**T6-1**		
Depth (m)	22-23	22	18-21	20-28	22-25	27	23-27	31	25-33	22-31
Habitat relief [1]	M-MH	M	M-MH	LM	LM-M	LM	M	L	M	H
Sediment drape[2]	m	lm	l-lm	lm-m	lm-m	m	m	m	m	m-mh
Coralline algae (% cover)	30-39	**63**	**63-80**	23-59	25-53	8	12--19	2	1--6	-
Ptilota serrata	**4.28-6.00**	**1.73**	0.00-0.27	-	-	-	0.00-0.9	-	-	-
Rhodymenia palmata	**5.34-7.94**	**2.12**	0.00-1.03	0.00-0.15	0.00-1.29	-	0.00-1.58	-	-	0.00-0.27
Agarum cribrosum	**0.19-0.39**	-	-	-	-	-	-	-	-	-
Coralline algae	4.73-7.34	**12.97**	**13.18-14.88**	4.26-13.06	4.27-10.31	2.06	2.74-3.55	0.64	0.26-1.58	0.00-0.03
Didemnum albidum	0.22-0.61	**2.03**	0.91-2.28	0.32-0.76	**2.36-2.84**	**2.50**	0.55-1.37	1.00	0.19-2.18	0.27-1.27
Aplidium spp.	0.00-0.09	**2.61**	0.48-3.88	1.13-2.90	**1.61-3.85**	1.50	0.89-1.52	0.71	0.06-0.58	0.00-0.03
Modiolus modiolus	1.09-3.48	1.91	**2.91-7.61**	0.19-2.39	1.25-2.71	0.53	0.48-1.55	0.29	0.16-0.76	0.00-0.33
juvenile *Asterias*	2.81-4.15	3.15	**2.56-6.82**	0.94-3.58	2.66-4.38	1.06	2.26-2.76	2.82	0.06-1.70	0.73-1.65
Terebratulina septentrionalis	0.00-6.58	**2.73**	0.00-0.34	-	0.00-0.55	-	**5.12-6.48**	-	**19.45-42.87**	0.00-0.06
Metridium senile	0.00-2.18	1.39	0.21-1.56	0.00-0.36	0.00-0.19	-	0.00-0.33	-	0.88-4.00	**2.36-64.42**
Tubularia sp.	0.00-0.27	-	-	-	-	-	-	-	-	0.00-2.81
Gersemia rubiformis	-	-	-	-	-	-	-	-	-	0.00-1.18
Tautogolabrus adspersus	**1.39-8.44**	2.06	**2.03-5.70**	0.26-1.76	0.75-3.42	0.59	1.45-3.44	0.07	0.81-1.64	1.00-1.81
Total algae	**17.16-19.06**	**16.82**	**13.75-15.61**	4.26-13.06	4.61-10.50	2.06	2.74-5.52	0.64	0.26-1.58	0.00-0.27
Total Invertebrates	14.75-37.94	29.12	23.03-34.41	8.42-19.55	23.16-31.70	20.97	**28.55-33.93**	9.50	**58.03-90.16**	15.21-78.12
Total fish	1.39-8.44	2.06	2.09-5.73	0.26-1.82	0.84-3.42	0.69	1.52-3.44	0.11	1.16-1.67	1.03-1.81

[1] L =low; LM = moderately low; M= moderate; MH = moderately high; H = high.
[2] l = light; lm = moderately light; m=moderate; mh = moderately heavy; h = heavy.

The major biotic difference between the sites in clusters 1 and 2 was the presence or absence of upright algae (Table 6-5). The two northern reference sites in cluster 1 (T7-1 and T7-2) supported numerous upright algae and moderate amounts of coralline algae. These stations were characterized by having moderate to moderately high relief and moderate sediment drape. In contrast, the sites in cluster 2 support few if any upright algae. Cluster 2 further divided into several slightly more cohesive subgroups. The first of these groups ($2a_1$) consisted of drumlin top areas that had moderate to moderately high relief and relatively light sediment drape. These sites were located on the drumlins immediately north and south of the outfall. The second group ($2a_2$) consisted of two of the southern reference sites (T8-1 and T8-2) and one flank site south of the outfall. These sites were characterized by having moderately low relief and moderately low to moderate sediment drape. The third group ($2a_3$) consisted of four sites located on the top and flank of the drumlin north of the outfall. Two of these sites historically supported some upright algae and joined with cluster 1 sites. The sites in this group were characterized by moderately low to moderate relief and moderate sediment drape. The remaining group in cluster 2 (2b) consisted of one northern reference site (T9-1) and one flank site (4-2). Both sites had moderate relief and moderate drape.

The remaining six sites, an outlier and clusters 3 and 4, all supported very few algae. The outlier to clusters 1 and 2, T6-1, was located on the flank of the drumlin south of the outfall. This outlier site had a low-relief cobble pavement overlain with a moderate sediment drape. The two sites in cluster 3 had moderate relief and moderate drape. One of these sites was located on the flank of the drumlin north of the outfall, while the other site was the new southern reference site located east northeast of Scituate. The three sites in cluster 4 were the two diffuser heads and the southern reference site nearest to the outfall (T10-1). These sites had relatively high relief and moderate to moderately heavy drape.

In addition to upright algae, the northern reference sites in cluster 1 also supported numerous invertebrates and fish. The sites differed in that T7-1 supported more cunner and T7-2 supported more brachiopods and mussels. The 15 sites in cluster 2 mainly varied in the percent cover of coralline algae supported and abundance of various invertebrates. The new southern reference site, T12-1, clustered with the other 11 sites in 2a. This site shared physical and biotic characteristics with both the northern and southern reference sites. T12-1 had the higher relief characteristic of the northern sites (T7) and the lower sediment drape characteristic of the southern sites (T8). It supported a relatively high percent cover of coralline algae (like T8-1 and T8-2) and moderately low numbers of dulse and filamentous red algae. Numerous brachiopods and encrusting invertebrates were also found on some of the larger boulders at this site. Representative photographs of this site can be seen in Figure 6-7. The other 11 sites in group 2a all had moderate to high (>23) percent cover of coralline algae and few if any upright algae. In contrast, the other three sites in cluster 2 have relatively low (<20) percent cover of coralline algae. The highest percent cover of coralline algae was encountered in the four sites in $2a_1$. These sites also had relatively little sediment drape. Mussels, juvenile *Asterias*, and cunner were also common inhabitants of these areas. The two southern reference sites in $2a_2$ supported moderate (47 and 59) percent cover of coralline algae, some mussels, and numerous encrusting invertebrates. These two areas also had relatively light sediment drape. The four sites in $2a_3$ supported moderate percent cover of coralline algae and numerous invertebrates. Three of these sites had a moderate amount of sediment drape. The fauna at the remaining three sites in cluster 2 (T2-2, T9-1, and T4-2) consisted of numerous encrusting invertebrates, as well as moderate numbers of brachiopods at the two sites in 2b. Site T6-1 consisted of a low relief, cobble pavement that supported relatively few organisms.

The larger boulders found at the two sites in cluster 3 supported high numbers of brachiopods. One of these sites, T11-1, was the new reference site near Scituate. This site had numerous large boulders strewn on a cobble pavement. In addition to supporting numerous brachiopods, these boulders also provided suitable attachment sites for a variety of other invertebrates, as well as hiding places for numerous cod. Representative photographs of the area are shown in Figure 6-8. The three sites in cluster 4 include the two diffuser sites and a high relief southern reference site. All three of these sites supported the frilled anemone *Metridium senile*. The active diffuser (#2 at T2-5) supported many more *M. senile* than the inactive diffuser (#44). Dense aggregations of this anemone were seen on most of the exposed surfaces of the dome, as well as in the indentations of the discharge ports. In contrast, more sea-peach tunicates *Halocynthia pyriformis* were found on the inactive diffuser (#44).

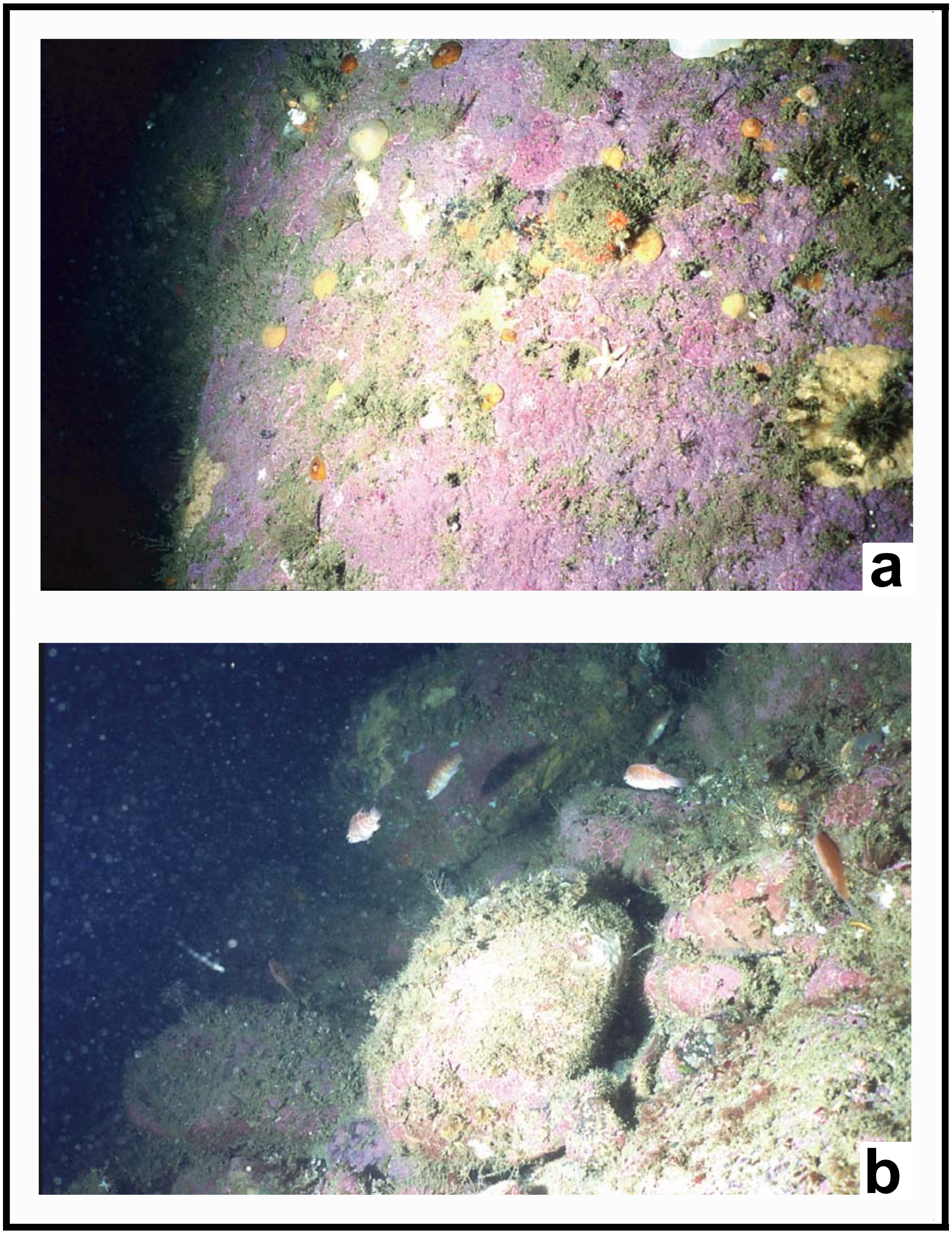


Figure 6-7. Representative photographs from the new southern reference station T12-1. (a) A large boulder supporting numerous invertebrates including *Metridium senile*, *Psolus fabricii*, juvenile *Asterias*, and many encrusting organisms. (b) Cunner and encrusting organisms in an area of cobbles and boulders.

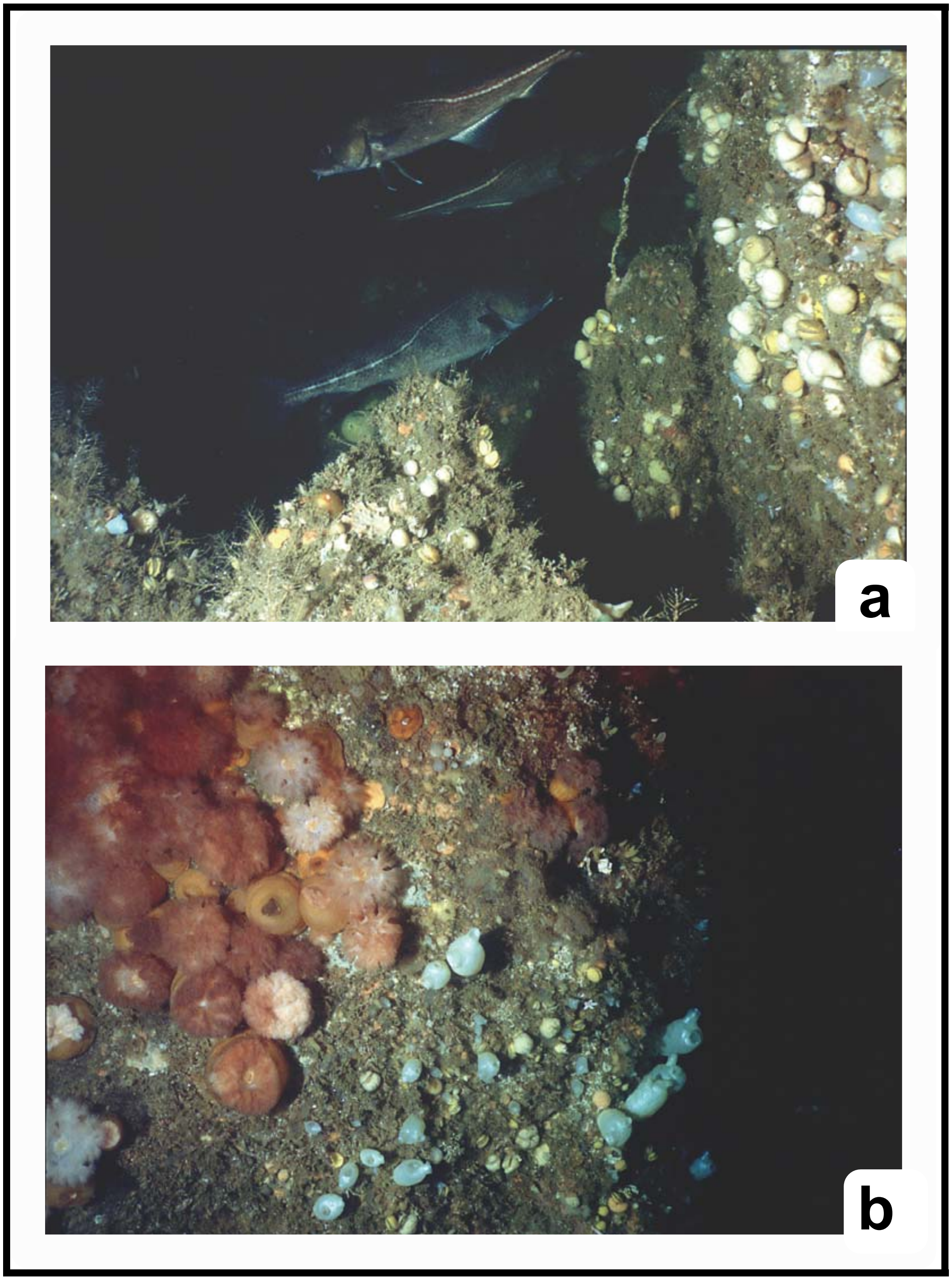


Figure 6-8. Representative photographs from T11-1, the new site off Scituate. (a) Large boulders provide suitable habitat relief for numerous cod, as well as attachment sites for the northern lamp shell, *Terebratulina septentrionalis*. (b) A large boulder inhabited by numerous frilled anemones *Metridium senile*, sea peaches *Halocynthia pyriformis*, lamp shells, and barnacles.

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 ten years. Seven of the surveys occurred under pre-discharge "baseline" conditions, while the last three surveys occurred under post-diversion 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 6-9 shows the habitat relief observed during the 1995 to 2003 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 moderately high to high on drumlin tops dominated by boulders (T1-2, T1-3, T2-2, T2-3, T4/6-1, T7, T9, and T10) to moderate to low on drumlins that consisted of a mix of cobbles and boulders (T1-4 and T8). The new southern reference site T12-1 had higher relief than the other nearby reference sites (T8-1 and T8-2). 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 on the drumlin south of the outfall (T4-1, T4-2, T4-3, T6-1, and T6-2) to moderate on the drumlin north of the outfall (T1-5 and T2-4).

Figure 6-10 shows the relative amount of sediment drape seen on the rock surfaces during the 1995 to 2003 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 and T8-2), 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). The tops of the drumlins were relatively homogeneous, so that lateral shifts in position did not result in widely different habitat characteristics (i.e., T1-3, T1-4, T4/6-1, T8, T9 and T10). In contrast, the edges of the drumlin tops and the flanks were more heterogeneous, such that small lateral shifts in position frequently resulted in substantially different habitat characteristics (i.e., T1-1, T1-2, T1-5 and T4-2). Several 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 6-11 shows the percent cover of coralline algae estimated from the slides taken during the 1996 to 2003 surveys. Coralline algae were generally most abundant on the top of drumlins (T1-3, T1-4, and T4/6-1) and least abundant on the flanks (T2-4, T4-1, and T6-1). The percent cover of corallines was most variable near the edges of the tops of drumlins or on the flanks, where small lateral shifts in location frequently resulted in different habitat characteristics.

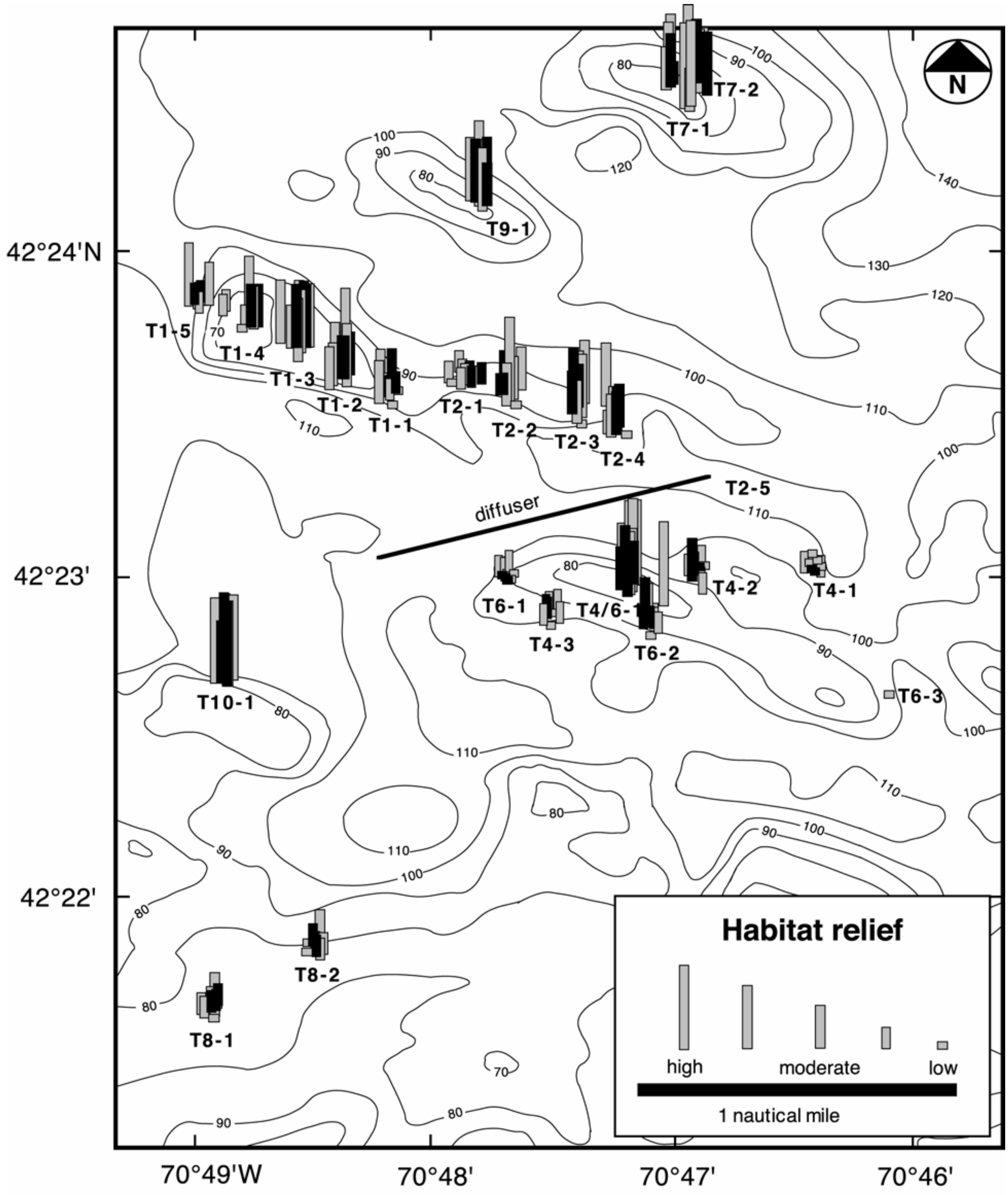


Figure 6-9. Habitat relief determined from the 1995–2003 nearfield hard-bottom surveys. Gray bars are pre-discharge values and black bars are post-discharge values.

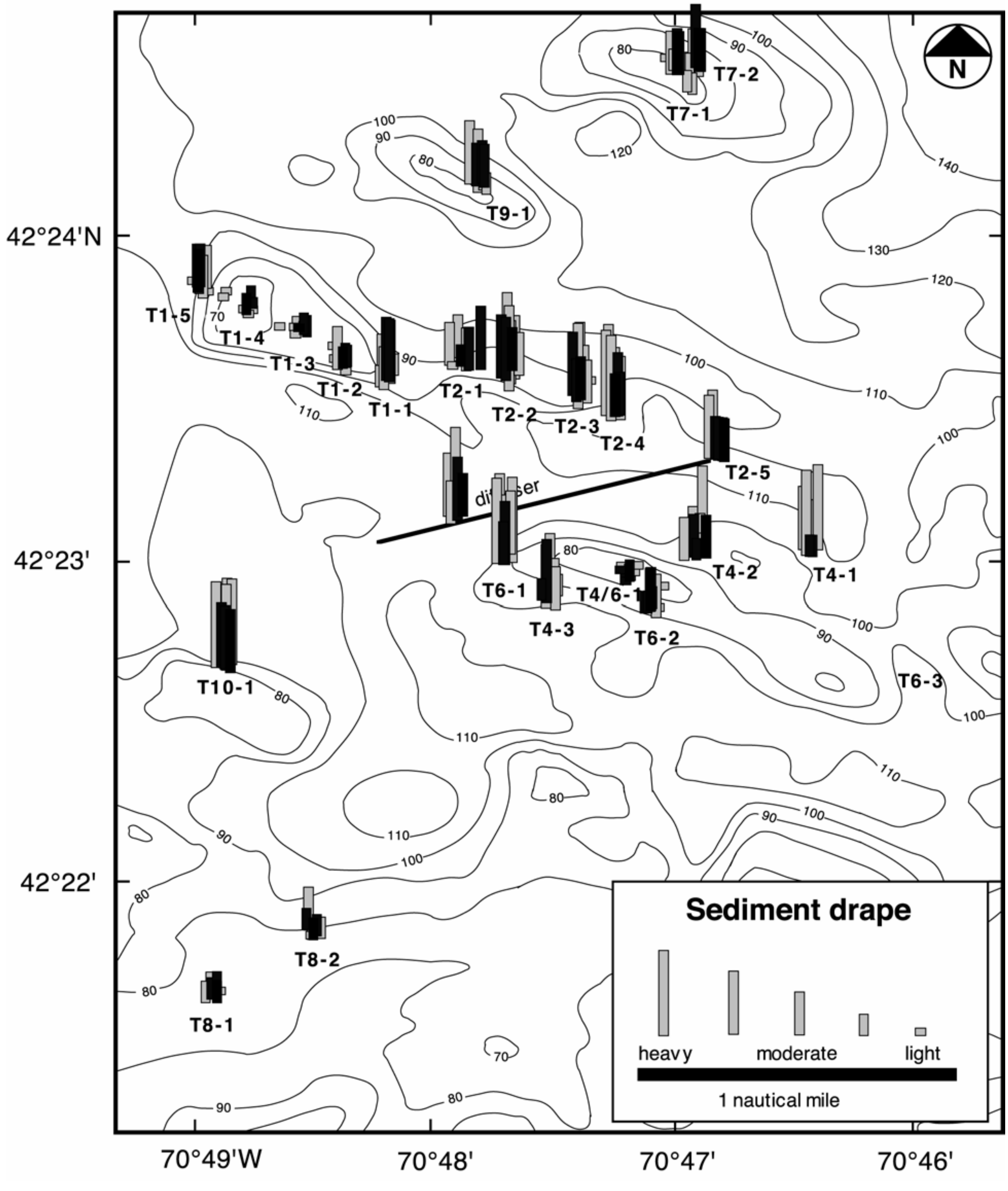


Figure 6-10. Sediment drape determined from the 1995–2003 nearfield hard-bottom surveys. Gray bars are pre-discharge values and black bars are post-discharge values.

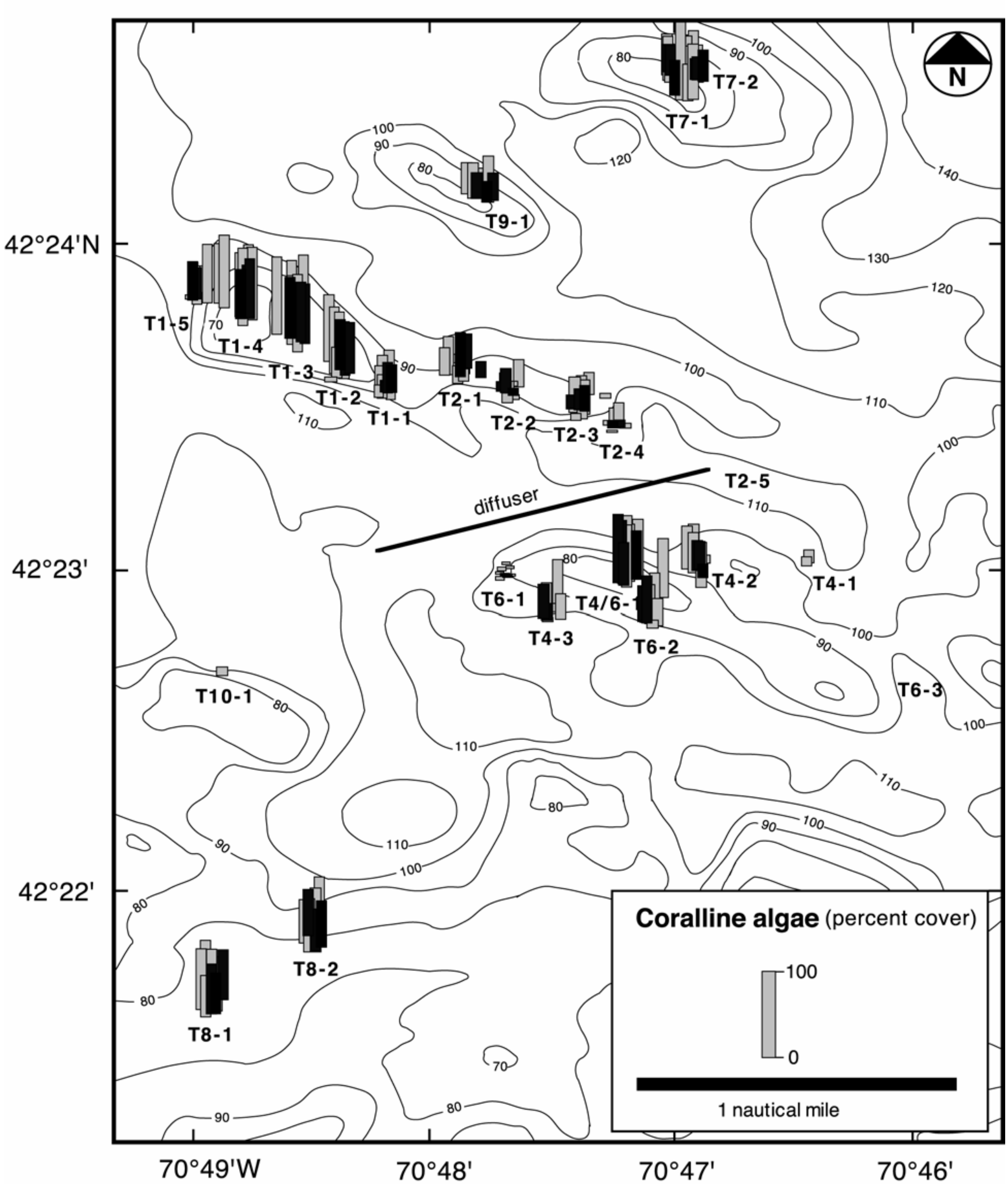


Figure 6-11. Percent cover of coralline algae determined from the 1995–2003 nearfield hard-bottom surveys. Gray bars are pre-discharge values and black bars are post-discharge values.

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, five stations located north of the outfall have shown slight decreases in percent cover during the post-discharge period. Table 6-6 shows the estimated percent cover of coralline algae for the 1996 to 2003 time period. The locations that had lower percent cover of coralline algae in 2001 and 2002 were three neighboring stations on the top of the drumlin immediately north of the outfall (T1-2, T1-3, and T1-4) and the two northernmost reference sites (T7-1 and T7-2). This decrease in percent cover was less pronounced in 2003. However, percent cover of coralline algae did decrease at the other northern reference site (T9-1).

It is unlikely that light attenuation with depth is a limiting factor for coralline algae, within the range of depths covered during this survey. Vadas and Steneck (1988) reported coralline algal cover of up to 80% at depths >50 m on Ammen Rock Pinnacle in the Gulf of Maine and Sears and Cooper (1978) reported finding coralline algae at depths of 47 m on offshore ledges in the Gulf of Maine. Additionally, coralline algae was observed at a depth of 34 m in Massachusetts Bay in 1999 in the vicinity of site T11-1 (B. Hecker, personal observation). In previous years, percent cover of coralline algae has been found to be inversely related to sediment drape (Kropp *et al.* 2002, Maciolek *et al.* 2003). 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 in Figure 6-12. The post-discharge decrease in percent cover of coralline algae can be seen at several stations on transect 1 and at the northern 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 2003, while on transect 7 it increased from moderately light to moderate at T7-1 and moderately light to moderately heavy at T7-2. In 2003, percent cover of coralline algae was also observed at the other northern reference site (T9-1). This site did not show a concurrent increase in sediment drape. In contrast, percent cover of coralline algae was not reduced, and sediment drape was not elevated, at the other waypoints. Reasons for the increase in sediment drape and decrease in coralline cover at these five locations and not at any of the other locations are not readily apparent, but may be related to the discharge.

In contrast to the wide distribution of coralline algae, the 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-discharge periods (Figure 6-13). 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. The first two species, *P. serrata* and *R. palmata*, were abundant in the middle of transect 2 and at the three northern reference sites (T7 and T9), while *A. cribosum* was abundant only at the two northernmost reference sites. Post-discharge abundances of upright algae were generally within the range of pre-discharge abundances for 2001 and 2002. The exception to this was a decrease in *P. serrata* and shotgun kelp at T9 during the first two post-discharge years. This decrease has continued in 2003 and also includes dulse. There does appear to be a general trend of decreased abundances of upright algae over time. However, their high spatial variability makes it hard to detect subtle changes in their distribution with any degree of confidence. This downward trend may be real, since it was observed at all stations that historically had sizable populations of upright algae.

Table 6-6. Estimated percent cover of coralline algae from 1996 to 2003.

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.

Transect	Waypoint	Pre-diversion					Post-diversion		
		1996	1997	1998	1999	2000	2001	2002	2003
1	1	35	42	37	26	16	15	34	28
	2	71	72	79	36*	79	47	61	67
	3	90	96	80	83	86	68	69	80
	4	87	83	82	70*	77	58	71	63
	5	68*	12	39	37	37	29	35	45
2	1	45	33	9*	35	14	18	39	53
	2	5	13	33*	13	10	9	28	8
	3	27	41	39	21	8*	17	23	25
	4	7	27	18	4	1	2	12	6
	5	<1	<1	<1			0	0	0
4	1		16*	<1	0	11	1	2	
	2	41	53	9*	8*	47	37	28	12
	3	12	12	56*	25	16	19	41	
4/6	1	72	67	77	72	71	73	80 (50)*	66
6	1	2	4	5	2	2	3	3	2
	2	69*	55	45	29	36	42	56	23
7	1	65*	43	49	47	52	32	36	39
	2	53	54	45	36	36	24	28	30
8	1		73	74	69	49	58	59	47
	2	82	75	65	51	58	48	56	59
9	1		40	54	28	38	30	36	19
10	1		12	<1	2	3	0	1	0
11	1								1
12	1								63
Diffuser	44		<1	<1		<1	0	0	0

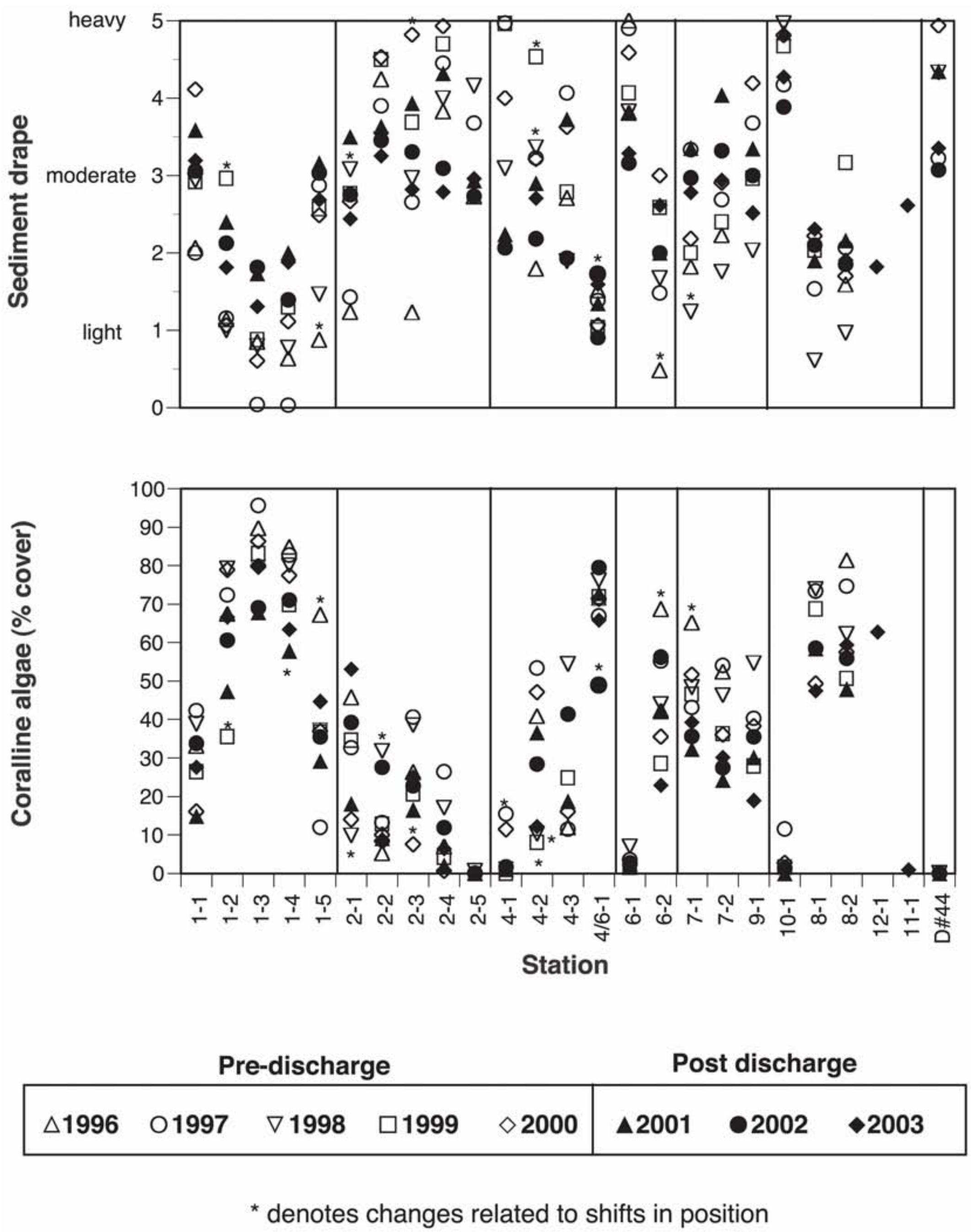


Figure 6-12. Sediment drape and percent cover of coralline algae at the nearfield hard-bottom sites determined from 35-mm slides taken during the 1996 to 2002 surveys.

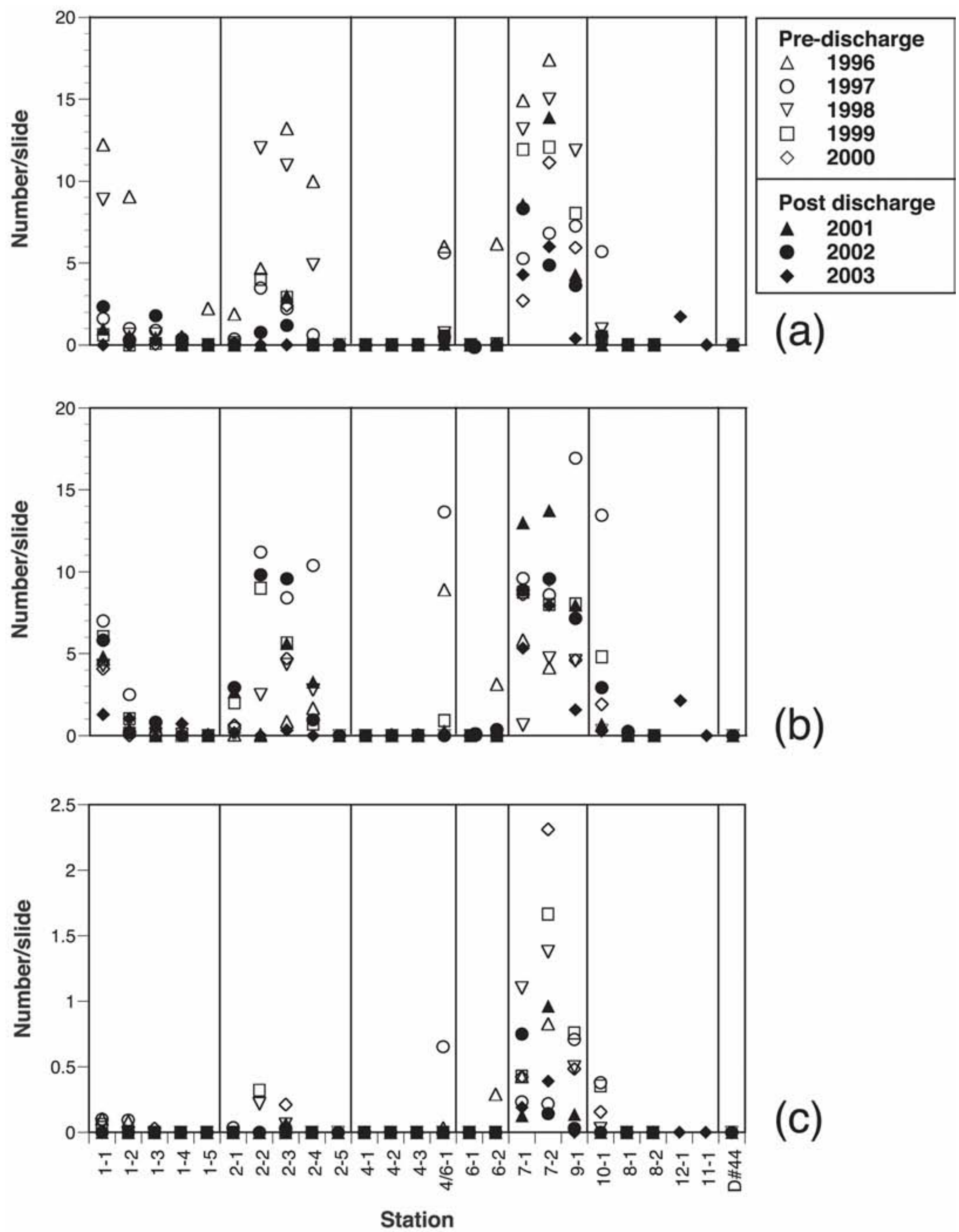


Figure 6-13. Abundance of three species of upright algae (a) *Ptilota serrata*, (b) *Rhodymenia palmata*, and (c) *Agarum cribosum* at the nearfield hard-bottom sites, as determined from 35-mm slides taken during the 1996–2003 surveys.

Another biotic change that was noted in 2003 was the presence of dense aggregations of adult barnacles at 13 of the 23 stations. This massive influx of barnacles appeared to reflect a large recruitment event that occurred in the summer/fall of 2002 (Dr. J. Turner, personal communication). This event was unusual in magnitude as well as timing. No similar large pulses of barnacle larvae have been seen in the nearfield in the last 12 years (Appendix D3). It is unlikely that this biotic shift is related to effluent from the outfall. Barnacles generally tend to have periodic massive recruitment events. These events frequently result in crowded aggregations of adults that subsequently die off. The large barnacle recruitment event that occurred in 2002 was unusual in that it occurred in the fall rather than in the spring. The fall timing may have provided optimum conditions for the larvae to settle and grow.

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 6-14). 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). While only a few weak departures from the baseline pattern were observed during 2001 and 2002, a more pronounced shift in community structure was observed in 2003 where departures from the pattern were found at five of the sites (Table 6-7). The major difference observed in 2003 was a shift in the benthic community at four of the sites (T1-1, T2-2, T2-3, and T9-1) from one dominated by upright algae (cluster 1) to one dominated by coralline algae (cluster 2). This shift reflected a decrease in the number of upright algae, rather than an increase in the percent cover of coralline algae. In 2003, very few upright algae were seen at T9-1 (see Figure 6-13) causing it to cluster with areas dominated by coralline algae. Upright algae were also less abundant, but still abundant enough, to cause the other two northern reference stations to cluster separately in 2003. The same pattern of decreased numbers of upright algae was also found at three sites on the drumlin north of the outfall (T1-1, T2-2, and T2-3), causing these sites to also fall into cluster 2. The positioning of site T6-1 as an outlier to clusters 1 and 2 in 2003 merely reflected 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 2003. 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) resembled that found at T8-1 and T8-2 in being dominated by coralline algae, but differed in that it also contained some upright algae (dulse and *Ptilota serrata*). In contrast, the new reference site nearer to Scituate (T11-1) differed from the other reference sites in that it supported very few algae.

The diffuser heads of the outfall continue to be colonized by *Metridium senile, Halocynthia pyriformis*, and *Asterias vulgaris*. The major difference observed in 2003 was the colonization of the inactive diffuser head (Diffuser #44) by an exceptionally dense aggregation of barnacles. In 2003, all top and upper side surfaces of the diffuser head that not been colonized by larger *M. senile* or *H. pyriformis* were covered by adult *Balanus*. Many of these barnacles appeared to be dying off, leaving large areas of uncolonized hard substrate. No barnacles were observed on this diffuser in 2002. In contrast, the head of the active diffuser (Diffuser #2 at T2-5) had no noticeable barnacles present. Instead, Diffuser #2 continues to support dense stands of *M. senile* on most of its exposed surfaces.

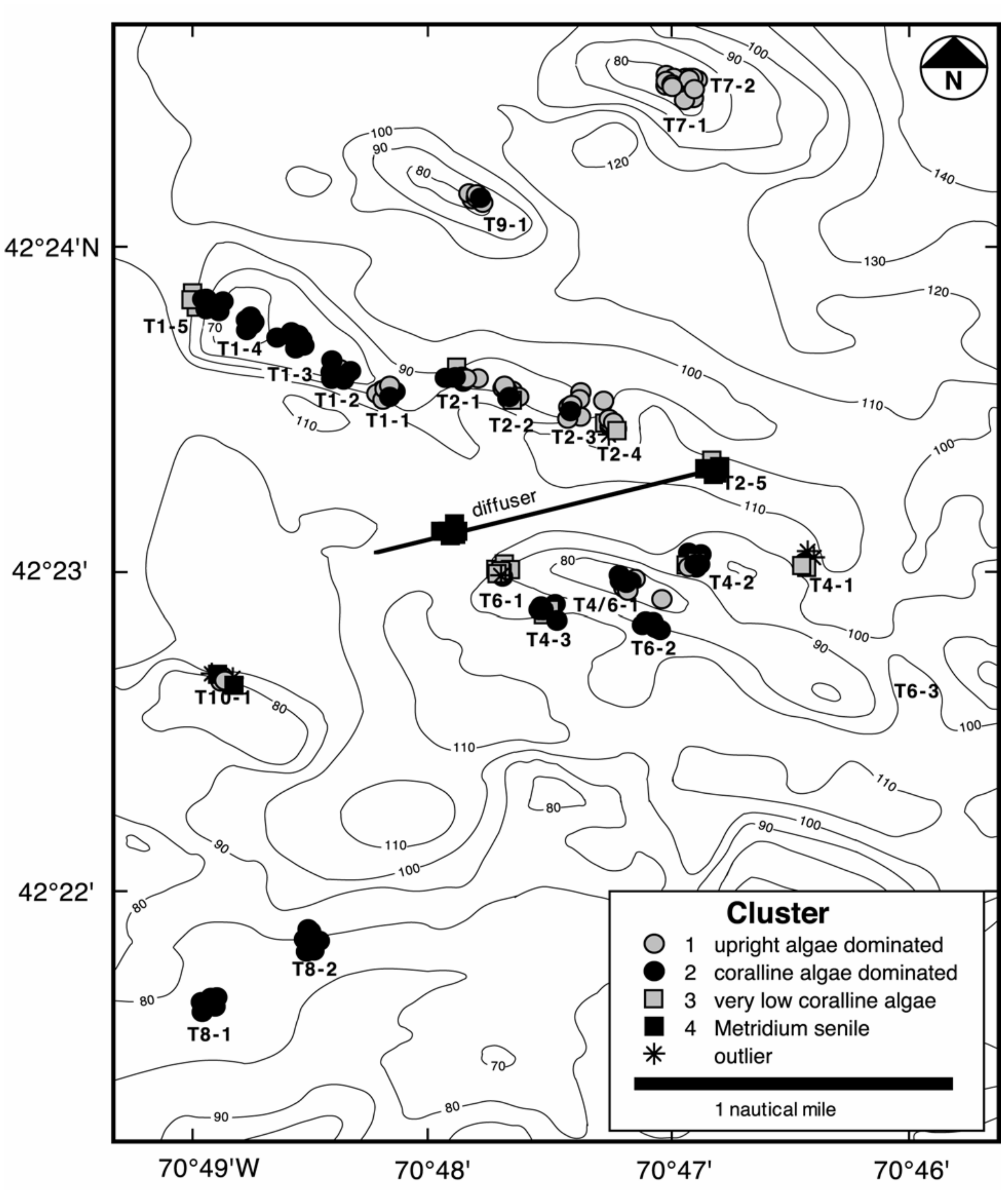


Figure 6-14. Benthic communities defined from classification of the 35-mm images taken during the 1995 to 2003 nearfield hard-bottom surveys.

Table 6-7. Cluster group designations defined by classification analysis of the waypoints surveyed from 1996 to 2002. Differences between pre- and post-discharge are highlighted by shading. Asterisks show differences explained by shifts in location.

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

Table 6-8 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 to 0.16 individuals per picture. Two other species, the crab *Cancer* sp. and the lobster *Homarus americanus*, appear to be increasing over time. In the still photographs, one to six *Cancer* crabs were seen annually between 1996 and 1999, 12 were seen in 2000, 43 were seen in 2001, 53 were seen in 2002, and 44 were seen in 2003. This pattern was also reflected in the video data, with 3–14 *Cancer* crabs observed annually between 1996 and 1999, 70 in 2000, 112 in 2001, 143 in 2002, and 135 in 2003. The video data for lobsters showed a similar increasing trend, with the highest numbers being seen in the last three years. Cod also showed a general increase between 1996 and 2002 and then showed a decrease in 2003. Prior to the outfall going on-line, no cod had been seen at the diffuser stations, yet in all three 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, where the presence of codfish was frequently used as an indicator of proximity to an actively discharging diffuser head.

Table 6-8. Number of individuals of selected species observed during the nearfield hard-bottom surveys, adjusted to include only stations that were surveyed in all eight years.

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

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 to 2000 baseline period, and have not substantially changed with activation of the outfall. Major departures from baseline conditions have not occurred during the first three years of discharge, however some subtler changes have been observed (Figure 6-15). A noticeable decrease in the abundance of upright algae was observed in 2003. This decrease was large enough to change the community designation (cluster) of four of the sites, but it was also noticed at several other sites for which cluster designation did not change. The abundance of upright algae was found to be quite variable throughout the baseline period. This variability frequently reflected exceptionally patchy distributions, with adjacent areas being either totally covered by algae or totally devoid of them. Additionally, year-to-year differences in their abundance have also been observed. Whether the pattern seen in 2003 is the start of an outfall related downward trend in upright algal populations, or merely reflects inherent cyclical changes, is presently not known.

Another post-diversion change that has been observed in the hard-bottom communities is 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 was most noticeable in 2001 and 2002, and was slightly less so in 2003. 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 altered 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.

The first three 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 four stations. Lush epifaunal growth continues to thrive on both diffuser heads surveyed for this study, and throughout many of the other stations visited. However, despite the fact that outfall impacts appear to be minimal at this time, changes in the hard-bottom communities could be chronic and/or cumulative, and may take a longer time to manifest themselves.

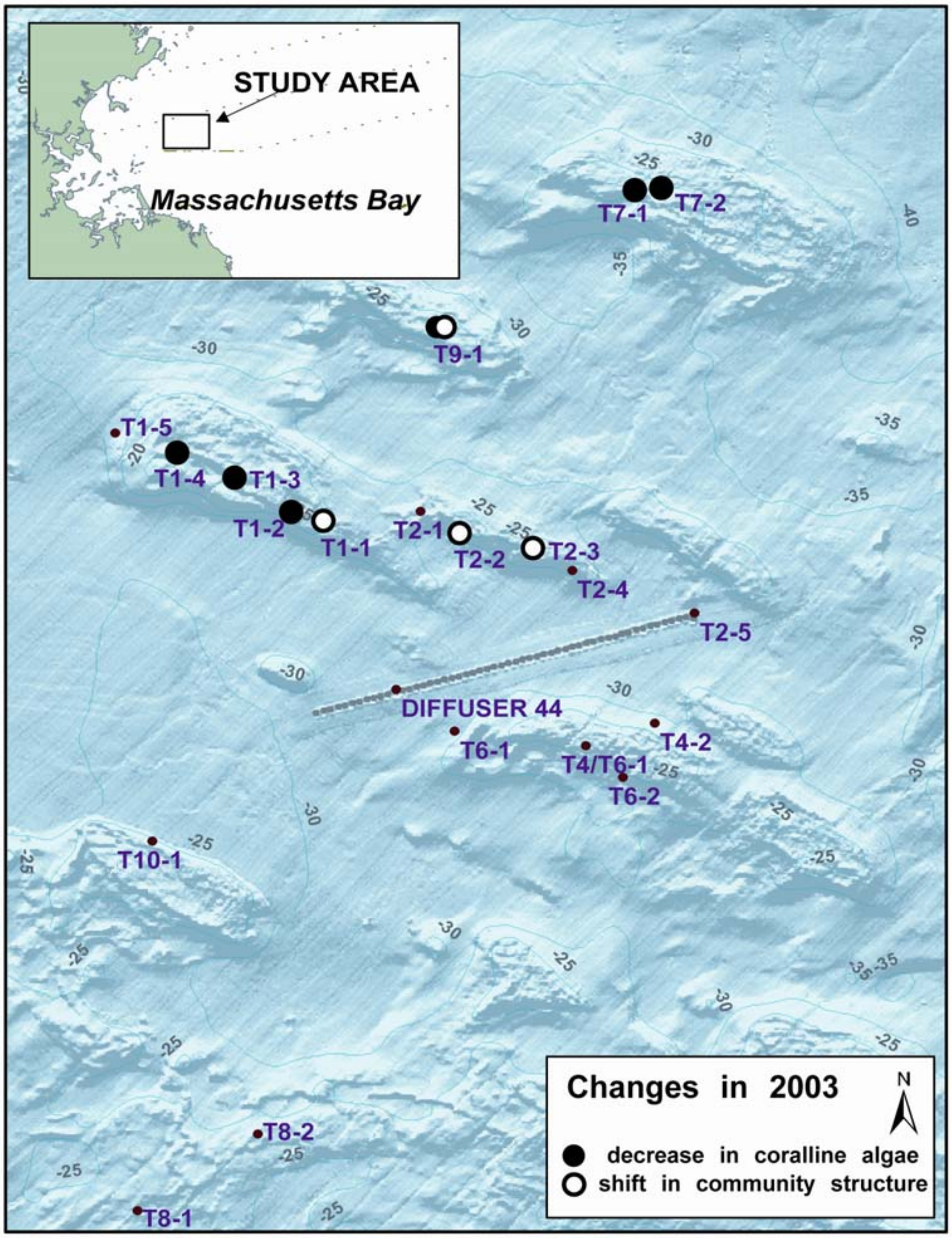


Figure 6-15. Map of changes observed in the hard-bottom communities in 2003.

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APPENDIX A1

Station Data:
Benthic Grab Samples (BN031/BF031)

Table A1-1. Station data and field observations for individual soft-bottom infauna and chemistry grab samples collected August 2003 (BN031/BF031).

Station ID	Sample ID	Date/Time (EDT)	Latitude (N)	Longitude (W)	Sample Type	RPD Depth (cm)	Sediment Texture	Fauna and Miscellaneous Observations
NF19	BF03100B	8/5/03 08:18	42.37157	-70.80497	Biol	0.4	silty fine sand with pebbles	Tubes, shells
	BF03100C	8/5/03 08:28	42.37175	-70.80495	Chem	0.5		Tubes, shells
NF17	BF031010	8/5/03 08:41	42.38142	-70.81480	Biol	All > than pene-tration depth >8-9.5	sandy	Tubes, isopod, shell hash
	BF031012	8/5/03 08:55	42.38118	-70.81502	Biol			Tubes, amphipod, shell hash
	BF031013	8/5/03 09:02	42.38132	-70.81490	Biol			Tubes
	BF031014	8/5/03 09:15	42.38122	-70.81492	Chem			Tubes, some shell hash
	BF031015	8/5/03 09:26	42.38127	-70.81493	Chem			Tubes, some shell hash
	BF031016	8/5/03 09:35	42.38143	-70.81472	Chem			Tubes, some shell hash
NF14	BF03101C	8/5/03 09:54	42.38665	-70.82275	Biol	2.0	sandy with pebbles	Tubes, worm
	BF03101D	8/5/03 10:06	42.38659	-70.82273	Chem	1.0		Tubes
NF12	BF031021	8/5/03 10:18	42.39000	-70.83072	Biol	0.2	sandy silt	Tubes
	BF031022	8/5/03 10:25	42.38988	-70.83067	Biol	1.0	sandy silt	Tubes
	BF031023	8/5/03 10:33	42.39013	-70.83045	Biol	0.5	sandy silt	Tubes, crab
	BF031024	8/5/03 10:43	42.39007	-70.83064	Chem	1.0	sandy silt	Amphipod tubes
	BF031025	8/5/03 10:54	42.38998	-70.83062	Chem	1.0	sandy silt	Amphipod tubes
	BF031026	8/5/03 11:03	42.39018	-70.83060	Chem	1.0	sandy silt	Amphipod tubes
NF09	BF03102E	8/5/03 11:20	42.39987	-70.84485	Biol	0.3	sandy silt	Amphipod tubes
	BF03102F	8/5/03 11:29	42.39995	-70.84480	Chem	2.0	sandy silt	Amphipod tubes, gelatinous egg sacs
NF07	BF031033	8/5/03 11:46	42.41008	-70.81488	Biol	0.2	sandy silt	Tubes, shell, rocks
	BF031034	8/5/03 11:54	42.40983	-70.81495	Chem	1.0	silty sand	Amphipod tubes
FF10	BF03103E	8/5/03 12:46	42.41418	-70.87875	Biol	1.2	sandy silt	Amphipod tubes
	BF03103F	8/5/03 12:54	42.41397	-70.87883	Biol	1.0	silty sand with pebbles or rocks	Tubes
	BF031047	8/5/03 13:18	42.41400	-70.87877	Biol	1.2		Tubes
	BF031048	8/5/03 13:28	42.41398	-70.87881	Chem	0.5		Amphipod tubes, amphipods
	BF03104A	8/5/03 13:40	42.41418	-70.87897	Chem	0.5		No animals noted
FF12	BF031055	8/5/03 14:18	42.38987	-70.89989	Biol	1.2	sandy silt	Amphipod tubes
	BF031056	8/5/03 14:33	42.39007	-70.89964	Biol	1.0	sandy silt	Amphipod tubes
	BF031057	8/5/03 14:37	42.39008	-70.89972	Biol	0.7	sandy silt	Amphipod tubes, isopod
	BF031058	8/5/03 14:45	42.39002	-70.89967	Chem	1.0	sandy silt	Amphipod tubes
	BF031059	8/5/03 14:53	42.39002	-70.89965	Chem	1.0	sandy silt	Amphipod tubes
NF16	BF031061	8/5/03 15:15	42.37845	-70.83783	Biol	1.5	sandy silt	Worm tubes, amphipod
	BF031062	8/5/03 15:25	42.37843	-70.83777	Chem	0.5	sandy silt	Some holes, no animals noted
NF15	BF031066	8/5/03 15:35	42.38230	-70.82761	Biol	0.3	sandy with pebbles	Worm, tubes, some shell hash
	BF031067	8/5/03 15:44	42.38222	-70.82790	Chem	0.3	silty sand	Amphipod tubes
NF10	BF03106B	8/5/03 15:57	42.39277	-70.83807	Biol	0.5	v. fine sandy silt	Amphipod tubes
	BF03106C	8/5/03 16:05	42.39263	-70.83826	Chem	0.4	silty sand	Amphipod tubes, amphipod, holes
NF18	BF031070	8/5/03 16:17	42.39668	-70.82205	Biol	0.5	silty sand with pebbles	Amphipods, tubes, gelatinous egg sacs
	BF031071	8/5/03 16:27	42.39657	-70.82200	Chem	2.0		Tubes
NF21	BF031075	8/5/03 16:41	42.40255	-70.83662	Biol	0.4	v. fine sandy silt	Amphipod tubes
	BF031076	8/5/03 16:49	42.40250	-70.83662	Chem	0.5	silt	Amphipod tubes, worm
NF08	BF03107B	8/5/03 17:05	42.39985	-70.86360	Biol	0.4	v. f. sandy silt	Amphipod tubes
	BF03107C	8/5/03 17:13	42.39982	-70.86345	Chem	1.0	silt	Amphipod tubes

Station ID	Sample ID	Date/Time (EDT)	Latitude (N)	Longitude (W)	Sample Type	RPD Depth (cm)	Sediment Texture	Fauna and Miscellaneous Observations
FF14	BF031085	8/6/03 08:52	42.41678	-70.65510	Biol	1.2	sandy silt	Amphipod tubes
	BF031087	8/6/03 09:03	42.41667	-70.65480	Biol	0.6	v.f. sandy silt	Amphipod tubes, amphipod
	BF031088	8/6/03 09:15	42.41680	-70.65480	Biol	0.6	sandy silt	Tubes, amphipod, bivalve
	BF03108C	8/6/03 09:54	42.41685	-70.65472	Chem	1.5	sandy silt	Amphipod tubes
	BF03108E	8/6/03 10:18	42.41655	-70.65472	Chem	2.0	silt with a little sand	Amphipod tubes
FF11	BF031096	8/6/03 12:04	42.65818	-70.50005	Biol	1.5	silt	Amphipod tubes
	BF031097	8/6/03 12:15	42.65855	-70.49993	Biol	0.4	v. f. sandy silt	Amphipod tubes
	BF031098	8/6/03 12:27	42.65838	-70.50010	Biol	1.0	silt	Amphipod tubes
	BF031099	8/6/03 12:41	42.65823	-70.49972	Chem	1.0	silt	Amphipod tubes
	BF03109B	8/6/03 13:05	42.65833	-70.49993	Chem	2.0	silt	Amphipod tubes
FF01A	BF03109F	8/6/03 14:03	42.56418	-70.67572	Chem	0.5	sandy silt	Amphipod tubes
	BF0310A0	8/6/03 14:13	42.56418	-70.67572	Chem	0.8	silty sand	A few amphipod tubes
	BF0310A1	8/6/03 14:27	42.56418	-70.67572	Biol	1.2	silty sand	Amphipods, tubes, gelatinous balls
	BF0310A2	8/6/03 14:33	42.56418	-70.67572	Biol	0.5	sandy silt	Tubes
	BF0310A3	8/6/03 14:40	42.56418	-70.67572	Biol	0.7	silty sand	Amphipods, tubes
NF05	BF0310A7	8/6/03 15:45	42.42713	-70.83390	Chem	0.7	sandy silt	Tubes
	BF0310A8	8/6/03 15:55	42.42702	-70.83379	Biol	0.5	silty sand	Amphipod tubes
NF04	BF0310B0	8/6/03 16:19	42.41533	-70.80647	Chem	2.0	silty sand	Tubes, small starfish
	BF0310B3	8/6/03 16:39	42.41530	-70.80645	Biol	1.0	sand	Amphipod tubes
FF04	BF0310BF	8/7/03 09:22	42.28843	-70.42496	Biol	0.4	silt	Tubes
	BF0310C0	8/7/03 09:32	42.28858	-70.42513	Biol	0.3	silt	Tubes
	BF0310C1	8/7/03 09:41	42.28857	-70.42515	Chem	0.3	silt	Tubes
	BF0310C2	8/7/03 09:51	42.28835	-70.42509	Biol	1.5	silt	Tubes
	BF0310C4	8/7/03 10:19	42.28831	-70.42530	Chem	1.0	silt	Tubes
FF05	BF0310CC	8/7/03 11:16	42.13337	-70.42255	Chem	0.3	silt	Amphipod tubes, brittle star
	BF0310CD	8/7/03 11:28	42.13337	-70.42255	Chem	1.0	silt	Amphipod tubes
	BF0310CE	8/7/03 11:44	42.13337	-70.42255	Biol	1.2	sandy silt	Tubes
	BF0310CF	8/7/03 11:51	42.13337	-70.42255	Biol	1.0	sandy silt	Amphipods, tubes
	BF0310D0	8/7/03 12:01	42.13337	-70.42255	Biol	1.2	sandy silt	Tubes
FF07	BF0310D4	8/7/03 13:11	41.95832	-70.26660	Biol	NR	silt	Brittle stars, tubes
	BF0310D5	8/7/03 13:18	41.95825	-70.26675	Chem	0.5	silt	Brittle stars
	BF0310D7	8/7/03 13:35	41.95832	-70.26656	Chem	1.0	silt	Brittle star
	BF0310D9	8/7/03 13:48	41.95832	-70.26645	Biol	0.6	silt	Large amphipod, tubes
	BF0310DB	8/7/03 13:58	41.95815	-70.26673	Biol	0.4	silt	Brittle stars, tubes
FF06	BF0310E3	8/7/03 14:39	41.89817	-70.40340	Chem	0.5	silt	Brittle stars, tubes
	BF0310E4	8/7/03 14:47	41.89827	-70.40332	Biol	0.8	silt	Brittle stars
	BF0310E5	8/7/03 14:53	41.89810	-70.40327	Chem	1.0	silt	Brittle stars
	BF0310E6	8/7/03 15:01	41.89828	-70.40330	Chem	1.0	silt	Brittle stars
	BF0310E7	8/7/03 15:08	41.89822	-70.40328	Biol	1.0	silt	Brittle stars
FF13	BF0310F6	8/8/03 08:15	42.31990	-70.82308	Biol	0.2	silt with pebbles	Tubes
	BF031100	8/8/03 08:57	42.31988	-70.82265	Biol	0.6	sandy silt	Tubes
	BF031101	8/8/03 09:05	42.31985	-70.82287	Chem	0.5	sandy silt	Crab, tubes
	BF031102	8/8/03 09:14	42.31987	-70.82275	Chem	0.6	sandy silt	No animals noted, burrow
	BF031103	8/8/03 09:21	42.31993	-70.82277	Biol	0.5	sandy silt	Tubes

Station ID	Sample ID	Date/Time (EDT)	Latitude (N)	Longitude (W)	Sample Type	RPD Depth (cm)	Sediment Texture	Fauna and Miscellaneous Observations
FF09	BF031109	8/8/03 10:06	42.31256	-70.65668	Chem	1.3	sandy silt	Tubes, gelatinous animal, fecal pellets
	BF03110A	8/8/03 10:14	42.31248	-70.65665	Biol	1.5	sandy silt	Tubes, fecal pellets
	BF03110B	8/8/03 10:22	42.31262	-70.65655	Chem	1.5	sandy silt	Amphipod, snail, tubes, gelatinous animal, fecal pellets
	BF03110C	8/8/03 10:30	42.31255	-70.65650	Biol	1.8	sandy silt	Tubes, fecal pellets
	BF03110D	8/8/03 10:37	42.31260	-70.65657	Biol	2.0	sandy silt	Tubes
NF24	BF031116	8/8/03 11:20	42.38066	-70.80185	Biol	0.5	sandy silt	Tubes
	BF031117	8/8/03 11:26	42.38062	-70.80193	Biol	0.2	sandy silt	Tubes
	BF031118	8/8/03 11:32	42.38060	-70.80167	Chem	0.5	sandy silt	Tubes, gelatinous sac
	BF031119	8/8/03 11:40	42.38066	-70.80164	Biol	1.0	sandy silt	Tubes, worm, gelatinous sac
	BF03111C	8/8/03 11:51	42.38050	-70.80172	Chem	0.3	sandy silt	Tubes
NF23	BF031123	8/8/03 12:18	42.39753	-70.80167	Chem	0.7	silty sand with pebbles	Amphipod tubes
	BF03112A	8/8/03 12:51	42.39773	-70.80177	Biol	NR		Cumacean, tubes, shells
NF13	BF031130	8/8/03 13:04	42.39007	-70.82262	Chem	1.0	medium sand with pebbles	Tubes
	BF031132	8/8/03 13:15	42.39008	-70.82253	Biol	2.1	sand	Tubes
NF20	BF03113C	8/8/03 13:42	42.37798	-70.84499	Biol	0.8	silty sand	Hermit crab, tubes
	BF03113D	8/8/03 13:54	42.37798	-70.84502	Chem	0.5	silty sand	crab, tubes
NF22	BF031142	8/8/03 14:12	42.34785	-70.81520	Chem	1.0	sandy silt	Tubes, burrows
	BF031144	8/8/03 14:30	42.34782	-70.8153534	Biol	1.0	sandy silt	Tubes, burrows
NF02	BF03114C	8/8/03 13:38	42.33838	-70.82843	Biol	0.8	sand	Tubes, gelatinous balls
	BF03114D	8/8/03 13:38	42.33837	-70.82841	Chem	0.3	silty sand	Tubes

APPENDIX A2

Station Data:
Sediment Profile Images (BR031)

Table A2-1. Target Positions for Sediment Profile Image stations.

STUDY_ ID	EVENT_ ID	STAT_ ID	LOCATION_DESC	STAT_ARRIV (EST)	BEG_ LATITUDE (N)	BEG_ LONGITUDE (W)	DEPTH (m)	NAV_ CODE	NAV_ QUAL
BMBSOFT	BR031	FF10	MASS BAY NEAR NAHANT	8/25/03 12:54	42.414200	-70.878617	28.7	DGPS	+/- 10m
BMBSOFT	BR031	FF12	MASS BAY NEAR NAHANT	8/25/03 13:10	42.390117	-70.899467	23.6	DGPS	+/- 10m
BMBSOFT	BR031	FF13	MASS BAY NEAR THIEVES LEDGE	8/25/03 8:45	42.319833	-70.822983	22.8	DGPS	+/- 10m
BMBSOFT	BR031	NF02	SOUTHWEST OF OUTFALL SITE	8/25/03 9:20	42.338417	-70.828150	30	DGPS	+/- 10m
BMBSOFT	BR031	NF04	NORTH OF OUTFALL SITE	8/25/03 11:09	42.415467	-70.806483	36.1	DGPS	+/- 10m
BMBSOFT	BR031	NF05	NORTHWEST OF OUTFALL SITE	8/25/03 11:20	42.427033	-70.834133	37.1	DGPS	+/- 10m
BMBSOFT	BR031	NF07	NORTH OF OUTFALL SITE	8/25/03 10:58	42.409783	-70.815017	35	DGPS	+/- 10m
BMBSOFT	BR031	NF08	NORTHWEST OF OUTFALL SITE	8/25/03 12:41	42.400167	-70.863333	30	DGPS	+/- 10m
BMBSOFT	BR031	NF09	NORTHWEST OF OUTFALL SITE	8/25/03 11:44	42.399833	-70.844850	31.4	DGPS	+/- 10m
BMBSOFT	BR031	NF10	WEST OF OUTFALL SITE	8/25/03 11:54	42.392750	-70.837983	33.2	DGPS	+/- 10m
BMBSOFT	BR031	NF12	WEST OF OUTFALL SITE	8/25/03 12:01	42.390033	-70.830417	34.6	DGPS	+/- 10m
BMBSOFT	BR031	NF13	WEST OF OUTFALL SITE	8/25/03 10:26	42.389817	-70.822483	33.9	DGPS	+/- 10m
BMBSOFT	BR031	NF14	WEST OF OUTFALL SITE	8/25/03 10:21	42.386567	-70.822833	35	DGPS	+/- 10m
BMBSOFT	BR031	NF15	WEST OF OUTFALL SITE	8/25/03 12:09	42.382283	-70.827833	33.1	DGPS	+/- 10m
BMBSOFT	BR031	NF16	WEST OF OUTFALL SITE	8/25/03 12:20	42.378467	-70.837667	31.1	DGPS	+/- 10m
BMBSOFT	BR031	NF17	WEST OF OUTFALL SITE	8/25/03 10:11	42.381417	-70.814933	31.1	DGPS	+/- 10m
BMBSOFT	BR031	NF18	NORTHWEST OF OUTFALL SITE	8/25/03 10:35	42.396617	-70.821767	35	DGPS	+/- 10m
BMBSOFT	BR031	NF19	SOUTH OF OUTFALL SITE	8/25/03 9:49	42.371667	-70.804883	35.7	DGPS	+/- 10m
BMBSOFT	BR031	NF20	WEST OF OUTFALL SITE	8/25/03 12:27	42.378183	-70.845100	29.6	DGPS	+/- 10m
BMBSOFT	BR031	NF21	NORTHWEST OF OUTFALL SITE	8/25/03 11:35	42.402467	-70.836417	33.7	DGPS	+/- 10m
BMBSOFT	BR031	NF22	SOUTH OF OUTFALL SITE	8/25/03 9:31	42.347833	-70.815033	35.4	DGPS	+/- 10m
BMBSOFT	BR031	NF23	NORTH OF OUTFALL SITE	8/25/03 10:46	42.397717	-70.801700	34.5	DGPS	+/- 10m
BMBSOFT	BR031	NF24	SOUTH OF OUTFALL SITE	8/25/03 9:59	42.380400	-70.801617	36.8	DGPS	+/- 10m

Table A2-2. Field Data from SPI Survey conducted in August 2003.

SurveyID	SampleID	Sample Date	Sample Time	StationID	Replicate *analyzed	Longitude	Latitude
BR031	BR03135E	8/25/03	1:57:15 PM	FF10	1*	-70.8786	42.4142
BR031	BR03135F	8/25/03	1:58:19 PM	FF10	2*	-70.8786	42.4143
BR031	BR031360	8/25/03	2:00:00 PM	FF10	3*	-70.8785	42.4141
BR031	BR031361	8/25/03	2:13:41 PM	FF12	1*	-70.8995	42.3901
BR031	BR031362	8/25/03	2:14:30 PM	FF12	2*	-70.8995	42.3902
BR031	BR031363	8/25/03	2:16:19 PM	FF12	3*	-70.8996	42.3901
BR031	BR0312B7	8/25/03	10:10:34 AM	FF13	1*	-70.8230	42.3198
BR031	BR0312B8	8/25/03	10:11:29 AM	FF13	2*	-70.8231	42.3198
BR031	BR0312B9	8/25/03	10:11:57 AM	FF13	3*	-70.8231	42.3199
BR031	BR0312BA	8/25/03	10:12:39 AM	FF13	4	-70.8232	42.3199
BR031	BR031321	8/25/03	10:24:11 AM	NF02	1*	-70.8282	42.3384
BR031	BR031322	8/25/03	10:24:45 AM	NF02	2*	-70.8281	42.3384
BR031	BR031323	8/25/03	10:25:39 AM	NF02	3*	-70.8281	42.3384
BR031	BR03133F	8/25/03	12:10:49 PM	NF04	1*	-70.8065	42.4155
BR031	BR031340	8/25/03	12:11:47 PM	NF04	2*	-70.8064	42.4155
BR021	BR031341	8/25/03	12:12:46 PM	NF04	3*	-70.8064	42.4156
BR021	BR031342	8/25/03	12:24:19 PM	NF05	1*	-70.8341	42.4270
BR021	BR031343	8/25/03	12:25:18 PM	NF05	2*	-70.8341	42.4271
BR021	BR031344	8/25/03	12:26:31 PM	NF05	3*	-70.8340	42.4271
BR021	BR03133C	8/25/03	12:02:00 PM	NF07	1*	-70.8150	42.4098
BR021	BR03133D	8/25/03	12:03:02 PM	NF07	2*	-70.8149	42.4099
BR021	BR03133E	8/25/03	12:04:08 PM	NF07	3*	-70.8148	42.4100
BR021	BR03135A	8/25/03	1:44:54 PM	NF08	1*	-70.8633	42.4002
BR021	BR03135B	8/25/03	1:45:33 PM	NF08	2*	-70.8632	42.4001
BR021	BR03135C	8/25/03	1:46:20 PM	NF08	3*	-70.8633	42.3999
BR021	BR03135D	8/25/03	1:47:00 PM	NF08	4	-70.8634	42.3999
BR021	BR031348	8/25/03	12:47:36 PM	NF09	1*	-70.8449	42.3998
BR021	BR031349	8/25/03	12:48:35 PM	NF09	2*	-70.8448	42.3999
BR021	BR03134A	8/25/03	12:49:33 PM	NF09	3*	-70.8448	42.3999
BR021	BR03134B	8/25/03	12:56:56 PM	NF10	1*	-70.8380	42.3928
BR021	BR03134C	8/25/03	12:58:00 PM	NF10	2*	-70.8380	42.3928
BR021	BR03134D	8/25/03	12:59:11 PM	NF10	3*	-70.8380	42.3928
BR021	BR03134E	8/25/03	1:04:51 PM	NF12	1*	-70.8304	42.3900
BR021	BR03134F	8/25/03	1:05:47 PM	NF12	2*	-70.8304	42.3900
BR021	BR031350	8/25/03	1:06:56 PM	NF12	3*	-70.8305	42.3900
BR021	BR031333	8/25/03	11:30:07 AM	NF13	1*	-70.8225	42.3898
BR021	BR031334	8/25/03	11:30:54 AM	NF13	2*	-70.8224	42.3898
BR021	BR031335	8/25/03	11:31:53 AM	NF13	3*	-70.8224	42.3899
BR021	BR031330	8/25/03	11:23:18 AM	NF14	1*	-70.8228	42.3866
BR021	BR031331	8/25/03	11:24:03 AM	NF14	2*	-70.8227	42.3866
BR021	BR031332	8/25/03	11:24:50 AM	NF14	3*	-70.8226	42.3867
BR021	BR031351	8/25/03	1:13:39 PM	NF15	1*	-70.8278	42.3823

SurveyID	SampleID	Sample Date	Sample Time	StationID	Replicate *analyzed	Longitude	Latitude
BR021	BR031352	8/25/03	1:14:34 PM	NF15	2*	-70.8278	42.3823
BR021	BR031353	8/25/03	1:15:27 PM	NF15	3*	-70.8279	42.3823
BR021	BR031354	8/25/03	1:22:28 PM	NF16	1*	-70.8377	42.3785
BR021	BR031355	8/25/03	1:23:26 PM	NF16	2*	-70.8377	42.3785
BR021	BR031356	8/25/03	1:24:31 PM	NF16	3*	-70.8376	42.3786
BR021	BR03132D	8/25/03	11:13:02 AM	NF17	1*	-70.8149	42.3814
BR021	BR03132E	8/25/03	11:13:48 AM	NF17	2*	-70.8149	42.3815
BR021	BR03132F	8/25/03	11:14:29 AM	NF17	3*	-70.8147	42.3815
BR021	BR031336	8/25/03	11:39:41 AM	NF18	1*	-70.8218	42.3966
BR021	BR031337	8/25/03	11:40:37 AM	NF18	2*	-70.8217	42.3967
BR021	BR031338	8/25/03	11:41:37 AM	NF18	3*	-70.8218	42.3967
BR021	BR031327	8/25/03	10:52:55 AM	NF19	1*	-70.8049	42.3717
BR021	BR031328	8/25/03	10:53:38 AM	NF19	2*	-70.8048	42.3717
BR021	BR031329	8/25/03	10:54:21 AM	NF19	3*	-70.8047	42.3717
BR021	BR031357	8/25/03	1:30:59 PM	NF20	1*	-70.8451	42.3782
BR021	BR031358	8/25/03	1:31:44 PM	NF20	2*	-70.8450	42.3783
BR021	BR031359	8/25/03	1:32:53 PM	NF20	3*	-70.8449	42.3784
BR021	BR031345	8/25/03	12:38:01 PM	NF21	1*	-70.8364	42.4025
BR021	BR031346	8/25/03	12:39:14 PM	NF21	2*	-70.8363	42.4025
BR021	BR031347	8/25/03	12:40:19 PM	NF21	3*	-70.8364	42.4026
BR021	BR031324	8/25/03	10:36:42 AM	NF22	1*	-70.8150	42.3478
BR021	BR031325	8/25/03	10:37:30 AM	NF22	2*	-70.8150	42.3479
BR021	BR031326	8/25/03	10:38:23 AM	NF22	3*	-70.8149	42.3479
BR021	BR031339	8/25/03	11:51:12 AM	NF23	1*	-70.8017	42.3977
BR021	BR03133A	8/25/03	11:52:02 AM	NF23	2*	-70.8017	42.3978
BR021	BR03133B	8/25/03	11:53:04 AM	NF23	3*	-70.8016	42.3978
BR021	BR03132A	8/25/03	11:02:31 AM	NF24	1*	-70.8016	42.3804
BR021	BR03132B	8/25/03	11:03:18 AM	NF24	2*	-70.8015	42.3804
BR021	BR03132C	8/25/03	11:04:13 AM	NF24	3*	-70.8015	42.3805

APPENDIX B1

Preliminary Data Treatments Performed on Bulk Sediment, *Clostridium perfringens*, and Contaminant Data 1992–2003

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

- *Nearfield* – refers to all nearfield stations plus stations FF10, FF12, and FF13, which were included because of their geographic association with the Massachusetts Bay outfall and Boston Harbor and the potential for transport of carbon from the outfall (see the Bays Eutrophication Model, HydroQual 2000).
- *Regional* – refers to all farfield stations, plus traditionally replicated nearfield stations NF12, NF17, and NF24.
- *Near*-Harbor Regional – refers to all regional stations located close to Boston Harbor, *i.e.,* NF12, NF17, NF24, FF10, FF12, and FF13.
- *Offshore Regional* – refers to all regional stations located far away from Boston Harbor, *i.e.,* FF01A, FF04, FF05, FF06, FF07, FF09, FF11, and FF14.
- 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*.

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

Data analyses (*e.g.,* correlations) were performed on nearfield and regional data sets from 1992 to 2003, 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]

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

- Station Mean – Average of all station replicates. Laboratory replicates were first averaged to determine a single value for a given replicate prior to calculation of station means. Station means were determined for each parameter within a given sampling year. Station mean values were used in the chemistry correlation analyses to determine the correspondence within bulk sediment properties and against contaminants in the nearfield and regional areas.
- Baseline Station Mean – Average of data for a given station over the baseline period, sampled during August surveys only. Each field sample replicate was treated as an individual sample. Baseline station mean values were determined for each station and parameter, and were compared to post-discharge (2001) data to evaluate changes in the system (*i.e.,* spatial, temporal).
- Nearfield Baseline Mean – Average of all nearfield stations including FF10, FF12, and FF13 sampled during August surveys only. Each field sample replicate was treated as an individual sample. Nearfield baseline mean values were determined for each parameter within a given sampling year and were used to assess temporal trends in the nearfield from 1992–2003. Data were also evaluated against monitoring thresholds.

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

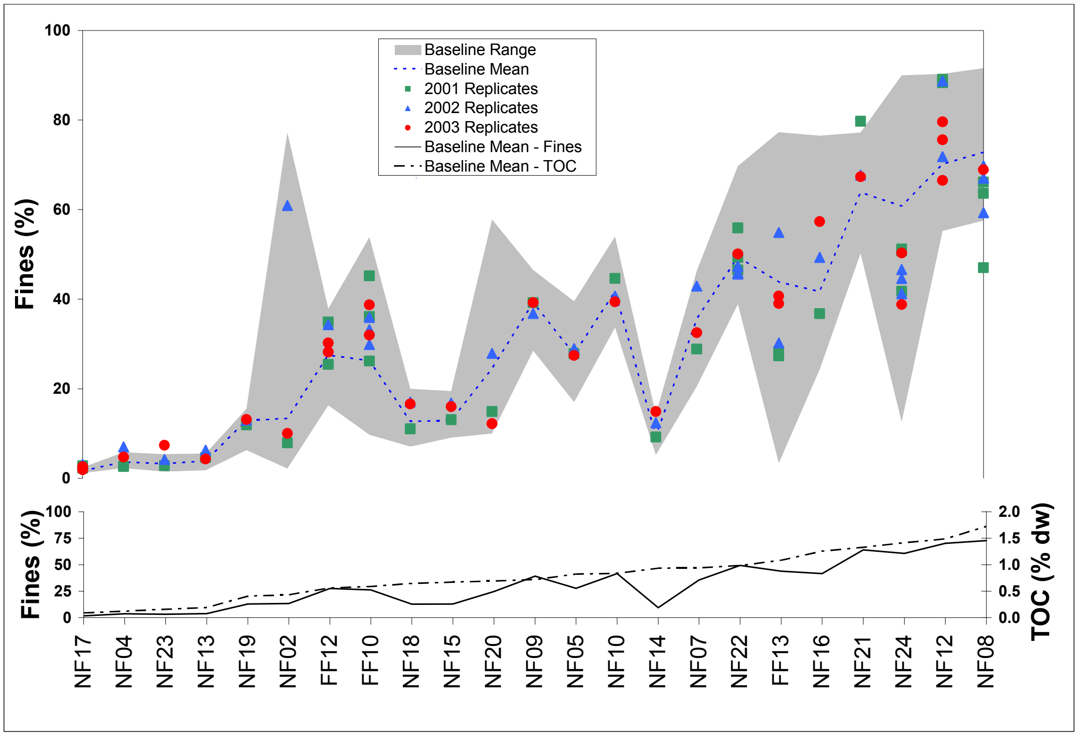
Results for sediment grain-size, total organic carbon (TOC), *Clostridium perfringens*, and contaminant data were compared from all stations by using histogram plots.

[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 (August 2001, 2002 and 2003) data were then compared to the baseline range and mean values for each nearfield station to evaluate how the post-diversion data fit in with our understanding of the baseline system. Nearfield stations were sorted by order of increasing TOC content using baseline mean data. Regional stations were sorted as a function of their north to south location relative to the new outfall.

APPENDIX B2

Nearfield and Regional Range Plots
Baseline Range (1992–2000), Mean (1992–2000), and Post-Diversion (2001-2003) Individual Replicate Data for Bulk Sediment, *Clostridium perfringens*, and Contaminant Parameters
August Surveys Only



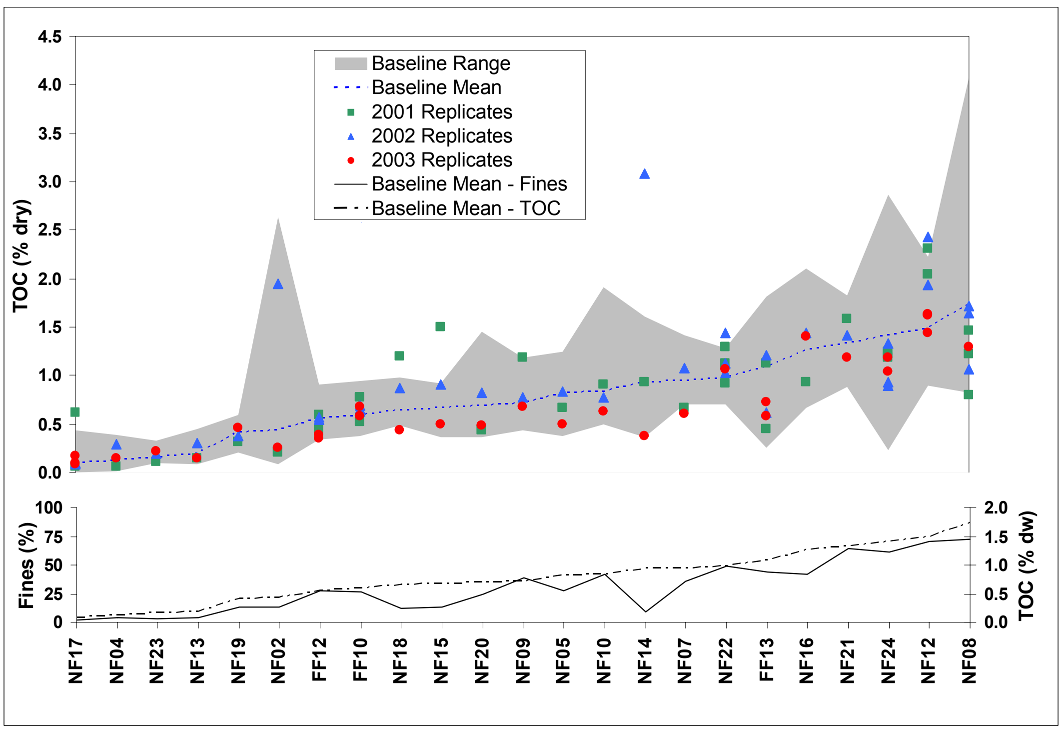
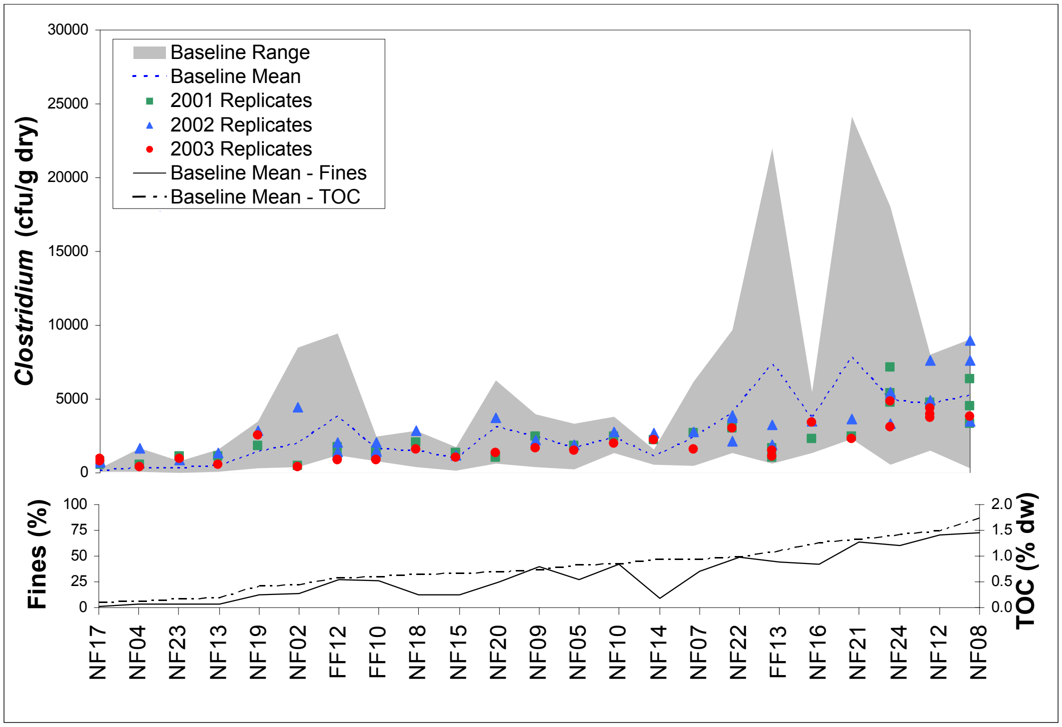


Figure B2-1. Percent fines (top) and TOC (bottom) for each nearfield station sampled in 2001 (squares), 2002 (triangles), 2003 (circles) and the range of values occurring during the baseline period (gray band). The baseline mean values are indicated by a dashed line within gray band. Stations are presented in order of increasing mean TOC concentration. Baseline station mean values for TOC (dashed line in subplot) and percent fines (solid line in subplot), plotted by station, are shown in the subplot.



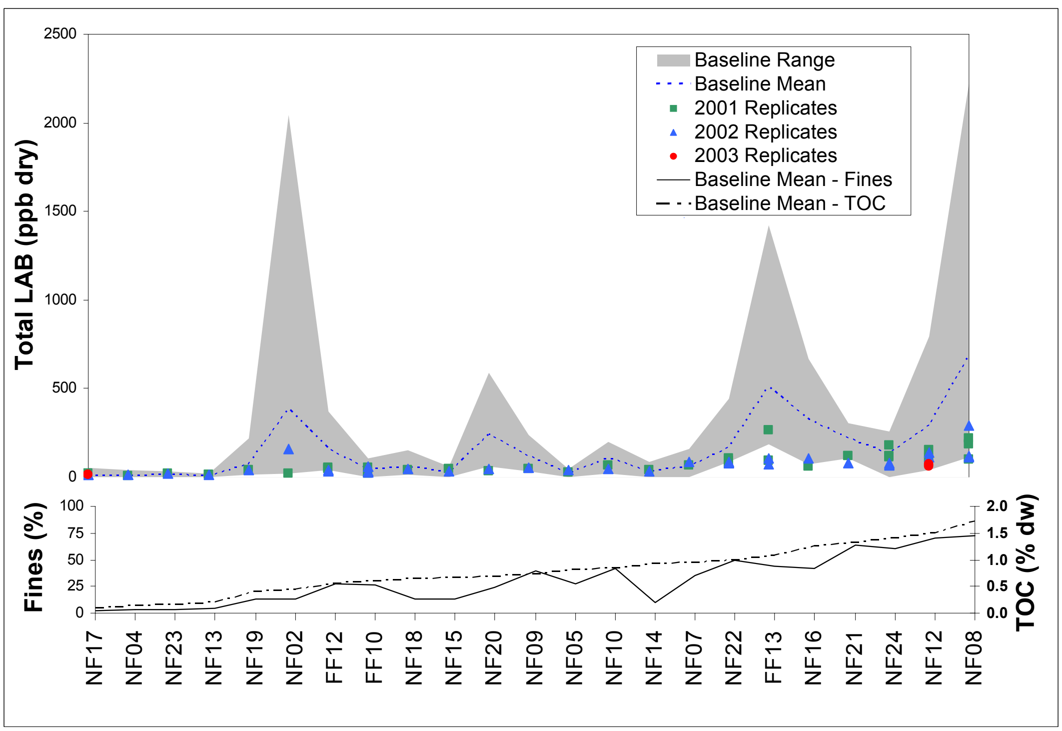
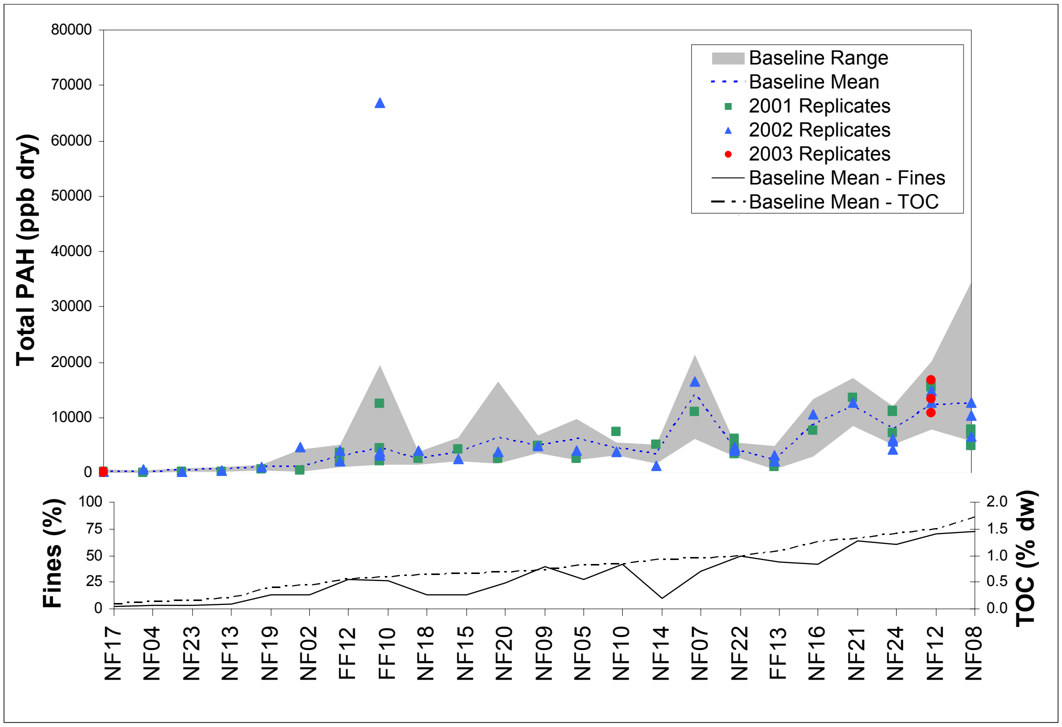


Figure B2-2. ***Clostridium perfringens*** **(top) and total LAB (bottom) for each nearfield station sampled in 2001 (squares), 2002 (triangles), 2003 (circles) and the range of values occurring during the baseline period (gray band). The baseline mean values are indicated by a dashed line within gray band. Stations are presented in order of increasing mean TOC concentration. Baseline station mean values for TOC (dashed line in subplot) and percent fines (solid line in subplot), plotted by station, are shown in the subplot.**



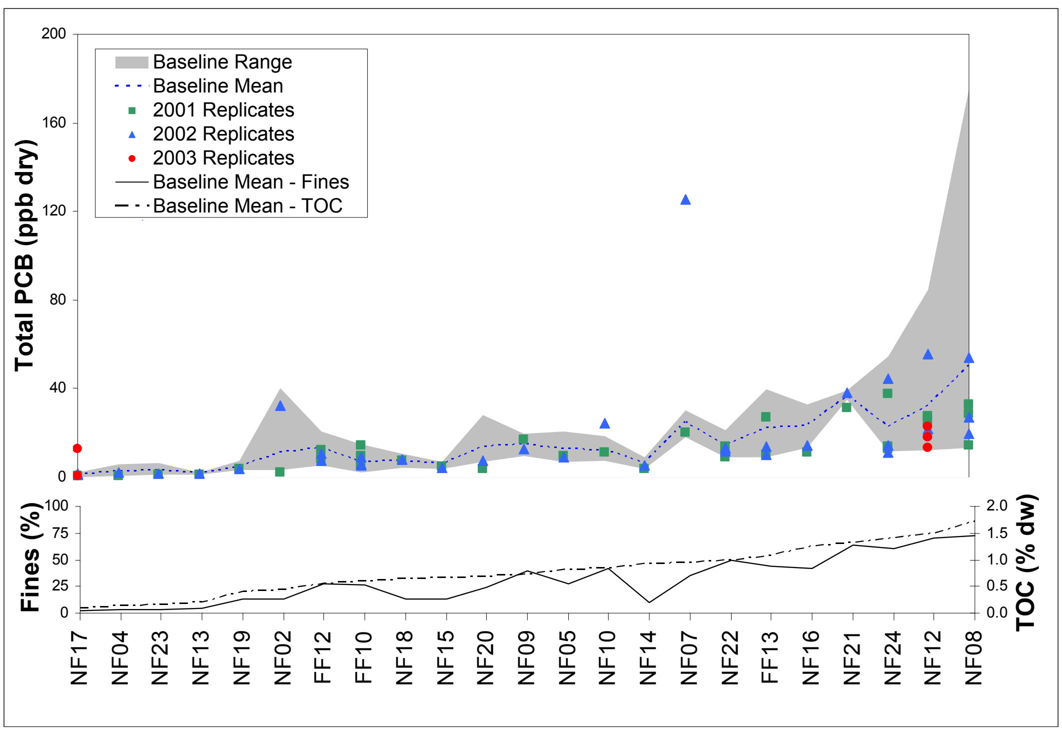
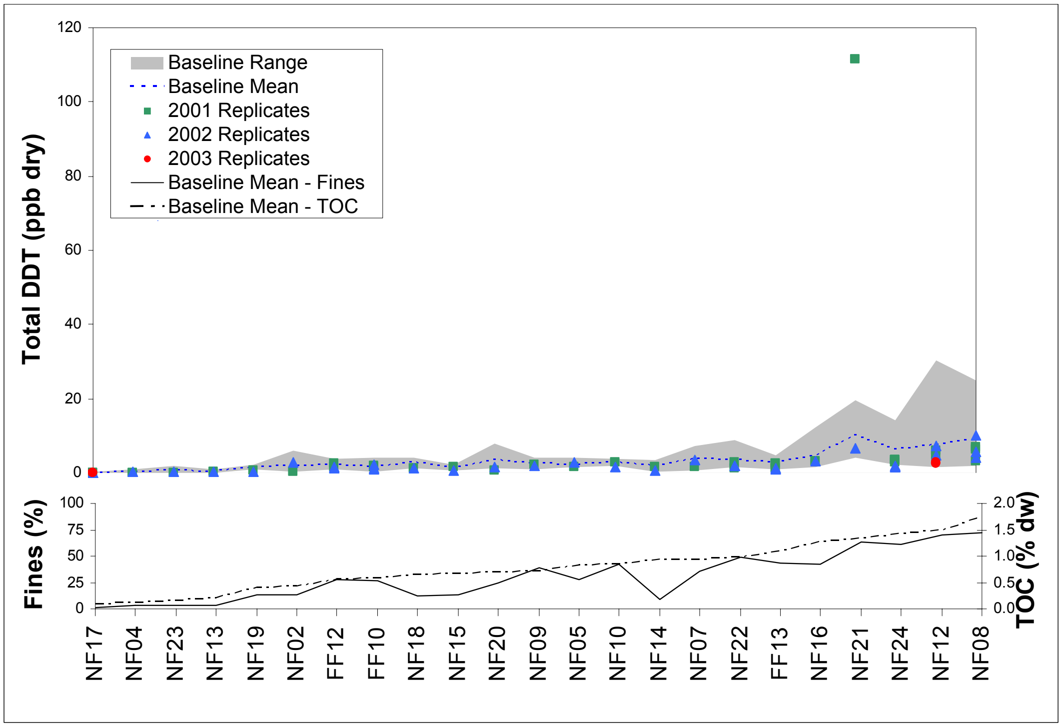


Figure B2-3. Total PAH (top) and total PCB (bottom) for each nearfield station sampled in 2001 (squares), 2002 (triangles), 2003 (circles) and the range of values occurring during the baseline period (gray band). The baseline mean values are indicated by a dashed line within gray band. Stations are presented in order of increasing mean TOC concentration. Baseline station mean values for TOC (dashed line in subplot) and percent fines (solid line in subplot), plotted by station, are shown in the subplot.



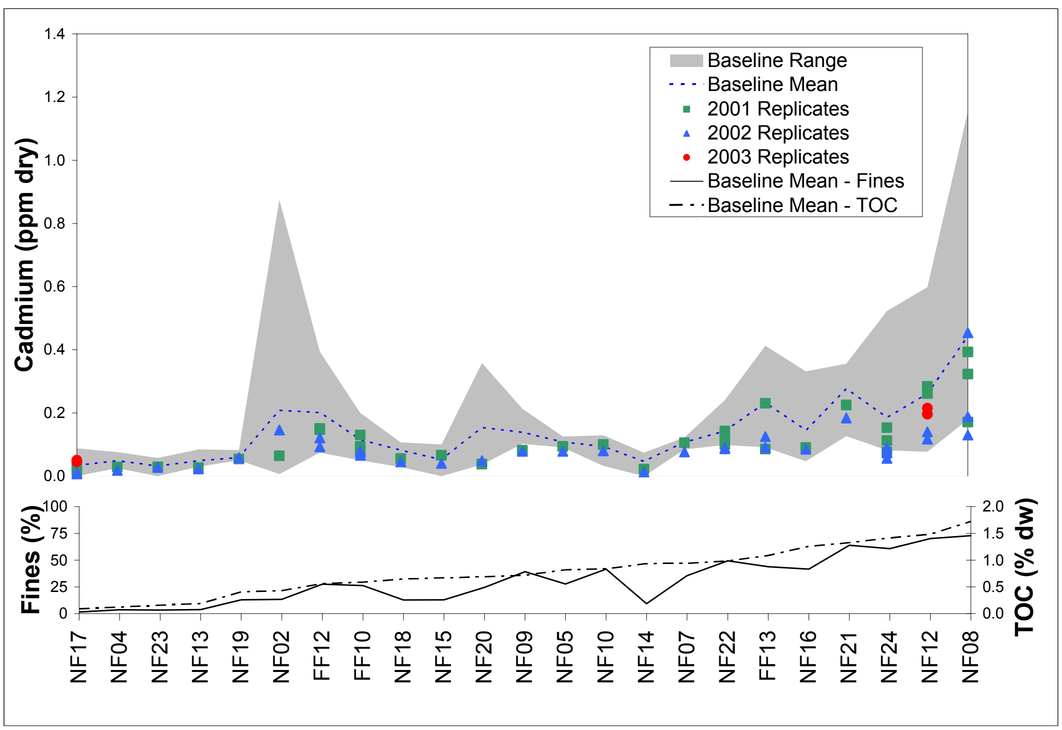
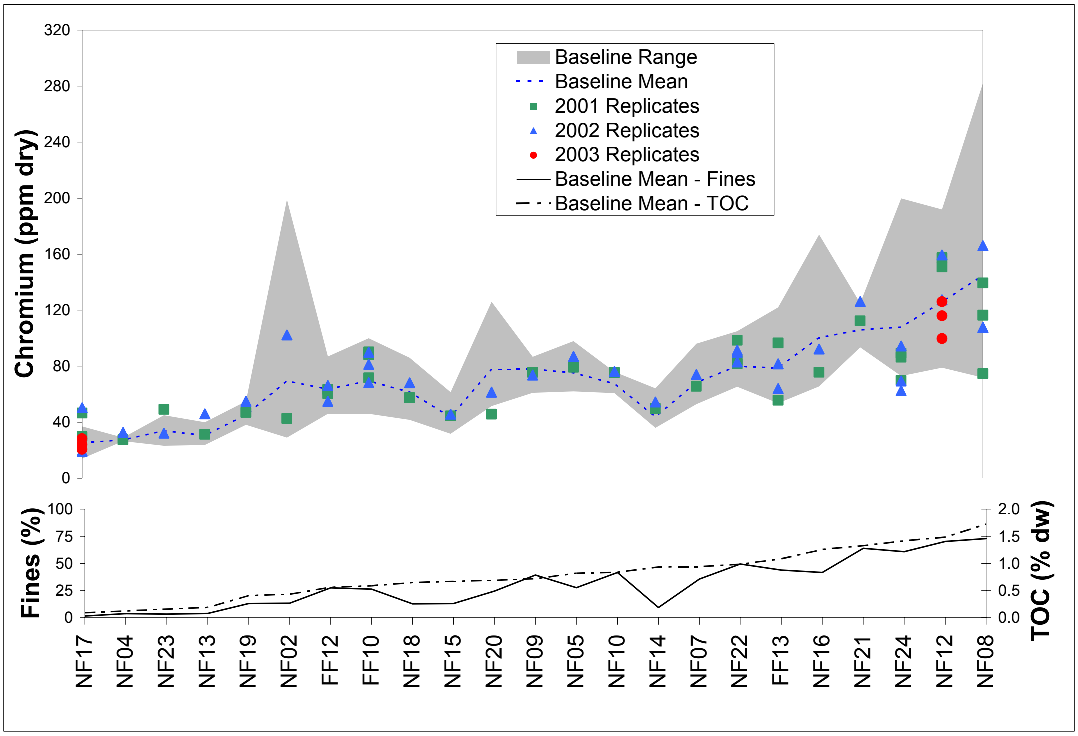


Figure B2-4. Total DDT (top) and cadmium (bottom) for each nearfield station sampled in 2001 (squares), 2002 (triangles), 2003 (circles) and the range of values occurring during the baseline period (gray band). The baseline mean values are indicated by a dashed line within gray band. Stations are presented in order of increasing mean TOC concentration. Baseline station mean values for TOC (dashed line in subplot) and percent fines (solid line in subplot), plotted by station, are shown in the subplot.



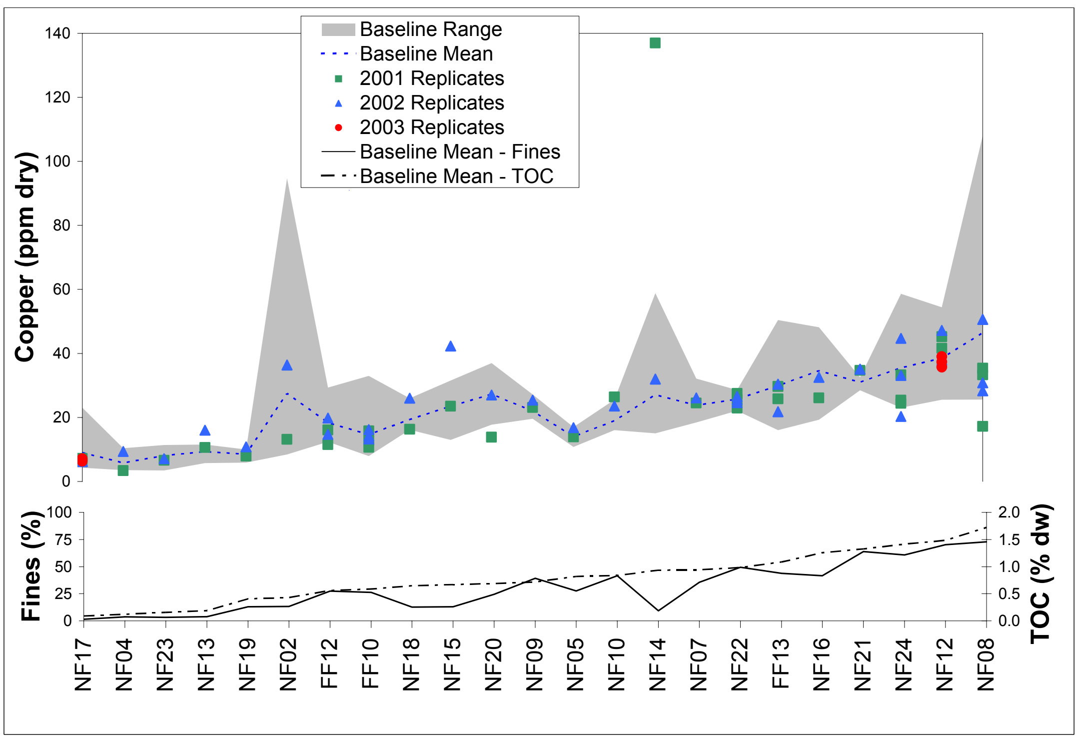
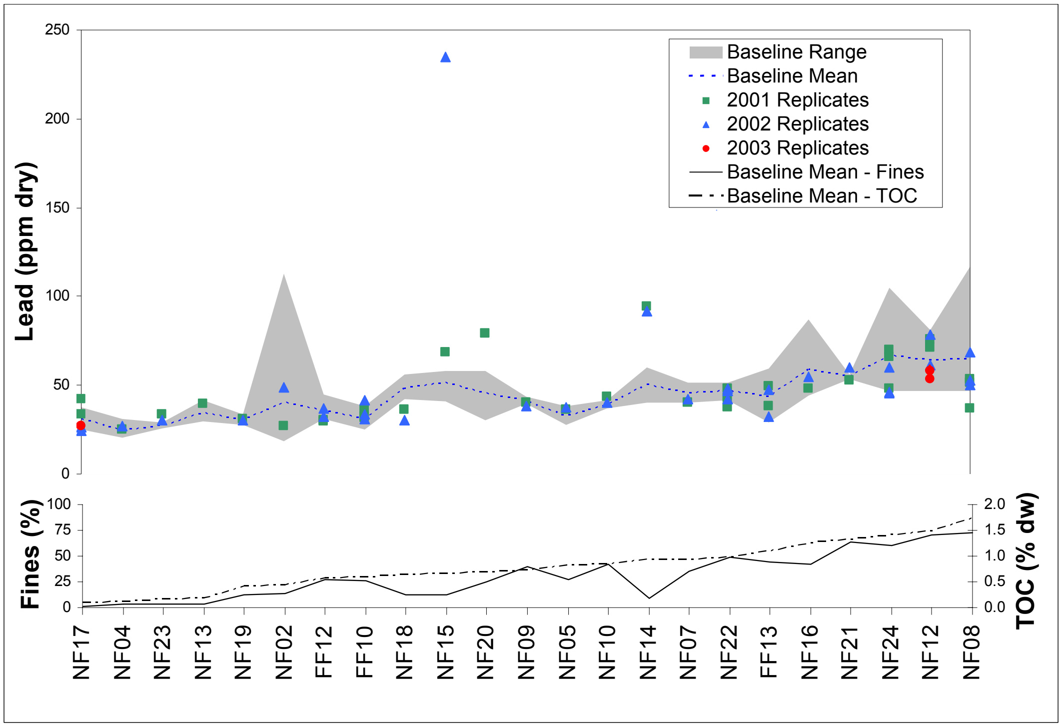


Figure B2-5. Chromium (top) and copper (bottom) for each nearfield station sampled in 2001 (squares), 2002 (triangles), 2003 (circles) and the range of values occurring during the baseline period (gray band). The baseline mean values are indicated by a dashed line within gray band. Stations are presented in order of increasing mean TOC concentration. Baseline station mean values for TOC (dashed line in subplot) and percent fines (solid line in subplot), plotted by station, are shown in the subplot.



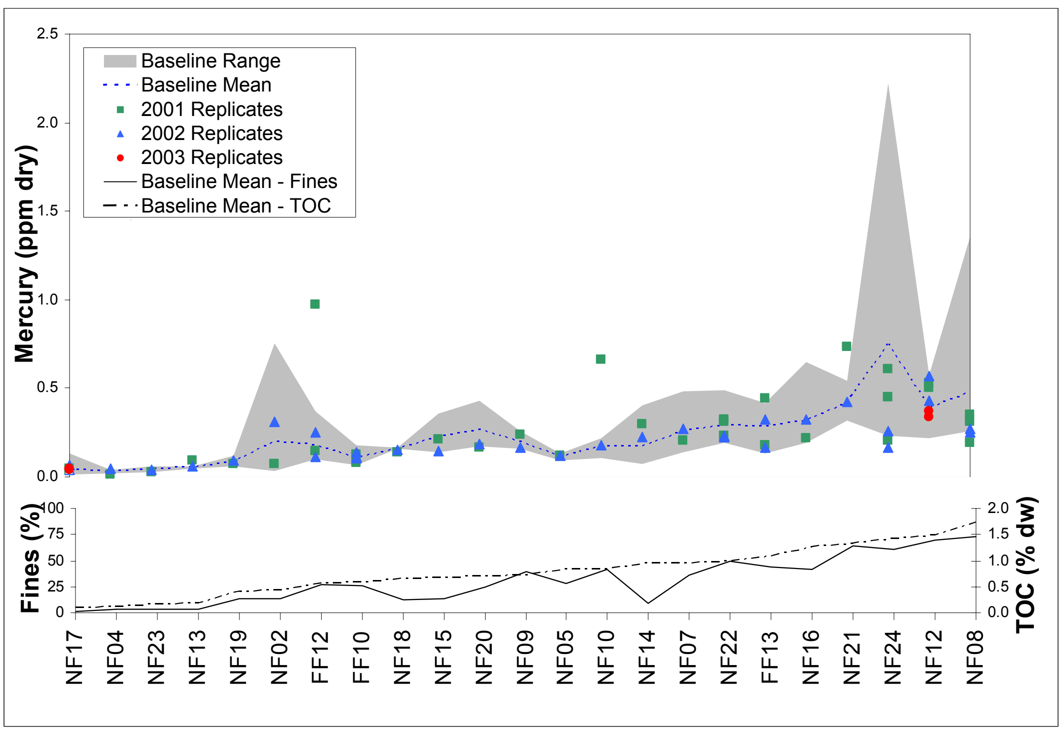
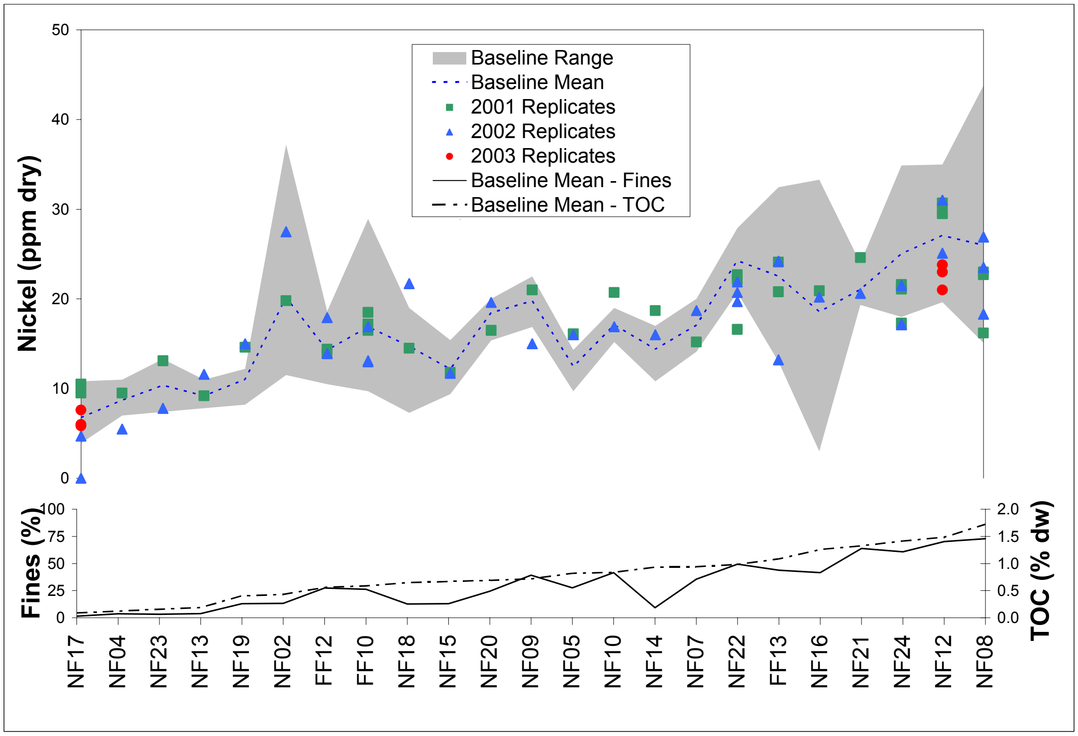


Figure B2-6. Lead (top) and mercury (bottom) for each nearfield station sampled in 2001 (squares), 2002 (triangles), 2003 (circles) and the range of values occurring during the baseline period (gray band). The baseline mean values are indicated by a dashed line within gray band. Stations are presented in order of increasing mean TOC concentration. Baseline station mean values for TOC (dashed line in subplot) and percent fines (solid line in subplot), plotted by station, are shown in the subplot.



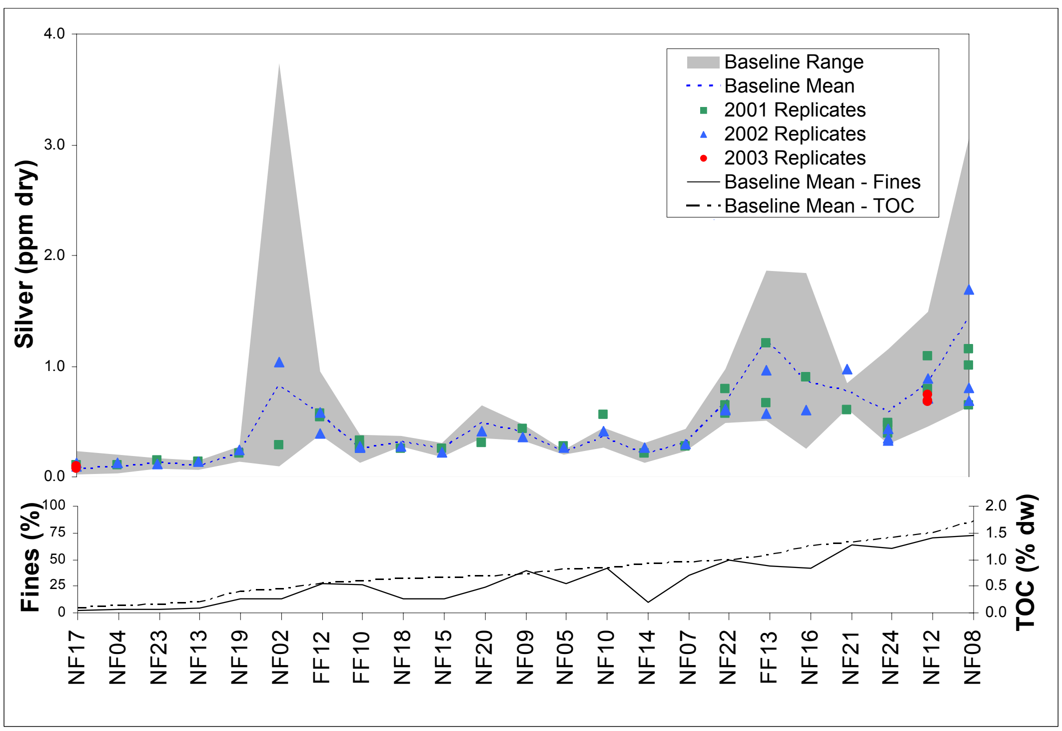


Figure B2-7. Nickel (top) and silver (bottom) for each nearfield station sampled in 2001 (squares), 2002 (triangles), 2003 (circles) and the range of values occurring during the baseline period (gray band). The baseline mean values are indicated by a dashed line within gray band. Stations are presented in order of increasing mean TOC concentration. Baseline station mean values for TOC (dashed line in subplot) and percent fines (solid line in subplot), plotted by station, are shown in the subplot.

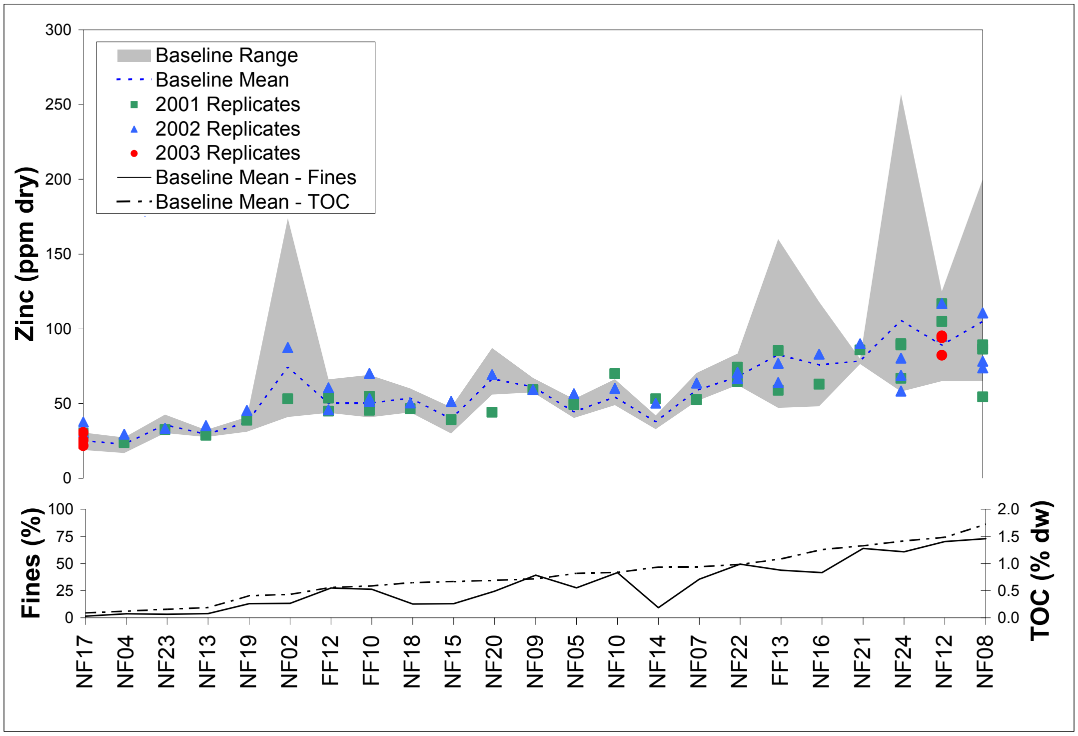
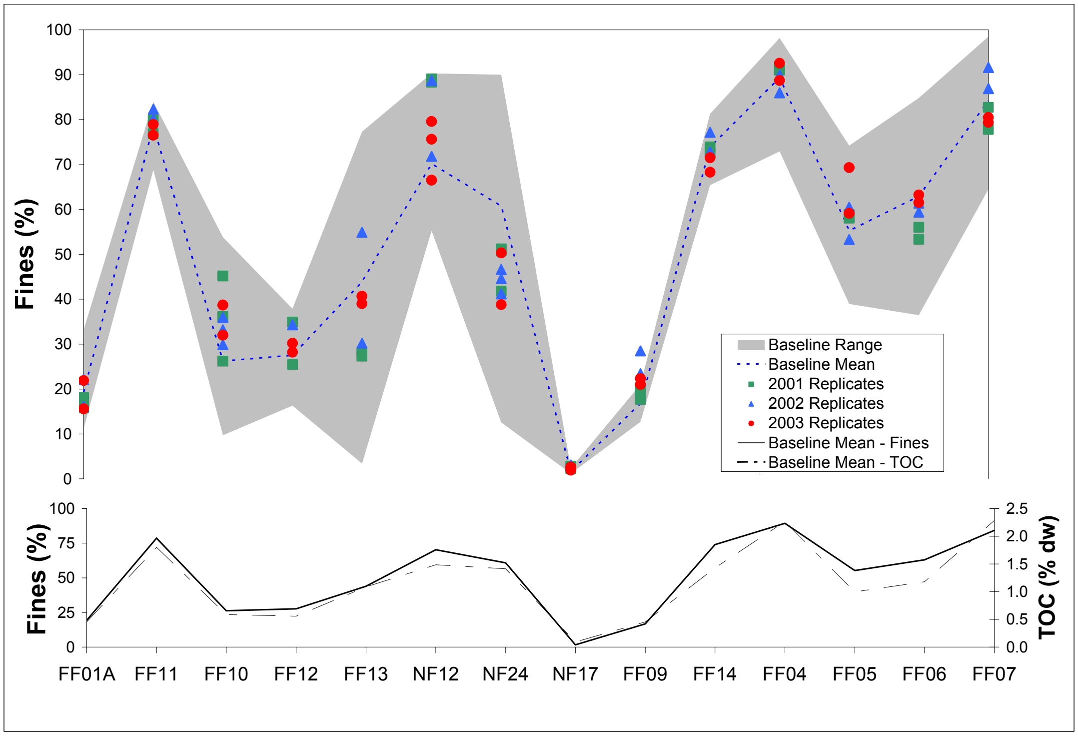


Figure B2-8. Zinc for each nearfield station sampled in 2001 (squares), 2002 (triangles), 2003 (circles) and the range of values occurring during the baseline period (gray band). The baseline mean values are indicated by a dashed line within gray band. Stations are presented in order of increasing mean TOC concentration. Baseline station mean values for TOC (dashed line in subplot) and percent fines (solid line in subplot), plotted by station, are shown in the subplot.



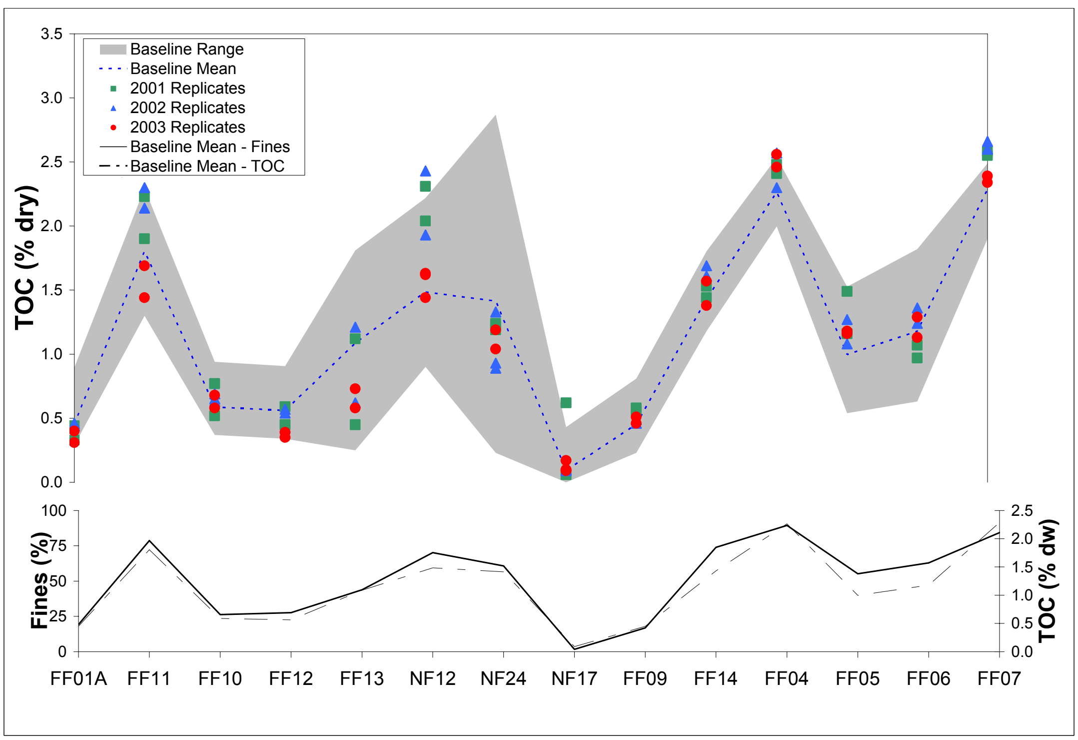


Figure B2-9. Percent fines (top) and TOC (bottom) for each regional station sampled in 2001 (squares), 2002 (triangles), 2003 (circles) and the range of values occurring during the baseline period (gray band). The baseline mean values are indicated by a dashed line within gray band. Stations are presented in order of location relative to the outfall, from north to south. Baseline station mean values for TOC (dashed line in subplot) and percent fines (solid line in subplot), plotted by station, are shown in the subplot.

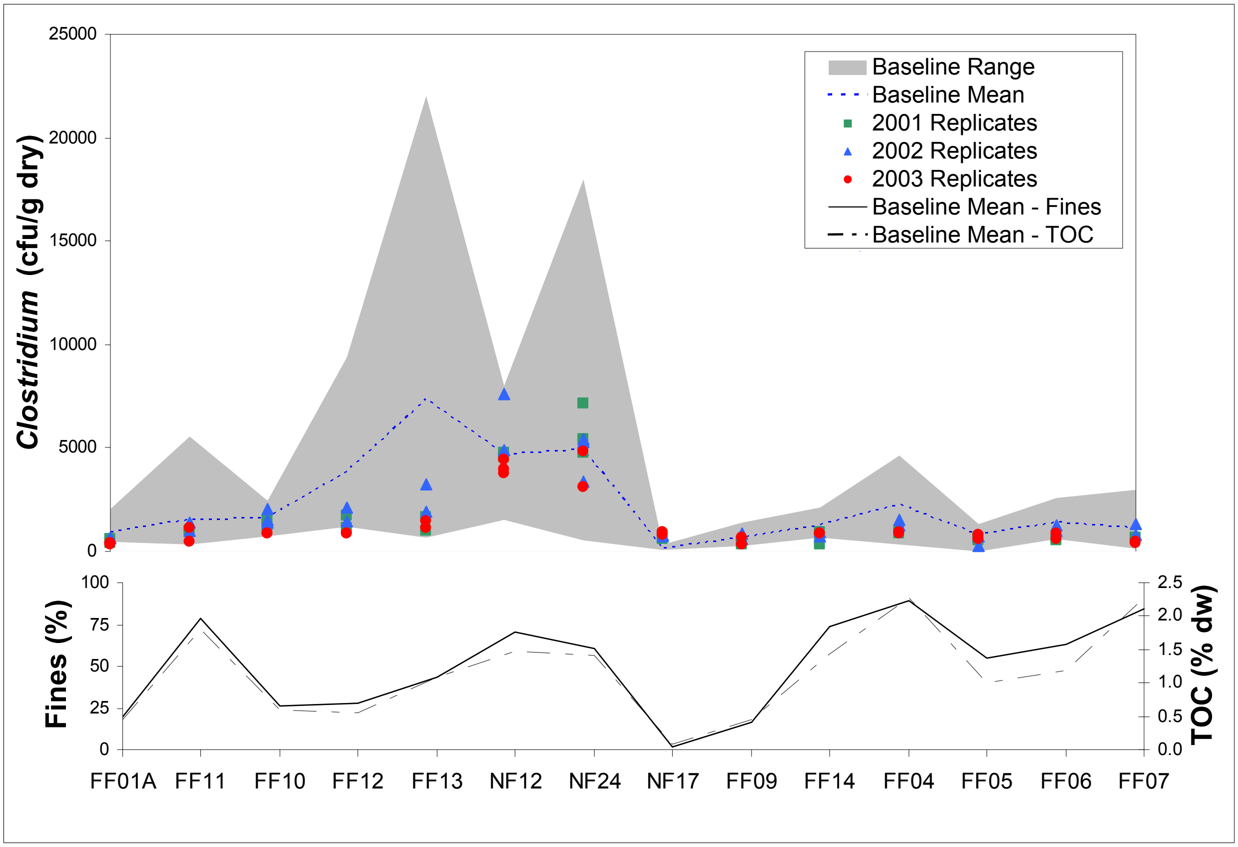


Figure B2-10. *Clostridium perfringens* for each regional station sampled in 2001 (squares), 2002 (triangles), 2003 (circles) and the range of values occurring during the baseline period (gray band). The baseline mean values are indicated by a dashed line within gray band. Stations are presented in order of location relative to the outfall, from north to south. Baseline station mean values for TOC (dashed line in subplot) and percent fines (solid line in subplot), plotted by station, are shown in the subplot.

Supplemental Histogram Plots
Nearfield and Regional Grain Size and TOC Data, Station Mean Values
1992–2003

(*These plots are referenced in Chapter 5, Soft-Bottom Infaunal Community*)

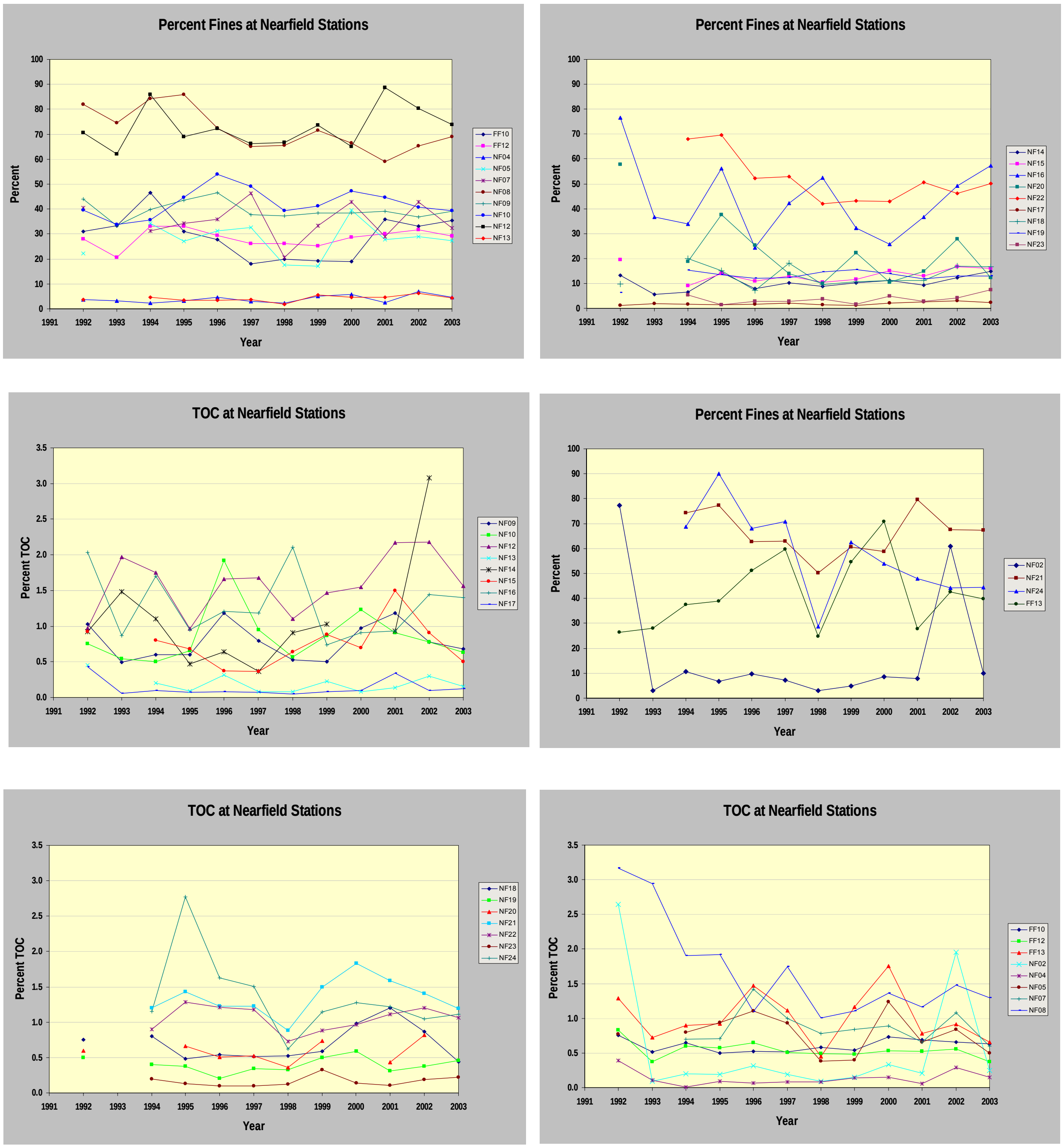
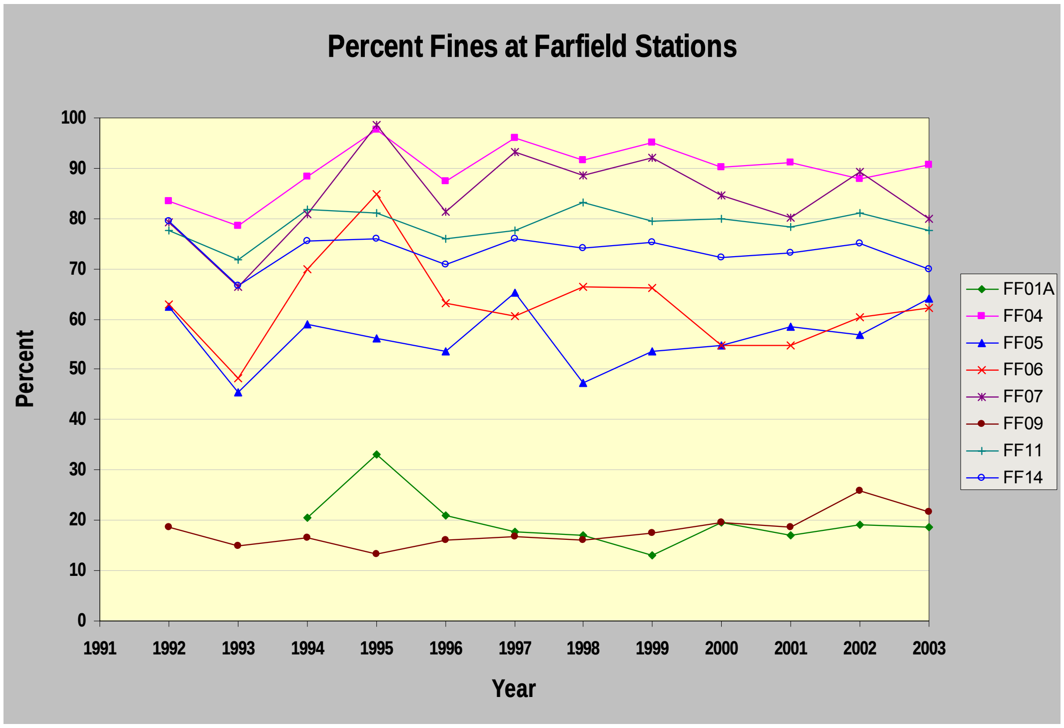


Figure B2-11. Percent Fines and TOC in sediments at Massachusetts Bay nearfield stations.



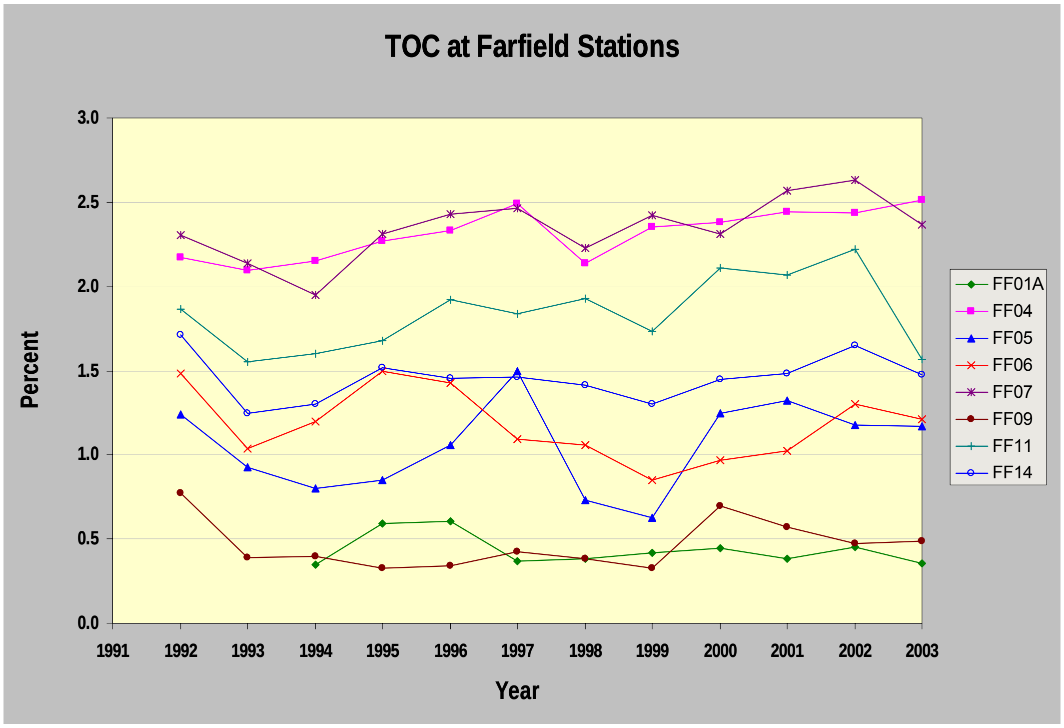


Figure B2-12. Percent Fines and TOC in sediments at Massachusetts and Cape Cod Bay regional stations.

APPENDIX B3

Nearfield *Clostridium* (non-normalized and normalized to Grain Size and TOC), Grain Size and TOC Response Pre- (2000) and Post-Diversion (2001–2003) Data (Station Mean Values, August Surveys Only)

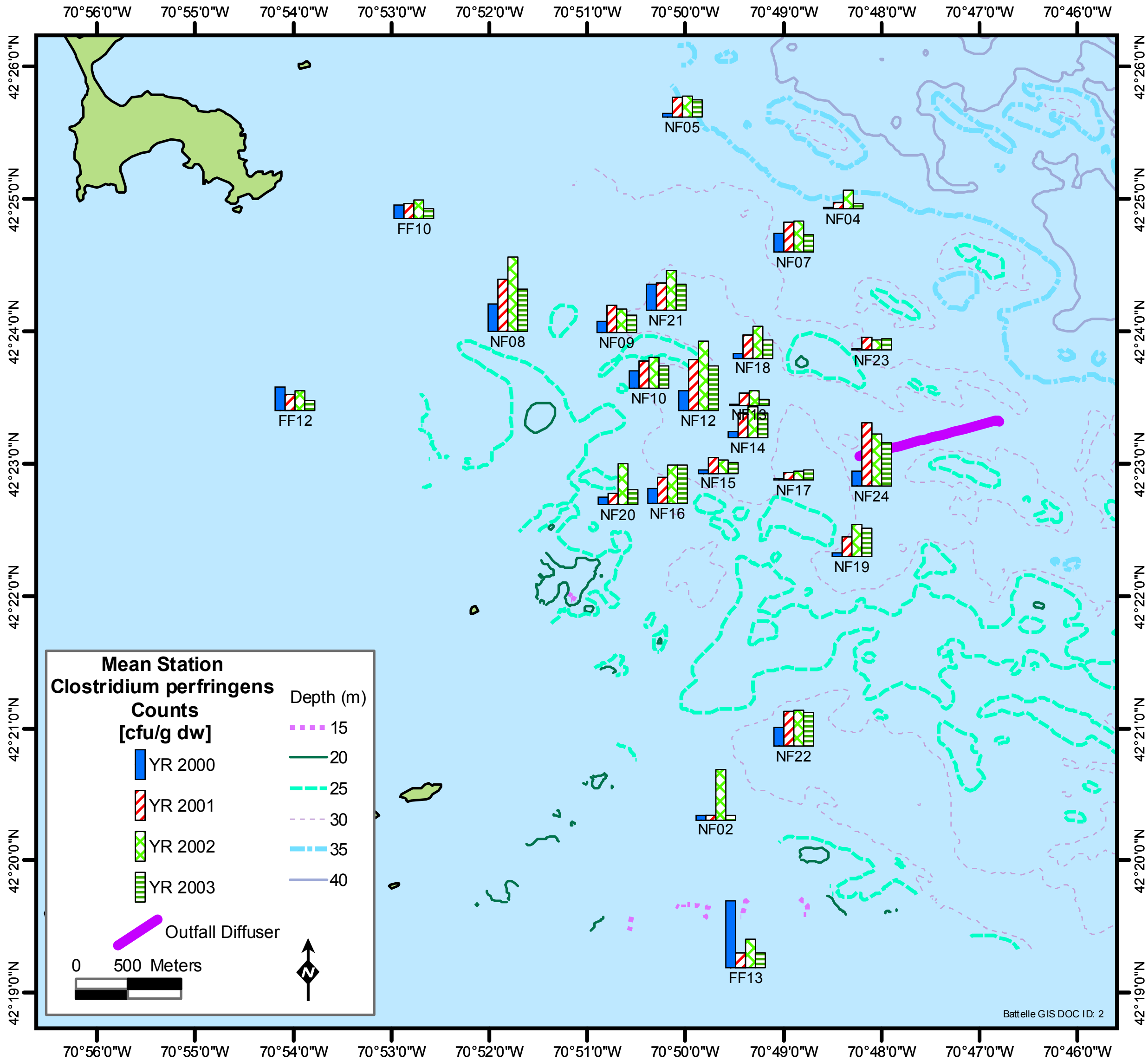


Figure B3-1. Station mean concentrations of *C. perfringens* (non-normalized) in nearfield sediments prior to (August 2000) and after (August 2001-2003) outfall activation.

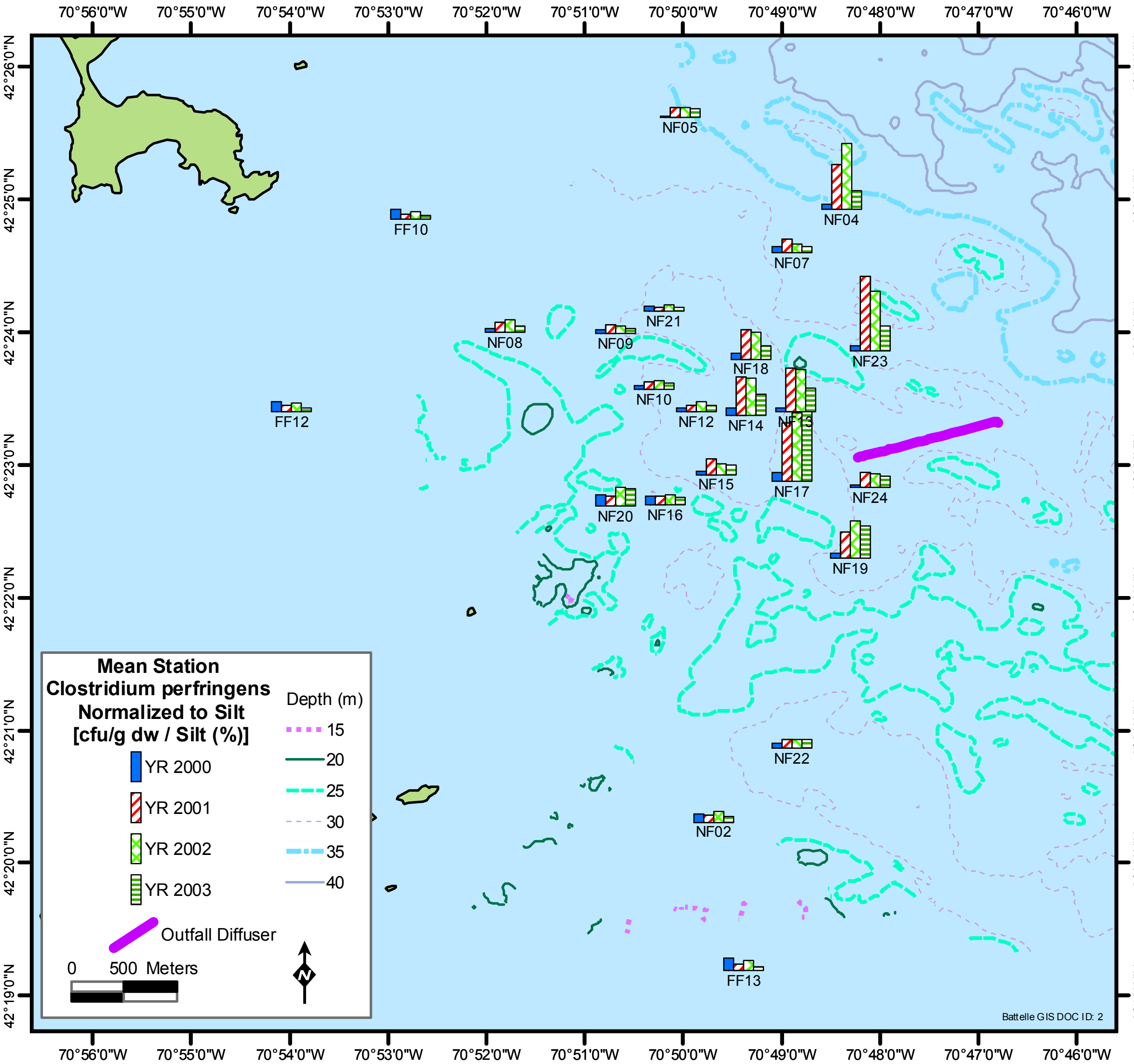


Figure B3-2. Station mean concentrations of *C. perfringens* (normalized to percent silt) in nearfield sediments prior to (August 2000) and after (August 2001-2003) outfall activation.

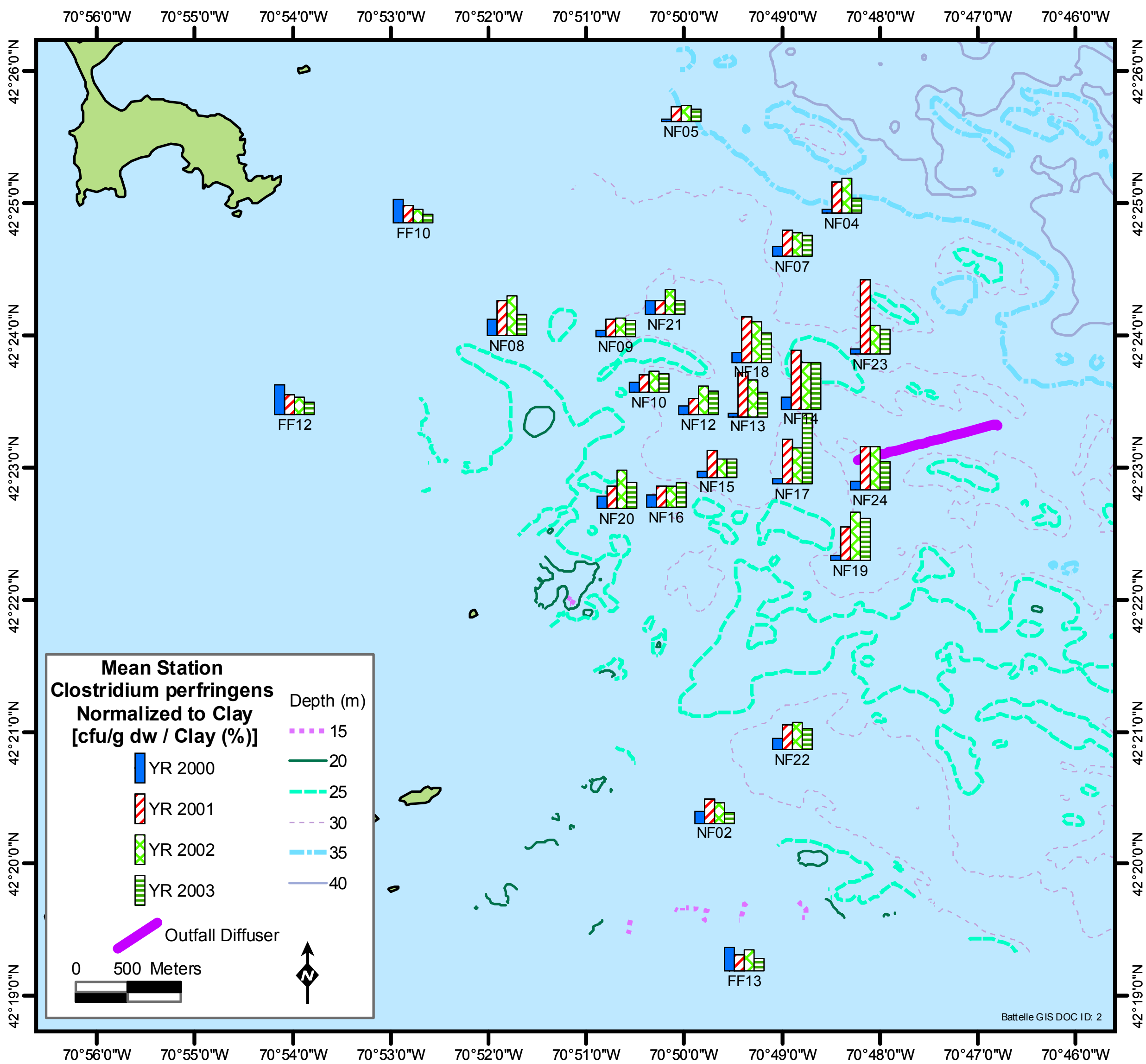


Figure B3-3. Station mean concentrations of *C. perfringens* (normalized to percent clay) in nearfield sediments prior to (August 2000) and after (August 2001-2003) outfall activation.

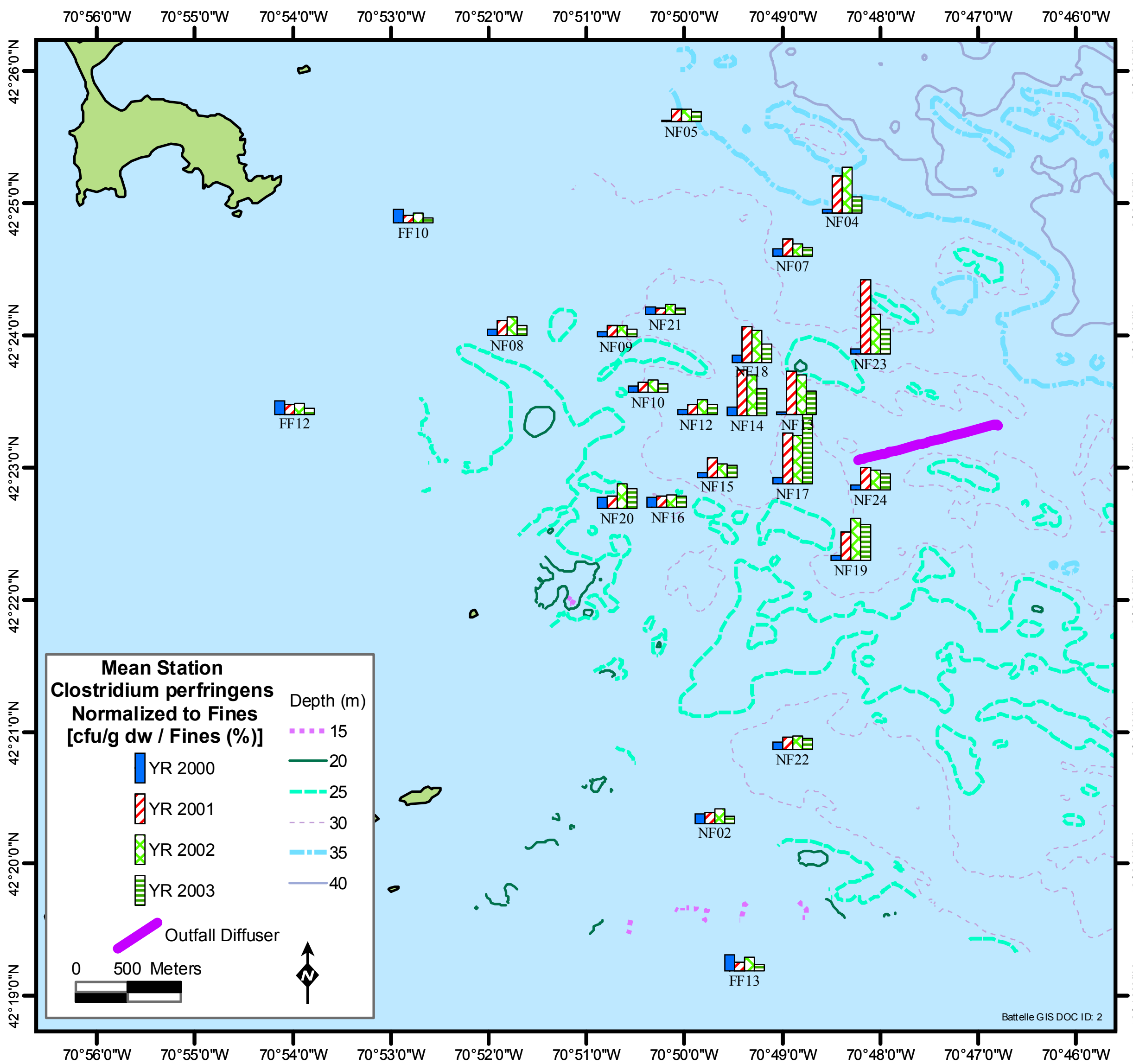


Figure B3-4. Station mean concentrations of *C. perfringens* (normalized to percent fines) in nearfield sediments prior to (August 2000) and after (August 2001-2003) outfall activation.

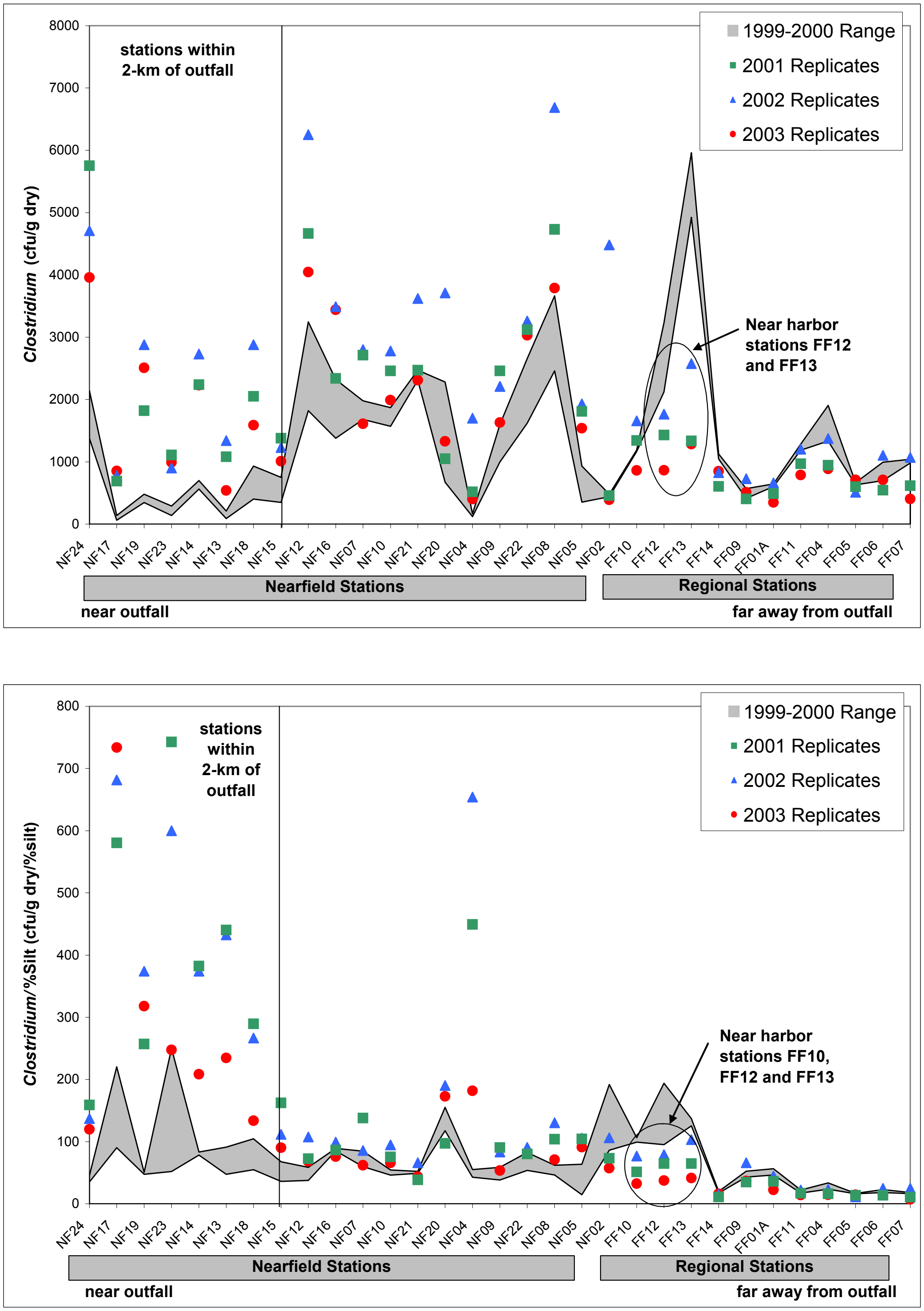
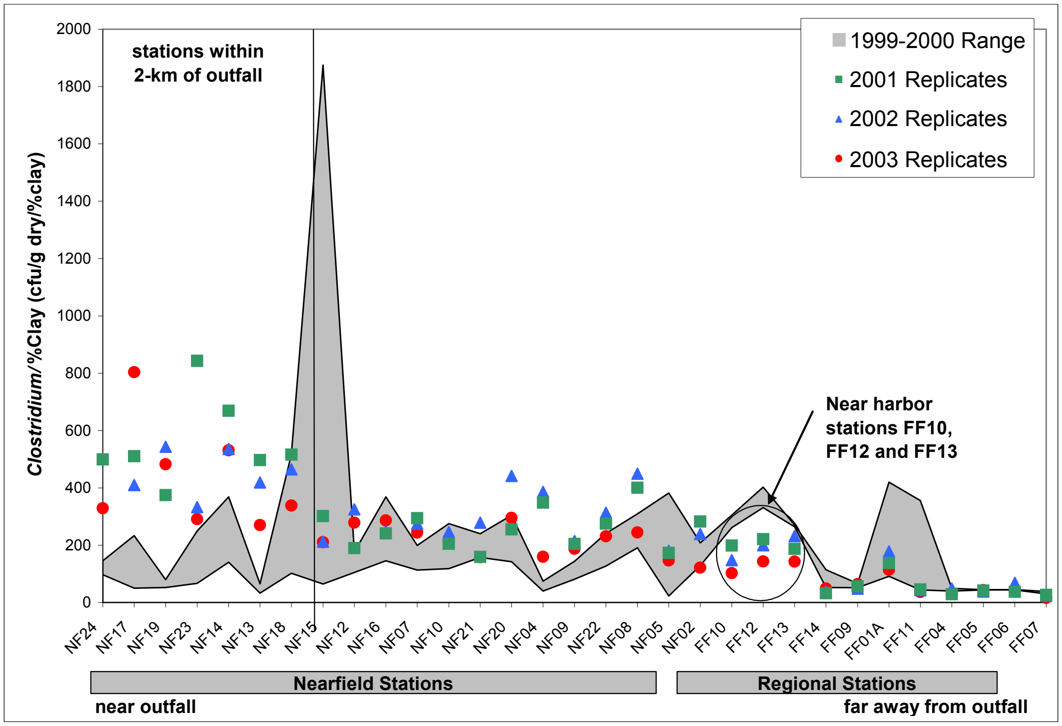


Figure B3-5. *C. perfringens* response non-normalized (A) and normalized to percent silt (B) for each nearfield and regional station sampled in 2001 (squares), 2002 (triangles), and 2003 (circles) and the range of values occurring during the 1999-2000 baseline period (gray band). Stations are presented in order of location relative to the outfall, from close (e.g., NF24) to more distant (e.g., NF02).



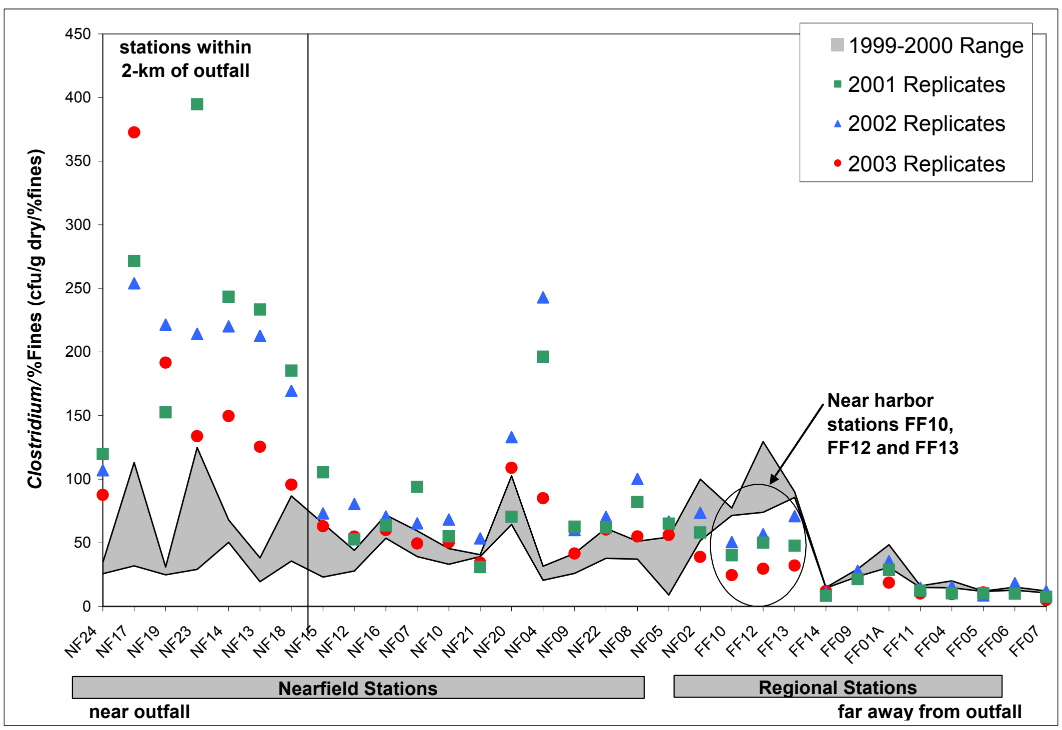


Figure B3-6. ***C. perfringens*** **response normalized to percent clay (A) and normalized to percent fines (B) for each nearfield and regional station sampled in 2001 (squares), 2002 (triangles), and 2003 (circles) and the range of values occurring during the 1999-2000 baseline period (gray band). Stations are presented in order of location relative to the outfall, from close (e.g., NF24) to more distant (e.g., NF02).**

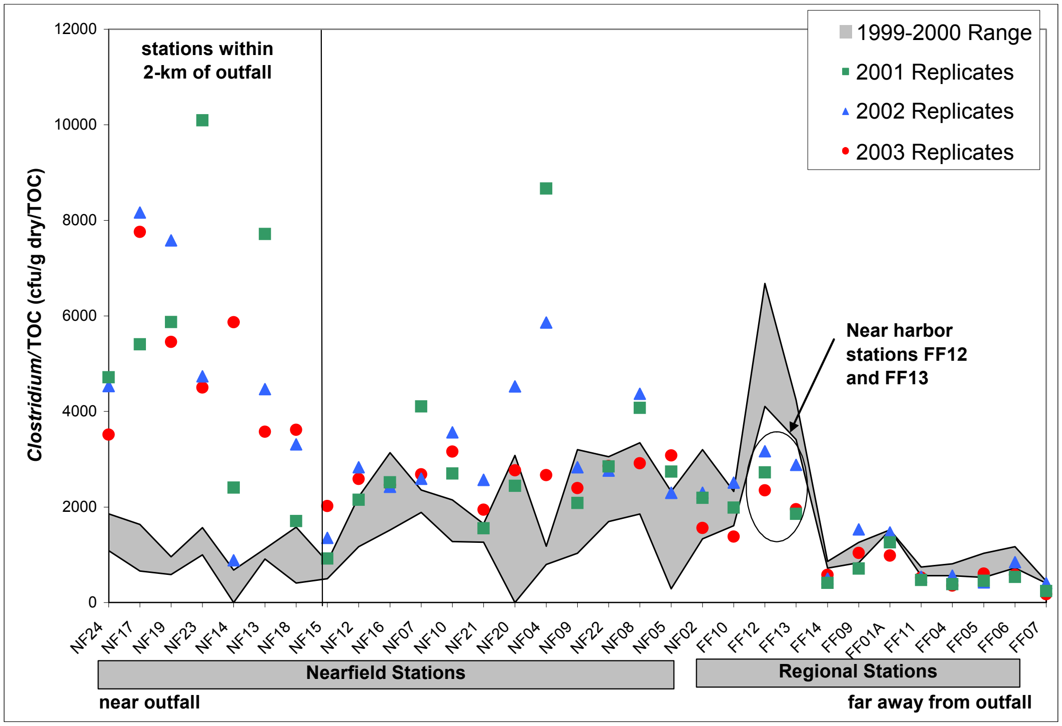


Figure B3-7. *C. perfringens* response normalized to TOC for each nearfield and regional station sampled in 2001 (squares), 2002 (triangles), and 2003 (circles) and the range of values occurring during the 1999-2000 baseline period (gray band). Stations are presented in order of location relative to the outfall, from close (e.g., NF24) to more distant (e.g., NF02).

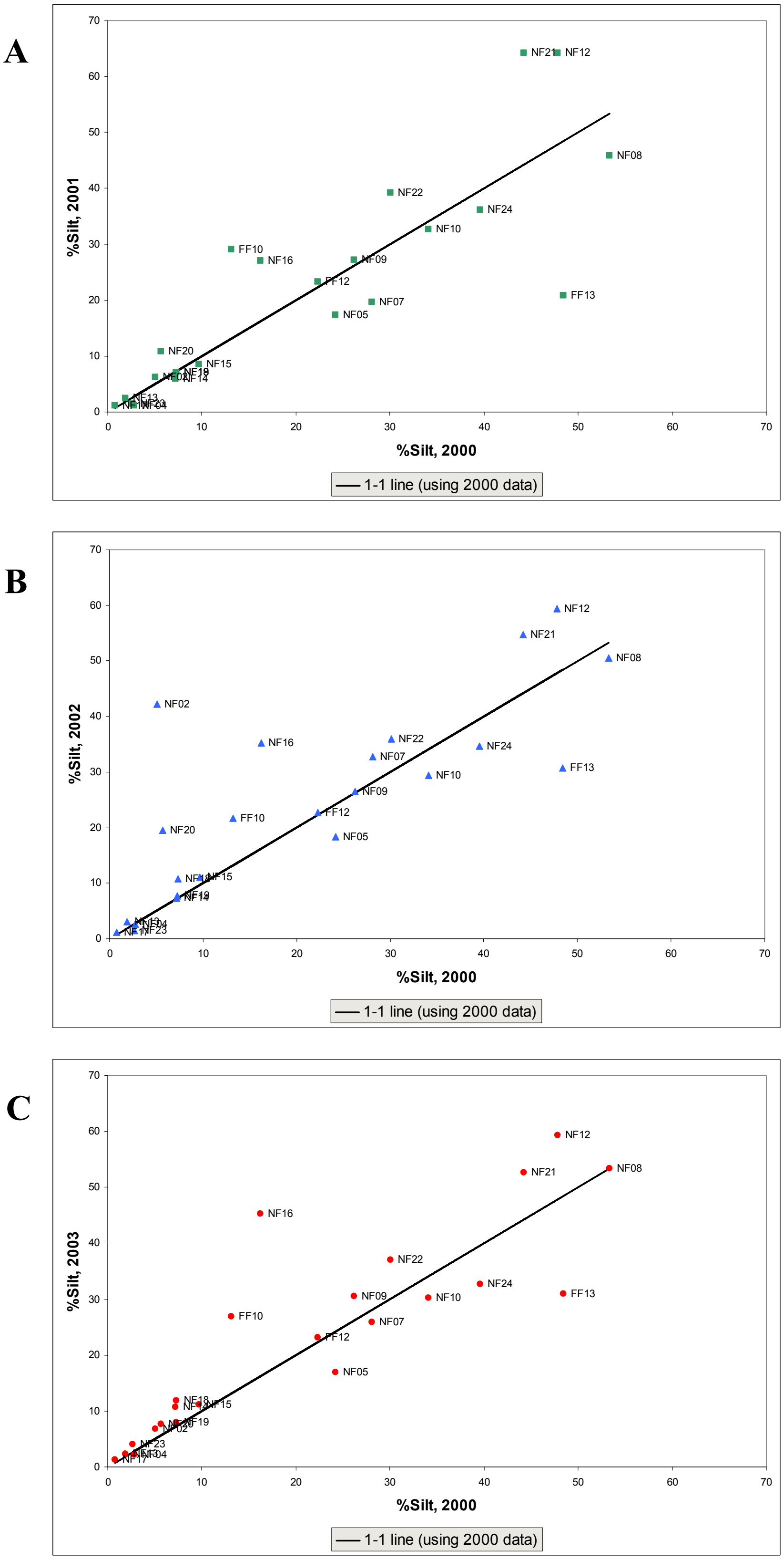
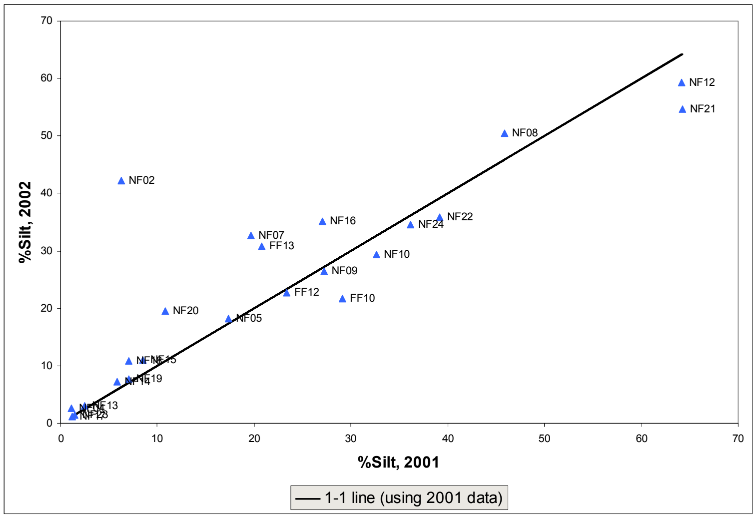
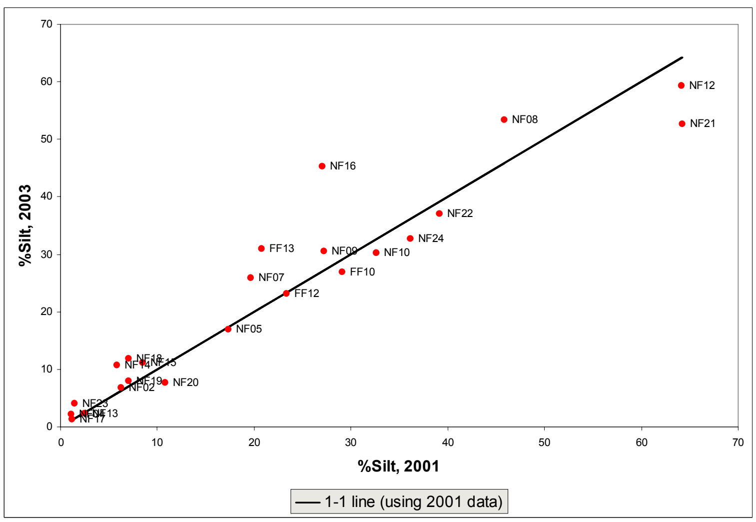


Figure B3-8. Correspondence between percent silt in 2000 and 2001 (A), 2000 and 2002 (B), and 2000 and 2003 (C).

A



B



C

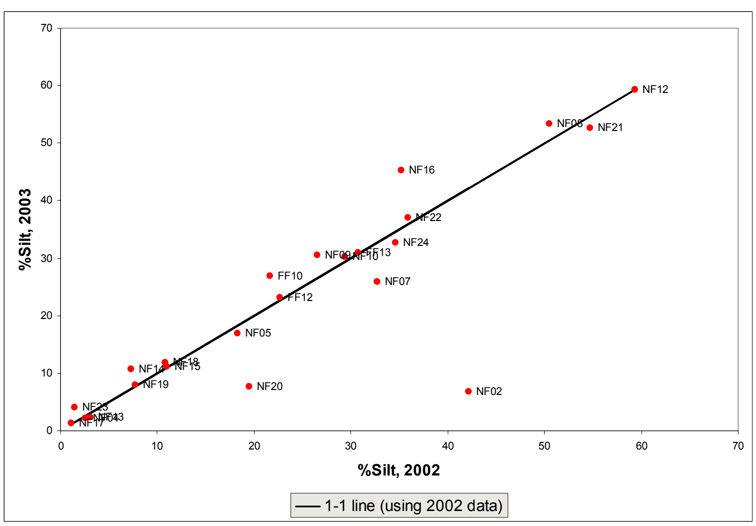


Figure B3-9. Correspondence between percent silt in 2001 and 2002 (A), 2001 and 2003 (B), and 2002 and 2003 (C).

A

B

C

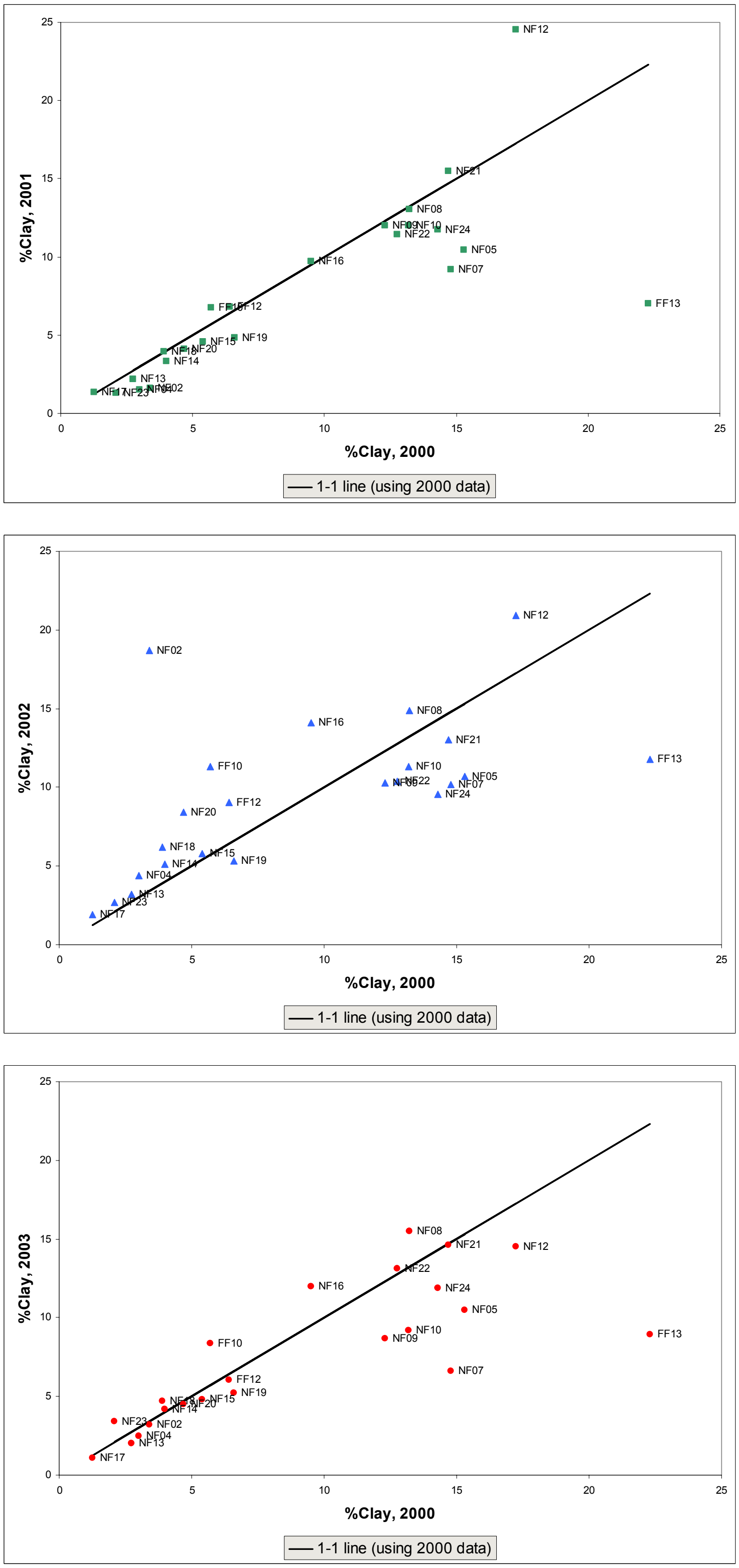


Figure B3-10. Correspondence between percent clay in 2000 and 2001 (A), 2000 and 2002 (B), and 2000 and 2003 (C).

A

B

C

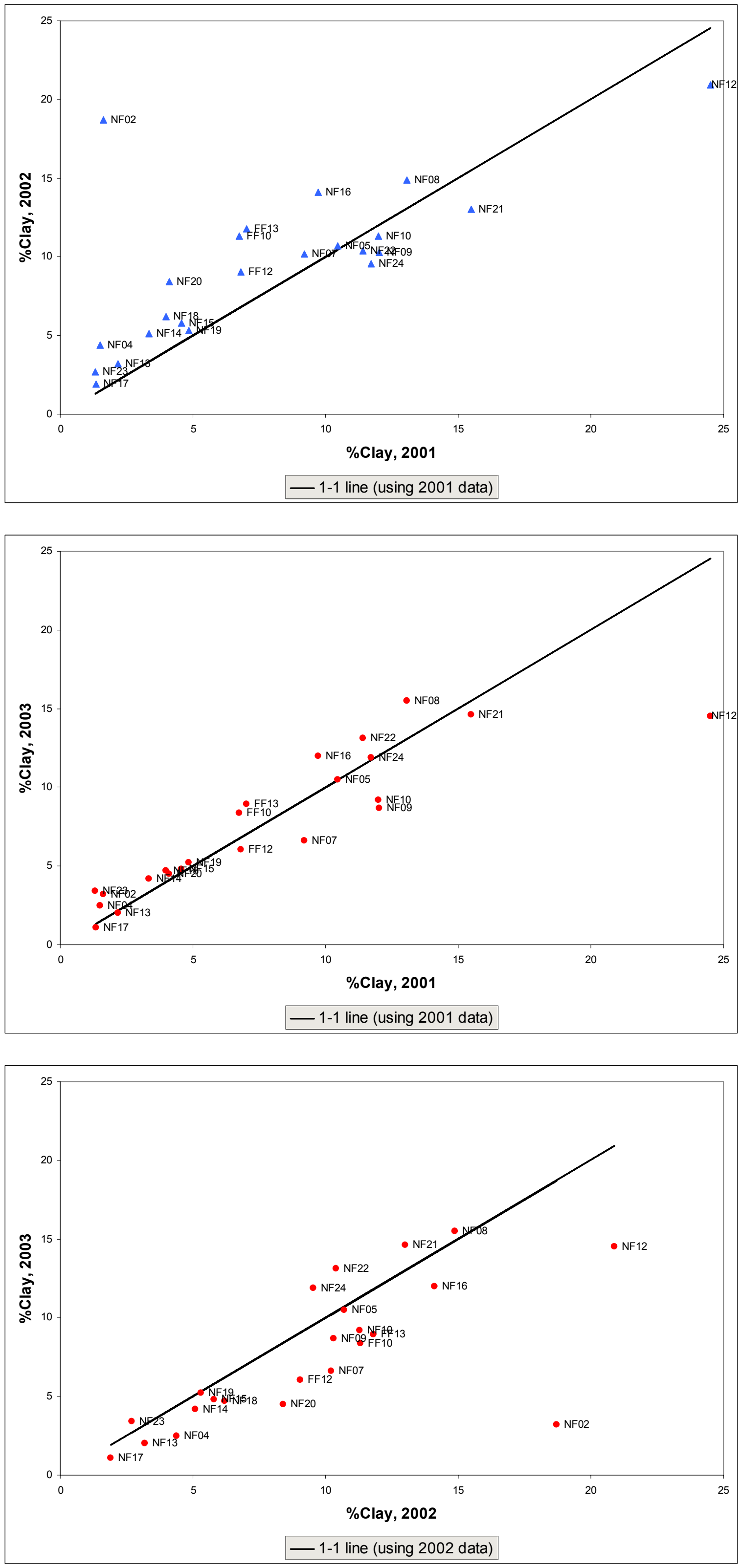


Figure B3-11. Correspondence between percent clay in 2001 and 2002 (A), 2001 and 2003 (B), and 2002 and 2003 (C).

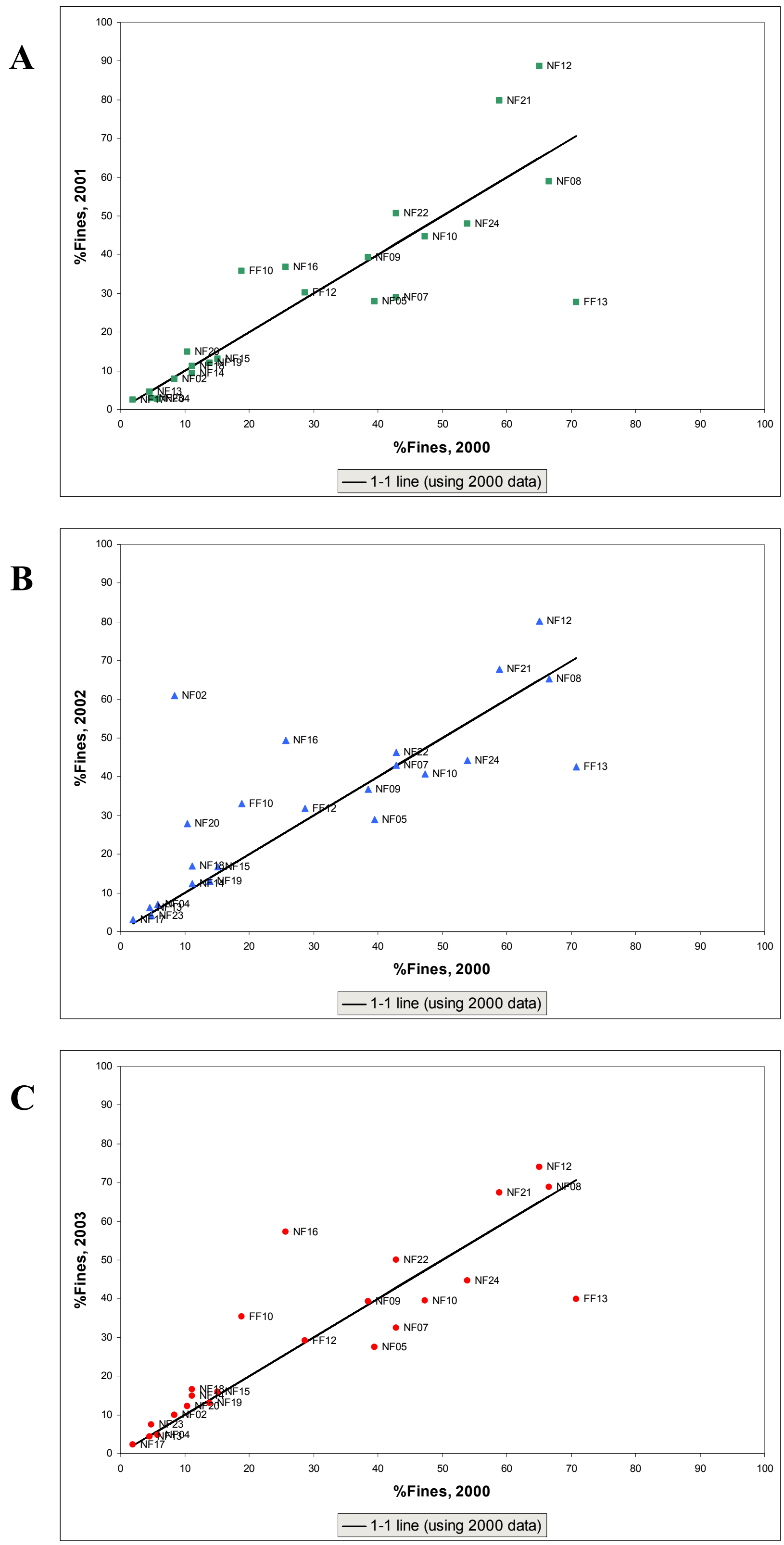
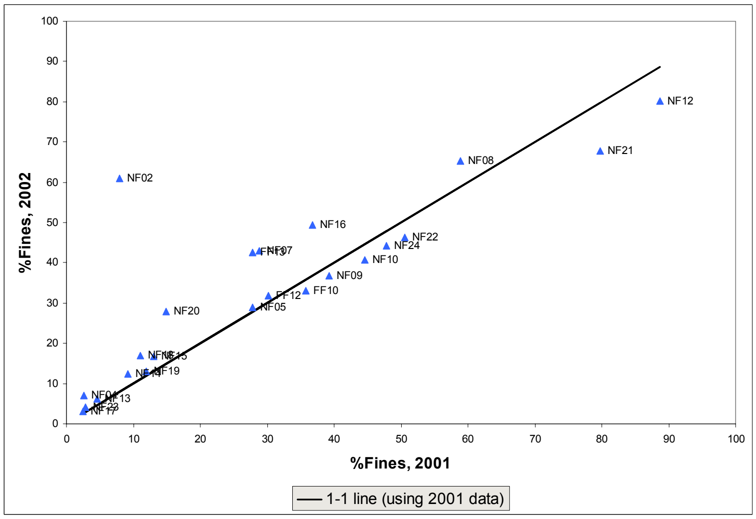
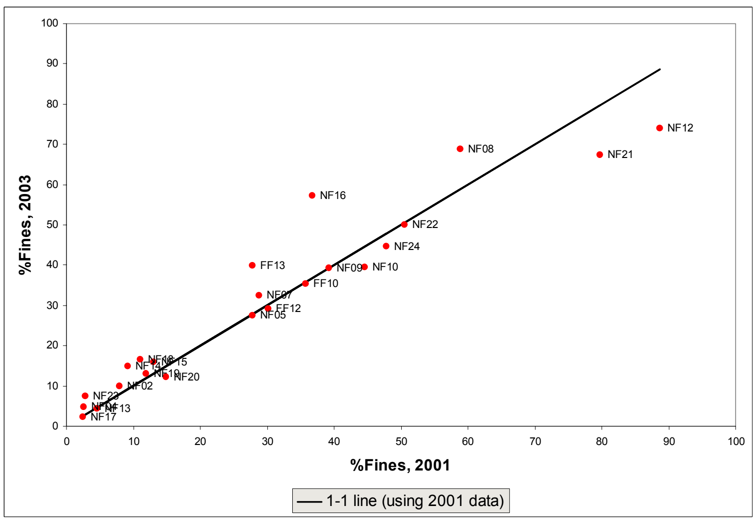


Figure B3-12. Correspondence between percent fines in 2000 and 2001 (A), 2000 and 2002 (B), and 2000 and 2003 (C).

A



B



C

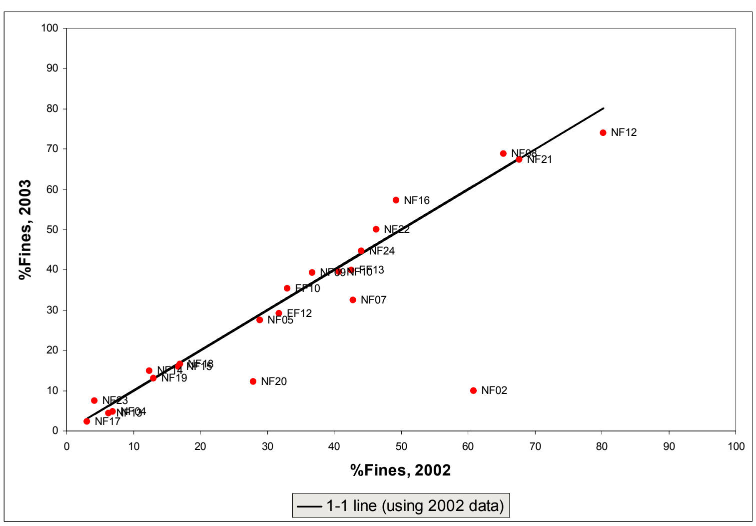


Figure B3-13. Correspondence between percent fines in 2001 and 2002 (A), 2001 and 2003 (B), and 2002 and 2003 (C).

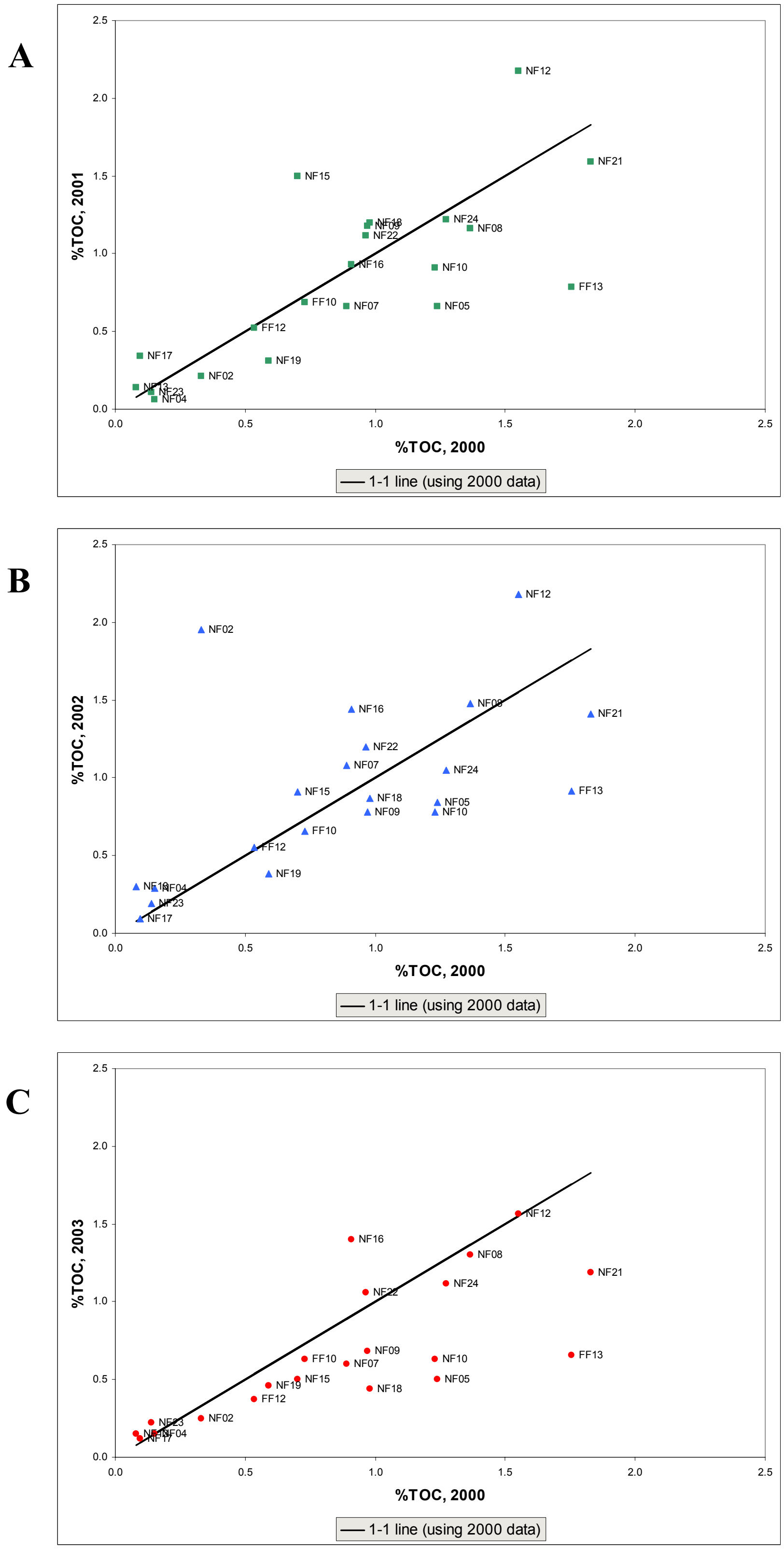


Figure B3-14. Correspondence between TOC in 2000 and 2001 (A), 2000 and 2002 (B), and 2000 and 2003 (C).

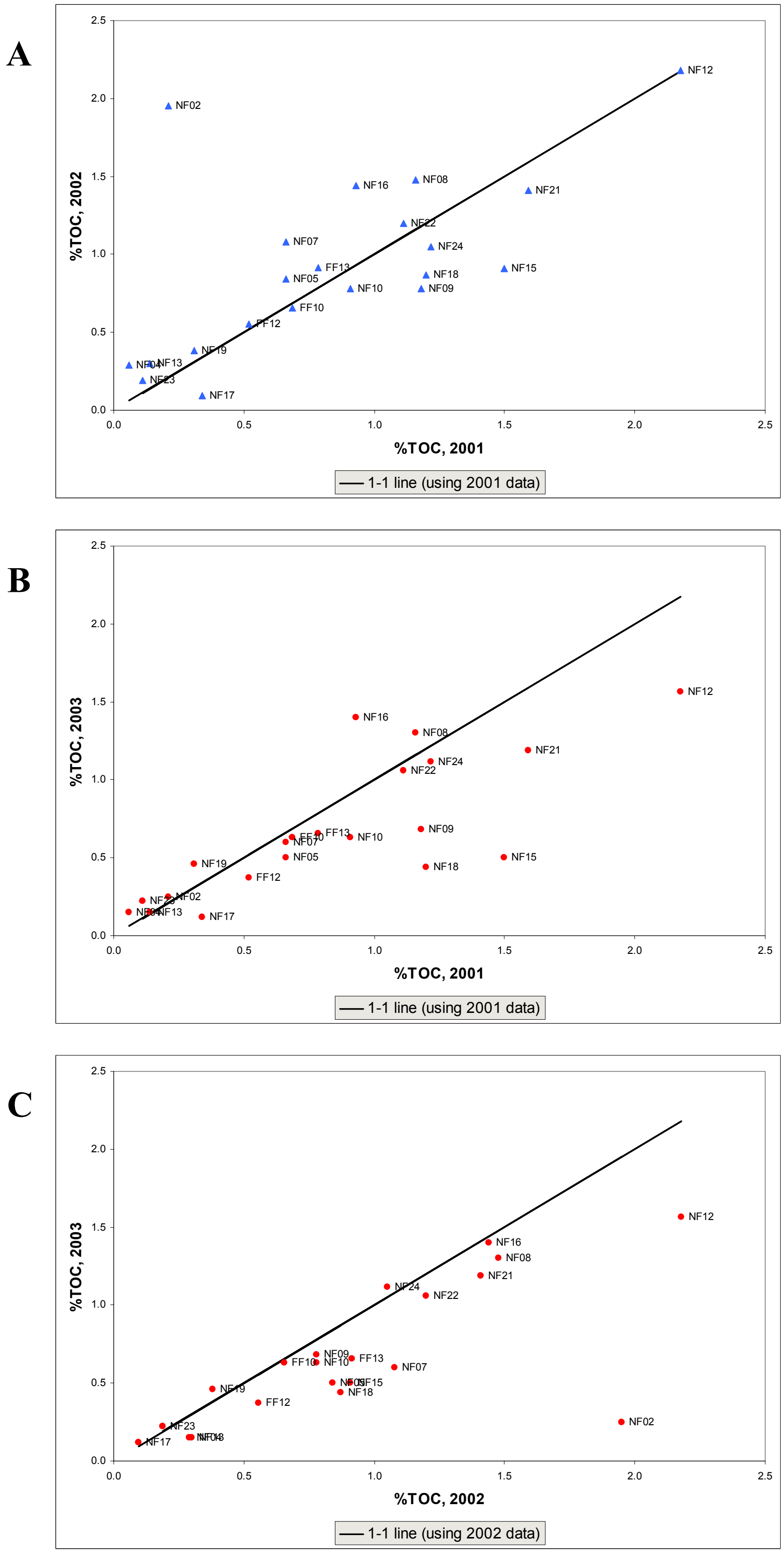


Figure B3-15. Correspondence between TOC in 2001 and 2002 (A), 2001 and 2003 (B), and 2002 and 2003 (C).

APPENDIX B4

Correlation Analysis Results for Nearfield and Regional Stations 1999–2003

Table B4-1. Correspondence within bulk sediment properties and against contaminants in the nearfield before and after the new outfall came on-line.

Parameter	Correspondence with Percent Fines			Critical Value (α=0.01)	Correspondence with TOC [a]			Critical Value (α=0.01)
	r	*n*	*p*		*r*	*n*	*p*	
	Pre-Diversion (1999 – 2000)							
Percent Fines					0.871	44	<0.01	0.393
TOC	0.871	44	<0.01	0.393				
Clostridium perfringens	0.786	46	<0.01		0.659	45	<0.01	0.393
Total PAH	0.661	31	<0.01	0.456	0.683	32	<0.01	0.449
Total PCB	0.831	31	<0.01		0.834	32	<0.01	
Total DDT	0.839	31	<0.01		0.797	32	<0.01	
Total LAB	0.800	31	<0.01		0.777	32	<0.01	
Al	0.779	31	<0.01		0.715	32	<0.01	
Cd	0.739	28	<0.01	0.478	0.686	28	<0.01	0.478
Cr	0.951	31	<0.01	0.456	0.859	32	<0.01	0.449
Cu	0.859	31	<0.01		0.875	32	<0.01	
Fe	0.755	31	<0.01		0.661	32	<0.01	
Pb	0.697	31	<0.01		0.835	32	<0.01	
Hg	0.908	31	<0.01		0.896	32	<0.01	
Ni	0.817	31	<0.01		0.760	32	<0.01	
Ag	0.708	31	<0.01		0.690	32	<0.01	
Zn	0.826	31	<0.01		0.769	32	<0.01	
	Post-Diversion (2001 – 2003) [b]							
Percent Fines					0.860	68	<0.01	0.325
TOC [a]	0.860	68	<0.01	0.325				
Clostridium perfringens	0.750	69	<0.01		0.795	68	<0.01	0.325
Total PAH	0.838	48	<0.01	0.372	0.778	47	<0.01	0.372
Total PCB [c]	0.537	48	<0.01		0.478	47	<0.01	
Total DDT [d]	0.385	48	<0.01		0.281	47	>0.05	
Total LAB	0.770	48	<0.01		0.736	47	<0.01	
Al	0.705	48	<0.01		0.648	47	<0.01	
Cd	0.845	48	<0.01		0.673	47	<0.01	
Cr	0.954	48	<0.01		0.856	47	<0.01	
Cu [e]	0.318	48	<0.05		0.495	47	<0.01	
Fe	0.787	48	<0.01		0.734	47	<0.01	
Pb [f]	0.106	46	>0.05	0.393	0.315	45	<0.05	0.393
Hg	0.765	48	<0.01	0.372	0.699	47	<0.01	0.372
Ni	0.828	48	<0.01		0.815	47	<0.01	
Ag	0.825	48	<0.01		0.732	47	<0.01	
Zn	0.945	48	<0.01		0.882	47	<0.01	

[a] TOC at NF14 in 2002 was unusually high and excluded from the post-discharge correlation analyses.
[b] Revisions to the monitoring plan, approved by the USEPA and Massachusetts DEP, were implemented in 2003. Only nearfield stations NF12 and NF17 were sampled for organic contaminants and metals in 2003.
[c] Total PCB at NF07 in 2002 was unusually high; if excluded from the correlation analysis then r = 0.887 (against Fines) and 0.794 (against TOC).
[d] Total DDT at NF21 in 2001 was unusually high; if excluded from the correlation analysis then r = 0.869 (against Fines) and 0.796 (against TOC).
[e] Copper at NF14 in 2001 was unusually high; if excluded from the correlation analysis then r = 0.804 (against Fines) and 0.883 (against TOC).
[f] Lead at NF15 in 2002 was unusually high; if excluded from the correlation analysis then r = 0.377 (against Fines) and 0.650 (against TOC).

Table B4-2a. Correspondence within bulk sediment properties and against contaminants for regional stations before and after the new outfall came on-line.

Parameter	Correspondence against Percent Fines			Critical Value (α=0.01)	Correspondence against TOC			Critical Value (α=0.01)
	r	*n*	*p*		*r*	*n*	*p*	
	Pre-Diversion (1999 – 2000)							
Percent Fines					0.929	28	<0.01	0.478
TOC	0.929	28	<0.01	0.478				
Clostridium perfringens	0.282	28	>0.05		0.261	28	>0.05	0.478
Total PAH	0.331	20	>0.05	0.561	0.343	20	>0.05	0.561
Total PCB	0.545	20	<0.05		0.510	20	<0.05	
Total DDT	0.832	20	<0.01		0.793	20	<0.01	
Total LAB	0.300	20	>0.05		0.352	20	>0.05	
Al	0.798	20	<0.01		0.821	20	<0.01	
Cd	0.369	19	>0.05	0.575	0.498	19	<0.05	0.575
Cr	0.817	20	<0.01	0.561	0.866	20	<0.01	0.561
Cu	0.683	20	<0.01		0.714	20	<0.01	
Fe	0.879	20	<0.01		0.939	20	<0.01	
Pb	0.662	20	<0.01		0.655	20	<0.01	
Hg	0.541	20	<0.05		0.550	20	<0.05	
Ni	0.856	20	<0.01		0.923	20	<0.01	
Ag	0.362	20	>0.05		0.392	20	>0.05	
Zn	0.788	20	<0.01		0.826	20	<0.01	
	Post-Diversion (2001 – 2003)[a]							
Percent Fines					0.952	42	<0.01	0.393
TOC	0.952	42	<0.01	0.393				
Clostridium perfringens	0.187	42	>0.05		0.187	42	>0.05	0.393
Total PAH	0.398	30	<0.05	0.463	0.337	30	>0.05	0.463
Total PCB	0.399	30	<0.05		0.365	30	<0.05	
Total DDT	0.652	30	<0.01		0.632	30	<0.01	
Total LAB	0.162	30	>0.05		0.169	30	>0.05	
Al	0.785	30	<0.01		0.745	30	<0.01	
Cd	0.567	30	<0.01		0.536	30	<0.01	
Cr	0.820	30	<0.01		0.786	30	<0.01	
Cu	0.598	30	<0.01		0.575	30	<0.01	
Fe	0.905	30	<0.01		0.937	30	<0.01	
Pb	0.593	30	<0.01		0.560	30	<0.01	
Hg	0.372	30	<0.05		0.328	30	>0.05	
Ni	0.932	30	<0.01		0.930	30	<0.01	
Ag	0.445	30	<0.05		0.421	30	<0.05	
Zn	0.925	30	<0.01		0.930	30	<0.01	

[a] Revisions to the monitoring plan, approved by the USEPA and Massachusetts DEP, were implemented in 2003. Only nearfield stations NF12 and NF17 were sampled for organic contaminants and metals in 2003.

Table B4-3b. Correspondence within bulk sediment properties and contaminants for offshore regional stations (*i.e.,* excluding FF10, FF12, FF13, NF12, NF17 and NF24) before and after the new outfall came on-line.

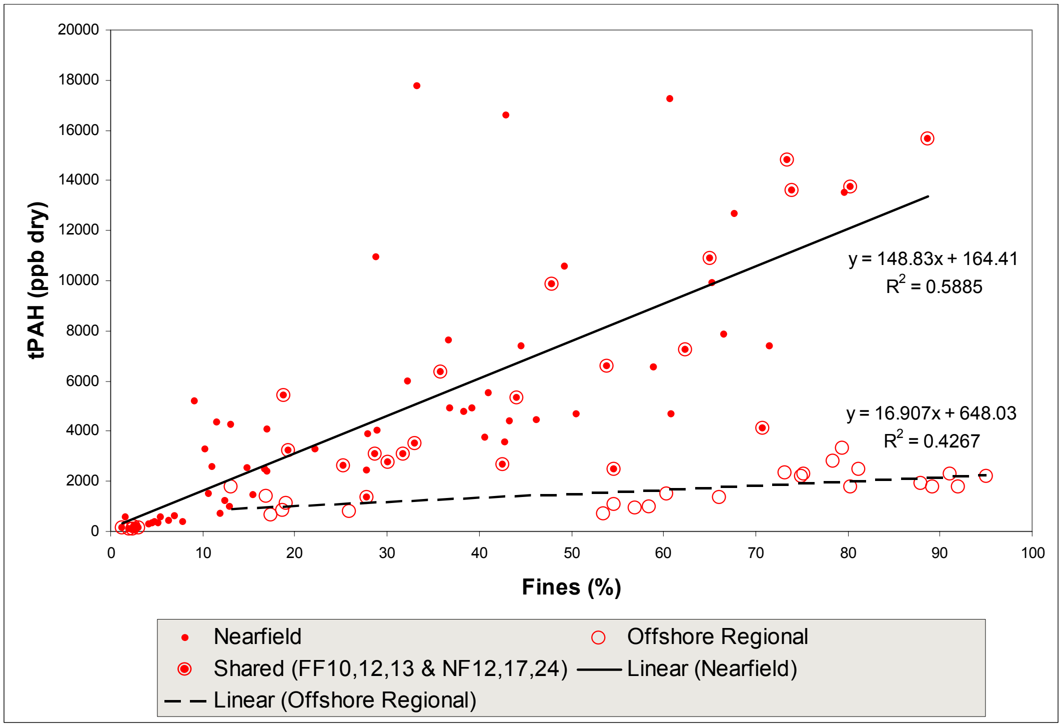
Parameter	Correspondence against Percent Fines			Critical Value (α=0.01)	Correspondence against TOC			Critical Value (α=0.01)
	r	*n*	*p*		*r*	*n*	*p*	
	Pre-Diversion (1999 – 2000)							
Percent Fines					0.907	16	<0.01	0.623
TOC	0.907	16	<0.01	0.623				
Clostridium perfringens	0.825	16	<0.01		0.795	16	<0.01	0.623
Total PAH	0.544	8	>0.05	0.834	0.605	8	>0.05	0.834
Total PCB	0.349	8	>0.05		0.229	8	>0.05	
Total DDT	0.860	8	<0.01		0.922	8	<0.01	
Total LAB	0.879	8	<0.01		0.834	8	<0.01	
Al	0.692	8	>0.05		0.765	8	<0.05	
Cd	0.573	8	>0.05		0.786	8	<0.05	
Cr	0.920	8	<0.01		0.931	8	<0.01	
Cu	0.964	8	<0.01		0.973	8	<0.01	
Fe	0.937	8	<0.01		0.968	8	<0.01	
Pb	0.885	8	<0.01		0.899	8	<0.01	
Hg	0.910	8	<0.01		0.873	8	<0.01	
Ni	0.917	8	<0.01		0.964	8	<0.01	
Ag	0.656	8	>0.05		0.687	8	>0.05	
Zn	0.952	8	<0.01		0.956	8	<0.01	
	Post-Diversion (2001 – 2003) [a]							
Percent Fines					0.941	24	<0.01	0.515
TOC	0.941	24	<0.01	0.515				
Clostridium perfringens	0.622	24	<0.01		0.598	24	<0.01	0.515
Total PAH	0.739	16	<0.01	0.623	0.716	16	<0.01	0.623
Total PCB	0.706	16	<0.01		0.608	16	<0.05	
Total DDT	0.654	16	<0.01		0.658	16	<0.01	
Total LAB	0.594	16	<0.05		0.636	16	<0.01	
Al	0.697	16	<0.01		0.721	16	<0.01	
Cd	0.714	16	<0.01		0.826	16	<0.01	
Cr	0.948	16	<0.01		0.933	16	<0.01	
Cu	0.919	16	<0.01		0.941	16	<0.01	
Fe	0.941	16	<0.01		0.977	16	<0.01	
Pb	0.895	16	<0.01		0.900	16	<0.01	
Hg	0.899	16	<0.01		0.873	16	<0.01	
Ni	0.947	16	<0.01		0.942	16	<0.01	
Ag	0.689	16	<0.01		0.731	16	<0.01	
Zn	0.954	16	<0.01		0.980	16	<0.01	

[a] Revisions to the monitoring plan, approved by the USEPA and Massachusetts DEP, were implemented in 2003. As a result, there are no applicable contaminant data for 2003 for offshore regional stations

Correlation Plots
Nearfield and Regional Data, 1999–2003

NF14 TOC (2002), NF07 total PCB (2002), NF21 total DDT (2001), NF14 Cu (2001), and NF15 Pb (2002) data were outliers (unusually high values), and were therefore excluded from the correlation analyses.

Shared stations referred to below are those nearfield and farfield stations that have traditionally been classified as both *nearfield* and *regional*, *i.e.,* NF12, NF17, NF24, FF10, FF12 and FF13).



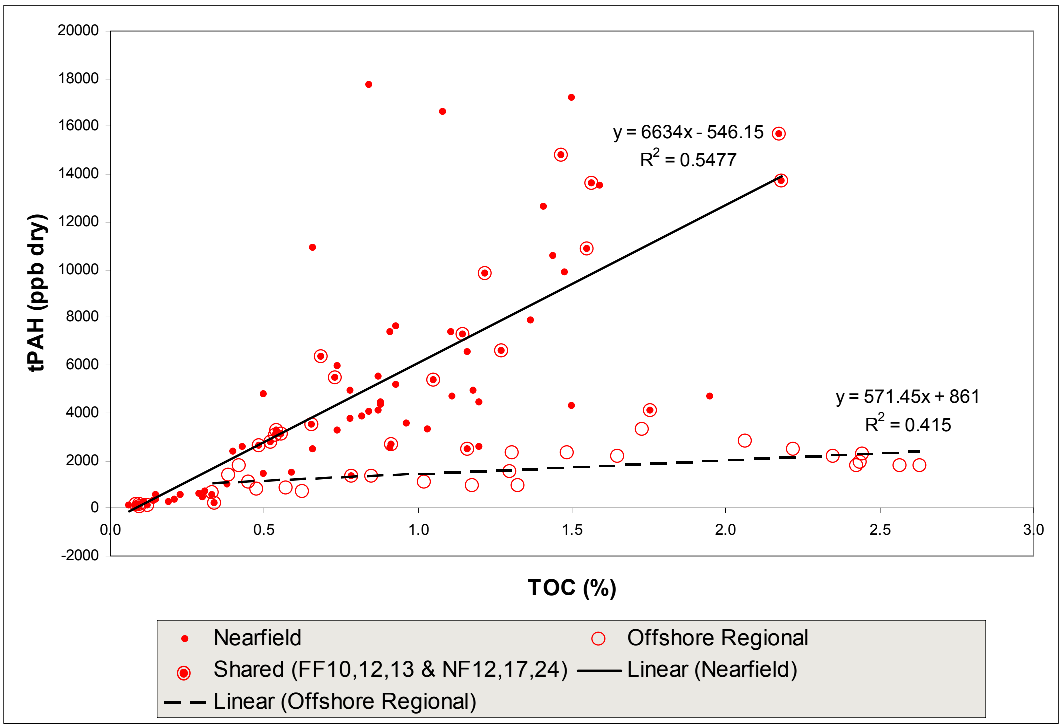
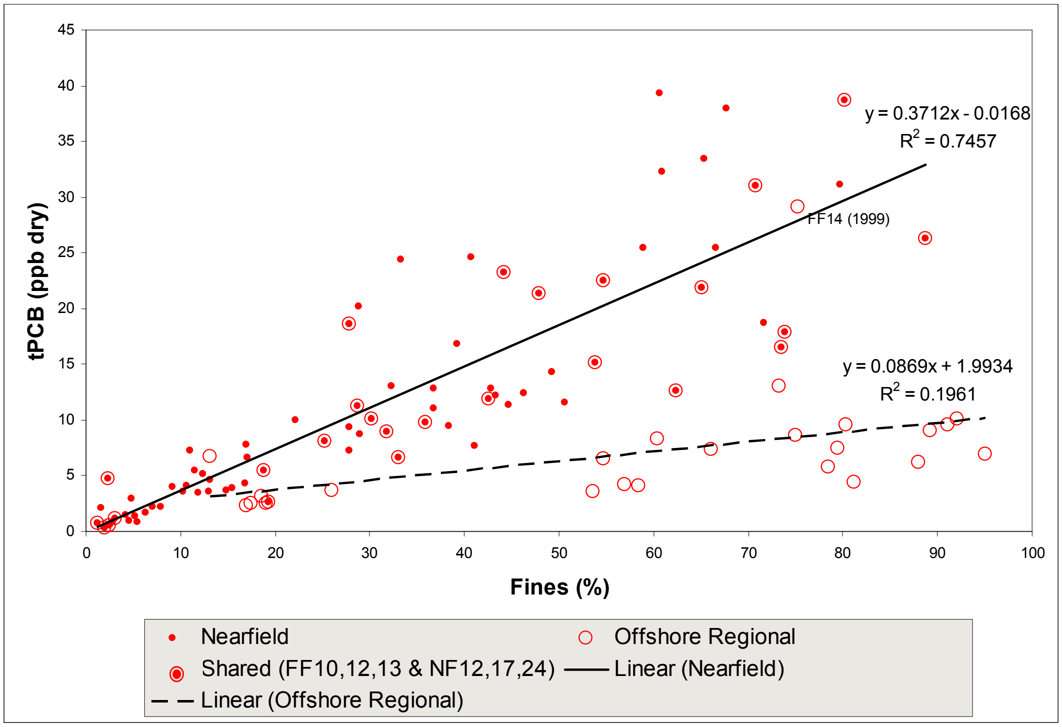


Figure B4-1. Correspondence between total PAH and percent fines (top) and TOC (bottom) at nearshore and offshore locations (using 1999-2003 station mean values).



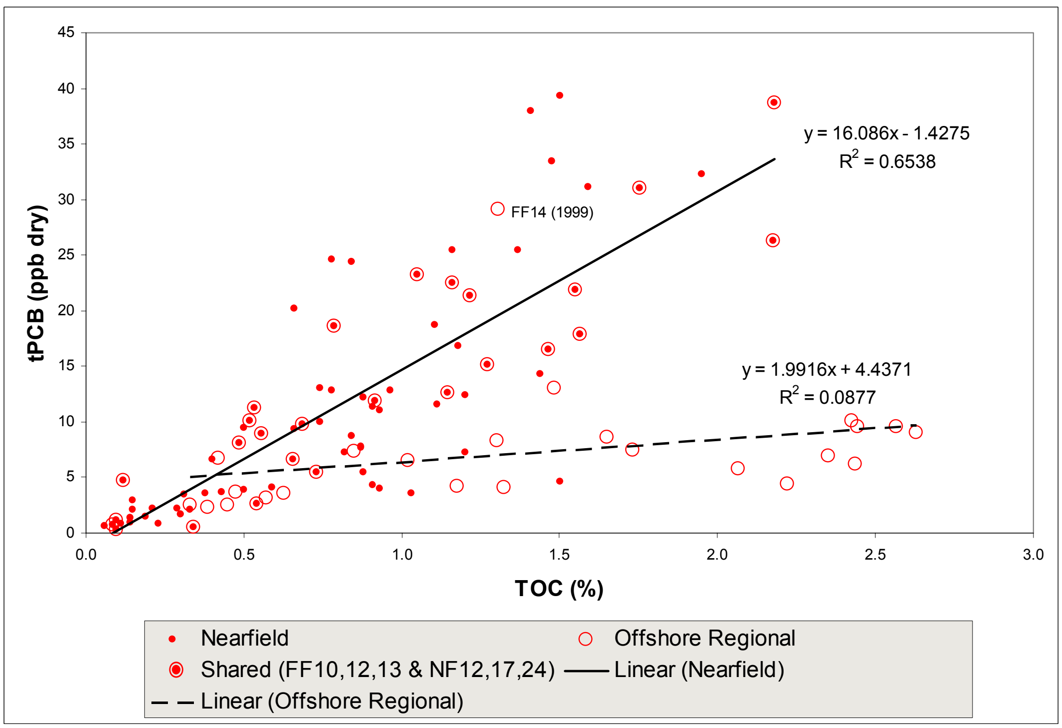


Figure B4-2. Correspondence between total PCB and percent fines (top) and TOC (bottom) at nearshore and offshore locations (using 1999-2003 station mean values).

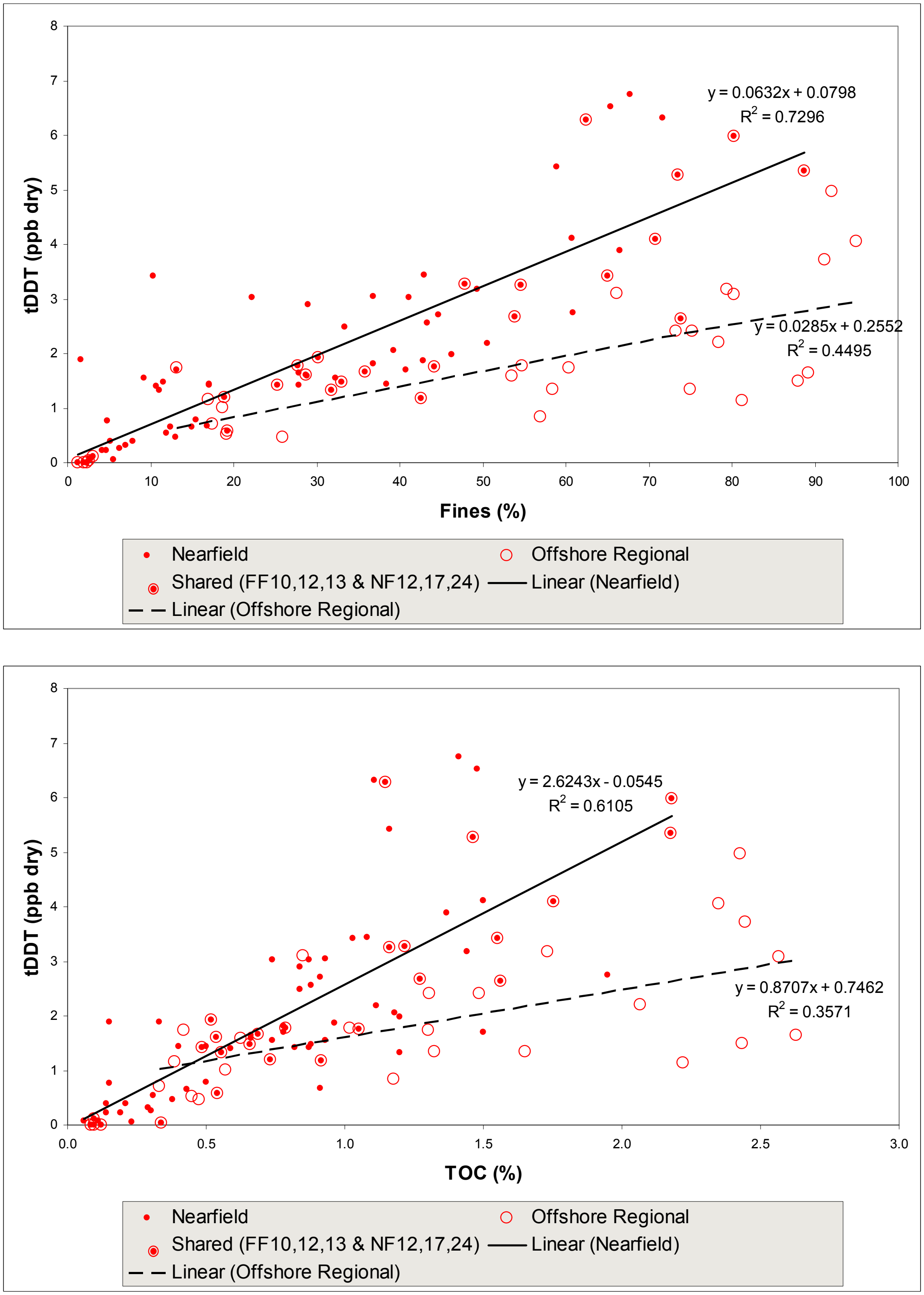
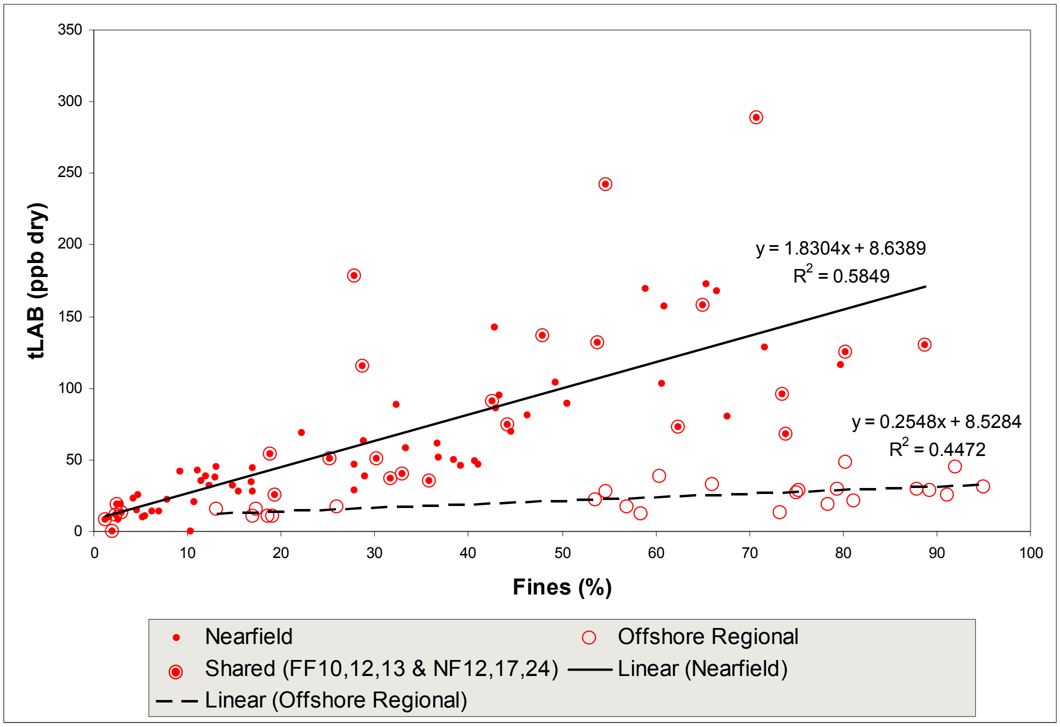


Figure B4-3. Correspondence between total DDT and percent fines (top) and TOC (bottom) at nearshore and offshore locations (using 1999-2003 station mean values).



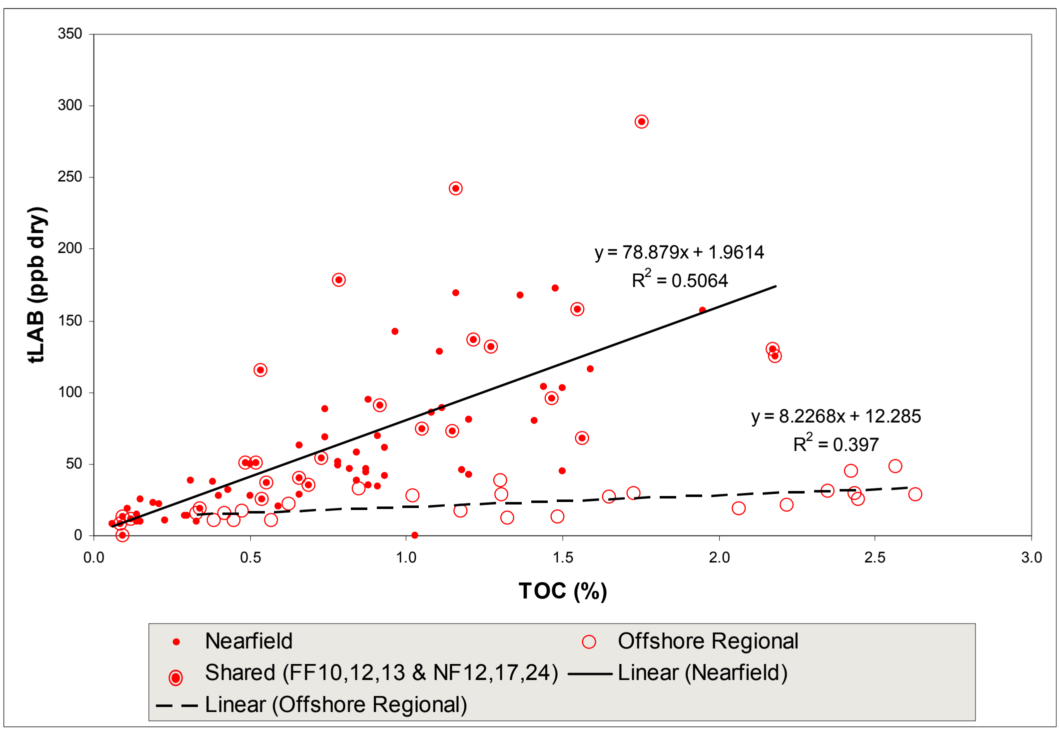
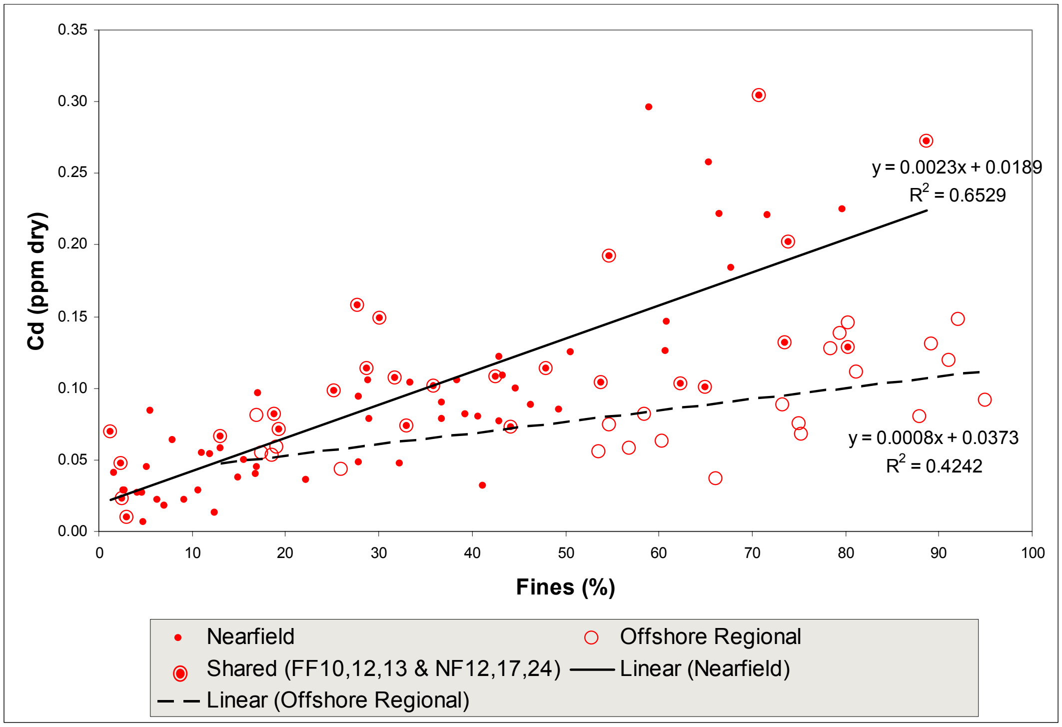


Figure B4-4. Correspondence between total LAB and percent fines (top) and TOC (bottom) at nearshore and offshore locations (using 1999-2003 station mean values).



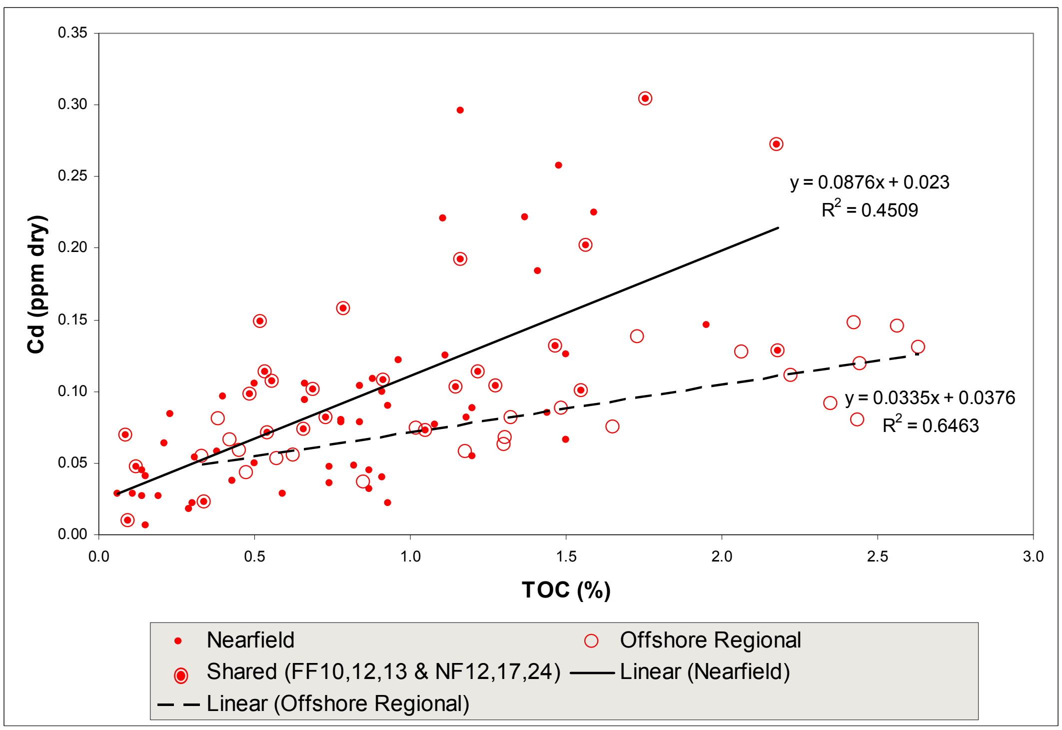
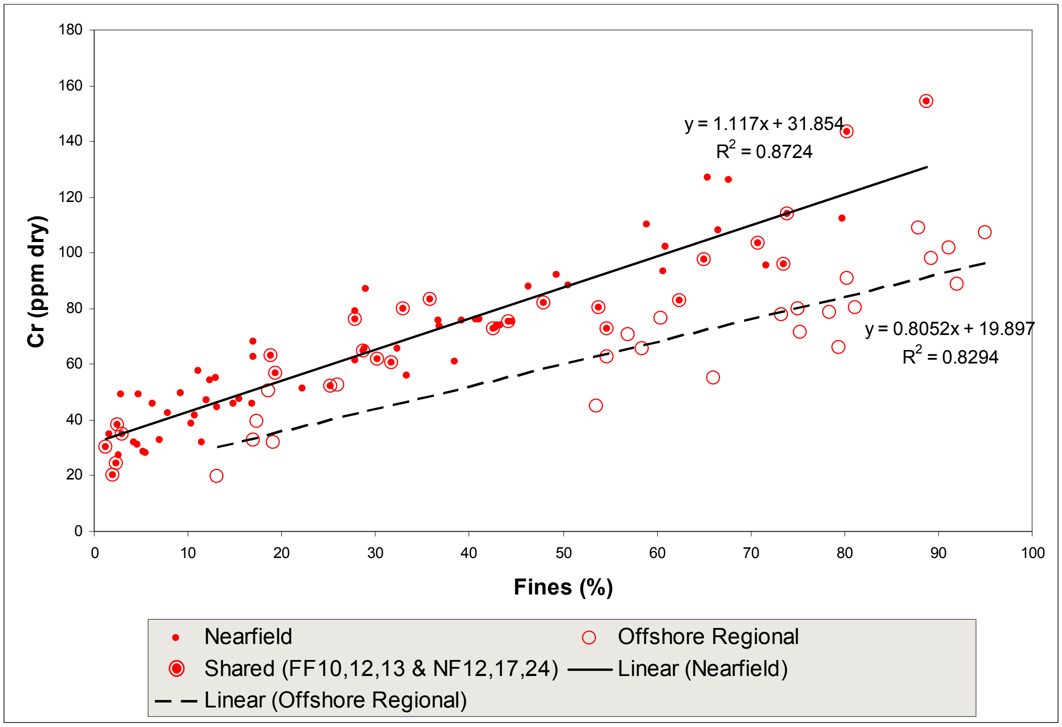


Figure B4-5. Correspondence between Cadmium (Cd) and percent fines (top) and TOC (bottom) at nearshore and offshore locations (using 1999-2003 station mean values).



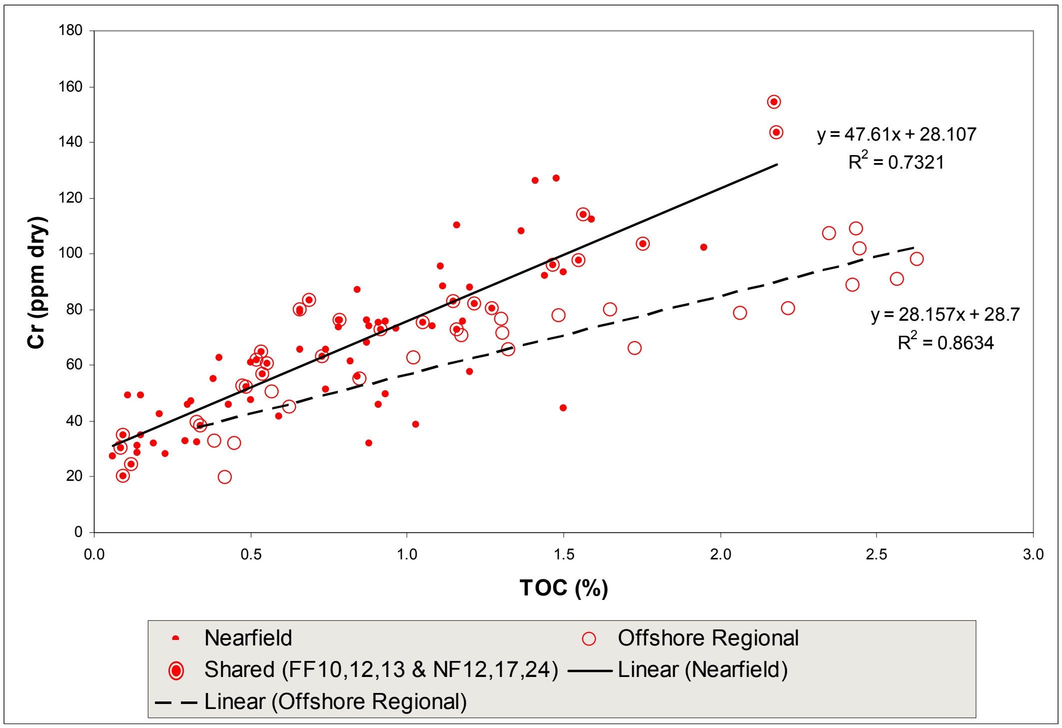
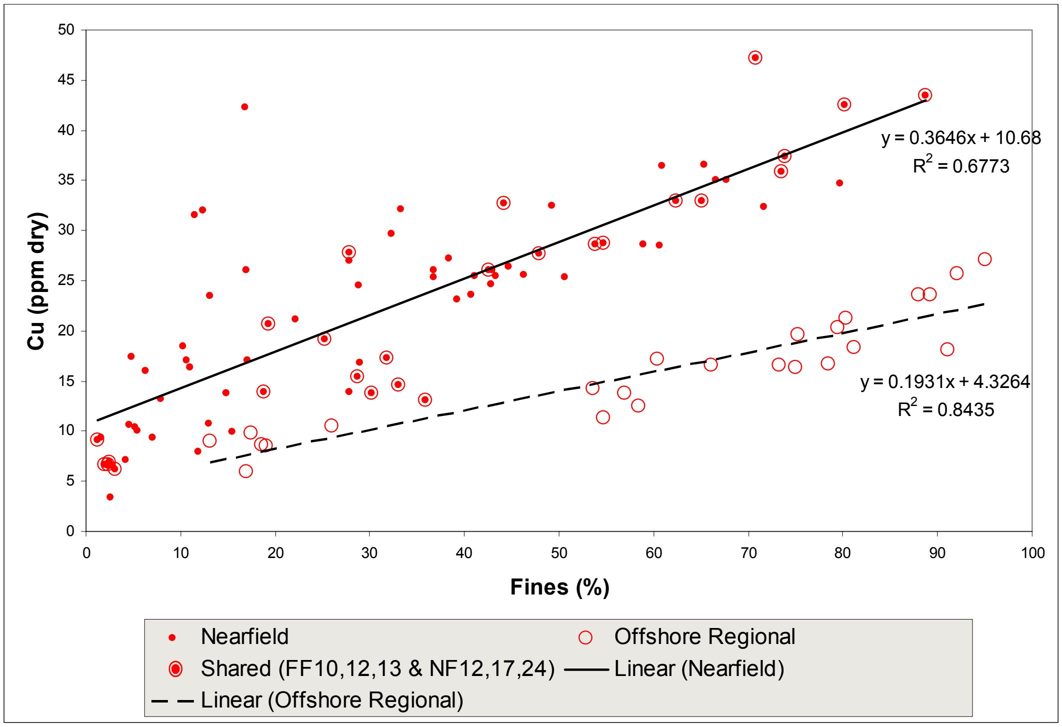


Figure B4-6. Correspondence between Chromium (Cr) and percent fines (top) and TOC (bottom) at nearshore and offshore locations (using 1999-2003 station mean values).



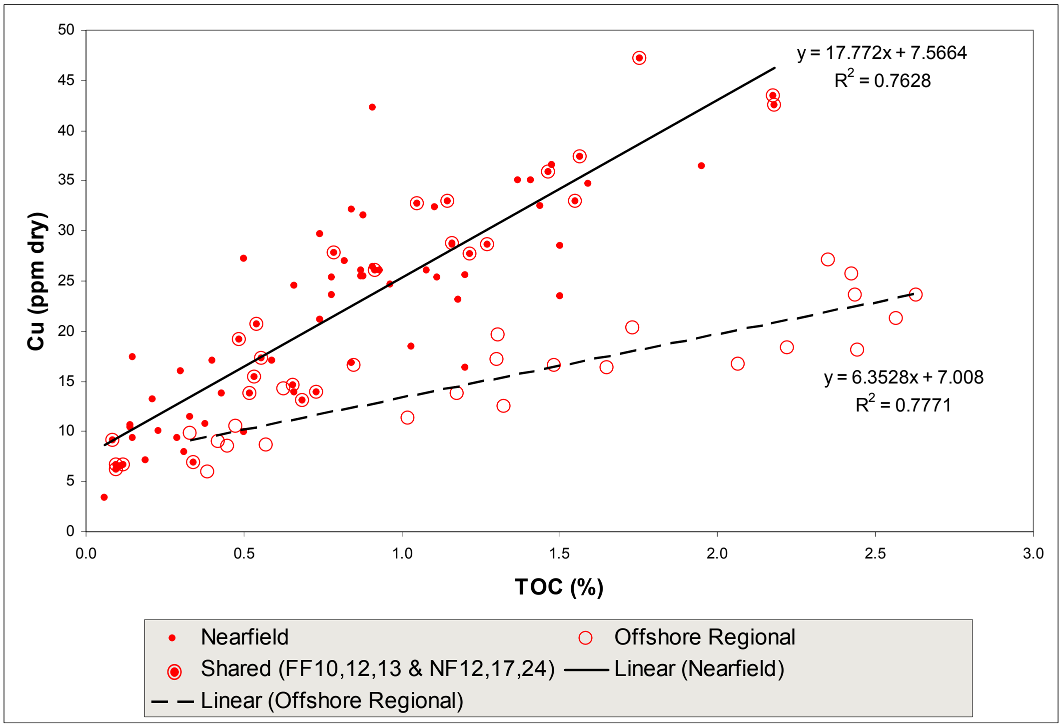
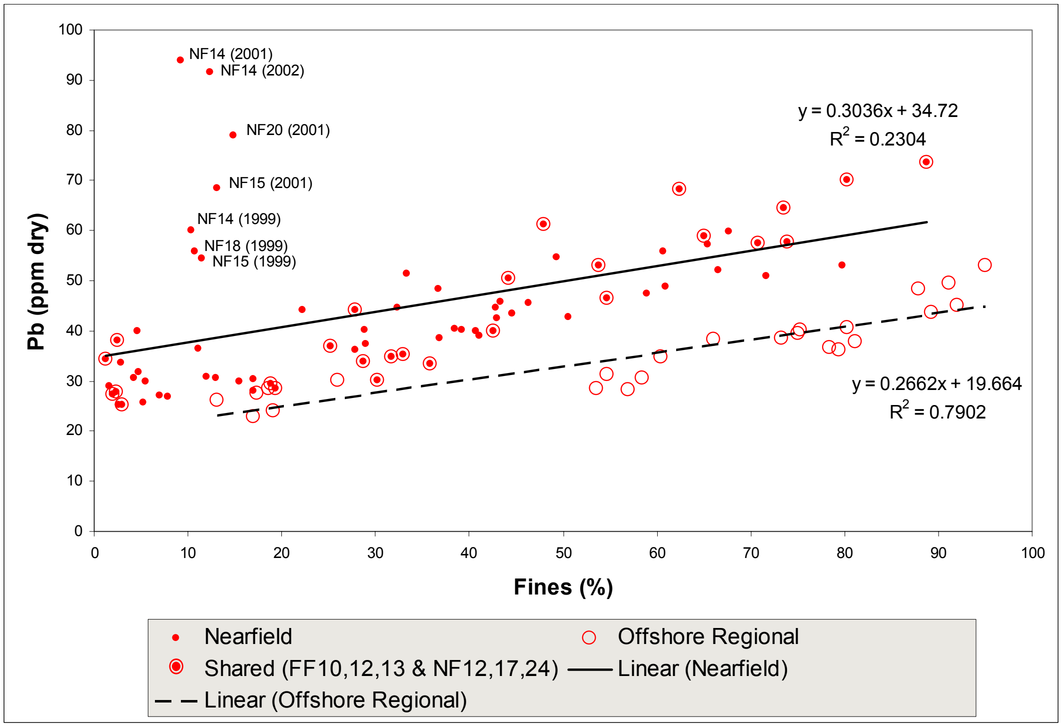


Figure B4-7. Correspondence between Copper (Cu) and percent fines (top) and TOC (bottom) at nearshore and offshore locations (using 1999-2003 station mean values).



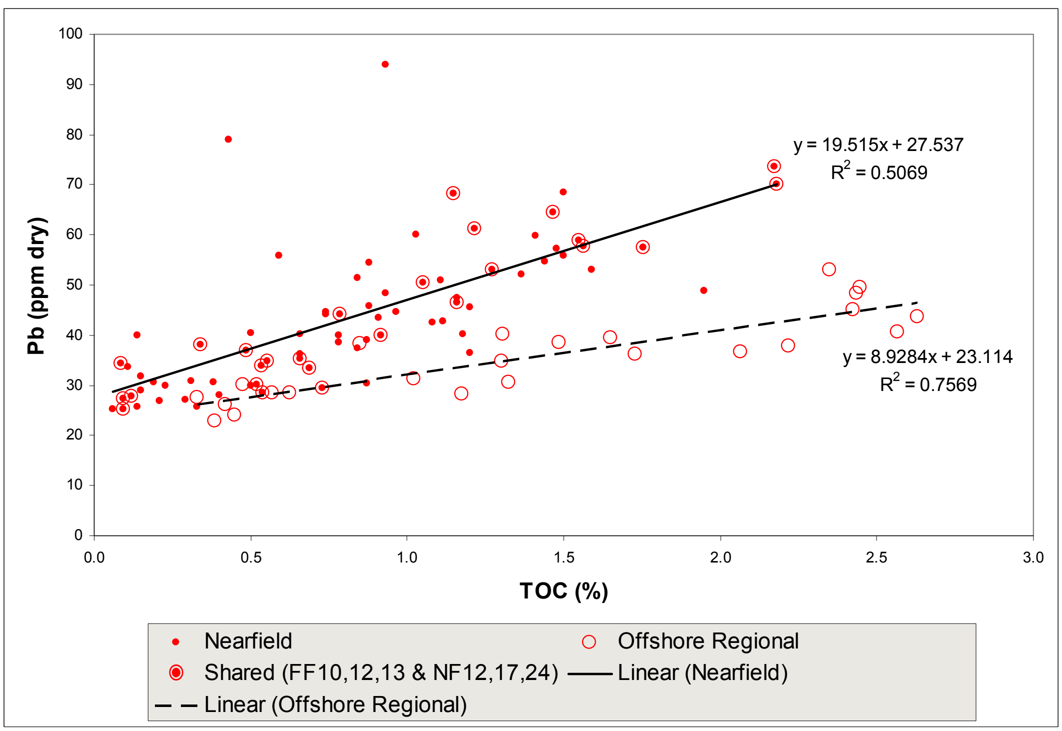
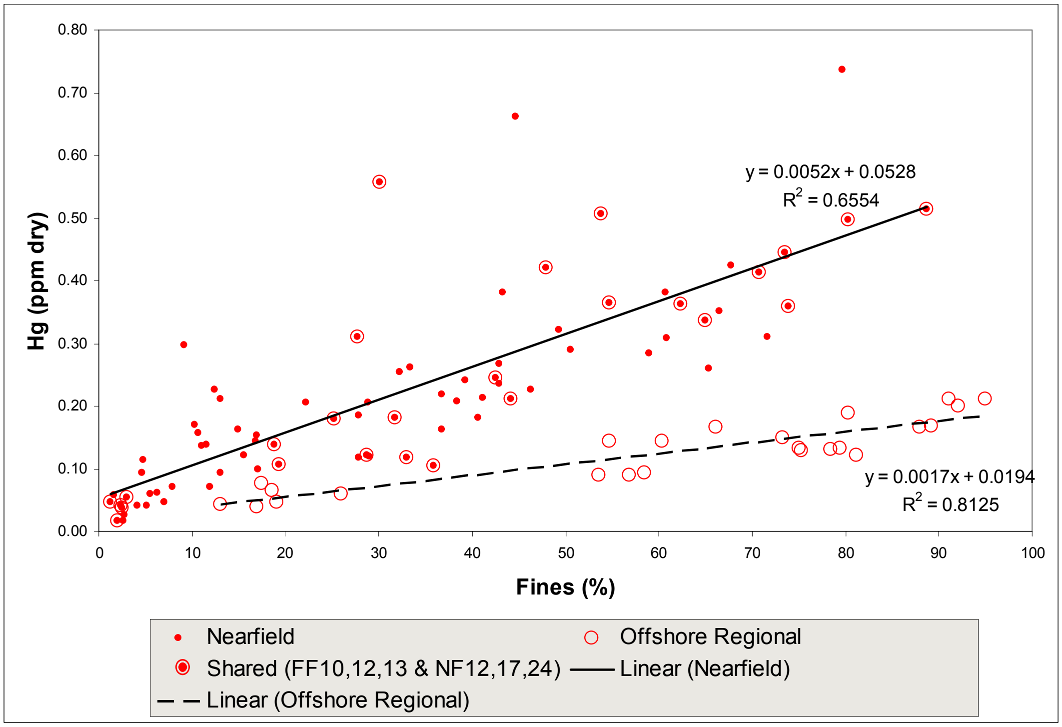


Figure B4-8. Correspondence between Lead (Pb) and percent fines (top) and TOC (bottom) at nearshore and offshore locations (using 1999-2003 station mean values).



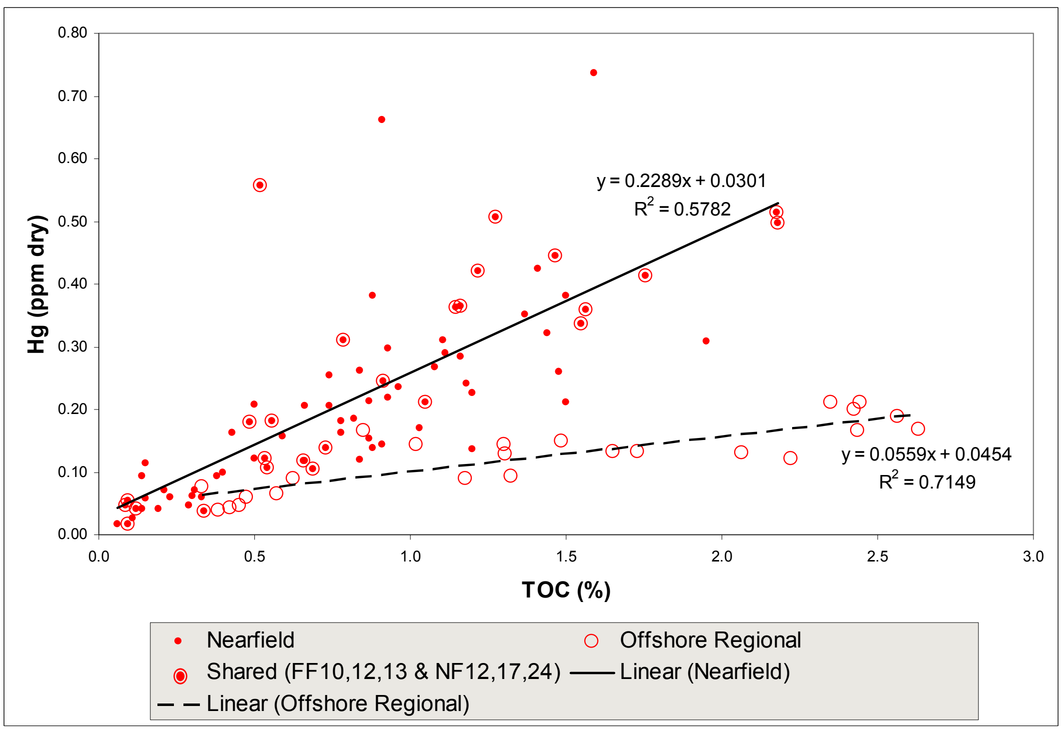
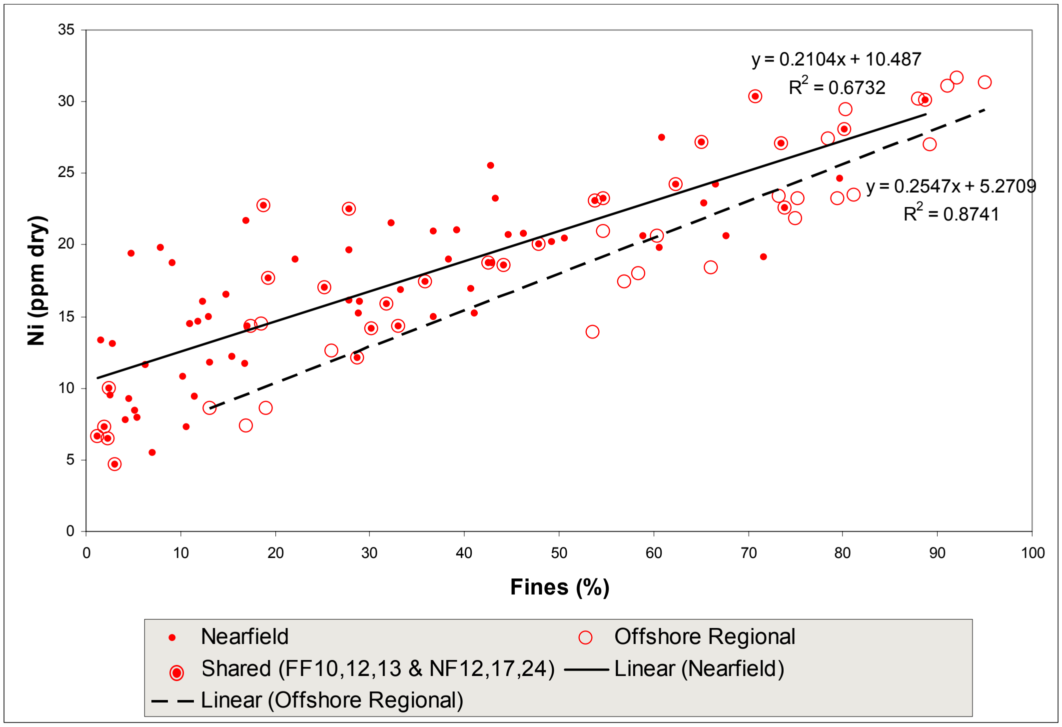


Figure B4-9. Correspondence between Mercury (Hg) and percent fines (top) and TOC (bottom) at nearshore and offshore locations (using 1999-2003 station mean values).



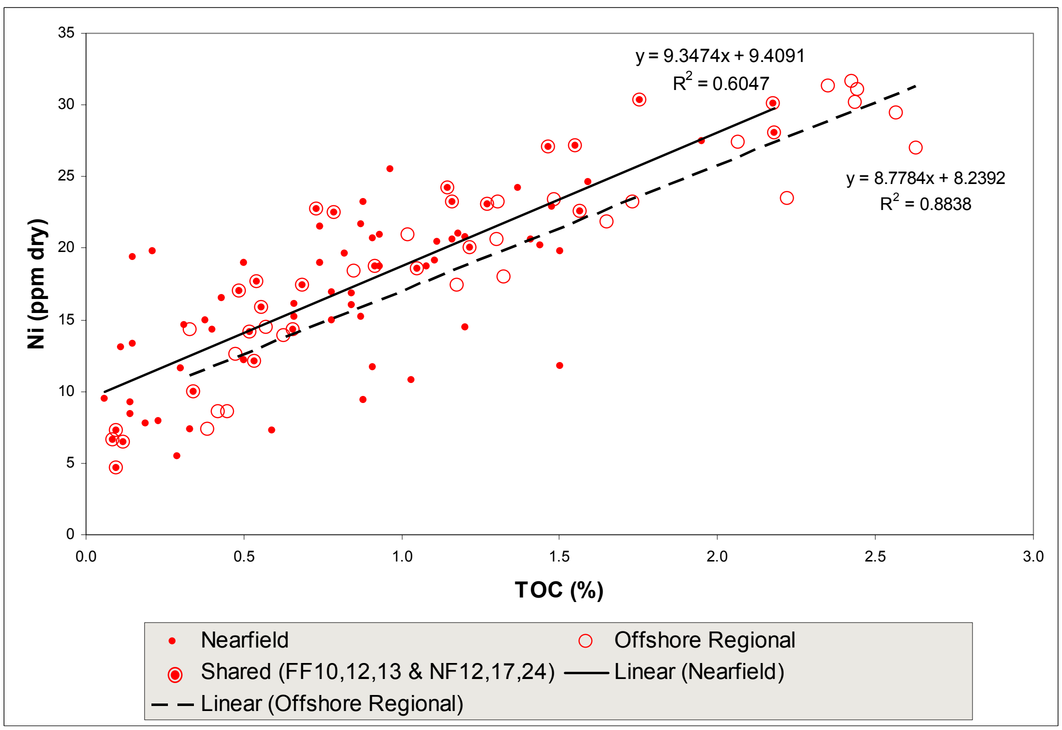
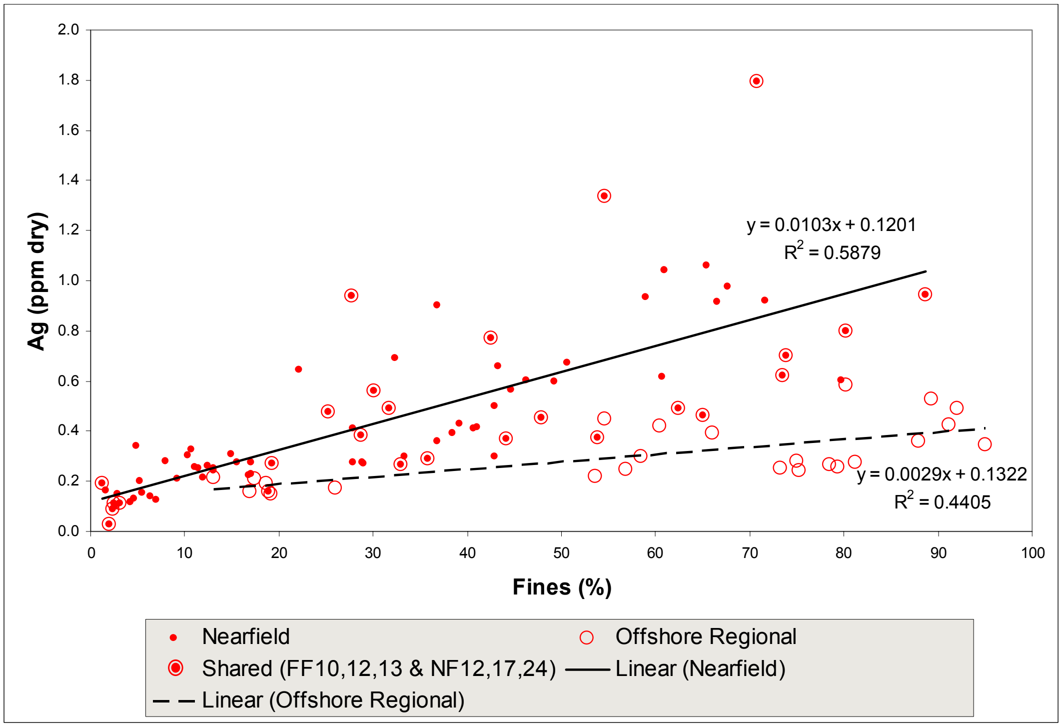


Figure B4-10. Correspondence between Nickel (Ni) and percent fines (top) and TOC (bottom) at nearshore and offshore locations (using 1999-2003 station mean values).



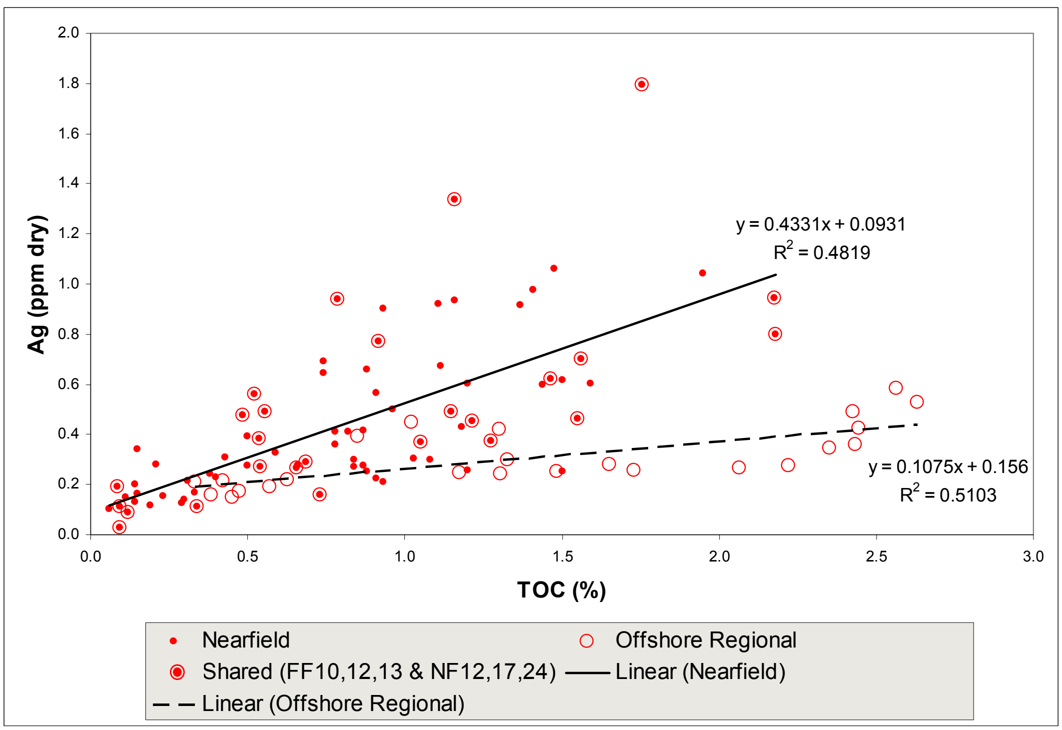
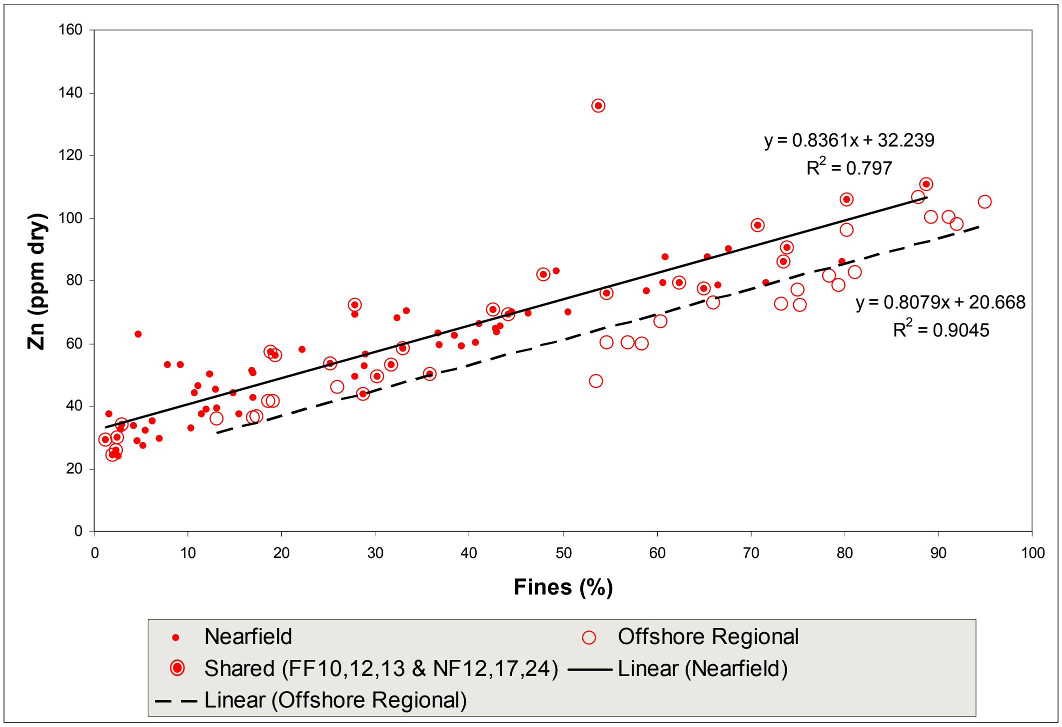


Figure B4-11. Correspondence between Silver (Ag) and percent fines (top) and TOC (bottom) at nearshore and offshore locations (using 1999-2003 station mean values).



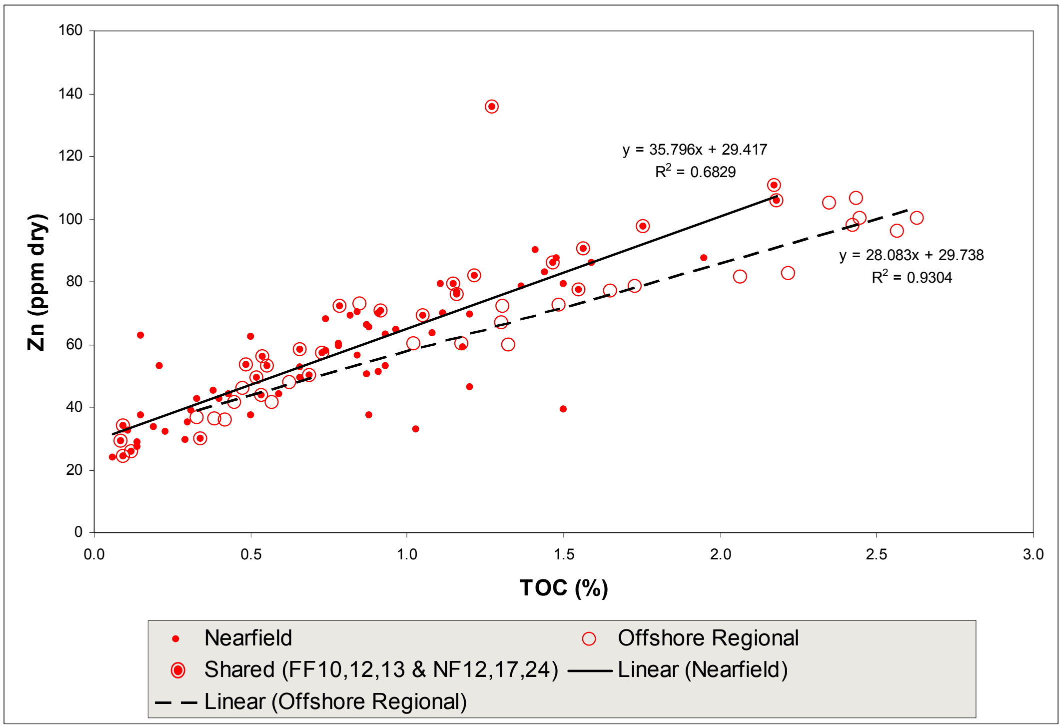
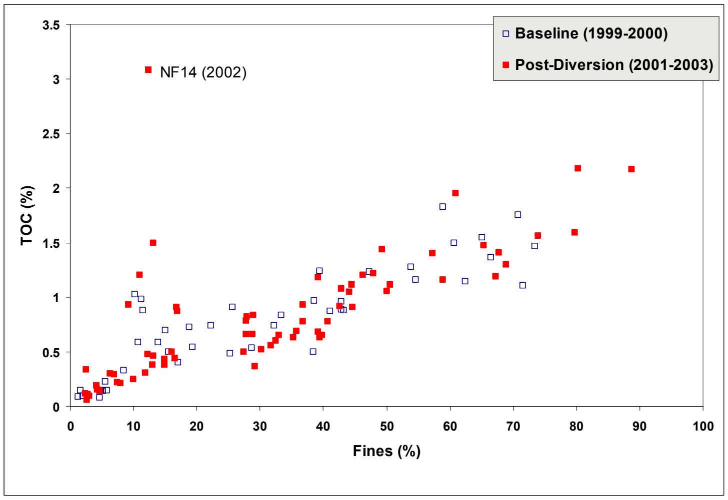


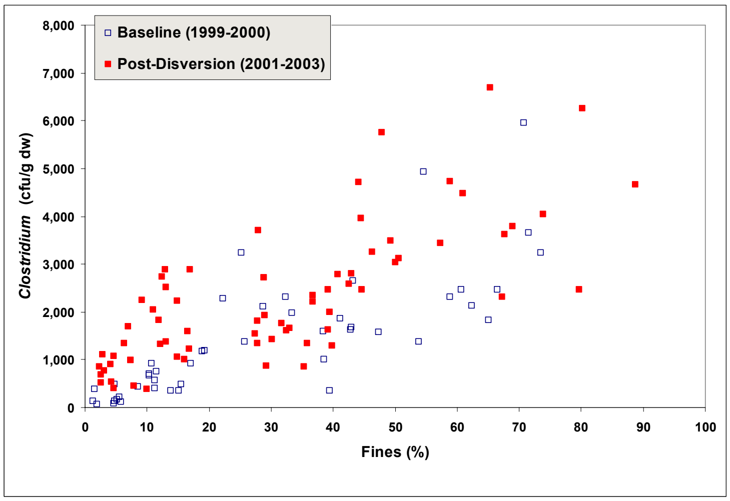
Figure B4-12. Correspondence between Zinc (Zn) and percent fines (top) and TOC (bottom) at nearshore and offshore locations (using 1999-2003 station mean values).

Supplemental Correlation Plots
Correspondence Between Grain Size and TOC, and Against Contaminants
Nearfield Data (Station Mean Values), 1999 – 2003

A



B



C

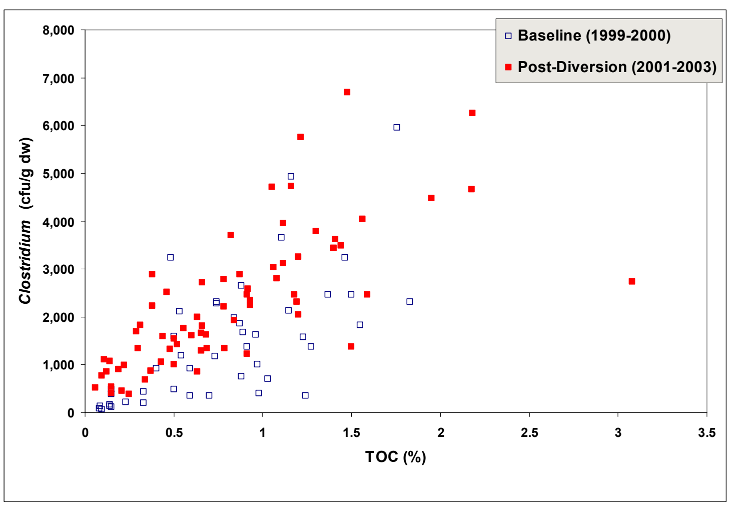
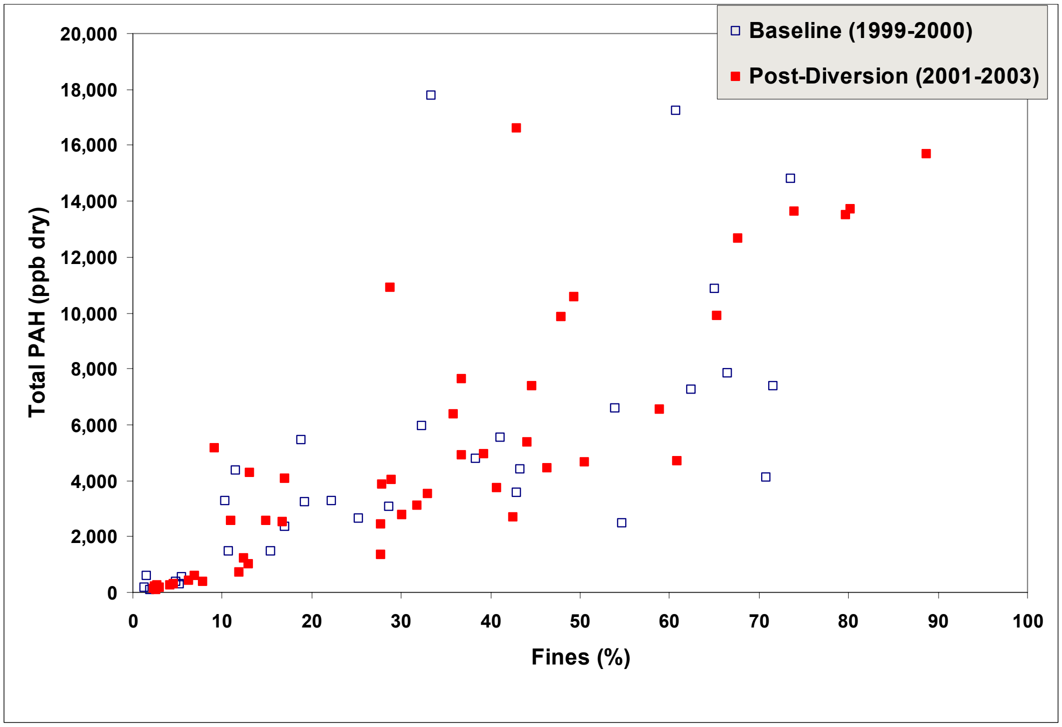


Figure B4-13. Correspondence between percent fines and TOC (A), between percent fines and *C. perfringens* (B), and between TOC and *C. perfringens* (C) during pre- (1999-2000) and post-diversion (2001-2003) periods.

A



B

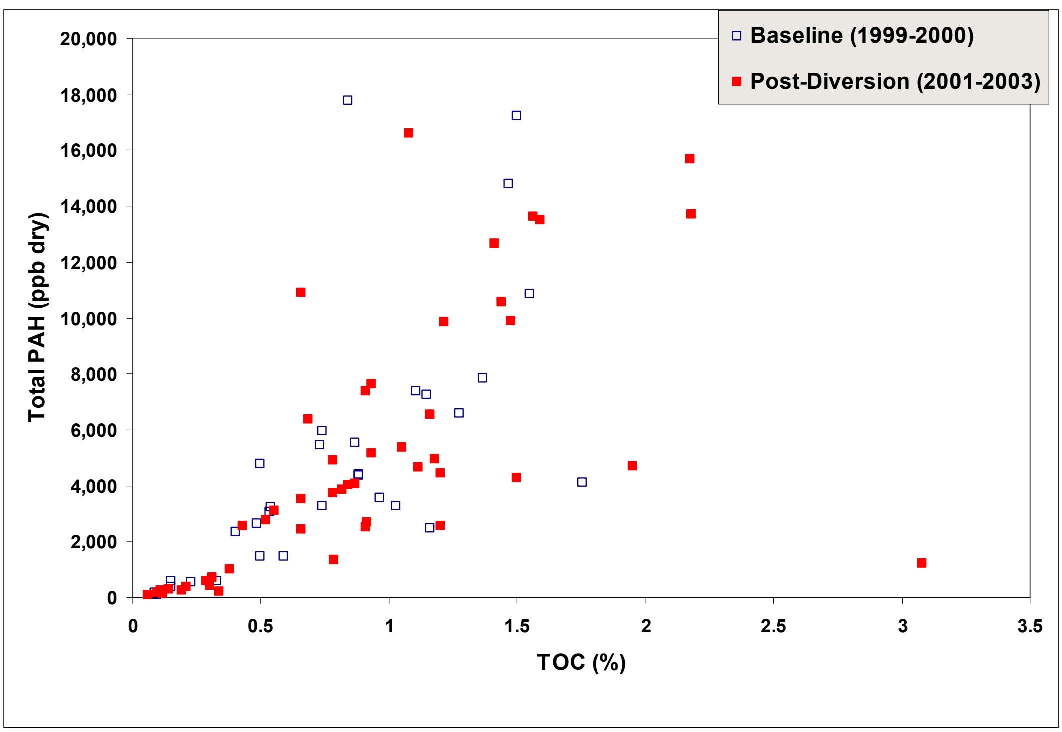
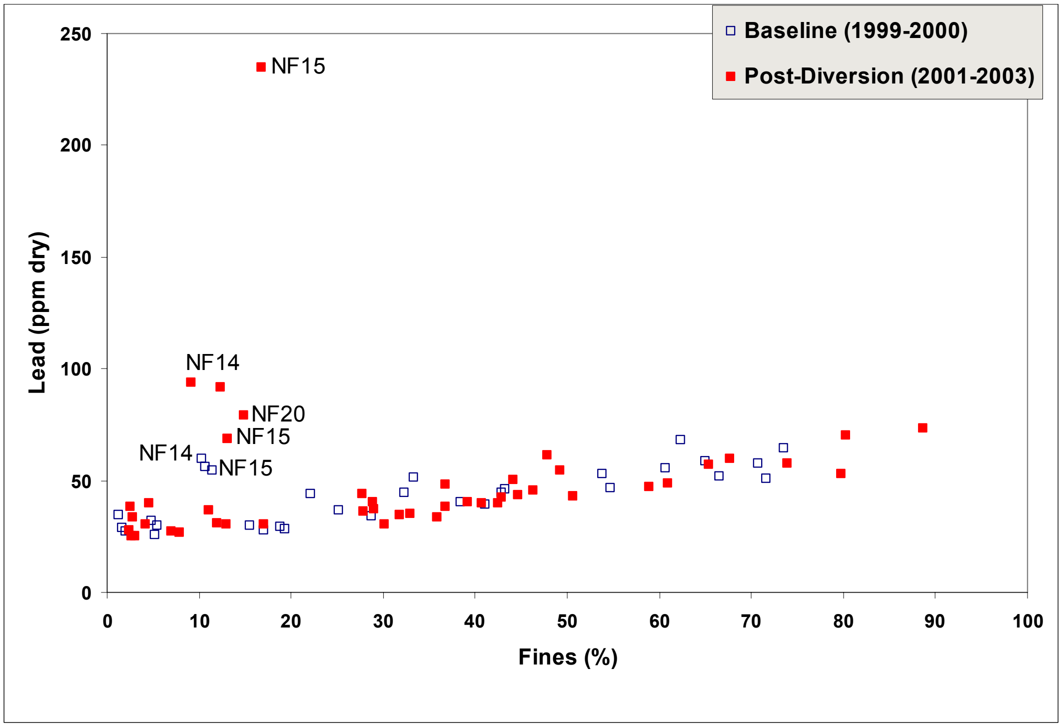


Figure B4-14. Correspondence between percent fines and total PAH (A), and between TOC and total PAH (B) during pre- (1999-2000) and post-diversion (2001-2003) periods.

A



B

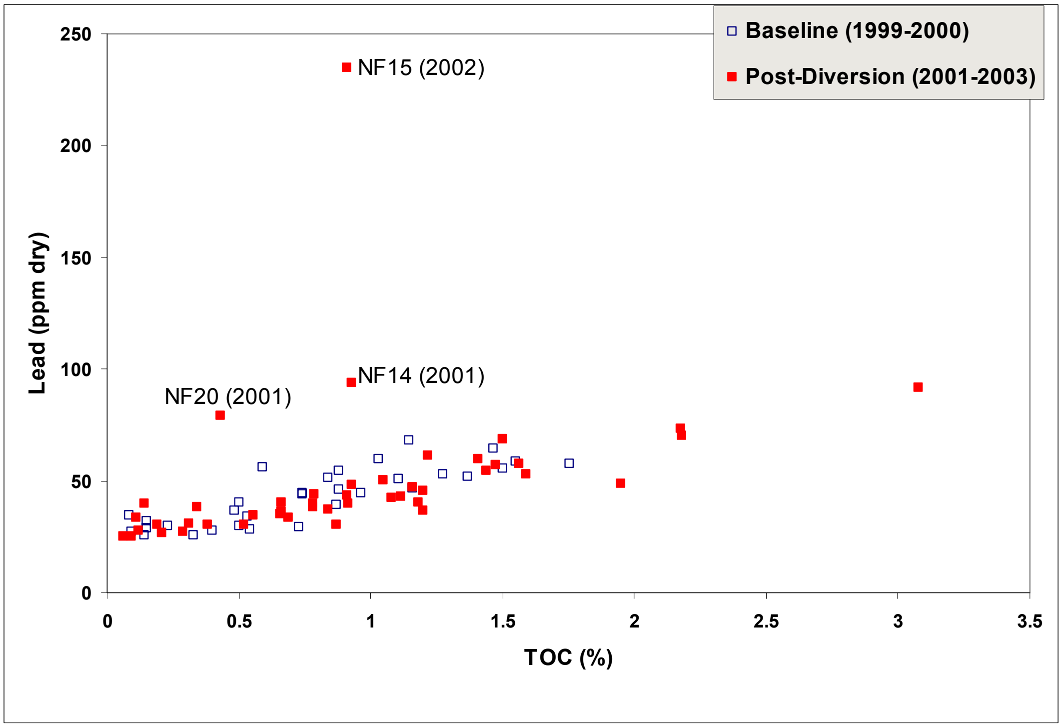


Figure B4-15. Correspondence between percent fines and lead (A), and between TOC and lead (B) during pre- (1999-2000) and post-diversion (2001-2003) periods.

APPENDIX C1

2003 Preliminary Treatment of Infaunal Species

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.						
5515020301	*Thyasira flexuosa*	G	1	*Thyasira gouldi*	5515020325	per IPW
5001231304	*Odontosyliis fulgurans*	G	2	Specimen reidentified by NJM as *Pionospyllis* sp. A	50012302SP01	per NJM
61693501SPP	*Melphidippa spp.*	B	2	Change name to *Melphidippa cf. goesi,* treat as Good species		per IPW
MERGE ONLY FOR ANALYSES FOR REPORT:						
3901SP01	*Turbellaria* sp. 1		3	Combine with *Turbellaria* spp. for report.	3901SPP	per SOP/Kropp
3901SP02	*Turbellaria* sp. 2		3	Combine with *Turbellaria* spp. for report.	3901SPP	per SOP/Kropp
3901SPP	*Turbellaria spp.*		3	Treat as Good species for report.	3901SPP	SOP
43030205SPP	*Micrura* spp.		3	Treat as Good species for report.	43030205SPP	SOP
5001630302	*Maldane glebifex*		3	Combine with *Maldane sarsi* for report.	5001630301	SOP
5001631102CF	*Euclymene cf. collaris*		3	Combine with *Euclymene collaris* for report	5001631102	SOP
5402010102	*Aplacophora* spp		3	Combine with *Chaetoderma nitidulum canadense for* report.	5402010102	per SOP/Kropp
5001631202	*Clymenura polaris*		3	Combine with *Clymenura* sp. A for report.	50016312SP01	per SOP/Kropp
50016817SP01	*Proclea* sp. 1		3	Combine with *Proclea graffi* for report.	5001681702	per SOP/Kropp
5001420101	*Apistobranchus tullbergi*		3	Combine with *Apistobranchus typicus* for report	5001420103	per SOP/Kropp/NJM
50020601TECT	*Pholoe tecta*		3	Combine with *Pholoe minuta* for report	5001060101	per SOP
8401SPP	*Ascidiacea* spp.		3	Combine with *Molgula manhattensis* for report.	8406030108	per JAB
84060301SPP	*Molgula* spp.		3	Combine with *Molgula manhattensis* for report.	8406030108	per JAB
50015004SPP	*Chaetozone* spp.		3	Combine with *Chaetozone setosa* for report.	50015004MB	per JAB
500150043SP04	*Chaetozone* sp. 4		3	Combine with *Chaetozone setosa* for report.	50015004MB	per JAB

50015004SP05	*Chaetozone* sp. 5		3	Combine with *Chaetozone setosa* for report.	50015004MB	per JAB
50012404SPP	*Nereis* spp.		3	Combine with *Nereis grayi* for report	5001240409	per CTM
56SPP	*Scaphopoda* spp.		3	Combine with *Dentalium entale* for report.	5601010201	per JAB and RK (2001)
3743010102	*Cerianthus borealis*		3	Combine with *Ceriantheopsis americanus* for report	3743010201	per IPW, who identified this species originally
374301SPP	*Cerianthidae* spp.		3	Combine with *Ceriantheopsis americanus* for report	3743010201	per IPW
3758SP02	*Actiniaria* sp. 2		3	Combine with *Ceriantheopsis americanus* for report	3743010201	per IPW
5001260401	*Sphaerodoridium claparedii*		3	Combine with *Sphaerodoridium* sp. A for report	50012604SP01	per NJM
616312SPP	*Munnidae* spp.		3	Combine with *Munna* sp. 1 for report	61631201SP01	per IPW
61631201SPP	*Munna* spp.		3	Combine with *Munna* sp.1 for report	61631201SP01	per IPW
50014016SP01	*Leitoscoloplos* sp. B		3	Combine with *Leitoscoloplos acutus* for report	5001400305	per JAB (*L*. sp.B apparently not used by Cove)
50014016SPP	*Leitoscoloplos* spp.		3	Combine with *Leitoscoloplos acutus* for report	5001400305	per JAB
	Ampharete baltica		3	Combine with *Ampharete acutifrons* for report		for consistency/NJM
Change designation to "W" and do not include in data export:						
5509090202	*Anomia simplex*	G	4	W	5509090202	Not infaunal
5509090203	*Anomia squamula*	G	4	W	5509090203	Not infaunal
55090902SPP	*Anomia spp.*	B	4	W	55090902SPP	Not infaunal

The 456 (after the merges listed above) taxa that were used for diversity and multivariate analysis are listed in Appendix C2. The following 173 categories were included for calculations of total abundances, but were 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.

The 22 taxa that are recorded as samples are processed, but are not included in any summations are:

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

APPENDIX C2

Species Identified in Massachusetts Bay Samples 1992–2003

Table C2-1. Species identified from Massachusetts Bay Outfall Monitoring Program samples from 1992–2003 (May 1992 and FF-08 samples are excluded) and used in the 2003 community analysis. Species collected in August 2003 samples are marked with an asterisk (*). Species new to the list in 2003 are underlined.

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

PLATYHELMINTHES
- Turbellaria spp. *

NEMERTEA
- *Amphiporus angulatus* (Fabricius, 1774)
- *Amphiporus bioculatus* McIntosh, 1873 *
- *Amphiporus caecus* Verrill, 1892 *
- *Amphiporus cruentatus* Verrill, 1879 *
- *Amphiporus groenlandicus* Oersted, 1844
- *Carinomella lactea* Coe, 1905 *
- Cephalothricidae sp. 1 *
- *Cerebratulus lacteus* (Leidy, 1851) *
- *Lineus pallidus* Verrill, 1879 *
- 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)*
- *Tetrastemma vittatum* Verrill, 1874
- *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) *
Praxillura ornata Verrill, 1880 *
Praxillella praetermissa (Malmgren, 1866) *
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 *
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) *
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) *
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* (name change)
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)
Trichobranchidae
Terebellides atlantis Williams, 1984 *
Terebellides stroemii Sars, 1835 *
Trichobranchus glacialis Malmgren, 1866) *
Trichobranchus roseus (Malm, 1874) *
Trochochaetidae
Trochochaeta carica (Birula, 1897) *
Trochochaeta multisetosa (Oersted, 1844) *
Trochochaeta watsoni (Fauvel, 1916) *
Oligochaeta
Enchytraiedae
Enchytraiedae sp. 1 *
Enchytraiedae sp. 2 *
Enchytraiedae sp. 3 *
Grania postclitellochaeta longiductа 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
Gammarelluss angulosus (Rathke, 1843) *
Haustoriidae
Acanthohaustorius millsi Bousfield, 1965 *
Acanthohaustorius spinosus Bousfield, 1962 *
Pseudohaustorius borealis Bousfield, 1965 *
Isaeidae
Photis pollex Walker, 1895 *
Photis reinhardi Krøyer, 1842 *
Protomedeia fasciata Krøyer, 1846 *
Ischyroceridae
Erichthonius fasciatus (Stimpson, 1853) *
Ischyrocerus anguipes (Krøyer, 1842) *
Jassa marmorata Holmes, 1903 *
Lysianassidae
Anonyx lilljeborgi Boeck, 1871*
Hippomedon propinquus Sars, 1895 *
Hippomedon serratus Holmes, 1905 *
Orchomenella minuta (Krøyer, 1842) *
Melitidae
Casco bigelowi (Blake, 1929) *
Maera loveni (Bruzelius, 1859) *
Megamoera dentata (Krøyer, 1842) *
Melitidae sp. 1 *
Melphidippidae
Melphidippa cf. *borealis* Boeck, 1871*
Melphidippa cf. *goesi* Stebbing, 1899

Oedicerotidae
Ameroculodes sp. 1 *
Bathymedon obtusifrons (Hansen, 1887) *
Deflexilodes intermedius (Shoemaker, 1830) *
Deflexilodes tesselatus (Schneider, 1884) *
Deflexilodes tuberculatus (Boeck, 1870) *
Monoculodes packardi Boeck, 1871 *
Westwoodilla brevicalcar Goës, 1866
Westwoodilla megalops (Sars, 1883)*

Phoxocephalidae
Eobrolgus spinosus (Holmes, 1905) *
Harpinia propinqua Sars, 1895 *
Phoxocephalus holbolli (Krøyer, 1842) *
Rhepoxinius hudsoni Barnard & Barnard, 1982 *
Pleustidae
Parapleustes gracilis Buchholz, 1874 *
Pleustes panoplus (Krøyer, 1838) *
Pleusymtes glaber (Boeck, 1861) *
Stenopleustes inermis Shoemaker, 1949 *
Podoceridae
Dulichia tuberculata Boeck, 1870 *
Dyopedos monacanthus (Metzger, 1875) *
Paradulichia typica Boeck, 1870 *
Pontogeniidae
Pontogenia inermis (Krøyer, 1842) *
Stenothoidae
Metopella angusta Shoemaker, 1949 *
Proboloides holmesi Bousfield, 1973 *
Synopiidae
Syrrhoe sp. 1 *

Cumacea
Bodobriidae
Pseudoleptocuma minor (Calman, 1912) *
Diastylidae
Diastylis cornuifer (Blake, 1929) *
Diastylis polita (S.I. Smith, 1879) *
Diastylis quadrispinosa (Sars, 1871) *
Diastylis sculpta Sars, 1871 *
Leptostylis cf. *ampullacea* (Lilljeborg, 1855) *
Leptostylis longimana (Sars, 1865) *
Lampropidae
Lamprops quadriplicata S.I. Smith, 1879 *
Leuconidae
Eudorella hirsuta Sars, 1869 *
Eudorella hispida Sars, 1871 *
Eudorella pusilla Sars, 1871 *
Eudorellopsis deformis (Krøyer, 1842) *
Leucon acutirostris Sars, 1865 *
Leucon fulvus Sars, 1865 *
Nannastacidae
Campylaspis rubicunda (Lilljeborg, 1855) *
Campylaspis nr. *sulcata* Sars, 1869) *
Pseudocumatidae
Petalosarsia declivis (Sars, 1865) *

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

Isopoda
Anthuriidae
Ptilanthura tenuis Harger, 1879 *
Chaetiiidae
Chiridotea tuftsi (Stimpson, 1883) *
Cirolanidae
Politolana polita (Stimpson, 1853) *

Gnathiidae
Gnathia cerina (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) *
Pandoridae
Pandora glacialis Leach, 1819 *
Pandora gouldiana Dall, 1886 *
Pandora nr. *inflata* Boss & Merrill, 1965 *
Pectinidae
Placopectin magellanicus (Gmelin, 1791) *
Periplomatidae
Periploma fragile (Totten, 1835)
Periploma leanum (Conrad, 1831) *
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
Asthenothaerus hemphilli Dall, 1886
Thracia conradi Couthouy, 1838 *
Thyasiridae
Thyasira gouldi Philippi, 1845 *
Thyasira nr. *minutus* (Verrill & Bush, 1898) *
Veneridae
Pitar morrhuanus Linsley, 1848 *
Gastropoda
Nudibranchia
Corambidae
Doridella obscura Verrill, 1870 *
Ophisthobranchia
Acteocinidae
Acteocina canaliculata (Say, 1822) *

Cylichnidae
Cylichana alba (Brown, 1827) *
Cylichna gouldi (Couthouy, 1839) *
Diaphanidae
Diaphana minuta (Brown, 1827) *
Retusidae
Retusa obtusa (Montagu, 1807) *
Prosobranchia
Buccinidae
Colus parvus (Verrill & Smith, 1882) *
Colus pubescens (Verrill, 1882) *
Colus pygmaeus (Gould, 1841) *
Epitoniidae
Epitonium greenlandicum (Perry, 1811) *
Lacunidae
Lacuna vincta (Montagu, 1803) *
Melanellidae
Couthouyella striatula (Couthouy, 1839) *
Nassariidae
Ilyanassa trivittata (Say, 1822) *
Naticidae
Euspira heros (Say, 1822) *
Euspira immaculata (Totten, 1835) *
Euspira triseriata (Say, 1826) *
Polinices pallidus Broderip & Sowerby, 1829 *
Pyramidellidae
Boonea impressa (Say, 1821) *
Fargoa gibbosa (Bush, 1909)
Odostomia sulcosa (Miaghels, 1843) *

Rissoidae
Onoba mighelsi (Stimpson, 1851) *
Onoba pelagica (Stimpson, 1851) *
Pusillina harpa (Verrill, 1880) *
Pusillina pseudoareeolata (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) *

APPENDIX C3

Benthic Infaunal Community Parameters

Table C3-1. Benthic community parameters for all samples, 2003.

Nearfield Stations							
		Abundance of		Number of Species			
Station	Rep	Total Indiv.	Good Species		H'	J'	LSA
FF10	1	1734	1684	67	3.73	0.62	13.95
FF10	2	2432	2408	68	3.13	0.51	13.01
FF10	3	2731	2680	89	3.22	0.50	17.71
FF12	1	2451	2396	57	3.44	0.59	10.49
FF12	2	3240	3218	60	3.15	0.53	10.47
FF12	3	2885	2823	63	3.29	0.55	11.43
FF13	1	2648	2546	52	2.83	0.50	9.25
FF13	2	3284	3222	61	3.25	0.55	10.68
FF13	3	3320	3233	56	3.14	0.54	9.62
NF02	1	3112	3095	75	3.47	0.56	13.85
NF04	1	2570	2526	86	4.40	0.68	17.22
NF05	1	2257	2216	114	4.76	0.70	25.46
NF07	1	3974	3889	94	3.80	0.58	17.35
NF08	1	3369	3328	74	4.14	0.67	13.41
NF09	1	2803	2775	88	3.91	0.60	17.31
NF10	1	3321	3302	80	3.80	0.60	14.78
NF12	1	3808	3762	65	3.77	0.63	11.16
NF12	2	3088	3066	75	3.65	0.59	13.88
NF12	3	3341	3289	72	3.68	0.60	13.00
NF13	1	1479	1449	74	3.95	0.64	16.49
NF14	1	Data not available					
NF15	1	2509	2471	82	3.74	0.59	16.31
NF16	1	3081	3034	75	3.53	0.57	13.92
NF17	1	621	573	50	4.05	0.72	13.17
NF17	2	1340	1317	73	4.30	0.70	16.66
NF17	3	834	786	60	4.17	0.71	15.11
NF18	1	4272	4242	93	3.25	0.50	16.80
NF19	1	4581	4564	84	3.24	0.51	14.62
NF20	1	3810	3665	80	3.35	0.53	14.44
NF21	1	3513	3439	87	3.92	0.61	16.23
NF22	1	4073	3995	84	3.81	0.60	15.04
NF23	1	3359	3254	109	4.29	0.63	21.73
NF24	1	5528	5470	77	2.79	0.45	12.69
NF24	2	4952	4898	80	2.88	0.46	13.58
NF24	3	6386	6282	89	2.77	0.43	14.68

Table C3-1 continued. Benthic community parameters for all samples, 2003.

Farfield Stations							
		Abundance		Number of Species			
Station	Rep	Total	Species		H'	J'	LSA
FF01A	1	3476	3413	102	3.00	0.45	19.78
FF01A	2	4038	3812	103	2.94	0.44	19.51
FF01A	3	3362	3291	93	2.85	0.44	17.80
FF04	1	1176	1167	60	4.48	0.76	13.40
FF04	2	1545	1509	78	4.66	0.74	17.44
FF04	3	1586	1564	79	4.75	0.75	17.55
FF05	1	2458	2369	96	4.88	0.74	20.09
FF05	2	2837	2707	95	4.60	0.70	19.16
FF05	3	2806	2755	104	4.59	0.69	21.37
FF06	1	3336	3275	63	2.67	0.45	11.06
FF06	2	5645	5603	85	2.63	0.41	14.22
FF06	3	2463	2442	65	3.42	0.57	12.27
FF07	1	4062	4033	54	2.77	0.48	8.81
FF07	2	7020	6978	62	2.76	0.46	9.37
FF07	3	5631	5620	69	2.53	0.41	11.07
FF09	1	2269	2221	115	4.57	0.67	25.73
FF09	2	2281	2206	111	4.28	0.63	24.63
FF09	3	2464	2418	107	4.58	0.68	22.92
FF11	1	3159	3125	86	3.24	0.50	16.36
FF11	2	5808	5761	92	3.17	0.49	15.55
FF11	3	4960	4884	104	3.38	0.50	18.67
FF14	1	3286	3239	90	4.38	0.67	17.16
FF14	2	2703	2645	88	4.39	0.68	17.52
FF14	3	3936	3850	98	4.50	0.68	18.31

Table C3-2. TOTAL ABUNDANCE at NEARFIELD STATIONS, 1994–2003*										
STATION	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
NF02	1860	3492	2544	2057	1185	4040	2792	1120	1928	3112
NF04	1248	1004	1955	3516	2111	1795	1933	1558	3074	2570
NF05	771	2219	1603	1712	1306	1367	1574	994	854	2257
NF07	1444	1942	1476	810	3042	2916	3294	1977	3764	3974
NF08	2202	2366	1443	2780	2563	2223	2095	3387	3530	3369
NF09	1825	1810	1755	3167	1686	1670	2964	1869	2404	2803
NF10	2964	2105	1680	4029	2378	3633	2504	2819	3887	3321
NF12	3008.3	2193.0	2334.7	3149.3	2878.7	1979.7	2690.3	3292.7	3393.0	3412.3
NF13	1903	1383	1639	1347	2126	2703	2041	1797	2022	1479
NF14	1871	2248	2124	3472	4179	3472	4205	2235	3125	no data
NF15	1754	2425	1660	3845	3323	2921	2810	2390	4869	2509
NF16	453	1897	1481	2087	2191	2500	2268	1166	4559	3081
NF17	1963.7	879.0	1648.0	725.3	940.0	1995.0	1798.3	1348.7	1242.7	931.7
NF18	1655	1437	1810	3031	3179	3518	2491	2042	3441	4272
NF19	1289	2609	2458	2831	2550	5079	3430	1708	4019	4581
NF20	439	2306	2904	3442	2944	2938	2540	1467	3914	3810
NF21	2521	1858	1437	1503	2172	3111	2312	1090	4273	3513
NF22	4296	2034	2944	2357	2179	1877	1434	2198	3413	4073
NF23	2068	2569	3621	2801	1317	2907	1786	1439	1733	3359
NF24	3164.0	1388.7	1591.3	1445.0	4190.0	3658.0	2677.7	4337.0	6529.3	5622.0
FF10	2774.0	1955.3	2240.0	2776.3	2840.3	2916.0	2169.7	1804.7	2289.0	2299.0
FF12	728.7	2531.7	3089.0	4058.7	2507.7	3077.3	2660.0	1980.0	2910.0	2858.7
FF13	1528.3	1091.7	2383.7	4194.3	3265.7	2226.0	4182.3	3863.7	5916.7	2578.8

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

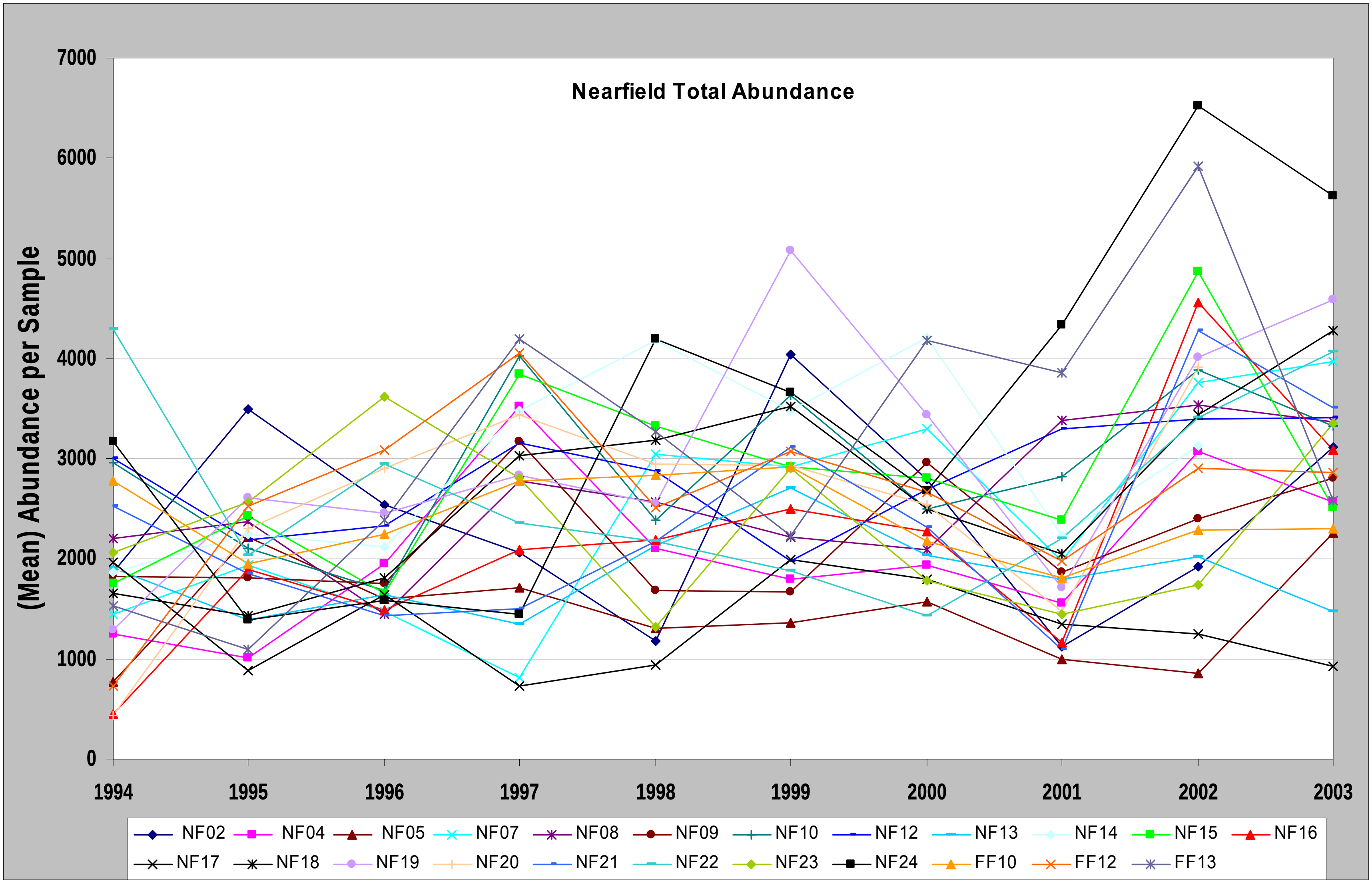


Figure C3-1. Total abundance at nearfield stations from 1994 through 2003. Values are average for three replicates at six of the stations (see Table C3-2) or are for single samples.

Table C3-3. SPECIES RICHNESS at NEARFIELD STATIONS, 1994–2003*

STATION	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
NF02	60	67	70	75	55	79	66	63	64	75
NF04	43	59	58	92	90	75	71	71	97	86
NF05	47	77	92	97	85	69	87	67	84	114
NF07	52	81	74	50	93	84	88	65	72	94
NF08	46	50	49	84	69	63	73	78	91	74
NF09	45	70	76	78	80	76	86	62	77	88
NF10	62	67	64	78	79	82	85	69	84	80
NF12*	54.3	62.7	70.7	83.0	85.0	65.3	66.3	64.7	66.3	70.7
NF13	54	48	57	50	84	74	76	80	84	74
NF14	63	75	75	79	98	86	73	71	84	no data
NF15	65	67	69	82	68	62	77	65	86	82
NF16	38	71	62	63	65	68	63	65	74	75
NF17*	47.7	45.0	62.7	49.7	49.3	56.7	51.3	51.3	64.7	61.0
NF18	73	84	81	114	92	93	88	81	94	93
NF19	65	78	98	77	76	88	74	65	68	84
NF20	37	64	83	74	78	70	72	74	79	80
NF21	55	70	67	76	80	79	57	45	83	87
NF22	72	51	72	73	72	63	56	61	73	84
NF23	74	80	83	92	71	78	63	69	77	109
NF24*	63.3	58.7	66.0	60.7	70.7	68.3	60.7	75.0	81.7	82.0
FF10*	77.0	78	82.0	91.7	92.0	89.0	74.3	78.3	75.3	74.7
FF12*	77.0	78	82.0	91.7	92.0	89.0	74.3	78.3	75.3	60.0
FF13*	47.3	41.3	54.0	59.0	57.0	55.7	56.0	55.7	63.7	67.3

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

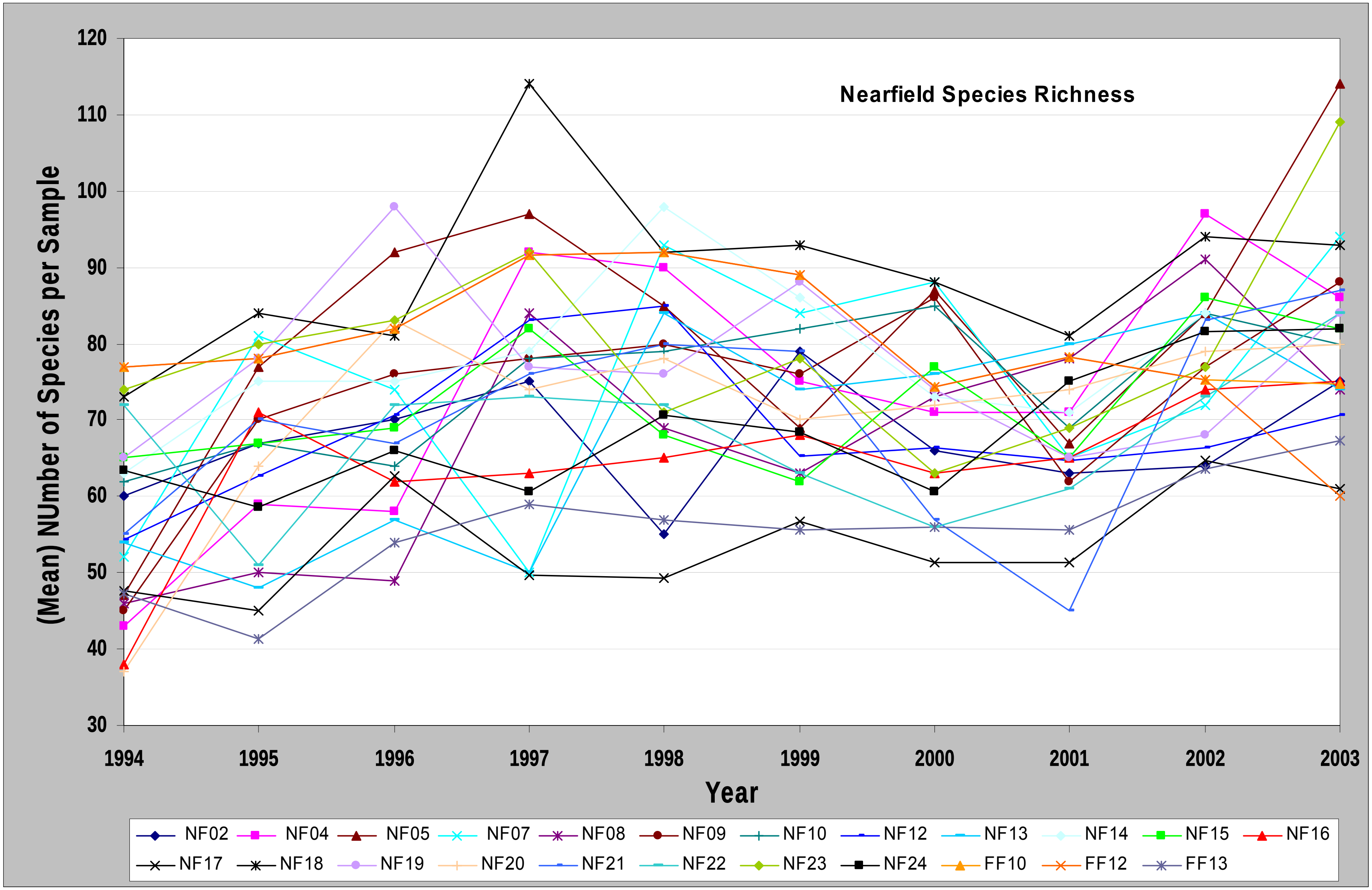


Figure C3-2. Species richness at nearfield stations from 1994 through 2002. Values are average for three replicates at six of the stations (see Table C3-3) or are for single samples.

Table C3-4. SHANNON DIVERSITY at NEARFIELD STATIONS, 1994–2003*

STATION	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
NF02	3.61	3.64	4.06	4.04	3.72	3.82	2.99	4.55	3.15	3.47
NF04	3.08	3.99	2.82	4.04	4.62	4.25	4.39	4.1	4.02	4.40
NF05	3.63	4.19	4.58	4.92	4.86	4.29	4.39	4.95	5.02	4.76
NF07	3.06	4.25	4.4	3.95	3.7	3.69	3.37	3.42	3.32	3.80
NF08	2.96	3.38	3.47	3.46	3.04	2.9	3.68	4.01	4.37	4.14
NF09	3.22	4.14	4.5	4.54	4.29	4.42	4.17	4.36	3.98	3.91
NF10	3.09	3.74	3.77	4.05	4.27	4.08	4.31	4.17	3.77	3.80
NF12*	3.2	3.7	4.0	4.2	4.3	4.3	3.9	3.9	3.5	3.7
NF13	3.4	3.88	3.35	2.94	4.18	4.24	4.21	4.58	4.74	3.95
NF14	3.88	3.49	3.67	4.34	3.97	3.39	4.22	4.18	4.24	no data
NF15	4.53	4.14	3.72	4.16	3.41	3.08	4.02	3.83	3.52	3.74
NF16	3.63	4.11	4.33	3.46	3.39	2.99	2.87	3.77	3.42	3.53
NF17*	2.5	3.6	3.7	3.8	3.5	3.7	4.0	3.4	4.3	4.2
NF18	4.38	3.91	4.29	4.38	4.09	3.58	3.98	4.31	3.09	3.25
NF19	4.58	4.1	4.48	3.87	3.55	2.76	3.48	3.33	3.06	3.24
NF20	4.18	3.76	4.05	3	3.51	2.77	3.1	4.05	3.04	3.35
NF21	3.43	4.16	4.32	4.25	3.87	3.06	3.24	3.68	3.34	3.92
NF22	3.46	3.82	3.96	4.11	4.14	3.92	4.1	3.9	3.48	3.81
NF23	4.42	4.38	4.44	3.8	4.15	4.35	4.36	4.61	4.44	4.29
NF24*	3.1	3.9	3.8	3.1	2.6	2.5	2.7	3.2	3.1	2.8
FF10*	4.1	4.4	4.6	4.6	4.1	3.7	3.5	4.0	3.6	3.4
FF12*	3.6	3.8	3.7	3.6	3.2	2.9	3.1	3.4	3.0	3.3
FF13*	3.6	3.0	3.9	2.5	2.7	2.9	3.1	3.2	3.2	3.3

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

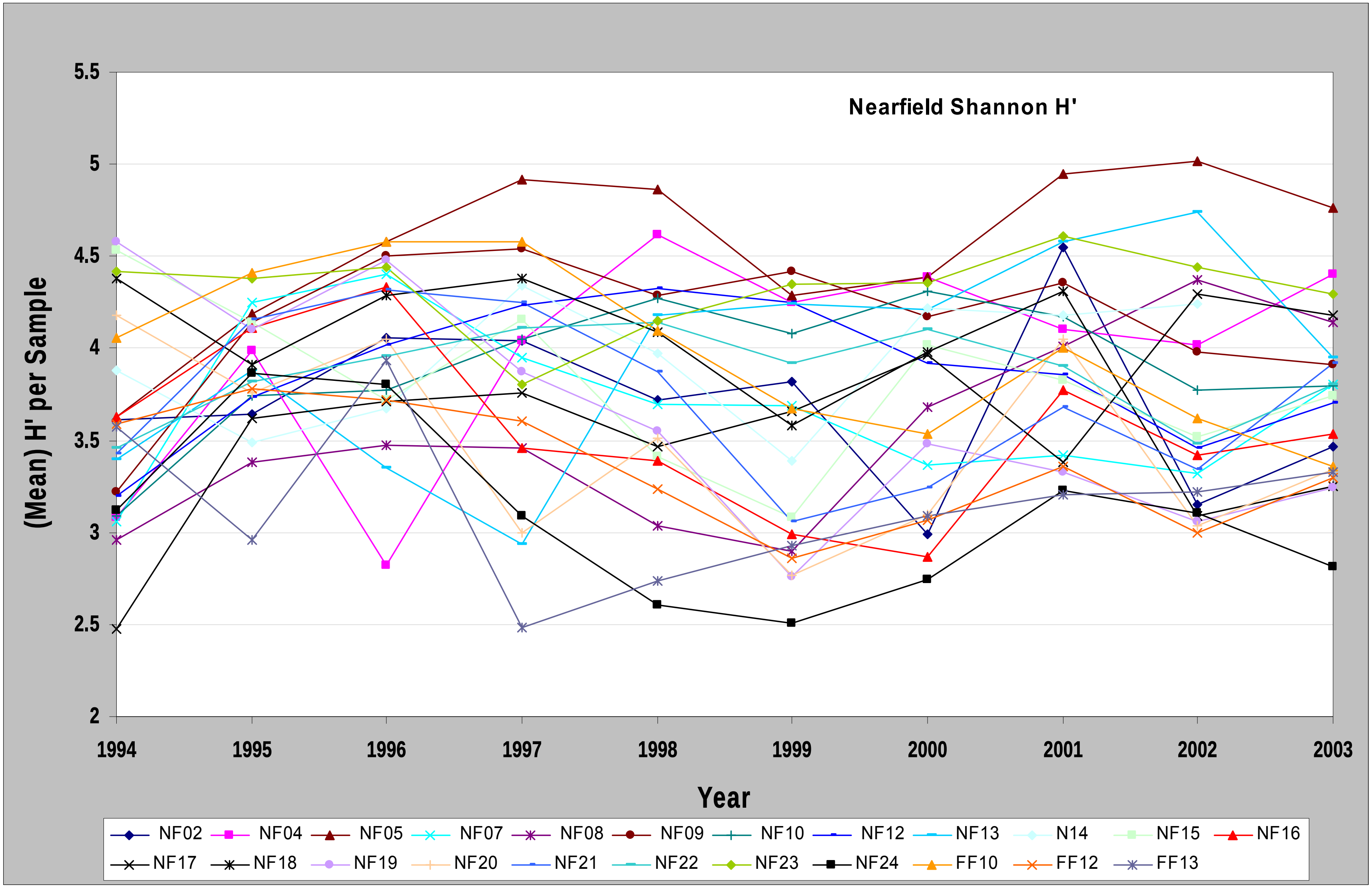


Figure C3-3. Shannon diversity (H′) at nearfield stations from 1994 through 2002. Values are the mean of three replicates at six of the stations (see Table C3-4) or are for single samples.

Table C3-5. EVENNESS at NEARFIELD STATIONS, 1994–2003*										
STATION	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
NF02	0.61	0.60	0.66	0.65	0.64	0.61	0.49	0.76	0.53	0.56
NF04	0.57	0.68	0.48	0.62	0.71	0.68	0.71	0.67	0.61	0.68
NF05	0.65	0.67	0.70	0.75	0.76	0.70	0.68	0.82	0.79	0.70
NF07	0.54	0.67	0.71	0.70	0.57	0.58	0.52	0.57	0.54	0.58
NF08	0.53	0.60	0.62	0.54	0.50	0.49	0.59	0.64	0.67	0.67
NF09	0.59	0.68	0.72	0.72	0.68	0.71	0.65	0.73	0.63	0.60
NF10	0.52	0.62	0.63	0.64	0.68	0.64	0.67	0.68	0.59	0.60
NF12*	0.60	0.60	0.70	0.70	0.70	0.70	0.70	0.60	0.60	0.60
NF13	0.59	0.69	0.57	0.52	0.65	0.68	0.67	0.72	0.74	0.64
NF14	0.65	0.56	0.59	0.69	0.60	0.53	0.68	0.68	0.66	no data
NF15	0.75	0.68	0.61	0.65	0.56	0.52	0.64	0.64	0.55	0.59
NF16	0.69	0.67	0.73	0.58	0.56	0.49	0.48	0.63	0.55	0.57
NF17*	0.40	0.70	0.60	0.70	0.60	0.60	0.70	0.60	0.70	0.71
NF18	0.71	0.61	0.68	0.64	0.63	0.55	0.62	0.68	0.47	0.50
NF19	0.76	0.65	0.68	0.62	0.57	0.43	0.56	0.55	0.50	0.51
NF20	0.80	0.63	0.64	0.48	0.56	0.45	0.50	0.65	0.48	0.53
NF21	0.59	0.68	0.71	0.68	0.61	0.49	0.56	0.67	0.52	0.61
NF22	0.56	0.67	0.64	0.66	0.67	0.66	0.71	0.66	0.56	0.60
NF23	0.71	0.69	0.70	0.58	0.67	0.69	0.73	0.76	0.71	0.63
NF24*	0.50	0.70	0.60	0.50	0.40	0.40	0.50	0.50	0.50	0.44
FF10*	0.60	0.70	0.70	0.70	0.60	0.60	0.60	0.60	0.60	0.54
FF12*	0.70	0.60	0.60	0.60	0.50	0.50	0.50	0.60	0.50	0.56
FF13*	0.60	0.60	0.70	0.40	0.50	0.50	0.50	0.60	0.50	0.55

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

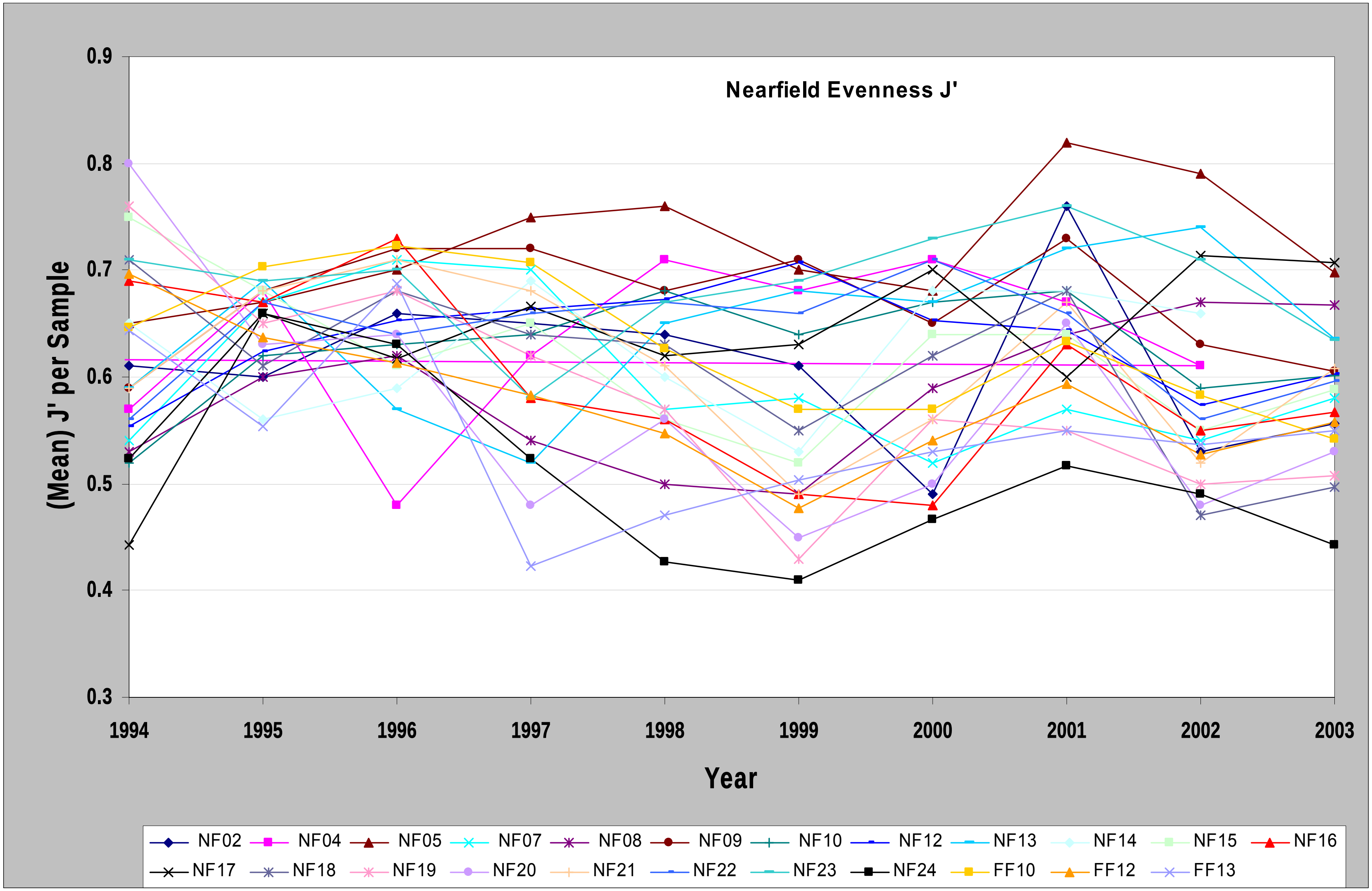


Figure C3-4. Evenness (Pielou's J)′ at nearfield stations from 1994 through 2002. Values are the mean of three replicates at six of the stations (see Table C3-5) or are for single samples.

Table C3-6. LOG-SERIES *ALPHA* at NEARFIELD STATIONS, 1994–2003*										
STATION	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
NF02	11.9	11.9	13.4	15.8	12.2	14.1	12.5	15.2	12.8	13.85
NF04	8.7	14.3	11.4	17.4	19.6	16.5	14.9	15.7	19.1	17.22
NF05	11.3	15.8	21.6	22.7	20.8	15.6	20.6	16.7	23.5	25.46
NF07	10.9	17.2	16.6	11.9	18.5	16.5	16.8	13.2	12.7	17.35
NF08	8.3	9.0	10.0	16.4	13.3	12.3	15.1	14.7	17.1	13.41
NF09	8.4	14.7	16.6	14.6	17.8	16.9	16.9	12.9	15.3	17.31
NF10	11.2	13.5	13.4	13.9	16.0	15.1	17.4	13.1	15.2	14.78
NF12*	9.5	12.2	13.9	15.9	16.7	13.3	12.7	11.7	11.8	12.68
NF13	10.5	10.1	11.6	10.3	18.1	14.8	16.0	18.2	17.9	16.49
NF14	12.9	15.2	15.3	14.5	18.2	16.3	13.0	14.8	15.9	no data
NF15	13.6	12.9	14.7	14.9	12.2	11.2	14.9	12.5	14.9	16.31
NF16	10.4	14.9	13.3	12.3	12.6	13.0	12.2	15.1	12.6	13.92
NF17*	9.0	10.5	13.4	12.8	11.5	11.0	10.3	11.6	15.7	14.98
NF18	16.0	20.0	17.8	23.8	18.1	17.9	18.3	17.3	17.9	16.80
NF19	14.9	15.4	20.7	14.7	14.9	15.3	13.4	13.5	11.6	14.62
NF20	10.2	12.4	16.1	13.4	15.0	13.1	14.2	16.9	14.1	14.44
NF21	10.0	14.8	14.8	17.1	16.7	15.0	10.8	9.8	14.6	16.23
NF22	12.3	9.7	13.5	14.4	14.7	13.0	12.2	12.9	13.2	15.04
NF23	15.6	16.4	15.5	18.4	16.5	15.5	13.9	15.4	16.6	21.73
NF24*	11.4	12.9	14.1	13.3	12.2	12.0	11.4	13.2	13.2	13.65
FF10*	14.9	16.8	17.0	18.7	18.6	17.8	15.5	17.9	15.5	14.89
FF12*	8.2	11.4	12.4	12.5	11.2	11.7	9.1	9.5	9.4	10.79
FF13*	9.3	8.6	9.9	9.8	10.0	10.6	9.3	9.3	10.0	9.85

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

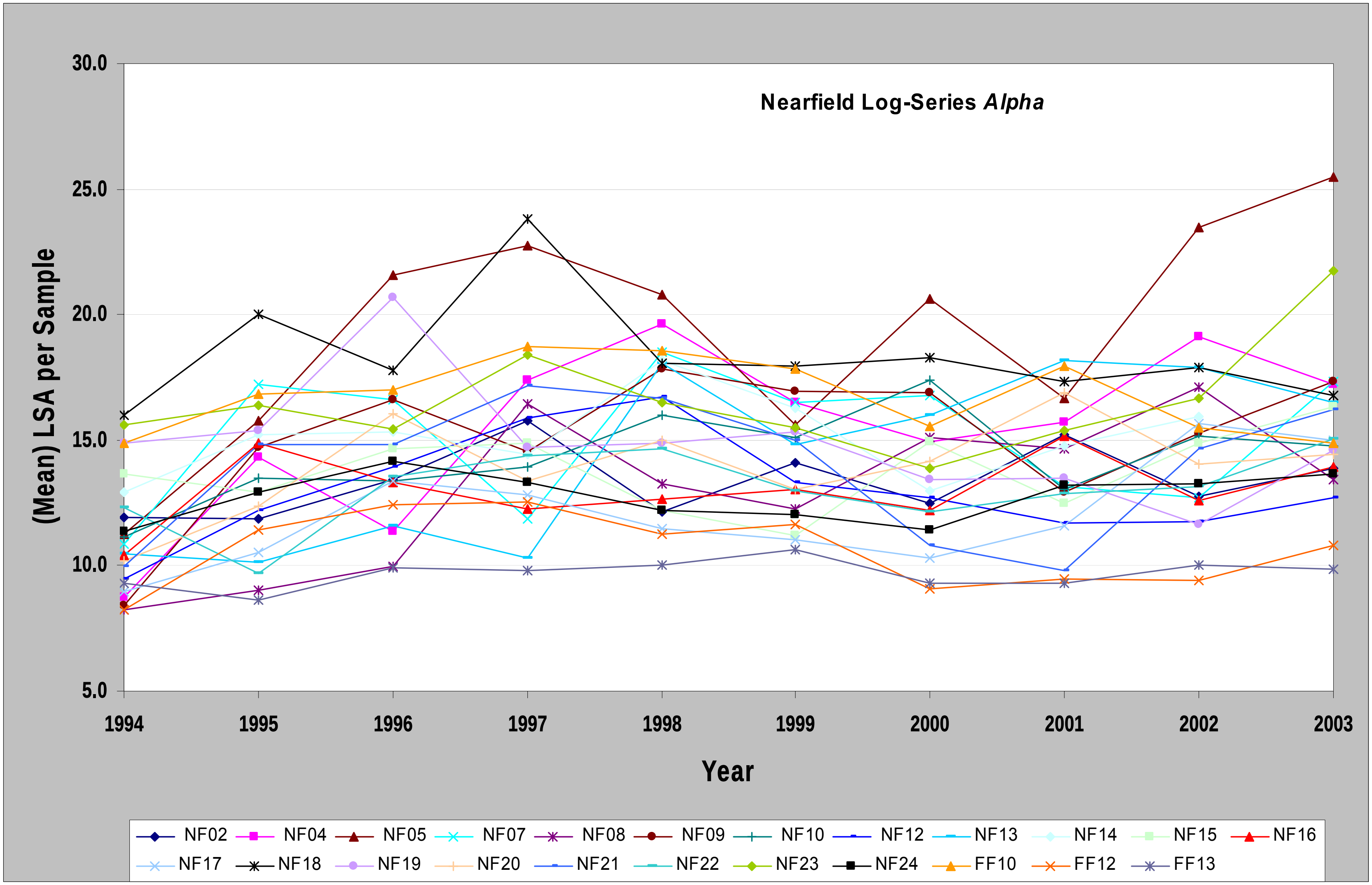


Figure C3-5. Log-series *alpha* at nearfield stations from 1994 through 2003. Values are the mean of three replicates at six of the stations (see Table C3-6) or are for single samples.

Table C3-7. MEAN TOTAL ABUNDANCE at FARFIELD STATIONS, 1992–2003.

Sta.	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
FF01	425.7	637.0										
FF01A			858.7	2841.0	2232.0	2168.3	2332.0	4230.7	3234.3	2091.3	2358.0	3625.3
FF04	866.0	370.7	553.3	417.3	524.7	1155.7	2436.0	1090.7	1271.7	1139.7	1556.7	1435.7
FF05	1052.3	945.3	351.7	922.0	793.7	842.0	1450.3	2438.7	2519.3	1981.3	1901.3	2700.3
FF06	1631.3	1744.7	581.3	1307.3	1094.3	996.3	1075.3	1216.7	641.0	395.7	490.7	3814.7
FF07	1856.0	2056.0	400.7	950.3	1628.3	2785.3	3801.3	2316.3	3755.7	3022.3	2974.7	5571.0
FF09	2806.0	1144.0	2304.7	2823.0	2524.0	2654.7	1929.7	2135.3	2226.3	1681.3	1969.3	2338.0
FF11	667.7	1072.3	696.7	1082.7	1730.7	1280.3	1649.7	5654.3	2258.0	3086.0	2889.3	4642.3
FF14	542.3	1016.7	662.7	853.3	965.7	832.3	2092.7	2146.7	1761.0	1406.3	553.0	3308.3

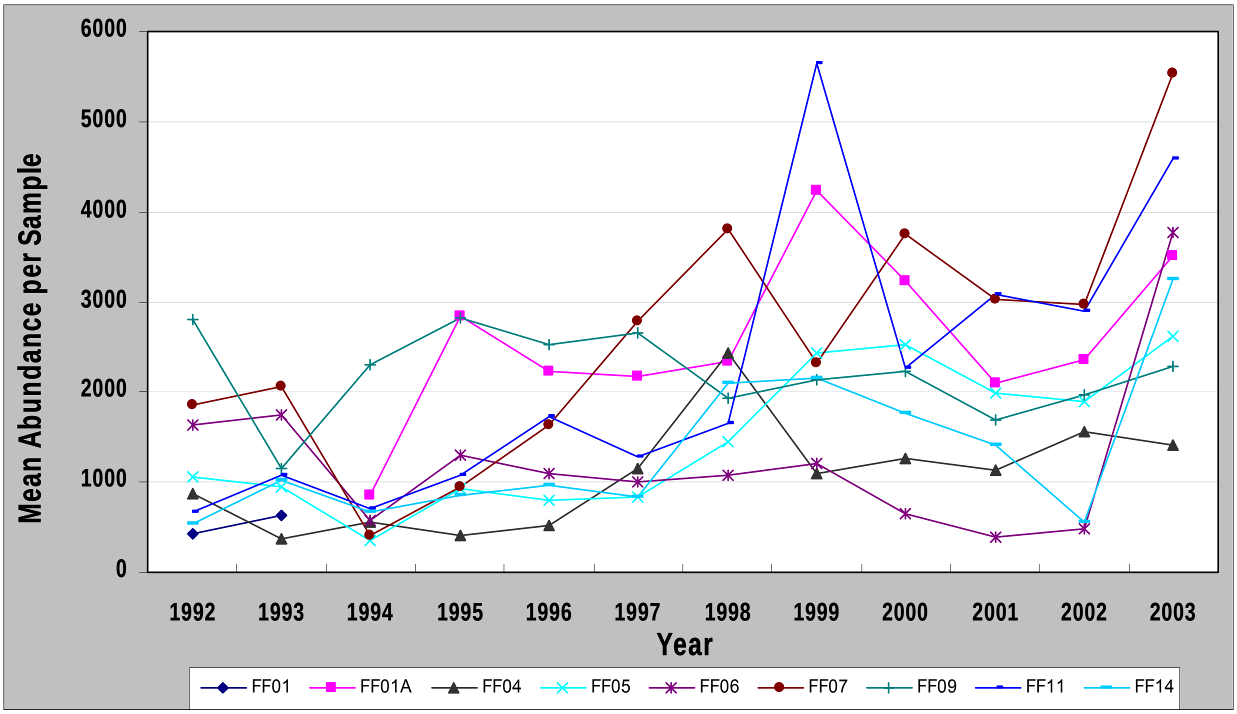


Figure C3-6. Abundance at farfield stations from 1992 through 2003. Values are the mean of three replicates.

Table C3-8. MEAN SPECIES RICHNESS at FARFIELD STATIONS, 1992–2003.

Sta.	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
FF1	53.7	55.0										
FF1A			60.0	73.0	74.7	86.7	81.7	88.0	76.3	68.7	74.7	99.3
FF04	47.0	36.0	41.3	36.7	45.3	57.0	58.3	60.3	64.0	50.7	62.3	72.3
FF05	48.3	52.7	39.7	51.0	65.3	62.7	68.0	73.7	76.7	75.3	78.0	98.3
FF06	54.3	67.0	43.7	53.0	66.0	63.3	62.3	51.0	42.0	35.7	55.3	71.0
FF07	47.0	48.0	31.0	49.3	60.7	64.0	66.0	54.7	55.7	45.3	50.3	61.7
FF09	71.3	58.0	69.7	69.3	78.3	97.3	93.0	85.3	98.3	102.0	96.7	111.0
FF11	36.0	52.3	48.0	42.7	54.0	61.0	66.7	74.7	56.0	68.7	76.0	94.0
FF14	43.3	47.7	44.7	52.7	64.7	63.7	73.3	71.0	73.3	62.0	56.7	92.0

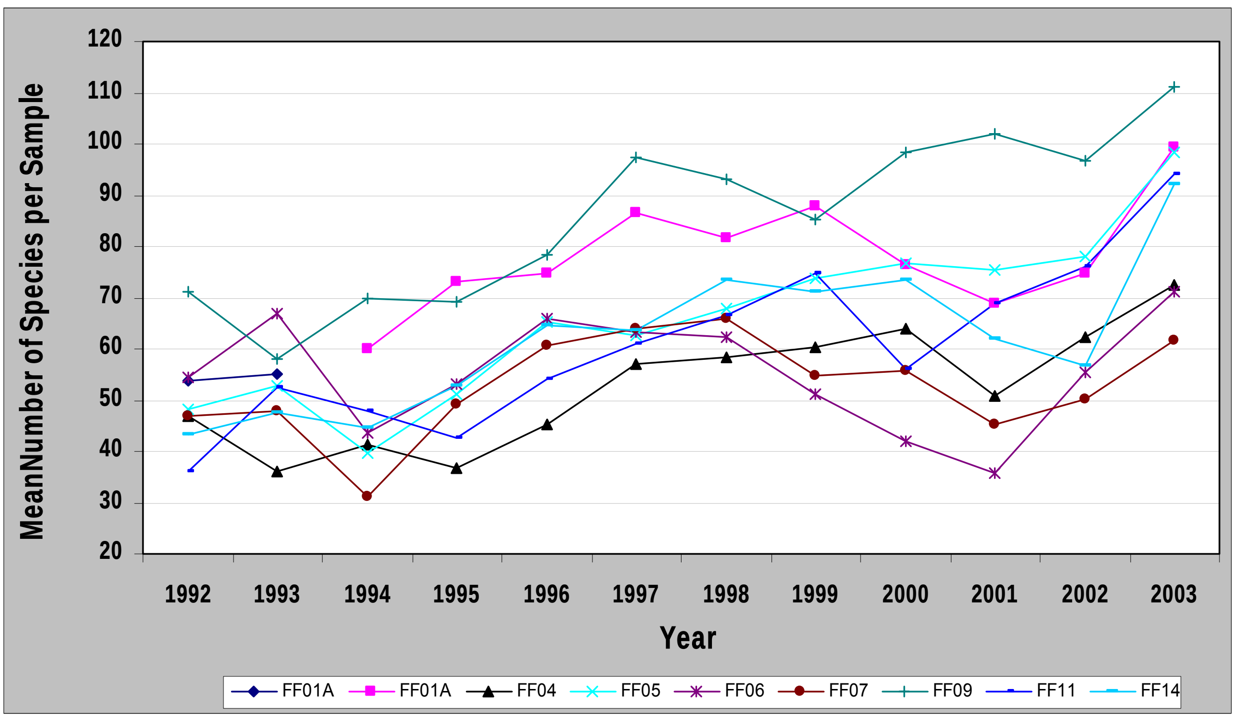


Figure C3-7. Species richness at farfield stations from 1992 through 2003. Values are the mean of three replicates.

Table C3-9. MEAN SHANNON DIVERSITY at FARFIELD STATIONS, 1992–2003.												
Sta.	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
FF1	4.64	4.50										
FF1A			4.39	2.33	3.04	3.81	3.15	2.98	2.76	2.97	3.25	2.93
FF04	3.03	3.87	4.06	3.82	4.21	4.19	3.65	4.41	4.25	4.17	4.30	4.63
FF05	2.26	3.81	4.43	3.54	4.50	4.27	4.24	4.28	4.37	4.70	4.55	4.69
FF06	3.55	4.21	3.87	4.15	4.61	4.59	4.39	3.93	3.87	3.55	4.60	2.91
FF07	3.40	3.74	3.32	3.79	3.87	3.49	3.47	3.20	3.11	2.86	2.79	2.69
FF09	3.05	3.11	3.18	2.29	2.95	3.65	4.15	3.86	4.34	4.97	4.26	4.48
FF11	3.25	3.90	3.80	2.56	2.85	3.11	3.39	2.79	2.79	3.57	3.62	3.27
FF14	3.67	3.87	4.09	4.21	4.64	4.49	4.68	4.41	4.59	4.50	4.74	4.42

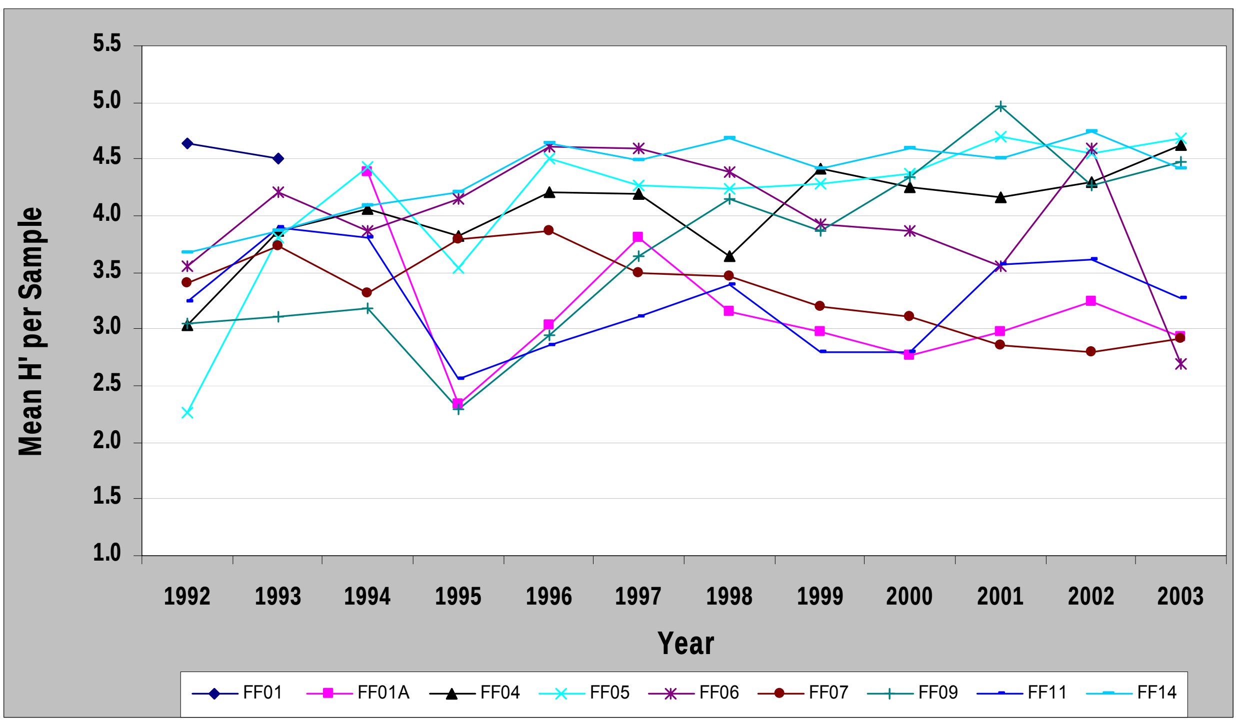


Figure C3-8. Shannon diversity at farfield stations from 1992 through 2003. Values are the mean of three replicates.

Table C3-10. MEAN EVENNESS at FARFIELD STATIONS, 1992–2003.												
STATION	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
FF1	0.81	0.78										
FF1A			0.75	0.38	0.49	0.59	0.50	0.46	0.44	0.49	0.52	0.44
FF04	0.55	0.75	0.76	0.74	0.77	0.72	0.62	0.75	0.71	0.74	0.72	0.75
FF05	0.40	0.67	0.83	0.62	0.75	0.72	0.70	0.69	0.70	0.75	0.72	0.71
FF06	0.62	0.69	0.71	0.72	0.76	0.77	0.74	0.69	0.72	0.69	0.79	0.48
FF07	0.61	0.67	0.67	0.67	0.65	0.58	0.57	0.55	0.54	0.52	0.49	0.45
FF09	0.50	0.53	0.52	0.37	0.47	0.55	0.64	0.61	0.66	0.74	0.65	0.66
FF11	0.63	0.68	0.68	0.47	0.49	0.52	0.56	0.45	0.48	0.59	0.58	0.50
FF14	0.68	0.70	0.75	0.73	0.77	0.75	0.75	0.72	0.74	0.76	0.81	0.68

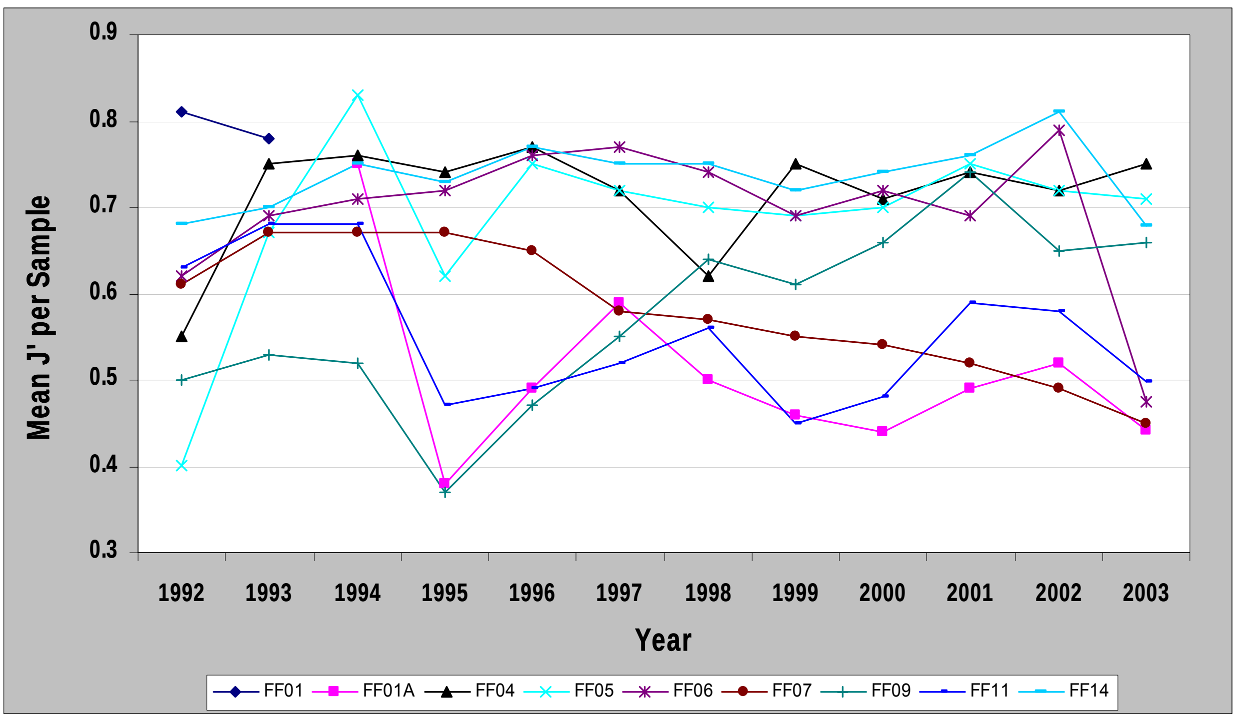


Figure C3-9. Evenness at farfield stations from 1992 through 2003. Values are the mean of three replicates.

Table C3-11. MEAN LOG-SERIES ALPHA at FARFIELD STATIONS, 1992–2003.												
STATION	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
FF1	16.70	14.86										
FF1A			15.19	13.87	15.04	18.27	16.75	15.97	14.29	13.84	14.81	19.03
FF04	10.87	10.80	10.64	10.27	12.27	12.84	11.01	14.32	14.53	11.28	13.16	16.13
FF05	10.56	12.38	12.09	12.37	17.56	16.08	15.19	14.69	15.63	16.89	16.53	20.21
FF06	10.86	14.14	11.61	11.65	15.88	15.24	14.94	11.09	10.33	9.78	16.72	12.52
FF07	9.02	9.10	8.42	11.57	12.63	11.95	11.55	10.15	9.33	7.73	8.67	9.75
FF09	13.40	13.23	13.63	13.07	15.58	20.14	20.96	18.45	21.71	24.90	21.65	24.43
FF11	8.42	11.78	12.37	9.07	10.95	13.93	14.12	12.50	10.56	12.95	14.51	16.86
FF14	11.45	10.51	12.00	13.10	16.26	17.12	15.04	14.94	16.10	15.03	16.39	17.66

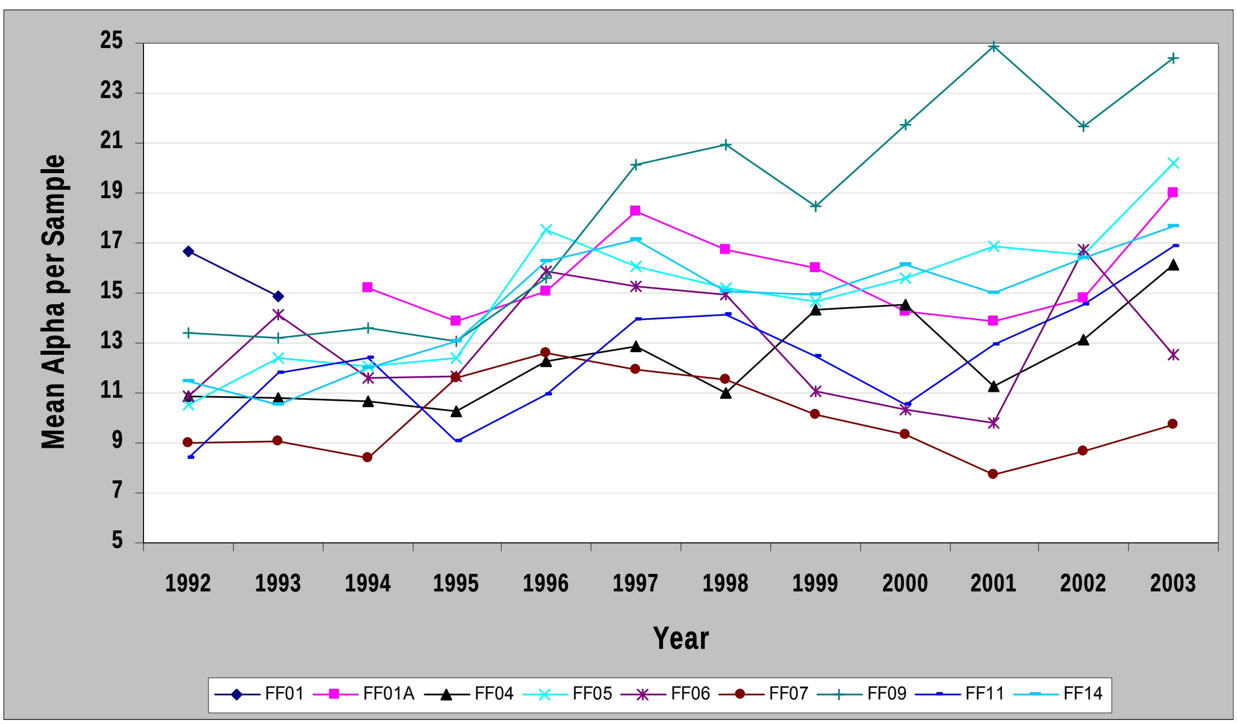


Figure C3-10. Log-series *alph*a at farfield stations from 1992 through 2003. Values are the mean of three replicates.

APPENDIX C4

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

Station	Rank	Species	Count	%	Cum %	2002 Rank	2001 Rank	2000 Rank
NF 02	1	*Prionospio steenstrupi*	954	30.7	30.7	2	2	1
	2	*Tharyx acutus*	592	19.0	49.7	1	5	2
	3	*Aricidea catherinae*	483	15.5	65.2	3	3	5
	4	*Mediomastus californiensis*	300	9.6	74.8	4	11	3
	5	*Edotia montosa*	97	3.1	77.9	18	22	16
	6	*Exogone hebes*	74	2.4	80.3	14	10	12
	7	*Leitoscoloplos acutus*	47	1.5	81.8	5	NP	24
	8	*Ninoe nigripes*	46	1.5	83.3	7	41	15
	9	*Owenia fusiformis*	44	1.4	84.7	22	21	18
	10	*Phyllodoce mucosa*	42	1.3	86.0	15	4	25
	11	*Spio limicola*	29	0.9	86.9	6	18	20
	12	*Spio thulini*	24	0.8	87.7	NP	13	23
	13	*Aglaophamus circinata*	23	0.7	88.4	22	11	26
	14	*Pholoe minuta*	19	0.6	89.0	NP	NP	NP
	14	*Phoronis architecta*	19	0.6	89.6	18	NP	21
(No. Species)	(84)	Station Total Abundance	3112			(64)	(63)	(66)
NF 04	1	*Exogone hebes*	428	16.7	16.7	1	1	2
	2	*Molgula manhattensis*	377	14.7	31.4	2	15	4
	3	*Phoronis architecta*	317	12.3	43.7	NP	13	NP
	4	*Asabellides oculata*	191	7.4	51.1	12	NP	NP
	5	*Dipolydora socialis*	118	4.6	55.7	4	11	7
	6	*Exogone verugera*	99	3.9	59.6	3	2	5
	6	*Euchone elegans*	99	3.9	63.5	29	7	26
	7	*Prionospio steenstrupi*	92	3.6	67.1	9	6	15
	8	*Owenia fusiformis*	81	3.2	70.3	13	27	9
	9	*Echinarachnius parma*	77	3.0	73.3	NP	19	26
	10	*Aricidea catherinae*	67	2.6	75.9	18	8	NP
	11	*Aglaophamus circinata*	49	1.9	77.8	8	23	21
	11	*Astarte undata*	49	1.9	79.7	6	NP	29
	12	*Euchone incolor*	31	1.2	80.9	19	19	31
	13	*Phyllodoce mucosa*	28	1.1	82.0	20	14	21
(No. Species)	(97)	Station Total Abundance	2570			(97)	(71)	(71)
NF 05	1	*Prionospio steenstrupi*	512	22.7	22.7	1	7	1
	2	*Spio limicola*	275	11.4	34.1	9	23	15
	3	*Mediomastus californiensis*	119	5.3	39.4	2	1	5
	4	*Levinsenia gracilis*	96	4.3	43.7	4	8	10
	5	*Tharyx acutus*	88	3.9	47.6	5	4	8
	6	*Nucula delphinodonta*	85	3.8	51.4	14	9	16
	7	*Asabellides oculata*	71	3.1	54.5	10	NP	NP
	8	*Phoronis architecta*	70	3.1	57.6	23	22	25
	9	*Parougia caeca*	64	2.8	60.4	15	20	24
	10	*Haploops fundiensis*	60	2.7	63.1	3	5	7
	11	*Aricidea catherinae*	59	2.6	65.7	14	17	11
	12	*Thyasira gouldi*	53	2.3	68.0	17	18	17
	13	*Crenella decussata*	39	1.7	69.7	7	NP	NP
	14	*Dipolydora socialis*	38	1.7	71.4	14	20	2
	15	*Onoba pelagica*	36	1.6	73.0	13	23	16
(No. Species)	(128)	Station Total Abundance	2257			(77)	(67)	(87)

Station	Rank	Species	Count	%	Cum %	2002 Rank	2001 Rank	2000 Rank
NF 07	1	*Prionospio steenstrupi*	1,621	40.8	40.8	1	1	1
	2	*Spio limicola*	454	11.4	52.2	2	2	2
	3	*Mediomastus californiensis*	204	5.1	57.3	3	3	4
	4	*Phyllodoce mucosa*	158	4.0	61.3	21	26	22
	5	*Tharyx acutus*	134	3.4	64.7	7	5	12
	6	*Phoronis architecta*	107	2.7	67.4	25	21	27
	7	*Dipolydora socialis*	97	2.4	69.8	12	43	3
	8	*Capitella capitata* complex	89	2.2	72.0	31	NP	20
	9	*Eteone longa*	72	1.8	73.8	20	26	25
	10	*Aphelochaeta marioni*	67	1.7	75.5	4	7	10
	11	*Ninoe nigripes*	61	1.5	77.0	11	11	7
	12	*Leitoscoloplos acutus*	54	1.4	78.4	14	30	25
	13	*Parougia caeca*	51	1.3	79.7	19	18	19
	14	*Pholoe minuta*	48	1.2	80.9	27	26	13
	15	*Nucula delphinodonta*	45	1.1	82.0	5	4	6
(No. Species)	(109)	Station Total Abundance	3974			(72)	(68)	(88)
NF 08	1	*Prionospio steenstrupi*	628	18.6	18.6	2	3	1
	2	*Ampharete acutifrons*	542	16.1	34.7	6	48	92
	3	*Phoronis architecta*	302	9.0	43.7	4	2	62
	4	*Tharyx acutus*	284	8.4	52.1	1	4	11
	5	*Spio limicola*	237	7.0	59.1	5	5	5
	6	*Mediomastus californiensis*	208	6.2	65.3	7	6	2
	7	*Monticellina baptisteae*	132	3.9	69.2	17	10	8
	8	*Ninoe nigripes*	111	3.3	72.5	8	12	8
	9	*Nucula delphinodonta*	94	2.8	75.3	12	14	13
	10	*Levinsenia gracilis*	75	2.2	77.5	9	8	6
	11	*Euchone incolor*	73	2.2	79.7	10	9	4
	12	*Scoletoma hebes*	68	2.0	81.7	17	25	NP
	13	*Leitoscoloplos acutus*	63	1.9	83.6	11	11	10
	14	*Nephtys incisa*	54	1.6	85.2	25	23	15
	15	*Dipolydora socialis*	48	1.4	86.6	13	7	3
(No. Species)	(85)	Station Total Abundance	3369			(91)	(78)	(73)
NF 09	1	*Prionospio steenstrupi*	1,008	36.0	36.0	1	1	1
	2	*Phoronis architecta*	294	10.5	46.5	11	4	35
	3	*Spio limicola*	281	10.0	56.5	2	2	3
	4	*Mediomastus californiensis*	131	4.7	61.2	4	3	4
	5	*Ampharete acutifrons*	105	3.7	64.9	3	19	56
	6	*Nucula delphinodonta*	103	3.7	68.6	5	10	6
	7	*Phyllodoce mucosa*	70	2.5	71.1	24	22	32
	8	*Tharyx acutus*	64	2.3	73.4	6	14	15
	9	*Monticellina baptisteae*	63	2.2	75.6	13	7	5
	10	*Ninoe nigripes*	55	2.0	77.6	7	9	8
	11	*Leitoscoloplos acutus*	38	1.4	79.0	9	40	21
	11	*Aricidea catherinae*	38	1.4	80.4	10	5	11
	11	*Maldane sarsi*	38	1.4	81.8	17	40	7
	12	*Levinsenia gracilis*	37	1.3	83.1	8	6	9
	13	*Aphelochaeta marioni*	32	1.1	84.2	12	12	20
(No. Species)	(108)	Station Total Abundance	2803			(77)	(62)	(89)

Station	Rank	Species	Count	%	Cum %	2002 Rank	2001 Rank	2000 Rank
NF 10	1	*Prionospio steenstrupi*	1,148.	34.6	34.6	1	2	1
	2	*Spio limicola*	423	12.7	47.3	2	1	4
	3	*Mediomastus californiensis*	338	10.2	57.5	5	3	2
	4	*Aricidea catherinae*	193	5.8	63.3	4	4	3
	5	*Phoronis architecta*	131	3.9	67.2	18	13	17
	6	*Ampharete acutifrons*	116	3.5	70.7	6	25	45
	7	*Aphelochaeta marioni*	89	2.7	73.4	9	7	8
	8	*Monticellina baptisteae*	88	2.6	76.0	14	6	7
	9	*Ninoe nigripes*	69	2.1	78.1	12	12	6
	10	*Levinsenia gracilis*	52	1.6	79.7	7	8	12
	11	*Leitoscoloplos acutus*	51	1.5	81.2	10	22	24
	12	*Nucula delphinodonta*	50	1.5	82.7	11	9	13
	13	*Euchone incolor*	48	1.4	84.1	13	14	11
	14	*Phyllodoce mucosa*	47	1.4	85.5	15	18	42
	15	*Edotia montosa*	39	1.2	86.7	16	16	9
(No. Species)	(92)	Station Total Abundance	3321			(84)	(69)	(85)
NF 13	1	*Prionospio steenstrupi*	511	34.6	34.6	6	8	7
	2	*Exogone hebes*	226	15.3	49.9	2	3	4
	3	*Phoronis architecta*	73	4.9	54.8	NP	22	NP
	4	*Echinarachnius parma*	66	4.5	59.3	NP	26	16
	5	*Aglaophamus circinata*	43	2.9	62.2	9	51	20
	6	*Tharyx acutus*	41	2.8	65.0	1	30	19
	7	*Phyllodoce mucosa*	40	2.7	67.7	22	6	22
	8	*Spio thulini*	39	2.6	70.3	NP	18	21
	9	*Aricidea catherinae*	31	2.1	72.4	17	19	17
	9	*Dipolydora socialis*	31	2.1	74.5	10	6	8
	10	*Politolana polita*	29	2.0	76.5	14	25	18
	11	*Mediomastus californiensis*	27	1.8	78.3	14	33	28
	11	*Asabellides oculata*	27	1.8	80.1	15	NP	NP
	12	*Exogone verugera*	21	1.4	81.5	3	4	3
	13	*Owenia fusiformis*	17	1.2	82.7	NP	28	28
(No. Species)	(79)	Station Total Abundance	1479			(84)	(80)	(76)
NF 15	1	*Prionospio steenstrupi*	971	38.7	38.7	1	1	1
	2	*Aricidea catherinae*	223	8.9	47.6	2	2	3
	3	*Phoronis architecta*	193	7.7	55.3	14	9	31
	4	*Phyllodoce mucosa*	145	5.8	61.1	11	10	30
	5	*Tharyx acutus*	110	4.4	65.5	9	12	28
	5	*Mediomastus californiensis*	110	4.4	69.9	5	4	2
	6	*Capitella capitata* complex	84	3.3	73.2	15	25	35
	7	*Exogone hebes*	78	3.1	76.3	7	5	6
	8	*Spio limicola*	53	2.1	78.4	4	6	8
	9	*Ninoe nigripes*	42	1.7	80.1	17	14	12
	10	*Eteone longa*	33	1.3	81.4	22	26	27
	11	*Spiophanes bombyx*	31	1.2	82.6	6	7	9
	11	*Nucula delphinodonta*	31	1.2	83.8	8	8	11
	12	*Nemertea* sp. 12	27	1.1	84.9	29	26	14
	12	*Aglaophamus circinata*	27	1.1	86.0	26	NP	NP
(No. Species)	(91)	Station Total Abundance	2509			(86)	(65)	(77)

Station	Rank	Species	Count	%	Cum %	2002 Rank	2001 Rank	2000 Rank
NF 16	1	*Prionospio steenstrupi*	1,178	38.2	38.2	1	1	1
	2	*Tharyx acutus*	447	14.5	52.7	2	3	6
	3	*Mediomastus californiensis*	296	9.6	62.3	3	2	2
	4	*Levinsenia gracilis*	154	5.0	67.3	8	5	3
	5	*Ninoe nigripes*	124	4.0	71.3	9	4	4
	6	*Parougia caeca*	97	3.1	74.4	15	9	11
	7	*Euchone incolor*	76	2.5	76.9	4	13	5
	8	*Spio limicola*	66	2.1	79.0	5	10	20
	9	*Leitoscoloplos acutus*	50	1.6	80.6	7	6	17
	10	*Monticellina baptisteae*	46	1.5	82.1	16	14	9
	11	*Nucula delphinodonta*	41	1.3	83.4	14	25	12
	12	*Nephtys incisa*	39	1.3	84.7	27	21	23
	13	Tubificidae sp. 2	35	1.1	85.8	10	18	16
	14	*Phyllodoce mucosa*	34	1.1	86.9	30	16	NP
	14	*Ampharete baltica*	34	1.1	88.0	NP	NP	NP
(No. Species)	(84)	Station Total Abundance	3081			(74)	(65)	(63)
NF 18	1	*Prionospio steenstrupi*	2,215	51.8	51.8	1	2	1
	2	*Aricidea catherinae*	352	8.2	60.0	2	4	6
	3	*Asabellides oculata*	317	7.4	67.4	5	NP	NP
	4	*Mediomastus californiensis*	161	3.8	71.2	4	3	4
	5	*Spio limicola*	118	2.8	74.0	3	26	26
	6	*Ampharete acutifrons*	80	1.9	75.9	7	59	NP
	7	*Ninoe nigripes*	61	1.4	77.3	12	22	9
	8	*Phyllodoce mucosa*	58	1.4	78.7	28	20	27
	9	*Nucula delphinodonta*	56	1.3	80.0	8	14	23
	10	*Euchone incolor*	51	1.2	81.2	9	65	22
	11	*Parougia caeca*	50	1.2	82.4	17	25	21
	12	*Pionosyllis* sp. A	48	1.1	83.5	31	NP	NP
	12	*Dipolydora socialis*	48	1.1	84.6	25	17	30
	13	*Pholoe minuta*	46	1.1	85.7	26	26	23
	13	*Monticellina dorsobranchialis*	46	1.1	86.8	16	9	18
(No. Species)	(102)	Station Total Abundance	4272			(94)	(81)	(88)
NF 19	1	*Prionospio steenstrupi*	1,833	40.0	40.0	1	1	1
	2	*Polydora* sp. 1	829	18.1	58.1	NP	NP	NP
	3	*Tharyx acutus*	517	11.3	69.4	2	11	35
	4	*Aricidea catherinae*	262	5.7	75.1	5	6	15
	5	*Mediomastus californiensis*	220	4.8	79.9	4	2	4
	6	*Phyllodoce mucosa*	103	2.2	82.1	10	16	14
	7	*Nucula delphinodonta*	85	1.9	84.0	6	3	3
	8	*Spio limicola*	81	1.8	85.8	3	62	13
	9	*Ninoe nigripes*	48	1.0	86.8	14	14	9
	10	*Exogone hebes*	42	0.9	87.7	9	8	8
	11	*Eteone longa*	40	0.9	88.6	18	20	23
	11	*Hiatella arctica*	40	0.9	89.5	30	24	33
	12	*Arctica islandica*	37	0.8	90.3	15	37	45
	13	*Pionosyllis* sp. A	29	0.6	90.9	NP	NP	NP
	13	*Euchone incolor*	29	0.6	91.5	8	7	5
(No. Species)	(93)	Station Total Abundance	4581			(68)	(65)	(74)

Station	Rank	Species	Count	%	Cum %	2002 Rank	2001 Rank	2000 Rank
NF 20	1	*Prionospio steenstrupi*	1,726	45.3	45.3	1	1	1
	2	*Aricidea catherinae*	438	11.4	56.7	24	11	2
	3	*Mediomastus californiensis*	258	6.8	63.5	3	3	3
	4	*Exogone hebes*	139	3.6	67.1	22	17	11
	5	*Tharyx acutus*	126	3.3	70.4	2	2	6
	6	*Levinsenia gracilis*	83	2.2	72.6	8	4	5
	7	*Phyllodoce mucosa*	75	2.0	74.6	17	17	23
	8	*Scoletoma hebes*	70	1.8	76.4	4	11	11
	9	Tubificidae sp. 2	69	1.8	78.2	7	9	36
	10	*Monticellina baptisteae*	67	1.8	80.0	11	7	7
	11	*Asabellides oculata*	55	1.4	81.4	16	NP	NP
	12	*Nucula delphinodonta*	47	1.2	82.6	10	6	37
	13	*Ninoe nigripes*	43	1.1	83.7	6	5	4
	13	*Monticellina dorsobranchialis*	43	1.1	84.8	9	8	14
	14	*Exogone verugera*	30	0.8	85.6	18	19	9
(No. Species)	(94)	Station Total Abundance	3810			(79)	(74)	(72)
NF 21	1	*Prionospio steenstrupi*	950	27.0	27.0	1	1	1
	2	*Spio limicola*	607	17.3	44.3	2	3	3
	3	*Mediomastus californiensis*	328	9.3	53.6	3	2	2
	4	*Tharyx acutus*	282	8.0	61.6	4	6	10
	5	*Ninoe nigripes*	161	4.6	66.2	7	5	5
	6	*Parougia caeca*	124	3.5	69.7	11	15	18
	7	*Aphelochaeta marioni*	88	2.5	72.2	8	12	25
	8	*Monticellina baptisteae*	83	2.4	74.6	13	9	7
	9	*Dipolydora socialis*	80	2.3	76.9	17	22	18
	10	*Levinsenia gracilis*	75	2.1	79.0	9	4	6
	11	*Nucula delphinodonta*	58	1.7	80.7	12	10	8
	12	*Phoronis architecta*	52	1.5	82.2	22	19	NP
	12	*Ampharete acutifrons*	52	1.5	83.7	6	20	NP
	13	*Phyllodoce mucosa*	36	1.0	84.7	22	14	NP
	13	*Leitoscoloplos acutus*	36	1.0	85.7	5	7	9
(No. Species)	(98)	Station Total Abundance	3513			(83)	(45)	(57)
NF 22	1	*Tharyx acutus*	927	22.8	22.8	2	2	7
	2	*Prionospio steenstrupi*	814	20.0	42.8	1	3	6
	3	*Mediomastus californiensis*	627	15.4	58.2	3	1	1
	4	*Spio limicola*	308	7.6	65.8	4	4	3
	5	*Levinsenia gracilis*	187	4.6	70.4	5	6	4
	6	*Parougia caeca*	121	3.0	73.4	11	10	21
	7	*Ampharete acutifrons*	96	2.4	75.8	15	36	NP
	8	*Ninoe nigripes*	90	2.2	78.0	9	7	5
	9	*Aricidea quadrilobata*	79	1.9	79.9	12	11	9
	10	*Phyllodoce mucosa*	60	1.5	81.4	28	17	21
	11	*Leitoscoloplos acutus*	55	1.4	82.8	6	9	13
	12	*Euchone incolor*	50	1.2	84.0	8	5	2
	13	*Eteone longa*	49.	1.2	85.2	14	34	15
	14	*Monticellina baptisteae*	37	0.9	86.1	16	12	10
	15	*Nemertea* sp. 12	33	0.8	86.9	21	15	23
(No. Species)	(98)	Station Total Abundance	4073			(73)	(61)	(56)

Station	**Rank**	**Species**	**Count**	**%**	**Cum %**	**2002 Rank**	**2001 Rank**	**2000 Rank**
NF 23	1	*Phoronis architecta*	989	29.4	29.4	NP	11	26
	2	*Prionospio steenstrupi*	291	8.7	38.1	15	10	12
	3	*Exogone hebes*	234	7.0	45.1	1	2	1
	4	*Asabellides oculata*	194	5.8	50.9	25	NP	NP
	5	*Molgula manhattensis*	169	5.0	55.9	2	4	6
	6	*Dipolydora socialis*	157	4.7	60.6	3	22	9
	7	*Aricidea catherinae*	136	4.0	64.6	15	5	15
	8	Enchytraeidae sp. 1	96	2.9	67.5	6	3	8
	9	*Phyllodoce mucosa*	84	2.5	70.0	18	12	16
	9	*Echinarachnius parma*	84	2.5	72.5	30	27	25
	10	*Pholoe minuta*	51	1.5	74.0	30	NP	NP
	11	*Aglaophamus circinata*	47	1.4	75.4	5	35	26
	12	*Chaetozone setosa* mb	46	1.4	76.8	20	9	26
	13	*Mediomastus californiensis*	45	1.3	78.1	24	22	NP
	14	*Tharyx acutus*	41	1.2	79.3	24	18	7
(No. Species)	(121)	Station Total Abundance	3359			(77)	(69)	(63)

NP = Not present in sample.

NEARFIELD REPLICATED STATIONS

Station	Rank	Species	Mean	Std. Dev.	%	Cum %	2002 Rank	2001 Rank	2000 Rank
NF 12	1	*Prionospio steenstrupi*	1048.3	141.8	30.7	30.7	1	5	1
	2	*Mediomastus californiensis*	464.0	137.1	13.6	44.3	3	1	3
	3	*Tharyx acutus*	283.7	71.3	8.3	52.6	2	3	9
	4	*Aricidea catherinae*	226.7	65.5	6.6	59.2	5	4	7
	5	*Phoronis architecta*	209.0	207.2	6.1	65.3	26	29	22
	6	*Spio limicola*	177.3	84.2	5.2	70.5	4	2	4
	7	*Levinsenia gracilis*	127.3	19.5	3.7	74.2	6	7	8
	8	*Parougia caeca*	110.7	50.4	3.2	77.4	11	8	18
	9	*Aphelochaeta marioni*	105.3	66.3	3.1	80.5	8	6	10
	10	*Ninoe nigripes*	98.3	27.8	2.9	83.4	9	9	11
	11	*Leitoscoloplos acutus*	69.7	18.0	2.0	85.4	7	12	15
	12	*Monticellina baptisteae*	66.7	35.5	2.0	87.4	12	13	6
	13	*Eteone longa*	33.0	4.4	1.0	88.4	18	23	20
	14	*Capitella capitata* complex	29.7	6.8	0.9	89.3	24	21	12
	15	*Aricidea quadrilobata*	21.3	10.0	0.6	89.9	13	18	19
(No. Species)	(118)	Station Mean Abundance	3412.3				(98)	(89)	(94)
NF 17	1	*Crassicorophium crassicorne*	156.7	15.5	16.8	16.8	2	5	1
	2	*Echinarachnius parma*	136.0	48.3	14.6	31.4	30	22	13
	3	*Exogone hebes*	128.7	102.8	13.8	45.2	6	2	4
	4	*Phyllodoce mucosa*	43.0	14.0	4.6	49.8	10	11	18
	5	*Prionospio steenstrupi*	39.7	44.5	4.3	54.1	12	10	32
	6	*Spiophanes bombyx*	38.3	11.5	4.1	58.2	3	3	8
	7	*Phoronis architecta*	31.3	46.7	3.4	61.6	NP	28	NP
	8	*Dipolydora socialis*	25.0	11.5	2.7	64.3	4	35	5
	9	*Owenia fusiformis*	24.7	29.7	2.7	67.0	36	9	37
	10	*Aglaophamus circinata*	18.7	21.1	2.0	69.0	9	45	23
	11	*Edotia montosa*	17.7	15.8	1.9	70.9	27	26	20
	12	*Chiridotea tuftsi*	17.3	21.0	1.9	72.8	19	16	10
	13	*Chaetozone setosa* mb	15.7	11.0	1.7	74.5	20	22	9
	14	*Politolana polita*	13.7	11.0	1.5	76.0	24	28	28
	15	*Galathowenia oculata*	12.3	8.0	1.3	77.3	35	14	30
(No. Species)	(112)	Station Mean Abundance	931.7				(104)	(85)	(72)

Station	**Rank**	**Species**	**Mean**	**Std. Dev.**	**%**	**Cum %**	**2002 Rank**	**2001 Rank**	**2000 Rank**
NF 24	1	*Prionospio steenstrupi*	3154.7	484.2	56.1	56.1	1	1	1
	2	*Tharyx acutus*	422.3	8.4	7.5	63.6	2	5	7
	3	*Mediomastus californiensis*	409.7	33.4	7.3	70.9	3	2	2
	4	*Aricidea catherinae*	362.7	83.9	6.5	77.4	4	4	3
	5	*Levinsenia gracilis*	123.7	23.1	2.2	79.6	10	7	4
	6	*Phyllodoce mucosa*	119.7	35.7	2.2	81.8	11	10	25
	7	*Spio limicola*	109.7	26.5	2.0	83.8	6	6	6
	8	*Eteone longa*	97.7	9.6	1.7	85.5	13	19	10
	9	*Ninoe nigripes*	75.7	11.9	1.3	86.8	16	17	8
	10	*Monticellina baptisteae*	56.7	28.1	1.0	87.8	21	18	11
	11	*Parougia caeca*	52.7	23.3	0.9	88.7	30	22	25
	12	*Euchone incolor*	45.7	7.0	0.8	89.5	9	8	5
	13	*Leitoscoloplos acutus*	45.0	10.4	0.8	90.3	8	12	13
	14	*Pholoe minuta*	42.7	18.0	0.8	91.1	28	26	23
	15	*Aphelochaeta marioni*	28.7	8.1	0.5	91.6	5	3	17
(No. Species)	(133)	Station Mean Abundance	5622.0				(111)	(104)	(90)
FF 10	1	*Prionospio steenstrupi*	1037.0	335.3	45.1	45.1	1	1	1
	2	*Aricidea catherinae*	318.3	144.3	13.8	58.9	2	2	3
	3	*Mediomastus californiensis*	147.0	30.0	6.4	65.3	4	3	2
	4	*Scoletoma hebes*	63.7	15.3	2.8	68.1	6	14	15
	5	*Ninoe nigripes*	56.7	9.8	2.5	70.6	8	8	6
	5	*Nucula delphinodonta*	56.7	42.7	2.5	73.1	3	7	5
	6	*Spio limicola*	52.7	31.8	2.3	75.4	5	4	24
	7	*Asabellides oculata*	50.0	43.0	2.2	77.6	12	48	NP
	8	*Monticellina baptisteae*	45.7	17.0	2.0	79.6	14	5	7
	9	*Ampharete acutifrons*	43.3	23.6	1.9	81.5	7	46	NP
	10	*Tharyx acutus*	38.7	12.2	1.7	83.2	8	13	19
	11	*Levinsenia gracilis*	38.0	17.3	1.7	84.9	13	10	14
	12	*Exogone hebes*	21.3	21.4	0.9	85.8	15	18	12
	13	*Monticellina dorsobranchialis*	21.0	11.8	0.9	86.7	26	9	31
	14	Tubificidae sp. 2	18.0	18.7	0.8	87.5	17	25	
(No. Species)	(125)	Station Mean Abundance	2299.0				(109)	(120)	(124)

NP = Not present in sample.

Station	Rank	Species	Mean	Std. Dev.	%	Cum %	2002 Rank	2001 Rank	2000 Rank
FF 12	1	*Prionospio steenstrupi*	1073.3	413.3	37.5	37.5	1	1	1
	2	*Owenia fusiformis*	499.7	132.7	17.5	55.0	2	2	3
	3	*Mediomastus californiensis*	258.0	18.0	9.0	64.0	3	3	2
	4	*Tharyx acutus*	165.3	46.2	5.8	69.8	4	4	4
	5	*Aricidea catherinae*	122.0	162.9	4.3	74.1	11	6	8
	6	*Scoletoma hebes*	101.7	16.9	3.6	77.7	5	5	7
	7	*Monticellina baptisteae*	66.3	8.1	2.3	80.0	7	7	6
	8	*Ninoe nigripes*	54.3	8.1	1.9	81.9	6	9	5
	9	*Spiophanes bombyx*	48.3	12.5	1.7	83.6	8	8	12
	10	*Monticellina dorsobranchialis*	44.7	9.5	1.6	85.2	12	10	10
	11	*Levinsenia gracilis*	43.7	6.42	1.5	86.7	10	12	9
	12	*Phyllodoce mucosa*	42.7	3.5	1.5	88.2	14	11	32
	13	*Ampharete acutifrons*	34.7	5.5	1.2	89.4	22	NP	NP
	14	*Phoronis architecta*	19.7	11.5	0.7	90.1	18	16	11
	15	*Metopella angusta*	18.7	12.7	0.7	90.8	17	NP	16
(No. Species)	(95)	Station Mean Abundance	2858.7				(74)	(68)	(71)
FF 13	1	*Prionospio steenstrupi*	1159.7	116.5	37.6	37.6	1	5	1
	2	*Mediomastus californiensis*	582.0	92.3	18.9	56.5	4	4	2
	3	*Aricidea catherinae*	344.7	120.0	11.2	67.7	3	3	5
	4	*Scoletoma hebes*	200.7	119.6	6.5	74.2	10	12	13
	5	*Monticellina baptisteae*	86.0	63.7	2.8	77.0	13	11	12
	6	Nemertea sp. 12	81.0	38.3	2.6	79.6	17	13	9
	7	*Phoronis architecta*	72.3	57.1	2.3	81.9	8	6	15
	8	*Phyllodoce mucosa*	71.3	35.4	2.3	84.2	9	7	11
	9	*Leitoscoloplos acutus*	49.7	24.5	1.6	85.8	6	17	26
	10	*Tubificoides apectinatus*	48.0	16.8	1.6	87.4	11	8	18
	11	*Tharyx acutus*	45.0	14.4	1.5	88.9	2	1	3
	12	*Ninoe nigripes*	40.3	26.2	1.3	90.2	16	20	23
	13	*Eteone longa*	34.0	4.6	1.1	91.3	7	21	21
	14	*Pholoe minuta*	19.7	9.5	0.6	91.9	NP	37	34
	15	*Microphthalmus pettiboneae*	12.0	19.9	0.4	92.3	38	31	17
(No. Species)	(95)	Station Mean Abundance	3084.0				(88)	(75)	(75)

NP = Not present in sample.

FARFIELD REPLICATED STATIONS

Station	Rank	Species	Mean	Std. Dev.	%	Cum %	2002 Rank	2001 Rank	2000 Rank
FF01A	1	*Prionospio steenstrupi*	2179.0	201.7	60.1	60.1	1	1	1
	2	*Nucula delphinodonta*	166.7	37.1	4.6	64.7	2	2	3
	3	*Aricidea catherinae*	91.7	13.5	2.5	67.2	3	8	10
	4	*Levinsenia gracilis*	76.3	4.7	2.1	69.3	4	5	5
	5	*Tharyx acutus*	65.0	11.1	1.8	71.1	5	3	9
	6	*Mediomastus californiensis*	53.0	7.5	1.5	72.6	7	12	7
	7	*Owenia fusiformis*	50.3	35.8	1.4	74.0	20	15	13
	8	*Eteone longa*	49.0	8.0	1.4	75.4	26	33	38
	9	*Asabellides oculata*	45.0	41.1	1.2	76.6	6	NP	NP
	10	*Euchone incolor*	44.7	7.4	1.2	77.8	10	6	6
	11	*Hiatella arctica*	43.3	33.2	1.2	79.0	26	37	16
	12	*Thyasira gouldi*	43.0	2.0	1.2	80.2	9	7	11
	13	*Ninoe nigripes*	39.7	13.5	1.1	81.3	14	9	8
	14	*Spio limicola*	36.7	7.2	1.0	82.3	12	11	7
	15	*Ampharete lindstroemi*	29.7	44.5	0.8	83.1	NP	NP	NP
(No. Species)	(158)	Station Mean Abundance	3625.3				(107)	(96)	(102)
FF04	1	*Chaetozone setosa* mb	155.3	11.7	10.8	10.8	3	2	2
	2	*Aricidea quadrilobata*	154.3	41.8	10.7	21.5	2	6	4
	3	*Cossura longocirrata*	147.3	56.1	10.3	31.8	1	1	1
	4	*Levinsenia gracilis*	95.0	15.6	6.6	38.4	6	4	3
	5	*Tubificoides apectinatus*	91.0	10.5	6.3	44.7	5	7	8
	6	*Spio limicola*	85.3	12.2	5.9	50.6	8	25	15
	7	*Prionospio steenstrupi*	61.7	19.6	4.3	54.9	9	17	10
	8	*Anobothrus gracilis*	59.7	23.8	4.2	59.1	4	3	9
	9	*Aphelochaeta marioni*	59.3	1.5	4.1	63.2	10	9	14
	10	*Syllides longocirrata*	56.0	15.1	3.9	67.1	7	8	16
	11	*Paramphinome jeffreysii*	45.3	26.3	3.2	70.3	12	5	7
	12	*Dentalium entale*	41.7	7.6	2.9	73.2	15	11	17
	13	*Thyasira gouldi*	34.0	7.0	2.4	75.6	13	16	12
	14	Nemertea sp. 12	29.0	10.5	2.0	77.6	19	13	11
	15	*Mediomastus californiensis*	22.7	8.3	1.6	79.2	14	10	5
(No. Species)	(121)	Station Mean Abundance	1435.7				(86)	(71)	(87)

NP = Not present in sample.

Station	Rank	Species	Mean	Std. Dev.	%	Cum %	2002 Rank	2001 Rank	2000 Rank
FF05	1	*Spio limicola*	518.3	106.6	19.2	19.2	3	4	2
	2	*Aricidea quadrilobata*	266.7	61.1	9.9	29.1	5	9	6
	3	*Prionospio steenstrupi*	257.3	44.2	9.5	38.6	2	7	4
	4	*Anobothrus gracilis*	251.3	43.5	9.3	47.9	1	3	3
	5	*Levinsenia gracilis*	122.7	32.6	4.5	52.4	6	5	9
	6	*Chaetozone setosa* mb	105.0	53.4	3.9	56.3	4	9	6
	7	*Cossura longocirrata*	77.0	1.7	2.9	59.2	7	10	11
	8	*Thyasira gouldi*	70.0	3.6	2.6	61.8	9	11	10
	9	*Mediomastus californiensis*	62.7	7.5	2.3	64.1	8	6	7
	10	*Mayerella limicola*	50.0	40.8	1.9	66.0	46	21	29
	11	*Dipolydora socialis*	46.0	13.5	1.7	67.7	24	2	8
	12	*Terebellides atlantis*	44.7	12.7	1.7	69.4	16	37	36
	13	*Nucula delphinodonta*	40.3	13.7	1.5	70.9	12	13	14
	14	Nemertea sp.12	37.7	14.0	1.4	71.3	15	19	15
	15	*Proclea graffiti*	34.3	11.2	1.3	74.6	15	17	16
(No. Species)	(159)	Station Mean Abundance	2700.3				(108)	(98)	(106)
FF06	1	*Euchone incolor*	2216.3	1240.2	58.1	58.1	3	NP	35
	2	*Cossura longocirrata*	310.7	37.9	8.1	66.2	1	1	1
	3	*Terebellides atlantis*	197.0	62.1	5.2	71.4	18	NP	28
	4	*Parougia caeca*	121.3	59.9	3.2	74.6	17	19	18
	5	*Aricidea quadrilobata*	96.3	65.6	2.5	77.1	2	22	51
	6	*Levinsenia gracilis*	83.3	16.7	2.2	79.3	5	4	5
	7	*Aricidea catherinae*	59.6	19.4	1.6	80.9	6	6	12
	8	*Tharyx acutus*	55.3	16.3	1.4	82.3	21	17	20
	9	*Nucula annulata*	54.0	6.6	1.4	83.7	10	11	7
	10	*Phoronis architecta*	51.0	17.3	1.3	85.0	30	NP	NP
	11	*Aphelochaeta marioni*	48.7	10.3	1.3	86.3	28	21	31
	12	*Ninoe nigripes*	44.3	34.2	1.2	87.5	9	8	9
	13	*Dipolydora socialis*	43.3	25.0	1.1	88.6	32	20	27
	14	*Mediomastus californiensis*	33.3	22.5	0.9	89.5	7	3	4
	15	*Nucula delphinodonta*	26.0	14.5	0.7	90.2	13	7	10
	(119)	Station Mean Abundance	3814.7				(78)	(55)	(69)

NP = Not present in sample.

Station	**Rank**	**Species**	**Mean**	**Std. Dev.**	**%**	**Cum %**	**2002 Rank**	**2001 Rank**	**2000 Rank**
FF07	1	*Cossura longocirrata*	2584.3	835.7	46.4	46.4	1	1	1
	2	*Euchone incolor*	1346.0	241.2	24.2	70.6	2	2	2
	3	*Aricidea catherinae*	334.7	173.6	6.0	76.6	3	3	9
	4	*Prionospio steenstrupi*	221.3	30.6	4.0	80.6	6	10	10
	5	*Aricidea quadrilobata*	188.3	100.4	3.4	84.0	8	6	6
	6	*Ninoe nigripes*	139.0	43.5	2.5	86.5	7	9	8
	7	*Mediomastus californiensis*	116.3	56.2	2.1	88.6	4	4	4
	8	*Tharyx acutus*	82.7	42.1	1.5	90.1	9	8	5
	9	Tubificidae sp. 2	78.0	45.9	1.4	91.5	5	7	3
	10	*Parougia caeca*	63.7	37.0	1.1	92.6	10	11	11
	11	*Apistobranchus typicus*	51.3	28.0	0.9	93.5	32	5	7
	12	*Terebellides atlantis*	41.0	10.6	0.7	94.2	19	20	17
	13	*Spio limicola*	30.7	16.5	0.6	94.8	16	16	14
	14	*Anobothrus gracilis*	21.7	10.3	0.4	95.2	24	29	36
	15	*Metopella angusta*	21.3	24.6	0.4	95.6	17	32	15
(No. Species)	(96)	Station Mean Abundance	5571.0				(69)	(64)	(66)
FF09	1	*Prionospio steenstrupi*	786.3	81.3	33.6	33.6	1	1	1
	2	*Anobothrus gracilis*	141.7	16.8	6.1	39.7	3	3	6
	3	*Levinsenia gracilis*	102.0	13.1	4.4	44.1	4	5	4
	4	*Dipolydora socialis*	93.0	25.5	4.0	48.1	2	2	2
	5	*Nucula delphinodonta*	91.7	22.5	3.9	52.0	5	4	5
	6	*Thyasira gouldi*	80.3	18.2	3.4	55.4	6	6	7
	7	*Phoronis architecta*	65.7	33.5	2.8	58.2	15	12	31
	8	*Aricidea quadrilobata*	52.7	6.5	2.3	60.5	7	7	12
	9	*Microclymene* sp.1	51.7	20.5	2.2	62.7	9	9	9
	10	*Mediomastus californiensis*	46.0	6.6	2.0	64.7	8	8	8
	11	*Crenella decussata*	45.7	6.7	2.0	66.7	16	NP	NP
	12	*Spio limicola*	44.0	12.1	1.9	68.6	26	47	14
	13	*Maldane sarsi*	37.3	24.8	1.6	70.2	30	17	23
	14	*Periploma papyratium*	36.3	7.6	1.6	71.8	14	NP	NP
	15	*Exogone verugera*	27.7	15.0	1.2	73.0	12	27	17
(No. Species)	(185)	Station Mean Abundance	2338.0				(136)	(134)	(133)

NP = Not present in sample.

Station	Rank	Species	Mean	Std. Dev.	%	Cum %	2002 Rank	2001 Rank	2000 Rank
FF 11	1	*Prionospio steenstrupi*	1962.3	627.9	42.3	42.3	1	1	1
	2	*Aricidea quadrilobata*	741.3	282.6	16.0	58.3	2	2	3
	3	*Anobothrus gracilis*	475.0	132.6	10.2	68.5	5	3	9
	4	*Euchone incolor*	214.3	37.6	4.6	73.1	3	4	4
	5	*Levinsenia gracilis*	139.7	38.2	3.0	76.1	4	5	2
	6	*Tubificoides apectinatus*	138.7	69.6	3.0	79.1	8	7	6
	7	*Chaetozone setosa* mb	124.0	30.4	2.7	81.8	9	9	7
	8	*Cossura longocirrata*	105.7	39.9	2.3	84.1	6	6	5
	9	*Spio limicola*	104.7	25.1	2.3	86.4	7	8	12
	10	Nemertea sp. 12	45.3	15.9	1.0	87.4	10	10	13
	11	*Eteone longa*	40.7	21.1	0.9	88.3	12	23	25
	12	*Mediomastus californiensis*	28.3	12.1	0.6	88.9	11	13	11
	13	*Ninoe nigripes*	26.0	3.5	0.6	89.5	20	25	19
	14	*Terebellides atlantis*	24.3	14.8	0.5	90.0	17	30	26
	15	*Syllides longocirrata*	22.3	11.7	0.5	90.5	15	43	34
(No. Species)	(146)	Station Mean Abundance	4642.3				(106)	(94)	(74)
FF 14	1	*Spio limicola*	655.3	81.4	19.8	19.8	1	5	1
	2	*Aricidea quadrilobata*	379.3	154.9	11.5	31.3	2	2	4
	3	*Prionospio steenstrupi*	331.0	45.0	10.0	41.3	3	8	3
	4	*Anobothrus gracilis*	284.3	127.0	8.6	49.9	20	1	8
	5	*Chaetozone setosa* mb	204.7	35.4	6.2	56.1	4	3	2
	6	*Tubificoides apectinatus*	109.0	15.7	3.3	59.4	7	7	6
	7	*Levinsenia gracilis*	98.3	26.8	3.0	62.4	4	6	7
	8	*Aphelochaeta marioni*	96.0	25.2	2.9	65.3	11	9	21
	9	*Cossura longocirrata*	94.3	38.9	2.9	68.2	5	11	12
	10	*Nucula delphinodonta*	85.3	30.1	2.6	70.8	12	10	10
	11	*Galathowenia oculata*	80.0	12.8	2.4	73.2	6	4	5
	12	*Sternaspis scutata*	73.3	6.8	2.2	75.4	10	12	9
	13	*Crenella decussata*	57.7	28.6	1.7	77.1	8	NP	NP
	14	*Periploma papyratium*	43.3	24.1	1.3	78.4	19	NP	NP
	15	Nemertea sp. 12	42.3	17.9	1.3	79.7	16	14	18
(No. Species)	(144)	Station Mean Abundance	3308.3				(81)	(96)	(101)

NP = Not present in sample.

APPENDIX C5

Species Loadings for Covariance Biplot of 2003 Massachusetts Bay Sample

Table C5-1. Species with Positive Loadings on both Axes 1 and 2 of the Covariance Biplot based on 2003 Massachusetts Bay Data.

Species	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5	Axis 6
Acanthohaustorius millsi	0.387	0.628	-0.247	-0.411	0.137	0.056
Acanthohaustorius spinosus	0.308	0.520	-0.220	-0.399	0.142	0.089
Adelodrilus sp. 1	0.222	0.144	0.081	0.759	0.041	0.177
Aeginina longicornis	0.079	0.024	0.367	-0.064	-0.535	-0.468
Aglaophamus circinata	0.590	0.450	0.064	0.274	-0.126	-0.100
Ameroculodes sp. 1	0.099	0.053	0.298	0.056	-0.514	-0.216
Ampelisca macrocephala	0.168	0.257	0.431	0.136	-0.049	-0.122
Ampharete lindstroemi	0.122	0.109	0.281	0.085	-0.445	-0.333
Amphiporus bioculatus	0.222	0.144	0.081	0.759	0.041	0.177
Amphiporus cruentatus	0.515	0.383	-0.074	-0.105	0.077	-0.032
Arctica islandica	0.472	0.036	0.158	0.433	-0.102	-0.042
Argissa hamatipes	0.039	0.163	0.029	-0.236	-0.068	-0.016
Asabellides oculata	0.292	0.056	0.412	0.440	-0.033	-0.104
Astarte borealis	0.345	0.539	-0.202	-0.253	0.147	0.120
Astarte undata	0.330	0.094	0.472	0.233	0.081	-0.102
Cancer borealis	0.463	0.625	-0.137	-0.322	0.203	0.043
Capitellidae sp. 2	0.153	0.137	0.100	0.331	-0.026	0.072
Cerastoderma pinnulatum	0.220	0.287	0.432	0.357	-0.001	0.064
Chiridotea tuftsi	0.383	0.618	-0.242	-0.401	0.138	0.067
Cirratulus cirratus	0.178	0.032	0.044	0.596	0.120	0.188
Clymenura sp. A	0.329	0.445	-0.132	-0.106	0.008	-0.093
Crangon septemspinosa	0.267	0.130	-0.118	-0.063	-0.025	-0.051
Crassicorophium crassicorne	0.486	0.694	-0.247	-0.319	0.088	-0.029
Crenella glandula	0.238	0.202	0.189	0.783	0.075	0.237
Cyclocardia borealis	0.219	0.171	0.095	0.379	-0.015	0.068
Diastylis polita	0.275	0.392	-0.114	-0.100	0.011	-0.078
Diastylis quadrispinosa	0.355	0.374	-0.046	0.095	0.026	-0.054
Diastylis sculpta	0.453	0.452	-0.055	-0.015	-0.032	-0.141
Dipolydora socialis	0.167	0.547	0.535	0.212	0.248	0.330
Echinarachnius parma	0.567	0.766	-0.121	-0.031	0.099	0.046
Edotia montosa	0.506	0.225	0.043	-0.034	-0.251	-0.281
Edwardsia elegans	0.144	0.224	0.349	-0.138	-0.473	-0.435
Enchytraeidae sp. 1	0.255	0.174	0.085	0.777	0.030	0.173
Enchytraeidae sp. 3	0.222	0.144	0.081	0.759	0.041	0.177
Ensis directus	0.194	0.172	0.017	0.151	-0.065	-0.005
Ericthonius fasciatus	0.278	0.333	0.413	0.506	-0.057	-0.030
Euchone elegans	0.159	0.139	0.106	0.348	-0.023	0.075
Euclymene collaris	0.450	0.434	0.047	0.584	-0.017	0.071
Eudorellopsis deformis	0.449	0.664	-0.233	-0.311	0.085	-0.029
Euspira immaculata	0.308	0.520	-0.220	-0.399	0.142	0.089
Exogone hebes	0.630	0.549	0.037	0.286	0.081	0.016
Exogone verugera	0.300	0.340	0.417	0.174	0.339	0.061
Grania postclitellochaeta longiducta	0.222	0.144	0.081	0.759	0.041	0.177

Species	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5	Axis 6
Harmothoe extenuata	0.238	0.032	-0.077	-0.035	0.020	-0.072
Hiatella arctica	0.409	0.370	0.262	-0.011	-0.391	-0.353
Hippomedon serratus	0.344	0.566	-0.230	-0.387	0.143	0.085
Laonice sp. 1	0.090	0.025	0.454	-0.034	-0.401	-0.396
Leptocheirus pinguis	0.164	0.271	-0.160	-0.088	0.040	-0.232
Lyonsia arenosa	0.386	0.612	-0.182	-0.390	0.055	0.031
Macoma balthica	0.153	0.137	0.100	0.331	-0.026	0.072
Molgula manhattensis	0.350	0.430	0.140	0.512	0.105	0.181
Nemertea sp. 15	0.279	0.002	0.059	0.075	0.052	-0.191
Nemertea sp. 16	0.308	0.520	-0.220	-0.399	0.142	0.089
Odostomia sulcosa	0.263	0.199	0.129	0.748	0.006	0.170
Orbinia swani	0.387	0.557	-0.221	-0.331	0.103	0.028
Pectinaria granulata	0.355	0.077	0.135	0.478	-0.168	-0.064
Pentamera calcigera	0.222	0.144	0.081	0.759	0.041	0.177
Periploma leanum	0.260	0.259	-0.066	0.078	-0.004	-0.037
Petalosarsia declivis	0.263	0.326	0.234	-0.158	-0.391	-0.319
Phascolion strombi	0.012	0.341	0.614	-0.065	0.372	0.096
Phoronis architecta	0.327	0.021	0.248	0.428	0.229	0.209
Phoxocephalus holbolli	0.457	0.672	-0.257	-0.403	0.124	0.031
Phyllodoce mucosa	0.725	0.099	-0.139	-0.037	0.203	-0.047
Politolana polita	0.446	0.638	-0.204	-0.284	0.090	0.049
Polycirrus eximius	0.076	0.193	0.244	0.052	0.056	0.128
Polygordius sp. A	0.585	0.676	-0.164	0.001	0.062	0.076
Protomedeia fasciata	0.412	0.335	0.162	0.375	-0.141	-0.092
Pseudunciola obliquua	0.342	0.433	-0.083	-0.006	-0.022	-0.071
Ptilanthura tenuis	0.428	0.469	0.177	0.039	-0.123	-0.194
Pythinella cuneata	0.430	0.695	-0.028	-0.263	0.087	0.001
Rhepoxynius hudsoni	0.506	0.728	-0.241	-0.256	0.124	0.056
Scolelepis cf. tridentata	0.206	0.166	0.128	0.119	-0.218	-0.153
Scoloplos armiger	0.504	0.173	-0.058	0.075	0.079	-0.142
Solariella obscura	0.290	0.318	-0.091	-0.017	-0.008	-0.069
Spio thulini	0.541	0.456	0.135	0.184	-0.015	-0.074
Spiophanes bombyx	0.630	0.567	-0.186	-0.167	-0.026	-0.102
Sthenelais limicola	0.470	0.704	-0.261	-0.377	0.112	0.003
Syllides convoluta	0.222	0.144	0.081	0.759	0.041	0.177
Syrrhoe sp. 1	0.553	0.716	-0.102	-0.132	0.050	-0.020
Tanaissus psammophilus	0.537	0.747	-0.223	-0.242	0.078	-0.002
Typosyllis hyalina	0.067	0.068	0.014	0.562	0.119	0.144
Unciola inermis	0.285	0.252	0.345	0.479	-0.129	-0.061
Unciola irrorata	0.241	0.459	0.249	-0.172	-0.125	-0.244

Table C5-2. Species with Positive Loadings on Axis 1 and Negative Loadings on Axis 2 of the Covariance Biplot based on 2003 Massachusetts Bay Data.

Species	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5	Axis 6
Ampelisca abdita	0.021	-0.145	-0.108	-0.036	0.147	-0.134
Ampharete acutifrons	0.197	-0.390	0.076	-0.065	0.164	-0.039
Anonyx liljeborgi	0.029	-0.082	0.322	0.001	-0.275	-0.123
Aricidea catherinae	0.443	-0.553	-0.037	-0.010	-0.066	-0.089
Axiothella catenata	0.047	-0.033	0.066	-0.024	0.068	-0.007
Capitella capitata complex	0.259	-0.293	0.046	0.070	0.069	-0.050
Cerebratulus lacteus	0.115	-0.365	-0.157	-0.068	0.187	0.003
Ceriantheopsis americanus	0.458	-0.042	-0.028	-0.215	0.101	-0.214
Chone duneri	0.181	-0.018	0.048	0.211	-0.049	0.072
Clymenella torquata	0.169	-0.224	0.040	-0.051	0.022	-0.077
Cyanophthalma cordiceps	0.092	-0.070	-0.033	0.012	-0.021	-0.035
Deflexilodes intermedius	0.047	-0.207	-0.105	-0.028	0.157	0.007
Deflexilodes tuberculatus	0.129	-0.150	-0.034	0.011	-0.011	-0.034
Dipolydora caulleryi	0.109	-0.128	0.071	-0.041	0.042	-0.089
Dipolydora quadrilobata	0.074	-0.173	0.049	0.033	0.166	0.035
Drilonereis magna	0.084	-0.090	0.029	-0.067	-0.009	-0.075
Dyopedos monacanthus	0.063	-0.181	-0.141	-0.076	0.014	-0.114
Echiurus echiurus	0.070	-0.063	0.106	0.021	0.056	-0.043
Enipo torelli	0.022	-0.135	-0.022	0.042	0.145	0.090
Eteone heteropoda	0.178	-0.353	-0.034	-0.059	0.167	-0.067
Eteone longa	0.120	-0.452	0.231	-0.098	-0.172	-0.397
Eteone trilineata	0.070	-0.063	0.106	0.021	0.056	-0.043
Euclymeninae sp. 1	0.093	-0.176	0.046	-0.025	0.120	-0.055
Eulalia viridis	0.087	-0.084	-0.013	0.011	-0.015	-0.031
Exogone longicirris	0.113	-0.112	0.022	-0.002	0.004	-0.043
Flabelligera affinis	0.216	-0.465	-0.155	-0.055	0.123	0.022
Gattyana amondseni	0.030	-0.060	0.371	0.189	-0.185	-0.074
Goniada maculata	0.108	-0.257	0.396	-0.014	0.018	-0.362
Harmothoe imbricata	0.054	-0.060	0.386	-0.037	0.004	-0.166
Hartmania moorei	0.034	-0.152	-0.033	-0.029	-0.023	0.191
Ilyanassa trivittata	0.144	-0.150	0.123	-0.104	-0.166	-0.239
Jassa marmorata	0.028	-0.119	-0.125	-0.049	-0.003	0.058
Mediomastus californiensis	0.277	-0.747	-0.033	-0.161	0.247	-0.113
Megamoera dentata	0.087	-0.084	-0.013	0.011	-0.015	-0.031
Microphthalmus pettiboneae	0.060	-0.118	-0.085	-0.035	0.031	-0.036
Monticellina baptisteae	0.304	-0.601	-0.096	-0.086	0.141	-0.115
Monticellina dorsobranchialis	0.317	-0.430	0.014	-0.124	0.043	-0.173
Musculus discors	0.072	-0.163	-0.058	-0.051	0.033	-0.063
Nemertea sp. 13	0.054	-0.108	-0.083	-0.031	0.028	-0.032
Nephtys caeca	0.071	-0.013	0.274	-0.075	-0.442	-0.405
Nereis grayi	0.073	-0.069	0.691	-0.076	0.147	-0.130
Ninoe nigripes	0.079	-0.741	-0.058	-0.224	0.015	0.014
Oedicerotidae sp. 2	0.037	-0.029	0.178	-0.073	-0.287	-0.271

Species	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5	Axis 6
Onoba mighelsi	0.126	-0.039	0.211	0.259	0.118	-0.017
Ophelina acuminata	0.001	-0.195	0.365	-0.168	0.153	-0.028
Ophryotrocha sp. 1	0.019	-0.109	-0.023	0.049	0.131	0.083
Orchomenella minuta	0.258	-0.013	0.136	-0.094	-0.193	-0.249
Owenia fusiformis	0.314	-0.005	0.002	-0.028	-0.174	-0.184
Pagurus acadianus	0.088	-0.095	0.022	0.003	0.001	-0.038
Pandora gouldiana	0.048	-0.115	-0.013	-0.038	0.005	-0.041
Pandora nr. inflata	0.041	-0.116	-0.018	0.006	0.065	0.039
Parapionosyllis longicirrata	0.071	-0.257	-0.095	-0.042	0.180	-0.015
Parapleustes gracilis	0.051	-0.119	-0.022	-0.022	0.042	-0.020
Petricola pholadiformis	0.058	-0.119	-0.085	-0.034	0.051	-0.051
Pherusa affinis	0.026	-0.085	0.273	-0.096	0.163	-0.022
Pholoe minuta	0.243	-0.111	0.475	0.228	-0.043	-0.190
Phyllodoce groenlandica	0.084	-0.090	0.029	-0.067	-0.009	-0.075
Phyllodoce maculata	0.177	-0.033	0.285	0.032	-0.358	-0.379
Pionosyllis sp. A	0.160	-0.127	0.256	0.104	0.117	-0.075
Pitar morrhuanus	0.071	-0.196	-0.078	-0.029	0.083	0.019
Placopecten magellanicus	0.083	-0.062	0.319	-0.080	-0.301	-0.348
Pleusymtes glaber	0.070	-0.095	0.084	0.027	0.089	-0.048
Polycirrus phosphoreus	0.146	-0.194	0.117	0.250	0.168	0.111
Polydora sp. 1	0.100	-0.098	-0.004	0.013	-0.007	-0.037
Prionospio steenstrupi	0.131	-0.443	0.459	-0.064	-0.058	-0.423
Scoletoma hebes	0.217	-0.389	-0.152	-0.143	0.062	-0.108
Sphaerosyllis brevifrons	0.052	-0.100	-0.031	-0.004	0.057	-0.033
Spio filicornis	0.388	-0.031	0.344	0.455	-0.036	-0.003
Stenopleustes inermis	0.059	-0.007	0.397	-0.090	-0.617	-0.307
Tharyx acutus	0.377	-0.591	-0.035	-0.080	0.069	-0.035
Thracia conradi	0.272	-0.274	0.429	0.190	0.088	0.062
Tubificidae sp. 2	0.132	-0.318	-0.048	-0.114	-0.008	0.103
Yoldia limatula	0.058	-0.119	-0.085	-0.034	0.051	-0.051

Table C5-3. Species with Negative Loadings on Axis 1 and Positive Loadings on Axis 2 of the Covariance Biplot based on 2003 Massachusetts Bay Data.

Species	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5	Axis 6
Abyssoninoe winsnesae	-0.391	0.134	-0.270	0.119	0.031	-0.148
Ampharete finmarchica	-0.234	0.120	0.003	-0.028	-0.215	0.227
Ancistrosyllis groenlandica	-0.161	0.070	-0.070	0.031	-0.022	-0.002
Anobothrus gracilis	-0.782	0.372	0.146	0.012	-0.036	0.102
Aphelochaeta monilaris	-0.455	0.245	-0.051	0.022	-0.294	0.122
Aphrodita hastata	-0.282	0.129	-0.204	0.105	0.106	-0.345
Arcteobia anticostiensis	-0.134	0.022	0.232	-0.068	0.292	0.041
Aricidea quadrilobata	-0.819	0.286	-0.214	0.062	-0.149	0.129
Baeonectes muticus	-0.158	0.140	0.538	-0.136	0.317	0.062
Bathymedon obtusifrons	-0.614	0.243	-0.231	0.044	-0.284	-0.022
Bostrichobranchus pilularis	-0.280	0.205	0.303	-0.094	0.088	0.175
Brada villosa	-0.127	0.002	0.482	-0.167	0.286	0.143
Byblis gaimardi	-0.161	0.070	-0.070	0.031	-0.022	-0.002
Campylaspis nr. sulcata	-0.426	0.221	0.046	-0.058	-0.362	0.348
Campylaspis rubicunda	-0.244	0.097	0.461	-0.130	-0.025	0.179
Carinomella lactea	-0.469	0.083	-0.285	0.125	0.215	-0.319
Cephalothricidae sp. 1	-0.629	0.324	-0.312	0.149	0.174	-0.345
Ceratocephale loveni	-0.176	0.053	-0.127	0.028	-0.101	0.076
Chaetoderma nitidulum canadense	-0.453	0.283	0.296	-0.027	-0.275	-0.267
Chaetozone setosa mb	-0.658	0.535	-0.326	0.228	0.031	-0.177
Chone cf. magna	-0.154	0.127	0.517	-0.160	-0.095	-0.011
Colus parvus	-0.144	0.145	0.377	-0.098	0.319	0.101
Cossura longocirrata	-0.496	0.080	-0.317	0.009	-0.163	0.310
Crenella decussata	-0.203	0.162	0.707	-0.124	0.233	-0.152
Ctenodiscus crispatus	-0.648	0.349	0.091	0.031	0.210	-0.064
Cylichna alba	-0.210	0.217	0.703	-0.157	0.414	0.104
Cylichna gouldi	-0.424	0.167	-0.133	-0.004	-0.337	0.312
Deflexilodes tesselatus	-0.354	0.029	0.067	-0.052	0.023	0.122
Dentalium entale	-0.668	0.274	-0.306	0.198	0.219	-0.394
Diastylis cornuifer	-0.346	0.109	0.044	-0.102	-0.290	0.562
Diplocirrus hirsutus	-0.636	0.338	0.139	-0.026	-0.241	0.239
Dorvillea sociabilis	-0.742	0.325	-0.303	0.147	-0.056	-0.216
Drilonereis longa	-0.295	0.128	-0.194	0.147	0.257	-0.313
Dulichia tuberculata	-0.054	0.207	0.426	0.007	-0.302	-0.258
Dysponetus pygmaeus	-0.264	0.116	-0.051	-0.010	-0.222	0.129
Erythrops erythrophthalma	-0.414	0.147	-0.051	-0.010	-0.010	0.258
Euchone papillosa	-0.295	0.128	-0.194	0.147	0.257	-0.313
Eudorella hispida	-0.553	0.220	-0.160	0.066	-0.129	0.033
Eudorella pusilla	-0.642	0.288	0.166	-0.044	-0.185	-0.007
Galathowenia oculata	-0.185	0.533	-0.069	-0.025	-0.029	0.045
Gattyana cirrosa	-0.133	0.038	-0.103	0.018	-0.107	0.080
Haploops fundiensis	-0.154	0.104	0.519	-0.069	0.201	-0.017
Harpinia propinqua	-0.416	0.282	0.737	-0.168	0.052	-0.087

Species	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5	Axis 6
Heteromastus filiformis	-0.552	0.255	-0.207	0.113	0.046	-0.284
Hippomedon propinquus	-0.044	0.006	0.244	0.014	0.078	-0.123
Ischyrocerus anguipes	-0.074	0.139	0.798	-0.140	-0.059	-0.249
Laonice cirrata	-0.143	0.065	0.519	-0.112	0.169	0.005
Leptasterias tenera	-0.234	0.120	0.003	-0.028	-0.215	0.227
Leptostylis longimana	-0.446	0.200	0.180	-0.129	-0.261	0.489
Leucon acutirostris	-0.535	0.228	-0.365	0.211	0.239	-0.500
Maldane sarsi	-0.158	0.080	0.621	-0.158	0.409	0.066
Mayerella limicola	-0.596	0.305	0.142	-0.036	-0.043	0.139
Megayoldia thraciaeformis	-0.229	0.083	-0.199	0.097	0.105	-0.209
Melinna cristata	-0.501	0.178	-0.280	0.097	-0.077	-0.044
Melphidippa cf. borealis	-0.157	0.046	-0.119	0.022	-0.116	0.087
Microclymene sp.1	-0.332	0.251	0.647	-0.157	0.420	0.121
Microspio sp. 1	-0.235	0.105	-0.085	0.079	0.002	-0.027
Molpadia oolitica	-0.122	0.038	-0.083	0.022	-0.050	0.039
Monocorophium acherusicum	-0.207	0.084	0.240	-0.070	0.149	-0.025
Monoculodes packardi	-0.597	0.257	-0.298	0.131	-0.062	-0.150
Munna sp. 1	-0.186	0.172	0.742	-0.174	0.470	0.084
Myriochele heeri	-0.236	0.177	-0.050	0.043	-0.110	0.096
Mystides borealis	-0.454	0.216	-0.048	-0.031	-0.394	0.311
Nephasoma diaphanes	-0.071	0.129	-0.012	0.373	0.042	0.033
Nuculana messanensis	-0.301	0.128	-0.221	0.104	0.083	-0.326
Nuculana pernula	-0.282	0.204	0.056	0.287	0.364	-0.224
Nuculoma tenuis	-0.704	0.393	0.279	0.030	0.051	-0.196
Oenopota cf. cancellatus	-0.195	0.133	0.355	-0.118	0.078	0.068
Onoba pelagica	-0.447	0.083	0.004	0.069	-0.017	0.101
Ophiura sarsi	-0.261	0.023	-0.072	-0.072	-0.230	0.432
Ophiura sp. 2	-0.448	0.203	-0.263	0.170	0.212	-0.390
Paradulichia typica	-0.400	0.303	0.711	-0.188	-0.035	0.040
Paramphinome jeffreysii	-0.533	0.233	-0.337	0.222	0.282	-0.502
Periploma papyratium	-0.551	0.277	0.569	-0.118	0.148	0.012
Photis pollex	-0.336	0.258	0.354	-0.124	-0.544	0.102
Pleurogonium inerme	-0.232	0.137	0.288	-0.097	-0.574	-0.119
Pleurogonium rubicundum	-0.112	0.006	0.363	-0.126	-0.430	-0.189
Pleurogonium spinosissimum	-0.122	0.098	0.378	-0.119	0.155	0.025
Praxillella praetermissa	-0.444	0.249	0.038	0.048	-0.515	0.442
Praxillura ornata	-0.181	0.198	0.635	-0.146	0.285	0.012
Priapulus caudatus	-0.298	0.087	-0.193	0.089	0.033	-0.121
Prionospio aluta	-0.482	0.214	-0.230	0.170	0.293	-0.338
Prionospio cirrifera	-0.451	0.270	0.218	-0.049	0.014	0.238
Proboloides holmesi	-0.401	0.234	0.214	-0.045	-0.086	0.086
Proclea graffii	-0.455	0.228	0.088	-0.084	-0.350	0.419
Propebela exarata	-0.223	0.219	0.458	0.003	0.424	-0.015
Retusa obtusa	-0.567	0.248	-0.098	0.005	-0.379	0.325
Rhodine loveni	-0.202	0.181	0.609	-0.167	0.440	0.114

Species	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5	Axis 6
Scalibregma inflatum	-0.663	0.261	-0.236	0.204	0.028	-0.270
Scoletoma fragilis	-0.318	0.009	0.579	-0.139	0.232	-0.066
Siliqua costata	-0.055	0.088	0.178	0.030	-0.350	-0.275
Sphaerodoropsis cf. longipalpa	-0.288	0.224	0.463	-0.109	0.302	0.175
Sphaerodoropsis sp. 1	-0.425	0.206	0.007	-0.004	-0.295	0.169
Sphaerosyllis erinaceus	-0.231	0.137	0.167	0.097	0.129	0.039
Spiochaetopterus oculatus	-0.254	0.081	-0.192	0.135	0.261	-0.304
Spiophanes kroeyeri	-0.640	0.378	0.194	-0.032	0.049	0.011
Spisula solidissima	-0.133	0.038	-0.103	0.018	-0.107	0.080
Stereobalanus canadensis	-0.462	0.248	0.182	-0.007	0.237	-0.178
Sternaspis scutata	-0.528	0.228	-0.139	0.054	-0.255	0.173
Syllides japonica	-0.252	0.057	0.296	-0.076	0.323	0.085
Syllides longocirrata	-0.662	0.287	-0.365	0.195	0.098	-0.365
Terebellides atlantis	-0.319	0.044	-0.079	-0.079	-0.288	0.583
Terebellides stroemii	-0.415	0.175	-0.223	0.135	0.179	-0.258
Tetrastemma elegans	-0.299	0.064	-0.228	0.048	-0.085	0.055
Thyasira gouldi	-0.597	0.377	0.575	-0.103	0.055	-0.190
Trichobranchus roseus	-0.665	0.300	-0.320	0.158	0.024	-0.282
Trochochaeta carica	-0.239	0.127	-0.011	0.072	-0.197	-0.157
Trochochaeta multisetosa	-0.516	0.083	0.095	0.097	0.042	0.127
Tubificoides apectinatus	-0.628	0.198	-0.443	0.192	0.104	-0.347
Tubulanus pellucidus	-0.539	0.240	-0.320	0.192	0.220	-0.472
Turbellaria spp.	-0.393	0.141	-0.271	0.102	0.005	-0.236
Westwoodilla megalops	-0.022	0.090	0.367	-0.033	-0.518	-0.328
Yoldia sapotilla	-0.777	0.285	-0.161	0.088	0.120	-0.042

Table C5-4. Species with Negative Loadings on both Axes 1 and 2 of the Covariance Biplot based on 2003 Massachusetts Bay Data.

Species	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5	Axis 6
Amphiporus caecus	-0.292	-0.116	0.159	0.009	0.440	-0.029
Aphelochaeta marioni	-0.479	-0.034	-0.290	0.262	0.265	-0.060
Aphelochaeta sp. 3	-0.005	-0.005	0.254	0.009	0.066	-0.067
Apistobranchus typicus	-0.127	-0.012	0.505	-0.165	0.294	0.208
Aricidea minuta	-0.054	-0.042	0.185	-0.129	0.025	0.179
Casco bigelowi	-0.019	-0.077	0.508	-0.188	0.096	-0.148
Diaphana minuta	-0.082	-0.072	0.273	-0.105	0.240	0.036
Euchone incolor	-0.079	-0.159	-0.128	-0.091	-0.328	0.486
Gitanopsis arctica	-0.005	-0.005	0.254	0.009	0.066	-0.067
Laonome kroeyeri	-0.009	-0.048	-0.031	0.219	-0.042	0.062
Leitoscoloplos acutus	-0.158	-0.478	-0.172	-0.056	0.310	-0.248
Levinsenia gracilis	-0.730	-0.030	0.240	-0.121	0.052	-0.116
Metopella angusta	-0.037	-0.247	0.161	-0.125	-0.239	0.118
Micrura spp.	-0.680	-0.006	-0.060	0.010	0.251	-0.135
Mya arenaria	-0.019	-0.335	-0.067	0.017	0.192	0.117
Nemertea sp. 12	-0.533	-0.022	-0.145	-0.016	0.209	-0.164
Nemertea sp. 2	-0.028	-0.252	-0.226	0.179	0.171	0.039
Nephtys ciliata	-0.020	-0.041	0.265	-0.105	0.112	-0.023
Nephtys cornuta	-0.087	-0.090	-0.150	0.041	0.157	-0.226
Nephtys incisa	-0.254	-0.266	0.296	-0.186	0.358	0.299
Nucula annulata	-0.093	-0.046	-0.065	-0.071	-0.202	0.502
Nucula delphinodonta	-0.115	-0.029	0.720	-0.130	-0.221	-0.251
Oenopota incisula	-0.104	-0.060	0.264	-0.096	-0.249	-0.175
Paranaitis speciosa	-0.053	-0.171	0.379	-0.097	0.303	0.188
Parougia caeca	-0.189	-0.321	0.053	-0.073	0.215	0.434
Praxillella gracilis	-0.285	-0.043	-0.220	0.125	0.205	-0.128
Sphaerodoridium sp. A	-0.087	-0.072	0.022	-0.103	-0.232	0.524
Spio limicola	-0.527	-0.065	0.033	0.073	0.073	-0.036

APPENDIX D

D1. Summary of Hard-Bottom Still Photographs 2003

D2. Summary of Video Footage 2003

D3. Densities of Barnacle Larvae 1992–2003

Appendix D1. Summary of data recorded from still photographs taken on 2003 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
Number of frames	31	32	33	33	32	32	32	33	33	26	32	27	28	31	32	33	33	31	33	33	31	33	31	725
Depth (m)	23	20	18	21	25	23	27	22	25	29	20	27	31	28	22	23	21	20	23	22	33	22	31	
Substrate [1]	b+ mx	b+ mx	b+c	mx+b	mx	mx	mx+b	b+ mx	b+ mx	d+rr	b+mx	b+mx	c+g	mx+b	b+ mx	b+ mx	mx+b	mx+b	b+ mx	b	b+c	b+ mx	d+rr	
Sediment drape	3.19	1.81	1.30	1.88	2.69	2.44	3.25	2.82	2.79	2.96	1.59	2.70	3.29	2.61	2.78	2.94	2.30	1.90	2.52	4.27	2.61	1.82	3.35	
Coralline algae (%)	28	67	80	63	45	53	8	25	6		66	12	2	23	39	30	47	59	19		1	63		
Ptilota serrata [2]			r	r											c	c-a			f			f-c		
Hydroid [2]	c	f-c	f-c	f-c	c	c	f-c	f-c	f-c	r-a	f-c	f-c	r-f	f	c-a	c-a	f-c	f-c	c	c-a	f-c	f-c	f-c	
spirorbids/barnacles [2]	f-c	f-c	f	c	f	f	r-f	f-c	f-c	r	a	f-a	r-f	r-a	f-c	f-c	r-f	r-f	c-a	f-a	f-a	r-f	f-a	
Coralline algae	148	450	491	435	200	330	66	141	52		440	74	18	132	235	156	332	405	117		8	428	1	4659
Ptilota serrata			9	2											137	198			13			57		416
Rhodymenia palmata	40	33	15	24		6		11							171	262	5		52	9		70		698
Agarum cribrosum															6	13								19
Sponge	4			2	2	8	16	5	4	7	6	3	2	3	6	5	3	4	5	1	26	10	7	129
Aplysilla sulfurea		6			2	14	15	20	8			9		9	9	11		1	3	1	23			131
Halichondria panicea	8	8		1	2	6	18	10	16	1	3	7	1	2	5	17	3		1	18	18			145
Haliclona spp. (upright)			1	1																	7			9
Suberites spp.	12				4	9	27	10	22			11	7	6	1	1	1		1	2	8			122
white divided								16	333		2	83				42			67	1	561			1105
orange/tan encrusting	65	109	53	66	105	80	152	119	118	18	42	93	7	21	35	54	70	32	54	48	116	96	45	1598
orange encrusting	40	25	3	15	47	40	17	41	24		43	21	2	4	25	59	11	16	22	5	54	33	1	548
gold encrusting		5				7		12	2		12	18			6	2	3	1						68
tan encrusting			5																					5
pink fuzzy encrusting		1	14	28	18	1	11	3	3		1		16	18	24	38	40	45	8		4	47	1	321
dark red/brown encrusting		3	1	5	1																			10
white translucent	76	188	72	79	66	56	79	193	239	86	115	132	9	59	105	160	46	52	137	54	213	84	50	2350
cream encrusting	1	1		5		6	9	5	1	9			2	1	1			2	6	2	3	6		60
rust-cream encrusting		1												1										2
filamentous white encrusting								3	1			1									1			6
Melonanchora elliptica									1					1	2									4

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
Haliclona spp. (encrusting)	3													1		1						1		6
general encrusting	14	9	8	7	10	4	10	10	6	7	10	3	11	10	13	9	8	3	18	8	51	23	9	261
red crust								2	20		1	8		3			7		3	7	14			65
red/orange crust				3																				3
Obelia geniculata															4	9								13
anemone			2						1			1		1		1			2			2		10
Metridium senile		23	14	7	1	6		5	29	1675	50	9				72	12	1		78	124	46	312	2464
Urticina felina	1	1	1		2			1		2		2		1		3				1	1		1	17
Gersemia rubiformis																				39				39
Tubularia sp.										73						9								82
gastropod																1								1
Tonicella marmorea		5	4	3	1						1			1	1			3				2		21
Crepidula plana		26	20			15			85							43		8	12			35		244
Coryphella sp.			1																					1
Buccinum undatum													1			1					2			4
nudibranch		1	1					1				1		1						1				6
Modiolus modiolus	84	161	251	133	40	46	17	43	25		93	13	8	6	35	115	46	74	51	11	5	63		1320
Placopecten magellanicus						1	1						2					1						5
Arctica islandica				1		1	3	2					9	2										18
Balanus spp.		196	61	964		10	53		400		1582	562			145	450	23	4	755	843	2280	103	2480	10911
Homarus americanus				1	1	1		1											1	1				6
Cancer spp.	4	3		5	2		5	1	2		1	3	7	2	1		4	4	2			1	1	48
Strongylocentrotus droebachiensis		7	16	7		6	1	11		1	15	2		2	3		2	13	4		1	6		97
starfish												1												1
juvenile *Asterias*	107	166	198	225	140	85	34	100	56	19	82	61	79	29	90	137	55	111	91	50	2	104	51	2072
Asterias vulgaris	9	23	11	6	10	6	4	30	4	31	20	88	37	8	9	10	48	6	16	3	24	4	109	516
Henricia sanguinolenta	32	57	47	44	36	43	28	42	52	11	74	31	3	4	24	53	13	35	38	32	22	34	24	779
Porania insignis											1													1
Crossaster papposus							1	1													3			5
Pteraster militaria							1											1					1	3
Solaster endeca													1				1				1			3
Psolus fabricii		6	13	7	5	2	1	1	1		6			1			7	16	2			16		84
Aplidium spp.	50	30	16	128	86	104	48	127	19		43	24	20	35	3		86	90	50		2	86	1	1048
Dendrodoa carnea	45	42	4	39	39	44	10	54	19		17	25	1	7	5	40	25	30	83	12	3	17	3	564

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
Didemnum albidum	83	73	39	65	82	91	80	78	72	33	29	37	28	10	7	20	25	12	18	9	6	67	17	981
Halocynthia pyriformis	4	6	4	2		2		24	21	11	7	8	1			13	17	2	19	8	4	20	82	255
white globular tunicate	26	45	38	67	33	76	5	15	8	1	25	15	11	10	40	52	41	36	35	4	31	31	3	648
Boltenia ovifera																					8			8
white *Halocynthia pyriformis*		1				1		10	10	6	1	2			2	17			2	2	74	13	101	242
bryozoan	30	32	4	22	43	27	71	13	65	39	10	24		1	12	12	1	1	20	72	41	14	64	618
red crust bryozoan		1		4																23	10	1	45	84
Myxicola infundibulum	20	36	25	60	2	10	7	19	6	1	16	5	1	1	4	28	2	6	2	7	3	9	7	277
Terebratulina septentrionalis			1					18	642		11	175				217			169	2	1329	90		2654
fish					1		1																	2
Tautogolabrus adspersus	53	167	188	67	24	78	19	113	54	47	111	93	2	8	270	46	58	12	48	52	25	68	31	1634
Myoxocephalus spp.	1	1			2														1				1	6
Macrozoarces americanus		1							1															2
Hemitripterus americanus																		1						1
Pseudopleuronectes americanus			1			1	1										1		1					5
Pholis gunnellus	1			2			1						1				1	1						7
Gadus morhua																					11			11

1

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

Appendix D2. Summary of data recorded from video footage taken on 2003 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	23	21	22	21	22	22	35	21	23	20	23	21	21	21	23	23	21	23	21	21	22	21	21	512
Begin Depth (m)	24.1	21.6	18.6	21	28	23.5	27.4	23.5	28	31.1	22.9	29.3	30.8	29.3	23.8	24.4	22.6	21	24.7	23.3	34.1	23.5	32.6	
End Depth (m)	22.6	20.4	18.3	21	24.4	23.5	25.3	21.3	25.6	29.6	20.4	26.5	31.4	28	22.6	24.4	19.2	20.4	22.9	21	33.2	21.9	29.9	
Substrate [1]	c+ob	b+c	b+c	b+c	c+ob	c+b	c+b	b+c	b+c	d+rr	b+c	c+b	cp	mx	b+c	b+c	cp+ob	c+b	b+c	b	cp+b	cp+b	d+rr	
Sediment drape[2]	m-mh	l-lm	l	lm	m	lm-m	m-mh	m	m	m	l-lm	m	m-mh	m	m	m	lm	lm	m	mh-h	m	lm	mh	
Habitat relief [3]	lm	m	mh	m	lm	lm	lm	m	m		m	m	l	lm	m	mh	lm	lm	m	h	m	m		
Suspended matter [4]	h	h	h		h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h			h	
Coralline algae [5]	f-c	a	a	a	c	c-a	f	f-c	r-f		f	a	r	f-c	c	f-c	c-a	a	f-c			c-a		
Ptilota serrata [5]			r												c-a	c-a			r			f-c		
Hydroid [5]	c	c	f-c	f-c	c	c	c	c	f-c	r-a	f-c	f-c	f	f	c-a	c-a	f-c	f-c	f-c	c-a	f-c	f-c	r-c	
Spirorbids/barnacles [5]	f-c	f	f-c	c	f	f	f	c	f	f	f	f-a	f	f-c	f-c	f-c	r-f	r-f	f-c	f	f	f	f	
Rhodymenia palmata [5]	f	r	f	f	r	r						r			c	c-a			r-f	r		f		
Agarum cribrosum [5]															c	c								
Sponge	1						1	1	2	2			1	2						3	10	3		26
Halichondria panicea [5]	f	f			f	f	c	c	f		f	c		r	r	c	r	r	f	c	c			
Haliclona oculata				1																	3			4
Suberites spp. [5]	c				c	f	c	c	f-c		c		f	c		r				r	c			
white divided sponge [5]							r	f	c-a		f-c					f-c			f-c		a			
Melonanchora elliptica									1												2			3
Haliclona spp. (encrusting)	2		1			1	1							2				1				1		9
Obelia geniculata [5]															c	c								
Anemone						1															1			2
Metridium senile [5]	f	c	f-c	r	r	f	r	r	f-c	a	f	c	r	r		f-c	r	r	f	c	c	c	c	
Urticina felina	2	2	3	1	5	3	2	3	4		2	2	1	4	1	4		1		2	3			45
Gersemia rubiformis																				c				
Tubularia sp. [5]										c-a														
Alcyonium digitatum																					1			1
Buccinum undatum				1				1																2
Bivalve								1																1
Modiolus modiolus [5]	c	c	a	a	c	c	f-c	c	f-c		f-c	c-a	r-f	f	c	c-a	c	c-a	c	c-a	c	c-a		
Placopecten magellanicus	2				2	2	2		1				5	1			1	2						18

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**
Arctica islandica [5]													f											
Balanus spp. [5]		a	c	a					c		a	a			c	c	f		a	a	a	c	a	
Homarus americanus	4	3	1	3	4	3	2	1	2	1	1	1				2	1	1	1	2				33
Cancer spp.	13	2		5	20	6	18	7	11		5	7	7	14	7	1	7	5	7	2	3	5		152
Strongylocentrotus droebachiensis [5]		c	c	f	r	f-c	r	f	r		r	c		r	r	f	r	c-a	f	r		r		
Starfish																	1	1						2
Juvenile *Asterias* [5]	c	c	a	c-a	f	c	c	c	c	f-c	c	c	f	f	c	c	f	c	c-a	c-a	c	c	f	
Asterias vulgaris [5]	r	f	r	f	c	f	c	c	c	c-a	c-a	f-c	c	f	c	f	c	c	f-c	c	c	r	c-a	
Henricia sanguinolenta [5]	f	f	c	f	f	f	f	f	f	f	f	c	r	r	f	c	f	f	c	c	f	c	f	
Crossaster papposus																					3			3
Pteraster militaria													1					1	1					3
Solaster endeca											1						2				1			4
Psolus fabricii [5]		r	f	f	r	r			r		r	c		f			r	f				f-c		
Aplidium spp. [5]	f	f	f	c	c	f-c	f	c	f	r-f	f-c	f	f	f-c	f	r	c	c	f	f	f	c	r	
Halocynthia pyriformis [5]	f	f	f	f		r		f	f	c	f	f			r	f-c	r	r	f	f	c	c	c	
Boltenia ovifera																					24			24
bryozoan [5]										r-c													c	
Membranipora sp.																1								1
Myxicola infundibulum [5]	c	c	f	c	r	f	f	c	f-c		c	c	r-f	f	r	c	f	f	f	f	c	f	r	
Terebratulina septentrionalis [5]							r	f	c-a		f-c					f-c			f-c		a			
Fish	2				1	1	1				2		1		1		3		1					13
Tautogolabrus adspersus [5]	c	c-a	a	c	f	f-a	f	f-c	f-c	f-c	f-c	c-a	r	f	c-a	c	f	f	f-c	c-a	f	c	c	
Myoxocephalus spp.	1	2	1		4	1	1	1							1		1	1	1		1	1	2	19
Macrozoarces americanus		1						1	1											1				4
Hemitripterus americanus		1			1													1						3
Pseudopleuronectes americanus			1		1	1			2			1					2		1					9
Gadus morhua		1	2													3				1	28	1	3	39
Dogfish																	2							2

1Substrate
[2] l = light; lm = moderately light; m=moderate; mh = moderately heavy; h = heavy.
[3]Habitat relief [1] L =low; LM = moderately low; M= moderate; MH = moderately high; H = high.
[4] Suspended matter
[5] a=abundant, c=common, f= few, r = rare.

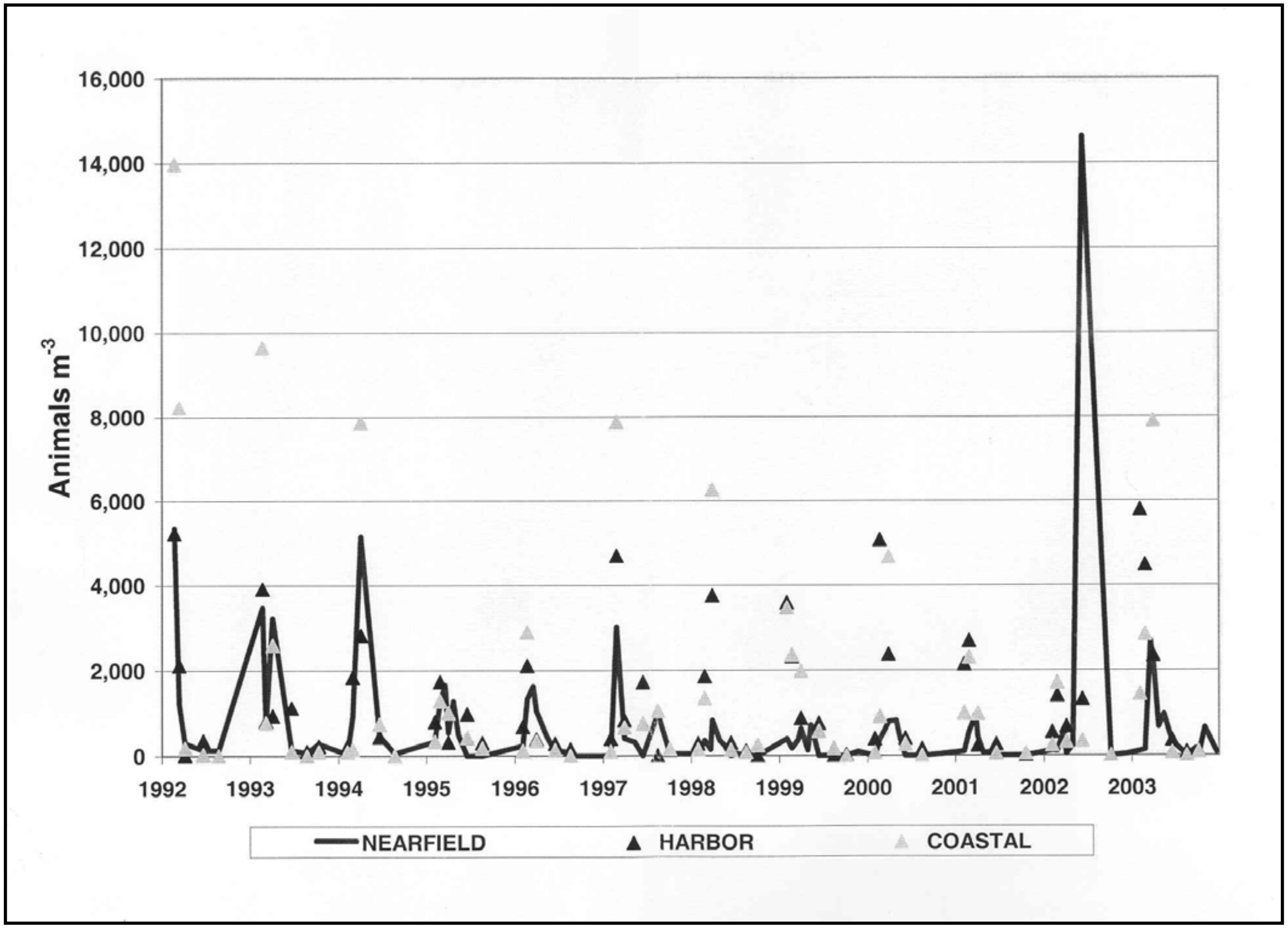


Figure D3-1. Density of barnacle larvae in the nearfield, harbor, and coastal waters from 1992 through 2003. Note the peak in density in nearfield waters during the summer/fall of 2002. Data supplied by Scott Libby, Battelle.

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