2001 outfall benthic monitoring report

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2001 Outfall Benthic Monitoring Report

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Executive Summary

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

To support the benthic monitoring, four types of surveys are conducted annually in the vicinity of the outfall. Sediment-profile image (SPI) surveys are conducted in August of each year to give a rapid, area-wide assessment of sediment quality and benthic community status. The nearfield and farfield soft-bottom surveys consist of traditional grab sampling to provide data on infaunal community structure, contaminant concentration and sediment composition. Twenty-three stations are sampled in the nearfield (defined as <8km from the outfall) and 8 in the farfield (reference stations >8km from the diffuser). To supplement the contaminant data collected in August, four stations in close proximity to the outfall are sampled again in the fall and early winter under the Contaminant Special Study surveys. And finally, because many of the depositional areas in the vicinity of the outfall are not composed of fine-grained material suitable for grab sampling, video and photographic surveys of the hardbottom habitats are also conducted once per year in late June.

The results of the 2001 outfall benthic monitoring do not indicate a substantive negative impact upon the seafloor environment. Indications from the first year of discharge data are that a possible effluent "signal" was detected in some sediment parameters at some stations in the vicinity of the discharge. This signal does not itself indicate degradation, and contaminant concentrations in nearfield sediments remain generally low. All indications are that there was no acute impact from the outfall discharge during its first year of operation, with benthic infaunal and epifaunal communities remaining characteristic of the communities observed during baseline monitoring. No Contingency Plan benthic monitoring thresholds were exceeded. These results are not surprising, as any impacts from the MWRA discharge to sediments or to seafloor communities are expected to be both modest and gradual.

Sediment Profile Images

The quality of benthic habitat in 2001 was very similar to the baseline since 1998. Sediment surfaces at the nearfield stations in 2001 continued to be dominated by biogenic structures and organism activity. Most stations with fine sediments had high densities of polychaete tubes, at least 1 tube/cm^2 or 10,000 tubes/m^2. Most of the cobble and pebble size sediments were covered with a thin drape of fine sediments, most of which had become incorporated into biogenic tubes. Sediment drape was observed on many cobbles and boulders during the nearfield hardbottom survey. Overall, the OSI and sedimentary environment did not change in 2001 relative to the recent baseline period. Sediments at many stations continued to be either heterogeneous ranging from silts-clays to cobbles, or homogeneous sands or silt-clays. The 2001 SPI data continued to reflect the importance of biological processes in structuring sediment surfaces that appeared to start in 1995 of the baseline data. The OSI values and analysis of benthic community point to similar levels of physical stress at the nearfield stations in 2001 relative to the last few years of the baseline period.

The depth of the apparent color RPD layer continued to reflect the dominance of biological processes at many of the stations in 2001. The averaged apparent color RPD layer depth ranged from 1.5 cm (FF13) to 3.5 cm (NF21) (Table 3-1). The grand average RPD layer depth for all stations in 2001 was 2.4 cm (SD = 0.65, SE = 0.14) and was statistically the same as in 2000, which was 2.6 cm (Figure 3-3). In the long-term, the average RPD for 2001 was well within the range of annual RPD's from the baseline period, with 1998 being the shallowest year at 1.6 cm and 1992 the deepest year at 2.7 cm (Figure 3-3). The 2001 annual average RPD layer depth did not represent a significant change from the grand average baseline RPD of 2.2 cm (SE = 0.08). Because the large sample size difference between the baseline period (n = 99) and 2001 data (n = 23), and the fixed nonrandom sampling design a bootstrap randomization (Efron and Tibshirani 1993) was used to assess the probability of a change in RPD relative to baseline conditions. A bootstrap of 10,000 estimates of the annual average RPD (9,999 resamples + data from 2001) with a sample size of 23 yielded a grand mean of 2.2 cm and a population distribution that was slightly positively skewed (Figure 3-5). Based on the bootstrapping, the approximate probability of getting an annual RPD as high as 2.4 cm, the actual value for 2001, was 0.115, which indicates 2.4 cm is still a likely estimate of the mean RPD in the nearfield. For the RPD to significantly decline (alpha of 0.05, one-tail test) would require the annual mean be <2.0 cm. The likelihood of an annual RPD being 0.5 cm lower than the baseline mean was 0.0007 for 2001. A similar bootstrapping analysis in which the estimates are drawn from six pools of the raw baseline data (one for each of the baseline years) may provide a more robust estimator of the likelihood of a change of this magnitude. Such an analysis may be pursued in a future report.

While the distribution of sediment textures at benthic habitats in the nearfield study area appeared to be dominated by physical processes, surface features were dominated by biogenic activity. Even station NF04 that appeared completely dominated by physical processes had many small tubes on the surface of pebbles. Tubes were the dominant surface biogenic structures and occurred at all stations. Subsurface biogenic structures and organisms were also common and widely distributed. The predominance of biological activity at most stations was indicative of a well developed fauna that was characterized as being intermediate to equilibrium in successional stage (Stage II to III). Overall, it appeared that biological processes were still predominant in structuring surface sediments, but signs of physical processes, such as bedforms, seemed to have increased in 2001 relative to 2000 and 1999 of the baseline data. These measures did not show a significant change in the benthic community in the first year following effluent diversion.

Sediment Geochemistry

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

Interestingly, *Clostridium perfringens* abundances increased in 2001 at stations within 10-km of the diffuser, breaking from the recent trend in decreasing abundance observed in the nearfield stations since 1998. Within this distance grouping, the increase in spore densities was most evident at nearfield stations located within 2-km of the western end of the new outfall, showing a localized, but modest, effect on nearby sediments from the discharge.

Sediment Contaminants

The inclusion of post-discharge (2001) data to the baseline continued to support a picture of two disparate regions – *nearfield* and *regional* – each defined in physical and chemical terms. In the nearfield sediments of Massachusetts Bay, there is a series of stations with heterogeneous sediments in relatively close proximity to the historic source of contaminants (*i.e.,* Boston Harbor). Nearfield stations were generally equidistant from this source. The major factors influencing the concentration of contaminants and sewage tracers were primarily related to grain size factors suggestive of different sediment depositional environments. The primary factor responsible for the variance in the data was sand content. The secondary factors were associated with anthropogenic analytes and fine particles.

In contrast, the sediments collected from regional stations were more spatially distributed and compositionally distinct. As evident in the nearfield data, sand content strongly influenced the variance in the regional data. In addition, the sewage tracer data showed that the proximity to the Harbor (the historic source of sewage contaminants) influenced the concentration of *Clostridium perfringens* and total LAB at some regional stations. However, the correlations between contaminants and bulk sediment properties were generally weaker for regional stations (organic contaminants in particular), suggesting that the primary controlling variables in the regional system were not strongly controlled by proximity to the Harbor. Rather, the composition of sediments at remote sampling locations was governed by the analytes associated with fines and may reflect regional inputs distinct from the Harbor.

With few exceptions, contaminant data from 2001 continued to be comparable to the baseline over time within each of these distinct regions. Notable exceptions included:

- Concentrations of Pb in 2001 increased above baseline at six nearfield stations (*i.e.,* NF17, NF23, NF15, NF10 NF20, NF14), with five out of the six nearfield stations located within 2-km of the western end of the new outfall.
- Total PAH, Pb, Hg, Ni, Ag, and Zn concentrations at NF10 in 2001 consistently fell above the baseline range for this station.
- Another station (NF21, located about 4 kilometers to the northwest of the outfall) had an unusually high concentration of total DDT. The result passed rigorous quality assurance tests (which included reanalysis). Stations closer to the outfall did not show DDT elevated over baseline concentrations, and the result is unusual enough that an analytical interference (false positive) cannot be ruled out. Draft data from the August 2002 nearfield sampling indicate no anomalously high DDT values, either at NF21 or at any other nearfield station.
- Principal components analysis (PCA) indicated that levels of anthropogenic compounds (pesticides, PCBs, PAH, and selected metals) in the nearfield and regional sediments generally decreased during the year following the activation of the diffuser system. On a preliminary basis, these data suggest that the treated effluent discharged from the diffuser is not significantly increasing the amount of anthropogenic contaminants in the study area sediments.

The qualitative overview offered by the PCA results support the increases noted above at stations NF10, NF14, and NF17. The remaining trends noted above were not confirmed by PCA due to the omission of selected samples (*e.g.,* NF21) and possibly the small magnitude or lack of reproducibility of the potential, location-specific trend.

Coats (1995) estimated the length of time between the onset of secondary effluent discharge at the new outfall and the detection of contaminant increases as the mean of nearfield sediments located within 2-km of the outfall *(i.e.,* NF13, NF14, NF17, NF19, NF23 and NF24). Coats (1995) suggested that Cd and Ag would show detectable increases in the nearfield sediments within 1.1 and 1.5 years of the new outfall coming online, respectively, based on estimated levels of contaminants in secondary treated effluent. Other contaminants were not expected to show increases until at least six or more years after the offshore effluent discharge began. Results from the first post-discharge sampling event (August 2001) represent approximately one year after onset of effluent discharge. The post-discharge results (individual stations evaluated) do not confirm with Coats predictions in their entirety in that:

- Apparent increases in Pb, not Cd or Ag, were observed at three (NF14, NF17, NF23) of the six nearfield stations identified above; and
- Total PAH and selected metals (Pb, Hg, Ni, Ag and Zn) increased at NF10, which is located outside the vicinity of predicted increase (2-km from new outfall) but is in the direction of the major deposition area predicted by the Water Quality Model (HydroQual 1995).

The post-discharge period increases identified above do not appear to be related to grain size or TOC factors, in that there was no corresponding increase in percent fines or TOC at stations NF14, NF17, NF23 or NF10 in August 2001 relative to August 2000. Additional sampling in future monitoring years will allow for a more robust evaluation against Coats model.

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

Infaunal Communities

The ten years of MWRA sampling that comprise the infaunal analyses include nine years of baseline monitoring (1992–2000) and one year of post outfall discharge sampling (2001). Description of the infaunal community during this time period, especially of that in the vicinity of the outfall, recorded a large reduction in abundance and numbers of species found in samples collected in 1993 versus those collected in 1992. Overall abundance per sample dropped from ~2241 in 1992 to ~1344 in 1993 and species numbers dropped from ~62 in 1992 to ~48 in 1993. In subsequent years, abundance and species numbers showed strong increases from 1993 to 1997–1999, followed by a steady decline thereafter. The Bay experienced a major disturbance in late 1992 when a significant storm struck the area. This storm, during which significant wave heights >7 m were recorded, had a pronounced effect on sediments in western Massachusetts Bay and has been suggested as a likely cause in the shifts in the infaunal community observed between 1992 and 1993. However, from 1991 to 1997 there were at least three other large storms that could have affected the benthos. The largest was the late October 1991 storm that produced significant wave heights of > 8 m and that has been suggested as contributing to the changes observed in the Boston Harbor infaunal communities in subsequent years. Two large storms in April 1997 did not appear to yield changes in the infaunal community similar to those observed after the 1992 storm although both produced waves having significant heights > 7 m. There have not been any larger storms since April 1997 (through 2000) recorded in Massachusetts Bay.

Following the 1992 storm, the 1994 sampling season showed the first in a series of impressive increases in nearfield abundance and species numbers indicating recovery for the storm event, that continued into 1997. At that time, it was not clear whether the increased values for the parameters would represent a new definition of the nearfield infaunal community or that they indicated a rebound from the catastrophic storm event and would eventually subside to pre-storm levels. Within the last two sampling seasons, especially the 2001 season, that later presumption appears to be the case. The average abundance value for pooled nearfield samples in 2001 was similar to the baseline mean value and to the 1992 pre-storm value. The number of species per sample in 2001 also was very similar to the baseline mean value (as it was in 2000) and slightly higher than the 1992 value. Species numbers and log-series alpha showed very similar patterns of change throughout the monitoring program. That still seems to be the case, although the 2001 value (13.1) shows a very slight, but not statistically significant, increase over the 2000 value (12.9). The patterns seen in these three descriptive metrics support the idea that the 1992 storm had an important impact on the infaunal communities in the nearfield and that a period of rebound occurred, but that it is now likely completed with the system approaching 1992 pre-storm conditions.

Descriptive community metrics for each station that compare the baseline period with the 2001 data were within the range of values that occurred during the baseline period.

As in previous years the grouping of nearfield stations in 2001 reflected the influence of sediment type and biogenic activity in structuring nearfield communities. Cluster analysis of the 2001 nearfield infauna data produced station and species groupings that were related to a combination of physical sedimentary properties and infaunal community structure. Analyses aligned the stations into three main groups with the major break in the data primarily related to sediment type and occurring between the finer sediment stations that had higher silt and clay percentages (groups I and II), and coarser sandier sediment (group III). On average, station group I had finer sediment grain-size, higher median TOC, Cperf, RPD layer depth, and OSI, and higher estimated successional stage than the other two groups. Station group II was highly concatenated or chained (the tendency of a station to join the dendrogram at the end), which was an indication that the infauna at the five stations composing group II were graded in their dissimilarity. Group III on average had the coarsest, most heterogeneous sediments with lowest TOC and successional stage. Group I and II stations tended to have higher levels of biogenic activity in the form of tube mats and higher infaunal activity. While more infauna was seen in the SPI images at group I stations, the median abundance and taxa per grab were about the same for all cluster groups. Also, the sediment surface at group I stations tended to be dominated by biological processes, while groups II and III tended to be physically dominated.

The cluster analysis of the long-term data base for the nearfield (1992 to 2001, 215 station-collections, first replicate, and 336 species with >20 occurrences) was heavily chained at the 10 group level. The general pattern of stations over the years was similar to the long-term analysis conducted over the previous two years with patterns related to both strong and weak within station similarity through time.

Overall, the 1992 to 2001 infaunal was not dominated any temporal strong trend. The dendrogram produced by the cluster analysis was heavily chained and indicated that within group station affinities were stronger than between groups. The strongest feature structuring the 1992 to 2001 infauna was within station similarity.

Hardbottom Communities

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

The pattern of hardbottom community structure has been remarkably consistent throughout the study period. Classification analysis of the 2001 data yielded results similar to those from the last five years of baseline monitoring. At many of the sites the benthic communities remained stable during the baseline period and this pattern did not change after the start of discharge. Three instances of departure from baseline conditions in cluster designation were noted in the 2001 data. All three of these instances appeared to reflect spatial variability in the benthic communities rather than changes in community structure related to the discharge.

Several striking trends, that may reflect widespread temporal changes in the population structure of individual taxa, have been noted over the time course of the nearfield hardbottom surveys. These changes do not appear to be related to the outfall discharge. The green sea urchin *Strongylocentrotus droebachiensis* has shown a steady decline in abundance from 478 individuals in 1996 to 181 individuals in 2001. In contrast, two other species, the crab *Cancer* sp. and the cod *Gadus morhua*, appear to be increasing. In the still photographs, one to six *Cancer* crabs were seen annually between 1996 and 1999, 20 were seen in 2000, and 54 were seen in 2001. This pattern was also reflected in the video data, with 3 to 17 *Cancer* crabs observed annually between 1996 and 1999, 105 in 2000, and 147 in 2001. A similar trend was seen in the video data for codfish, with none seen in 1996 to 41 seen in 2001. Interestingly, no cod had been seen at the diffuser stations during the baseline years, yet in 2001 six and eight cod were seen at T2-5 and Diffuser #44, respectively. Codfish generally tend to shy away from the ROV, frequently ducking behind rocks, but at the diffuser sites they were much less hesitant and occasionally came right up to the vehicle. In contrast, the codfish seen at the other stations tended to avoid the ROV.

The hardbottom benthic communities near the outfall were relatively stable over the 1995 to 2000 baseline time period, and this did not substantially change with the activation of the outfall. The remarkable similarities among all the surveys indicate that major departures from baseline conditions have not occurred during the first year of discharge. An increase in sediment drape, and a concurrent decrease in percent cover of coralline algae, was noted in 2001 on the top of the drumlin north of the outfall and at the two northernmost reference sites. Whether these changes are related to the outfall discharge is presently not known.

1. INTRODUCTION

In 1972, public concern about the state of the nation's marine resources led Congress to enact the Clean Water Act. Key provisions of the Act initially required all publicly owned treatment plants to provide primary and secondary treatment for discharged effluent, and soon after to monitor the impact of their outfalls. When the Massachusetts Water Resources Authority (MWRA) was created in 1985, it assumed control of Boston's water and sewer systems and with it, responsibility for the outfall monitoring. MWRA's multidirectional approach to minimizing the effects of wastewater discharge includes source reduction, improved treatment, and better dilution. Under MWRA's direction, major improvements to Boston's wastewater discharge system have become nationally recognized as milestones in the successful cleanup of Boston Harbor.

Major improvements to the water and sediment quality in Boston Harbor began with the abatement of sludge discharge into the Harbor in late1991. In 1995, a new primary treatment facility at the Deer Island plant was brought online. Secondary treatment at the Deer Island plant was achieved in two phases in 1997 and 1998. Also in 1998, a major source of discharge to the South Harbor was eliminated when the final diversion of effluent from Nut Island to Deer Island was complete. The final phase of secondary treatment at Deer Island was completed in 2000 and became operational in 2001. Perhaps the most ambitious phase of the plan was realized in September 2000 when the transfer of effluent from Deer Island to the offshore outfall went online. The transfer was designed to improve the water quality in Boston Harbor and to increase effluent dilution with minimal impact on the offshore environment.

A permit issued to MWRA by EPA and MADEP under the National Pollutant Discharge Elimination System (NPDES) regulates the new outfall. In addition to limiting the amount of discharge pollution, the permit requires reporting on treatment plant operation and maintenance. The permit also requires MWRA to monitor the outfall effluent and the ambient receiving waters. While some studies began during 1989-1991, a broader baseline monitoring program began in 1992. Baseline monitoring was initially planned to last for approximately three years, but delays in outfall construction allowed a relatively long period for baseline studies. As a result, greater documentation of natural variability and a better understanding of the system have been developed and are discussed in this report.

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

The 2001 outfall benthic surveys presented in this report represent the first full year of post-discharge benthic monitoring. Data were collected from each of the benthic monitoring program's four components: sediment profile images (SPI), geochemical properties, contaminants, and sewage tracers in sediment, benthic infaunal community, and hardbottom community. Survey methods are described in Section 2. The results and analyses of the sediment profile images are presented in Section 3. Sediment geochemistry studies, conducted via the collection of sediment grab samples, consist of grain-size analysis, total organic carbon (TOC) content determination, and contaminant concentration analyses and are presented in Section 4. Infaunal communities in Massachusetts Bay and Cape Cod Bay are described in Section 5 and include an evaluation of infaunal communities in relation to the suite of sediment geochemical parameters measured. The hardbottom community is documented by semi-quantitative studies conducted with a remotely operated vehicle (ROV). Still photographs and video are collected from hardbottom locations in and around the nearfield. Analyses of the hardbottom survey data constitute Section 6.

In the interpretation of benthic data, a review of both historical and recent system-wide events is considered relevant. Because storms are thought to be a major vehicle for sediment transport in the nearfield, Section 5 includes a review of significant historical storm data. Additionally, recent relevant observations in the area (since the 2000 nearfield sediment sampling) are considered. For example, in the fall of 2000 (just after the 2000 benthic survey), increased algal concentrations were noted in the nearfield. This algal event resulted in nearfield chlorophyll concentrations high enough to exceed the program caution level for that parameter (Libby *et al*, 2001). Further investigation indicated that the fall 2000 algal bloom was a regional event, and not due to increased nutrients from the outfall. Furthermore, 2001data from the nearfield show water column chlorophyll levels to be relatively low (Libby *et al* in prep). The event appears to have had no effect on the benthos in 2001. The 2001 caged mussel study resulted in another significant nearfield event. The concentrations of total chlordane and total PAH found in mussels moored at the outfall site for 60 days in the summer of 2001 were found in to be high enough to exceed the MWRA caution level for those parameters. The investigation concluded that while the total chlordane and total PAH levels were higher than expected, the overall environmental impact is low. Increased levels of contaminants in sediments were expected in the vicinity of the outfall, but only cadmium and silver were predicted to show up in the first 1-2 years after startup (Coats 1995). A review of current contaminant data relative to the early predictions is found in section 4.

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

2. FIELD OPERATIONS

By Jeanine D. Boyle

2.1 Sampling Design

2.1.1 Softbottom

Sediment Samples—The nearfield benthic surveys, conducted annually in August, are designed to provide spatial coverage and local detail of faunal communities inhabiting depositional environments within about 8 km of the diffuser. Samples for sediment chemistry and benthic infauna were collected at 23 nearfield stations (Figure 2-1). The target locations for the nearfield stations are listed in the CW/QAPP (Kropp and Boyle 2001). The actual locations of each grab sample collected are listed in Appendix A.

Farfield benthic surveys, also conducted annually in August each year, are designed to contribute reference and early-warning data on softbottom habitats in Massachusetts and Cape Cod Bays. Grab samples were collected at 8 farfield stations in Massachusetts and Cape Cod Bays (Figure 2-2) for infaunal and chemical analyses. The target locations for the farfield stations are listed in the CW/QAPP (Kropp and Boyle 2001). Sampling in the Stellwagen Bank National Marine Sanctuary (Stations FF04 and FF05) was conducted under sampling permit SBNMS-2001-003. Specific coordinates for each grab sample collected are listed in Appendix A.

The Nearfield Contaminant Special Study Surveys are designed to examine the possible short-term impacts of the new outfall discharge on sedimentary contaminant concentrations and their interrelationships with possible sedimentary organic carbon changes in depositional environments near the effluent outfall. In the present post-discharge condition, Contaminant Special Study surveys are scheduled to be conducted three times per year (February, August, and October). The Nearfield Contaminant Special Study stations include; NF08, NF22, NF24, and FF10. Criteria used to select these four locations were:

- Historically, stations (except FF10) were comprised of fine grained material (>50% sand/silt);
- Stations were in relatively stable areas (except for FF10, grain size composition >50% sand/silt over the period monitored);
- Stations (except FF10) had high total organic carbon (TOC) content, relative to other locations nearby (at least 1% TOC);
- Stations were within the zone of increased particulate organic carbon deposition predicted by the Bay Eutrophication Model (BEM, Hydroqual and Normandeau, 1995); and
- Selection of these stations complements and expands on stations (NF12, NF17) periodically sampled by the USGS.

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

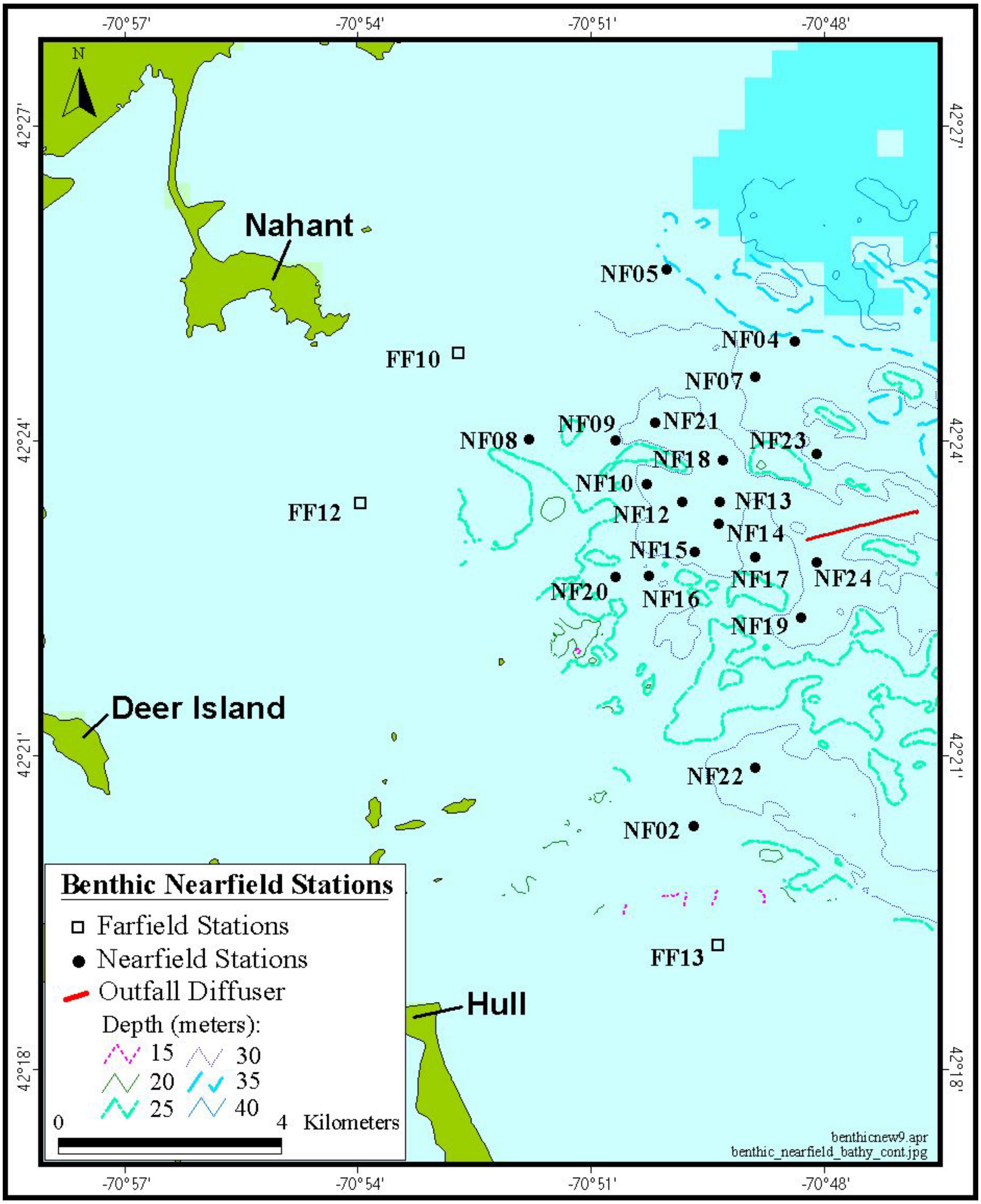


Figure 2-1. Locations of nearfield and selected farfield grab stations sampled in August 2001.

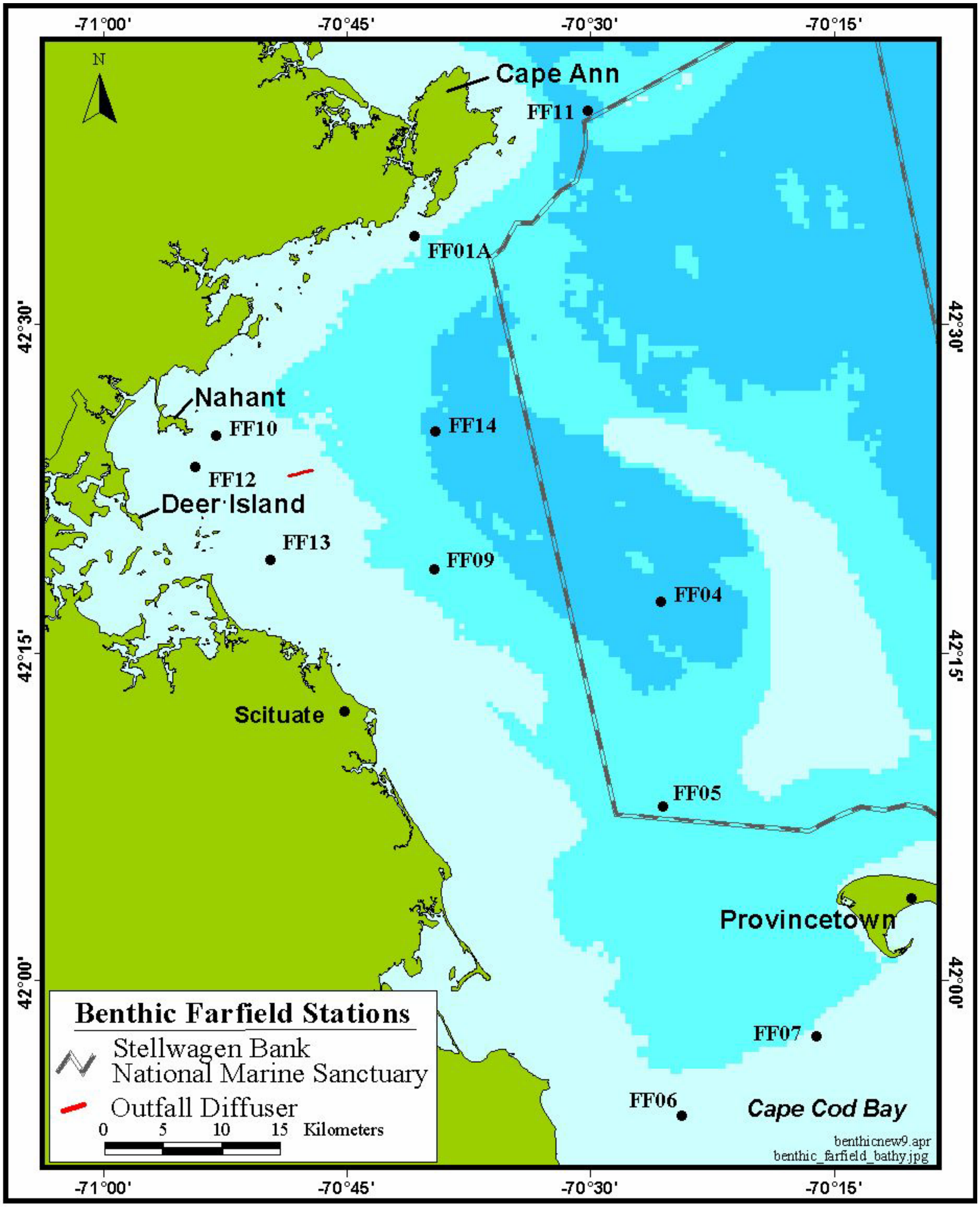


Figure 2-2. Locations of farfield grab stations sampled in August 2001.

Sediment Profile Images—The Nearfield Sediment Profile Image surveys are conducted in August of each year at 20 nearfield and 3 farfield stations (Figure 2-1) to give an area-wide, qualitative/ semi-quantitative assessment of sediment quality and benthic community status that can be integrated with the results of the more localized, quantitative surveys to determine sedimentary conditions near the outfall. Furthermore, these surveys provide rapid comparison of benthic conditions to the benthic triggering thresholds. Traditional sediment profile imagery (35-mm slides) allows a faster evaluation of the benthos to be made than can be accomplished through traditional faunal analyses. A more rapid analysis of the SPI data is accomplished by fitting the profile camera prism with a digital video camera arranged to view the same sediment profile as the 35-mm film camera. The target locations for the SPI sampling are the same as those for the nearfield grab sampling effort. The actual locations of all sediment profile images collected in 2001 are listed in Appendix A.

2.1.2 Hardbottom

Because of the relative sparseness of depositional habitats in the nearfield and in the vicinity of the diffusers, a continuing study of hardbottom habitats has been implemented to supplement the softbottom studies. The nearfield hardbottom surveys are conducted in June of each year. Videotape footage and 35-mm slides were taken at 20 waypoints along six transects and at three additional discrete waypoints (T91, T10-1 and Diffuser 44).

2.2 Surveys/Samples Collected

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

Table 2-1. Survey dates and numbers of samples collected on benthic surveys in 2001.

Survey	ID	Date(s)	Samples Collected								
			Inf	TOC	Gs	Cp	C	Tm	SPI	35	V
Nearfield Benthic	BN011	15, 16, 17, and 18 August 2001	26	28	28	28	28	28	–	–	–
Farfield Benthic	BF011	13, 14, 15, 16, 17 August 2001	33	23	23	23	23	23	–	–	–
SPI	BR011	20, 21, 22 August 2001	–	–	–	–			64	–	23
Hardbottom	BH011	26, 27, 29 June and 9, 10 July	–	–	–	–			–	~713	46
Nearfield Contaminant	BC011	14 February 2001	–	12	12	12	12	12			
Nearfield Contaminant	BC012	15, 17, 18 August 2001	–	12	12	12	12	12	–	–	–
Nearfield Contaminant	BC013	26 October 2001		12	12	12	12	12			

Key:

Inf, Infauna
Gs, grain size
C, contaminant
35, 35-mm slides (hardbottom)
Tm, trace metals

TOC, total organic carbon
Cp, *Clostridium perfringens*
SPI, individual sediment profile images (slides)
V, video segments (hardbottom)

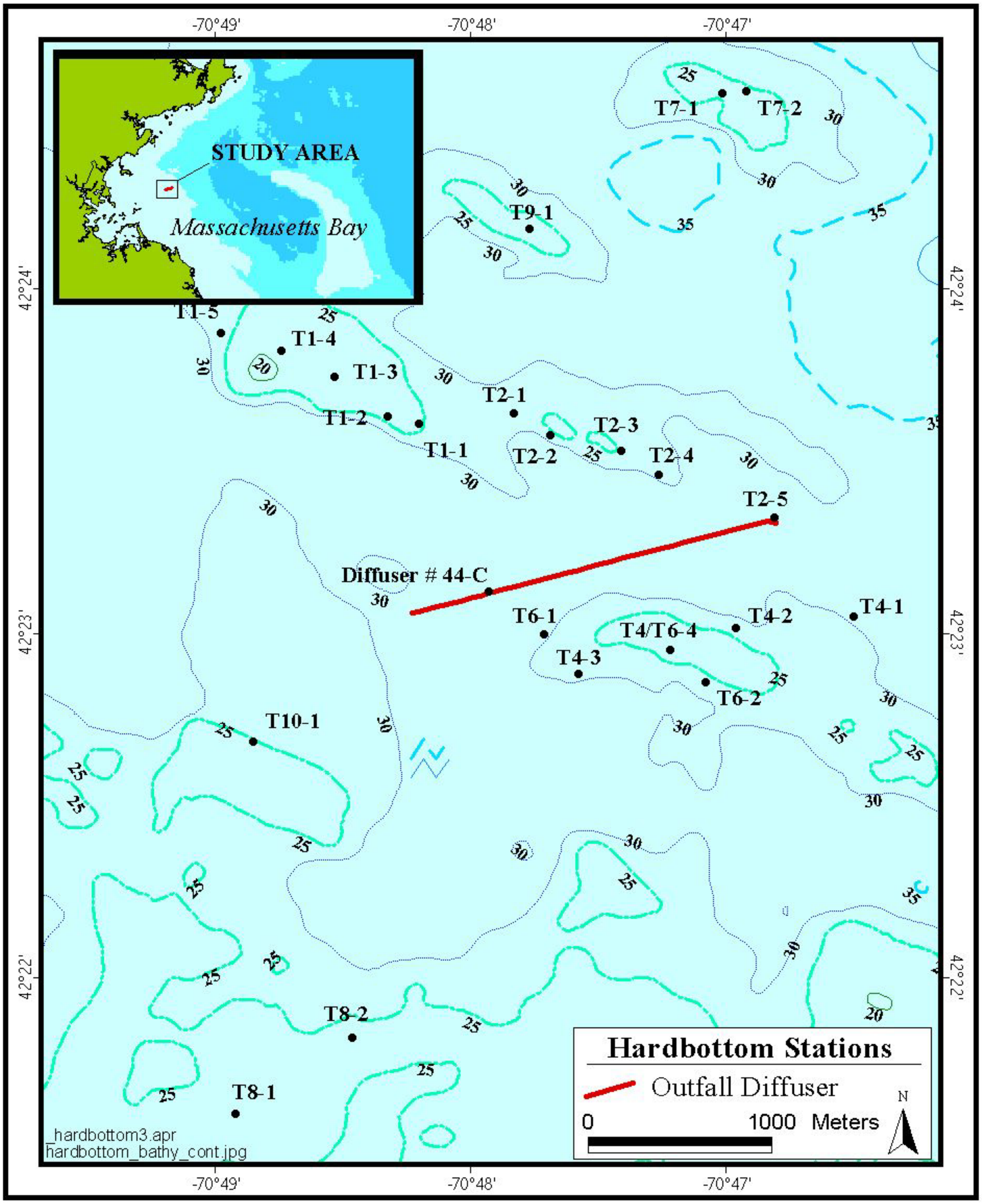


Figure 2-3. Locations of hardbottom stations sampled in June and July 2001.

2.3 Field Methods Overview

The following is a brief overview of the methods and protocols used on the benthic surveys. More detailed descriptions of the methods are contained in the CW/QAPP (Kropp and Boyle 2001).

2.3.1 Vessel / Navigation

All 2001 outfall benthic surveys were conducted from Battelle's research vessel, the R/V *Aquamonitor*. Vessel positioning was accomplished with the BOSS Navigation system. This system consists of a Northstar differential global positioning system (DGPS) interfaced to the 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 into six satellites at one time. The system is calibrated with coordinates obtained from USGS navigation charts at the beginning and end of each survey day.

At each sampling station, the vessel is positioned as close to target coordinates as possible. The NAVSAM© navigation and sampling software collects and stores navigation data, time, and station depth every 2 seconds throughout the sampling event, and assigns a unique ID 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 (6, 5-m rings) for all MWRA benthic surveys. A station radius of up to 30 m is considered acceptable for benthic sampling in Massachusetts Bay.

2.3.2 Grab Sampling

Nearfield/Farfield Benthic Surveys—The Nearfield/Farfield Benthic Survey BN011/BF011 was conducted in August 2001. At all 11 farfield stations and 3 nearfield stations (NF12, NF17, and NF24), a 0.04-m^2 modified van Veen grab sampler was used to collect 3 replicate samples for infaunal analysis and 2 replicate samples for *Clostridium perfringens*, sediment grain size, contaminant, and TOC analyses. At each of the remaining 18 nearfield stations, 1 grab sample for infaunal analysis and one grab sample for *C. perfringens*, sediment grain size, contaminant, and TOC content were collected. Additional subsamples for contaminant analysis were collected from the four Contaminant Special Study stations. Infaunal samples were sieved onboard the survey vessel over a 300-μm-mesh sieve and fixed in buffered formalin. The "chemistry" sample was skimmed off the top 2 cm of the grab by using a Kynar-coated scoop, and was homogenized in a clean glass bowl before being distributed to appropriate storage containers. The TOC and contaminant samples were frozen, whereas the *C. perfringens* and grain size samples were placed on ice in coolers.

Nearfield Contaminant Special Study—Contaminant Special Study surveys were conducted in February, August, and October 2001. The August sample collection as part of this study was carried out in conjunction with the nearfield/farfield benthic survey, BN/BF011. Three replicate samples from each of the contaminant special study stations were collected for the analysis of TOC, grain size, *Clostridium,* and contaminants (organic and metals). Samples were collected from the top 2 cm of the 0.01m^2 Kynar-coated grab and processed as described above.

2.3.3 SPI

During the August 2001 SPI Survey (BR011), a Hulcher Model Minnie sediment profile camera fitted with a digital video camera was deployed three times at each station. The profile camera was set to take two pictures, using Fujichrome 100P slide film, on each deployment at 2 and 12 seconds after bottom contact. In the event that sediments were soft the two-picture sequence would ensure that the sediment-water interface would be photographed before the prism window over penetrated. The combination of video and film cameras ensured accurate and reliable collection of sediment profile images. Any replicates that appeared to be disturbed during deployment were retaken. Dr. Robert Diaz conducted the survey. Dr. Diaz recorded the date, time, station, water depth, photo number and estimated camera penetration in his field log. Each touch down of the camera was marked as an event on the NAVSAM©. The video image was recorded for use as part of the "Quick Look" analysis of nearfield conditions. A comparison of the RPDs estimated from the "Quick Look" versus those from the stills analysis is presented in section 3.

2.3.4 Hardbottom

The June 2001 Hardbottom Survey (BH011) of the nearfield examined 20 waypoints distributed along 6 transects (T1, T2, T4, T6, T7, and T8), plus 3 additional waypoints (T9-1, T10-1, and Diffuser 44). BH011 was the first video survey conducted at the outfall since it went online in September 2000. Thirty-two images and 22 minutes of video were collected at an active riser (#2) near station T2-5. A MiniRover MK II ROV equipped with a Benthos low-light, high-resolution video camera, a Benthos Model 3782 35-mm minicamera with strobe, 150 W halogen lamps, a compass, and a depth gauge was deployed from the survey vessel to obtain the necessary video and slides. The ROV was guided as close to the bottom as possible so that the clarity of the video and photographs was maximized. Approximately 20 minutes of video footage per waypoint were recorded along a randomly selected heading. Along this route, still photographs were taken as selected by the Senior Scientist, Dr. Barbara Hecker, until an entire (36 exposure) roll of 35-mm film was exposed at each waypoint.

The date, time, and ROV depth were recorded on the videotapes and appeared on the video monitor during the recording. The start of and stop of each video tape, the start of each roll of film, and the capture of each 35-mm image were recorded as "events" on the NAVSAM© system. The time displayed on the video monitor (and recorded on the tape) was synchronized with the NAVSAM© clock. When a still photograph was taken, the event and frame-identifying observations (made by the Senior Scientist) were recorded on the videotape. The NAVSAM© produced labels that were attached to each video cartridge and each film canister. All slides were developed onboard to monitor camera performance. Slides were labeled manually at the lab after mounting. All slides were scanned into electronic images and copied onto a CD for archival.

3. 2001 SEDIMENT PROFILE CAMERA RECONNAISSANCE OF NEARFIELD BENTHIC HABITATS

3.1 Baseline Nearfield SPI

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

In the nearfield area the dynamics of the RPD layer depth are related principally to the interaction of physical and biological processes that structured bottom communities. Bottom instability driven by waves and currents leads to a patchy mosaic of successional Stage I pioneering communities, which are associated with shallower RPD measurements. Stage I communities dominated the nearfield area from 1992 to 1997, with Stage II communities dominating from 1998 to 2000. It also seemed that factors responsible for the depth of the RPD layer were acting at the regional scale in the nearfield since yearly patterns in RPD depth were consistent across stations.

The general benthic habitat quality at nearfield stations, as expressed by the Organism Sediment Index (OSI), indicated that benthic communities at some of the stations in the nearfield were subjected to some form of stress (values of the OSI <6, Rhoads and Germano 1986). The most likely source of stress being physical processes since water and sediment quality within the nearfield was always good. The general physical and biological conditions at the nearfield stations reflected the physically dynamic nature of the processes that dominate the area. The 1998 through 2000 data indicated an increasing trend the OSI and in the importance of biological processes.

3.2 Materials and Methods

3.2.1 Field Methods

The 20 nearfield and 3 farfield stations were sampled 20 August 2001. Ten nearfield stations were resampled on 22 August to insure sufficient replicate coverage because of suspect camera operation on the 20th. Sediment profile images were collected at all stations on film. Real time video was collected at only six stations because of problems with the video prism camera.

3.2.2 Quick Look Analysis

The Quick Look analysis was developed in 1998 to meet the needs of rapid data turn around for assessment of benthic triggers, one of which is an area wide 50% reduction in the average depth of the redox potential discontinuity (RPD) layer (MWRA 2001). The exposed film was developed 24 August, the last day of field operations, and the Quick Look analysis completed 28 August. See Kropp *et al.* (2001) for details on the Quick Look analysis.

3.2.3 Image Analysis

The sediment profile images were first analyzed visually by projecting the images and recording all features seen into a preformatted standardized spreadsheet file. The images were then digitized using a Nikon 2000 scanner and analyzed using the Adobe PhotoShop and NTIS Image programs. Data from each image were sequentially saved to a spreadsheet file for later analysis. Details of how these data were obtained can be found in Diaz and Schaffner (1988), Rhoads and Germano (1986), and Kropp *et al.* (2001).

3.3 Results and Discussion

3.3.1 Quick Look vs. Detailed Analyses

Overall, there was a high degree of correspondence between the Quick Look and full detailed image analyses (Table 3-1). The correlation between the two analyses for the apparent color RPD layer depth, one of the benthic trigger parameters (MWRA 2001), was 0.82 ($n = 23$, $p = <0.001$) with the detailed analysis tending to give shallower RPDs relative to the Quick Look analysis by 0.2 cm, which was a significant difference (paired t-test, $df = 22$, $p = 0.025$).

3.3.2 Physical processes and sediments

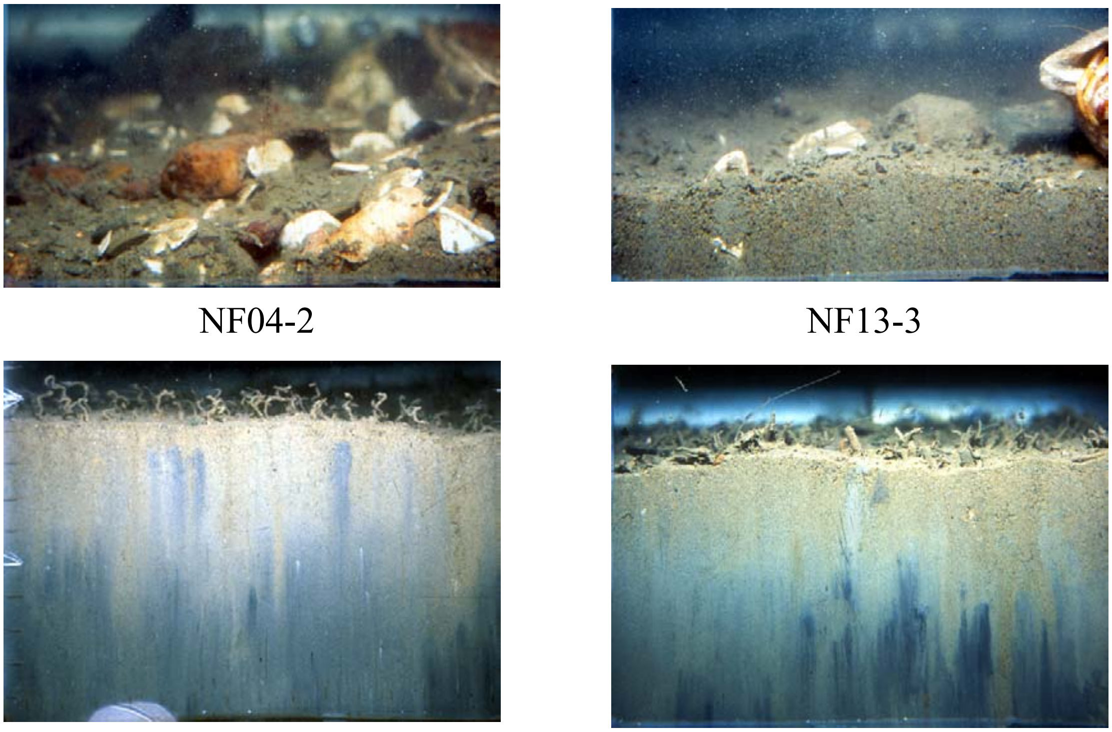
The general appearance of the sediments at the nearfield stations in 2001 was similar to the last several years, with some variation between stations. Overall, grain size at most of the 23 stations in 2001 was similar to 2000 and ranged from cobbles and pebbles (NF04) to mixed sandy-silt-clay sediments (NF05 or NF22) (Figure 3-1). Changes in the sediments, relative to 2000, reflected the spatial heterogeneity associated with the nearfield area. Sediments appeared to be coarser in 2001 at Stations NF04 and NF17, and finer at Stations FF13 and NF02. Sediment layering observed at Stations NF05 and NF07 in 2000 were not present in 2001 (Table 3-2). Heterogeneous sediments, more than two sediment end members, occurred at 10 stations. Homogeneous sandy sediments occurred at two stations and 11 stations had homogeneous fine sediments. The modal grain size descriptor continued to be fine-sand-silt-clay (FSSICL), which occurred at nine stations (Table 3-1). The finer grain sizes associated with the eight stations that had pebble or cobble, indicative of high kinetic energy or transport bottoms, were primarily silts at Stations NF14, NF15, NF16, NF18 and NF20, and sands at Stations FF10, NF04, and NF23 (Table 3-1). Most of the fine sediment drape on cobble and pebble sediments, which in 2000 appeared to be loose and unconsolidated, was incorporated into biogenic tubes.

Bedforms, typically associated with higher energy bottoms, were seen at eight stations (Table 3-1). The presence of bedforms increased in 2000, relative to previous years, and their continued presence may be related to relatively higher bottom energies in 2000 and 2001. In the absence of storm-induced bottom currents, benthic organisms would tend to eradicate physical structures such as bedforms during quiescent periods as those experienced in 1998 and 1999 when biogenic activity at the sediment surface increased. Surface relief or bed roughness was lower at stations that appeared to have sediment surfaces that were dominated by biological processes relative to stations dominated by physical processes or a combination of both (ANOVA, $df = 2$, $p = 0.013$). At biologically dominated stations, surface relief averaged 0.8 cm and typically consisted of irregular surfaces such as feeding mounds (NF16) or tubes (NF21) caused by the biogenic activity of benthic organisms. In physically dominated sandy and coarse habitats, surface relief averaged 1.3 cm and was caused by pebble/cobbles (FF10) or bedforms (NF17). Prism penetration and sediment grain size were also closely related, with the lowest penetration occurring at hard sand-gravel-pebble bottoms and the highest in mixed sediments. The lowest average penetration was 1.0 cm at Station NF04 with fine-medium-sand-pebble sediment and the highest was 13.1 cm at Station NF12 with fine-sand-silt-clay sediments (Table 3-1).

Table 3-1. Summary of SPI parameters for nearfield stations, August 2001. Data from all replicates were averaged for quantitative parameters and summed for qualitative parameters (for example, the presence of tubes in one replicate resulted in a + for the station).

STAT	PEN. (cm)	SR (cm)	RPD (cm)	QL* RPD (cm)	GRAIN SIZE	PROCESS	AMP	STICK	TUBE	BED.	WORM	BUR	VOIDS OXIC	SS	OSI
FF10	2.0	1.6	>1.5	1.3	FS to CB	PHY	-	-	+	-	0.0	3.0	0.0	I-II	4.5
FF12	2.9	1.0	2.0	1.7	VFS	BIO/PHY	-	+	+	+	2.3	5.0	0.0	I-II	5.0
FF13	8.2	1.9	1.5	1.3	FSSI	BIO/PHY	+	+	MAT	-	3.7	3.0	1.0	I-III	5.0
NF02	5.7	1.1	2.2	2.5	FSSI	BIO/PHY	-	-	+	+	1.3	5.0	0.0	I-II	5.0
NF04	1.0	0.9	>1.5	1.8	FSMS to PB	PHY	-	-	+	-	0.0	0.0	0.0	I-II	4.5
NF05	6.1	1.0	3.1	2.7	FSSICL	BIO	+	+	MAT	-	1.7	5.7	0.7	II-III	8.7
NF07	7.3	0.6	3.4	3.2	FSSICL	BIO	-	-	+	-	12.0	5.3	0.7	II-III	8.0
NF08	11.8	0.8	2.7	2.8	SIFS	BIO/PHY	-	+	+	-	3.3	7.0	1.0	II-III	8.0
NF09	6.7	0.8	2.9	2.3	FSSICL	BIO	-	-	+	-	6.0	7.0	0.7	II-III	8.3
NF10	7.5	1.6	2.4	2.0	FSSICL	BIO/PHY	-	+	+	-	6.2	7.2	1.2	II-III	7.2
NF12	13.1	0.6	2.9	2.7	FSSICL	BIO	-	-	MAT	-	5.3	8.7	2.7	II-III	8.7
NF13	2.1	1.0	>2.1	2.2	FSMS to GR	BIO/PHY	-	-	+	+	0.0	0.0	0.0	I-II	5.2
NF14	2.9	1.7	>2.8	2.5	FSSI to PB	PHY	-	-	+	-	0.2	0.0	0.0	I-II	6.2
NF15	4.2	1.6	2.4	1.9	FSSI to PB	PHY	-	+	+	+	2.2	2.0	0.6	I-III	6.4
NF16	5.6	1.4	3.3	2.8	FSSICL to CB	BIO/PHY	-	+	+	-	5.3	6.7	1.0	II-III	8.7
NF17	2.1	0.9	>2.1	2.1	FSMS	PHY	-	-	+	+	0.0	0.0	0.0	I-II	5.2
NF18	4.8	1.8	>2.8	1.8	FSSICL to PB	PHY	-	-	+	-	2.3	2.0	0.3	I-II	6.7
NF19	5.3	0.8	1.6	1.8	FSSI to GR	PHY	-	-	+	+	4.5	2.0	0.0	I-II	4.5
NF20	2.8	1.3	>2.0	1.5	FSSI to PB	PHY	-	-	+	+	0.3	1.3	0.0	I-II	5.0
NF21	12.7	0.6	3.5	2.8	SIFS	BIO	-	+	+	-	8.3	10.7	2.7	III	10.0
NF22	9.9	1.0	3.2	3.3	FSSICL	BIO	-	-	MAT	-	7.7	6.0	1.7	II-III	8.7
NF23	1.9	1.4	>1.6	2.2	FSMS to PB	PHY	-	-	+	+	0.0	0.0	0.0	I-II	4.6
NF24	12.0	1.1	2.7	2.7	FSSICL	BIO/PHY	-	-	+	-	8.3	7.7	0.7	II-III	7.3

* QL – RPD estimated from quick-look analysis of images.



NF04-2 NF13-3

NF22-2 NF05-3

STATION	RPD AVE	GRAIN SIZE	SURFACE FEATURES	AMPHIPOD TUBES	WORM TUBES	SURFACE FAUNA	SUB. FAUNA WORMS	BURROWS	SUCC. STAGE	OSI
NF04-2	IND	FSMS,GR,PB,SH	PHY	NONE	FEW	Tubes on pebbles & shell			I-II	
NF05-3	3.2	FSSICL	BIO	MANY	MAT	Amphipod on stick	1	4	II-III	9
NF13-3	>2.8	FSMS, GR, PB, SH	BIO/PHY	NONE	MANY	Large hermit carb, Bedform	0	0	I-II	6
NF22-2	2.6	FSSICL	BIO	NONE	MAT	Twisted tubes	2	10	II-III	8

Figure 3-1. Example nearfield images for 2001. Each tick mark along the side of the images is 1 cm.

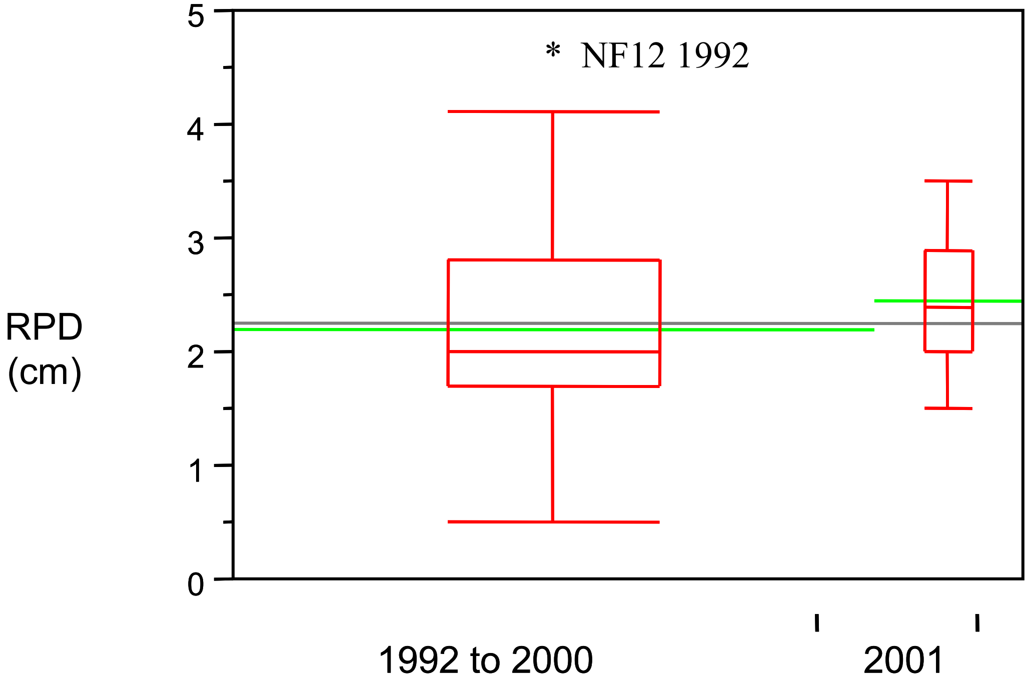
3.3.3 Apparent Color RPD Depth

The average apparent color RPD layer depth ranged from 1.5 cm (FF13) to 3.5 cm (NF21) with an average of 2.4 cm (SD = 0.65 cm). At the three porous sand and gravel stations (NF04, NF13, and NF17), the apparent color RPD layer depths were deeper than the prism penetration (expressed with a > in Table 3-1) for all replicates. For these stations, prism penetration was then assumed to be at least a conservative minimum estimate of the RPD layer depth and was included in the calculation of the average RPD layer depth. At another five stations, at least one of the replicate images had an RPD layer depth that was deeper than the prism penetration depth (Table 3.1). At many stations, biogenic activity in the form of burrow structures increased the depth to which oxic sediments penetrated. Sediments that appeared to be oxic, light brown to reddish in color, extended >10 cm below the sediment-water-interface at Stations NF08, NF12, and NF24. The deepest RPD layers were associated with mixed sand-silt-clay sediments, which were also associated with higher levels of biogenic activity (for example, compare NF13 to NF22, Figure 3-1).

Table 3-2. Sediment grain size estimated from sediment profile images for nearfield stations from 1992 to 2001.

			MAJOR MODAL SEDIMENT DESCRIPTOR				
STAT	1992	1995	1997	1998	1999	2000	2001
NF02	VFS	CS	SIFS	PB to GR	CB to FSSI	CB to MSCS	FSSI
NF04	FS	FS	VFS	FS	GR to FS	FS	PB to FSMS
NF05	FS	VFS	VFS	VFS	FS/SICL	FS/SICL	FSSICL
NF07	VFS	VFS	VFS	VFS	SIFS	SIFS/CL	FSSICL
NF08	VFS	SIFS	VFS	VFS	SIFS	SIFS	SIFS
NF09	VFS	VFS	VFS	VFS	FSSI	FSSI	FSSICL
NF10	VFS	VFS	VFS	VFS	FSSICL	FSSICL	FSSICL
NF12	VFS	SI	SIFS	SIFS	FSSICL	FSSICL	FSSICL
NF13	FS	FS to VFS	FS	PB to SIFS	FSMS	PB to FSMS	GR to FSMS
NF14	FS	VFS	VFS	PB to VFS	PB to SIFS	PB to FSSICL	PB to FSSI
NF15	FS	VFS	VFS	GR to FS	PB to FSSI	PB to FSSI	PB to FSSI
NF16	VFS	SIFS	VFS	SIFS	FSSICL	PB to FSSI	CB to FSSICL
NF17	FS	FS	FS	FS	GR to FSMS	PB to FSMS	FSMS
NF18	VFS	VFS	VFS	GR to VFS	PB to SIFS	FSSICL	PB to FSSICL
NF19	.	CS to VFS	VFS	FSSICL	FSSICL	CB to FSSICL	GR to FSSI
NF20	VFS	CS to VFS	GR to FSMS	GR to SICL	PB to SIFS	PB to SIFS	PB to FSSI
NF21	.	SIFS	VFS	SIFS	SIFS	SIFS	SIFS
NF22	.	SIFS	SIFS	SIFS	SIFS	SIFS	FSSICL
NF23	.	CS to VFS	FS	FS	PB to FSSICL	GR to FSMS	PB to FSMS
NF24	.	SI	SIFS	FSSICL	PB to FSSICL	FSSICL	FSSICL
FF10	VFS	.	VFS	VFS	CB to SIFS	PB to GR	CB to FS
FF12	.	.	VFS	FS	FS	VFS	VFS
FF13	.	.	SIFS	SIFS	CB to FSSI	CB to SI	FSSI
	Layered	Silts	Silty Sands	Fine-sand	Coarser sand	Gravely	Pebble/Cobble

For assessing outfall effects, the MWRA (2001) set a 50% change in the apparent color RPD layer depth over the study area as a critical trigger level. The average apparent color RPD for 2001 was not different from the long-term baseline RPD, which includes all data from the six collections between 1992 and 2000 (Figure 3-2). Overall, it appeared that the RPD layer depth tended to decrease in 2001 relative to 2000 but was still above the long-term average (Figure 3-3).

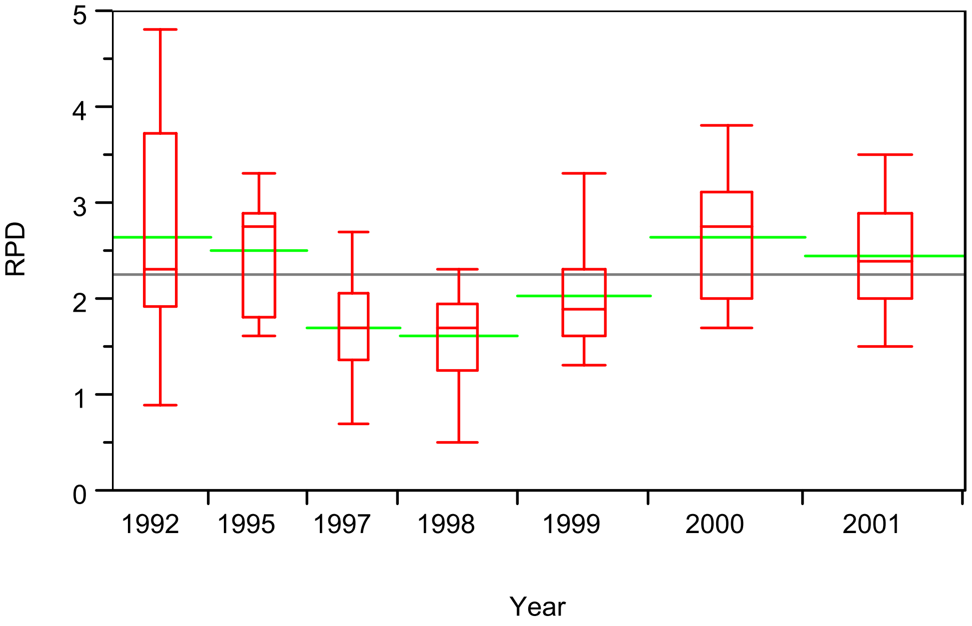


Year	N	Mean	SE	Lower 95%	Upper 95%
1992 to 2000	99	2.2	0.08	2.0	2.4
2001	23	2.4	0.16	2.1	2.8

Figure 3-2. Comparison of apparent color RPD layer depth (cm) for 2001 to the other six years the nearfield stations were sampled. Box is interquartile range, short bar is median, wide bar is mean and wiskers are range of data. Width of box is proportional to sample size. The RPD for NF12 in 1992 was a high outlier. Horizontal line is grand mean for all years.

3.3.4 Biogenic Activity

Biological processes dominated the sediment surface at 6 of 23 stations and physical processes dominated at 9 of 23 stations. The sediment surface at the remaining eight stations appeared to be structured by both physical and biological processes. Biogenic structures associated with activities of successional Stage II and III fauna dominated biological processes. The surface biogenic structures observed included biogenic whips or sticks made by amphipods (for example NF05, Figure 3-1), likely in the genus *Dyopedos* (Mattson and Cedhagen 1989). *Dyopedos monacanthus* occurred at low abundances in infaunal samples at 12 stations in 2001 (Section 5). Other biogenic features were small and large worm tubes (NF05), epibenthic organisms (FF10), burrow openings (NF15), biogenic mounds (NF16), and shells (NF04). Subsurface biogenic structures and actives were associated with infaunal organisms and included active oxic burrows (NF21), and water-filled oxic voids (NF16). Free-burrowing infaunal worms occurred at 18 stations. At Station NF07 the average number of worms was 12.0 per image, with a maximum of 16



				95% CI	
Year	N	Mean	SE	Lower	Upper
1992	14	2.7	0.18	2.3	3.0
1995	14	2.5	0.18	2.1	2.9
1997	13	1.7	0.18	1.3	2.1
1998	17	1.6	0.16	1.3	1.9
1999	19	2.0	0.15	1.7	2.3
2000	22	2.6	0.14	2.4	2.9
2001	23	2.4	0.14	2.2	2.7

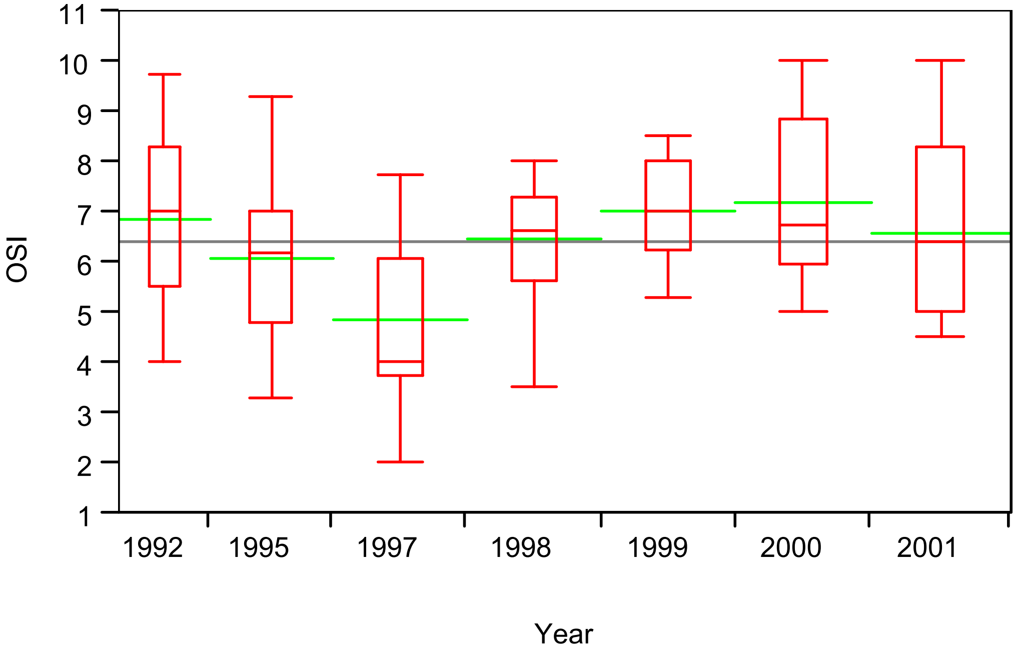
Figure 3-3. Apparent color RPD layer depth (cm) summarized by year for all data from nearfield stations. Box is interquartile range, short bar is median, wide bar is mean and wiskers are total range of data. Horizontal line is grand mean for all years.

worms at NF07-1. Most stations had high densities of polychaete tubes, >1 tube/cm^2, based on tubes that were within 1 cm of the prism faceplate this would scale to >10,000 tubes/m^2, and 4 stations (FF13, NF05, NF12, and NF22) had mat densities of tubes, >50,000 tubes/m^2. Many stations (9 of 23) had a twisted medium size polychaete tube, possibly belonging to *Ampharete* spp. (N. Maciolek, personal communication), which was about 1 mm to 2 mm in diameter and projected 1 cm to 2 cm above the sediment surface (Figure 3-1). Three species of *Ampharete* occurred in the 2001 infaunal samples, with *A. finmarchica* the most abundant and wide spread occurring at all but one station (Section 5).

3.3.5 Successional Stage and Organism Sediment Index

The modal successional stage of the infaunal communities was estimated to be between pioneering (Stage I) and intermediate (Stage II) and occurred at 11 stations. Two stations were a combination of Stage I and equilibrium Stage III, and nine stations appeared to have combined traits of Stage II and III communities, with Station NF21 having Stage III communities (Table 3-1). The high degree of biogenic sediment reworking observed in many images was consistent with Stage II and III successional designations. Stations that included the lower successional stage designation (Stage I) had little indication of biogenic activity, other than small worm tubes on the sediment surface, and tended to have coarser grained sediments (Table 3-1).

In 2001 the average Organism Sediment Index (OSI) was 6.6 (SE = 0.32), which was statistically the same as the 2000 average of 7.2 (SE = 0.35) (Figure 3-4). However, the overall lower OSI numbers in 2001 relative to 2000 were primarily related to an artifact of how the RPD is scored by the index and do not reflect a reduction in biogenic activity. The slight shallowing of the RPD layer depth in 2001, on average 0.2 cm (Figure 3-3), put most of the RPD's into a lower score category for the calculation of the index. Rhoads and Germano (1986) developed the OSI for assessing stress in estuarine and coastal embayments and found that for the northeast region OSI values <6 were associated with benthic communities under some form of stress, either from organic loading or physical processes, while higher



Year	N	Mean	SE	95% CI Lower	Upper
1992	15	6.8	0.40	6.0	7.6
1995	20	6.1	0.35	5.4	6.7
1997	22	4.8	0.33	4.2	5.5
1998	22	6.4	0.33	5.8	7.1
1999	22	7.0	0.33	6.4	7.7
2000	22	7.2	0.33	6.5	7.8
2001	23	6.6	0.32	5.9	7.2

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

values were associated with well developed communities. Ten stations, which all appeared to be physically stressed with no signs of stress from organic loading, had OSI values <6. Eight of these 10 stations had coarse heterogeneous or sandy sediments. The other two stations (FF13 and NF02) had finer sediments (Table 3-1).

3.3.6 Summary of 2001 SPI Data

The quality of benthic habitat in 2001 was very similar to the last three baseline years. Sediment surfaces at the nearfield stations continued to be dominated by biogenic structures and organism activity in 2001. Most stations with fine sediments had high densities of polychaete tubes, at least 1 tube/cm^2 or 10,000 tubes/m^2. Most of the cobble and pebble size sediments were covered with a thin drape of fine sediments, most of which had become incorporated into biogenic tubes. Sediment drape was observed on many cobbles and boulders during the nearfield ROV survey (Section 6). Overall, the OSI (Figure 3-4) and sedimentary environment did not change much in 2001 relative to the recent baseline period of 1999 and 2000 (Table 3-2). Sediments at many stations continued to be either heterogeneous ranging from silts-clays to cobbles, or homogeneous sands or silt-clays. The 2001 SPI data continued reflect the importance of biological processes in structuring sediment surfaces that appeared to start in 1995 of the baseline data. The OSI values (Figure 3-4) and analysis of benthic community point to similar levels of physical stress at the nearfield stations in 2001 relative to the last few years of the baseline period (Kropp *et al*. 2001, 2002).

The depth of the apparent color RPD layer continued to reflect the dominance of biological processes at many of the stations in 2001. The averaged apparent color RPD layer depth ranged from 1.5 cm (FF13) to 3.5 cm (NF21) (Table 3-1). The grand average RPD layer depth for all stations in 2001 was 2.4 cm (SD = 0.65, SE = 0.14) and was statistically the same as in 2000, which was 2.6 cm (Figure 3-3). In the long-term, the average RPD for 2001 was well within the range of annual RPD's from the baseline period, with 1998 being the shallowest year at 1.6 cm and 1992 the deepest year at 2.7 cm (Figure 3-3). The 2001 annual average RPD layer depth did not represent a significant change from the grand average baseline RPD of 2.2 cm (SE = 0.08). Because the large sample size difference between the baseline period (n = 99) and 2001 data (n = 23), and the fixed nonrandom sampling design a bootstrap randomization (Efron and Tibshirani 1993) was used to assess the probability of a change in RPD relative to baseline conditions. A bootstrap of 10,000 estimates of the annual average RPD (9,999 resamples + data from 2001) with a sample size of 23 yielded a grand mean of 2.2 cm and a population distribution that was slightly positively skewed (Figure 3-5). Based on the bootstrapping, the approximate probability of getting an annual RPD as high as 2.4 cm, the actual value for 2001, was 0.115, which indicates 2.4 cm is still a likely estimate of the mean RPD in the nearfield. For the RPD to significantly decline (alpha of 0.05, one-tail test) would require the annual mean be <2.0 cm. The likelihood of an annual RPD being 0.5 cm lower than the baseline mean was 0.0007 for 2001. A similar bootstrapping analysis in which the estimates are drawn from six pools of the raw baseline data (one for each of the baseline years) may provide a more robust estimator of the likelihood of a change of this magnitude. Such an analysis may be pursued in a future report.

While the distribution of sediment textures at benthic habitats in the nearfield study area appeared to be dominated by physical processes, surface features were dominated by biogenic activity. Even station NF04 that appeared completely dominated by physical processes had many small tubes on the surface of pebbles. Tubes were the dominant surface biogenic structures and occurred at all stations. Subsurface biogenic structures and organisms were also common and widely distributed. The predominance of biological activity at most stations was indicative of a well developed fauna that was characterized as being intermediate to equilibrium in successional stage (Stage II to III). Overall, it appeared that biological processes were still predominant in structuring surface sediments, but signs of physical processes, such as bedforms, seemed to have increased in 2001 relative to 2000 and 1999 of the baseline data.

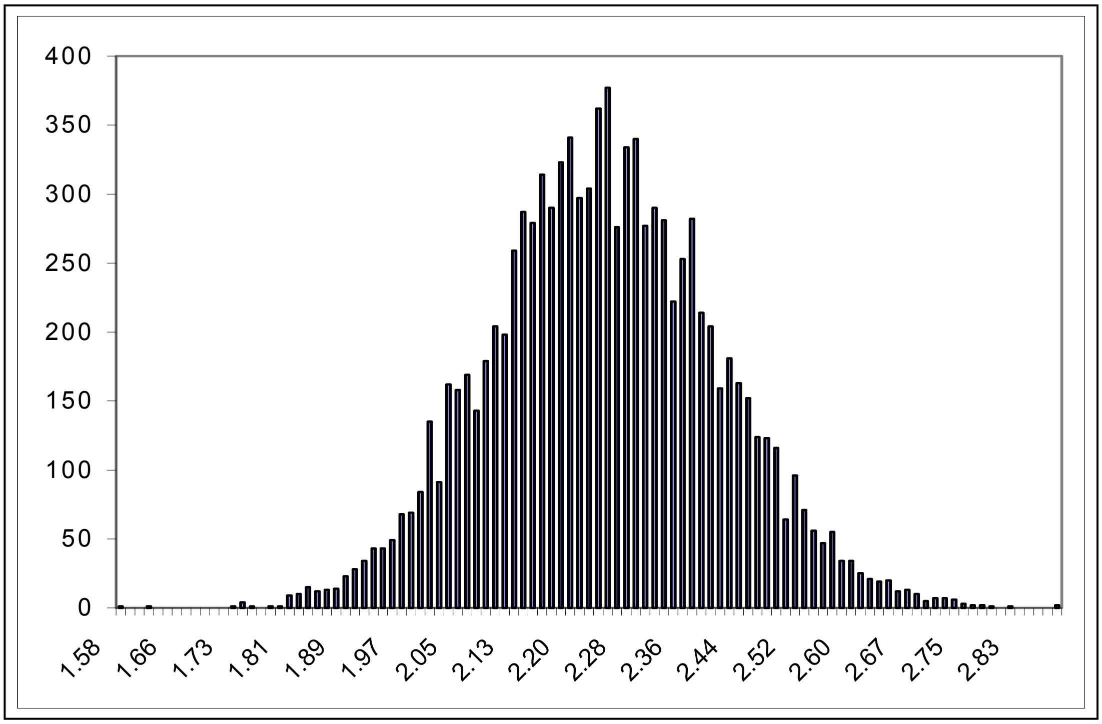


Figure 3-5. Bootstrap of 10,000 estimates of the annual average RPD layer depth for the baseline period (9,999 resamples + 1 actual datum) with a sample size of 23.

4. CHEMISTRY

by Deirdre T. Dahlen and Stephen Emsbo-Mattingly

4.1 Status of the Bay

Baseline data collected in Massachusetts Bay from 1992 to 2000 showed multiple regions defined by physical and chemical composition. The heterogenous sediments at MWRA nearfield stations (Figure 2-1) were in close proximity to and roughly equidistant from the primary historic source of contaminants, Boston Harbor. Nearfield stations were generally equidistant from the harbor. The major factors influencing the concentration of contaminants and sewage tracers are primarily related to grain size, which suggests different sediment depositional environments. The primary factor responsible for the variance in the data is sand content. The secondary factors are associated with anthropogenic[1] analytes (selected pesticides and metals) and fine particles (selected metals).

In contrast, the sediments collected from the regional stations (Figure 5-1) are more spatially dispersed and compositionally distinct. As in the nearfield data, sand content strongly influenced the variance in the regional data. In addition, the sewage tracer data showed that the station proximity to Boston Harbor (the historic source of sewage contaminants) influenced the concentration of *Clostridium perfringens* and total linear alkyl benzenes (LAB) at regional stations. The distribution of fine particles and the analytes associated with them (total organic carbon and selected metals) also helped compositionally define some of the more remote sampling locations. In short, the composition of sediments at remote sampling locations may reflect regional inputs to the sediment that are distinct from the historic sewage discharge from Boston Harbor.

Results from the correlation analysis between contaminants and bulk sediment properties (percent fines and TOC) also support a system with two disparate regions. Correlations between contaminants and bulk sediment properties in the nearfield are relatively high, with r^2 of 0.5 or greater for most parameters. The correlations were generally weaker for regional stations (organic contaminants in particular), further suggesting that the primary controlling variables in the regional system are neither governed by proximity to Boston Harbor, nor the depositional nature of the station.

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

4.2 Methods

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

Laboratory procedures followed those outlined in the Benthic Monitoring CW/QAPP (Kropp and Boyle, 2001). Summaries of the procedures are provided below.

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

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

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

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

4.2.2 Contaminants

Analyses of sediments for organic constituents and metals were performed following methods outlined in Table 4-1. Samples were analyzed for the parameters listed in Table 4-2, including linear alkyl benzenes (LABs), polycyclic aromatic compounds (PAH), polychlorinated biphenyls (PCBs), chlorinated pesticides, and metals. Analytical methods followed general NS&T methodologies (Peven *et al*., 1993a, Peven *et al*., 1993b). More detailed information is provided in the CW/QAPP (Kropp and Boyle 2001).

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

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

[a] See CW/QAPP (Kropp and Boyle 2001) for complete details regarding analytical methods.

Table 4-2. Sediment chemistry analytical parameters.

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

4.2.3 Statistical Analysis, Data Terms, and Data Treatments

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

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

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

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

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

Data Treatments— In the discussion of bulk sediment and contaminant data, numerous terms are used to describe the data. See Appendix C-1 for a complete listing of terms referenced in this report. Appendix C-1 also summarizes data analyses (e.g., PCA, correlations) and evaluations (e.g., histogram plots) performed on the data to assess temporal and spatial trends over time.

4.3 Results and Discussion

Bulk sediment, *Clostridium perfringens*, and contaminant results for all nearfield and regional samples (August surveys only) were evaluated separately to examine spatial and temporal characteristics. Baseline range, baseline station mean, and August 2001 values are reported in Appendix C (nearfield — Appendix C-2; regional — Appendix C-3). All sediment results are discussed in terms of dry weight using baseline range, baseline station mean, station, and nearfield baseline mean values.

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

4.3.1 Nearfield Chemistry 1992–2001

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

To demonstrate this, the baseline range (*i.e.,* minimum and maximum concentration over the baseline period) and mean (*i.e.,* average concentration, by parameter and station, over the baseline period) values were determined, by station, for bulk sediment properties, *Clostridium perfringens*, and contaminant parameters as described in Section 4.2.3. Post-discharge (August 2001) data were then compared to the baseline range and mean values for each nearfield station to evaluate how the post-discharge data fit in with our understanding of the baseline system. Nearfield stations were sorted by order of increasing TOC content using baseline mean data. With few exceptions, post-discharge data for all parameters fell within the baseline range indicating that 2001 was representative of the baseline period (representative parameters shown in Figure 4-1; all data in Appendix C-2). Exceptions included cases where the post-discharge concentration for an individual station replicate fell either below or above the baseline range. Notable exceptions included:

- 2001 concentrations for organic contaminants (*i.e.,* TLAB, TPCB, and TDDT) generally fell below the baseline station mean value at each station, but were within the baseline range in most cases (four station replicates noticeably fell below the baseline range for TLAB, TPCB and TDDT). In contrast, TOC and several metals generally fell above the baseline range for one to six stations.
- NF20 showed concentrations of organic (*i.e.,* TLAB, TPCB, TDDT) and metal (*i.e.,* Cd, Cu, Cr, Hg, Ag, Zn) contaminants that consistently fell below the baseline range in 2001.
- Another station (NF21, located about 4 kilometers to the northwest of the outfall) had an unusually high concentration of total DDT. The result passed rigorous quality assurance tests (which included reanalysis). Stations closer to the outfall did not show DDT elevated over baseline concentrations, and the result is unusual enough that an analytical interference (false positive) cannot be ruled out. Draft data from the August 2002 nearfield sampling indicate no anomalously high DDT values, either at NF21 or at any other nearfield station.
- NF10 in 2001 had total PAH, Pb, Hg, Ni, Ag, and Zn concentrations that consistently fell above the baseline range. Interestingly, the 2001 concentration of TOC at NF10 fell within the baseline range and was very similar to the baseline station mean value.
- Concentrations of Pb in 2001 fell above the baseline range at more stations (NF17, NF23, NF15, NF20 and NF14) than did other metals.

The PCA results revealed four generalized trends among the data collected from the nearfield sediment samples (Figure 4-2 a, b, c). First, high percent sand was inversely correlated with organic and inorganic analyte concentrations. Presumably, this relationship reflected the dilution of these analytes with sand. The samples that contained relatively high levels of sand included NF02, NF04, NF17, NF13, NF19, and NF23. Second, anthropogenic analytes (*e.g.,* TPEST, TCHLOR, TDDT, and Cd) were measured at

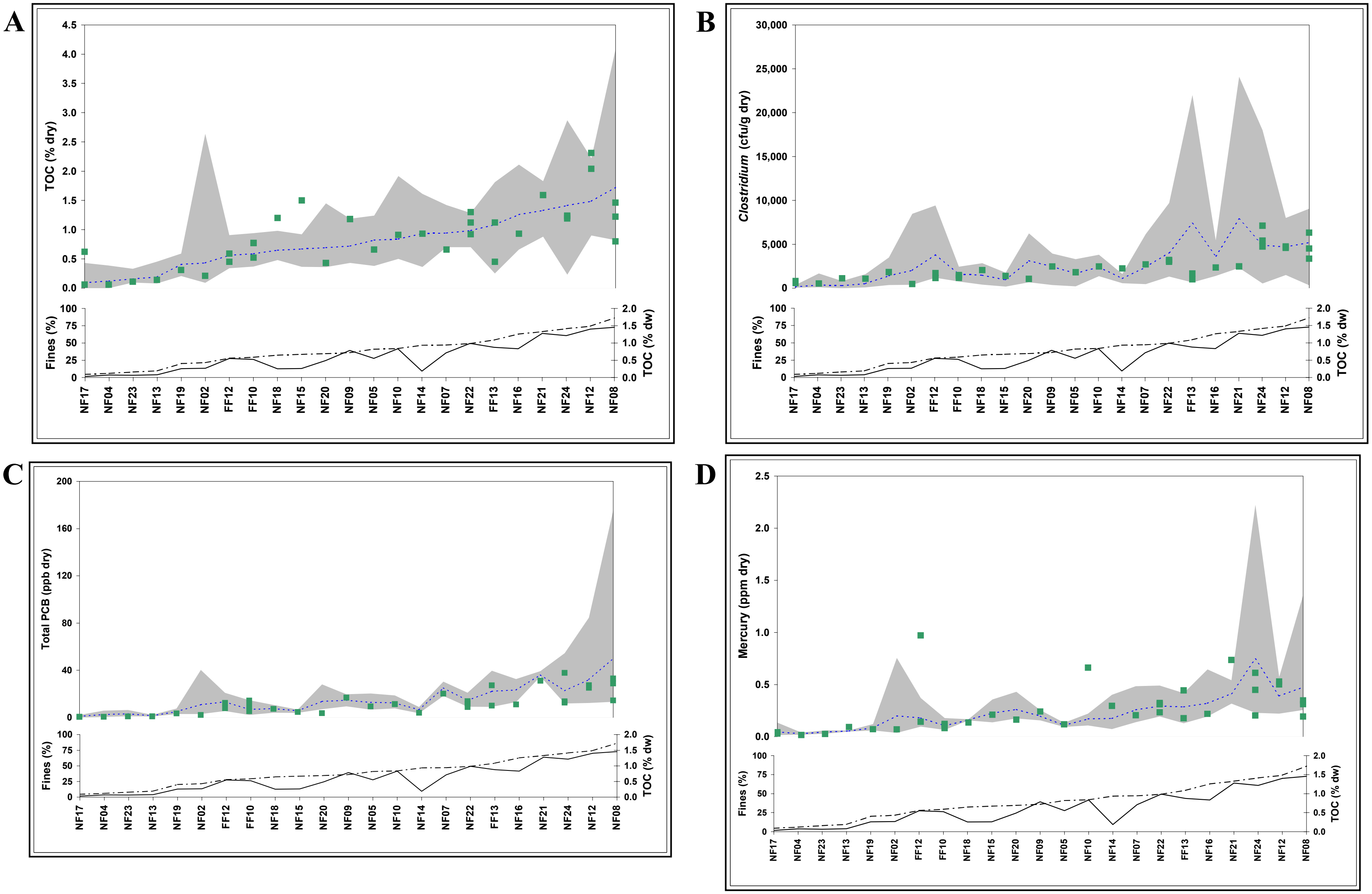


Figure 4-1. Representative parameters (TOC, *Clostridium perfringens*, total PCB, mercury) for each nearfield station sampled in 2001 (squares) and the range of values occurring during the baseline period (gray band). The baseline means value is indicated (dashed line within gray band). Stations are presented in order of increasing mean TOC concentration (dashed line in sub-plot). Baseline station mean values for TOC and percent fines, pl otted by station, are shown in the sub-plot.

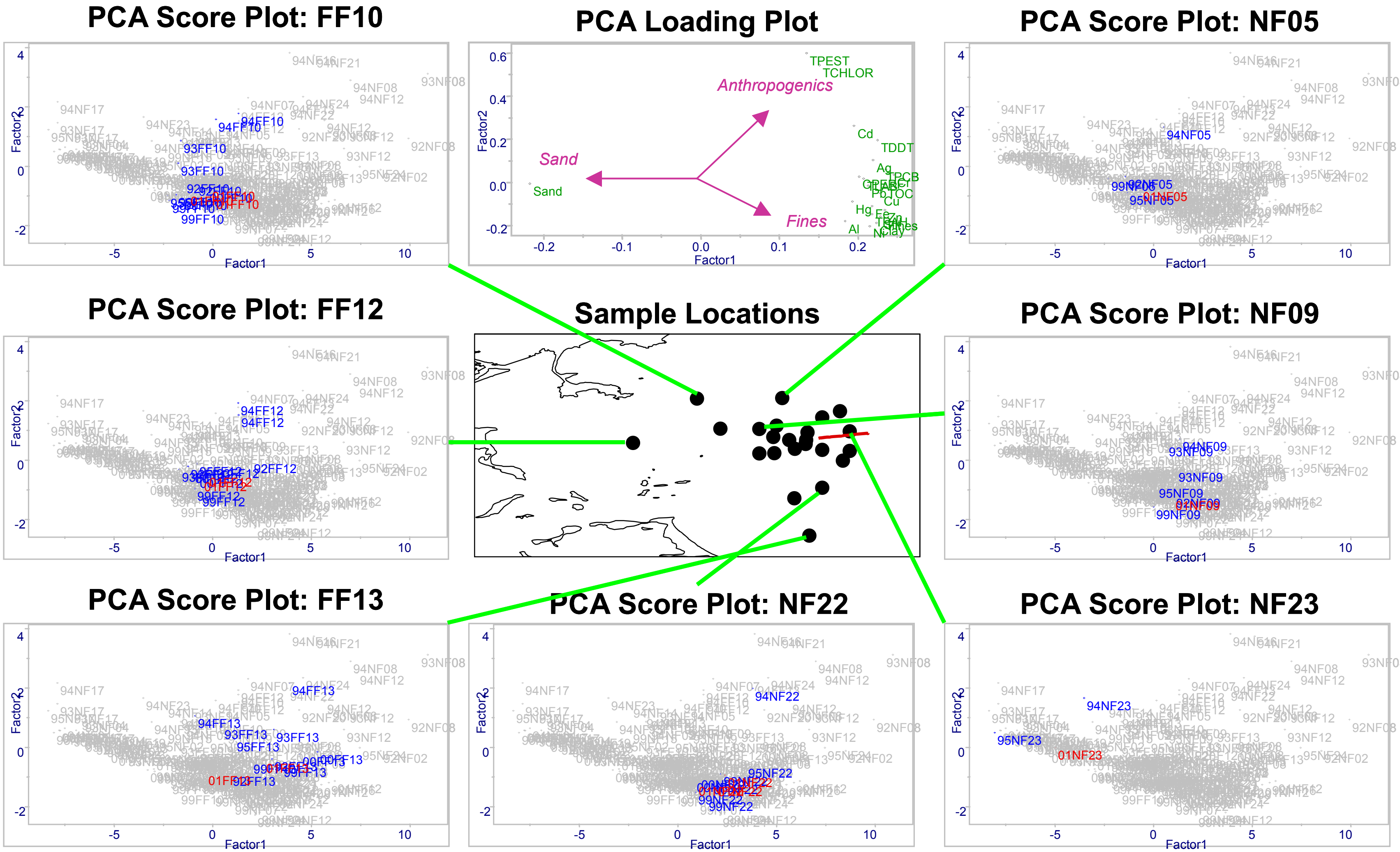
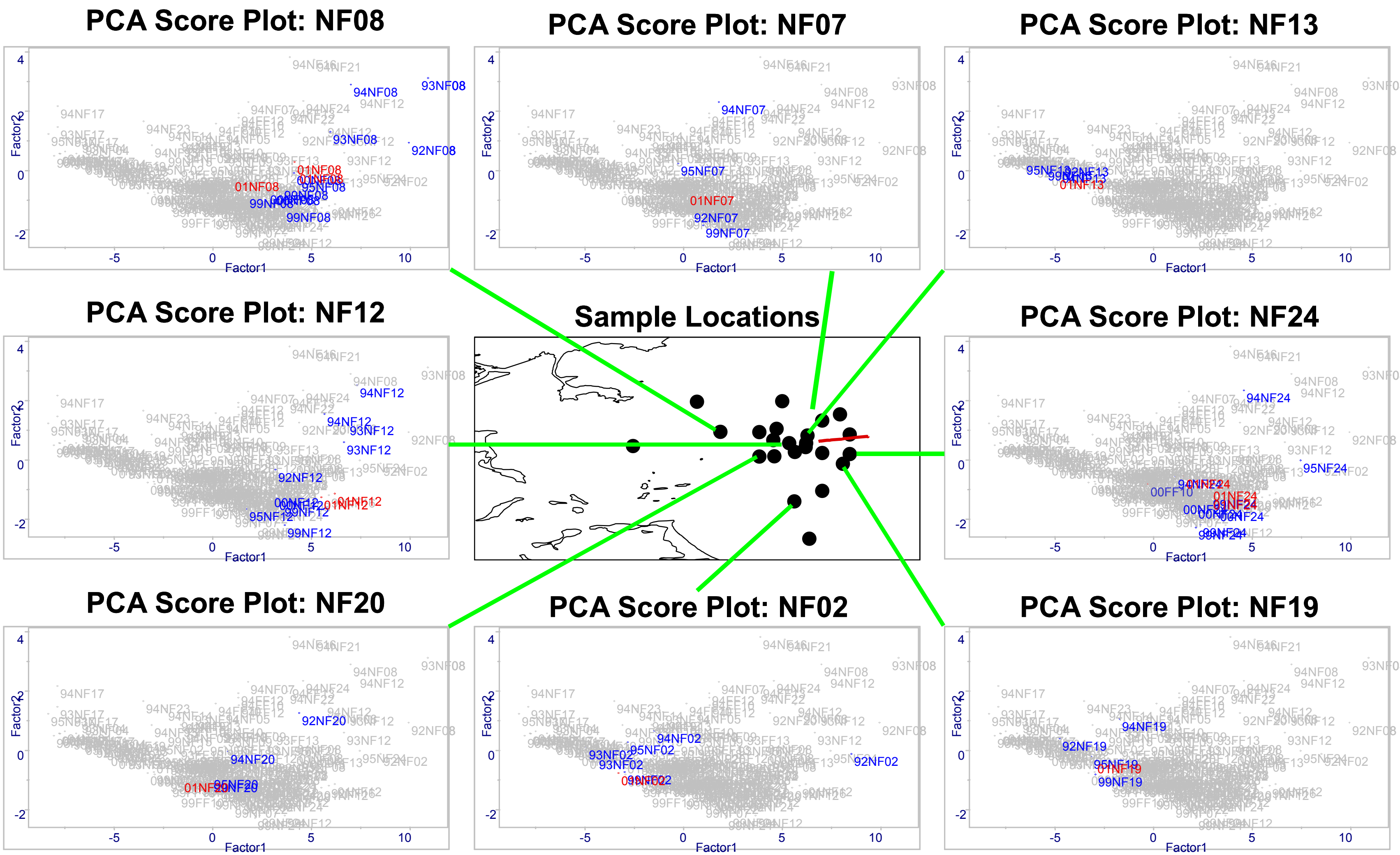


Figure 4-2a. Comparison of nearfield sediments from the baseline period (1992-2000) and 2001 using PCA. Principal components 1 and 2 represented 69% and 6% of the variability, respectively. Score plots are replicated to demonstrate the relative spatial and temporal composition of all nearfield samples.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



PCA Score Plot: NF08

PCA Score Plot: NF07

PCA Score Plot: NF13

PCA Score Plot: NF12

Sample Locations

PCA Score Plot: NF24

PCA Score Plot: NF20

PCA Score Plot: NF02

PCA Score Plot: NF19

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

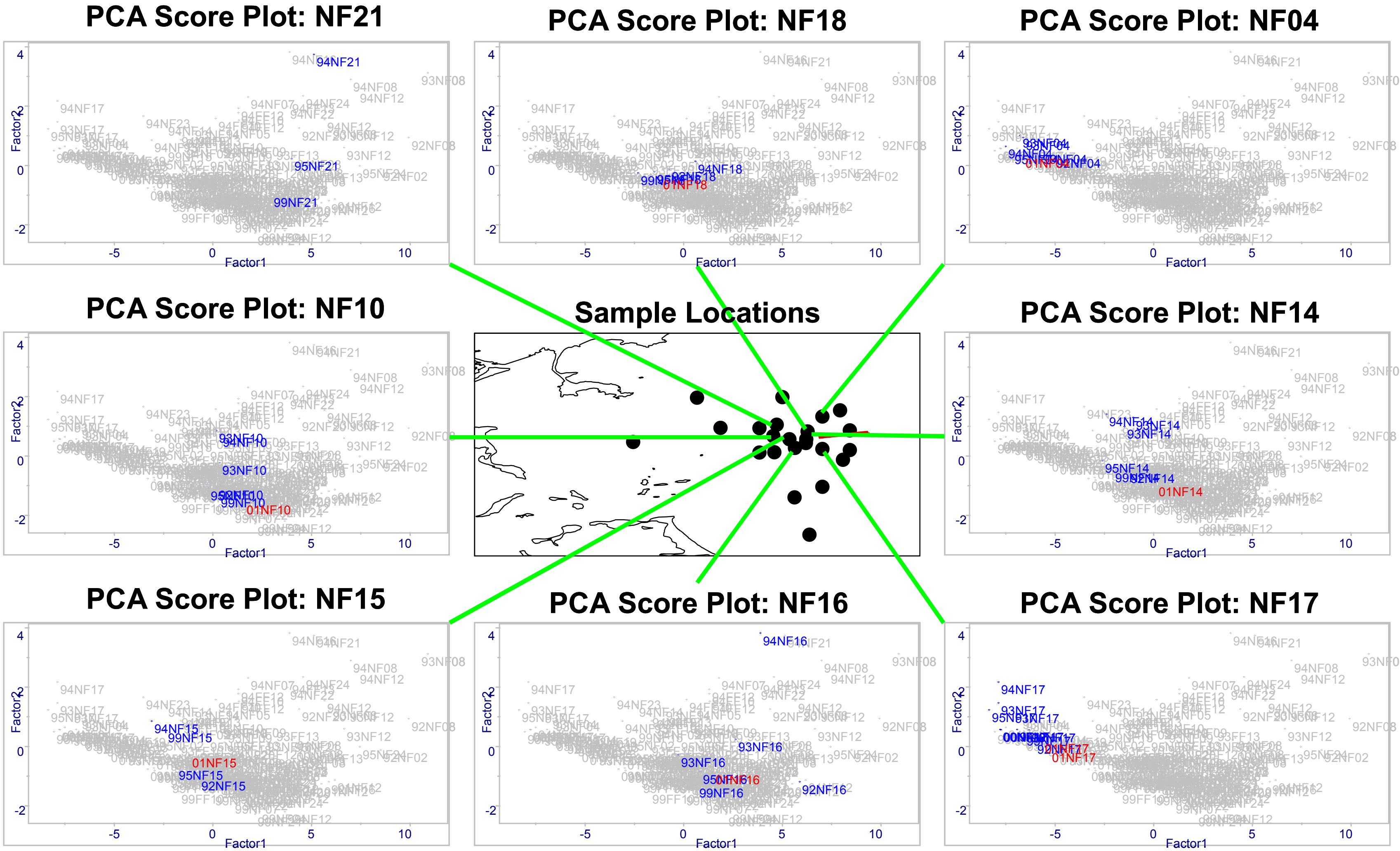


Figure 4-2c. Comparison of nearfield sediments from the baseline period (1992-2000) and 2001 using PCA (continued). Principal components 1 and 2 represented 69% and 6% of the variability, respectively. Score plots are replicated to demonstrate the relative spatial and temporal composition of all nearfield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

relatively high levels in the early years of the baseline study (*e.g.,* 1992 to 1994) at the following locations: FF10, FF12, FF13, NF05, NF07, NF08, NF09, NF10, NF12, NF16, NF20, NF21, NF22, and NF24. These sample locations may have received higher pollutant loading during these baseline years.

Other anthropogenic analytes (*e.g.,* TPCB, CPERF, and Cd) were influential, but did not further differentiate the samples due to a more uniform distribution in the nearfield sediments. Third, for most of the baseline period and 2001, small particles (fines = silt+clay), Ni, Zn, Fe, Hg, Al, Cu, and TPAH were detected in samples FF13, NF08, NF09, NF12, NF13, NF16, NF21, NF22, and NF24. The samples that were largely undifferentiated into the first three groups constituted the fourth sample grouping. Samples in the fourth group contained intermediate amounts of sand and fines during most of the baseline period and 2001. This group included FF10, FF12, NF05, NF07, NF10, NF14, NF15, NF18, and NF20.

The PCA score plots demonstrate the relative variability among baseline and 2001 sediment samples. For example, the anthropogenic and metal composition of NF08 and NF12 varied more widely than NF18 and NF02. In general, the reduction in compositional variability was inversely proportional to the sand composition; *i.e.*, sediment samples with high sand content (NF13, NF04, and NF17) exhibited some of the smallest variability as demonstrated by the relative tightness of these clusters. Perhaps more importantly, the 2001 samples (colored red in Figure 4-2) typically fell within the overall variability of the baseline samples (colored blue in Figure 4-2). In addition, the 2001 samples did not deviate strongly in the direction of the anthropogenic analytes. The consistent trend away from the anthropogenic analytes among numerous sampling stations over time (including 2001) suggests the sediments are no longer receiving harmful organic and inorganic compounds associated with the historical discharges of untreated or inadequately treated sewage from Boston Harbor. However, several 2001 samples from stations NF10, NF14, and NF17 trended slightly towards the “Fines” analyte group (bottom right) relative to the baseline samples. While this movement was very subtle and within the apparent variability of the measurement methods, samples collected from these locations should be evaluated for the reproducibility of these trends in the future.

4.3.2 Regional Chemistry 1992–2001

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

To demonstrate this, the baseline range and mean values were determined, by station, for bulk sediment properties, *Clostridium perfringens*, and contaminant parameters as described in Section 4.2.3. Post-discharge (August 2001) data were then compared to the baseline range and mean values for each regional station to evaluate how the 2001 data fit within the baseline system. Regional stations were sorted as a function of their north to south location relative to the new outfall. With few exceptions, 2001 data for all parameters fell within the baseline range indicating that 2001 continued to be representative of the baseline period (representative parameters shown in Figure 4-3; all data shown in Appendix C-3). Unlike the nearfield, there were fewer cases where post-discharge data fell outside the baseline range for the regional stations. Exceptions included:

- 2001 concentrations of TOC fell slightly above the baseline range at NF12, NF17 and FF07.
- 2001 concentrations of Cr and Pb fell slightly above the baseline range at NF17 (for one replicate only).

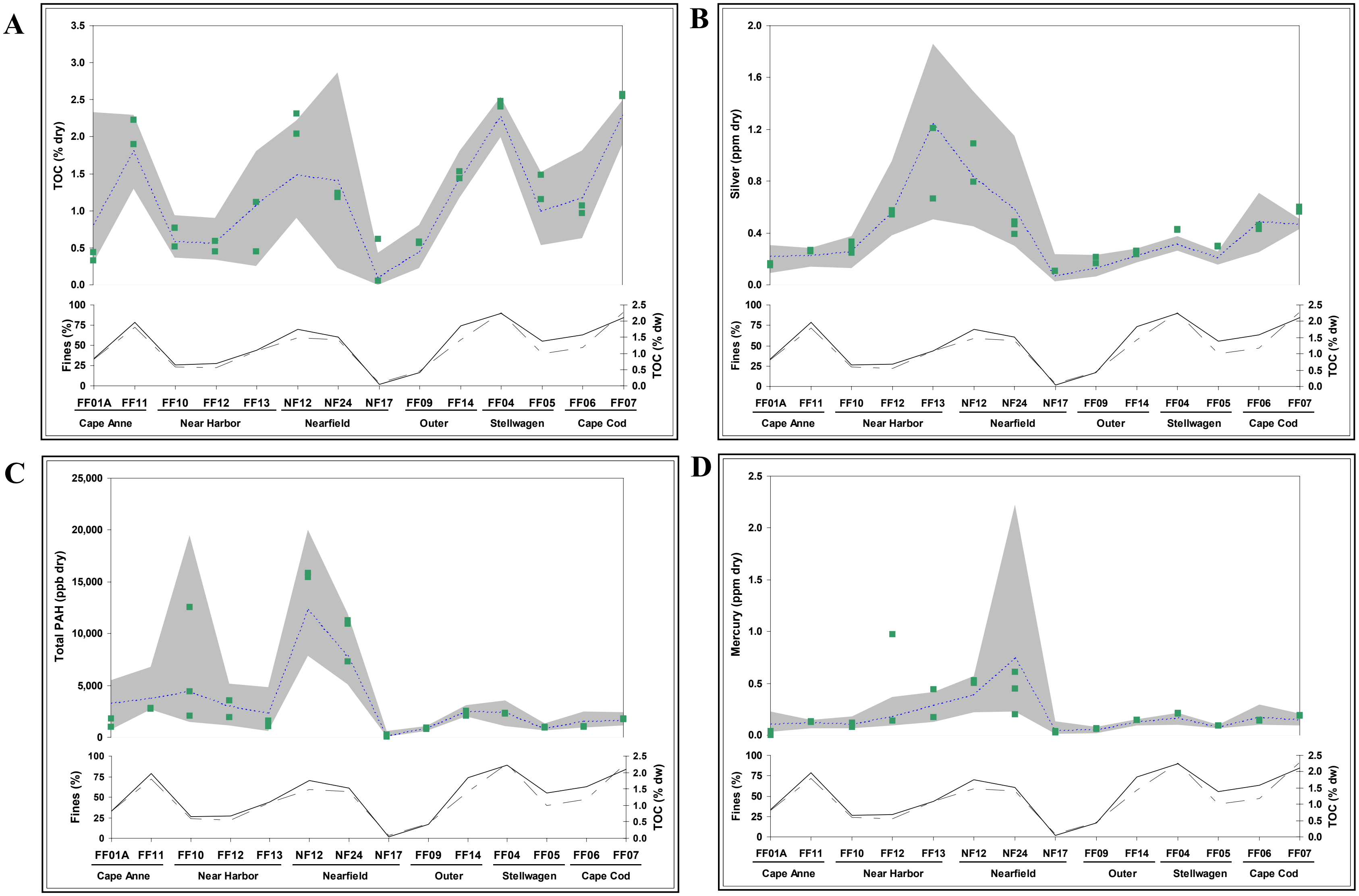


Figure 4-3. Representative parameters (TOC, silver, total PAH, mercury) for each regional station sampled in 2001 (squares) and the range of values occurring during the baseline period (gray band). The baseline means value is indicated (dashed line within gray band). Stations are presented in order of location relative to the outfall, from north to south. Baseline station mean values for TOC and percent fines, plotted by station, are shown in the sub-plot.

- 2001 concentration of Hg fell above the baseline range at FF12 (for one replicate only).
- 2001 concentration of Ag fell slightly above the baseline range at FF04 (for one replicate only) and FF07 (both replicates).

Consistent with the nearfield, 2001 concentrations of sewage tracer and organic contaminants at regional stations were within the baseline range, and values were frequently measured at levels equal to or below the baseline station mean (Appendix C-3).

The PCA results revealed four generalized trends among the data collected from the regional sediment samples (Figure 4-4 a, b). First, high percent sand was inversely correlated with organic and inorganic analyte concentrations. Presumably, this relationship reflected the reduction of fine particulates and commensurate increase in the quantity of sand.

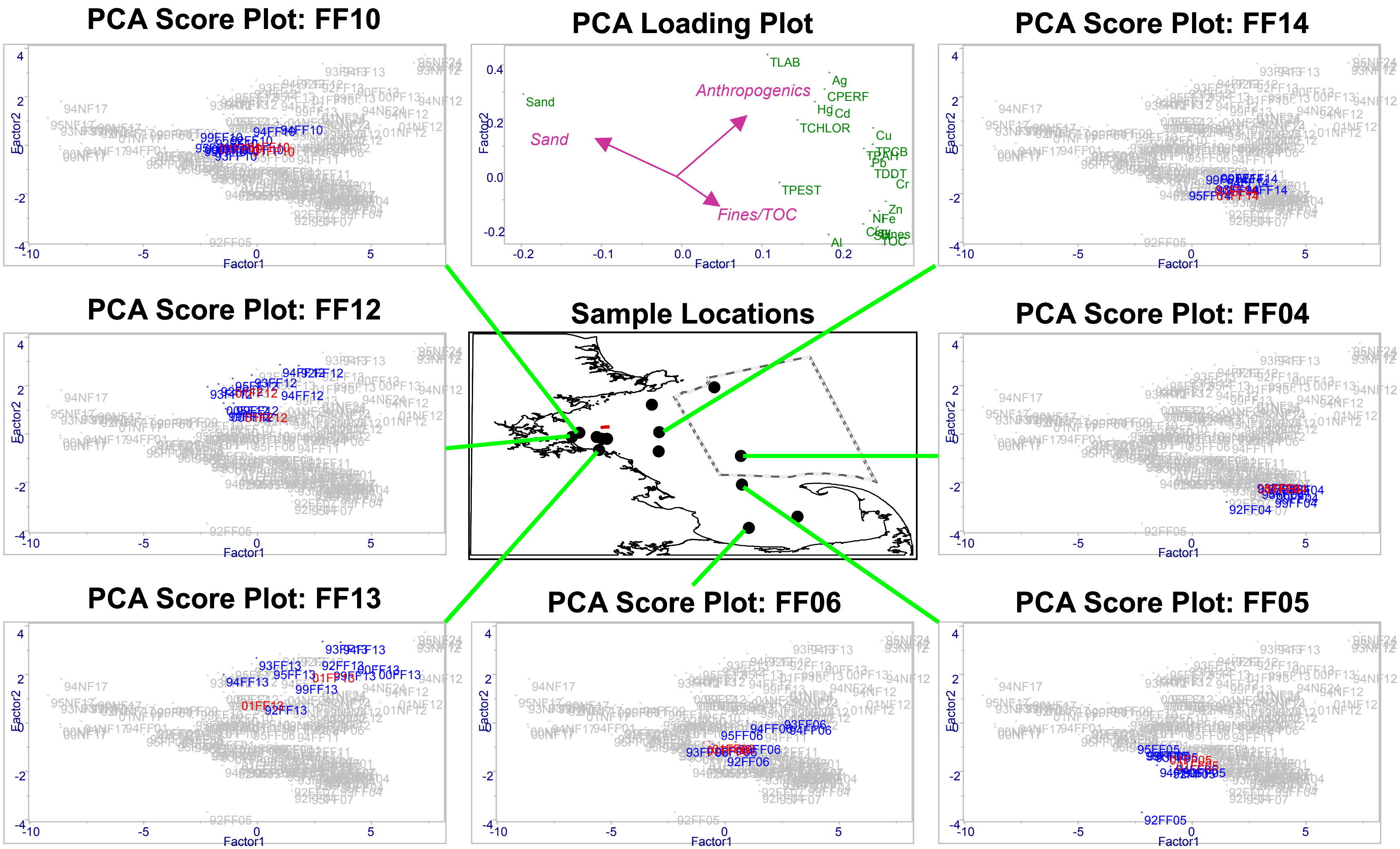
The samples that contained relatively high levels of sand included NF12, NF17, FF01 (1994, 1995, 1999, 2001), and FF09. Second, anthropogenic analytes (*e.g.,* TLAB, Ag, CPERF, Hg, Cd, and TCHLOR) were measured at relatively high levels in the early baseline period (1992 to 1994) at the following locations: FF12, FF13, NF12, and NF24. These sample locations may have received higher pollutant loading, especially during the early 1990s. Other anthropogenic analytes (*e.g.,* TPCB, TPAH, Pb and Cr) were influential, but did not further differentiate the samples due to a more uniform distribution in the regional sediments. Third, for most of the baseline period and 2001, relatively high concentrations of fines and associated parameters (TOC, Ni, Zn, Al, and Fe) were detected in samples FF01 (sampled in 1992 and 1993 only), FF04, FF05, FF06, FF07, FF11, and FF14. The fourth sample group contained one station (FF10) that was largely undifferentiated into the first three groups. This station contained intermediate amounts of sand and fines during most of the baseline period and 2001.

Relative to the nearfield sediments, the regional sample groupings exhibited greater compositional definition from one another. This increased definition among regional samples was attributed to the greater spatial separation of the sampling locations and local isolation of compositional features. Consequently, the loading factors differ slightly from the nearfield and regional PCA runs presented in Figures 4-2 (a,b,c) and 4-4 (a,b), respectively. The separation of sampling locations also explains why the anthropogenic and metal compositions of NF12 and FF13 varied more widely than FF04, FF05, FF07, FF09, and FF14. In general, the more distant the sampling location from Boston Harbor, the more tightly it tended to cluster; *i.e.*, the greater its local compositional character. Perhaps more importantly, the 2001 samples (colored red in Figure 4-4 a,b) typically fell within the overall variability of the baseline samples (colored blue in Figure 4-4 a,b). In addition, the 2001 samples did not deviate strongly in the direction of the anthropogenic analytes. Thus, as before, the sediments in 2001 are not spatially or temporally accumulating harmful organic or inorganic compounds relative to the baseline period.

4.3.3 Spatio/Temporal Response of Sewage Tracers 1992–2001

The spatio/temporal distribution of *Clostridium perfringens* at all nearfield and farfield (excluding northern farfield stations FF01, FF01A, and FF11) stations from 1992–2001 (August surveys only) was evaluated to determine if the gradient in *Clostridium perfringens* observed by USGS (Parmenter and Bothner 1993) is consistent or has changed as harbor cleanup has proceeded. The USGS study observed decreasing spore density (normalized to percent fines) in bottom sediments with distance from Boston Harbor.

The gradient in *Clostridium perfringens* densities with distance from Boston Harbor (defined as the Deer Island Light) was evaluated for the period 1992–2001. *Clostridium perfringens* data were normalized to percent fines because spores preferentially attach to fine-grained particles (Parmenter and Bothner 1993). Further, evaluations in the 2000 OBR (Kropp *et al,* 2001) showed that grain size was likely a major


PCA Score Plot: FF10

PCA Loading Plot

PCA Score Plot: FF14

PCA Score Plot: FF12

Sample Locations

PCA Score Plot: FF04

PCA Score Plot: FF13

PCA Score Plot: FF06

PCA Score Plot: FF05

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

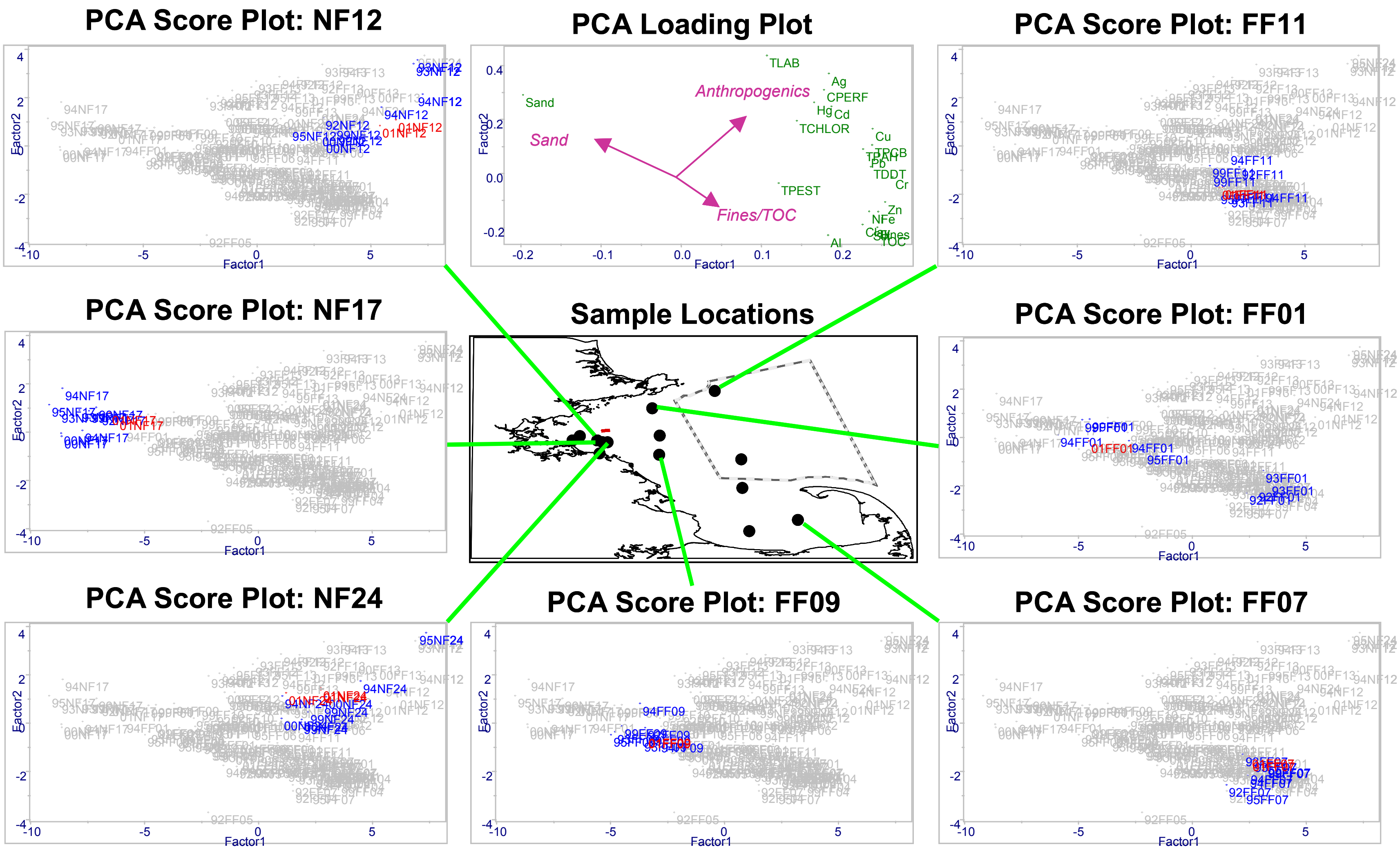


Figure 4-4b. Comparison of regional sediments from the baseline period (1992-2000) and 2001 using PCA (continued). Principal components 1 and 2 represented 58% and 12% of the variability, respectively. Score plots are replicated to demonstrate the relative spatial and temporal composition of all nearfield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

controlling factor influencing *Clostridium perfringens* abundance. Each sampling year showed trends consistent with USGS findings and indicated that *Clostridium perfringens* densities (normalized to percent fines) decreased with distance from Boston Harbor. There was also a wide range in abundance of *Clostridium perfringens* (normalized to percent fines) for stations within 20 km of Deer Island Light (Figure 4-5). In contrast, stations further away from Deer Island Light consistently had lower spore densities (Figure 4-5). With the exception of stations located closest to the new outfall, post-discharge data (normalized to percent fines) showed results consistent with the trend toward decreasing abundance observed in the system since 1998. Stations located within 2-km of the new outfall showed an increase in *Clostridium perfringens* densities (normalized to percent fines) in August 2001 compared to 1998-2000 values, suggesting that there could be a highly localized effect from the effluent discharge at the new outfall (Figures 4-5 and 4-6).

Clostridium perfringens results were also evaluated based on four distance classifications including a Harbor near-in group (<10 km), two mid-distance groups (>10 km but <20 km and >20 km but <40 km) and a far-distance group (>40 km) from Deer Island Light. Yearly means (normalized to percent fines) and 95 % confidence intervals were determined for the four distance classifications. With one exception, 2001 results were consistent with trends observed in the system over the baseline period. For example, values of *Clostridium perfringens* (normalized to percent fines) for near-in stations (<10 km) continued to show a sustained decrease in abundance in 1998–2001 relative to earlier years (Figure 4-6). In addition, *Clostridium perfringens* (normalized to percent fines) concentrations in 2001 for stations further away from Deer Island Light (>20 km) were consistent with trends observed in the system over the baseline period, in that values were considerably less than near-in station values, and were also less variable from 1992–2001 (Figure 4-6).

Interestingly, *Clostridium perfringens* concentrations (as did another sewage tracer, total LAB) increased in 2001[2] for mid-distance stations (>10 km but <20 km), thereby breaking from the recent trend toward decreasing abundance observed in the system since 1998 (Figure 4-6). Stations in this distance classification include all nearfield stations plus FF10 and FF13. *Clostridium perfringens* data were further evaluated to determine if the observed increase was evident for all nearfield stations, or whether the increase was isolated to selected stations. Station mean values of *Clostridium perfringens* (normalized to percent fines) in 2000 and 2001 were evaluated as a function of distance from the western end of the new outfall (diffuser #55). The increase in *Clostridium perfringens* observed in the system in 2001 was clearly isolated to those nearfield stations located within 2-km of diffuser #55, suggesting that effluent discharge at the new outfall is having a highly localized effect on nearby sediments (Figure 4-7).

As was described in the 2000 OBR (Kropp *et al*, 2001), the decreasing abundance observed since 1998 for near-in stations does not appear to be method related. Rather, the decreasing abundance of *Clostridium perfringens* suggests that the documented reductions in effluent solids loading during the 1990s (Werme and Hunt, 2001) also reflects a reduction in *Clostridium* spore loads that is being seen in nearby sediments.

Trends in another effluent marker, total LAB, strengthen this observation. Concentrations of total LAB measured at near-in stations (<20 km) decreased markedly (60 to 80%) in 1995 compared to previous years; with similar low concentrations observed in 1999-2001 (Figure 4-6). While primary treatment came on-line in 1995, there is no clear evidence that it resulted in the marked decrease in total LAB concentrations. The largest decrease in LAB loadings to the Harbor occurred in the late 1980s and early 1990s when Proctor and Gambel installed pretreatment equipment to cleanup their industrial discharge to the south system (*i.e.*, reduction in surfactant loadings to the influent) and subsequently closed their plant

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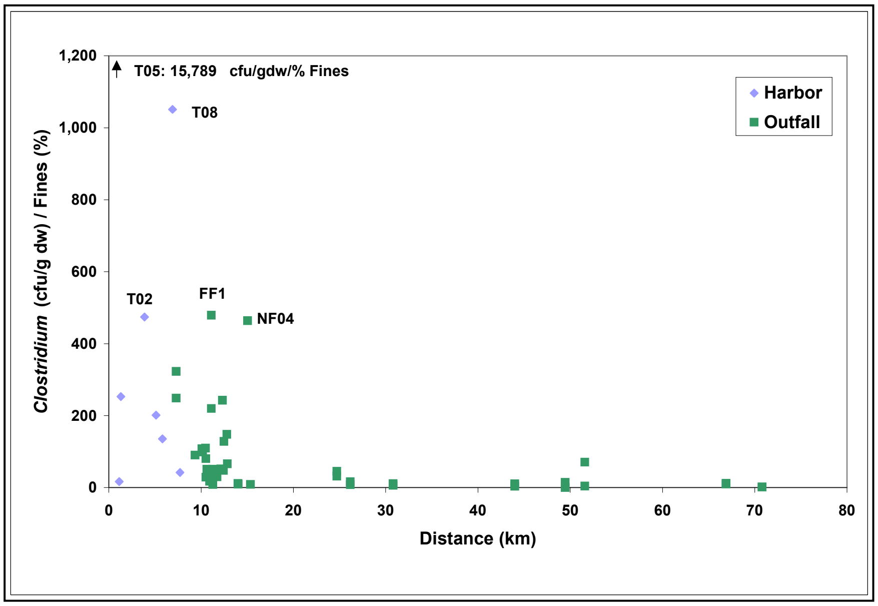
[2] The actual increases were quite modest (see Figure 4-1B). Only when *Clostridium* counts are normalized to the percent fines in the sediments is the pattern apparent (Figures 4-6 and 4-7).



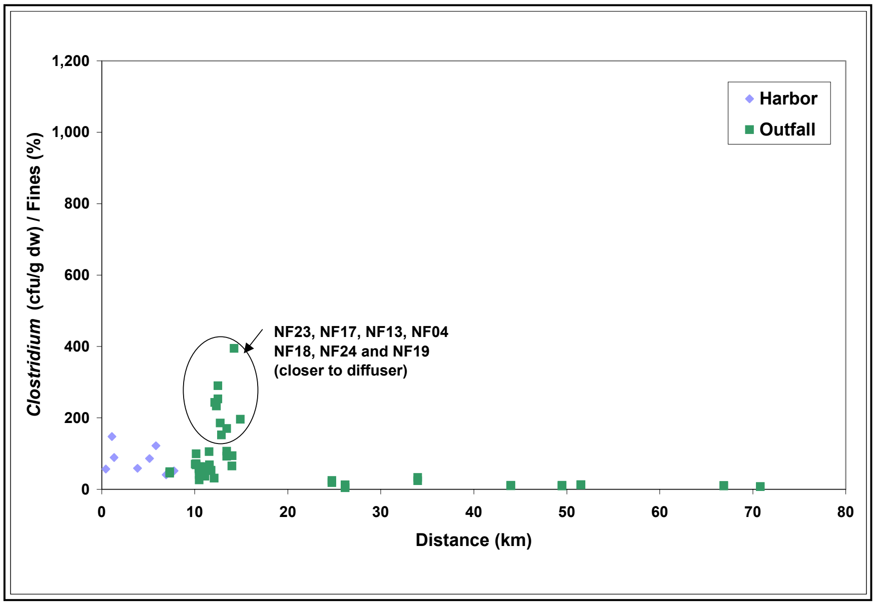
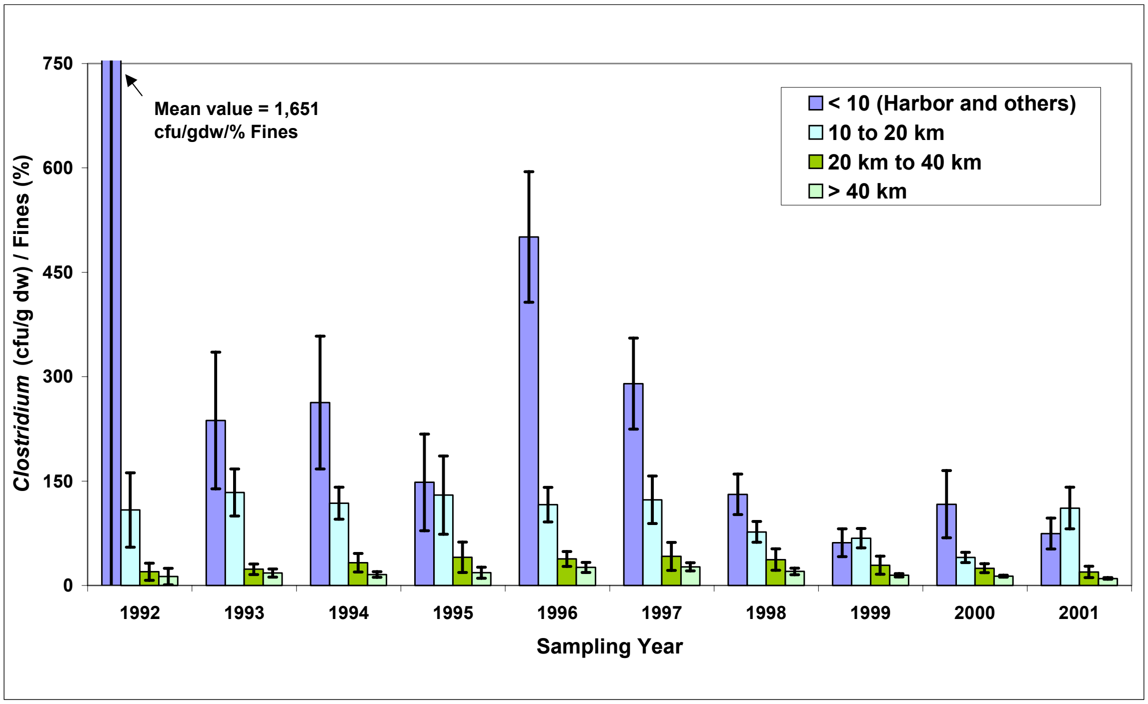


Figure 4-5. Distribution of *Clostridium perfringens* (normalized to percent fines) with distance from Deer Island Light in 1992 (top) and 2001 (bottom) showed that abundances at stations located closer to the Harbor have generally decreased in recent years, while post-discharge abundances (2001) increased at stations located closer to the new outfall.



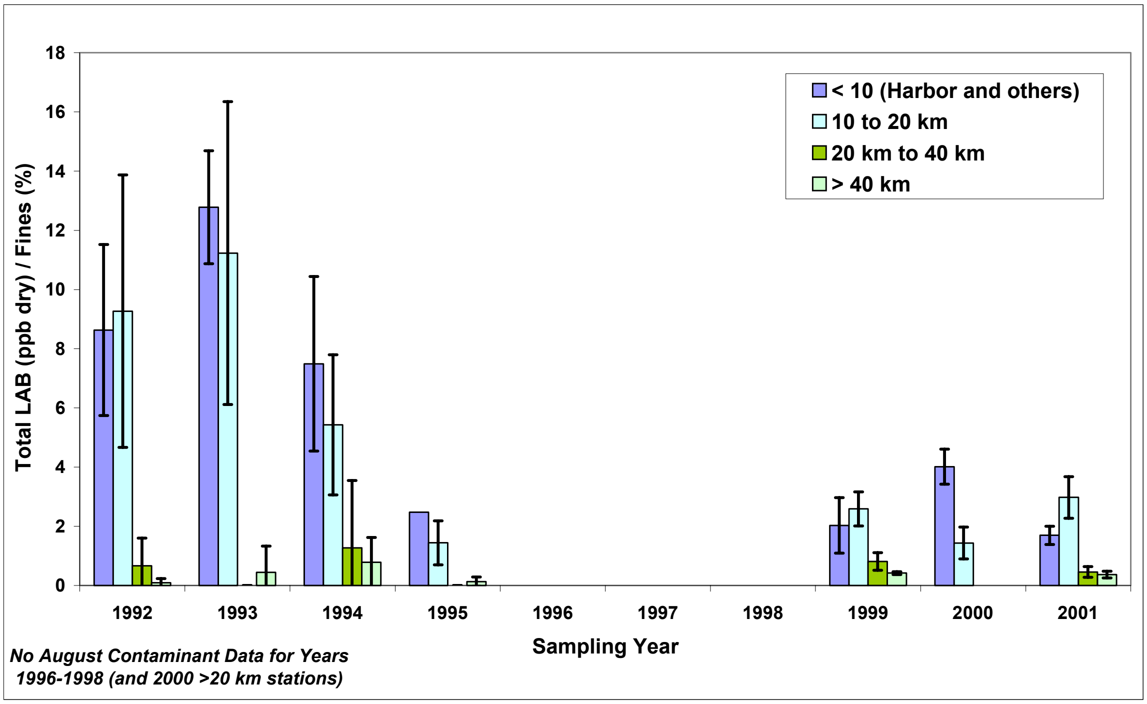


Figure 4-6. Yearly mean concentrations of *Clostridium perfringens* (top) and total LAB (bottom), normalized to percent fines, by distance classification from Deer Island Light showed that abundances at near in stations (<10-km) have decreased since 1998 (and 1994 for total LAB), while post-discharge abundances (2001) increased at mid-distance stations (>10-km and <20-km) located closer to the new outfall. (Error bars represent 95% confidence limits.)

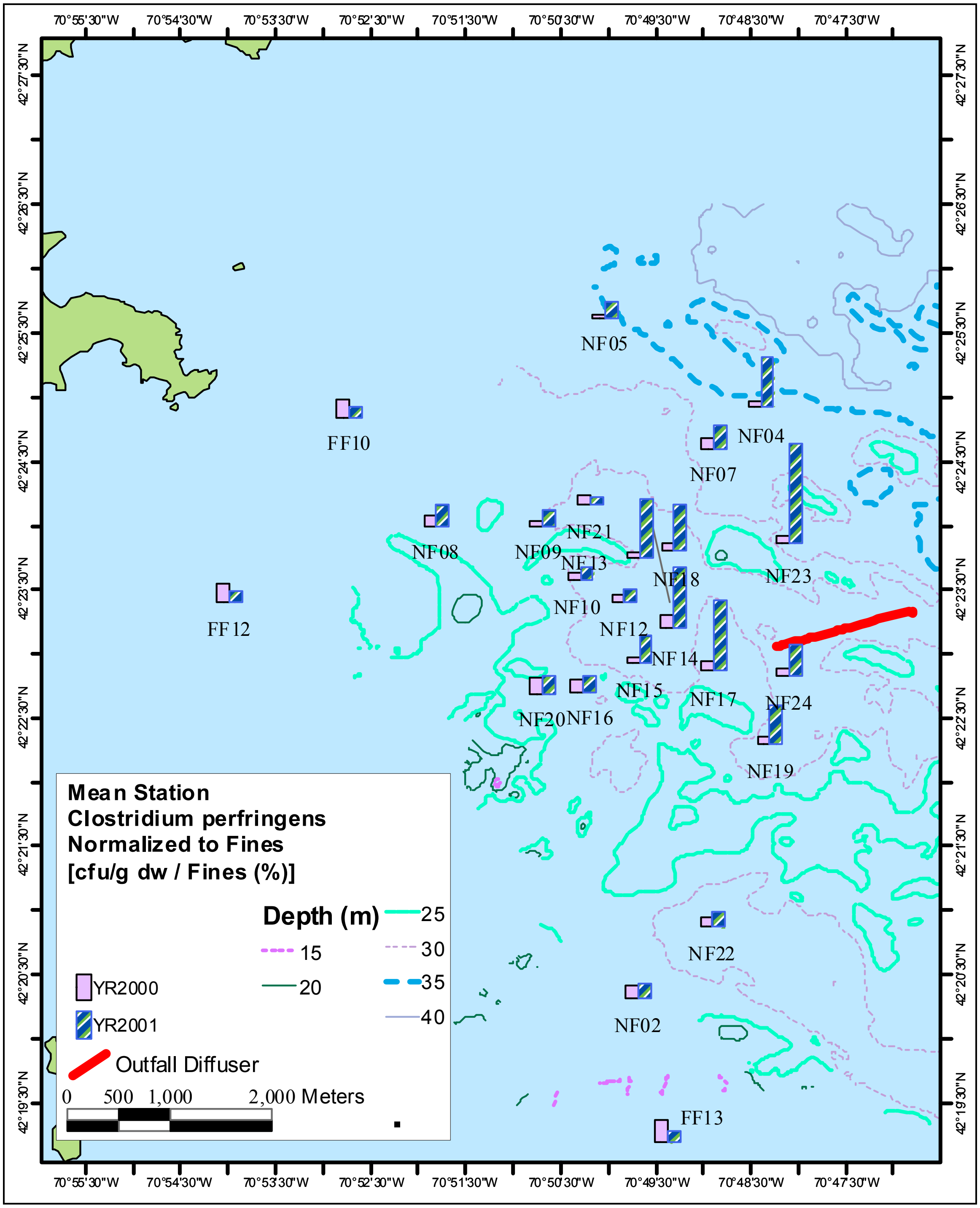


Figure 4-7. Station mean concentrations of *Clostridium perfringens* (normalized to percent fines) in nearfield sediments, collected in August 2000 and 2001 showed that the increase in *Clostridium perfringens* observed in the system was limited to stations located within 2-km of diffuser #55.

(personal communication with Ken Keay, 2002). The observed decrease in 1995 may therefore be attributed to a combination of removal of discharge to the Harbor (*i.e.*, Proctor and Gambel discharge), facility improvements, and natural attenuation. Silver, another sewage tracer, was fairly constant over time (in the <20 km sample set) and did not show the marked decrease observed with *Clostridium perfringens* and total LAB.

4.3.4 Chemistry Interrelationships

Baseline data showed a system with two distinct regions – *nearfield* and *regional* areas – with different controlling factors that influenced the concentrations of contaminants. The correlation between contaminant concentrations and bulk sediment properties was stronger in the nearfield compared to the regional stations. This indicates that the contaminant variability in the nearfield is dominated by grain size and TOC, whereas contaminant concentrations in the farfield are influenced by factors other than the proximity to source (Boston Harbor) and depositional properties of the station.

Correlation analyses were performed for nearfield and regional stations (August surveys only), using station mean values from 1992 to 2001. Correlation coefficients (r values) – using both baseline data and baseline plus 2001 data – were compared to determine if the correspondence between controlling variables and contaminants in the system were substantially different in 2001.

Nearfield—Results from the correlation analysis are presented in Table 4-3. Inclusion of 2001 data into the nearfield correlation analysis showed results consistent with baseline system trends. For example, grain size continued to be strongly correlated with TOC across all years (Table 4-3). Similarly, the correlation between contaminants and bulk sediment properties (percent fines, TOC) were strong and generally similar, with correlations against TOC being slightly higher overall (Table 4-3, representative parameters shown in Figure 4-8). In addition, total LAB, Cu, and Pb continued to be more strongly correlated against TOC as compared to percent fines (27–34 % higher *r* value when correlated against TOC vs. percent fines).

Interestingly, the correlation between Cu and bulk sediment properties was slightly weaker (smaller r values) overall with inclusion of the 2001 data (Table 4-3).

These findings confirm that the contaminant variability in the nearfield is dominated by grain size and TOC, and that the controlling variables in the nearfield system did not alter substantially as a result of the outfall coming on-line in September 2000.

Regional—Results from the correlation analysis are presented in Table 4-4. As was observed in the nearfield, inclusion of 2001 data into the regional correlation analysis showed results consistent with baseline system trends. Grain size and TOC continued to be strongly correlated (Table 4-4). Similarly, the correspondence between *Clostridium perfringens* and percent fines continued to be poor, indicating that unlike in the nearfield fines and *Clostridium* do not co-occur. Last, although the regression coefficients were high, the correspondence between bulk sediment properties and most contaminants (exceptions include total DDT, Al, Fe, Ni, and Zn) was generally not as strong as the correspondence observed in the nearfield (compare r values presented in Tables 4-3 and 4-4). This suggests perhaps that contaminant and *Clostridium* concentrations at regional stations are influenced by regional factors (*i.e.,* not source specific), rather than local sources (*e.g.,* outfall).

Table 4-3. Correspondence within bulk sediment properties and against contaminants in the nearfield during the baseline (1992–2000) and baseline plus 2001 period.

Parameter	Correspondence with Percent Fines			Correspondence with TOC		
	r	*n*	*p*	*r*	*n*	*p*
	Baseline (1992-2000)					
Percent Fines	1.000	198	<0.01	0.824	198	<0.01
TOC	0.824	196	<0.01	1.000	196	<0.01
Clostridium perfringens	0.637	198	<0.01	0.590	196	<0.01
Total PAH	0.660	113	<0.01	0.728	113	<0.01
Total PCB	0.703	113	<0.01	0.821	113	<0.01
Total DDT	0.711	113	<0.01	0.758	113	<0.01
Total LAB	0.495	113	<0.01	0.709	113	<0.01
Al	0.628	113	<0.01	0.564	113	<0.01
Cd	0.682	113	<0.01	0.793	113	<0.01
Cr	0.823	113	<0.01	0.889	113	<0.01
Cu	0.717	113	<0.01	0.895	113	<0.01
Fe	0.664	113	<0.01	0.697	113	<0.01
Pb	0.716	113	<0.01	0.895	113	<0.01
Hg	0.714	113	<0.01	0.819	113	<0.01
Ni	0.808	113	<0.01	0.770	113	<0.01
Ag	0.693	113	<0.01	0.816	113	<0.01
Zn	0.781	113	<0.01	0.878	113	<0.01
	Baseline plus 2001					
Percent Fines	1.000	219	<0.01	0.820	219	<0.01
TOC	0.820	219	<0.01	1.000	219	<0.01
Clostridium perfringens	0.631	221	<0.01	0.584	219	<0.01
Total PAH	0.687	136	<0.01	0.736	136	<0.01
Total PCB	0.711	136	<0.01	0.802	136	<0.01
Total DDT [a]	0.407	136	<0.01	0.369	136	<0.01
Total LAB	0.474	136	<0.01	0.669	136	<0.01
Al	0.634	136	<0.01	0.569	136	<0.01
Cd	0.685	136	<0.01	0.769	136	<0.01
Cr	0.833	136	<0.01	0.876	136	<0.01
Cu	0.565	136	<0.01	0.751	136	<0.01
Fe	0.668	136	<0.01	0.679	136	<0.01
Pb	0.636	136	<0.01	0.837	136	<0.01
Hg	0.717	136	<0.01	0.794	136	<0.01
Ni	0.806	136	<0.01	0.762	136	<0.01
Ag	0.688	136	<0.01	0.788	136	<0.01
Zn	0.793	136	<0.01	0.867	136	<0.01

[a] Total DDT at NF21 in 2001 (event BF011) was unusually high; if excluded from the correlation analysis then r = 0.712 (against Fines) and 0.744 (against TOC).

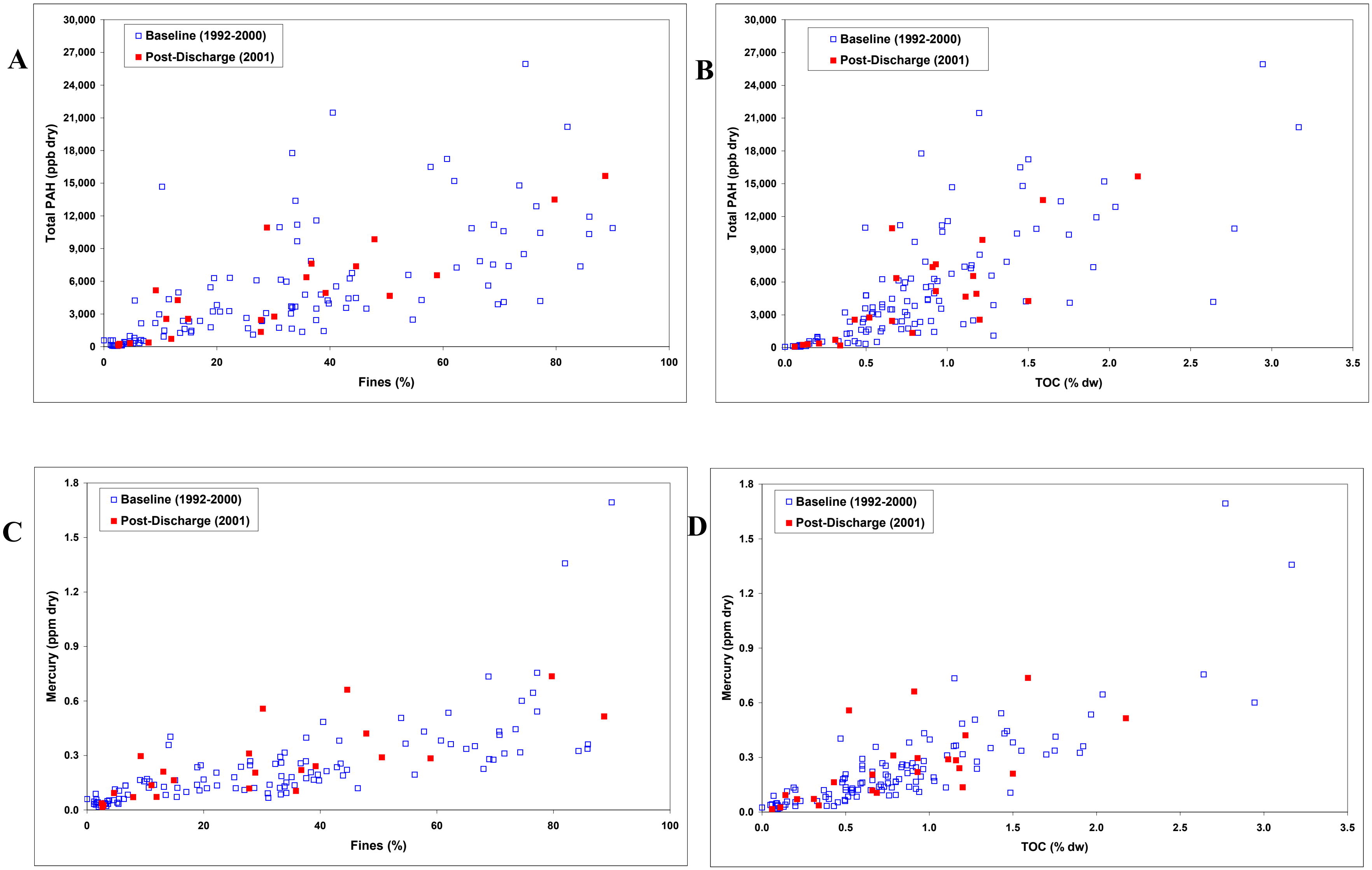


Figure 4-8. Correspondence between bulk sediment properties (percent fines, TOC) and representative contaminants (total PAH, mercury) in the nearfield from 1992 to 2001 showed that TOC and grain size strongly influenced contaminant concentrations.

Table 4-4. Correlation coefficients within bulk sediment properties and against contaminants for regional stations during the baseline (1992–2000) and baseline plus 2001 period.

Parameter	Correspondence against Percent Fines			Correspondence against TOC		
	r	*n*	*p*	*r*	*n*	*p*
	Baseline (1992-2000)					
Percent Fines	1.000	125	<0.01	0.925	125	<0.01
TOC	0.925	125	<0.01	1.000	125	<0.01
Clostridium perfringens	0.152	125	>0.05	0.209	125	<0.05
Total PAH	0.292	75	<0.05	0.261	75	<0.05
Total PCB	0.442	75	<0.01	0.499	75	<0.01
Total DDT	0.566	75	<0.01	0.545	75	<0.01
Total LAB	0.062	75	>0.05	0.018	75	>0.05
Al	0.692	75	<0.01	0.708	75	<0.01
Cd	0.363	75	<0.01	0.486	75	<0.01
Cr	0.681	75	<0.01	0.727	75	<0.01
Cu	0.508	75	<0.01	0.582	75	<0.01
Fe	0.793	75	<0.01	0.895	75	<0.01
Pb	0.592	75	<0.01	0.669	75	<0.01
Hg	0.323	75	<0.01	0.398	75	<0.01
Ni	0.823	75	<0.01	0.905	75	<0.01
Ag	0.212	75	>0.05	0.282	75	<0.05
Zn	0.777	75	<0.01	0.883	75	<0.01
	Baseline plus 2001					
Percent Fines	1.000	139	<0.01	0.925	139	<0.01
TOC	0.925	139	<0.01	1.000	139	<0.01
Clostridium perfringens	0.155	139	>0.05	0.201	139	<0.05
Total PAH	0.305	89	<0.01	0.271	89	<0.05
Total PCB	0.436	89	<0.01	0.466	89	<0.01
Total DDT	0.571	89	<0.01	0.537	89	<0.01
Total LAB	0.051	89	>0.05	0.015	89	>0.05
Al	0.689	89	<0.01	0.705	89	<0.01
Cd	0.380	89	<0.01	0.473	89	<0.01
Cr	0.693	89	<0.01	0.727	89	<0.01
Cu	0.514	89	<0.01	0.569	89	<0.01
Fe	0.799	89	<0.01	0.898	89	<0.01
Pb	0.579	89	<0.01	0.643	89	<0.01
Hg	0.312	89	<0.01	0.368	89	<0.01
Ni	0.836	89	<0.01	0.904	89	<0.01
Ag	0.226	89	<0.05	0.286	89	<0.01
Zn	0.793	89	<0.01	0.883	89	<0.01

4.3.5 Nearfield Contaminant Special Study 1998–2001

The Nearfield Contaminant Special Study was initiated in October 1998 with the intention of conducting the study three times a year. However, it was not until 2001 that the NCSS was conducted three times a year; prior to 2001 the NCSS was conducted on a sporadic basis (August 1999 and 2000, October 2000). Sediment samples were collected in triplicate at NF08, NF22, NF24, and FF10 to address possible short-term transport and impact with a focus on high TOC/depositional areas. October 2000 and February, August and October 2001 sampling represent post-discharge sampling events.

The mean TOC concentrations from the pre- and post-discharge periods were compared to determine if the mean TOC concentration had increased following the outfall coming on-line in September 2000. Had the post-discharge, mean TOC value increased considerably, then this could justify testing the NCSS results against the hypothesis which lead to the establishment of the study[3]. Results from the comparison showed that there was only a slight increase in the mean TOC concentration following the outfall coming on-line in September 2000 (pre-discharge mean value ± standard deviation = 0.97 ± 0.35, $n = 35$; post-discharge mean value ± standard deviation = 1.00 ± 0.31, $n = 48$). As a result the NCSS data were not evaluated to test Gordon Wallace's hypothesis. While a formal evaluation of the model was not carried out, metals, for which Wallace specifically developed his model, do not appear to show any systematic change at the NCSS stations.

Bulk sediment and contaminant results from the replicate analyses of sediment samples are reported in Appendix C-4. Data included in Appendix C-4 are presented as station mean values and standard deviation of the triplicate analyses. All results are reported on a dry weight basis to three significant figures.

Grain Size—Patterns in sediment composition were not substantially different in 2001 compared to system trends observed during the baseline period (Figure 4-9; detailed ternary plots by station shown in Appendix C-5). FF10 continued to be comprised of coarse-grained sediments, with gravel plus sand content generally 60% and higher (Appendix C-5). Sediment collected at NF08 continued to be more silty, with fines content typically 60% and higher (Appendix C-5). With the exception of one sample replicate, sediment composition at NF22 was very consistent across sampling years, and was comprised of relatively equal parts coarse and fine-grained particles (Appendix C-5). NF22 (replicate 2) sediment from October 2001 contained more fine-grained particles (71% fines) compared to sediments over the baseline period (October 1998 to August 2000). Sediment composition at NF24 continued to be highly variable; with samples having overall slightly higher sand content after the new outfall went on-line (Appendix C-5).

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[3] Gordon Wallace first developed his model in the 1995 OBR (Hillbig et al. 1997, Technical report 96-5). Recommendations leading the NCSS study were made during the 1997 OMTF subcommittee meeting; meeting minutes provided in Appendix C-6.

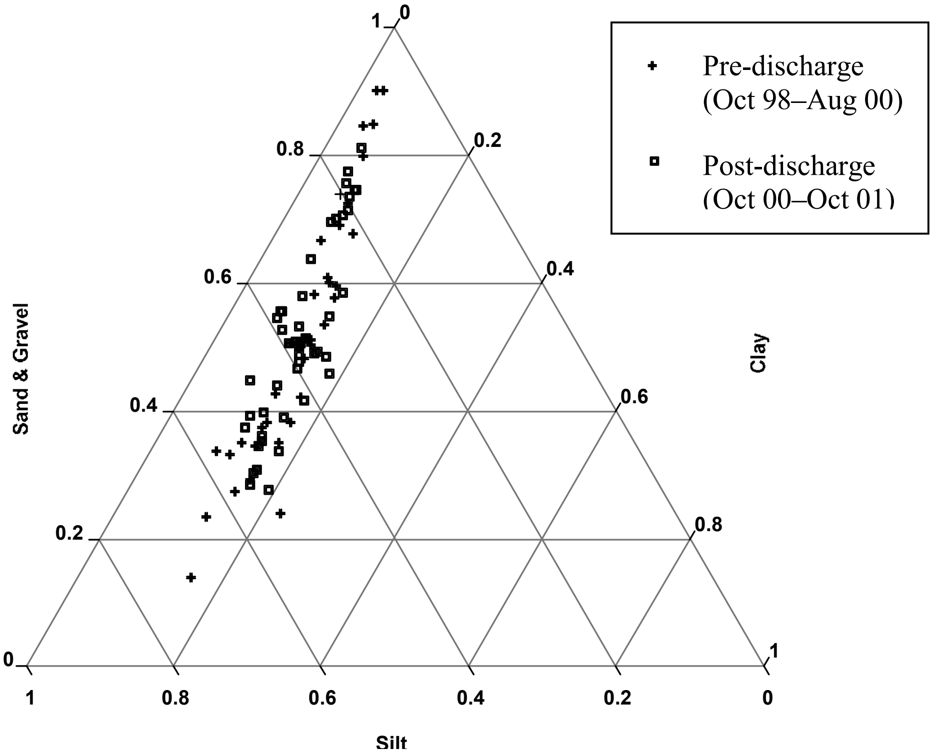
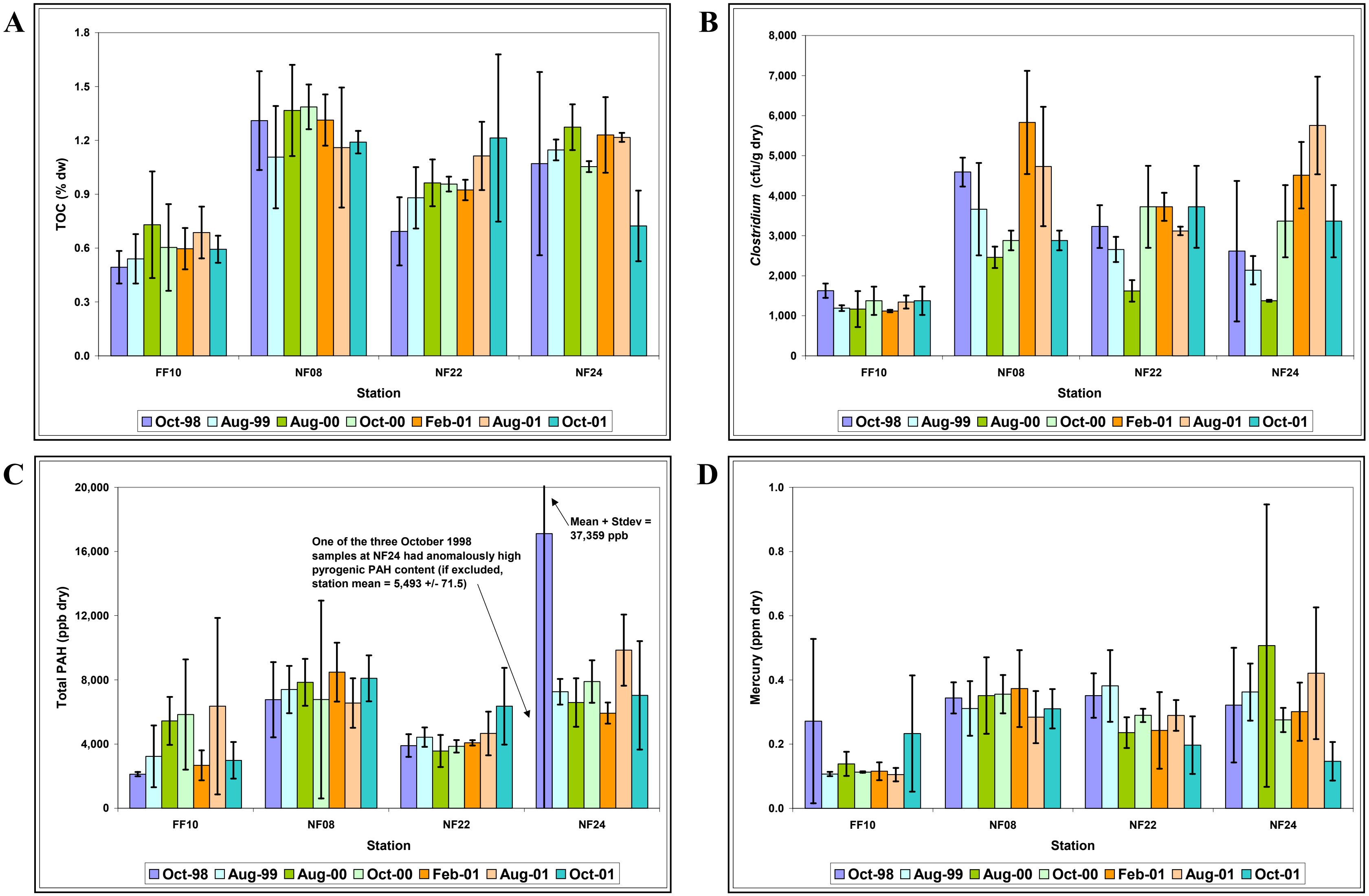


Figure 4-9. Grain size composition at NCSS stations showed that patterns in sediment composition were not substantially different in 2001 compared to baseline (1998-2000) data.

TOC—With one exception, post-discharge values of TOC did not change substantially from the baseline system values (Figure 4-10a). The exception included a slight decrease in TOC content at NF24 in October 2001 compared to earlier sampling periods. TOC at NF22 does show an overall trend of increasing concentrations since October 1998 (Figure 4-10a).

***Clostridium perfringens*—**With the exception of NF24, post-discharge, station mean values of *Clostridium perfringens* were not substantially different compared to baseline system values (Figure 4-10b). *Clostridium perfringens* abundance at NF24, the station located directly adjacent to the outfall, increased immediately after the outfall came on-line and continued to increase until October 2001, when abundances decreased (as did TOC) back to October 2000 levels (Figure 4-10b). These findings are consistent with results from the *Clostridium* regional analysis (Section 4.3.3), suggesting that the observed increase at NF24 may be due to a highly localized effect of effluent discharge at the new outfall. While there were no substantial changes in *Clostridium perfringens* densities at FF10, NF08 and NF22, post-discharge values at NF08 and NF22 did differ from the recent trend toward decreasing abundance observed since 1998. Values at these stations (NF08 and NF22) increased after the new outfall came on-line. *Clostridium perfringens* densities at NF08 increased initially but returned to system baseline values by October 2001; whereas spore densities at NF22 remained similar to levels observed since the outfall came on-line (Figure 4-10b).

Contaminants—Post-discharge concentrations did not show an increase in sediment contaminants following startup of the new diffuser, consistent with the very low levels observed by MWRA in the treated effluent. Post-discharge concentrations of organic and metal contaminants were not substantially different from baseline values (representative parameters shown in Figure 4-10c,d). Further, a slight decrease in the post-discharge, station mean concentration of selected metals (Hg, Ag, Pb, Cr) was observed at NF24 during the October 2001 sampling event. This is also consistent with the observed decrease in TOC content at this station (Appendix C-4, Figure 4-10d).



One of the three October 1998 samples at NF24 had anomalously high pyrogenic PAH content (if excluded, station mean = 5,493 +/- 71.5)

Mean + Stdev = 37,359 ppb

Figure 4-10. Station mean concentrations of TOC (a), *Clostridium perfringens* (b), total PAH (c), and mercury (d) at NCSS stations showed that, with few exceptions, bulk sediment properties and contaminants were not substantially different in 2001 compared to baseline data (1998-2000). (Error bars represent standard deviation.)

Chemistry Interrelationships—Correspondence within bulk sediment properties and against contaminants was evaluated for all NCSS stations (NF08, NF22, NF24, FF10) sampled from October 1998 to October 2001. Correspondence was evaluated using the individual replicates from each station, not station mean values. Correlation coefficients (r values) – using both baseline data and baseline plus post-discharge data – were then compared to determine if there were measurable changes in the system as a result of the new outfall coming on-line in September 2000.

Results from the correlation analysis are presented in Table 4-5. With few exceptions, inclusion of post-discharge data into the NCSS correlation analysis showed results fairly similar to baseline system trends, with slightly weaker (smaller r values) correlations overall against TOC. Exceptions included:

- weaker correlation (smaller r values) for total LAB and Al against percent fines;
- stronger (higher r value) for Ni against percent fines;
- stronger correlation for *Clostridium perfringens* against TOC; and
- weaker correlation for total PAH against TOC

Table 4-5. Correspondence within bulk sediment properties and against contaminants at Contaminant Special Study stations from October 1998 to October 2001.

Parameter	**Correspondence against Percent Fines**			**Correspondence against TOC [a]**		
	r	***n***	***p***	***r***	***n***	***p***
Percent Fines	1.000	84	<0.01	0.773	83	<0.01
TOC [a]	0.773	83	<0.01	1.000	83	<0.01
Clostridium perfringens	0.566	84	<0.01	0.631	83	<0.01
Total PAH [b]	0.095	84	>0.05	0.241	83	<0.05
Total PCB	0.606	84	<0.01	0.688	83	<0.01
Total DDT	0.426	84	<0.01	0.329	83	<0.01
Total LAB	0.329	84	<0.01	0.573	83	<0.01
Al	0.408	84	<0.01	0.420	83	<0.01
Cd	0.538	84	<0.01	0.590	83	<0.01
Cr	0.628	84	<0.01	0.717	83	<0.01
Cu [c]	0.520	84	<0.01	0.545	83	<0.01
Fe	0.515	84	<0.01	0.619	83	<0.01
Pb	0.629	84	<0.01	0.667	83	<0.01
Hg	0.488	84	<0.01	0.509	83	<0.01
Ni	0.362	84	<0.01	0.508	83	<0.01
Ag	0.680	84	<0.01	0.628	83	<0.01
Zn [d]	0.382	84	<0.01	0.504	83	<0.01

[a] Anomalously high TOC value for one of the three replicates at FF10 in August 2000; data excluded from correlation analysis.

[b] Unusually high total PAH value for one of the three replicates at NF24 in October 1998; if excluded from correlation analysis then r = 0.431 (against Fines) and 0.634 (against TOC)

[c] Unusually high Cu value for one of the three replicates at NF24 in February 2001; if excluded from correlation analysis then r = 0.667 (against Fines) and 0.697 (against TOC)

[d] Unusually high Zn value for one of the three replicates at NF24 in August; if excluded from correlation analysis then r = 0.650 (against Fines) and 0.762 (against TOC)

Otherwise, as would be expected there were no noticeable changes in the system's correspondence between controlling variables and contaminants following effluent discharge at the new outfall. For example, grain size remained strongly correlated to TOC (Table 4-5). In addition, the correlation between contaminants and bulk sediment properties (percent fines, TOC) were generally similar, with correlations against TOC being slightly higher overall for all contaminants except total DDT and Ag (representative parameters shown in Figure 4-11).

Comparison to Nearfield—Results presented in Kropp *et al.* (2000) showed that the temporal response of the baseline for representative organic and metal contaminants was similar for both the NCSS stations and the nearfield on average. 2001 contaminant results from the NCSS stations on average were similar to the nearfield baseline mean values, suggesting that the four NCSS stations continued to be reasonably representative of the nearfield (see Appendix C-4).

4.4 Comparison of Baseline Data to Thresholds

Nearfield baseline levels were established for contaminants in sediment based on the mean aerial distribution for nearfield stations. Baseline and 95 % confidence intervals were determined for each sampling year from 1992–1995 and 1999–2001 (August surveys only) and were evaluated against the MWRA monitoring thresholds based on the Long *et al*. (1995) ER-M values (Table 4-6). The list of PAHs included in the Long (1995) ER-M total PAH summation differs from the list of PAHs included in the total PAH summations presented in this report. However, the total PAH values presented in this report are more conservative because they include many more PAHs compared to Long (1995). Also, note that nearfield samples collected from 1996 to 1998 were not analyzed for contaminant parameters and as a result these sampling years are not included in the threshold comparisons. Further, nearfield contaminant results from 2000 are from a limited sampling year. These baseline data (2000) are included in Table 4-6 and Figure 4-12 for illustrative purposes only.

There were no threshold exceedances in August 2001. Further, the temporal response of the baseline for organic and metal contaminants showed relatively constant means without substantial variability (see Figure 4-12 for representative parameters). Annual mean values for any given year were generally representative of the baseline over time and were well below ER-M thresholds (Table 4-6). Interestingly, the 95% upper confidence limit for total DDT in 2001 fell above the significant increase value[4] (Figure 4-12b). The elevated concentration for total DDT resulted from one station, NF21, that had an unusually high total DDT measured in August 2001 (see Section 4.3).

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

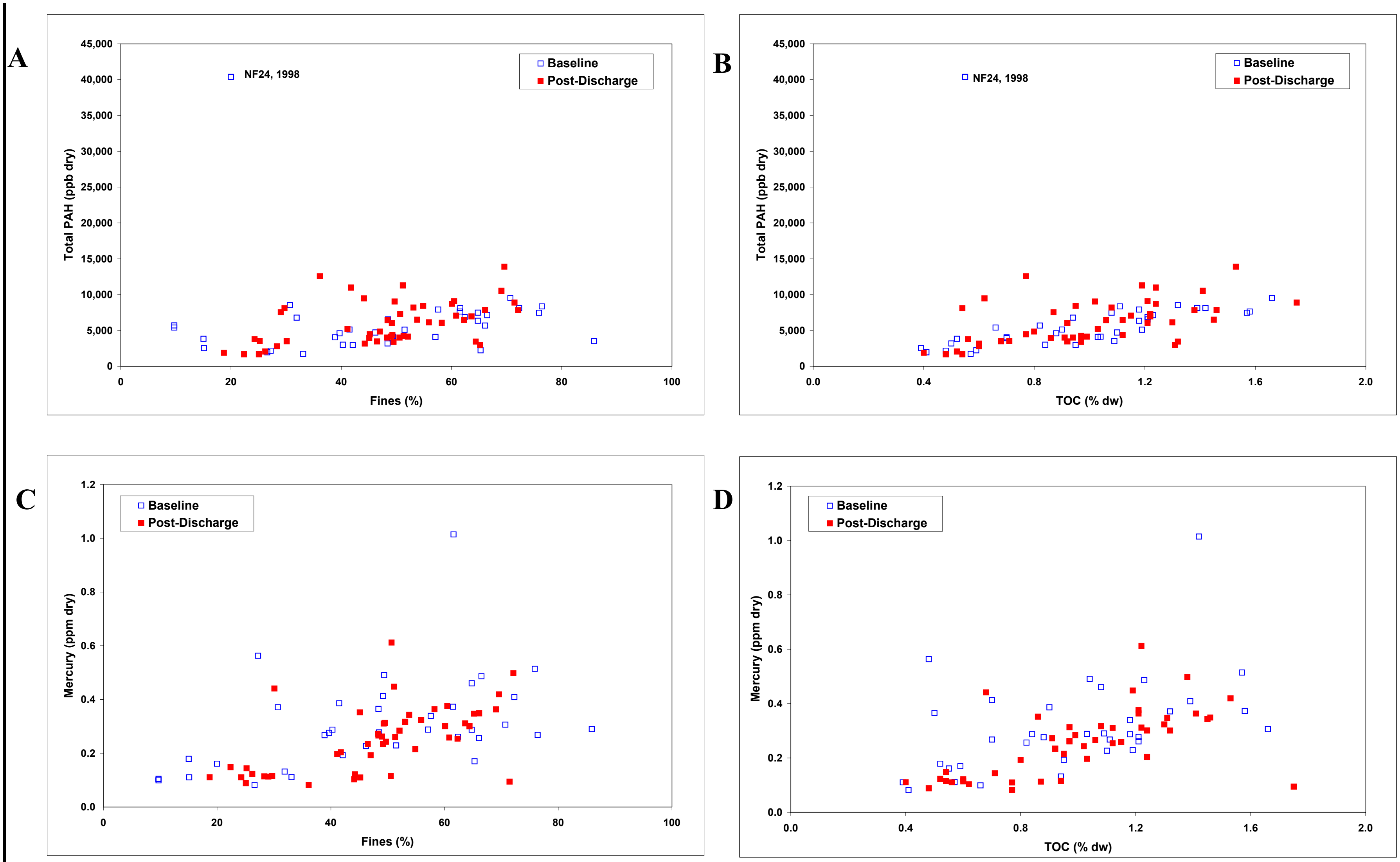

Figure 4-11. Correspondence between bulk sediment properties (percent fines, TOC) and representative contaminants (total PAH, mercury) showed that TOC and grain size strongly influenced contaminant concentrations at NCSS stations from 1998 to 2001.

Table 4-6. Comparison of annual nearfield baseline mean concentrations and thresholds (ER-M) for the period 1992–2001.

Parameter	Units (dry)	ER-M [a]	1992		1993		1994		1995 [b]		1999		2000 [c]		2001 Post-Discharge	
			Mean	Stdev	Mean	Stdev	Mean	Stdev	Mean	Stdev	Mean	Stdev	Mean	Stdev	Mean	Stdev
Total PAH[d,e]	ng/g	44792	5560	6230	5690	8090	4430	3650	5030	5030	5360	5130	5330	3220	5290	4600
Total PCB[d]	ng/g	180	14.7	16.3	28.6	39.1	15.2	11.9	16	14.5	10.3	8.66	15.3	9.78	12.7	10.3
Total DDT[d]	ng/g	46.1	3.3	3.5	3.82	5.44	5.27	6.53	2.59	3.12	2.7	3.2	2.36	1.42	5.28	18.6
Total Chlordane[d]	ng/g	6 [f]	0.108	0.322	0.52	0.652	0.862	0.826	0.234	0.382	0.175	0.193	0.311	0.225	0.334	0.254
Total Pesticide[d]	ng/g	NA	1.18	2.11	1.12	0.993	4.04	2.85	0.269	0.281	0.0664	0.152	0.442	0.26	0.178	0.15
Total LAB[d]	ng/g	NR	299	542	392	568	221	282	77.7	97	68	59	130	77.1	77	61.6
Al	pct dry	NR	5.26	0.686	4.97	0.938	5.14	1.13	4.55	1.02	4.98	0.858	5.26	0.713	5.5	0.607
Cd	: g/g	9.6	0.189	0.218	0.228	0.255	0.153	0.136	0.175	0.123	0.0896	0.0644	0.131	0.088	0.12	0.0902
Cr	: g/g	370	85.1	56	80.2	60.1	86.8	44.6	64.8	39.6	61.9	23.3	77.2	26.4	75.1	32
Cu	: g/g	270	27.6	23.9	26.1	19.2	22.8	12.5	19.2	13.1	23.2	9.33	25.6	12.1	24.3	22.2
Fe	pct dry	NR	2.31	0.733	2.15	0.829	2.25	0.676	1.8	0.535	2.33	0.446	2.45	0.542	2.38	0.54
Pb	: g/g	218	47.2	23.6	42.9	20.7	43.8	14.5	43	17	44.2	13.8	44.7	12.4	46.4	16.6
Hg	: g/g	0.71	0.28	0.29	0.199	0.198	0.217	0.22	0.289	0.432	0.225	0.138	0.274	0.217	0.269	0.224
Ni	: g/g	51.6	18.2	7.63	18.5	8.9	17	7.49	15.5	6.32	17.3	6.82	22	7.06	18.1	5.25
Ag	: g/g	3.7	0.707	0.902	0.575	0.719	0.553	0.495	0.471	0.332	0.493	0.314	0.559	0.504	0.489	0.312
Zn	: g/g	410	69.7	45	60.8	38.8	56.9	23.7	56.6	27.2	59.2	19.1	74.7	47.4	60	22.6
Gravel	pct	NR	8.04	17.3	4.03	10.7	4.08	9.09	3.3	6.5	5.9	11.3	7.89	14.7	4.95	9.62
Sand	pct	NR	59.5	23.6	68	22.8	60	26.1	61.4	26.9	59.6	23.5	57.3	20.7	60.4	22.4
Silt	pct	NR	24.7	18.3	23.1	20.2	28.1	22.1	25.5	21.5	26.2	19.8	24.8	18.1	26	18.8
Clay	pct	NR	7.74	6.95	4.88	3.98	7.79	6.55	9.8	14.4	8.3	5.92	9.94	6.05	8.7	5.89
Fines[d]	pct	NR	32.5	24.3	28	23.7	35.9	27.7	35.3	28	34.5	24.9	34.8	23.7	34.7	24.3
TOC	pct	NR	1.05	0.656	0.847	0.924	0.786	0.555	0.802	0.695	0.75	0.422	0.943	0.528	0.885	0.537
Clostridium	cfu/g	NR	2850	3110	3090	2600	3600	2540	4980	5750	1940	1410	1460	1370	2490	1690

[a] From Long *et al*. (1995)
[b] No contaminant data collected for August surveys conducted from 1996 to 1998.
[c] The 2000 data represent a reduced sampling year and cannot be compared to the threshold. Data are included for illustrative purposes.
[d] Grain size and contaminant groups defined in Section 4.2.3
[e] Total PAH reported was calculated from an extended list of individual PAHs that were not included in the ERM total PAH group (Long 1995)
[f] ER-M value is for Total Chlordane; ER-M value from Long and Morgan (1991)
NR = Not regulated

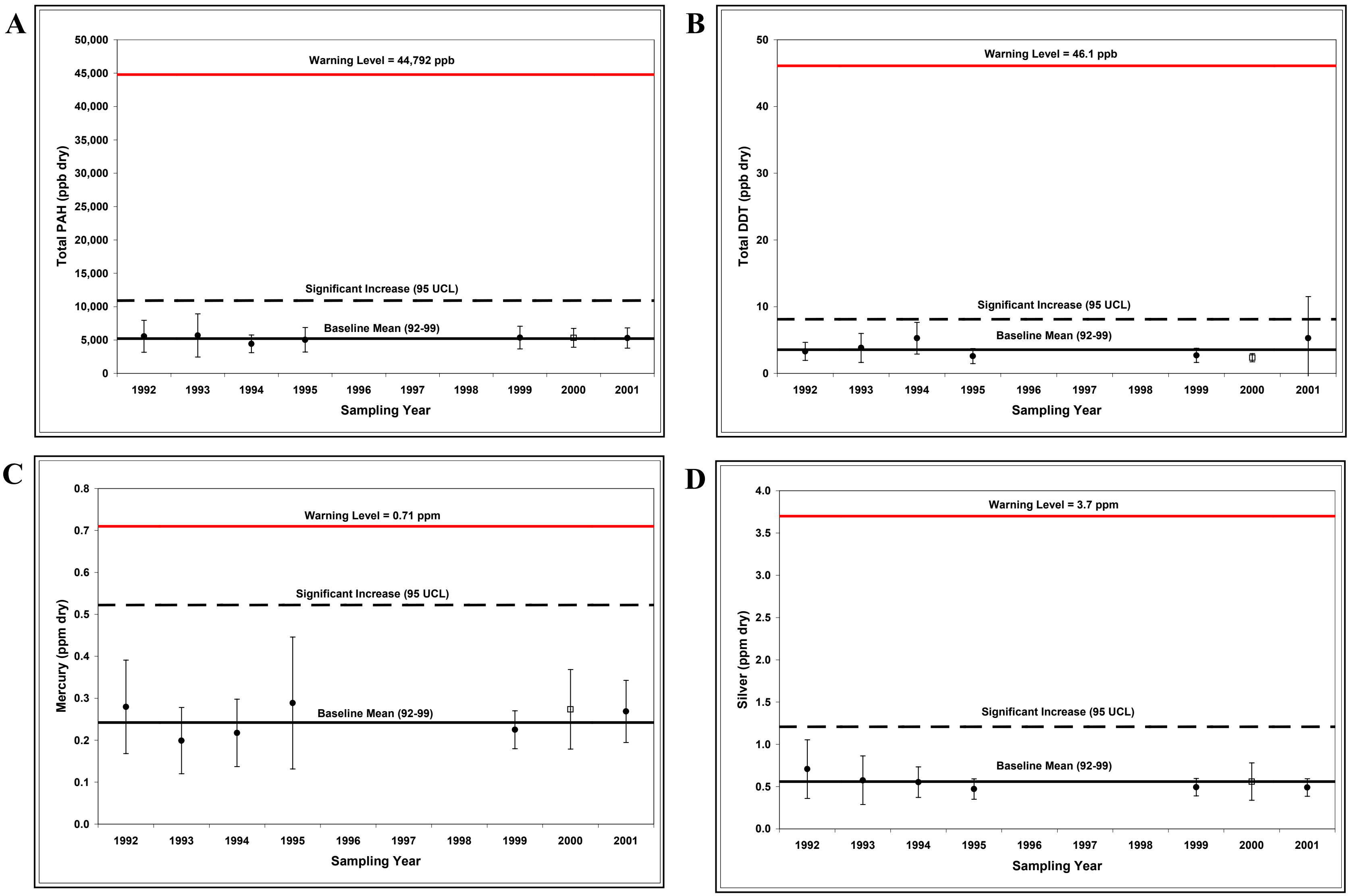

Figure 4-12. Nearfield annual mean values for representative contaminants from 1992 to 2001 showed relatively constant means and were well below the ER-M monitoring thresholds. Post-discharge annual mean values continued to be representative of the baseline over time. (No contaminant data collected from 1996 to 1998; error bars represent 95% confidence limits; UCL = upper confidence limit.)

4.5 Conclusions

The inclusion of post-discharge (2001) data to the baseline continued to support a picture of two disparate regions – *nearfield* and *regional* – each defined in physical and chemical terms. In the nearfield sediments of Massachusetts Bay, there is a series of stations with heterogeneous sediments in relatively close proximity to the historic source of contaminants (*i.e.,* Boston Harbor). Nearfield stations were generally equidistant from this source. The major factors influencing the concentration of contaminants and sewage tracers were primarily related to grain size factors suggestive of different sediment depositional environments. The primary factor responsible for the variance in the data was sand content. The secondary factors were associated with anthropogenic analytes and fine particles.

In contrast, the sediments collected from regional stations were more spatially distributed and compositionally distinct. As evident in the nearfield data, sand content strongly influenced the variance in the regional data. In addition, the sewage tracer data showed that the proximity to Boston Harbor (the historic source of sewage contaminants) influenced the concentration of *Clostridium perfringens* and total LAB at some regional stations. However, the correlations between contaminants and bulk sediment properties were generally weaker for regional stations (organic contaminants in particular), suggesting that the primary controlling variables in the regional system are not strongly controlled by proximity to Boston Harbor. Rather, the composition of sediments at remote sampling locations was governed by the analytes associated with fines and may reflect regional sediment inputs distinct from Boston Harbor.

With few exceptions, contaminant data from 2001 continued to be comparable to the baseline over time within each of these distinct regions. Notable exceptions included:

- Concentrations of Pb increased by 1.1 to 1.6 times above baseline at nearfield stations NF17, NF23, NF15, NF10 NF20 and NF14 relative to baseline.
- NF10 total PAH, Pb, Hg, Ni, Ag, and Zn concentrations consistently fell above the baseline range for this station.
- Another station (NF21, located about 4 kilometers to the northwest of the outfall) had an unusually high concentration of total DDT. The result passed rigorous quality assurance tests (which included reanalysis). Stations closer to the outfall did not show DDT elevated over baseline concentrations, and the result is unusual enough that an analytical interference (false positive) cannot be ruled out. Draft data from the August 2002 nearfield sampling indicate no anomalously high DDT values, either at NF21 or at any other nearfield station.
- A multidimensional statistical analysis using principal components analysis (PCA) indicated that levels of anthropogenic compounds (pesticides, PCBs, PAH, and selected metals) in the nearfield and regional sediments generally decreased during the year following the activation of the diffuser system. On a preliminary basis, these data suggest that the treated effluent discharged from the diffuser is not significantly increasing the amount of anthropogenic toxins in the study area sediments.

  However, the qualitative overview offered by the PCA results support the increases noted above at stations NF10, NF14, and NF17. The remaining trends noted above were not confirmed by PCA due to the omission of selected samples (*e.g.,* NF21) and possibly the small magnitude or lack of reproducibility of the potential, location-specific trend.

Coats (1995) predicted the estimated length of time between the onset of secondary effluent discharge at the new outfall and the detection of contaminant increases as the mean of nearfield sediments located within 2-km of the outfall *(i.e.,* NF13, NF14, NF17, NF19, NF23 and NF24). Coats suggested that Cd and Ag would show detectable increases in the nearfield sediments within 1.1 and 1.5 years of the new outfall coming online, respectively, based on estimated levels of contaminants in secondary treated effluent. Other contaminants were not expected to show increases until at least six or more years after the offshore effluent discharge began (Coats 1995). Results from the first post-discharge sampling event (August 2001) represent approximately one year after onset of effluent discharge. The post-discharge results[5] do not confirm with Coats predictions in their entirety in that:

- Apparent increases in Pb, not Cd or Ag, were observed at three (NF14, NF17, NF23) of the six nearfield stations identified above [NF14 – August 2001 concentration approximately 2 times baseline mean; NF17 and NF23 – August 2001 concentrations <1.4 times baseline mean]; and
- Total PAH and selected metals (Pb, Hg, Ni, Ag and Zn) increased at NF10, which is located outside the vicinity of predicted increase (2-km from new outfall) but is in the direction of the major deposition area predicted by the Water Quality Model (HydroQual 1995).

The post-discharge period increases identified above do not appear to be related to grain size or TOC factors, in that there was no corresponding increase in percent fines or TOC at stations NF14, NF17, NF23 or NF10 in August 2001. However, results from August 2001 only represent the first sampling event after onset of effluent discharge. Additional sampling (*i.e.,* more data points) in future monitoring years will allow for a more robust evaluation against Coats model.

Perhaps most interesting was the observed increase in 2001 *Clostridium perfringens* abundances (normalized to percent fines) for nearfield stations located within 2-km of the western end of the new outfall (diffuser #55). As noted above, 2001 Pb concentrations also increased above baseline at six nearfield stations, five of which also are located with 2-km of the new outfall. This suggests that effluent discharge at the new outfall is having a detectable but highly localized effect on nearby sediments.

While *Clostridium* abundances increased at stations located closer to the new outfall*, Clostridium perfringens* abundances in 2001 continued the recent trend toward decreasing abundance observed since 1998 (total LAB also decreased since 1994) for stations located closer to the Harbor. This suggests that the documented reductions in effluent solids loading during the 1990s (Werme and Hunt, 2001) also reflect a reduction in *Clostridium* spore loads.

While increases in selected contaminants and *Clostridium perfringens* abundances were observed in the system in 2001, baseline means values for organic and metal contaminants in the nearfield continued to be well below the MWRA thresholds in 2001.

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

5. 2001 SOFT-BOTTOM INFAUNAL COMMUNITIES

by Robert J. Diaz and Roy K. Kropp

5.1 Baseline Conditions in Massachusetts Bay

Studies of the Massachusetts Bay infaunal communities sponsored by MWRA since 1992 have featured two components chosen to approximate an area of possible impact of the outfall on the benthos and an area not expected to be impacted. The former area, the nearfield, is comprised of stations located primarily north and west of the outfall diffuser system located about 9 miles off Deer Island. It consists now of 23 stations, 6 of which (NF12, NF17, NF24, FF10, FF12, FF13) are sampled for infauna in triplicate. The latter area, the farfield, includes stations located from the northern extreme of Massachusetts Bay near Cape Ann to Cape Cod Bay, which constitutes Massachusetts Bay's southern limit. The farfield consists of 8 stations, all of which are sampled for infauna in triplicate.

The nearfield stations are relatively shallow and are of similar depth (~27–37 m). They have generally been grouped into two categories, roughly based on the sedimentary regime present. Most of the stations have been grouped into a "fine" sediment category typically characterized by polychaete worms such as *Prionospio steenstrupi*, *Spio limicola*, *Mediomastus californiensis*, and *Aricidea catherinae*. Fewer stations comprise a "sandy" sediment category (primarily NF13, NF17, and NF23) that lists several worms and crustaceans (*e.g.*, the worms *Polygordius* sp. A and *Exogone* spp., and the amphipods *Crassicorophium crassicorne* and *Unciola* spp.) among its distinctive fauna. In addition to the influence of its habitat heterogeneity on infaunal community structure, the nearfield area is often affected by strong winter storms and their resulting sediment resuspension episodes (*e.g.*, Hilbig and Blake 2000, Bothner 2001), which impact the communities.

The farfield stations span a considerable range in geography and depth (~33–89 m). These two features are most likely the major ones explaining differences in community structure among the farfield stations. Polychaete worms (*e.g.*, *Euchone incolor*, *Aricidea quadrilobata*, and *Levinsenia gracilis*) are the predominant organisms at most of the stations. An amphipod, *Leptocheirus pinguis*, is a prominent community constituent at station FF06 in Cape Cod Bay.

The ten years of MWRA sampling that comprise the analyses presented in this chapter include nine years of baseline monitoring (1992–2000) and one year of post outfall discharge sampling (2001). Description of the infaunal community during this time period, especially of that in the vicinity of the outfall, recorded a large reduction in abundance and numbers of species found in samples collected in 1993 versus those collected in 1992 (see figure in Section 5.3.2). Overall abundance per sample dropped from ~2241 in 1992 to ~1344 in 1993 and species numbers dropped from ~62 in 1982 to ~48 in 1993. In subsequent years, abundance and species numbers showed strong increases from 1993 to 1997–1999, followed by a steady decline thereafter (Kropp *et al.* 2002; this section). The Bay experienced a major disturbance in late 1992 when a significant storm struck the area. As has been mentioned previously, this storm, during which significant wave heights >7 m were recorded (Butman *et al*. 2002), had a pronounced effect on sediments in western Massachusetts Bay (Bothner *et al.* 1994, Bothner 2001) and has been mentioned as a likely cause in the shifts in the infaunal community observed between 1992 and 1993 (*e.g.*, Kropp *et al.* 2002). However, from 1991 to 1997 there were at least three other large storms that could have affected the benthos. The largest was the late October 1991 storm that produced significant wave heights of > 8 m (Butman *et al*. 2002) and that has been suggested as contributing to the changes observed in the Boston Harbor infaunal communities in subsequent years (Blake *et al.* 1998). Two large storms in April 1997 did not appear to yield changes in the infaunal community similar to those observed after the 1992 storm although both produced waves having significant heights > 7 m (http://woodshole.er.usgs.gov). Incidentally, since April 1997 (through 2000) there have not been any larger storms, although two in early 1998 produced significant wave heights of about 6 m. The storm's impacts will be discussed further in Section 5.3.2.

The apparent impacts of the 1992 storm have important implications for the baseline monitoring and the threshold limits that resulted from that monitoring. The infaunal community patterns witnessed during the baseline monitoring clearly reflect the initial disturbance of the community by the storm (*i.e*., the decrease in abundance and species in 1993), the rebound from that disturbance, and the likely recovery towards conditions that probably prevail during low storm periods. Thus the degree of variation observed in the baseline metrics during the baseline period is relatively large, probably larger than would have been generated had there not been the late 1992 storm. While providing an accurate picture of the possible natural range of variation in the nearfield infaunal community that can occur under certain extreme conditions (the particular wave height:duration combination of the 1992 storm is likely fairly rare as it has occurred only once from 1990 to 2000), 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. That possibility needs to be considered in subsequent analyses of the infaunal community.

5.2 Methods

5.2.1 Laboratory Analyses

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

During shipboard or laboratory processing, some soft-bodied specimens in four samples were partially damaged such that the identifications and counts of these taxa may be uncertain. The affected samples were NF22, FF05-1, FF05-2, and FF05-3. As part of the current analyses, data from those samples were examined semi-quantitatively to determine whether or not there was a noticeable impact of the damage on the data.

5.2.2 Data Analyses

Preliminary Data Treatment—Prior to performing any of the analyses of the 2001 and 1992–2001 MWRA datasets, several modifications were made. These were generally similar to those performed for the 2000 Outfall Benthic Report (Kropp *et al*. 2002) and are described in detail there. A summary of the changes comprises Appendix D-2).

Calculations of abundance included all infaunal taxa occurring in each sample, whether identified to species level or not. Calculations based on species (diversity, evenness, number of species) included only those taxa identified to species level, or treated as such.

A list of all taxa identified during the Outfall Monitoring Program (1992–2001) is contained in Appendix D-3.

Designation of Station Groupings—For the infaunal analyses, the stations termed "nearfield" include all stations having NF designations plus stations FF10, FF12, and FF13 (Figure 5-1). This was done to allow all western Massachusetts Bay Stations to be included in a single analysis. Stations termed "regional" include all stations having FF designations. For some analyses, this regional data set also included the three nearfield stations (NF12, NF17, NF24) at which triplicate infaunal grab samples are collected (Figure 5-1).

5.2.3 Diversity Analysis

The software package BioDiversity Professional, Version 2 (© 1997 The Natural History Museum / Scottish Association for Marine Science) was used to perform calculations of total species, log-series alpha, Shannon's Diversity Index (*H′*), the maximum *H′* (Hmax), and Pielou's Evenness (*J′*). Shannon's *H′* was calculated by using $\log_2$ because that is closest to Shannon's original intent. Pielou's (1966) *J′*, which is the observed *H′* divided by Hmax, is a measure of the evenness component of diversity. Magurran (1988) describes all of the diversity indices used here. BioDiversity Pro is available at http://www.sams.ac.uk/dml/projects/benthic/bdpro/index.htm.

BioDiversity Pro also provides a calculation of abundance that includes only species-level taxa. This number was compared to the abundance calculations based on all taxa to determine the proportion of the Massachusetts Bay infauna that was identifiable to species.

5.2.4 Cluster & Ordination

Cluster analyses were preformed with the program COMPAH96 (available on E. Gallagher's web page, http://www.es.umb.edu/edgwebp.htm), originally developed at the Virginia Institute of Marine Science in the early 1970's. The station and species cluster groups were generated using unweighted pair group mean average sorting (UPGMA) and chord normalized expected species shared (CNESS) to express resemblance (Trueblood *et al* 1994). For calculation of CNESS the random sample size constant was set to 15 (Kropp *et al.,* 2000). Principle component (PCA) and nonmetric multidimensional scaling (MDS) analyses were used for assessing the strength of cluster group membership based on sediment, sediment profile image, hydrocarbon, and heavy metal data. PCA were preformed using SAS (SAS Institute, Inc., Cary, NC) and MDS with PRIMER (Clarke and Gorley, 2001).

5.2.5 Benthic Threshold Calculations

Values were calculated for four diversity measures—number of species, Shannon diversity (*H′*), Pielou's evenness (*J′*), and log-series alpha and compared to the MWRA threshold values (MWRA 2002). An additional value, the relative abundance of seven selected opportunist species (*Ampelisca abdita*, *Ampelisca macrocephala*, *Ampelisca vadorum*, *Capitella capitata* complex, *Mulinia lateralis*, *Polydora cornuta*, *Streblospio benedicti*) was calculated and compared to its respective thresholds. The 2001 values were calculated for the entire nearfield data set by using the program "Benthic" written by Ellen Baptiste-Carpenter and Tom Nitroy (6 November 2001) and modified by Suh Yuen Liang. Because the calculations were made 18 December 2001, the dataset on which they were based did not incorporate any modifications made later. These changes primarily were editorial corrections to taxon names and most likely did not affect the threshold comparisons.

5.3 Results and Discussion

5.3.1 2001 Sample Handling Problem

The potential impact of the sample handling problem on the data analyses was semi-quantitatively examined by comparing the total abundance and the proportion identified to species level for each questionable sample collected in 2001 to those collected in 1992–2000. Additionally, the abundance of annelids and proportion of those identified to species were examined for the 2000 data only. Regarding total abundance and the proportion identified, all four samples had values lower than the range of values

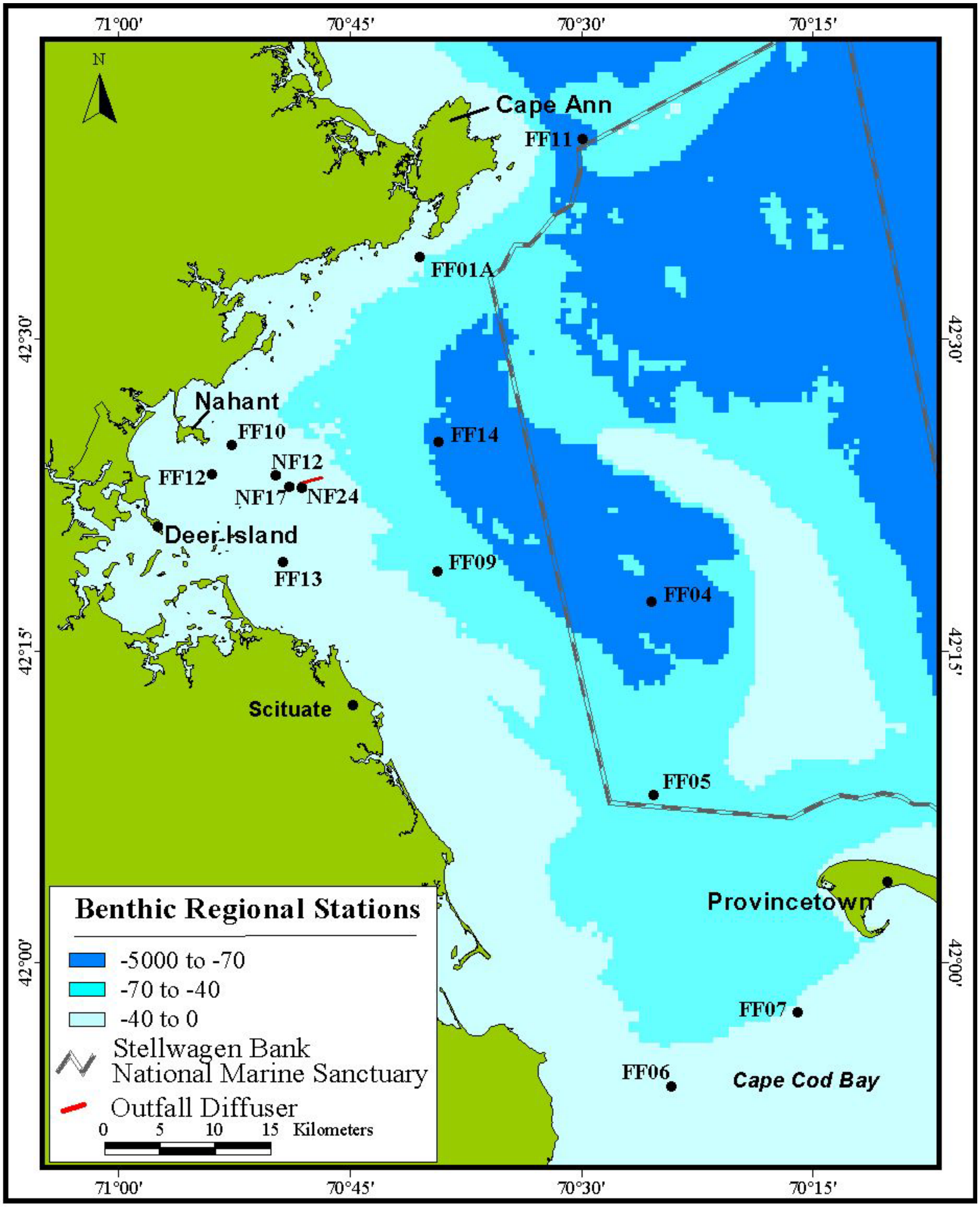

Figure 5-1. Stations included in regional analyses.

obtained for 1992–2000 (Appendix D-4). For station NF22, the proportion of individuals identified to species in 2001 was 66%, the lowest encountered during the 10 years of the study. Of the 742 specimens that were not identified to species, at least 94% were unidentified polychaete worms. This proportion is likely much higher than is typical for the station.

For station FF05, the proportions of individuals identified to species in 2001 were 77%, 68%, and 76% for replicates 1–3, respectively. All three values were lower than the lowest value (79% in 1995) previously encountered for the station. Of the specimens that were not identified to species, at least 84% were unidentified polychaete worms.

As will be evident in the following sections, none of the ecological community metrics calculated for stations NF02 and FF05 stand apart from those measured during the baseline period. Also, cluster analyses showed that both stations clustered in a manner similar to that seen in other years.

Based on these simple analyses, it appears that the sample handling problem may have adversely impacted the data analyses based on species-level identifications that are reported in the following sections.

5.3.2 Nearfield Descriptive Community Measures, 1992–2001

The descriptive community measures can be examined for the nearfield as a whole and for individual stations.

Pooled Nearfield Characteristics—In the 2000 Outfall Benthic Report (Kropp *et al*. 2002), it was suggested that the pooled nearfield values for three of the descriptive community metrics, abundance, numbers of species, and log-series alpha, showed different relative quantity levels. Each of the three showed low values during the early years of monitoring, from 1992 to about 1995 or 1996, followed by high values during the later years of monitoring. This observation suggested that the metrics showed a step-wise pattern, *i.e.*, low, then high values during the time period. As has been recognized previously, a major storm that occurred in late 1992 significantly affected sediments in western Massachusetts Bay (Bothner *et al*. 1994, Bothner 2001) no doubt causing the decreases in abundance and species numbers seen in 1993. The 1994 season showed the first in a series of impressive increases in nearfield abundance and species numbers indicating recovery for the storm event, that continued into 1997 (Figure 5-2). At that time, it was not clear whether the increased values for the parameters would represent a new definition of the nearfield infaunal community or that they indicated a rebound from the catastrophic storm event and would eventually subside to pre-storm levels. Within the last two sampling seasons, especially the 2001 season, that later presumption appears to be the case. The average abundance value for pooled nearfield samples in 2001 was similar to the baseline mean value and to the 1992 pre-storm value (Figure 5-2). The number of species per sample in 2001 also was very similar to the baseline mean value (as it was in 2000) and slightly higher than the 1992 value (Figure 5-2). It has been mentioned before (Kropp *et al.* 2002) that species numbers and log-series alpha showed very similar patterns of change throughout the monitoring program. That still seems to be the case (Figure 5-2), although the 2001 value (13.1) shows a very slight, but probably not statistically significant, increase over the 2000 value (12.9). The patterns seen in these three descriptive metrics support the idea that the 1992 storm had an important impact on the infaunal communities in the nearfield and that a period of rebound occurred, but that it is now likely completed and the system is approaching pre-storm conditions.

Two other descriptive community metrics, Shannon diversity (H') and Pielou's evenness (J') have not shown the same temporal pattern of change as just described (Figure 5-2). Each metric has shown little absolute change during the monitoring period and has been highly variable within each year, both of which make trends difficult to recognize.

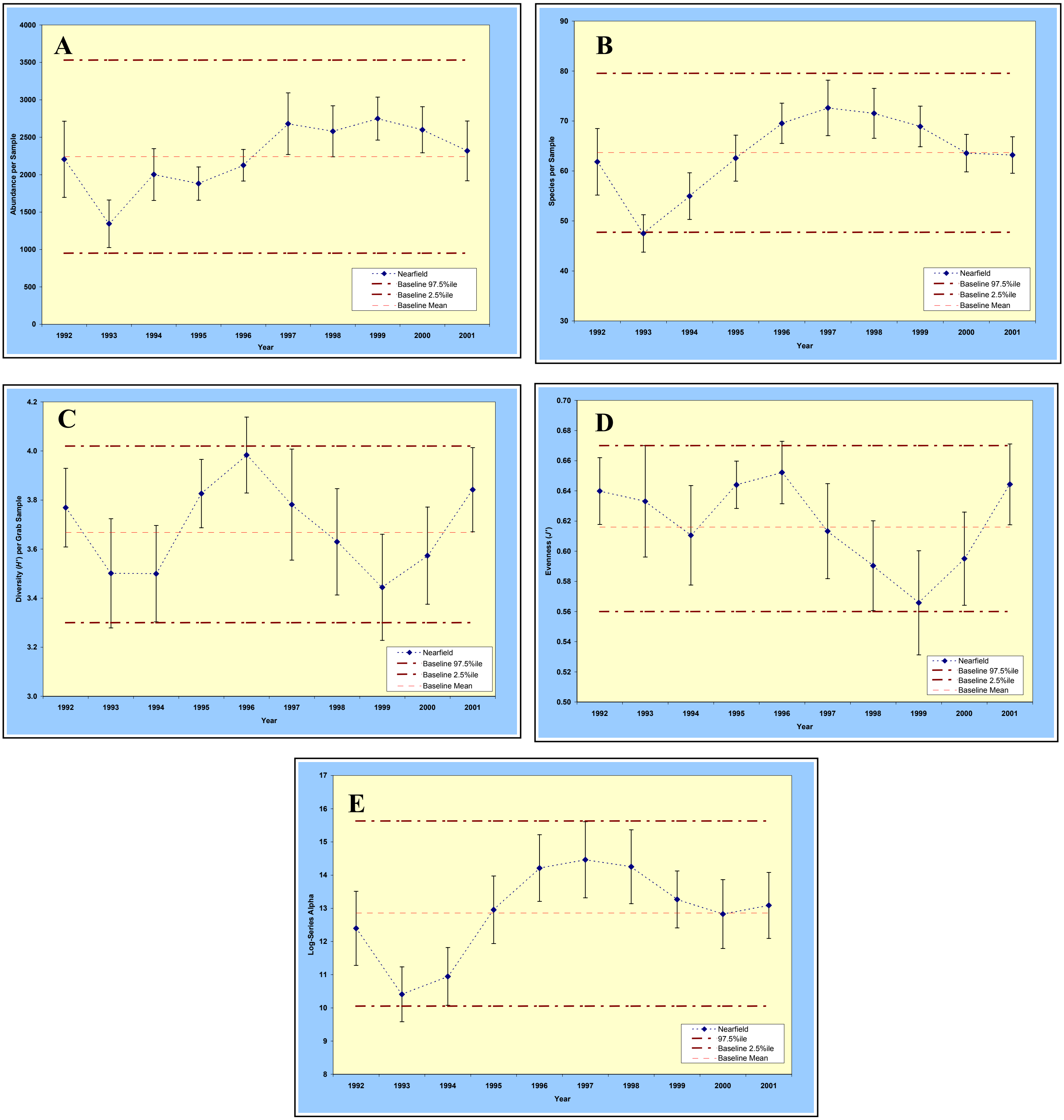

Figure 5-2. Pooled annual mean (± 95% confidence intervals) infaunal abundance (A), numbers of species (B), Shannon diversity (*H'*) (C), evenness *(J')* (D), and log-series alpha (E) for nearfield stations sampled from 1992 to 2001.

One question that remains unanswered, and may be difficult to answer, is why the late 1992 storm had such a significant impact on the benthos. Data on the significant wave heights recorded at NOAA Buoy 44013 (located about 1 nm southwest of the outfall since 1991 are included in Figure 5-2. These data, which include events that produced significant wave heights of about 4 m (here used as a somewhat arbitrary definition of a “distinctive storm” because there appear to be many fewer of that size as compared to 3 m or less) or more as estimated from plots provided by USGS (Butman 2002), are used here to indicate potentially important storm events, recognizing that wave height alone may not be the most important factor in predicting impacts to the benthos. The late 1992 storm produced wave heights of about 7.5 m. Four other storms since 1991 have produced waves about as large or larger; the 1991 Halloween storm (~9 m), two April 1997 storms (~7.5 m), and a December 1994 storm (~7 m), yet apparently none significantly impacted the benthos. Factors that distinguish the 1992 storm from the others, and therefore possibly explain its impact to the benthos, are that it was of longer duration (*i.e.*, produced waves > 5 m for several days) and had considerable associated swell that resulted in strong wave currents on the sea floor (Bradford Butman, personal communication, 2002) that resulted in tremendous sediment resuspension, probably more than that associated with any of the other major storms. This combination of wave height and duration is probably relatively rare in Massachusetts Bay as it occurred only once between 1990 and 2000. Another possible factor is that the 1992 storm was followed by a succession of large storms over the next few months (Figure 5-2). From January to March 1993, there were at least 6 storms that produced significant wave heights of 4 m or greater and likely caused considerable sediment resuspension, with two in March producing waves about 6 m in height. Thus, it appears that the impact to the infaunal community in the nearfield that was first observed in 1993 was the result of a particularly large storm of long duration that was followed in rapid succession by several other significant storms such that the sea floor was likely highly disturbed for several months.

Station-level Nearfield Characteristics—To evaluate how the 2001 values for the descriptive community metrics for each station compare to those for the baseline period, we plotted the 2001 values (Appendix D-5) versus the minimum and maximum values obtained during the baseline period. With very few exceptions, the 2001 values for each metric were within the range of values established within the baseline period (Figure 5-3). The nearfield stations are shown in each plot in increasing order of the baseline mean TOC content (data from Section 4.0). Plotting the stations in this manner reveals one interesting observation. The 2001 abundance values were higher than their respective baseline mean values for 10 out of the 12 samples collected from the 6 stations having an average baseline mean TOC content >1%. At stations having baseline mean TOC concentrations <1%, most samples were at or below their respective baseline mean abundance values (Figure 5-3). The meaning of this observation is not clear. None of the other metrics showed any noticeable relationship between 2001 values and baseline mean TOC concentration (Figure 5-3). The 12 most abundant species at each nearfield station are listed in Appendix D-6.

5.3.3 Regional Descriptive Community Measures, 1992–2001

Pooled Regional Characteristics—Descriptive community metric values for the pooled regional stations throughout the monitoring period show patterns that are somewhat similar to those shown by the nearfield stations (Figure 5-4). However, part of the similarity is related to the inclusion of the six replicated stations located in the vicinity of Boston Harbor or the outfall in the regional analyses. Total infaunal abundance declined from 1992 to 1993, and then showed a steady increase through 1999 and a decrease the last two years. The number of infaunal species per regional station through the monitoring showed a striking “S”-shaped pattern of change (Figure 5-4) with a decrease in 1993 followed by a slow increase through 1997–1998 and a steady decrease since then. As with the nearfield samples, the diversity metric, log-series alpha, showed a pattern very similar to that shown by species numbers. It is very likely that these patterns, which differ from those previously reported for only the farfield stations (Kropp *et al.* 2002), reflect the influence of the severe late 1992 storm on the shallow stations located in the nearfield

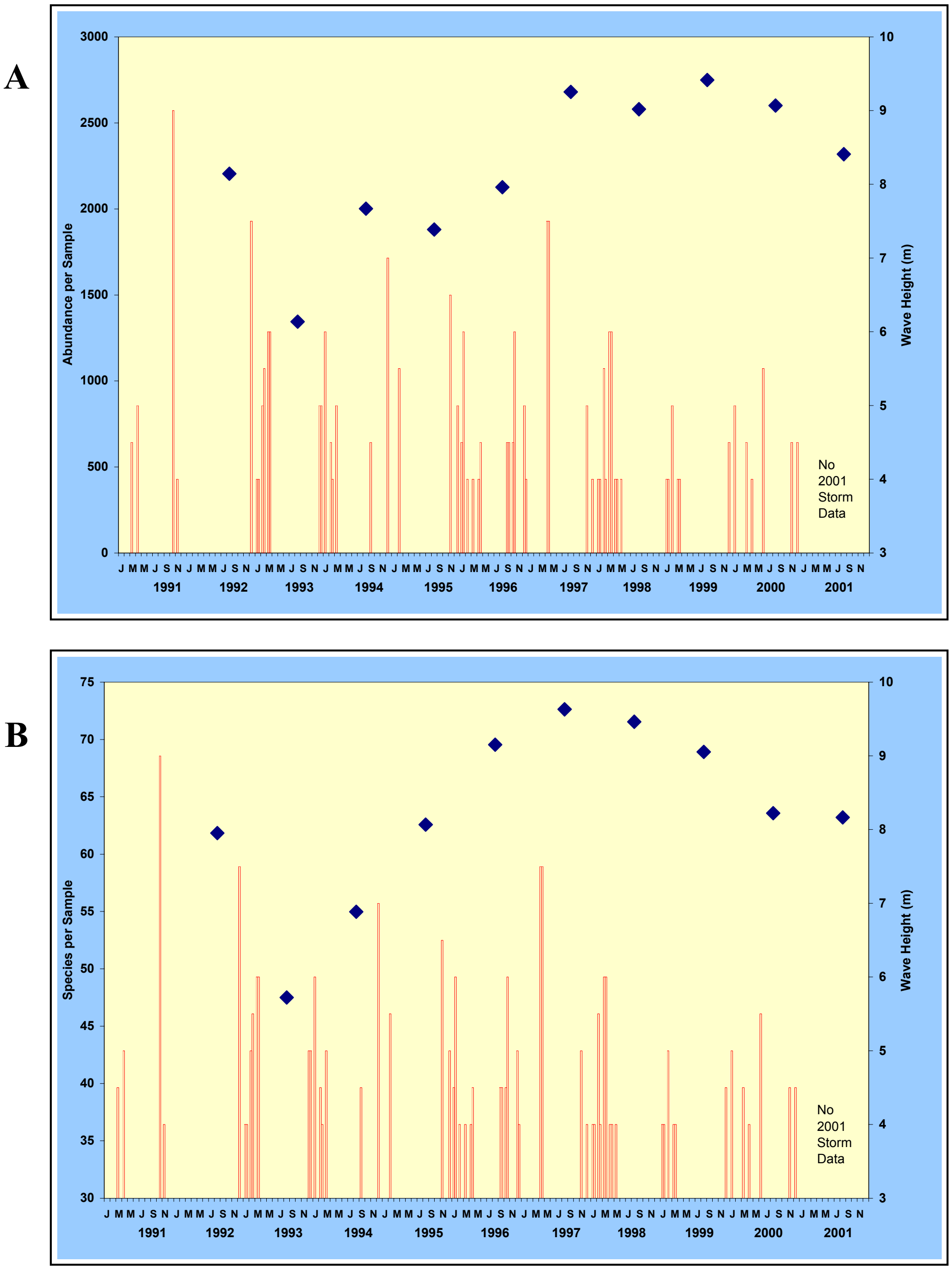

Figure 5-2a. Abundance (a) and species (b) graphs are shown with the occurrence of significant storms during the period 1991–2000.

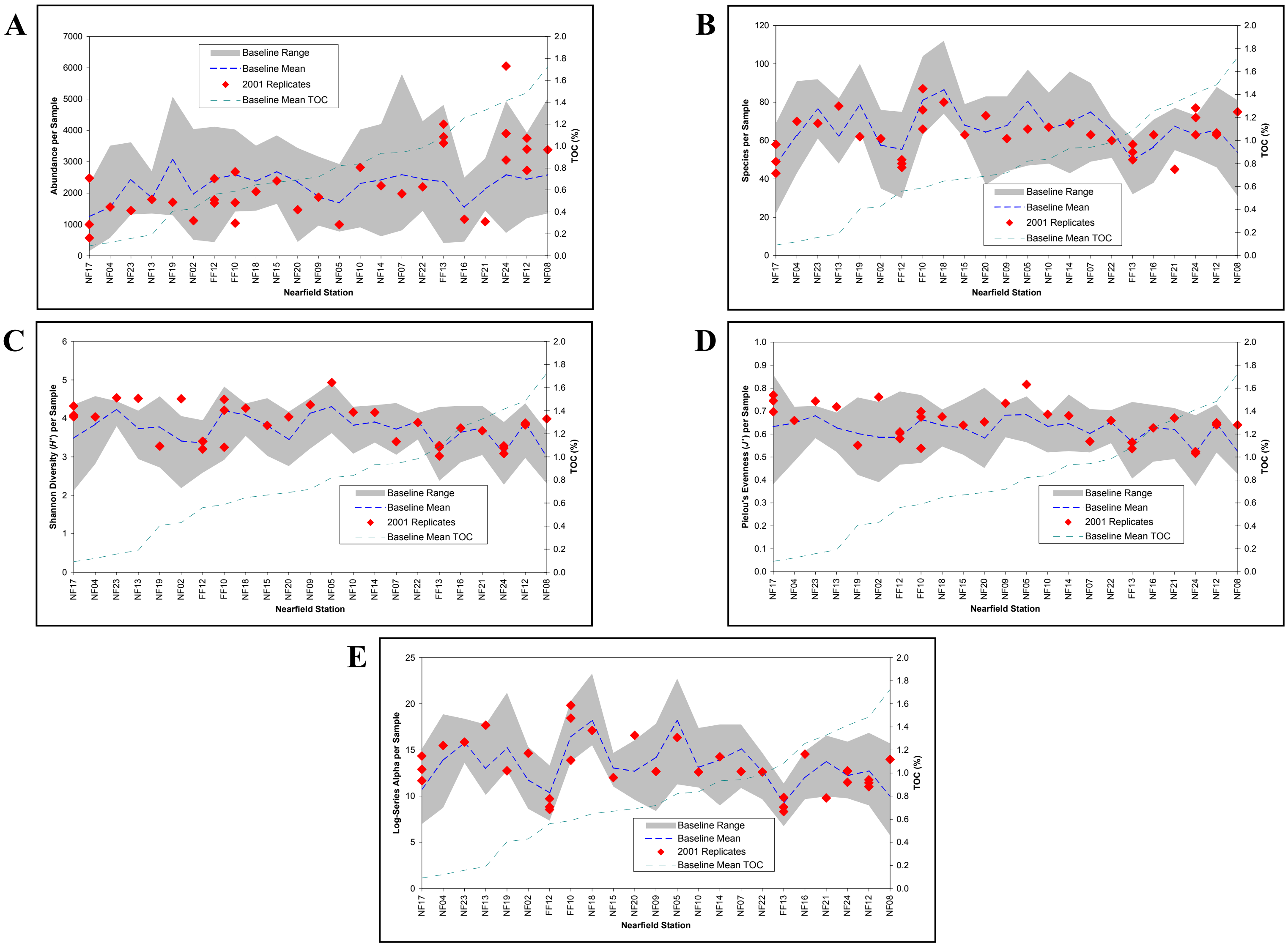

Figure 5-3. Infaunal abundance, numbers of species, Shannon diversity (*H'*), evenness *(J')*, and log-series alpha for each nearfield station sampled in 2001 (diamonds) and the range of values occurring during the baseline period (gray band). The baseline mean value is indicated (coarse dashed line). Stations are presented in order of increasing mean TOC concentration (fine dashed line).

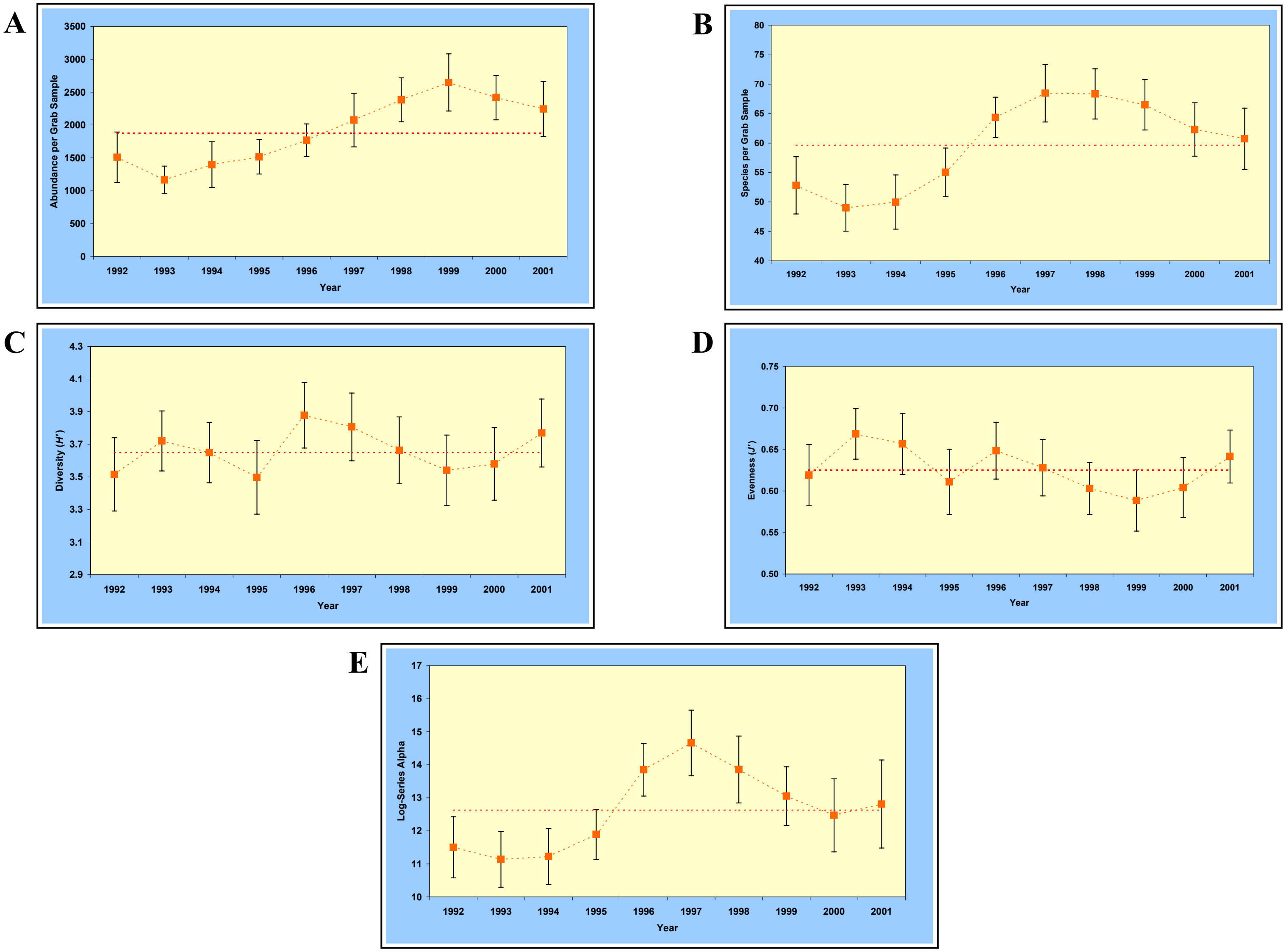

Figure 5-4. Pooled annual mean (± 95% confidence intervals) infaunal abundance, numbers of species, Shannon diversity (*H'*), evenness (*J'*), and log-series alpha for regional stations sampled from 1992 to 2001.

area. Mean values for the two other diversity indices calculated, *H'* and *J'*, have varied relatively little during the monitoring program (Figure 5-4). Shannon diversity has ranged from 3.5 in 1995 to 3.9 in 1996. Evenness has varied from 0.59 in 1999 to 0.67 in 1993. Neither metric has reflected the influence of the 1992 storm.

Station-level Regional Characteristics—As for the nearfield stations, descriptive community metrics for the regional stations in 2001 (Appendix D-5) were compared to the range of values found during the baseline period. Values for the abundance and numbers of species were within each station's baseline range for all but a few samples (Figure 5-5). However, station FF09 showed higher diversity and evenness values than previously measured there (Figure 5-5). Stations in Figure 5-5 are plotted approximately north to south with the nearfield stations being plotted before the offshore stations having similar latitudinal locations. Given this plotting pattern there is no apparent geographic pattern that describes whether or not 2001 samples were more or less than the baseline mean for any of the metrics. The 12 most abundant species at each nearfield station are listed in Appendix D-6.

5.3.4 Nearfield Multivariate Analyses

2001 Nearfield Multivariate Analysis—As in previous years the grouping of nearfield stations in 2001 reflected the influence of sediment type and biogenic activity in structuring nearfield communities. Cluster analysis of the 2001 nearfield infauna data produced station and species groupings that were related to a combination of physical sedimentary properties and infaunal community structure. At the three-group level, the major break in the data was primarily related to sediment type and occurred between the finer sediment stations in groups I and II that had higher silt and clay percentages, and coarser sandier sediment group III (Table 5-1). On average, station group I had finer sediment grain-size, higher median TOC, Cperf, RPD layer depth, and OSI, and higher estimated successional stage than the other two groups (Figure 5-6, Table 5-1). Station group II was highly concatenated or chained (the tendency of a station to join the dendogram at the end), which was an indication that the infauna at the five stations composing group II were graded in their dissimilarity. Similar graded station patterns were produced by nonmetric multidimensional scaling (MDS) analysis of the infaunal data where cluster group II stations positioned around a tighter core of group I stations (Figure 5-7). The arrangement of stations in group II may represent a gradient in physical processes affecting the stations with NF15 and NF19 being the physically dominated end and NF05 the biologically dominated end of the gradient. In both cluster and MDS analyses station NF05 was the most dissimilar of the stations in group II. Overall, group II had fine to heterogeneous sediments with lower TOC and variable successional stage. Group III on average had the coarsest most heterogeneous sediments with lowest TOC and successional stage. Group I and II stations tended to have higher levels of biogenic activity in the form of tube mats and higher infaunal activity (Figure 5-6). While more infauna were seen in the SPI images at group I stations, the median abundance and taxa per grab were about the same for all cluster groups (Figure 5-6). Also, the sediment surface at group I stations tended to be dominated by biological processes, while groups II and III tended to be physically dominated.

Subgroups within the major station groups were also associated with differences in sediment grain-size. This was most obvious within group I where subgroups Ib and Ic had higher median percent coarse sediments (sand plus gravel) than subgroup Ia. As sediment coarsened within the cluster groups and subgroups the median OSI tended to decline. Station NF05 that formed subgroup IIc was the only exception (Table 5-1). Abundance followed a similar pattern with station FF13 that was subgroup IIb being the exception. However, the patterns for median total taxa per grab were more complex with subgroups Ia, IIc, and IIIb having the highest median taxa for each of the major cluster groups (Figure 5-8, Table 5-1).

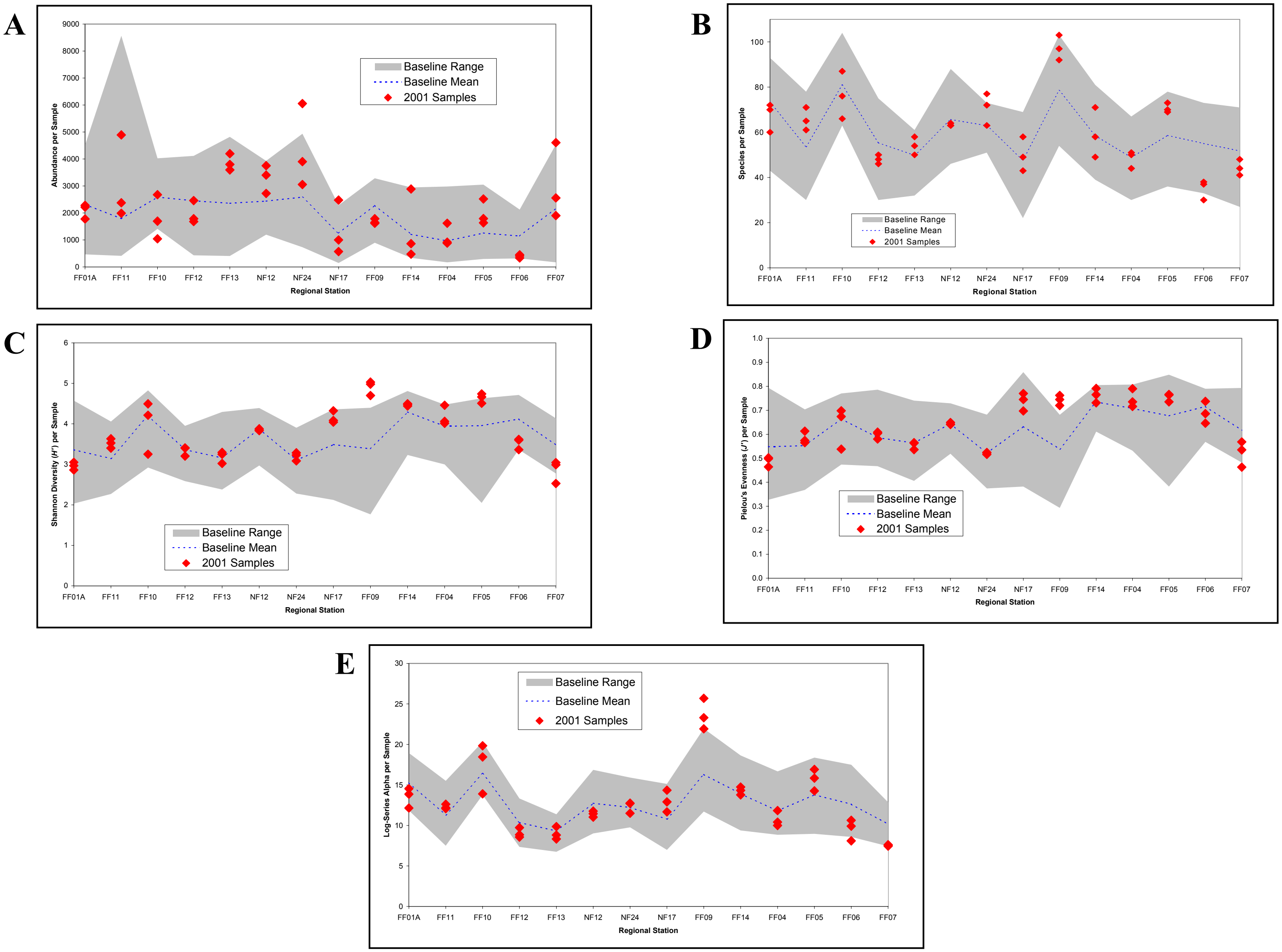

Figure 5-5. Infaunal abundance, numbers of species, Shannon diversity (*H’*), evenness (*J’*), and log-series alpha for each regional station sampled in 2001 (diamonds) and the range of values occurring during the baseline period (gray band). The baseline mean value is indicated (coarse dashed line).

Table 5-1. Nearfield 2001 physical and biological parameters from SPI and sediment analysis averaged by station cluster group. Cluster based on the first replicate grab for each station and Gallagher's CNESS dissimilarity with group average sorting. Taxa with 3 or few occurrences were not included in the analysis.

	Stat		Process		Bed	.	SS		Grain Size		Sand+Gravel		Cperf
		RPD		Tube		Worm		OSI		Silt+Clay		TOC	
Ia	FF10	>1.5	PHY	+	-	0	I-II	4.5	FS to CB	36	64	0.7	1343
	NF09	2.9	BIO	+	-	6.0	II-III	8.3	FSSICL	39	61	1.2	2460
	NF10	2.4	BIO/PHY	+	-	6.2	II-III	7.2	FSSICL	45	55	0.9	2460
	NF12	2.9	BIO	MAT	-	5.3	II-III	8.7	FSSICL	89	11	2.3	4665
	NF24	2.7	BIO/PHY	+	-	8.3	II-III	7.3	FSSICL	48	52	1.2	5753
	NF08	2.7	BIO/PHY	+	-	3.3	II-III	8.0	SIFS	59	41	1.2	4730
Ib	NF07	3.4	BIO	+	-	12.0	II-III	8.0	FSSICL	29	71	0.7	2710
	NF21	3.5	BIO	+	-	8.3	III	10.0	SIFS	80	20	1.6	2470
	NF22	3.2	BIO	MAT	-	7.7	II-III	8.7	FSSICL	51	49	1.1	3120
	NF16	3.3	BIO/PHY	+	-	5.3	II-III	8.7	FSSICL to CB	37	63	0.9	2340
	NF20	>2.0	PHY	+	+	0.3	I-II	5.0	FSSI to PB	15	85	0.4	1050
IIa	NF15	2.4	PHY	+	+	2.2	I-III	6.4	FSSI to PB	13	87	1.5	1380
	NF19	1.6	PHY	+	+	4.5	I-II	4.5	FSSI to GR	12	88	0.3	1820
	FF12	2	BIO/PHY	+	+	2.3	I-II	5.0	VFS	30	70	0.5	1430
IIb	FF13	1.5	BIO/PHY	MAT	-	3.7	I-III	5.0	FSSI	28	72	0.8	1335
IIc	NF05	3.1	BIO	MAT	-	1.7	II-III	8.7	FSSICL	28	72	0.7	1810
IIIa	NF04	>1.5	PHY	+	-	0	I-II	4.5	FSMS to PB	3	97	0.1	520
	NF13	>2.1	BIO/PHY	+	+	0	I-II	5.2	FSMS to GR	5	95	0.1	1080
	NF23	>1.6	PHY	+	+	0	I-II	4.6	FSMS to PB	3	97	0.1	1110
IIIb	NF14	>2.8	PHY	+	-	0.2	I-II	6.2	FSSI to PB	9	91	0.9	2240
	NF18	>2.8	PHY	+	-	2.3	I-II	6.7	FSSICL to PB	11	89	1.2	2050
IIIc	NF02	2.2	BIO/PHY	+	+	1.3	I-II	5.0	FSSI	8	92	0.2	460
	NF17	>2.1	PHY	+	+	0	I-II	5.2	FSMS	3	97	0.3	690

```
----------------------I
----------------------I--I
--I                      I
--I--------I             I-----I
-----------I-------------I     I
-------------------------------I
-----------------I             I
-----------I     I----------I  I----------I
-----------I-----I          I  I          I
--I                         I--I          I
--I-------------------------I             I
                                          I-I
-------------------------------I          I I
-------------------------------I----------I I--I
--------------------------------------------I  I--I
-----------------------------------------------I  I--------------I
--------------------------------------------------I              I
                                                                 I
--------------I                                                  I
--------------I----------I                                       I
-------------------------I---------------------I                 I
-------------------------------I               I--------I        I
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-----------------------------------------------------------I
0.38        0.50          0.65          0.80          0.95     1.10
```

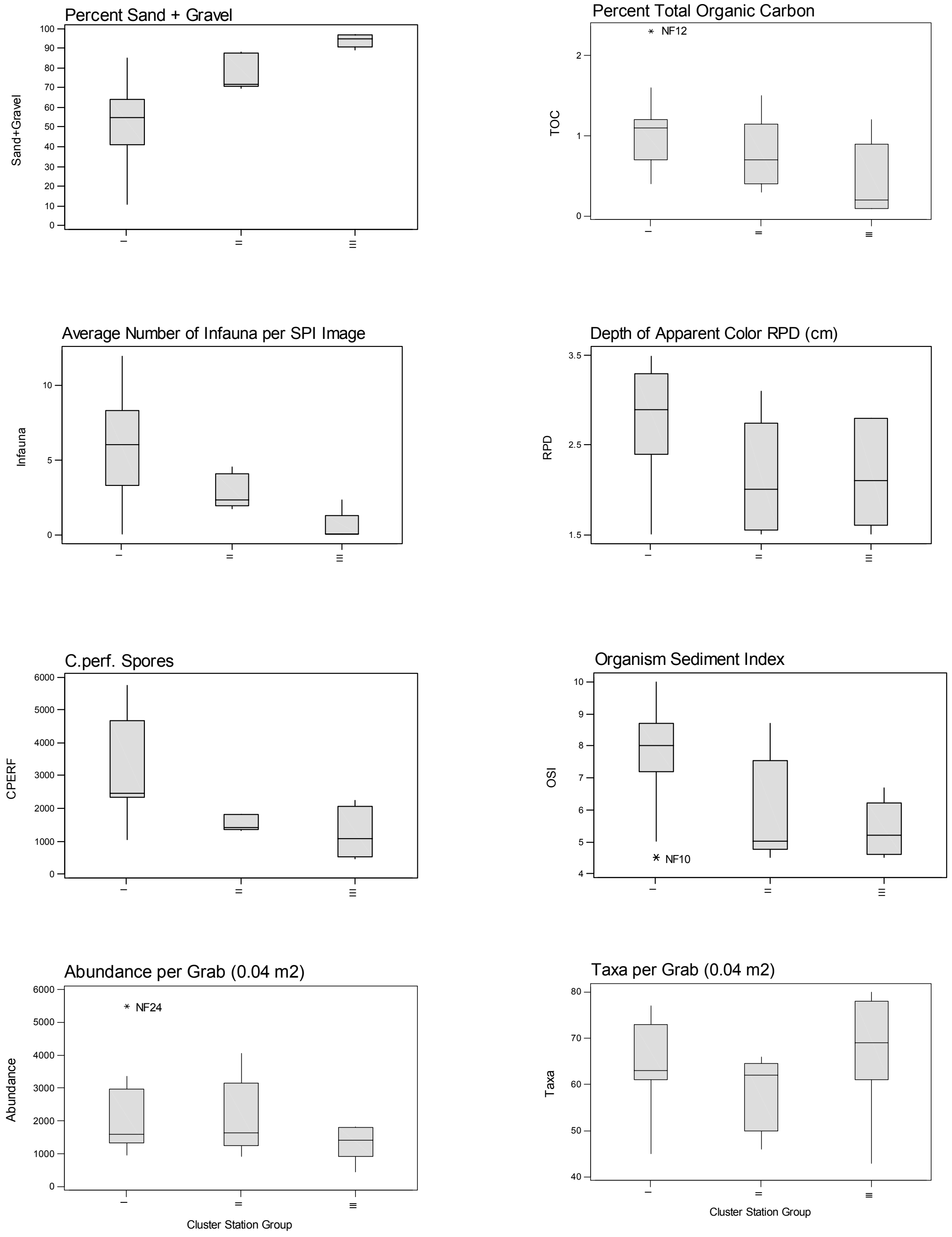


Figure 5-6. Box plot of nearfield sediment, SPI and infaunal parameters by major cluster group. Box is interquartile range, bar is median, tails are 2.5 times the interquartile range, and * are outliers.

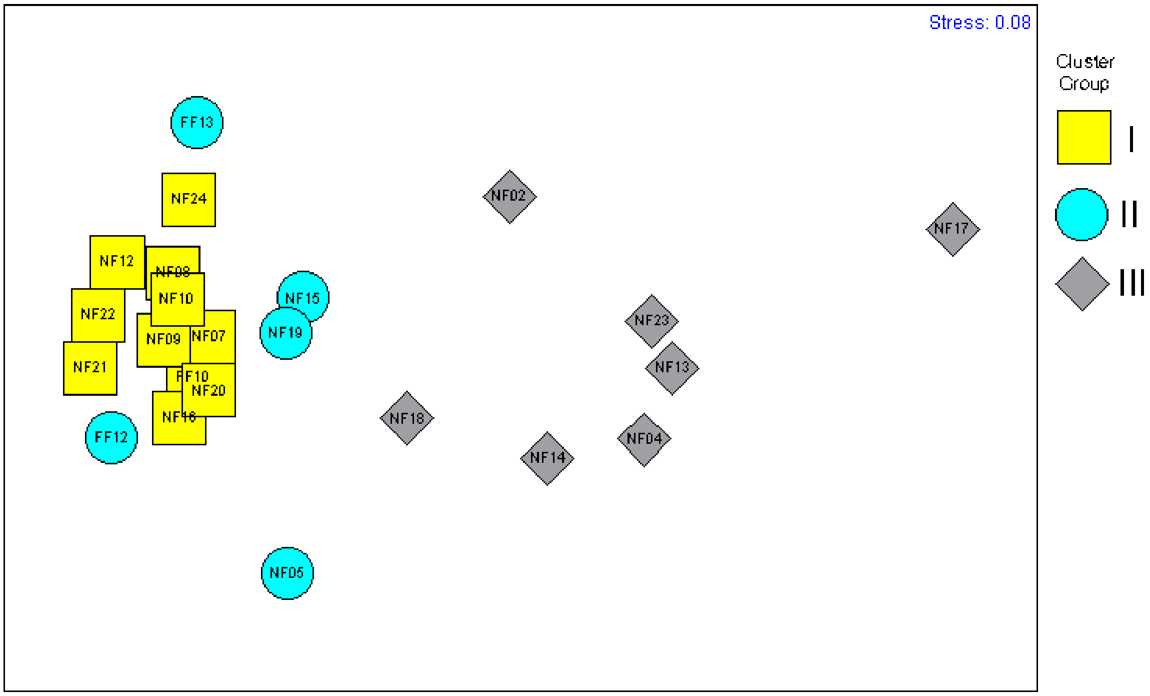


Figure 5-7. Nonmetric multidimensional scaling plot of 2001 nearfield infauna data with major cluster groupings superimposed.

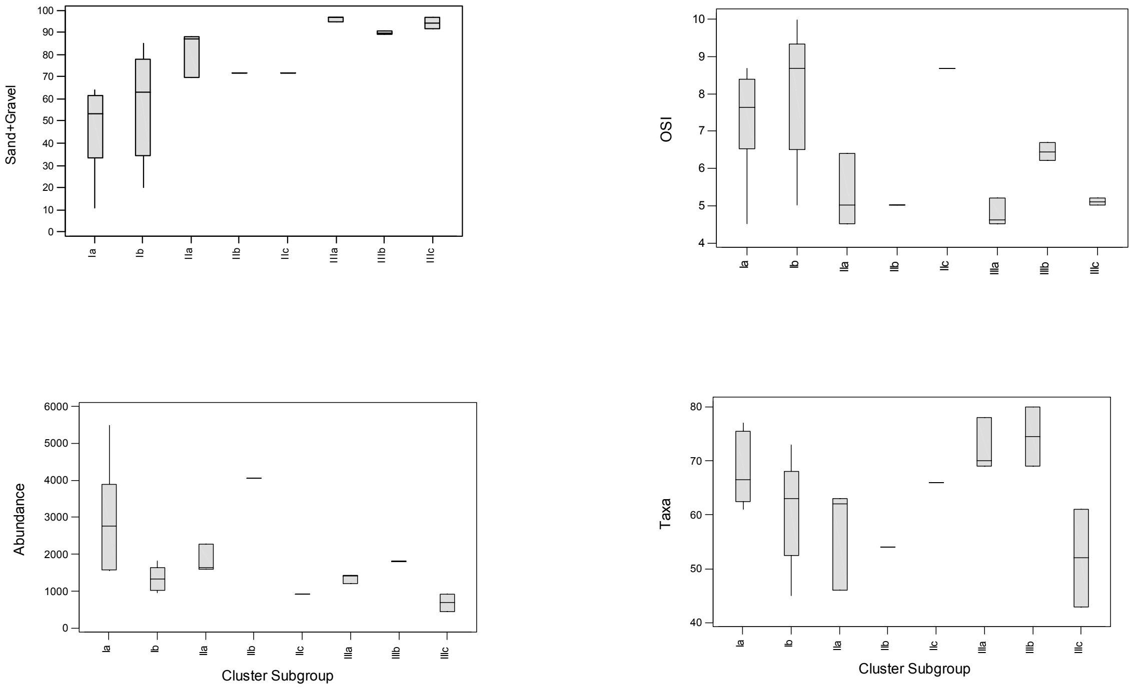


Figure 5-8. Box plot of selected nearfield sediment, SPI, and infaunal parameters by cluster subgroup. Box is interquartile range, bar is median, and tails are 2.5 times the interquartile range.

Species cluster analysis of the 2001 nearfield infauna was based on the 113 species in the reduced data set, which included only the first replicate at a station. At about the 0.1 CNESS dissimilarity level six species groups formed with the major break between groups A, B, C and D, E, F (Figure 5-9, Tables 5-2, 5-3).

```
      Species Group
A ----I
      I----I
B ----I    I
           I----I
C ---------I    I
                I
D ---------I    I
           I    I
E --I      I----I
    I      I
F --I------I
    0.1      -0.1
      Dissimilarity
```

Figure 5-9. Major species group dendrogram of 2001 nearfield infauna data with only first replicate and species with three or fewer occurrences dropped (Gallagher's CNESS dissimilarity [*m* = 15] with group average sorting). Species are listed in Table 5-2.

Species groups A, B, and C tended to be associated with station groups I, IIa, and IIb. Groups D, E and F were primarily associated with station groups IIc and III (Table 5-2). Species group A was the largest with 38 species in three subgroups that represented finer sediment species such as *Prionospio steenstrupi, Mediomastus californiensis,* or *Euchone incolor*. Group A also contained five of the top-ten numerical dominant species, the three mentioned above plus *Spio limicola* and *Levinsenia gracilis* (Table 5-2). Group B was composed of nine species that were not numerical dominants but tended to prefer finer sediment stations such as *Nucula delphinodonta*. Group C was the smallest species group with three species, two of which were among the top-ten dominants *Aricidea catherinae* and *Phoronis architecta*, that were strongly associated with subgroup IIb (station FF13). Group D was 21 species with affinity for coarser sediment stations in groups IIc and III, and contained one numerically dominant *Aphelochaeta marioni*. Group E was 28 species with strong affinity for sandy to coarse sediments of group III stations and contained two top dominants *Exogone hebes,* and *E. verugera.* Many of the species in group E corresponded to those comprising a sand-dwelling fauna identified in previous years (Kropp *et al.,* 2000). Group F was 14 species that tended to have lower abundance but were broadly distributed across all station groups, for example *Phyllodoce mucosa* and *Dipolydora socialis* (Table 5-2).

Additional analysis of the infaunal data with the sediment contaminant data using both MDS and principle components analysis (PCA) pointed to sediment grain-size as the primary factor determining both community and contaminant patterns. No contaminant effects on infaunal communities could be detected above the influence of sediment grain-size. Similar results were found in 2000 (Kropp *et al.* 2002).

Comparison of 2001 Nearfield Multivariate Community Analysis to Previous Years—The cluster analysis of the long-term data base for the nearfield (1992 to 2001, 215 station-collections, first replicate, and 336 species with >20 occurrences) was heavily chained at the 10 group level (Figure 5-10). The general pattern of stations over the years was similar to the long-term analysis conducted over the previous two years with patterns related to both strong and weak within station similarity through time (Kropp *et al.* 2000, 2001). Station NF05 continues to have strong within station similarity through time and was the only station that formed an exclusive group (V) (Table 5-4). There were four stations with nine or 10 years occurrence in one station group: NF09 and NF10 in group I, NF12 in VI, and NF17 in X.

Table 5-2. Average abundance of species with a collection total of >125 individuals by cluster group (Individuals/0.04 m^2) for 2001 nearfield infauna. The top 41 taxa (113 taxa were included in the cluster analysis) represented 93% of all individuals and 21% of all taxa for 2001.

		Station Group							
		Ia	**Ib**	**IIa**	**IIb**	**IIc**	**IIIa**	**IIIb**	**IIIc**
Group	**Species**	FF10 NF08 NF09 NF10 NF12 NF24	NF07 NF16 NF20 NF21 NF22	FF12 NF15 NF19	FF13	NF05	NF04 NF13 NF23	NF14 NF18	NF02 NF17
A	*Prionospio steenstrupi*	723	364	646	499	39	47	301	62
	Mediomastus californiensis	325	224	187	517	93	5	147	14
	Tharyx acutus	237	129	68	711	62	16	86	32
	Spio limicola	243	116	31	3	10	2	9	6
	Levinsenia gracilis	83	60	18	5	38	0	13	1
	Ninoe nigripes	41	55	32	6	31	1	9	1
	Euchone incolor	53	32	33	24	3	3	3	2
	Monticellina baptisteae	55	17	20	10	1	0	11	0
	Leitoscoloplos acutus	28	21	5	22	1	0	1	0
	Parougia caeca	22	17	12	15	17	4	4	1
	Monticellina dorsobranchialis	12	14	11	3	24	2	21	0
	Micrura spp.	21	8	7	3	6	0	1	0
	Scoletoma hebes	7	6	18	22	0	0	0	0
B	*Owenia fusiformis*	19	1	213	0	0	5	3	3
	Nucula delphinodonta	28	42	59	0	35	11	19	0
	Spio thulini	1	1	25	0	1	11	32	10
	Edotia montosa	9	7	13	3	1	8	1	2
C	*Aricidea catherinae*	250	11	120	689	18	38	58	55
	Phoronis architecta	112	9	33	774	5	21	4	0
	Photis pollex	7	7	10	399	0	25	1	13
D	*Aphelochaeta marioni*	288	12	26	6	75	4	2	0
	Crenella glandula	5	8	6	0	39	13	45	1
	Ericthonius fasciatus	0	0	0	0	66	11	31	4
	Tubificoides apectinatus	4	6	0	52	20	1	10	5
	Astarte undata	3	3	6	0	22	4	33	1
	Anobothrus gracilis	8	7	2	1	29	0	4	0
E	*Exogone hebes*	10	6	49	2	6	253	306	31
	Exogone verugera	64	13	13	2	24	124	193	5
	Crassicorophium crassicorne	0	0	0	0	0	141	71	43
	Spiophanes bombyx	6	3	47	13	0	89	1	49
	Enchytraeidae sp. 1	0	0	0	0	0	142	10	0
	Polygordius sp. A	2	2	23	1	0	48	4	56
	Nemertea sp. 12	13	8	3	13	3	16	17	17
	Unciola inermis	0	0	0	0	0	33	70	1
	Protomedeia fasciata	0	0	0	0	23	33	49	6
	Phyllodoce maculata	8	3	2	13	2	16	4	1
	Galathowenia oculata	7	5	3	1	0	3	4	12
F	*Phyllodoce mucosa*	24	7	23	123	10	28	16	40
	Dipolydora socialis	32	1	14	39	8	26	23	60
	Cerastoderma pinnulatum	2	6	0	0	1	15	26	18
	Ampharete finmarchica	16	9	2	3	0	3	20	1

Table 5-3. Cluster analysis species groups for 2001 nearfield infaunal data based on >3 occurrences, Gallagher's CNESS dissimilarity and UPGMA sorting.

A'	*Prionospio steenstrupi*
	Mediomastus californiensis
	Eteone longa
	Trochochaeta multisetosa
	Levinsenia gracilis
	Ninoe nigripes
	Parougia caeca
	Micrura spp.
	Scoletoma fragilis
	Euchone incolor
	Terebellides atlantis
	Spio limicola
	Thracia conradi
	Nephtys incisa
	Cossura longocirrata
	Leitoscoloplos acutus
	Aricidea quadrilobata
	Tharyx acutus
	Monticellina baptisteae
	Monticellina dorsobranchialis
	Scoletoma hebes
	Tubificidae sp. 2
	Carinomella lactea
	Ceriantheopsis americanus
A"	*Maldane sarsi*
	Onoba pelagica
	Clymenella torquata
	Ampharete acutifrons
	Stenopleustes inermis
	Pherusa affinis
	Cancer borealis
	Sphaerosyllis longicauda
A'''	*Argissa hamatipes*
	Pleurogonium rubicundum
	Metopella angusta
	Sphaerodoridium sp. A
	Goniada maculata
	Exogone longicirris
B	*Owenia fusiformis*
	Edotia montosa
	Scoloplos armiger
	Arctica islandica
	Paradulichia typica
	Nucula delphinodonta
	Pholoe minuta
	Spio thulini
	Nereis procera
C	*Aricidea catherinae*
	Phoronis architecta
	Photis pollex
D	*Aphelochaeta marioni*
	Apistobranchus typicus
	Amphiporus angulatus
	Laonome kroeyeri
	Gattyana amondseni
	Crenella glandula
	Astarte undata
	Spio filicornis
	Ericthonius fasciatus
	Unciola irrorata
	Harpinia propinqua
	Edwardsia elegans
	Dyopedos monacanthus
	Ampelisca macrocephala
	Orchomenella minuta
	Eudorella pusilla
	Diastylis quadrispinosa
	Leptocheirus pinguis
	Anobothrus gracilis
	Thyasira gouldi
	Tubificoides apectinatus
E	*Exogone hebes*
	Crassicorophium crassicorne
	Enchytraeidae sp. 1
	Exogone verugera
	Unciola inermis
	Protomedeia fasciata
	Euchone elegans
	Ptilanthura tenuis
	Phyllodoce maculata
	Polycirrus medusa
	Euclymene collaris
	Spiophanes bombyx
	*Grania postclitellochaeta longid*ucta
	Solariella obscura
	Diastylis sculpta
	Nemertea sp. 2
	Echinarachnius parma
	Petalosarsia declivis
	Phascolion strombi
	Polygordius sp. A
	Nemertea sp. 12
	Tanaissus psammophilus
	Hippomedon serratus
	Galathowenia oculata
	Ilyanassa trivittata
	Phoxocephalus holbolli
	Syrrhoe sp. 1
	Cyclocardia borealis
F	*Phyllodoce mucosa*
	Tetrastemma vittatum
	Dipolydora socialis
	Capitella capitata complex
	Aglaophamus circinata
	Pleurogonium inerme
	Hiatella arctica
	Microphthalmus pettiboneae
	Ophelina acuminata
	Cerastoderma pinnulatum
	Dipolydora concharum
	Ampharete finmarchica
	Alvania castanea
	Chone duner

A.

```
I    --I
       I-I
II   --I I
         I-I
III  ----I I--I
           I  I
IV   ------I  I-I
              I I
V    ---------I I---I
                I   I
VI   -----------I   I
                    I--------I
VII  ---------------I        I
                    I        I-----I
VIII ---------------I        I     I
                             I     I
IX   ------------------------I     I
                                   I
X    ------------------------------I
    0.83          1.03           1.23
              Dissimilarity
```

B.

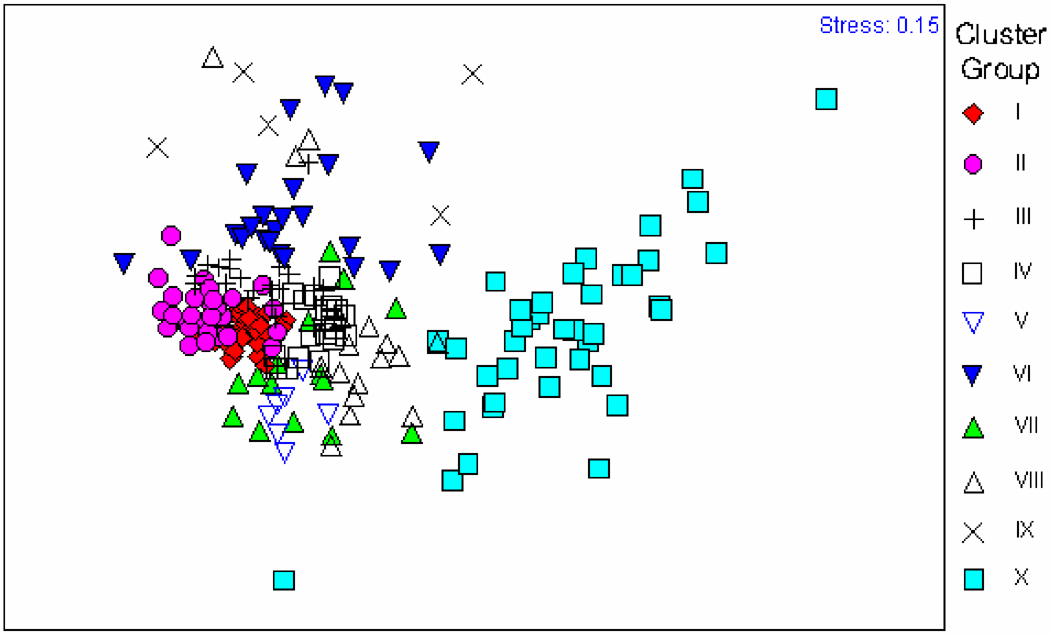


Figure 5-10. Long-term relationship, 1992 to 2001, of nearfield stations based on pattern in infaunal data. A: Cluster dendrogram based on summed replicates from each station (taxa with 20 or fewer occurrences were excluded, Gallagher's CNESS dissimilarity, and UMPGA sorting). B: Nonmultidimensional scaling plot based on summed replicates (all taxa included, Bray-Curtis similarity, square root transformation). Stations are listed in Table 5-4.

Table 5-4. Station cluster groups from long-term analysis of nearfield infaunal data plus FF10, FF12 and FF13 from 1992 to 2001. Stations with 9 or 10 years in one group are indicated with a box.

Cluster	Year	Station
I	1993	FF10
	1994	FF10
	1995	FF10
	1996	FF10
	1997	FF10
	2000	NF08
	1993	NF09
	1994	NF09
	1995	NF09
	1996	NF09
	1997	NF09
	1998	NF09
	1999	NF09
	2000	NF09
	2001	NF09
	1992	NF10
	1993	NF10
	1994	NF10
	1995	NF10
	1996	NF10
	1997	NF10
	1998	NF10
	1999	NF10
	2000	NF10
	2001	NF10
	1995	NF12
	1996	NF12
	1997	NF12
	1998	NF12
	1999	NF12
	2000	NF12
	2001	NF12
	1994	NF21
	1995	NF21
	1998	NF21
II	1995	NF07
	2001	NF07
	1994	NF08
	1995	NF08
	1992	NF12
	1993	NF12
	1994	NF12
	1992	NF16
	1993	NF16
	1995	NF16
	1996	NF16
	1997	NF16
III	1998	FF10
	2001	FF10
	1999	FF13
	1996	NF08
	1997	NF08
	1998	NF08
	1999	NF08
	2001	NF08
	1996	NF15
	1998	NF16
	1999	NF16
	2000	NF16
	2001	NF16
	1992	NF20
	1996	NF20
	1997	NF20
	1998	NF20
	1999	NF20
	2000	NF20
	2001	NF20
	1999	NF24
	2000	NF24
	2001	NF24
IV	1996	NF02
	1997	NF04
	1996	NF07
	1998	NF07
	1999	NF07
	2000	NF07
	1995	NF15
	1997	NF15
	1998	NF15
	1999	NF15
	2000	NF15
	2001	NF15
	1995	NF19
	1996	NF19
	1997	NF19
	1998	NF19
	1999	NF19
	2000	NF19
	2001	NF19
	1996	NF24
V	1995	NF05
	1996	NF05
	1997	NF05
VI	1992	FF12
	1993	FF12
	1995	FF12
	1996	FF12
	1997	FF12
	1998	FF12
	1999	FF12
	2000	FF12
	2001	FF12
	1992	FF13
	1993	FF13
	1994	FF13
	1997	FF13
	2000	FF13
	2001	FF13
	1992	NF02
	1994	NF02
	1995	NF02
	1998	NF02
	1999	NF02
	2000	NF02
	2001	NF02
	1992	NF08
	1993	NF08
VII	1992	FF10
	1992	NF05
	1992	NF07
	1994	NF07
	1992	NF09
	1992	NF13
	1992	NF14
	1993	NF14
	1994	NF14
	1992	NF15
	1994	NF15
	1992	NF18
	1992	NF19
	1994	NF19
	1994	NF22
	1994	NF24
VIII	1999	FF10
	1995	FF13
	1996	FF13
	1998	FF13
	1998	NF04
	1995	NF14
IX	1994	FF12
	1993	NF02
	1997	NF02
	1994	NF16
	1994	NF20
X	2000	FF10
	1992	NF04
	1993	NF04
	1994	NF04
	1995	NF04
	1996	NF04
	1999	NF04
	2000	NF04
	2001	NF04
	1994	NF05
	1997	NF07
	1994	NF13
	1995	NF13
	1996	NF13
	1997	NF13
	1998	NF13
	1999	NF13
	2000	NF13
	2001	NF13
	1997	NF14
	2000	NF14
	2001	NF14
	1992	NF17
	1993	NF17
	1994	NF17
	1995	NF17
	1996	NF17
	1997	NF17
	1998	NF17
	1999	NF17
	2000	NF17
	2001	NF17
	1994	NF23
	1995	NF23
	1996	NF23
	1997	NF23
	1998	NF23
	1999	NF23
	2000	NF23
	2001	NF23

Table 5-4 (continued). Station cluster groups from long-term analysis of nearfield infaunal data plus FF10, FF12 and FF13 from 1992 to 2001. Stations with 9 or 10 years in one group are indicated with a box.

Cluster	Year	Station	Cluster	Year	Station	Cluster	Year	Station	Cluster	Year	Station
II	1995	NF20	V	1998	NF05	VIII	1996	NF14			
	1996	NF21		1999	NF05		1998	NF14			
	1997	NF21		2000	NF05		1999	NF14			
	1999	NF21		2001	NF05		1994	NF18			
	2000	NF21					1995	NF18			
	2001	NF21					1996	NF18			
	1995	NF22					1997	NF18			
	1996	NF22					1998	NF18			
	1997	NF22					1999	NF18			
	1998	NF22					2000	NF18			
	1999	NF22					2001	NF18			
	2000	NF22									
	2001	NF22									
	1995	NF24									
	1997	NF24									
	1998	NF24									

Overall, the 1992 to 2001 infauna was not dominated by any strong temporal trend. The dendrogram produced by the cluster analysis was heavily chained and indicated that within group station affinities were stronger than between groups (Figure 5-10). No temporal pattern between stations was seen in the MDS analysis when year was plotted (Figure 5-11). The strongest feature structuring the 1992 to 2001 infauna was within station similarity. Based on species composition and the multivariate analyses, nothing distinguished the first year of discharge data from nearfield from the baseline.

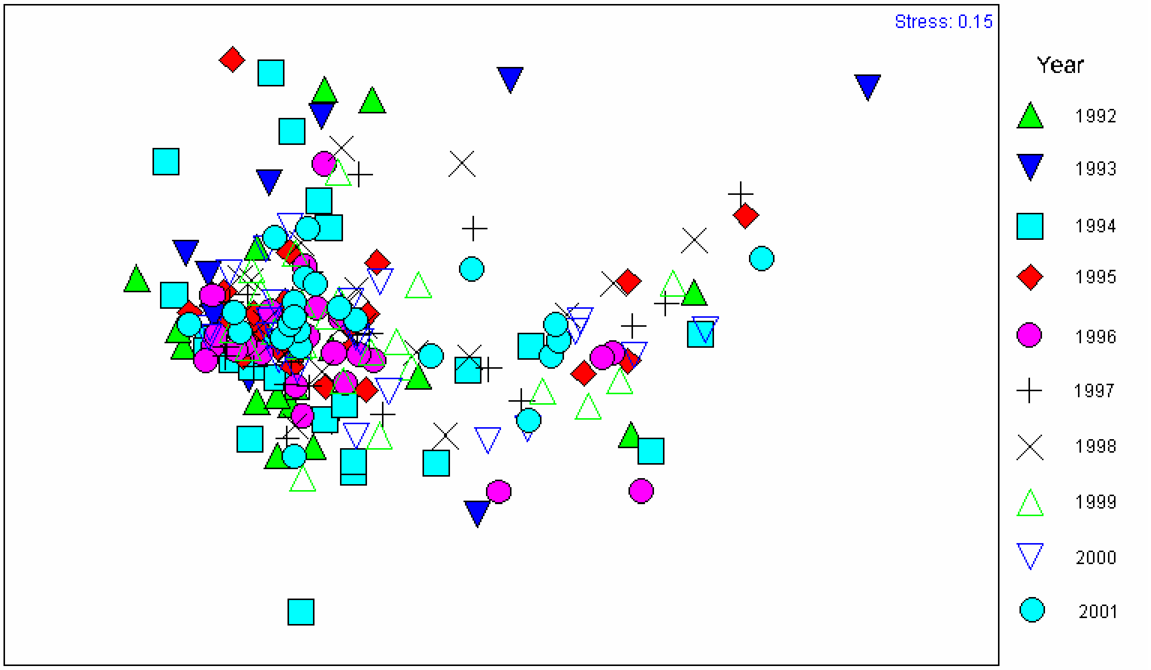


Figure 5-11. Nearfield stations plotted by year in MDS space. Plot was based on first replicate and included all taxa (Bray-Curtis similarity, square root transformation).

At the seven group level species formed into four clusters A, B to D, E and F, and G. Species group A contained the overall collection dominants that were broadly distributed across all station groups with five of the top 10 numerical dominants in group A (Table 5-5). The three most abundant species were *Prionospio steenstrupi, Mediomastus californiensis*, and *Spio limicola*. *Prionospio steenstrupi* was also the most broadly distributed species and occurred in 210 of the 215 nearfield station-year collection combinations. Only four other species occurred at over 200 station-year combinations, they were *Mediomastus californiensis*, *Aricidea catherinae, Tharyx acutus*, and *Exogone hebes*. These were also in the top 10 numerical dominants (Table 5-5). Groups B, C, and D included many of the epibenthic or epifaunal species such as *Dipolydora socialis* and *Cancer borealis*, and free-burrowing species, such as *Nereis grayi* and *Cerbratulus lacteus*. For the most part species in these groups were not prominent (>50% occurrence at the 215 station-year combinations) in the nearfield over the 1992 to 2001 period. The exceptions being *Dipolydora socialis* and *Pholoe minuta* (Table 5-5). Groups E, F, and G were composed of species with a preference for sandier sediments with groups E and F species tending to prefer finer sands to mixed mud-sand stations, typified by species such as *Phoronis architecta* and *Asabellides oculata*, and group G slightly coarser grained sands typified by Enchytraeidae sp. 1 (Table 5-5).

5.3.5 Farfield Multivariate Analysis

2001 Farfield Multivariate Analysis—Station cluster analysis of the 2001 infaunal data for the eight farfield stations not associated with the nearfield indicated that within station similarity was stronger than between stations. At the four group level station between station group dissimilarity was high and was related to a combination of geography, sediment grain-size, and depth. Group I contained Stations FF05 and FF14, eastern stations with 64–75 m water depth, and Stations FF04 and FF11, 89 m depth. Stations FF01A and FF09, the shallower Massachusetts Bay stations (36–49 m) formed group II and Cape Cod Bay stations (FF06 and FF07), the shallowest at 33–39 m, formed group III. The relationship between station groups was similar based on MDS analysis with the stations that formed cluster group I closely spaced and those of groups II and III more distantly spaced (Figure 5-12). Group II stations had lower TOC and heterogeneous sandy sediments that ranged from very-coarse to fine-sand. Groups I and III had higher TOC and finer sediments (Figure 5-12).

The species cluster analysis, based on summed replicates and all 191 taxa that occurred at the eight farfield stations, produced two distinct groups of taxa, groups A, B and C, and D and E (Figure 5-13). Each of the species groups contained numerical dominants (Table 5-6), however; most of the species occurred in low numbers (<100 individuals for all 24 farfield replicate grabs). Among the top ten numerical dominant species, Group A contained the top dominant *Prionospio steenstrupi* along with *Nucula delphinodonta.* While group A was broadly distributed across all eight stations it had highest affinity with group II. Species group B was composed of lower abundance species, such as *Dipolydora socialis*, the eleventh numerical dominant and was most well represented in groups I and II. Group C had the numerical dominants *Cossura longocirrata, Euchone incolor, Levinsenia gracilis,* and *Mediomastus californiensis* that were broadly distributed across all station cluster groups. Group D contained *Aricidea quadrilobata*, *Anobothrus gracilis*, and *Spio limicola* and had strongest association with station groups I and II. Group E contained *Chaetozone setosa* mb and was associated with station group I (Table 5-6).

As was found in the nearfield, analysis of the infaunal data with the sediment contaminant data using both MDS and PCA pointed to sediment grain-size as the primary factor determining both community and contaminant patterns. No contaminant effects on infaunal communities could be detected above the influence of sediment grain-size. Similar results were found in 2000 (Kropp *et al*. 2002).

Table 5-5. Average abundance of species with a collection total of >1000 individuals or >20 station occurrences by cluster group (Individuals/0.04 m^2) for 1992 to 2001 nearfield infauna.

Species		Collection		Station Cluster Group									
Group	**Species**	**Total**	**Occurrence**	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**
A	*Prionospio steenstrupi*	103633	210	340	369	1067	1018	277	617	142	816	85	80
	Mediomastus californiensis	41402	207	277	303	284	177	110	238	214	153	9	15
	Spio limicola	34554	187	329	244	38	155	23	37	645	10	1	17
	Ninoe nigripes	12447	183	87	106	116	48	27	34	47	49	12	4
	Aphelochaeta marioni	10467	166	95	52	63	98	124	8	52	18	1	2
	Euchone incolor	8723	181	54	95	70	78	13	14	9	19	1	2
	Monticellina baptisteae	8166	157	76	54	54	5	8	38	94	4	10	2
	Levinsenia gracilis	7012	175	47	86	67	17	37	17	12	9	15	0
	Nucula delphinodonta	6378	175	62	26	23	76	55	1	26	16	3	8
	Leitoscoloplos acutus	4023	188	28	33	27	13	5	34	14	10	3	0
	Parougia caeca	2410	186	13	24	18	15	16	5	6	11	0	2
	Maldane sarsi	1844	63	40	2	0	4	8	0	13	0	0	1
	Micrura spp.	1690	181	12	11	13	8	5	6	9	6	3	1
	Monticellina dorsobranchialis	1659	158	7	13	19	5	7	7	7	8	6	1
	Metopella angusta	1300	150	8	4	6	16	5	9	3	4	8	1
	Amphiporus angulatus	691	128	5	6	7	3	2	3	1	1	0	1
	Thracia conradi	402	74	7	3	2	1	0	1	0	0	0	0
	Yoldia sapotilla	287	69	2	5	0	1	2	0	2	0	0	0
	Mayerella limicola	286	38	5	3	0	1	0	0	1	0	0	0
	Periploma papyratium	246	50	4	2	0	0	0	1	1	0	0	0
	Hippomedon propinquus	239	25	0	0	8	1	0	0	0	0	0	1
	Dentalium entale	232	46	2	2	3	1	0	0	0	0	0	0
	Cossura longocirrata	113	55	1	1	1	0	0	0	0	0	0	0
	Enipo torelli	73	45	1	0	0	0	1	0	0	0	0	0
	Terebellides atlantis	70	34	0	1	0	0	0	0	0	0	0	0
	Pitar morrhuanus	60	34	1	0	0	0	0	0	0	0	0	0
	Deflexilodes intermedius	49	24	0	0	0	0	0	0	1	0	0	0
	Stereobalanus canadensis	33	24	0	0	0	0	0	0	0	0	0	0
B	*Dipolydora socialis*	19495	165	92	7	6	193	88	29	441	18	5	85
	Crenella decussata	3048	77	11	3	9	12	22	0	32	35	9	20
	Pholoe minuta	2459	199	7	10	11	24	5	6	24	20	7	6
	Dipolydora quadrilobata	2333	75	6	1	0	4	1	2	100	1	1	8
	Crenella glandula	1331	79	4	2	3	5	20	0	1	15	0	14
	Sphaerosyllis longicauda	289	87	1	1	0	2	4	0	3	4	1	1
	Nereis grayi	201	52	0	0	1	3	1	0	2	3	1	0
	Cancer borealis	103	54	0	0	0	1	1	0	1	1	0	1
	Phascolion strombi	38	27	0	0	0	1	1	0	0	0	0	0
C	*Apistobranchus typicus*	390	85	2	2	2	3	6	0	2	5	0	1
	Pionosyllis sp. A	240	37	0	0	0	1	1	0	2	10	0	0
	Leitoscoloplos sp. B	212	48	1	2	1	2	0	1	0	1	0	0
D	*Protomedeia fasciata*	3165	82	0	0	1	1	13	3	0	113	5	25
	Thyasira gouldi	632	90	5	1	2	5	26	0	7	0	0	0
	Harpinia propinqua	544	61	1	0	1	4	20	0	3	11	0	0
	Leptocheirus pinguis	435	53	0	2	2	0	11	0	0	5	1	4
	Cerebratulus lacteus	300	83	2	4	2	0	0	1	1	0	2	0
	Sphaerodoridium sp. A	260	86	1	1	3	3	1	0	0	3	0	0
	Orchomenella minuta	202	60	1	0	0	2	3	1	0	4	1	1
	Aeginina longicornis	169	28	1	0	0	1	9	0	3	0	0	0
	Dulichia tuberculata	111	36	0	0	0	2	1	0	0	1	0	0
	Diastylis quadrispinosa	77	47	0	0	0	0	1	0	0	1	1	1
	Paradulichia typica	63	28	0	0	0	2	1	0	0	1	0	0
	Polycirrus phosphoreus	56	22	0	0	0	0	0	0	0	0	0	0

Table 5-5 (continued). Average abundance of species with a collection total of >1000 individuals or >20 station occurrences by cluster group (Individuals/0.04 m^2) for 1992 to 2001 nearfield infauna.

Species Group	Species	Collection		Station Cluster Group									
		Total	Occurrence	I	II	III	IV	V	VI	VII	VIII	IX	X
D	*Nuculoma tenuis*	47	21	0	1	0	0	1	0	0	0	0	0
	Oenopota incisula	33	24	0	0	0	0	1	0	0	0	0	0
E	*Aricidea catherinae*	21834	207	127	83	133	81	18	304	32	79	74	18
	Tharyx acutus	18946	202	66	89	99	32	74	327	89	38	9	18
	Owenia fusiformis	5467	113	13	1	1	78	1	123	6	2	7	7
	Phoronis architecta	3740	159	17	5	29	25	6	50	19	13	2	2
	Photis pollex	3396	177	8	2	9	22	3	58	9	22	9	11
	Scoletoma hebes	1408	71	4	1	11	0	0	33	3	7	7	0
	Dyopedos monacanthus	1393	54	3	1	3	8	8	23	8	10	22	1
	Arctica islandica	976	155	3	4	4	5	2	6	13	3	9	3
	Argissa hamatipes	645	153	2	1	6	4	1	6	2	5	5	2
	Lyonsia arenosa	278	59	0	0	2	2	0	2	1	4	0	1
	Edwardsia elegans	270	97	1	0	0	1	1	3	1	1	4	1
	Diastylis sculpta	195	77	0	0	1	0	0	2	1	2	3	2
	Ensis directus	155	31	0	0	1	0	0	3	0	1	4	1
	Pleurogonium inerme	148	51	1	0	0	1	1	2	0	2	3	0
	Pythinella cuneata	127	24	0	0	0	1	0	1	0	1	6	1
	Pherusa affinis	71	43	0	0	1	1	0	0	0	0	0	0
F	*Hiatella arctica*	4668	168	3	1	9	15	9	43	41	41	169	18
	Ampharete acutifrons	2061	122	17	7	1	18	7	1	40	9	0	0
	Asabellides oculata	1428	88	3	1	4	1	2	9	33	18	10	1
	Laonome kroeyeri	329	87	2	1	1	3	1	1	7	0	0	0
	Spio filicornis	187	61	0	0	1	1	0	1	2	2	1	1
	Actiniaria *sp. 2*	172	55	1	0	1	1	0	1	1	1	5	0
	Aphelochaeta monilaris	119	23	1	0	0	0	0	1	3	0	0	0
	Pectinaria granulata	110	31	0	0	0	2	0	1	0	1	1	0
	Gattyana cirrosa	37	22	0	0	0	0	0	0	0	1	0	0
G	*Exogone hebes*	15248	200	11	12	16	85	14	7	82	169	5	200
	Exogone verugera	11042	188	29	11	18	37	67	1	119	94	3	113
	Crassicorophium crassicorne	8113	84	0	0	1	1	0	2	1	13	3	194
	Spiophanes bombyx	4640	174	8	3	14	36	0	35	2	11	6	54
	Unciola inermis	4430	52	0	0	0	0	2	0	0	42	1	92
	Phyllodoce mucosa	4037	188	10	5	13	40	6	45	5	21	12	21
	Polygordius sp. A	3937	129	1	1	7	16	0	27	0	6	3	65
	Cerastoderma pinnulatum	3601	142	2	1	15	12	5	13	4	32	49	44
	Enchytraeidae sp. 1	3323	25	0	0	0	0	0	0	0	0	1	83
	Nemertea sp. 12	1325	110	7	5	14	7	4	7	0	5	0	5
	Euchone elegans	673	40	0	0	0	0	0	0	4	1	0	14
	Ampharete finmarchica	566	83	2	1	4	2	0	2	2	5	0	5
	Unciola irrorata	541	52	0	0	0	0	23	1	0	7	1	6
	Galathowenia oculata	412	129	2	2	1	2	6	2	1	1	0	2
	Chaetozone setosa mb	365	58	1	0	0	1	2	0	2	1	0	6
	Cephalothricidae sp. 1	318	81	2	3	2	3	1	0	0	1	1	1
	Petalosarsia declivis	205	72	1	0	0	1	3	0	1	1	0	2
	Sphaerosyllis brevifrons	181	30	0	0	0	0	0	0	2	0	0	3
	Solariella obscura	144	25	0	0	0	0	0	0	0	0	0	3
	Cyclocardia borealis	128	42	0	0	0	2	0	0	1	1	0	1
	Politolana polita	126	31	0	0	0	0	0	0	0	0	0	3
	Hippomedon serratus	104	34	0	0	0	0	0	0	0	0	0	2
	Tetrastemma vittatum	90	38	0	0	0	0	0	1	0	0	0	1
	Diaphana minuta	50	31	0	0	0	0	1	0	0	0	0	0

A.

```
        Sand    TOC   Cperf
I   FF14   7    1.5   605 --I
    FF05  42    1.3   600 --I--I
    FF11  22    2.1   970 -----I-------------I
    FF04   9    2.4   945 -------------------I--------------------------------I
                                                                              I
II  FF09  81    0.6   405 --------------------------------I                   I-------------I
    FF01A 82    0.4   490 --------------------------------I-------------------I             I
                                                                                            I
III FF06  45    1.0   545 ----------------------------------------------------I             I
    FF07  20    2.6   615 ----------------------------------------------------I-------------I
             0.62        0.70           0.80           0.90           1.00           1.09
```

Dissimilarity

B.

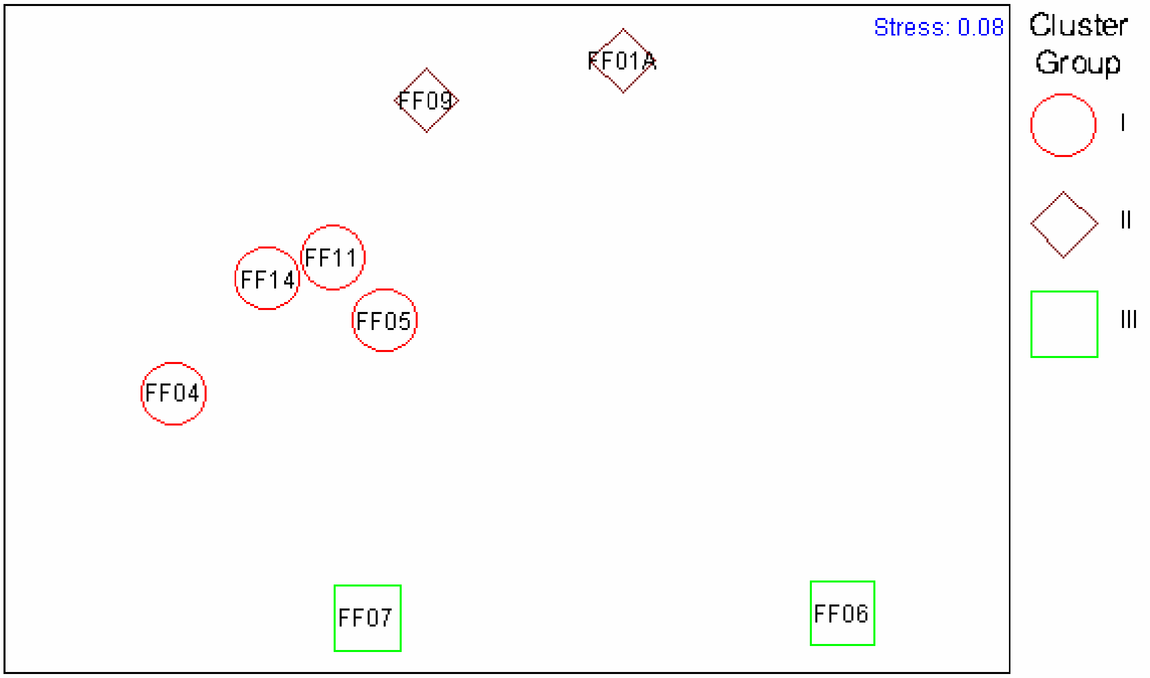


Figure 5-12. Relationship between 2001 farfield stations based on patterns in infaunal data. A) Cluster dendrogram with summed replicates from each station (all taxa were included, Gallagher's CNESS dissimilarity, and UMPGA sorting). B) MDS plot based on summed replicates (all taxa included, Bray-Curtis similarity, square root transformation).

```
  Species Group
A  ----I
       I----I
B  ----I    I
            I----I
C  ---------I    I
                 I
D  --I           I
     I-----------I
E  --I
     0.07     -0.16
     Dissimilarity
```

Figure 5-13. Major species group dendrogram of 2001 farfield infauna data based on summed replicates and all taxa (Gallagher's CNESS dissimilarity [*m* = 15] with group average sorting).

Comparison of 2001 Farfield Multivariate Community Analysis to Previous Years—Trends in the farfield were assessed using only the eight stations located outside of the nearfield area. The three farfield stations (FF10, FF12, FF13) located within the nearfield were included in the nearfield assessment. The primary pattern in the farfield station clusters from the combined 1992 to 2001 analyses was related to the strong within station similarity through time and secondarily to temporal trends. This basic pattern in the farfield infaunal data has been present for at least the last five years (Blake *et al.,* 1998, Kropp *et al.,* 2000, 2001). At the three group level farfield stations separated into two distinct clusters (Figure 5-14). Group I was the deeper stations with subgroup I' consisting of stations FF01, FF04, FF05, FF11 and FF14 during the 1992 to 1994 period and represented the strongest temporal trend in the data. Subgroup I" contained the same stations for the 1995 to 2001 period (Table 5-7). Subgroup I"' contained a single station FF05 for 1994, which was the only year that *Prionospio steenstrupi* did not occur. For all other years it averaged about 350 individuals/m^2 at FF05. Group II contained all years for stations FF09 (II') and FF01A (II" with 1999 in II'). Group III was the Cape Cod Bay stations FF06 and FF07 for all years with subgroup III' a mix of both stations and III" primarily FF06 (Table 5-7).

Overall, the 1992 to 2001 farfield infaunal data was dominated primarily by strong spatial differences between stations and secondarily by temporal trends (Figure 5-15). Temporal trends at the deepest stations (FF04, FF05, FF11, and FF14) were more pronounced than spatial differences between these same stations. The reverse was the case at shallower stations located to the north (FF01A and FF09) and in Cape Cod Bay (FF06 and FF07) (Table 5-7)

The primary grouping of species in the farfield reflected regional differences among the farfield stations in species distribution and abundance. At the five group level, species formed three distinct clusters, A and B, C, and D and E. Group A contained the top numerical dominant *Prionospio steenstrupi*, also the top dominant at nearfield stations, which occurred at all but two of the 80 farfield station/year combinations (FF05 and FF07 in 1994). Group B species were a mix of species associated with either fine-sandy sediments, such as *Phoronis architecta*, or structure, such as *Edotia montosa*. Groups A and B were most characteristic of station group II which also had the coarsest sediments of the farfield station groups. Group C tended to contain species that preferred finer sediments such as *Cossura longocirrata* and *Mediomastus californiensis*, both in the top ten numerical dominants. Group D contained more abundance and occurrence dominants than any of the other groups and was the group most representative of farfield infauna out of the direct influence of the Harbor. Numeric and occurrence dominant species included *Spio limicola, Levinsenia gracilis, Aricidea quadrilobata,* and *Anobothrus gracilis* (Table 5-8). Group D was broadly distributed across all station groups with slight preference for group I stations (Table 5-8). Group E was also broadly distributed across station groups with one numerical dominant *Euchone incolor*.

Table 5-6. Abundance of species with a collection total of >1000 individuals arranged by cluster group based on summed replicate analysis (Individuals/0.12 m^2) for 2001 farfield infauna. The top 40 taxa of 191 included in the cluster analysis represented 93% of all individuals and 21% of all taxa for 2001.

Taxa		Group I				Group II		Group III	
		FF14	**FF05**	**FF11**	**FF04**	**FF09**	**FF01A**	**FF06**	**FF07**
A	*Prionospio steenstrupi*	167	240	2762	34	747	3385	2	130
	Nucula delphinodonta	112	86	30	25	335	441	33	46
	Tharyx acutus	8	23	4	0	8	243	5	205
	Spiophanes bombyx	0	2	0	0	0	220	0	0
	Crenella glandula	47	0	0	0	56	56	0	0
	Photis pollex	2	31	0	0	22	68	0	13
	Edotia montosa	3	3	0	0	9	77	0	10
B	*Dipolydora socialis*	44	381	20	40	359	0	2	0
	Thyasira gouldi	64	198	25	35	189	125	8	8
	Thracia conradi	32	111	6	3	91	31	1	2
	Phoronis architecta	32	24	14	5	85	25	0	1
	Maldane sarsi	6	0	23	0	61	31	0	0
	Mayerella limicola	0	33	14	27	46	0	0	0
C	*Cossura longocirrata*	102	205	338	492	29	4	254	4228
	Euchone incolor	2	238	643	22	96	127	0	1156
	Levinsenia gracilis	247	287	612	314	225	186	99	48
	Mediomastus californiensis	56	261	78	70	136	68	134	465
	Aricidea catherinae	1	0	1	0	2	106	36	491
	Apistobranchus typicus	1	0	0	2	6	12	0	395
	Harpinia propinqua	8	23	19	3	77	17	251	3
	Nemertea sp. 12	60	37	100	39	84	21	42	15
	Ninoe nigripes	8	30	23	7	21	79	30	193
	Tubificidae sp. 2	0	0	0	0	14	0	25	288
D	*Aricidea quadrilobata*	358	536	1168	193	154	14	4	386
	Anobothrus gracilis	428	378	903	334	353	22	0	5
	Spio limicola	270	349	182	20	3	70	0	45
	Galathowenia oculata	282	79	80	26	63	7	10	27
	Parougia caeca	75	73	167	38	76	8	3	124
	Micrura spp.	29	54	55	23	21	19	4	28
	Sternaspis scutata	88	22	44	1	0	0	2	6
	Yoldia sapotilla	47	8	2	8	38	9	5	10
E	*Chaetozone setosa mb*	267	182	123	327	19	0	0	4
	Tubificoides apectinatus	182	41	276	191	5	3	4	15
	Aphelochaeta marioni	127	23	22	88	34	13	1	2
	Syllides longocirrata	46	29	1	117	0	0	0	65
	Paramphinome jeffreysii	8	2	0	221	1	0	0	1
	Onoba pelagica	41	22	56	13	4	0	6	13
	Dentalium entale	24	26	27	62	1	0	0	0
	Leitoscoloplos acutus	33	19	33	16	10	2	0	2
	Heteromastus filiformis	58	6	6	40	0	1	0	0

A

```
I′  --I
      I
      I--------I
      I        I-----I
I″  --I        I     I
               I     I
I″′ -----------I     I
                     I-----I
II′ -----I           I     I
         I           I     I
         I-----------I     I
         I                 I
II″ -----I                 I
                           I
III′--------I              I
            I              I
            I--------------I
            I
III″--------I
       1.03          1.23
         Dissimilarity
```

B

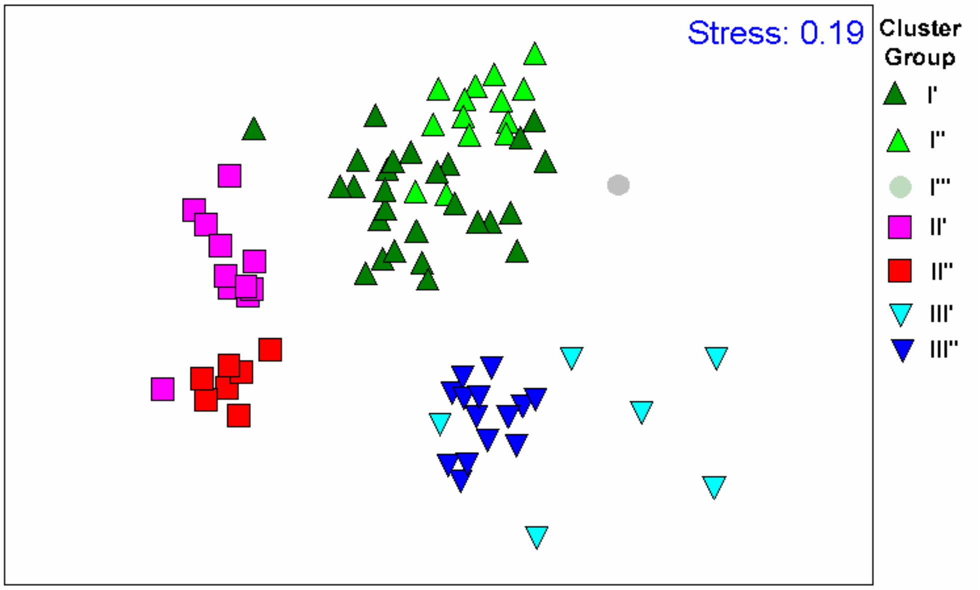


Figure 5-14. Long-term relationship between farfield stations based on pattern in infaunal data, 1992 to 2001. A) Cluster dendrogram with summed replicates from each station (all taxa were included, Gallagher's CNESS dissimilarity, and UMPGA sorting). B) MDS plot based on summed replicates (all taxa included, Bray-Curtis similarity, square root transformation).

Table 5-7 Station cluster groups from long-term analysis of farfield infaunal data, 1992 to 2001. Stations with 9 or 10 years in one subgroup are indicated with a box.

Cluster Group	Year	Station
I'	1992	FF01
	1993	FF01
	1992	FF04
	1993	FF04
	1994	FF04
	1992	FF05
	1993	FF05
	1995	FF05
	1992	FF11
	1993	FF11
	1994	FF11
	1992	FF14
	1993	FF14
	1994	FF14
I"	1995	FF04
	1996	FF04
	1997	FF04
	1998	FF04
	1999	FF04
	2000	FF04
	2001	FF04
	1996	FF05
	1997	FF05
	1998	FF05
	1999	FF05
	2000	FF05
	2001	FF05
	1995	FF11
	1996	FF11
	1997	FF11
	1998	FF11
	1999	FF11
	2000	FF11
	2001	FF11
	1995	FF14
	1996	FF14
	1997	FF14
	1998	FF14
	1999	FF14
	2000	FF14
	2001	FF14
I'"	1994	FF05

Cluster Group	Year	Station
II'	1999	FF01A
	1992	FF09
	1993	FF09
	1994	FF09
	1995	FF09
	1996	FF09
	1997	FF09
	1998	FF09
	1999	FF09
	2000	FF09
	2001	FF09
II"	1994	FF01A
	1995	FF01A
	1996	FF01A
	1997	FF01A
	1998	FF01A
	2000	FF01A
	2001	FF01A
III'	1992	FF06
	1993	FF06
	1995	FF06
	1996	FF06
	1997	FF06
	1992	FF07
	1993	FF07
	1995	FF07
	1996	FF07
	1997	FF07
	1998	FF07
	1999	FF07
	2000	FF07
	2001	FF07
III"	1994	FF06
	1998	FF06
	1999	FF06
	2000	FF06
	2001	FF06
	1994	FF07

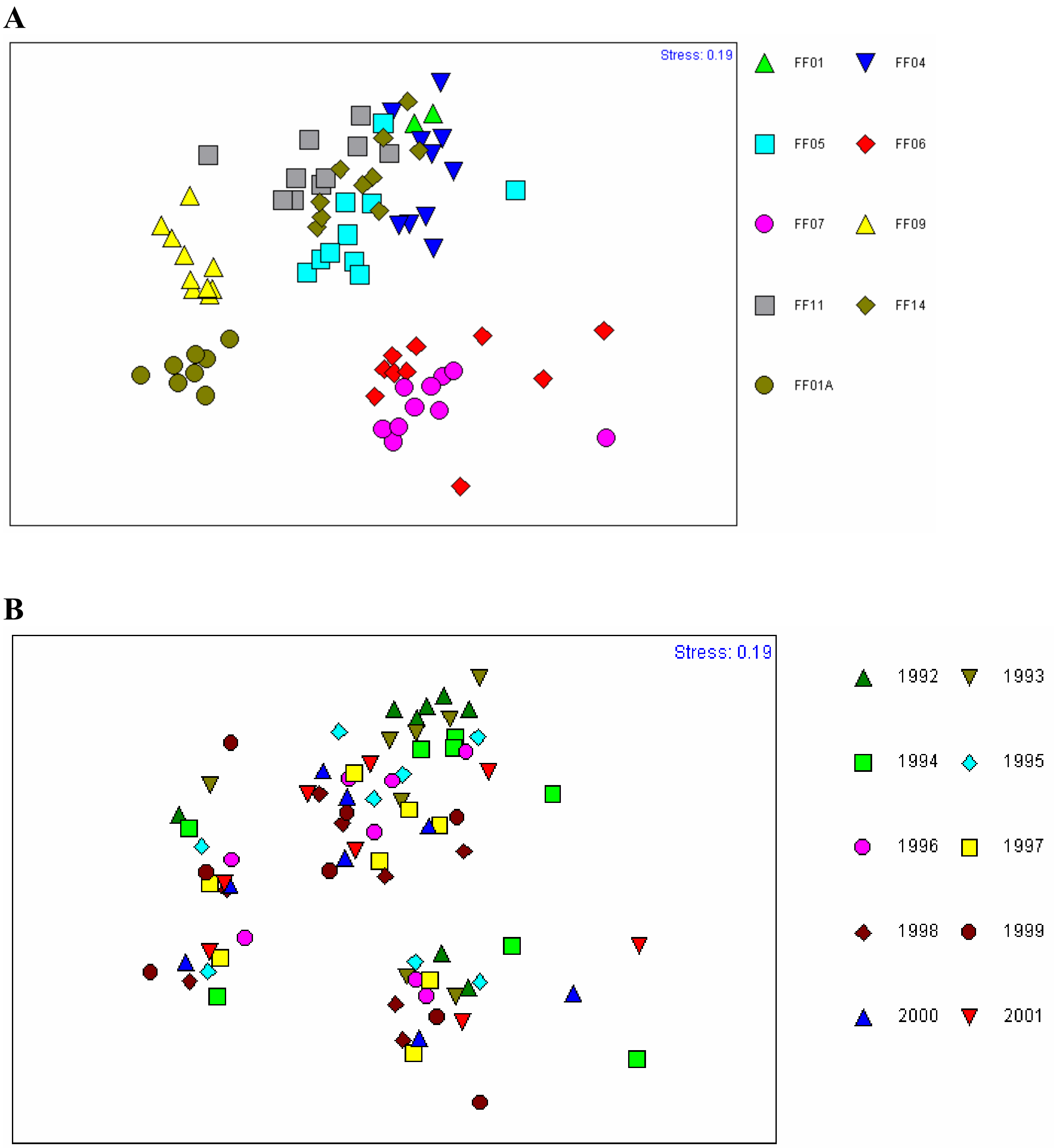


Figure 5-15. Long-term relationships, 1992 to 2001, between farfield stations based on MDS analysis: A) Plot of station patterns. B) Plot of temporal patterns.

Table 5-8. Average abundance of species with a collection total of >1000 individuals or >40 station occurrences by cluster group (Individuals/0.12 m^2) for 1992 to 2001 farfield infauna.

Species Group	Taxa	Collection Total	Occurrence	I'	I''	I'''	II'	II''	III'	III'
A	*Prionospio steenstrupi*	87138	78	167	1111	0	2521	3637	98	42
	Dipolydora socialis	12599	66	11	71	32	789	30	104	26
	Phyllodoce mucosa	540	45	1	2	1	33	8	2	4
	Haploops fundiensis	520	59	5	3	6	28	7	1	1
	Goniada maculata	232	46	3	3	0	5	7	0	0
B	*Nucula delphinodonta*	7598	76	21	62	33	141	392	62	73
	Photis pollex	1467	73	2	15	2	28	38	32	4
	Spiophanes bombyx	1359	23	0	1	0	34	137	0	0
	Cerastoderma pinnulatum	1012	30	0	1	0	54	54	1	1
	Edotia montosa	832	43	1	1	1	23	66	5	1
	Phoronis architecta	687	46	0	4	0	30	21	7	1
C	*Cossura longocirrata*	29836	75	65	184	15	10	1	1544	370
	Mediomastus californiensis	20856	80	109	211	70	191	161	666	165
	Tharyx acutus	6273	53	1	3	0	22	230	300	20
	Tubificidae sp. 2	5164	32	0	0	0	2	0	356	24
	Aricidea catherinae	5024	41	0	0	0	12	91	243	142
	Ninoe nigripes	4797	80	21	19	60	54	115	152	66
	Thyasira gouldi	4095	72	56	52	52	68	87	29	18
	Harpinia propinqua	3297	72	15	28	31	67	46	10	184
	Apistobranchus typicus	2962	63	5	20	0	8	44	139	2
	Onoba pelagica	2714	65	9	41	20	1	0	74	68
	Terebellides atlantis	1696	57	2	7	1	1	1	92	27
	Pholoe minuta	1575	78	6	13	2	49	36	19	13
	Metopella angusta	1486	66	2	20	30	22	12	38	7
	Nephtys incisa	1142	71	2	12	10	11	1	36	24
	Eteone longa	920	73	10	11	13	14	17	9	11
	Capitella capitata complex	805	66	6	3	4	21	10	22	5
	Eudorella pusilla	496	64	4	2	16	7	8	15	6
	Stenopleustes inermis	451	44	0	2	0	8	10	15	5
	Amphiporus angulatus	405	58	2	5	0	8	3	6	7
	Cylichna gouldi	347	50	3	7	2	1	0	4	6
	Pleurogonium rubicundum	339	49	1	6	18	3	9	3	0
	Scoletoma fragilis	336	64	1	2	1	3	3	14	3
	Gattyana amondseni	181	42	1	1	0	4	3	1	9
	Leptostylis longimana	154	42	0	2	0	1	0	4	3
	Mya arenaria	126	44	1	2	1	1	1	2	2
D	*Spio limicola*	29738	75	606	158	121	1000	90	367	19
	Aricidea quadrilobata	14617	80	163	342	57	45	35	158	15
	Levinsenia gracilis	13689	80	150	267	106	185	124	64	84
	Anobothrus gracilis	8939	79	47	255	13	87	23	15	7
	Chaetozone setosa mb	6652	67	117	179	0	12	2	3	0
	Tubificoides apectinatus	5310	62	106	139	1	1	1	3	2
	Scalibregma inflatum	2190	60	59	8	26	93	4	5	1
	Yoldia sapotilla	1981	75	28	33	51	31	13	13	7
	Dentalium entale	1829	53	13	57	0	9	0	0	0
	Micrura spp.	1679	80	14	26	4	22	17	26	9
	Aphelochaeta marioni	1606	77	12	27	3	34	13	15	3
	Leitoscoloplos acutus	1515	69	38	24	11	19	10	4	0
	Syllides longocirrata	1295	55	13	15	1	0	0	49	5
	Maldane sarsi	1012	47	34	4	1	23	23	0	0

Table 5-8 (continued). Average abundance of species with a collection total of >1000 individuals or >40 station occurrences by cluster group (Individuals/0.12 m^2) for 1992 to 2001 farfield infauna.

Species Group	Taxa	Collection Total	Occurrence	I'	I"	I"'	II'	II"	III'	III'
D	*Heteromastus filiformis*	759	47	18	18	3	1	0	0	0
	Carinomella lactea	309	62	3	5	0	1	2	6	1
	Enipo torelli	157	47	3	1	2	2	1	3	1
	Chaetoderma nitidulum canadense	84	40	1	2	1	1	1	0	0
E	*Euchone incolor*	24921	75	16	425	0	139	76	794	6
	Parougia caeca	3055	78	14	64	1	31	9	46	15
	Galathowenia oculata	2344	69	3	71	0	21	4	7	3
	Sternaspis scutata	1968	60	12	64	0	0	0	4	1
	Nemertea sp. 12	1694	46	3	38	0	27	14	10	17
	Thracia conradi	1097	36	0	25	0	29	13	0	1
	Cephalothricidae sp. 1	605	40	0	17	0	10	3	2	0
	Stereobalanus canadensis	152	40	0	2	0	1	1	5	1

5.3.6 Relationship Between Nearfield and Farfield Stations

In 1993 all the nearfield stations were sampled with three replicates and from 1994 to 2001 only nearfield stations NF12, NF17, and NF24 had three replicates collected. These replicated nearfield stations were combined with all farfield stations to assess the long-term relationship between the two general areas. While the combined nearfield and farfield infaunal analysis was completely chained, at the ten group level the station clusters were very similar to those generated by the separate analyses of the nearfield and farfield data sets. Groups I, II, III, VI, IX, and X were exclusively stations in the nearfield area, which included the three farfield stations near the harbor (Table 5-9). The remaining four groups were exclusively the eight farfield stations located away from the nearfield (Figure 2-2). Species groups were also similar to those produced by the separate analyses (compare Table 5-10 to Tables 5-5 and 5-8). Most of the numerically dominant species were broadly distributed across all station groups.

The farfield station groupings were very similar between analyses and reinforced the differences between the near harbor area, which included the nearfield stations and three of the farfield stations, and the distant farfield areas of Cape Anne (FF01A and FF11), Outer (FF09 and FF14), Stellwagen (FF04 and FF05), and Cape Cod (FF06 and FF07) (compare Tables 5-7 and 5-9). The near harbor station groups did not match the nearfield only analysis as well because most of the nearfield stations were not replicated and not included in the combined analysis (compare Tables 5-4 and 5-9). The affinity of the near harbor farfield station FF10 was clearly with the nearfield area while stations FF12 and FF13 were more aligned with farfield stations FF01A and FF09 near Cape Anne and Outer areas respectively (Table 5-9). The only nearfield station to be in a farfield group was NF08 in 1993. In 1993, nine of the nearfield stations were sampled with three replicate grabs.

Table 5-9. Station cluster groups from long-term analysis of all replicated nearfield and farfield stations from 1992 to 2001. Stations with all years in one group are indicated with a box.

Cluster Group	Year	Station	Cluster Group	Year	Station	Cluster Group	Year	Station
I	1992	FF10	IV	1994	FF01A	VII	1992	FF01
I	1993	FF10	IV	1995	FF01A	VII	1993	FF01
I	1994	FF10	IV	1996	FF01A	VII	ALL	FF04
I	1995	FF11	IV	1997	FF01A	VII	ALL	FF05
I	1996	FF11	IV	1998	FF01A	VII	ALL	FF11
I	1993	NF09	IV	2000	FF01A	VII	ALL	FF14
I	1993	NF10	IV	2001	FF01A			
						VIII	ALL	FF06
II	ALL	NF12	V	1999	FF01A	VIII	ALL	FF07
II	1993	NF16	V	ALL	FF09			
II	1995	NF24				IX	1994	FF12
II	1996	NF24	VI	1992	FF12	IX	1993	NF04
II	1997	NF24	VI	1993	FF12	IX	1993	NF14
II	1998	NF24	VI	1997	FF12	IX	1994	NF24
II	1999	NF24	VI	1998	FF12			
II	2000	NF24	VI	1999	FF12	X	1993	NF02
II	2001	NF24	VI	2000	FF12	X	ALL	NF17
			VI	2001	FF12			
III	1997	FF10	VI	ALL	FF13			
III	1998	FF10	VI	1995	FF14			
III	1999	FF10	VI	1996	FF14			
III	2000	FF10	VI	1993	NF08			
III	2001	FF10						

Table 5-10. Average abundance of species that were >1 individual/0.12 m2 and occurred in at least 8 of 10 station cluster groups, from analysis of all replicated nearfield and farfield stations from 1992 to 2001. Blank cell indicates average was <1 individual/0.12 m^2.

Group	Taxa	I	II	III	IV	V	VI	VII	VIII	IX	X
A	*Prionospio steenstrupi*	780	1973	2430	3637	2521	2355	769	81	45	31
	Dipolydora socialis	220	215	70	30	789	45	49	80	559	89
	Nucula delphinodonta	350	68	291	392	140	3	47	65	9	
	Pholoe minuta	24	54	25	35	49	15	10	17	44	6
	Edotia montosa	45	11	49	66	22	21	1	3	27	4
	Crenella decussata	88	12	55	32	4		3	1	54	
	Ampharete acutifrons	66	12	35	7	35	3	1	2	1	
	Asabellides oculata	47	4	23	18	10	12	2		27	1
	Edwardsia elegans	3	1	4	48	8	6			1	1
B	*Spiophanes bombyx*	15	15	104	137	34	92			5	211
	Hiatella arctica	35	11	49	29	23	30		1	190	210
	Exogone hebes	51	33	109	4	62	4			216	125
	Polygordius sp. A	1	4	27	23	4	12	1	6		263
	Cerastoderma pinnulatum	6	4	125	54	54	21			2	110
	Sphaerosyllis longicauda	3	2	1		4		1	1	1	1

Table 5-10 (continued). Average abundance of species that were >1 individual/0.12 m2 and occurred in at least 8 of 10 station cluster groups, from analysis of all replicated nearfield and farfield stations from 1992 to 2001. Blank cell indicates average was <1 individual/0.12 m^2.

Species Group	Taxa	I	II	III	IV	V	VI	VII	VIII	IX	X
C	*Mediomastus californiensis*	556	1072	430	161	191	793	173	516	138	8
	Aricidea catherinae	202	485	521	90	11	766		212	206	34
	Tharyx acutus	152	295	150	230	22	864	2	216	116	16
	Ninoe nigripes	206	221	206	115	54	132	20	126	57	2
	Aphelochaeta marioni	171	393	70	13	33	12	21	11	201	
	Monticellina baptisteae	248	182	197	9	2	140	2	3	338	
	Owenia fusiformis	29	11	82	56	5	409	2			20
	Photis pollex	22	7	41	37	27	245	10	23	22	5
	Leitoscoloplos acutus	129	86	36	9	19	120	28	2	19	
	Phoronis architecta	38	25	46	21	29	158	2	4	3	
	Phyllodoce mucosa	10	31	24	8	32	108	1	2	18	83
	Eteone longa	21	26	7	17	14	29	10	9	45	
	Pleurogonium rubicundum	6	10	10	8	3	31	4	2	38	
	Arctica islandica	17	9	13	33	9	12		4	43	3
	Argissa hamatipes	5	3	13	8	5	20		2	7	4
D	*Spio limicola*	1244	779	145	89	1000	33	306	262	843	2
	Levinsenia gracilis	37	253	48	124	184	46	223	69	34	
	Aricidea quadrilobata	3	18	3	35	44		275	114	6	
	Anobothrus gracilis	4	2	14	23	86		180	12	1	
	Chaetozone setosa mb	11	3		1	12	1	153	2	2	19
	Tubificoides apectinatus		5	8	1		42	124	2	3	4
	Parougia caeca	19	56	29	8	30	16	45	36	6	8
	Thyasira gouldi	34	2	15	87	67	1	52	25		
	Micrura spp.	39	41	26	16	22	30	21	20	13	1
	Nemertea sp. 12	4	19	10	14	26	21	25	12		5
	Galathowenia oculata	2	5	4	4	21	2	47	5	1	4
	Scalibregma inflatum	13	5		3	92	1	25	3	1	
	Amphiporus angulatus	13	22	6	3	7	8	4	5		
	Carinomella lactea	1	6	6	2	1	7	4	4		
E	*Euchone incolor*	52	270	66	76	139	44	278	557	9	
	Tubificidae sp. 2	24	9	29		2	27		256	8	3
	Harpinia propinqua	5	1	14	46	66		23	62	1	
	Apistobranchus typicus	3	9	4	44	8		14	97	17	
	Metopella angusta	12	26	25	11	21	22	14	28	14	
	Capitella capitata complex	17	25	4	10	20	38	3	17	25	4
	Nephtys incisa	11	22	7	1	11	22	8	32	12	
	Stenopleustes inermis	8	11	7	9	7	7	1	12	4	2
	Trochochaeta multisetosa	1	13	6	1	4	4	7		1	
	Periploma papyratium	6	5	10	7	4	1	5	4		
	Scoletoma fragilis	3	4	1	3	3		1	10	1	
	Gattyana amondseni	2	3	3	2	3		1	3	4	

5.4 Benthic Community Threshold Comparisons

5.4.1 Diversity Measures

The 2001 values for the five threshold measures calculated 18 December 2001. All of the values were within the threshold limits (Table 5-11).

Table 5-11. Comparison of MWRA benthic threshold values with corresponding 2001 values.

Parameter	Threshold Values		2001 Value	Threshold Exceeded?
	2.5th %tile	97.5th %tile		
Species per Sample	47.95	81.09	63.1	No
Log-series Alpha	10.13	15.88	13.1	No
Shannon Diversity (*H'*)	3.32	4.02	3.8	No
Pielou's Evenness (*J'*)	0.56	0.67	0.64	No
Relative Abundance [1]	10 %	25 %	0.34 %	No

[1] The relative abundance of seven opportunist taxa: Ampelisca abdita, Ampelisca macrocephala, Ampelisca vadorum, Capitella capitata complex, Mulinia lateralis, Polydora cornuta, Streblospio benedicti.

5.4.2 Opportunists

The average relative abundance of the seven opportunist taxa included in the threshold evaluation was about 0.3 % (Table 5-11). This value is one of the two lowest values obtained during the last ten years of monitoring in Massachusetts Bay (Figure 5-16a). The actual abundance of these seven taxa across the nearfield stations in 2001 also was very low, with 235 individuals found (Figure 5-16b).

In 2001, the relative abundance of opportunists at most nearfield stations was near or less than the mean value for the baseline period (Figure 5-17). Relative opportunist values were greater than the baseline mean values at three station, NF02, NF05, and NF17. At only one of these stations, NF02, was the 2001 value well outside the baseline range. Station FF13 historically has had the highest relative abundance and total abundance of opportunists among the nearfield stations (Figures 5-17a, b). Station FF13 is close to the mouth of Boston harbor and has occasionally had relatively high abundances of taxa, such as *Ampelisca abdita*, that are commonly seen in the Harbor. In 2001, however, the total and relative abundance of opportunists at station FF13 were near the low end of the baseline range.

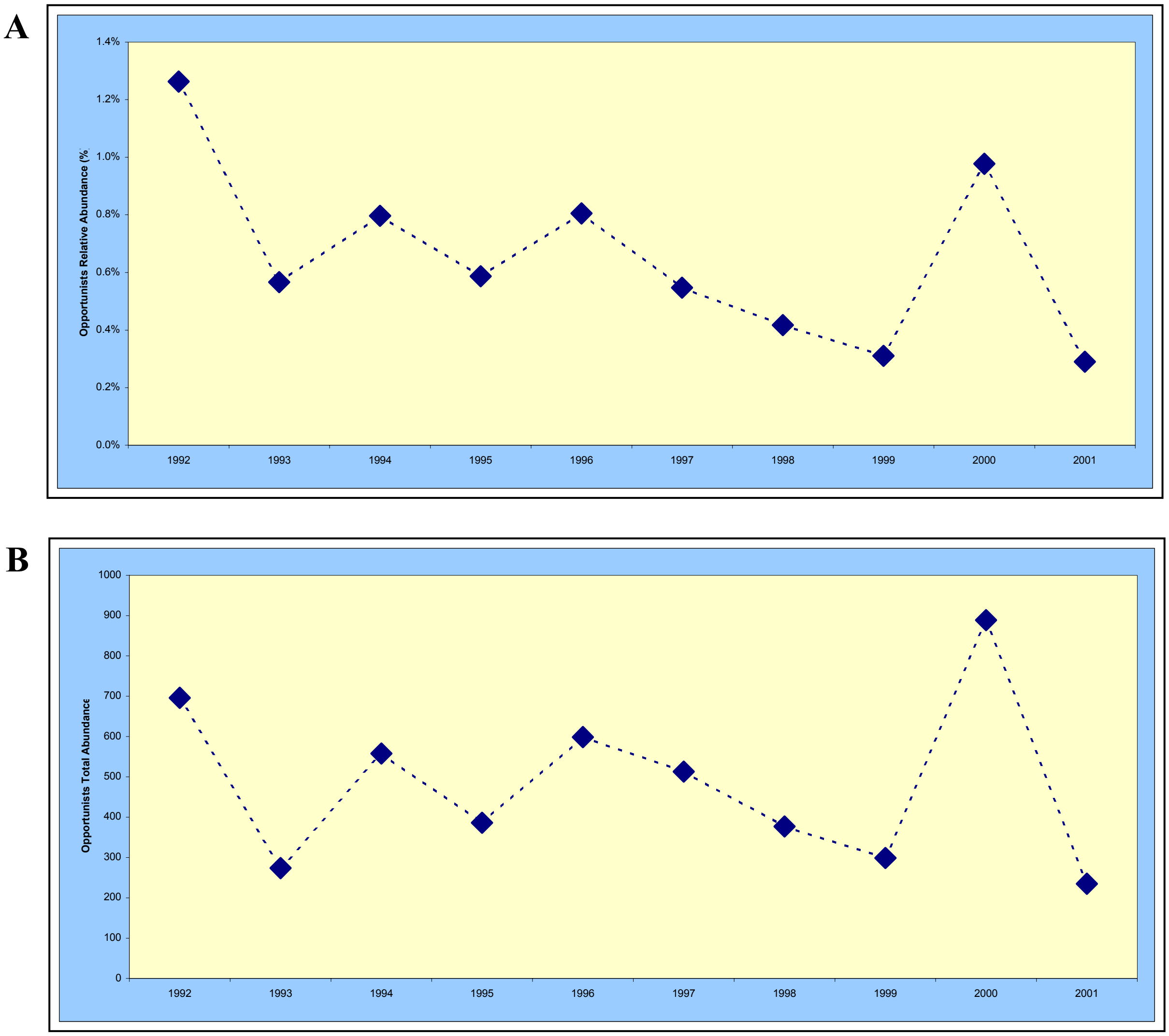
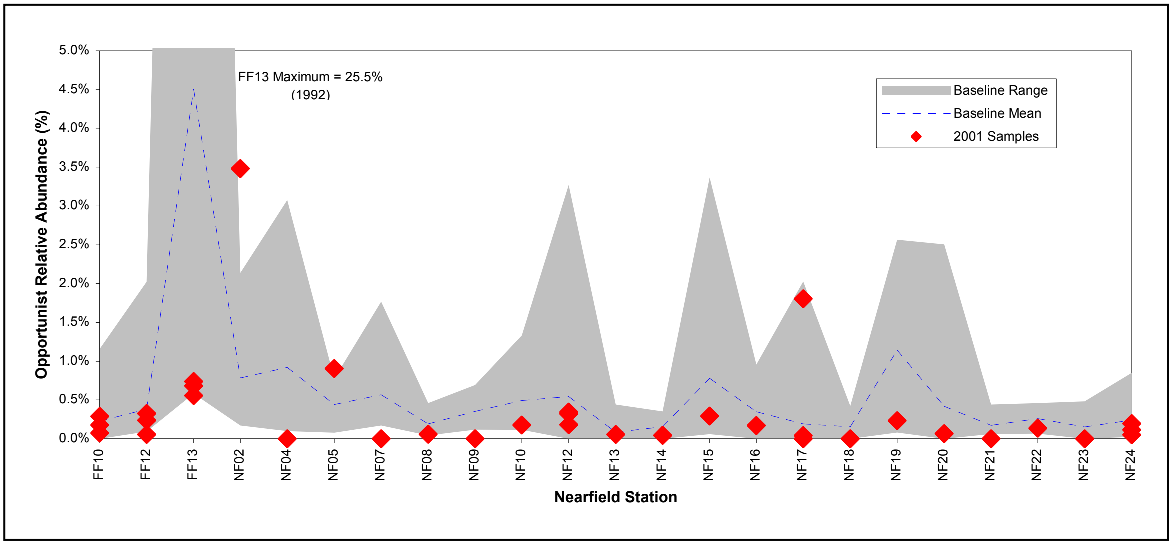


Figure 5-16. Relative (A) and actual (B) abundance of seven opportunist taxa collected in the nearfield from 1992 to 2001.

A



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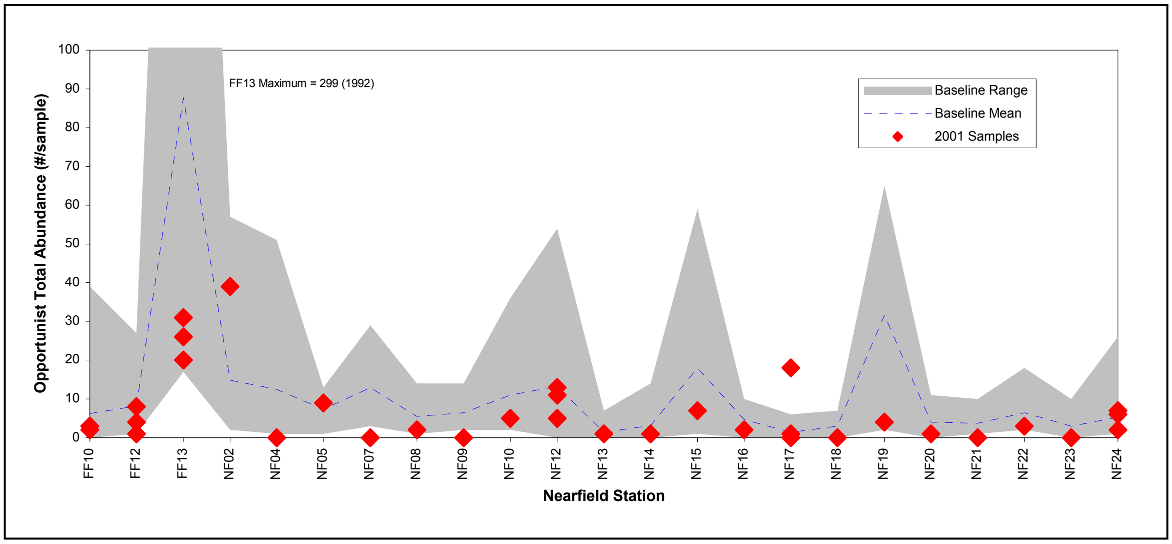


Figure 5-17. Relative (A) and actual (B) abundance of seven opportunist taxa collected from each nearfield station in 2001 (diamonds) and the range of values occurring during the baseline period (gray band).

6. 2001 HARDBOTTOM STUDIES

by Barbara Hecker

6.1 State of the Bay

The nearfield hardbottom communities inhabiting drumlins in the vicinity of the outfall have been surveyed annually for the last eight 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. During the baseline time period, the sampling design changed from videotaping a series of transects near the outfall in 1994 (Coats *et al.* 1995), to surveying discrete stations (waypoints) on the drumlins immediately north and south of the outfall, and at several reference sites on drumlins further away (1995-2001). The emphasis on data products also has changed from reliance mainly on videotape to more emphasis on still photographs. The video images cover a much broader area and are mainly useful for assessing habitat relief and variability and enumeration of rare, larger mobile fauna, while the still photographs offer much higher resolution for enumeration of most of the fauna.

Analyses of the visual images collected during the last six years of the baseline period (1995-2000) have shown that the hardbottom 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 hardbottom areas near the outfall. The encrusting coralline algae usually dominate in areas that have little sediment drape, while upright algae frequently dominate in areas with substantial sediment drape. Coralline algae is the most abundant and widely distributed taxon encountered in this area. The areal coverage and distribution of coralline algae has been quite stable during the baseline period. The percent cover of coralline algae appears to be strongly related to amount of sediment drape, with cover being highest in areas with little drape and lowest in areas with moderately heavy-to-heavy drape. This may reflect susceptibility of the encrusting growth form of coralline algae to smothering by fine particles. In contrast, the abundance and distribution of upright algae appear to be mainly controlled by habitat relief. These algae are quite patchily distributed and only abundant in areas of moderate to high relief. Areas supporting high abundances of upright algae also tend to have moderate to heavy sediment drape, with the numerous holdfasts of the algae appearing to actively trap sediment.

The pattern of benthic community structure in the hardbottom areas has been quite consistent throughout the baseline time period. The communities at many of the sites remained the same from1995 to 2000.

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

The nearfield hardbottom survey conducted during late June and early July of 2001 was the first survey of the drumlin areas since the outfall went online. All of the waypoints were successfully surveyed, including an actively discharging diffuser head at the eastern end of the outfall. This chapter reports on the results of the 2001 survey and compares these results to pre-discharge baseline conditions.

6.2 Methods

Both video footage and still photographs were obtained at each of the 23 waypoints (Table 6-1). The photographic coverage ranged from 18-30 minutes of video footage and 13-31 still photographs (35-mm slides) at each waypoint. At least 25 usable still photographs were obtained at each of 21 of the waypoints, while only 13 and 15 were obtained at the remaining two waypoints (T10-1 and T1-3, respectively). The strobe was knocked out of alignment when the ROV hung up on a large boulder part way through T10-1 and the film from T1-3 jammed on the take-up spool during development. A total of 641 useable still photographs were taken and used in the following data analysis.

6.2.1 Visual Analysis

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

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

Table 6-1. Photographic coverage at locations surveyed during the 2001 nearfield hardbottom survey.

Transect	Waypoint	Location on drumlin	Depth (m)	Video (min)	Stills (# frames)
1	1	Top	24.3	21	29
1	2	Top	22.5	21	30
1	3	Top	22.9	22	15
1	4	Top	23.9	21	30
1	5	Flank	31.2	21	25
2	1	Top	26.2	24	28
2	2	Flank	30.0	23	30
2	3	Top	25.4	22	30
2	4	Flank	31.3	18	29
2	5	Diffuser #2	34.3	21	31
4	1	Flank	34.2	25	29
4	2	Flank	30.2	22	29
4	3	Flank	32.4	20	29
4/6	1	Top	24.8	21	29
6	1	Flank	32.0	21	31
6	2	Flank	29.7	21	30
7	1	Top	26.0	19	31
7	2	Top	25.1	20	27
8	1	Top	25.1	18	29
8	2	Top	25.4	19	31
9	1	Top	25.7	23	29
10	1	Top	26.9	20	13
Diffuser	#44		34.6	30	27

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 at *Ptilota serrata*), colonial hydroids, and small barnacles and/or spirorbid polychaetes that were frequently too abundant to count reliably were assessed in terms of relative abundance. The following categories were used to assess abundances of taxa that were not counted on the still photographs:

Category	Percent Cover	Numerical Value Assigned for Analysis
rare	1-5	1
few	6-10	2
common	11-50	5
abundant	51-90	15
very abundant	>90	20

Organisms were identified to the lowest possible taxonomic level, about half of them to species, with the aid of pictorial keys of the local flora and fauna (Martinez and Harlow 1994, Weiss 1995). Many of the encrusting species could not be identified to species. Most of these were assigned to descriptive categories (*e.g.*, “orange-tan encrusting”); however, each of these descriptive categories possibly includes several species. Additionally, some species might be split between two similar descriptive categories (*e.g.*, “orange encrusting” and “orange lumpy encrusting”), as a result of differences in viewing angles and lighting. Because of high relief in many of the habitats surveyed, all reported abundances should be considered to be extremely conservative. In many areas, only part of the surfaces of large boulders were visible; thus, actual faunal abundances in these areas were undoubtedly much higher than the counts indicated. A summary of the 2001 slide analysis is included in Appendix E-1.

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 2001 video analyses is included in Appendix E-2.

6.2.2 Data Analysis

Data were pooled for all slides taken at each waypoint. Comparisons among waypoints were facilitated by normalizing species counts to mean number of individuals per slide to account for differences in the number of slides collected at each site. Hydroids and small barnacles and/or spirorbids were omitted from the data analysis because they consisted of several species, could not be accurately assessed, and it was impossible to tell if they were alive. General taxonomic categories (*i.e.*, fish, sponge, etc.) were included in estimates of total faunal abundances, but were omitted from community analysis. Only taxa with an abundance of ten or more individuals in the entire data set were retained for community analysis. This process resulted in 41 out of the original 65 taxa being retained for community analysis. The white and pink color-morphs of *Halocynthia pyriformis* (sea peach tunicates) were pooled.

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

6.3 Results

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

6.3.1 Distribution of Habitat Types

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

Two diffuser heads were visited during the 2001 survey, one that was actively discharging effluent (T2-5, Diffuser #2) and one that was not activated (Diffuser #44). The sea floor in the vicinity of both diffusers consisted of angular rocks in the small boulder size category. This resulted in a high relief island (the diffuser) surrounded by a moderate relief field of boulders. Sediment drape was moderate at the active diffuser and moderately heavy at the inactive one. Both of the diffuser heads were colonized by numerous anemones, sea peach tunicates, and sea stars.

6.3.2 Distribution and Abundance of Epibenthic Biota

Eighty-one taxa were seen during the visual analyses of the 2001 nearfield hardbottom survey still photographs and videotapes (Table 6-2). Sixty-five of these taxa were seen on the still photographs. Taxonomic counts or estimates of abundances included 5,812 algae, 15,400 invertebrates, and 730 fish (Table 6-3). Coralline algae was the most abundant taxon observed during the survey, with an estimated abundance of 3,350 individuals. This taxon consists of at least 5 different species that had been identified as *Lithothamnion* spp. in surveys conducted prior to 2000. Voucher specimens collected in September 2000 belonged to five species of corallines, *Leptophytum laevae*, *Leptophytum foecundum*, *Phymatolithon lamii*, *Phymatolithon laevigatum*, and *Lithothamnion glaciale*. Differences between these species cannot be discerned on the basis of photographs, so all pink encrusting coralline alga were lumped into one taxon. Two other algae commonly seen were dulse (*Rhodymenia palmata*) and a red filamentous alga *Ptilota serrata*, with abundances of 1,517 and 909 individuals, respectively. The red filamentous alga had previously been identified as *Asparagopsis hamifera*, but a voucher specimen collected at T7-1 in 2000 was identified as *Ptilota serrata*. Another alga, the shotgun kelp *Agarum cribosum*, also was seen during this survey. This large alga was most abundant at T7-2, where some of the individuals seen were being overgrown by an encrusting organism that appears to be a species of the lacey bryozoan *Membranipora*. This overgrowth of shotgun kelp by *Membranipora* was first observed at this site during the 2000 survey. *Agarum cribosum* was also seen at 3 other stations, but the bryozoan was not seen encrusting the kelp at those stations.

The most abundant invertebrates observed on the still photographs were the northern sea star *Asterias vulgaris* (2,550 juveniles and 365 adults), the frilled anemone *Metridium senile* (2,313 individuals), the horse mussel *Modiolus modiolus* (1,628 individuals), the sea pork tunicate *Aplidium* spp. (1,045 individuals), an unidentified white translucent sponge (984 individuals), the brachiopod *Terebratulina septentrionalis* (948 individuals), and an unidentified orange/tan sponge (729 individuals). Other common invertebrate inhabitants of the drumlins included the northern white crust tunicate *Didemnum*

Table 6-2. Taxa observed during the 2001 nearfield hardbottom survey.

	Taxon	Common Name		Taxon	Common Name
	Algae		*	*Arctica islandica*	quahog
	Coralline algae	pink encrusting algae		Crustaceans	
	Ptilota serrata	filamentous red algae	*	*Balanus* spp.	acorn barnacle
	Rhodymenia palmata	dulse		*Homarus americanus*	lobster
	Agarum cribrosum	shotgun kelp	**	Crab	
	Fauna			*Cancer* spp.	Jonah or rock crab
	Sponges			hermit crab	
	sponge			Echinoderms	
*	*Aplysilla sulfurea*	yellow sponge		*Strongylocentrotus droebachiensis*	green sea urchin
	Halichondria panicea	crumb-of-bread sponge		juvenile *Asterias*	Small white sea star
**	*Haliclona oculata*	finger sponge		*Asterias vulgaris*	northern sea star
**	*Haliclona* spp.	encrusting sponge		*Henricia sanguinolenta*	blood star
	Melonanchora elliptica	warty sponge		*Crossaster papposus*	spiny sun star
	Polymastia?	siphon sponge?	*	*Pteraster militaria*	winged sea star
	Suberites spp.	fig sponge (cream, globular)	**	*Solaster endeca*	sun star
	white divided	sponge on brachiopod	*	*Ophiopholis aculeata*	daisy brittle star
*	orange/tan encrusting	sponge		*Psolus fabricii*	scarlet holothurian
*	orange encrusting	sponge		Tunicates	
*	tan encrusting	sponge	**	tunicate	
*	pink fuzzy encrusting	sponge		*Aplidium* spp.	sea pork tunicate
*	white translucent	sponge	*	*Ciona intestinalis*	sea vase tunicate
*	cream encrusting	sponge	*	*Dendrodoa carnea*	drop of blood tunicate
*	filamentous white encrusting	sponge	*	*Didemnum albidum*	northern white crust
*	General encrusting organism			*Halocynthia pyriformis*	sea peach tunicate
	Cnidarians			*Boltenia ovifera*	stalked tunicate
	hydroids			Bryozoans	
	Campanularia sp.	hydroid	*	bryozoan	
*	*Corymorpha pendula*	solitary hydroid		*Membranipora* sp.	sea lace bryozoan
	Obelia geniculata	zig-zag hydroid	*	?*Crisia* spp.	bryozoan
	anemone		*	red crust bryozoan	bryozoan
	Metridium senile	frilly anemone		Miscellaneous	
	Urticina felina	northern red anemone		*Myxicola infundibulum*	slime worm

Table 6-2. Taxa observed during the 2001 nearfield hardbottom survey (cont'd).

	Taxon	Common Name		Taxon	Common Name
*	*Fagesia lineata*	lined anemone		spirorbids/small barnacles	
	Cerianthus borealis	northern cerianthid		*Terebratulina septentrionalis*	northern lamp shell
*	*Alcyonium digitatum*	dead man's fingers		Fish	
	Gersemia rubiformis	red soft coral		fish	
	Mollusks			*Gadus morhua*	cod
	gastropod		**	*Hemitripterus americanus*	sea raven
*	*Tonicella marmorea*	mottled red chiton		*Lophius americanus*	goosefish
*	*Crepidula plana*	flat slipper limpet		*Macrozoarces americanus*	ocean pout
*	nudibranch			*Myoxocephalus* spp.	sculpin
*	*Coryphella* sp.	red-gilled nudibranch		*Pseudopleuronectes americanus*	winter flounder
	Buccinum undatum	waved whelk	**	*Prionotus* spp.	sea robin
	Neptunea decemcostata	ten-ridged whelk	**	*Sebastes fasciatus*	rosefish
	Modiolus modiolus	horse mussel		*Tautogolabrus adspersus*	cunner
	Placopecten magellanicus	sea scallop	**	Dogfish	

* Only seen on still photographs
** Only seen on video

Table 6-3. List of taxa seen on still photographs taken during the 2001 nearfield hardbottom survey, arranged in order of abundance.

Taxon	Count	Taxon	Count
Algae		sponge	16
Coralline algae	3350[1]	*Urticina felina*	15
Rhodymenia palmata	1517	?*Crisia* spp.	15
Ptilota serrata	909[1]	*Arctica islandica*	13
Agarum cribrosum	36	*Obelia geniculata*	12
Total algae	**5812**	*Pteraster militaria*	12
		Ciona intestinalis	9
Invertebrates		tan encrusting sponge	7
juvenile *Asterias*	2550	*Membranipora* spp.	7
Metridium senile	2313	red crust bryozoan	5
Modiolus modiolus	1628	*Alcyonium digitatum*	4
Aplidium spp.	1045	*Homarus americanus*	4
white translucent sponge	984	hermit crab	4
Terebratulina septentrionalis	948	*Boltenia ovifera*	4
orange/tan encrusting sponge	729	filamentous white encrusting sponge	3
Halocynthia pyriformis	565	*Coryphella* sp.	3
orange encrusting sponge	521	*Crossaster papposus*	3
Didemnum albidum	513	*Corymorpha pendula*	2
Henricia sanguinolenta	470	*Cerianthus borealis*	2
Asterias vulgaris	365	*Tonicella marmorea*	2
white divided sponge on brachiopod	363	*Neptunea decemcostata*	2
general encrusting organism	360	*Polymastia?* sponge	1
Myxicola infundibulum	215	*Fagesia lineata*	1
bryozoan	186	gastropod	1
Strongylocentrotus droebachiensis	181	*Buccinum undatum*	1
Aplysilla sulfurea	179	nudibranch	1
Psolus fabricii	161	*Ophiopholis aculeata*	1
Dendrodoa carnea	153	hydroids	*
cream encrusting sponge	145	spirorbid/barnacle complex	*
Suberites spp.	131	**Total invertebrates**	**15400**
pink fuzzy encrusting sponge	115		
Balanus spp.	112	**Fish**	
Crepidula plana	67	*Tautogolabrus adspersus*	680
Halichondria panicea	62	*Myoxocephalus* spp.	23
Cancer spp.	54	*Pseudopleuronectes americanus*	13
Gersemia rubiformis	35	*Gadus morhua*	9
Campanularia sp.	28	fish	2
Melonanchora elliptica	26	*Macrozoarces americanus*	2
Placopecten magellanicus	24	*Lophius americanus*	1
anemone	22	**Total fish**	**730**

* Not counted

[1] Estimated

albidum (513 individuals), the blood sea star *Henrecia sanguinolenta* (470 individuals), and numerous sponges and encrusting organisms. The most abundant fish observed in the still photographs was the cunner *Tautogolabrus adspersus* (680 individuals).

Coralline algae was the most abundant and widely distributed taxon encountered during the survey. This encrusting alga was seen at 20 of the 23 waypoints, being absent from the two diffuser sites and from T10-1. Mean areal coverage of coralline algae ranged from 1% at T4-1 to 73% at T4/6-1. Figure 6-1 shows the relationships between depth, sediment drape, percent cover of coralline algae, and topography. Amount of sediment drape did not show a strong relationship with either depth or topography. Percent cover of coralline algae was quite variable and showed a weak general trend of higher cover at shallower depths. However, the strongest relationship was between percent cover of coralline algae and degree of sediment drape. Corallines were most abundant in areas that had minimal sediment drape on the rock surfaces and least abundant in areas that had heavy sediment cover. In contrast, the two most abundant upright algae, *Ptilota serrata* and *Rhodymenia palmata* had much more restricted distributions, with *P. serrata* being common at only 5 of the sites and *R. palmata* being common at only 7 of the sites. These upright algae frequently dominated in areas characterized by high relief and a moderate to heavy sediment drape. The reduced percent cover of coralline algae in areas supporting high abundances of upright algae appeared to be related to fine particles being trapped by the holdfasts of the upright algae and blanketing the rock surfaces. In areas with heterogeneous substrate characteristics, *P. serrata* and *R. palmata* frequently dominated on the tops of boulders, while corallines dominated on the cobbles and smaller boulders in between.

Several of the commonly seen invertebrates also exhibited wide distributional patterns. The northern sea star *Asterias vulgaris* was found at all of the sites. Juvenile *Asterias* were usually much more abundant than adults and were most abundant on the top of drumlins. The highest abundances of juvenile *Asterias* were found at T9-1, T4/6-1, T1-3 and T2-3, and the lowest abundances were found at T4-1 and T8-1. The horse mussel *Modiolus modiolus* was also very widely distributed, being found at all but three sites (T4-1 and the two diffuser sites). This mussel was most abundant on the top of drumlins, where large numbers frequently were observed nestled among cobbles and at the bases of boulders (T7-1, T9-1 and T7-2). Because of the mussel's cryptic nature of being nestled in among rocks and frequently being almost totally buried, the observed abundances should be considered very conservative. The number of mussels definitely would be underestimated in areas of high relief, because the bases of larger boulders frequently were not visible in the images. Two species of tunicates also were widely distributed. The sea pork tunicate *Aplidium* spp. was found at all but one of the sites and was most abundant at T1-5, T6-2, T8-1, and T8-2. The northern white crust tunicate *Didemnum albidum* was also found at all but one of the sites surveyed. The blood sea star *Henrecia sanguinolenta* was observed at all of the sites, and was most abundant on boulders in areas of high relief (T1-3, T4/6-1, T9-1 and T10-1).

Several other abundant invertebrates exhibited much more restricted distributions. Four of these species appeared to be primarily restricted to large boulders. The brachiopod *Terebratulina septentrionalis* was found at 11 of the sites, but was only seen in high abundances at 3 of them (T2-3, T2-4, and T9-1). This species appeared to be restricted to the sides of large boulders where it might be protected from sediment loading, which could clog their filtering apparatuses. Another species that was markedly more abundant on large boulders was the frilled anemone *Metridium senile*. This anemone was found at 14 sites, but was abundant at only 6 of them. It was abundant on large boulders at T1-2, T1-3, T9-1, and T10-1, and was very abundant on the two diffuser heads (#2 and #44). This anemone was usually seen on the tops of boulders. The sea peach tunicate *Halocynthia pyriformis* was found at 15 sites but was only found in high abundances on the two diffuser heads. The species with the most restricted distribution was the soft coral *Gersemia rubiformis*, which was seen only at T10-1 where it commonly inhabited the tops of large boulders characteristic of this site.

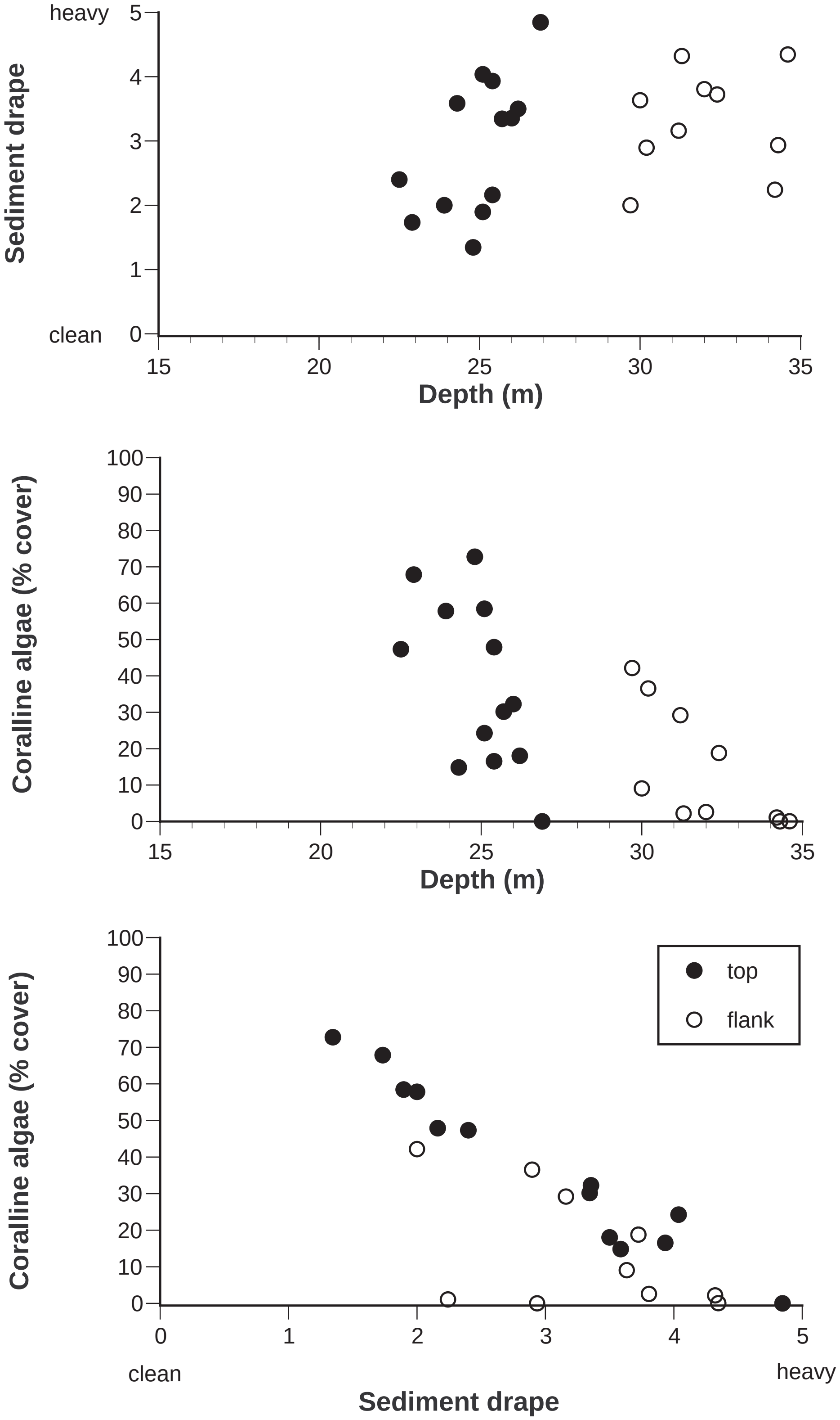


Figure 6-1. Depth, sediment drape, and percent cover of coralline algae of the sites from the 2001 nearfield hardbottom survey.

The distribution of the green sea urchin *Strongylocentrotus droebachiensis* appeared to be related to food availability rather than specific substrate characteristics. This urchin was widely distributed, but was only found in high abundances in regions that had high cover of coralline algae (T1-2, 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 18 sites, but was abundant at only 6 of them (T1-2, T2-4, T4/6-1, T6-2, T8-1, and T8-2). Reasons for its high abundance at some sites, and not at others, were not readily apparent.

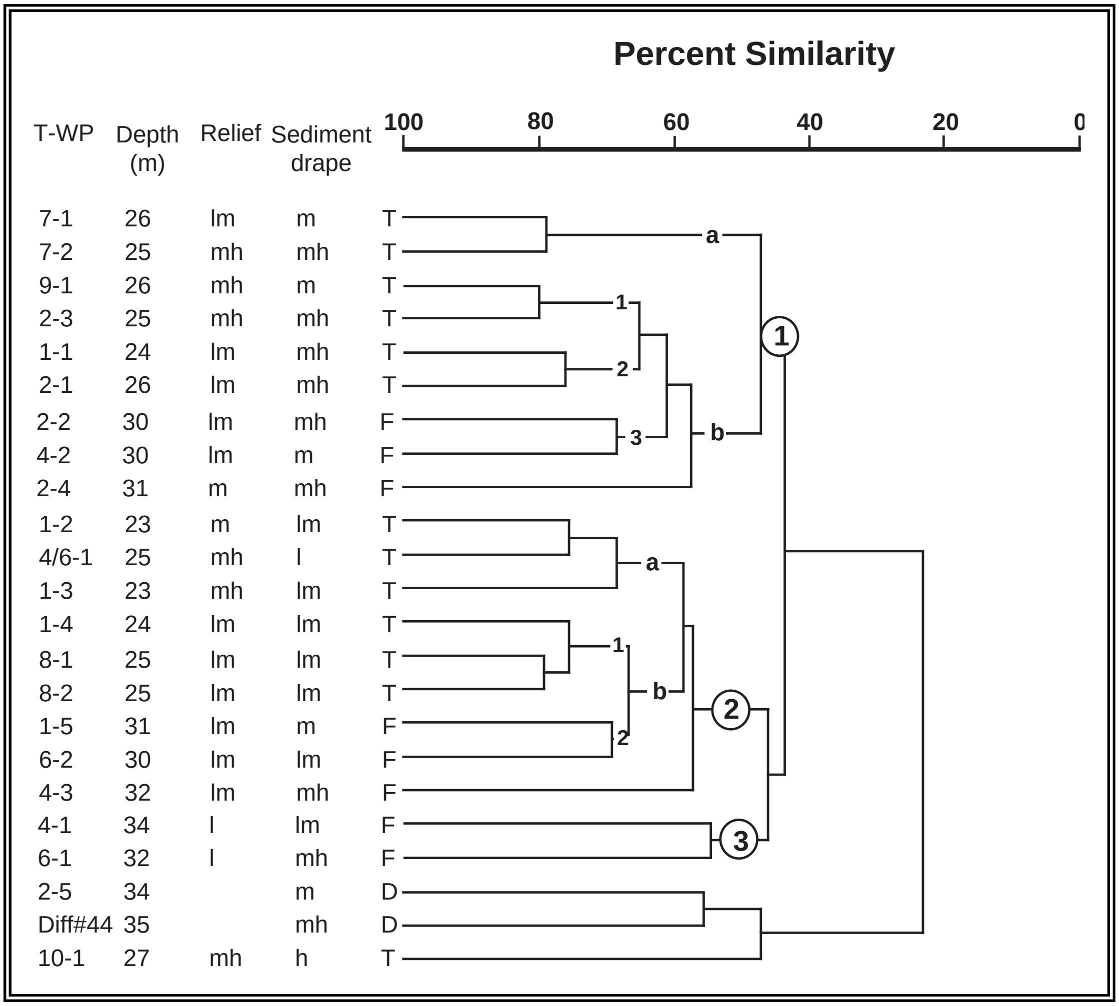
Encrusting invertebrate taxa generally were most abundant in moderate to high relief areas that had light to moderate sediment drape on the rock surfaces. This is not surprising because most juveniles of attached taxa require sediment-free surfaces for settlement. Additionally, clean rock surfaces are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

The fish fauna was dominated by the cunner *Tautogolabrus adspersus*, which was observed at 21 of the waypoints. This fish was most abundant in moderate to high relief areas, where it tended to congregate among large boulders (T1-2, T1-3, T4/6-1, and T7-2). In areas of heterogeneous relief, *T. adspersus* frequently was seen only in the vicinity of boulders. Five other fish species, sculpin (*Myoxocephalus* spp.), winter flounder (*Pseudopleuronectes americanus*), ocean pout (*Macrozoarces americanus*), cod (*Gadus morhua*), and goosefish (*Lophius americanus*) also were seen on the still photographs. The sculpin and flounder were usually in areas of lower relief, while cod and ocean pout were only observed in areas of higher relief. Only one goosefish was seen.

6.3.3 Community Structure

Classification of the 23 waypoints and 41 taxa (retained for analysis) defined three clusters of stations and three outlier areas (Figure 6-2). The first two clusters further divided into slightly more cohesive subgroups. The first cluster consisted drumlin top and flank areas that had relatively heavy sediment drape. The drumlin top areas included the three northern reference sites (T7-1, T7-2, and T9) and three sites on the drumlin north of the outfall (T1-1, T2-1, and T2-3). The three flank areas in cluster 1 were sites on drumlins adjacent to the outfall. The second cluster consisted of drumlin top and flank areas that had mostly light to moderate sediment drape. These included the two southernmost reference sites (T8-1 and T8-2), as well as sites on the drumlins north and south of the outfall. The third cluster consisted of 2 low-relief areas that were located on the flanks of the drumlin south of the outfall (T4-1 and T6-1). The first two outliers areas consisted of the two diffuser heads (#2 at T2-5 and #44) and the areas immediately surrounding them. The last outlier was the reference site located just southwest of the outfall (T10-1). This area is characterized by moderately high relief and heavy sediment drape. The clustering structure appeared to be determined by a combination of drumlin topography, habitat relief, sediment drape, and geographic location. Neighboring waypoints with similar habitat characteristics tended to cluster together. Habitat characteristics and range of abundances of dominant taxa for each of the cluster groups are presented in Table 6-4.

Encrusting coralline algae were common inhabitants of all but a few of the areas comprising the first two cluster groups. Differences among the areas in these two cluster groups were mainly related to the relative proportion of encrusting and upright algae at each of the sites. All except two of the areas in Cluster 1 supported numerous upright algae, *Ptilota serrata* and *Rhodymenia palmata*. In contrast, the areas in Cluster 2 were dominated by encrusting coralline algae and supported few, if any, upright algae. The nine areas in Cluster 1 divided into four subgroups and one individual site. The divisions reflected shifts in the composition of the communities inhabiting these areas, as well as differences in the abundances of their biotic inhabitants. All of the areas, except the two flank sites in subgroup $1b_3$,



T-WP	Depth (m)	Relief	Sediment drape	
7-1	26	lm	m	T
7-2	25	mh	mh	T
9-1	26	mh	m	T
2-3	25	mh	mh	T
1-1	24	lm	mh	T
2-1	26	lm	mh	T
2-2	30	lm	mh	F
4-2	30	lm	m	F
2-4	31	m	mh	F
1-2	23	m	lm	T
4/6-1	25	mh	l	T
1-3	23	mh	lm	T
1-4	24	lm	lm	T
8-1	25	lm	lm	T
8-2	25	lm	lm	T
1-5	31	lm	m	F
6-2	30	lm	lm	F
4-3	32	lm	mh	F
4-1	34	l	lm	F
6-1	32	l	mh	F
2-5	34		m	D
Diff#44	35		mh	D
10-1	27	mh	h	T

Figure 6-2. Cluster analysis of data collected from still photographs taken during the 2001 nearfield hardbottom survey.

supported upright algae. Subgroup 1a, which consisted of the two northernmost reference sites (T7-1 and T7-2), supported the highest abundances of both dulse and filamentous red algae, as well as the horse mussel *Modiolus modiolus*. Subgroup 1b$_1$, which consisted of the other northern reference site (T9-1) and T2-3, supported moderate numbers of both upright algae, as well as high numbers of juvenile northern sea stars *Asterias vulgaris* and northern lamp shells *Terebratulina septentrionalis*. In contrast, the two-drumlin top areas in subgroup 1b$_2$ supported mainly dulse, the sea pork *Aplidium* spp. and juvenile *A. vulgaris*. The two flank areas in subgroup 1b$_3$ supported the highest number of adult *A. vulgaris*. The other drumlin flank area in cluster 1, site T2-4, supported numerous *T. septentrionalis* and moderate numbers of dulse, juvenile *A. vulgaris*, and the sea peach *Halocynthia pyriformis*. The biota at the northernmost reference sites consisted of roughly an equal mix of algae and invertebrates, while the biota at the remaining sites in this cluster was dominated by invertebrates.

The benthic communities at all of the areas in Cluster 2 were dominated by either coralline algae or invertebrates, but never by upright algae. The areas in this cluster further divided into three subgroups and one individual site. Coralline algae was the dominant component of the benthic communities found at all six of the drumlin top sites in this cluster (subgroups 2a and 2b$_1$), with all of the sites having greater than 47 percent cover. The three sites in subgroup 2a had moderate to moderately high relief and supported numerous juvenile *A. vulgaris*, moderate numbers of green sea urchins *Stongylocentrotus*

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

Cluster	1					2				3			
	a	b_1	b_2	b_3	T2-4	a	b_1	b_2	T4-3		T2-5	Diff #44	T10-1
Depth (meters)	25-26	25-26	24-26	30	31	23-25	24-25	30-31	32	32-34	34	35	27
Habitat relief[a]	LM-MH	MH	LM	LM	M	M-MH	LM	LM	LM	L			MH
Sediment drape[b]	m-mh	m-mh	mh	m-mh	mh	l-lm	lm	lm-m	mh	lm-mh	m	mh	h
Location[c]	T	T	T	F	F	T	T	F	F	F	D	D	T
Ptilota serrata	**8.6-13.9**	**3.0-4.3**	0.0-1.0	-	0.1	0.0-0.5	-	-	-	-	-	-	-
Rhodymenia palmata	**13.0-13.7**	**5.6-8.0**	**2.7-4.8**	-	**3.3**	0.0-0.4	0.0-0.1	-	-	-	-	-	0.7
Coralline algae	4.3-5.7	2.9-5.5	3.6-4.4	2.3-5.9	0.6	**8.0-14.0**	**8.2-12.6**	5.0-7.7	4.3	0.5-0.7	-	-	-
Coralline algae (percent cover)	24-32	17-30	15-18	9-37	2	**47-73**	**48-58**	29-42	19	1-3	-	-	-
Modiolus modiolus	**7.3-11.9**	2.4-9.7	1.3-2.7	1.0-2.8	0.9	0.4-4.0	2.1-2.8	0.2-1.3	0.1	0.0-0.3	-	-	1.5
Asterias vulgaris (juvenile)	4.0-4.5	**7.8-8.4**	4.2-6.0	3.8-4.7	3.6	**4.4-10.5**	0.6-4.4	1.2-4.6	1.5	0.6-1.3	1.1	3.9	4.6
Asterias vulgaris (adult)	0.3-0.4	0.3-0.5	0.3-0.4	**1.6-1.9**	0.6	0.3-0.6	0.1-0.2	0.3	0.6	0.4-0.7	**1.4**	0.5	0.6
Terebratulina septentrionalis	0.0-0.3	**6.7-7.1**	0.0-0.1	0.9-3.1	**9.7**	0.0-4.5	-	-	-	-	-	-	-
Aplidium spp.	0.1-0.3	1.1-1.6	**2.3-2.5**	1.2-1.4	2.2	0.3-1.9	**2.8-4.3**	**3.6-4.2**	0.1	0.1-1.2	0.5	-	0.3
Strongylocentrotus droebachiensis	0.1-0.4	0.2	0.2	0.0-0.1	-	**0.7-1.1**	0.1-0.8	0.2-0.3	-	-	0.2	0.3	-
Metridium senile	0.0-0.1	0.0-2.6	-	0.0-0.1	0.1	0.2-5.4	0.0-0.1	0.0-0.1	-	-	**54.8**	**10.9**	**7.46**
Halocynthia pyriformis	0.0-0.2	0.3-0.8	0.0-0.2	0.4-1.8	1.7	0.0-0.1	-	-	-	-	**4.4**	**9.3**	1.1
Gersemia rubiformis	-	-	-	-	-	-	-	-	-	-	-	-	**2.7**
Tautogolabrus adspersus	1.2-5.4	0.7-2.2	0.3	0.0-0.2	0.9	**3.3-3.8**	0.0-0.4	0.1-0.5	0.1	-	0.8	0.3	1.8
Algae	**27.4-32.9**	11.6-17.9	7.0-9.4	2.3-5.9	4	**9.0-14.3**	**8.2-12.6**	5.0-7.7	4.3	0.5-0.7	-	-	0.7
Invertebrates	22.2-27.9	**33.2-46.9**	16.6-22.9	23.7-26.9	**41.8**	**16.1-33.7**	11.0-15.5	9.9-21.4	9	2.2-6.3	**70.3**	**29.2**	**30.7**
Fish	1.3-5.5	0.7-2.4	0.3-0.4	0.2-0.4	0.9	3.3-3.8	0.0-0.4	0.2-0.7	0.2	0-0.1	0.9	0.3	1.8
Total	**56.6-60.6**	**47.1-65.4**	26.3-30.2	29.6-29.8	**46.7**	**28.9-51.7**	20.5-27.8	15.0-29.8	13.6	2.8-7.1	**71.2**	**29.5**	**33.2**

Key:

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

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

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

droebachiensis, and high numbers of cunner *Tautogolabrus adspersus*. In contrast, the three sites in subgroup $2b_1$ had moderately low relief and supported high numbers of *Aplidium* spp. The two flank sites in subgroup $2b_2$ also supported high numbers of *Aplidium* spp., but had a lower percent cover of coralline algae. The remaining flank site in this cluster (T4-3) supported relatively low numbers of algae and fauna. All of the areas in cluster 2 supported more invertebrates than algae.

The two-drumlin flank areas in Cluster 3 had low relief, variable sediment drape and were relatively depauperate. In contrast, the three outlier areas supported quite dense invertebrate communities. The two diffusers heads provided suitable attachment sites for numerous *Metridium senile* and *Halocynthia pyriformis*, with the active diffuser (#2 at T2-5) supporting more *M. senile* and the inactive diffuser (#44) supporting more *H. pyriformis*. The rock rubble surrounding the diffusers supported few organisms. The sea floor at the remaining outlier area, T10-1, consisted mainly of large boulders that provided suitable attachment sites for numerous *M. senile* and the red soft coral *Gersemia rubiformis*, This site also supported numerous juvenile *A. vulgaris* and moderate numbers of cunner.

6.4 Spatial and Temporal Trends in the Nearfield Hardbottom Benthos

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

In addition to a sampling plan that evolved to address specific issues, the emphasis on data products also has evolved. The 1994 and 1995 data sets relied mainly on an analysis of video footage. Some still photographs were also taken at each of the sites during the 1995 survey. Analysis of these photographs showed that the resolution afforded by the still photographs was far superior to that of the video images, and hence subsequent emphasis has been shifted to analysis of still photographs. The video images cover a much broader area than the still photographs, and are primarily used to assess habitat relief, spatial heterogeneity, and the occurrence of large, rare biota. The still photographs are used to provide detailed data on habitat characteristics (substrate size classes and amount of sediment drape), estimated percent cover of encrusting algae, estimated relative abundances of upright algae, and faunal composition of the benthic communities.

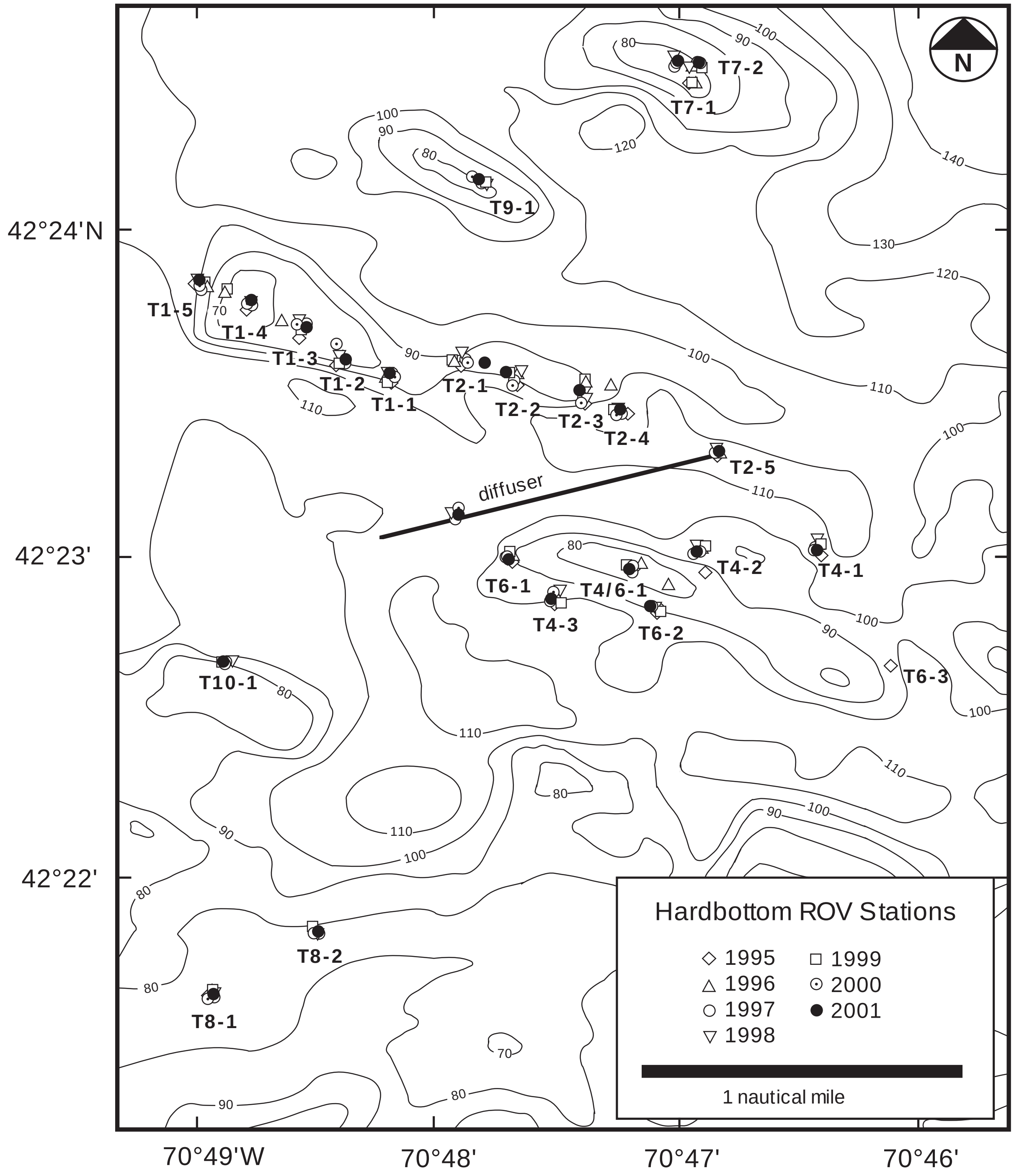


Figure 6-3. Nearfield hardbottom stations surveyed from 1995 to 2001.

The hardbottom habitats are spatially quite variable, but have shown several consistent trends. At many of the waypoints, year-to-year variations in habitat characteristics tended to be relatively small. Figure 6-4 shows the habitat relief observed during the 1995 to 2001 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 sea floor on the flanks of drumlins was quite variable, but usually consisted of a cobble pavement interspersed with patches of sand, gravel and occasional boulders. Habitat relief on the flanks ranged from low (T4-1, T4-2, T4-3, T6-1, and T6-2) to moderate (T1-5 and T2-4), depending on how many boulders were present. Figure 6-5 shows the relative amount of sediment drape seen on the rock surfaces during the 1995 to 2001 surveys. Sediment drape tended to be light on the shallowest part of the drumlins adjacent to the outfall (T1-2, T1-3, T1-4 and T4/6-1), moderately light at the southernmost reference sites (T8), and moderately heavy or heavy at the other southern reference site (T10), the northern reference stations (T7-2 and T9-1), and some of the flank stations (T4-1 and T6-1). The tops of the drumlins were relatively homogeneous, so that lateral shifts in position did not result in widely different habitat characteristics (*i.e.*, T1-3, T1-4, T4/6-1, T8, T9 and T10). In contrast, the edges of the drumlin tops and the flanks were more heterogeneous, such that small lateral shifts in position frequently resulted in substantially different habitat characteristics (*i.e.*, T1-1, T1-2, T1-5 and T4-2). It was noted that several of the stations north of the outfall had slightly more sediment drape in 2001 than at any time during the baseline period.

The benthic communities inhabiting the hardbottom areas showed similar patterns both pre- and post-discharge. Algae dominated on the tops of drumlins, while invertebrates (mostly encrusting or attached forms) were increasingly dominant on the flanks. Encrusting coralline algae was the most abundant and widely distributed taxon encountered during each year of the study. Figure 6-6 shows the percent cover of coralline algae estimated from the 35-mm images taken during the 1995 to 2001 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. The distribution and areal coverage of coralline algae remained relatively stable during the 1995 to 2000 “baseline” period, and showed slight decreases in percent cover at several stations in 2001. Table 6-5 shows the estimated percent cover of coralline algae for the 1996 to 2001 time period. The locations that had lower percent cover of coralline algae in 2001, were three neighboring stations on the top of the drumlin immediately north of the outfall (T1-2, T1-3, and T1-4) and the two northernmost reference sites (T7-1 and T7-2).

It is unlikely that light attenuation with depth is a limiting factor for coralline algae, within the range of depths covered during this survey. Vadas and Steneck (1988) reported coralline algal cover of up to 80% at depths >50 m on Ammen Rock Pinnacle in the Gulf of Maine and Sears and Cooper (1978) reported finding coralline algae at depths of 47 m on offshore ledges in the Gulf of Maine. Additionally, numerous coralline algae have been observed at a depth of 34 m at a hardbottom site in Massachusetts Bay near Scituate (B. Hecker, personal observation). The overall relationships among depth, sediment drape and percent cover of coralline algae can best be seen on Figure 6-7. Sediment drape on rock surfaces shows a slight tendency to increase with increasing depth and coralline algae shows a weak trend of decreasing cover with increasing depth. The plot of percent cover of coralline algae versus sediment drape shows that the abundance of corallines appears to be strongly related to sediment drape; percent cover was highest in areas that had little drape and lowest in areas with moderate to heavy drape. This is not surprising, because the encrusting growth form of coralline algae would make them susceptible to smothering by fine particles.

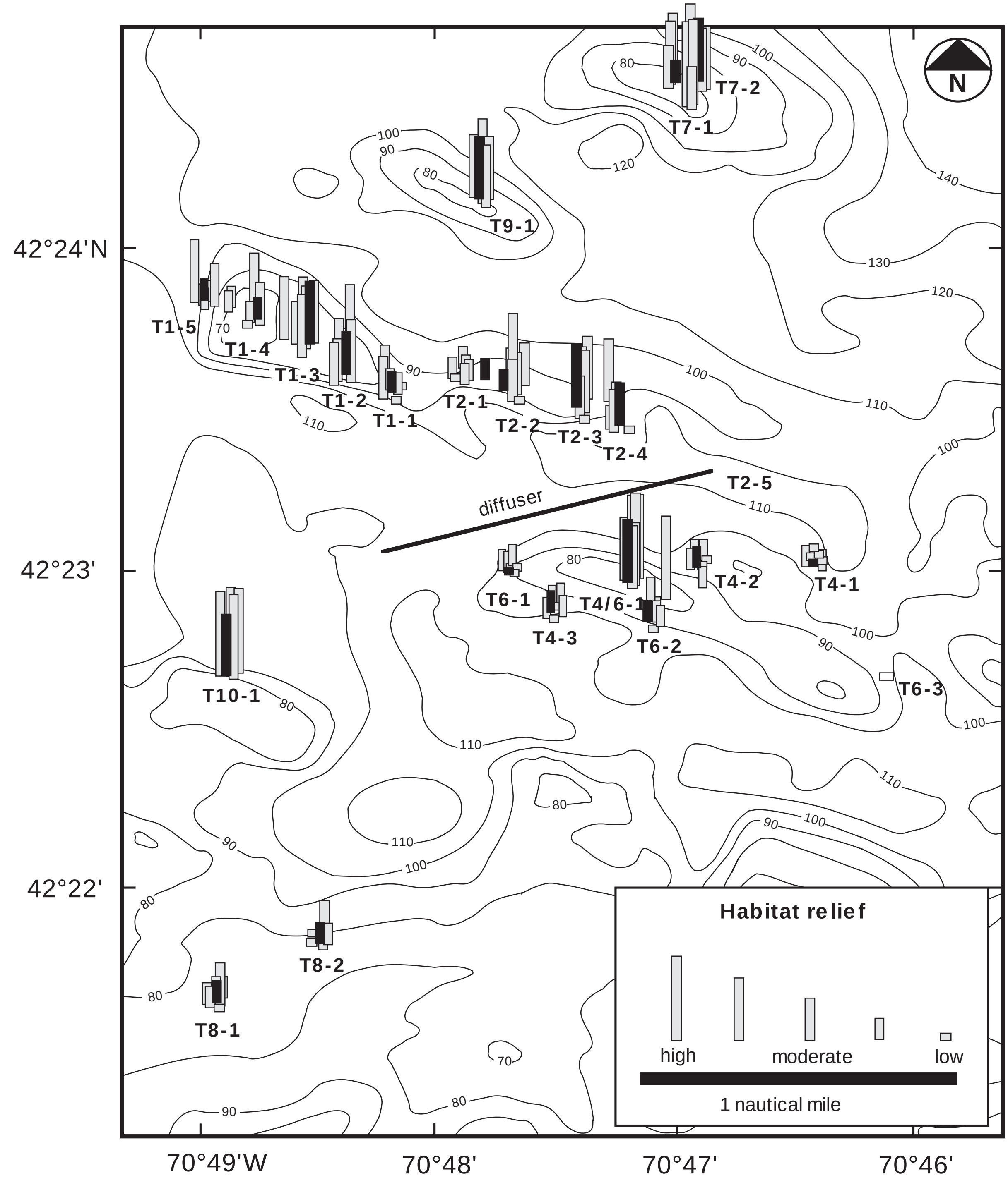


Figure 6-4. Habitat relief determined from the 1995 to 2001 nearfield hardbottom surveys. Gray bars are pre-discharge values and black bars are post-discharge (2001) values.

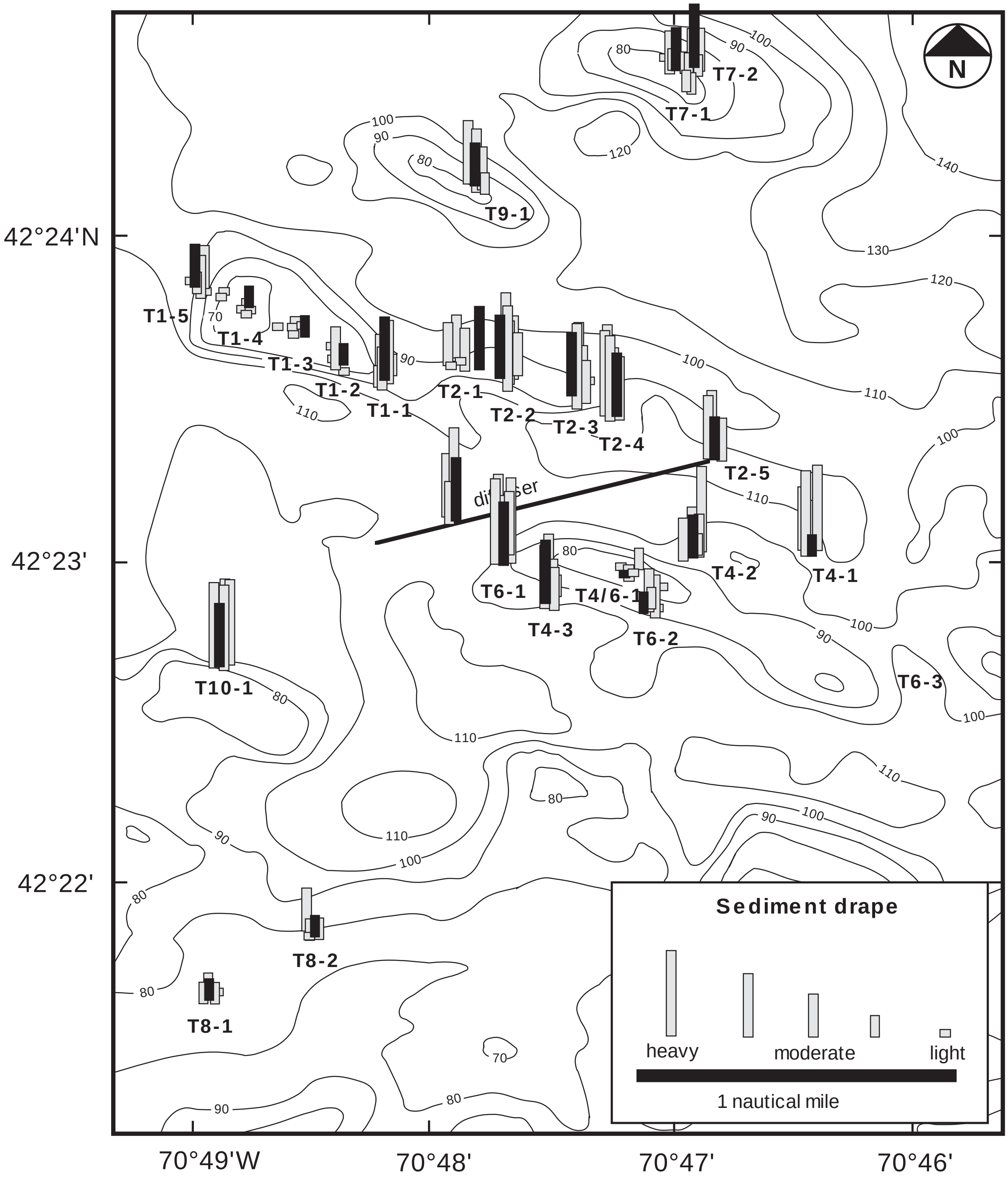


Figure 6-5. Sediment drape determined from the 1995 to 2001 nearfield hardbottom surveys. Gray bars are pre-discharge values and black bars are post-discharge (2001) values.

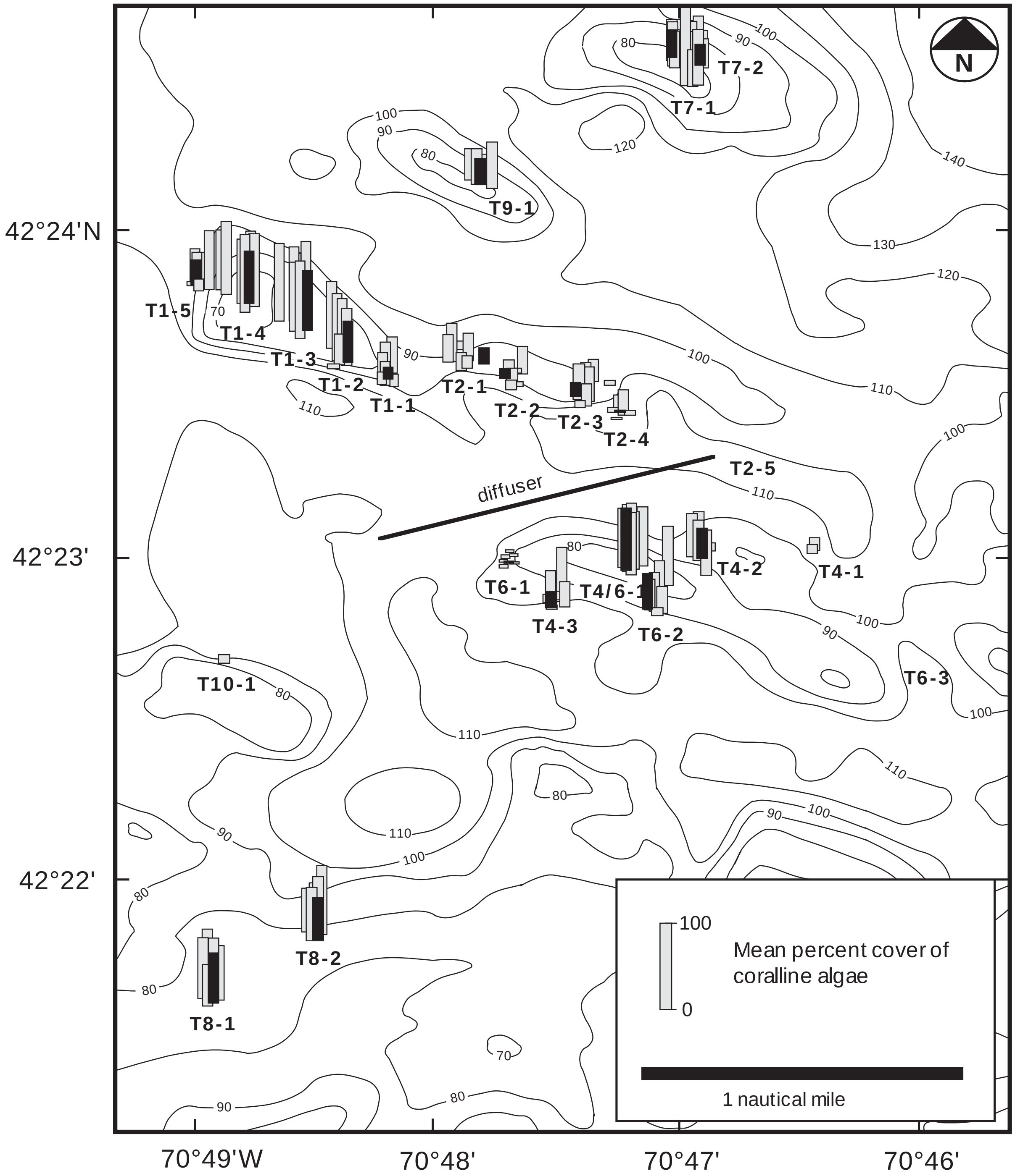


Figure 6-6. Percent cover of coralline algae determined from the 1995 to 2001 nearfield hardbottom surveys. Gray bars are pre-discharge values and black bars are post-discharge (2001) values.

Table 6-5. Estimated percent cover of coralline algae from 1996 to 2001. Large differences between pre- and post-discharge are highlighted by shading. Asterisks mark differences that appear to be related to shifts in position of the areas surveyed.

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

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

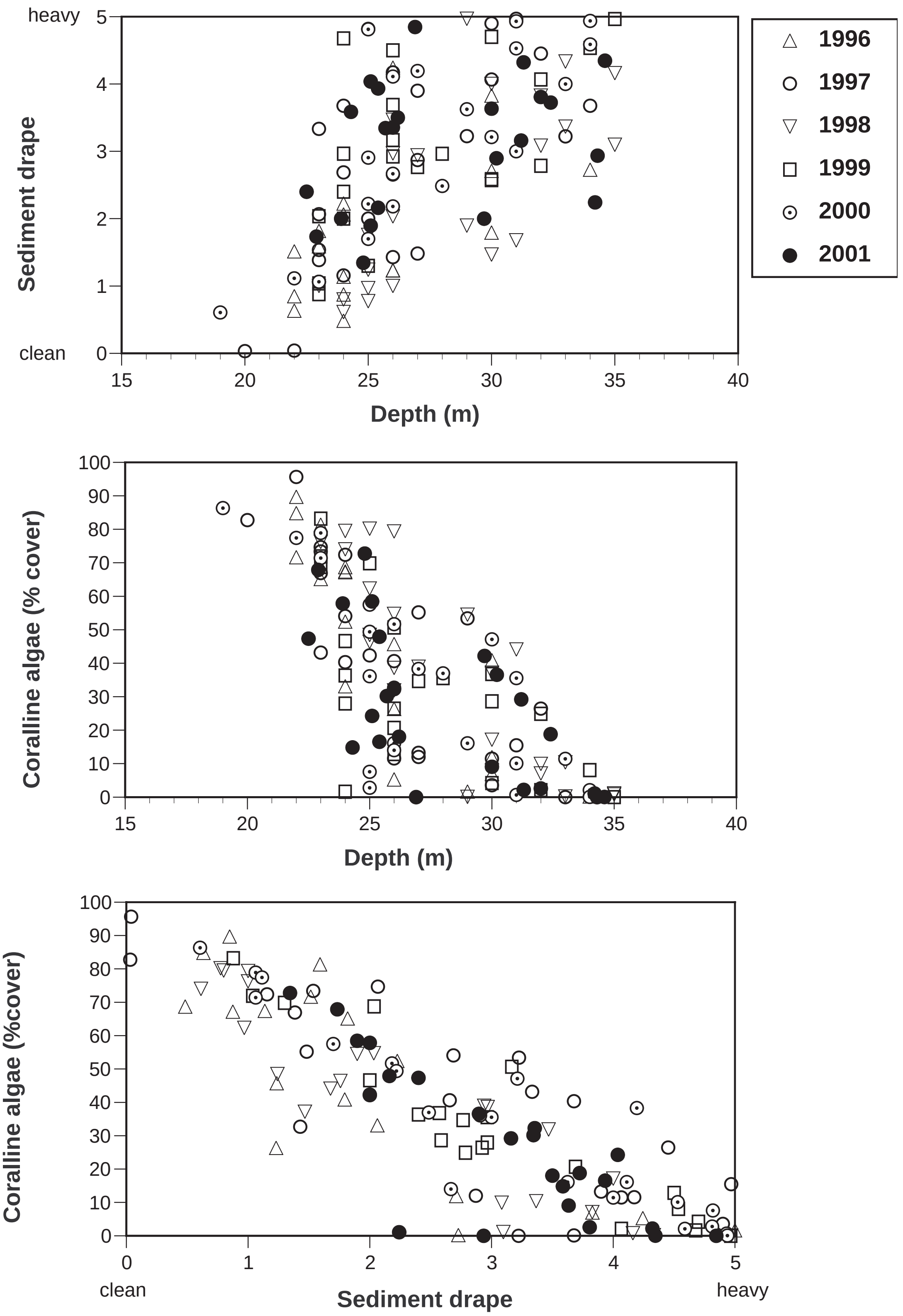


Figure 6-7. Depth, sediment drape, and percent cover of coralline algae determined from the 35-mm images taken at each waypoint during the 1996 to 2001 nearfield hardbottom surveys.

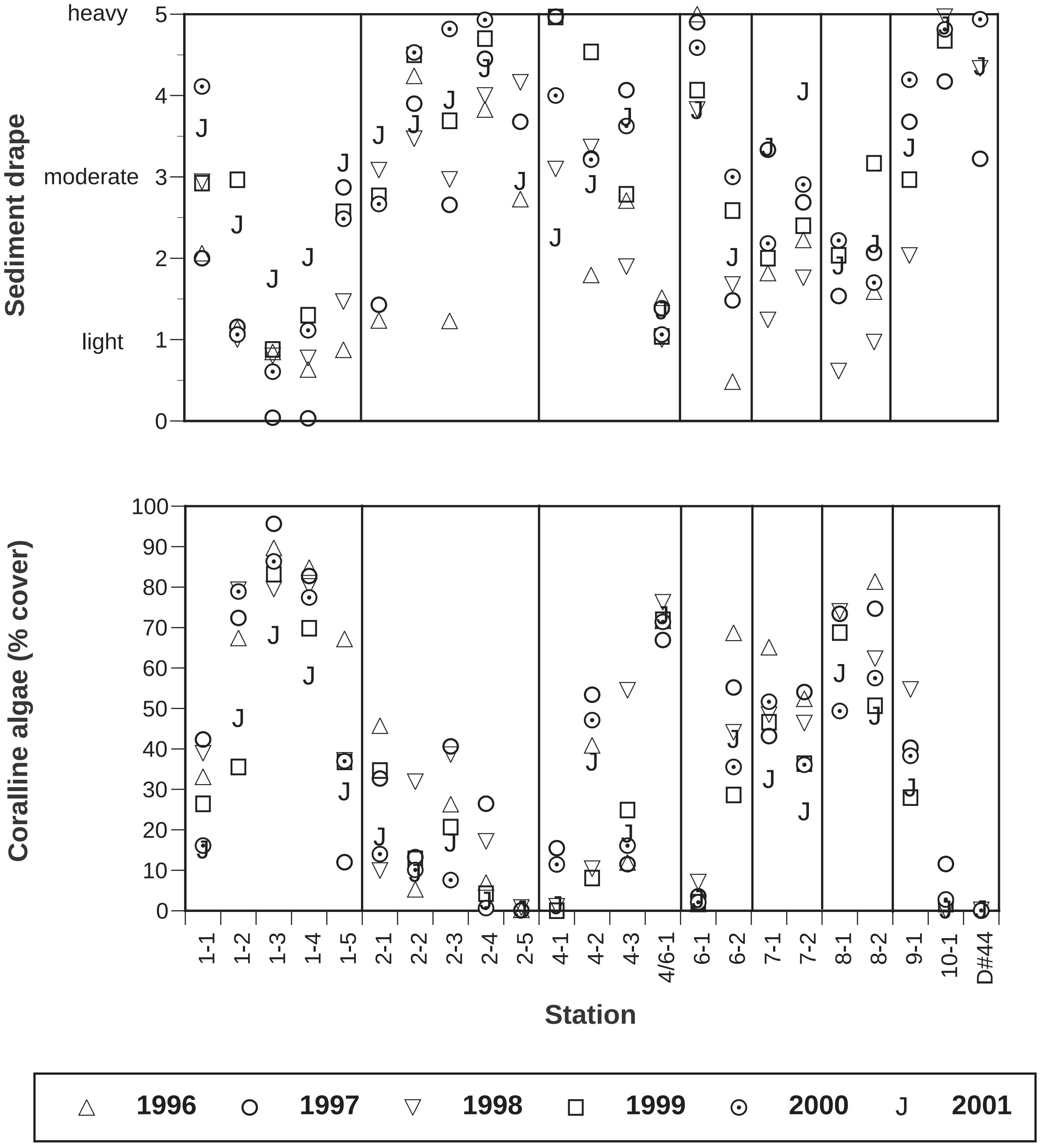


Figure 6-8. Sediment drape and percent cover of coralline algae at the nearfield hardbottom sites determined from 35-mm slides taken during the 1996 to 2001 surveys.

In contrast to the wide distribution of coralline algae, the distribution of the three upright algae inhabiting the drumlins, the filamentous red alga *Ptilota serrata,* the dulse *Rhodymenia palmata*, and the shotgun kelp *Agarum cribosum*, were quite restricted. Additionally, the abundance of these algae varied quite widely during the baseline period (Figure 6-9). This high variance appears to reflect a high degree of patchiness in the small-scale (within station) spatial distributions (see T2, T7 and T9) of the upright algae, rather than temporal changes. Dense stands of upright algae were frequently seen neighboring areas totally devoid of them. The observed spatial patchiness may reflect the fact that upright algae were only 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 only abundant at the northern reference sites. The abundances found in 2001 were generally within the range of pre-discharge abundances, with the exceptions that *P. serrata* and shotgun kelp were less abundant at T9 in 2001 and dulse was more abundant at T7 in 2001. However, the high variability in the abundance of these algae during the baseline period would make it hard to detect subtle changes with any degree of confidence.

The pattern of benthic community structure has been remarkably consistent in the hardbottom areas. Figure 6-10 shows the distribution of benthic communities defined by hierarchical classification analysis. The dendogram depicting the 2001 data (Figure 6-2) was similar to those from the last five years of baseline (see Blake *et al.* 1997, Blake *et al.* 1998, Kropp *et al.* 2000, Kropp *et al.* 2001, Kropp *et al*. 2002 for the 1996, 1997, 1998,1999, and 2000 dendograms). At many of the sites the benthic communities remained stable during the baseline period and this pattern did not change with the start of discharge (Table 6-6). Good examples of this can be seen at all three of the northern reference sites (T7 and T9) and T2-3 which were always in cluster 1, and the two southernmost reference sites (T8) and the top of the drumlin north of the outfall (T1-2, T1-3, and T1-4) which were always in cluster 2. Three instances of departure from baseline conditions in cluster designation were noted in the 2001 data. All three of these instances appear to reflect spatial variability in the benthic communities rather than changes in community structure due to the discharge. The benthic community at T2-1 was dominated by coralline algae during the baseline period and by upright algae in 2001. However, the area surveyed in 2001 was located slightly east of the station, and was closer to an area dominated by upright algae during the pre-discharge period (T2-2). The other two instances of waypoints differing in cluster designation between pre- and post-discharge were waypoints T4-1 and T4-2, both of which showed substantial spatial variability during the baseline period.

The baseline surveys showed that the diffuser heads were heavily colonized by *Metridium senile*, *Halocynthia pyriformis* and *Asterias vulgaris*. The same communities were found on both the active (T2-5, Diffuser #2) and inactive (Diffuser#44) diffusers in 2001. The diffuser head at T2-5 had last been surveyed in 1997 when it supported exceptionally dense aggregations of *M. senile*. This diffuser head went online in 2000 and was actively discharging in 2001 with dense stands of this anemone still present on the top and in the port indentations of the diffuser head. In contrast, diffuser #44 had last been surveyed in 2000, and was colonized by more *H. pyriformis* than *M. senile*, as well as by a large finger sponge *Haliclona* sp (Appendix F, Plate 10, in Kropp *et al*, 2002). In 2001, this diffuser which has remained inactivate was still colonized by the tunicates and anemones, but the large sponge had disappeared. It is impossible to tell if the sponge has disappeared due to the discharge activity or whether it was damaged during the 2000 survey.

Several striking trends, that may reflect widespread temporal changes in the population structure of individual taxa, have been noted over the time course of the nearfield hardbottom surveys. These changes do not appear to be related to the outfall discharge. The green sea urchin *Strongylocentrotus droebachiensis* has shown a steady decline in abundance from 478 individuals in 1996 to 181 individuals

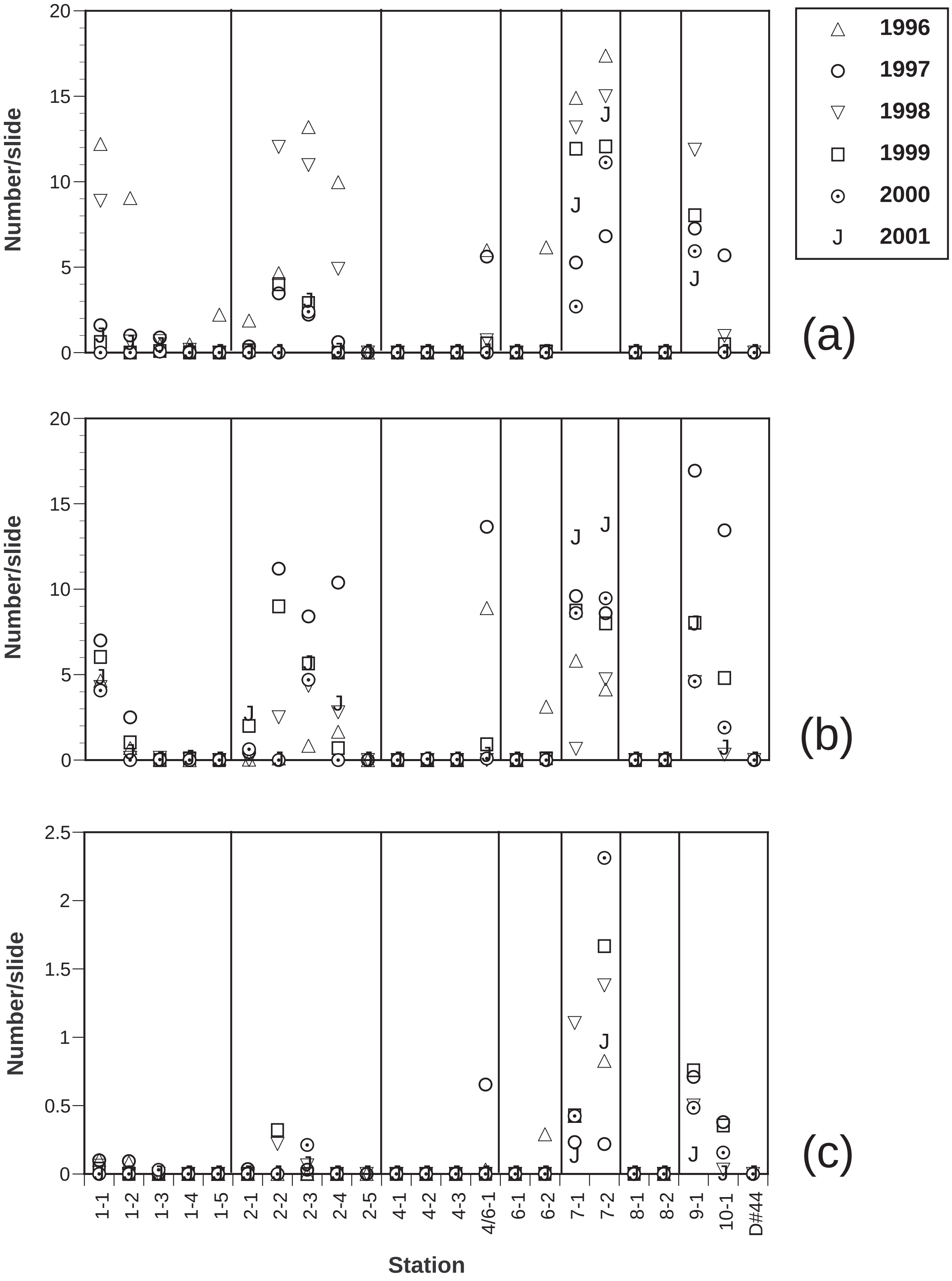


Figure 6-9. Abundance of three species of upright algae, (a) *Ptilota serrata*, (b) *Rhodymenia palmata*, and (c) *Agarum cribosum*, at the nearfield hardbottom sites determined from 35-mm slides taken during the 1996 to 2001 surveys.

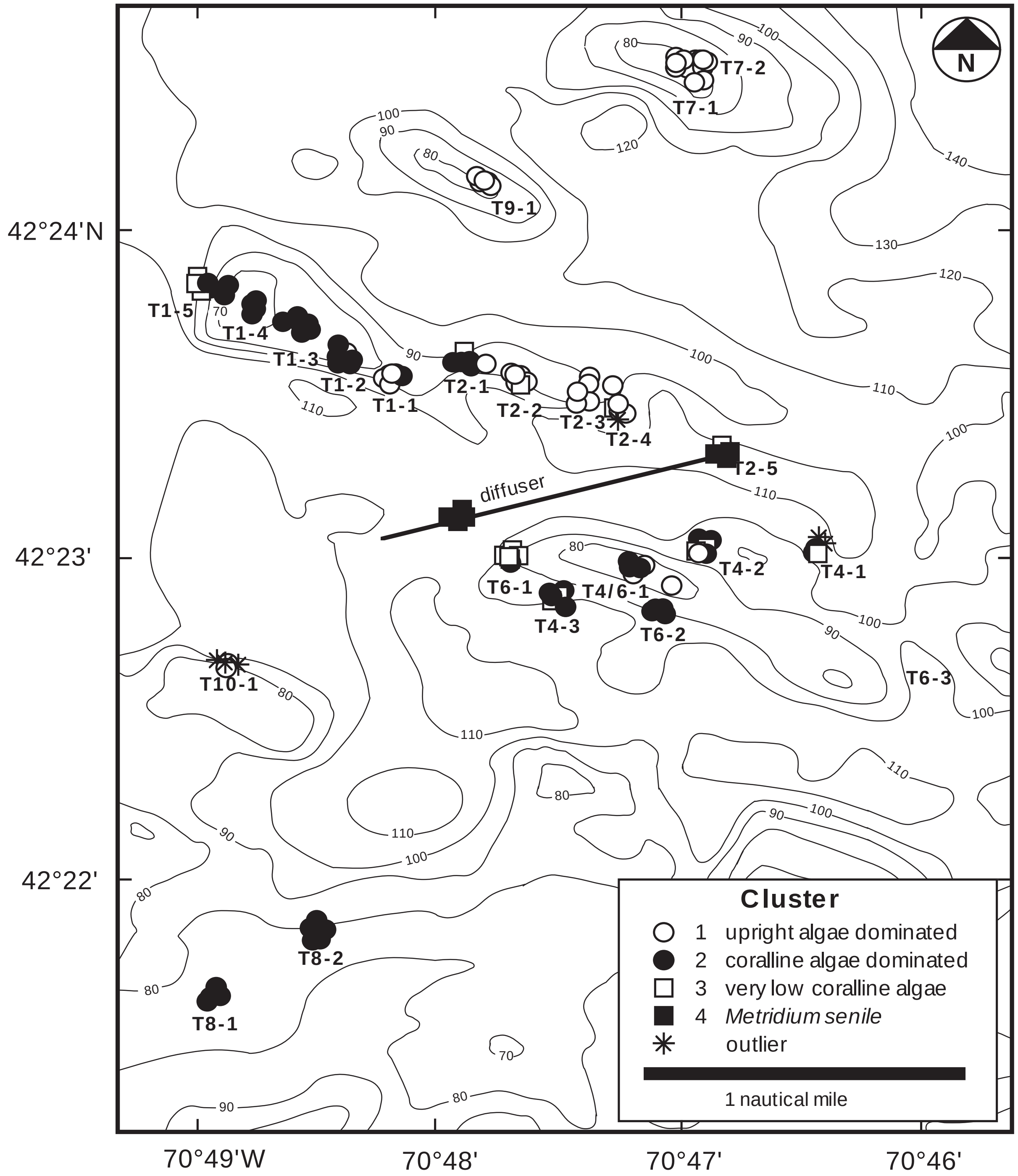


Figure 6-10. Map of benthic communities defined from classification of the 35-mm images taken during the 1995 to 2001 nearfield hardbottom surveys.

Table 6-6. Cluster group designations defined by classification analysis of the waypoints surveyed from 1996 to 2001. Differences between pre- and post-discharge are highlighted by shading. Asterisks show differences explained by shifts in location.

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

in 2001. In contrast, two other species, the crab *Cancer* sp. and the cod *Gadus morhua*, appear to be increasing. In the still photographs, one to six *Cancer* crabs were seen annually between 1996 and 1999, 20 were seen in 2000, and 54 were seen in 2001. This pattern was also reflected in the video data, with 3 to 17 *Cancer* crabs observed annually between 1996 and 1999, 105 in 2000, and 147 in 2001. A similar trend was seen in the video data for codfish, with none seen in 1996 to 41 seen in 2001. Interestingly, no cod had been seen at the diffuser stations during the baseline years, yet in 2001 six and eight cod were seen at T2-5 and Diffuser #44, respectively. Codfish generally tend to shy away from the ROV, frequently ducking behind rocks, but at the diffuser sites they were much less hesitant and occasionally came right up to the vehicle. In contrast, the codfish seen at the other stations tended to avoid the ROV.

The increase in the number of codfish and *Cancer* crabs in recent years has also been noted by local fishermen (Frank Mirarchi, personal communication).

Our results from the baseline period, and the first post-discharge year, generally were similar to those reported by Coats *et al.* (1995) from the 1994 video survey. Four of the eight transects covered in this report (Transects 1, 2, 4 and 6) were the same as those included in the 1994 survey. The 1994 survey consisted of near continuous video coverage along the transects, while the present design focuses on topographically selected points (waypoints) along the transects that include representative drumlin top and flank locations. The 1995-2001 surveys respectively identified 76, 72, 100, 84, 78, 65, and 65 taxa, compared to 37 identified from the 1994 survey. Rather than indicating changes in the benthic communities, the greater number of taxa identified from the post-1994 surveys appear to be related to the enhanced visual resolution of the still photographs. Many of the additional taxa identified in the later surveys are encrusting forms that would be difficult to resolve on video images. Additionally, the ROV has been kept much closer to the sea floor in the post-1994 surveys (right on the bottom as opposed to an altitude of 1 to 3 meters). Differences in taxonomic designations also exist between the 1994 and post-1994 surveys. Coats *et al.* identified an abundant pinnate red alga as *Rhodymenia* sp A, this appears to be the filamentous red alga that we have designated as *Ptilata serrata* based on collection of a voucher specimen (identified as *Asparagopsis hamifera* in the 1995 to 1999 surveys). Additionally, their Porifera sp. A was an orange encrusting sponge, which is probably the orange/tan sponge commonly seen during the present study.

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

General faunal distribution patterns were similar among the 1994 to 2001 surveys. All surveys found algae to be most abundant on the tops of drumlins. Coats *et al.* reported that *Rhodymenia palmata*, *Rhodymenia* sp. A (a pinnate red alga), and *Agarum cribosum* were found together on hard substrata at shallower depths. In the later surveys (1995-2000), coralline algae were found to dominate on cobbles and smaller boulders, while *Ptilata serrata*, *R. palmata*, and *A. cribosum* were found to dominate on the tops of larger boulders. While Coats *et al.* estimated percent cover of *Lithothamnion* they did not discuss its distribution. All three sets of surveys (1987, 1994, and 1995-2000) also found that the anemone *Metridium senile* and the cunner *Tautogolabrus adspersus* were most abundant near large boulders. Coats *et al.* reported that the distribution of the green sea urchin *Strongylocentrotus droebachiensis* was depth related, with the urchins being most abundant at shallower depths. Despite the general decrease in overall abundance of the urchin noted earlier, a similar pattern was found in the 1995-2001 surveys. The highest abundance of urchins is usually found on the top of drumlins where their primary food source, coralline algae, was most abundant (Sebens 1986). Because of the different overall focus of the Coats *et al.* (1995) report, more detailed comparisons of community structure and factors that control it can not be made.

The hardbottom benthic communities near the outfall were relatively stable over the 1995 to 2000 baseline time period, and this did not substantially change with the activation of the outfall. The remarkable similarities among all the surveys indicate that major departures from baseline conditions have not occurred during the first year of discharge. An increase in sediment drape, and a concurrent decrease in percent cover of coralline algae, was noted in 2001 on the top of the drumlin north of the outfall and at the two northernmost reference sites. Whether these changes are related to the outfall discharge is presently not known. The baseline data did indicate that coralline algae was the most promising indicator species for detecting habitat degradation as a result of the outfall coming on line. It was the most predictable taxon encountered in terms of abundance, distributional pattern, and habitat requirements. Coralline algae was the least patchily distributed taxon, dominated in all areas that were shallower than 33 m and had little sediment drape, and was common in areas of both high and low relief.

The outfall might be expected to alter the amount of particulate material reaching the sea floor. A continued increase of sediment drape, and/or a continued decrease in the percent cover of coralline algae might be expected if the discharge from the outfall were causing accumulation of materials in the vicinity of the drumlins. Changes might also be expected in the depth distribution of coralline algae if discharges from the outfall alter properties of the water column that affect light penetration. If water clarity is reduced it is expected that the lower depth limit of high coralline algal coverage would be reduced. Conversely, if water clarity were increased, then it is expected that high coralline algal coverage could extend into some of the deeper areas. No noticeable changes in the depth distribution of coralline algae were observed during the first year of discharge.

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