# Outfall Benthic Monitoring Report: 2010 results

Massachusetts Water Resources Authority

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Report 2011-14

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# Outfall Benthic Monitoring Report: 2010 Results

Submitted to


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## APPENDICES

# 1. INTRODUCTION

## 1.1 Background

Since 1992, the Massachusetts Water Resource Authority (MWRA) has conducted long-term monitoring in Massachusetts Bay and Cape Cod Bay (Figure 1) to evaluate the potential effects of discharging secondarily treated effluent 15 kilometers (km) offshore in Massachusetts Bay. Relocating the outfall raised concerns about potential effects of the discharge on the offshore benthic (bottom) environment. These concerns focused on three issues: eutrophication and related low levels of dissolved oxygen; accumulation of toxic contaminants in depositional areas; and smothering of animals by particulate matter. Monitoring studies conducted by the MWRA (1991, 1997, 2004) have collected extensive information over a nine-year baseline period (1992–2000) and a ten-year post-diversion period (2001–2010). These data allow for a more complete understanding of the bay system and provide data to explain any changes in the parameters of interest and to address the question of whether MWRA's discharge has contributed to any such changes.

The purpose of this summary report is to present key findings from the 2010 sampling season with respect to questions posed as part of the monitoring program, especially with regard to the potential accumulation of toxic contaminants in sediments and alterations in both the soft-and hard-bottom benthic communities. A comprehensive presentation of methods and evaluation of the long-term sediment monitoring data collected since 1992 is provided in the *Outfall Benthic Interpretive Report: 1992–2007 Results* (Maciolek et al. 2008).

## 1.2 2010 Threshold Exceedance

In August 2010, two of the four infaunal biodiversity measures tracked by MWRA as Contingency Plan thresholds exceeded their caution level threshold ranges. The nearfield averages for both Shannon-Wiener diversity (H′) and Pielou's evenness (J′) were both slightly higher than the upper threshold limit. These were the first threshold exceedances observed in the sediment monitoring studies. These results were communicated to regulators and the public in January 2011 (MWRA 2011) and discussed at a meeting of EPA's Outfall Monitoring Science Advisory Panel (OMSAP) in June 2011.

A further evaluation of these findings was conducted and is described in detail in Section 3.3 of this report. The findings from this evaluation were consistent with those presented at the OMSAP meeting; i.e., there is no evidence that the threshold exceedances resulted from an impact of the outfall discharge on infaunal communities, but resulted from natural variability in the benthic communities monitored in the vicinity of MWRA's outfall.

# 2. METHODS

Methods used to collect, analyze, and evaluate all sample types are consistent with those reported by Maciolek et al. (2008) for previous monitoring years. Sediment Profile Images (SPI) were collected in triplicate at 23 nearfield stations. For sampling of the soft-bottom sediments, 2010 represented an "even" sampling year under the revised monitoring program (MWRA 2004): approximately half of the baseline nearfield (Figure 1) and farfield (Figure 2) stations were sampled for grain size composition, total organic carbon (TOC), the sewage tracer *Clostridium perfringens*, and benthic infauna. Two nearfield stations (NF12 and NF17) were sampled for organic contaminants (polycyclic aromatic hydrocarbons [PAH], chlorinated pesticides and polychlorinated biphenyls [PCBs]) and metals (aluminum, cadmium, chromium, copper, iron, lead, mercury, nickel, silver and zinc).

Seventeen soft-bottom stations were sampled in August 2010:

- Transition area stations FF10 and FF13, located between Boston Harbor and the offshore outfall
- Nearfield stations NF17, NF18, NF19, and NF23, located in close proximity (<2 km) to the offshore outfall
- Nearfield stations NF05, NF07, NF08, NF09, NF12, NF16, and NF22, located in Massachusetts Bay but farther than 2 km from the offshore outfall
- Farfield reference stations FF04, FF05, FF07, and FF09, located in Massachusetts Bay and Cape Cod Bay

Camera transects (Figure 3) were performed as in previous years. All 23 hard-bottom waypoints were surveyed successfully during 2010, including an actively discharging diffuser head at the eastern end of the outfall. At least 21 minutes of both analog and high definition (HD) video footage was obtained at all of the waypoints. The analog video was analyzed and the HDV was archived for potential future analysis.

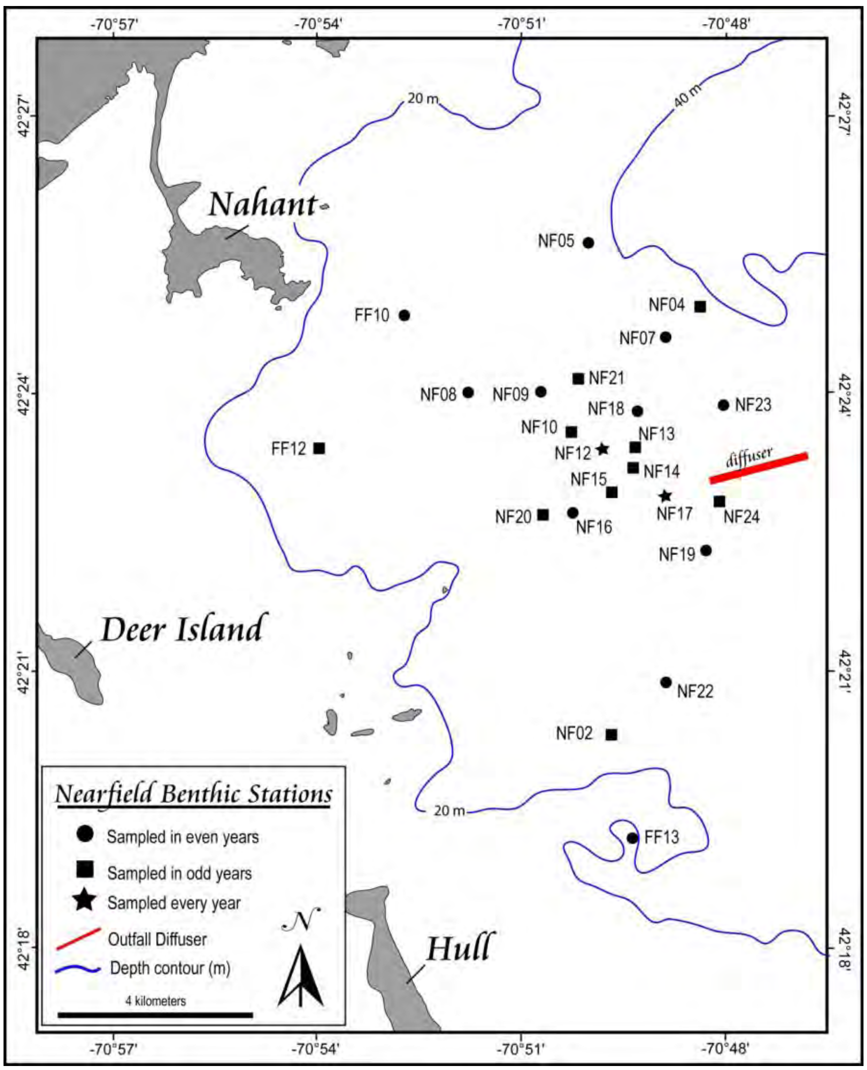


**Figure 1. Locations of nearfield benthic stations sampled in August 2010. All stations were sampled by SPI and those denoted by circle and star symbols were sampled by grab.**

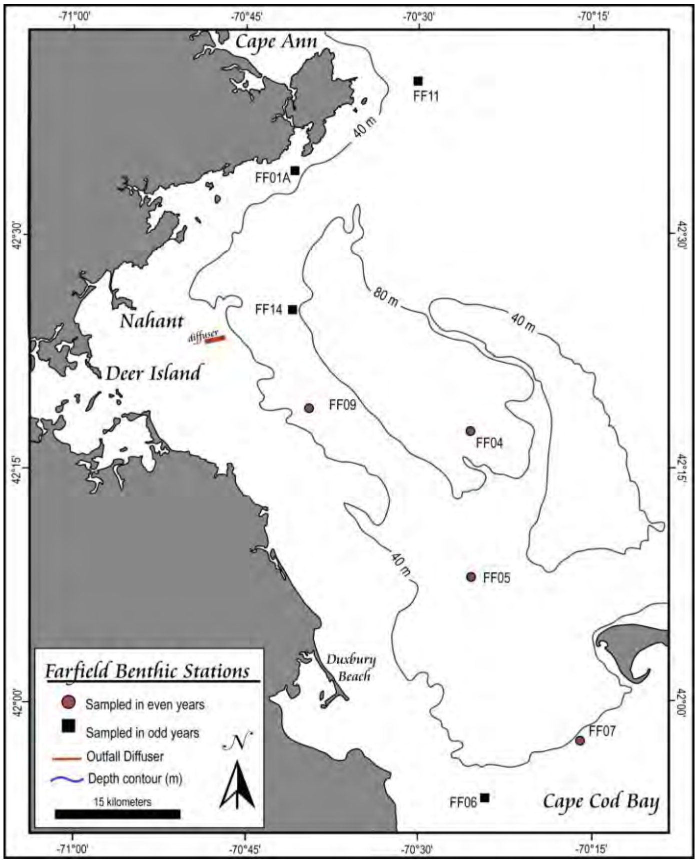


**Figure 2. Locations of farfield grab stations sampled in August 2010 (indicated by red circles).**

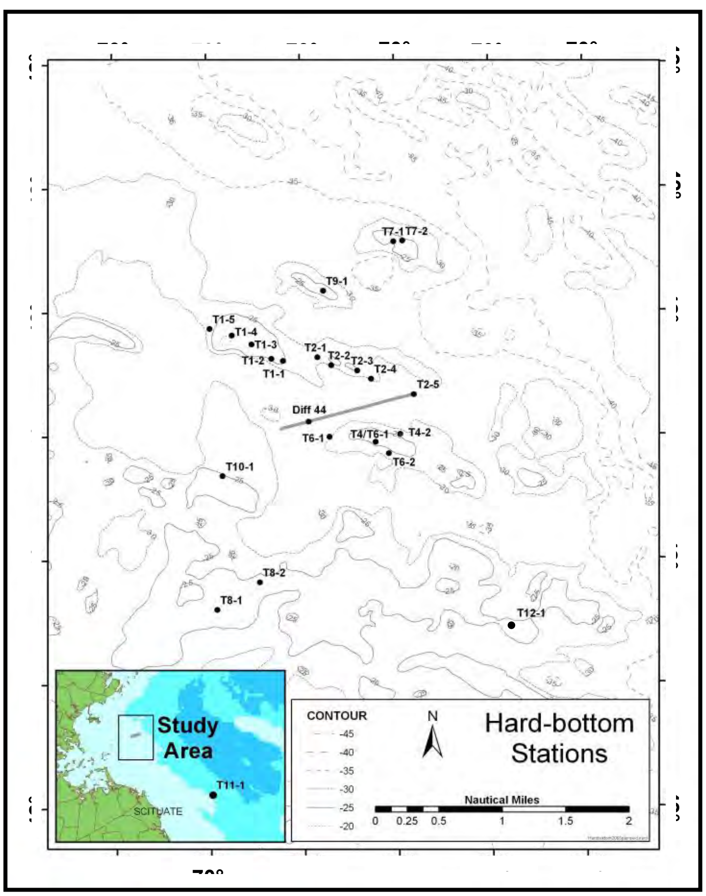


**Figure 3. Locations of hard-bottom transects sampled in August 2010.**

# 3. RESULTS

## 3.1 2010 Sediment Chemistry

### 3.1.1 Results

Sediment data (i.e., station mean values) were evaluated on a station-specific and regional (i.e., transition area, nearfield <2 km from outfall, nearfield >2 km from outfall, and farfield) basis to assess changes, if any, in sediment quality that may have resulted from diversion of the effluent discharge to the Massachusetts Bay outfall. Statistical evaluations were performed using JMP (version 5.1). All tests were performed using log-transformed data for those chemicals with a log-normal distribution. Statistical comparisons between the baseline and post-diversion mean values were performed at the 0.05 significance level. For each test, this provided a 95 percent confidence that a conclusion of a significant difference would not be reached if the two sets of values came from truly comparable populations. Note that no multiple comparison adjustments were applied in these analyses.

**Grain Size and Total Organic Carbon.** The grain size distributions for the 17 stations sampled in 2010 were within the range of values measured over the larger monitoring period (1992–2009), and included a range of sediment types from coarse- to fine-grained sediment (Figure 4). With the exception of station NF24, which was not sampled in 2010, transition area and nearfield stations in close proximity (<2 km) to the offshore outfall are typically comprised of coarse-grained sediment (note how data typically cluster near the gravel+sand axis of the ternary plot in Figure 4). Sediments sampled further away from the offshore outfall are heterogeneous, and encompass coarse- to fine-grained sediment (note how data are distributed from the gravel+sand to silt axes in Figure 4).

The 2010 TOC data were within or at the low end of the range of values measured over the larger monitoring period (Figure 5A). While not significant at the 95% level of confidence, post-diversion mean concentrations of TOC in surficial sediment at the transition area and near the outfall decreased slightly compared to baseline mean values (Figure 5B).

***Clostridium perfringens*.** The 2010 data were consistent with trends observed over the larger monitoring period (Maciolek et al. 2009). Notably, the *C. perfringens* data clearly trace the diversion of treated effluent discharge from the harbor to the bay evidenced primarily by (1) a significant ($p < 0.01$) decrease between the baseline and post-diversion mean values at the transition area and (2) a significant ($p < 0.01$) increase between the baseline and post-diversion mean values in sediments located near the outfall (Figure 6B). The *C. perfringens* effluent signature appears to be highly localized, as there is no significant difference between the baseline and post-diversion mean values in nearfield sediments located further away from the outfall. A significant ($p = 0.02$) decrease between baseline and post-diversion mean values of *C. perfringens* is observed at the farfield area of Massachusetts and Cape Cod Bays (Figure 6B), which is also consistent with trends observed over the larger monitoring period (Maciolek et al. 2009).

**Anthropogenic Contaminants.** The 2010 data for stations NF12 and NF17 were within the range of values measured over the larger monitoring period for most chemicals. For station NF12, the 2010 data were frequently below the baseline mean. Total pesticide, total PCB, copper, and silver concentrations were at the low end of the baseline range in 2010, while aluminum concentrations were at the high end or above the baseline range in 2010 (representative contaminants total PCB and aluminum are shown in Figures 7 and 8, respectively).

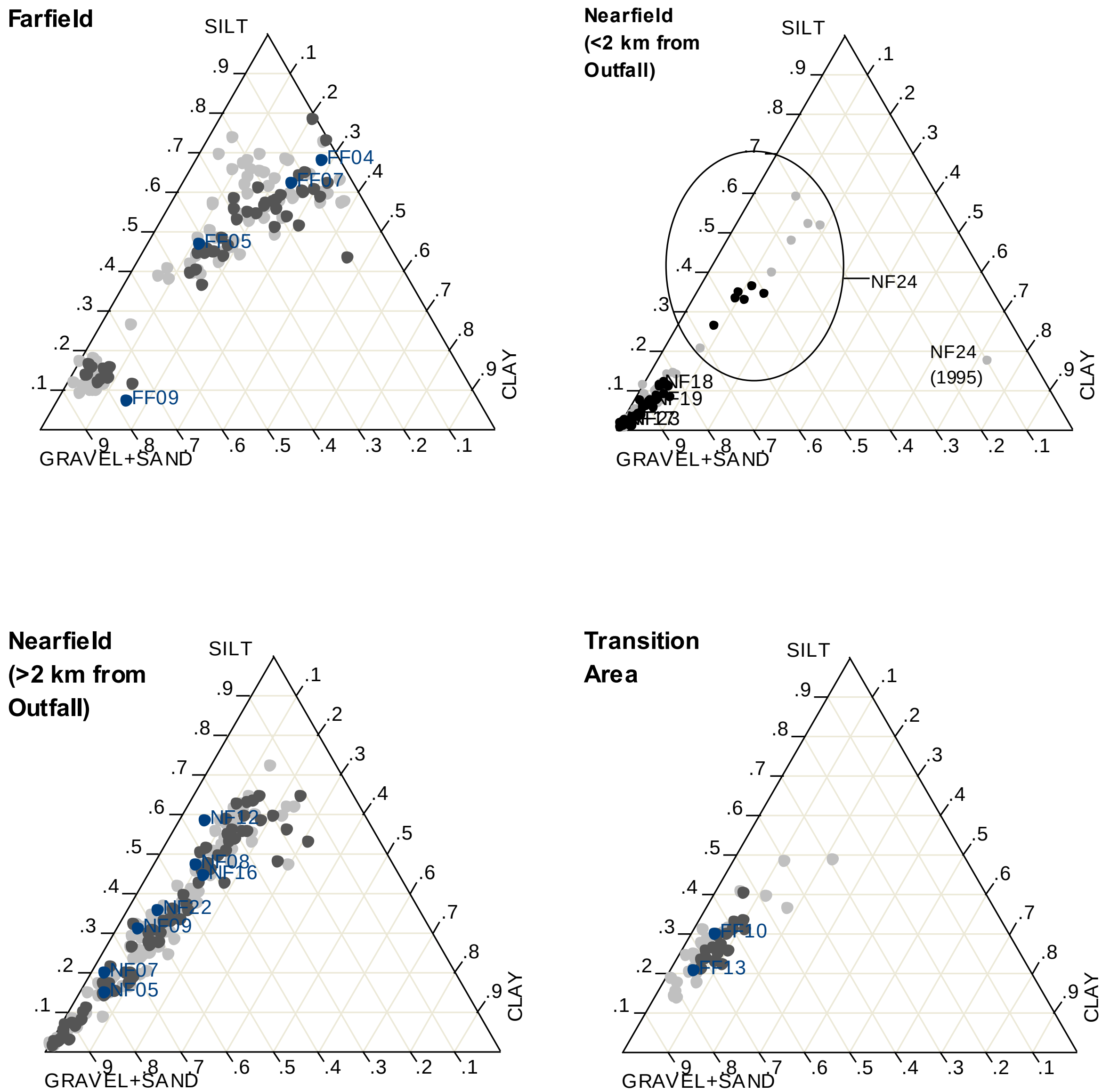


**Figure 4. Distribution of percentages of gravel+sand, silt, and clay in surface sediment in Massachusetts and Cape Cod Bays, 1992–2010. (Grey symbols represent baseline, black symbols represent post-diversion 2001–2009 data, and blue symbols represent the post-diversion 2010 data. 2010 stations are labeled).**

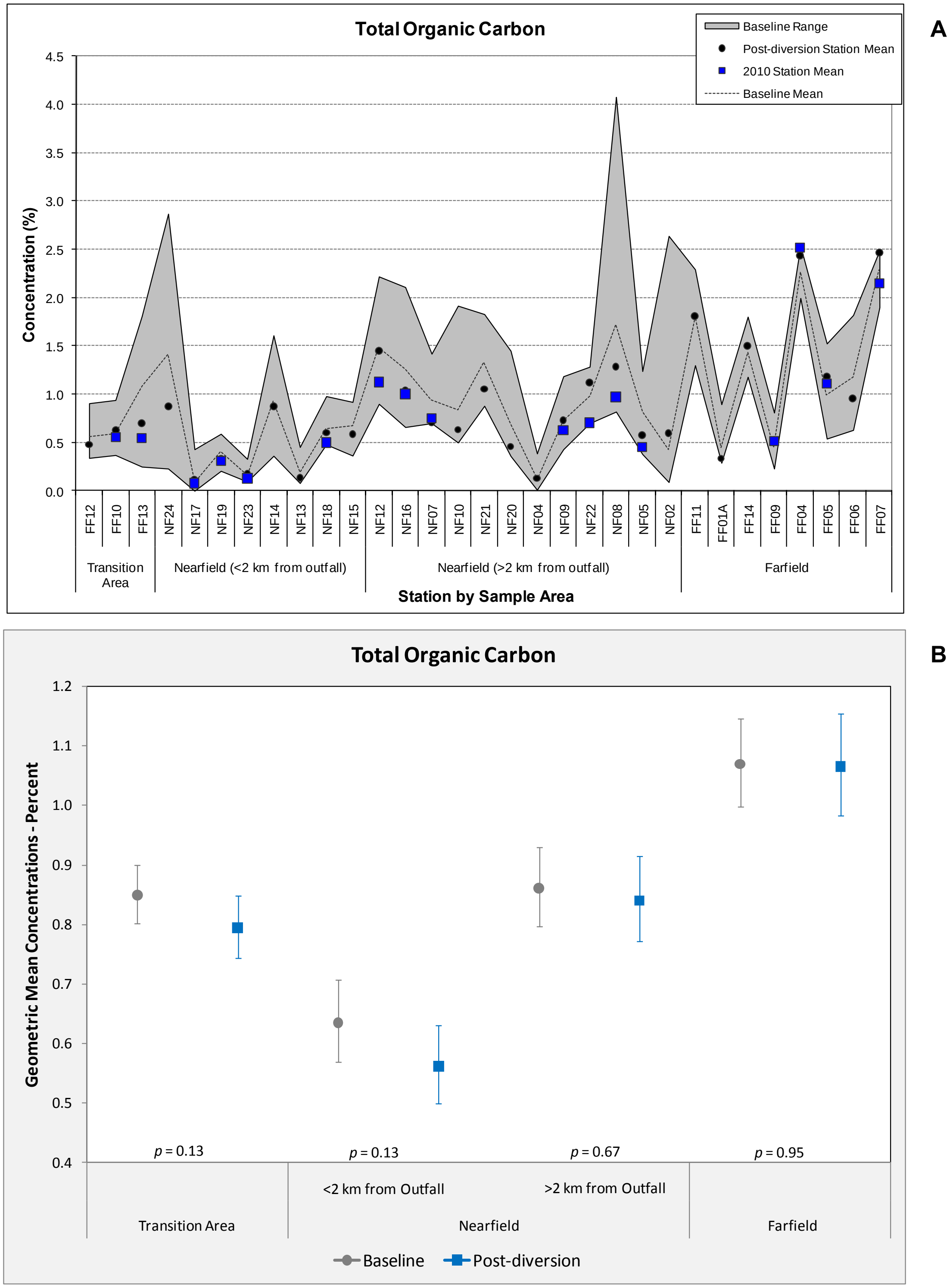


**Figure 5. Distribution of TOC, by station (A) and region (B), in surface sediment in Massachusetts and Cape Cod Bays, 1992–2010. A: station-specific trends where the gray band represents the range of values during baseline (1992–2000), the dashed line represents the baseline mean, and symbols represent the post-diversion data. B: regional trends where the symbols represent the geometric mean TOC concentration of all stations within a given region (farfield, nearfield, and transition areas) during baseline and post-diversion periods; the vertical bars represent the 95% confidence intervals around the mean values.**

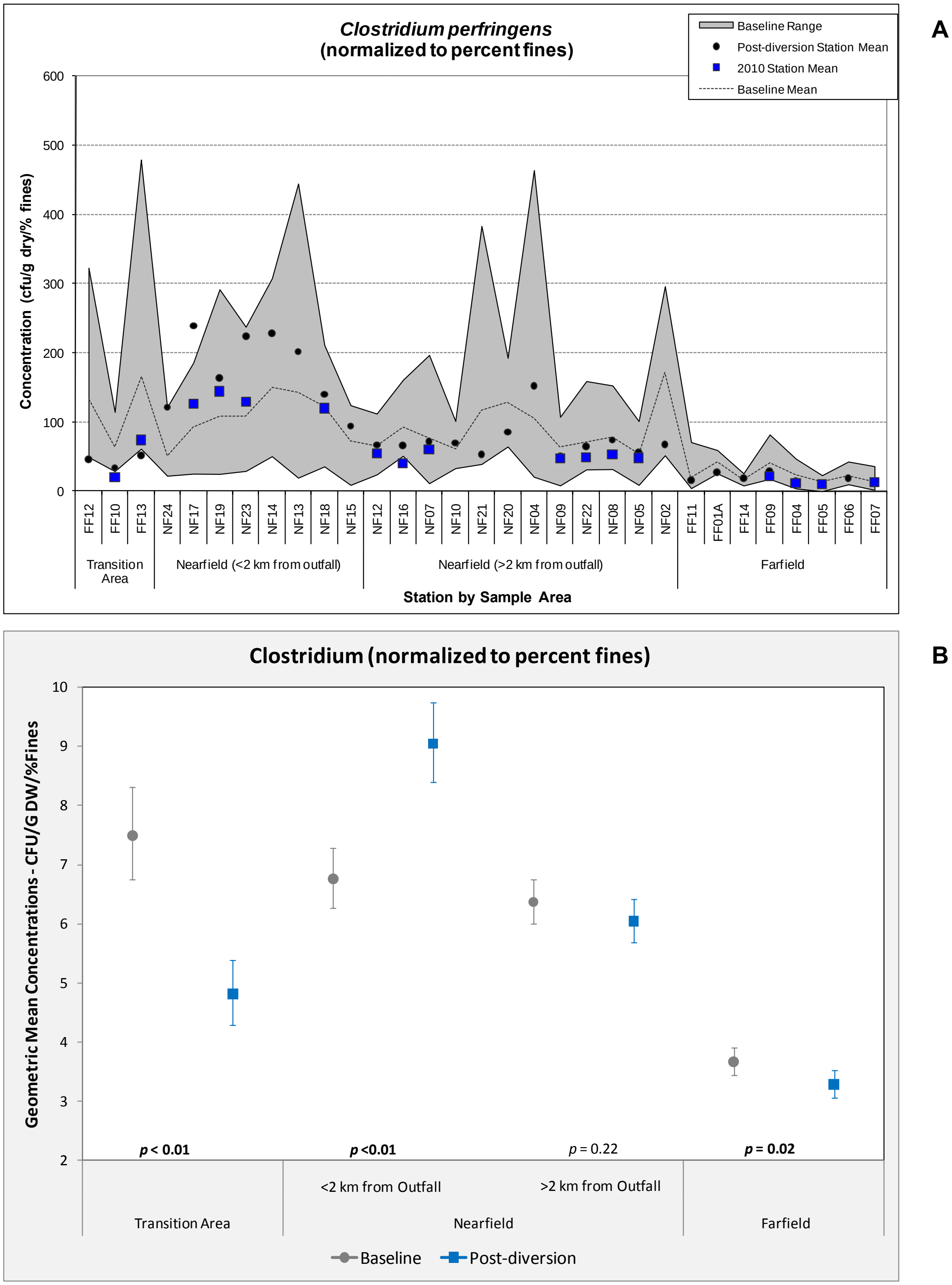


**Figure 6. Distribution of *C. perfringens* abundances (normalized to percent fines), by station (A) and region (B), in surface sediment in Massachusetts and Cape Cod Bays, 1992–2010. A: station-specific trends where the gray band represents the range of values during baseline (1992–2000), the dashed line represents the baseline mean, and symbols represent the post-diversion data. B: regional trends where the symbols represent the geometric mean *C. perfringens* abundance (normalized) of all stations within a given region (farfield, nearfield, and transition areas) during baseline and post-diversion periods; the vertical bars represent the 95% confidence intervals around the mean values.**

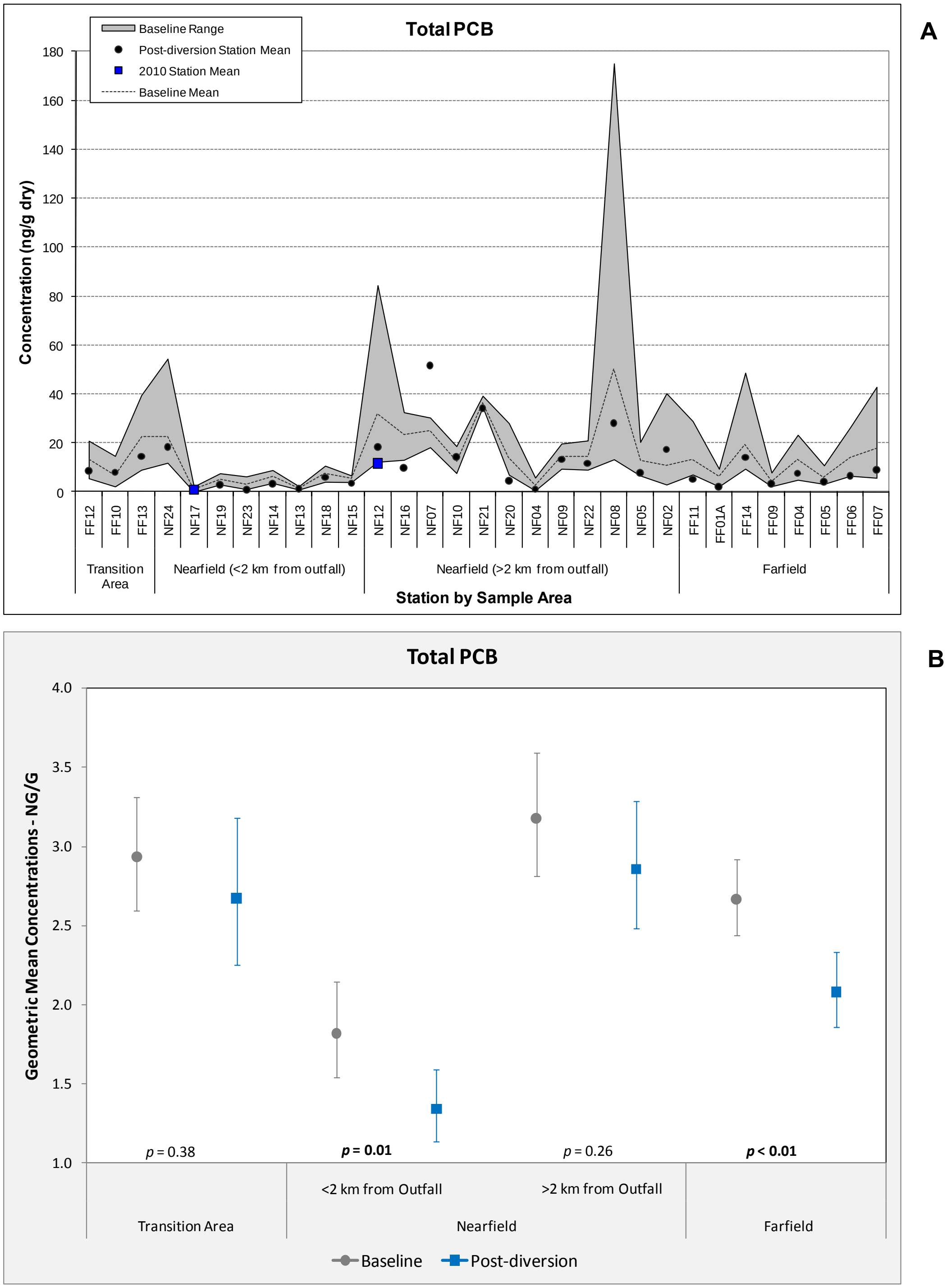


**Figure 7. Distribution of total PCB, by station (A) and region (B), in surface sediment in Massachusetts and Cape Cod Bays, 1992-2010. A: station-specific trends where the gray band represents the range of values during baseline (1992-2000), the dashed line represents the baseline mean, and symbols represent the post-diversion data. B: regional trends where the symbols represent the geometric mean concentration of all stations within a given region (farfield, nearfield, and transition areas) during baseline and post-diversion periods, the vertical bars represent the 95% confidence intervals around the mean values.**

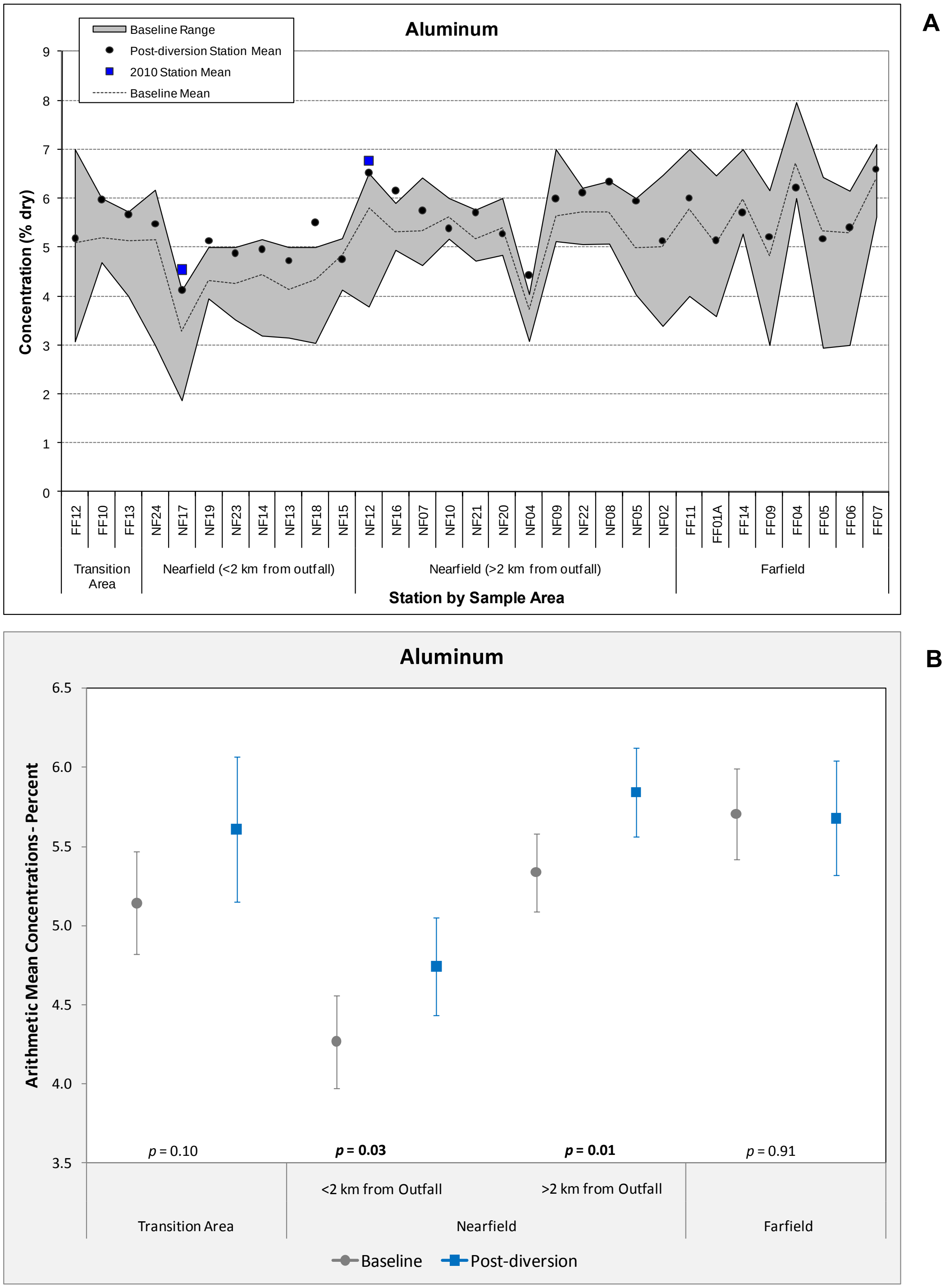


**Figure 8. Distribution of aluminum, by station (A) and region (B), in surface sediment in Massachusetts and Cape Cod Bays, 1992-2010. A: station-specific trends where the gray band represents the range of values during baseline (1992-2000), the dashed line represents the baseline mean, and symbols represent the post-diversion data. B: regional trends where the symbols represent the arithmetic mean chemical concentration of all stations within a given region (farfield, nearfield, and transition areas) during baseline and post-diversion periods, the vertical bars represent the 95% confidence intervals around the mean values.**

There is some evidence of a significant ($p < 0.05$) difference between the baseline and post-diversion mean concentrations for some contaminants in surficial sediments of Massachusetts and Cape Cod Bays. For example, there has been a significant decrease in post-diversion mean concentrations of total DDT, total PCB (Figure 7), total pesticide, total chlordane, and/or mercury in surficial sediments at nearfield and/or farfield areas[1], suggesting that reduced inputs to the system (e.g., banning of chemicals such as DDTs and PCBs in the 1970s and 1980s), slight methodological differences used throughout the monitoring program[2], and natural recovery processes have reduced surface contamination over time. Post-diversion mean concentrations of aluminum increased in nearfield sediments (Figure 8); an explanation for the increase is not evident. Overall, the long-term monitoring data suggest that the transfer of the MWRA effluent discharge into Massachusetts Bay has not resulted in an increase of anthropogenic contaminants in the surficial sediment. Rather, post-diversion concentrations of contaminants such as PCBs and chlorinated pesticides have decreased compared to baseline values.

### 3.1.2 Sediment Correlations

Results from the Pearson pair-wise correlation analysis performed on the nearfield and farfield sediment data from 1999–2010 are summarized in Table 1. In general, contaminants were positively correlated with percent fines and TOC, indicating that fine-grained sediments with higher organic carbon content characteristic of depositional environments generally contain higher contaminant concentrations, and coarse-grained sediments with lower organic carbon typically contain lower contaminant concentrations.

### 3.1.3 Sediment Quality

Results from the comparison of the 2010 sediment data to the effects-range low (ER-L) and effects-range median (ER-M) sediment quality guidelines (SQGs) are summarized in Table 2. This evaluation is limited to the two stations sampled in 2010 for contaminants (NF12 and NF17). A more comprehensive evaluation of sediment quality for the long-term monitoring data is presented in Maciolek et al. (2008). In 2010, concentrations of 11 individual PAHs, total PAH, total DDD, and three metals were above the ER-L SQG at station NF12 (Table 2). This station is comprised of fine-grained sediment (64% fines), and is located in close proximity to Boston Harbor, the historic source of anthropogenic contamination. Contaminant concentrations at NF12 in 2010 were similar to (within baseline range) and in some cases lower than (below baseline mean) those seen during baseline monitoring (see Section 3.1.2). There were no exceedances of the SQGs at station NF17 (Table 2), a station comprised of sandy sediment (>95% gravel+sand) also located in close proximity to the harbor. There were no exceedances of the ER-M SQG values in 2010.

[1] Significant ($p < 0.05$) difference between baseline and post-diversion mean concentrations (log-transformed) for:

- Transition Area: Post-diversion total pesticide decreased.
- Nearfield <2 km from Outfall: Post-diversion total DDT, total PCB, total pesticide, total chlordane, and mercury decreased. Post-diversion aluminum increased.
- Nearfield >2 km from Outfall: Post-diversion total pesticide and total chlordane decreased and aluminum increased.
- Farfield: Post-diversion total DDT, total PCB, total pesticide, total chlordane decreased.

[2] The analytical method changed in 2004 from gas chromatography with electron capture detection (GC/ECD) to gas chromatography mass spectrometry (GC/MS) operated in the selected ion monitoring (SIM) mode. Based on findings from a Before/After Control Impact study (BACI) using Cape Cod Bay as the control (Hall et al. 2010), this methodological change could have contributed to a slight bias low of the data (BACI study evaluated fish tissue data) compared to data from previous monitoring years, especially for DDTs, PCBs, and chlordanes (Hall 2011).

**Table 1. Pearson product-moment correlation coefficients (*r*) for nearfield and farfield sediments, 1999–2010.**

| Variable | Nearfield | | | | Farfield | | | |
|---|---|---|---|---|---|---|---|---|
| | *r* value By Fines | *r* value By TOC[1] | *p* value | Count | *r* value By Fines | *r* value By TOC[1] | *p* value | Count |
| TOC[1] | 0.78 | 1.0 | < 0.01 | 201 | 0.94 | 1.0 | < 0.01 | 68 |
| *C. perfringens*[1] | 0.70 | 0.70 | < 0.01 | 202 | 0.60 | 0.48 | < 0.01 | 68 |
| Aluminum | 0.62 | 0.70 | < 0.01 | 114 | 0.53 | 0.62 | < 0.01 | 32 |
| Cadmium[1] | 0.74 | 0.47 | < 0.01 | 111 | 0.61 | 0.57 | < 0.01 | 32 |
| Chromium[1] | 0.89 | 0.83 | < 0.01 | 114 | 0.89 | 0.90 | < 0.01 | 32 |
| Copper[1] | 0.72 | 0.86 | < 0.01 | 112 | 0.93 | 0.90 | < 0.01 | 32 |
| Iron | 0.77 | 0.71 | < 0.01 | 114 | 0.91 | 0.93 | < 0.01 | 32 |
| Lead[1] | 0.52 | 0.62 | < 0.01 | 112 | 0.91 | 0.88 | < 0.01 | 32 |
| Mercury[1] | 0.78 | 0.86 | < 0.01 | 114 | 0.64 | 0.66 | < 0.01 | 32 |
| Nickel | 0.73 | 0.76 | < 0.01 | 114 | 0.74 | 0.83 | < 0.01 | 32 |
| Silver[1] | 0.77 | 0.85 | < 0.01 | 114 | 0.61 | 0.71 | < 0.01 | 32 |
| Zinc | 0.91 | 0.77 | < 0.01 | 114 | 0.95 | 0.89 | < 0.01 | 32 |
| Total DDT[2] | 0.81 | 0.74 | < 0.01 | 114 | 0.76 | 0.75 | < 0.01 | 32 |
| Total PAH[1,2] | 0.78 | 0.85 | < 0.01 | 114 | 0.65 | 0.56 | < 0.01 | 32 |
| Total PCB[1,2] | 0.82 | 0.87 | < 0.01 | 114 | 0.69 | 0.71 | < 0.01 | 32 |

[1] Log-transformed data used in the correlation analysis.
[2] See Maciolek et al. (2008) for a description of how the totals were calculated.

**Table 2. 2010 Station Mean Values Compared to ER-L and ER-M Sediment Quality Guidelines.**[1]

| Contaminant | Units | 2010 Station Mean | | Sediment Quality Guideline | |
|---|---|---|---|---|---|
| | | NF12 | NF17 | ER-L | ER-M |
| **PAHs** | | | | | |
| Acenaphthene | ng/kg dry | **85** | 9.09 | 16 | 500 |
| Acenaphthylene | | **91** | 1.41 | 44 | 640 |
| Anthracene | | **329** | 19 | 85.3 | 1100 |
| Benz(a)anthracene | | **594** | 28 | 261 | 1600 |
| Benzo(a)pyrene | | **675** | 27 | 430 | 1600 |
| Chrysene | | **517** | 26 | 384 | 2800 |
| Dibenzo(a,h)anthracene | | **98** | 3.50 | 63.4 | 260 |
| Fluoranthene | | **1336** | 62 | 600 | 5100 |
| Fluorene | | **114** | 9.47 | 19 | 540 |
| Naphthalene | | 91 | 3.36 | 160 | 2100 |
| Phenanthrene | | **915** | 66 | 240 | 1500 |
| Pyrene | | **1222** | 57 | 665 | 2600 |
| Total_PAH[2] | | **11803** | 571 | 4,022 | 44,792 |
| **Pesticides/PCBs** | | | | | |
| cis-Chlordane | ng/kg dry | 0.102 | non-detect | 0.50 | 6.0 |
| Dieldrin | | non-detect | non-detect | 0.02 | 8.0 |
| Total_DDD[2] | | **2.15** | 0.033 | 2.0 | 20 |
| Total_DDE[2] | | 1.31 | non-detect | 2.2 | 27 |
| Total_PCB[2] | | 12 | 0.91 | 22.7 | 180 |
| **Metals** | | | | | |
| Cadmium | mg/kg dry | 0.17 | 0.052 | 1.2 | 9.6 |
| Chromium | | 80 | 26 | 81 | 370 |
| Copper | | 28 | 3.74 | 34 | 270 |
| Lead | | **56** | 33 | 46.7 | 218 |
| Mercury | | **0.297** | 0.032 | 0.15 | 0.71 |
| Nickel | | **21** | 7.55 | 20.9 | 51.6 |
| Silver | | 0.43 | 0.076 | 1.0 | 3.7 |
| Zinc | | 82 | 28 | 150 | 410 |

[1] SQGs from Long et al. (1995).
[2] See Maciolek et al. (2008) for a description of how the totals were calculated.
**Red bold** values represent concentrations above the ER-L SQG value.

## 3.2 2010 Sediment Profile Imaging

There was little change in SPI for 2010 relative to the last several years. Physical processes still dominated the surface sediments. Sediments at many stations continued to be heterogeneous, ranging from sandy-silt-clay to cobble. Sediments, estimated successional stage (SS), and the organism sediment index (OSI) were similar to previous years. There did appear to be more biogenic structures at the sediment surface in 2010 relative to 2009, but this trend was not statistically significant. At several stations, what appeared to be asymmetric bed forms were observed in the surface video (NF17, NF19, and NF22). Tubes and burrow openings were the most common biogenic structures seen in the SPI. Most stations had moderate densities (about 24 tubes per image) of small (<1 mm diameter) polychaete tubes. Lumbrinerid polychaetes egg capsules were seen at four stations (NF14, NF15, NF18, and NF24; Figure 9). These egg capsules were common in five of the last six years (they were not seen in 2009). Subsurface biogenic structures appeared to be the same types and as common in 2010 as they were in 2009 images.

**Figure 9. NF24-1 Lumbrinerid egg capsule on surface near center of image, scale is in cm.**

The grand average aRPD for all stations in 2010 appeared to be shallower than in 2009 but still deeper than baseline (Figure 10). Post-baseline period aRPD remained deeper than during the baseline period (Table 3). For three stations that had measured aRPD layers in all years, two were the same and one increased in aRPD depth (Figure 11). There was no indication of organic carbon accumulation in sediments. The operation of the outfall does not appear to have affected benthic habitat quality. From 1995 to 2010, changes and trends in SPI variables appeared to be related to broader regional forcing factors, such as storminess.

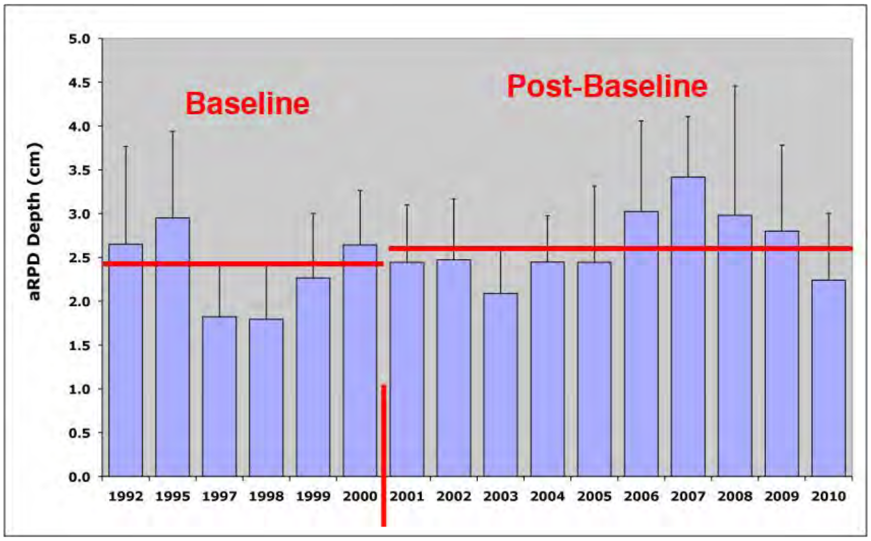


**Figure 10. Average aRPD layer depth at nearfield stations by year for all 23 stations.**

**Table 3. Summary of key SPI parameters comparing baseline and post baseline periods.**

| Parameter | Baseline Years 1992–2000 | Post-Baseline Years 2001–2010 |
|---|---|---|
| SS | Advanced from I to II-III | Bimodal: I-II and II-III |
| OSI - Low | 4.8 (1997) | 5.8 (2003) |
| OSI - High | 7.2 (2000) | 7.9 (2008) |
| aRPD - Low | 1.8 cm (1997 and 1998) | 2.1 cm (2003) |
| aRPD -High | 3.0 cm (1995) | 3.4 cm (2007) |
| aRPD - Grand Mean | 2.3 (0.47 SD) cm | 2.7 (±0.40 SD) cm |

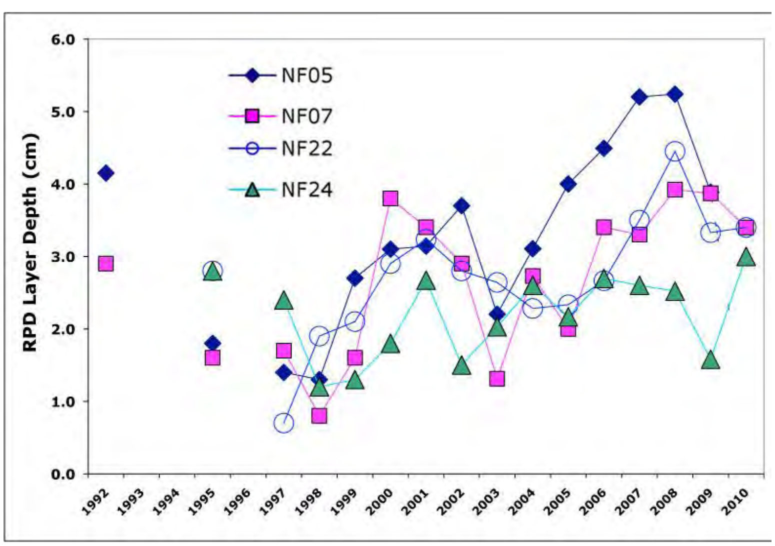


**Figure 11. Trends for nearfield stations that had measured aRPD layer depths.**

## 3.3 2010 Soft-Bottom Benthic Infaunal Communities

### 3.3.1 Nearfield Species Composition

Twenty-one infaunal samples were collected and analyzed from 13 nearfield stations in 2010; the samples yielded 28,922 organisms that were assigned to 203 valid taxa and 31 indeterminate categories (compared with 39,369 organisms in 2008, a 26.5% reduction in total abundance). Species composition at all nearfield stations, including the numerically dominant species, has been consistent over the past several years, although absolute numbers and numerical rank in the samples of a particular species may have changed from year to year. Most (five of the top seven) dominant taxa in 2010 were the same species that were reported in 2008 for the same subset of stations, and were even more similar to the dominant species for all samples collected since 1992, although in many cases the abundances in 2010 were much lower.

**Table 4. Overall infaunal dominants from 1992–2010 compared to 2008 and 2010 dominants for the even-year subset of stations.**

| Overall Dominants since 1992 | 2008 Dominants | 2010 Dominants |
|---|---|---|
| *Prionospio steenstrupi* | *Prionospio steenstrupi* | *Prionospio steenstrupi* |
| *Mediomastus californiensis* | *Tharyx acutus* | *Mediomastus californiensis* |
| *Spio limicola* | *Mediomastus californiensis* | *Levinsenia gracilis* |
| *Aricidea catherinae* | *Aricidea catherinae* | *Tharyx acutus* |
| *Tharyx acutus* | *Crassicorophium crassicorne* | *Spio limicola* |
| *Molgula manhattensis* | *Levinsenia gracilis* | *Aricidea catherinae* |
| *Ninoe nigripes* | *Leitoscoloplos acutus* | *Ninoe nigripes* |

The spionid polychaete *Prionospio steenstrupi* has been the numerical dominant in Massachusetts Bay for the past several years and has been recorded from all sediment types found at the nearfield stations. In 2008, the number of individuals of *P. steenstrupi* at this subset of stations accounted for over 30% of all organisms in the nearfield samples and in 2006, 27% (Maciolek et al. 2007, 2009). However, between 2008 and 2010, the abundance of *P. steenstrupi* declined to about a third of its total density (from ~12,000 to 4,500 individuals) and in 2010 accounted for only 15.6% of the organisms collected. The 2010 mean density was the lowest recorded since the early 1990s (Figure 12).

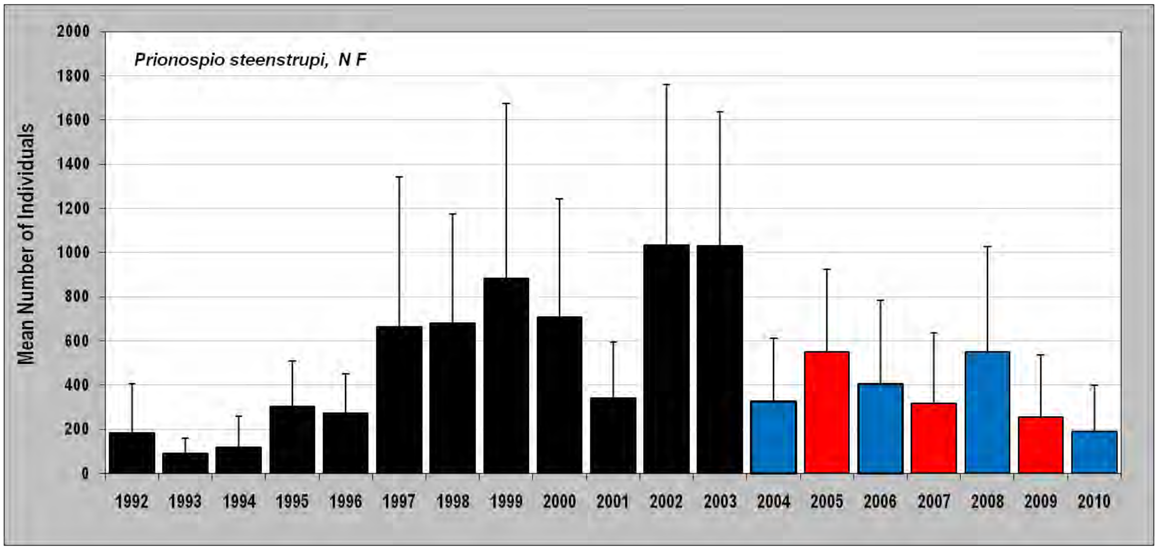


**Figure 12. Annual mean density of *Prionospio steenstrupi* at nearfield stations. Two subsets of stations were sampled after 2003, one in 2004/2006/2008/2010 (blue bars) and the other in 2005/2007/2009 (red bars).**

### 3.3.2 Nearfield Benthic Community Parameters

Preliminary examination of the 2010 nearfield results by MWRA indicated an exceedance of contingency plan threshold levels for the Shannon-Wiener (H′) and Pielou's J′ (evenness) benthic community parameters (Table 5). Those results represented a "Caution" level threshold exceedance and required regulatory and public notification (MWRA 2001, 2011). Other parameters were well within threshold ranges. Diversity analyses were again run in Primer 6, based on the "good" species in the data set. MWRA calculations are based on a slightly different set of good species and merges; the present calculations are based on those used in previous reports (e.g., Maciolek et al. 2008) and resulted in similar exceedances.

**Table 5. Contingency Plan thresholds compared to 2010 benthic community values, as calculated by MWRA.**

| Parameter | Low Threshold | High Threshold | 2010 | Exceedance? |
|---|---|---|---|---|
| Total species | 48.4 | 82 | 65.1 | No |
| Log-series *alpha* | 9.99 | 16.47 | 14.37 | No |
| Shannon-Wiener H′ | 3.37 | 4.14 | 4.23 | Yes, Caution |
| Pielou's J′ | 0.58 | 0.68 | 0.70 | Yes, Caution |
| Percent Opportunists | | 10% | 0.60% | No |

Evaluation of the mean diversity indices revealed the following:

- Abundance per sample was lower than in 2008, but comparable to 2006 – mean abundances have been lower than the baseline mean since 2004 (Figure 13)
- Number of species per sample was slightly higher than baseline (65.5 vs. baseline of 65.0) but not the highest or the lowest seen for this station subset (Figure 13)
- Evenness J′ was higher than baseline (0.7 vs. baseline of 0.62) (Figure 14).
- Shannon H′ was much higher than baseline (4.24 vs. baseline of 3.68), but similar to that calculated for 2004 for this station subset (Figure 14)
- Log-series *alpha* was slightly lower than in 2008 (14.47 in 2010 vs. 15.26 in 2008), but higher than baseline (13.06) (Figure 14).

When plotted with one standard deviation (SD), the ranges generally encompass other annual means. There were no particularly notable changes in the fauna that might account for the higher evenness, except the drop in density of *P. steenstrupi*, which allowed other species to appear more important in the community structure. Natural fluctuations in the populations of benthic organisms appear to have resulted in the higher Shannon diversity and evenness values.

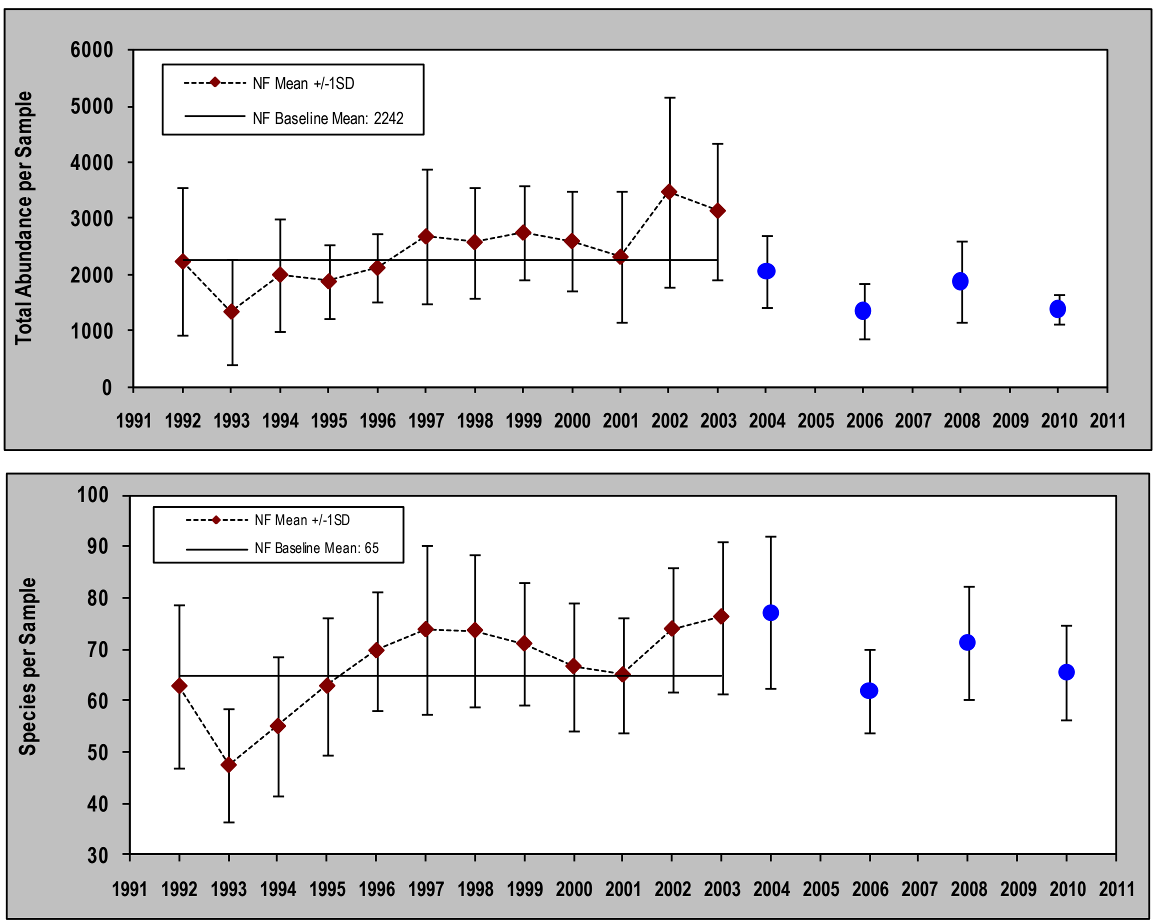


**Figure 13. Annual mean density and species per sample at nearfield stations. The even-year station subset is compared with the baseline values for the entire station set.**

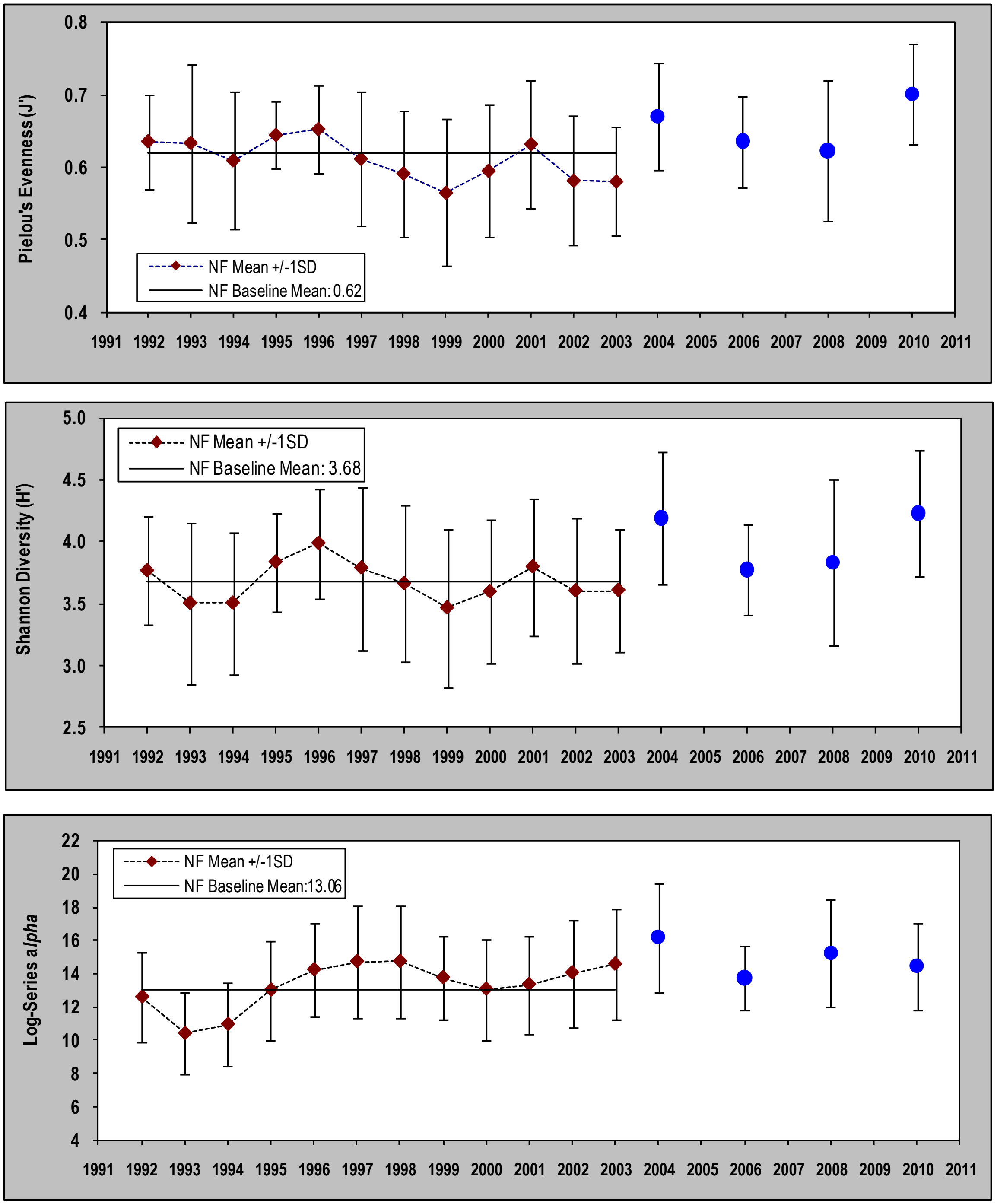


**Figure 14. Annual mean evenness (J′), Shannon diversity (H′) and log-series *alpha* per sample at nearfield stations. The even-year station subset is compared with the baseline values for the entire station set.**

### 3.3.3 Evaluation of Selected Nearfield Stations

The cause of the increase in J′ (evenness) and H′ (Shannon diversity) was not apparent from a regional evaluation of the nearfield stations: apart from the severe decline in the populations of *Prionospio steenstrupi*, which resulted in the greater importance of other species in the samples, there was no immediately obvious cause for the elevation of those parameters. In order to determine if the exceedances in diversity and evenness reflected a local (station) or regional (nearfield) event, additional analyses were performed, including an evaluation of individual stations. The following questions were asked:

- Did all nearfield stations exhibit elevated evenness and Shannon diversity, or only a few?
- Where elevated, was this against the regional baseline or against historical levels at individual stations?
- Did abundances of any species other than *Prionospio steenstrupi* exhibit a notable change?
- Did any station exhibit signs of recent disturbance (as evaluated by Gallagher's non-dimensional diversity technique)?

#### *3.3.3.1 Did all nearfield stations exhibit elevated evenness and Shannon diversity, or only a few?*

Evenness values for individual samples collected in August 2010 ranged from a low of 0.55 or 0.56 at FF13 to a high of 0.76 recorded for five samples, including all three replicates from NF12 (Appendix A, Table A1). Only FF13, NF07 and one replicate from NF17 were below the high threshold of 0.70; all other samples (i.e., 16 of 21 individual samples) had an evenness of 0.70 or higher. If the triplicate samples at the four stations at which they were collected were averaged first, 10 of the 13 stations had evenness values above 0.70; the exceptions being FF13, NF07, and NF17.

Similarly, Shannon diversity ranged from a low of 3.14 to a high of 4.80, with FF13, NF07 and NF17 having the lowest diversity and NF18 and NF12 having the highest diversity (Appendix A, Table A1). As with evenness, 16 of 21 individual samples and 10 of the 13 stations had an H′ of 4.14 or higher.

Stations at which H′ and J′ values increased the most between 2008 and 2010 were NF16, NF 17 (based on the mean of three replicates), and NF 19, in that order (Appendix A, Table A2). However, NF16 was intermediate in terms of change (actually exhibited a decline) in *alpha* and number of species; NF17 exhibited minimal change in those same two parameters, and NF 19 had a small increase in *alpha* but a small decrease in number of species (Table A2). Stations that showed the least amount of change in evenness and Shannon diversity were NF05, NF08, and NF12; Shannon diversity at NF05 actually decreased between sampling dates, as did *alpha* and number of species (Table A2). Thus, a station at which the most change occurred (NF17) did not exceed the 0.70 J′ and 4.14 H′ threshold levels, whereas stations that increased by lesser amounts in those parameters (NF05, NF08, NF12) had high evenness and Shannon diversity.

#### *3.3.3.2 Where elevated, was this against the regional baseline or against historical levels at individual stations?*

Several stations were examined in detail (Figure 15, Appendix B) to look for any indication that 2010 was an unusual year. Individual stations in the study area have always exhibited different patterns of change in community parameters from year to year and also relative to the baseline, which is an average value based on the years before the outfall went online.

The 2010 results do not appear to be unusual for FF10, FF13, or NF08. H′ diversity at Station FF10 was as high or higher in previous years as in 2010 and has usually been higher than baseline (Figure 15 A–B, Appendix 3). Similarly, the evenness value (0.74) recorded at FF10 in 2010 was also recorded in 1993 and 2004. Diversity and evenness at FF13 have generally been lower than the baseline values, and this was also the case in 2010 (Figure 15C–D). NF08 has shown a trend toward higher diversity and evenness since the beginning of the monitoring program, possibly influenced by the fluctuations in the density of *Prionospio steenstrupi* (Figure 15 E–F), which in turn may be related to higher levels of total organic carbon (TOC) at that station in 1992–1993 (for TOC data, see Blake et al. 1993and Coats et al. 1995). Allowing for a lag time for the population to respond, the high density of *P. steenstrupi* appears to have followed a pulse of sediment moderately contaminated with PAH, *Clostridium perfringens*, and TOC that probably originated from Boston Harbor during severe storms in 1991 and 1992. Decline in the levels of TOC may have led to decreased abundances of *P. steenstrupi*, which in turn resulted in higher diversity at that station. A similar pattern was not evident at other stations. Evenness values at NF08 for samples collected in 2004, 2006, 2008, as well as 2010 were all equal to or higher than 0.70.

Appendix B includes additional analyses of these three stations as examples of natural fluctuations at stations in the nearfield area.

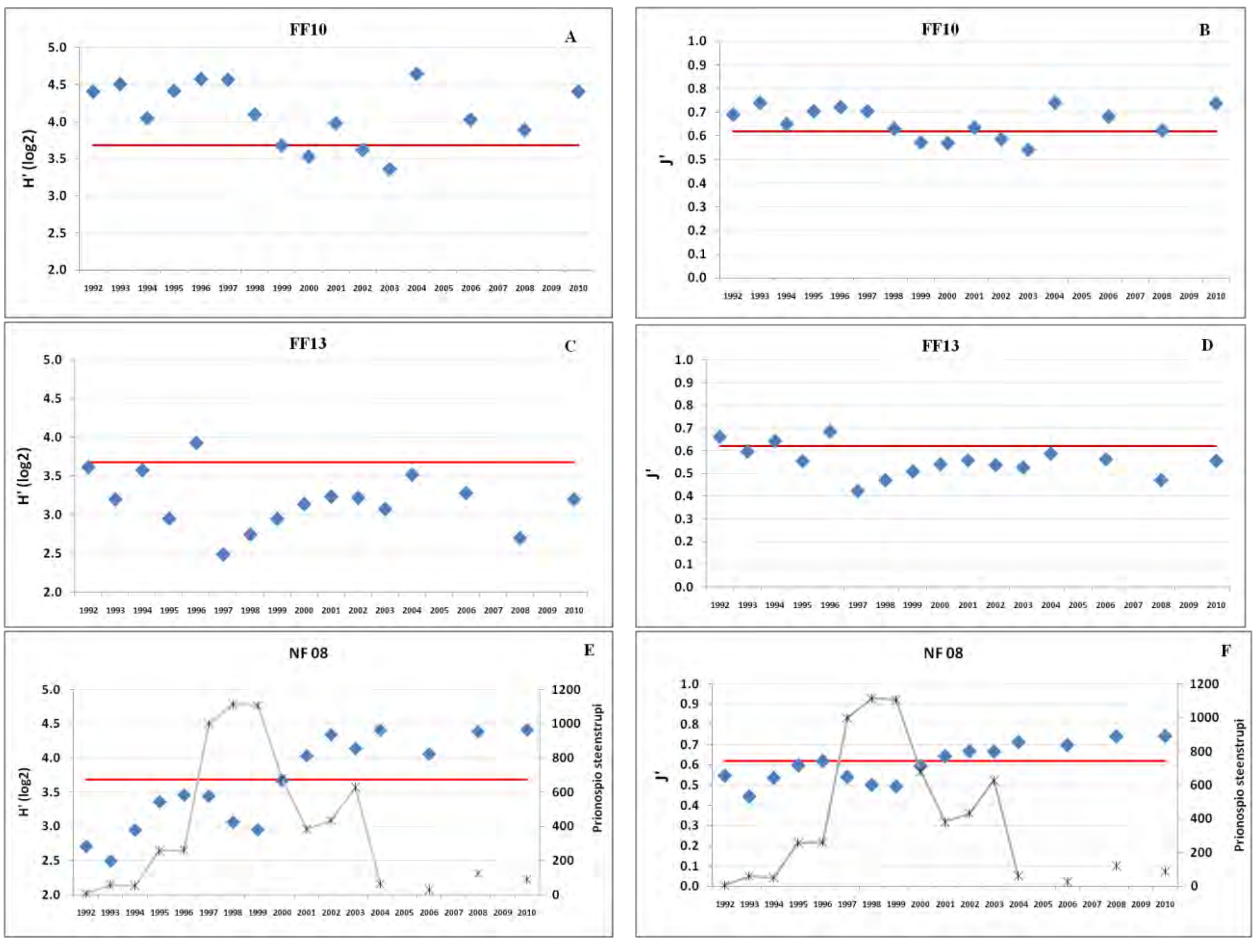


**Figure 15. Shannon diversity, H′ and evenness, J′ at Stations FF10(A–B), FF13 (C–D), and NF08 (E–F) relative to the respective baseline mean (red line) for all nearfield stations. The abundance of *Prionospio steenstrupi* is plotted for NF08(E–F); note that diversity and evenness tend to be lower during periods of high *P. steenstrupi* abundance, especially in 1997–2000.**

### *3.3.3.3 Did abundances of any species other than* **Prionospio steenstrupi** *exhibit a notable change?*

No other species exhibited as extreme a change in densities as *P. steenstrupi*, although other species did show minor fluctuations in total abundances.

### *3.3.3.4 Did any station exhibit signs of recent disturbance (as evaluated by the NDDC technique)?*

A non-dimensional diversity curve for each 2010 sample was generated using programs written by Dr. Eugene Gallagher, UMass Boston, for the Matlab platform. This analysis, which evaluates the difference between the Sanders-Hurlbert rarefaction curve and the theoretical log-series curve for each sample, suggested that 2010 Stations FF13 and NF08 might be disturbed (Figure 16) because those samples fell below the level chosen to suggest a disturbance. As discussed above, however, these two stations do not appear to have experienced any unusual changes in the recent sampling year.

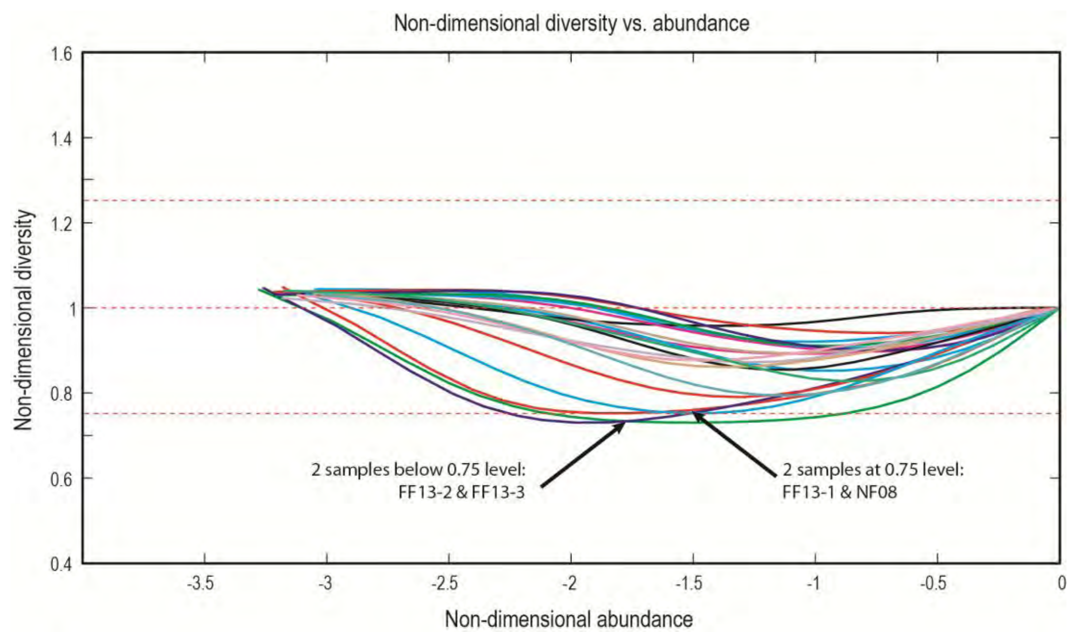


**Figure 16. Non-dimensional diversity curves for nearfield samples collected in 2010.**

### 3.3.4 Evaluation of 2010 Farfield Data

Twelve infaunal samples were collected and analyzed from four farfield stations in 2010; the samples yielded 20,719 organisms (vs. 25,514 in 2008) that were assigned to 166 valid taxa and 26 indeterminate categories.

Mean benthic community parameters were calculated for these samples. Mean total abundance, species per sample, Shannon H′ and Fisher's log-series *alpha* were all lower than in 2008, but evenness (J′) was essentially the same (Figures 17 and 18, Appendix A, Table A3). The standard deviations around the means were large, as seen in previous years, reflecting the wide geographical range of the stations and the different habitats sampled.

Diversity indices were examined by station for 2008 and 2010 in order to evaluate differences since the last time the stations were sampled.

- Station FF04 showed the largest changes: a large drop in abundance, a drop in the number of species, and a drop in Fisher's *alpha* and Shannon diversity; evenness (J') was essentially the same. A few species recorded at FF04 in 2008 were either
  - absent in 2010: e.g., *Aphelochaeta marioni*, *Aricidea quadrilobata*, *Dentalium entale*, *Dorvillea sociabilis*, *Euchone incolor*, *Spio limicola* or
  - occurred in lower numbers: e.g., *Prionospio steenstrupi*, Nemertea sp. 12, *Nuculoma tenuis*, *Syllides longocirrata*, and *Thyasira gouldi*
  - The change in total density *of P. steenstrupi* (from 608 to 35 individuals per three replicates) was probably the most significant change.

- Station FF05 showed a drop in the number of species and a large drop in abundance, but diversity parameters were essentially the same
- Station FF07: all parameters were essentially the same between the two sampling years
- Station FF09 showed a small drop in most parameters

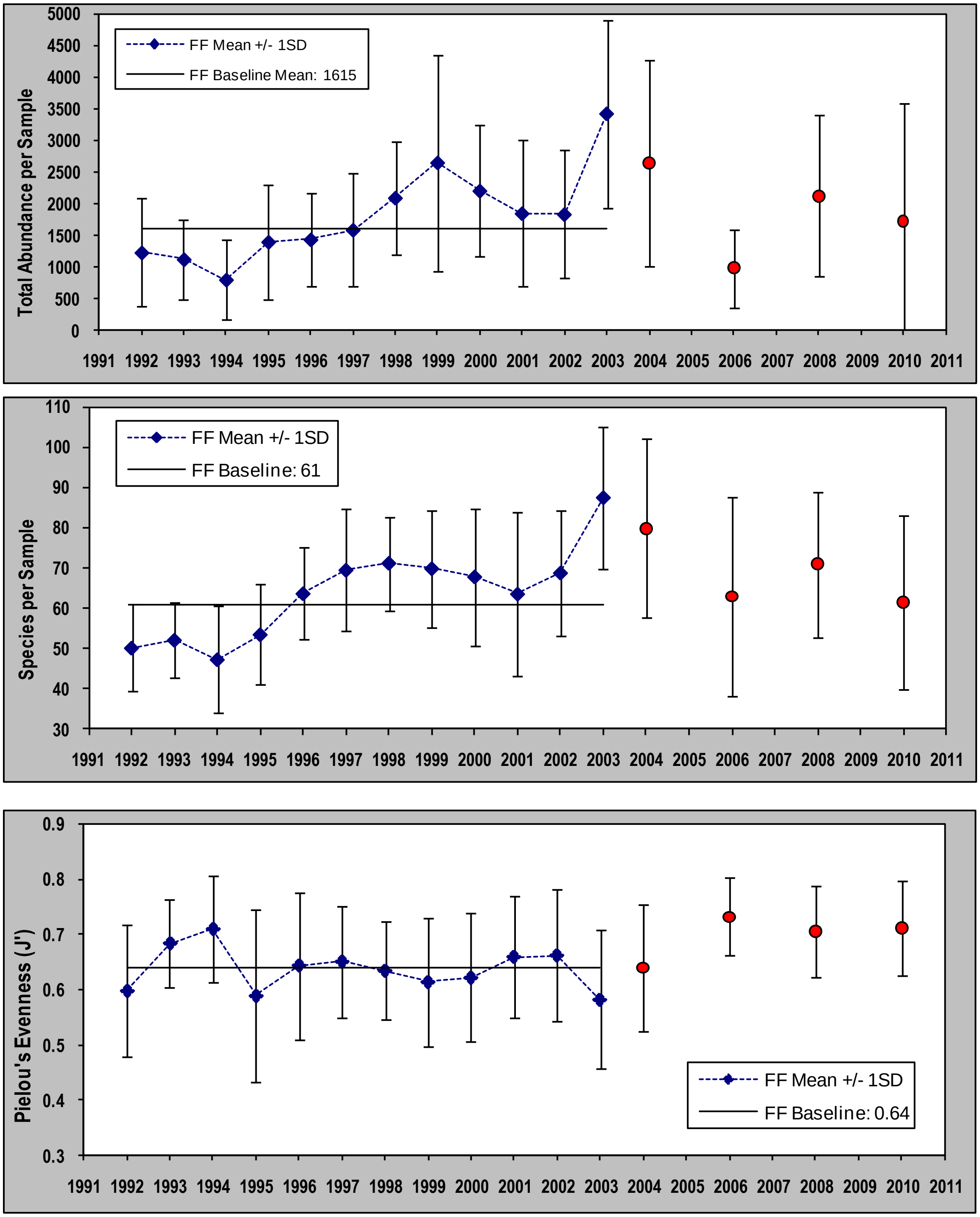


**Figure 17. Annual mean density, species per sample, and evenness (J′) at farfield stations. The even-year station subset is compared with the baseline values for the entire station set.**

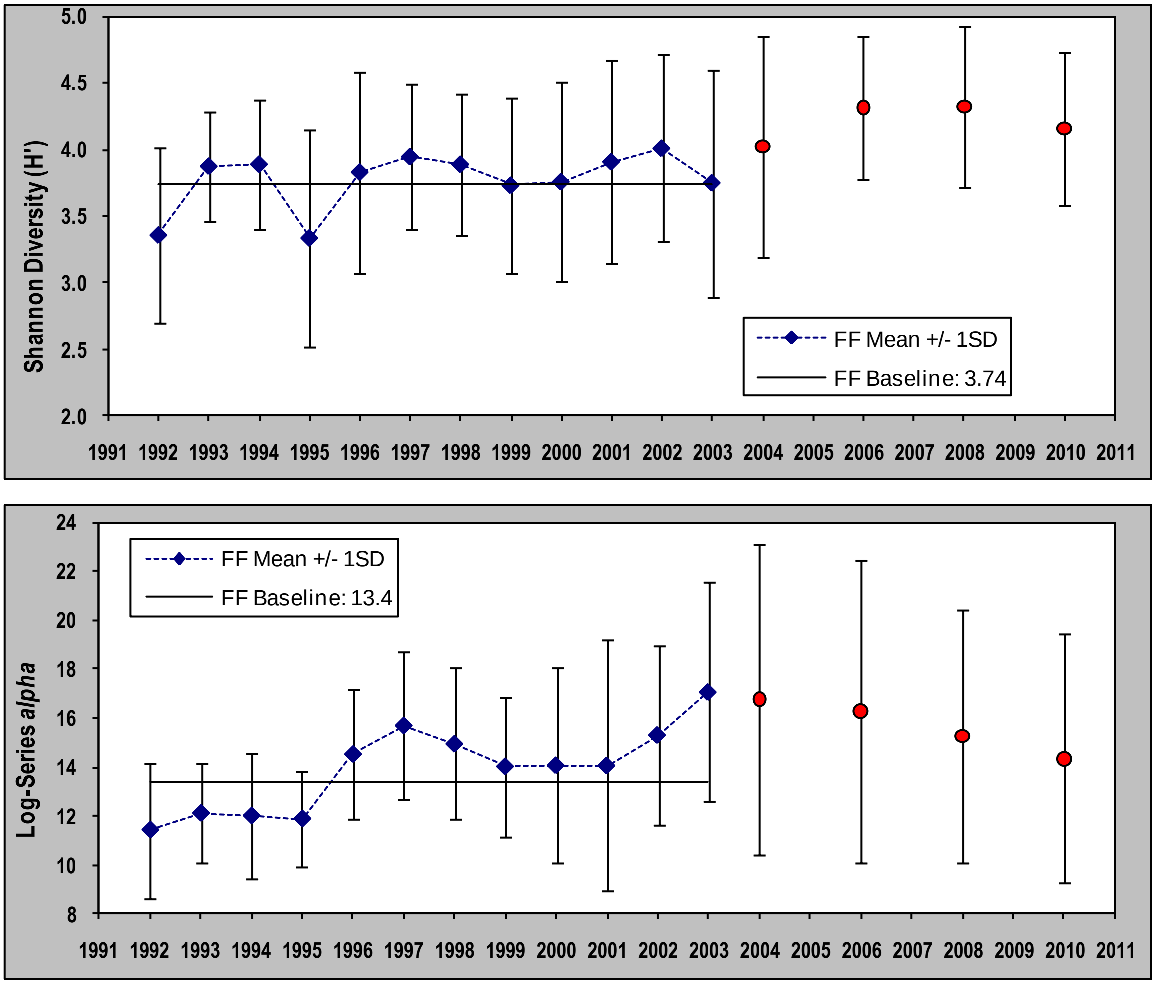


**Figure 18. Annual Shannon diversity (H′) and log-series *alpha* at farfield stations. The even-year station subset is compared with the baseline values for the entire station set.**

***Dominant Species*—**The fauna that characterizes the farfield generally differs from that seen in the nearfield: the farfield stations span a greater depth range (33–89 m) and are geographically widespread, with sediment types that are generally finer than those seen in the nearfield. Polychaete worms (*e.g., Euchone incolor, Aricidea quadrilobata,* and *Levinsenia gracilis*) are the predominant organisms at most of the stations, although *P. steenstrupi* is common at several. A different species of polychaete, *Cossura longocirrata*, is dominant at station FF07 in Cape Cod Bay, along with *Euchone incolor*, which typically indicates the presence of the deep-burrowing but rarely collected holothurian *Molpadia oolitica*[3] (Rhoads and Young 1971). Dominant species in 2010 were identical to those seen in 2008 at these stations, with only minor changes in relative abundance (Table 6). Mean abundances of *P. steenstrupi* and *E. incolor* decreased by 47.1 % and 43.9%, respectively, while *Anobothrus gracilis* and *Aricidea catherinae* increased by 74.1% and 70.2%, respectively.

**Table 6. Top numerical dominants in 12 farfield samples collected in August 2008 and 2010.**

| 2008 | | 2010 | |
|---|---|---|---|
| **Taxon** | **Total No. Indiv.** | **Taxon** | **Total No. Indiv.** |
| *Euchone incolor* | 4,212 | *Aricidea catherinae* | 3,677 |
| *Cossura longocirrata* | 2,854 | *Cossura longocirrata* | 2,766 |
| *Prionospio steenstrupi* | 2,436 | *Euchone incolor* | 2,362 |
| *Aricidea catherinae* | 2,161 | *Anobothrus gracilis* | 1,405 |
| *Aricidea quadrilobata* | 1,159 | *Prionospio steenstrupi* | 1,288 |
| *Mediomastus californiensis* | 931 | *Levinsenia gracilis* | 1,006 |
| *Levinsenia gracilis* | 825 | *Aricidea quadrilobata* | 915 |
| *Anobothrus gracilis* | 807 | *Ninoe nigripes* | 637 |
| *Spio limicola* | 738 | *Mediomastus californiensis* | 592 |
| *Ninoe nigripes* | 605 | *Spio limicola* | 590 |

[3] *Molpadia oolitica* is a large animal that is not well sampled by the small grabs used for infaunal monitoring. It is occasionally observed at deep-water sites sampled by the larger (deeper) grabs used for chemistry sampling.

## 3.4 2010 Hard-bottom Benthic Habitats and Fauna

### 3.4.1 Results

Photographic coverage in 2010 ranged from 23 to 35 minutes of video footage at each waypoint and a total of 585 minutes of video were viewed and analyzed. The video footage taken this year differed slightly from that taken in previous years. The ROV was flown at a slightly reduced speed to permit better resolution of the images on the HDV. Additionally, the ROV was occasionally paused and settled on the seafloor to allow for some screen grabs to be collected. Thus, even though more minutes of video were collected at each station, the area viewed was probably quite similar to previous years. Summaries of the 2010 video analyses are included in Appendix B.

Data collected from the video taken during the 2010 survey was generally similar to data obtained from previous post-diversion surveys. The seafloor on the tops of drumlins consisted of a moderate to moderately high relief mix of glacial erratics in the boulder and cobble size categories, while the seafloor on the flanks of drumlins frequently consisted of a low to moderately low relief seafloor characterized by cobbles with occasional boulders. The highest relief stations (moderate to moderately-high relief) were located on the tops of drumlins on either side of the outfall (T1-2, T1-3 and T4/6-1) and at one southern reference station (T10-1). The lowest relief stations were located on the flanks of the drumlin immediately south of the outfall (T4-2 and T6-1). Sediment drape generally ranged from moderately light to moderate on the tops of drumlins and moderate to moderately heavy on the flanks of drumlins. An exception to this was T10-1, a drumlin top station that had moderately-heavy to heavy drape. Habitat relief and sediment drape were quite variable within many of the sites surveyed. The seafloor in the vicinity of both diffuser heads consisted of angular rocks in the small boulder size category. This resulted in a high relief island (the diffuser head) surrounded by a moderate relief field of small boulders. Drape at the diffuser sites was moderately heavy.

Sixty-one taxa, 4 algal species, 41 invertebrate species, 12 fish species, and 4 general categories were seen during the 2010 video analyses (Table 7). The four algae recorded during the survey, were encrusting coralline algae and three species of upright algae, *Palmaria palmata* (dulse), *Ptilota serrata* (red filamentous algae), and *Agarum cribrosum* (shotgun kelp), are shown on Figure 19. Coralline algae were the most widespread, being found at 21 of the 23 waypoints. These encrusting algae were abundant or common-to-abundant at 6 of the drumlin top waypoints, common or few-to-common at another 6 waypoints (drumlin flanks, the northern reference sites, and one southern reference site), and few or rare at the remaining 9 sites (drumlin flanks and the farfield southern reference site T11-1). *Palmaria palmata* was only slightly less widespread being recorded at 17 waypoints. This species was commonly observed at only 4 of the waypoints (T1-2, T1-3, T1-4, and T7-2), few to commonly observed at an additional 7 waypoints (T1-1, T2-3, T7-1, T9-1, T10-1, T8-1, and T12-1), and rarely to few observed at the remaining 6 waypoints. In contrast, the distribution of *P. serrata* was more restricted being observed at only 9 of the waypoints. This filamentous red alga was most common at 4 drumlin top waypoints (T1-3, T1-4, northern reference site T7-1, and southern reference site T12-1). It was observed in slightly reduced numbers at an additional 3 waypoints (T1-2, and northern reference sites T7-1 and T9-1), and only a few were observed at the remaining 2 waypoints. The third upright alga, *Agarum cribrosum*, had the most restricted distribution, being seen only at 4 sites, the three northern reference waypoints and T1-3.

**Table 7. Taxa observed during the 2010 nearfield hard-bottom video survey.**

| Name | Common name | Name | Common name |
|---|---|---|---|
| **Algae** | | **Echinoderms** | |
| Coralline algae | pink encrusting algae | *Strongylocentrotus droebachiensis* | green sea urchin |
| *Ptilota serrata* | filamentous red algae | small white starfish | juvenile *Asterias* |
| *Palmaria palmata* | dulse | *Asterias vulgaris* | northern sea star |
| *Agarum cribrosum* | shotgun kelp | *Crossaster papposus* | spiny sunstar |
| | | *Henricia sanguinolenta* | blood star |
| **Invertebrates** | | *Porania insignis* | badge star |
| **Sponges** | | *Pteraster militaria* | winged sea star |
| general sponge | | *Solaster endeca* | smooth sunstar |
| *Haliclona oculata* | finger sponge | *Psolus fabricii* | scarlet holothurian |
| *Haliclona* spp. (encrusting) | sponge | | |
| *Melonanchora elliptica* | warty sponge | **Tunicates** | |
| *Polymastia* sp. A | encrust yellow sponge | *Aplidium/Didemnum* spp. | cream encrust tunicate |
| *Polymastia* sp. B | siphon sponge | *Boltenia ovifera* | stalked tunicate |
| *Suberites* spp. | fig sponge | *Botrylloides violaceus* | Pacific tunicate |
| cream sponge w/ projections | sponge | *Halocynthia pyriformis* | sea peach tunicate |
| yellow-cream encrust sponge | sponge | | |
| white divided sponge | sponge on brachiopod | **Miscellaneous** | |
| | | *Membranipora* sp. | sea lace bryozoan |
| **Coelenterates** | | *Myxicola infundibulum* | slime worm |
| hydroids | | barnacle/spirorbid complex | |
| *Obelia geniculata* | hydroid | *Terebratulina septentrionalis* | northern lamp shell |
| *Tubularia* sp. | hydroid | | |
| general anemone | | **Fishes** | |
| *Metridium senile* | frilly anemone | general fish | |
| *Urticina felina* | northern red anemone | dogfish | |
| *Cerianthus borealis* | northern cerianthid | *Anarhichas lupus* | wolffish |
| *Alcyonium digitatum* | dead man's fingers | *Hemitripterus americanus* | sea raven |
| *Gersemia rubiformis* | red soft coral | *Gadus morhua* | cod |
| | | *Macrozoarces americanus* | ocean pout |
| **Molluscs** | | *Microgadus tomcod* | tomcod |
| *Tonicella marmorea* | mottled red chiton | *Myoxocephalus* spp. | sculpin |
| *Crepidula plana* | flat slipper limpet | *Pholis gunnellus* | rock gunnel |
| *Buccinum undatum* | waved whelk | *Pollachius virens* | pollock |
| *Modiolus modiolus* | horse mussel | *Pseudopleuronectes americanus* | winter flounder |
| *Placopecten magellanicus* | sea scallop | *Sebastes fasciatus* | rosefish |
| *Arctica islandica* | ocean quahog | *Tautogolabrus adspersus* | cunner |
| | | | |
| **Crustaceans** | | **Other** | |
| *Cancer* spp. | Jonah or rock crab | whelk egg case | |
| *Homarus americanus* | lobster | | |

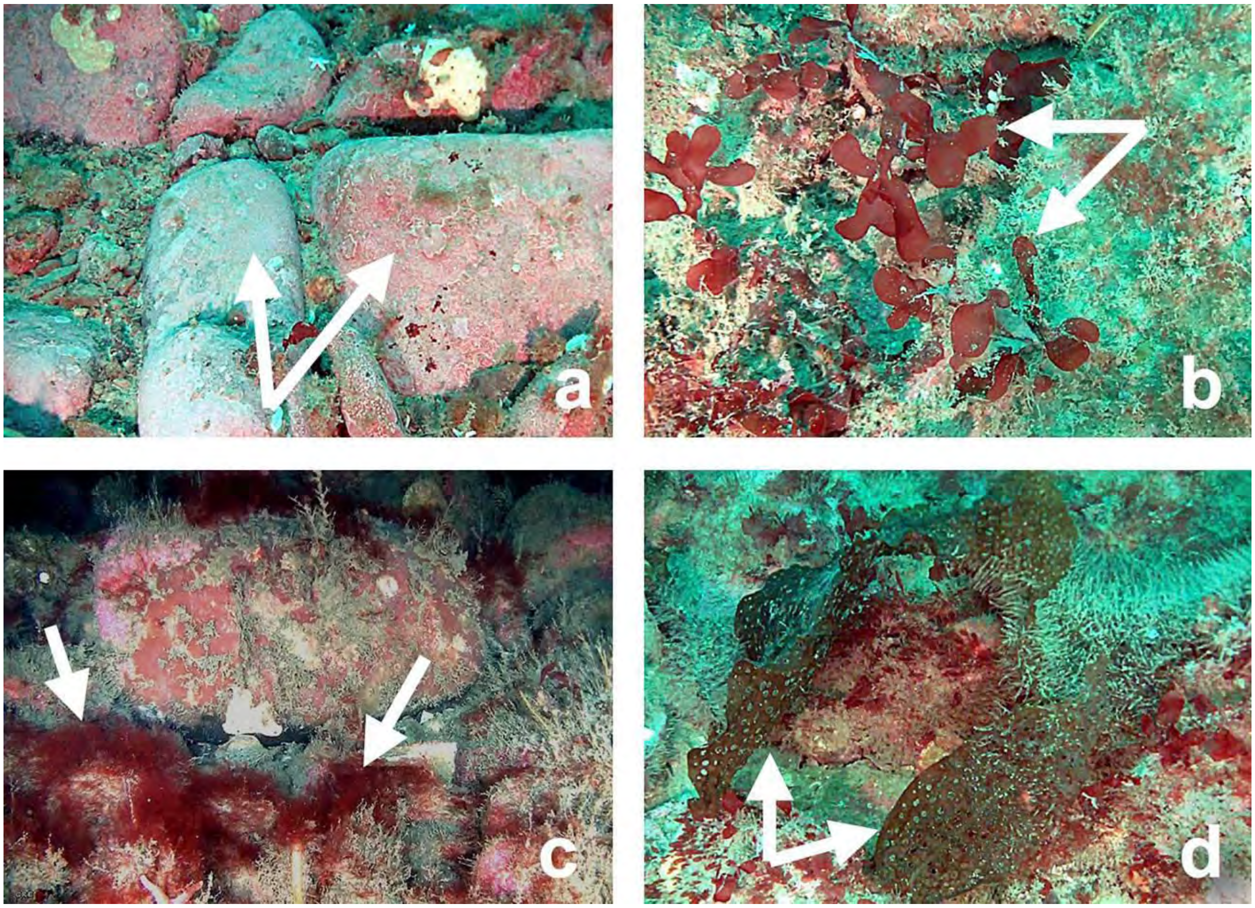


**Figure 19. Screen captures of HD video showing the four algal species encountered during the 2010 hard-bottom survey. (a) Abundant coralline algae (pink) encrusting rock surfaces at waypoint T1-4. A colony of northern white crust tunicate *Didemnum albidum* is visible on rock in the upper right of the frame. (b) Several colonies of dulse *Palmaria palmata* on a boulder at waypoint T1-2. (c) Numerous red filamentous algae *Ptilota serrata* on rocks at southern reference site T12-1. (d) Two fronds of shotgun kelp *Agarum cribrosum* on a boulder at waypoint T1-3. The shotgun kelp is heavily encrusted with the zigzag hydroid *Obelia geniculata*.**

Seven of the 41 invertebrate taxa observed were recorded at 20 or more waypoints. These widespread invertebrates included the northern red anemone *Urctinia felina*, the horse mussel *Modiolus modiolus*, juvenile and adult northern sea stars *Asterias vulgaris*, the blood star *Henricia sanguinolenta*, white and cream encrusting tunicates (*Aplidium*/*Didemnum* spp.), and the slime worm *Myxicola infundibulum*. An additional five taxa, the encrusting yellow sponge *Polymastia* sp. A, the lobster Homarus americanus, *Cancer* crabs, the sea peach tunicate *Halocynthia pyriformis*, and the brachiopod *Terebratulina septentrionalis*, were also quite widely distributed being recorded at 14 to 19 waypoints. In contrast, eleven other taxa had exceptionally restricted distributions and were each only seen at one waypoint. Notable amongst these were the red coral *Gersemia rubiformis* which was seen only at waypoint T10-1, and two sponge taxa that were seen only at waypoint T11-1. The remaining eight taxa were just rarely seen and did not appear to be habitat specific. One species of note was the invasive lacey bryozoan *Membranipora membranipora*, which was seen encrusting dulse at 7 of the stations (T1-2, T1-3, T1-4, T7-1, T7-2, T8-1, and T12-1). Additionally, it was also observed encrusting shotgun kelp at T7-2.

Four of the nine fish species were also widely distributed. The cunner *Tautogolabrus adspersus* was observed at 22 of the 23 waypoints. This species was most abundant at drumlin top waypoints with moderate to high relief. The winter flounder *Pseudopleuronectes americanus* was observed at 17 waypoints, and was most abundant in areas of lower relief. The sculpin *Myoxocephalu*s spp. and the cod *Gadus morhua* were also quite widely distributed, with each being observed at 15 waypoints. The cod was most common in areas of higher relief, while the sculpin was commonly observed in areas of lower to moderately-low relief. In contrast, several other fish species were exceptionally rare, with only one wolfish *Anarhichas lupus* and one sea raven *Hemitripterus americanus* seen during the entire survey.

The taxa inhabiting the diffuser heads of the outfall have remained stable over time and did not change when the outfall went online. The inactive diffuser head (Diffuser #44) continues to support a moderate population of the sea peach tunicate *Halocynthia pyriformis* and a sparse population of the frilled anemone *Metridium senile* (Figure 20). In contrast, the active diffuser head (Diffuser #2 at T2-5) supports a very dense population of *M. senile*, with anemones covering most of the available surfaces of the diffuser head (Figure 21). Additionally, numerous *M. senile* have also colonized the riprap around the base of the diffuser. The riprap in the vicinity of both diffuser heads continues to be colonized by a variety of encrusting organisms.

Far fewer areas of fresh physical disturbance were observed at the northern reference sites during the 2010 survey. However, numerous areas of older disturbance, characterized by turned over boulders that had small patches of coralline algae, fewer hydroids and upright algae, and lesser drape than the surrounding areas, were observed at T7-2.

Heavy settlements of barnacles were observed at three of the stations (T4.6-1, T6-2, and T7-2), where numerous rocks were totally encrusted with larger, live barnacles (Figure 22). Rocks that had recently supported dense stands of barnacles were observed at an additional 5 stations (T1-3, T2-1, T9-1, T10-1, and Diffuser #44). The rocks in these areas bore the remains of numerous barnacle bases and were also occasionally littered with disarticulates barnacle plates.

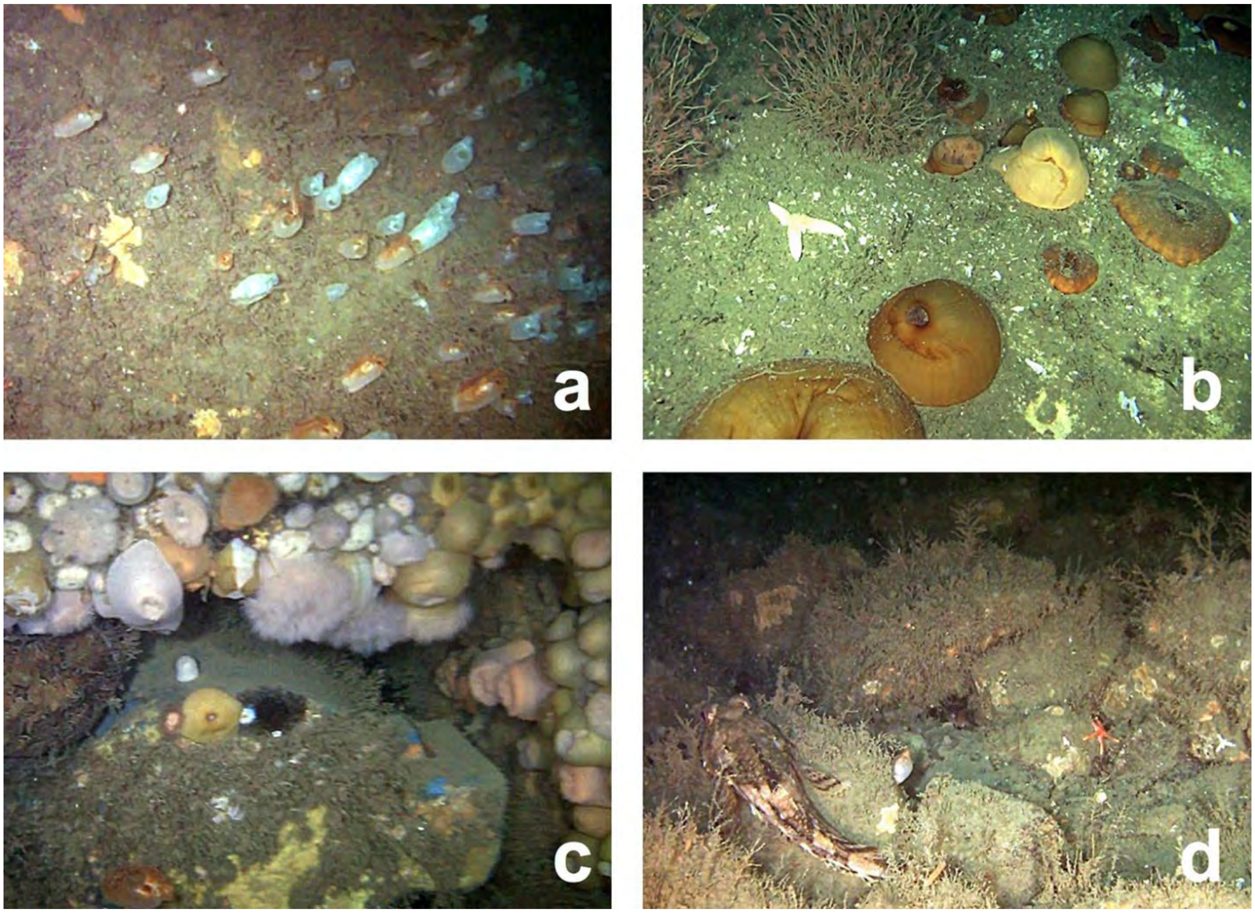


**Figure 20. Screen captures of HD video taken at inactive diffuser head #44 during the 2010 hard-bottom survey. (a) Numerous sea peaches *Halocynthia pyriformis* colonizing the side of diffuser head #44. (b) A sparse population of frilled anemones *Metridium senile* colonizing the top of diffuser head #44. A three-legged northern sea star *Asterias vulgaris* and two colonies of the hydroid *Tubularia* sp. are also visible. (c) Numerous *M. senile* surrounding a port on inactive diffuser head #44. (d) Rip-rap in the vicinity of diffuser #44 being colonized by bryozoans and a sea peach. A blood star *Henricia sanguinolenta* and a sculpin *Myoxocephalus* spp. are also visible.**

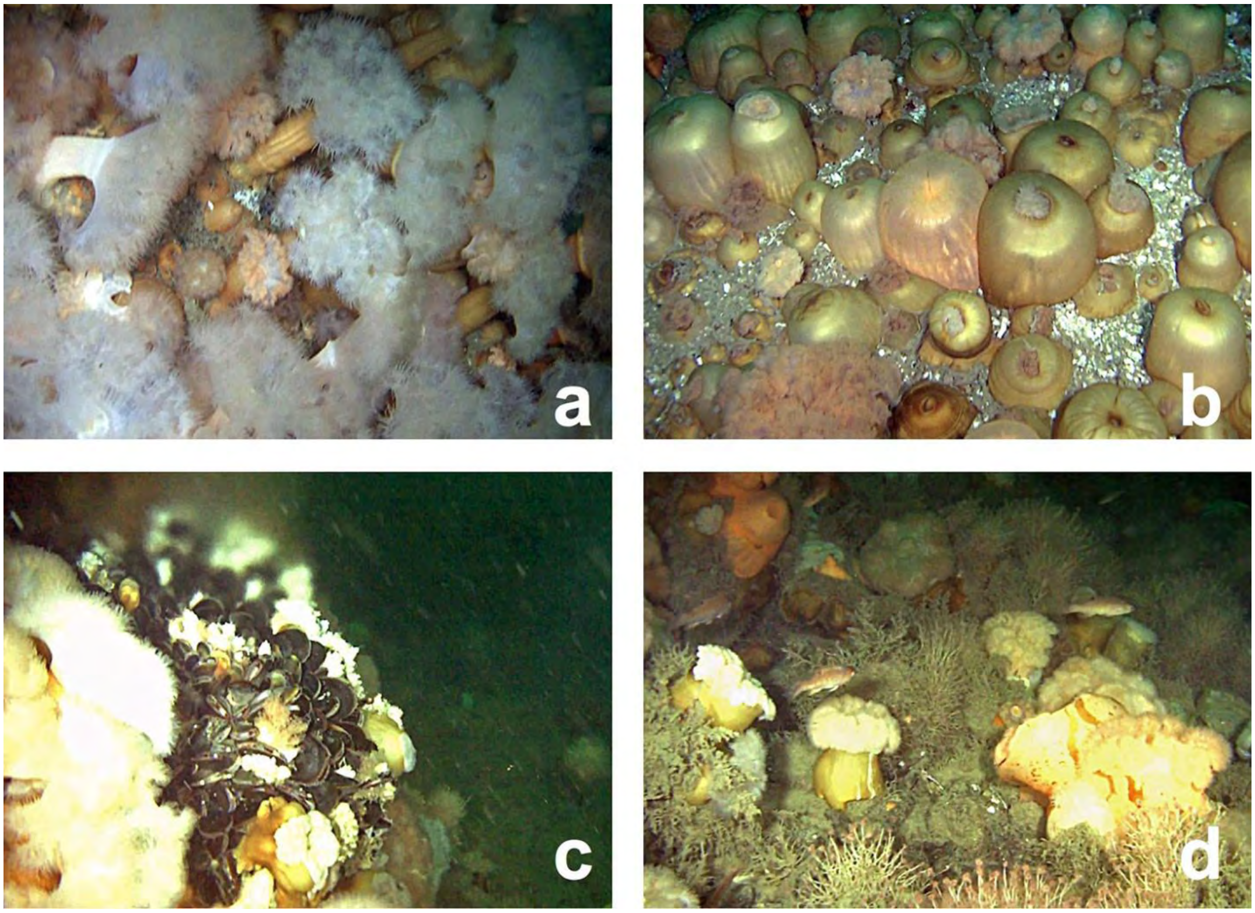


**Figure 21. Screen captures of HD video taken at active diffuser head #2 at station T2-5 during the 2010 hard-bottom survey. (a) Numerous frilled anemones *Metridium senile* colonizing the side of diffuser head #2. (b) A dense stand of retracted *M. senile* on the top of diffuser head #2. (c) Numerous mussels and *M. senile* surrounding an active port on the side of diffuser head #2. The mussels appear to be the blue mussel *Mytilus edulis*. The blurry water at the top of the frame reflects the density differential between the fresh water effluent and seawater. (d) Rip-rap near the base of diffuser #2 being colonized by *M. senile*. Cunner and colonies of the hydroid *Tubularia* sp. are also visible.**

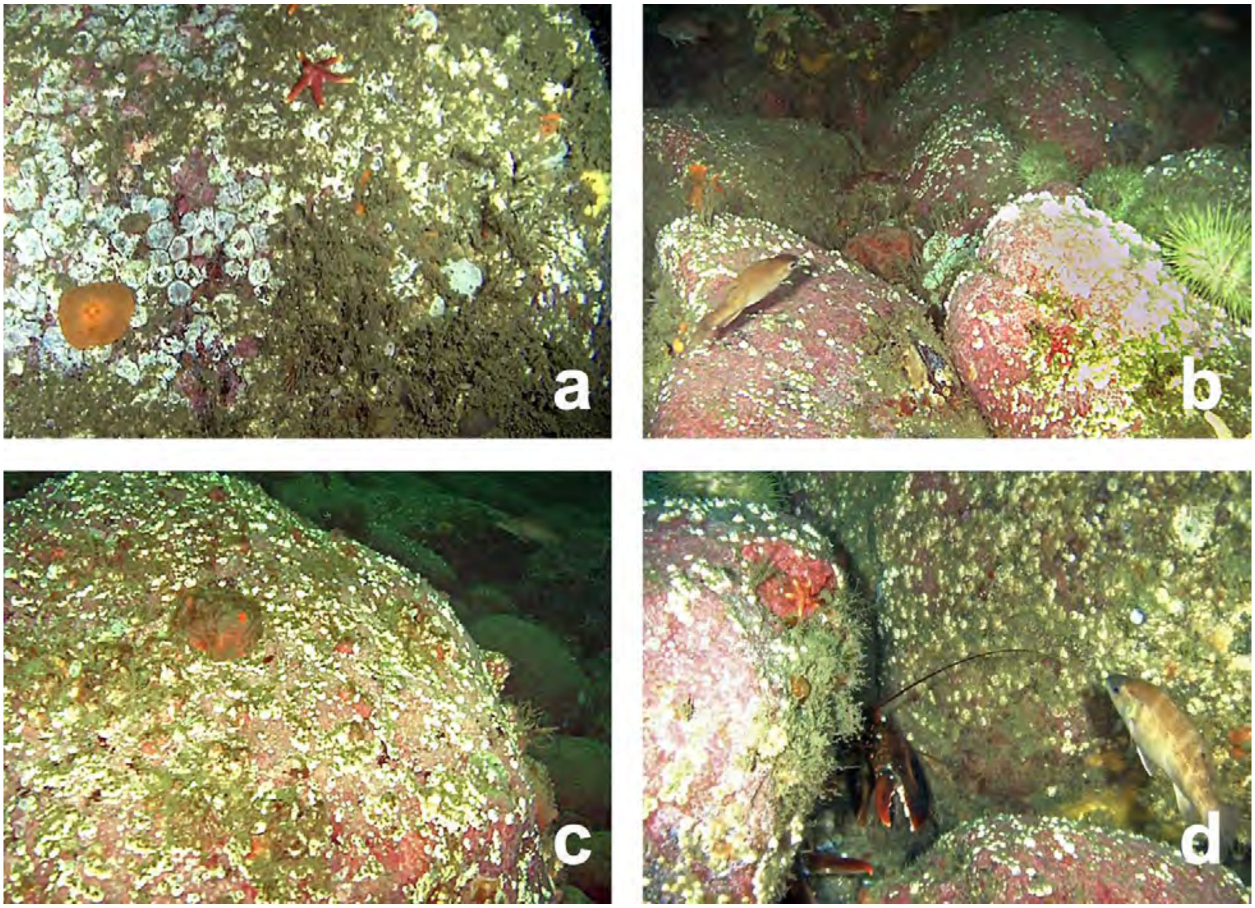


**Figure 22. Screen captures from HD video showing the barnacle settlement event observed on the 2010 hard-bottom survey. (a) Numerous barnacle bases covering a boulder at site T2-1. A retracted frilled anemone *Metridium senile* and a blood star *Henricia sanguinolenta* are also visible. (b) Numerous live barnacles on boulders at site T2-1. A cunner *Tautogolabrus adspersus* and four green sea urchins *Strongylocentrotus droebachiensis* are also visible. (c) Numerous live and dead barnacles on a boulder at site T4/6-1. A retracted scarlet holothurian *Psolus fabricii* (round reddish organism) and a cunner are also shown. (d) Live barnacles encrusting boulders surrounding a lobster burrow at site T6-2. The lobster's claws and a cunner are also visible.**

### 3.4.2 Comparison of 2010 Data with Pre- and Post-Diversion Results

Previous general trends of increased sediment drape, decreased percent cover of coralline algae, and a decline in upright algae, observed in the post-discharge years continued in 2010. Table 8 shows the amount of sediment drape seen on the rock surfaces during the 1996–2010 video surveys. Sediment drape was lightest on the shallowest parts of the two drumlins adjacent to the outfall (T1-2, T1-3, T1-4, and T4/6-1), slightly heavier at the southernmost reference sites (T8-1, T8-2, and T12-1), and moderate to moderately heavy at the northern reference sites (T7-1, T7-2, and T9-1). Drape was also generally heavier on the flanks of the drumlins north and south of the outfall (T1-1, T2-2, T2-3, T2-4, T4-2, and T6-1). Drape was consistently heaviest at T10-1, the southern reference site located west-southwest of the outfall. Based on an analysis of the slides taken from 1996 to 2008, sediment drape had been slightly higher at several of the stations north of the outfall (T1-2, T1-3, T1-4, T7-1, and T7-2) during the post-diversion years, and had gradually increased on the drumlin south of the outfall since 2005. In the video data, this post-diversion increase in drape is still evident at T1-2, T1-3, and T1-4, but not evident at the northern reference stations T7-1 and T7-2.

**Table 8. Sediment drape observed in video footage taken during the 1996–2010 hard-bottom surveys.**

| | | Pre-diversion | | | | | Post diversion | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
| Northern reference | T7-1 | l* | lm-h | l | l-h | m | m-mh | m | m | m | mh | m-mh | m | lm-mh | m | m |
| | T7-2 | l-h | mh | c-m | mh | m | mh | m | m | m | m | m | m | lm-m | m | lm-m |
| | T9-1 | | m-h | l-m | mh | h | m | m | m | lm | m | lm-m | m | lm-m | lm-mh | lm-m |
| Northern transect | T1-1 | l | l-m | l-h | mh | m | mh | m | m-mh | lm | m | m-mh | m | m-mh | m-mh | lm-m |
| | T1-2 | l | c-m | l | m* | l | lm | m | l-lm | m | lm | lm-m | lm | lm-m | lm | lm-m |
| | T1-3 | l | c-vl | c-vl | c-l | l | l | m | l | lm | lm | lm | lm | lm-m | l-m | l-m |
| | T1-4 | l | c-vl | c-vl | lm* | l | lm | l | lm | lm | lm | lm | lm | l-lm | lm-m | l-m |
| | T1-5 | l* | m | l-lm | m | m | m-mh | m | m | m | m | m | m | m | m | m |
| | T2-1 | l-lm | m | lm-h* | l-mh | l-mh | m | m | lm-m | lm | m | lm-m | lm | lm-m | m | lm |
| | T2-2 | h | m-h | m-h | l-h | h | m-mh | mh | m-mh | m | m | m-mh | m | m-mh | mh | m-mh |
| | T2-3 | l-lm | l-m | m | h | h | mh | m | m | m | m | m-mh | m | lm-mh | m-mh | mh |
| | T2-4 | m-mh | m-h | m-h | h | h | m-mh | mh | m | m | m | m-mh | mh | mh | mh | m-mh |
| Southern transect | T4/6-1 | vl | l-m | c-l | l | l | l | lm | l-lm | l | lm | lm | lm | l-lm | l-lm | l-lm |
| | T4-1 | lm-m | h | m | h | h | lm-m | lm | | | | | | | | |
| | T4-2 | l-m | m | mh* | h* | m | m | m | m | m | m | m | m | m-mh | m | m |
| | T4-3 | m-h | m-h | l-m* | mh | mh | mh | lm | | | | | | | | |
| | T6-1 | h | h | h | h | h | mh-h | m | m-mh | m | m | mh | m | m-mh | m | m |
| | T6-2 | vl* | l-m | l-m | l-m | m | lm | lm | m | m | lm | m-mh | m | m-mh | lm-m | lm-m |
| Southern reference | T10-1 | | mh-h | h | h | h | h | mh-h | mh-h | mh | mh | mh-h | h | h | h | mh-h |
| | T8-1 | l-m | l-m | c-vl | lm | lm | lm | lm | lm | lm | lm | lm-m | lm | m | lm-m | lm-m |
| | T8-2 | l | l-m | c-l | m | lm | l-lm | lm | lm | lm | lm | l-lm | lm | lm | lm | lm |
| | T12-1 | | | | | | | | lm | lm | lm | l-m | | m | lm-m | lm-m |
| | T11-1 | | | | | | | | m | m | m | m | m | | mh | m-mh |
| Diffusers | T2-5 | m | m | m-h | | | mh | m-mh | m | m | m | m-mh | mh | m-mh | mh | mh |
| | D44 | | | h | | h | h | m | mh | mh | mh | m-mh | mh | mh-h | mh | m-mh |

| h | mh-h | mh | m-mh | m | lm-m | lm | l-lm | l |
|---|---|---|---|---|---|---|---|---|
| heavy | | | | moderate | | | | light |

Encrusting coralline algae has historically been the most abundant and widely distributed taxon encountered during the hard-bottom surveys. Table 9 shows the relative cover of coralline algae observed in video footage taken during the 1996 to 2010 surveys. Coralline algae were generally most abundant on the tops of drumlins on either side of the outfall (T1-2, T1-3, T1-4, and T4/6-1) and two southern reference sites (T8-1 and T8-2), and least abundant on the flanks of the drumlins (T2-2, T2-4, T4-2, and T6-1). The cover of coralline algae was most variable near the edges of the tops of drumlins or on the flanks, where small lateral shifts in location frequently resulted in large differences in coralline algal cover. Cover of coralline algae was quite stable during the baseline period and remained stable at most of the stations during the first four years of the post-diversion period. A consistent decrease in cover of coralline algae is noticeable at the northern reference sites since 2002, and at three drumlin top sites north of the diffuser (T1-2, T1-3, and T1-4) since 2004. Less pronounced decreases in cover of coralline algae are seen at sites T1-5, T2-1, T2-2 and T2-3 since 2005, and at southern reference sites T8-1 and T8-2 since 2006. This pattern differs slightly from that observed in the analysis of the still images, where waypoints T1-2, T1-3, T1-4, T7-1, and T7-2, consistently had less percent cover of coralline algae since 2001. However, the subsequent decrease in cover of coralline algae in 2005, and its spread to the southern areas was observed in both the video and still images, but was less pronounced in the data collected from video images.

**Table 9. Relative cover of coralline algae observed in video footage taken during the 1996–2010 hard-bottom surveys.**

| | | Pre-diversion | | | | | Post diversion | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
| Northern reference | T7-1 | c-a | a | c-a | c | c-a | c-a | f-c | c | c | f-c | f-c | f-c | f-a | f-c | f-c |
| | T7-2 | c-a | c-va | c-a | c | c | f-c | c | f-c | c | f-c | f-c | c | c-a | f-c | f-c |
| | T9-1 | | c-a | c-a | c | c | c-a | c | f-c | c | f-c | c | c | c | f-c | f-c |
| Northern transect | T1-1 | va | c | c-a | c | c | f-c | f-c | f-c | c | f-c | f-c | f-c | f-c | f-c | f |
| | T1-2 | a | va | a | c* | a | c-a | c | a | f-c | c-a | c | c-a | c-a | c-a | c |
| | T1-3 | a | va | a | va | a | va | a | a | a | a | c | c-a | c | c-a | c-a |
| | T1-4 | va | va | a | a | a | a | a | a | c-a | c-a | c-a | c-a | c-a | c-a | c-a |
| | T1-5 | a* | c | c | c | c-a | f-c | f-c | c | c | f | r-f | f | r-f | f | f |
| | T2-1 | f-a | f-c | r-f* | c | c | f-c | c | c-a | c | f | c | f-a | f-c | f | c |
| | T2-2 | r | f | f-c* | r-c | c | f-c | r-f | f | f | f | r | r-f | f | f | f |
| | T2-3 | c | r | c | c | f* | f-c | f-c | f-c | f | f | f-c | r-f | f-c | f | f |
| | T2-4 | f | r | f | f | - | r | f | r-f | r | r | r | f | r-f | f | r |
| Southern transect | T4/6-1 | va | c-a | a | a | a | va | a | a | a | a | a | c-a | c-a | a | a |
| | T4-1 | r | f | r | - | c | - | r | | | | | | | | |
| | T4-2 | c | c-a | r-f* | f* | a | c | f-c | f | f-c | f-c | f-c | r | f | f | r-f |
| | T4-3 | f | f | c | f-c | c | f-c | c | | | | | | | | |
| | T6-1 | r | r | r | r | r | r | - | r | - | - | - | - | - | r | r |
| | T6-2 | c-a* | c | c-a | c | c | c | c | f-c | f-c | f-c | f | f | f-c | c | c-a |
| Southern reference | T10-1 | | r-f | - | r | - | - | - | - | r-c | r | - | - | - | - | r-f |
| | T8-1 | a | c-a | a | c-a | c | a | c-a | c-a | c-a | a | c | c-a | f-c | c | c-a |
| | T8-2 | a | a-va | a | c | a | c-a | c | a | a | a | c-a | c-a | c-a | c-a | c-a |
| | T12-1 | | | | | | | | c-a | c-a | c | c-a | | c | c-a | c |
| | T11-1 | | | | | | | | - | f | f | f | r-f | | f | r-f |
| Diffusers | T2-5 | - | - | r | | | - | - | - | - | - | - | - | - | - | - |
| | D44 | | | - | | - | - | - | - | - | - | - | - | - | - | - |

| a | c-a | c | f-c | f | r-f | r | - |
|---|---|---|---|---|---|---|---|
| abundant | | common | | few | | rare | none |

In general, the relative abundances of upright algae varied widely during both the pre- and post-diversion periods, and at many sites have shown a general decrease over time. Some of this variability appears to reflect patchiness in the spatial distributions of the upright algae, while some may just reflect natural cycles in the composition of algal communities. Table 10 shows the relative abundance of *P. palmata* over the 1996 to 2010 time period. During the pre-diversion period, dulse was consistently most abundant at the northern reference sites (T7-1, T7-2, and T9-1) and common at two waypoints north of the outfall (T2-2 and T2-3). During most of the post-diversion years, the relative abundance of *P. palmata* has decreased at these five sites, and additionally it dropped to an area wide low in 2003 and 2004. In contrast, since 2005 dulse has been seen in modest abundances at stations where it had historically been largely absent, such as on the drumlin immediately north of the outfall (T1-1, T1-2, T1-3, and T1-4), and at two of the southern reference sites (T8-1 and T8-2). This pattern follows that observed in data collected from still images between 1996 and 2008.

**Table 10. Relative abundance of *Palmaria palmata* (dulse) observed in video footage taken during the 1996– 2010 hard-bottom surveys.**

| | | Pre-diversion | | | | | Post diversion | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
| Northern reference | T7-1 | c | c-a | f | c | c-a | c-a | c-a | c | f-c | c-a | c-a | f-c | c-a | f-a | f-c |
| | T7-2 | c | c | c-a | c-a | c | a | c-a | c-a | a | c | f-c | f-c | f | r-c | f-a |
| | T9-1 | | a-va | c | a | a | c-a | c | r-f | f | r-c | f | f | f | f-c | f-c |
| Northern transect | T1-1 | a | a | c | c | f-c | f-c | c | f | f | c | f | r-f | f-c | c | f-c |
| | T1-2 | f | - | r | f | - | r-f | - | r | r | r | f-c | f | f-c | f | c-a |
| | T1-3 | - | - | r | - | r | f | f | f | r | f-c | f-c | f-c | c-a | f-a | c-a |
| | T1-4 | - | - | - | - | - | r | - | f | r | f | f | f | f-c | f-c | f-a |
| | T1-5 | r* | - | - | - | - | - | - | r | - | - | - | r | r | r | r |
| | T2-1 | - | c | - | f | r | f | r | r | - | - | r | - | r-f | r-f | r |
| | T2-2 | - | va | c | c | - | - | c | - | - | r-f | - | - | r | - | - |
| | T2-3 | c | c | c | c | c | f-c | c | - | f | f | f-c | f | f | f-c | f-c |
| | T2-4 | c | c | f-c | r | - | r-f | - | - | - | - | - | - | r | - | - |
| Southern transect | T4/6-1 | f | c* | - | r | r | r | - | r | - | - | r | r | r | r-f | r-f |
| | T4-1 | - | - | - | - | - | - | - | | | | | | | | |
| | T4-2 | - | - | - | - | - | - | - | - | - | - | f | r | - | - | - |
| | T4-3 | - | - | - | - | - | - | - | | | | | | | | |
| | T6-1 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | T6-2 | c* | - | r | - | - | - | - | - | - | - | - | - | - | r-f | r-f |
| Southern reference | T10-1 | | c-a | r | c | c | r | f-c | r | f-c | f | f | r | - | f | f-c |
| | T8-1 | - | - | - | - | - | - | - | - | r | f | r-c | f | f-c | r-f | f-c |
| | T8-2 | - | - | - | - | - | - | - | - | - | r | f | r | r | r-f | r |
| | T12-1 | | | | | | | | f | f | f | f-c | | f-a | f-c | f-c |
| | T11-1 | | | | | | | | - | - | - | - | - | | r-f | r |
| Diffusers | T2-5 | - | - | - | | | - | - | - | - | - | - | - | - | - | - |
| | D44 | | | - | | - | - | - | - | - | - | - | - | - | - | - |

| a | c-a | c | f-c | f | r-f | r | - |
|---|---|---|---|---|---|---|---|
| abundant | | common | | few | | rare | none |

Table 11 shows the relative abundance of *Ptilota serrata* over the 1996 to 2009 time period. Historically, this filamentous red alga was consistently most abundant at the northern reference sites (T7-1, T7-2, and T9-1), and only occasionally common to abundant at sites on drumlins on either side of the outfall (T1-1, T2-2, T2-3, T2-4, and T4/6-1). The relative abundance of *P. serrata* has decreased at the northern reference sites over time, and has virtually disappeared at many of the other sites during most of the post-diversion years. Abundances of *P. serrata* reached an all time low at all stations during 2007, when it was observed in very modest abundances at only 3 of the sites. This alga does appear to be rebounding at one of the northern reference sites (T7-1). It is also appearing in sizable abundances at two drumlin top sites north of the outfall (T1-3 and T1-4), and at one of the southern reference sites (T12-1). Similar patterns were also observed in the data collected from still images between 1996 and 2008. These patterns may reflect different stages in a successional sequence of algal communities.

**Table 11. Relative abundance of *Ptilota serrata* (filamentous red alga) observed in video footage taken during the 1996–2010 hard-bottom surveys.**

| | | Pre-diversion | | | | | Post diversion | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
| Northern reference | T7-1 | va | c-a | a | a | c | c-a | c-a | c-a | f-a | c-a | c-a | f-c | c-a | f-a | f-c |
| | T7-2 | va | c-a | a | a | c-a | a | c | c-a | a | a | f-a | f-c | f-c | r-c | f-a |
| | T9-1 | | a-va | c-a | a | c-a | c | f-c | r | f | r-c | - | - | - | f-c | f-c |
| Northern transect | T1-1 | a | - | c-a | - | - | - | f | - | - | - | - | - | - | f | - |
| | T1-2 | a | - | f | - | - | - | - | - | - | - | - | - | - | f-c | f-c |
| | T1-3 | f | - | f | - | - | f | - | r | c-a | r | r-c | f-c | c-a | c-a | c-a |
| | T1-4 | r-f | - | - | - | - | - | - | - | r-f | - | f | - | f-c | c-a | f-a |
| | T1-5 | f-c* | - | - | - | - | - | - | - | - | - | r-f | - | - | r-f | - |
| | T2-1 | f | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | T2-2 | f | c | a* | c | - | - | - | - | - | - | - | - | - | - | - |
| | T2-3 | a | - | c-a | f-c | f-c | - | r-f | - | - | - | r | - | - | - | - |
| | T2-4 | a | r | c | - | - | - | - | - | - | - | - | - | - | - | - |
| Southern transect | T4/6-1 | c-va | c-a | f | f | - | - | - | - | - | - | - | - | r | r-f | r-f |
| | T4-1 | - | - | - | - | - | - | - | | | | | | | | |
| | T4-2 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | T4-3 | - | - | - | - | - | - | - | | | | | | | | |
| | T6-1 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | T6-2 | c-va* | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Southern reference | T10-1 | | c-a | f-c | f | - | - | - | - | - | - | - | - | - | r | r |
| | T8-1 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | T8-2 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | T12-1 | | | | | | | | f-c | f-c | - | f | | f-a | f-c | c-a |
| | T11-1 | | | | | | | | - | - | - | - | - | | - | - |
| Diffusers | T2-5 | - | - | - | | | - | - | - | - | - | - | - | - | - | - |
| | D44 | | | - | | - | - | - | - | - | - | - | - | - | - | - |

| a | c-a | c | f-c | f | r-f | r | - |
|---|---|---|---|---|---|---|---|
| abundant | | common | | few | | rare | none |

The other upright alga, the shotgun kelp *Agarum cribrosum*, has historically been consistently abundant only at the northern reference sites (Table 12). This species was frequently quite patchily distributed even within waypoints, with many *A. cribrosum* fronds observed in some areas while none were observed in adjacent areas. There has been a general decrease in shotgun kelp at all of the northern reference sites, with the decreases being most pronounced at T7-2 and T9-1. Shotgun kelp was occasionally encountered at a few of the other waypoints during the pre-diversion period, but has rarely been encountered elsewhere in the post diversion period. Data collected from the slide images showed a dramatic decline in *A. cribrosum* at T7-1 from a high in 2000, when it was heavily overgrown by the invasive bryozoan *Membranipora membranipora*. This decline was much less evident in the data collected from video images.

**Table 12. Relative abundance of *Agarum cribrosum* (shotgun kelp) observed in video footage taken during the 1996–2010 hard-bottom surveys.**

| | | Pre-diversion | | | | | Post diversion | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
| Northern reference | T7-1 | c | f | a | c | a | f-c | c | c | c | c | f-c | f-c | c | c | c |
| | T7-2 | va | f-c | a | c-a | a | c-a | c | c | c-a | a | c | r | - | f | r-a |
| | T9-1 | | va | c-a | a | c | c | f | - | r | r | - | - | - | r | r |
| Northern transect | T1-1 | f | f | f | - | r | - | - | - | - | - | - | - | - | - | - |
| | T1-2 | c | f | r | - | - | r | - | - | - | - | - | - | - | - | - |
| | T1-3 | - | - | - | r | r | - | r | - | - | - | - | - | r | - | f-c |
| | T1-4 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | T1-5 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | T2-1 | - | - | - | r | - | - | - | - | - | - | - | - | - | - | - |
| | T2-2 | - | - | c* | c | - | - | r | - | - | - | - | - | - | - | - |
| | T2-3 | r | r | f-c | r | c* | f | r | - | - | - | - | - | - | - | - |
| | T2-4 | - | - | r | - | - | - | - | - | - | - | - | - | - | - | - |
| Southern transect | T4/6-1 | f | c* | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | T4-1 | - | - | - | - | - | - | - | | | | | | | | |
| | T4-2 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | T4-3 | - | - | - | - | - | - | - | | | | | | | | |
| | T6-1 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | T6-2 | c* | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Southern reference | T10-1 | | a | - | c | f-c | - | r | - | r | - | r | - | - | - | - |
| | T8-1 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | T8-2 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | T12-1 | | | | | | | | - | r | - | - | | - | - | - |
| | T11-1 | | | | | | | | - | - | - | - | - | | - | - |
| Diffusers | T2-5 | - | - | - | | | - | - | - | - | - | - | - | - | - | - |
| | D44 | | | - | | - | - | - | - | - | - | - | - | - | - | - |

| a | c-a | c | f-c | f | r-f | r | - |
|---|---|---|---|---|---|---|---|
| abundant | | common | | few | | rare | none |

Part of the decline in both coralline and upright algae at the northern reference sites during the post diversion period may reflect post 9/11 increases in anchoring activity of tankers at these sites. Over the last several years numerous instances of heavily disturbed seafloors have been observed at all 3 northern reference sites. This may result in a seafloor that is a mosaic of areas in differing stages of recovery from physical disturbance.

Several long-term trends have been noted in the abundances of some of the larger mobile taxa. These trends appear to reflect widespread temporal changes in abundances rather than changes related to the outfall. Table 13 shows the abundance of several of these species observed during the video surveys in years 1996 to 2009. The numbers of *Cancer* crabs, cod (*Gadus morhua*), and lobster (*Homarus americanus*) observed during the surveys have generally increased over time. The number of *Cancer* crabs seen annually ranged from 3 to 15 individuals between 1996 and 1999, then increased to 168 individuals in 2002, fell to a low of 12 individuals in 2008, and rebounded to 85 in 2009. The number of crabs seen annually varies widely, but the general trend appears to be towards higher numbers over time. The number of lobsters seen during the surveys has also increased over time, ranging from 2 to 18 individuals per year in the pre-diversion period to 40 to 79 individuals per year in all but one year of the post diversion period. Cod have shown a similar pattern with none to 22 individuals seen annually during the pre-diversion years and 21 to 91 individuals seen annually during all but two of the post diversion years.

**Table 13. Number of individuals of four selected species observed during the hard-bottom video surveys from 1996 to 2010, adjusted to include only stations that were surveyed in all the years (with the exception of two stations added after 1996).**

| | Pre-discharge | | | | | Post-discharge | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
| **Minutes of video** | 438 | 487 | 439 | 422 | 444 | 448 | 495 | 469 | 454 | 466 | 419 | 440 | 443 | 448 | 531 |
| ***Gadus morhua*** **(cod)** | - | 6 | 12 | 22 | 11 | 41 | 53 | 10 | 52 | 64 | 59 | 40 | 64 | 91 | 38 |
| ***Pseudopleuronectes americanus*** **(winter flounder)** | 20 | 14 | 30 | 34 | 11 | 18 | 19 | 9 | 24 | 17 | 11 | 16 | 47 | 40 | 91 |
| ***Cancer*** **spp. (rock crab)** | 6 | 3 | 4 | 15 | 92 | 123 | 168 | 144 | 115 | 67 | 81 | 108 | 28 | 85 | 34 |
| ***Homarus americanus*** **(lobster)** | 6 | 2 | 11 | 4 | 18 | 21 | 31 | 33 | 12 | 10 | 35 | 36 | 12 | 79 | 35 |

The data obtained from an analysis of the video images showed similar patterns to that observed in data obtained from analysis of the slides. The data from the video analysis was not quite as sensitive as that obtained from the slides, and also showed a slight time lag in discerning changes. This is not surprising since the data from the video is frequently a range of relative abundances encountered at a waypoint rather than a discrete number that represents an average of 25 to 30 slides. Ranges would be much less sensitive to subtle changes in the relative abundances of the biota. However, both techniques showed similar patterns, so the video analysis appears to be sensitive enough to discern more dramatic changes.

# 4. MONITORING QUESTIONS

The benthic monitoring program was designed to address seven questions (MWRA 2001) regarding sediment contamination and tracers and benthic communities:

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

The long-term monitoring data indicated that there have been localized increases and/or decreases in concentrations of some contaminants at one or more stations during the post-diversion period. For example, total pesticide, total PCB, copper, and silver concentrations are at the low end of the baseline range at stations NF12 and NF17 in 2010, while aluminum concentrations are at the high end or above the baseline range.

A statistical analysis of the long-term monitoring data suggest that mean concentrations of total DDT, total PCB, total pesticide, total chlordane, and/or mercury decreased significantly (at the 95% level of confidence) between the baseline and post-diversion periods in the nearfield and/or farfield regions of Massachusetts and Cape Cod Bays, while aluminum concentrations increased in nearfield sediments. The observed decrease could be associated with reduced inputs to the system, slight methodological differences used throughout the monitoring program, and natural recovery processes that have reduced surface contamination over time. An explanation for the post-diversion increase in aluminum is not evident. Overall, sediment data to date indicate that concentrations of organic contaminants (PCBs and chlorinated pesticides) and selected metals (aluminum and mercury) have changed in surficial sediment from some nearfield and/or farfield regions.

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

*C. perfringens* abundances (not normalized to percent fines) measured in surficial sediments throughout Massachusetts and Cape Cod Bays ranged from undetected (NF23 in 1995) to 24,100 colony forming units per grams (cfu/g) dry weight (NF21 in 1997) prior to diversion. In general, *C. perfringens* abundances were low throughout the bay, with slightly higher levels observed closer to Boston Harbor. Abundances generally decreased with distance from the harbor, with farfield sediments located far away from Boston Harbor (>20 km) having the lowest *C. perfringens* abundances.

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

The long-term monitoring data show a highly localized change in the abundance and spatial distribution of *C. perfringens* (normalized to percent fines) in surficial sediments following effluent diversion to the offshore outfall in 2000. That is, post-diversion mean abundances of *C. perfringens* decreased significantly (compared to baseline) in surficial sediments located near the former Harbor outfall (i.e., transition area sediments) and increased significantly (compared to baseline) in surficial sediments located near the new offshore outfall (i.e., sediments within 2 km of offshore outfall). Mean abundances of *C. perfringens* in surficial sediments located further away from the offshore outfall (i.e., nearfield sediments >2 km from the offshore outfall) did not change significantly between the baseline and post-diversion monitoring periods.

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

For assessing outfall effects, the MWRA (1997) set a 50% reduction in the apparent color RPD layer depth over the study area as a critical trigger level. Similarly, a 50% increase in apparent color RPD over the baseline would be noteworthy. Maciolek et al. (2007) compared baseline to discharge years and found the discharge years had significantly deeper RPD layers (baseline to discharge years multiplier 0.202, SE = 0.097, p = 0.038). The addition of the deeper RPD layer data from 2007 made the discharge years even more different than baseline years. In 2010, as in 2009, the grand average aRPD for all stations appeared to be shallower than in immediately preceding years, but still deeper than baseline .

- *Has the soft-bottom community changed?*

There have been clear temporal changes in the soft-bottom benthic infaunal community over the years of the monitoring program, including changes in total infaunal density, species composition and richness, and, to some extent, diversity. By 2002 infaunal abundance (per sample) had increased by roughly 60% over abundances recorded in the early years of the program, due primarily to increased abundances of only a few species, especially *Prionospio steenstrupi*, which replaced another spionid polychaete, *Spio limicola*, as the numerical dominant at the medium- to fine-grained stations. Such fluctuations are characteristic of marine benthic invertebrate species and cannot be construed as related to the operation of the outfall. The high variability at some stations, which contrasts with the stability of other stations over time, suggests that several processes, physical as well as biological, operate in this system, e.g., the occasional scouring of the bottom by storms also contributes to the fluctuation in overall invertebrate densities recorded from the benthic grab samples.

The larger patterns elucidated over time for the Massachusetts Bay stations have remained stable throughout the program. In similarity tests, the farfield stations have always differed from the nearfield, e.g., the Cape Cod Bay stations comprise a suite of species that gives them a unique signature. Nearfield stations FF10, FF12, and FF13 can be distinguished from the remaining nearfield stations, reflecting the transitional sediment texture at those stations; similarly, the nearfield sandy stations such as NF17 can be distinguished from nearfield fine-grained stations. These patterns have held whether the entire station set is sampled, or whether the odd- or even-year subsets are considered.

In 2010, mean Shannon diversity (H′) and Pielou's evenness (J′) exceeded the Contingency Plan upper threshold levels set by the MWRA for those parameters (4.24 for H′ and 0.70 for J′), resulting in a "caution" that was reported to EPA and the public. The detailed evaluation of both the regional data set and several individual stations did not reveal any major change in the benthic community apart from a change in the abundance of *P. steenstrupi*: a major decline in the abundance of this species caused the diversity and evenness at several stations to increase. There is no evidence that the operation of the outfall was related to the population fluctuation of this species.

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

Detailed investigation of individual stations has not suggested any localized outfall impact, even at stations within 2 km of the outfall (*e.g.*, NF17) where elevated levels of the sewage tracer *Clostridium perfringens* had suggested a modest impact of the discharge in previous years. None of the species dominant at any of the stations are those considered to be opportunists responding to organic enrichment, which has, in fact, not been seen at the outfall sites.

The cause of the exceedance reported in 2010 for two benthic community parameters, J′ (evenness) and H′ (Shannon diversity), was not apparent from a regional evaluation of the nearfield stations: apart from the severe decline in the populations of *Prionospio steenstrupi*, which resulted in the greater importance of other species in the samples, there was no immediately obvious cause for the elevation of those two parameters. There is no evidence that the threshold exceedances resulted from an impact of the outfall discharge on infaunal communities, but resulted from natural variability in the benthic communities monitored in the vicinity of MWRA's outfall.

♦ *Has the hard-bottom community changed?*

The hard-bottom benthic communities near the outfall remained relatively stable over the 1996–2000 baseline time period, and have not changed substantially with activation of the outfall in September 2000. Major departures from baseline conditions have not occurred during the post-diversion years; however, some modest changes have been observed. Increases in sediment drape, and concurrent decreases in cover of coralline algae, were observed at several drumlin-top sites north of the outfall and at the two northernmost reference sites during all of the post-diversion years. The decrease in coralline algae became more pronounced in 2005 and spread to a number of additional sites south of the outfall. Decreased cover of coralline algae at the stations close to the outfall may be related to the diversion, or may just reflect long-term changes in sedimentation, and hence coralline algae, patterns. Additionally, a decrease in the number of upright algae was observed at many of the stations. However, it is unlikely that this decrease was attributable to diversion of the outfall, since the general decline had started in the late 1990s and the number of upright algae appears to be increasing again at a number of stations. The decline has been quite pronounced at the northern reference stations and may reflect physical disturbance of the seafloor, possibly due to anchoring of tankers at these locations following September 11, 2001. Disturbance of the seafloor in the form of overturned boulders and areas of shell lag has been noticed at the northern reference sites. Lush epifaunal growth continues to thrive on the diffuser heads surveyed for this study and throughout many of the other stations visited. The outfall impacts appear to be minimal at this time.

# 5. REFERENCES

Blake, JA, B Hilbig, and DC Rhoads. 1993. Final Report for Massachusetts Bay outfall monitoring program: soft bottom benthic biology and sedimentology, 1992 baseline conditions in Massachusetts and Cape Cod Bays. Massachusetts Water Resources Authority. Report 1993-10. 108 pp. + 4 appendices.

Bothner, MH. 2001. Concentrations of metals and bacterial spores in sediments near the Massachusetts Bay outfall before and after discharge began. USGS Open-file Report 01-356.

Butman, B, CR Sherwood, and PS Dalyander. 2008. Northeast storms ranked by wind stress and wave-generated bottom stress observed in Massachusetts Bay, 1990–2006. *Continental Shelf Research* 28:1231–1245.

Coats, DA, E Imamura, and JF Campbell. 1995. 1993 Annual Soft-Bottom Benthic Monitoring: Massachusetts Bay Outfall Studies. Massachusetts Water Resources Authority. Report 1995-2. 137 pp.

Long ER, DD MacDonald, SL Smith, and FD Calder. 1995. Incidence of Adverse Biological Effects Within Ranges of Chemical Concentrations in Marine and Estuarine Sediments. *Environmental Management*. 19, No.1: 81–97.

Maciolek NJ, RJ Diaz, DT Dahlen, B Hecker, IP Williams, CD Hunt, and W Smith. 2007. 2006 Outfall Benthic Monitoring Report. Boston: Massachusetts Water Resources Authority. Report 2007-08. 162 pp.

Maciolek NJ, SA Doner, RJ Diaz, DT Dahlen, B Hecker, IP Williams, CD Hunt, and W Smith. 2008. Outfall Benthic Monitoring Interpretive Report 1992–2007. Boston: Massachusetts Water Resources Authority. Report 2008-20. 149 pp.

Maciolek, NJ, DT Dahlen, RJ Diaz, and B Hecker. 2009. Outfall Benthic Monitoring Report: 2008 Results. Boston: Massachusetts Water Resources Authority. Report 2009-13. 36 pages plus appendices.

MWRA. 1991. Massachusetts Water Resources Authority effluent outfall monitoring plan phase I: baseline studies. Boston: Massachusetts Water Resources Authority. Report 1991-ms-02. 95 pp.

MWRA. 1997. Massachusetts Water Resources Authority Contingency Plan. Boston: Massachusetts Water Resources Authority. Report 1997-ms-69. 41 pp.

MWRA. 2001. Massachusetts Water Resources Authority Contingency Plan Revision 1. Boston: Massachusetts Water Resources Authority. Report ENQUAD ms-071. 47 pp.

MWRA. 2004. Massachusetts Water Resources Authority Effluent Outfall Ambient Monitoring Plan Revision 1, March 2004. Boston: Massachusetts Water Resources Authority. Report 1-ms-092. 65 pp.

MWRA. 2011. MWRA Contingency Plan Threshold Exceedance: Infaunal diversity for August 2010. 8 pp. http://www.mwra.state.ma.us/harbor/pdf/20110107amx_diversity.pdf

Rhoads, DC and DK Young. 1971. Animal-sediment relations in Cape Cod Bay, Massachusetts II. Reworking by *Molpadia oolitica*. *Marine Biology* 11:255–161.

# APPENDIX A

# 2010 Infaunal Community Parameters

**Table A1. Benthic community parameters for all samples collected in August 2010.**

| Nearfield Stations | | | | | | |
|---|---|---|---|---|---|---|
| **Station** | **Rep** | **Total Indiv.** | **Number of Species** | **H′** | **J′** | **LSA** |
| FF10 | 1 | 1124 | 52 | 4.20 | 0.74 | 11.27 |
| FF10 | 2 | 1484 | 70 | 4.50 | 0.73 | 15.26 |
| FF10 | 3 | 1118 | 69 | 4.51 | 0.74 | 16.25 |
| FF13 | 1 | 1522 | 50 | 3.14 | 0.56 | 9.92 |
| FF13 | 2 | 1903 | 58 | 3.29 | 0.56 | 11.30 |
| FF13 | 3 | 1827 | 54 | 3.16 | 0.55 | 10.44 |
| NF05 | 1 | 1171 | 70 | 4.64 | 0.76 | 16.33 |
| NF07 | 1 | 1204 | 60 | 3.91 | 0.66 | 13.28 |
| NF08 | 1 | 1219 | 61 | 4.41 | 0.74 | 13.52 |
| NF09 | 1 | 1254 | 68 | 4.62 | 0.76 | 15.42 |
| NF12 | 1 | 1648 | 64 | 4.53 | 0.76 | 13.25 |
| NF12 | 2 | 1625 | 76 | 4.77 | 0.76 | 16.53 |
| NF12 | 3 | 1654 | 73 | 4.73 | 0.76 | 15.63 |
| NF16 | 1 | 1346 | 69 | 4.45 | 0.73 | 15.39 |
| NF17 | 1 | 1216 | 65 | 3.75 | 0.62 | 14.68 |
| NF17 | 2 | 1046 | 61 | 4.19 | 0.71 | 14.13 |
| NF17 | 3 | 1145 | 65 | 4.47 | 0.74 | 14.93 |
| NF18 | 1 | 1532 | 92 | 4.80 | 0.74 | 21.49 |
| NF19 | 1 | 1332 | 73 | 4.46 | 0.72 | 16.60 |
| NF22 | 1 | 1504 | 59 | 4.17 | 0.71 | 12.24 |
| NF23 | 1 | 1048 | 67 | 4.23 | 0.70 | 15.95 |

| Farfield Stations | | | | | | |
|---|---|---|---|---|---|---|
| **Station** | **Rep** | **Total Indiv.** | **Number of Species** | **H′** | **J′** | **LSA** |
| FF04 | 1 | 305 | 38 | 4.14 | 0.79 | 11.46 |
| FF04 | 2 | 408 | 35 | 3.86 | 0.75 | 9.18 |
| FF04 | 3 | 321 | 37 | 4.00 | 0.77 | 10.82 |
| FF05 | 1 | 921 | 72 | 4.73 | 0.77 | 18.56 |
| FF05 | 2 | 568 | 59 | 4.62 | 0.79 | 16.65 |
| FF05 | 3 | 675 | 59 | 4.64 | 0.79 | 15.78 |
| FF07 | 1 | 1744 | 37 | 3.33 | 0.64 | 6.64 |
| FF07 | 2 | 4557 | 65 | 3.39 | 0.56 | 10.75 |
| FF07 | 3 | 6323 | 67 | 3.30 | 0.54 | 10.47 |
| FF09 | 1 | 1406 | 88 | 4.59 | 0.71 | 20.93 |
| FF09 | 2 | 1598 | 82 | 4.64 | 0.73 | 18.48 |
| FF09 | 3 | 1893 | 99 | 4.69 | 0.71 | 22.40 |

**Table A2. Net change in benthic community parameters between 2008 and 2010.**

| Station[1] | J′ | | Station[1] | H′ | | Station | LSA[1] | | Station | S[1] |
|---|---|---|---|---|---|---|---|---|---|---|
| **NF16** | **0.170** | | **NF16** | **0.919** | | NF18 | 2.828 | | NF18 | 4.0 |
| NF17 | 0.138 | | NF17 | 0.827 | | FF13 | 1.517 | | NF08 | 1.0 |
| NF19 | 0.118 | | NF19 | 0.673 | | NF19 | 1.175 | | FF13 | 0.7 |
| FF10 | 0.114 | | NF18 | 0.560 | | NF17 | 0.311 | | NF17 | -0.3 |
| NF23 | 0.086 | | FF10 | 0.512 | | NF08 | -0.560 | | NF19 | -5.0 |
| FF13 | 0.085 | | FF13 | 0.499 | | NF22 | -1.369 | | NF22 | -6.0 |
| NF18 | 0.079 | | NF23 | 0.331 | | FF10 | -1.452 | | NF12 | -6.3 |
| NF07 | 0.059 | | NF09 | 0.186 | | NF09 | -1.556 | | NF09 | -7.0 |
| NF09 | 0.047 | | NF07 | 0.165 | | **NF16** | **-1.726** | | **NF16** | **-11.0** |
| NF22 | 0.025 | | NF22 | 0.052 | | NF23 | -2.015 | | NF05 | -12.0 |
| NF12 | 0.017 | | NF08 | 0.026 | | NF07 | -2.449 | | FF10 | -12.7 |
| NF05 | 0.003 | | NF12 | 0.014 | | NF12 | -2.936 | | NF07 | -14.0 |
| NF08 | 0.001 | | NF05 | -0.153 | | NF05 | -3.219 | | NF23 | -16.0 |

[1]Stations arranged in order of greatest increase to greatest decrease for each parameter. NF16 bolded for ease of tracking.

**Table A3. Comparison of benthic community parameters for farfield samples collected in August 2008 and 2010.**

| 2008 | S | Total Abundance | Fisher | H'(log2) | J' | 2010 | S | Total Abundance | Fisher | H'(log2) | J' |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **2008FF041** | 50 | 1087 | 10.89 | 4.26 | 0.76 | **2010FF041** | 38 | 305 | 11.46 | 4.14 | 0.79 |
| **2008FF042** | 49 | 612 | 12.68 | 4.28 | 0.76 | **2010FF042** | 35 | 408 | 9.18 | 3.86 | 0.75 |
| **2008FF043** | 63 | 1781 | 12.82 | 4.50 | 0.75 | **2010FF043** | 37 | 321 | 10.82 | 4.00 | 0.77 |
| **AVE** | 54.0 | 1160.0 | 12.13 | 4.35 | 0.76 | **AVE** | 36.7 | 344.7 | 10.49 | 4.00 | 0.77 |
| **SD** | 7.81 | 587.91 | 1.08 | 0.13 | 0.00 | **SD** | 1.53 | 55.43 | 1.18 | 0.14 | 0.02 |
| | | | | | | | | | | | |
| **2008FF051** | 74 | 1042 | 18.52 | 4.81 | 0.77 | **2010FF051** | 72 | 921 | 18.56 | 4.73 | 0.77 |
| **2008FF052** | 67 | 1294 | 15.07 | 4.62 | 0.76 | **2010FF052** | 59 | 568 | 16.65 | 4.62 | 0.79 |
| **2008FF053** | 77 | 2067 | 16.04 | 4.85 | 0.77 | **2010FF053** | 59 | 675 | 15.78 | 4.64 | 0.79 |
| **AVE** | 72.7 | 1467.7 | 16.54 | 4.76 | 0.77 | **AVE** | 63.3 | 721.3 | 17.00 | 4.66 | 0.78 |
| **SD** | 5.13 | 534.11 | 1.78 | 0.12 | 0.01 | **SD** | 7.51 | 181.00 | 1.42 | 0.06 | 0.01 |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| **2008FF071** | 64 | 4092 | 10.78 | 3.39 | 0.57 | **2010FF071** | 37 | 1744 | 6.64 | 3.33 | 0.64 |
| **2008FF072** | 62 | 4412 | 10.23 | 3.40 | 0.57 | **2010FF072** | 65 | 4557 | 10.75 | 3.39 | 0.56 |
| **2008FF073** | 53 | 3870 | 8.69 | 3.35 | 0.58 | **2010FF073** | 67 | 6323 | 10.47 | 3.30 | 0.54 |
| **AVE** | 59.7 | 4124.7 | 9.90 | 3.38 | 0.57 | **AVE** | 56.3 | 4208.0 | 9.29 | 3.34 | 0.58 |
| **SD** | 5.86 | 272.47 | 1.08 | 0.03 | 0.01 | **SD** | 16.77 | 2309.36 | 2.30 | 0.04 | 0.05 |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| **2008FF091** | 94 | 1922 | 20.93 | 4.89 | 0.75 | **2010FF091** | 88 | 1406 | 20.93 | 4.59 | 0.71 |
| **2008FF092** | 101 | 1664 | 23.77 | 4.93 | 0.74 | **2010FF092** | 82 | 1598 | 18.48 | 4.64 | 0.73 |
| **2008FF093** | 96 | 1671 | 22.42 | 4.56 | 0.69 | **2010FF093** | 99 | 1893 | 22.40 | 4.69 | 0.71 |
| **AVE** | 97.0 | 1752.3 | 22.37 | 4.79 | 0.73 | **AVE** | 89.7 | 1632.3 | 20.60 | 4.64 | 0.72 |
| **SD** | 3.61 | 146.98 | 1.42 | 0.20 | 0.03 | **SD** | 8.62 | 245.31 | 1.98 | 0.05 | 0.01 |

# APPENDIX B

# Analysis of Selected Nearfield Stations

## FF10 (off Nahant)

In addition to the charts presented in Figure 15, Section 3.3.3.2, a cluster diagram based on a Bray-Curtis similarity analysis of all samples collected at this station was plotted (Figure B-1). This analysis indicated that samples collected in 2010 were similar to those collected in 2004, 2006, and 2008.

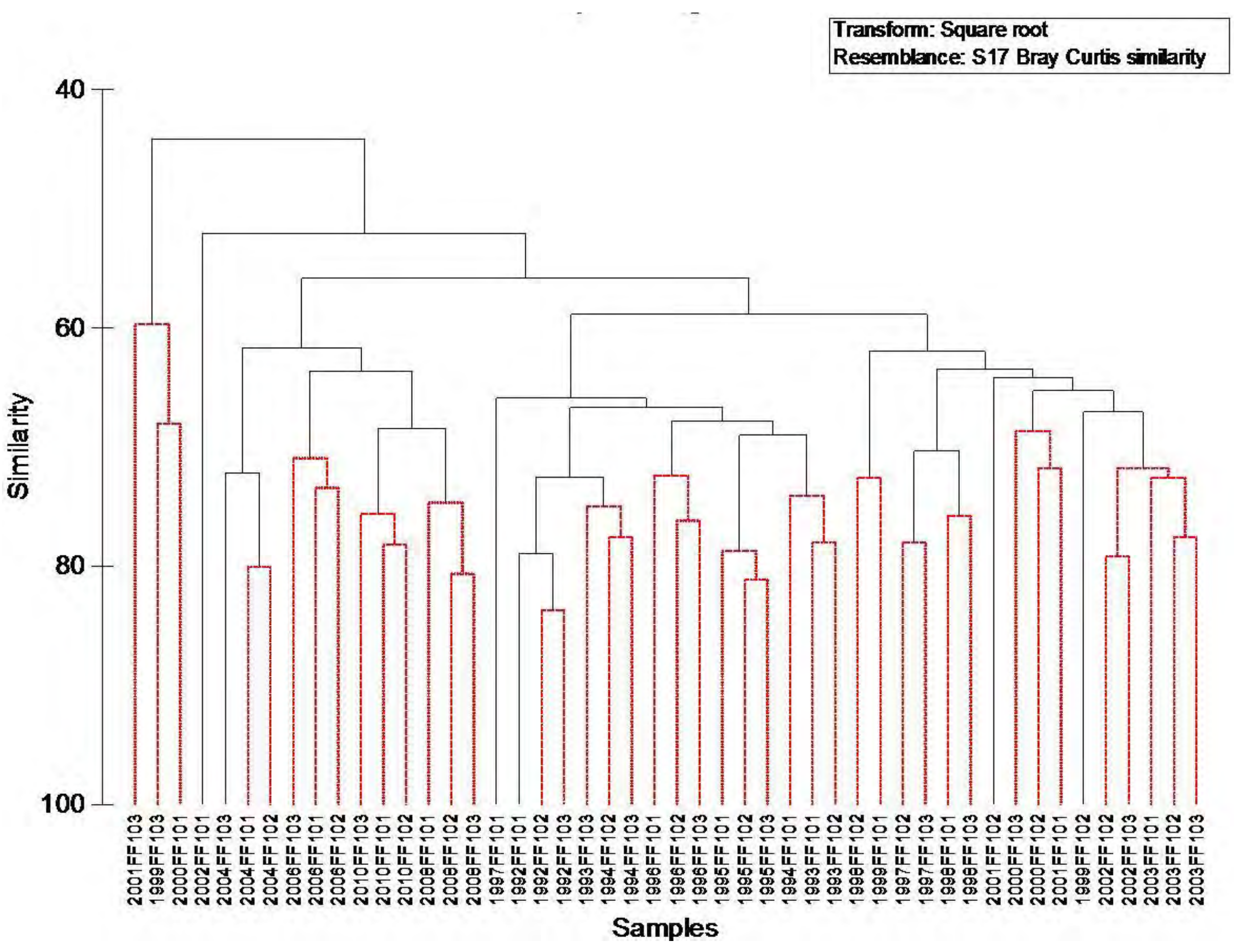


**Figure B-1. Similarity analysis of samples collected at FF10 1992–2010. Samples connected by red lines indicate a significant cluster as defined by SIMPER.**

## FF13 (off Hull, close to mouth of Boston Harbor)

Trends in Shannon diversity and evenness were roughly similar at FF13to those seen at FF10, but with lower values throughout and a more precipitous drop in 1997 (Figure 15 C–D). Evenness J′ at FF13 has ranged from a low of 0.40 in 1997 to a high of 0.74 in 1996, with a median value of 0.55 and an average of 0.56. Shannon diversity has ranged from a low of 2.49 in 1997 to a high of 3.93 in 2010; the diversity of 3.20 in 2010 is the median value obtained for years 1992–2008.

In addition to the charts presented in Figure 15, Section 3.3.3.2, a cluster diagram based on a Bray-Curtis similarity analysis of all samples collected at this station was plotted (Figure B-2). This analysis indicated that samples collected in 2010 were most similar to those collected in 2006 and 2008, and also to those from 1998 and 1999.

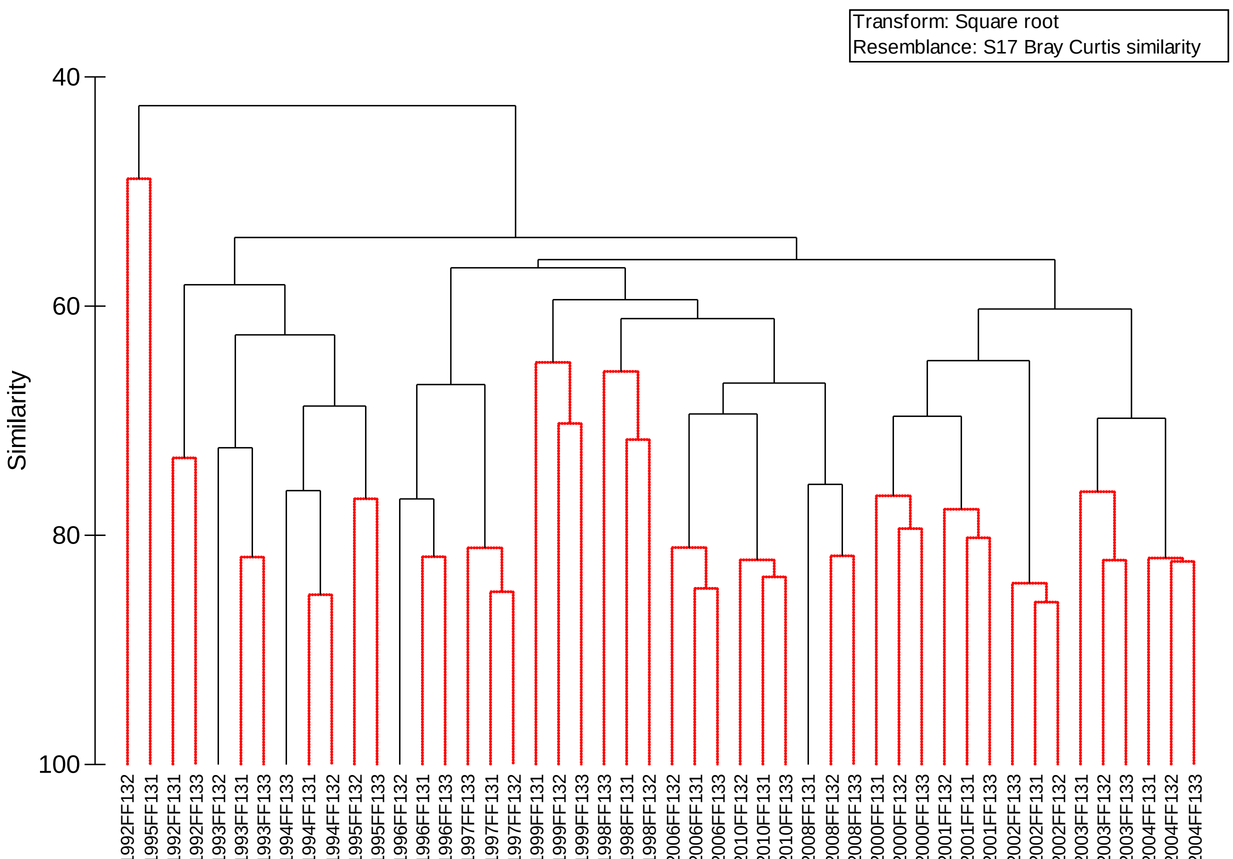


**Figure B-2. Similarity analysis of samples collected at FF13 1992–2010. Samples connected by red lines indicate a significant cluster as defined by SIMPER.**

Non-dimensional diversity curves of the 48 samples collected at FF13(Figure B-3) indicated that about 75% exhibit a large departure from log-series and might be considered "disturbed" in some way. The majority of the most "disturbed" samples are from the early years of monitoring, when this station might have been influenced by discharges from Boston Harbor.

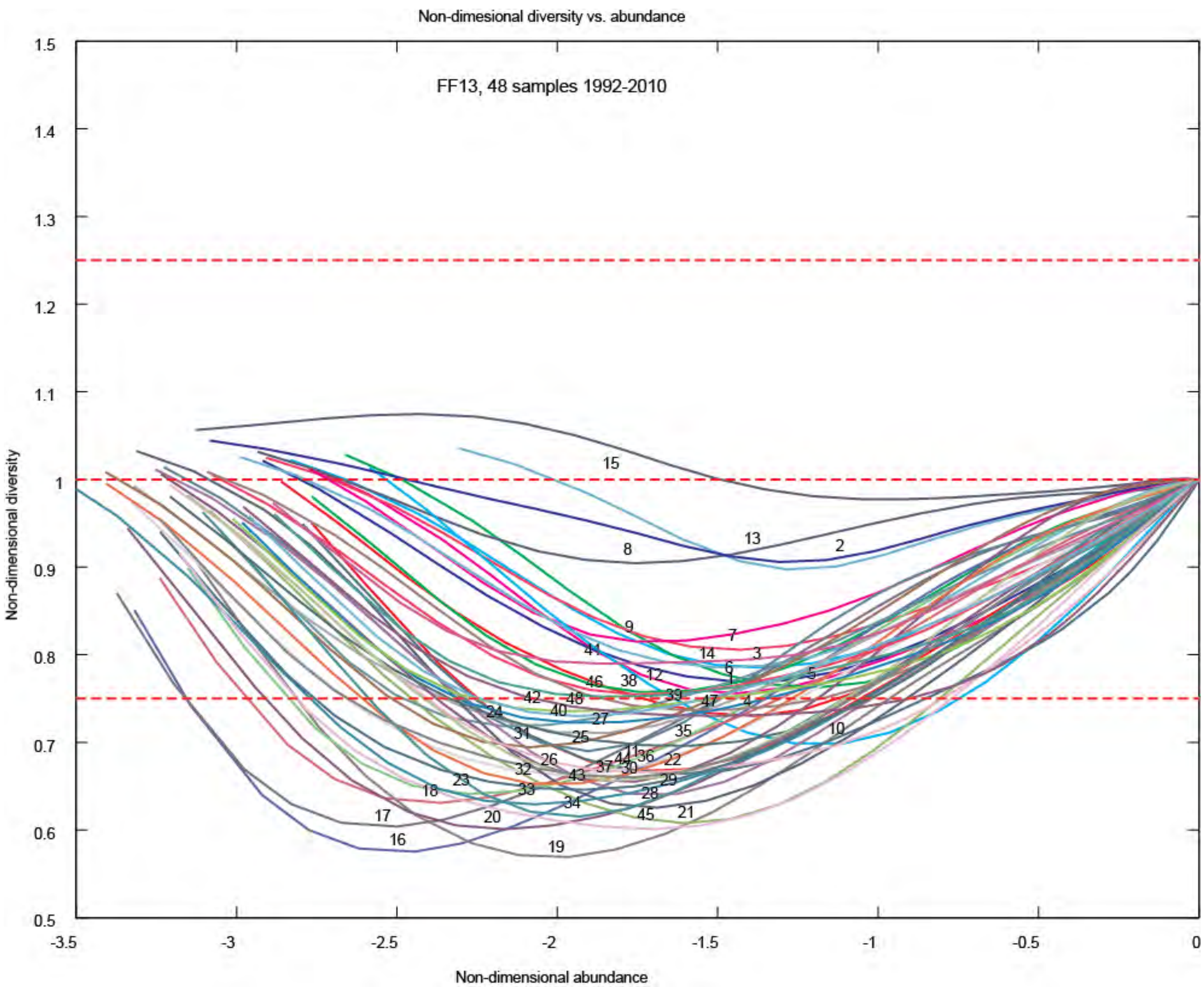


**Figure B-3. Non-dimensional diversity curves of samples collected at FF13 1992–2010. The curves are labeled 1-48, corresponding to each of the samples in sequence through the sampling years.**

PCA-H analysis of the 48 samples indicated that the latest samples from 2010 occupied the same quadrant as those from 2008 and some from earlier years, including 1994 and 1998 (Figure B-4A). The Euclidean biplot (Figure B-4B) suggests the species that most influenced the arrangement of stations.

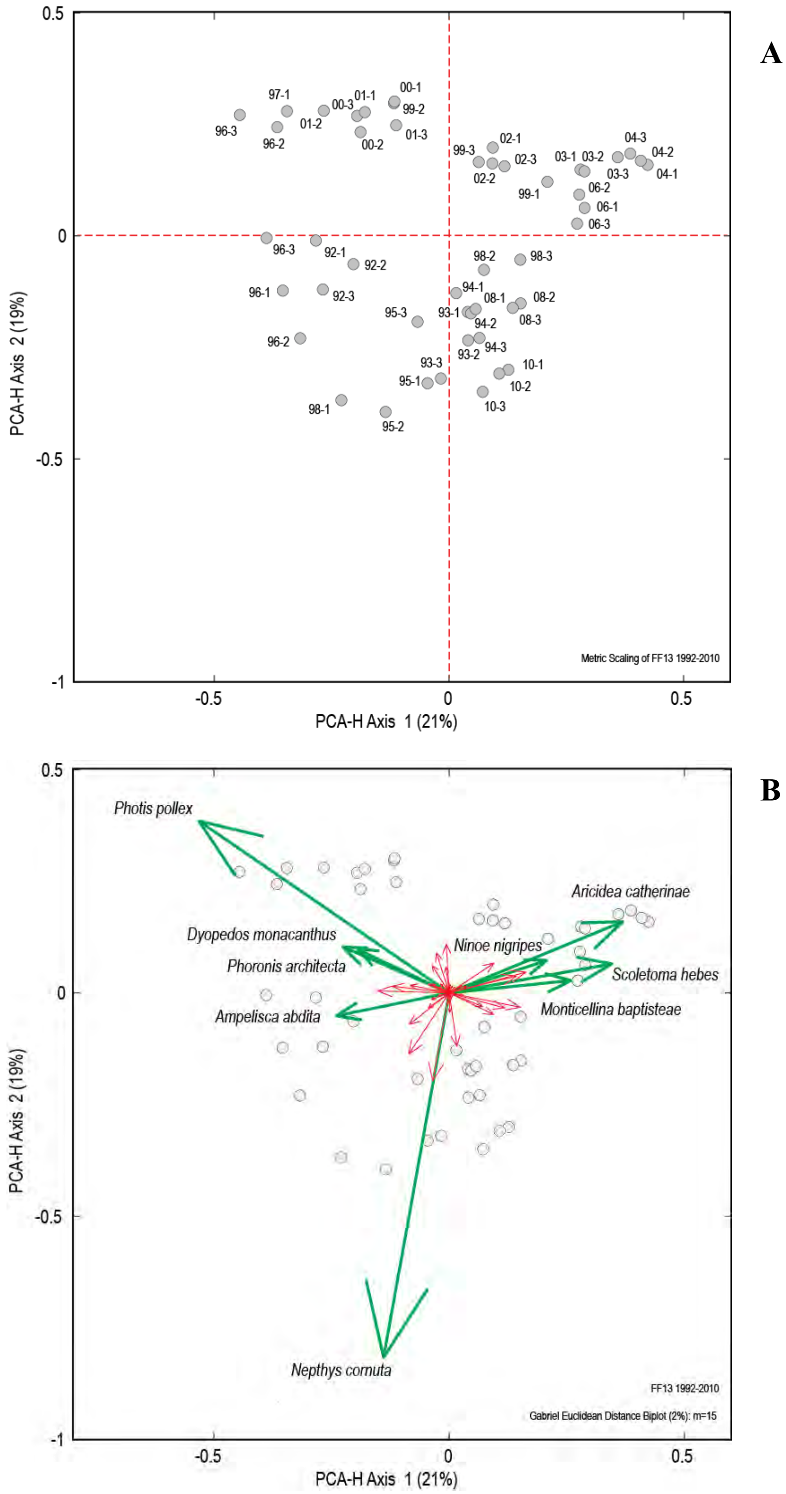


**Figure B-4. PCA-H analysis of samples collected at FF13 1992–2010. A. Metric scaling of the stations. B. Euclidean distance biplot showing the species that contributed at least 2%.**

## NF08( near the diffuser)

NF08 has shown a trend toward higher diversity and evenness since the beginning of the monitoring program, possibly influenced by the fluctuations in the density of *Prionospio steenstrupi* (Figure 15 E). Evenness values at NF08 for samples collected in 2004, 2006, 2008, as well as 2010 were all equal to or higher than 0.70 (Figure 15F).

Bray-Curtis similarity cluster analysis indicated that samples from the last several collecting years (2004, 2006, 2008, and 2010) formed a significant cluster (Figure B5).

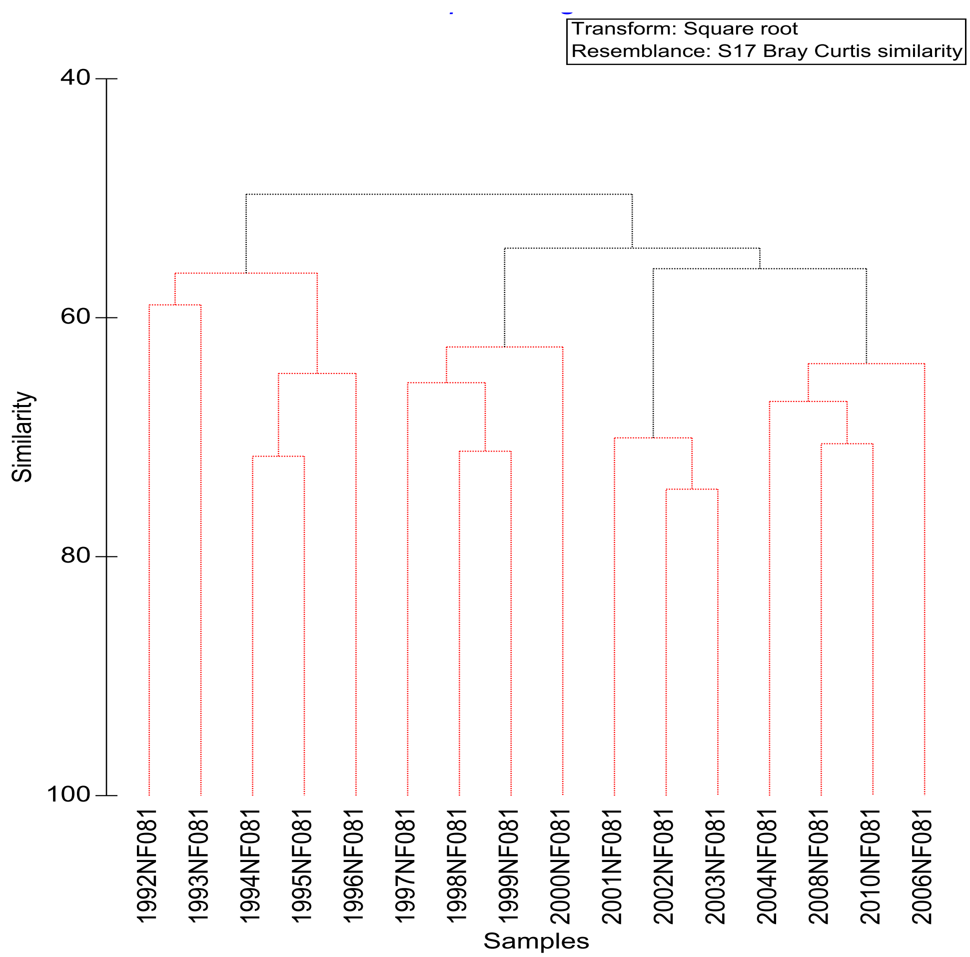


**Figure B-5. Similarity analysis of samples collected at FF10 1992–2010. Samples connected by red lines indicate a significant cluster as defined by SIMPER.**

Non-dimensional diversity curves of the single samples taken at NF08 from 1992–2010 indicate a more severe departure from log-normal in the earlier years of monitoring than during more recent years. The curves for 2008 and 2010 are well within the defined space for “healthy” communities, while those from 1993–1994 and 1997–2000 indicate some disturbance.

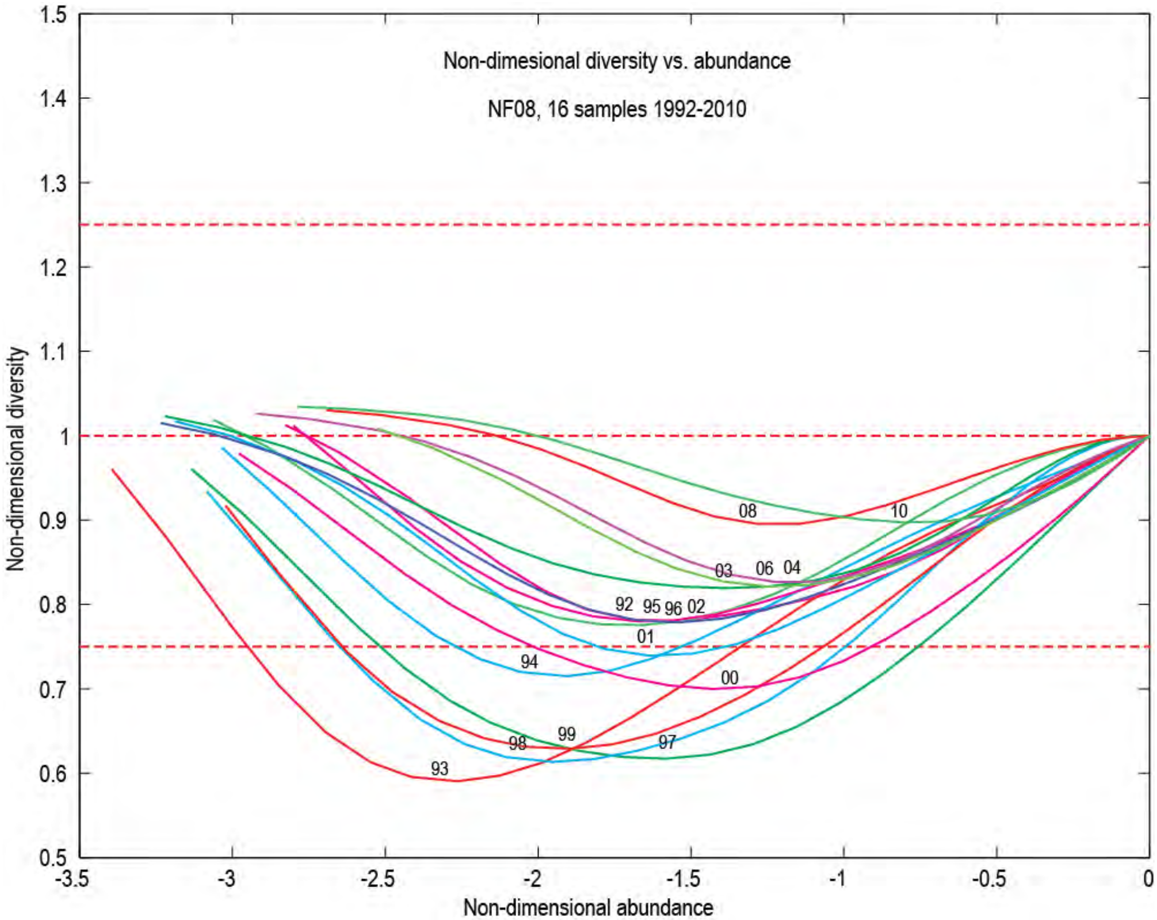


**Figure B-6. Non-dimensional diversity curves of samples collected at NF08 1992–2010. The curves are labeled to indicate the sampling year.**

PCA-H analysis of the 16 samples from NF08 indicated that the latest samples from 2010 occupied roughly the same space on axis 2 as those from 2000–2008, with a spread along axis 1 (Figure B-7A). The Euclidean biplot (Figure B-4B) suggests the species that most influenced the arrangement of stations.

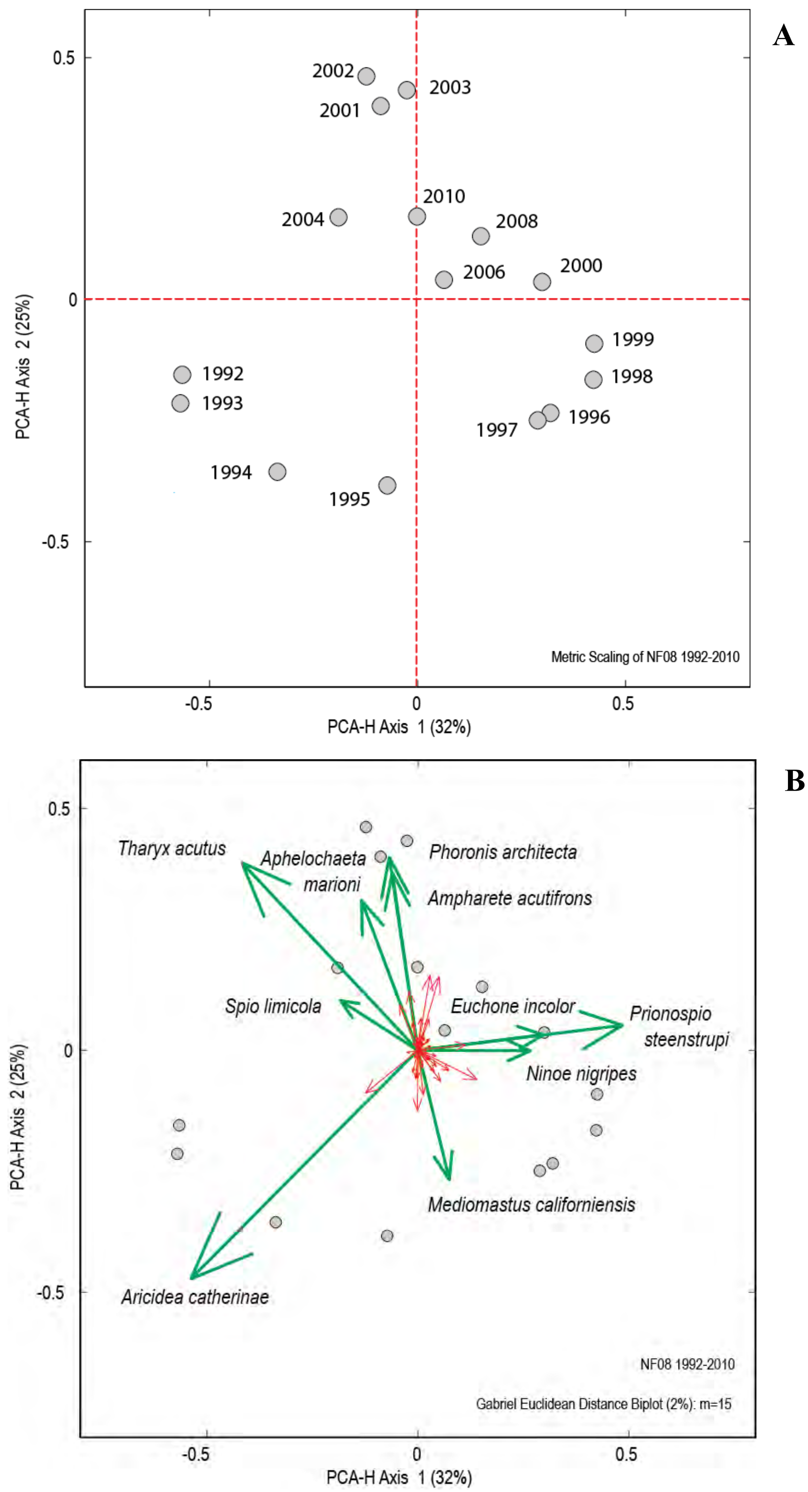


**Figure B-7. PCA-H analysis of samples collected at NF08 1992–2010. A. Metric scaling of the stations. B. Euclidean distance biplot showing the species that contributed at least 2%.**

# APPENDIX C

# 2010 Hard-Bottom Video Analysis

## Table C1. Summary of data recorded from video footage taken on the 2010 hard-bottom survey.

| Station | T1-1 | T1-2 | T1-3 | T1-4 | T1-5 | T2-1 | T2-2 | T2-3 | T2-4 | T4/6-1 | T4-2 | T6-1 | T6-2 | T7-1 | T7-2 | T9-1 | T10-1 | T8-1 | T8-2 | T12-1 | T11-1 | T2-5 | D#44 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Minutes used | 24 | 25 | 28 | 25 | 26 | 25 | 23 | 25 | 28 | 26 | 25 | 23 | 24 | 27 | 21 | 24 | 25 | 27 | 22 | 25 | 29 | 32 | 26 | 585 |
| Depth (m) beginning | 25 | 23 | 21 | 23 | 29 | 29 | 31 | 28 | 30 | 22 | 29 | 32 | 28 | 27 | 26 | 27 | 25 | 25 | 24 | 25 | 33 | 32 | 35 | |
| Depth (m) end | 25 | 24 | 21 | 22 | 29 | 27 | 34 | 28 | 35 | 24 | 31 | 32 | 25 | 26 | 27 | 24 | 25 | 25 | 24 | 24 | 32 | 32 | 34 | |
| Substrate [1] | mx | b+c | b+c | mx | c+ob | b+c | c+b | b+c | b+c | b+c | cp+g | cp | b+c | mx | b+c | b+c | b+c | c+ob | mx | b+c | b+c | d+rr | d+rr | |
| Drape [2] | lm-m | lm-m | l-m | l-m | m | lm | m-mh | mh | m-mh | l-lm | m | m | lm-m | m | lm-m | lm-m | mh-h | lm-m | lm | lm-m | m-mh | mh | m-mh | |
| Relief [3] | L-M | M-MH | M-MH | LM-M | LM | M | LM-M | M | LM-M | M-MH | L | L | M | LM-M | M | LM-M | M-MH | L-LM | LM | M | M | M-MH | M-MH | |
| Suspended material | h | h | | | | h | h | h | h | | h | h | h | h | h | h | h | h | h | h | h | h | h | |
| Coralline algae | f | c | c-a | c-a | f | c | f | f | r | a | r-f | r | c-a | f-c | f-c | f-c | r-f | c-a | c-a | c | r-f | | | |
| *Ptilota serrata* | | f-c | c-a | f-a | | | | | | r-f | | | | f-c | f-a | f-c | r | | | c-a | | | | |
| general hydroid | f-c | c | c | r-c | f-c | f-c | c | c-a | f-c | f-c | f | f | f | c | f-a | c-a | f-a | f-c | f-c | f-a | c | f-a | c | |
| barnacle/spirorbid complex | r-f | r-f | r | c-a | f | f-a | | | | f-a | f-c | f | c-a | | f-a | f | | f | | | | | | |
| *Palmaria palmata* | f-c | c-a | c-a | f-a | r | r | | f-c | | r-f | | | r-f | f-c | f-a | f-c | f-c | f-c | r | f-c | r | | | |
| *Agarum cribosum* | | | f-c | | | | | | | | | | | c | r-a | r | | | | | | | | |
| general sponge | | 3 | | | | 4 | 3 | 4 | 6 | | | 1 | 2 | | | 1 | 1 | 1 | | | 7 | 1 | | 34 |
| *Polymastia* sp. A | c | f | r | | r | c | c | c | f-c | f | | | c | f | f-c | c | c | r | r-f | r | c | | r | |
| *Polymastia* sp. B | 17 | | | | | | | | | | | | | 1 | 1 | | | | | | | | | 19 |
| *Haliclona oculata* | | | | | | | | | 5 | | | | | 1 | 1 | 1 | | | | 2 | | 6 | 19 | 35 |
| *Suberites* spp. | f-c | | | | c | c | c | c | f-c | | r | r | r | r | r | f | f | | r | | c | f | | |
| white divided sponge | | | c | | r | r | f-c | c | c-a | | r | | | r | c | c-a | c | | | f | a | | | |
| *Melonanchora elliptica* | | | | | | | | 1 | | | 1 | | | | | | | | | | | | | 2 |
| *Haliclona* spp. (encrusting) | | | | | | | 2 | | 1 | 1 | | | | | | | | | | | | | | 4 |
| cream sponge /proj. | | | | | | | | | | | | | | | | | | | | | c | | | |
| yellow-cream encrust sponge | | | | | | | | | | | | | | | | | | | | | c | | | |
| *Obelia geniculata* | | | f | | | | | | | | | | | f | r-a | | | | | | | | | |
| general anemone | | | | | | | | 1 | | | 1 | | 2 | | | | | | | 1 | 2 | | | 7 |
| *Metridium senile* | | | r | | | | | r | | f | | | | | f | f | r | | | | f-c | f-a | r-c | |
| *Urticina felina* | 2 | 7 | 1 | 1 | 1 | 8 | 6 | 3 | 1 | 5 | 3 | 2 | 3 | 2 | 1 | 1 | 6 | 2 | 2 | | 3 | 8 | 1 | 69 |
| *Cerianthus borealis* | | | | | | | | | 5 | | 1 | 2 | | | | | | | | | | | | 8 |
| *Gersemia rubiformis* | | | | | | | | | | | | | | | | | r-f | | | | | | | |

| Station | T1-1 | T1-2 | T1-3 | T1-4 | T1-5 | T2-1 | T2-2 | T2-3 | T2-4 | T4/6-1 | T4-2 | T6-1 | T6-2 | T7-1 | T7-2 | T9-1 | T10-1 | T8-1 | T8-2 | T12-1 | T11-1 | T2-5 | D#44 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Tubularia sp.* | | | | | | | | | | r | | | | | r-c | f | | | | | | f-a | f | |
| *Alcyonium digitatum* | | | | | | | | | 1 | | | | | | | | | | | | | | | 1 |
| *Tonicella marmorea* | | | | | | | | | | 2 | | | | | | | | | | | | | | 2 |
| *Crepidula plana* | | | | | | | | | | | | | | | | | | f | | | | | | |
| *Buccinum undatum* | | | | | | 1 | | | | | | | | | | | | 1 | | | | | | 2 |
| *Modiolus modiolus* | c | c | c-a | c-a | f | f-c | f | f-c | f | a | f-c | f | a | c-a | c | c-a | c-a | c-a | c-a | c-a | f-c | r-c | | |
| *Placopecten magellanicus* | | 1 | | | 1 | | 1 | | 1 | | 12 | 7 | | | | | | 6 | 1 | | | | 3 | 33 |
| *Arctica islandica* | | | | | | | | | | | f | | | | | | | | | | | | | |
| *Homarus americanus* | 1 | 1 | 5 | | 1 | 4 | 2 | 5 | | 1 | 1 | | 4 | | 3 | 1 | 4 | 2 | | 1 | 1 | | | 37 |
| *Cancer spp.* | 2 | 6 | 1 | 2 | 2 | 2 | 1 | | | 3 | 1 | 4 | 1 | 1 | 1 | | 2 | 3 | 2 | | | | | 34 |
| *hermit crab* | | | | | | | | | | | 3 | | | | | | | | | | | | | 3 |
| *Strongylocentrotus droebachiensis* | r | f | f-c | r | | c | | | | c | | | c | | | f | f-c | | c | f-c | | r | r | |
| *small white starfish* | c | c | c-a | c | f | c | f-c | f-c | c | a | c | f-c | c-a | c-a | c-a | c-a | c-a | c | c | f-c | f | r | f | |
| *Asterias vulgaris* | f | | f-c | f-c | f | f | r | r | r | f-c | r | f | f | r | f-c | f | f-c | c | c | | | r | r-c | |
| *Henricia sanguinolenta* | f-c | f-c | f | f-c | f-c | f-c | f | f | f-c | f-c | f-c | f-c | f-c | f-c | f-c | c | f-c | f-c | f-c | f-c | c | f-c | r-f | |
| *Porania insignis* | | | | | | | | | | | | | | | | | 1 | | | | | | | 1 |
| *Crossaster papposus* | | | | | | | | | | | 1 | | | | | | | | | | 3 | | | 4 |
| *Pteraster militaria* | | | | | | | | | | | | | | | | | | | 1 | | | | | 1 |
| *Solaster endeca* | | | | | | | | | | | | 1 | | | | | | | | | | | | 1 |
| *Psolus fabricii* | f | f | f | | | r | f | | | f-c | | | r | | | f | r | r | f | r | | | | |
| *Botrylloides violaceus* | | 2 | | | 1 | | 3 | 6 | 5 | | | | 1 | | 1 | | 5 | | | | 1 | | | 25 |
| *Aplidium/Didemnum* | f-c | c | f | f | f-c | f | f | c | f-c | f | r-f | f | f-c | f | f | f-c | f | f-c | f-c | f | | | r | |
| *Halocynthia pyriformis* | f | r | c | r | r | r | r | r | f | f-c | | | f | r | f-c | f-c | f-c | | r | f | c | r | f-c | |
| *Boltenia ovifera* | | | | | | | | | | | | | | | | | | | | | 20 | 3 | | 23 |
| *Membranipora membranipora* | | c | c-a | f-a | | | | | | | | | | f-c | c | | | f | | f | | | | |
| *Myxicola infundibulum* | f-c | c | f | r | r | r | r-f | f-c | r | r | | r | c | c | | f | f | f | r | f | c | | r-f | |
| *Terebratulina septentrionalis* | r | | c | | r | r | f-c | c | c-a | | r | | | r | c | c-a | c | | | f | a | | | |
| *general fish* | | | | | | | | | | | | 1 | | | | | | | | | 1 | | | 2 |
| *Tautogolabrus adspersus* | f-c | c-a | c-a | f-c | f | c-a | f | c | f-c | c-a | | r | c | f-c | c | c-a | c-a | f | f | a | f-c | c-a | f-c | |
| *Myoxocephalus spp.* | | 1 | 1 | 1 | | | 4 | 2 | 2 | 2 | 1 | 4 | | | 1 | 2 | | 1 | | | 3 | 1 | 2 | 28 |
| *Macrozoarces americanus* | | | | | | | 1 | | | | 3 | 2 | | | | | | | | | | | | 6 |
| *Anarhichas lupus* | | | | | | | | | | | | | | | 1 | | | | | | | | | 1 |

| Station | T1-1 | T1-2 | T1-3 | T1-4 | T1-5 | T2-1 | T2-2 | T2-3 | T2-4 | T4/6-1 | T4-2 | T6-1 | T6-2 | T7-1 | T7-2 | T9-1 | T10-1 | T8-1 | T8-2 | T12-1 | T11-1 | T2-5 | D#44 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Hemitripterus americanus* | | | | | | | | | | | | | | | | | | | | | 1 | | 1 | 2 |
| *Pseudopleuronectes americanus* | 11 | 2 | | 1 | 5 | 3 | 1 | 6 | 7 | 1 | 5 | 22 | | 1 | | 3 | | 13 | 8 | 1 | | | 2 | 92 |
| *Sebastes fasciatus* | | | | | | 3 | 1 | | | | | | | | | | | | | | | 4 | 1 | 9 |
| *Pholis gunnellus* | | | | 1 | | 1 | | | | | | | | | | | | 1 | 1 | | | | | 4 |
| *Gadus morhua* | 1 | 2 | 4 | | | | | 1 | 3 | 5 | | | 1 | 3 | 3 | 1 | 10 | | | 3 | 18 | 3 | 1 | 59 |
| Dogfish | | | | | | | | | 1 | 1 | | | | | | | | | | | | | | 2 |
| *Pollachius virens* | 2 | 1 | | 1 | | | | 3 | 4 | 1 | | | | | | | | 1 | 1 | | | | | 14 |
| *Microgadus tomcod* | | | | | | 1 | | 1 | | | | | 1 | | | | 1 | | 2 | 1 | | | | 7 |
| egg case | | | 1 | | 2 | | 1 | | | | | | | 4 | | | | | | | | | | 8 |

[1] b=boulder, ob= occasional boulders, c=cobble, cp=cobble pavement, d=diffuser head, r=riprap
[2] l = light; lm = moderately light; m=moderate; mh = moderately heavy; h = heavy
[3] L =low; LM = moderately low; M= moderate; MH = moderately high; H = high
[4] a=abundant, c=common, f= few, r = rare

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