Outfall Benthic Monitoring Report: 2008 Results

Massachusetts Water Resources Authority

Environmental Quality Department
Report 2009-13

Citation:

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.

Outfall Benthic Monitoring Report: 2008 Results

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September 30, 2009
Report No. 2009-13

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1. INTRODUCTION

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) have collected extensive information over a nine-year baseline period (1992–2000) and an eight-year post-diversion period (2001–2008). 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 2008 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).

2. METHODS

Methods used to collect, analyze, and evaluate all sample types are consistent with those reported by Maciolek et al. for previous monitoring years (2008). Sediment Profile Images (SPI) were collected in triplicate at 23 nearfield stations. For sampling of the soft-bottom sediments, 2008 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*, sediment chemistry, and benthic infauna. Seventeen soft-bottom stations were sampled in August 2008:

- 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 greater than 2 km from the offshore outfall
- Farfield reference stations FF04, FF05, FF07 and FF09 in Massachusetts and Cape Cod Bays

Camera transects (Figure 3) were performed as in previous years. Twenty-two of the 23 hard-bottom waypoints were successfully surveyed during 2008, including an actively discharging diffuser head at the eastern end of the outfall. The farfield southern reference station (T11-1) was not surveyed in 2008 due to time constraints resulting from technical issues with the still cameras.

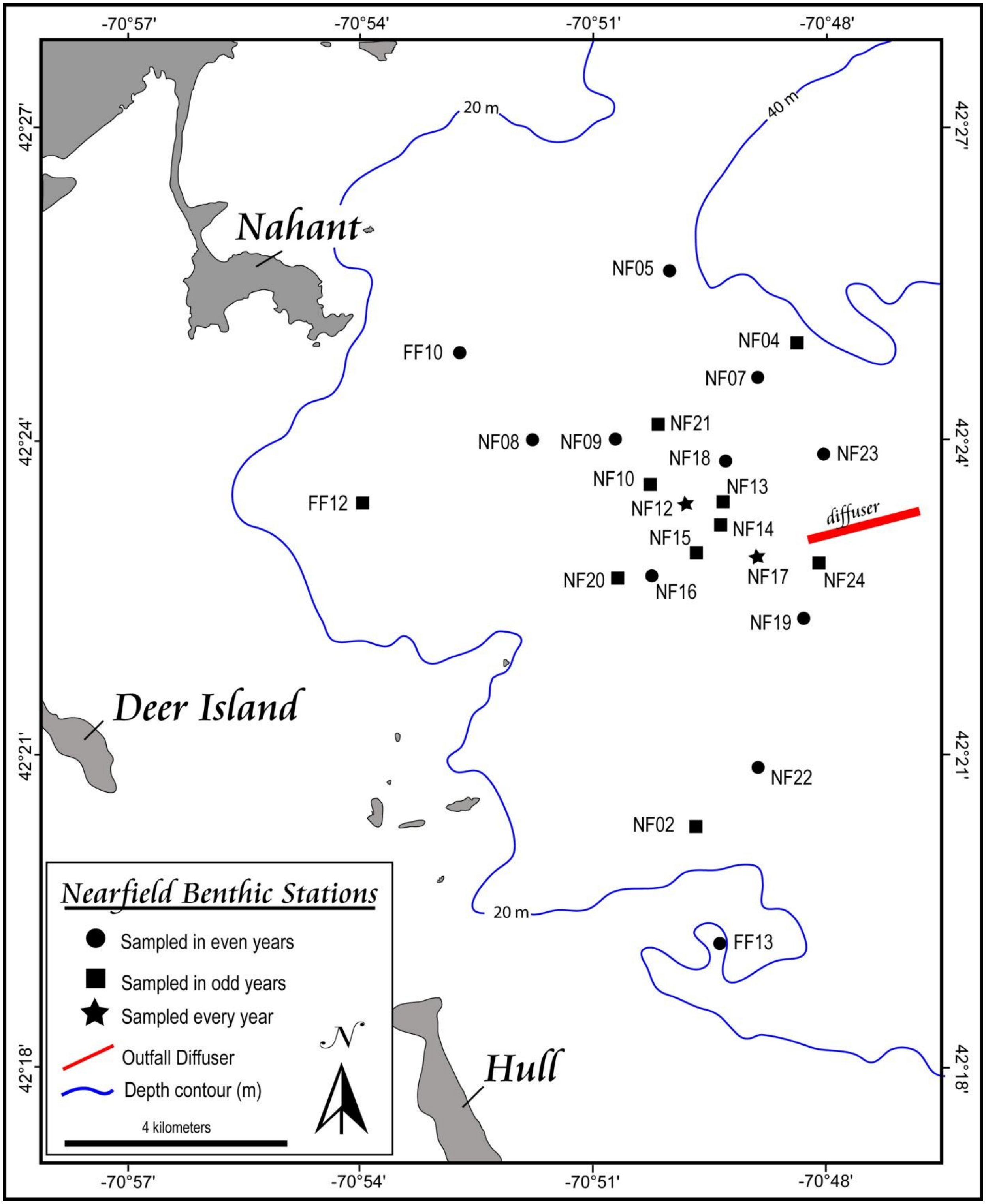

Figure 1. Locations of nearfield benthic stations sampled in August 2008. All stations were sampled by SPI and those denoted by circle and star symbols were sampled by grab.

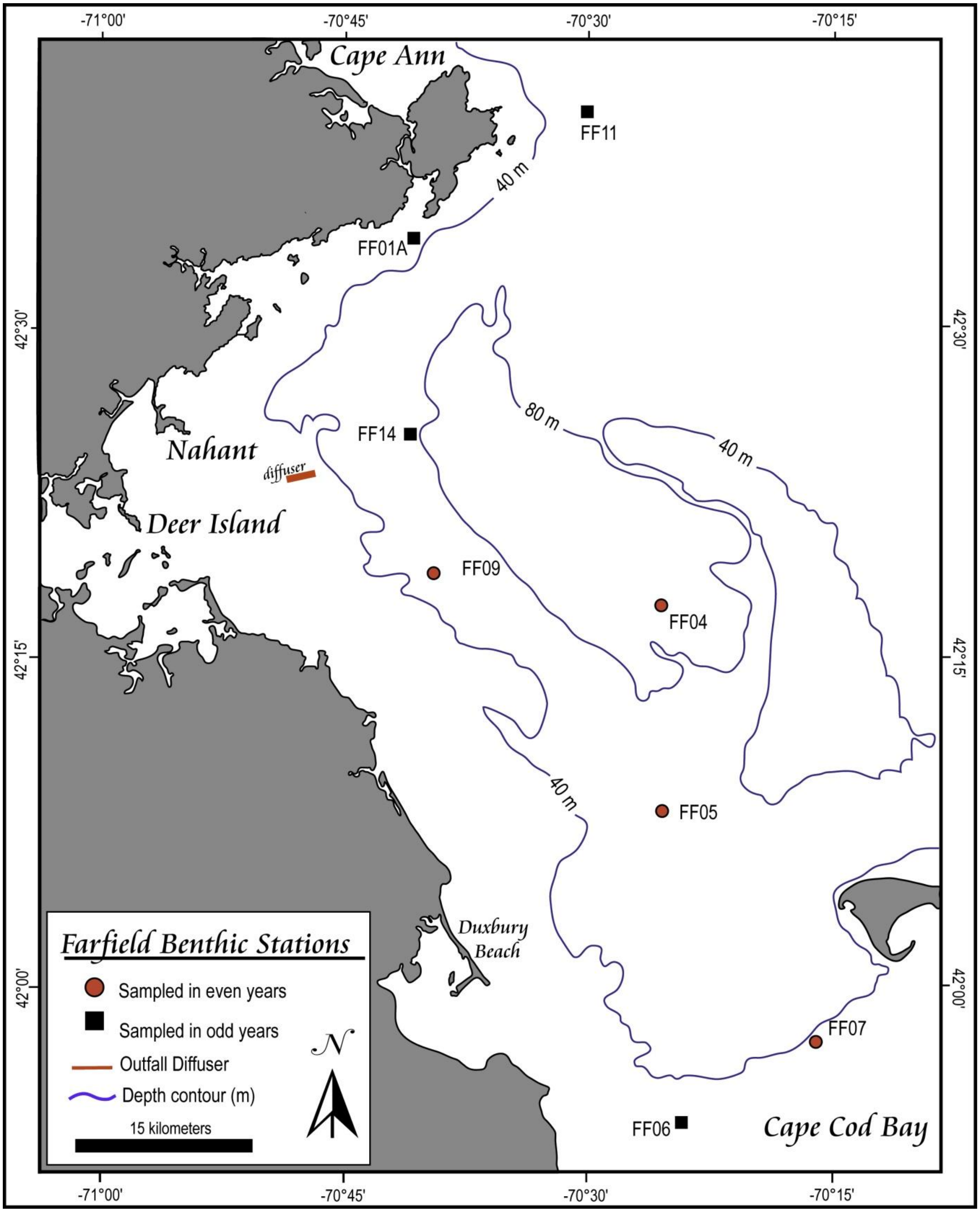

Figure 2. Locations of farfield grab stations sampled in August 2008 (indicated by red circles).

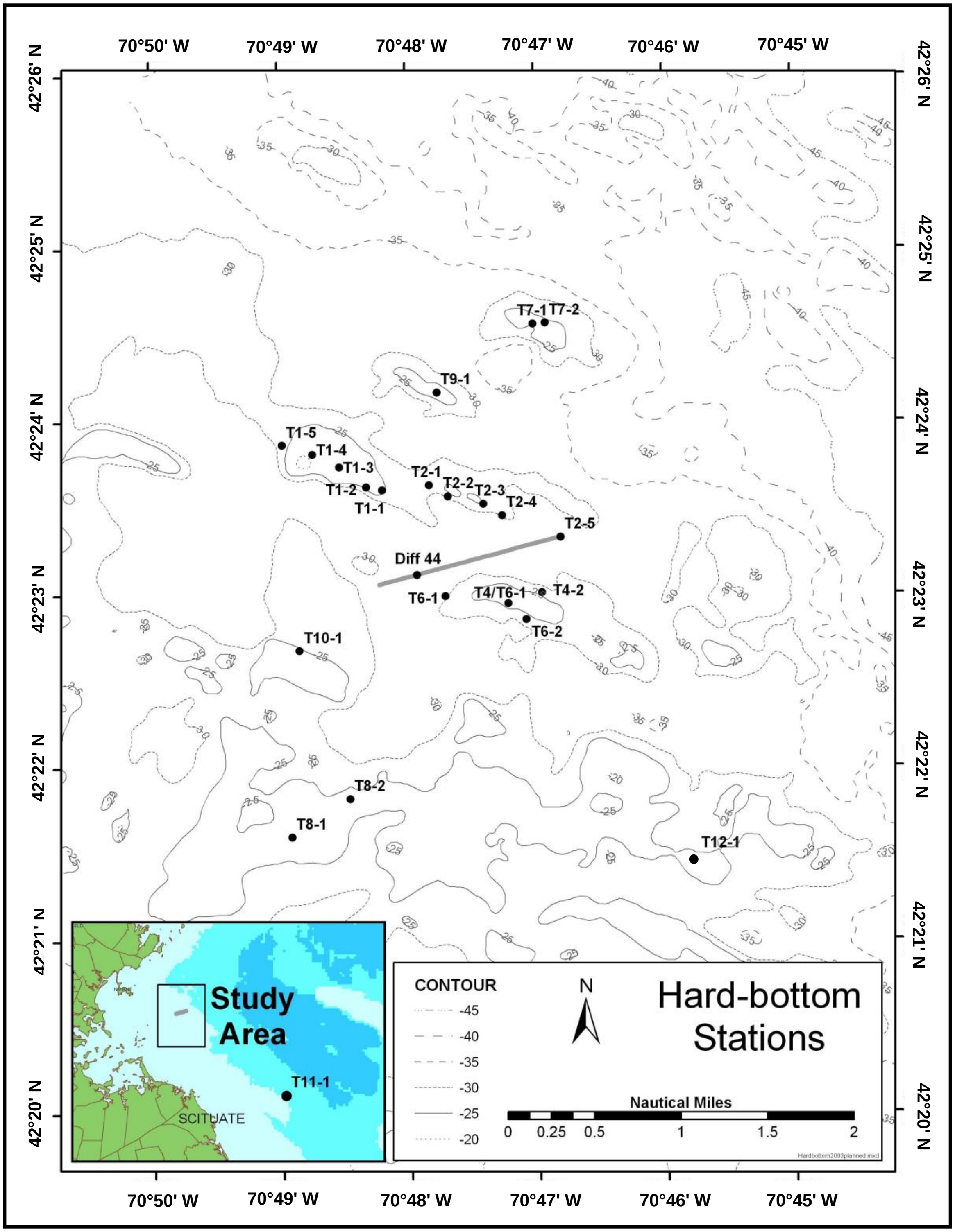

Figure 3. Locations of hard-bottom transects sampled in August 2008.

3. RESULTS

3.1 Sediment Chemistry

3.1.1 2008 Results

Grain Size and Total Organic Carbon. The grain size distributions for the 17 stations sampled in 2008 were within the range of values measured over the larger monitoring period (1992–2007), and included a range of sediment types from coarse- to fine-grained sediment (Figure 4). Transition area and nearfield stations in close proximity (<2 km) to the offshore outfall were typically comprised of coarse-grained sediment (approximately 60% or higher gravel+sand at transition area and 87% or higher gravel+sand for nearfield stations within 2 km of outfall) (Figure 4A, B). Sediments sampled further away from the offshore outfall were heterogeneous, and encompassed coarse- to fine-grained sediment (Figure 4C, D).

The 2008 TOC data are within the range of values measured over the larger monitoring period at some stations and below the lower end of the baseline range at others, especially nearfield locations (Figure 5). While not significant, mean concentrations of TOC decreased slightly between the baseline and post-diversion periods at the transition (baseline mean 0.84% vs. post-diversion mean 0.68%) and nearfield (i.e., >2 km from outfall; baseline mean 1.2% vs. post-diversion mean 1.0%) stations of Massachusetts Bay (Figure 5B). Mean TOC concentrations increased slightly in the farfield region (baseline mean 1.5% vs. post-diversion mean 1.7%) and remained relatively flat at nearfield locations located <2 km from the outfall (baseline: 0.33% vs. post-diversion mean 0.30%) (Figure 5B).

Clostridium perfringens. The 2008 data are consistent with trends observed in the long-term monitoring data (Maciolek et al. 2008). Notably, the *C. perfringens* data clearly trace the diversion of treated effluent discharge from the harbor to the bay evidenced primarily by (1) a decrease ($p<0.05$) between the baseline and post-diversion mean values at the transition area and (2) an increase ($p<0.05$) between the baseline and post-diversion mean values in sediments located nearby the outfall (Figure 6). The *C. perfringens* effluent signature appears to be highly localized, as there was no significant difference between the baseline and post-diversion mean values in sediments located further away from the outfall (nearfield >2 km from the outfall and farfield).

Anthropogenic Contaminants. The 2008 data are generally consistent with trends observed in the long-term monitoring data (Maciolek et al. 2007 and 2008). Notably, contaminant concentrations in surface sediments at Massachusetts and Cape Cod Bays are highly variable, which often reflects the variability in sediment grain-size characteristics and TOC. In addition, chemical concentrations were frequently within the range of values measured over the larger monitoring period (1992–2007), although concentrations of copper, mercury, silver and total PCB were below the baseline range at several stations in 2008, especially nearfield locations that also had a coincident decrease in TOC (total PCB and silver shown in Figure 7). For most chemicals, there was no significant difference between the baseline and post-diversion mean concentrations, suggesting that the transfer of the MWRA effluent discharge into Massachusetts Bay has not resulted in an increase of anthropogenic contaminants in the surficial sediment. Post-diversion mean concentrations of total DDT and total PCB decreased significantly (p values < 0.04) compared to the baseline mean value at the nearfield[1] region of Massachusetts Bay (total PCB shown in Figure 7). The observed decrease is likely associated with reduced inputs from the banning of these chemicals in the 1970s and 1980s. Post-diversion mean concentrations of aluminum increased ($p < 0.02$) at the nearfield (including transition area, Figure 7) region of Massachusetts Bay;

[1] For total DDT, decrease was significant for nearfield sediments located <2 km from the outfall. For total PCB, decrease was significant for nearfield sediments located >2 km from the outfall.

while significant changes in grain size composition were not evident, changes in aluminum in coastal sediments like these normally indicate changes in silt-clays, rather than anthropogenic impacts.

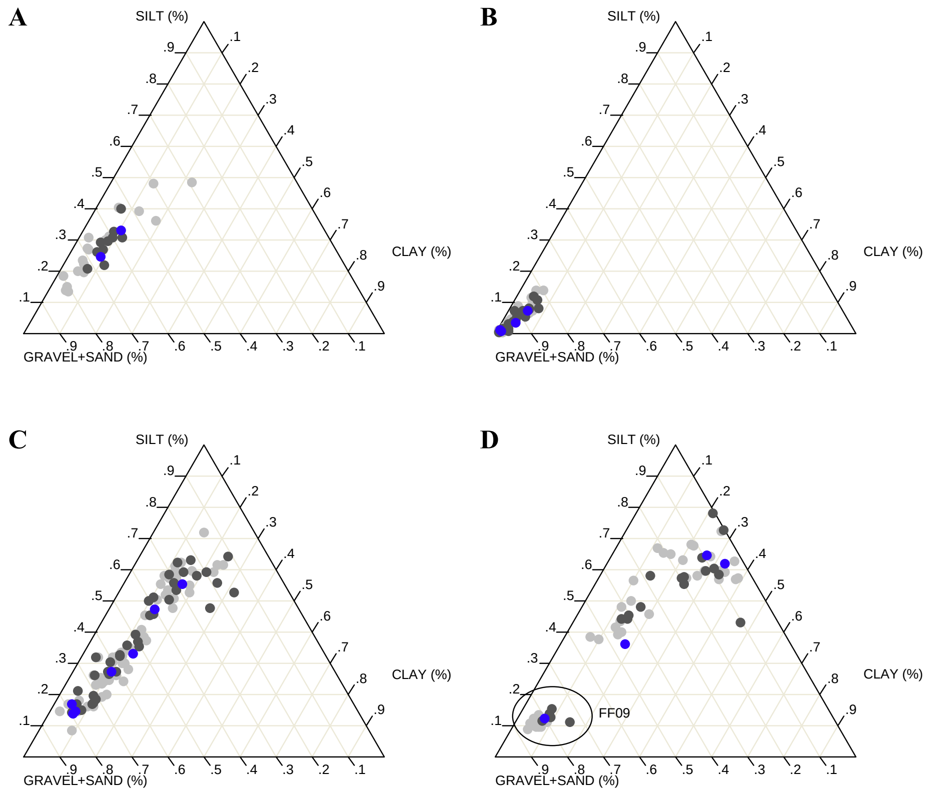

Figure 4. Distribution of percentages of gravel+sand, silt, and clay in surface sediment in Massachusetts and Cape Cod Bays, 1992–2008. A = transition area; B = nearfield, <2 km from outfall; C = nearfield, >2 km from the outfall; and D = farfield. Grey symbols represent baseline, black symbols represent post-diversion 2001–2007 data, and blue symbols represent the post-diversion 2008 data.

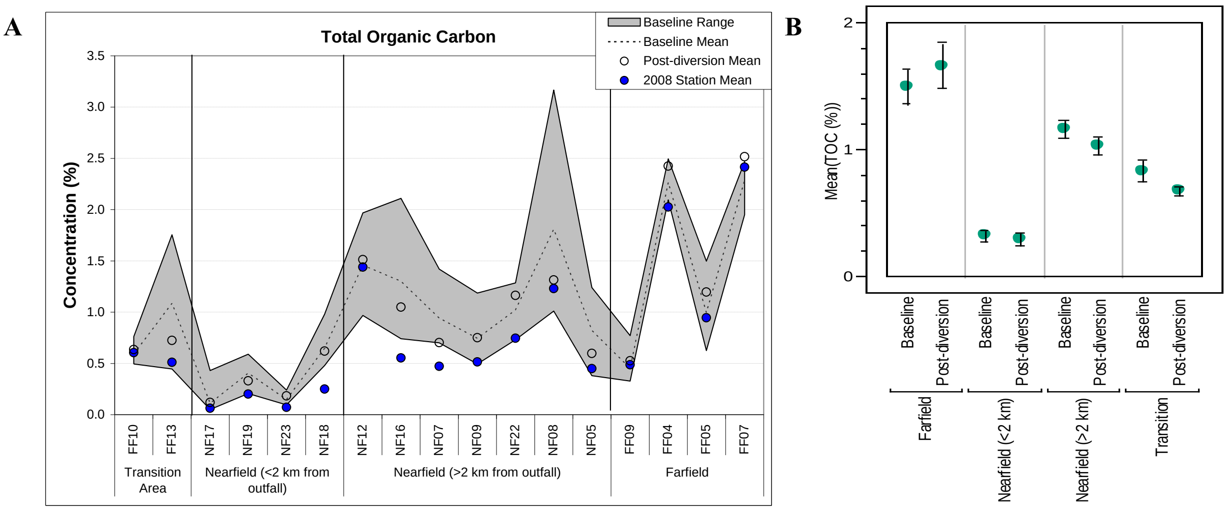

Figure 5. Distribution of TOC, by station (A) and region (B), in surface sediment from Massachusetts and Cape Cod Bays, 1992–2008. A: Station-specific trends where the gray band represents the range of values during baseline (1992–2000), the dashed line represents the baseline mean, and symbols represent the post-diversion data. B: Regional trends where the symbols represent the 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 standard error around the mean values.

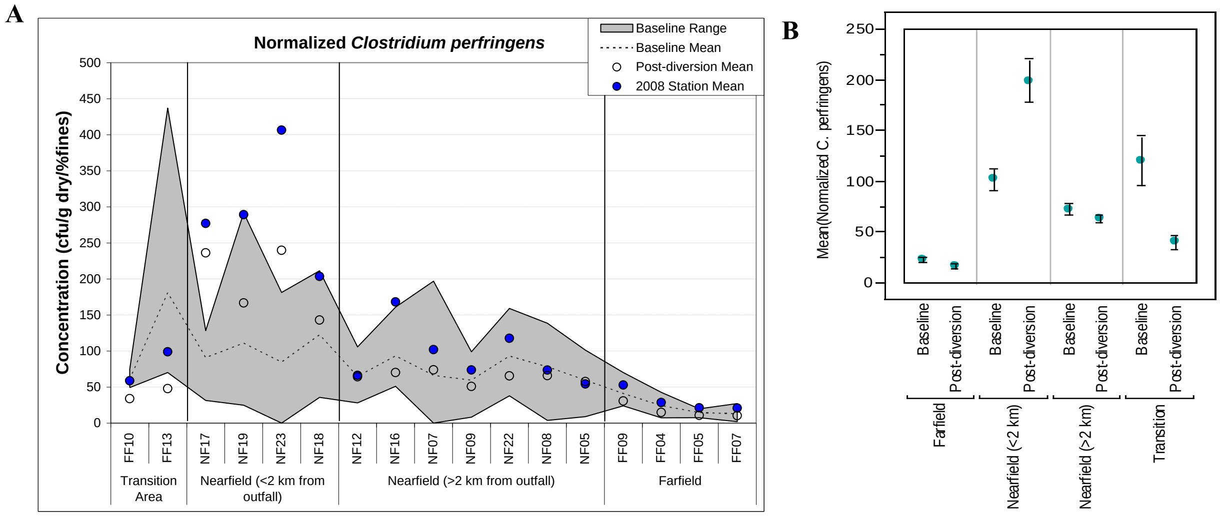

Figure 6. Distribution of *C. perfringens* abundances (normalized to percent fines), by station (A) and region (B), in surface sediment from Massachusetts and Cape Cod Bays, 1992–2008. A: Station-specific trends where the gray band represents the range of values during baseline (1992–2000), the dashed line represents the baseline mean, and symbols represent the post-diversion data. B: Regional trends where the symbols represent the 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 standard error around the mean values.

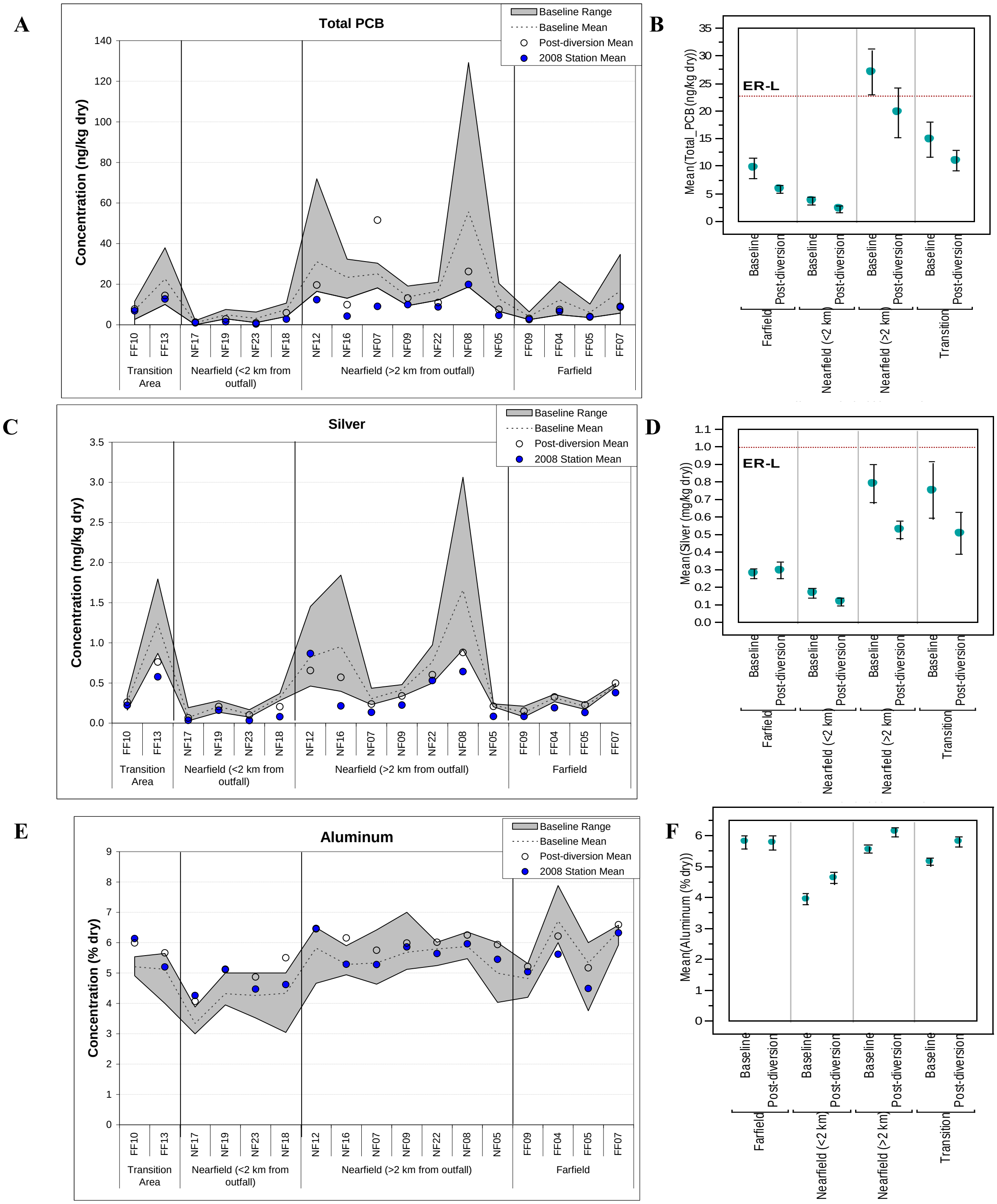

Figure 7. Distribution of Total PCB (A), silver (C) and Aluminum (E), by station (A, C, E) and region (B, D, F), in surface sediment from Massachusetts and Cape Cod Bays, 1992–2008. A, C, E: Station-specific trends where the gray band represents the range of values during baseline (1992–2000), the dashed line represents the baseline mean, and symbols represent the post-diversion data. B, D, F: Regional trends where the symbols represent the 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 standard error around the mean values and the red line represents the effects range-low (ER-L) sediment quality guideline.

3.1.2 Sediment Correlations

Results from the Pearson pair-wise correlation analysis performed on the nearfield and farfield sediment data from 1999–2008 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.

Table 1. Pearson product-moment correlation coefficients (*r*) for nearfield and farfield sediments, 1999–2008.

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]	0.81	1.00	<0.01	108	0.95	1.00	<0.01	32
C. perfringens[1]	0.70	0.70	<0.01	107	0.55	0.43	<0.02	32
Aluminum	0.71	0.79	<0.01	68	0.73	0.72	<0.01	16
Cadmium[1]	0.81	0.66	<0.01	67	0.78	0.82	<0.01	16
Chromium[1]	0.89	0.88	<0.01	68	0.93	0.96	<0.01	16
Copper[1]	0.84	0.89	<0.01	66	0.94	0.89	<0.01	16
Iron[1]	0.82	0.82	<0.01	68	0.90	0.93	<0.01	16
Lead[1]	0.87	0.72	<0.01	68	0.88	0.87	<0.01	16
Mercury[1]	0.85	0.92	<0.01	68	0.89	0.87	<0.01	16
Nickel	0.83	0.86	<0.01	68	0.91	0.93	<0.01	16
Silver[1]	0.79	0.88	<0.01	68	0.73	0.78	<0.01	16
Zinc[1]	0.92	0.89	<0.01	68	0.97	0.98	<0.01	16
Total_DDT[1,2]	0.72	0.87	<0.01	62	0.89	0.88	<0.01	16
Total_PAH[1,2]	0.78	0.89	<0.01	68	0.90	0.92	<0.01	16
Total_PCB[1,2]	0.80	0.88	<0.01	68	0.92	0.94	<0.01	16

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

3.1.3 Sediment Quality

Results from the comparison of the 2008 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 was limited to eight metals and two organic contaminants. A more comprehensive evaluation of sediment quality for the long-term monitoring data with respect to the sediment quality guidelines for 26 chemicals (including individual PAHs) is presented in Maciolek et al. (2008).

Overall, concentrations of total PAH and selected metals (i.e., chromium, lead, mercury and nickel) were above the ER-L SQG at 3 or more stations sampled in 2008 (Table 2). The highest number of SQG exceedances occurred at stations comprised of fine-grained sediments located in close proximity to Boston Harbor, the historic source of anthropogenic contamination (i.e., NF12, NF08 and NF22). There were no exceedances of the ER-M SQG value.

Table 2. 2008 station mean values compared to ER-L and ER-M sediment quality guidelines.[1]

Stat Id	Cadmium (mg/kg dry)	Chromium (mg/kg dry)	Copper (mg/kg dry)	Lead (mg/kg dry)	Mercury (mg/kg dry)	Nickel (mg/kg dry)	Silver (mg/kg dry)	Zinc (mg/kg dry)	Total_PAH[2] (ng/kg dry)	Total_PCB[2] (ng/kg dry)
Nearfield Locations (sorted by decreasing percent fines content)										
NF12	0.184	**113.5**[3]	31.05	**60.9**	**0.2925**	**22.15**	0.8665	86.45	**9169.09**	12.38
NF08	0.289	**102**	23.2	**50**	**0.21**	18.9	0.642	78	**8946.45**	19.83
NF22	0.132	**84.8**	22.5	**47.8**	**0.184**	18.1	0.531	73.2	**4426.23**	8.80
FF10	0.172	**97.85**	16.9	37.5	0.1122	17.5	0.222	66.8	**4506.02**	6.90
NF09	0.14	72.8	17	40.8	0.135	15.9	0.224	61.2	**7532.43**	9.91
FF13	0.1725	72.8	22.35	38.9	**0.1765**	18.15	0.5765	71.85	1609.64	12.73
NF07	0.129	51.4	13.7	37.4	**0.179**	14.1	0.134	47.2	**11171.74**	9.06
NF16	0.101	63.2	18	**49.7**	**0.162**	15.2	0.214	61.7	**13849.25**	4.25
NF05	0.0824	64.1	5.38	31.1	0.0569	11.9	0.0838	42.4	4000.10	4.66
NF18	0.0714	44.5	6.75	27.5	0.0618	10.5	0.0793	39.2	1780.64	2.78
NF19	0.11	50.9	3.26	28.7	0.0482	9.83	0.16	38.3	367.53	1.54
NF17	0.06765	42.55	<2.94	32.95	0.03215	8.165	0.03495	29.65	128.48	0.98
NF23	0.0419	35.6	<2.96	29.9	0.0117	7.6	0.0321	32.4	330.97	0.39
Farfield Locations (sorted by decreasing percent fines content)										
FF04	0.119	**109**	23.1	45.35	0.145	**25.4**	0.191	99	2163.08	6.62
FF07	0.1715	**98.9**	19.7	42.55	0.114	**28.65**	0.379	98.5	1606.28	8.68
FF05	0.07555	61	9.84	30.7	0.0608	13.85	0.132	54.2	813.99	3.78
FF09	0.08555	55.05	6.72	31.55	0.0413	12.5	0.08365	44.7	883.71	2.56
NOAA Sediment Quality Guidelines										
ER-L	1.200	81.00	34.00	46.70	0.150	20.90	1.000	150.00	4022.00	22.70
ER-M	9.600	370.00	270.00	218.00	0.710	51.60	3.700	410.00	44792.00	180.00

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

3.2 Sediment Profile Imaging

Overall, 2008 was similar to 2007 with physical processes dominating surface sediments. Sediments, estimated successional stage (SS), and the organism sediment index (OSI) were all similar to 2007. The grand average aRPD for all stations in 2008 appeared to be shallower than in 2007 but still deeper than baseline (Figure 8). Post-diversion period aRPD remained deeper than the baseline period (Table 3). For the nine stations that actually had measured aRPD layers, most increased in depth. Only NF24 stayed the same (Figure 9). There was also no indication of organic carbon accumulation in sediments. The operation of the outfall, starting in 2001, did not appear to affect benthic habitat quality. From 1995 to 2008, changes and trends in SPI variables appeared to be related to broader regional forcing factors, such as storminess.

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

Parameter	Baseline Years 1992–2000	Post-Diversion Years 2001–2008
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 (0.88 SD) cm	2.7 (0.83 SD) cm

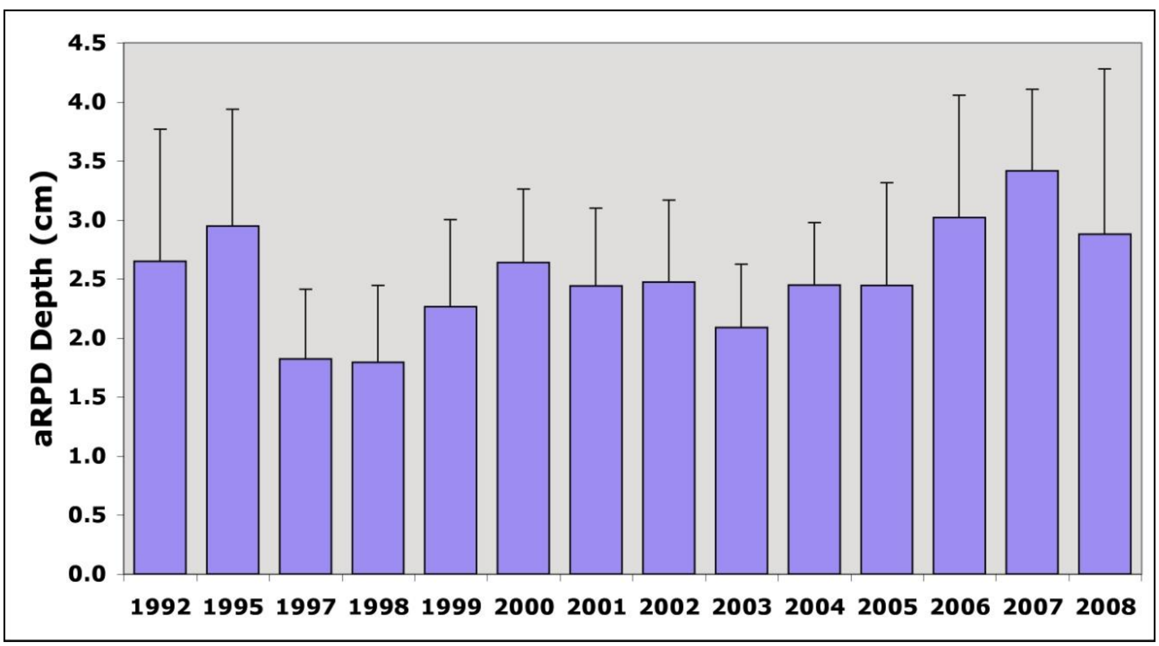

Figure 8. Average aRPD layer depth at nearfield stations by year.

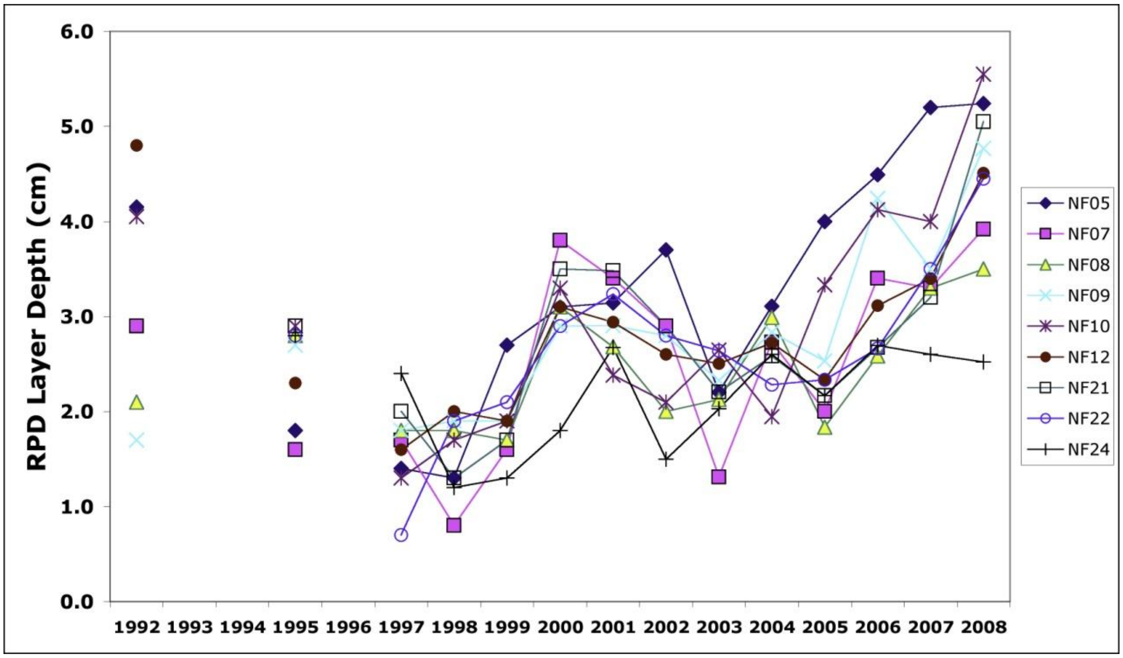

Figure 9. Trends for nearfield stations that had measured aRPD layer depths.

Biogenic structures at the sediment surface in 2008 appeared to be similar to previous years but more abundant relative to 2007 SPI. Tubes and what appeared to be feeding pits or mounds were common. Most stations had moderate densities (about 24 tubes per image) of small (<1 mm diameter) polychaete tubes. Station NF02 had a tube that appeared to belong to an amphipod (Figure 10).

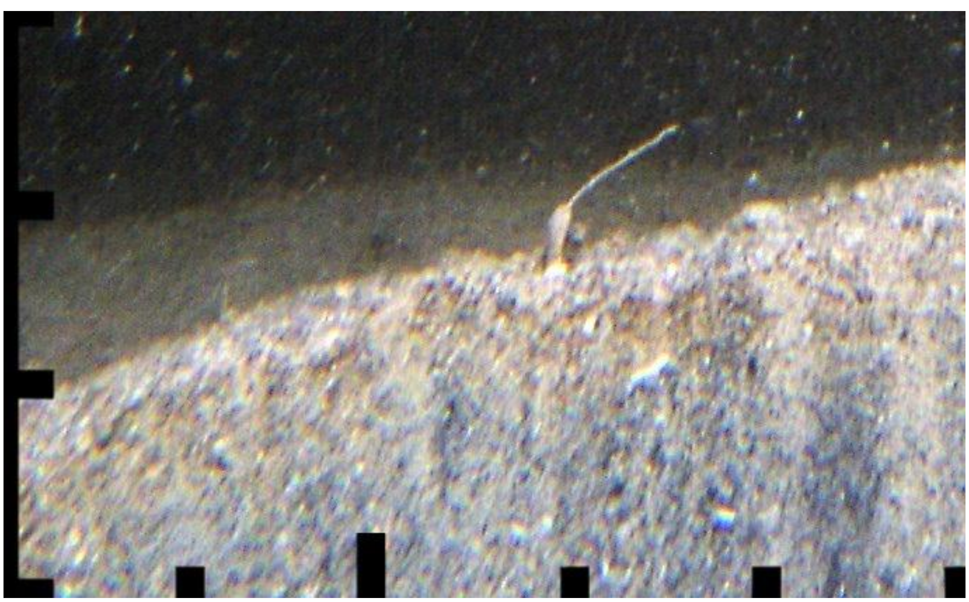

Figure 10. NF02-3 Amphipod tube in fine-medium sand. Scale is in cm units.

Most of the pebble and cobble size sediments were covered with tubes, which was also the case in 2007. Clusters of tubes and rounded sediment structures, likely foraminiferans, were observed at many stations (Figures 11 and 12). Mobile megafauna were not observed in the SPI images, however, the video indicated that there were small shrimp (mostly *Crangon* spp.) and hermit crabs at several stations.

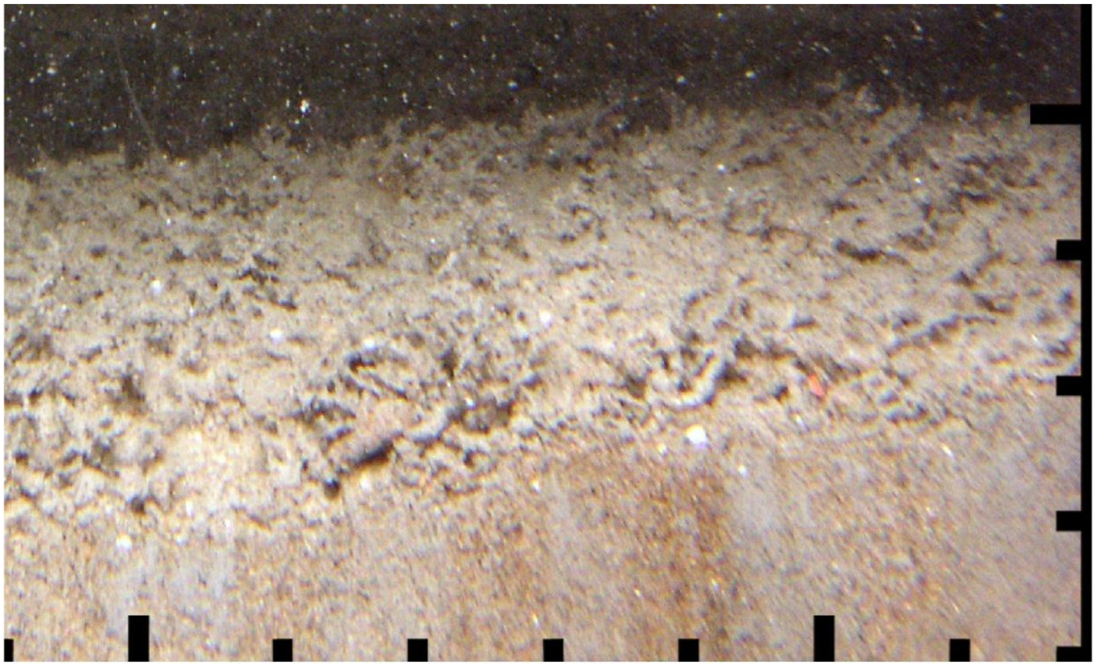

Figure 11. Tubes in clusters at station NF17. Scale is in cm units.

Figure 12. Rounded sediment structures at station NF12 that may be foraminiferans or some other biogenic structure. Scale is in cm units.

The small round structures that in previous years were thought to be small tunicates were identified by S. Doner (AECOM) as egg capsules of lumbrinerid polychaetes (Figure 13). These egg capsules were observed at stations NF13, NF14, and NF15. These were common in 2004 and 2005, not observed in 2006, and observed at the same three stations in 2007. Subsurface biogenic structures appeared to be the same types and as common in 2008 as they were in 2007 images.

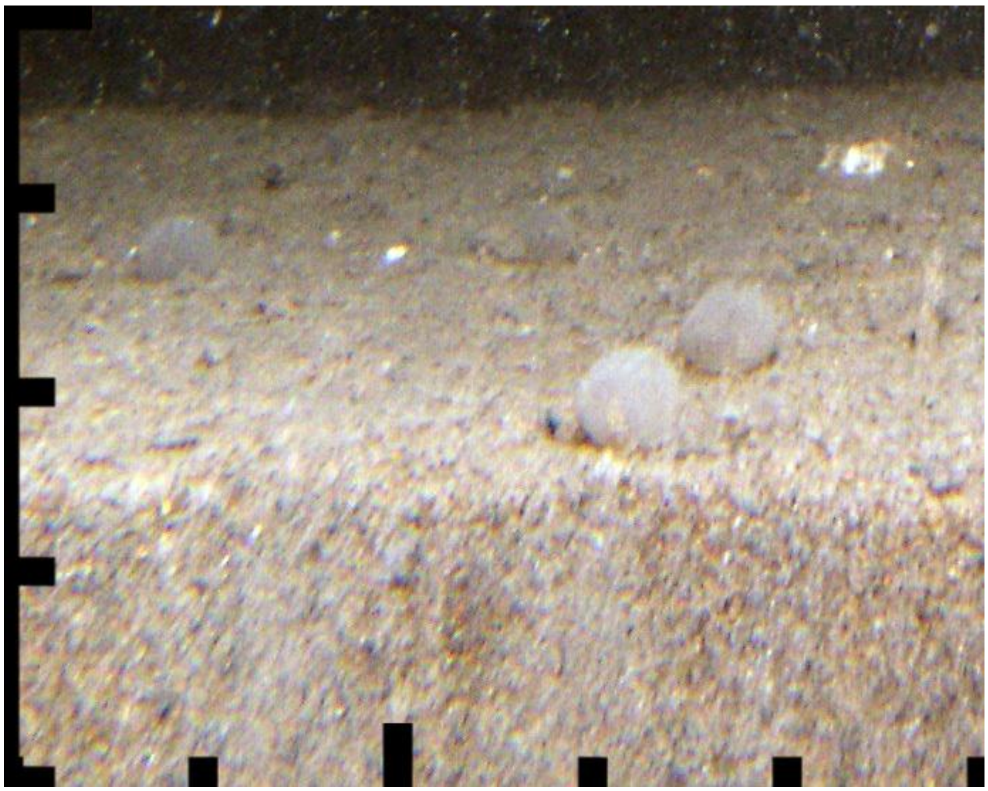

Figure 13. Egg cases of a lumbrinerid polychaete on fine-medium sand at NF13-4. Scale is in cm units.

Overall, the sediment surface appeared to be structured by a combination of physical and biological processes. Ten of 23 stations appeared predominantly physically dominated and at 13 stations a combination of biological and physical processes structured sediment surfaces. Sediments at many stations continue to be heterogeneous, ranging from sandy-silt-clays to cobble.

3.3 2008 Soft-Bottom Benthic Infaunal Communities

3.3.1 Nearfield 2008

Twenty-one infaunal samples were collected and analyzed from nearfield stations in 2008; the samples yielded 39,369 organisms that were assigned to 207 valid taxa and 27 indeterminate categories. Several benthic community parameters, including the number of organisms and species in each sample, and the calculated measures of diversity (Shannon H′, Fisher's log-series *alpha*) and evenness (Pielou's J′), were determined for each sample. All nearfield samples collected prior to the outfall becoming operational in September 2000 were used to determine a baseline average value for each parameter. Baseline values were not recalculated after the stations were divided into subsets to be sampled on a rotating basis because the subsets, which were chosen randomly, are considered to be reflective of the original range of values (MWRA 2003).

Baseline values and the mean value for each parameter for each year from beginning in 1992 are plotted below (Figures 14 and 15). The means for all parameters except evenness were higher than those recorded for the same subset of stations in 2006; evenness was very slightly lower, with a value of 0.62 in 2008 compared with 0.64 in 2006. None of the increases appear to be statistically significant, as indicated by the wide standard deviations around the annual means.

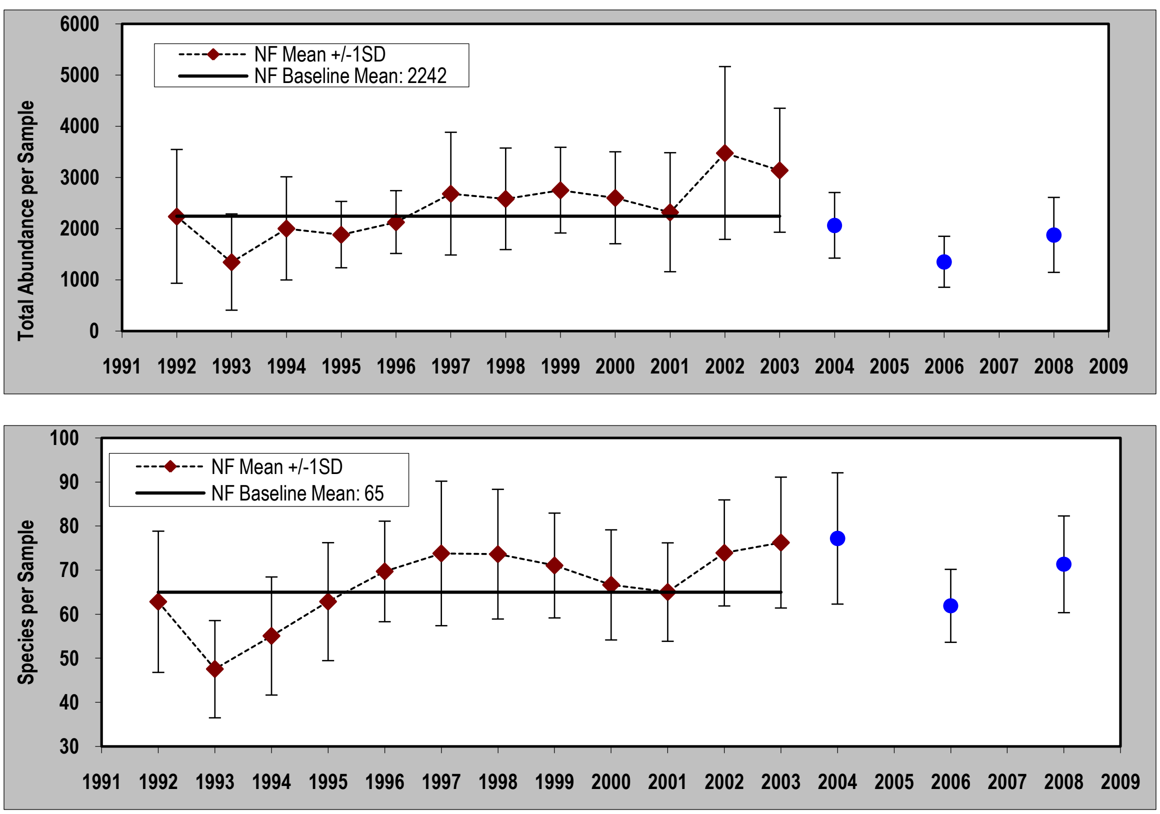

Figure 14. Mean total abundance and species per sample for 21 nearfield samples.

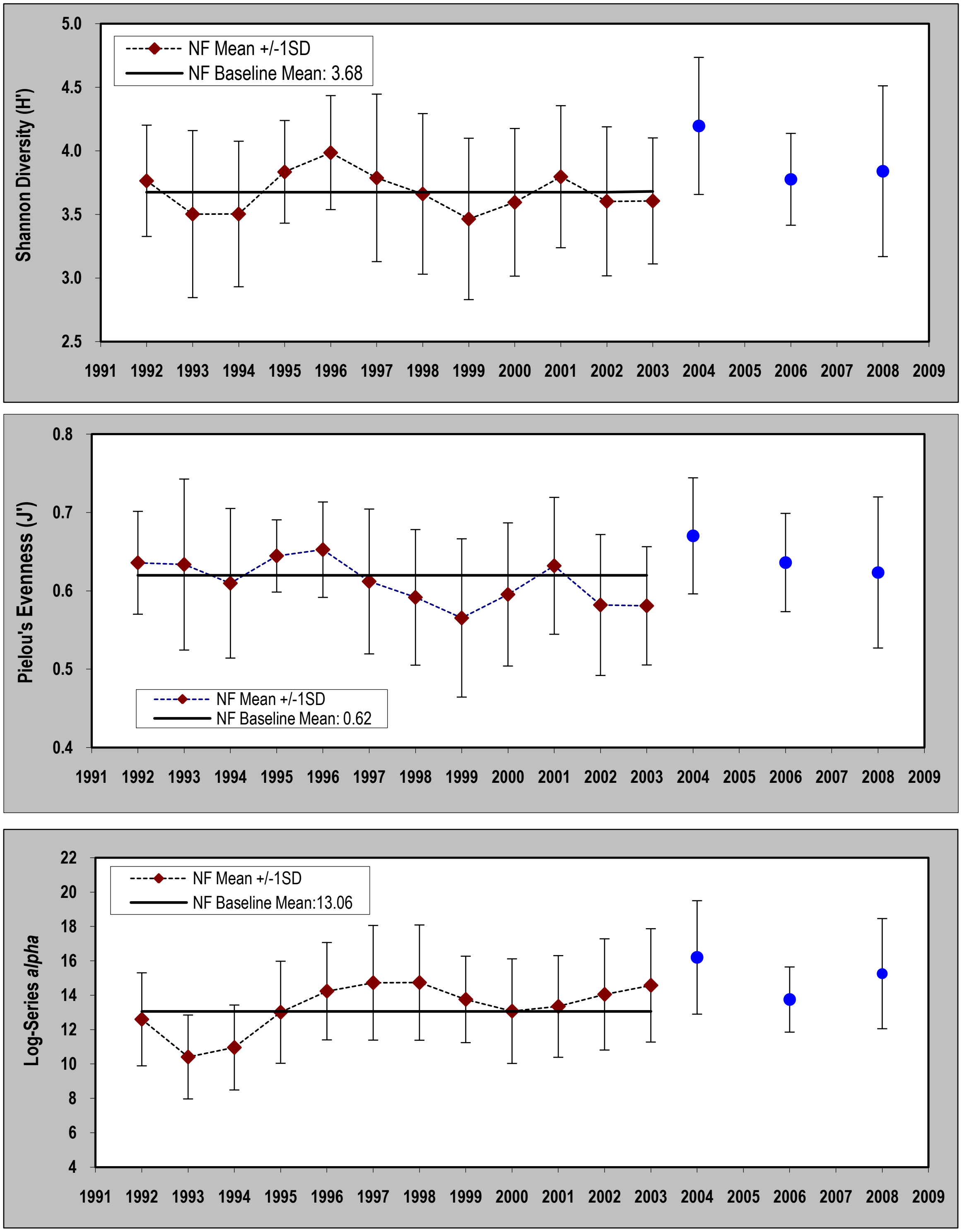

Figure 15. Mean Shannon and Fisher's *alpha* diversity and evenness per sample for 21 nearfield samples.

Dominant Species—Dominant species at the nearfield stations have been consistent over the past several years, although changes in their absolute numbers and numerical rank in the samples have changed from year to year. Most of the dominant taxa in 2008 were the same species that were reported in 2006 for the same subset of stations; new in 2008 to the top ten ranked species were the amphipod *Crassicorophium crassicorne* and the polychaete *Leitoscoloplos acutus* (Table 4). The spionid polychaete *Prionospio steenstrupi* has been the numerical dominant in Massachusetts Bay for the past several years, and is found in all sediment types, which range from 5 to 70 % fines, found at the nearfield stations. In 2008, the number of individuals of *P. steenstrupi* was nearly double that recorded in 2007; this species accounted for over 30% of all organisms in the nearfield samples (Figure 16, Table 4), which is slightly more than the 27% for the same subset of stations in 2006 (Maciolek et al. 2007)

Table 4. Top numerical dominants in 21 nearfield samples collected in August 2008.

Taxon	Total No. Indiv.
Prionospio steenstrupi	11,978
Tharyx acutus	3,485
Mediomastus californiensis	2,591
Aricidea catherinae	1,796
Crassicorophium crassicorne	1,601
Levinsenia gracilis	1,334
Leitoscoloplos acutus	1,201
Monticellina baptisteae	1,004
Molgula manhattensis	889
Ninoe nigripes	862

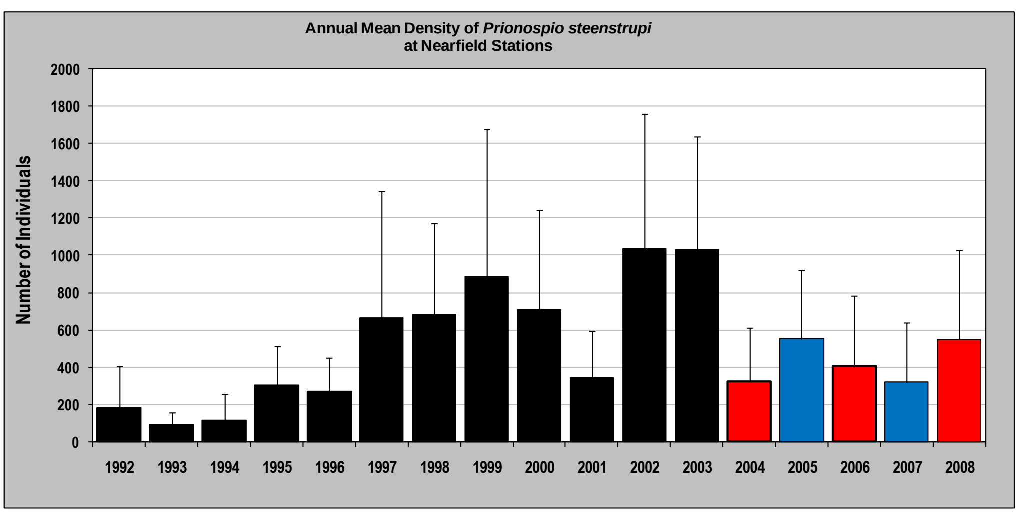

Figure 16. Annual mean density of *Prionospio steenstrupi* at nearfield stations. Two subsets of stations were sampled, one in 2004/2006/2008 and the other in 2005/2007.

3.3.2 Farfield 2008

Twelve infaunal samples were collected and analyzed from four farfield stations in 2008; the samples yielded 25,514 organisms that were assigned to 170 valid taxa and 26 indeterminate categories. Baseline values and the mean value for each parameter for each year from beginning in 1992 are plotted below (Figures 17 and 18). The means for total abundance and species richness (Figure 17) were higher than those recorded for the same subset of stations in 2006. The increase in mean abundance in the farfield was due primarily, as in the nearfield, to an increase in abundance of the polychaete *Prionospio steenstrupi*. In addition, several other species such as the amphipod *Crassicorophium crassicorne* and the polychaetes *Mediomastus californiensis* and *Spiophanes bombyx* contributed to the higher numbers. Diversity indices were either the same or slightly lower in 2008 compared with 2006 (Figure 18). None of the changes appear to be statistically significant, as indicated by the very large standard deviations around the annual means.

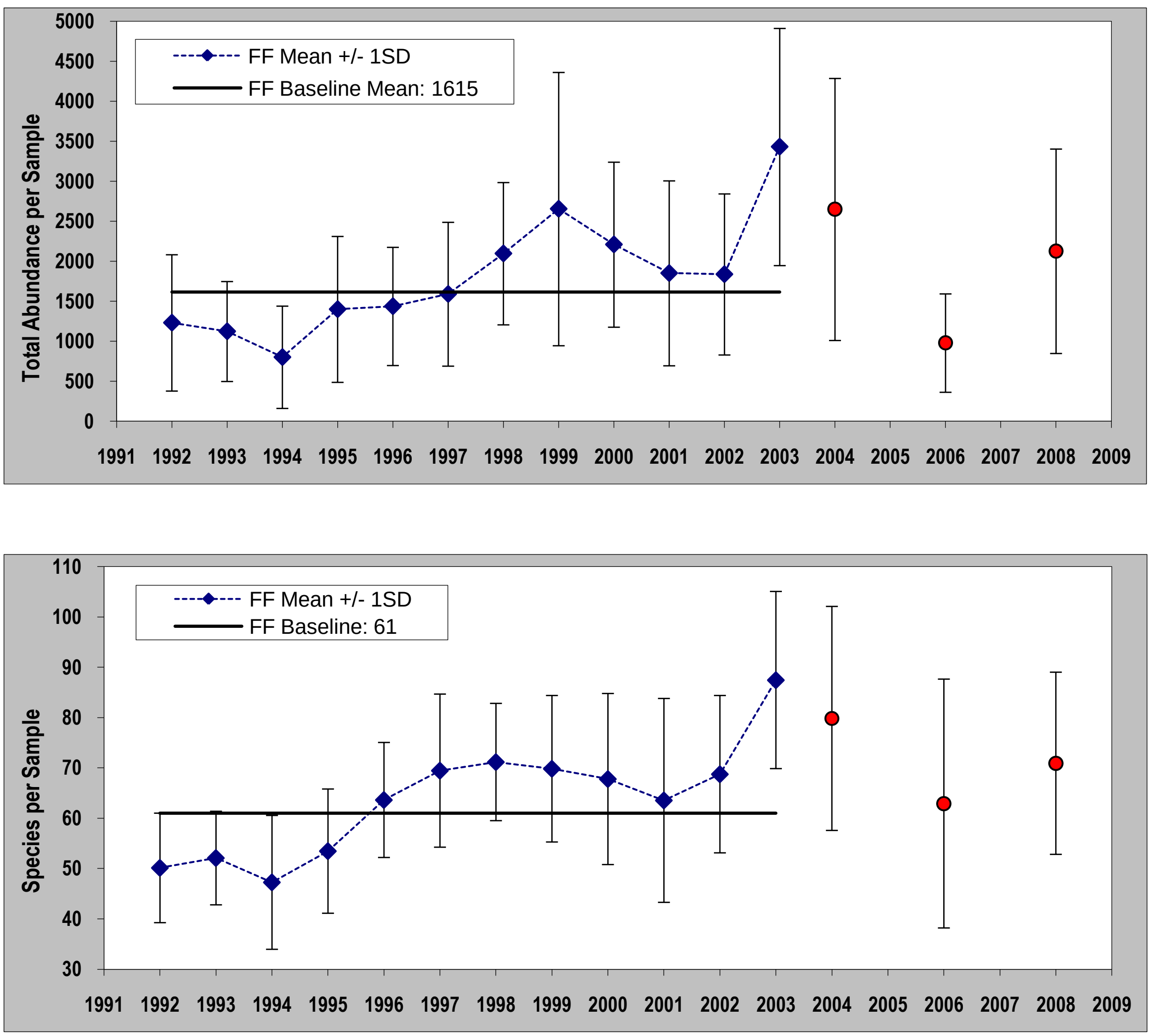

Figure 17. Mean total abundance and species per sample for 12 farfield samples.

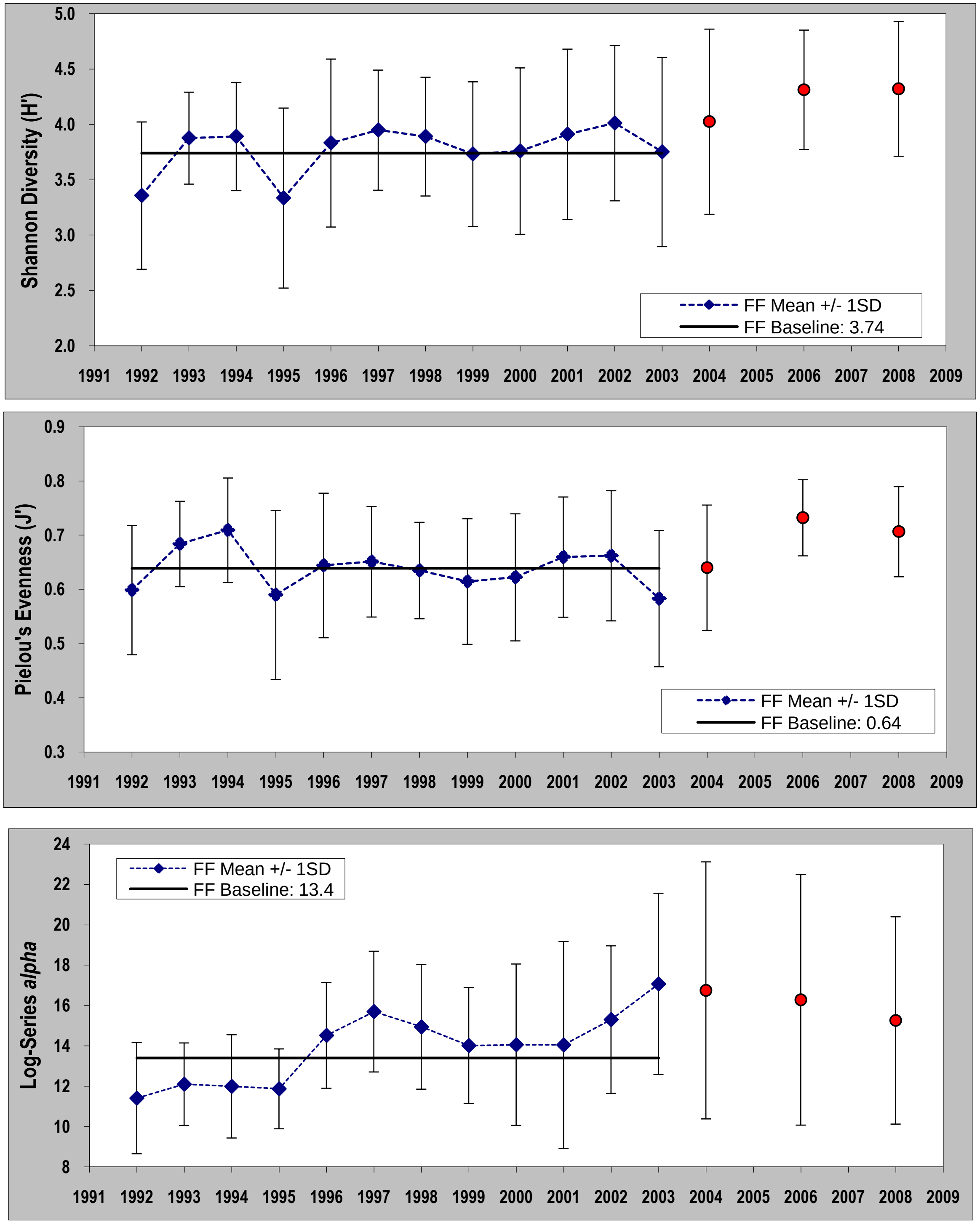

Figure 18. Mean Shannon (H′) and Fisher's *alpha* diversity and evenness per sample for 12 farfield samples.

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*[2] (Rhoads and Young 1971). Dominant species in 2008 were similar to those seen in previous years at these stations (Table 5).

Table 5. Top numerical dominants in 12 farfield samples collected in August 2008.

Taxon	Total No. Indiv.
Euchone incolor	4,212
Cossura longocirrata	2,854
Prionospio steenstrupi	2,436
Aricidea catherinae	2,161
Aricidea quadrilobata	1,159
Mediomastus californiensis	931
Levinsenia gracilis	825
Anobothrus gracilis	807
Spio limicola	738
Ninoe nigripes	605

Samples collected in the post-diversion period (2001–2008) have not indicated any discernable impact of the discharge on the infauna. The few statistical differences detected in the benthic community parameters, such as increased numbers of certain species and increased dominance by certain species at one or two of the nearfield stations, are considered to be natural fluctuations in the populations and not related to the outfall discharge (Maciolek et al. 2007). During the baseline period (1992–2000), multivariate analyses of the infauna data suggested that sediment grain size was the dominant factor in structuring the benthic communities. The nearfield stations fall into one of two major sediment regimes: fine sediments characterized by the polychaete annelids *Prionospio steenstrupi*, *Spio limicola*, *Mediomastus californiensis*, and *Aricidea catherinae*; and sandy sediments (primarily NF13, NF17, and NF23) characterized by the syllid polychaetes *Exogone hebes* and *E. verugera* and the amphipods *Crassicorophium crassicorne* and *Unciola* spp. In addition to the influence of habitat heterogeneity, the nearfield area, in water depths of 27–35 m, is often affected by strong winter storms (e.g., Bothner 2001, Butman et al. 2008), which cause episodes of sediment resuspension that potentially impact the benthic communities.

[2] *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 Hard-Bottom Benthic Habitats and Fauna

3.4.1 2008 Results

Photographic coverage in 2008 ranged from 19 to 25 minutes of video footage and 26 to 36 usable still photographs (35-mm slides) at each waypoint. A total of 693 still photographs and 466 minutes of video were viewed and analyzed. The ROV rode slightly nose-down compared to previous years during the 2008 survey, resulting in less area viewed per slide and consequently lower counts of larger, mobile organisms (such as lobsters, crabs, and fish) and higher counts of smaller and/or cryptic organisms (such as limpets, mussels, and small tunicates). Summaries of the 2008 slide and video analyses are included in Appendices B and C.

Data collected from the 2008 survey was generally similar to data obtained from the 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 consisted of a low to moderately low relief seafloor characterized by cobbles with occasional boulders. One southern reference site (T10-1) consisted mainly of large boulders, which resulted in a high relief habitat. 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, which 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 ranged from moderate to moderately heavy.

Seventy-eight taxa were seen during the 2008 visual analyses. Taxonomic counts or estimates of abundances from the still photographs included 5,596 algae, 24,624 invertebrates, and 453 fish (Table 6). Four algal species were seen in 2008, with encrusting coralline algae being the most abundant and widespread (recorded at 18 stations). In contrast, the upright algae *Palmaria palmata* (dulse), *Ptilota serrata* (red filamentous algae), and *Agarum cribrosum* (shotgun kelp) were less abundant and had more restricted distributions (recorded at 16, 9, and 2 stations, respectively). Of the 64 invertebrate taxa seen, the five most abundant were the horse mussel *Modiolus modiolus*, the frilled anemone *Metridium senile*, the northern white crust tunicate *Didemnum albidum*, barnacles *Balanus* sp., and juvenile northern sea stars *Asterias vulgaris* (small white starfish). Of these five taxa, *M. senile* was the only one that had a relatively restricted distribution. It was seen at six stations, but was abundant only on the two diffuser heads. The other four abundant invertebrates were seen at 12 to 22 stations. The cunner *Tautogolabrus adspersus* was the most abundant and widespread fish observed during this survey, being seen at 20 stations. This fish was most abundant in areas of higher relief. The other seven fish seen were much less abundant and had more restricted distributions (recorded at one to eight stations).

The taxa inhabiting the diffuser heads of the outfall have remained stable over time and did not change when the outfall went on line. The inactive diffuser head (Diffuser #44) continues to support a sparse population of the sea peach tunicate *Halocynthia pyriformis* and the frilled anemone *Metridium senile* (Figure 19). 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 20). Additionally, numerous *M. senile* have also colonized the riprap along the base of the diffuser. The riprap in the vicinity of both diffuser heads continues to be colonized by a variety of encrusting organisms.

Table 6. Abundance of taxa seen in still photographs taken during the 2008 nearfield hard-bottom survey.

Taxon	Count	Taxon	Count
Algae			
Coralline algae	2568*	*Ophiopholis aculeata*	36
Palmaria palmata	1832	general anemone	25
Ptilota serrata	1185*	red crust bryozoan	25
Agarum cribrosum	11	*Urticina felina*	21
Total algae	**5596**	*Tubularia* sp.	20
		Cancer spp.	16
Invertebrates		*Homarus americanus*	12
Modiolus modiolus	3112	*Placopecten magellanicus*	11
Metridium senile	3057	*Haliclona oculata*	10
Didemnum albidum	2675	*Obelia geniculata*	7
Balanus spp.	1784	*Melonanchora elliptica*	6
Dendrodoa carnea	1690	*Cerianthus borealis*	5
small white starfish	1651	*Tonicella marmorea*	5
white translucent sponge	1124	*Buccinum undatum*	5
globular translucent	949	*Haliclona* spp. (encrusting)	4
general bryozoan	827	general nudibranch	4
Terebratulina septentrionalis	775	general bivalve	3
Crepidula plana	739	*Crossaster papposus*	3
orange encrusting sponge	693	general starfish	2
Henricia sanguinolenta	658	*Pteraster militaria*	2
pink fuzzy encrusting sponge	540	*Alcyonium digitatum*	1
orange/tan encrusting sponge	533	general gastropod	1
general encrusting	523	*Lepas* spp.	1
Halocynthia pyriformis	478	hermit crab	1
white divided sponge	389	general crab	1
Aplidium spp.	259	*Solaster endeca*	1
Boltenia echinata	251	burrowing holothurian	1
Polymastia sp. A	240	general hydroid	**
Psolus fabricii	197	spirorbids	**
Asterias vulgaris	185	**Total invertebrates**	**24624**
Myxicola infundibulum	182		
general sponge	131	**Fish**	
?*Crisia* spp.	130	*Tautogolabrus adspersus*	418
Gersemia rubiformis	126	*Pseudopleuronectes americanus*	11
gold encrusting sponge	103	*Myoxocephalus* spp.	9
Suberites spp.	81	*Pholis gunnellus*	8
Arctica islandica	73	*Macrozoarces americanus*	2
Aplysilla sulphurea	62	*Gadus morhua*	2
Strongylocentrotus droebachiensis	55	general fish	1
lemon yellow sheet sponge	44	*Hemitripterus americanus*	1
Botrylloides violaceus	41	*Sebastes fasciatus*	1
cream encrusting sponge	38	**Total fish**	**453**

* estimated
** not counted

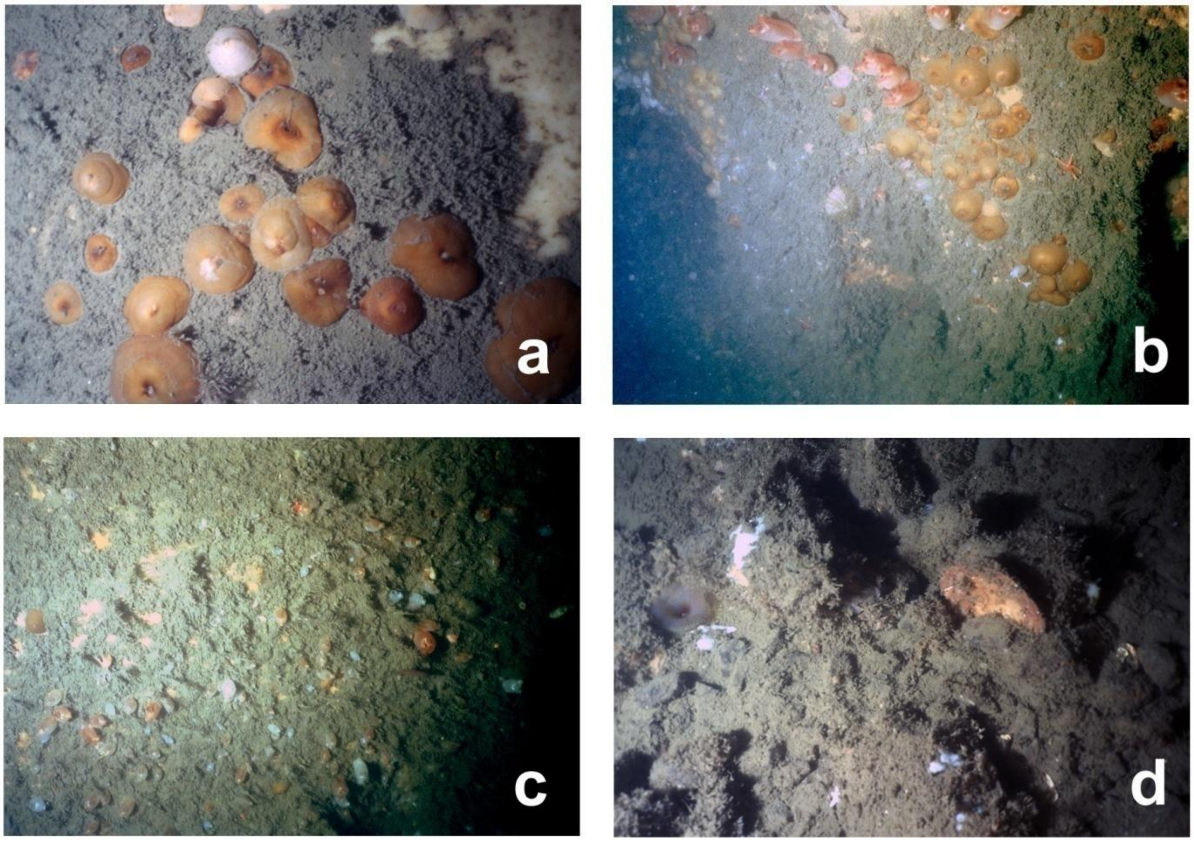

Figure 19. Photographs taken in 2008 showing colonization of the head of inactive Diffuser #44. The top (a) of the diffuser is colonized by a sparse population of the frilled anemone *Metridium senile*, while the sides (b and c) are colonized by *M. senile* and the sea peach tunicate *Halocynthia pyriformis*. The riprap at the base of the diffuser (d) is being colonized by a few encrusting taxa.

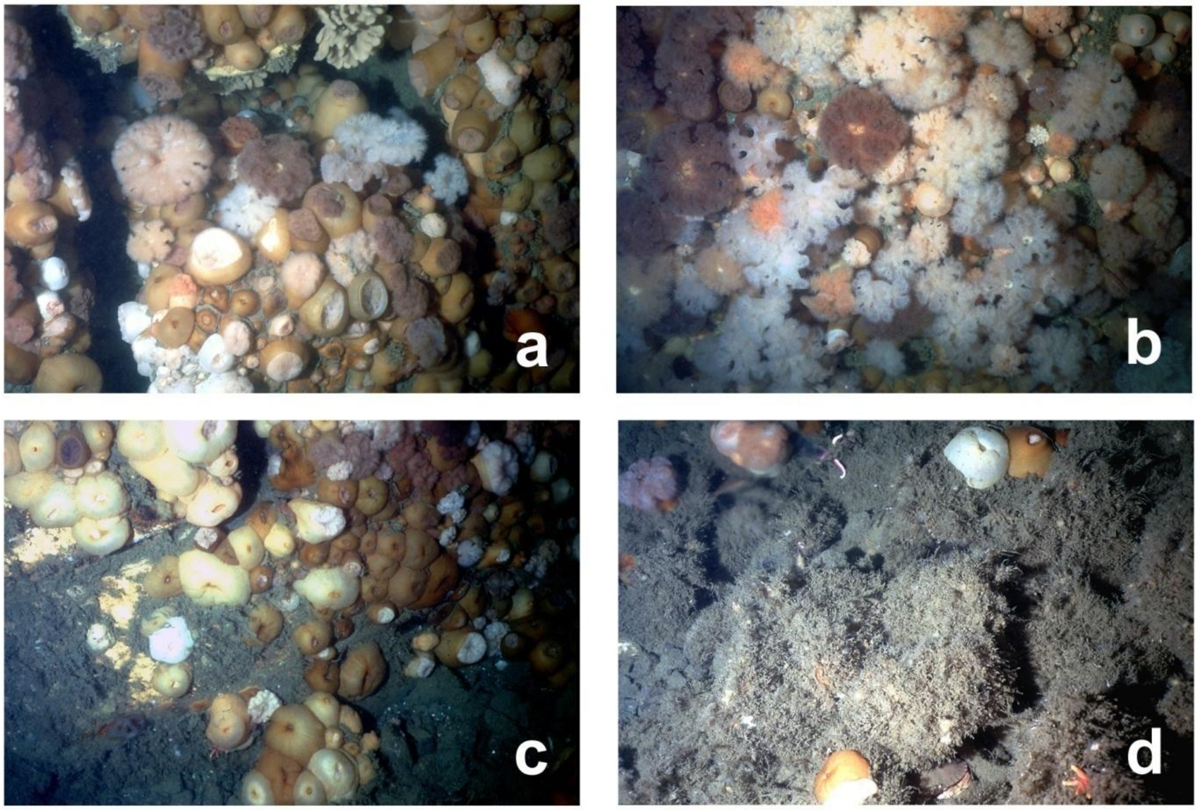

Figure 20. Photographs taken in 2008 showing colonization of the head of active Diffuser #2 at site T2-5. The top and sides (a, b, and c) of the diffuser are colonized by a dense population of *Metridium senile*. The riprap near the base of the diffuser (d) is also being colonized by *M. senile* and some encrusting taxa.

3.4.2 Comparison of 2008 Data with Pre- and Post-Diversion Results

With a few exceptions, previous trends of increased sediment drape, decreased percent cover of coralline algae, and a general decline in upright algae, observed in the previous post-discharge years, continued in 2008. Figure 21 shows the amount of sediment drape seen on the rock surfaces during the 1996–2008 surveys. Sediment drape was lightest on the shallowest part 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 heavy 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 west-southwest of the outfall. Sediment drape has been 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. Additionally, since 2005, drape has gradually increased on the drumlin south of the outfall, and this increase was more pronounced in 2008 at several of the southern reference sites (T8-1, T8-2 and T10-1).

Encrusting coralline algae has historically been the most abundant and widely distributed taxon encountered during the hard-bottom surveys. Figure 22 shows the percent cover of coralline algae estimated from the slides taken during the 1996–2008 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 least abundant on the flanks of the drumlins (T2-2, T2-4, T4-2, and T6-1). The percent cover of coralline algae was most variable near the edges of the tops of drumlins or on the flanks, where small lateral shifts in location frequently resulted in large differences in coralline algal cover. Percent 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. The major exception to this occurred at five stations located north of the outfall (T1-2, T1-3, T1-4, T7-1, and T7-2), which consistently had less percent cover of coralline algae during each of the post-diversion years. The decrease in percent cover became more pronounced, and spread to the southern areas, in 2005. The lower percent cover of coralline algae extended into 2008 and became quite pronounced at the southern reference stations.

The abundances of upright algae varied widely during both the pre- and post-diversion periods, but have shown a general decrease over time (Figures 23 and 24). Some of this variability appears to reflect patchiness in the small-scale (within station) spatial distributions of the upright algae. Both dulse (*Palmaria palmata*) and the filamentous red alga (*Ptilota serrata*) were generally most abundant at the northern reference sites (T7-1, T7-2, and T9-1) and on the drumlin immediately north of the outfall (T1-1, T2-2, T2-3, and T2-4). *Palmaria palmata* was most abundant in 1997, declined in 1998, slowly increased until 2001 or 2002, decreased in 2003, and has remained relatively steady for the last five years. On the drumlin immediately north of the outfall, dulse was present but variable at several stations until 2003, when it decreased at all of the stations. Since then it has been increasing again at several of the stations. Dulse, which had historically been largely absent from most of the stations south of the outfall, has been seen in modest abundances at these stations from 2006 through 2008. The other abundant upright alga *P. serrata* has historically also been abundant only at the stations north of the outfall. Its density has steadily decreased at many of these stations since 1998. This alga appears to be rebounding at two of the northern sites (T7-1 and T1-3) and one of the southern reference site (T12-1). The other upright alga, the shotgun kelp *Agarum cribrosum*, has historically been abundant at only one of the northern reference sites (T7-2). This alga has decreased dramatically from a high in 2000, when it was heavily overgrown by the invasive bryozoan *Membranipora membranipora*. Since then only occasional fronds *of A. cribrosum* are seen at the northern reference sites.

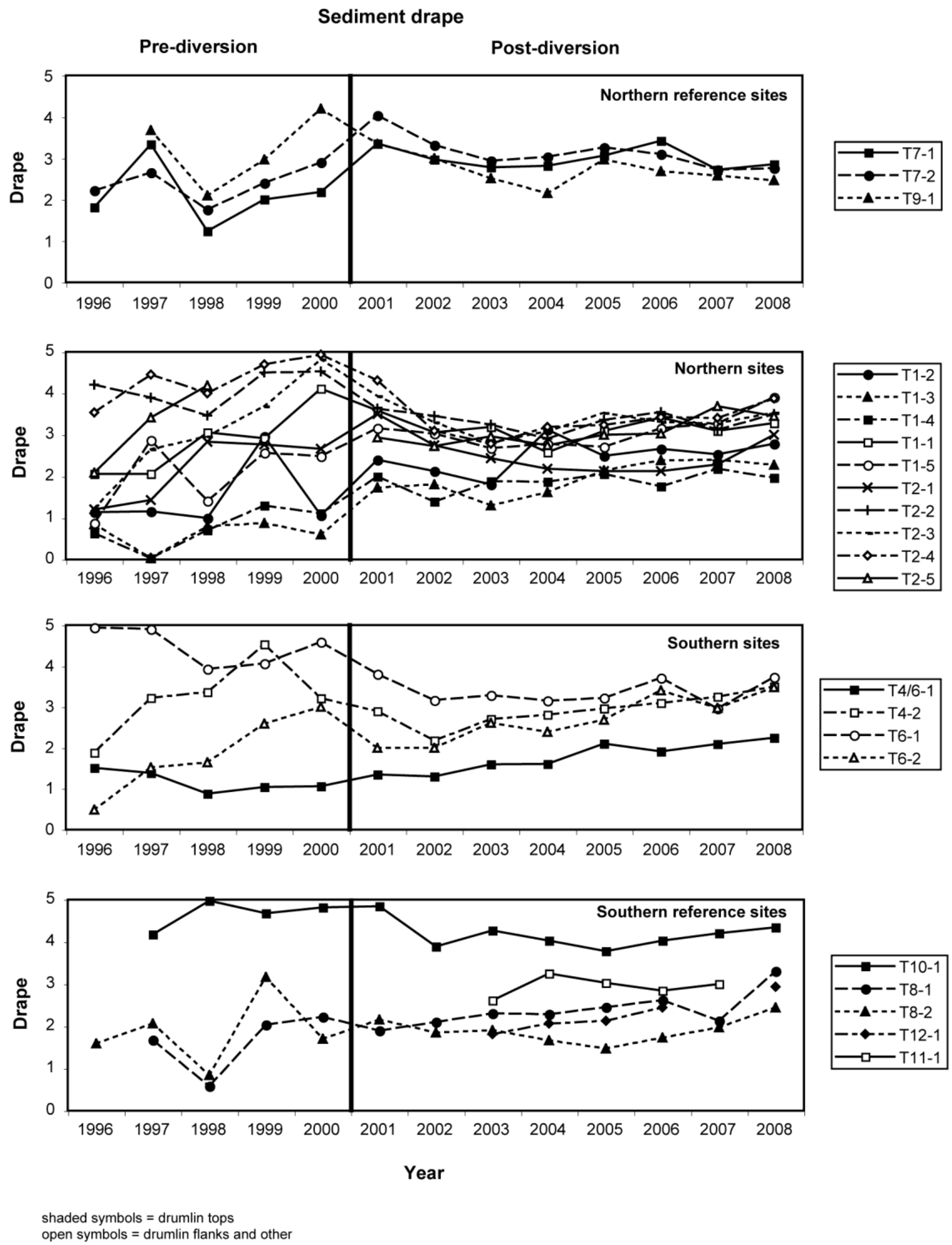

Figure 21. Sediment drape over time at the hard-bottom sites, as determined from 35-mm slides taken during the 1996–2008 surveys. Closed symbols are drumlin top locations and open symbols are drumlin flank or other stations.

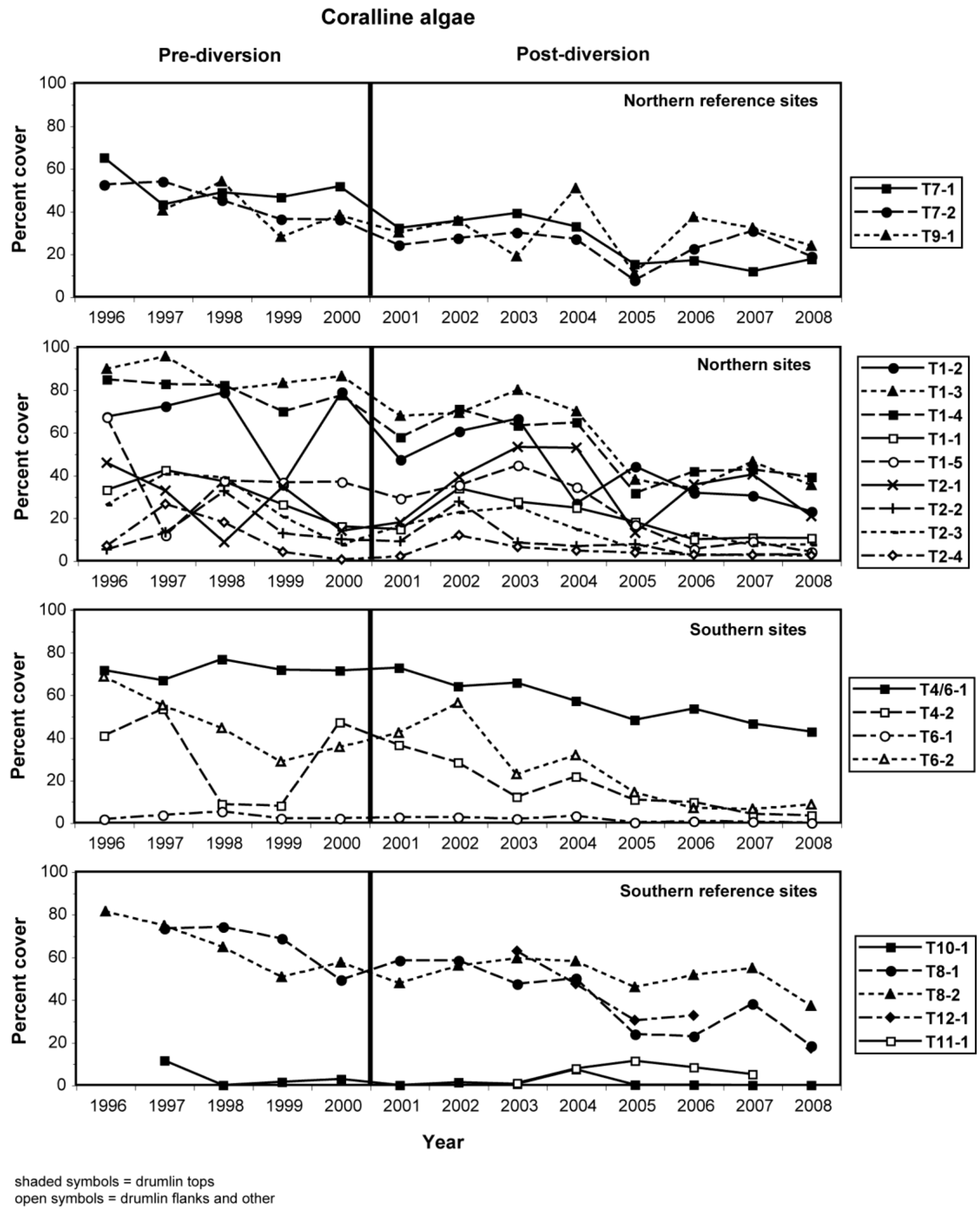

Figure 22. Percent cover of coralline algae over time at the hard-bottom sites, as determined from 35-mm slides taken during the 1996–2008 surveys. Closed symbols are drumlin top locations and open symbols are drumlin flank or other stations.

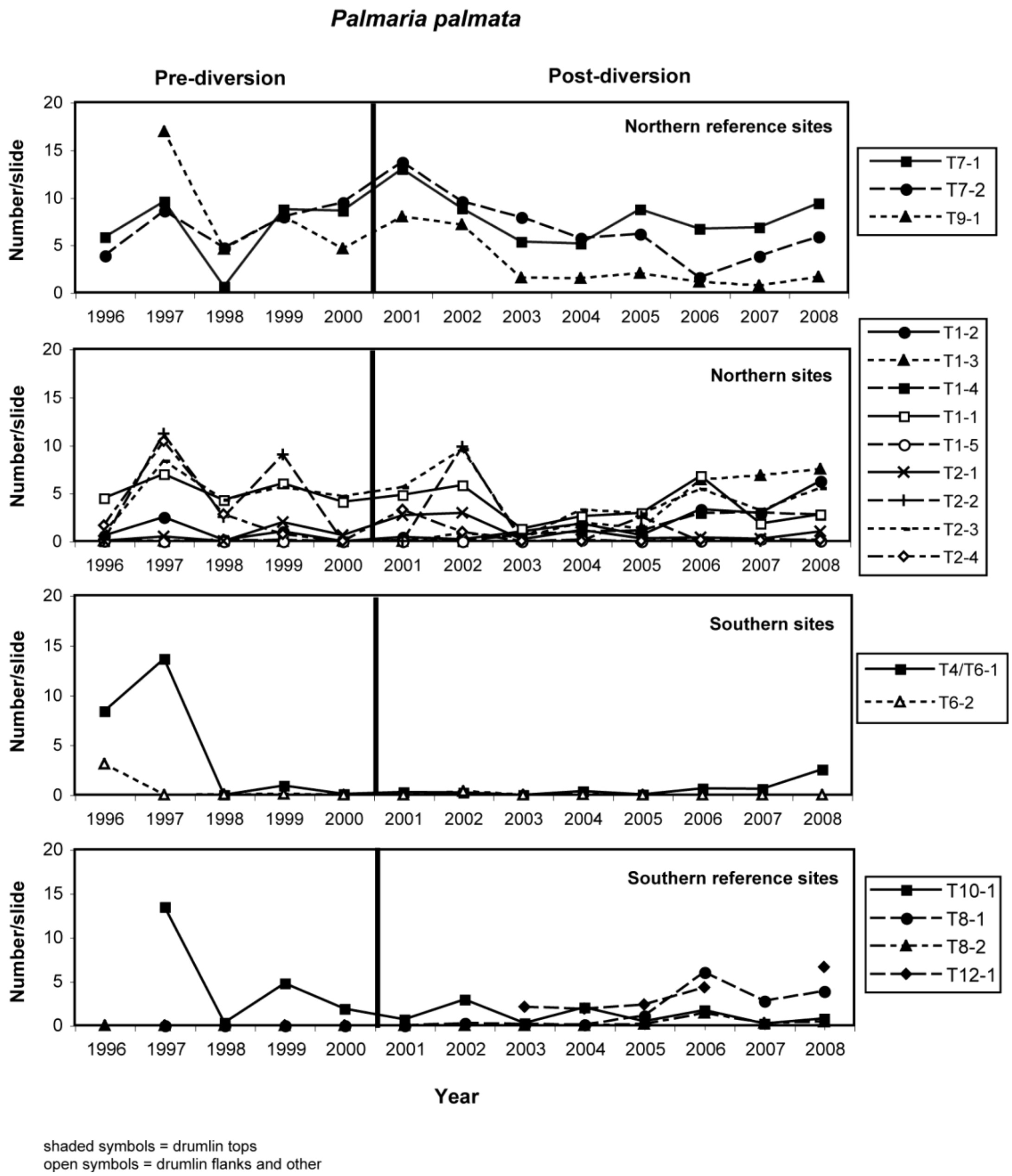

Figure 23. Abundance of dulse *Palmaria palmata* over time at the nearfield hard-bottom sites, as determined from 35-mm slides taken during the 1996–2008 surveys. Closed symbols are drumlin top locations and open symbols are drumlin flank or other stations.

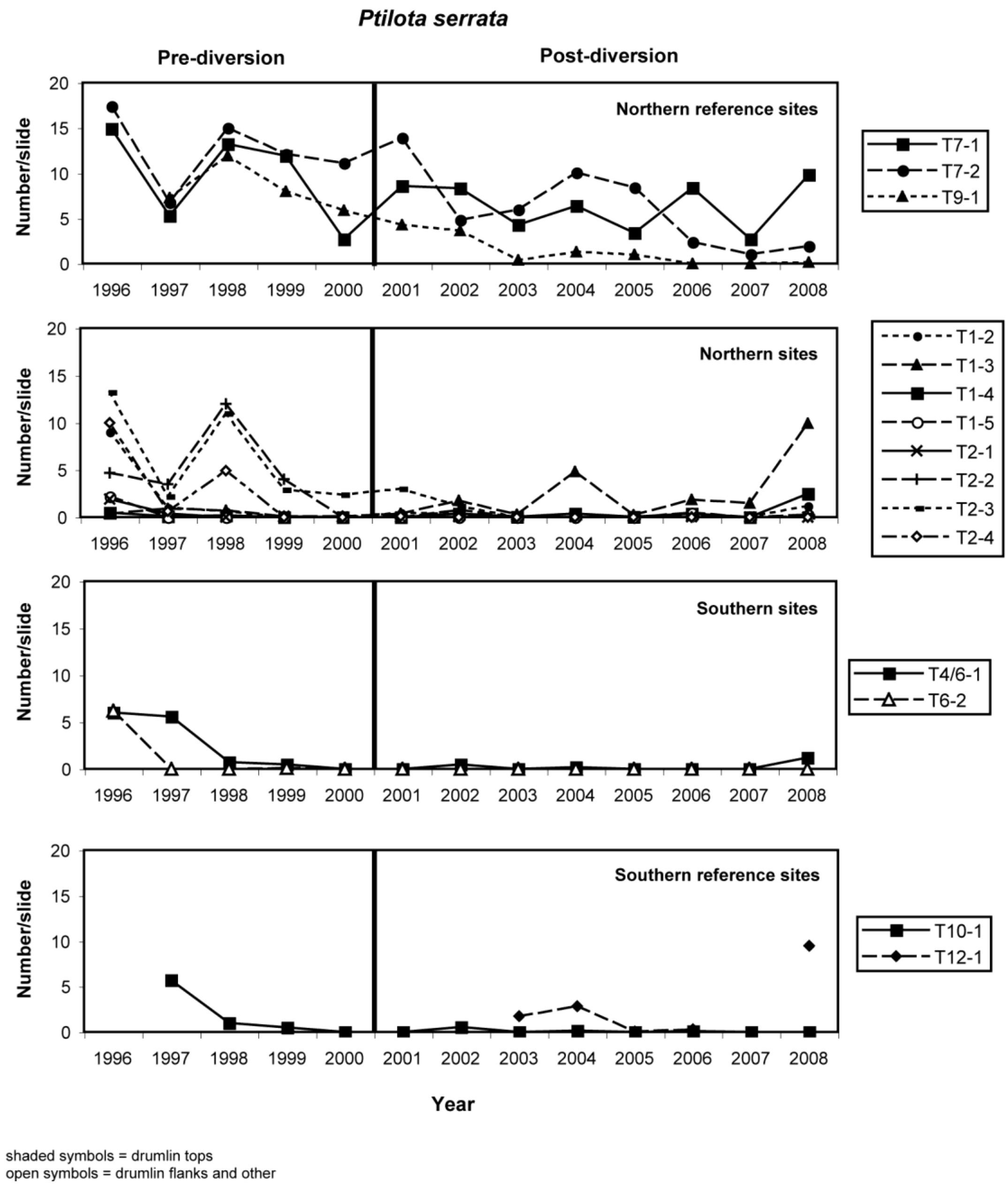

Figure 24. Abundance of the filamentous red alga *Ptilota serrata* over time at the nearfield hard-bottom sites, as determined from 35-mm slides taken during the 1996–2008 surveys. Closed symbols are drumlin top locations and open symbols are drumlin flank or other stations.

The total number of species seen on the still photographs at each of the stations does not appear to have been impacted by diversion of the outfall (Figure 25). At most of the stations, the number of species seen during the post-diversion period was well within the range of species seen during the pre-diversion period. Low-relief deep drumlin flank stations tended to support fewer species than drumlin top stations and the fewest species were generally seen at the two diffuser stations.

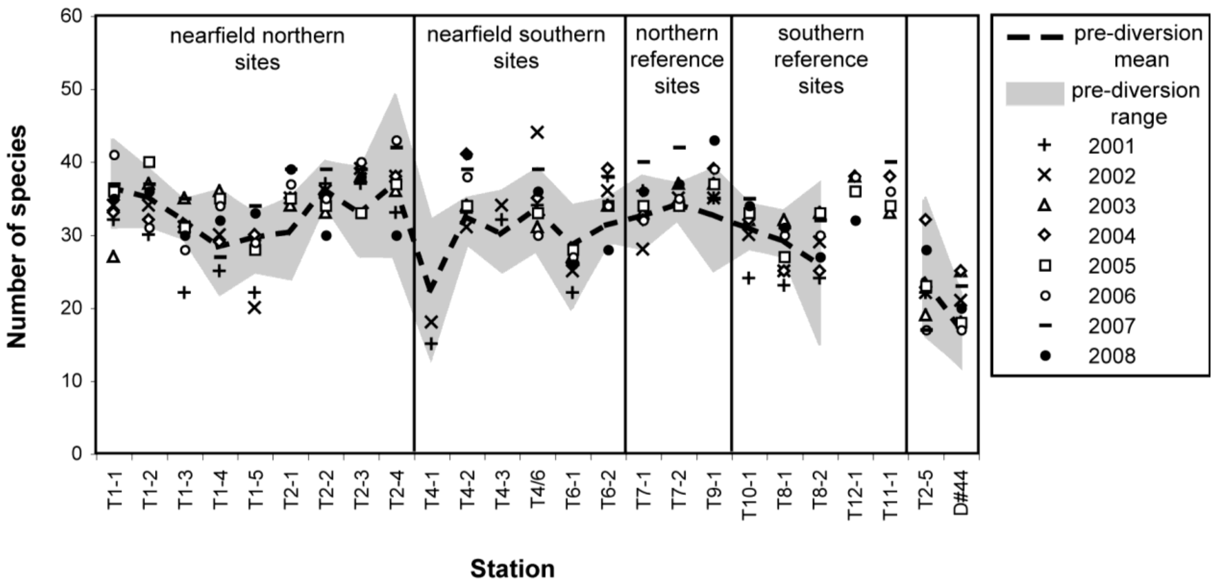

Figure 25. Total number of species seen on still photographs collected at the nearfield hard-bottom sites during the 1996–2008 surveys. The dashed line shows the mean baseline value and the shaded area shows the range of baseline values. Only species that were recognized during the pre-diversion period were included.

Hierarchical classification of data collected from still photographs taken during the 1996–2007 time period indicated that the clustering structure appears to be controlled by a combination of geographic location and topography, and to a lesser degree by time period (see detailed discussion in Maciolek et al. 2008). Several smaller groupings of stations also appeared to reflect yearly differences; however, the overwhelming structuring factor appeared to be geographic location with neighboring stations frequently clustering together or different years of the same station clustering together. Some cluster groups were comprised of both pre- and post-diversion years, while others consisted mainly of years from one diversion period. The subtle grouping of stations by diversion period may reflect minor shifts in benthic communities due to outfall diversion, or it may merely reflect changes in benthic communities over time. It is interesting to note that the northern and southern reference stations and the nearfield drumlin top stations generally did not separate on the basis of diversion period, while some of the stations on the flanks of drumlins nearer the outfall did separate into pre- and post-diversion periods.

Non-metric dimensional scaling (NMDS) analysis of the 1996–2007 data was also carried out (Maciolek et al., 2008), but the overlap of stations indicates that the two-dimensional NMDS did not provide a good solution for the data. Several small clusters of stations and one outlier clearly separated away from the main grouping of stations, but other station clusters had a little spatial overlap with adjacent clusters, and the clusters 1–4 had a fair amount of spatial overlap in the NMDS space with neighboring clusters. One interesting observation was a subtle shift of points representing the post-diversion period toward the upper right of the NMDS space. This shift probably represents the decrease in coralline algae observed over time, since stations with high percent cover of coralline algae were located toward the bottom left of the ordination space. The strong influence of geographic location and topography on the clustering structure was also reflected in the NMDS diagram (see detailed discussion in Maciolek et al. 2008)

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 7 shows the abundance of several of these species during the years 1996 to 2008. The low abundances of these organisms in the stills taken during 2008 probably reflect the nose-in camera angle mentioned earlier. The data collected from video were not impacted by the low angle of the still camera, and hence may be a better indicator of true relative abundances. Abundances of the green sea urchin *Strongylocentrotus droebachiensis* have varied cyclically, decreasing from a high of 0.83 individuals per photograph in 1996 to a low of 0.25 individuals per photograph in 2000, and then increasing and decreasing several more times. *Cancer* crabs, cod (*Gadus morhua*), and lobster (*Homarus americanus*) all appear to be more abundant during the post-diversion period than during the pre-diversion period. The video data show that the decline in *Cancer* crabs observed in 2008 is probably real and not just an artifact of camera angle.

Table 7. Number of individuals of selected species observed during the nearfield hard-bottom surveys, adjusted to include only stations that were surveyed in all 12 years (with the exception of two stations added after 1996).

	Baseline					Post-diversion							
	1996*	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Video													
Minutes of video	438	487	439	422	444	448	495	469	454	466	419	440	443
Cancer spp. (rock crab)	6	3	4	15	92	123	168	144	115	67	81	108	12
Gadus morhua (cod)	-	6	12	22	11	41	53	10	52	64	59	40	64
Homarus americanus (lobster)	6	2	11	4	18	21	31	33	12	10	35	36	28
Still Photographs													
Number of photographs	534	622	635	551	635	583	672	661	675	664	666	661	661
Strongylocentrotus droebachiensis	444	339	282	299	157	180	249	90	113	82	145	116	55
Cancer spp. (rock crab)	4	1	4	6	14	44	63	47	16	22	56	49	12
Gadus morhua (cod)	-	-	2	3	-	9	12	-	3	17	5	19	16
Homarus americanus (lobster)	1	-	3	3	5	4	13	6	5	9	19	15	2

* did not include T9-1 and T10-1

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 suggest that concentrations of most contaminants in surficial sediment at stations in Massachusetts and Cape Cod Bays have not changed following effluent diversion to the offshore outfall in 2000. While widespread changes have not been observed, localized increases and/or decreases in concentrations of some contaminants in surficial sediment have occurred at one or more stations during the post-diversion period. For example, concentrations of copper, mercury, silver, and total PCB were below the baseline range at several stations in 2008, especially nearfield locations that also had a coincident decrease in TOC. A statistical analysis of the long-term monitoring data indicated that mean concentrations of total DDT, total PCB, and aluminum changed significantly (at the 95% level of confidence) between the baseline (1992–2000) and post-diversion (2001–2008) periods[3]. That is, mean concentrations of total DDT and total PCB in nearfield sediments decreased significantly between the baseline and post-diversion monitoring periods. The observed decrease is likely associated with the banning of these chemicals in the 1970s and 1980s, which in turn reduced inputs of these chemicals to the system. Post-diversion mean concentrations of aluminum increased ($p<0.05$) in nearfield sediments; while significant changes in grain size composition were not evident, changes in aluminum in coastal sediments like these normally indicate changes in silt-clays, rather than anthropogenic impacts. Overall, sediment data to date indicate that post-diversion concentrations of most anthropogenic contaminants in surficial sediment have not changed substantively compared to the baseline.

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

Clostridium perfringens abundances (not normalized to percent fines) measured in surficial sediments throughout Massachusetts and Cape Cod Bays ranged from 63 colony forming units per gram (cfu/g) dry weight (NF17 in 2000) to 24,100 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.,

[3] Statistical analysis results based on long-term monitoring data for stations sampled during ‘even’ monitoring years (i.e., stations NF05, NF07, NF08, NF09, NF12, NF16, NF17, NF18, NF19, NF22, NF23, FF04, FF05, FF07, FF09, FF10, and FF13). Statistical analysis results may vary depending on how the data are aggregated (all stations, even year stations, or odd year stations).

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 and farfield sediments) 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. In 2006, 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. The grand average aRPD for all stations in 2008 appeared to be shallower than in 2007 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 17 years of the monitoring program, including changes in total infaunal density, species composition and richness, and, to a lesser 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 dominant at the medium- to fine-grained stations. Much of the decline in abundances seen in 2003–2007 was again due to the population fluctuation of the same species. Such fluctuations are characteristic of invertebrate species and cannot be construed as related to the operation of the outfall.

Some benthic community parameters have fluctuated in a sine-wave-like pattern, with increases followed by declines. Although mean Shannon diversity dropped below baseline in 2002, 2003, and 2005, it has not fallen below the lower threshold level of 3.30 in any year. Diversity as measured by log-series *alpha* also fell below baseline in 2005, but not below the critical threshold level of 9.95, and had recovered when next measured in 2007.

The high variability at some stations, which contrasts with the stability of other stations over time, suggests that several processes, biological as well as physical, operate in this system. Annual fluctuations in the population densities of several species, especially the dominant polychaetes at the finer-grained stations, and the occasional scouring of the bottom by storms both contribute to the 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.

- *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.

- *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 percent 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 percent 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 in upright algae has been quite pronounced at the northern reference stations and may in part 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 was noted at T7-1 (2007) and T7-2 (2006). Lush epifaunal growth continues to thrive on the diffuser heads surveyed for this study and throughout many of the other stations visited. However, despite the fact that outfall impacts appear to be minimal at this time, changes in the hard-bottom communities could be chronic and/or cumulative, and may take longer to manifest themselves.

5. REFERENCES

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APPENDIX A

2008 Infaunal Community Parameters

Table A1. Benthic community parameters for all samples collected in August 2008.

Nearfield Stations						
Station	**Rep**	**Total Indiv.**	**Number of Species**	**H′**	**J′**	**LSA**
FF10	1	2277	78	3.61	0.57	15.67
FF10	2	2039	69	3.94	0.65	13.88
FF10	3	1849	82	4.13	0.65	17.60
FF13	1	3461	55	2.76	0.48	9.29
FF13	2	3488	50	2.74	0.49	8.27
FF13	3	3021	55	2.60	0.45	9.56
NF05	1	1291	82	4.79	0.75	19.55
NF07	1	1748	74	3.74	0.60	15.73
NF08	1	993	60	4.38	0.74	14.08
NF09	1	1416	75	4.44	0.71	16.97
NF12	1	1520	79	4.57	0.72	17.81
NF12	2	1090	70	4.54	0.74	16.78
NF12	3	1360	83	4.89	0.77	19.62
NF16	1	1844	80	3.53	0.56	17.12
NF17	1	1182	59	3.20	0.54	13.13
NF17	2	997	63	3.55	0.59	15.03
NF17	3	1767	70	3.17	0.52	14.63
NF18	1	2091	88	4.24	0.66	18.66
NF19	1	2484	78	3.79	0.60	15.43
NF22	1	1605	65	4.12	0.68	13.61
NF23	1	1846	83	3.90	0.61	17.97

Farfield Stations						
Station	**Rep**	**Total Indiv.**	**Number of Species**	**H′**	**J′**	**LSA**
FF04	1	1087	50	4.26	0.76	10.89
FF04	2	612	49	4.28	0.76	12.68
FF04	3	1781	63	4.50	0.75	12.82
FF05	1	1042	74	4.81	0.77	18.52
FF05	2	1294	67	4.62	0.76	15.07
FF05	3	2067	77	4.85	0.77	16.04
FF07	1	4092	64	3.39	0.57	10.78
FF07	2	4412	62	3.40	0.57	10.23
FF07	3	3870	53	3.35	0.58	8.69
FF09	1	1922	95	4.89	0.74	21.21
FF09	2	1664	101	4.93	0.74	23.77
FF09	3	1671	96	4.56	0.69	22.42

APPENDIX B

2008 Hard-Bottom Still Photographs Analysis

Table 1. Summary of data recorded from still photographs taken on 2008 hard-bottom survey.

Station	T1-1	T1-2	T1-3	T1-4	T1-5	T2-1	T2-2	T2-3	T2-4	T4-2	T4/6-1	T6-1	T6-2	T7-1	T7-2	T9-1	T10-1	T8-1	T8-2	T12-1	T2-5	D#44	Total
# of frames	31	33	32	28	33	30	30	26	32	30	33	33	31	34	33	32	32	36	29	32	31	32	693
Average depth (m)	25.7	24.9	22.1	24.0	29.6	25.9	29.7	24.4	28.9	29.7	24.3	31.3	28.9	24.9	25.5	25.0	26.6	23.3	24.0	25.7	32.3	32.7	
Substrate	b+mx	b+c	b+c	b+c	mx	mx+b	cp+mx	b+c	b+mx	cp+mx	b+mx	c+g	mx	b+c	b+c	b+mx	b	c+mx	b+mx	b+mx	d+rr	d+rr	
Drape range	m-mh	m	lm-m	lm	mh	m	m-mh	m-mh	mh	m-mh	lm-m	m-mh	m-mh	lm-mh	m	lm-m	mh-h	m-mh	lm-m	m	m-mh	m-h	
Drape (average)	3.29	2.79	2.28	1.96	3.91	3.00	3.50	3.54	3.88	3.50	2.24	3.73	3.48	2.85	2.76	2.47	4.34	3.31	2.45	2.94	3.45	3.88	
Coralline algae (percent cover)	11	23	35	39	4	21	3	8	2	3	43	0	9	18	19	24	-	18	37	17	-	-	
Ptilota serrata	-	r-f	c-a	r-c	r	-	-	r	-	-	r-f	-	-	c-a	f-c	r	-	-	-	c-a	-	-	
general hydroid	f-c	f-a	f-c	f-c	f-c	f-c	r-c	f-c	f-a	r-c	f-a	r-f	r-f	f-c	f-c	f-c	f-c	f-c	f-c	f-a	r-a	f-a	
barnacle/spirorbid complex	r	r-c	r-c	r-c	r-f	r-f	r	r-f	r	r	r-c	r	r	f-c	f-a	f-c	r	r	r	r	r	r	
Palmaria palmata	86	207	240	77	2	31	-	144	5	-	84	-	-	319	195	53	25	140	12	212	-	-	1832
Agarum cribosum	-	-	1	-	-	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-	-	-	11
general sponge	7	5	-	1	1	8	6	7	7	2	2	2	-	2	9	7	23	7	3	9	15	8	131
Aplysilla sulphurea	2	5	-	-	-	13	1	6	7	4	2	-	5	2	-	11	3	-	1	-	-	-	62
Polymastia sp. A	16	12	-	3	2	14	7	35	21	12	11	-	12	5	12	14	54	-	1	9	-	-	240
Haliclona oculata	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	1	-	-	-	1	2	4	10
Suberites spp.	9	1	-	-	15	9	7	9	4	8	3	-	6	-	-	3	4	3	-	-	-	-	81
white divided sponge	2	34	-	-	-	2	6	65	40	27	1	-	-	-	6	35	162	-	-	7	2	-	389
orange/tan encrusting sponge	19	34	27	30	47	9	39	18	43	54	14	11	14	28	23	61	10	22	13	15	2	-	533
orange encrusting sponge	69	50	13	30	33	56	19	38	34	27	26	1	9	54	71	54	29	25	40	15	-	-	693
gold encrusting sponge	3	3	-	-	1	39	-	-	-	-	22	-	-	-	1	8	-	25	-	1	-	-	103
pink fuzzy encrusting sponge	14	20	21	53	41	15	16	6	-	19	13	11	32	28	72	11	4	61	69	33	1	-	540
white translucent sponge	56	84	46	30	92	67	69	47	35	85	61	9	51	63	90	58	35	65	44	33	4	-	1124
cream encrusting sponge	1	-	-	-	1	1	-	-	11	3	8	-	-	-	-	5	-	3	-	4	1	-	38
Melonanchora elliptica	-	-	-	-	1	1	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6
Haliclona spp. (encrusting)	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	4
lemon yellow sheet sponge	-	-	-	-	-	-	-	2	-	1	-	-	-	37	4	-	-	-	-	-	-	-	44
general encrusting	23	24	19	8	23	37	23	34	30	34	15	11	49	38	27	36	15	11	18	24	14	10	523
globular translucent	156	133	43	15	7	52	20	123	139	25	51	-	1	23	11	24	39	12	4	21	45	5	949

Station	T1-1	T1-2	T1-3	T1-4	T1-5	T2-1	T2-2	T2-3	T2-4	T4-2	T4/6-1	T6-1	T6-2	T7-1	T7-2	T9-1	T10-1	T8-1	T8-2	T12-1	T2-5	D#44	Total
Obelia geniculata	-	-	1	-	-	-	-	-	-	-	-	-	-	6	-	-	-	-	-	-	-	-	7
general anemone	-	-	-	-	-	1	2	-	2	3	2	1	2	-	7	1	3	-	1	-	-	-	25
Metridium senile	-	-	-	2	-	-	-	1	-	1	18	-	-	-	1	-	-	-	-	-	2721	313	3057
Urticina felina	-	1	1	2	2	1	-	1	-	1	-	-	3	3	1	1	2	-	-	-	2	-	21
Cerianthus borealis	-	-	-	-	-	-	-	-	-	2	-	3	-	-	-	-	-	-	-	-	-	-	5
Gersemia rubiformis	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	125	-	-	-	-	-	126
Tubularia sp.	-	1	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	14	4	20
Alcyonium digitatum	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	1
general gastropod	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1
Tonicella marmorea	-	-	-	-	-	-	-	-	1	-	-	-	-	1	-	1	-	-	1	1	-	-	5
Crepidula plana	5	-	12	41	-	120	-	75	-	20	241	-	-	90	59	28	40	8	-	-	-	-	739
Buccinum undatum	-	1	-	1	-	-	-	1	-	-	-	-	-	2	-	-	-	-	-	-	-	-	5
general nudibranch	-	-	-	-	-	1	-	-	-	-	-	-	1	-	1	-	-	1	-	-	-	-	4
general bivalve	-	-	-	-	-	-	1	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	3
Modiolus modiolus	181	290	111	127	43	175	81	167	181	74	449	4	31	171	416	308	178	40	56	22	7	-	3112
Placopecten magellanicus	1	-	-	-	-	-	1	-	1	4	-	2	-	-	-	-	-	2	-	-	-	-	11
Arctica islandica	1	-	-	-	-	1	22	-	4	18	-	13	9	-	-	1	-	1	2	1	-	-	73
Balanus spp.	11	9	88	75	-	150	-	171	-	-	58	-	24	642	226	-	310	-	-	20	-	-	1784
Lepas spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	1
Homarus americanus	-	2	1	2	-	1	-	-	-	-	1	-	-	1	-	1	1	1	1	-	-	-	12
Cancer spp.	-	1	1	1	-	3	1	2	-	-	-	1	-	1	-	1	2	-	-	-	2	-	16
hermit crab	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1
general crab	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1
Strongylocentrotus droebachiensis	1	5	1	3	-	7	-	4	-	1	12	-	-	-	3	4	-	-	5	-	3	6	55
general starfish	-	-	-	-	-	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	2
small white starfish	94	139	124	74	67	79	72	42	34	84	116	57	40	111	136	139	31	55	74	44	18	21	1651
Asterias vulgaris	9	8	14	2	13	11	3	7	2	11	4	18	4	31	7	1	8	10	10	-	-	12	185
Henricia sanguinolenta	25	48	40	19	18	32	11	46	20	22	49	7	14	52	51	37	53	23	20	23	16	32	658
Crossaster papposus	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	1	-	-	-	-	-	-	3
Pteraster militaria	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	2
Solaster endeca	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1

Station	T1-1	T1-2	T1-3	T1-4	T1-5	T2-1	T2-2	T2-3	T2-4	T4-2	T4/6-1	T6-1	T6-2	T7-1	T7-2	T9-1	T10-1	T8-1	T8-2	T12-1	T2-5	D#44	Total
Ophiopholis aculeata	-	1	-	-	3	-	1	-	-	-	-	-	-	-	1	-	-	18	10	1	1	-	36
Psolus fabricii	5	38	12	23	2	3	-	5	4	9	26	-	1	4	8	7	4	3	26	14	1	2	197
burrowing holothurian	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	1
Botrylloides violaceus	-	4	2	3	-	1	-	-	4	-	4	-	-	-	1	-	19	2	-	1	-	-	41
Boltenia echinata	32	10	1	-	3	7	2	53	7	10	9	-	8	9	16	15	53	2	4	10	-	-	251
Aplidium spp.	11	10	4	11	12	14	4	1	3	2	7	4	5	-	1	31	1	64	66	7	1	-	259
Dendrodoa carnea	89	116	47	55	71	123	105	57	32	139	144	14	99	110	120	111	40	67	122	23	5	1	1690
Didemnum albidum	183	248	193	101	147	147	139	109	106	195	74	37	114	62	151	165	99	187	42	85	34	57	2675
Halocynthia pyriformis	7	33	13	-	1	-	1	2	2	37	25	-	-	-	14	13	27	1	-	74	1	227	478
general bryozoan	51	44	12	12	29	61	45	46	35	42	30	2	36	58	47	45	33	8	7	77	33	74	827
?*Crisia* spp.	7	-	-	-	1	13	1	-	-	26	8	1	1	45	11	13	2	1	-	-	-	-	130
red crust bryozoan	2	-	-	5	-	2	-	4	-	1	-	-	-	1	4	2	3	-	-	-	-	1	25
Myxicola infundibulum	12	26	3	6	2	14	3	25	41	7	10	-	1	4	5	5	8	-	-	3	5	2	182
Terebratulina septentrionalis	8	164	1	1	1	3	9	90	63	63	1	-	3	1	14	56	272	-	-	20	3	2	775
general fish	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Tautogolabrus adspersus	23	25	41	9	-	6	1	5	24	8	68	-	1	46	21	23	45	6	13	11	35	7	418
Myoxocephalus spp.	-	-	-	1	-	-	-	-	-	1	-	3	1	2	1	-	-	-	-	-	-	-	9
Macrozoarces americanus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	-	2
Hemitripterus americanus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1
Pseudopleuronectes americanus	-	-	-	-	1	-	-	-	-	-	-	2	-	-	-	1	-	3	2	-	-	2	11
Sebastes fasciatus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1
Pholis gunnellus	-	1	-	-	1	1	-	-	-	-	-	1	-	1	-	-	-	-	-	1	1	1	8
Gadus morhua	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	2

[1] b=boulder, c=cobble, cp=cobble pavement, mx=mix, g=gravel, d=diffuser head, rr=riprap
[2] a=abundant, c=common, f= few, r = rare.

APPENDIX C

2008 Hard-Bottom Video Analysis

Table 2. Summary of data recorded from video footage taken on the 2008 hard-bottom survey.

Station	T1-1	T1-2	T1-3	T1-4	T1-5	T2-1	T2-2	T2-3	T2-4	T4-2	T4/6-1	T6-1	T6-2	T7-1	T7-2	T9-1	T10-1	T8-1	T8-2	T12-1	T2-5	D#44	Total
Minutes used	20	20	22	20	20	21	20	20	21	22	20	25	21	22	22	22	20	24	22	23	20	19	466
Depth (m) beginning	25	24.7	20.7	24.4	29	26.5	29.9	24.4	28.7	28.7	22.6	31.1	28	24.4	24.4	24.7	25	22.3	23.2	26.2	32.1	32.6	
Depth (m) end	26.2	24.7	23.8	24.7	29	26.2	29	24.7	30.5	29.9	25	31.7	29.6	25	25.9	25	27.4	24.1	24.4	25.3	30.8	33	
Substrate	cp+b	b+c	b+c	b+c	cp+b	cp+ob	cp+mx	b+c	b+c	cp+mx	b+c	cp	c+mx	b+c	b+c	b+c	b+c	c+b	c+b	b+c	d+rr	d+rr	
Drape	m-mh	lm-m	lm-m	l-lm	m	lm-m	m-mh	lm-mh	mh	m-mh	l-lm	m-mh	m-mh	lm-mh	lm-m	lm-m	h	m	lm	m	m-mh	mh-h	
Relief	lm	m	mh	m	lm	lm	lm	m	m	lm	m	l	lm	m	m	m	h	lm	lm	m	m	m	
Suspended material	h	h	h	h	h	h	h	h		h	h		h			h	h	h	h		h	h	
Coralline algae	f-c	c-a	c	c-a	r-f	f-c	f	f-c	r-f	f	c-a	-	f-c	f-a	c-a	c	-	f-c	c-a	c	-	-	
Ptilota serrata	-	-	c-a	f-c	-	-	-	-	-	-	r	-	-	c-a	f-c	-	-	-	-	f-a	-	-	
general hydroid	c	f-c	c	f-c	c	f-c	c	f-a	f-c	f-c	f-c	f	f	f-c	f-c	f-c	c	f-c	f-c	c	f-a	c-a	
barnacle/spirorbid complex	r	r-f	r	r-f	r	f	r	c	r	r	r-c	r	r	f-c	f-c	f-c	r	r	r	r	r-f	r-f	
Palmaria palmata	f-c	f-c	c-a	f-c	r	r-f	r	f	r	-	r	-	-	c-a	f	f	-	f-c	r	f-a	-	-	
Agarum cribosum	-	-	r	-	-	-	-	-	-	-	-	-	-	c	-	-	-	-	-	-	-	-	
general sponge	2	-	1	1	-	2	6	5	3	3	-	-	-	-	3	2	5	1	2	2	3	-	41
Polymastia sp. A	f-c	f	r	r	r	f-c	c	c	f	r	f	-	f-c	f	f	f	c	r	r	f-c	-	-	
Haliclona oculata	-	-	-	-	-	-	-	3	2	1	-	-	-	-	-	1	-	-	-	3	4	15	29
Suberites spp.	f-c	-	-	-	f-c	f-c	c	c	f	f	-	-	f-c	-	r	r-f	c	f	r	r	-	-	
white divided sponge	f	f-c	-	-	-	-	f	f	c	f-c	f	-	-	-	-	f-c	f-c	r	-	f-c	-	-	
Melonanchora elliptica	-	-	-	-	1	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
Haliclona spp. (encrusting)	2	-	-	-	1	2	2	1	1	-	-	-	1	-	-	-	-	1	-	-	-	-	11
Obelia geniculata	-	-	r	-	-	-	-	-	-	-	-	-	-	c	-	-	-	-	-	-	-	-	
general anemone	-	-	-	-	-	-	-	1	1	2	-	1	-	-	-	-	-	-	-	-	1	-	6
Metridium senile	r	-	-	r	-	-	-	r	-	-	f	-	r	-	r	-	-	-	r	f	f-a	r-c	
Urticina felina	2	2	2	2	4	1	1	2	1	-	1	-	1	3	1	4	4	-	-	-	3	-	34
Cerianthus borealis	-	-	-	-	-	-	-	-	-	1	-	10	-	-	-	-	-	-	-	-	-	-	11
Gersemia rubiformis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	c-a	-	-	-	-	-	
Tubularia sp.	-	-	-	-	-	-	-	-	-	-	-	r	-	-	-	-	-	-	-	-	-	f	
Buccinum undatum	-	-	1	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	2
Modiolus modiolus	f-c	c-a	c-a	c-a	f-c	c	f-c	c-a	c	f-c	c-a	f	f-c	c	a	c-a	c	c	c	c	f	-	
Placopecten magellanicus	1	-	-	-	-	-	-	-	1	7	1	1	-	-	-	-	-	7	-	1	-	-	19
Arctica islandica	-	-	-	-	-	-	-	-	-	-	-	f	-	-	-	-	-	-	-	-	-	-	

Station	T1-1	T1-2	T1-3	T1-4	T1-5	T2-1	T2-2	T2-3	T2-4	T4-2	T4/6-1	T6-1	T6-2	T7-1	T7-2	T9-1	T10-1	T8-1	T8-2	T12-1	T2-5	D#44	Total
Homarus americanus	-	1	1	2	-	-	-	-	-	1	1	-	-	1	-	-	1	2	2	1	-	-	13
Cancer spp.	1	2	1	3	-	3	3	1	1	-	4	-	-	4	-	2	1	1	-	-	-	1	28
hermit crab	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Strongylocentrotus droebachiensis	f	f	f	f-c	-	f-c	r	f	-	r	c	-	-	f	f-c	f-c	-	-	f-c	-	r	f	
small white starfish	c	c	c	c-a	f-c	c	c	f-c	f	c	c-a	f-c	c	c	c-a	c-a	c-a	c	c	c	f	f	
Asterias vulgaris	f	f	f	r	f-c	c	f	f	f	f-c	r	f-c	c	c	f-c	f	f-c	f-c	c	r	r	f-c	
Henricia sanguinolenta	f	c	c	f-c	f	f	f	f-c	f	f-c	f-c	f	f	f	f	c	c	f	f	c	f	f	
Crossaster papposus	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	2
Pteraster militaria	-	-	-	-	1	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	2
Solaster endeca	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	2
Psolus fabricii	f-c	c-a	c	c	-	f	f	f	f	f	f-c	-	-	r	f-c	c	f	r	c	c	-	r	
Botrylloides violaceus	-	1	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	2	-	-	-	-	4
Aplidium/*Didemnum* complex	c	c-a	f	f-c	f-c	f-c	c	f	c	f-c	r	f	c	f	f	f	r	c-a	f	f-c	f	f	
Halocynthia pyriformis	r	f	r	r	-	r	-	r	f	f	f	-	f	-	f	f	f	-	-	f	-	r-c	
Boltenia ovifera	-	-	1	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	3	1	-	6
Myxicola infundibulum	f	f-c	-	-	r	f-c	f	c	c	f	f	r	r	f	c	f	f	f	f	f	-	-	
Terebratulina septentrionalis	f	f-c	-	-	-	-	f	f	c	f-c	f	-	f	-	f	f-c	f-c	r	-	f-c	-	-	
general fish	-	-	-	-	1	3	-	-	-	3	2	-	-	2	3	5	1	-	1	12	-	-	33
Tautogolabrus adspersus	f-c	c	c-a	c	r	f	f	f-c	c	f	c-a	-	r	a	f	c	a	f	f	c	f-a	r-f	
Myoxocephalus spp.	-	1	1	1	2	-	-	1	-	3	-	10	1	2	1	-	1	1	-	-	1	-	26
Macrozoarces americanus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	-	2
Hemitripterus americanus	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1
Pseudopleuronectes americanus	-	1	-	-	5	-	-	1	-	4	-	11	-	-	-	1	1	9	8	-	1	5	47
Pholis gunnellus	-	-	-	-	1	-	-	-	-	1	-	-	1	-	-	-	-	-	-	1	-	-	4
Gadus morhua	-	5	2	8	-	3	2	12	5	4	5	-	-	2	2	5	6	-	1	1	2	-	65

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

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