Outfall Benthic Monitoring Report: 2009 Results

Massachusetts Water Resources Authority

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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, 2004) have collected extensive information over a nine-year baseline period (1992–2000) and a nine-year post-diversion period (2001–2009). 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 2009 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. (2008) for previous monitoring years. Sediment Profile Images (SPI) were collected in triplicate at 23 nearfield stations. For sampling of the soft-bottom sediments, 2009 represented an "odd" 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).

Sixteen soft-bottom stations were sampled in August 2009:

- Transition area station FF12, located between Boston Harbor and the offshore outfall
- Nearfield stations NF13, NF14, NF15, NF17, and NF24, located in close proximity (<2 km) to the offshore outfall
- Nearfield stations NF02, NF04, NF10, NF12, NF20 and NF21, located in Massachusetts Bay but greater than 2 km from the offshore outfall
- Farfield reference stations FF01A, FF06, FF11, and FF14 in Massachusetts and Cape Cod Bays

Camera transects (Figure 3) were performed as in previous years. All 23 hard-bottom waypoints were surveyed successfully during 2009, including an actively discharging diffuser head at the eastern end of the outfall. At least 19 minutes of analog video footage was obtained at all of the waypoints, and at least 19 minutes of high definition video (HDV) was obtained at 20 of the waypoints. The analog video was analyzed and the HDV was archived for potential future analysis.

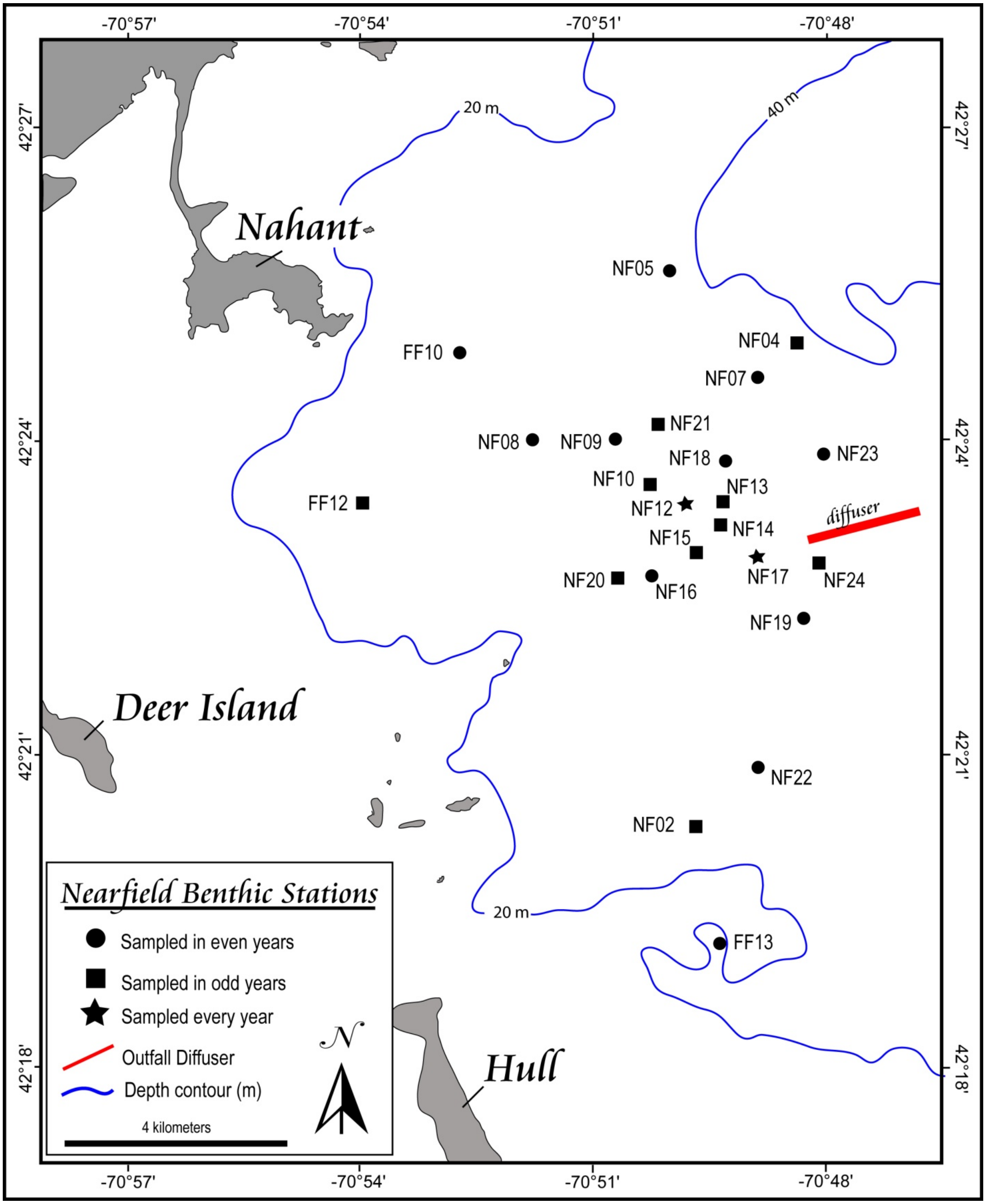

Figure 1. Locations of nearfield benthic stations sampled in August 2009. All stations were sampled by SPI and those denoted by square and star symbols were sampled by grab.

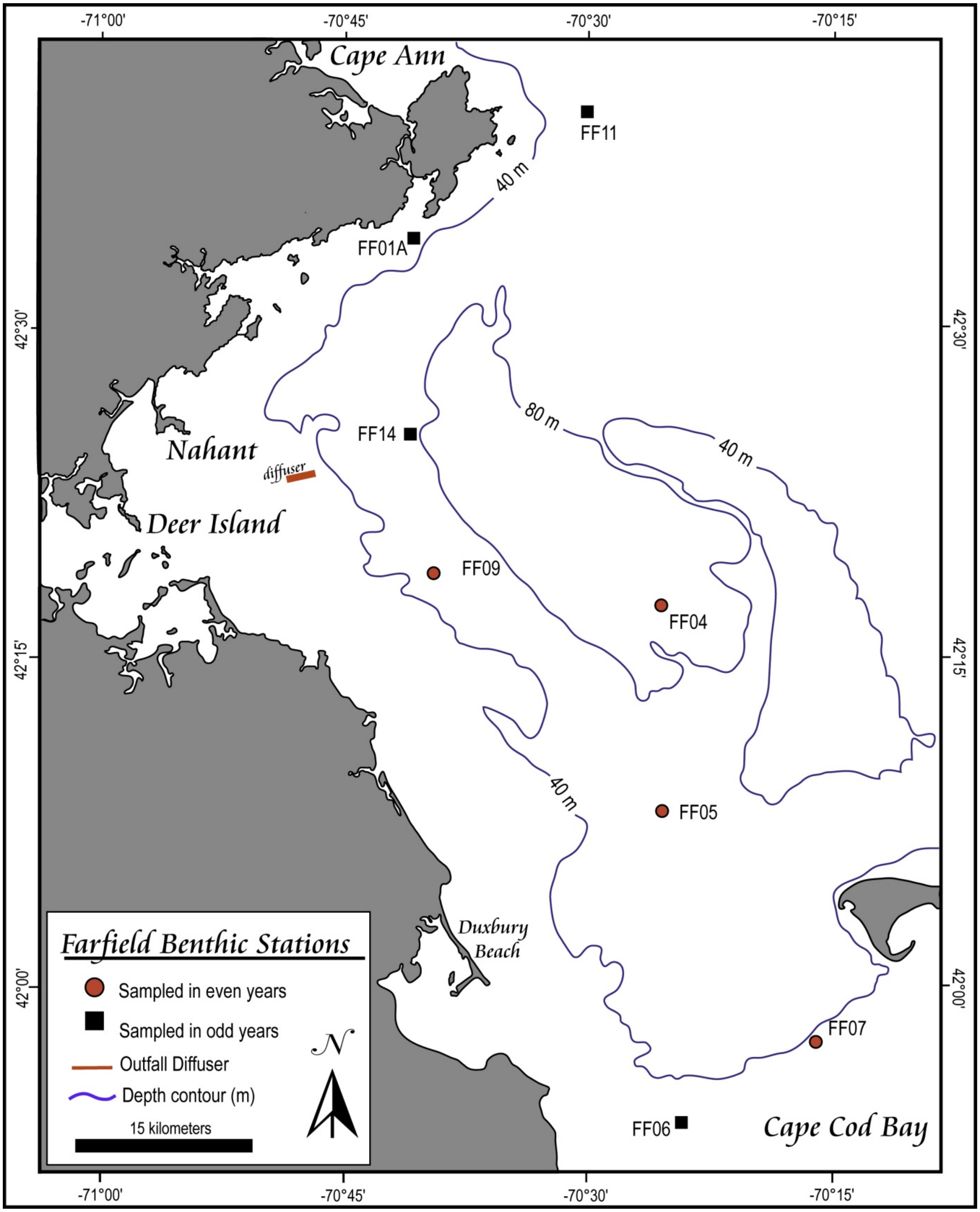

Figure 2. Locations of farfield grab stations sampled in August 2009 (indicated by black squares).

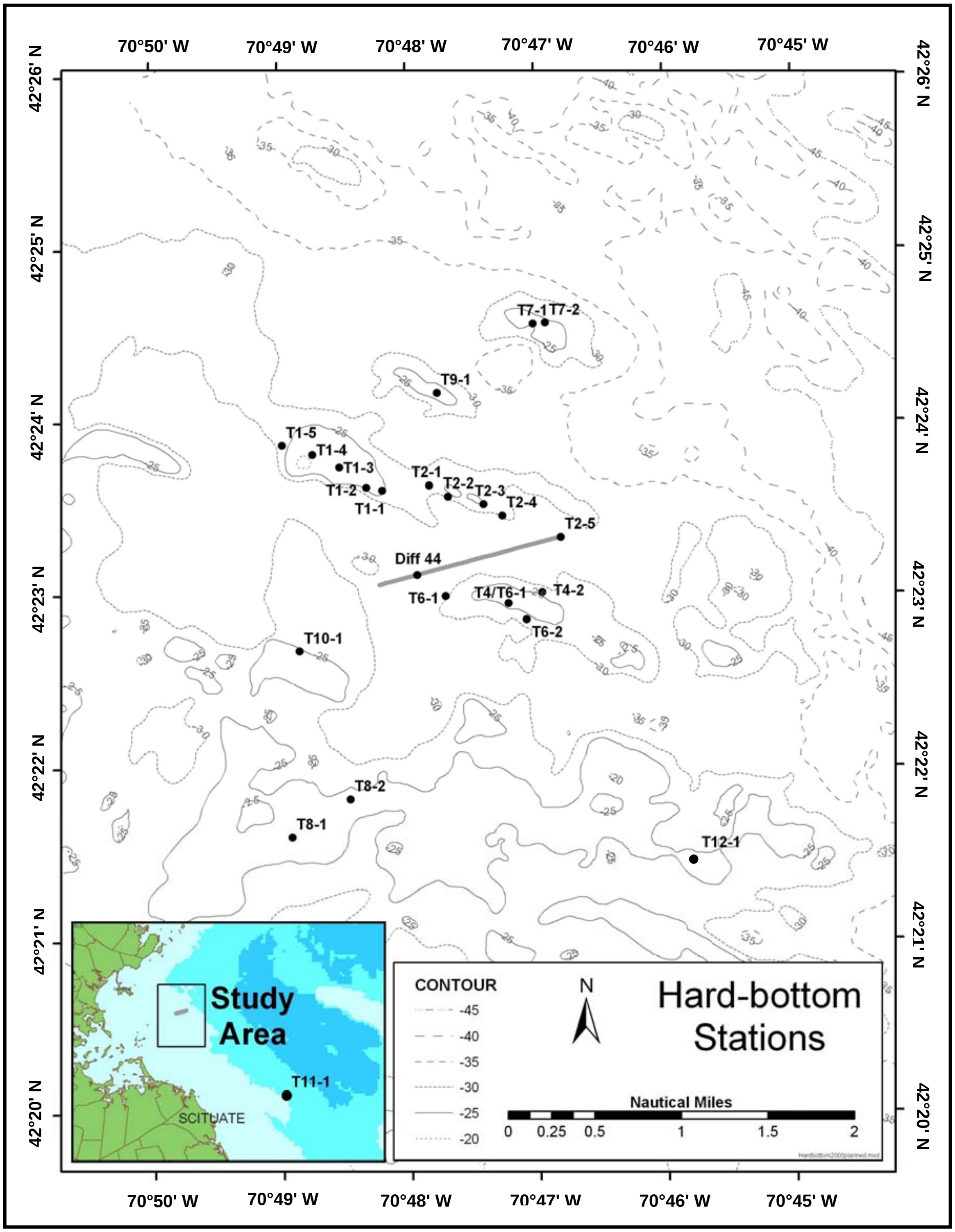

Figure 3. Locations of hard-bottom transects sampled in August 2009.

3. RESULTS

3.1 Sediment Chemistry

3.1.1 2009 Results

Grain Size and Total Organic Carbon. The grain size distributions for the 16 stations sampled in 2009 were within the range of values measured over the larger monitoring period (1992-2008), 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 (see how data typically cluster near the gravel+sand axis of the ternary plot in Figure 4). Sediments sampled further away from the offshore outfall were heterogeneous, and encompassed coarse- to fine-grained sediment (see how data are distributed from the gravel+sand to silt axes in Figure 4).

The 2009 TOC data were within or at the low end of the range of values measured over the larger monitoring period at most stations (Figure 5A). While not significant, mean concentrations of TOC decreased slightly between the baseline and post-diversion periods at the transition and nearfield regions of Massachusetts Bay, and remained relatively flat at the farfield (Figure 5B).[1]

Clostridium perfringens. The 2009 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 decrease ($p<0.001$) between the baseline and post-diversion mean values at the transition area and (2) an increase ($p<0.001$) between the baseline and post-diversion mean values in sediments located near 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 nearfield sediments located further away from the outfall.

Anthropogenic Contaminants. The 2009 data for stations NF12 and NF17 were within the range of values measured over the larger monitoring period for most chemicals. Total pesticide, total PCB, and silver concentrations were at the low end of the baseline range in 2009, while aluminum concentrations were at the high end or above the baseline range in 2009. 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. Mean pesticide and PCB concentrations decreased significantly (at the 95% level of confidence) between the baseline and post-diversion periods in the nearfield and farfield regions of Massachusetts and Cape Cod Bays (total PCB shown in Figure 7).[2] 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 significantly ($p<0.05$) at the nearfield region of Massachusetts Bay. The post-diversion increase in aluminum could be associated with small changes in grain-size distributions rather than due to a chemical factor, given that aluminum is primarily an indicator of aluminosilicate mineral content in sediments and is usually not associated with anthropogenic contamination.

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[1] Transition area: baseline mean 0.75% vs. post-diversion mean 0.61%; Nearfield >2 km from outfall: baseline mean 0.97% vs. post-diversion mean 0.85%; Nearfield <2 km from outfall: baseline mean 0.55% vs. post-diversion mean 0.44%; and Farfield: baseline and post-diversion means of 1.4%.
[2] Post-diversion decrease significant for total_CHLOR (all regions except transition area), total_DDT (farfield and nearfield <2 km from outfall), total_PEST (all regions), and total_PCB (farfield and nearfield <2 km from outfall).

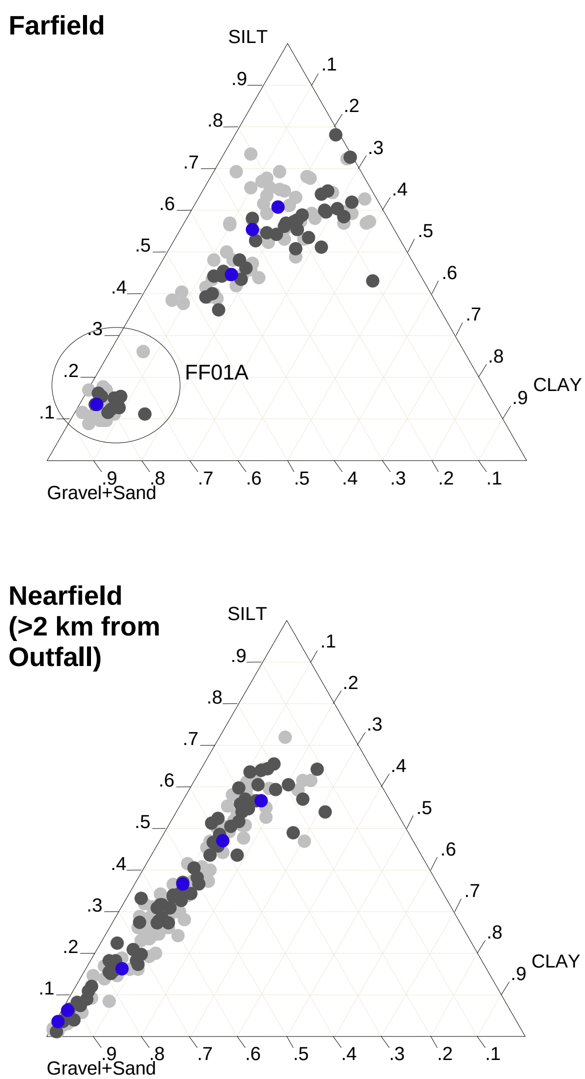


Figure 4. Distribution of percentages of gravel+sand, silt, and clay in surface sediment in Massachusetts and Cape Cod Bays, 1992–2009. (Grey symbols represent baseline, black symbols represent post-diversion 2001–2008 data, and blue symbols represent the post-diversion 2009 data).

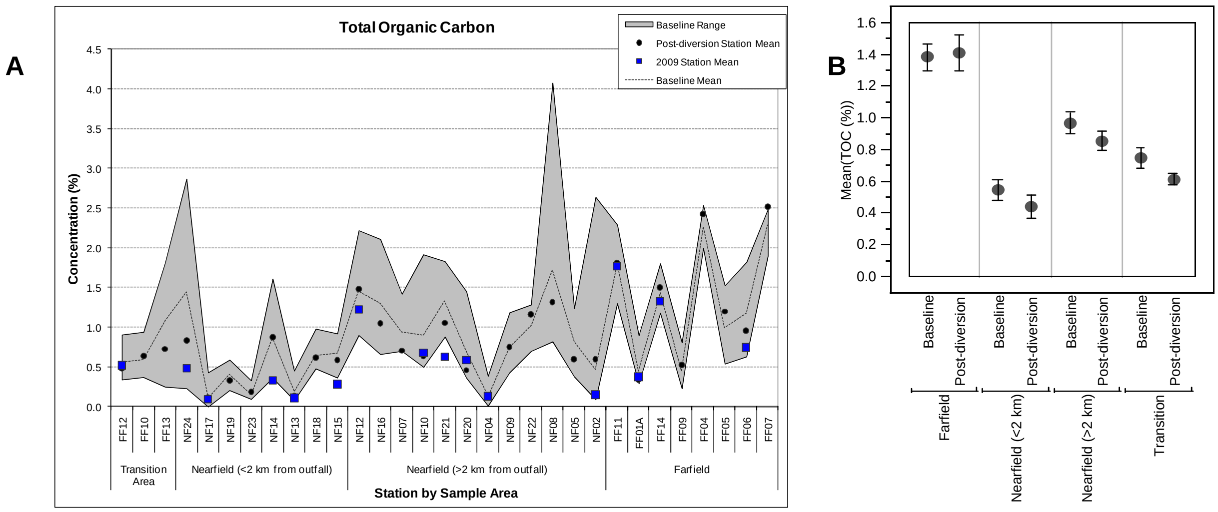


Figure 5. Distribution of TOC, by station (A) and region (B), in surface sediment in Massachusetts and Cape Cod Bays, 1992–2009. A: station-specific trends where the gray band represents the range of values during baseline (1992–2000), the dashed line represents the baseline mean, and symbols represent 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.

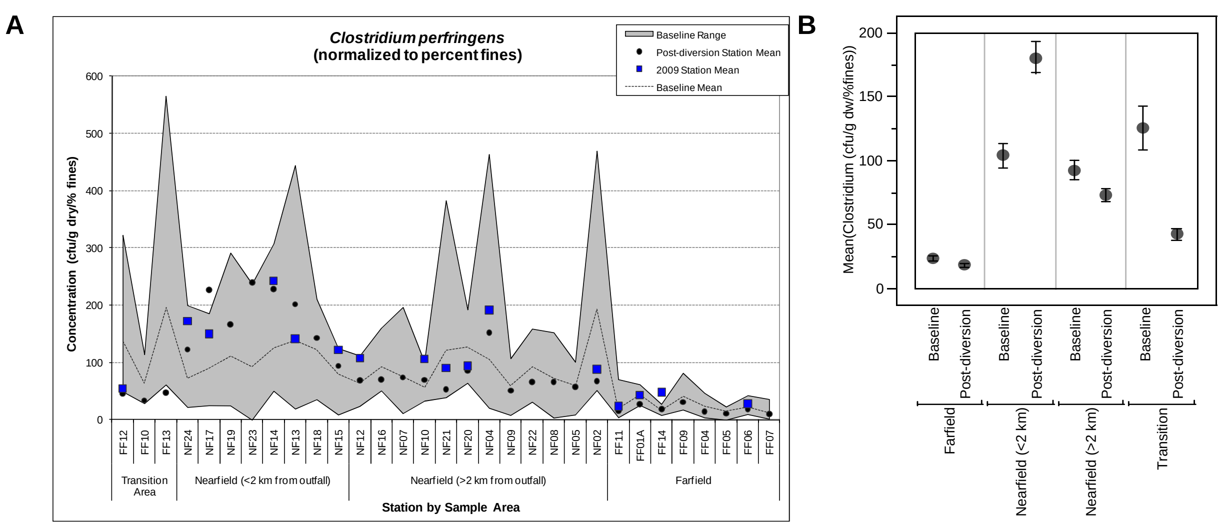


Figure 6. Distribution of *C. perfringens* abundances (normalized to percent fines), by station (A) and region (B), in surface sediment in Massachusetts and Cape Cod Bays, 1992–2009. A: station-specific trends where the gray band represents the range of values during baseline (1992–2000), the dashed 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.

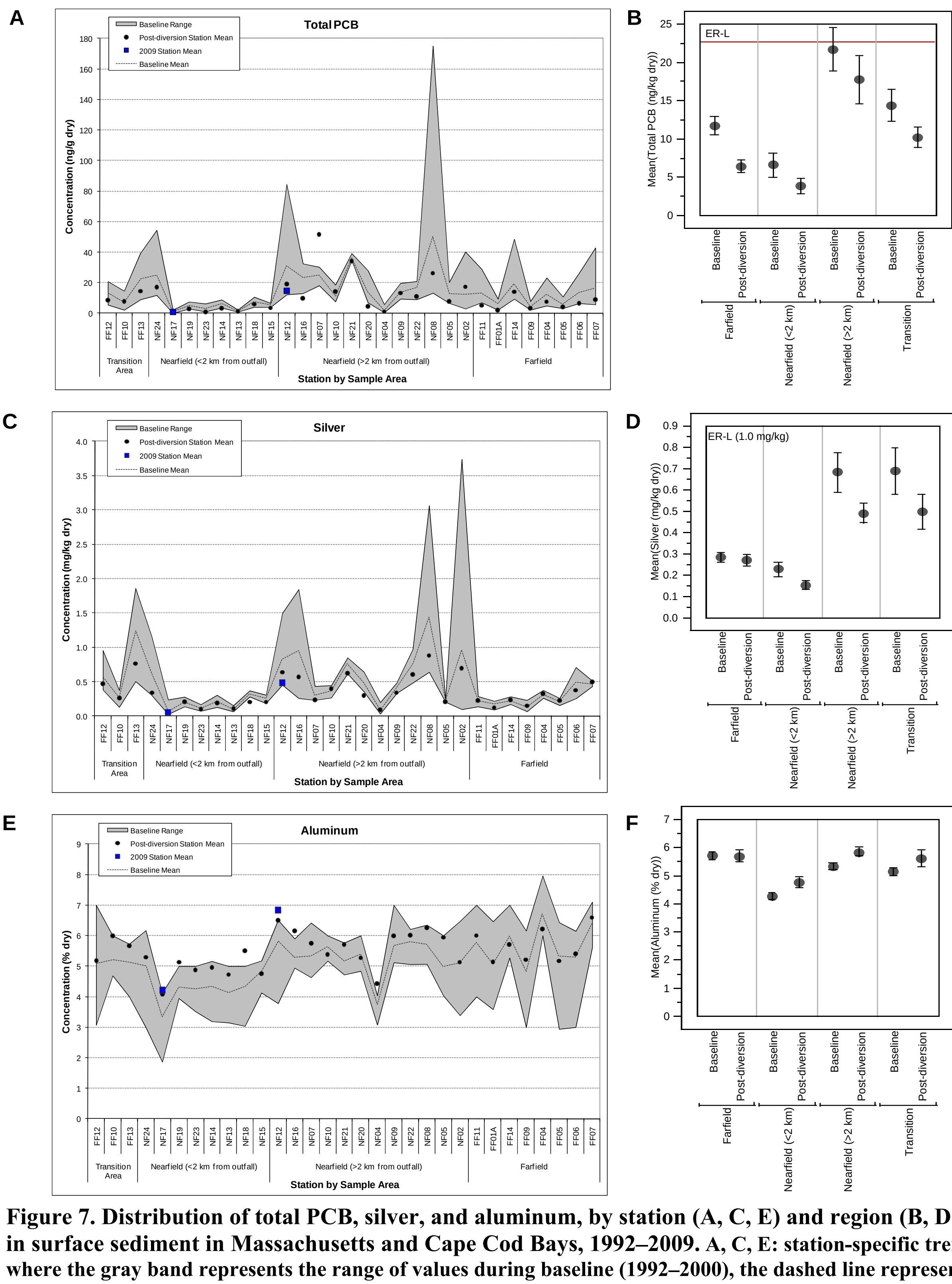


Figure 7. Distribution of total PCB, silver, and aluminum, by station (A, C, E) and region (B, D, F), in surface sediment in Massachusetts and Cape Cod Bays, 1992–2009. **A, C, E: station-specific trends where the gray band represents the range of values during baseline (1992–2000), the dashed line represents 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 1999–2009 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, 1999–2009.

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]	0.77	1.0	<0.01	188	0.93	1.0	<0.01	64
C. perfringens[1]	0.70	0.69	<0.01	189	0.59	0.47	<0.01	64
Aluminum	0.61	0.70	<0.01	112	0.53	0.62	<0.01	32
Cadmium[1]	0.74	0.46	<0.01	109	0.61	0.57	<0.01	32
Chromium[1]	0.89	0.83	<0.01	112	0.89	0.90	<0.01	32
Copper[1]	0.71	0.85	<0.01	110	0.93	0.90	<0.01	32
Iron[1]	0.75	0.72	<0.01	112	0.92	0.94	<0.01	32
Lead[1]	0.51	0.62	<0.01	110	0.91	0.88	<0.01	32
Mercury[1]	0.77	0.85	<0.01	112	0.64	0.66	<0.01	32
Nickel	0.72	0.75	<0.01	112	0.74	0.83	<0.01	32
Silver[1]	0.77	0.84	<0.01	112	0.61	0.71	<0.01	32
Zinc	0.91	0.76	<0.01	112	0.95	0.89	<0.01	32
Total DDT[2]	0.81	0.73	<0.01	112	0.76	0.75	<0.01	32
Total PAH[1,2]	0.78	0.85	<0.01	112	0.65	0.56	<0.01	32
Total PCB[1,2]	0.82	0.87	<0.01	112	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.

3.1.3 Sediment Quality

Results from the comparison of the 2009 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 the two stations sampled in 2009 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 2009, concentrations of 11 individual PAHs, total PAH, total DDD, and 4 metals were above the ER-L SQG at station NF12 (Table 2). Post-diversion contaminant concentrations at NF12 tend to be lower than baseline in general and lower in 2009 in particular (representative contaminants shown in Figure 8). This station is comprised of fine-grained sediment (72.5% fines), and is 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 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 2009.

Table 2. 2009 station mean values compared to ER-L and ER-M sediment quality guidelines.[1]

Contaminant	Units	2009 Station Mean		Sediment Quality Guideline	
		NF12	NF17	ER-L	ER-M
PAHs					
Acenaphthene	ng/kg dry	**78**	0.45	16	500
Acenaphthylene		**71**	1.47	44	640
Anthracene		**285**	2.37	85.3	1100
Benz(a)anthracene		**523**	6.99	261	1600
Benzo(a)pyrene		**548**	6.79	430	1600
Chrysene		**444**	6.85	384	2800
Dibenzo(a,h)anthracene		**78**	1.60	63.4	260
Fluoranthene		**1,114**	13	600	5100
Fluorene		**91**	0.67	19	540
Naphthalene		102	2.38	160	2100
Phenanthrene		**721**	5.75	240	1500
Pyrene		**1,009**	11	665	2600
Total_PAH[2]		**10,142**	131	4,022	44,792
Pesticides/PCBs					
cis-Chlordane	ng/kg dry	0.19	non detect	0.50	6.0
Dieldrin		non-detect	non-detect	0.02	8.0
Total_DDD[2]		**2.96**	0.048	2.0	20
Total_DDE[2]		1.80	0.029	2.2	27
Total_PCB[2]		14.7	0.89	22.7	180
Metals					
Cadmium	mg/kg dry	0.154	0.0584	1.2	9.6
Chromium		**107**	33.2	81	370
Copper		28.7	3.24	34	270
Lead		**53.6**	29.7	46.7	218
Mercury		**0.275**	0.0359	0.15	0.71
Nickel		**21.7**	8.06	20.9	51.6
Silver		0.483	0.0556	1.0	3.7
Zinc		81.3	28.6	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.

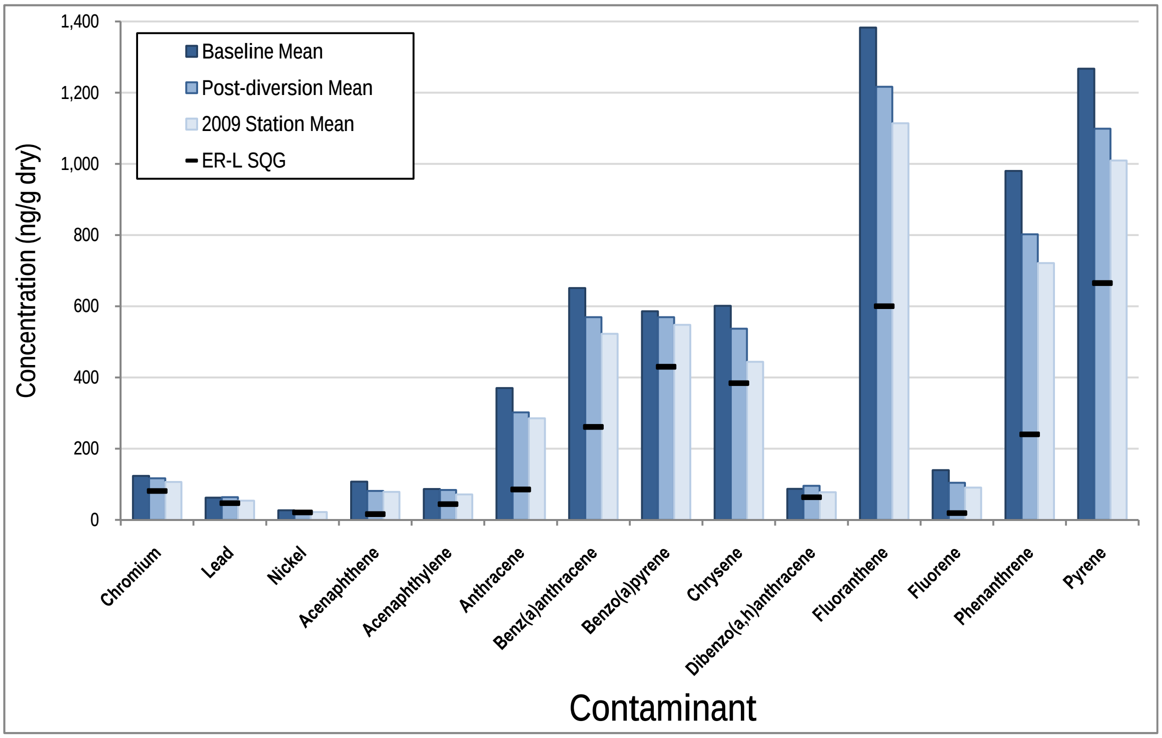


Figure 8. Comparison of baseline, post-diversion, and 2009 station mean concentrations at Station NF12 for representative contaminants with concentrations above the effects range-low (ER-L) sediment quality guidelines (SQGs).

In conclusion, sediment data from the 2009 monitoring year were generally consistent with trends observed in the long-term monitoring data. The *C. perfringens* data continued to show a clear signature of effluent discharge on nearby sediments following the effluent diversion. However, the chemical data at stations NF12 and NF17 continued to indicate that the transfer of the MWRA effluent discharge into Massachusetts Bay has not resulted in a general widespread increased of anthropogenic contaminations in the surficial sediment.

3.2 Sediment Profile Imaging

3.2.1 2009 Results

Biogenic structures at the sediment surface in 2009 appeared to be similar to those seen in previous years but not as abundant relative to 2008 SPI. Hurricane Bill, which passed offshore of the region two days prior to sampling, may have generated waves and bottom currents in the nearfield that destroyed unconsolidated biogenic structures, such as feeding mounds and pits. At several stations, e.g., FF12, what appeared to be linear bed forms were present. Tubes were still the most common biogenic structure seen in the SPI. Most stations had moderate densities (about 24 tubes per image) of small (<1 mm diameter) polychaete tubes.

Most of the pebble and cobble size sediments were covered with tubes in 2009, which was also the case in 2008. Mobile megafauna were observed at several stations and included hermit crabs, cancer crabs, and a cunner (Figure 9). No lumbrinerid polychaetes egg capsules were seen in 2009. These egg capsules were common in four of the last five years. Subsurface biogenic structures appeared to be the same types and as common in 2009 as they were in images taken in 2008.

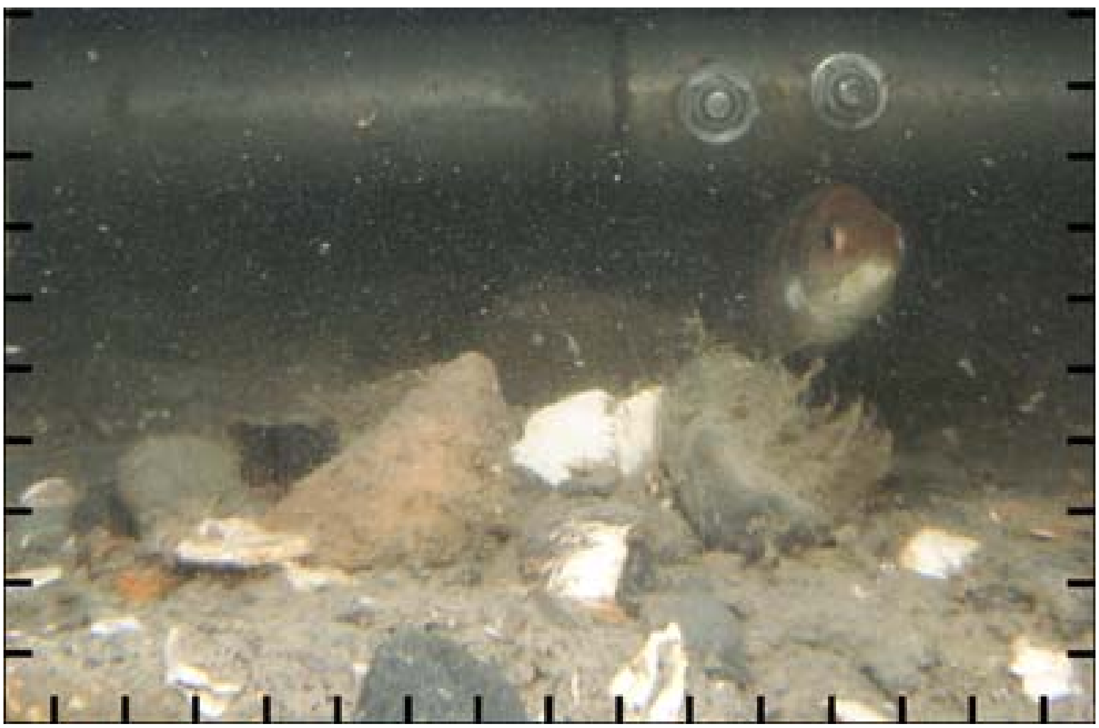


Figure 9. Cunner hovering over the bottom at station NF02.

Overall, the sediment surface appeared to be structured by a combination of physical and biological processes, but there were more stations in 2009, relative to 2008, that appeared predominantly physically dominated (17 of 23 stations). Sediments at many stations continued to be heterogeneous, ranging from sand-silt-clays to cobble. The general appearance of the sediments in 2009 was similar to that in 2008.

3.2.2 Nearfield Baseline and Post-Baseline Years

Sediment profile images (SPI) were first collected at nearfield stations in 1992 (Figure 10). There are now nine baseline years and nine post-baseline years.

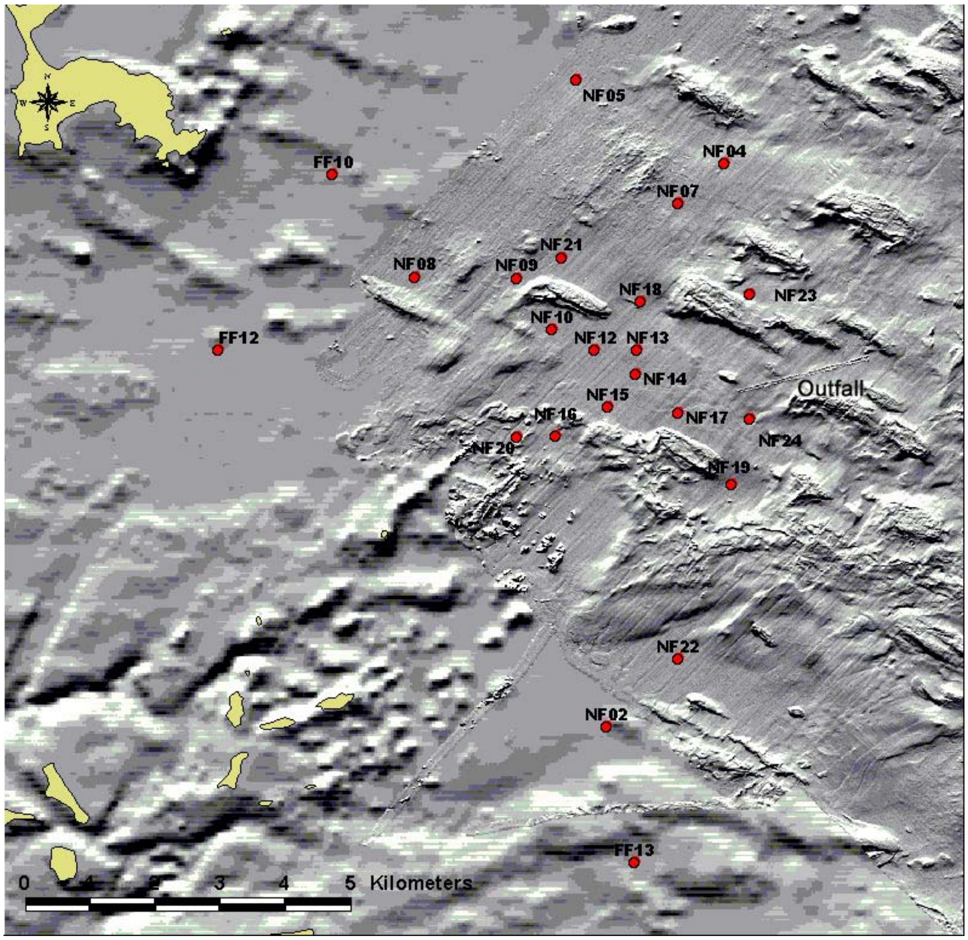


Figure 10. Location of nearfield SPI stations overlain on multibeam bathymetry of the area.

Much of the change in the nearfield SPI occurred during the baseline years (1992–2000). There appeared to be less change in the post-baseline period (2001–2009). Estimated modal successional stage advanced from pioneering to intermediate and equilibrium stages during the baseline period (Table 3). Post-baseline, successional stage was bimodal and dominated by pioneering and equilibrium stages. There was less evidence of pioneering stage fauna post-baseline.

Table 3. Summary of nearfield SPI variables for baseline and post-baseline years.

	Baseline Years 1992–2000 9-Year Interval	Post-Baseline Years 2001–2009 9-Year Interval
Successional Stage	Advanced from I to II – III	Bimodal: I-II and II-III
OSI - Low	4.8 (1997)	5.8 (2003)
OSI - High	7.2 (2000)	7.9 (2008)
RPD - Low	1.8 cm (1997 and 1998)	2.1 cm (2003)
RPD – High	3.0 cm (1995)	3.4 cm (2007)
Annual Mean RPD Measured	2.2 (0.49 SD) cm	2.9 (0.64 SD) cm
Annual Mean RPD All Values	2.3 (0.47 SD) cm	2.7 (0.41 SD) cm

The depth of the apparent color redox potential discontinuity layer (aRPD) varied from year to year with an annual low of 1.8 cm in 1997 and 1998 to 3.4 cm in 2007 (Figure 11).

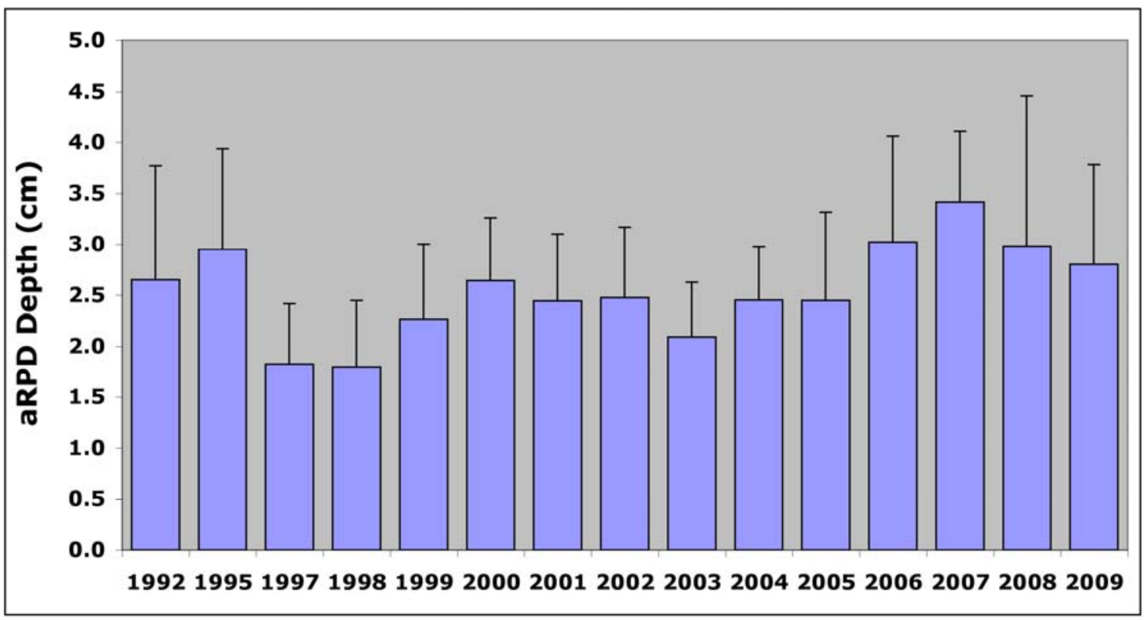


Figure 11. Mean (+1 SE) annual aRPD layer depth for all nearfield stations.

Of the 23 stations sampled, nine had a measured aRPD values for all years in which they were imaged. At these stations, the aRPD measurements tended to track together, indicating that broader regional forces were controlling the depth of the aRPD layer (Figure 12). There were no patterns between aRPD and the outfall.

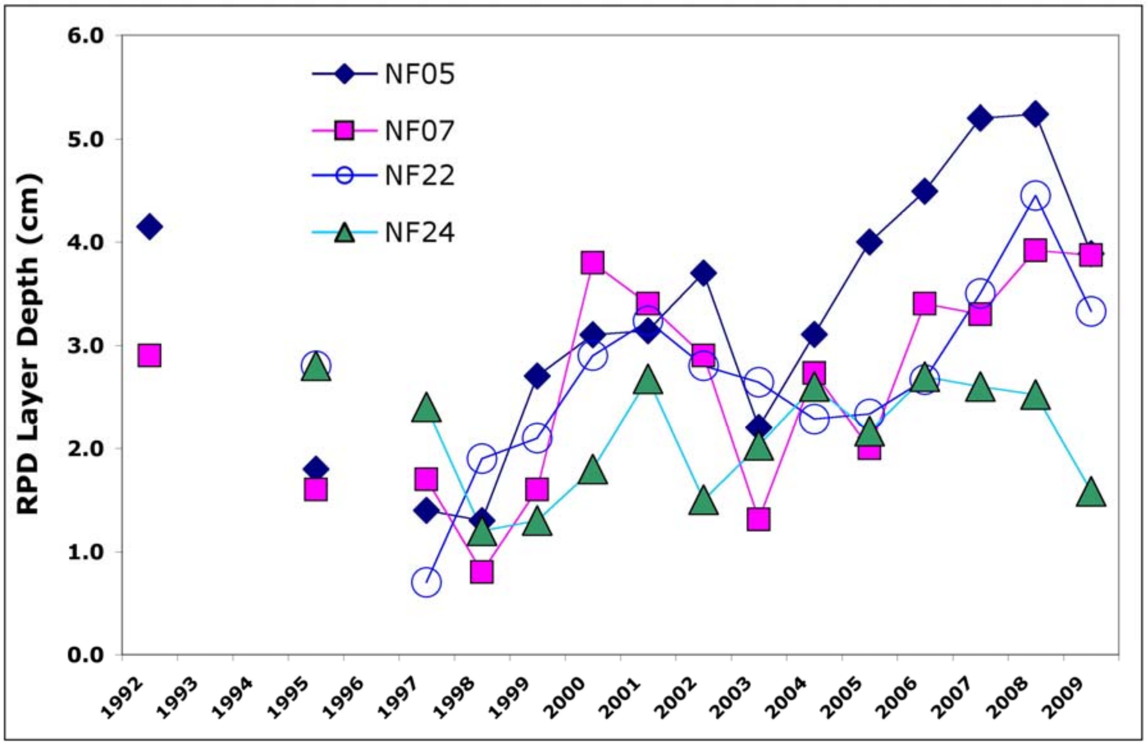


Figure 12. aRPD layer depth for four of the nine stations with measured values in all sampled years.

Four stations with similar sediment grain size (mixed fine-sand-silt-clay) were selected as representative of conditions in the nearfield (Figures 13–16). Station NF24 was south of the outfall and 0.4 km away. Station NF22 was south of the outfall and 4.2 km away. Stations NF07 and NF05 were north of the outfall and 3.0 and 5.4 km away, respectively. Given the proximity of NF24 to the outfall, it was expected that this station would have the greatest probability of being affected by outfall operation; however, there was no indication that NF24 had changed pre- and post-baseline. Changes at NF24 over the 18-year period tracked the other nearfield stations.

The operation of the outfall, which started in late 2000, does not appear to have affected benthic habitat quality. Annual post-baseline aRPD was always deeper than the baseline period. The lowest annual average Organism Sediment Index (OSI) occurred in 1997 during the baseline years. Highest annual average OSI occurred in 2008. There also did not appear to be any accumulation of fine sediments or organic matter at stations near the outfall, or at any of the other nearfield stations. From 2005 to 2009, there was a decline in the level of biogenic activity. The number of burrows and infauna per image declined from long-term averages (Figure 17).

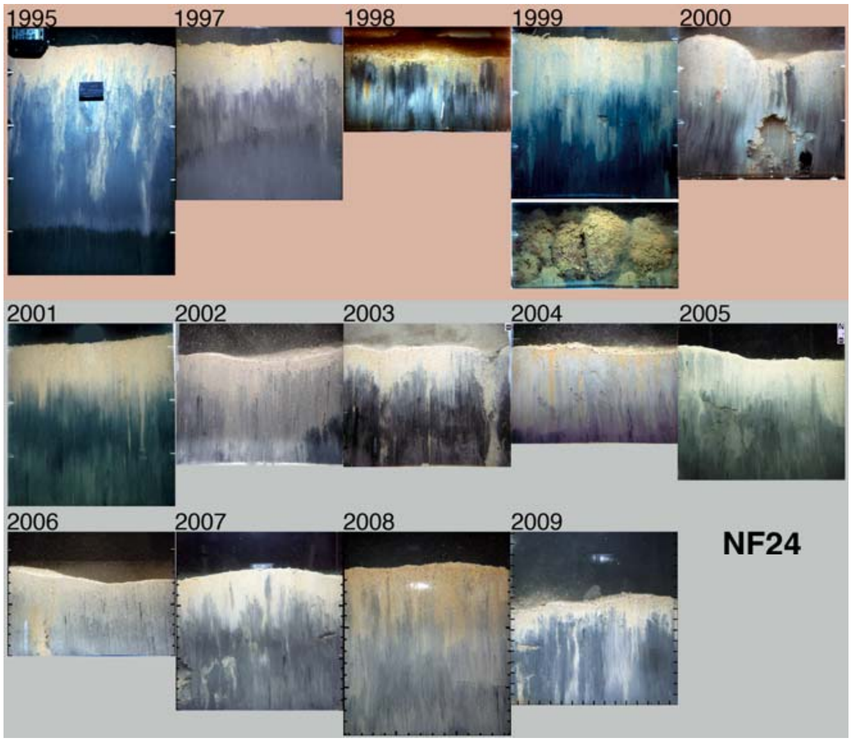


Figure 13. Thumbnail SPI images from NF24. Baseline was 1992–2000; images from 1992 were not available. Scale along the side of each image is in cm.

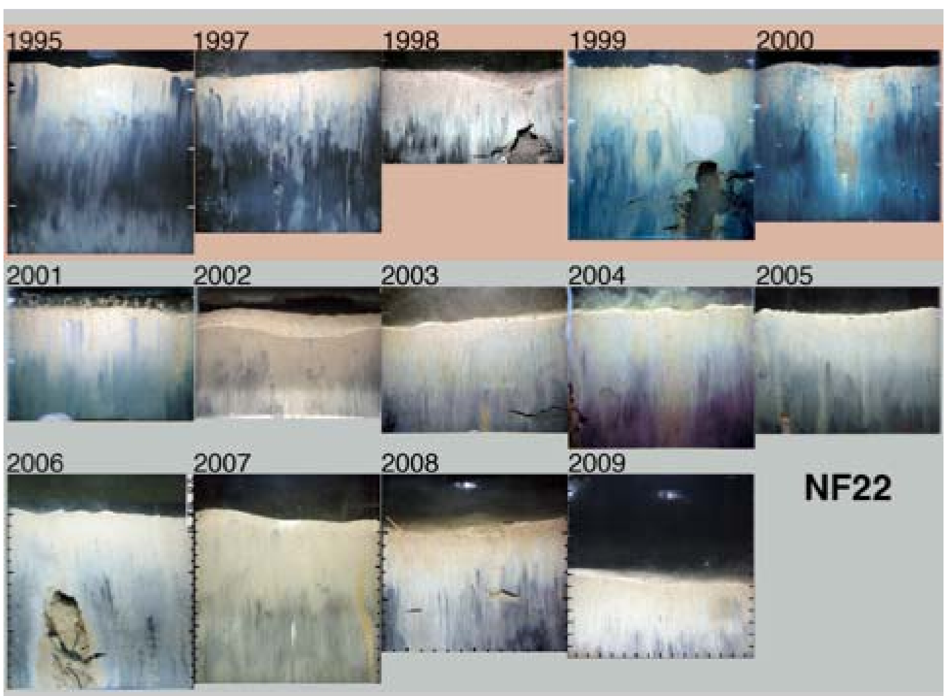


Figure 14. Thumbnail SPI images from NF22. Baseline was 1992–2000; images from 1992 were not available. Scale along the side of each image is in cm.

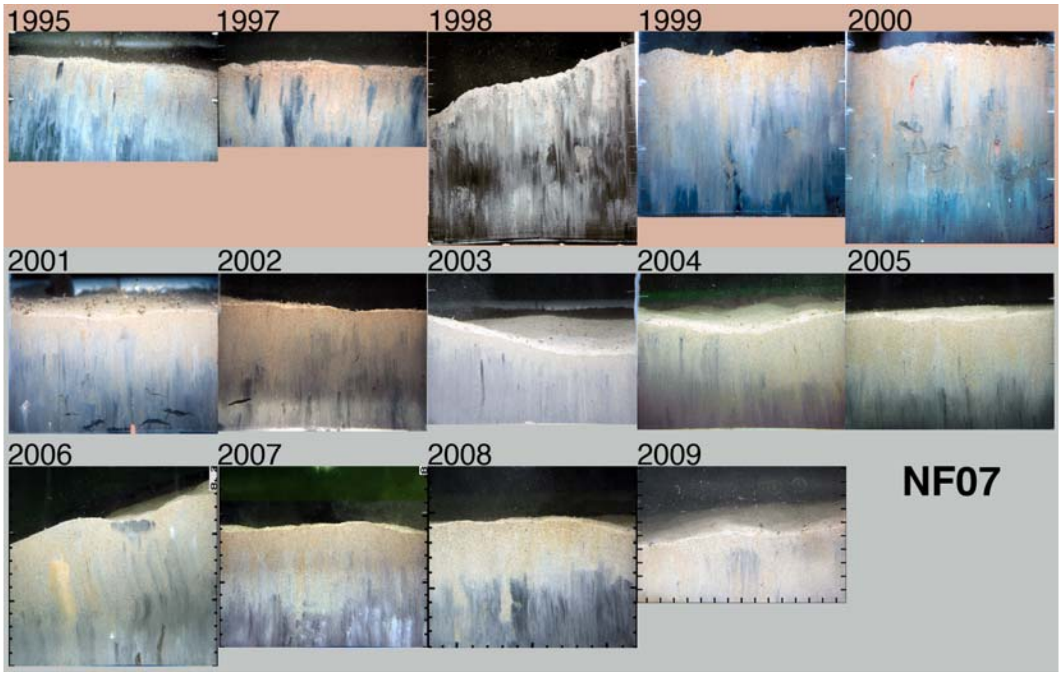


Figure 15. Thumbnail SPI images from NF07. Baseline was 1992–2000; images from 1992 were not available. Scale along the side of each image is in cm.

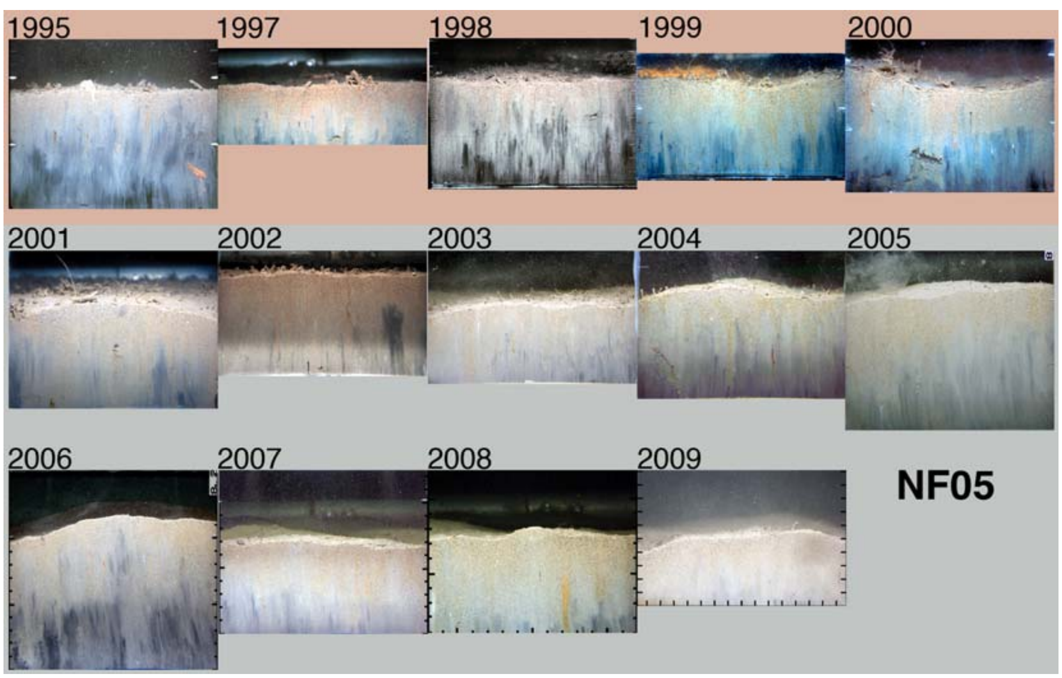
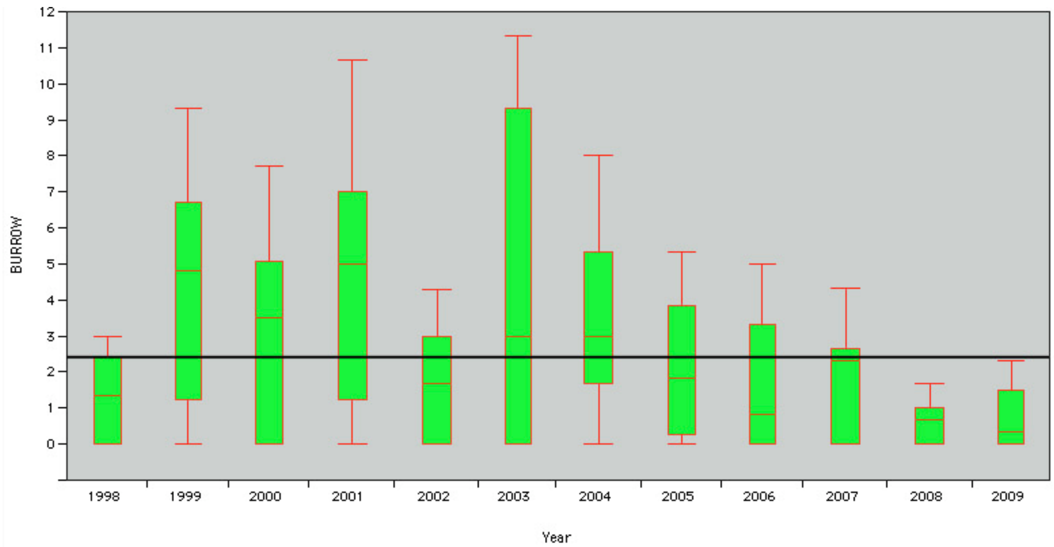


Figure 16. Thumbnail SPI images from NF05. Baseline was 1992–2000; images from 1992 were not available. Scale along the side of each image is in cm.



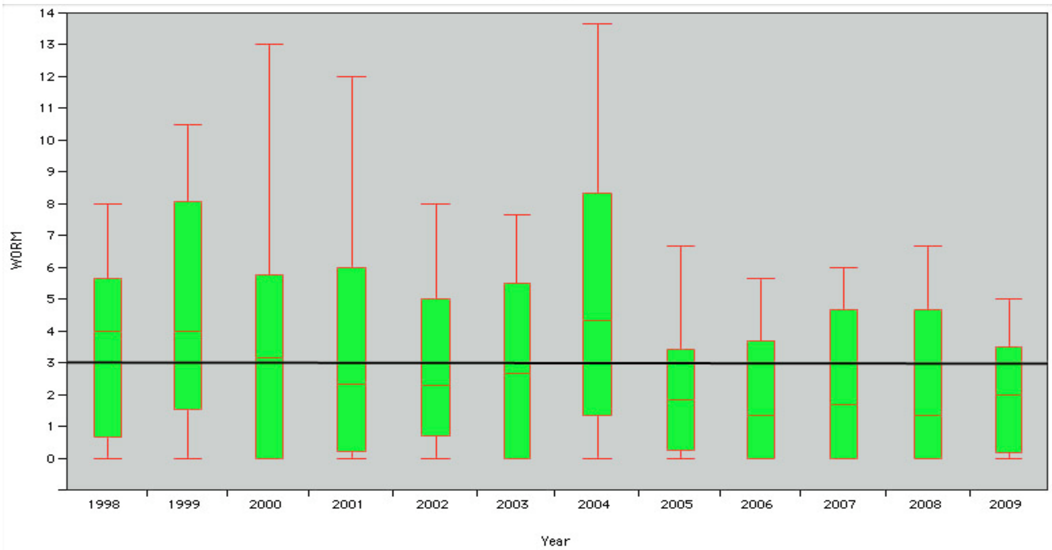


Figure 17. Box-plots of the number of burrows (top graph) and infauna (bottom graph) seen in SPI images. Box is interquartile range, whiskers are range, and bar in box is median.

3.3 2009 Soft-Bottom Benthic Infaunal Communities

3.3.1 Nearfield 2009

Twenty infaunal samples were collected and analyzed from 12 nearfield stations in 2009; the samples yielded 45,002 organisms that were assigned to 215 valid taxa and 32 indeterminate categories. Species composition at the 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 of the dominant taxa in 2009 were the same species that were reported in 2007 for the same subset of stations; only the polychaete *Ampharete baltica* is newly listed in the top numerical dominants (Table 4). The overall dominance of ascidians, which in earlier years were identified as *Molgula*, was the result of the abundance of this taxon at NF17; very few were recorded at other stations.

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 the alternate set of stations was nearly double that recorded in 2007 and accounted for over 30% of all organisms in the nearfield samples. However, in 2009, at the same subset of stations that was sampled in 2007, the average density of *P. steenstrupi* was similar to that recorded in 2007 and much lower than the 2008 average (Figure 18).

Table 4. Top numerical dominants in 20 nearfield samples collected in August 2007 and 2009.

Taxon	Total No. Individuals	
	2009	2007 (rank)
Ascidiacea	9,620	1,085 (8) (*Molgula*)
Prionospio steenstrupi	6,129	6,596 (1)
Aricidea catherinae	2,191	2,117 (5)
Mediomastus californiensis	2,176	3,499 (2)
Crassicorophium crassicorne	1,982	2,146 (4)
Owenia fusiformis	1,685	2,322 (3)
Tharyx acutus	1,469	1,569 (6)
Exogone hebes	1,142	918 (10)
Ampharete baltica	1,123	—
Ninoe nigripes	1,110	1,025 (9)
Spio limicola	1,092	471 (13)
Levinsenia gracilis	1,062	1,157 (7)

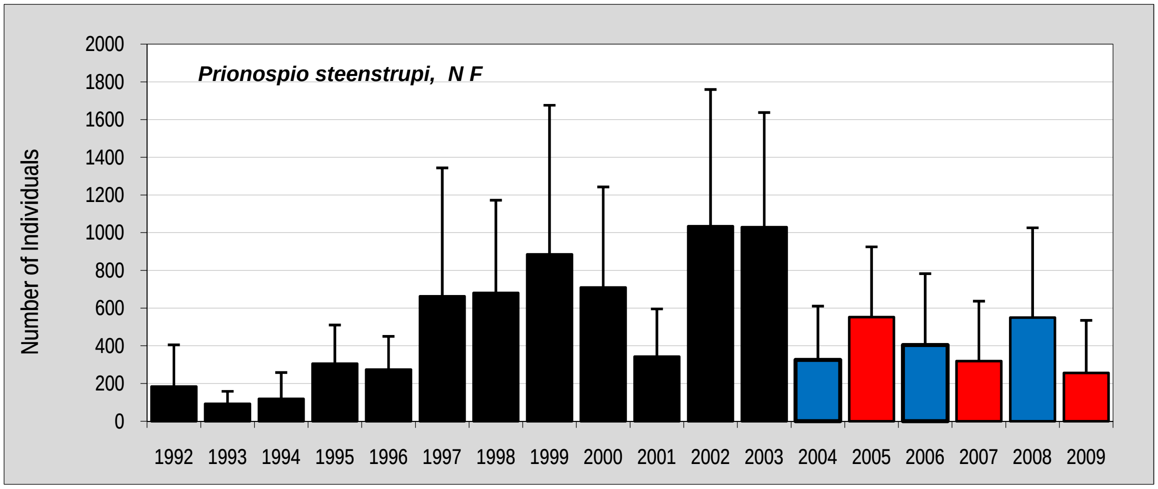


Figure 18. Annual mean density of *Prionospio steenstrupi* at nearfield stations. Two subsets of stations were sampled after 2003, one in 2004/2006/2008 (blue bars) and the other in 2005/2007/2009 (red bars).

The means for all benthic community parameters except evenness were higher than those recorded for the same subset of stations in 2007 and all were equal to or above the respective baseline means, which are based on all 23 nearfield stations (Figures 19 and 20). None of the increases appears to be statistically significant, as indicated by the wide standard deviations around the annual means. Evenness was very slightly lower, with a value of 0.62 in 2009 compared with 0.63 in 2007; however the averages for this parameter and the two diversity measures were influenced by the very high abundance of ascidians at NF17. If this taxon is removed from the calculations, higher averages are obtained for all parameters (note orange squares in Figure 20).

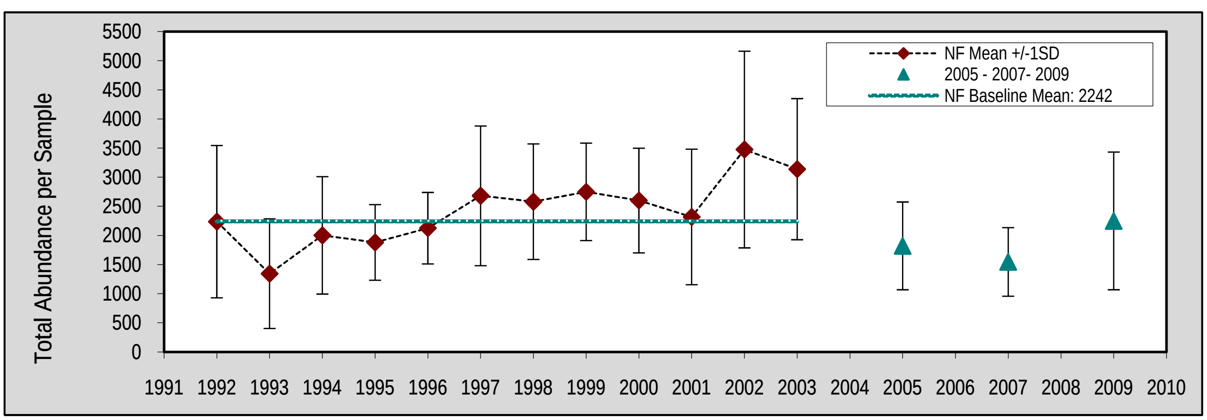


Figure 19. Mean total abundance for nearfield samples from 1992–2009. Baseline means are calculated for the full set of 23 nearfield stations; means for 2005, 2007, and 2009 are based on the "odd-year" subset of stations.

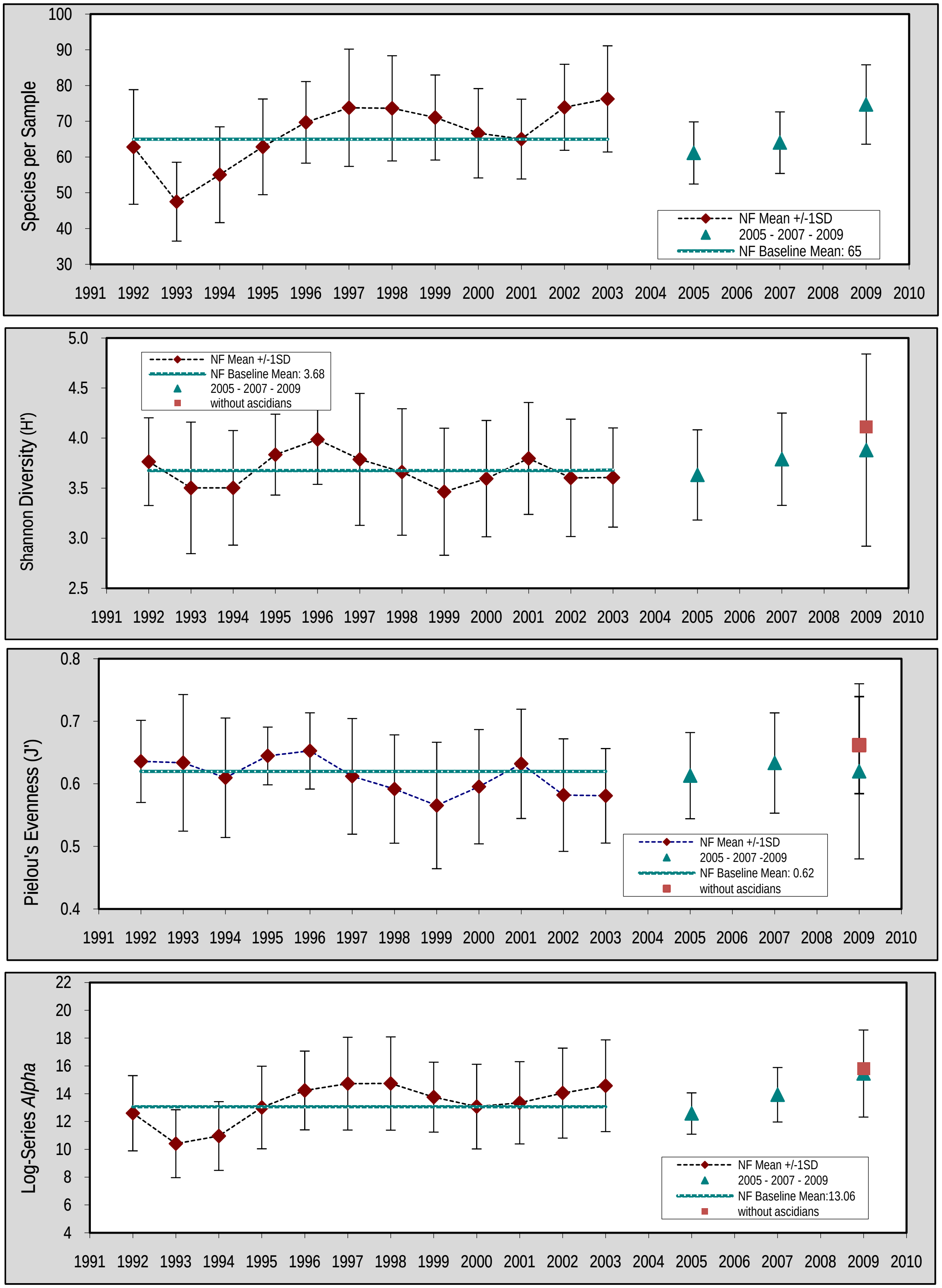


Figure 20. Mean species richness, Shannon diversity, Fisher's *alpha*, and evenness per sample at nearfield stations from 1992–2009. Baseline means are calculated for the full set of 23 nearfield stations; means for 2005, 2007, and 2009 are based on the "odd-year" subset of stations.

Farfield 2009

Twelve infaunal samples were collected and analyzed from four farfield stations in 2009; the samples yielded 13, 390 organisms that were assigned to 170 valid taxa and 20 indeterminate categories. The fauna that characterizes the farfield differs from that seen in the nearfield: the farfield stations span a greater depth range (33–89 m) than the nearfield stations and are geographically widespread, with sediment types that are generally finer than those seen in the nearfield. Several species of polychaete worms (e.g., *P. steenstrupi*, *Ninoe nigripes,* and *Levinsenia gracilis*) are common at several stations throughout the farfield but others have a more limited distribution, such as *Cossura longocirrata* and *Euchone incolor*, which are dominant at stations in Cape Cod Bay. *Euchone incolor* is a small sabellid that typically indicates the presence of the deep-burrowing but rarely collected holothurian *Molpadia oolitica*[3] (Rhoads and Young 1971). Other species such as the bivalve *Nucula delphinodonta* are typically seen at FF01A to the north and are not as common in the finer sediments of Cape Cod Bay. Dominant species in 2009 were similar to those seen in previous years at these stations. One exception was *E. incolor*, with only 258 individuals collected overall and only 180 from FF06 (Table 5); in 2007 a total of 1500 individuals of *E. incolor* were recorded (Maciolek et al. 2008). This order-of-magnitude lower abundance may have been due to the patchy nature of the distribution of this species.

Table 5. Top numerical dominants in 12 farfield samples collected in August 2009.

Taxon	Total No. Indiv.
Prionospio steenstrupi	2,681
Nucula delphinodonta	961
Levinsenia gracilis	940
Aricidea quadrilobata	866
Aricidea catherinae	694
Mediomastus californiensis	684
Cossura longocirrata	589
Ninoe nigripes	578
Tharyx acutus	454
Cerastoderma pinnulatum	382
Asabellides oculata	279
Euchone incolor	258
Anobothrus gracilis	253
Owenia fusiformis	252

[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.

The mean total abundance at farfield stations in 2009 was below the baseline average and much lower than recorded for the same subset of stations in 2007, but comparable to abundances recorded in the early 1990s (Figures 21 and 22). The recent decline was due to the decrease in abundance of several species, but primarily that of the polychaete *Prionospio steenstrupi*, which declined to approximately 40% of the number recorded in 2007. In addition, declines in the populations of several other species such as the bivalve *Nucula annulata* and the polychaetes *Aricidea quadrilobata*, *Tharyx acutus,* and *Euchone incolor* contributed to the overall lower numbers. The pattern of decline in total abundance at each station (Figure 21) suggests that this is a widespread regional effect; it has been especially pronounced at the deeper stations FF11 and FF14, where the decline has been evident for several years.

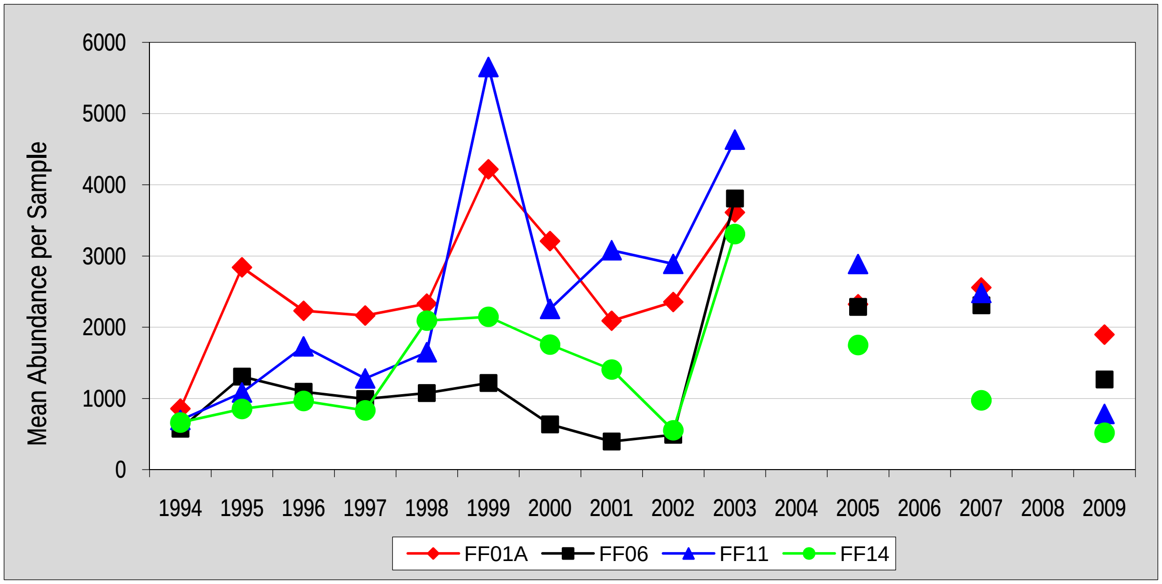


Figure 21. Pattern of mean abundance at each of four farfield stations.

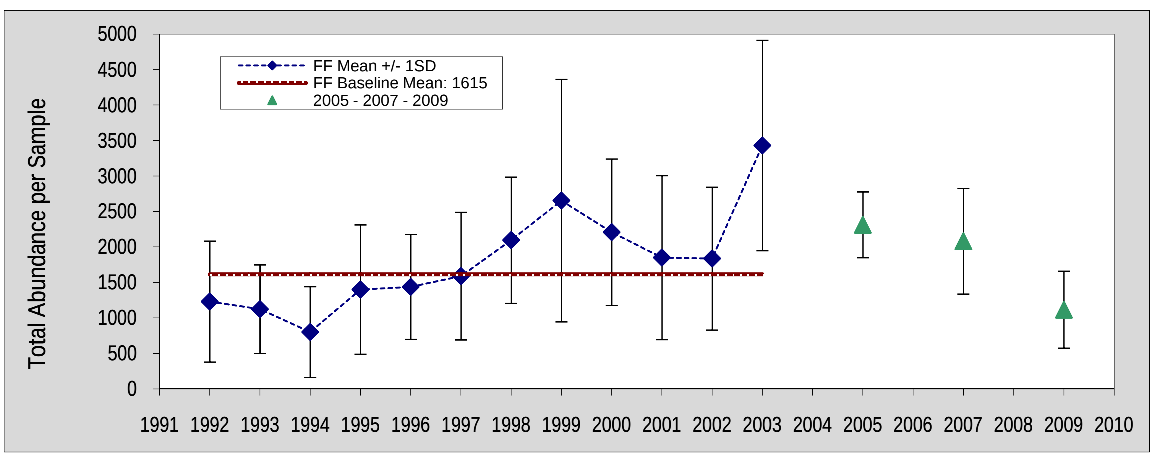


Figure 22. Mean total abundance at farfield samples from 1992–2009.

The mean number of species per sample was lower in 2009 compared with 2007, and at 58.8 species was only slightly lower than the baseline average of 61 (Figure 23). The wide standard deviation around the mean reflects the large range of values among the four geographic areas sampled and suggests that there have been no real differences over the past few years of sampling. Similarly, the mean Shannon diversity index and Fisher's *alpha* were also lower in 2009 as well as being lower than the baseline, but again had large standard deviations around the means. The low value for evenness (J′ = 0.51) suggests that the samples were dominated by one or a few species (Figure 24).

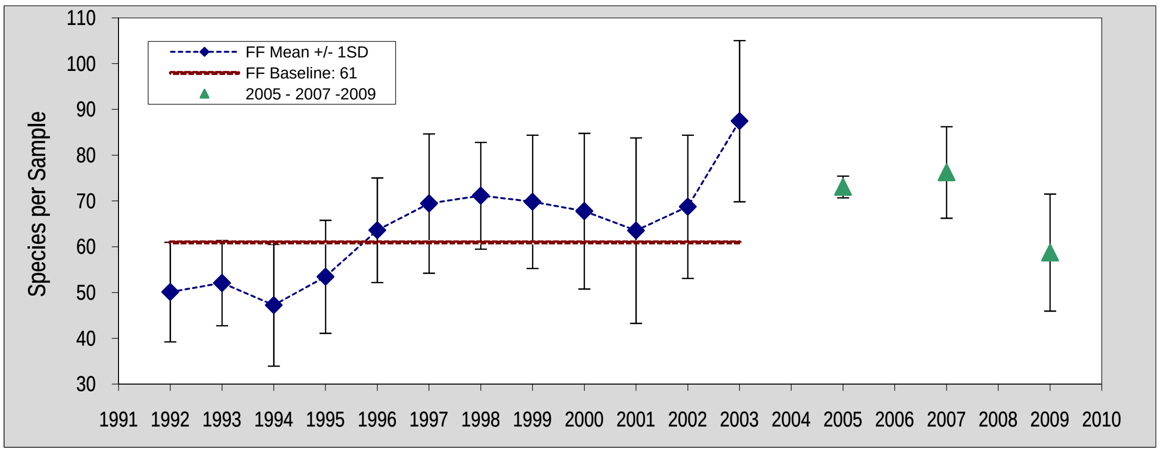


Figure 23. Annual mean species richness at farfield stations through 2009.

Samples collected in the post-diversion period (2001–2009) have not indicated any discernable impact of the discharge on the infauna. The differences detected in the benthic community parameters in both the nearfield and farfield areas, such as increased numbers of certain species and increased dominance by certain species at one or two of the nearfield stations, are considered 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.

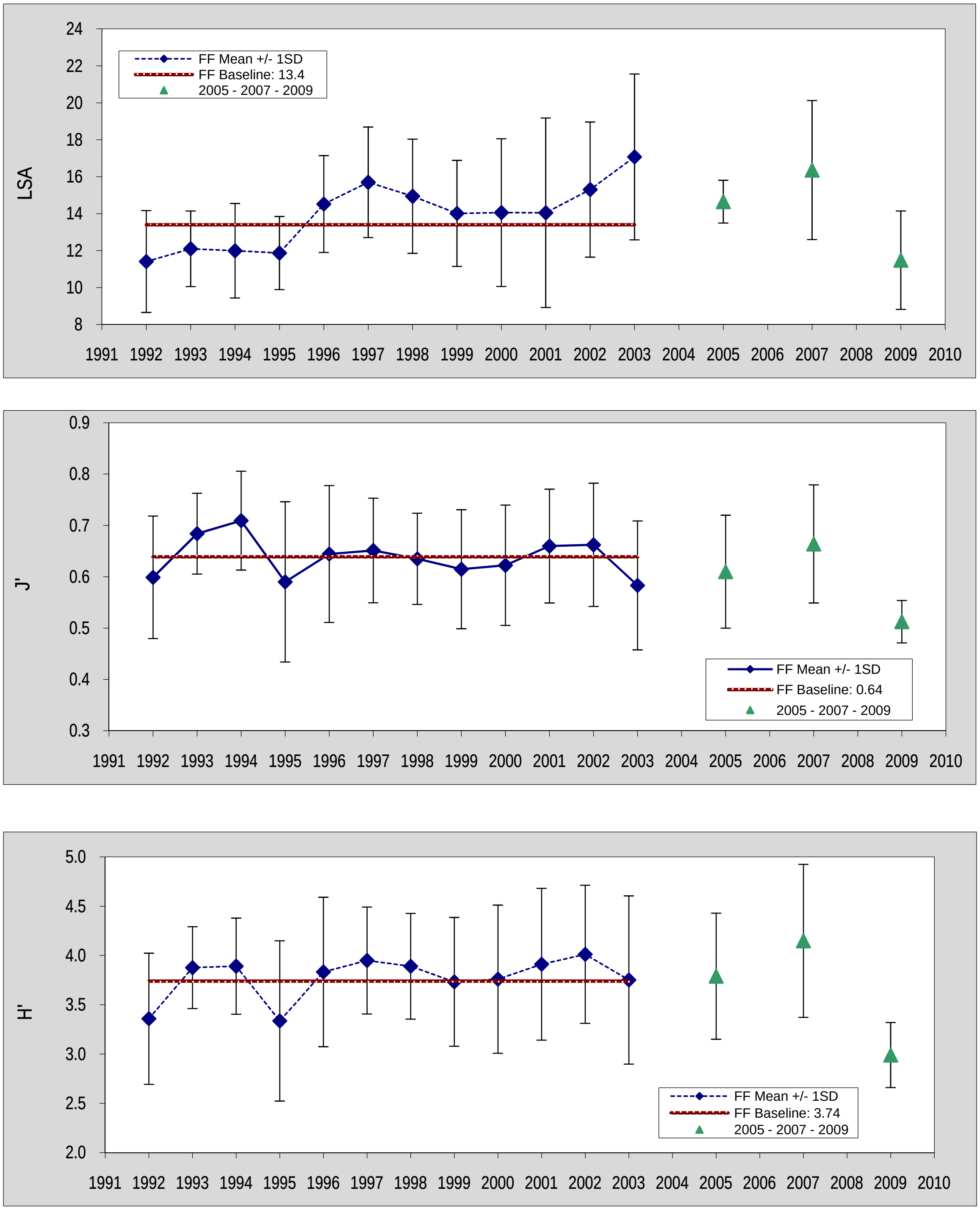


Figure 24. Annual mean Shannon (H′) index, Pielou's' evenness (J′), and Fisher's *alpha* at farfield stations through 2009.

3.4 Hard-Bottom Benthic Habitats and Fauna

3.4.1 2009 Results

Photographic coverage in 2009 ranged from 19 to 24 minutes of video footage at each waypoint and a total of 489 minutes of video were viewed and analyzed. The video footage taken this year differed slightly from that taken in previous years. The added drag of the HDV camera compromised the maneuverability of the ROV. This occasionally resulted in slightly less area being viewed, but the resulting reduced speed of the ROV permitted better resolution of some of the images. On a few occasions, the vehicle plowed into the bottom and could only be maneuvered sideways, resulting in imaging fewer of the very mobile organisms. Maneuverability issues were most noticeable at waypoints T2-3 and T7-1 where the ROV rode relatively high off the seafloor, T12-1 were the footage was quite jerky and uneven, and T4-2 were the ROV was very nose-in to the sediment and could only be flown sideways. Summaries of the 2009 video analyses are included in Appendix B.

Data collected from the 2009 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 frequently 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 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.

Fifty taxa, 4 algal species, 37 invertebrate species, 9 fish species, and 5 general categories were seen during the 2009 video analyses (Table 6). 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). Coralline algae (Figure 25a) were the most widespread, being found at 20 of the 23 waypoints. These encrusting algae were abundant or common-to-abundant at six of the drumlin top waypoints, common or few-to-common at another six waypoints (drumlin flanks and the northern reference sites), and few or rare at the remaining eight sites (drumlin flanks and the farfield southern reference site T11-1). *Palmaria palmata* (Figure 25b) was only slightly less widespread being recorded at 17 waypoints. This species was commonly observed at only three of the waypoints (T7-1, T1-1 and T1-3), few to commonly observed at an additional four waypoints (T9-1, T1-4, T2-3, and T12-1), and rarely to few observed at the remaining 10 waypoints. In contrast, the distribution of *P. serrata* (Figure 25c) was more restricted being observed at 11 waypoints. This filamentous red alga was most common at three drumlin top waypoints (northern reference site T7-1, and T1-3 and T1-4). It was observed in slightly reduced numbers at an additional three waypoints (northern reference site T9-1, T1-2, and southern reference site T12-1), and only a few were observed at the remaining five waypoints. The third upright alga, *Agarum cribrosum* (Figure 25d), had the most restricted distribution, being seen only at the three northern reference waypoints, and was commonly observed at only one of these (T7-1).

Table 6. Taxa observed during the 2009 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	general starfish	
Palmaria palmata	dulse	small white starfish	juvenile *Asterias*
Agarum cribosum	shotgun kelp	*Asterias vulgaris*	northern sea star
		Crossaster papposus	spiny sunstar
Invertebrates		*Henricia sanguinolenta*	blood star
Sponges		*Porania insignis*	badge star
general sponge		*Pteraster militaria*	winged sea star
Haliclona oculata	finger sponge	*Solaster endeca*	smooth sunstar
Haliclona spp. (encrusting)	sponge	*Psolus fabricii*	scarlet holothurian
Melonanchora elliptica	warty sponge		
Polymastia sp. A	encrust yellow sponge	**Tunicates**	
Polymastia sp. B	siphon sponge	*Aplidium/Didemnum* spp.	cream encrust tunicate
Suberites spp.	fig sponge	*Boltenia ovifera*	stalked tunicate
cream sponge with projections	sponge	*Botrylloides violaceus*	Pacific tunicate
yellow-cream encrust sponge	sponge	*Halocynthia pyriformis*	sea peach tunicate
white divided sponge	sponge on brachiopod		
		Miscellaneous	
Coelenterates		*Membranipora* sp.	sea lace bryozoan
hydroids		*Myxicola infundibulum*	slime worm
Tubularia sp.	hydroid	barnacle/spirorbid complex	
general anemone		*Terebratulina septentrionalis*	northern lamp shell
Metridium senile	frilly anemone		
Urticina felina	northern red anemone	**Fishes**	
Cerianthus borealis	northern cerianthid	general fish	
Gersemia rubiformis	red soft coral	Dogfish	
		Gadus morhua	cod
Molluscs		*Macrozoarces americanus*	ocean pout
Busicotypus canaliculatus	channeled whelk	*Myoxocephalus* spp.	sculpin
Modiolus modiolus	horse mussel	*Pholis gunnellus*	rock gunnel
Placopecten magellanicus	sea scallop	*Pollachius virens*	pollock
Arctica islandica	ocean quahog	*Pseudopleuronectes americanus*	winter flounder
		Sebastes fasciatus	rosefish
Crustaceans		*Tautogolabrus adspersus*	cunner
Balanus spp.	acorn barnacle		
Cancer spp.	Jonah or rock crab	whelk egg case	
Homarus americanus	lobster		

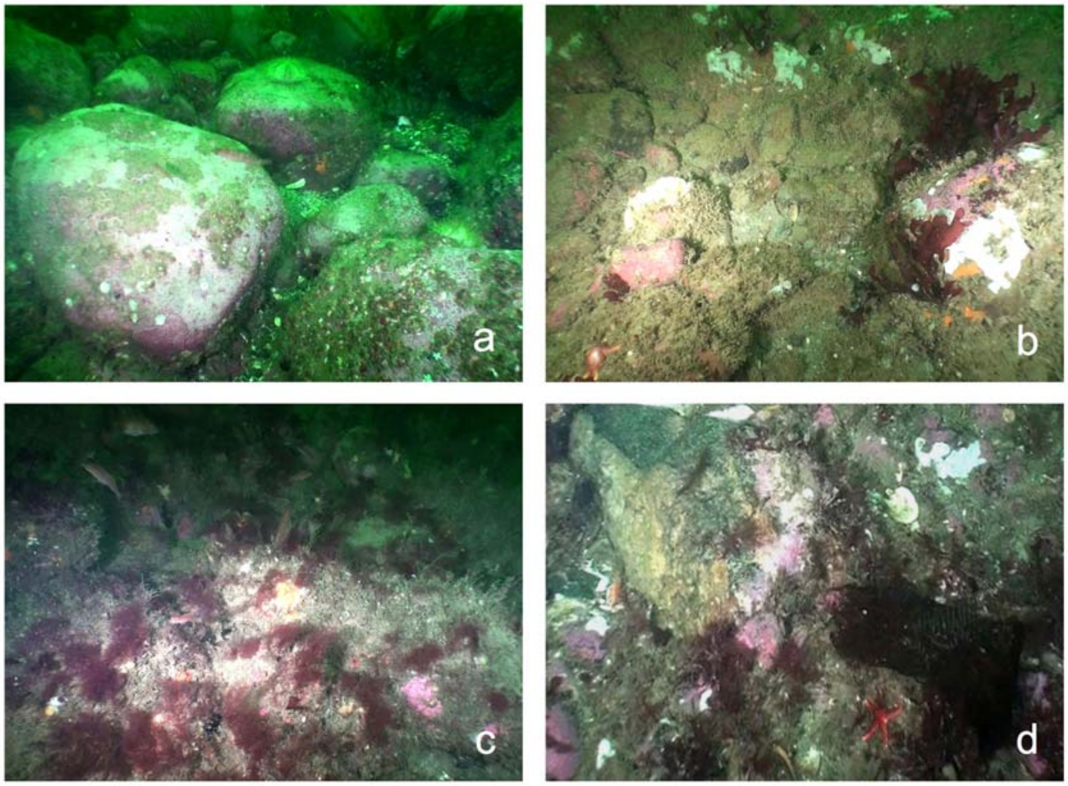


Figure 25. Screen captures of HD video showing the four algae that were encountered during the 2009 hard-bottom survey. (a) Coralline algae encrusting rock surfaces at waypoint T1-3. (b) Several large colonies of dulse *Palmaria palmata* on a boulder at southern reference site T8-1. Aslo seen are northern white crust tunicates *Didemnum albidum* and the blood star *Henricia sanguinolenta*. (c) Numerous red filamentous algae *Ptilota serrata* at northern reference site T9-1. (d) A frond of shotgun kelp *Agarum cribrosum* on a boulder at northern reference site T7-1. Northern white crust, a blood star, and a horse mussel *Modiolus modiolus* (center of lower edge) are also shown.

Seven of the 37 invertebrate taxa observed were recorded at 20 or more waypoints. These widespread invertebrates included the encrusting yellow sponge *Polymastia* sp. A, the horse mussel *Modiolus modiolus*, the lobster *Homarus americanus*, *Cancer* crabs, juvenile and adult northern sea stars *Asterias vulgaris*, the blood star *Henricia sanguinolenta*, and white and cream encrusting tunicates (*Aplidium*/*Didemnum* spp.). An additional four taxa, the sea peach tunicate *Halocynthia pyriformis*, the slime worm *Myxicola infundibulum*, the brachiopod *Terebratulina septentrionalis*, and the northern red anemone *Urctinia felina*, were also quite widely distributed being recorded at 15 to 19 waypoints. In contrast, several other taxa had exceptionally restricted distributions. The red coral *Gersemia rubiformis* was seen only at waypoint T10-1, and two sponge taxa were seen only at waypoint T11-1. Four of the nine fish species were also widely distributed. The cunner *Tautogolabrus adspersus* was observed at all 23 waypoints. This species was most abundant at drumlin top waypoints with moderate to high relief. The sculpin *Myoxocephalus* spp. and the cod *Gadus morhua* were also quite widely distributed, with each being observed at 19 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. The winter flounder *Pseudopleuronectes americanus* was observed at 16 waypoints, and no habitat preference was discerned. In contrast, the rosefish *Sebastes fasciatus* was only observed at waypoint T2-5 in the vicinity of active diffuser head of riser #2.

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 sparse populations of the sea peach tunicate *Halocynthia pyriformis* and the frilled anemone *Metridium senile*. 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. 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.

Many areas of physical disturbance were observed at the two northernmost reference stations (T7-1 and T7-2) during the 2009 survey. At both stations, much of the seafloor appeared to be impacted to some degree by physical disturbance in the form of turned-over boulders and extensive patches of shell lag (broken exposed valves of dead mussels). The seafloors with older disturbance were characterized by turned-over boulders that had small patches of coralline algae, a few spirorbids and/or barnacles attached, and little drape (Figure 26a–b). The seafloors with newer disturbance were characterized by boulders that appeared to have been turned over recently exposing bare rock surfaces, and having no drape, coralline algae, or attached fauna (Figure 26c–d). Shell lag was also quite common in areas of newer disturbance.

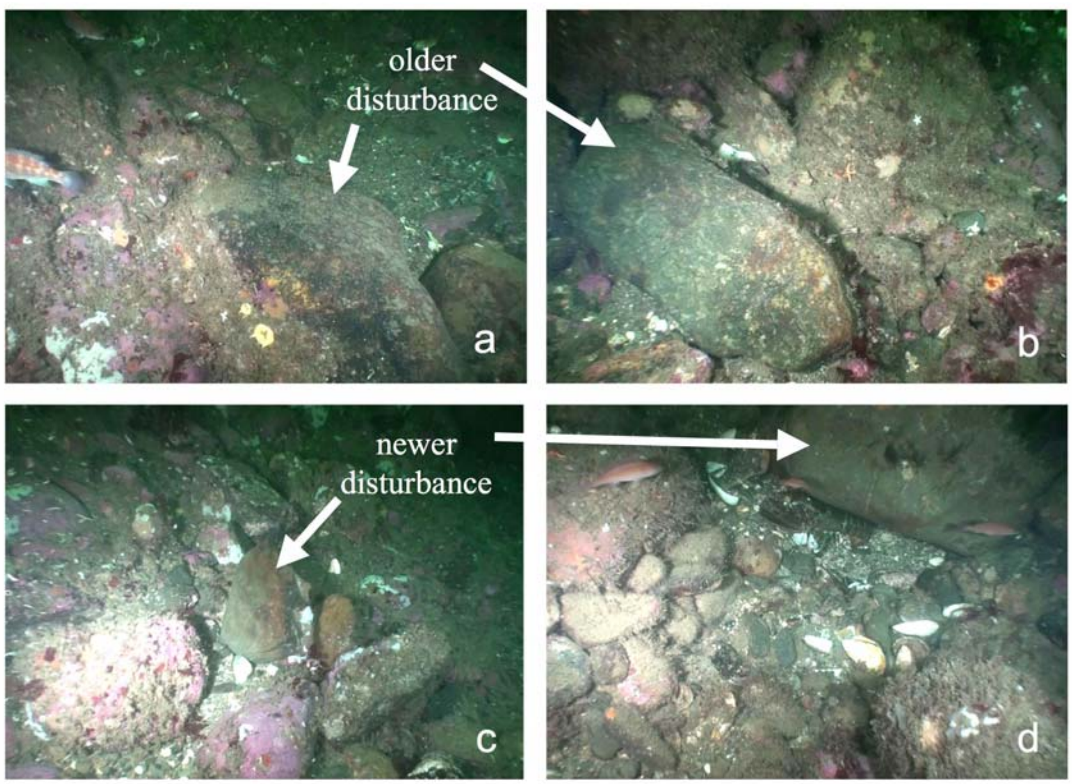


Figure 26. Screen captures of HD video taken in 2009 at the two northernmost reference stations showing physical disturbance possibly caused by the anchoring of tankers. The older disturbed seafloors shown in a & b are characterized by turned over boulders that have small patches of coralline algae, a few spirorbids and/or barnacles attached, and little drape (a at T7-2 and b at T7-1). The newer disturbed seafloors shown in c & d are characterized by boulders that appear to have been turned over recently exposing bare rock surfaces, and having no drape, coralline algae, or attached fauna (c at T7-1 and d at T7-2). Also, notice the area of shell lag in d. A lobster is also visible just below the arrowhead in d. Examples of turned over rocks are highlighted by arrows.

3.4.2 Comparison of 2009 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 2009. Table 7 shows the amount of sediment drape seen on the rock surfaces during the 1996–2009 video 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. 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 7. Sediment drape observed in video footage taken during the 1996–2009 hard-bottom surveys.

		Pre-diversion					Post diversion								
		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Northern reference	T7-1	l*	lm-h	l	l-h	m	m-mh	m	m	m	mh	m-mh	m	lm-mh	m
	T7-2	l-h	mh	c-m	mh	m	mh	m	m	m	m	m	m	lm-m	m
	T9-1		m-h	l-m	mh	h	m	m	m	lm	m	lm-m	m	lm-m	lm-mh
Northern transect	T1-1	l	l-m	l-h	mh	m	mh	m	m-mh	lm	m	m-mh	m	m-mh	m-mh
	T1-2	l	c-m	l	m*	l	lm	m	l-lm	m	lm	lm-m	lm	lm-m	lm
	T1-3	l	c-vl	c-vl	c-l	l	l	m	l	lm	lm	lm	lm	lm-m	l-m
	T1-4	l	c-vl	c-vl	lm*	l	lm	l	lm	lm	lm	lm	lm	l-lm	lm-m
	T1-5	l*	m	l-lm	m	m	m-mh	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
	T2-2	h	m-h	m-h	l-h	h	m-mh	mh	m-mh	m	m	m-mh	m	m-mh	mh
	T2-3	l-lm	l-m	m	h	h	mh	m	m	m	m	m-mh	m	lm-mh	m-mh
	T2-4	m-mh	m-h	m-h	h	h	m-mh	mh	m	m	m	m-mh	mh	mh	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
	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
	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
	T6-2	vl*	l-m	l-m	l-m	m	lm	lm	m	m	lm	m-mh	m	m-mh	lm-m
Southern reference	T10-1		mh-h	h	h	h	h	mh-h	mh-h	mh	mh	mh-h	h	h	h
	T8-1	l-m	l-m	c-vl	lm	lm	lm	lm	lm	lm	lm	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
	T12-1								lm	lm	lm	l-m		m	lm-m
	T11-1								m	m	m	m	m		mh
Diffusers	T2-5	m	m	m-h			mh	m-mh	m	m	m	m-mh	mh	m-mh	mh
	D44			h		h	h	m	mh	mh	mh	m-mh	mh	mh-h	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 8 shows the relative cover of coralline algae observed in video footage taken during the 1996 to 2009 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 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 has been 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 have been 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 8. Relative cover of coralline algae observed in video footage taken during the 1996 to 2009 hard-bottom surveys.

		Pre-diversion					Post diversion								
		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
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
	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
	T9-1		c-a	c-a	c	c	c-a	c	f-c	c	f-c	c	c	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
	T1-2	a	va	a	c*	a	c-a	c	a	f-c	c-a	c	c-a	c-a	c-a
	T1-3	a	va	a	va	a	va	a	a	a	a	c	c-a	c	c-a
	T1-4	va	va	a	a	a	a	a	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
	T2-1	f-a	f-c	r-f*	c	c	f-c	c	c-a	c	f	c	f-a	f-c	f
	T2-2	r	f	f-c*	r-c	c	f-c	r-f	f	f	f	r	r-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
	T2-4	f	r	f	f	-	r	f	r-f	r	r	r	f	r-f	f
Southern transect	T4/6-1	va	c-a	a	a	a	va	a	a	a	a	a	c-a	c-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
	T4-3	f	f	c*	f-c	c	f-c	c							
	T6-1	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
Southern reference	T10-1		r-f	-	r	-	-	-	-	r-c	r	-	-	-	-
	T8-1	a	c-a	a	c-a	c	a	c-a	c-a	c-a	a	c	c-a	f-c	c
	T8-2	a	a-va	a	c	a	c-a	c	a	a	a	c-a	c-a	c-a	c-a
	T12-1								c-a	c-a	c	c-a		c	c-a
	T11-1								-	f	f	f	r-f		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 9 shows the relative abundance of dulse *Palmaria palmata* over the 1996 to 2009 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 dropped to an area wide low in 2003. 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 9. Relative abundance of *Palmaria palmata* (dulse) observed in video footage taken during the 1996–2009 hard-bottom surveys.

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

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

Table 10 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 three 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 10. Relative abundance of *Ptilota serrata* (filamentous red alga) observed in video footage taken during the 1996–2009 hard-bottom surveys.

		Pre-diversion					Post diversion								
		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
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
	T7-2	va	c-a	a	a	c-a	a	c	c-a	a	a	f-a	f-c	f-c	r-c
	T9-1		a-va	c-a	a	c-a	c	f-c	r	f	r-c	-	-	-	f-c
Northern transect	T1-1	a	-	c-a	-	-	-	f	-	-	-	-	-	-	f
	T1-2	a	-	f	-	-	-	-	-	-	-	-	-	-	f-c
	T1-3	f	-	f	-	-	f	-	r	c-a	r	r-c	f-c	c-a	c-a
	T1-4	r-f	-	-	-	-	-	-	-	r-f	-	f	-	f-c	c-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
	T4-1	-	-	-	-	-	-	-							
	T4-2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	T4-3	-	-	-	-	-	-	-							
	T6-1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	T6-2	c-va*	-	-	-	-	-	-	-	-	-	-	-	-	-
Southern reference	T10-1		c-a	f-c	f	-	-	-	-	-	-	-	-	-	r
	T8-1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	T8-2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	T12-1								f-c	f-c	-	f		f-a	f-c
	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 11). 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.

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 three northern reference sites. This may result in a seafloor that is a mosaic of areas in differing stages of recovery from physical disturbance.

Table 11. Relative abundance of *Agarum cribrosum* (shotgun kelp) observed in video footage taken during the 1996–2009 hard-bottom surveys.

		Pre-diversion					Post diversion								
		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Northern reference	T7-1	c	f	a	c	a	f-c	c	c	c	c	f-c	f-c	c	c
	T7-2	va	f-c	a	c-a	a	c-a	c	c	c-a	a	c	r	-	f
	T9-1		va	c-a	a	c	c	f	-	r	r	-	-	-	r
Northern transect	T1-1	f	f	f	-	r	-	-	-	-	-	-	-	-	-
	T1-2	c	f	r	-	-	r	-	-	-	-	-	-	-	-
	T1-3	-	-	-	r	r	-	r	-	-	-	-	-	r	-
	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

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 12 shows the abundance of several of these species observed during the video surveys in years 1996–2009. 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 12. Number of individuals of selected species observed during the hard-bottom video surveys, 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**
Minutes of video	438	487	439	422	444	448	495	469	454	466	419	440	443	448
***Cancer* spp. (rock crab)**	6	3	4	15	92	123	168	144	115	67	81	108	12	85
***Gadus morhua* (cod)**	-	6	12	22	11	41	53	10	52	64	59	40	64	91
***Homarus americanus* (lobster)**	6	2	11	4	18	21	31	33	12	10	35	36	28	79

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 suggest that concentrations of most contaminants in surficial sediment at 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. In 2009, total pesticide, total PCB, and silver concentrations were at the low end of the baseline range at stations NF12 and NF17, while aluminum concentrations were at the high end or above the baseline range.

A statistical analysis of the long-term monitoring data indicated that mean pesticide and PCB concentrations decreased significantly (at the 95% level of confidence) between the baseline and post-diversion periods in the nearfield and farfield regions of Massachusetts and Cape Cod Bays, while aluminum concentrations increased. The observed decrease in pesticide and PCB concentrations 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. An explanation for the post-diversion increase in aluminum is not evident. Overall, sediment data to date indicate that post-diversion (2001–2009) concentrations of most anthropogenic contaminants in surficial sediment have not changed substantively compared to the baseline (1992–2000).

- *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. 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 2009 appeared to be shallower than in 2007 and 2008, 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 dominant at the medium- to fine-grained stations. Much of the decline in mean total abundance at the nearfield stations in 2003–2007 and increase in 2009 was due to the population fluctuation of the numerically dominant species. Such fluctuations are characteristic of marine benthic 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. In 2009, Shannon diversity and Fisher's *alpha* were higher than at the same set of stations in 2007 and both indices were well above the baseline average. 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 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. 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.

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APPENDIX A

2009 Infaunal Community Parameters

Table A1. Benthic community parameters for all samples collected in August 2009.

Nearfield Stations						
Station	**Rep**	**Total Indiv.**	**Number of Species**	**H′**	**J′**	**LSA**
FF12	1	1821	57	3.75	0.64	11.19
FF12	2	2170	59	3.37	0.57	11.19
FF12	3	1772	65	3.87	0.64	13.27
NF02	1	1220	69	3.97	0.65	15.88
NF04	1	943	65	4.33	0.72	15.91
NF10	1	2072	88	4.55	0.70	18.67
NF12	1	1635	89	4.93	0.76	20.23
NF12	2	1545	80	4.86	0.77	17.93
NF12	3	1648	87	5.03	0.78	19.62
NF13	1	2265	85	4.25	0.66	17.48
NF14	1	1820	87	4.60	0.71	19.07
NF15	1	2480	83	4.71	0.74	16.56
NF17	1	4175	65	2.04	0.34	10.94
NF17	2	6604	79	1.77	0.28	12.62
NF17	3	2666	54	2.14	0.37	9.60
NF20	1	2113	89	4.58	0.71	18.84
NF21	1	1789	77	4.63	0.74	16.44
NF24	1	1837	75	3.56	0.57	15.76
NF24	2	2169	70	3.47	0.57	13.85
NF24	3	2258	71	3.26	0.53	13.95

Farfield Stations						
Station	**Rep**	**Total Indiv.**	**Number of Species**	**H′**	**J′**	**LSA**
FF01A	1	1650	73	3.03	0.49	13.22
FF01A	2	1924	78	3.12	0.50	13.87
FF01A	3	2118	80	3.15	0.50	14.02
FF06	1	1146	52	2.95	0.52	9.47
FF06	2	1171	56	3.09	0.53	10.33
FF06	3	1483	54	2.91	0.50	9.40
FF11	1	672	41	2.47	0.46	8.00
FF11	2	821	41	2.46	0.46	7.63
FF11	3	852	46	2.59	0.47	8.73
FF14	1	523	63	3.39	0.57	14.80
FF14	2	614	65	3.48	0.58	14.68
FF14	3	416	56	3.36	0.58	13.63

APPENDIX B

2009 Hard-Bottom Video Analysis

Table B1. Summary of data recorded from video footage taken on the 2009 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	21	21	20	21	22	20	20	21	20	23	20	22	23	21	22	22	23	21	24	22	19	21	20	489
Depth (m) beginning	24	22	22	24	30	27	29	29	31	25	31	34	29	27	28	26	31	26	27	27	35	34	34	
Depth (m) end	25	23	22	24	31	26	33	29	32	25	33	34	28	28	24	27	27	26	28	26	34	30	35	
Substrate [1]	b+c	b+c	b+c	b+c	c+ ob	c+ mx	c+b	c+b	b+c	b+c	cp	cp	b+c	b+c	b+c	b+c	b+c	cp+mx	c+b	b+c	c+b	d+rr	d+rr	
Drape [2]	m-mh	lm	l-m	l-lm	m	m	mh	m-mh	mh	l-lm	m	m	lm-m	m	m	lm-mh	h	lm-m	lm	lm-m	mh	mh	mh	
Relief [3]	M	M	MH	M	LM	LM	LM	M	M	M	L	L	M	M	M	M	H	LM	LM	M	LM	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-a	c-a	f	f	f	f	f	a	f	r	c	f-c	f-c	f-c		c	c-a	c-a	f			
Ptilota serrata	f	f-c	c-a	c-a	r-f					r-f				f-a	r-c	f-c	r			f-c				
general hydroid	c-a	f-c	f-c	f	c	r-c	c-a	c-a	f-a	r-f	f-c	r-f	f-c	c	c-a	f-c	c-a	f	f-c	f-c	c-a	f-a	f-a	
barnacle/spirorbid complex	r	r-f	f	f-c		f				f	f	r-f	f	f-a	f-c			f	f	f	f	r-c		
Palmaria palmata	c	f	f-a	f-c	r	r-f		f-c		r-f			r-f	f-a	r-c	f-c	f	r-f	r-f	f-c	r-f			
Agarum cribosum														c	f	r								
general sponge	4	2			1	1	1	3	4		2			1	1	1		1		4	11	2	1	40
Haliclona oculata	1					2		2	2					2						2	7	18	20	56
Haliclona spp. (encrust.)	4							1											2					7
Melonanchora elliptica						1																		1
Polymastia sp. A	c	r	r-f	r	r	c	c-a	c-a	c	r	r		c	f	r-f	c	c		f	r	f		r	
Polymastia sp. B						2					2													4
Suberites spp.	f				c	f	c	f-c	f		r-f	r	f				f		r		f	r		
cream sponge w/ project.																					c-a			
yellowish encrust. sponge																					c-a			
white divided sponge	f		r			r	c	f-c	c-a		c	r	f		f	c	f-c		r	f-c	c-a			
Tubularia sp.										a												f-c	r-f	
general anemone										1														1
Metridium senile				r						a							r		r			c-a	r-c	
Urticina felina	2	2	6	6		5	1	2	4			4	10			2	2	1	3	3	7	10	1	71
Cerianthus borealis											1	1									1			3
Gersemia rubiformis																	f-c							
Busicotypus canaliculatus											1													1
Modiolus modiolus	c-a	c-a	c-a	c-a	f-c	f-c	c	c	f-c	c-a	f-c	f	c	c-a	c-a	c-a	c	f-c	c	c	a			
Placopecten magellanicus	3	1			3		3				11	20						3	1				2	47
Arctica islandica									r		r													

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
Balanus spp.			f							f						f								
Cancer spp.	2	3	4	6	6	2	3	4	11	6	5	5	6	3			5	3	2	3		5	4	88
Homarus americanus	2	3	2	2	6	2	7	9	7	2	3		2	3	4	3	13	1	5	2		2	1	81
Strongylocentrotus droebachiensis	r	c	c	f-c		r		f		c			f-c		r	c			c	r		r	r	
general starfish															1									1
small white starfish	c	c-a	a	c-a	c	f-c	c	c	c	a	f-c	f-c	c	c-a	c-a	c-a	c	f-c	c	f-c	c	f	f	
Asterias vulgaris	f	r	f-c		r	f	f	r	r	r	f	f-c	f	r	r	f-c	f	c	c	f	r	r	r	
Crossaster papposus											6										4			10
Henricia sanguinolenta	c	c	f-c	c	f-c	f-c	c	c	c	c	f-c	f-c	c	c	c	c	c	f	c	f-c	c	f	f	
Porania insignis																	1							1
Psolus fabricii	r	f	r-f	f-c				r	r	c						f			r	c-a				
Pteraster militaria		4																			1			5
Solaster endeca																					1			1
Aplidium/Didemnum spp.	f-c	f	r-f	f	f-c	f-c	c	c	f-c	r-f	f-c	f	c	f-c	f	f	f	f-c	f-c	f-c	r-f		f	
Boltenia ovifera																1					4		1	6
Botrylloides violaceus			4	9	1				5						1		4		2	2	5			33
Halocynthia pyriformis	r	f	f	f			r	f	f	c	r	r	f	r		r	f		f	f-c	f	r	r-c	
Membranipora sp.			f-c											f						f				
Myxicola infundibulum	f-c	f			r	r	f-c	c	f-c	f-c	r			r	f-c	r				r	c-a		f	
Terebratulina septentrionalis	f		r			r	c	f-c	c-a		c	r	f	r	f	c	f-c		r	f-c	c-a			
general fish	4	4	5	3	8	7	3	2	4	15	3			11	11	23	3	1	2	9	8	7		133
Dogfish																					1			1
Gadus morhua	1	4	8	9			1	1	4	5	2		4	3	18	10	4		1	6	4	3	13	101
Macrozoarces americanus													1							2				3
Myoxocephalus spp.	2	1	1	1	6	4	3	1	2	2	5		3	1	1		1	3	3	3		2		45
Pholis gunnellus	1					1				1					1								1	5
Pollachius virens		15	19			1	1	3						6	8	19	3		1	1	2	1		80
Pseudopleuronectes americanus			1	3	3	3		2	2	2	7	2	1		2			8	2	2		1	1	42
Sebastes fasciatus																						7		7
Tautogolabrus adspersus	c	c	c-a	c-a	f	f-c	f-c	c	f-c	c-a	f	f	c	c-a	c-a	c-a	c-a	f	f	f-c	f	c	f-c	

[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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