Outfall Benthic Monitoring Report: 2011 Results

Massachusetts Water Resources Authority

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Outfall Benthic Monitoring Report: 2011 Results

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EXECUTIVE SUMMARY

Benthic monitoring during 2011 represented the first year of data collection following the 2010 revision to the Ambient Monitoring Plan (MWRA 2010). Under the current plan, 14 soft-bottom stations are sampled annually for sediment conditions and infauna. Sediment contaminants are evaluated at the same 14 stations, but only every third year. Hard-bottom surveys are also conducted every third year (at 23 nearfield stations); both sediment contaminant monitoring and hard-bottom surveys were conducted in 2011. Sediment profile imaging (SPI) sampling under the current plan remains the same as in previous years, with 23 nearfield stations sampled annually.

Monitoring objectives are focused on addressing three primary concerns regarding potential impacts to the benthos from the wastewater discharge: (1) eutrophication and related low levels of dissolved oxygen; (2) accumulation of toxic contaminants in depositional areas; and (3) smothering of animals by particulate matter.

As in past years during the post-diversion period, the spatial distribution of the highest *Clostridium perfringens* concentrations during 2011 identified effluent solids deposition only at sites closest to the discharge. There was no indication in 2011 monitoring results that fine sediments or TOC are accumulating at sites near the outfall. These findings are consistent with prior year monitoring results (Maciolek et al. 2008, 2011).

Sediment contaminant monitoring in 2011 found no indication that toxic contaminants from the wastewater discharge are accumulating in depositional areas surrounding the outfall. No Contingency Plan threshold exceedances for sediment contaminants were reported in 2011. Patterns in the spatial distribution of higher contaminant concentrations primarily reflect both the percentage of fine particles in the sediment, and the proximity to historic sources of contaminants in Boston Harbor.

There were threshold exceedances in 2011 for two infaunal diversity measures: (1) Pielou's Evenness (J') and (2) Shannon-Wiener Diversity (H'). No exceedances were reported for other infaunal diversity measures or for the percent opportunistic species. Spatial comparisons of the 2011 values for J' and H' indicated that there was no association between high evenness or diversity values (or low values) and proximity to the outfall diffuser. Temporal comparisons of J' and H' values demonstrated no indication of increases in the post-diversion period compared to the baseline at stations closest to the outfall. Increases in J' and H' that resulted in threshold exceedances were driven by nearfield stations that are more than two kilometers from the outfall, and less likely to be influenced by the discharge. Furthermore, J' and H' have increased in both nearfield and farfield locations, suggesting region-wide changes, unrelated to the discharge. Multivariate analyses found no evidence of impacts from the offshore outfall on infaunal communities in Massachusetts Bay. These results further support findings that increased J'and H' are a region-wide occurrence, unrelated to the discharge. Infaunal data in 2011 continue to suggest that animals near the outfall have not been smothered by particulate matter from the wastewater discharge.

The 2011 SPI survey found no indication that the wastewater discharge has resulted in low levels of dissolved oxygen in nearfield sediments. The average thickness of the sediment oxic layer in 2011 was greater than reported during the baseline period. These results support previous findings that eutrophication and the associated decrease in oxygen levels have not been a problem at the nearfield benthic monitoring stations (Maciolek et al. 2008).

Hard-bottom benthic communities near the outfall have not changed substantially during the post-diversion period as compared to the baseline period. Some modest changes in hard-bottom communities (coralline algae and upright algae cover) have been observed; nonetheless, factors driving these changes are unclear. Since declines in upright algae started in the late 1990s, it is unlikely that the decrease was attributable to diversion of the outfall.

TABLE OF CONTENTS

PAGE

APPENDICES

LIST OF FIGURES

PAGE

LIST OF TABLES

PAGE

1. INTRODUCTION

1.1 Background

The Massachusetts Water Resource Authority (MWRA) has conducted long-term monitoring since 1992 in Massachusetts Bay and Cape Cod Bay to evaluate the potential effects of discharging secondarily treated effluent 15 kilometers (km) offshore in Massachusetts Bay. Relocation of the outfall from Boston Harbor to Massachusetts Bay in September, 2000, raised concerns about potential effects of the discharge on the offshore benthic (bottom) environment. These concerns focused on three issues: (1) eutrophication and related low levels of dissolved oxygen; (2) accumulation of toxic contaminants in depositional areas; and (3) smothering of animals by particulate matter.

Under its Ambient Monitoring Plan (MWRA (1991, 1997, 2004, 2010) the MWRA has collected extensive information over a nine-year baseline period (1992–2000) and an eleven-year post-diversion period (2001–2011). These studies include surveys of sediments and soft-bottom communities using traditional grab sampling and sediment profile imaging (SPI); and surveys of hard-bottom communities using a remotely operated vehicle (ROV). Data collected by this program allow for a more complete understanding of the bay system and provide a basis to explain any changes in benthic conditions and to address the question of whether MWRA's discharge has contributed to any such changes. A comprehensive presentation of methods and evaluation of the long-term sediment monitoring data collected from 1992 to 2007 is provided in the Outfall Benthic Interpretive Report: 1992–2007 Results (Maciolek et al. 2008).

Results of 2011 benthic monitoring were presented at MWRA's Annual Technical Workshop on May 1, 2012. PowerPoint presentations from this workshop are provided in Appendix A. The purpose of this report is to summarize key findings from the 2011 benthic surveys, with a focus on the most noteworthy observations relevant to understanding the potential effects of the discharge on the offshore benthic environment.

1.2 2011 Threshold Exceedance

Two infaunal biodiversity measures tracked by MWRA as Contingency Plan thresholds exceeded their caution level threshold ranges for samples collected in August 2011. The nearfield averages for both Shannon-Wiener diversity (H′) and Pielou's evenness (J′) were slightly higher than the upper threshold limit. These results were communicated to regulators and the public in December 2011 (MWRA 2011a). Threshold exceedances for these two parameters were also reported in January 2011 for 2010 monitoring (MWRA 2011b).

A further evaluation of these findings was conducted and is described in section 3.2 of this report. The findings from this evaluation were consistent with those presented in the 2010 Outfall Benthic Monitoring Report (Maciolek et al. 2011); i.e., there is no evidence that the threshold exceedances resulted from an impact of the outfall discharge on infaunal communities, but resulted from natural variability in the benthic communities monitored in the vicinity of MWRA's outfall.

2. METHODS

Benthic monitoring during 2011 represented the first year of data collection following the 2010 revision to the Ambient Monitoring Plan (MWRA 2010). The current plan calls for a reduced number of soft-bottom (i.e., sediment and infauna) stations, with all stations sampled annually. Sediment contaminant monitoring and hard-bottom surveys were both conducted in 2011, and these components of the monitoring program will be conducted every third year under the current plan. SPI sampling under the current plan remains the same as in previous years.

Methods used to collect, analyze, and evaluate all sample types remain largely consistent with those reported by Maciolek et al. (2008) for previous monitoring years. Detailed descriptions of the methods are contained in the Quality Assurance Project Plan (QAPP) for Benthic Monitoring 2011–2014 (Nestler et al. 2011). A brief overview of methods, focused on information that is not included in the QAPP, is provided in Sections 2.1 to 2.3.

2.1 Field Methods

Sediment and infauna sampling was conducted at 14 stations on August 19 and 20, 2011 (Figure 2-1):

- Transition area station FF12, located between Boston Harbor and the offshore outfall
- Nearfield stations NF13, NF14, NF17, and NF24, located in close proximity (<2 km) to the offshore outfall
- Nearfield stations NF04, NF10, NF12, NF20, NF21, and NF22, located in Massachusetts Bay but farther than 2 km from the offshore outfall
- Farfield reference stations FF01A, FF04, and FF09, located in Massachusetts Bay and Cape Cod Bay

Sampling at Station FF04 within the Stellwagen Bank National Marine Sanctuary was conducted in accordance with Research permit SBNMS-2010-001.

Soft-bottom stations were sampled for grain size composition, total organic carbon (TOC), the sewage tracer *Clostridium perfringens*, and benthic infauna. All stations were also 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).

SPI samples were collected in triplicate at 23 nearfield stations on August 18, 2011 (Figure 2-2).

Camera transects (Figure 2-3) were performed as in previous years. All of the 23 hard-bottom waypoints were successfully surveyed on June 21 to 27, 2011, including an actively discharging diffuser head at the eastern end of the outfall. At least 20 minutes of both analog and high definition video (HDV) footage was obtained at all of the waypoints.

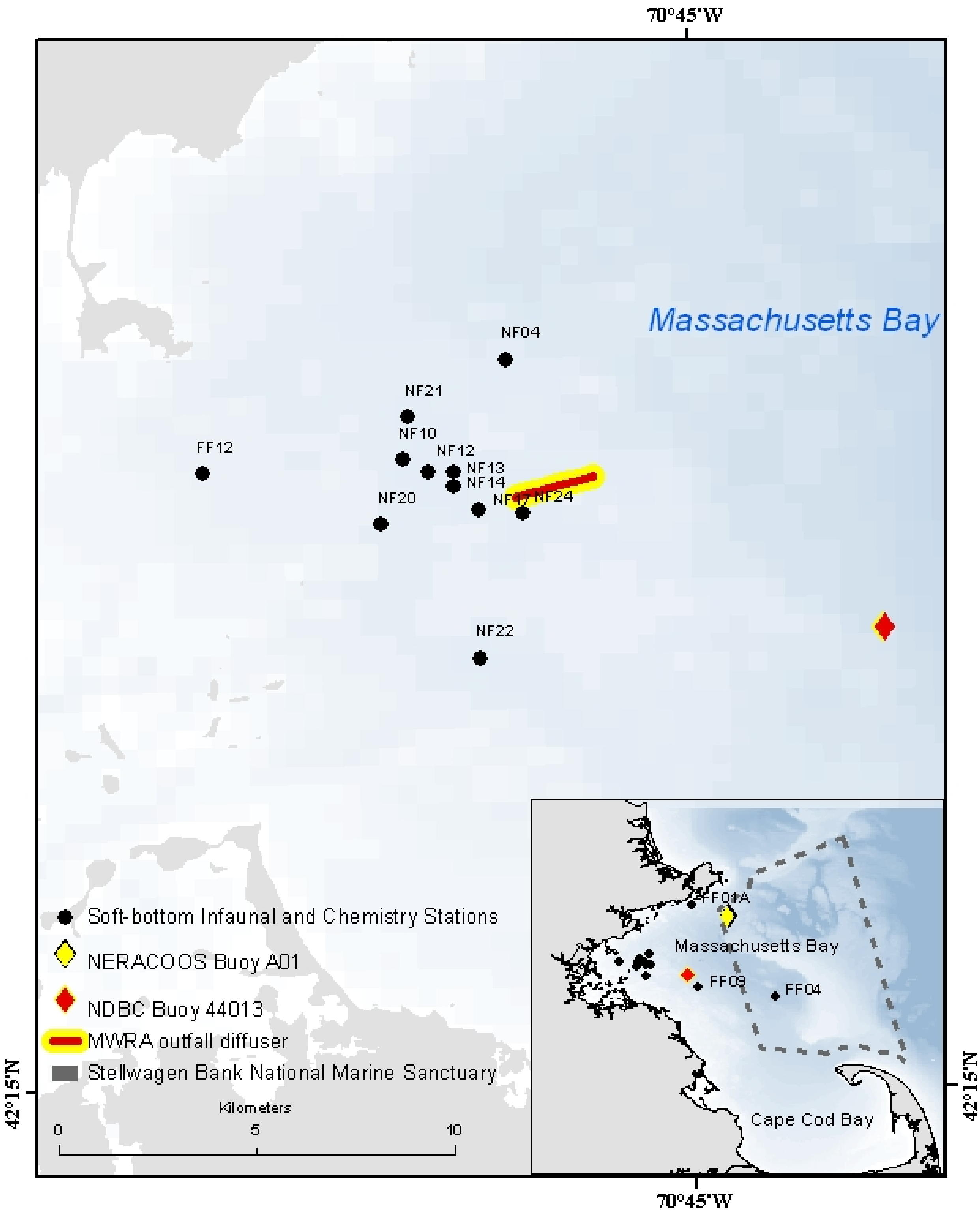

Figure 2-1. Locations of soft-bottom sampling stations for 2011.

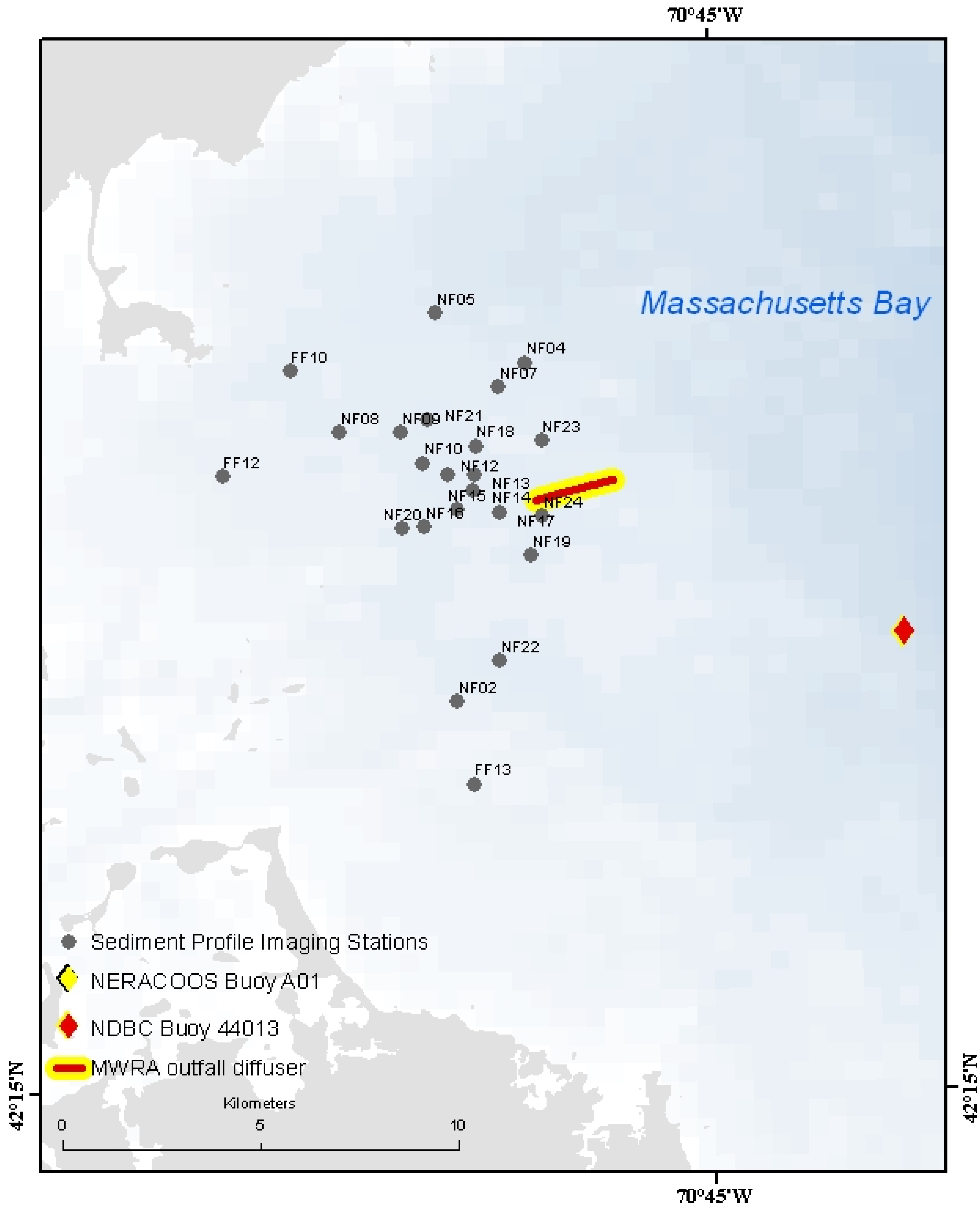

Figure 2-2. Locations of sediment profile imaging stations for 2011.

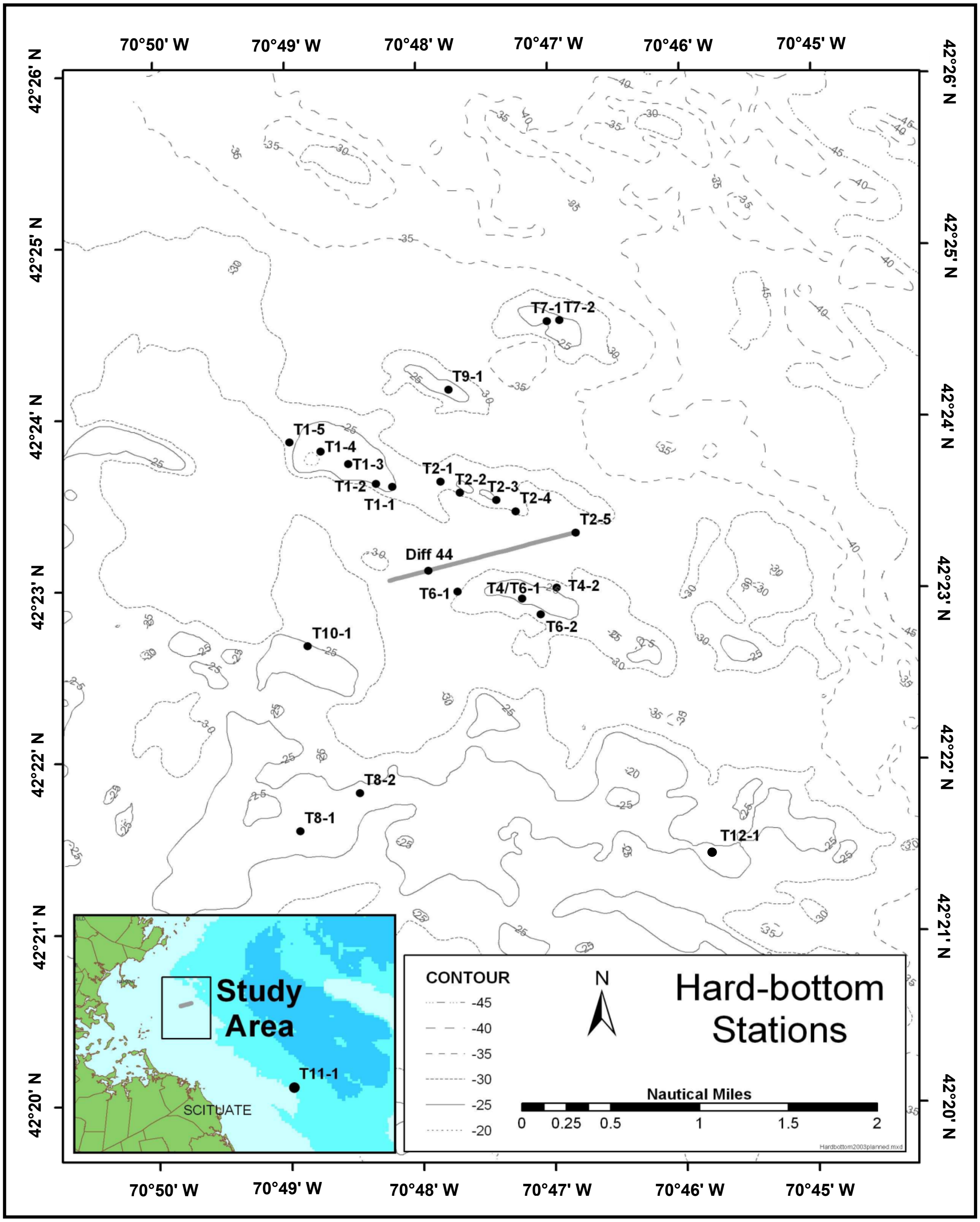

Figure 2-3. Locations of hard-bottom benthic monitoring stations for 2011.

2.2 Laboratory Methods

Laboratory methods were consistent with the QAPP (Nestler et al. 2011) except that infaunal samples were processed by AECOM Marine and Coastal Center as described by Maciolek et al. (2010). Analog video collected during the hard-bottom survey was analyzed and the HDV was archived for potential future analysis.

2.3 Data Handling, Reduction, and Analysis

All benthic data were extracted directly from the HOM database and imported into Excel. Data handling, reduction, graphical presentations and statistical analyses were performed as described in the QAPP (Nestler et al. 2011) or by Maciolek et al. (2008).

Additional multivariate techniques were used to evaluate infaunal communities following threshold exceedances for two biodiversity measures. Multivariate analyses were performed using PRIMER v6 (Plymouth Routines in Multivariate Ecological Research) software to examine spatial patterns in the overall similarity of benthic assemblages in the survey area (Clarke 1993, Warwick 1993, Clarke and Green 1988). These analyses included classification (cluster analysis) by hierarchical agglomerative clustering with group average linking and ordination by non-metric multidimensional scaling (MDS). Bray-Curtis similarity was used as the basis for both classification and ordination. Prior to analyses, infaunal abundance data were fourth-root transformed to ensure that all taxa, not just the numerical dominants, would contribute to similarity measures.

Cluster analysis produces a dendrogram that represents discrete groupings of samples along a scale of similarity. This representation is most useful when delineating among sites with distinct community structure. MDS ordination produces a plot or “map” in which the distance between samples represents their rank ordered similarities, with closer proximity in the plot representing higher similarity. Ordination provides a more useful representation of patterns in community structure when assemblages vary along a steady gradation of differences among sites. Stress provides a measure of adequacy of the representation of similarities in the MDS ordination plot (Clarke 1993). Stress levels less than 0.05 indicate an excellent representation of relative similarities among samples with no prospect of misinterpretation. Stress less than 0.1 corresponds to a good ordination with no real prospect of a misleading interpretation. Stress less than 0.2 still provides a potentially useful two-dimensional picture, while stress greater than 0.3 indicates that points on the plot are close to being arbitrarily placed. Together, cluster analysis and MDS ordination provide a highly informative representation of patterns of community-level similarity among samples. The “similarity profile test” (SIMPROF) was used to provide statistical support for the identification of faunal assemblages (i.e., selection of cluster groups). SIMPROF is a permutation test of the null hypothesis that the groups identified by cluster analysis (samples included under each node in the dendrogram) do not differ from each other in multivariate structure.

3. RESULTS AND DISCUSSION

3.1 Sediment Conditions

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

Sediment conditions were characterized by three parameters measured during 2011 at each of the 14 sampling stations: (1) *Clostridium perfringens*, (2) grain size (gravel, sand, silt, and clay), and (3) total organic carbon (Table 3-1).

Spores of the anaerobic bacterium *Clostridium perfringens* provide a sensitive tracer of effluent solids. Temporal analyses of *C. perfringens* at the 14 sampling sites demonstrated that a sharp increase occurred coincident with diversion of effluent to the offshore outfall at sites within two kilometers from the diffuser (Figure 3-1). *C. perfringens* concentrations have declined or remained comparable to the baseline at all other locations during the post-diversion period. *C. perfringens* counts (normalized to percent fines) in samples collected during 2011 were highest at stations NF14 and NF24 (Table 3-1); both stations are located within two kilometers from the outfall (Figure 3-2).

The grain size composition of the sediments in 2011 remained consistent with results reported in prior years (Figure 3-3). There was considerable variability among the 14 stations with grain size profiles ranging from predominantly sand (e.g., NF13, NF17, and NF24) to almost entirely silt and clay (i.e., FF04), with most stations having mixed sediments (Table 3-1, Figure 3-4).

Concentrations of total organic carbon (TOC) in 2011 also remained similar to values reported in prior years at most stations (Figure 3-5). Concentrations of TOC track closely to percent fine sediments (i.e., silt + clay), with higher TOC values generally associated with higher percent fines (Maciolek et al. 2008). Nonetheless, at station NF12, the nearfield station with the highest percent fines, TOC concentrations for 2011 were the lowest reported in the history of the program and were comparable to values reported at farfield stations with mostly sandy sediments (i.e., FF01A and FF09) (Figure 3-5).

As in past years during the post-diversion period, the spatial distribution of the highest *C. perfringens* concentrations during 2011 identified effluent solids deposition only at sites closest to the discharge. And there was no indication in 2011 monitoring results that fine sediments or TOC are accumulating at sites near the outfall. These findings are consistent with prior year monitoring results (Maciolek et al. 2008, 2011).

Table 3-1. 2011 monitoring results for sediment condition parameters.

	Transition Area	Nearfield (<2 km from outfall)				Nearfield (>2 km from outfall)						Farfield		
Parameter	**FF12**	**NF13**	**NF14**	**NF17**	**NF24**	**NF04**	**NF10**	**NF12**	**NF20**	**NF21**	**NF22**	**FF01A**	**FF04**	**FF09**
Clostridium perfringens **(cfu/g dry/%fines)**	48	66	180	57	151	68	67	64	47	49	70	31	27	55
Total Organic Carbon (%)	0.29	0.06	0.21	0.03	0.68	0.12	0.37	0.44	0.25	0.88	0.7	0.22	2.11	0.34
Gravel (%)	1.5	0.6	42.8	0.0	0.2	0.2	0.5	0.2	28.8	0.5	1.6	0.5	0.0	0.7
Sand (%)	67.5	96.1	49.9	96.2	56.0	90.8	65.3	34.4	58.1	48.6	51.5	84.8	3.6	82.4
Silt (%)	23.0	1.1	4.2	0.6	34.1	3.0	23.5	46.1	9.2	45.2	36.4	10.5	58.4	8.6
Clay (%)	7.9	2.2	3.0	3.3	9.8	6.0	10.8	19.3	3.9	5.7	10.4	4.2	37.9	8.3
Percent Fines (Silt + Clay)	30.9	3.3	7.2	3.9	43.8	9.0	34.3	65.5	13.1	50.9	46.9	14.7	96.4	16.9

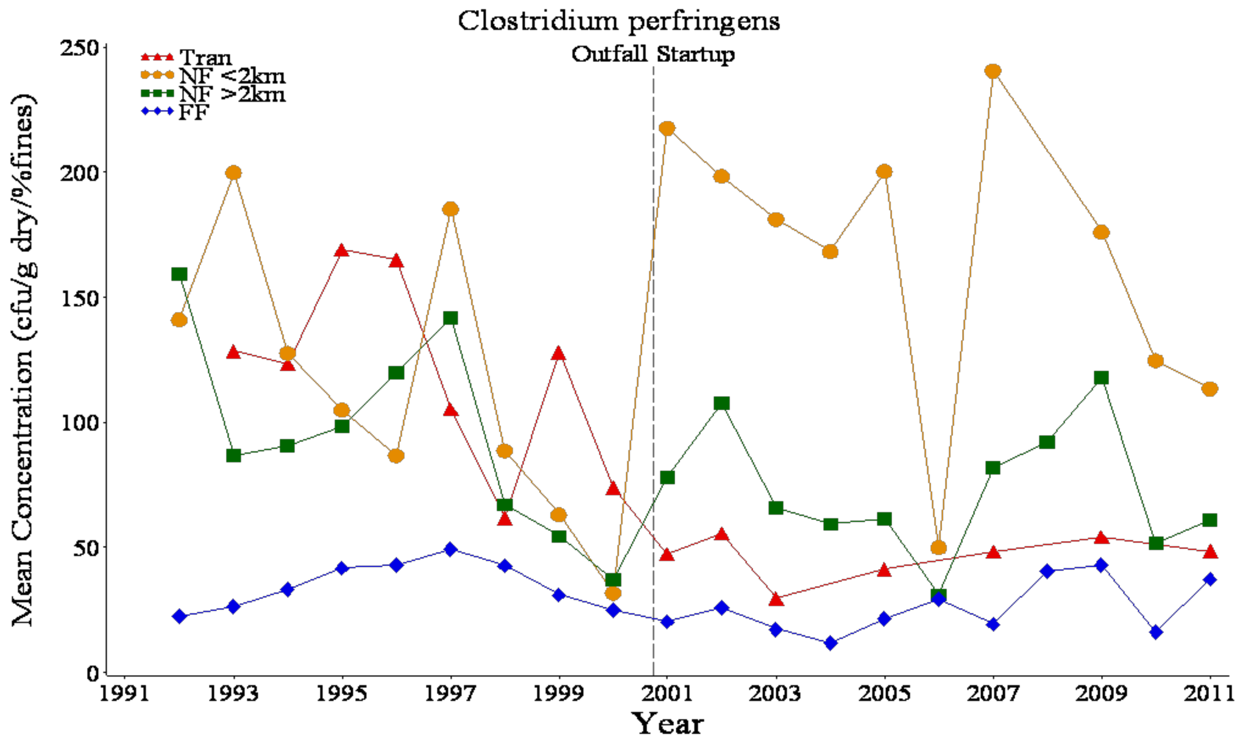

Figure 3-1. Mean concentrations of *Clostridium perfringens* in four areas of MA Bay, 1992 to 2011. Tran=Transition area; NF<2km=nearfield, less than two kilometers from the outfall; NF>2km=nearfield, more than two kilometers from the outfall; FF=farfield.

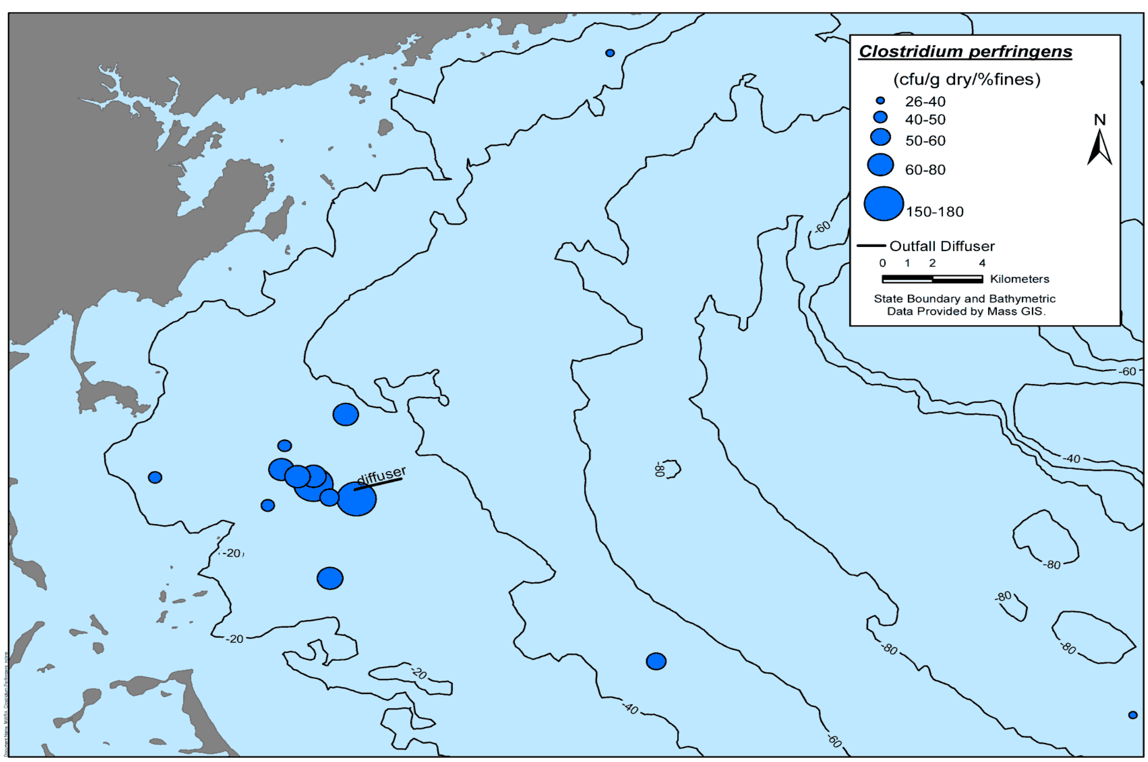

Figure 3-2. 2011 monitoring results for *Clostridium perfringens*.

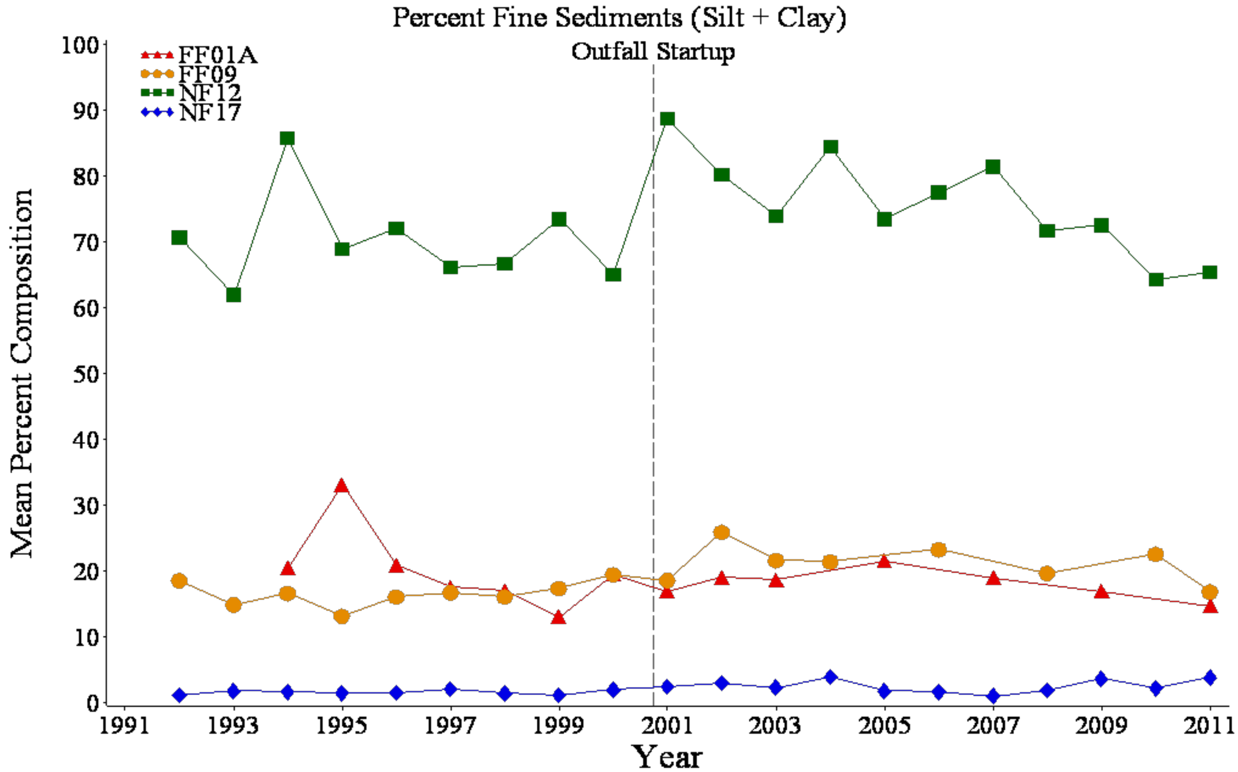

Figure 3-3. Mean percent fine sediments at four stations in MA Bay, 1992 to 2011.

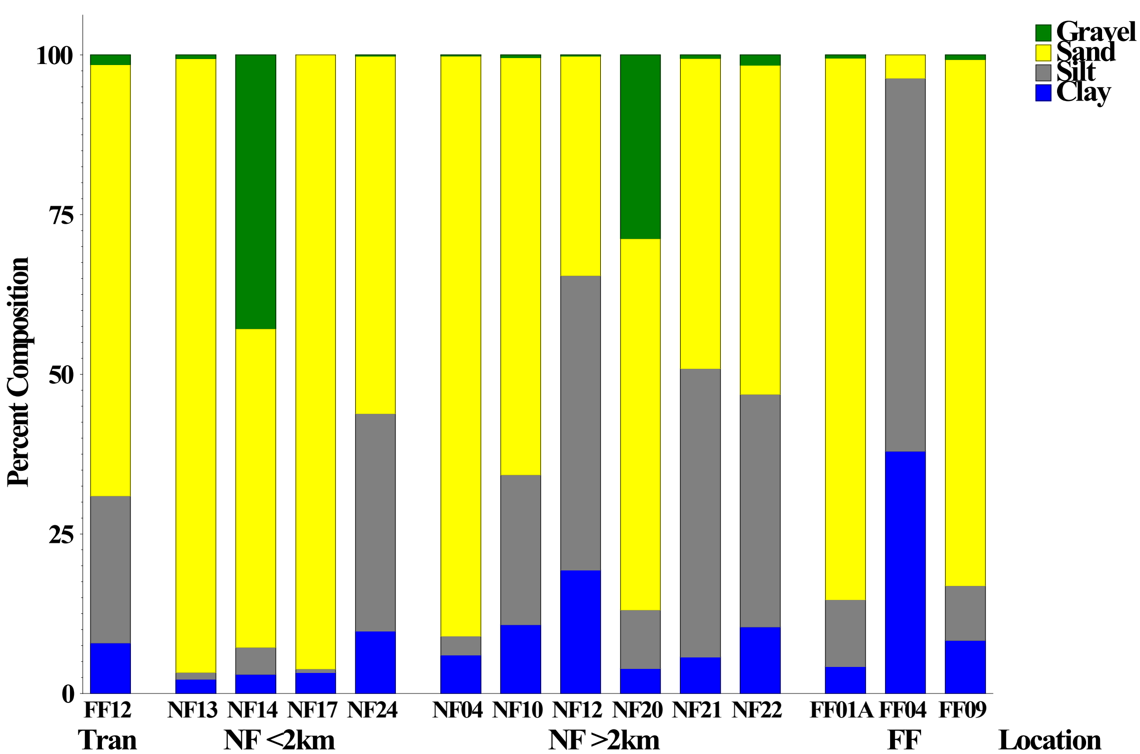

Figure 3-4. 2011 monitoring results for sediment grain size.

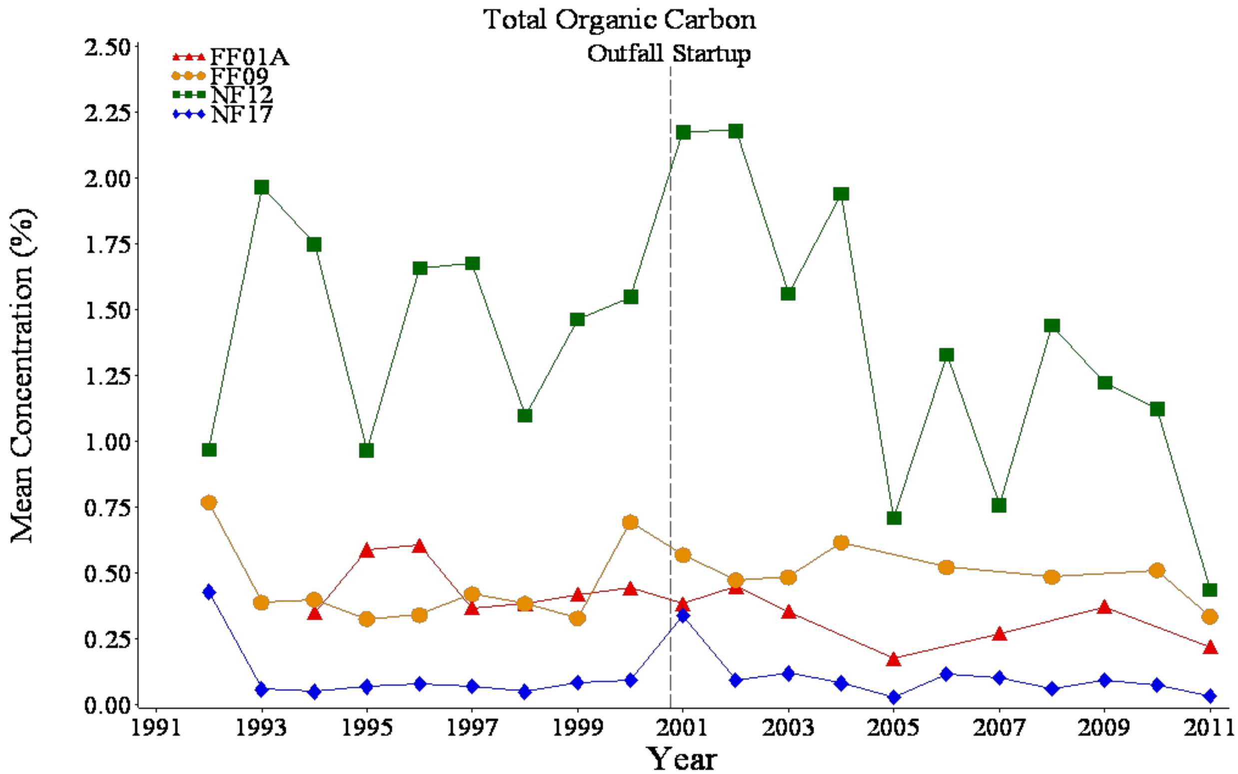

Figure 3-5. Mean concentrations of TOC at four stations in MA Bay, 1992 to 2011.

3.1.2 Anthropogenic Contaminants

Sediment samples collected during 2011 were analyzed for anthropogenic contaminants including both metals and organics. The "Effects Range Low" (ER-L) sediment quality guidelines from NOAA, based on the toxicity of contaminants to infaunal organisms, provide a useful measure against which to compare sediment contaminant concentrations (Long et al. 1995). In 2011, lead, mercury, nickel, total DDT, total PAH, and total PCB each had at least one value reported (i.e., at one of the 14 stations) that exceeded the ER-L limit (Table 3-2). Nine of the 14 stations sampled in Massachusetts Bay had values for at least one contaminant that exceeded the ER-Ls, and these stations were from areas throughout Massachusetts Bay. No contaminant concentrations reported in 2011 exceeded the baseline range (i.e., 1992-2000) of values for the 14 sampling stations however (Table 3-2).

Most of the highest values reported during 2011 were at station NF21, which is more than two kilometers from the outfall (Table 3-2). Mercury concentrations at station NF21 exceeded the ER-M sediment quality guideline. The ER-M (effects range median) represents a contaminant level above which adverse impacts to benthic organisms are often detected (Long et al. 1995). Higher contaminant levels are strongly correlated with smaller sediment particle sizes (Maciolek et al. 2008; Bothner et al. 2007). The two stations with the highest contaminant concentrations, NF12 and NF21, have the highest percent fines of the nearfield stations, and are relatively close to Boston Harbor, the main historic source for contaminants in MA Bay. The influence of percent fines and proximity to contaminant sources is evident in comparisons of contaminant concentrations at NF12, NF21, FF04 (farfield station, high percent fines), and NF17 (nearfield station, less than 2km from outfall, sandy sediment) (Figures 3-6 to 3-9).

The MWRA's Contingency Plan established threshold levels (based on ER-Ls) against which to measure sediment contaminant concentrations at the nearfield stations (MWRA 2001). No Contingency Plan threshold exceedances for any sediment contaminants were reported in 2011. Statistical analyses in previous monitoring reports (Maciolek et al. 2008, 2009) documented the lack of evidence of contaminants from effluent accumulating in the sediments. The 2011 results support these findings. The spatial distribution of higher contaminant concentrations primarily reflects both the percentage of fine particles in the sediment, and the proximity to historic sources of contaminants in Boston Harbor (Maciolek et al. 2008; Bothner et al. 2007).

Table 3-2. 2011 sediment contaminant values that exceeded ER-L levels.

		Transition Area	Nearfield (<2 km from outfall)		Nearfield (>2 km from outfall)				Farfield		Sediment Quality Guidelines	
Parameter	**Units**	**FF12**	**NF14**	**NF24**	**NF10**	**NF12**	**NF20**	**NF21**	**NF22**	**FF04**	**Baseline range**	**ER-L**	**ER-M**
Lead	mg/kg dry			50.0		57.0		50.8		55.6	21.6 - 92.8	46.7	218
Mercury				0.21		0.23		1.01	0.17	0.17	0.02 - 1.69	0.15	0.71
Nickel						22.9	22.2			34.0	4.8 - 33.5	20.9	51.6
Total DDT	ng/kg dry	2.01	1.90	3.64	2.32	5.94	1.61	8.04	2.90	3.73	0 - 19.66	1.58	46.1
Total PAH				5353		8112		10388	4434		64 - 17223	4022	44792
Total PCB								34.6			0 - 71.9	22.7	180

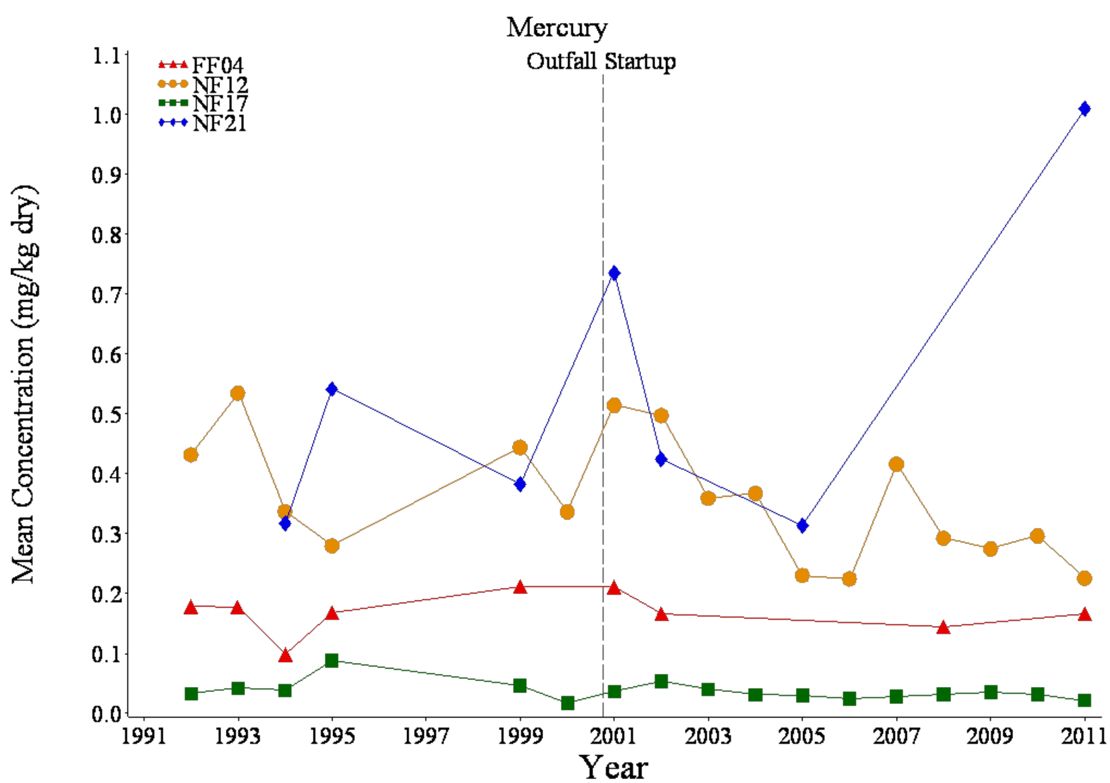

Figure 3-6. Mean concentrations of Mercury at four stations in MA Bay, 1992 to 2011.

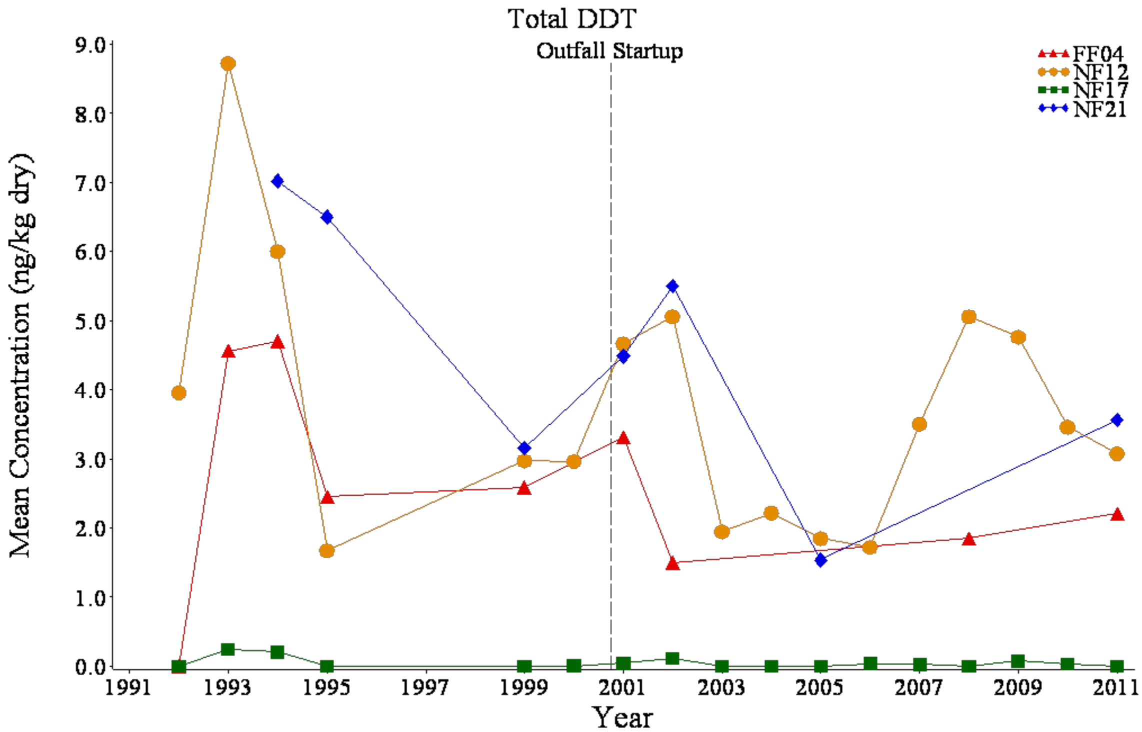

Figure 3-7. Mean concentrations of Total DDT at four stations in MA Bay, 1992 to 2011.

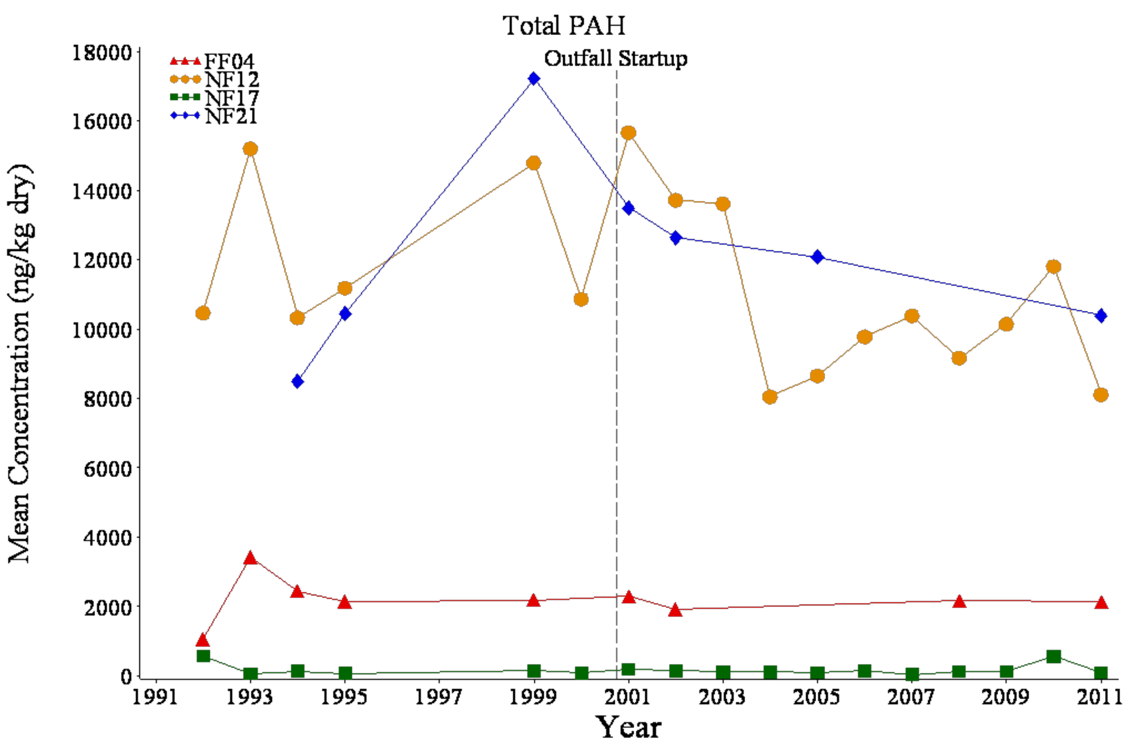

Figure 3-8. Mean concentrations of Total PAH at four stations in MA Bay, 1992 to 2011.

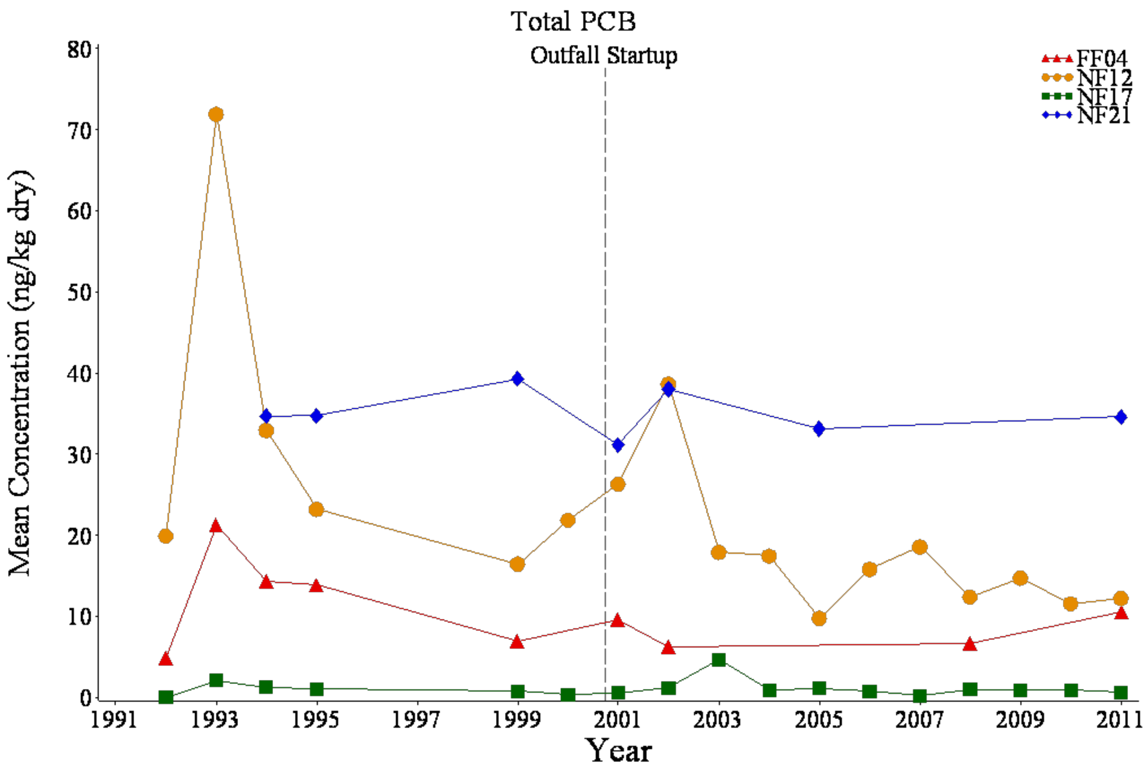

Figure 3-9. Mean concentrations of Total PCB at four stations in MA Bay, 1992 to 2011.

3.2 Benthic Infauna

3.2.1 Community Parameters

A total of 15,067 infaunal organisms were counted from the 14 samples in 2011. Organisms were classified into 229 discrete taxa; 199 of those taxa were species-level identifications. Abundance values reported herein reflect the total counts from both species and higher taxonomic groups, while diversity measures are based on the species-level identifications only (Table 3-3).

Abundance values reported for 2011 were comparable to the previous year, and among the lowest reported since 1993 and 1994 (Figure 3-10). The numbers of species reported for 2011, averaging around 60 to 70 species per sample, was consistent with numbers reported since the late-1990s (Figure 3-11).

There were threshold exceedances in 2011 for Pielou's Evenness (J') and Shannon-Wiener Diversity (H'); no exceedances were reported for other diversity measures or for the percent opportunistic species (Table 3-4). The exceedances for J' and H' were based on higher values relative to the baseline range. Contingency Plan threshold exceedances for the same parameters were observed in 2010 (Maciolek et al. 2011). Analyses of infaunal data in 2011 were focused on assessing whether the threshold exceedances reflect an influence from the outfall or region-wide changes in faunal assemblages, unrelated to the discharge.

Spatial comparisons of the 2011 values for J' and H' indicated that there was no association between high evenness or diversity values (or low values) and proximity to the outfall diffuser (Figures 3-12 and 3-13). Temporal comparisons of J' and H' values demonstrated no indication of increases in the post-diversion period compared to the baseline at stations closest to the outfall (Figures 3-14 and 3-15). Increases in J' and H' that resulted in threshold exceedances were driven by nearfield stations that are more than two kilometers from the outfall, and less likely to be influenced by the discharge. Furthermore, J' and H' have increased in both nearfield and farfield locations, suggesting region-wide changes, unrelated to the discharge. As reported by Maciolek et al. (2011), region-wide declines in the abundance of the spionid polychaete, *Prionospio steenstrupi*, are likely an important factor in the recent increases in J' and H'. This species has been the numerically dominant taxon in the MA Bay samples since the mid to late 1990's, but has declined substantially in recent years (Figure 3-16).

Table 3-3. 2011 monitoring results for infaunal community parameters.

	Transition Area	Nearfield (<2 km from outfall)				Nearfield (>2 km from outfall)						Farfield		
Parameter	**FF12**	**NF13**	**NF14**	**NF17**	**NF24**	**NF04**	**NF10**	**NF12**	**NF20**	**NF21**	**NF22**	**FF01A**	**FF04**	**FF09**
Total Abundance (per grab)	894	1874	1345	1367	818	1407	1075	1147	519	1100	1169	1293	139	920
Number of Species (per grab)	64	71	74	65	68	73	61	61	57	56	58	70	27	66
Log-series alpha	15.80	14.66	16.90	14.39	17.68	16.36	14.07	13.83	16.41	12.49	12.86	15.99	10.03	16.43
Shannon-Wiener Diversity (H')	4.15	4.06	4.43	3.61	4.46	3.87	4.17	4.28	4.76	4.00	3.83	4.35	2.99	4.36
Pielou's Evenness (J')	0.69	0.66	0.71	0.60	0.73	0.63	0.70	0.72	0.82	0.69	0.65	0.71	0.63	0.72

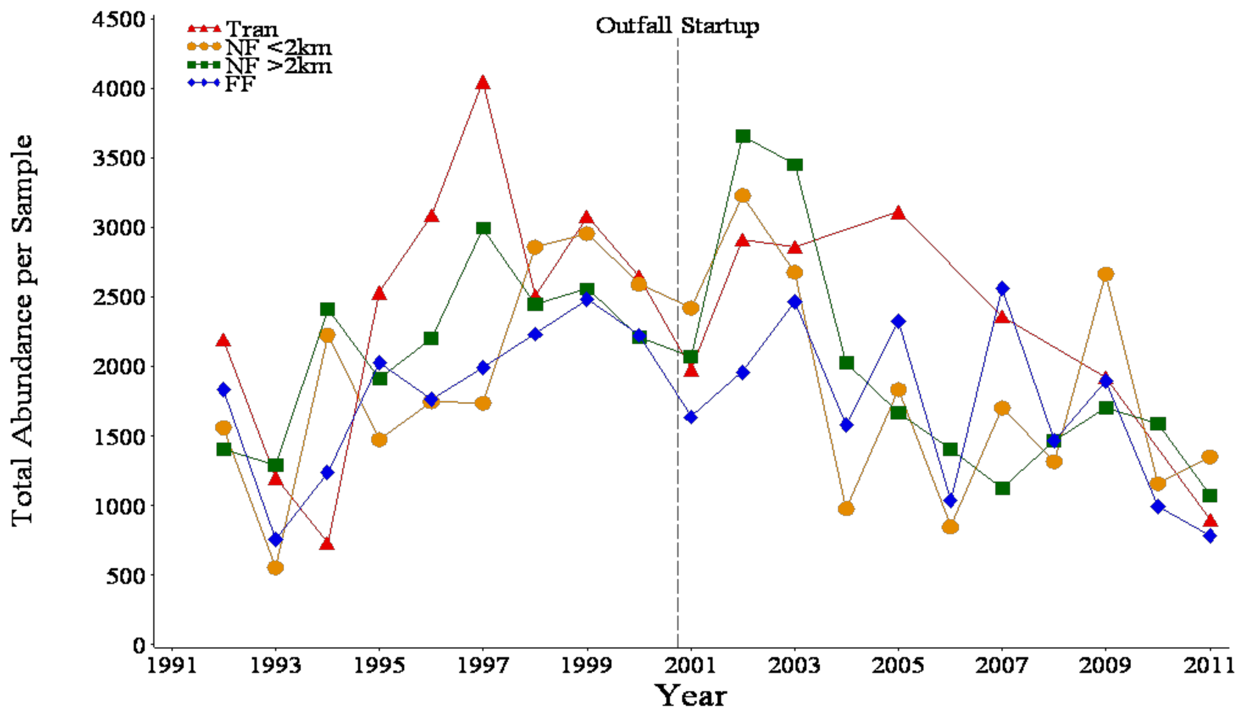

Figure 3-10. Mean infaunal abundance per sample at four areas of MA Bay, 1992 to 2011. Tran=Transition area; NF<2km=nearfield, less than two kilometers from the outfall; NF>2km=nearfield, more than two kilometers from the outfall; FF=farfield.

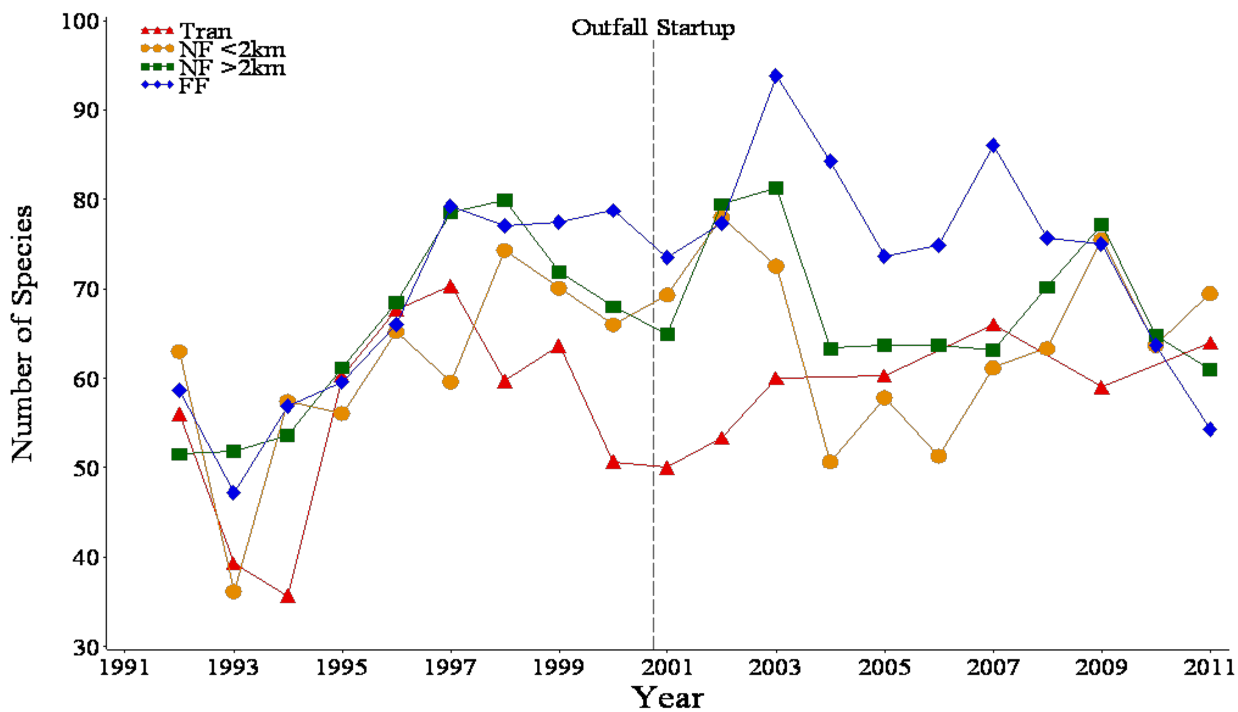

Figure 3-11. Mean number of species per sample at four areas of MA Bay, 1992 to 2011. Tran=Transition area; NF<2km=nearfield, less than two kilometers from the outfall; NF>2km=nearfield, more than two kilometers from the outfall; FF=farfield.

Table 3-4. Infaunal monitoring threshold results, August 2011 samples.

Parameter	Threshold range		Result	Exceedance?
	Low	High		
Total species	43	81.9	64.4	No
Log-series Alpha	9.42	15.8	15.04	No
Shannon-Weiner H'	3.37	3.99	4.15	Yes, Caution Level
Pielou's J'	0.57	0.67	0.69	Yes, Caution Level
Apparent RPD	1.18	NA	3.06	No
Percent opportunists		10%	0.19%	No

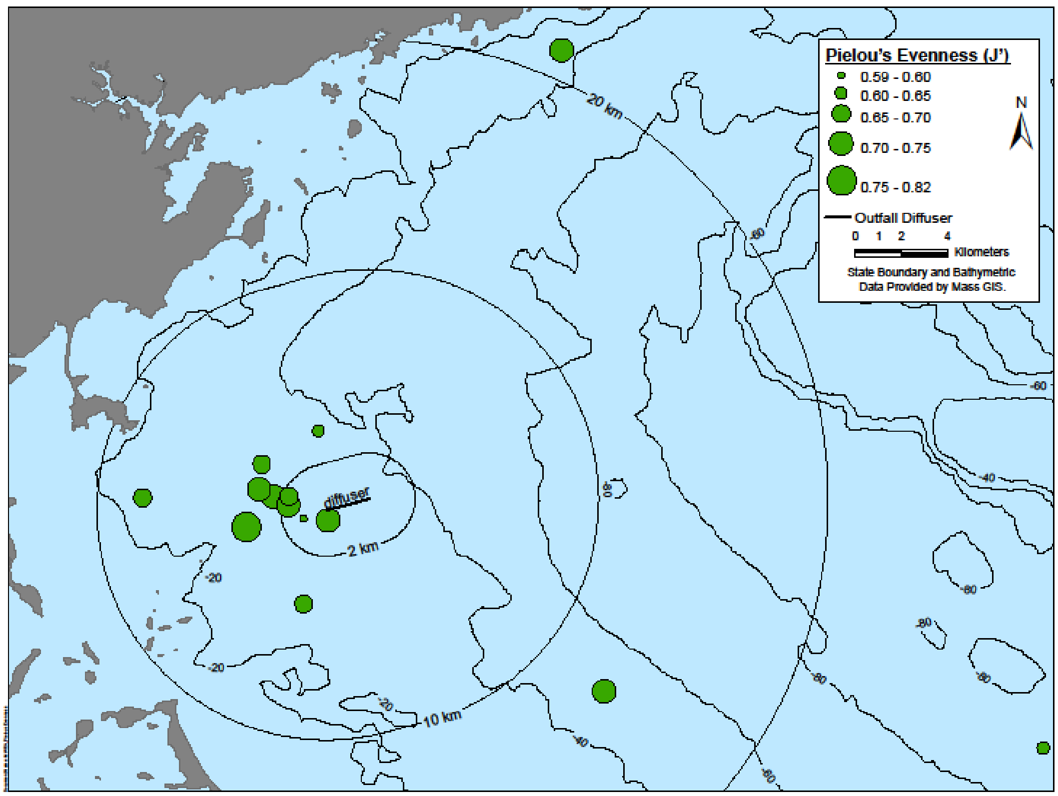

Figure 3-12. 2011 values for Pielou's evenness (J').

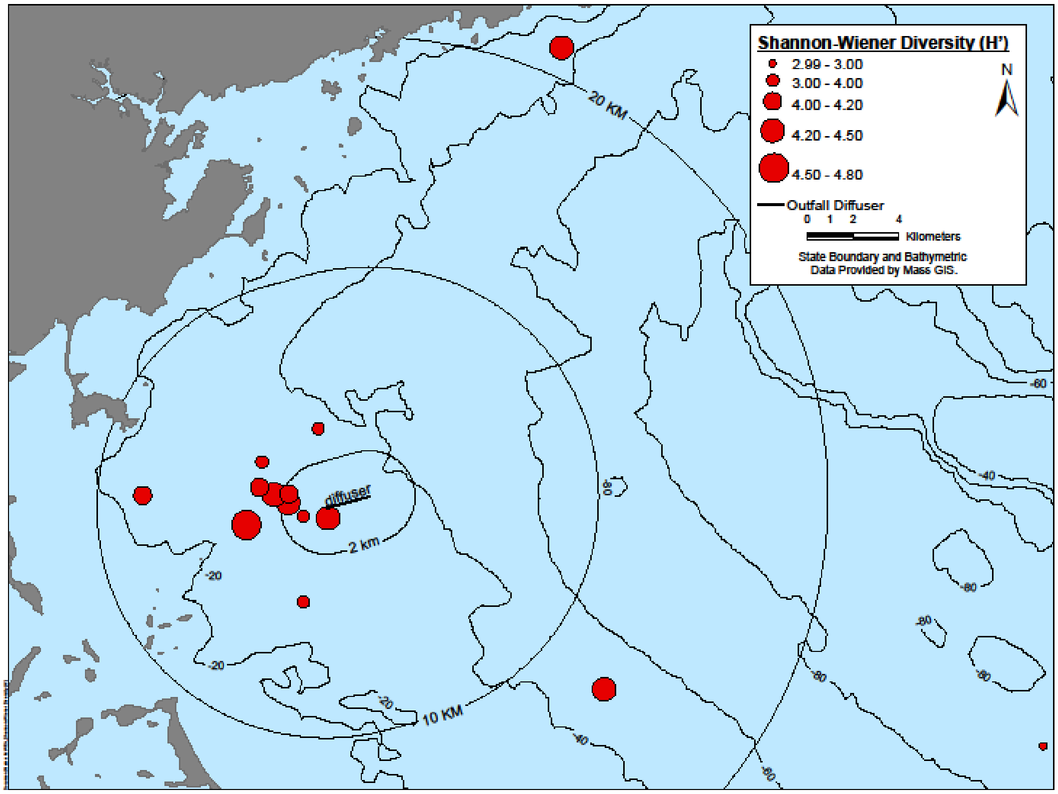

Figure 3-13. 2011 values for Shannon-Wiener diversity (H').

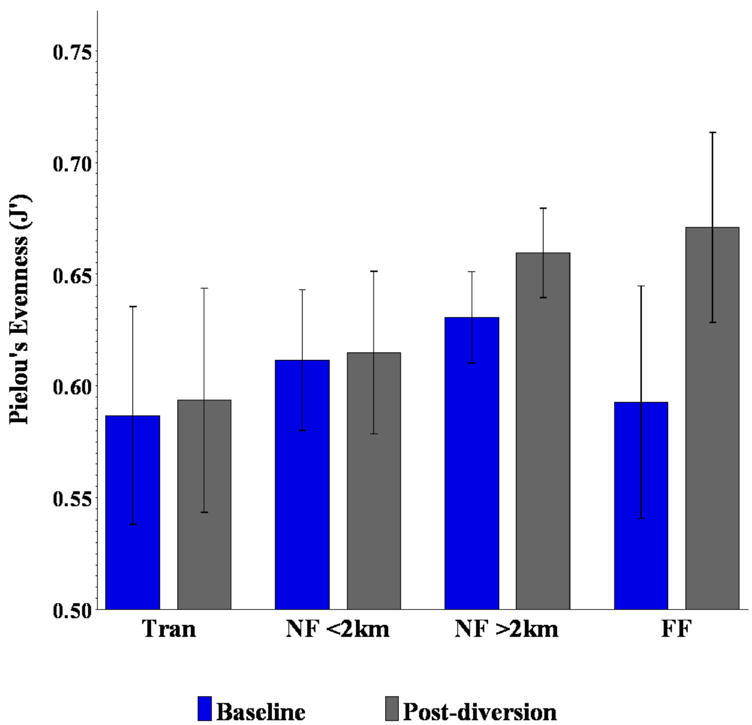

Figure 3-14. Mean J' per sample at four areas of MA Bay during the baseline (1992 to 2000) and post-diversion (2001 to 2011) periods. Tran=Transition area; NF<2km=nearfield, less than two kilometers from the outfall; NF>2km=nearfield, more than two kilometers from the outfall; FF=farfield.

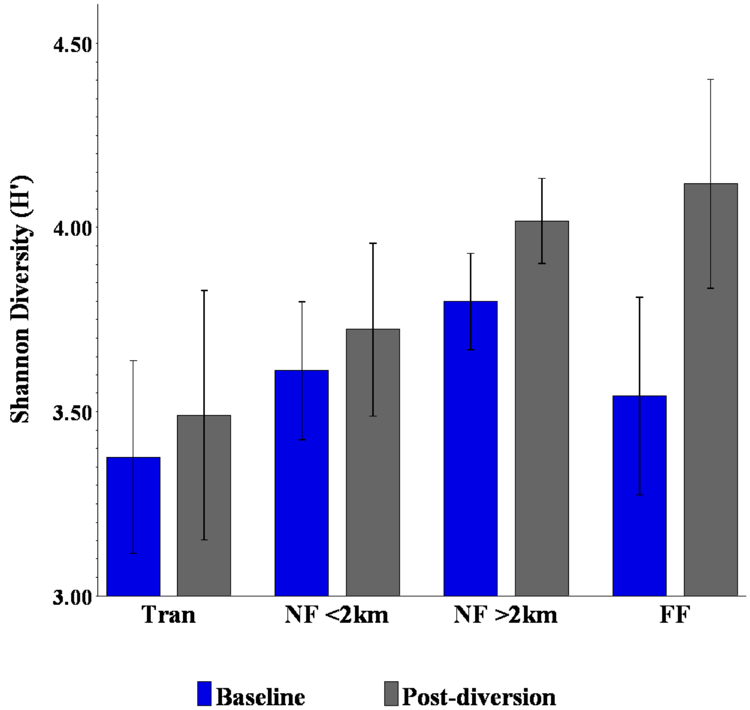

Figure 3-15. Mean H' per sample at four areas of MA Bay during the baseline (1992 to 2000) and post-diversion (2001 to 2011) periods. Tran=Transition area; NF<2km=nearfield, less than two kilometers from the outfall; NF>2km=nearfield, more than two kilometers from the outfall; FF=farfield.

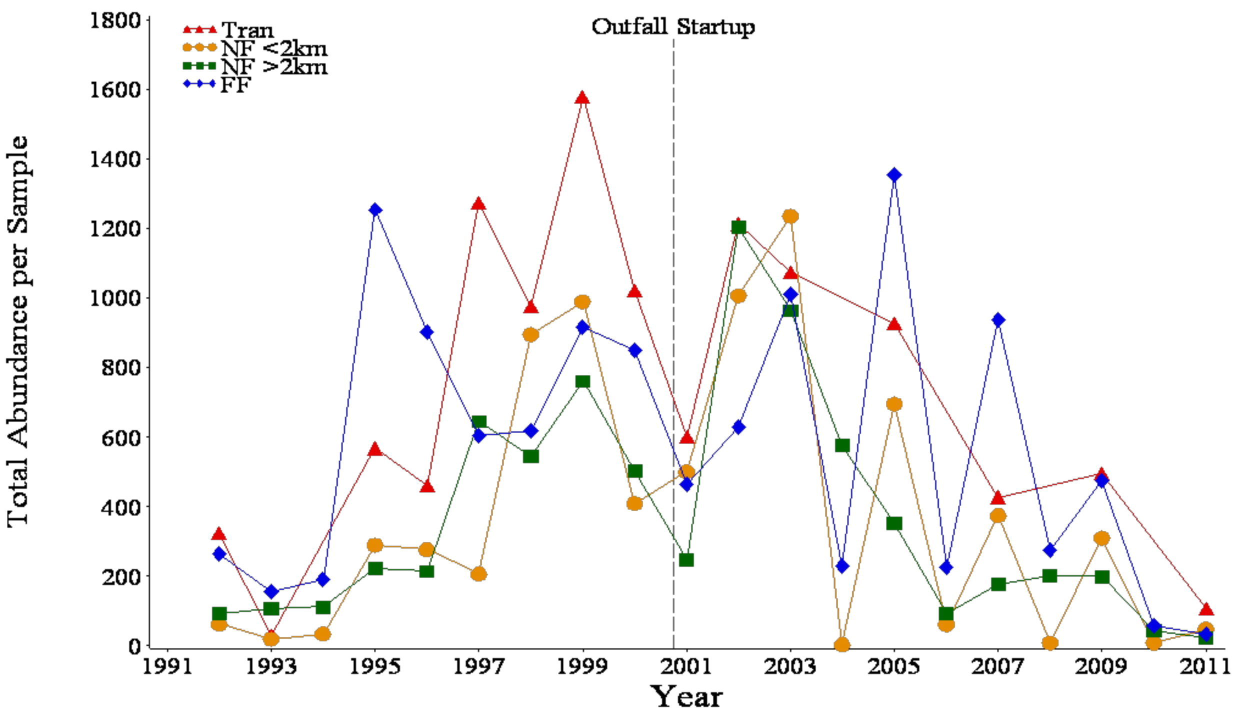

Figure 3-16. Mean abundance per sample of Prionospio steenstrupi at four areas of MA Bay, 1992 to 2011. Tran=Transition area; NF<2km=nearfield, less than two kilometers of from the outfall; NF>2km=nearfield, more than two kilometers from the outfall; FF=farfield.

3.2.2 Infaunal Assemblages

Multivariate analyses were used to assess spatial and temporal patterns in the faunal assemblages at the MA Bay sampling stations. Three main assemblages were identified in a cluster analysis of the 14 samples from 2011 (Figure 3-17). Assemblages varied considerably in species composition, but were mostly dominated by polychaetes (Table 3-5). The three main assemblages occurred at stations within two kilometers of the discharge and also at stations more than two kilometers from the discharge (Figure 3-18). Thus, stations closest to the discharge are not characterized by a unique faunal assemblage reflecting effluent impacts. Comparisons of faunal distribution to habitat conditions indicated that patterns in the distribution of faunal assemblages follow differences in sediment types and bottom depth at the sampling stations (Figures 3-19 and 3-20).

Temporal analyses of faunal assemblages at five stations during 1992 to 2011 indicated that assemblages varied little over time and that samples were generally most similar to others collected at the same station over time (Figure 3-21). To the extent that an assemblage from one station was similar to the assemblage found at another station, the two most similar assemblages were found at a nearfield station within two kilometers from the outfall (NF14) and a farfield station (FF01A) (Figure 3-21).

Multivariate analyses found no evidence of impacts from the offshore outfall on infaunal communities in MA Bay. This further supports findings that increased J' and H' are a region-wide occurrence unrelated to the discharge.

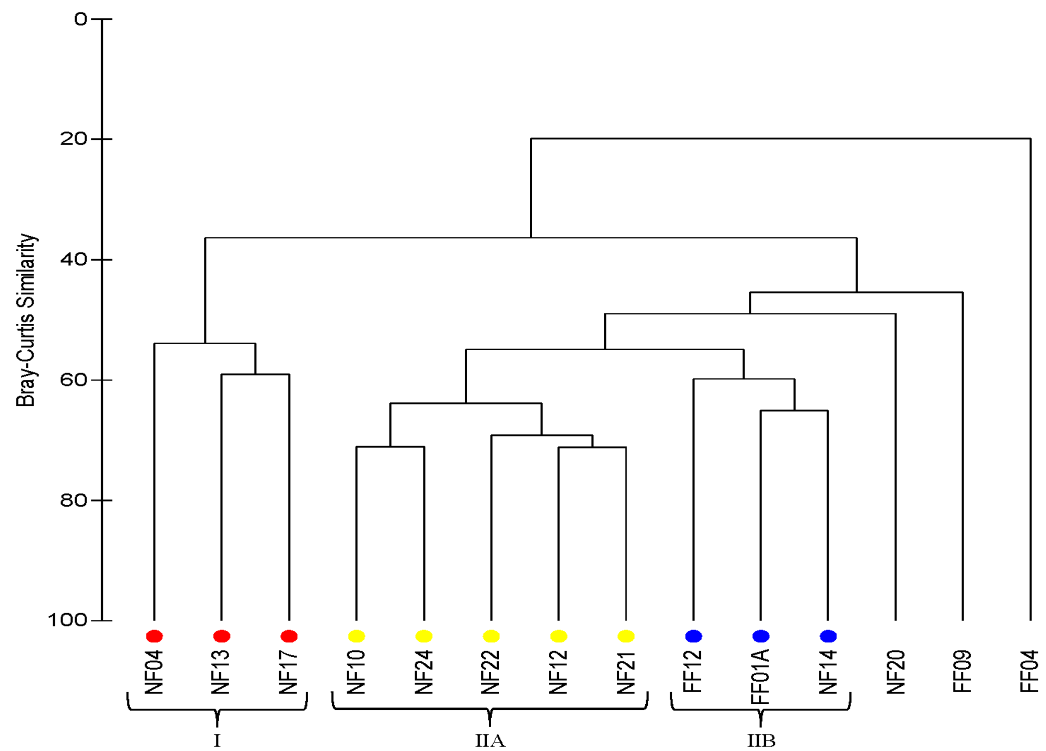

Figure 3-17. Results of cluster analysis of the 2011 infauna samples.

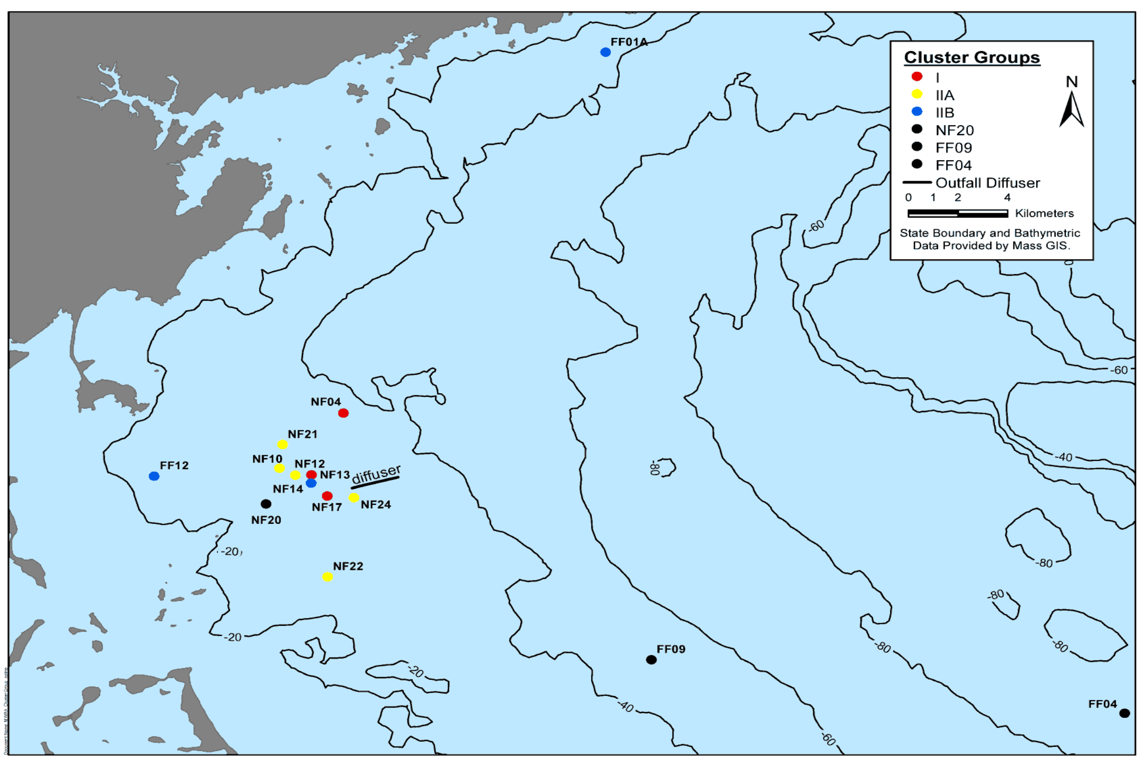

Figure 3-18. Station map showing faunal assemblages identified by cluster analysis of the 2011 infauna samples.

Table 3-5. Abundance (mean # per grab) of numerically dominant taxa (10 most abundant per group) composing infaunal assemblages identified by cluster analysis of the 2011 samples.

Family	Species	I	IIA	IIB	NF20	FF09	FF04
Mollusca (Bivalvia)							
Cardiidae	*Parvicardium pinnulatum*	89.7	0.2	78.0	8.0	-	-
Mytilidae	*Crenella decussata*	6.7	1.4	16.3	14.0	52.0	-
Nuculidae	*Nucula delphinodonta*	20.0	26.4	81.3	3.0	72.0	-
Solenidae	*Ensis directus*	34.3	-	48.0	-	-	-
Thyasiridae	*Thyasira gouldi*	-	6.0	2.7	-	51.0	3.0
Annelida (Polychaeta)							
Ampharetidae	*Anobothrus gracilis*	-	0.4	-	-	103.0	12.0
Amphinomidae	*Paramphinome jeffreysii*	-	-	-	-	-	2.0
Capitellidae	*Mediomastus californiensis*	8.3	165.6	91.7	55.0	11.0	1.0
Cirratulidae	*Chaetozone anasimus*	10.3	-	-	-	-	2.0
	Monticellina baptisteae	11.0	73.4	54.3	39.0	-	-
	Monticellina cf. dorsobranchialis	2.0	21.8	32.3	18.0	-	-
	Tharyx acutus	29.0	126.6	60.0	37.0	1.0	-
Cossuridae	*Cossura longocirrata*	-	2.8	-	-	1.0	8.0
Lumbrineridae	*Ninoe nigripes*	1.0	58.4	39.7	14.0	13.0	16.0
Maldanidae	*Euclymene collaris*	101.7	-	-	17.0	-	-
	Maldane sarsi	-	2.4	-	-	49.0	6.0
	Rhodine loveni	-	-	-	-	32.0	-
Orbiniidae	*Leitoscoloplos acutus*	0.3	33.2	20.3	3.0	4.0	2.0
Oweniidae	*Owenia fusiformis*	12.7	5.6	104.7	-	-	-
Paraonidae	*Aricidea catherinae*	51.0	9.8	133.0	34.0	-	-
	Aricidea quadrilobata	-	7.0	-	-	32.0	2.0
	Levinsenia gracilis	1.3	126.6	28.7	8.0	84.0	67.0
Polygordiidae	*Polygordius jouinae*	312.0	1.4	14.7	5.0	-	-
Sabellidae	*Euchone incolor*	2.3	34.4	20.0	1.0	47.0	-
Spionidae	*Prionospio steenstrupi*	1.7	36.8	91.0	37.0	20.0	1.0
	Spio limicola	7.7	132.2	18.0	-	167.0	-
Syllidae	*Eusyllis sp. 2*	-	-	-	23.0	-	-
	Exogone hebes	162.7	2.2	19.3	49.0	5.0	-
	Exogone verugera	18.3	1.4	9.0	20.0	10.0	-
Annelida (Oligochaeta)							
Enchytraeidae	*Marionina welchi*	48.3	-	-	-	-	-
Tubificidae	*Tubificoides intermedius*	-	1.2	-	29.0	-	-
Arthropoda (Amphipoda)							
Aoridae	*Unciola inermis*	54.3	-	0.3	-	-	-
Corophiidae	*Crassicorophium crassicorne*	183.3	-	0.7	3.0	-	-
Chordata (Urochordata)							
Molgulidae	*Molgula manhattensis*	88.3	1.2	1.3	2.0	-	-

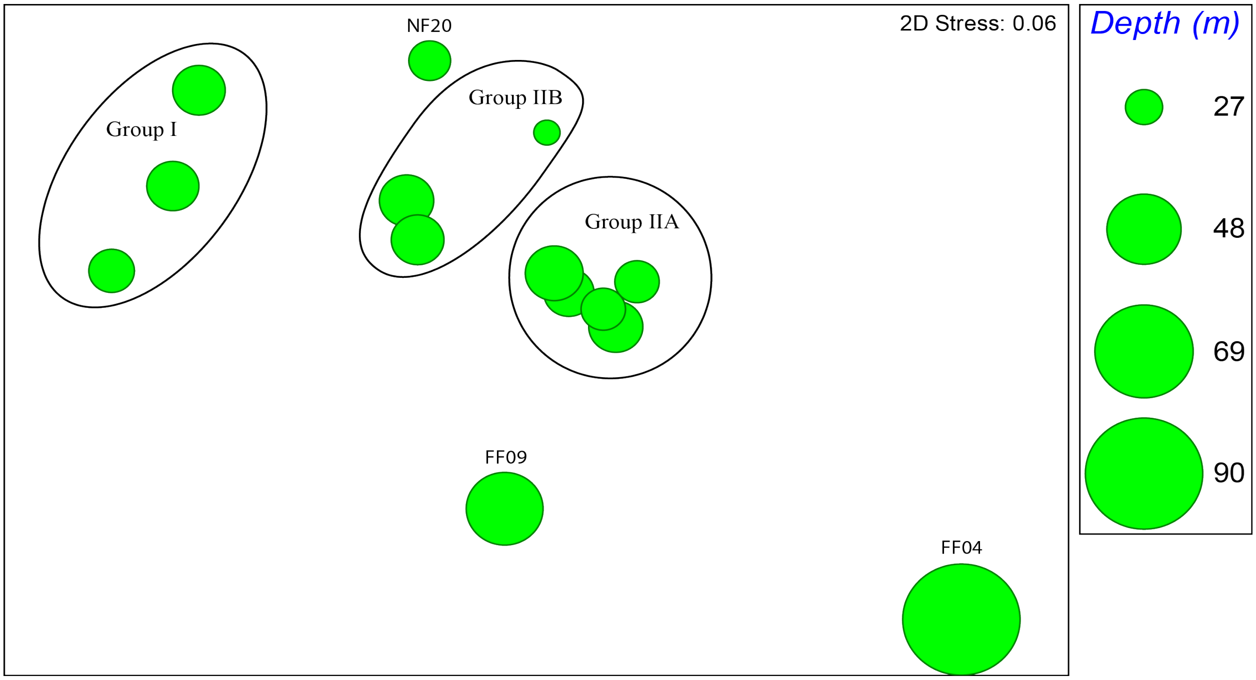

Figure 3-19. Bottom depth superimposed on nMDS ordination plot of the 2011 infauna samples. Each point on the plot represents one of the 14 samples; similarity of species composition is indicated by proximity of points on the plot. Faunal assemblages (Groups I-IIB) identified by cluster analysis are circled on the plot. The ordination and cluster analysis are both based on Bray-Curtis Similarity.

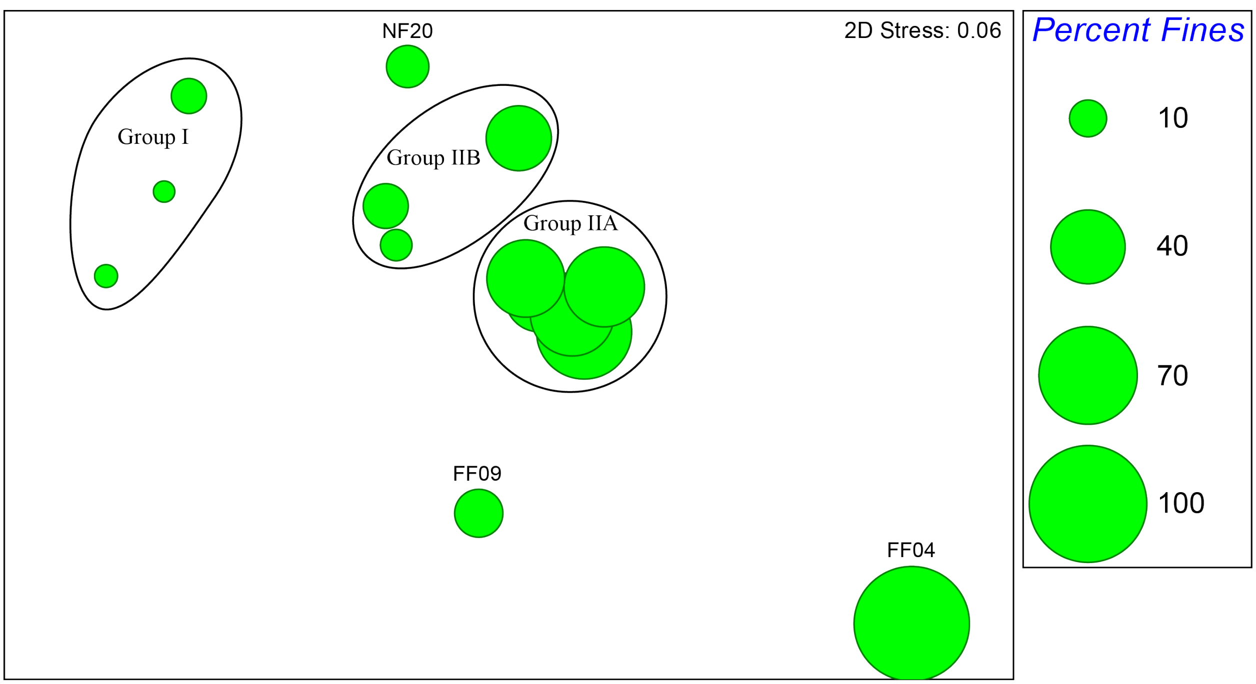

Figure 3-20. Percent fine sediments superimposed on nMDS ordination plot of the 2011 infauna samples. Each point on the plot represents one of the 14 samples; similarity of species composition is indicated by proximity of points on the plot. Faunal assemblages (Groups I-IIB) identified by cluster analysis are circled on the plot. The ordination and cluster analysis are both based on Bray-Curtis Similarity.

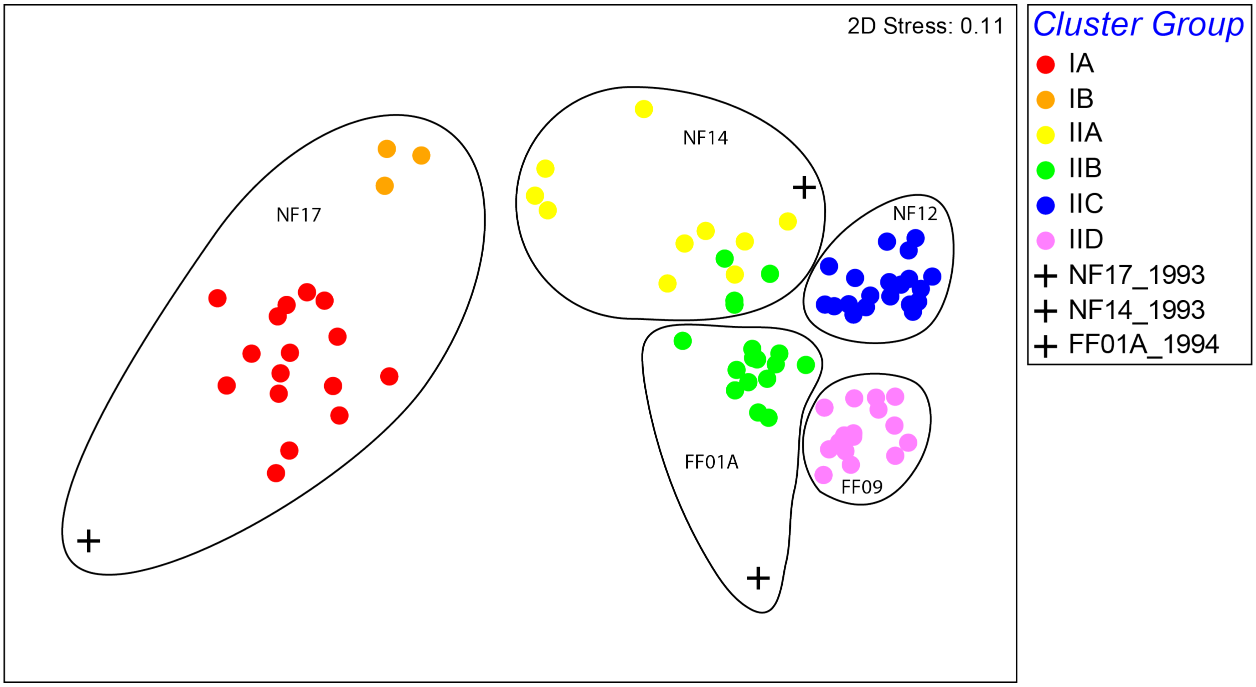

Figure 3-21. Cluster groups represented by colored dots superimposed on nMDS ordination plot of infauna samples from five stations, 1992 to 2011. Each point on the plot represents one sample; similarity of species composition is indicated by proximity of points on the plot. Each of the five stations is circled and labeled on the plot. The ordination and cluster analysis are both based on Bray-Curtis Similarity.

3.3 Sediment Profile Imaging

There was little change in SPI for 2011 relative to all post-baseline years. For sandy and silty bottom areas around the outfall, benthic habitat conditions in 2011 were similar to the previous ten years. There was little change in any of the sediment profile image parameters at any of the 23 nearfield monitoring stations. When baseline conditions (1992 to 2000) are compared with post-discharge (2001 to 2011) operation conditions there is no evidence of an outfall effect (Table 3-6). None of the minimum or maximum values for SPI parameters occurred in 2011. Physical processes still dominated the surface sediments. Sediments at many stations continued to be heterogeneous, ranging from sandy-silt-clay to cobble (Figures 3-22 and 3-23).

Table 3-6. Summary of SPI parameters pre- and post-baseline years for all nearfield stations. The year each table value occurred is in parentheses.

	Baseline Years 1992-2000 9-Year Interval	Post-Baseline Years 2001-2011 11-Year Interval
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)
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	3.0 (0.60 SD) cm
Annual Mean RPD All Values	2.4 (0.47 SD) cm	2.7 (0.40 SD) cm

The grand mean of the thickness of the apparent color redox-potential discontinuity (aRPD) layer in 2011 did not exceed the threshold of a 50% decrease from the baseline conditions. Post-baseline period aRPD remained deeper than during the baseline period (Table 3-6). If mean sRPD is calculated using only measured values, instead of including images where the RPD is deeper than the depth of the SPI image, the average thickness of the aRPD for 2011 would be 3.3 cm (SD = 0.91 cm). For 2011, there were no tends in the stations with measured aRPD layers (Figure 3-24). Since 2001, the thickness of the aRPD has tended to become deeper, which is an indication of higher quality benthic habitat conditions. For four stations that had measured aRPD layers in all years, NF22 was the same, NF24 trended up, and NF05 and NF07 trended down slightly in aRPD depth (Figure 3-25). There was no indication of organic carbon accumulation in sediments for any of the pre- or post-baseline years. The operation of the outfall does not appear to have affected benthic habitat quality. From 1995 to 2011, changes and trends in SPI variables appeared to be related to broader regional forcing factors, such as storm activity.

Overall, the sediment surface appeared to be structured primarily by physical processes and secondarily by biological processes. The dominance of hydrodynamic and physical factors (Butman et al. 2008), such as tidal and storm currents, turbulence, and sediment transport, is the principal reason that benthic habitat quality remains high in the nearfield area. The high-energy environment in the region of the outfall

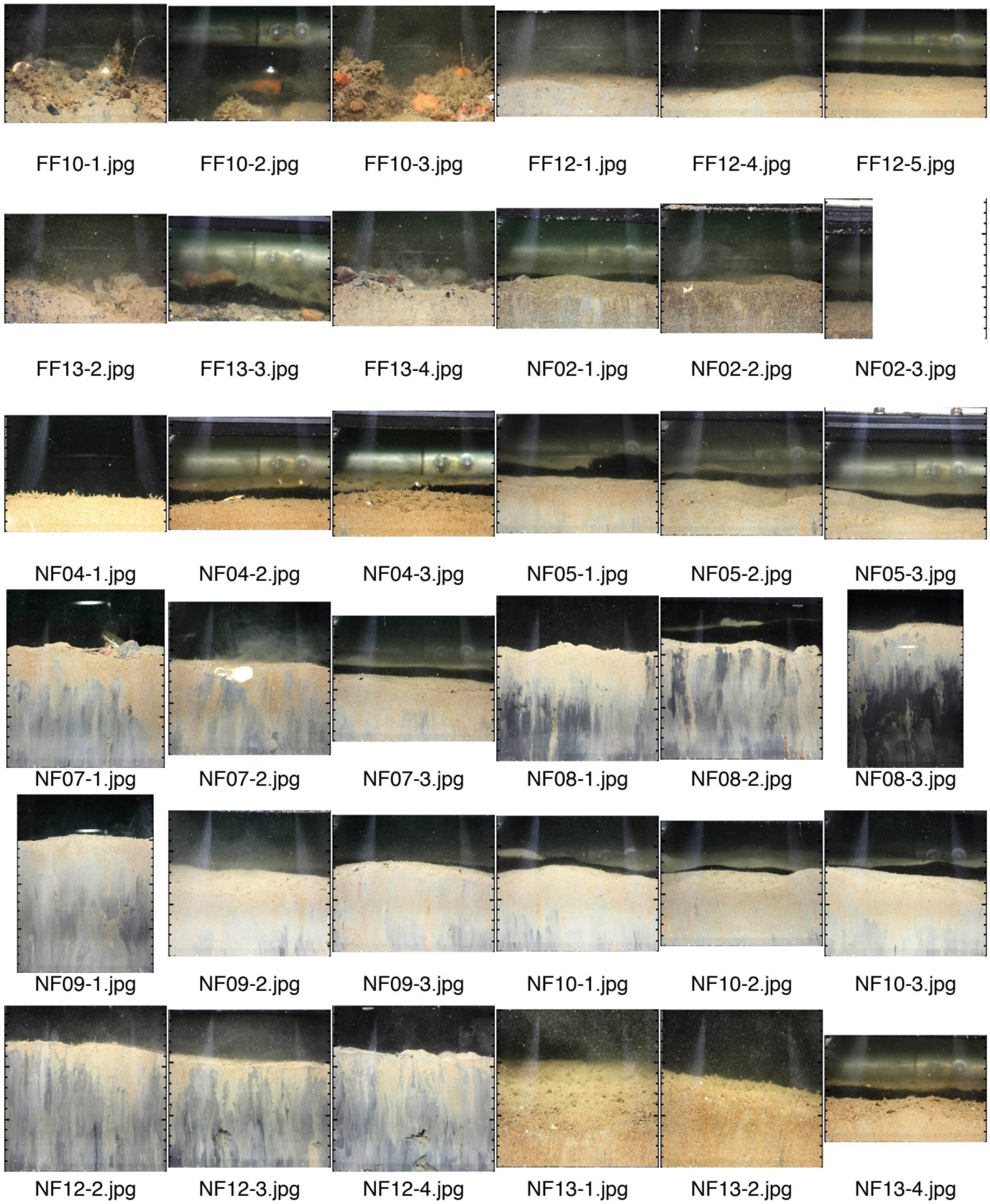

Figure 3-22. Thumbnail SPI images from 2011. Scale along the side of each image is in cm.

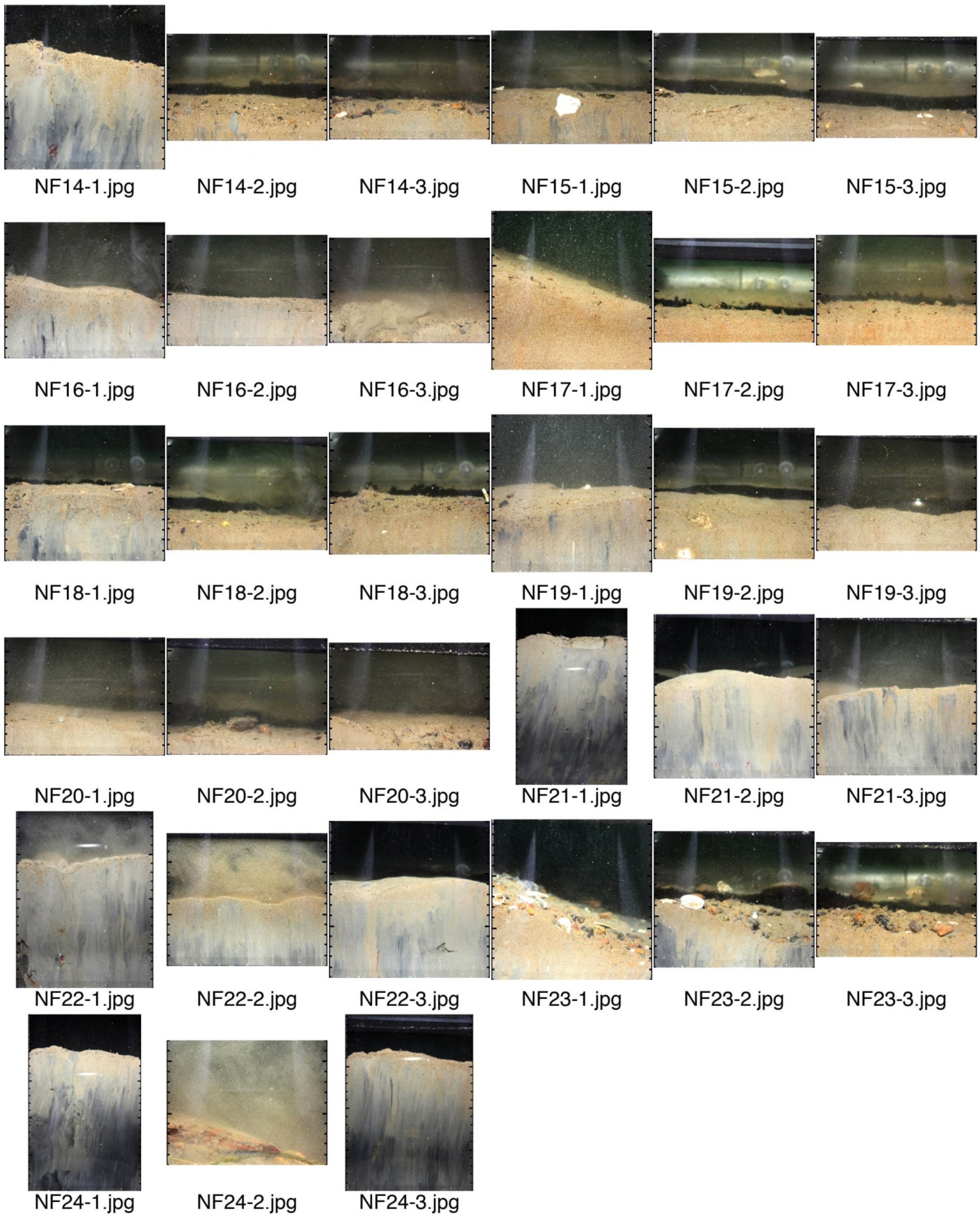

Figure 3-23. Thumbnail SPI images from 2011. Scale along the side of each image is in cm.

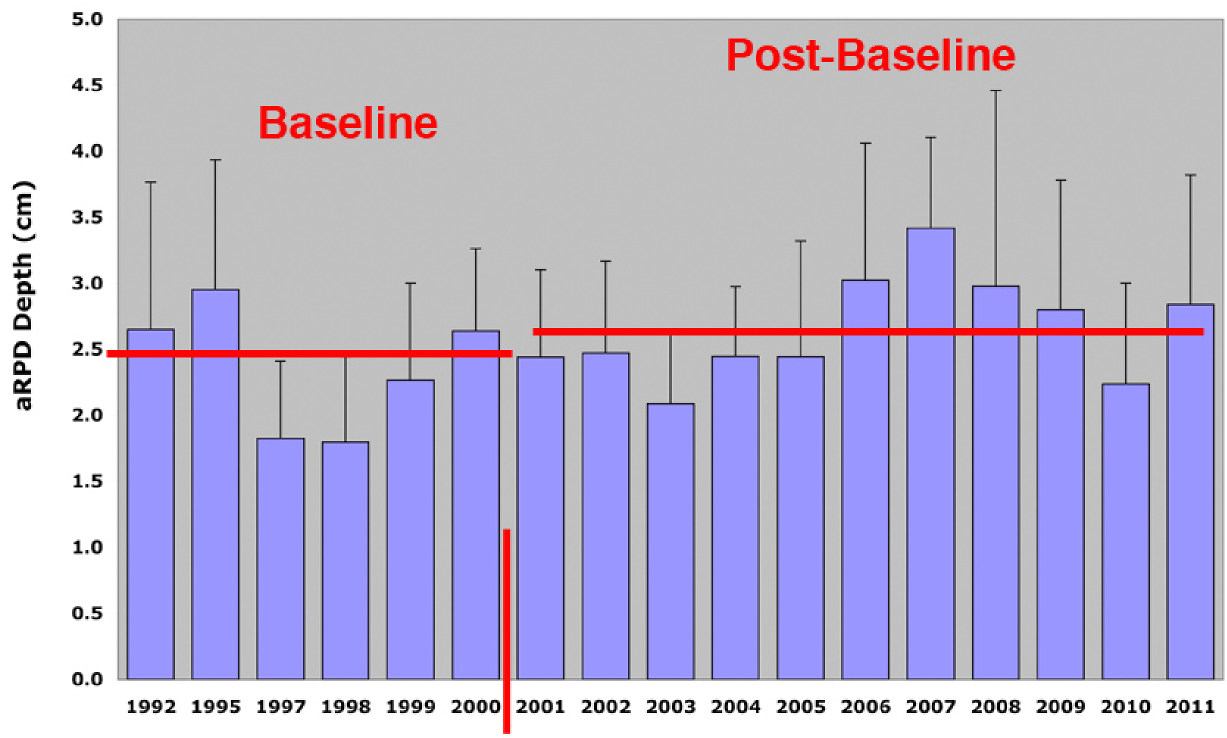

Figure 3-24. Average aRPD layer depth at nearfield stations by year for all 23 stations.

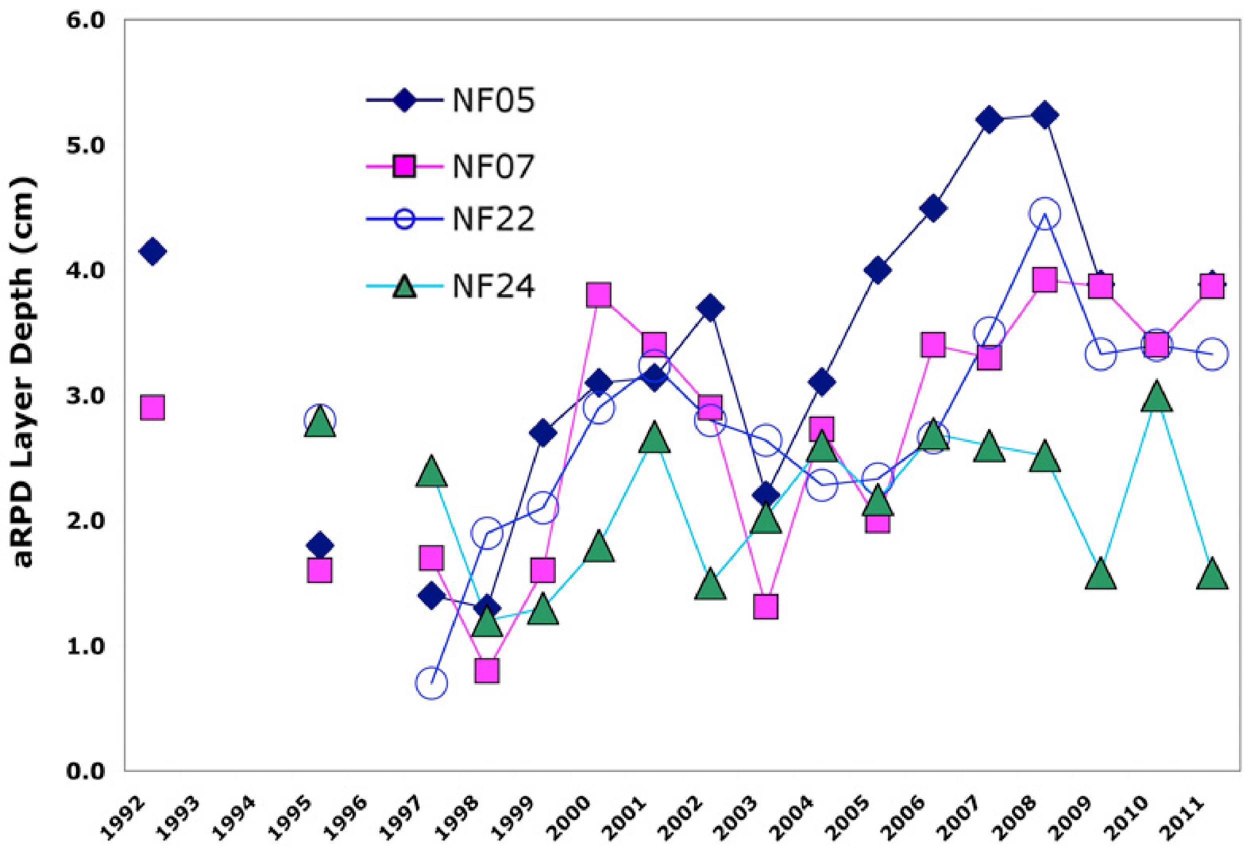

Figure 3-25. Long-term trends for nearfield stations that had measured aRPD layer depths.

disperses effluents quickly and prevents degradation of soft bottom benthic habitat. This is a general characteristic of ocean outfalls, where benthic impacts are limited to the area immediately around the outfall (<100 to 500 meters) (Juanes and Canteras 1995). The lack of accumulation of organic matter in the sediments is the principle reason for lack of benthic impacts in the nearfield. Pearson and Rosenberg (1978) generalized the response of benthic communities to organic loading, which appear to be similar in all marine systems. A summary of literature on benthos and TOC found large changes occurring around 3% TOC (Hyland et al. 1999). It is likely that benthic habitat quality in the nearfield will remain high if sediment organic content continues to remain low.

A key question that the SPI survey addresses is whether the sediments have become more or less anoxic; that is, whether the thickness of the sediment oxic layer has decreased or increased. For assessing outfall effects, the MWRA (1997) set a 50% reduction in the apparent color RPD layer depth over the study area as a critical trigger level. Similarly, a 50% increase in apparent color RPD over the baseline would be noteworthy. Maciolek et al. (2008) compared baseline to discharge years and found that the discharge years had significantly deeper RPD layers (baseline to discharge years multiplier 0.202, SE = 0.097, p = 0.038). The 2011 aRPD was above the baseline period RPD of 2.3 cm (SD = 0.88 cm). To exceed the threshold aRPD value, the aRPD would have to decline from the baseline mean of 2.3 cm by at least 1.3 cm, given the variability of the baseline data (CV = 37%).

3.4 Hard-Bottom Benthic Habitats and Fauna

Photographic coverage in 2011 ranged from 20 to 26 minutes of video footage at each waypoint and a total of 523 minutes of video were viewed and analyzed. Conditions observed in the video footage taken this year were similar to those seen in 2010, which differed slightly from that taken in previous years. The ROV was flown at a slightly reduced speed to permitted better resolution of the images on the HDV. Additionally, the ROV was occasionally paused and settled on the seafloor to allow for potential future screen grabs to be collected. A summary of the 2011 video analysis is included in Appendix B.

Physical conditions at each site during the 2011 survey were generally similar to those observed during 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. Sediment drape generally ranged from moderately light to moderate on the tops of drumlins and moderate to moderately heavy on the flanks of drumlins. As has been observed in previous years, 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.

The species seen during the 2011 survey are shown in Appendix C. A total of fifty-eight taxa, 4 algal species, 41 invertebrate species, 9 fish species, and 4 general categories were seen during the 2011 video analyses. The species and the number of species have remained relatively constant over the course of this study. The distribution of the species has also remained relatively constant during the last several years. Coralline algae continued to be the most common and widespread component of the benthic communities, being found at 21 of the 23 waypoints. The other three algal species, *Palmaria palmata* (dulse), *Ptilota serrata* (filamentous red algae), and *Agarum cribrosum* (shot-gun kelp) were also seen in numbers similar to those observed in previous years. Many of the dulse seen this year were encrusted with the *Membanipora* sp. tunicate. Common invertebrates seen in 2011 included: the horse mussel *Modiolus modiolus*, juvenile and adult northern sea stars *Asterias vulgaris*, the blood star *Henricia sanguinolenta*, white and cream encrusting tunicates (*Aplidium*/*Didemnum* spp.), the encrusting yellow sponge *Polymastia* sp. A, the sea peach tunicate *Halocynthia pyriformis*, and the brachiopod *Terebratulina septentrionalis*. Their abundances and distributions were also similar to those observed in previous years. The similarity to previous years also extended to the fish taxa, with the cunner *Tautogolabrus adspersus* being the most abundant and widely distributed fish encountered within the study area.

The taxa inhabiting the diffuser heads of the outfall continue to remain stable over time and did not change when the outfall went online. The inactive diffuser head (Diffuser #44) continues to support a moderate population of the sea peach tunicate *Halocynthia pyriformis* and a sparse population of the frilled anemone *Metridium senile* (Figure 3-26 a and b). 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 3-26 c and d). Additionally, numerous *M. senile* have also colonized the riprap around the base of the diffuser. The riprap in the vicinity of both diffuser heads continues to be colonized by a variety of encrusting organisms.

Occasional areas of physical disturbance were still discernible at the northern reference sites during the 2011 survey. These areas appeared to be older disturbances, characterized by overturned boulders that had small patches of coralline algae, fewer hydroids, fewer upright algae, and lesser drape than the surrounding areas.

Comparison of 2011 Data with Pre- and Post-Diversion Results

Previous general trends of decreased percent cover of coralline algae and declines in the number of upright algae observed in previous post-discharge years continued into 2011. Encrusting coralline algae has historically been the most abundant and widely distributed taxon encountered during the hard-bottom surveys. Table 3-7 shows the relative cover of coralline algae observed in video footage taken during the 1996 to 2011 surveys. Coralline algae were generally most abundant on the tops of drumlins on either side of the outfall (T1-2, T1-3, T1-4, and T4/6-1) and two southern reference sites (T8-1 and T8-2), and least abundant on the flanks of the drumlins (T2-2, T2-4, T4-2, and T6-1). The 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. 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 are seen at several other sites 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 has been less pronounced in the data collected from video images.

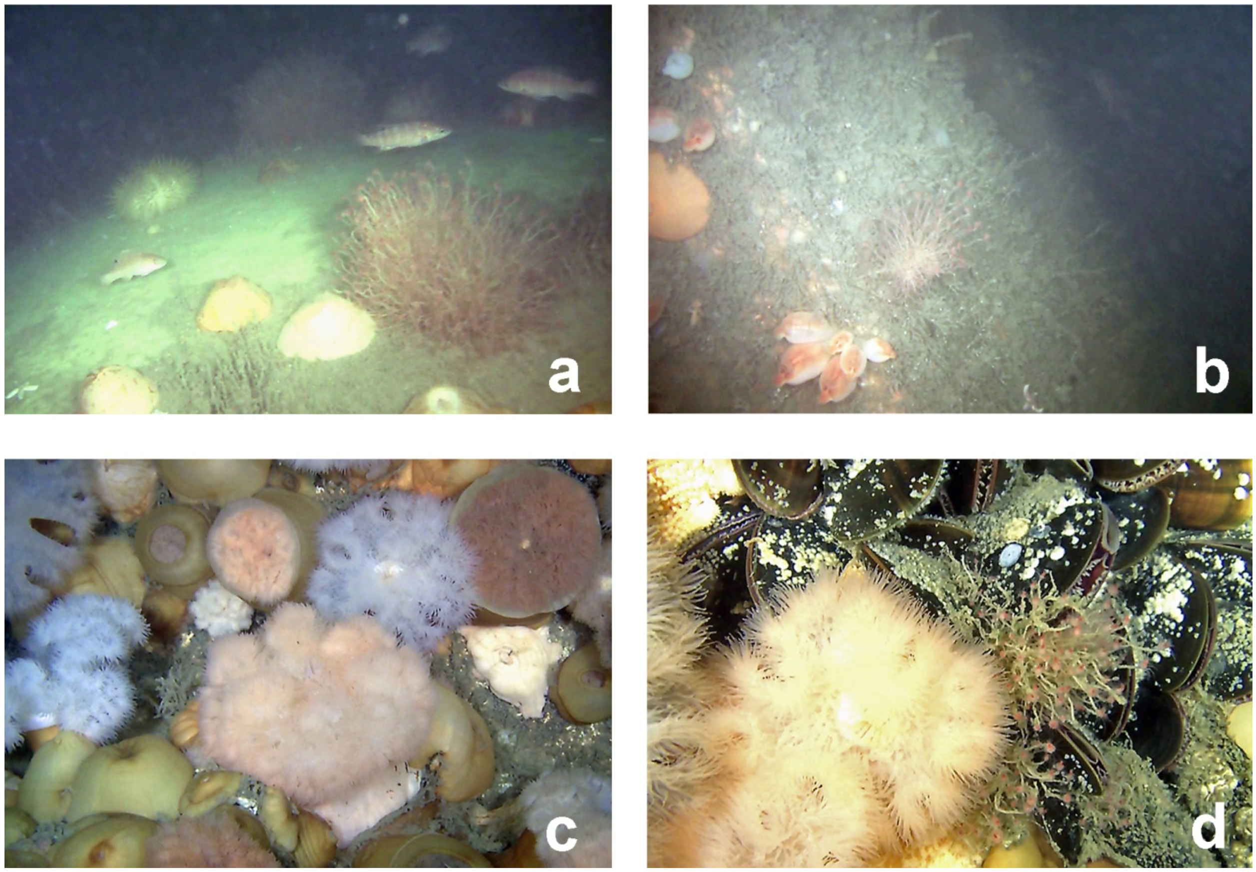

Figure 3-26. Screen captures of HD video taken at inactive diffuser head #44 (a and b) and active diffuser head #2 (c and d) during the 2011 hard-bottom survey. (a) A sparse population of frilled anemones *Metridium senile* colonizing the top of diffuser head #44, with several colonies of the hydroid *Tubularia* sp. and a few *Asterias vulgaris* and cunner also visible. (b) Sea peaches *Halocynthia pyriformis* colonizing the side of diffuser head #44. A colony of Tubularia sp. and a *M. senile* are also visible. (c) Numerous frilled anemones *Metridium senile* colonizing diffuser head #2. (d) Numerous blue mussels *Mytilus edulis* and some *M. senile* surrounding an active port on the side of diffuser head #2.

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 3-8 shows the relative abundance of *Palmaria palmata* over the 1996 to 2011 time period. During the pre-diversion period, dulse was consistently most abundant at the northern reference sites and common at two waypoints north of the outfall. During most of the post-diversion years, the relative abundance of *P. palmata* has decreased at these five sites, and additionally it dropped to an areawide low in 2003 and 2004. In contrast, since 2005 dulse has been seen in modest abundances at stations where it had historically been largely absent, such as on the drumlin immediately north of the outfall, and at two of the southern reference sites. This pattern follows that observed in data collected from still images between 1996 and 2008.

Table 3-7. Relative cover of coralline algae observed in video footage taken during the 1996 to 2011 hard-bottom surveys.

		Pre-diversion					Post diversion										
		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Northern reference	T7-1	c-a	a	c-a	c	c-a	c-a	f-c	c	c	f-c	f-c	f-c	f-a	f-c	f-c	f-c
	T7-2	c-a	c-va	c-a	c	c	f-c	c	f-c	c	f-c	f-c	c	c-a	f-c	f-c	c
	T9-1		c-a	c-a	c	c	c-a	c	f-c	c	f-c	c	c	c	f-c	f-c	c
Northern transect	T1-1	va	c	c-a	c	c	f-c	f-c	f-c	c	f-c	f-c	f-c	f-c	f-c	f	f
	T1-2	a	va	a	c*	a	c-a	c	a	f-c	c-a	c	c-a	c-a	c-a	c	f-c
	T1-3	a	va	a	va	a	va	a	a	a	a	c	c-a	c	c-a	c-a	c
	T1-4	va	va	a	a	a	a	a	a	c-a	c-a	c-a	c-a	c-a	c-a	c-a	c
	T1-5	a*	c	c	c	c-a	f-c	f-c	c	c	f	r-f	f	r-f	f	f	f
	T2-1	f-a	f-c	r-f*	c	c	f-c	c	c-a	c	f	c	f-a	f-c	f	c	f-c
	T2-2	r	f	f-c*	r-c	c	f-c	r-f	f	f	f	r	r-f	f	f	f	f
	T2-3	c	r	c	c	f*	f-c	f-c	f-c	f	f	f-c	r-f	f-c	f	f	f
	T2-4	f	r	f	f	-	r	f	r-f	r	r	r	f	r-f	f	r	r
Southern transect	T4/6-1	va	c-a	a	a	a	va	a	a	a	a	a	c-a	c-a	a	a	a
	T4-1	r	f	r	-	c	-	r									
	T4-2	c	c-a	r-f*	f*	a	c	f-c	f	f-c	f-c	f-c	r	f	f	r-f	r-f
	T4-3	f	f	c	f-c	c	f-c	c									
	T6-1	r	r	r	r	r	r	-	r	-	-	-	-	-	r	r	-
	T6-2	c-a*	c	c-a	c	c	c	c	f-c	f-c	f-c	f	f	f-c	c	c-a	f
Southern reference	T10-1		r-f	-	r	-	-	-	-	r-c	r	-	-	-	-	r-f	r
	T8-1	a	c-a	a	c-a	c	a	c-a	c-a	c-a	a	c	c-a	f-c	c	c-a	c-a
	T8-2	a	a-va	a	c	a	c-a	c	a	a	a	c-a	c-a	c-a	c-a	c-a	c-a
	T12-1								c-a	c-a	c	c-a		c	c-a	c	c
	T11-1								-	f	f	f	r-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

Table 3-9 shows the relative abundance of *Ptilota serrata* over the 1996 to 2011 time period. Historically, this filamentous red alga was consistently most abundant at the northern reference sites, and only occasionally common to abundant at sites on drumlins on either side of the outfall. The relative abundance of *P. serrata* has decreased at the northern reference sites over time, and has virtually disappeared at many of the other sites during most of the post-diversion years. Abundances of *P. serrata* reached an all time low at all stations during 2007, when it was observed in very modest abundances at only 3 of the sites. This alga does appear to be rebounding at one of the northern reference sites. It is also appearing in sizable abundances at two drumlin top sites north of the outfall, and at one of the southern reference sites. 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.

Another upright alga, the shotgun kelp *Agarum cribrosum*, has historically been consistently abundant only at the northern reference sites. 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. This species 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

Table 3-8. Relative abundance of *Palmaria palmata* (dulse) observed in video footage taken during the 1996 to 2011 hard-bottom surveys.

		Pre-diversion					Post diversion										
		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Northern reference	T7-1	c	c-a	f	c	c-a	c-a	c-a	c	f-c	c-a	c-a	f-c	c-a	f-a	f-c	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	f-a	f-c
	T9-1		a-va	c	a	a	c-a	c	r-f	f	r-c	f	f	f	f-c	f-c	f
Northern transect	T1-1	a	a	c	c	f-c	f-c	c	f	f	c	f	r-f	f-c	c	f-c	f-c
	T1-2	f	-	r	f	-	r-f	-	r	r	r	f-c	f	f-c	f	c-a	c
	T1-3	-	-	r	-	r	f	f	f	r	f-c	f-c	f-c	c-a	f-a	c-a	c-a
	T1-4	-	-	-	-	-	r	-	f	r	f	f	f	f-c	f-c	f-a	f-c
	T1-5	r*	-	-	-	-	-	-	r	-	-	-	r	r	r	r	r
	T2-1	-	c	-	f	r	f	r	r	-	-	r	-	r-f	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	f-c	f
	T2-4	c	c	f-c	r	-	r-f	-	-	-	-	-	-	r	-	-	-
Southern transect	T4/6-1	f	c*	-	r	r	r	-	r	-	-	r	r	r	r-f	r-f	f
	T4-1	-	-	-	-	-	-	-									
	T4-2	-	-	-	-	-	-	-	-	-	-	f	r	-	-	-	r-f
	T4-3	-	-	-	-	-	-	-									
	T6-1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	T6-2	c*	-	r	-	-	-	-	-	-	-	-	-	-	r-f	r-f	-
Southern reference	T10-1		c-a	r	c	c	r	f-c	r	f-c	f	f	r	-	f	f-c	f-c
	T8-1	-	-	-	-	-	-	-	-	r	f	r-c	f	f-c	r-f	f-c	f-c
	T8-2	-	-	-	-	-	-	-	-	-	r	f	r	r	r-f	r	f
	T12-1								f	f	f	f-c		f-a	f-c	f-c	c
	T11-1								-	-	-	-	-		r-f	r	r
Diffusers	T2-5	-	-	-			-	-	-	-	-	-	-	-	-	-	-
	D44			-		-	-	-	-	-	-	-	-	-	-	-	-

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

by the invasive bryozoan *Membranipora membranipora*. This decline was much less evident in the data collected from video images. In 2010 and 2011 this alga has also been seen at one site north of the outfall. Specifics of the abundance and distribution of shot-gun kelp over the time course of this study can be seen in Appendix A-3.

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 instances of disturbed seafloors have been observed at all 3 northern reference sites. This may result in a seafloor that is a mosaic of areas in differing stages of recovery from physical disturbance.

Several long-term trends have been noted in the abundances of some of the larger mobile taxa. These trends appear to reflect widespread temporal changes in abundances rather than changes related to the outfall. 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, to 28 to 168 individuals between 2001 and 2011. The number of crabs seen annually varies widely, but the general trend appears to be towards higher numbers

Table 3-9. Relative abundance of *Ptilota serrata* (filamentous red alga) observed in video footage taken during the 1996 to 2011 hard-bottom surveys.

		Pre-diversion					Post diversion										
		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Northern reference	T7-1	va	c-a	a	a	c	c-a	c-a	c-a	f-a	c-a	c-a	f-c	c-a	f-a	f-c	f-c
	T7-2	va	c-a	a	a	c-a	a	c	c-a	a	a	f-a	f-c	f-c	r-c	f-a	f-c
	T9-1		a-va	c-a	a	c-a	c	f-c	r	f	r-c	-	-	-	f-c	f-c	f
Northern transect	T1-1	a	-	c-a	-	-	-	f	-	-	-	-	-	-	f	-	-
	T1-2	a	-	f	-	-	-	-	-	-	-	-	-	-	f-c	f-c	c
	T1-3	f	-	f	-	-	f	-	r	c-a	r	r-c	f-c	c-a	c-a	c-a	a
	T1-4	r-f	-	-	-	-	-	-	-	r-f	-	f	-	f-c	c-a	f-a	f-c
	T1-5	f-c*	-	-	-	-	-	-	-	-	-	r-f	-	-	r-f	-	-
	T2-1	f	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	T2-2	f	c	a*	c	-	-	-	-	-	-	-	-	-	-	-	-
	T2-3	a	-	c-a	f-c	f-c	-	r-f	-	-	-	r	-	-	-	-	-
	T2-4	a	r	c	-	-	-	-	-	-	-	-	-	-	-	-	-
Southern transect	T4/6-1	c-va	c-a	f	f	-	-	-	-	-	-	-	-	r	r-f	r-f	f-c
	T4-1	-	-	-	-	-	-	-									
	T4-2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	T4-3	-	-	-	-	-	-	-									
	T6-1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	T6-2	c-va*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Southern reference	T10-1		c-a	f-c	f	-	-	-	-	-	-	-	-	-	r	r	-
	T8-1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	r
	T8-2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	T12-1								f-c	f-c	-	f		f-a	f-c	c-a	c-a
	T11-1								-	-	-	-	-		-	-	-
Diffusers	T2-5	-	-	-			-	-	-	-	-	-	-	-	-	-	-
	D44			-		-	-	-	-	-	-	-	-	-	-	-	-

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

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 12 to 79 individuals per year in the post diversion period. Cod have shown a similar pattern with none to 22 individuals seen annually during the pre-diversion years and 38 to 91 individuals seen annually during all but one of the post diversion years. Specifics of the abundance of these species over the time can be seen in Appendix A-3.

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. Examples of the visual changes observed over time at a few representative sites can be seen in the plates in Appendix D.

- ♦ *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 although 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 active 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.

4. SUMMARY OF RELEVANCE TO MONITORING OBJECTIVES

Benthic monitoring for MWRA's offshore ocean outfall is focused on addressing three primary concerns regarding potential impacts to the benthos from the wastewater discharge: (1) eutrophication and related low levels of dissolved oxygen; (2) accumulation of toxic contaminants in depositional areas; and (3) smothering of animals by particulate matter.

The 2011 SPI survey found no indication that the wastewater discharge has resulted in low levels of dissolved oxygen in nearfield sediments. The average thickness of the sediment oxic layer in 2011 was greater than reported during the baseline period. These results support previous findings that eutrophication and the associated decrease in oxygen levels have not been a problem at the nearfield benthic monitoring stations (Maciolek et al. 2008).

Sediment contaminant monitoring in 2011 found no indication that toxic contaminants from the wastewater discharge are accumulating in depositional areas surrounding the outfall. No Contingency Plan threshold exceedances for sediment contaminants were reported in 2011. Patterns in the spatial distribution of higher contaminant concentrations primarily reflect both the percentage of fine particles in the sediment, and the proximity to historic sources of contaminants in Boston Harbor.

Surveys of both soft and hard-bottom benthic communities continue to suggest that animals near the outfall have not been smothered by particulate matter from the wastewater discharge. There were threshold exceedances in 2011 for two infaunal diversity measures: (1) Pielou's Evenness (J') and (2) Shannon-Wiener Diversity (H'); however, analyses of these parameters suggest region-wide changes in faunal communities, unrelated to the discharge. Both analyses of spatial and temporal patterns in community parameters and multivariate analyses, found no evidence of impacts to infaunal communities from the wastewater discharge in Massachusetts Bay. Furthermore, hard-bottom benthic communities near the outfall have not changed substantially during the post-diversion period as compared to the baseline period. Some modest changes in hard-bottom communities (coralline algae and upright algae cover) have been observed; nonetheless, factors driving these changes are unclear. Since declines in upright algae started in the late 1990s (prior to wastewater diversion to the outfall), it is unlikely that the decrease was attributable to diversion of the outfall.

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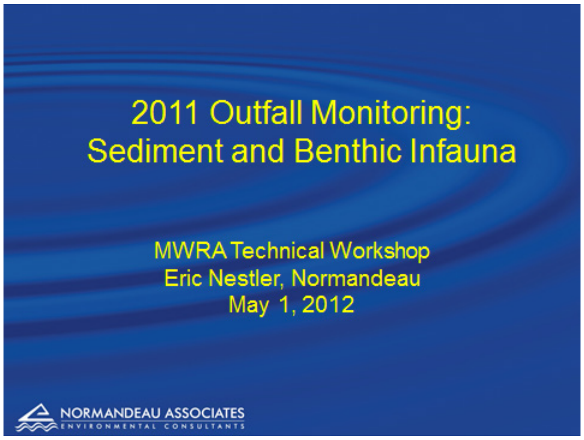
Appendix A Annual Technical Meeting Presentations for Outfall Benthic Monitoring in 2011

Appendix A1. 2011 Outfall Monitoring: Sediment and Benthic Infauna


2011 Outfall Monitoring:
Sediment and Benthic Infauna
MWRA Technical Workshop
Eric Nestler, Normandeau
May 1, 2012
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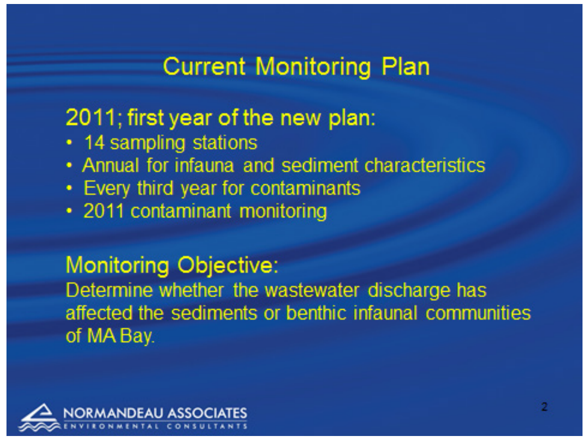
Current Monitoring Plan
2011; first year of the new plan:
• 14 sampling stations
• Annual for infauna and sediment characteristics
• Every third year for contaminants
• 2011 contaminant monitoring
Monitoring Objective:
Determine whether the wastewater discharge has affected the sediments or benthic infaunal communities of MA Bay.
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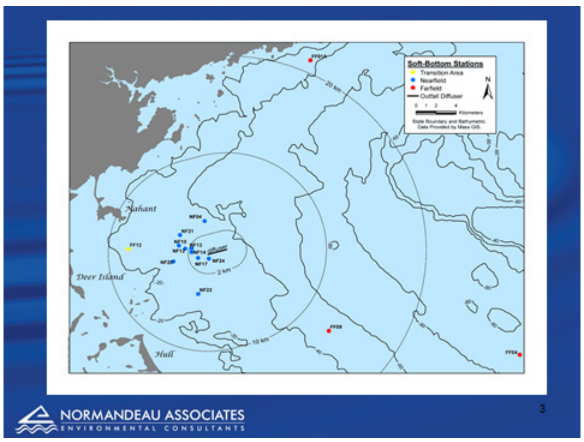
Soft-Bottom Stations
Transition Area
Nearfield
Farfield
Outfall Diffuser
N
0 1 2 4
Kilometers
State Boundary and Bathymetric Data Provided by Mass GIS.
Nahant
Deer Island
Hull
20 km
10 km
2 km
FF12
NF04
NF21
NF10
NF13
NF14
NF20
NF17
NF24
NF22
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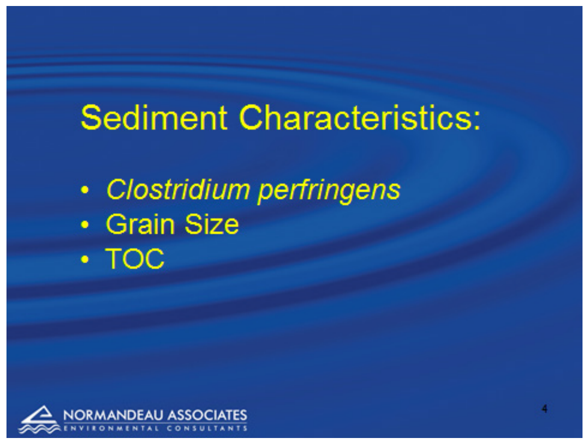
3


Sediment Characteristics:
• *Clostridium perfringens*
• Grain Size
• TOC
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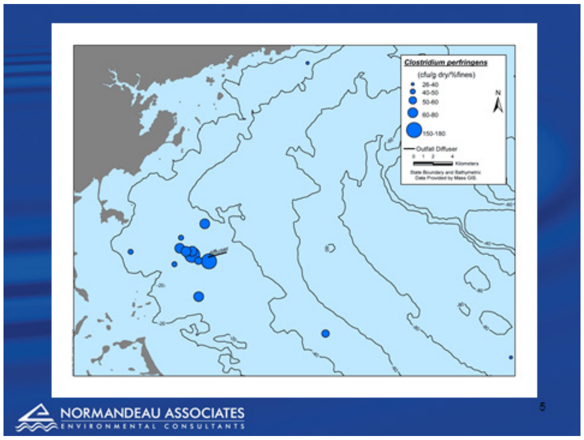
4


Clostridium perfringens
(cfu/g dry/%fines)
26-40
40-50
50-60
60-80
150-180
Outfall Diffuser
0 1 2 4
Kilometers
State Boundary and Bathymetric Data Provided by Mass GIS
N
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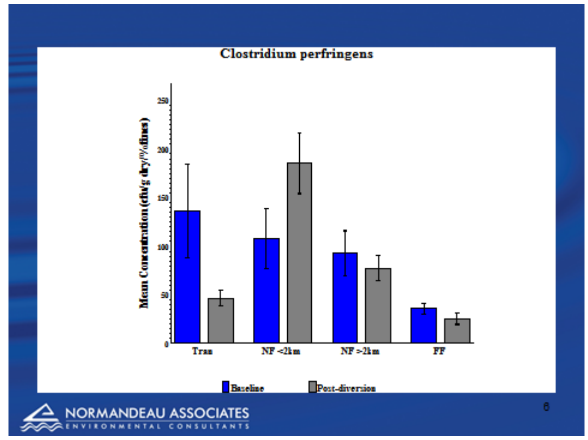
5


Clostridium perfringens
Mean Concentration (cfu/g dry/%fines)
250
200
150
100
50
0
Tran
NF <2km
NF >2km
FF
Baseline
Post-diversion
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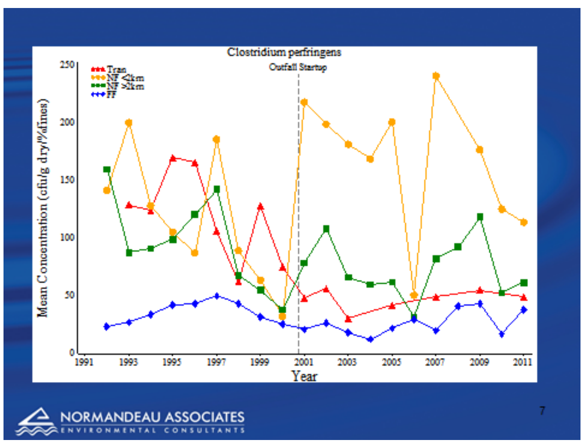
6


Clostridium perfringens
Outfall Startup
Tran
NF <2km
NF >2km
FF
Mean Concentration (cfu/g dry/%fines)
250
200
150
100
50
0
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
Year
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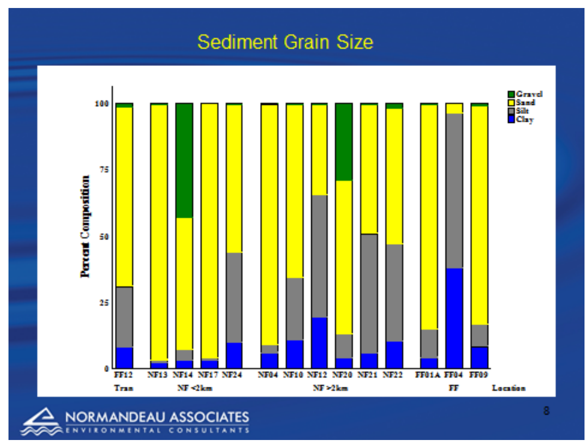
7


Sediment Grain Size
Gravel
Sand
Silt
Clay
Percent Composition
100
75
50
25
0
FF12
NF13
NF14
NF17
NF24
NF04
NF10
NF12
NF20
NF21
NF22
FF01A
FF04
FF09
Tran
NF <2km
NF >2km
FF
Location
NORMANDEAU ASSOCIATES
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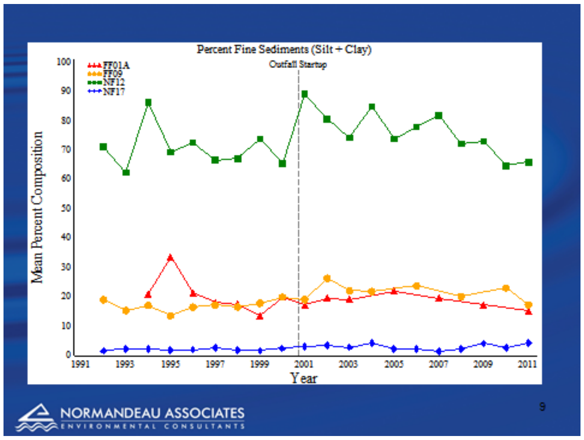
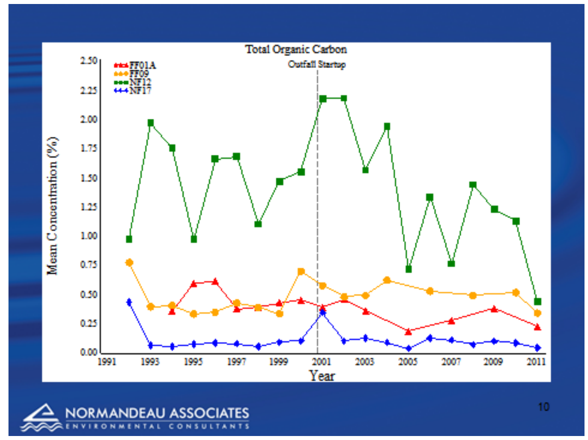
8





Sediment Contaminants:

- Metals
- Organics

No Contingency Plan Threshold Exceedances in 2011

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11

2011 contaminant values that exceed ER-L

Parameter	Transition Area	Nearfield (<2 km from outfall)		Nearfield (>2 km from outfall)					Farfield	Baseline range*	Sediment Quality Guidelines	
	FF12	NF14	NF24	NF10	NF12	NF20	NF21	NF22	FF04		ER-L	ER-M
Percent Fines (Silt + Clay)	30.9	7.2	43.8	34.3	65.5	13.1	50.9	46.9	96.4			
Lead			50.0		57.0		50.8		55.6	21.6 - 92.8	46.7	218
Mercury			0.21		0.23		1.01	0.17	0.17	0.02 - 1.69	0.15	0.71
Nickel					22.9	22.2			34.0	4.8 - 33.5	20.9	51.6
Total DDT	2.01	1.90	3.64	2.32	5.94	1.61	8.04	2.90	3.73	0 - 19.66	1.58	46.1
Total PAH			5353		8112		10388	4434		64 - 17223	4022	44792
Total PCB							34.6			0 - 71.9	22.7	180

Value exceeds ER-M
Highest reported value in 2011

*None exceed baseline range

Values above ER-L, but no threshold exceedances

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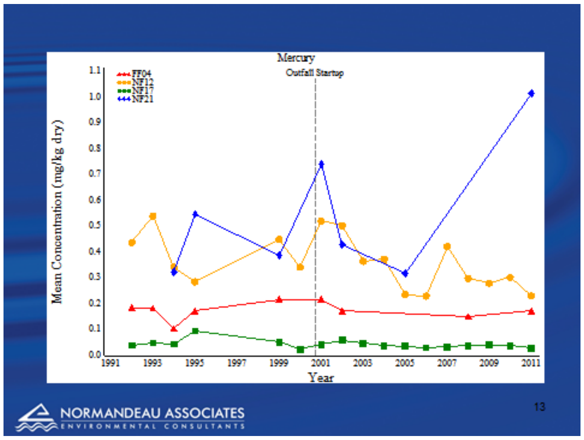
12


Mercury
Outfall Startup
FF04
NF12
NF17
NF21
Mean Concentration (mg/kg dry)
Year
1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011
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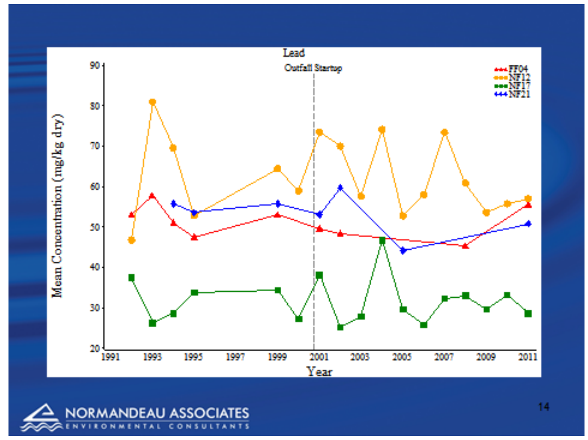
13


Lead
Outfall Startup
FF04
NF12
NF17
NF21
Mean Concentration (mg/kg dry)
Year
1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011
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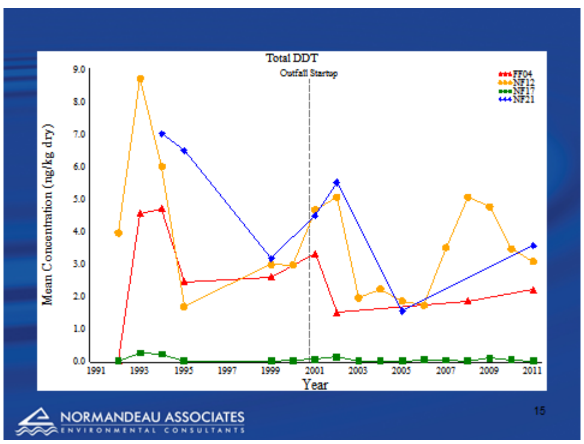
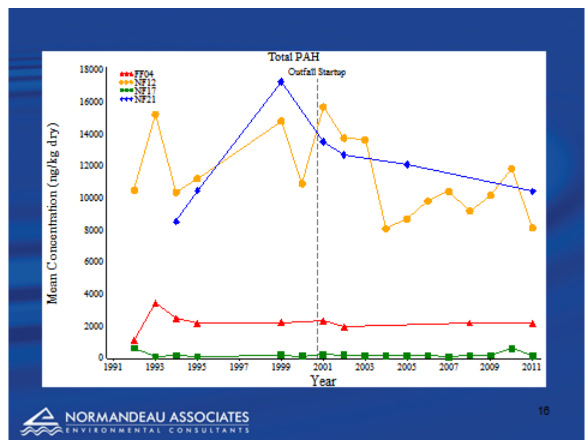
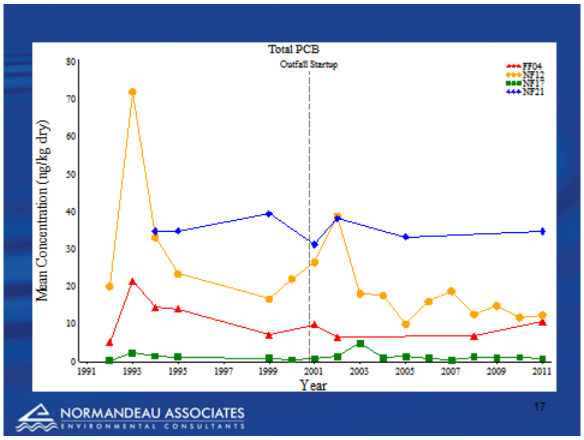
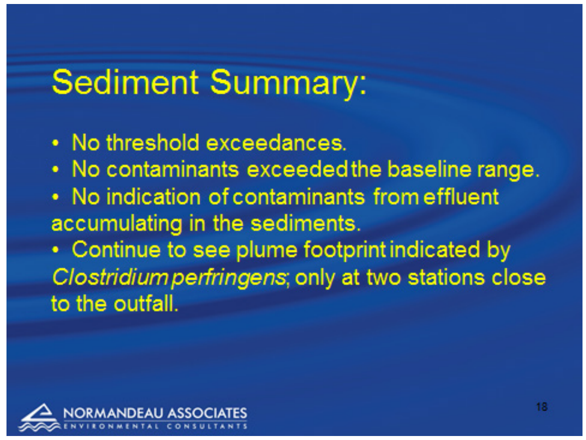
14


Total DDT
Outfall Startup
FF04
NF12
NF17
NF21
Mean Concentration (ng/kg dry)
Year
1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011
NORMANDEAU ASSOCIATES
ENVIRONMENTAL CONSULTANTS
15


Total PAH
Outfall Startup
FF04
NF12
NF17
NF21
Mean Concentration (ng/kg dry)
Year
1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011
NORMANDEAU ASSOCIATES
ENVIRONMENTAL CONSULTANTS
16


Total PCB
Outfall Startup
FF04
NF12
NF17
NF21
Mean Concentration (ug/kg dry)
Year
NORMANDEAU ASSOCIATES
ENVIRONMENTAL CONSULTANTS
17


Sediment Summary:
• No threshold exceedances.
• No contaminants exceeded the baseline range.
• No indication of contaminants from effluent accumulating in the sediments.
• Continue to see plume footprint indicated by *Clostridium perfringens*; only at two stations close to the outfall.
NORMANDEAU ASSOCIATES
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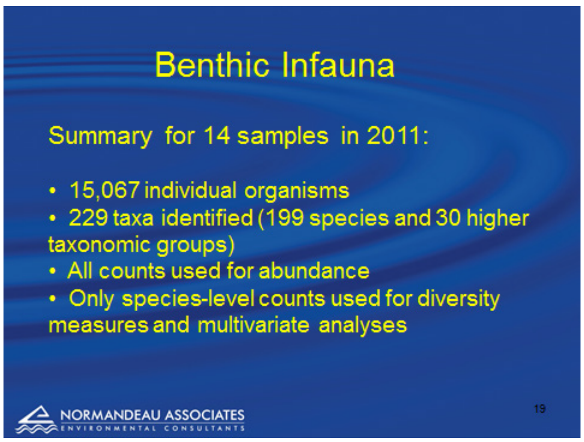
Benthic Infauna
Summary for 14 samples in 2011:
• 15,067 individual organisms
• 229 taxa identified (199 species and 30 higher taxonomic groups)
• All counts used for abundance
• Only species-level counts used for diversity measures and multivariate analyses
NORMANDEAU ASSOCIATES
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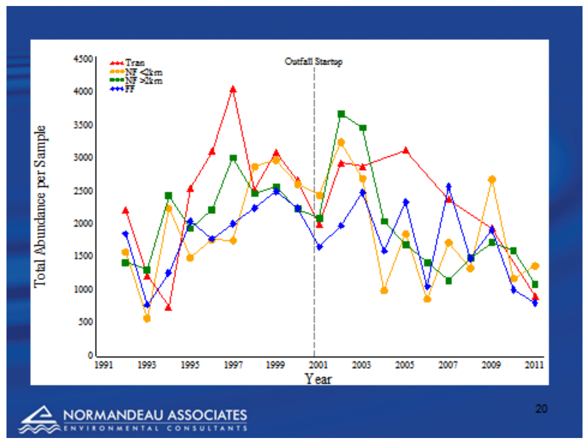
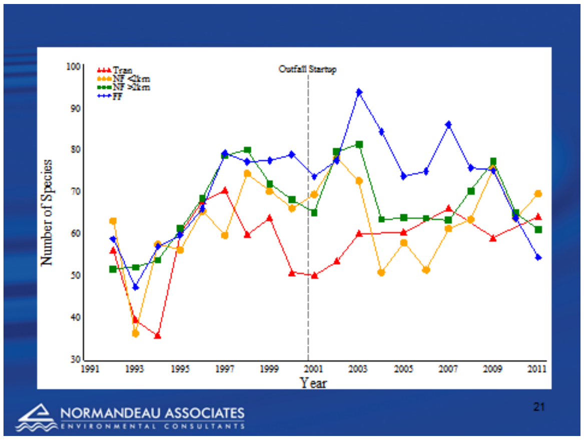
19


Tran
NF <2km
NF >2km
FF
Outfall Startup
Total Abundance per Sample
Year
NORMANDEAU ASSOCIATES
ENVIRONMENTAL CONSULTANTS
20


Tran
NF <2km
NF >2km
FF
Outfall Startup
Number of Species
Year
1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011
30 40 50 60 70 80 90 100
NORMANDEAU ASSOCIATES
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21


2011 Threshold Exceedances:
• Contingency Plan threshold exceedances for: Pielou's Evenness (J') and Shannon-Wiener Diversity (H').
• Threshold exceedances for J' and H' were also reported for 2010.
•No exceedances for: Total species, log-series alpha, or percent opportunists.
NORMANDEAU ASSOCIATES
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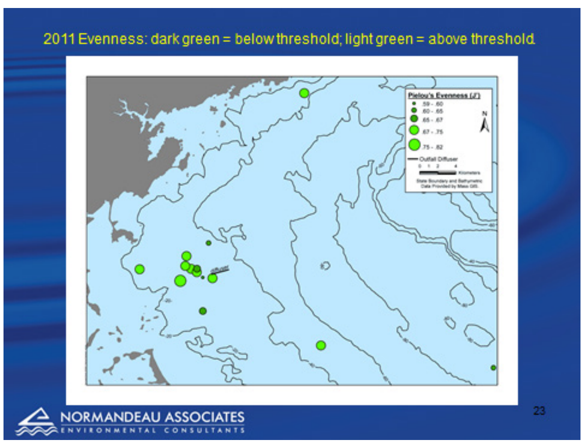
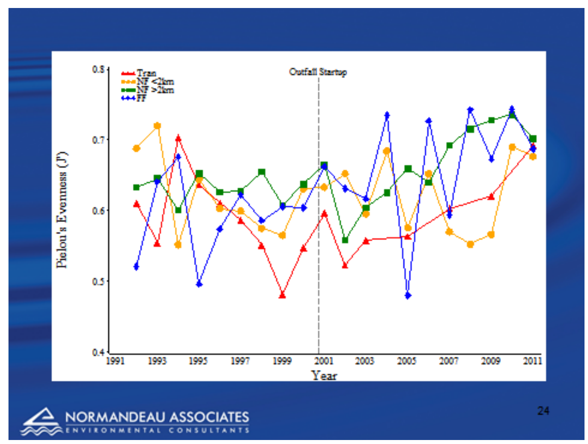
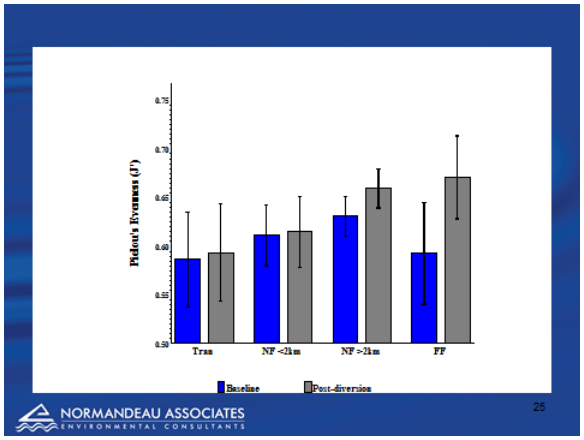
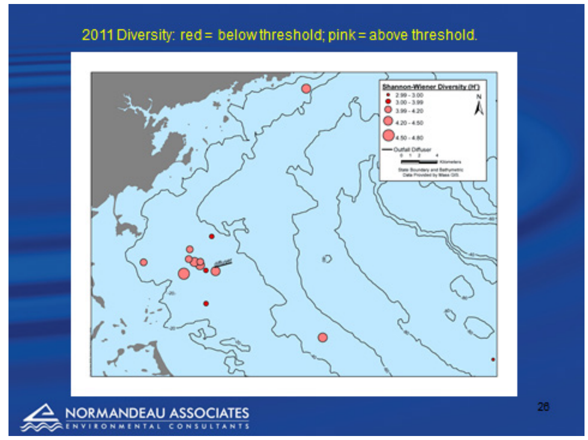

2011 Evenness: dark green = below threshold; light green = above threshold.
NORMANDEAU ASSOCIATES
ENVIRONMENTAL CONSULTANTS
23


Tran
NF <2km
NF >2km
FF
Outfall Startup
Pielou's Evenness (J')
Year
1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011
0.4 0.5 0.6 0.7 0.8
NORMANDEAU ASSOCIATES
ENVIRONMENTAL CONSULTANTS
24


Pielou's Evenness (J')
0.75
0.70
0.65
0.60
0.55
0.50
Tran
NF <2km
NF >2km
FF
Baseline
Post-diversion
NORMANDEAU ASSOCIATES
ENVIRONMENTAL CONSULTANTS
25


2011 Diversity: red = below threshold; pink = above threshold.
Shannon-Wiener Diversity (H')
NORMANDEAU ASSOCIATES
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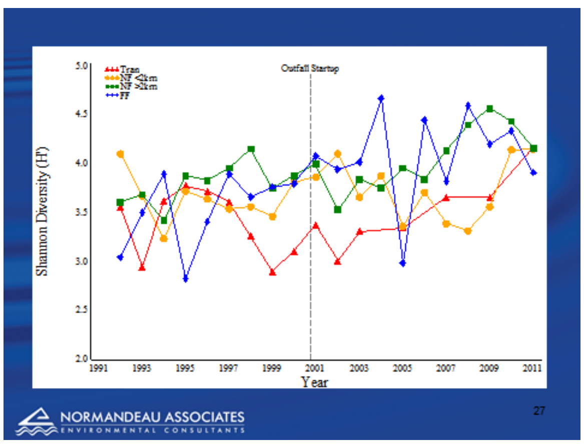
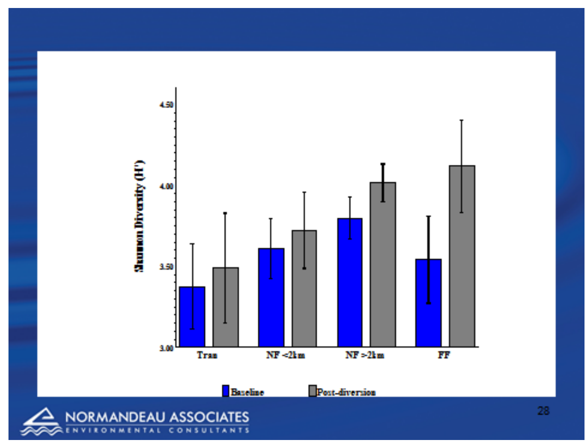
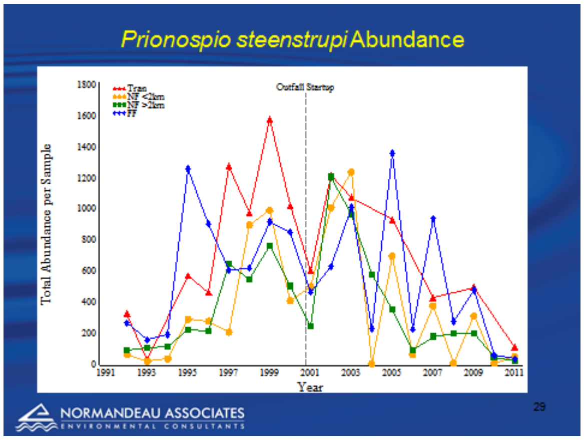
26


Shannon Diversity (H')
5.0
4.5
4.0
3.5
3.0
2.5
2.0
Tran
NF <2km
NF >2km
FF
Outfall Startup
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
Year
NORMANDEAU ASSOCIATES
ENVIRONMENTAL CONSULTANTS
27


Shannon Diversity (H')
4.50
4.00
3.50
3.00
Tran
NF <2km
NF >2km
FF
Baseline
Post-diversion
NORMANDEAU ASSOCIATES
ENVIRONMENTAL CONSULTANTS
28



Spatial Patterns:

- Multivariate analyses to assess patterns in the distribution of faunal assemblages
- 2011 Samples
- Bray-Curtis Similarity
- Cluster Analysis
- nMDS Ordination Plots

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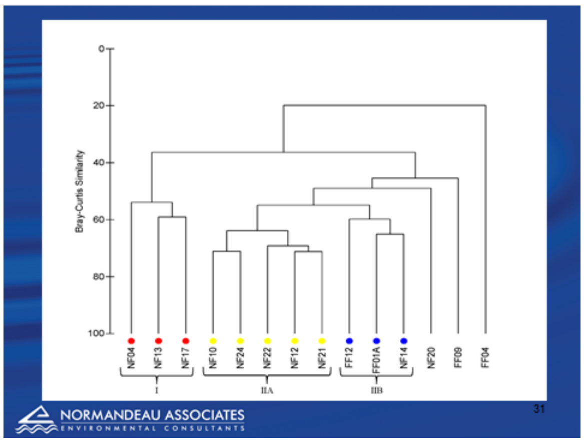
30



2011 Infaunal Assemblages:

Group I
- *Polygordius jouinae, Crassicorophium crassicorne, Exogone hebes*
- Sand

Group IIA
- *Mediomastus californiensis, Spio limicola, Levinsenia gracilis, Tharyx acutus*
- Sandy silt

Group IIB
- *Aricidea catherinae, Owenia fusiformis, Mediomastus californiensis, Prionospio steenstrupi*
- Silty sand; gravel

Outliers: NF20, FF09, FF04
- Various polychaete species
- Depth, sediment type

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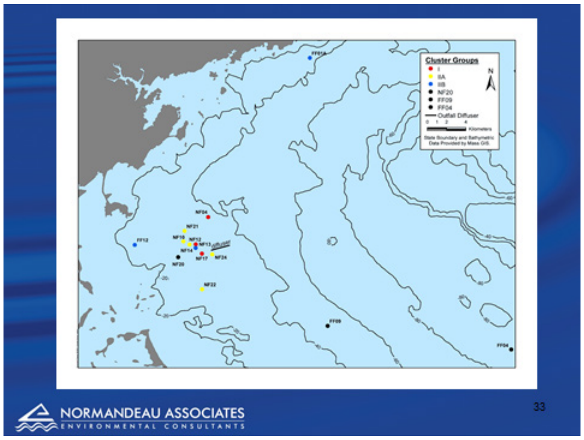
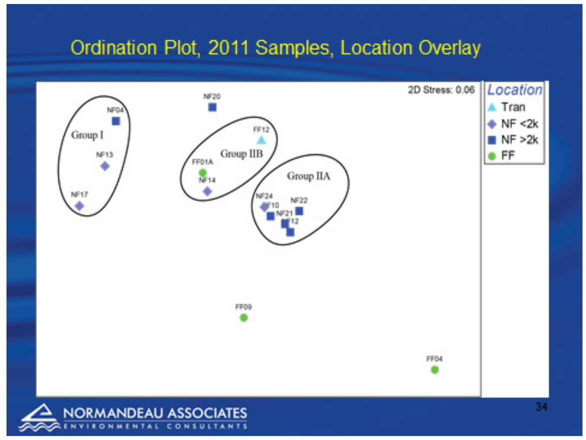
32


Cluster Groups
NORMANDEAU ASSOCIATES
ENVIRONMENTAL CONSULTANTS
33


Ordination Plot, 2011 Samples, Location Overlay
2D Stress: 0.06
Location
Tran
NF <2k
NF >2k
FF
Group I
Group IIB
Group IIA
NF20
NF04
NF13
NF17
FF12
FF01A
NF14
NF24
NF22
NF21
FF09
FF04
NORMANDEAU ASSOCIATES
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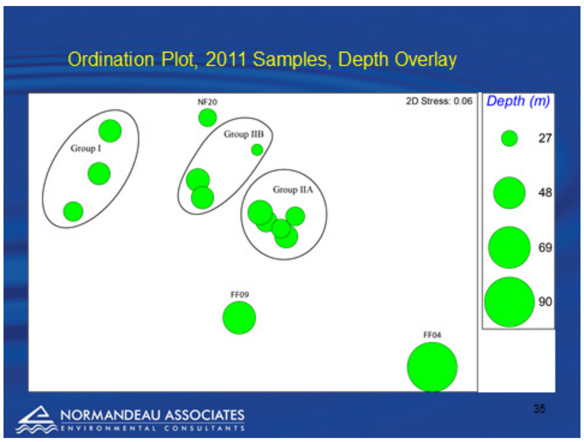
34


Ordination Plot, 2011 Samples, Depth Overlay
2D Stress: 0.06
Depth (m)
27
48
69
90
NF20
Group I
Group IIB
Group IIA
FF09
FF04
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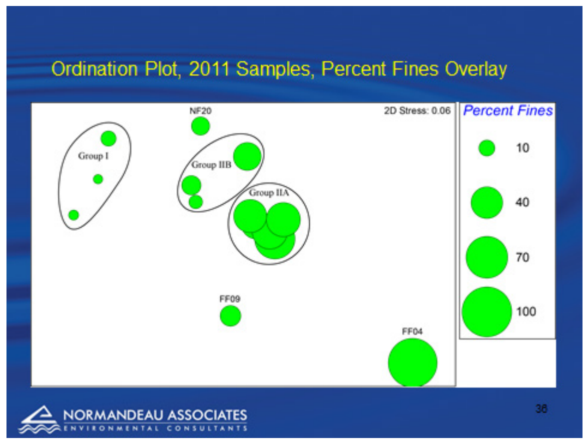
35


Ordination Plot, 2011 Samples, Percent Fines Overlay
2D Stress: 0.06
Percent Fines
10
40
70
100
NF20
Group I
Group IIB
Group IIA
FF09
FF04
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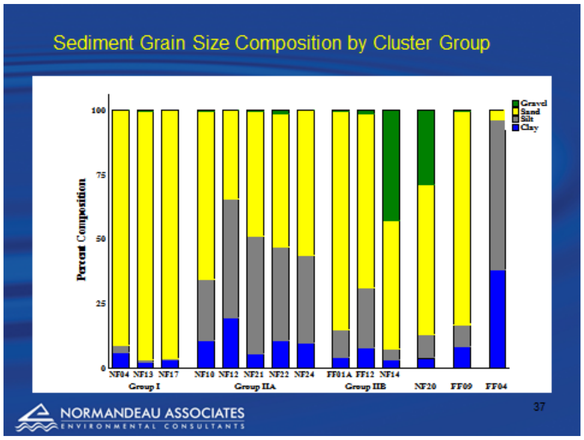
36


Sediment Grain Size Composition by Cluster Group
Percent Composition
Gravel
Sand
Silt
Clay
NF04 NF13 NF17
Group I
NF10 NF12 NF21 NF22 NF24
Group IIA
FF01A FF12 NF14
Group IIB
NF20
FF09
FF04
NORMANDEAU ASSOCIATES
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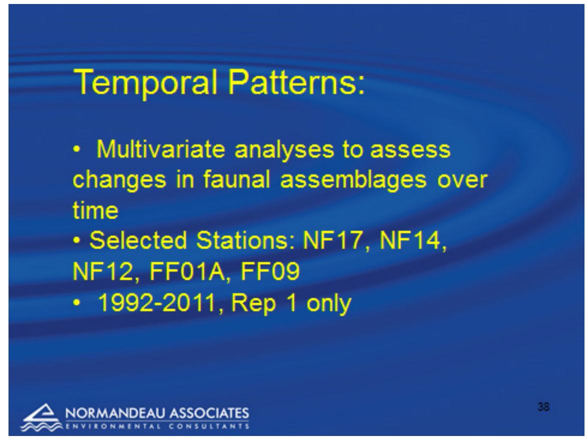
37


Temporal Patterns:
• Multivariate analyses to assess changes in faunal assemblages over time
• Selected Stations: NF17, NF14, NF12, FF01A, FF09
• 1992-2011, Rep 1 only
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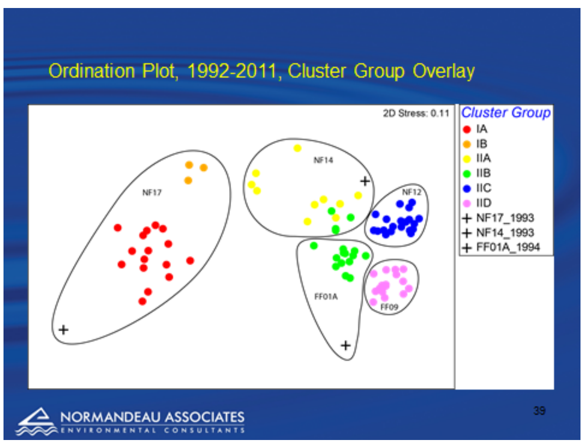
38


Ordination Plot, 1992-2011, Cluster Group Overlay
2D Stress: 0.11
Cluster Group
IA
IB
IIA
IIB
IIC
IID
NF17_1993
NF14_1993
FF01A_1994
NF17
NF14
NF12
FF01A
FF09
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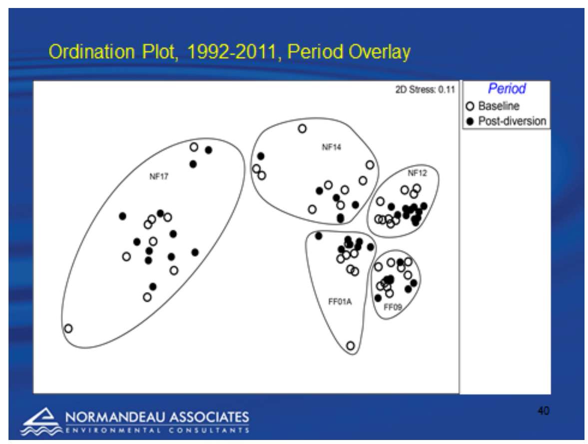
39


Ordination Plot, 1992-2011, Period Overlay
2D Stress: 0.11
Period
Baseline
Post-diversion
NF17
NF14
NF12
FF01A
FF09
NORMANDEAU ASSOCIATES
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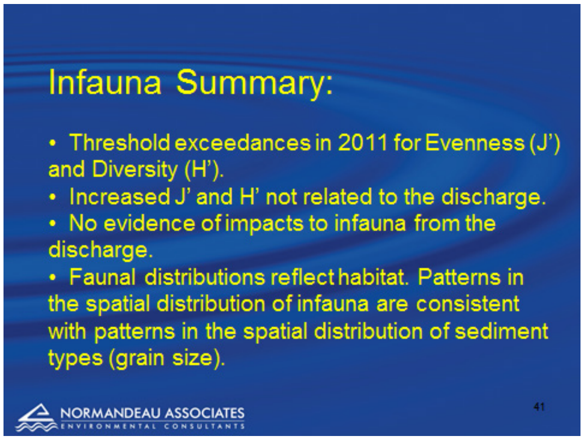
40


Infauna Summary:
• Threshold exceedances in 2011 for Evenness (J') and Diversity (H').
• Increased J' and H' not related to the discharge.
• No evidence of impacts to infauna from the discharge.
• Faunal distributions reflect habitat. Patterns in the spatial distribution of infauna are consistent with patterns in the spatial distribution of sediment types (grain size).
41
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Acknowledgements:
• Massachusetts Water Resources Authority
• Normandeau: Ann Pembroke, Program manager; Hannah Proctor, Laboratory Manager; Erik Fel'Dotto, Field Manager
• AECOM, Environment, Marine & Coastal Center
• Barry A. Vittor and Associates, Inc.
42
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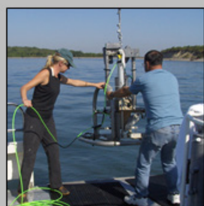
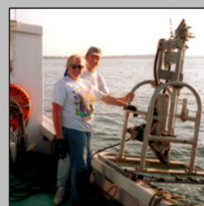
Appendix A2. 2011 Harbor and Bay Sediment Profile Imaging

2011 Harbor and Bay Sediment Profile Imaging

Robert Diaz et al.
R.J. Diaz & Daughters

Normandeau
Battelle

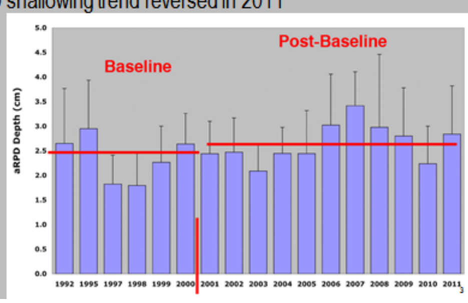
Nearfield Summary Baseline vs. Post-Baseline

	Baseline Years 1992-2000 9-Year Interval	Post-Baseline Years 2001-2010 10-Year Interval
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)
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	3.0 (0.60 SD) cm
Annual Mean RPD All Values	2.4 (0.47 SD) cm	2.7 (0.40 SD) cm

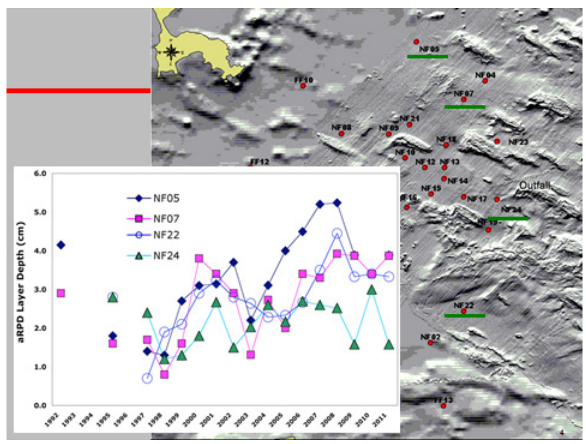
2

Nearfield Summary for 2011

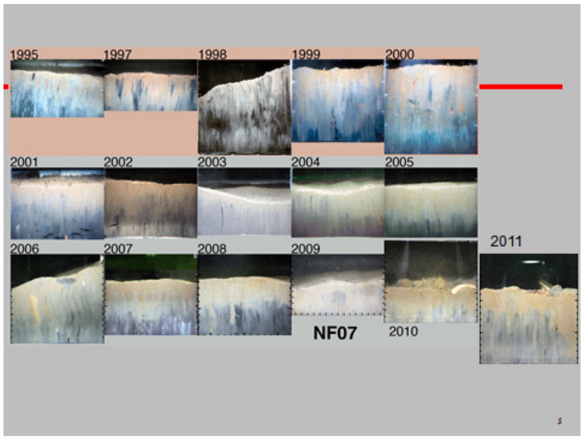
- Sediments similar to other years
- aRPD shallowing trend reversed in 2011

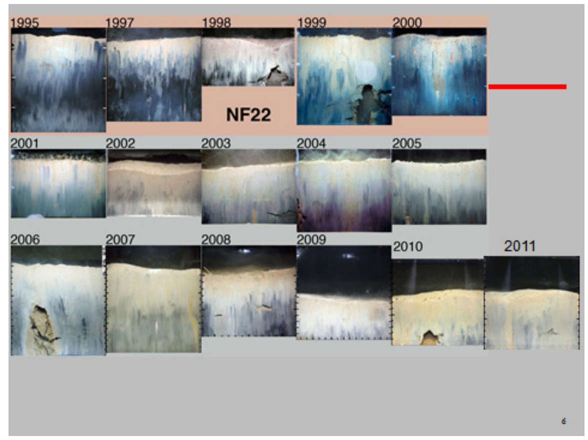


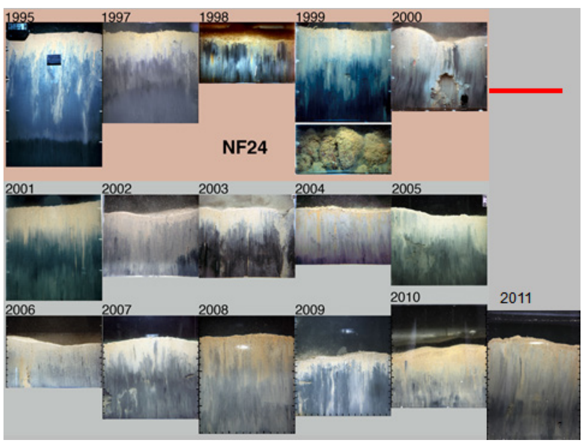
3



4

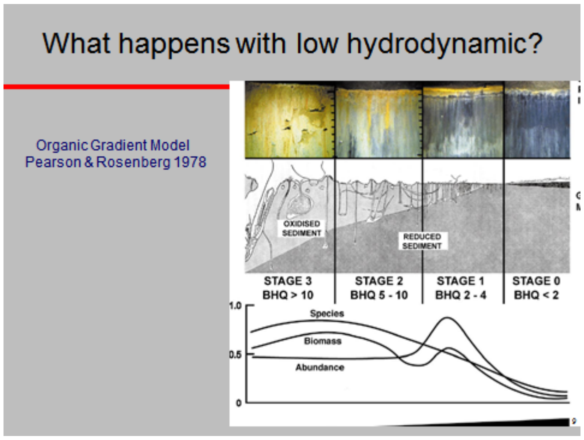


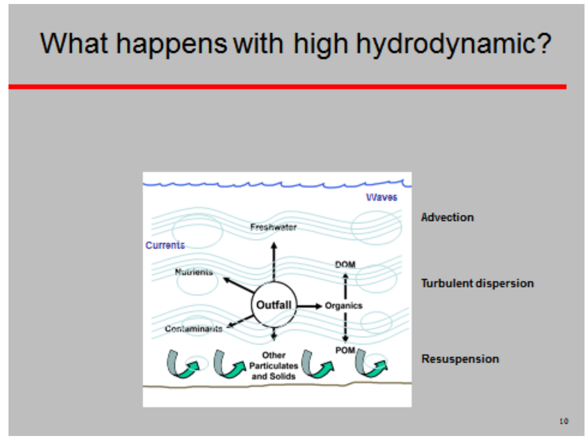


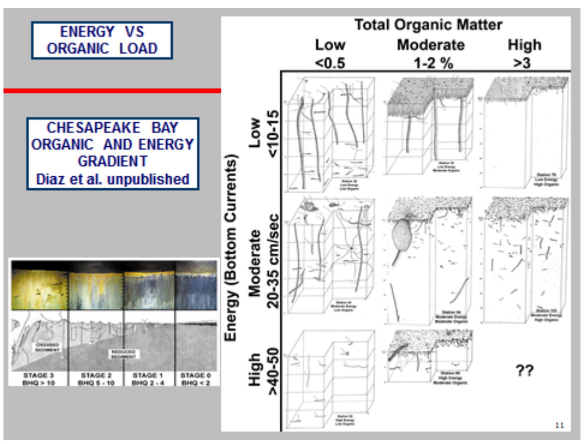


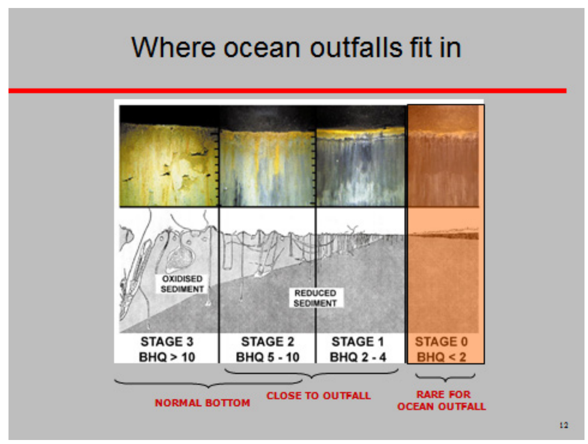
Nearfield Summary

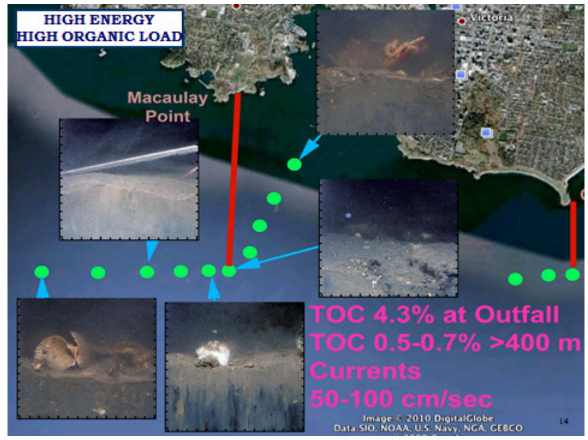
- Operation of outfall, starting in 2001, did not effect benthic habitat quality
- aRPD Post-Baseline deeper than Baseline
- Sediment characteristics remained similar through time
- Changes tended to be regional
- No individual station pattern

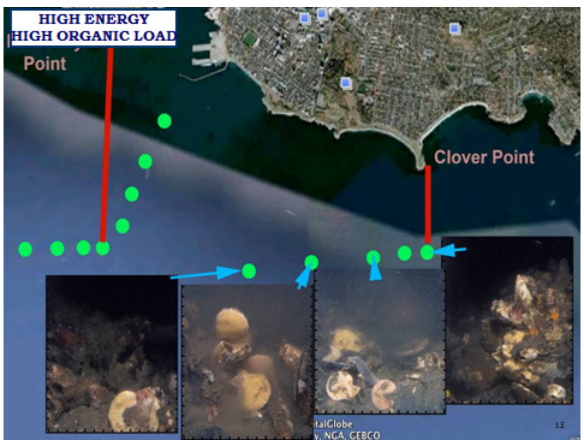

What happens with low hydrodynamic?
Organic Gradient Model
Pearson & Rosenberg 1978
OXIDISED SEDIMENT
REDUCED SEDIMENT
STAGE 3 BHQ > 10
STAGE 2 BHQ 5 - 10
STAGE 1 BHQ 2 - 4
STAGE 0 BHQ < 2
1.0
0.5
0
Species
Biomass
Abundance
9


What happens with high hydrodynamic?
Waves
Currents
Freshwater
Nutrients
DOM
Outfall
Organics
Contaminants
POM
Other Particulates and Solids
Advection
Turbulent dispersion
Resuspension
10


ENERGY VS ORGANIC LOAD
CHESAPEAKE BAY ORGANIC AND ENERGY GRADIENT
Diaz et al. unpublished
Total Organic Matter
Low <0.5
Moderate 1-2 %
High >3
Energy (Bottom Currents)
Low <10-15
Moderate 20-35 cm/sec
High >40-50
??
11


Where ocean outfalls fit in
OXIDISED SEDIMENT
REDUCED SEDIMENT
STAGE 3 BHQ > 10
STAGE 2 BHQ 5 - 10
STAGE 1 BHQ 2 - 4
STAGE 0 BHQ < 2
NORMAL BOTTOM
CLOSE TO OUTFALL
RARE FOR OCEAN OUTFALL
12

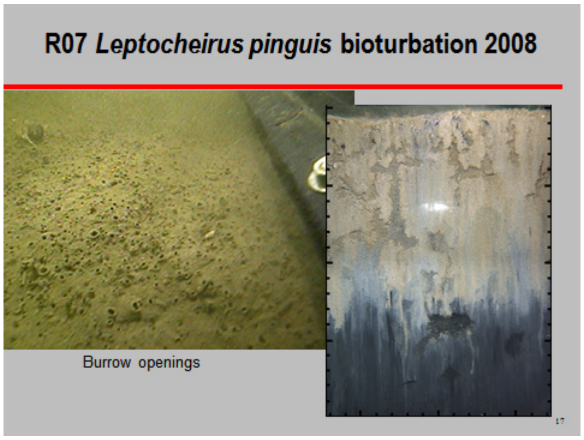


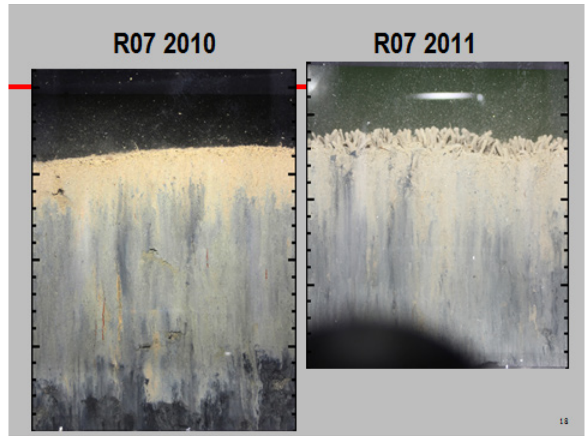


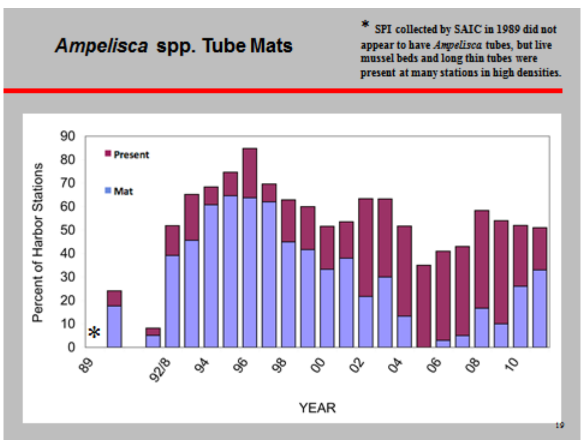
Harbor Summary for 2011

- Sediments, aRPD, Successional Stage, and OSI about the same.
- Eel grass bed at R08 on Deer Island Flats, 4th year.
- *Ampelisca* spp. tube mats 33% of stations and present 51% of stations.
- *Leptocheirus pinguis* bioturbation not obvious.
- Physical processes prominent in structuring surface sediments.
- Microalgal mats not observed.

16


R07 *Leptocheirus pinguis* bioturbation 2008
Burrow openings
17


R07 2010
R07 2011
18


Ampelisca spp. Tube Mats
* SPI collected by SAIC in 1989 did not appear to have *Ampelisca* tubes, but live mussel beds and long thin tubes were present at many stations in high densities.
Present
Mat
Percent of Harbor Stations
90
80
70
60
50
40
30
20
10
0
*
89
92/8
94
96
98
00
02
04
06
08
10
YEAR
19


1990 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011
CHARLES RIVER
DORCHESTER BAY
QUINCY BAY
DEER ISLAND FLATS
OFF LONG ISLAND
PRESIDENT ROADS
NANTASKET ROADS
HINGHAM BAY
20

Trends in Sewage Loading

>90% reduction of organic loadings to Boston Harbor from 11,400 to 1,150 metric tons of carbon per year

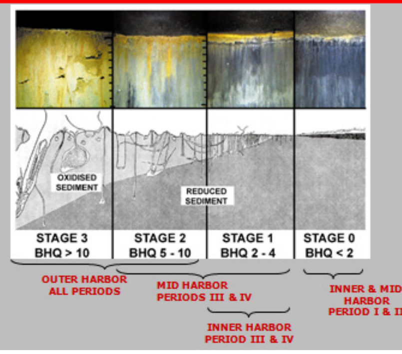
Estimated 240 g C/m^2/yr to sustain amphipods at mat density

Period	Interval	Total C Tons C/yr	C From Sewage	C From PP	*Ampelisca* Mat Area km^2 (%)	*Ampelisca* C Required (% of Total C)
II	1992-98	99,000	12%	88%	68 (54%)	16,300 (16%)
III	Mid-98-2000	61,500	6%	94%	47 (38%)	11,200 (18%)
IVa	2001-05	54,900	2%	98%	22 (18%)	5,300 (10%)
IVb/05-06	2005-06	32,520	3%	97%	2 (2%)	500 (1%)

Taylor 2006. Period I-highest loadings, discharges from Deer and Nut Island; Period III Nut Island discharge ceased, Deer Island secondary treatment; Period IV post-transfer of discharge to offshore, IV
Boston Harbor = 125 km^2

21

Where Harbor changes fit in



22

Big Picture:

Nearfield has not changed in benthic habitat quality for infauna because of limited extent of outfall effects and strong dominance of hydrodynamics.

Harbor has improved in benthic habitat quality for infauna primarily from following the Pearson-Rosenberg organic gradient model with hydrodynamics being secondary.

23

Appendix A3. 2011 Nearfield Hard-bottom Communities


NEARFIELD HARDBOTTOM COMMUNITIES
Barbara Hecker
Hecker Environmental Consulting


• Benthic communities inhabiting hard-bottom drumlins vicinity of the outfall
• Complementary to soft-bottom studies
• Has the hard-bottom community changed?


Acknowledgements
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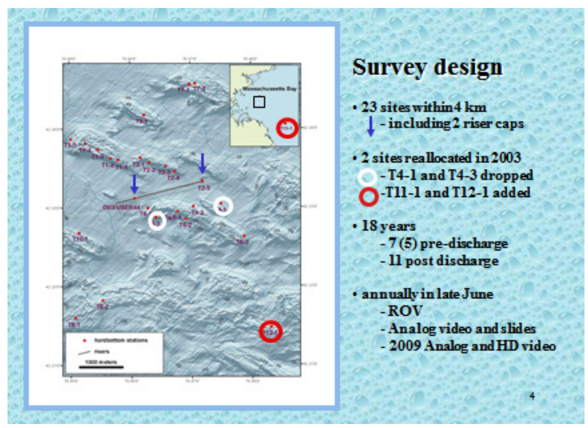
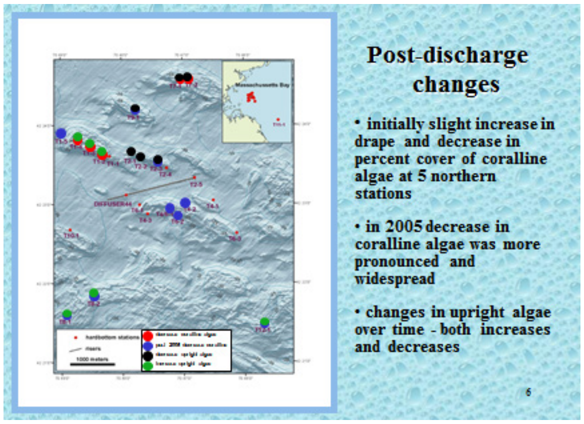
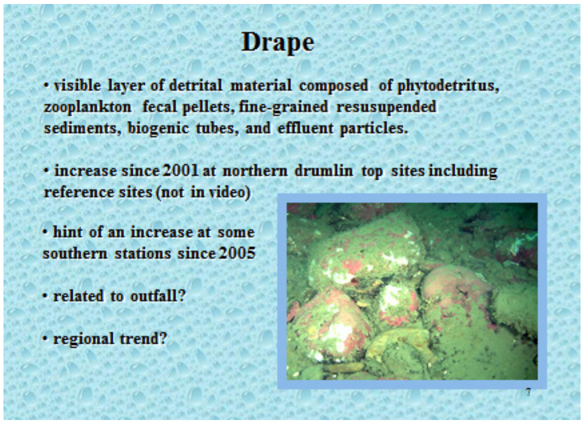
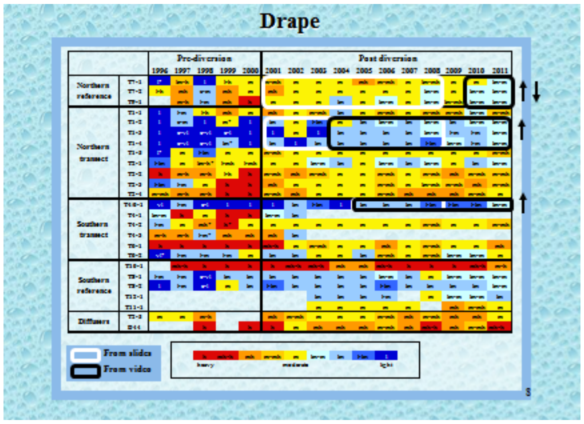
Battelle - Carlton Hunt, Ellie Baptiste-Carpenter
Normandeau - Ann Pembroke, Eric Nestler

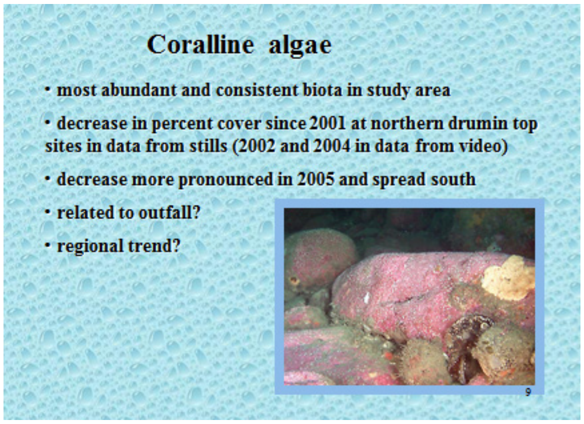

Survey design
• 23 sites within 4 km
- including 2 riser caps
• 2 sites reallocated in 2003
- T4-1 and T4-3 dropped
-T11-1 and T12-1 added
• 18 years
- 7 (5) pre-discharge
- 11 post discharge
• annually in late June
- ROV
- Analog video and slides
- 2009 Analog and HD video
4

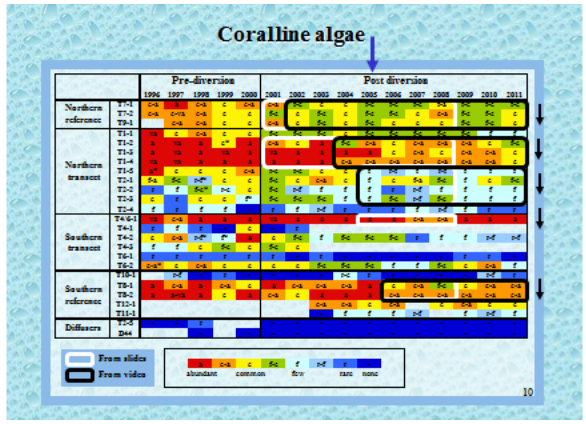

Previous findings
• Hard-bottom areas are spatially variable
• Biotic communities have remained relatively stable between 1996 and 2010
• Some subtle shifts in community structure over time
• Post-discharge changes have been relatively modest
• Lush growth continues on the active riser
• Physical disturbance may be compromising northern reference sites
• Data from video less sensitive than from stills and has a lag time


Post-discharge changes
• initially slight increase in drape and decrease in percent cover of coralline algae at 5 northern stations
• in 2005 decrease in coralline algae was more pronounced and widespread
• changes in upright algae over time - both increases and decreases
6

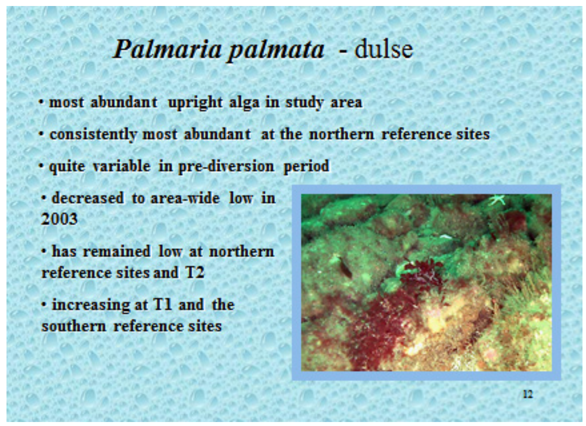

Drape
• visible layer of detrital material composed of phytodetritus, zooplankton fecal pellets, fine-grained resuspended sediments, biogenic tubes, and effluent particles.
• increase since 2001 at northern drumlin top sites including reference sites (not in video)
• hint of an increase at some southern stations since 2005
• related to outfall?
• regional trend?
7

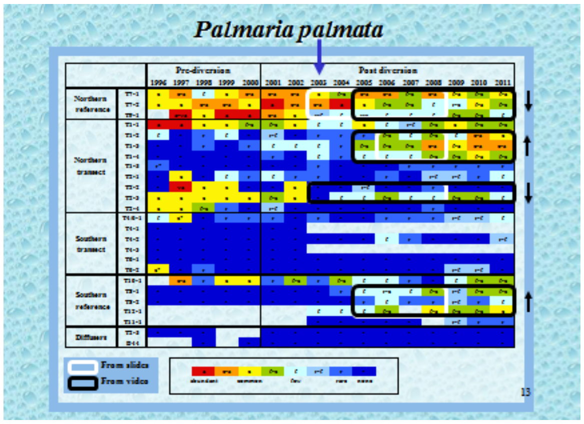

Drape
Pre-diversion
Post diversion
1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011
Northern reference
Northern transect
Southern transect
Southern reference
Diffusers
From slides
From video
heavy
moderate
light
8

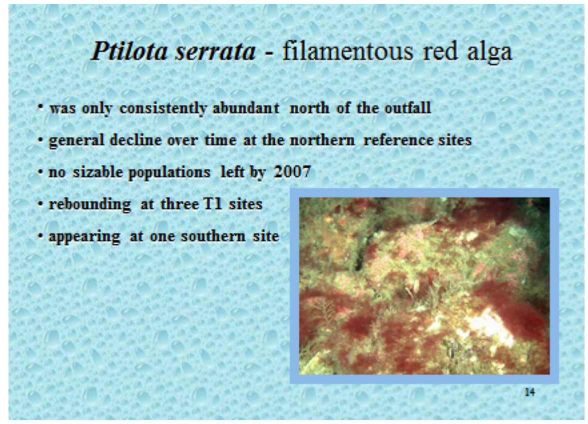

Coralline algae
• most abundant and consistent biota in study area
• decrease in percent cover since 2001 at northern drumin top sites in data from stills (2002 and 2004 in data from video)
• decrease more pronounced in 2005 and spread south
• related to outfall?
• regional trend?
9

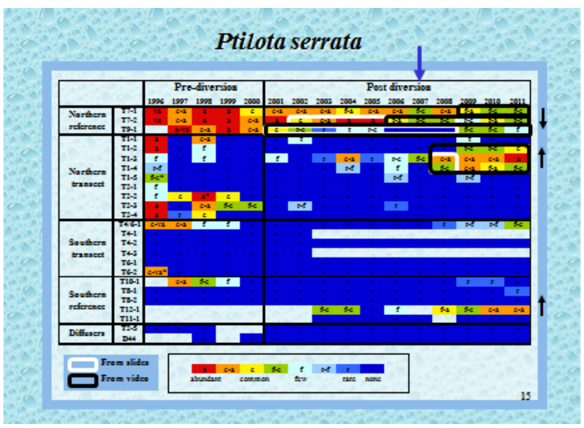

Coralline algae
Pre-diversion
Post diversion
1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011
Northern reference
T7-1 T7-2 T9-1
Northern transect
T1-1 T1-2 T1-3 T1-4 T1-5 T2-1 T2-2 T2-3 T2-4
Southern transect
T4/6-1 T4-1 T4-2 T4-3 T6-1 T6-2
Southern reference
T10-1 T8-1 T8-2 T12-1 T11-1
Diffusers
T2-5 D44
From slides
From video
a c-a c f-c f r-f r -
abundant common few rare none
10

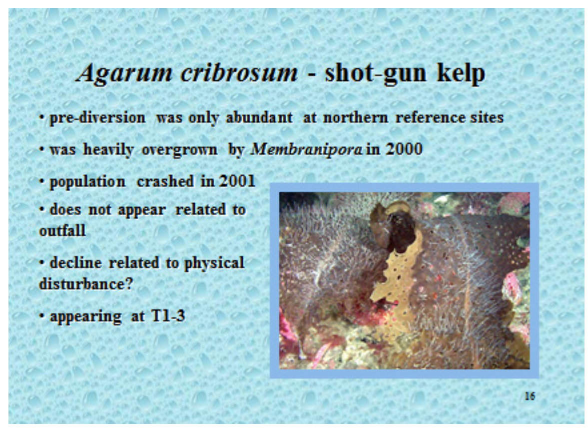

Upright algae
• restricted to shallower stations and patchy distributions
• general decrease in abundance over time, now reversing
• initially only abundant at northern reference sites
• last several years seeing some at southern reference sites
• changes appear to be cyclical and not related to the outfall
• physical disturbance may explain some of the decreases at northern reference sites

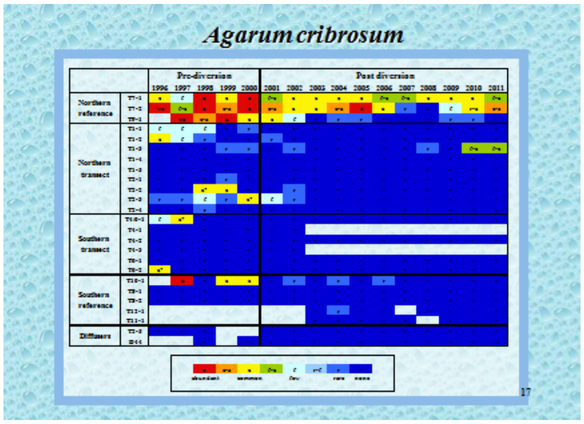

Palmaria palmata - dulse
• most abundant upright alga in study area
• consistently most abundant at the northern reference sites
• quite variable in pre-diversion period
• decreased to area-wide low in 2003
• has remained low at northern reference sites and T2
• increasing at T1 and the southern reference sites
12

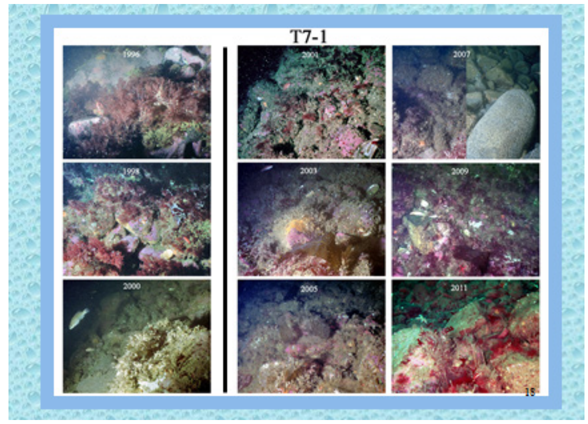

Palmaria palmata
Pre-diversion
Post diversion
1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011
Northern reference
Northern transect
Southern transect
Southern reference
Diffusers
From slides
From video
abundant common few rare none
13

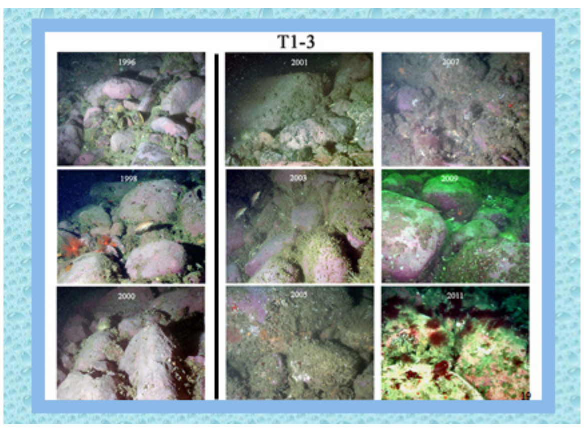

Ptilota serrata - filamentous red alga
• was only consistently abundant north of the outfall
• general decline over time at the northern reference sites
• no sizable populations left by 2007
• rebounding at three T1 sites
• appearing at one southern site
14

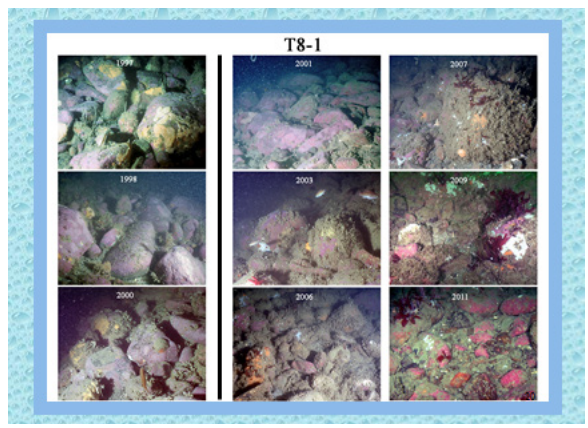

Ptilota serrata
Pre-diversion
Post diversion
1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011
Northern reference
Northern transect
Southern transect
Southern reference
Diffusers
From slides
From video
abundant common few rare none
15

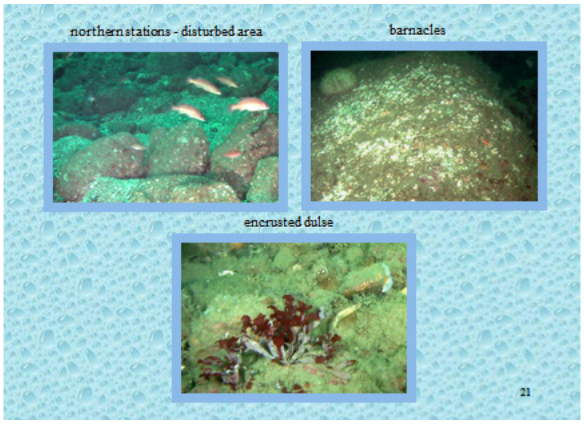

Agarum cribrosum - shot-gun kelp
• pre-diversion was only abundant at northern reference sites
• was heavily overgrown by *Membranipora* in 2000
• population crashed in 2001
• does not appear related to outfall
• decline related to physical disturbance?
• appearing at T1-3
16


Agarum cribrosum
Pre-diversion
Post diversion
Northern reference
Northern transect
Southern transect
Southern reference
Diffusers
abundant
common
few
rare
none
17


T7-1
1996
1998
2000
2001
2003
2005
2007
2009
2011
18


T1-3
1996
1998
2000
2001
2003
2005
2007
2009
2011

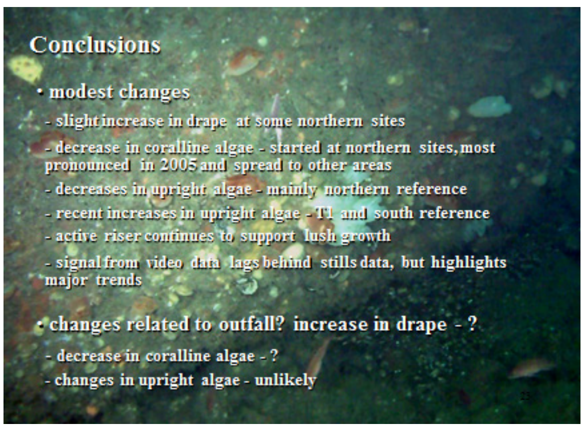

T8-1
1998
2000
2001
2003
2006
2007
2009
2011

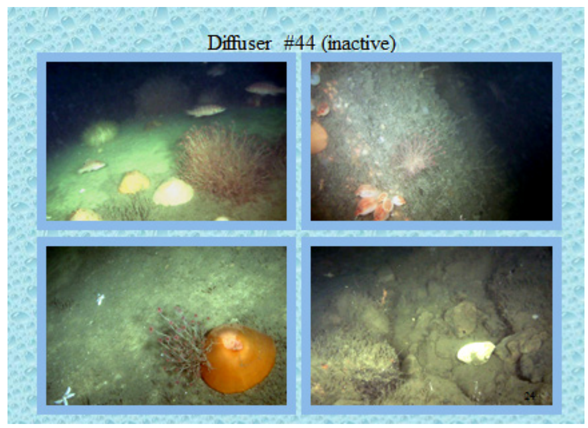


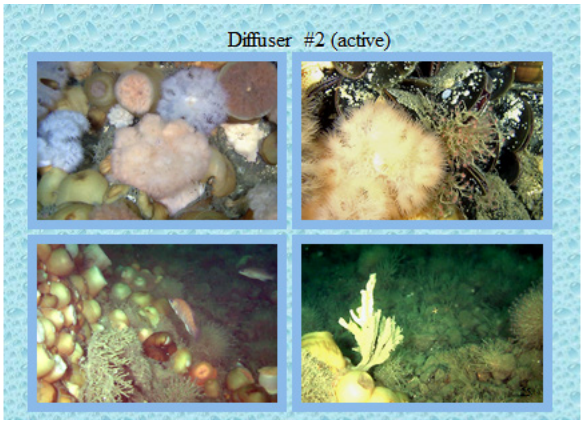
Long term changes

	Pre-discharge					Post-discharge										
	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Minutes of video	438	487	439	422	444	448	495	489	454	466	419	440	443	448	531	479
Gadus morhua (cod)	-	6	12	22	11	41	53	10	52	64	59	40	64	91	38	44
Pseudopleuronectes americanus (winter flounder)	20	14	30	34	11	18	19	9	24	17	11	16	47	40	91	62
Cancer spp. (rock crab)	6	3	4	15	92	123	168	144	115	67	81	108	28	85	34	35
Homarus americanus (lobster)	6	2	11	4	18	21	31	33	12	10	25	36	12	79	25	36

22






Diffuser #2 (active)

Appendix B Summary of data recorded from video footage taken on the 2011 hard-bottom survey

Appendix B. Summary of data recorded from video footage taken on the 2011 hard-bottom survey.

Station	T1-1	T1-2	T1-3	T1-4	T1-5	T2-1	T2-2	T2-3	T2-4	T4/ 6-1	T4-2	T6-1	T6-2	T7-1	T7-2	T9-1	T10-1	T8-1	T8-2	T12-1	T11-1	T2-5	D#44	Total
Minutes used	24	22	21	22	21	24	20	23	23	22	23	20	22	20	26	22	26	23	24	22	22	25	26	523
Depth (m) beginning	27.3	25.4	23.2	25.1	31.5	26.6	31.3	26.9	31	25	31.6	33	30.7	25.9	25.9	27.7	25.7	24.4	25.3	24.1	33.3	33.2	34.6	
Depth (m) end	27.1	28.3	23.7	26	30.3	27.8	33.7	30.8	34.4	25.4	28.5	34.1	29.5	26.9	26.2	27.7	26	25.5	24.6	25.7	33.2	30.8	34.1	
Substrate [1]	mx	b+c	b+c	mx	c+ob	mx	b+c	b+c	cp+ob	b+c	cp+mx	cp+ob	c+b	b+c	b+c	b+c	b+c	c+mx	c+mx	c+b	c+b	d+rr	d+rr	
Drape [2]	m-mh	lm-m	lm-m	lm-m	m-mh	lm-m	m-mh	m-mh	m	l-lm	m-mh	mh	m	lm-m	lm-m	lm-m	m-h	lm-m	lm-m	lm	m	m	mh-h	
Relief [3]	L-M	LM-M	MH	M	L-LM	M	M	M	LM	M	LM-M	L-LM	LM-M	M	M-MH	M	MH-H	L-LM	LM-M	M	LM-M	M-MH	M-MH	
Suspended material[5]	h	h	h	h	h	h	vh	vh	vh	vh	vh	vh	vh	h	vh	vh	vh	vh	h	vh	vh	vh	vh	
Coralline algae	f	f-c	c	c	f	f-c	f	f	r	a	r-f		f	f-c	c	c	r	c-a	c-a	c	f			
Ptilota serrata		c	a	f-c						f-c				f-c	f-c	f		r		c-a				
general hydroid	c-a	c-a	c	f-c	f-c	c	c	c-a	c	c	c	f-c	f-c	f-c	c	f-c	c-a	f-c	f-c	c	c	r-a	a	
barnacle/spirorbid complex		f	c	f-a	f	c	f		r	c		r-f				f-c			f			f		
Palmaria palmata	f-c	c	c-a	f-c	r	f		f		f	r-f			f-a	f-c	f	f-c	f-c	f	c	r			
Agarum cribosum			f-c											f-c	c-a									
general sponge	1		1	1		3	2	4	2		2	1		1	6	2	1	1		1	4	1		34
Polymastia sp. A	f-c	f-c	f	r	f	c	c	c	f-c	r	f	r	c	r	c	f-c	c	r	f	c	f		c	
Polymastia sp. B	3																							3
Haliclona oculata	1						1	2	1											8	9	10	14	46
Suberites spp.	f-c	r			f-c	f	c	f-c	f-c		c		c				c	r		r	c	r	r	
white divided sponge	r		f-c		r	f	f	c	c		f	r	f	r	f-c	f-a	f		r	r-c	a			
Phakellia spp.																					14		1	15
Melonanchora elliptica	1					1														1				3
Haliclona spp. (encrusting)						1																		1
cream sponge/proj																					c			
yellowish-cream encrusting sponge																					a			
Obelia geniculata			f												c									
general anemone						3				1		1		1										6
Metridium senile			f					f		r						f	r					c-a	f-c	
Urticina felina	2	2		1	3	8	4	4	1	4	5		1		2		1		2	4	3	10	1	58
Cerianthus borealis									1		1													2
Gersemia rubiformis																	c							

Station	T1-1	T1-2	T1-3	T1-4	T1-5	T2-1	T2-2	T2-3	T2-4	T4/ 6-1	T4-2	T6-1	T6-2	T7-1	T7-2	T9-1	T10-1	T8-1	T8-2	T12-1	T11-1	T2-5	D#44	Total
Tubularia sp.								c							c	f				f		c-a	c	
Crepidula plana					r					f	f							f						
Buccinum undatum										1						1			1				1	4
Modiolus modiolus	c	f-c	a	c-a	f-c	c	f	c	c	a	c-a	f	c	c	c-a	a	a	c	c	c	f-c	f		
Mytilus edulis			f					r	f	r	f					f			r			f-c		
Placopecten magellanicus	1						1				1	6						1						10
Arctica islandica									r		r													
Balanus sp.		r-c	a	c-a		f-c		f		c	r-c			c	c	f								
Homarus americanus	2	1	3	5	1	1	2		4	2	2	1	1	4	2	1	3	3	3	3				44
Cancer spp.	1	1		1	1	2	1		3	3	3	1	5	1	1	1	3	1	4		1		1	35
hermit crab															1									1
Strongylocentrotus droebachiensis		r	f-c			c		r		c						f	c		c				f	
small white starfish	f-c	f-c	c-a	c	f	c	f	f	c	c	c	c	c	c-a	a	c-a	c-a	c	c	c-a	c	f-c	r-f	
Asterias vulgaris	r		f			r		r				f	r-c	f-c	f	r	r	f	c	r	r	f	r	
Henricia sanguinolenta	f-c	f-c	c	f-c	f-c	f-c	c	f	c	c	c	f-c	f	f-c	f-c	f	c	f-c	c	c	c	r-f	f	
Crossaster papposus																					1			1
Psolus fabricii			f	r		f		f		c						f	f		c	f-c	f		r	
Botrylloides violaceus	1	3	4	6		8		1		4					1	4	17	4	1	6	5			65
Aplidium/Didemnum	f-c	f-c	f-c	f	f-c	f	f	f	f	f	f-c	r-f	f-c	f-c	f	f	r	c-a	f-c	f	r-f		r-f	
Dendrodoa carnea																							r	
Halocynthia pyriformis	r	r	f-c		r	r	r	f-c	f	f	r		r-f	r	f-c	r-c	f			f	c	r	c	
Boltenia ovifera																					5			5
Membranipora membranipora	f-c	c	c-a	f-c				r						f-a	f-c		f-c	f-c		f				
Myxicola infundibulum	f-c	f-c		f		f	f	f	f	c	c	r	r		r	c	c	c	f		c	r	f	
Terebratulina septentrionalis	r		f-c		r	f	f	c	c		f-c	r	f	r	f-a	f-a	f		r	r-a	a	r	r	
general fish				5		2		3		2					1		1		3	1		1		19
Tautogolabrus adspersus	f-c	f-c	a	f-c	f	c-a	f-c	f-c	f	f	f-c	r-f	r-f	f-a	c-a	c	a	f	f-c	c	f-c	c-a	c	
Myoxocephalus spp.	1	2		1	1	1			2		2		6	4				4	2	1				27
Macrozoarces americanus																		1						1
Hemitripterus americanus		1						1																2
Pseudopleuronectes americanus	1	4		2	6	3		1	4	3	2	10	4			2		15	3		3		2	65
Sebastes fasciatus			1																		1	6		8

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
Pholis gunnellus											1	1	1		1									4
Gadus morhua			6			1		3							7	1	7	1	1	1	3	2	3	36
Pollachius virens															1	2				4				7
egg case						1																		1

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

Appendix C Taxa observed during the 2011 nearfield hard-bottom video survey

Appendix Table C. Taxa observed during the 2011 nearfield hard-bottom video survey.

Name	Common name	Name	Common name
Algae			
Coralline algae	pink encrusting algae	**Echinoderms**	
Ptilota serrata	filamentous red algae	*Strongylocentrotus droebachiensis*	green sea urchin
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		*Psolus fabricii*	scarlet holothurian
general sponge			
Haliclona oculata	finger sponge	**Tunicates**	
Haliclona spp. (encrusting)	sponge	*Aplidium/Didemnum* spp.	cream encrust tunicate
Melonanchora elliptica	warty sponge	*Boltenia ovifera*	stalked tunicate
Polymastia sp. A	encrust yellow sponge	*Botrylloides violaceus*	Pacific tunicate
Polymastia sp. B	siphon sponge	*Dendrodoa carnea*	drop-of-blood tunicate
Phakellia spp.	chalice sponge	*Halocynthia pyriformis*	sea peach tunicate
Suberites spp.	fig sponge		
cream sponge /projections	sponge	**Miscellaneous**	
yellow-cream encrust sponge	sponge	*Membranipora* sp.	sea lace bryozoan
white divided sponge	sponge on brachiopod	*Myxicola infundibulum*	slime worm
		barnacle/spirorbid complex	
Coelenterates		*Terebratulina septentrionalis*	northern lamp shell
hydroids			
Obelia geniculata	hydroid	**Fishes**	
Tubularia sp.	hydroid	general fish	
general anemone		*Hemitripterus americanus*	sea raven
Metridium senile	frilly anemone	*Gadus morhua*	cod
Urticina felina	northern red anemone	*Macrozoarces americanus*	ocean pout
Cerianthus borealis	northern cerianthid	*Myoxocephalus* spp.	sculpin
Gersemia rubiformis	red soft coral	*Pholis gunnellus*	rock gunnel
		Pollachius virens	pollock
Molluscs		*Pseudopleuronectes americanus*	winter flounder
Crepidula plana	flat slipper limpet	*Sebastes fasciatus*	rosefish
Buccinum undatum	waved whelk	*Tautogolabrus adspersus*	cunner
Modiolus modiolus	horse mussel		
Mytilus edulis	blue mussel	**Other**	
Placopecten magellanicus	sea scallop	whelk egg case	
Arctica islandica	ocean quahog		
Crustaceans			
Balanus sp.	barnacle		
Cancer spp.	Jonah or rock crab		
Homarus americanus	lobster		
hermit crab			

Appendix D 2011 hard-bottom still images

Appendix D. 2011 hard-bottom still images

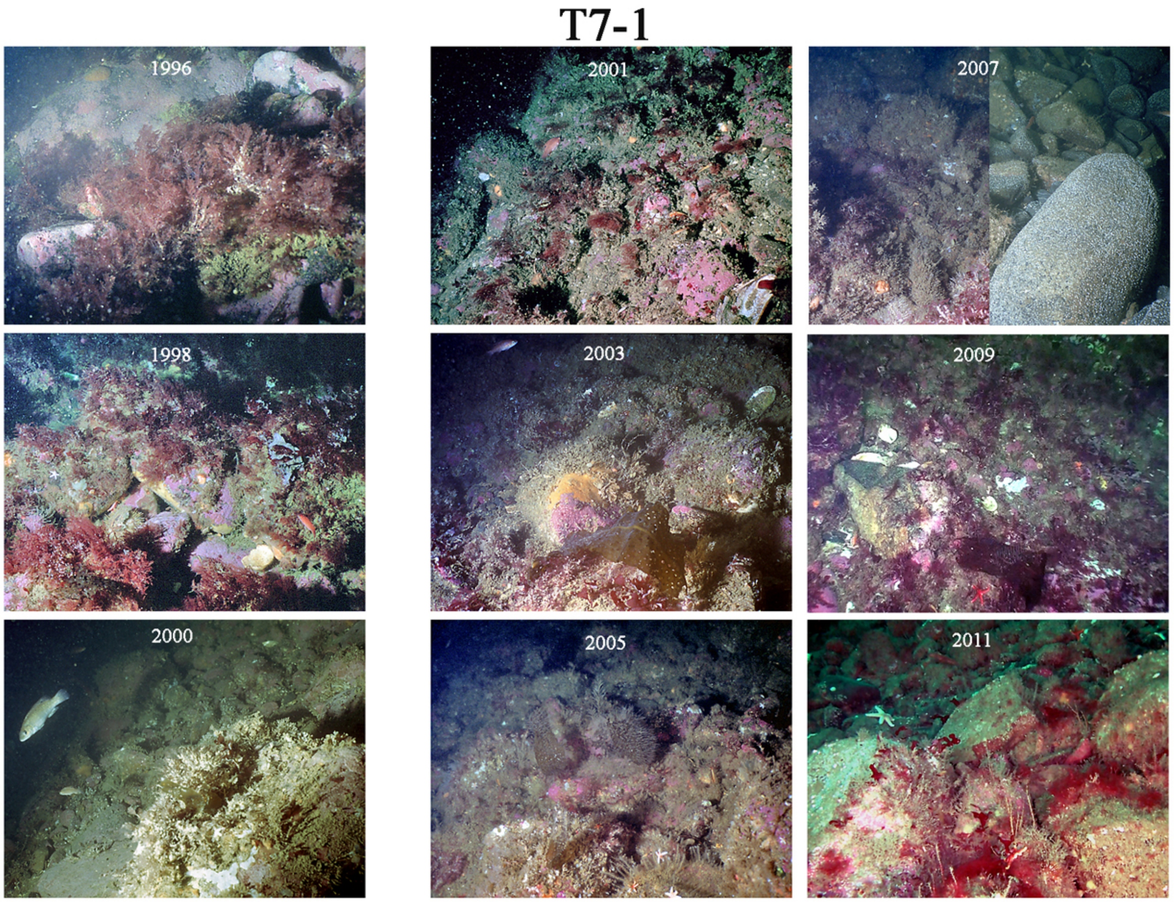


Plate 1. Representative images through time at T7-1 one of the northern reference sites. The three images on the left (1996, 1998 and 2000) show this site during the pre-diversion years. The benthic community was dominated by upright algae during this period. The six images on the right show representative images from the post diversion period. The number of upright algae and the percent cover of coralline algae generally decreased over time. Some of these changes may reflect physical disturbance of the seafloor by tankers anchoring at the northern reference sites. One such disturbed area can be seen in the right half of 2007 image, where overturned boulders are characterized by little drape, little coralline algae cover, and few encrusting organisms.

T1-3

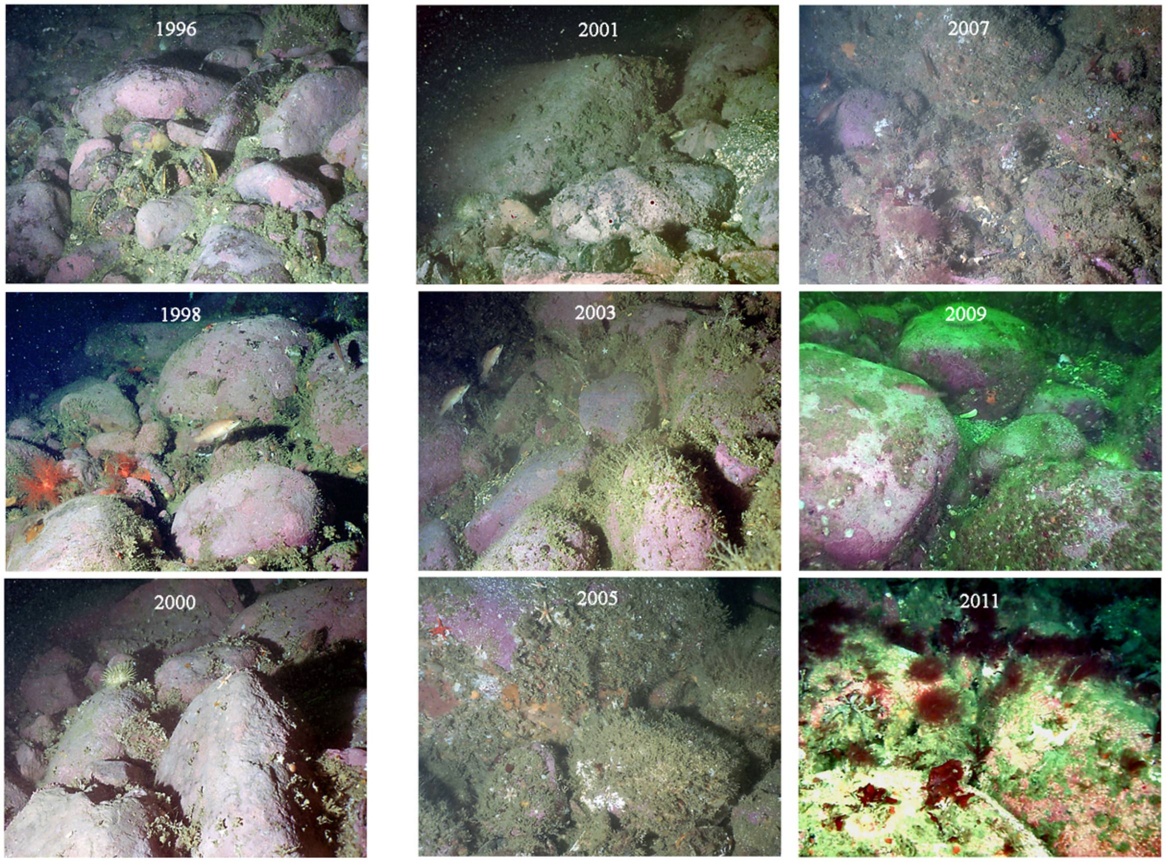


Plate 2. Representative images through time at T1-3 a drumlin top site north of the outfall. The three images on the left (1996, 1998 and 2000) show this site during the pre-diversion years. The benthic community was totally dominated by coralline algae and the rocks had very little drape during this period. The six images on the right show representative images from the post diversion period. The percent cover of coralline algae generally decreased over time and the amount of drape on the rock surfaces increased. Additionally, upright algae has started to appear at this site in the last few years.

T8-1

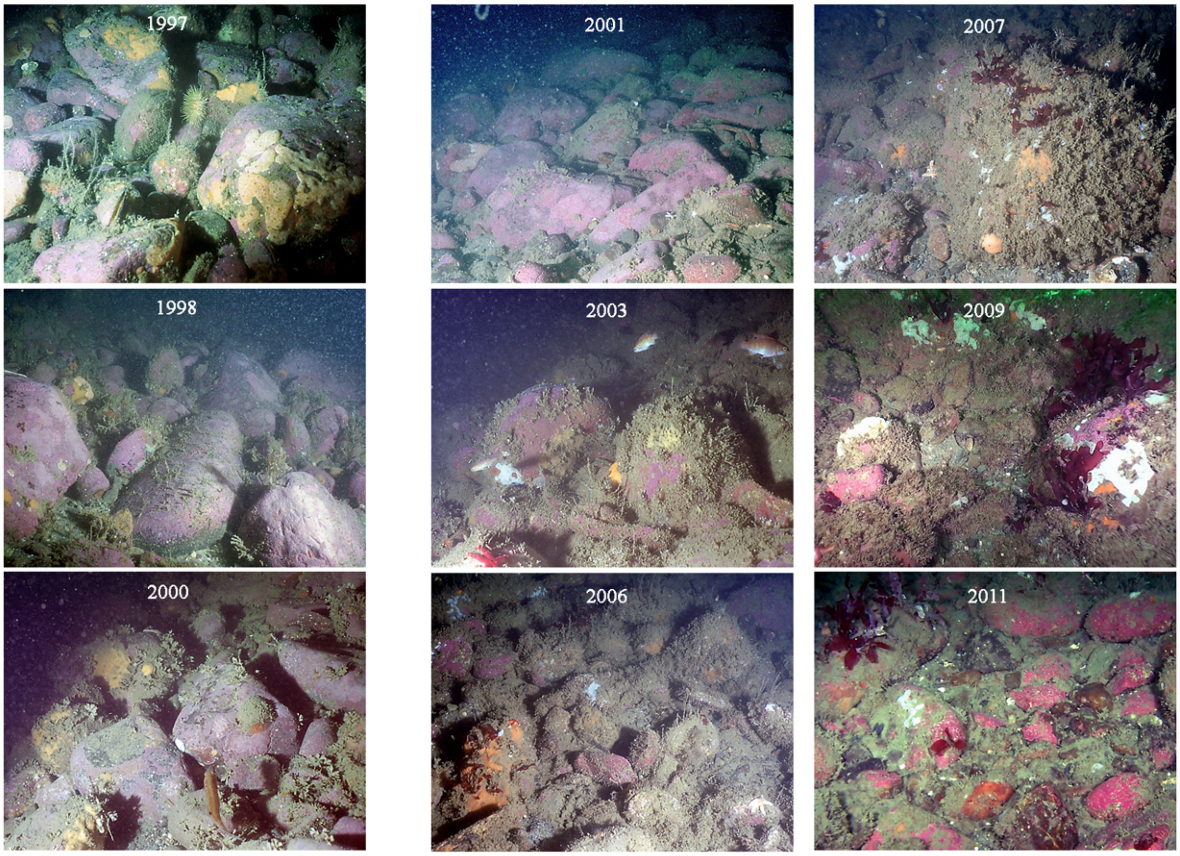


Plate 3. Representative images through time at T8-1 one of the southern reference sites. The three images on the left (1997, 1998 and 2000) show this site during the pre-diversion years. The benthic community was dominated by coalline algae during this period. The six images on the right show representative images from the post diversion period. The percent cover of coralline algae generally decreased over time and more drape can be seen on the rock surfaces. Additionally, numerous colonies of dulse (*Palmaria palmata*) have been seen at this site in the last few years.

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