Outfall Benthic Monitoring Report: 2014 Results

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Submitted to

Massachusetts Water Resources Authority
Environmental Quality Department
100 First Avenue
Charleston Navy Yard
Boston, MA 02129
(617) 242-6000

prepared by

Eric C. Nestler[1]
Robert J. Diaz[2]
Barbara Hecker[3]
Ann E. Pembroke[1]
Kenneth E. Keay[4]

[1]Normandeau Associates, Inc.
25 Nashua Road
Bedford, NH 30110

[2]Diaz and Daughters
6198 Driftwood Lane
Ware Neck, VA 23178

[3]Hecker Environmental
26 Mullen Way
Falmouth, MA 02540

[3]Massachusetts Water Resources Authority
100 First Avenue
Charleston Navy Yard
Boston, MA 02129

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EXECUTIVE SUMMARY

Benthic monitoring during 2014 included soft-bottom sampling for sediment conditions and infauna at 14 nearfield and farfield stations, and sediment profile imaging (SPI) at 23 nearfield stations.

Sediment conditions were characterized based on spore counts of the anaerobic bacterium, *Clostridium perfringens*, and analyses of sediment grain size composition and total organic carbon (TOC). As in past years during the post-diversion period, *C. perfringens* concentrations during 2014 were highest at sites closest to the discharge. Statistical analyses conducted for the 2006 and 2007 outfall benthic monitoring reports (Maciolek et al. 2007, 2008) confirmed that findings of higher *Clostridium* at stations close to the outfall were statically significant and consistent with an impact of the outfall discharge. The results for *C. perfringens* provide evidence of solids from the effluent at sites in close proximity (within 2 km) to the outfall. No such evidence of the wastewater discharge was apparent in the monitoring results for sediment grain size or TOC during 2014. These findings are also consistent with prior monitoring results (Nestler et al. 2014a, Maciolek et al. 2008).

Sediment contaminant monitoring in 2014 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 2014. Previous statistical analyses also documented the lack of evidence of contaminants from effluent accumulating in the sediments (Maciolek et al. 2008, 2009). The 2014 results support these findings. 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 2014 for two infaunal diversity measures: (1) Shannon-Wiener Diversity (H′) and (2) Pielou’s Evenness (J′). No exceedances were reported for other infaunal diversity measures or for the percent opportunistic species. Exceedances of H′ and J' have been reported each year since 2010. The diversity threshold exceedance results for 2014 were communicated to regulators and the public in December 2014 (MWRA 2014). During these past five years, annual Nearfield averages for H′ and J' have been higher than during the baseline period, resulting in exceedances of the upper threshold limits. Evaluations of the 2014 threshold exceedances were limited in scope, and focused on assessing whether the current year’s results agree with previous findings. Previous findings include the results of an in-depth evaluation of whether increased H′ and J' reflect an influence of the wastewater discharge on infaunal communities that was conducted on the first four years of exceedances (Nestler et al. 2014a). The 2014 results were consistent with previous findings (Nestler et al. 2014a, Nestler et al. 2013, Nestler et al. 2012, Maciolek et al. 2011), confirming that there is no evidence that the threshold exceedances resulted from an impact of the outfall discharge on infaunal communities. Recent increases in H′ and J′ appear to be a region-wide occurrence, strongly influenced by relatively low abundance in a few dominant species, and unrelated to the discharge. Relatively low abundance of the polychaete *Prionospio steenstrupi* has been the most influential factor in the threshold exceedances. Although this species has remained among the numerical dominants in recent years, its annual abundances have been lower than previously reported. The results of these threshold exceedance evaluations suggest that it may be appropriate to revisit the need for upper diversity triggers for MWRA’s infaunal Contingency Plan thresholds. Infaunal data in

2014 continue to suggest that the macrobenthic communities at sampling stations near the outfall have not been adversely impacted by the wastewater discharge.

The 2014 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 2014 was greater than during the baseline period, and the highest reported during post-discharge years. These results support previous findings that organic loading and the associated decrease in oxygen levels have not been a problem at the nearfield benthic monitoring stations (Nestler et al. 2014a, Maciolek et al. 2008). The outfall is located in an area dominated by hydrodynamic and physical factors, including tidal and storm currents, turbulence, and sediment transport (Butman et al. 2008). These physical factors, combined with the high quality of the effluent discharged into the Bay (Taylor 2010), are the principal reasons that benthic habitat quality has remained high in the nearfield area.

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

Appendix A **Annual Technical Meeting Presentations for Outfall Benthic Monitoring in 2014**
  Appendix A1. 2014 Harbor and Outfall Monitoring: Sediment conditions and contaminants
  Appendix A2. 2014 Harbor and Outfall Monitoring: Benthic Infauna
  Appendix A3. 2014 Harbor and Bay Sediment Profile Imaging
  Appendix A4. 2014 Nearfield Hard-bottom Communities
Appendix B **Summary of data recorded from video footage taken on the 2014 hard-bottom survey**
Appendix C **Taxa observed during the 2014 nearfield hard-bottom video survey**
Appendix D **2014 hard-bottom still images**

LIST OF FIGURES

PAGE

LIST OF TABLES

PAGE

1. INTRODUCTION

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, 2001, 2004, 2010) the MWRA has collected extensive information over a nine-year baseline period (1992–2000) and a fourteen-year post-diversion period (2001–2014). 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).

Benthic monitoring during 2014 was conducted following the current version of the Ambient Monitoring Plan (MWRA 2010). Under this plan, annual monitoring includes soft-bottom sampling for sediment conditions and infauna at 14 nearfield and farfield stations, and Sediment Profile Imaging (SPI) at 23 nearfield stations. Every third year, hard-bottom surveys are conducted (at 23 nearfield stations) and sediment contaminants are evaluated (at the same 14 stations where infauna and sediment condition samples are collected). Both sediment contaminant monitoring and hard-bottom surveys were conducted in 2014.

The purpose of this report is to summarize key findings from the 2014 benthic surveys, with a focus on the most noteworthy observations relevant to understanding the potential effects of the discharge on the offshore benthic environment. Results of 2014 benthic monitoring were presented at MWRA's Annual Technical Workshop on April 1, 2015. PowerPoint presentations from this workshop are provided in Appendix A.

2. METHODS

Methods used to collect, analyze, and evaluate all sample types remain largely consistent with those reported for previous monitoring years (Nestler et al. 2013, Maciolek et al. 2008). Detailed descriptions of the methods are contained in the Quality Assurance Project Plan (QAPP) for Benthic Monitoring 2014–2017 (Nestler et al. 2014). 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 6 and 7, 2014 (Figure 2-1). To aid in analyses of potential spatial patterns reported herein, these stations are grouped, based on distance from the discharge, into four "monitoring areas" within Massachusetts Bay:

- 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 effort at these stations has varied somewhat during the monitoring program. In particular, from 2004-2010 some stations were sampled only during even years (NF22, FF04 and FF09), Stations NF17 and NF12 were sampled each year, and the remaining stations were sampled only during odd years.

Sampling at Station FF04 within the Stellwagen Bank National Marine Sanctuary was conducted in accordance with Research permit SBNMS-2013-003.

Soft-bottom stations were sampled for grain size composition, total organic carbon (TOC), and the sewage tracer *Clostridium perfringens*. 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). Infauna samples were also collected using a 0.04-m^2 Ted Young-modified van Veen grab, and were rinsed with filtered seawater through a 300-µm-mesh sieve.

Sediment Profile Imaging (SPI) samples were collected in triplicate at 23 nearfield stations on August 11, 2014 (Figure 2-2).

Video camera transects (Figure 2-3) were performed as in previous years. A Benthos Mini-Rover ROV (remotely operated vehicle) was used to survey most of the waypoints instead of an Outland Technology 100, due to technical difficulties encountered with the Outland vehicles. The Benthos Mini-Rover is a slightly smaller and less powerful vehicle and hence moved more slowly over the seafloor. Additionally, Mini-Rover is also slightly acoustically noisier than the Outland 100. A GoPro Hero 3 camera mounted on the ROV was used to obtain simultaneous HD video and still images (at 10-second intervals) throughout each transect. All of the 23 hard-bottom waypoints were successfully surveyed on June 23 to 27, 2014, including an actively discharging diffuser head at the eastern end of the outfall. At least 19 minutes of both analog and high definition (HD) video footage was obtained at all but one of the waypoints, T1-2, where only 13 minutes of video was collected.

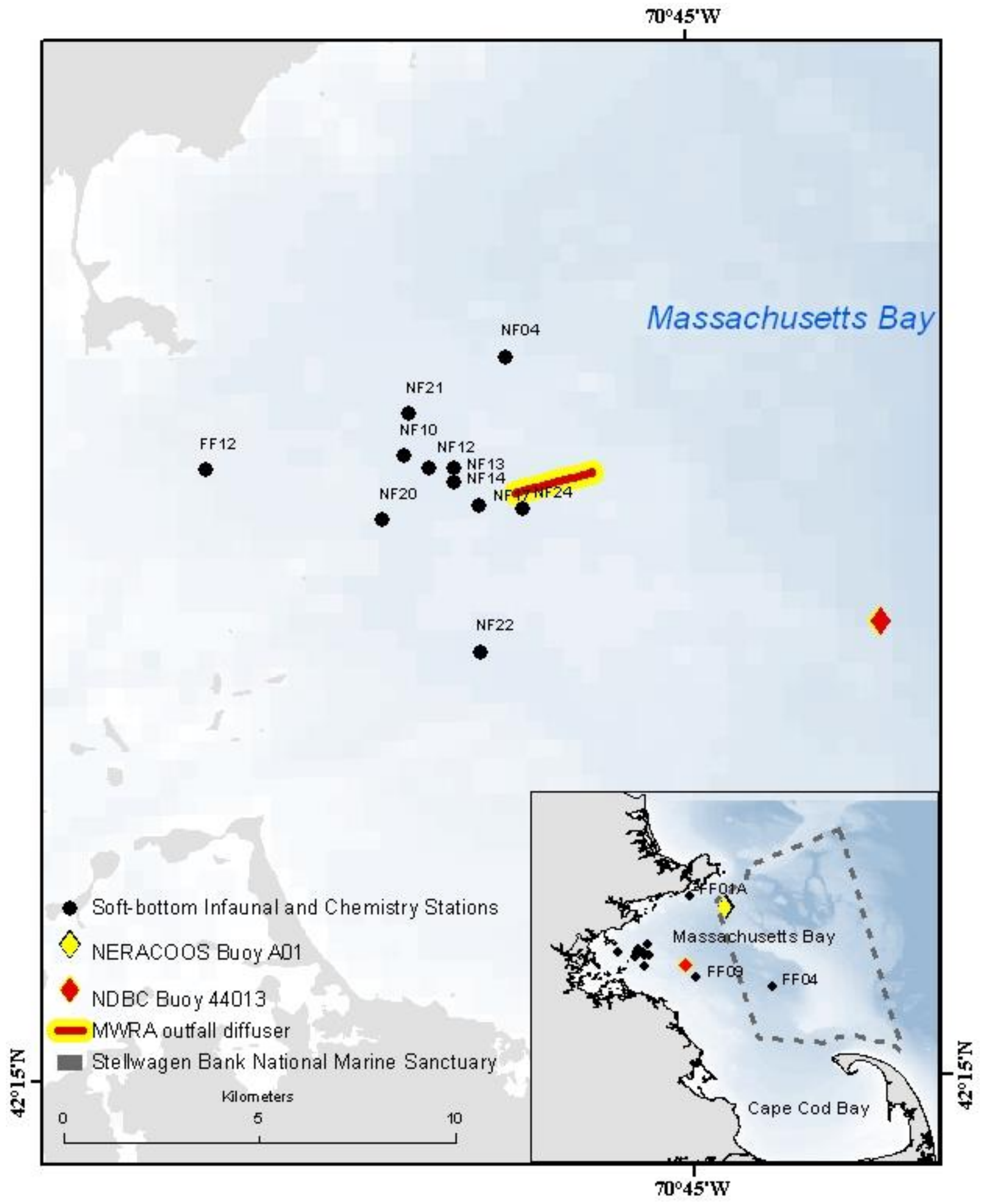


Figure 2-1. Locations of soft-bottom sampling stations for 2014.

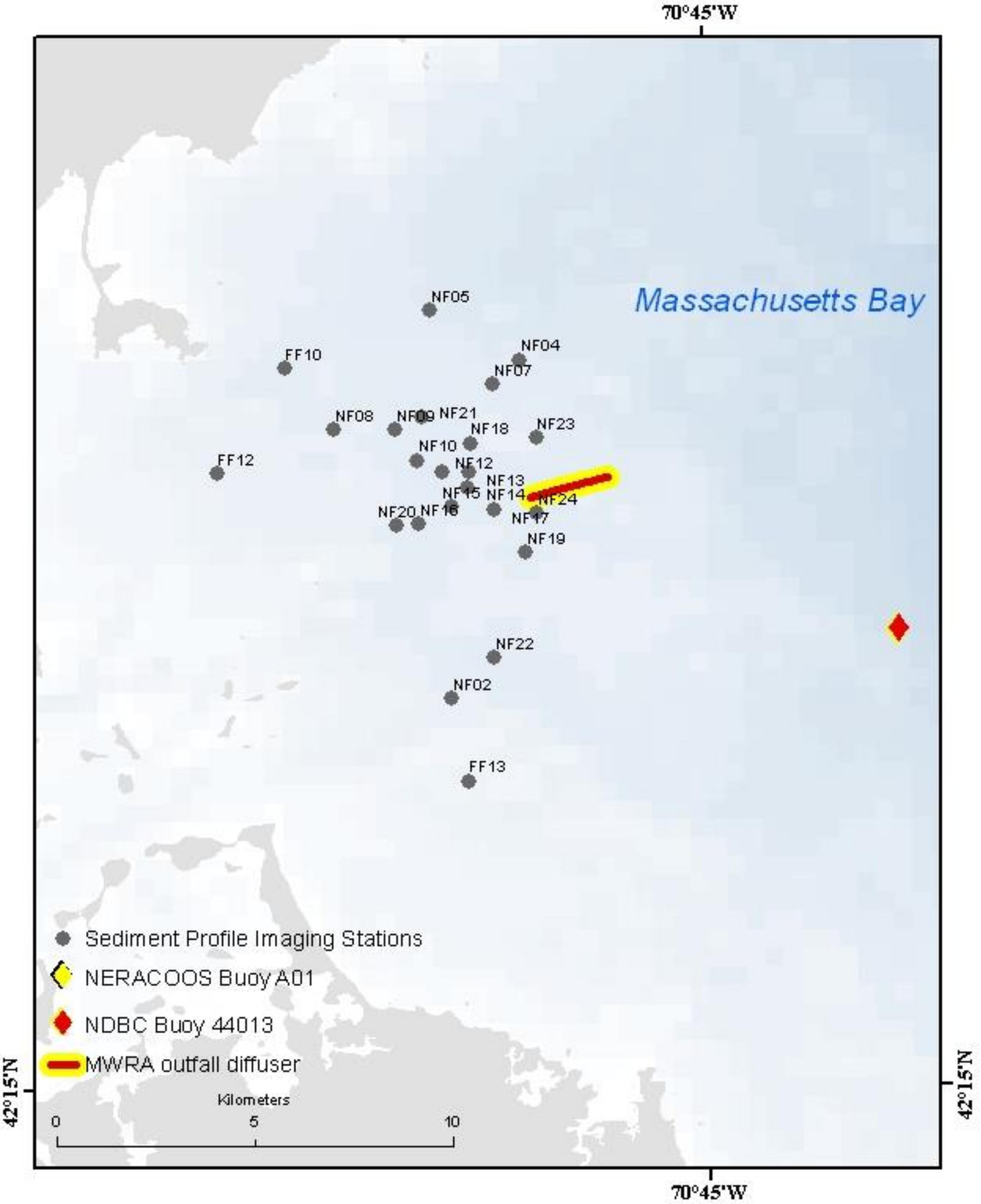


Figure 2-2. **Locations of sediment profile imaging stations for 2014.**

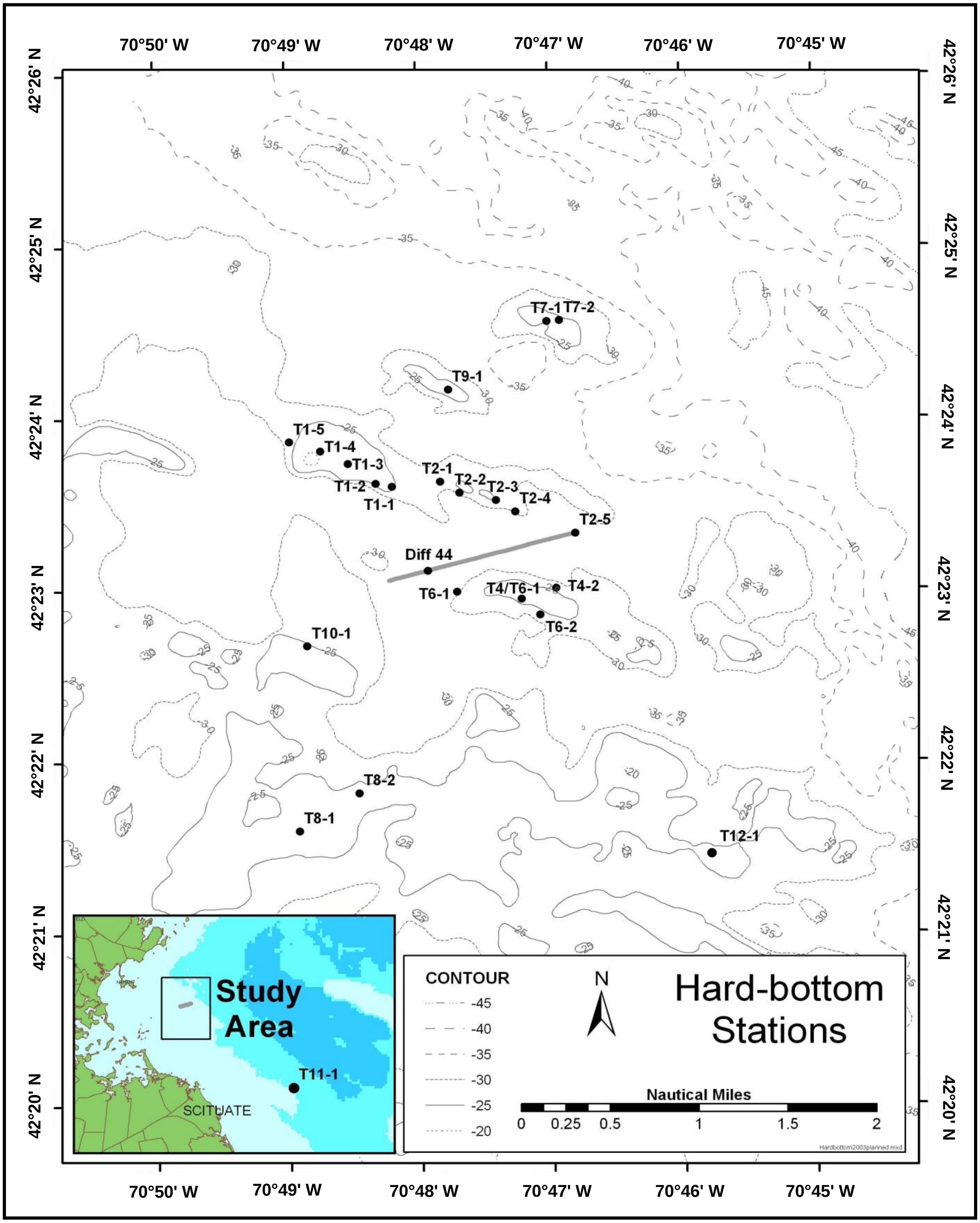


Figure 2-3. Locations of hard-bottom benthic monitoring stations for 2014.

2.2 Laboratory Methods

All sample processing, including sorting, identification, and enumeration of organisms, was done following methods consistent with the QAPP (Nestler et al. 2014b). Analog video collected during the hard-bottom survey was analyzed and the HDV and stills were 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. 2014b) or by Maciolek et al. (2008).

Additional multivariate techniques were used to evaluate infaunal communities. 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 2014 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 monitoring areas during the post-diversion period. *C. perfringens* counts (reported as colony forming units per gram dry weight, normalized to percent fines) in samples collected during 2014 were highest at stations NF17, NF14, and NF13 (Table 3-1); three stations located within two kilometers from the outfall (Figure 3-2). Sensitive statistical analyses conducted in support of the outfall benthic monitoring reports for 2006 and 2007 (Maciolek et al. 2007, 2008) confirmed that findings of higher *C. perfringens* at stations close to the outfall were statically significant and consistent with an impact of the outfall discharge.

Sediment texture varied considerably among the 14 stations, ranging from predominantly sand (e.g., NF13, NF17, NF04, and FF01A) to almost entirely silt and clay (i.e., FF04), with most stations having mixed sediments (Table 3-1, Figure 3-3). Sediment texture has remained generally consistent over time at most stations (Figures 3-4 and 3-5). Bothner et al. (2002) reported that sediment transport at water depths less than 50 meters near the outfall site in Massachusetts Bay occurs largely as a result of wave-driven currents during strong northeast storm events. Strong storms during February and March 2013 (R. Geyer, personal communication), may have resulted in larger than average changes in the percent fine sediments at a number of stations that year (Figures 3-4 and 3-5). Year-to-year changes in sediment texture from 2013 to 2014 were also larger than typical at several stations. The percent fines in 2014, in general, had returned to levels that were closer to the historical averages than they had been the previous year (Figures 3-4 and 3-5). The percent fine sediments at station NF24 in 2014 were lower than had been reported in any previous year at that station (Figure 3-5).

Concentrations of total organic carbon (TOC) in 2014 remained similar to values reported in prior years at most stations (Figure 3-6). 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). This pattern is evident in comparisons of Figures 3-4 and 3-6.

As in past years during the post-diversion period, *Clostridium perfringens* concentrations during 2014 continue to indicate a footprint of the effluent plume, but only at sites closest to the discharge. Although *C. perfringens* counts continue to provide evidence of effluent solids depositing near the outfall, there is no indication that the wastewater discharge has resulted in changes to the sediment grain size composition at the Massachusetts Bay sampling stations, and there is no indication of organic enrichment. TOC concentrations remain comparable to, or lower than, values reported during the baseline period, even at sites closest to the outfall. These findings are consistent with prior year monitoring results (Nestler et al. 2014a, Maciolek et al. 2008).

Table 3-1. 2014 monitoring results for sediment condition parameters.

Monitoring Area	Station	*Clostridium perfringens* (cfu/g dry/%fines)	Total Organic Carbon (%)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Percent Fines (Silt + Clay)
Transition Area	**FF12**	55	0.46	0.6	76.8	17.1	5.6	22.7
Nearfield (<2 km from outfall)	**NF13**	255	0.11	0.7	96.3	1.6	1.3	3.0
	NF14	305	1.93	29.4	62.2	5.3	3.1	8.4
	NF17	541	0.08	0.1	98.7	0.8	0.4	1.2
	NF24	146	0.38	0	80.7	14.5	4.7	19.3
Nearfield (>2 km from outfall)	**NF04**	147	0.10	0	96.4	2.1	1.5	3.6
	NF10	95	0.57	0	70.5	21.5	8.0	29.5
	NF12	50	0.86	0	42.3	46.9	10.8	57.7
	NF20	151	0.86	16.7	65.8	11.3	6.2	17.4
	NF21	67	1.08	0	35.2	52.5	12.3	64.8
	NF22	86	0.64	1.2	60.2	29.4	9.2	38.6
Farfield	**FF01A**	10	0.35	0	87.9	9.9	2.2	12.1
	FF04	25	2.33	0	6.6	61.6	31.8	93.4
	FF09	57	0.43	0	82.6	10.2	7.3	17.4

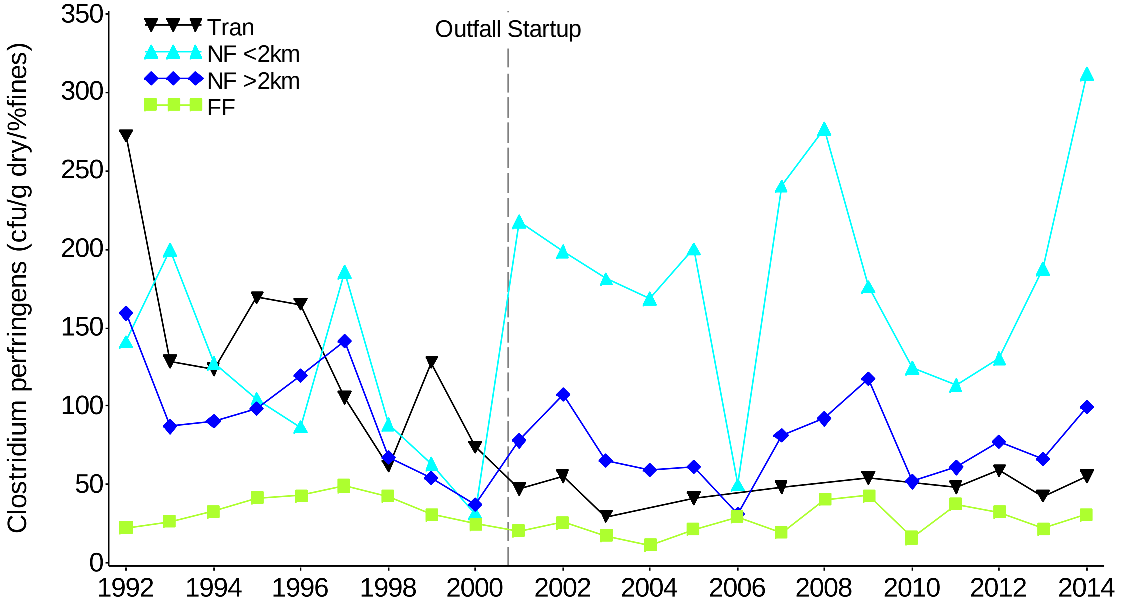


Figure 3-1. Mean concentrations of *Clostridium perfringens* in four areas of Massachusetts Bay, 1992 to 2014. Tran=Transition area; NF<2km=nearfield, less than two kilometers from the outfall; NF>2km=nearfield, more than two kilometers from the outfall; FF=farfield.

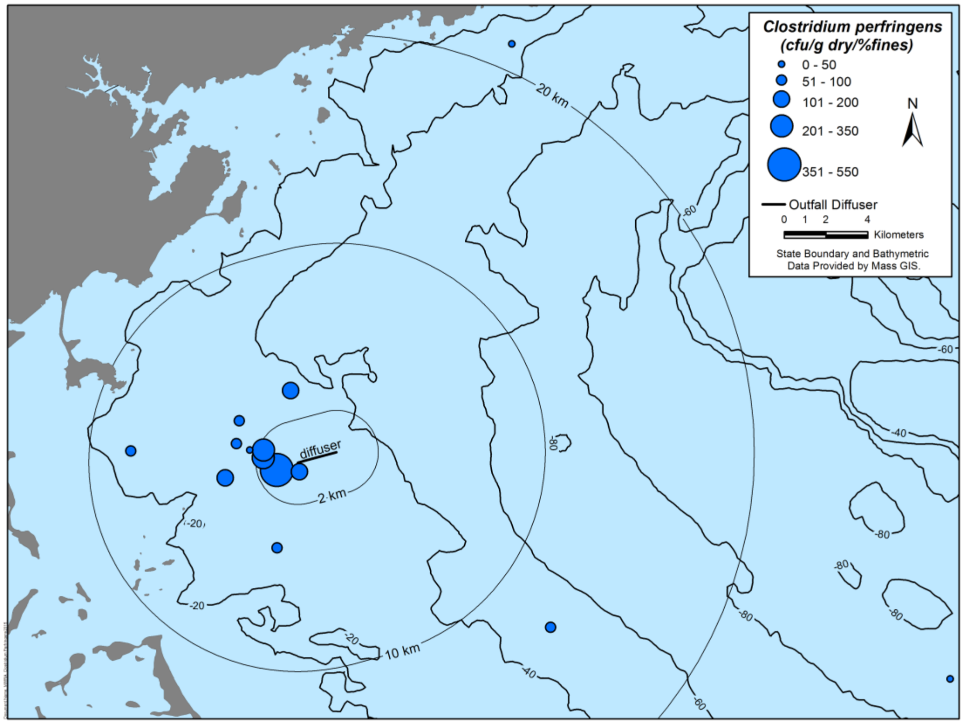


Figure 3-2. 2014 monitoring results for *Clostridium perfringens*.

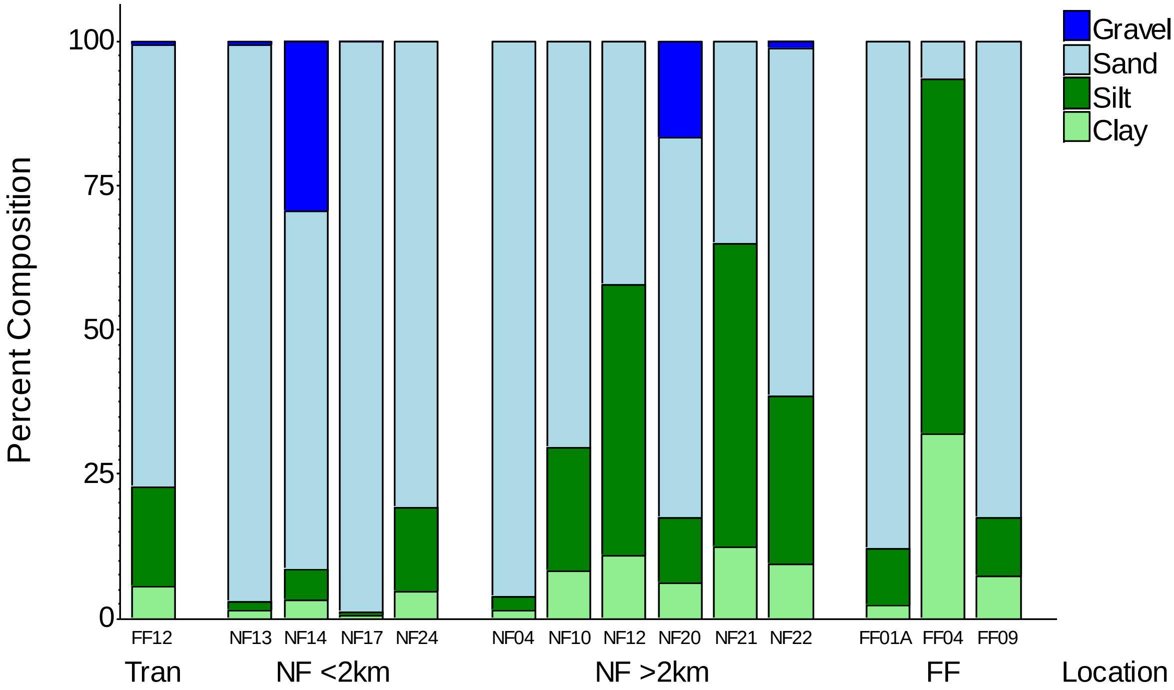


Figure 3-3. 2014 monitoring results for sediment grain size.

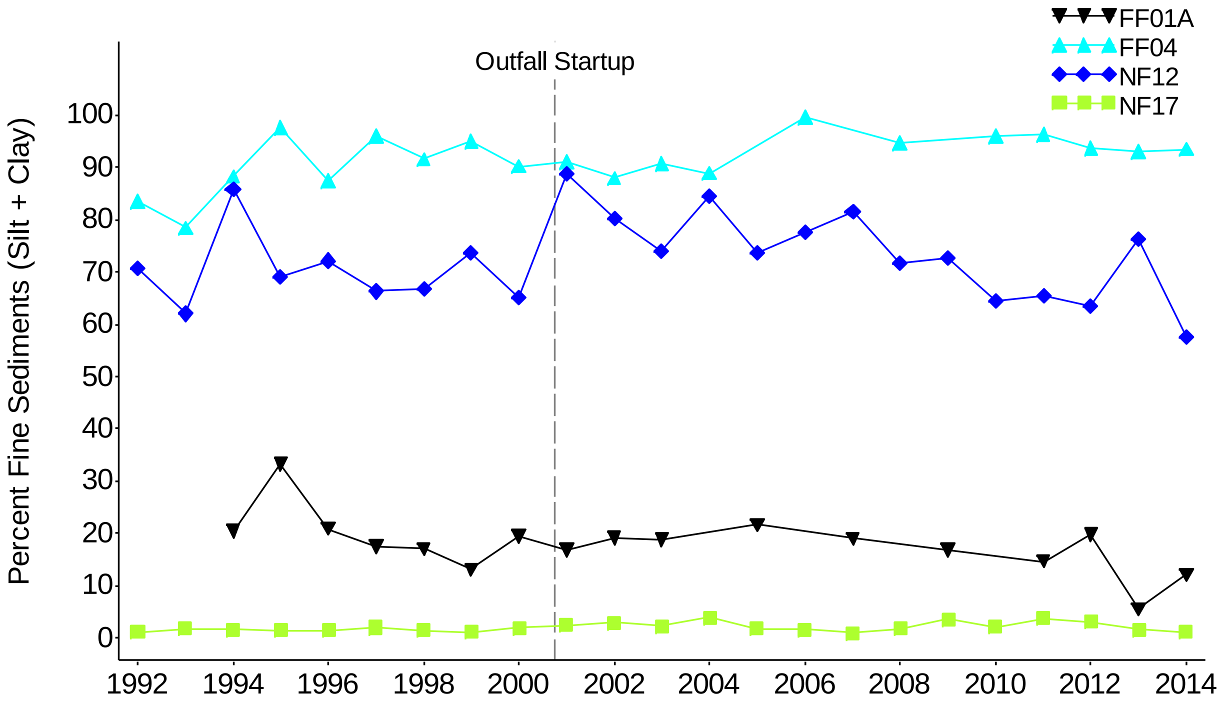


Figure 3-4. **Mean percent fine sediments at FF01A, FF04, NF12 and NF17; 1992 to 2014.**

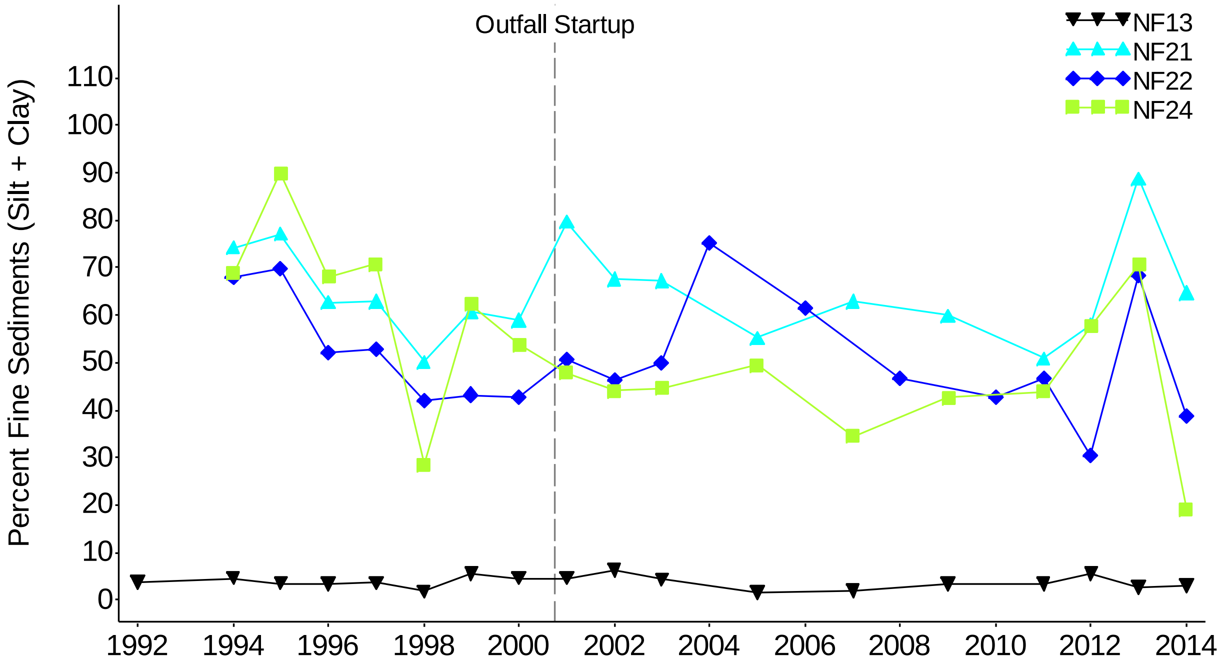


Figure 3-5. **Mean percent fine sediments at NF13, NF21, NF22 and NF24; 1992 to 2014.**

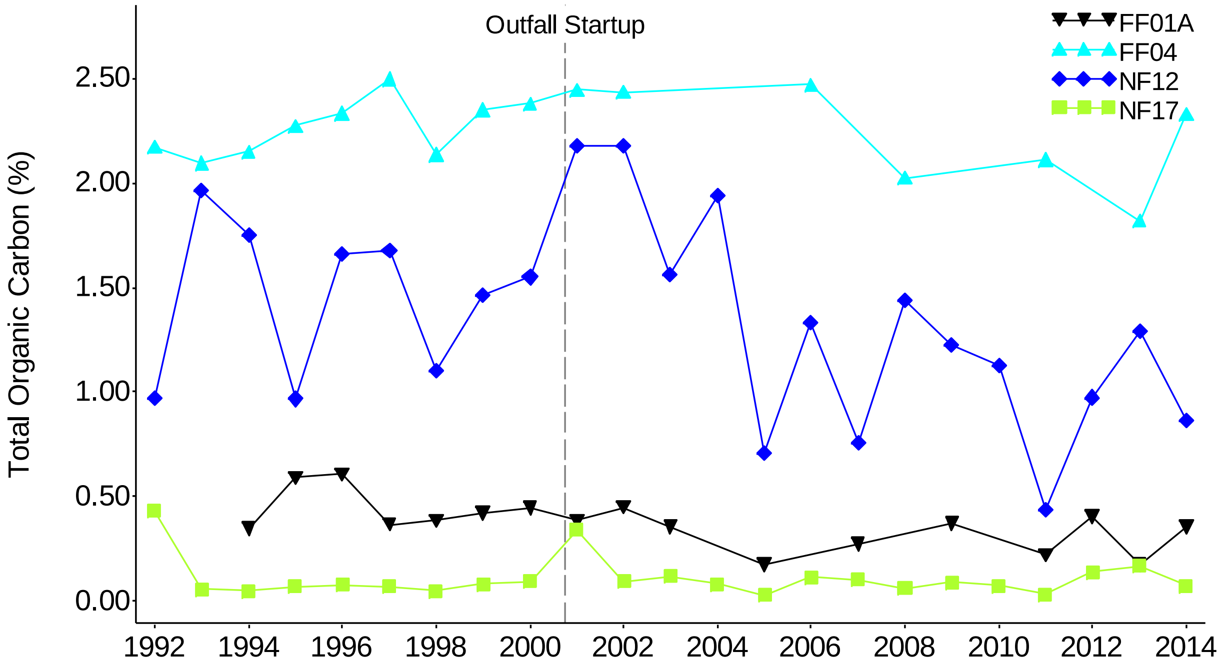


Figure 3-6. **Mean concentrations of TOC at four stations in Massachusetts Bay, 1992 to 2014.**

3.1.2 Anthropogenic Contaminants

Sediment samples collected during 2014 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 2014, chromium, copper, mercury, nickel, total DDT, total PAH, and total PCB values exceeded the ER-L limit at one or more stations (Table 3-2). Eight 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. Most of the highest values reported during 2014 were at stations more than two kilometers from the outfall (Table 3-2). Station NF14 was the only station less than two kilometers from the outfall where an ER-L exceedance (copper) was observed. The copper concentration at NF14 was anomalously high in comparison to previous years (Figure 3-7). The ER-M (effects range median) represents a contaminant level above which adverse impacts to benthic organisms are often detected (Long et al. 1995). No contaminant values reported during 2014 exceeded the ER-M sediment quality guideline (Table 3-2).

Higher contaminant levels are strongly correlated with smaller sediment particle sizes (Maciolek et al. 2008; Bothner et al. 2007). The three stations with the highest concentrations for most contaminants, FF04, NF21, and NF12, also have the highest percent fine sediments (compare Table 3-2 to Figure 3-3). Proximity to contaminant sources also influences contaminant concentrations. Nearfield stations NF12 and NF21 have a lower percent fines than farfield station FF04 (station with the highest percent fines), but higher concentrations of several contaminants; NF12 and NF21 are closer to Boston Harbor, the main historic source for contaminants in Massachusetts Bay, than FF04. In contrast to these stations, NF17 (nearfield station, less than 2km from outfall) has sandy sediments and low contaminant concentrations (Figures 3-3, 3-8 to 3-12). Thus, contaminant concentrations at NF12, NF21, FF04, and NF17 reflect influences of both percent fines and proximity to contaminant sources at these stations (Figures 3-8 to 3-12).

The MWRA's Contingency Plan established threshold levels 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 2014. 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 2014 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. 2014 sediment contaminant values that exceeded ER-L levels.

		Nearfield (<2 km from outfall)	Nearfield (>2 km from outfall)					Farfield		Sediment Quality Guidelines	
Parameter	**Units**	**NF14**	**NF10**	**NF12**	**NF20**	**NF21**	**NF22**	**FF04**	**FF09**	**ER-L**	**ER-M**
Chromium	mg/kg dry							93		81	370
Copper		128								34	270
Mercury			0.15	0.19		0.23	0.16	0.20		0.15	0.71
Nickel								23.2		20.9	51.6
Total DDT	ng/kg dry					2.06	1.82	3.21	1.74	1.58	46.1
Total PAH				9077	6220	8318				4022	44792
Total PCB						30.3				22.7	180

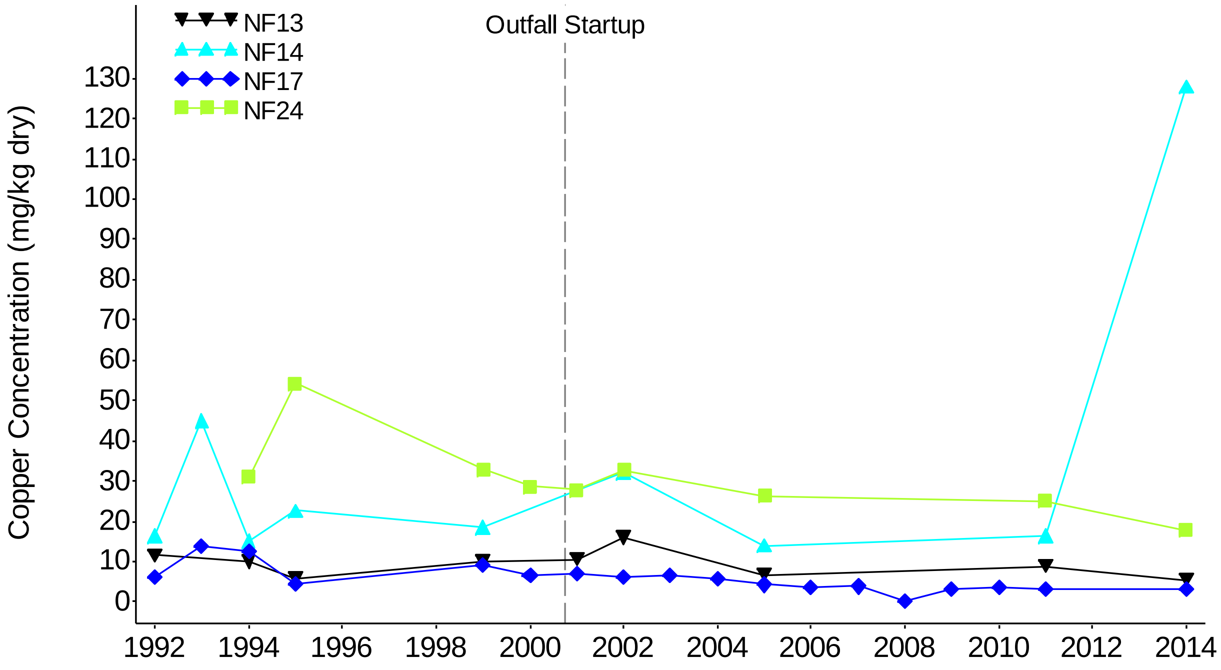


Figure 3-7. Mean concentrations of Copper at Nearfield stations within two kilometers from the discharge, 1992 to 2014.

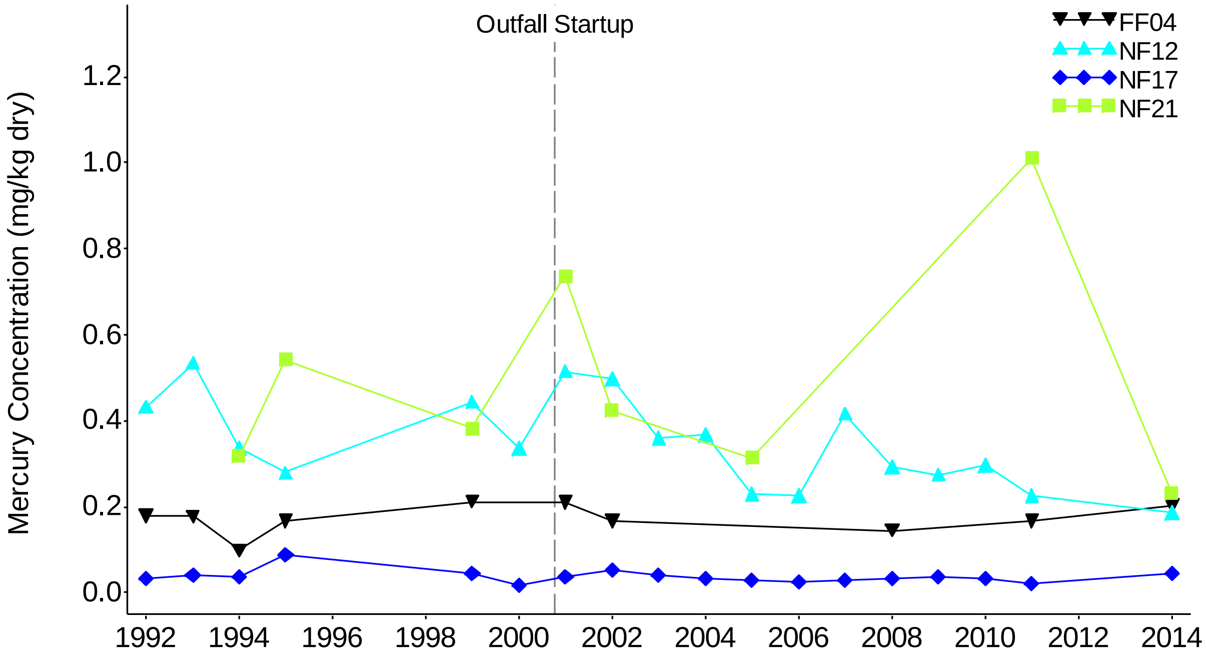


Figure 3-8. **Mean concentrations of Mercury at four stations in Massachusetts Bay, 1992 to 2014.**

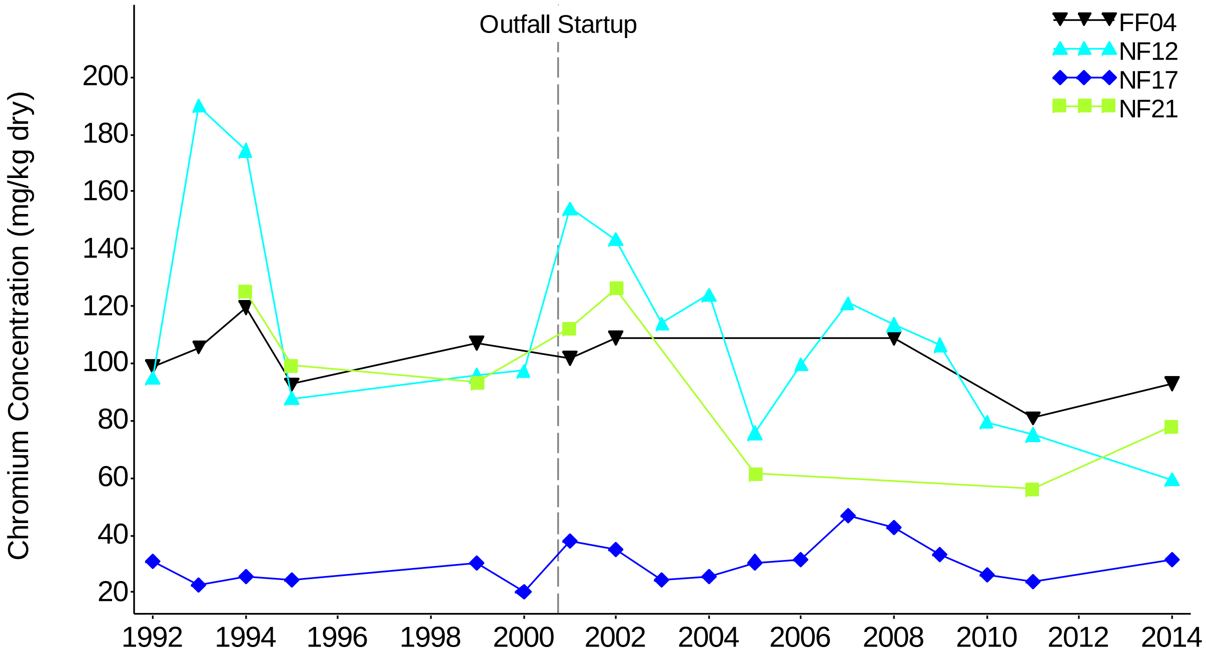


Figure 3-9. **Mean concentrations of Chromium at four stations in Massachusetts Bay, 1992 to 2014.**

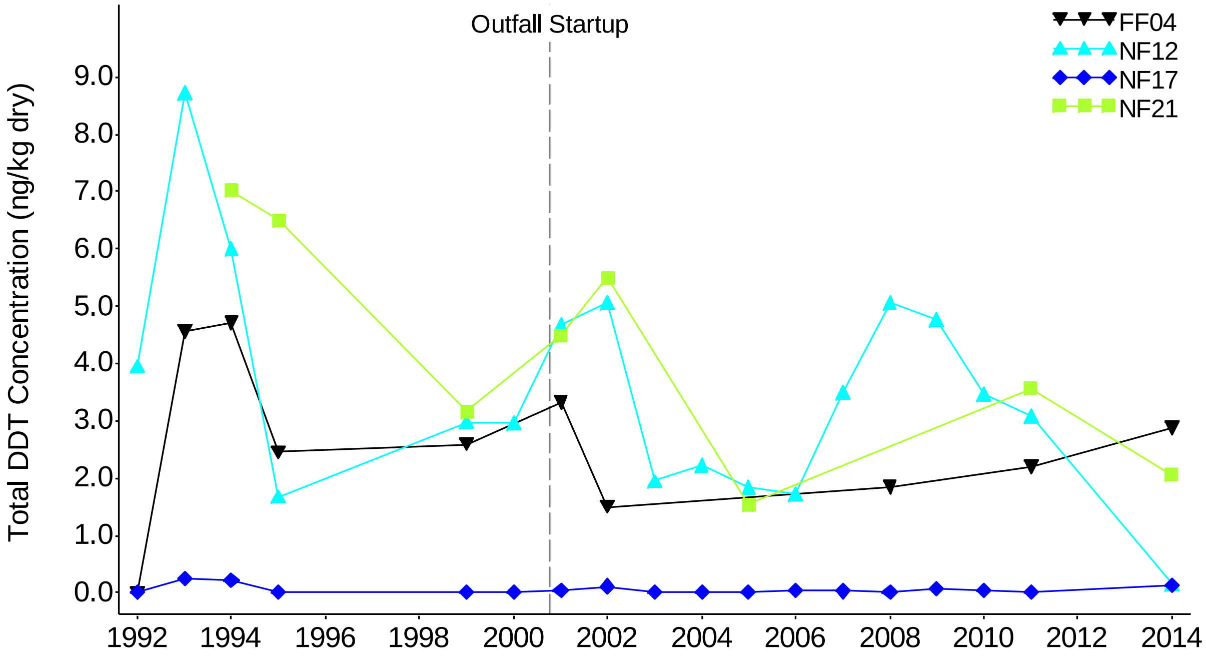


Figure 3-10. Mean concentrations of Total DDT at four stations in Massachusetts Bay, 1992 to 2014.

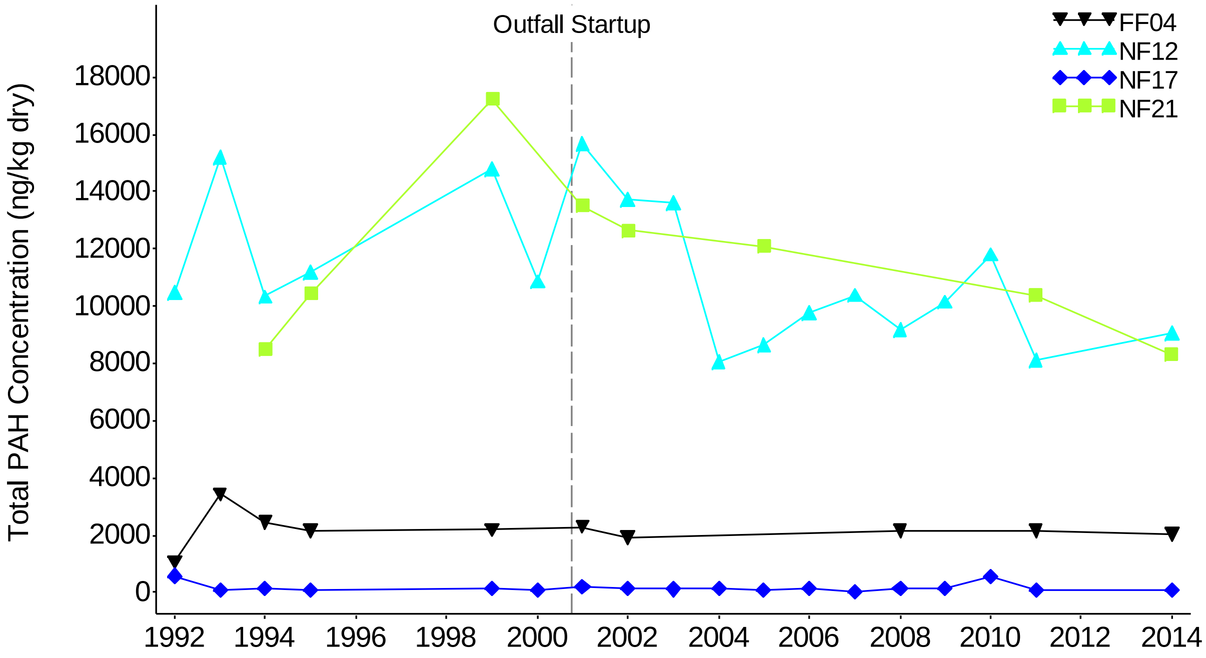


Figure 3-11. Mean concentrations of Total PAH at four stations in Massachusetts Bay, 1992 to 2014.

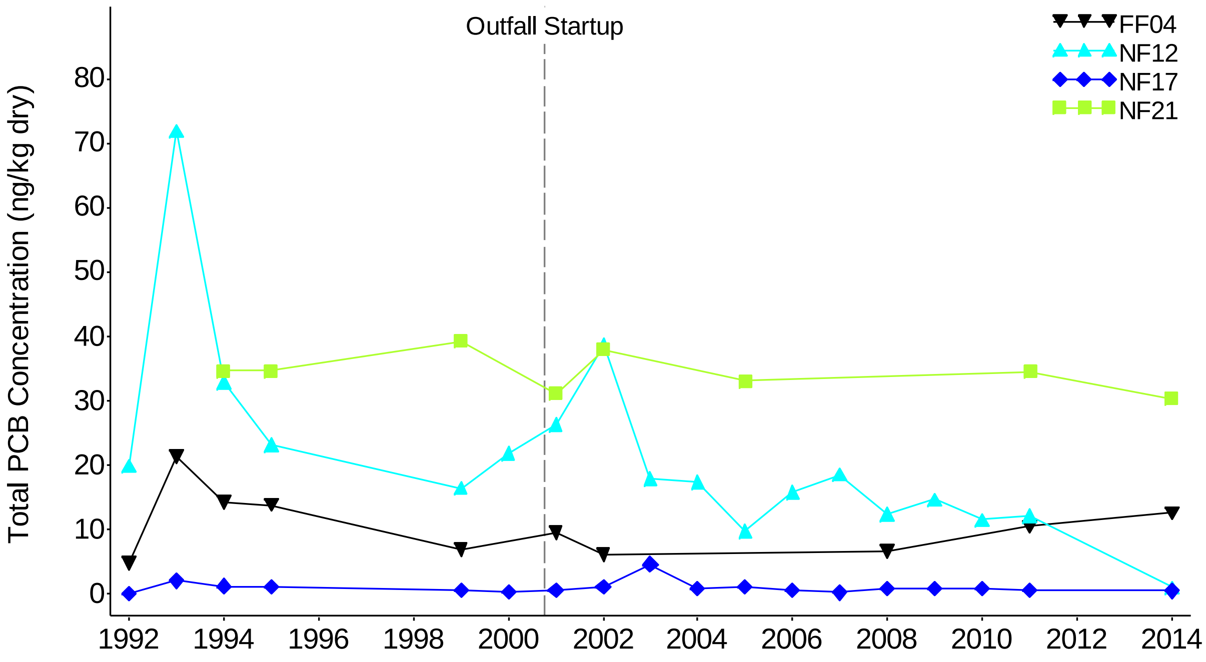


Figure 3-12. Mean concentrations of Total PCB at four stations in Massachusetts Bay, 1992 to 2014.

3.2 Benthic Infauna

3.2.1 Community Parameters

A total of 21,863 infaunal organisms were counted from the 14 samples in 2014. Organisms were classified into 210 discrete taxa; 183 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 2014 were higher than the previous year at all four monitoring areas in Massachusetts Bay (Figure 3-13). The highest abundances were at Station FF12, the only station in the "Transition Area" between Boston Harbor and Massachusetts Bay. The numbers of species per sample in 2014 were higher than in 2013 at all areas except for the farfield, where values were marginally lower than the previous year (Figure 3-14). Lower species richness in the farfield was driven largely by lower numbers of species at Station FF01A in 2014 (57; Table 3-3) than in 2013 (70; Nestler et al. 2014a).

Contingency Plan threshold exceedances were reported in 2014 for Shannon-Wiener Diversity (H′) and Pielou's Evenness (J′); no exceedances were reported for other diversity measures or for the percent opportunistic species (Table 3-4). Exceedances for these same two parameters have occurred each year since 2010 (Nestler et al. 2014a). High diversity and high evenness are generally recognized as indications of healthy, undisturbed communities (Magurran 1988). Low diversity and evenness typically reflect stressed or impacted communities. Nonetheless, several studies of infaunal assemblages along gradients of organic enrichment have reported the highest levels of diversity and evenness under conditions of low-level enrichment (Pearson and Rosenberg 1978). Thus, threshold levels for infaunal diversity have both upper and lower limits. During these past five years, annual Nearfield averages for H′ and J' have been higher than during the baseline period, resulting in exceedances of the upper threshold limit (Figures 3-15 and 3-16).

In-depth evaluations of threshold exceedances for H' and J' were conducted in previous years (Nestler et al. 2014a). Those evaluations were focused on answering two questions related to the exceedances: (1) "What factors are driving the exceedances?" and (2) "Do the exceedances reflect an influence from the outfall, or region-wide changes in faunal assemblages, unrelated to the discharge?" Nestler et al. (2014a) concluded that the exceedances were largely driven by relatively lower abundances of a few numerically dominant species, and found no evidence to suggest that these changes were related to the wastewater discharge. Thus, evaluations of the 2014 threshold exceedances were limited in scope, and focused on verifying that the current year's findings agree with previously described patterns regarding driving factors and evidence for outfall impacts.

The spionid polychaete, *Prionospio steenstrupi*, was identified as the most influential species contributing to H' and J' exceedances (Nestler et al. 2014a). Two other polychaetes, *Spio limicola* and *Mediomastus californiensis*, were also identified as influential contributors. The abundances for these three species, along with the two top dominants from 2014 (the polychaetes *Aricidea catherinae* and *Tharyx acutus*) are compared over time in Figure 3-17. *P. steenstrupi* was the numerically dominant taxon in the Massachusetts Bay samples from the mid 1990's to the mid 2000's (Figures 3-17 and 3-18). During years in which *P. steenstrupi* numbers were relatively low, other dominants were often abundant (e.g., *S. limicola* in 1994). During the past five years, relatively low abundance has been reported for all three of the most influential species, while the abundance of other dominant species has also remained relatively low (Figure 3-17). H' and J' exceedances continue to be driven by low abundances of dominant species that had previously been more abundant.

Spatial and temporal patterns in H' and J' also continue to suggest that the exceedances are not related to the outfall. Spatial comparisons of the 2014 values for H' and J' did not suggest an association between high diversity or evenness values and proximity to the outfall diffuser (Figures 3-19 and 3-20). Temporal comparisons of H' and J' values demonstrated no indication of increases in the post-diversion period as compared to the baseline, at stations closest to the outfall (Figures 3-21 and 3-22). H' and J' have increased in both nearfield and farfield areas, suggesting region-wide changes, unrelated to the discharge.

Table 3-3. 2014 monitoring results for infaunal community parameters.

Monitoring Area	Station	Total Abundance (per grab)	Number of Species (per grab)	Log-series alpha	Shannon-Wiener Diversity (H′)	Pielou's Evenness (J')
Transition Area	**FF12**	3,182	58	10.09	3.52	0.60
Nearfield (<2 km from outfall)	**NF13**	1,134	71	17.07	4.37	0.71
	NF14	1,013	62	14.67	3.87	0.65
	NF17	739	50	12.24	4.14	0.73
	NF24	1,896	61	12.07	3.95	0.67
Nearfield (>2 km from outfall)	**NF04**	761	48	11.56	4.21	0.75
	NF10	2,064	72	14.54	4.04	0.66
	NF12	2,286	73	14.41	4.02	0.65
	NF20	1,975	71	14.63	4.06	0.66
	NF21	1,351	65	14.32	4.23	0.70
	NF22	2,126	59	11.26	3.96	0.67
Farfield	**FF01A**	1,331	57	12.17	3.76	0.64
	FF04	501	36	8.90	2.89	0.56
	FF09	1,504	91	21.52	4.55	0.70

Table 3-4. Infaunal monitoring threshold results, August 2014 samples.

Parameter	Threshold range		Result	Exceedance?
	Low	High		
Total species	43.0	81.9	62.73	No
Log-series Alpha	9.42	15.8	13.35	No
Shannon-Weiner H′	3.37	3.99	4.03	Yes, Caution Level
Pielou's J'	0.57	0.67	0.68	Yes, Caution Level
Apparent RPD	1.18	NA	4.01	No
Percent opportunists	10% (Caution) 25% (Warning)		0.12%	No

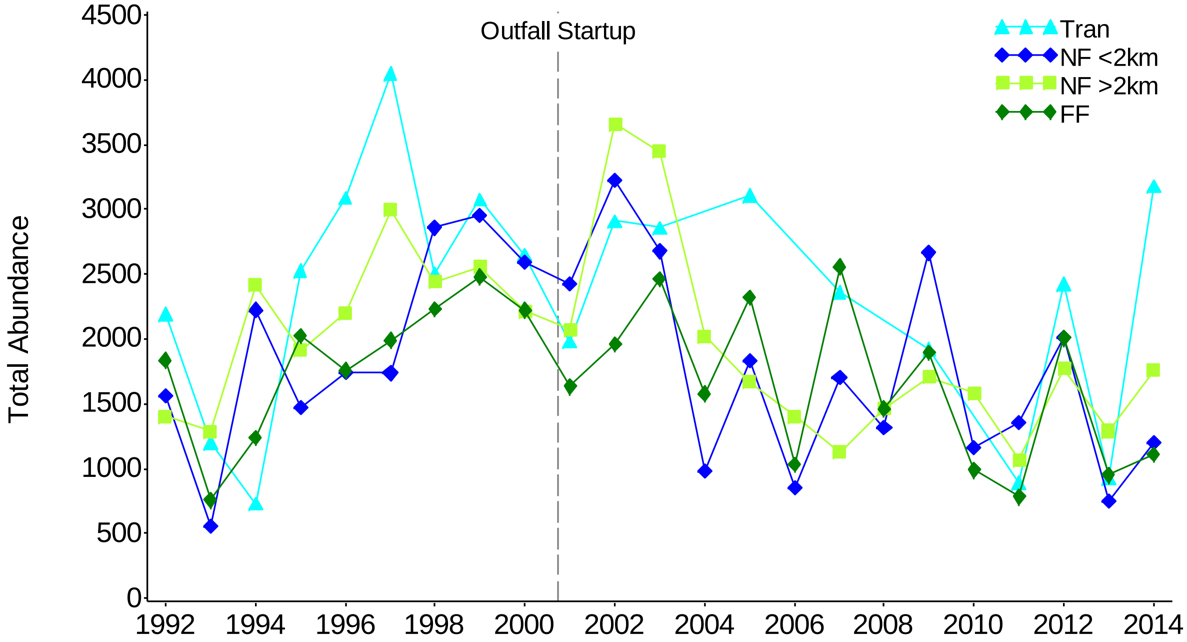


Figure 3-13. Mean infaunal abundance per sample at four areas of Massachusetts Bay, 1992 to 2014. Tran=Transition area; NF<2km=nearfield, less than two kilometers from the outfall; NF>2km=nearfield, more than two kilometers from the outfall; FF=farfield.

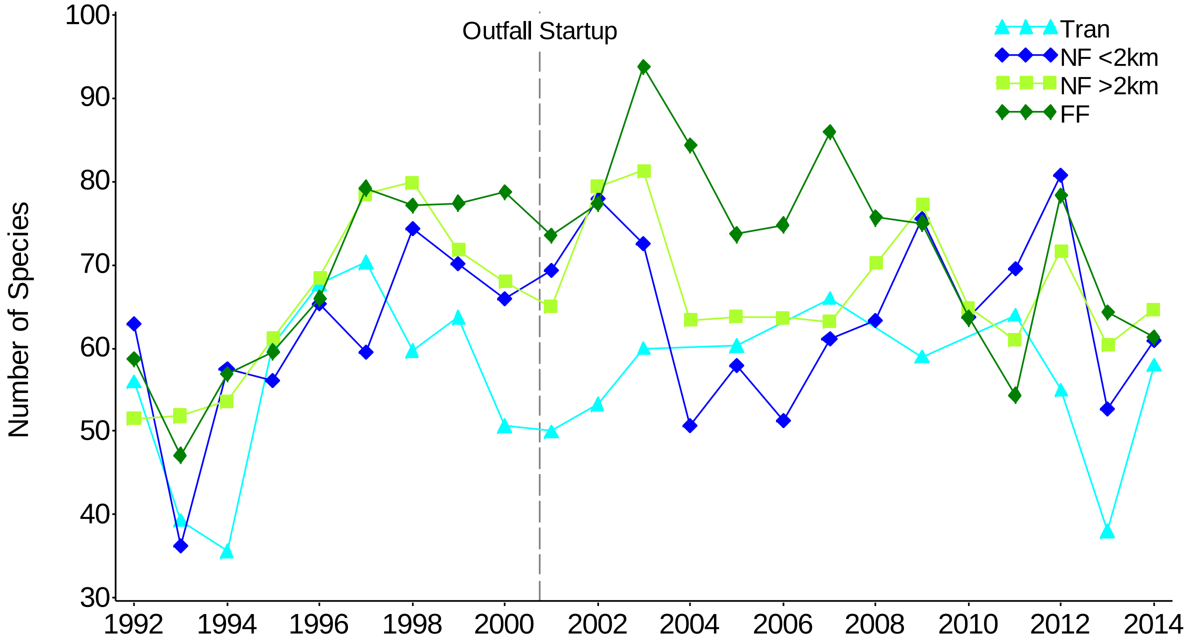


Figure 3-14. Mean number of species per sample at four areas of Massachusetts Bay, 1992 to 2014. Tran=Transition area; NF<2km=nearfield, less than two kilometers from the outfall; NF>2km=nearfield, more than two kilometers from the outfall; FF=farfield.

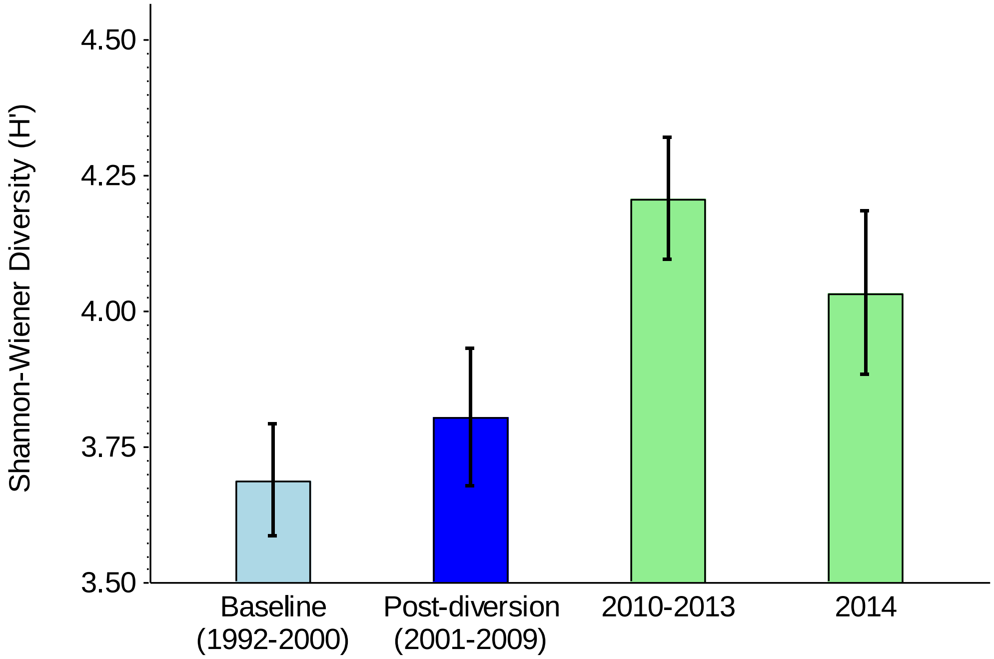


Figure 3-15. Mean H' per sample at nearfield stations in Massachusetts Bay during the baseline (1992 to 2000) and post-diversion (2001 to 2009) periods compared to 2010 to 2013 and 2014.

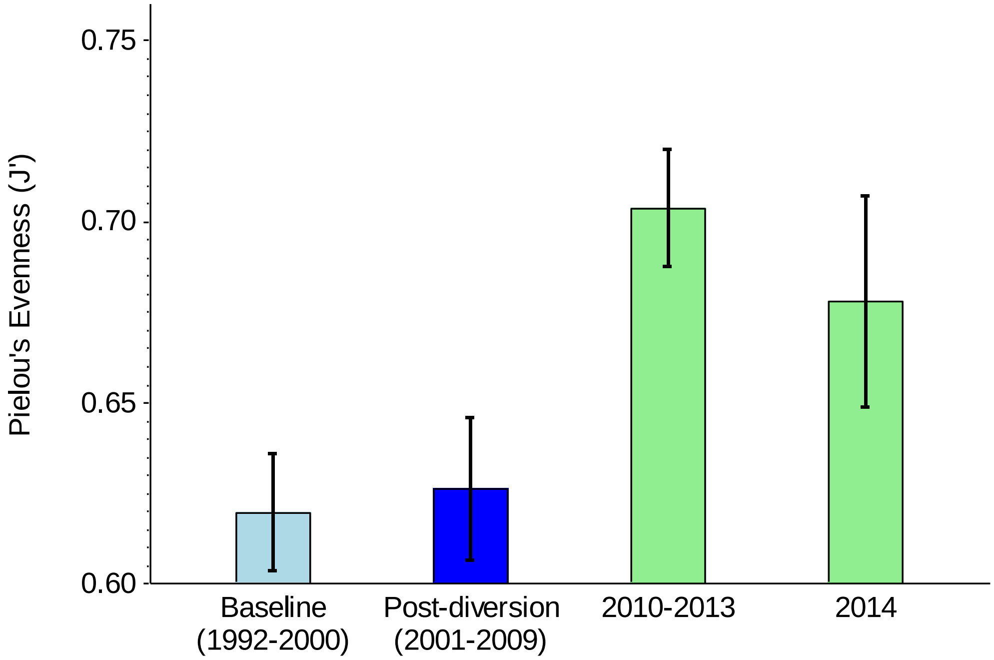


Figure 3-16. Mean J' per sample at nearfield stations in Massachusetts Bay during the baseline (1992 to 2000) and post-diversion (2001 to 2009) periods compared to 2010 to 2013 and 2014.

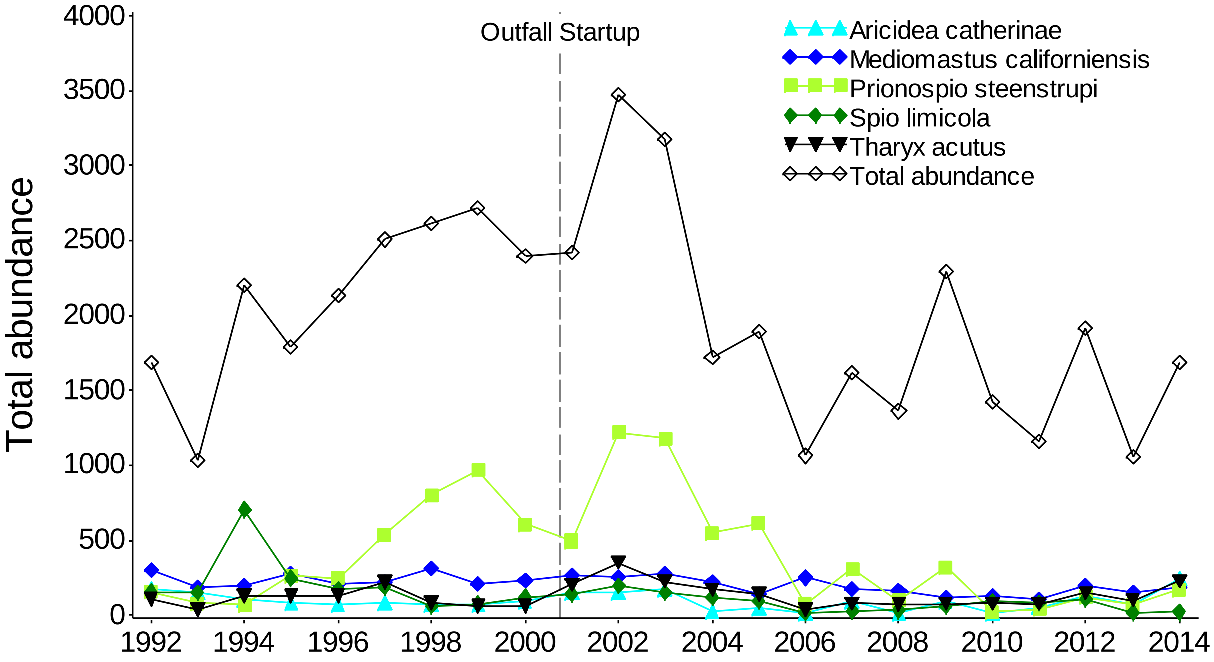


Figure 3-17. Mean abundance per sample of five dominant species compared to total abundance at nearfield stations in Massachusetts Bay, 1992 to 2014.

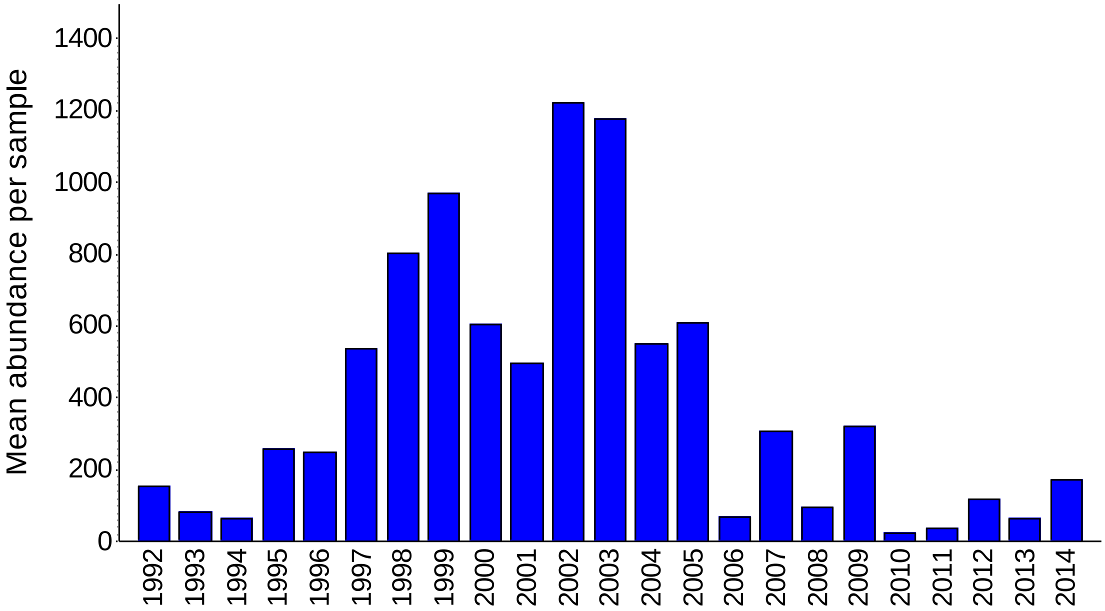


Figure 3-18. Mean annual abundance of *Prionospio steenstrupi* at the nearfield stations in Massachusetts Bay, 1992 to 2014.

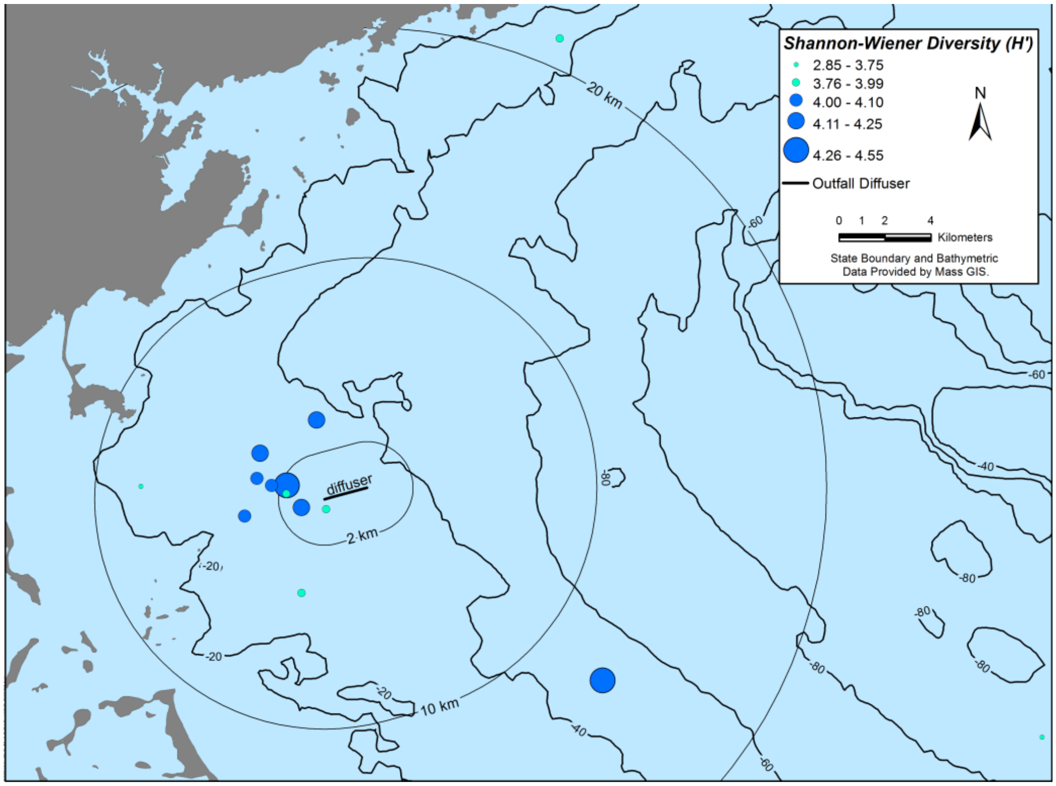


Figure 3-19. **2014 values for H': light = below threshold; dark = above threshold.**

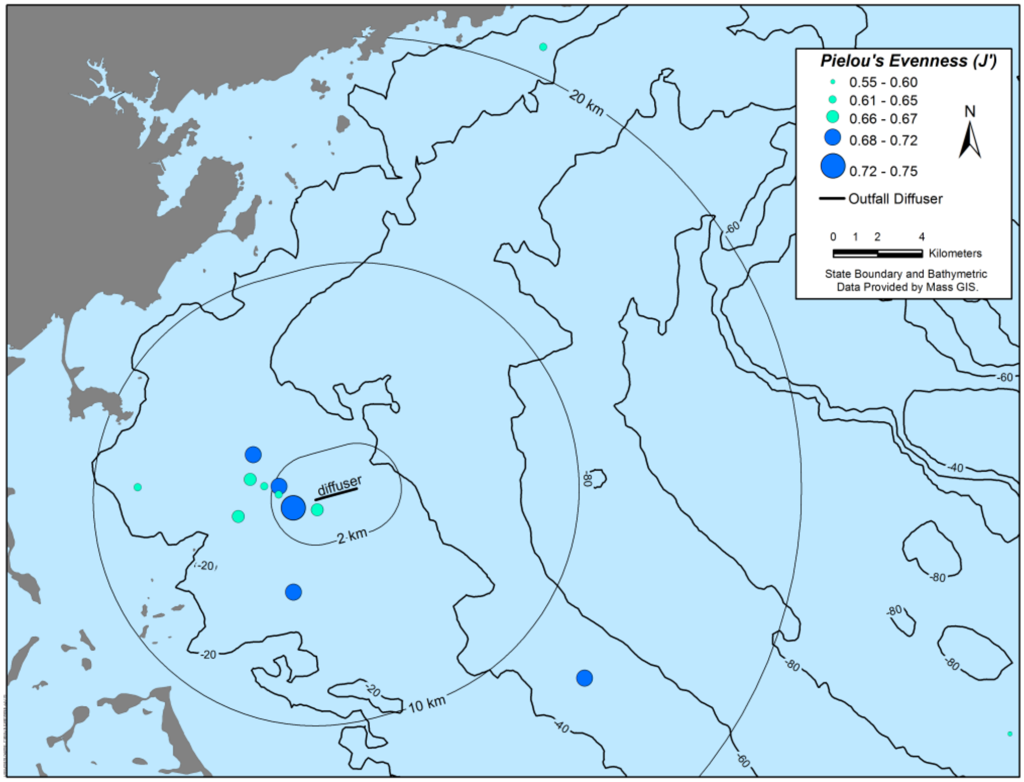


Figure 3-20. **2014 values for J': light = below threshold; dark = above threshold.**

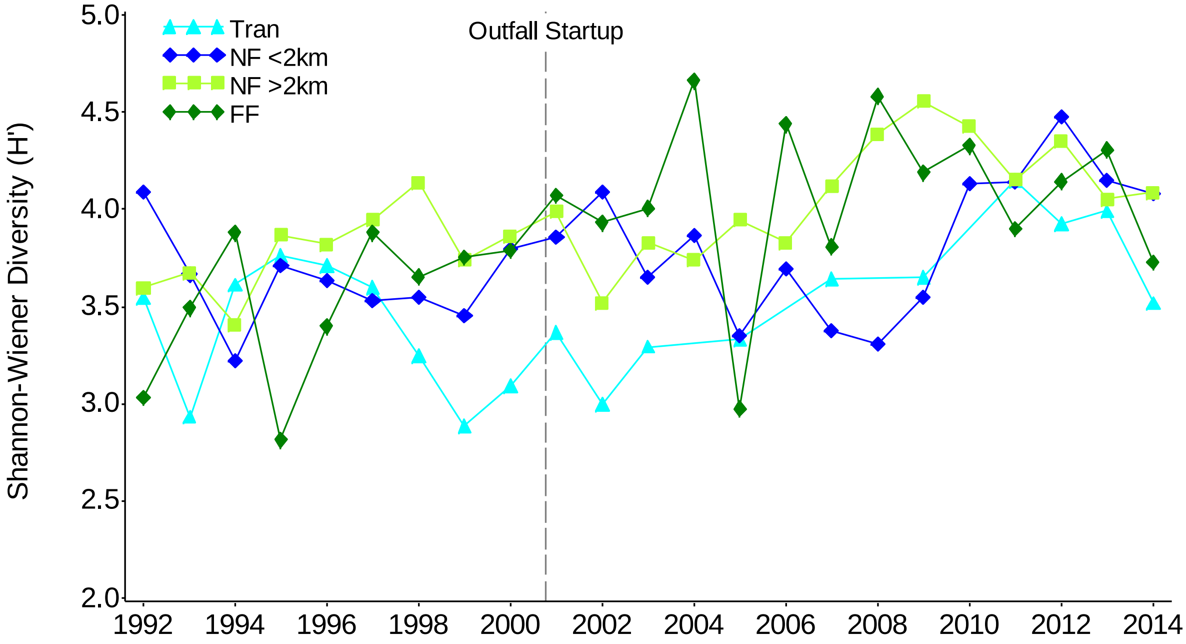


Figure 3-21. Mean H' per sample at four areas of Massachusetts Bay, 1992 to 2014. Tran=Transition area; NF<2km=nearfield, less than two kilometers of from the outfall; NF>2km=nearfield, more than two kilometers from the outfall; FF=farfield.

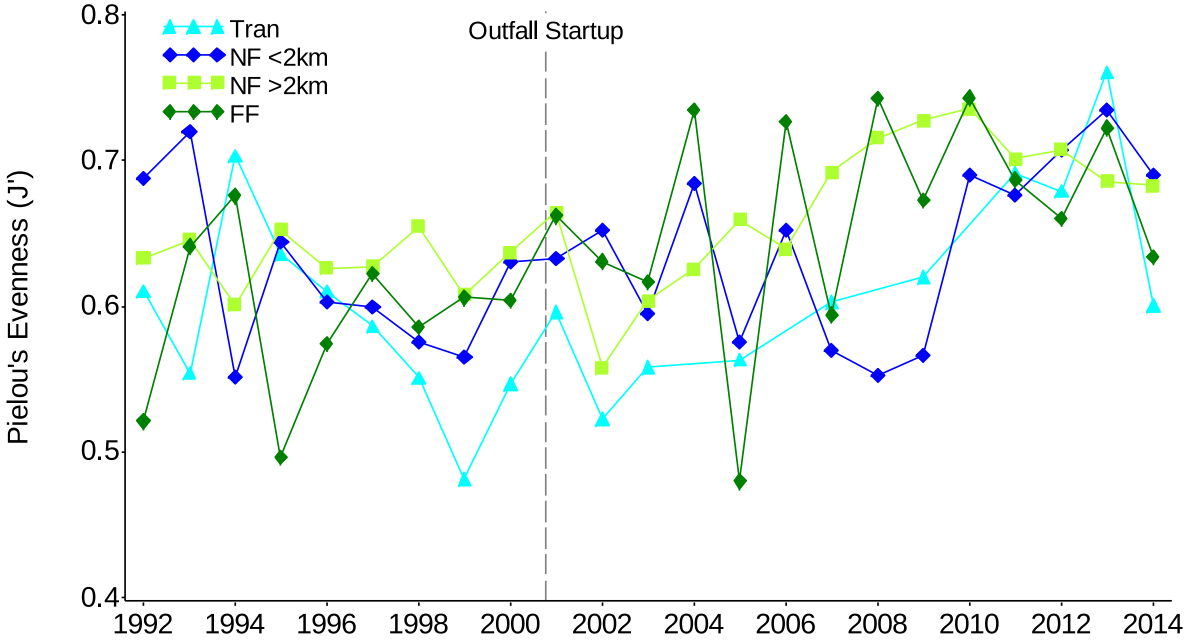


Figure 3-22. Mean J' per sample at four areas of Massachusetts Bay, 1992 to 2014. Tran=Transition area; NF<2km=nearfield, less than two kilometers of from the outfall; NF>2km=nearfield, more than two kilometers from the outfall; FF=farfield.

3.2.2 Infaunal Assemblages

Multivariate analyses based on Bray-Curtis Similarity were used to assess spatial patterns in the faunal assemblages at the Massachusetts Bay sampling stations. Two main assemblages (with an outlier assemblage at Station FF04) were identified in a cluster analysis of the 14 samples from 2014 (Figure 3-23). Each of the main assemblages contained sub-assemblages that could be differentiated by species composition. Assemblages varied considerably in species composition, but were mostly dominated by polychaetes (Table 3-5). Three different assemblages occurred at the four stations within two kilometers of the discharge; and assemblages similar to those nearest the discharge were found at stations more than two kilometers from the discharge (Figure 3-23). Thus, stations closest to the discharge were not characterized by a unique faunal assemblage reflecting effluent impacts.

Comparisons of faunal distribution to habitat conditions indicated that stations with similar sediment types supported similar faunal assemblages (Figure 3-24). Figure 3-24 illustrates that much of the spatial pattern of association between faunal assemblages and sediment texture can be demonstrated by looking only at the percent fine (i.e., silt and clay) fraction of the sediments. Multivariate analyses of the 2014 data found no evidence of impacts from the offshore outfall on infaunal communities in Massachusetts Bay.

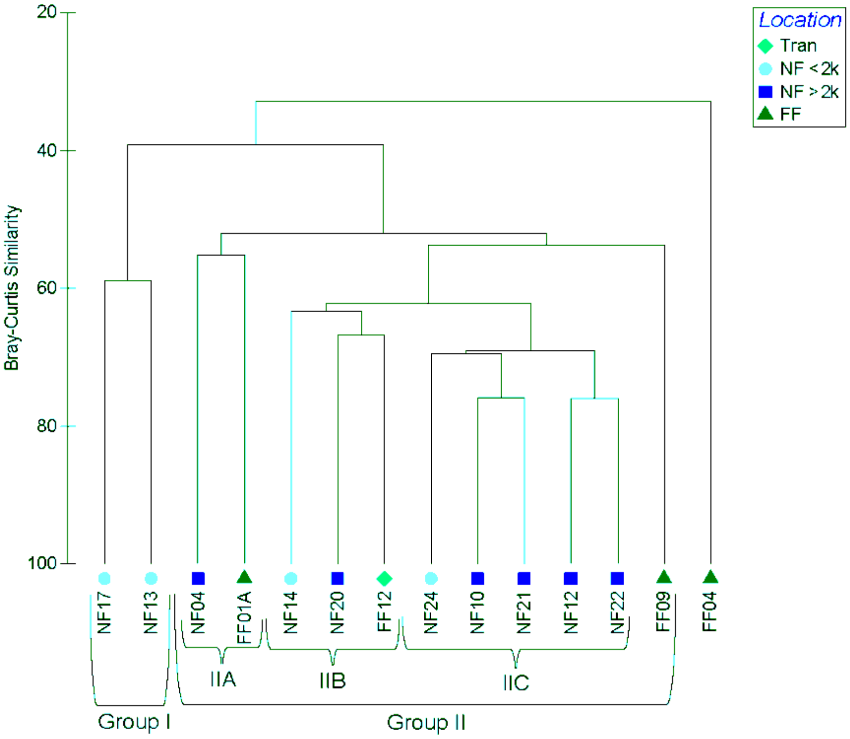


Figure 3-23. Results of cluster analysis of the 2014 infauna samples.

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 2014 samples.

		Group I	Group II				
Family	**Species**	**NF17 & NF13**	**NF04 & FF01A**	**IIB (n=3)**	**IIC (n=5)**	**FF09**	**FF04**
Nemertea							
Lineidae	*Micrura spp.*	0.5	1.5	4.0	16.2	14.0	9.0
Mollusca (Bivalvia)							
Nuculidae	*Nucula delphinodonta*	7.5	218.5	27.7	29.4	117.0	-
Periplomatidae	*Periploma papyratium*	-	9.5	7.3	2.4	29.0	10.0
Annelida (Polychaeta)							
Ampharetidae	*Anobothrus gracilis*	-	6.0	1.7	2.8	343.0	22.0
Amphinomidae	*Paramphinome jeffreysii*	-	-	-	0.2	-	12.0
Capitellidae	*Mediomastus californiensis*	3.0	13.5	154.3	267.4	46.0	6.0
Cirratulidae	*Aphelochaeta cf. monilaris*	41.0	11.5	3.0	72.4	9.0	3.0
	Chaetozone anasimus	16.5	1.0	-	-	4.0	19.0
	Monticellina baptisteae	4.5	36.5	85.3	96.4	-	-
	Monticellina cf. dorsobranchialis	-	14.0	54.3	38.4	-	-
	Tharyx acutus	50.0	44.0	202.7	347.8	29.0	-
Cossuridae	*Cossura longocirrata*	-	-	0.3	4.4	4.0	25.0
Dorvilleidae	*Parougia caeca*	10.5	-	22.3	62.0	15.0	2.0
Lumbrineridae	*Ninoe nigripes*	1.5	26.5	55.7	135.8	74.0	43.0
	Scoletoma hebes	0.5	-	77.0	15.4	3.0	1.0
Maldanidae	*Maldane sarsi*	-	-	-	-	36.0	-
Nephtyidae	*Nephtys incisa*	-	-	1.3	5.6	11.0	15.0
Orbiniidae	*Leitoscoloplos acutus*	1.0	6.5	22.7	56.4	12.0	1.0
Oweniidae	*Owenia fusiformis*	1.5	94.0	11.0	5.6	4.0	-
Paraonidae	*Aricidea catherinae*	89.5	103.5	584.7	112.2	-	-
	Aricidea quadrilobata	-	2.5	3.7	37.2	50.0	7.0
	Levinsenia gracilis	-	33.0	60.3	150.4	115.0	273.0
Polygordiidae	*Polygordius jouinae*	29.5	19.5	3.7	3.6	1.0	-
Sabellidae	*Euchone incolor*	-	22.5	31.0	47.4	94.0	6.0
Spionidae	*Prionospio steenstrupi*	5.0	106.0	265.7	171.0	89.0	1.0
	Spio limicola	-	15.0	2.7	27.0	85.0	1.0
	Spiophanes bombyx	95.0	55.0	94.3	38.6	7.0	-
Syllidae	*Exogone hebes*	108.5	30.5	37.3	6.0	13.0	-
Annelida (Oligochaeta)							
Enchytraeidae	*Marionina welchi*	56.5	-	0.3	-	-	-
Arthropoda (Amphipoda)							
Lysianassidae	*Orchomenella minuta*	64.5	-	1.0	-	-	-
Phorona (Phoronida)							
	Phoronis muelleri	28.5	13.5	24.0	11.0	10.0	-
Chordata (Urochordata)							
Molgulidae	*Molgula manhattensis*	69.5	-	1.7	-	1.0	-

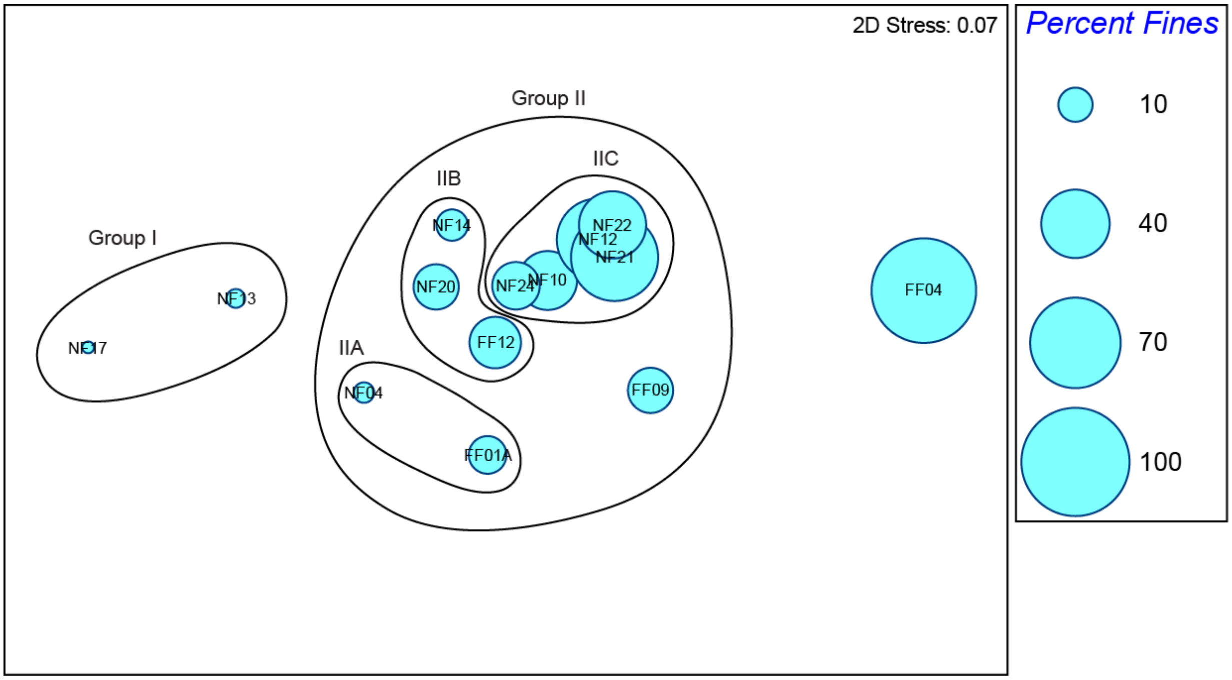
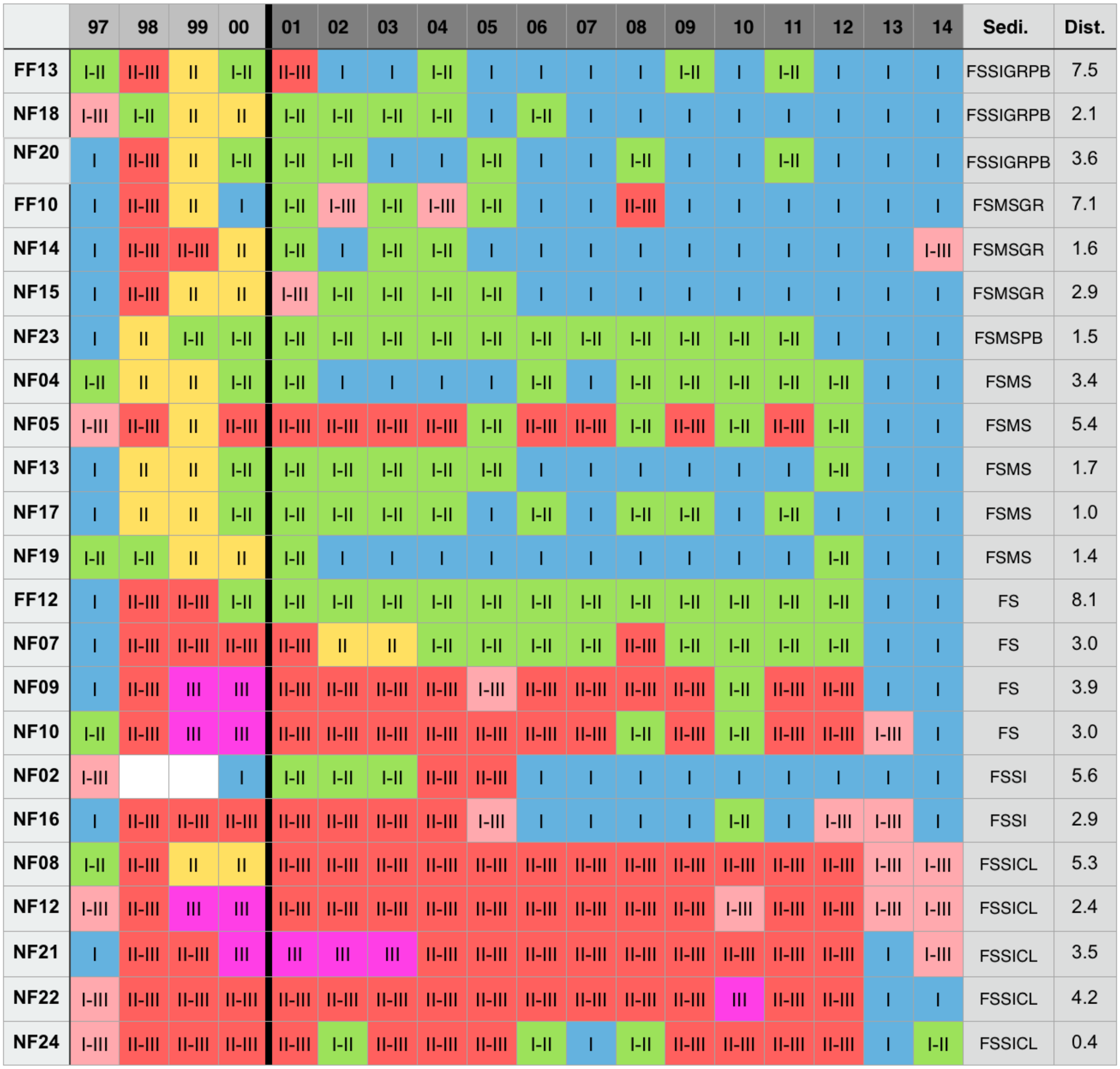


Figure 3-24. Percent fine sediments superimposed on nMDS ordination plot of the 2014 infauna samples. Each point on the plot represents one of the 14 samples; similarity of species composition is indicated by proximity of points on the plot. Faunal assemblages (Groups I-II, and sub-groups) identified by cluster analysis are circled on the plot. The ordination and cluster analysis are both based on Bray-Curtis Similarity.

3.3 Sediment Profile Imaging

As with the previous years, in 2014 there was little change in any of the sediment profile image parameters at the 23 nearfield monitoring stations, but a trend was noticed in estimated successional stage. Starting in 2013 there was a trend toward increasing pioneering Stage I and decline in intermediate and equilibrium Stage II and III successional estimates from SPI images (Figure 3-25). This trend in estimated successional stage runs counter to the trend in benthic communities, which has recently been increasing in diversity, both species richness and evenness components (See Section 3.2). Benthic data



	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	Sedi.	Dist.
FF13	I-II	II-III	II	I-II	II-III	I	I	I-II	I	I	I	I	I-II	I	I-II	I	I	I	FSSIGRPB	7.5
NF18	I-III	I-II	II	II	I-II	I-II	I-II	I-II	I	I-II	I	I	I	I	I	I	I	I	FSSIGRPB	2.1
NF20	I	II-III	II	I-II	I-II	I-II	I	I	I-II	I	I	I-II	I	I	I-II	I	I	I	FSSIGRPB	3.6
FF10	I	II-III	II	I	I-II	I-III	I-II	I-III	I-II	I	I	II-III	I	I	I	I	I	I	FSMSGR	7.1
NF14	I	II-III	II-III	II	I-II	I	I-II	I-II	I	I	I	I	I	I	I	I	I	I-III	FSMSGR	1.6
NF15	I	II-III	II	II	I-III	I-II	I-II	I-II	I-II	I	I	I	I	I	I	I	I	I	FSMSGR	2.9
NF23	I	II	I-II	I-II	I-II	I-II	I-II	I-II	I-II	I-II	I-II	I-II	I-II	I-II	I-II	I	I	I	FSMSPB	1.5
NF04	I-II	II	II	I-II	I-II	I	I	I	I	I-II	I	I-II	I-II	I-II	I-II	I-II	I	I	FSMS	3.4
NF05	I-III	II-III	II	II-III	II-III	II-III	II-III	II-III	I-II	II-III	II-III	I-II	II-III	I-II	II-III	I-II	I	I	FSMS	5.4
NF13	I	II	II	I-II	I-II	I-II	I-II	I-II	I-II	I	I	I	I	I	I	I-II	I	I	FSMS	1.7
NF17	I	II	II	I-II	I-II	I-II	I-II	I-II	I	I-II	I	I-II	I-II	I	I-II	I	I	I	FSMS	1.0
NF19	I-II	I-II	II	II	I-II	I	I	I	I	I	I	I	I	I	I	I-II	I	I	FSMS	1.4
FF12	I	II-III	II-III	I-II	I-II	I-II	I-II	I-II	I-II	I-II	I-II	I-II	I-II	I-II	I-II	I-II	I	I	FS	8.1
NF07	I	II-III	II-III	II-III	II-III	II	II	I-II	I-II	I-II	I-II	II-III	I-II	I-II	I-II	I-II	I	I	FS	3.0
NF09	I	II-III	III	III	II-III	II-III	II-III	II-III	I-III	II-III	II-III	II-III	II-III	I-II	II-III	II-III	I	I	FS	3.9
NF10	I-II	II-III	III	III	II-III	II-III	II-III	II-III	II-III	II-III	II-III	I-II	II-III	I-II	II-III	II-III	I-III	I	FS	3.0
NF02	I-III			I	I-II	I-II	I-II	II-III	II-III	I	I	I	I	I	I	I	I	I	FSSI	5.6
NF16	I	II-III	II-III	II-III	II-III	II-III	II-III	II-III	I-III	I	I	I	I	I-II	I	I-III	I-III	I	FSSI	2.9
NF08	I-II	II-III	II	II	II-III	II-III	II-III	II-III	II-III	II-III	II-III	II-III	II-III	II-III	II-III	II-III	I-III	I-III	FSSICL	5.3
NF12	I-III	II-III	III	III	II-III	II-III	II-III	II-III	II-III	II-III	II-III	II-III	II-III	I-III	II-III	II-III	I-III	I-III	FSSICL	2.4
NF21	I	II-III	II-III	III	III	III	III	II-III	II-III	II-III	II-III	II-III	II-III	II-III	II-III	II-III	I	I-III	FSSICL	3.5
NF22	I-III	II-III	II-III	II-III	II-III	II-III	II-III	II-III	II-III	II-III	II-III	II-III	II-III	III	II-III	II-III	I	I	FSSICL	4.2
NF24	I-III	II-III	II-III	II-III	II-III	I-II	II-III	II-III	II-III	I-II	I	I-II	II-III	II-III	II-III	II-III	I	I-II	FSSICL	0.4

Figure 3-25. Annual estimates of successional stage from SPI images. Stations are sorted from coarser sediments (Sedi.) to finer (CL = Clay, FS = Fine-Sand, GR = Gravel, MS = Medium-Sand, SI = Silt, PB = Pebble). Distance (Dist.) is km from the station to the outfall.

indicated that communities were actually Stage II to Stage III with no evidence of Stage I. While the cause of this trend is not certain it is likely related to a slight coarsening of sediment grain-size and a concomitant decline in visible biogenic structures in the SPI images. The theoretical underpinning for estimating successional stage from SPI incorporates elements from Pearson and Rosenberg's (1978) model for response of benthos to organic gradients and Rhoads and Germano's (1986) model for response of benthos to disturbance. Both of these response models were developed with data from muddy estuarine and near coastal sediments, and have proven to be reliable in these settings for estimating benthic impacts and benthic habitat quality (Germano et al. 2011).

In dynamic sand sediments the successional stage predictive abilities of these models is limited. Benthic community parameters associated with prediction of successional stages from Pearson-Rosenberg and Rhoads-Germano models become increasingly difficult to observe as the silt-clay fraction of sediments declines. Successional stage predictive biogenic parameters from SPI images are broad relative indicators of association between successional stage and benthic physical and biological parameters as typically applied in SPI investigations (Table 3-6). In higher energy coastal environments, such as the nearfield region around the outfall, traditional concepts of successional stage do not apply. The primary reason for this is that the low levels of organic matter in the sediments and the physically dynamic nature of the bottom that creates sediment instability combine to lead to specialized benthic communities. This pattern can be seen in Chesapeake Bay where benthic communities follow the classical successional models along organic gradients in areas of low energy but exhibit a more complex response in moderate and high

Table 3-6. General weight given to SPI data used to assess successional stage.

	Successional Stage		
Parameter	**I - Pioneering**	**II - Intermediate**	**III - Equlibrium**
aRPD Layer Depth (cm)	<1	1-3	>2-3
Maximun aRPD Depth (cm)	<2	>2	>3-4
Small Tubes (<1 mm dia.)	+++	++	+
Large Tubes (>2 mm dia.)	-	++	+++
Burrows	-	++	+++
Feeding Voids	-	++	+++
Small Infauna	+++	++	+
Large Infauna	-	+	++
Epifauna	+	++	++
- = Not Associated With	+ = Associated With	++ = Moderately Associated With	+++ = Strongly Associated With

energy regimes where the characteristic pioneering Stage I community described by Odum (1969) is absent from high organic substrates (Diaz unpublished data). This is the case for the MWRA outfall where there is no evidence of a pioneering Stage I community. Data from other coastal ocean outfalls where benthic impacts were documented show the main effects were an increase in Stage I pioneering or opportunistic species, a decrease in species richness and/or diversity, and an increase in total abundance (Punete and Diaz In Preparation).

At fine-sand-silt-clay nearfield stations NF08, NF12, and NF21 benthic habitat conditions have remained relatively consistent from 1997 to 2014 with little difference between baseline and post outfall periods (Figure 3-25). For coarser sediment stations, those with gravel and pebble, Stage I designations were more common in the post outfall period. Fine to medium sand stations were similar in both baseline and post outfall periods and tended to be designated as Stage I to II. Since 2013 all but one sandy station (NF10) was designated as Stage I. Sediments at many stations continued to be heterogeneous, ranging from sandy-silt-clay to cobble. Overall, the sediment surface appeared to be structured primarily by physical processes and secondarily by biological processes.

Low or no detectable impacts in benthic infauna based on SPI and community analyses for coastal ocean outfalls in general appears to be related to low accumulation rates for organic matter and dominance of high energy physical processes (Punete and Diaz In Preparation). Data from other coastal ocean sewage outfalls around the world at depths greater than 20 m indicated benthic impacts were not detected or were limited to within 500 m of the outfall at 19 of 25 outfalls evaluated. More extensive benthic impacts reaching outward >500 m from the outfall were found at 6 of 25 outfalls evaluated (Table 3-7). The lack of accumulation of organic matter in the sediments related to the combination of high levels of sewage treatment (Taylor 2010); relatively high physical energy (Butman et al. 2008) is the principle reason for lack of benthic impacts at nearfield stations. Of the five coastal ocean outfalls evaluated that had secondary or better treatment, benthic impacts were detected >500 m from the outfall only at Sant Adriá del Besós, Spain. The five other outfalls with benthic impacts >500 m all had primary treatment (Table 3-7).

When baseline conditions (1992 to 2000) are compared with post outfall (2001 to 2014) operation conditions there is no evidence of an outfall effect on benthic habitat quality based on SPI (Table 3-8). The grand average apparent color redox-potential discontinuity layer (aRPD) for 2014 was the highest of all the post outfall years. The second highest year was 2013, continuing an aRPD deepening trend that started in 2011 (Figure 3-26). From the start of annual SPI sampling in 1997, the aRPD has never been observed at stations N04, NF13, and N17 due to the coarse sediment and apparent high sediment porosity.

Being the highest annual average for post outfall monitoring, the grand mean of the thickness of the aRPD layer in 2014 did not exceed the threshold of a 50% decrease from the baseline conditions. If only measured values are considered the thickness of the aRPD for 2014 would be 4.8 cm (SD = 1.23 cm, 10 stations in mean). At 13 of the 23 stations, the aRPD was deeper than prism penetration due to coarse grain size and high sediment compaction that limited penetration. If all stations are included in the aRPD calculation the mean for 2014 was 4.0 cm (SD = 1.33 cm). Overall, post-baseline period aRPD remained deeper than during the baseline period (Table 3-7). Since 2001, the thickness of the annual grand mean

Table 3-7. Summary of coastal ocean outfalls with benthic infaunal evaluations, characterized according to length, depth, treatment level and flow rate. Modified from Puente and Diaz (In Preparation).

Country	Site	Treat-ment^{a}	Length (km)	Depth (m)	Size (m3 day-1)	Wave height (Hsm) (m)^{b}	Effect^{c}	Reference
Australia	Bondi (Sydney)	1’	2.2	63	130,000	1.3	>500	Otway 1995, Otway et al. 1996
	Malabar (Sydney)	1’	3.6	60-80	456,000	1.3	>500	Otway 1995; Otway et al. 1996
	North Head (Sydney)	1’	3.7	60-65	336,000	1.3	>500	Otway 1995; Otway et al. 1996; Roberts 1996
Canada	Mcaulay Point (Victoria)	0	1.8	60	32,000	1.8	<500	Chapman et al. 1996; MacDonald & Smorong 2006; Taylor et al. 1998
	Strait of Georgia	1’	7.5	89	180,000	1.8	>500	Burd et al. 2012
Chile	Penco (Concepción)	Pre	1.3	22	12,000	2.5	None	Leppe and Padilla 1999
	Tomé (Concepción)	Pre	1.2	35	15,000	2.5	None	Leppe and Padilla 1999
Greece	Saronikos Gulf (Athens)	1”	0.3	65	600,000	0.4	>500	Simboura et al 1995; Sheppard 1977
Italy	Trieste/Servola (Gulf of Trieste)	1’	7	23	81,000	0.2	<500	Cibic et al. 2008
Portugal	Lisbon (Estoril)	Pre	2.8	40	138,000	1.4	<500	Silva et al. 2004
South Africa	Durban (Central)	Pre	4.2	60	135,000	1.7	<500	McClurg et al. 2007
	Durban (Southern)	Pre	3.2	50	230,000	1.7	<500	McClurg et al. 2007
Spain	Sant Adriá del Besós	2’	0.6	10-25	400,000	0.5	>500	Cardell et al. 1999
	Santander (Cantabria)	Mixed	2.8	45	75,000	2.1	None	Echavarri-Erasun 2007; Juanes et al. 2004

Country	Site	Treat-ment[a]	Length (km)	Depth (m)	Size (m3 day-1)	Wave height (Hsm) (m)[b]	Effect[c]	Reference
	Ulía. San Sebastián-Pasajes	0	1.2	50	55,000	1.7	<500	Franco et al. 2004
	Zarautz	Pre	0.9	30	5,000	1.7	<500	Aguirrezabalaga et al. 1996
United Kingdom	Edinburgh	1’	1.5	30	135,000	1.3	None	Read et al. 1983
USA	Boston, MWRA (MA)	2’	15	32	1,329,000	0.8	None	Hilbig and Blake 2000; Maciolek et al. 2008; Nestler et al. 2013; Smolow 2015
	O'ahu, Honolulu, Barbers Point (HI)	0	3.7	66	65,000	2.3	<500	Smith and Dollar 1987
	O'ahu, Honouliuli (HI)	1’	2	61	86,000	2.3	None	Shuai et al. 2014
	O'ahu, Mokapu (HI)	2’	4	32	52,000	2.1	None	Shuai et al. 2014
	O'ahu, Sand Island (HI)	1’	2.7	72	257,000	2.3	None	Shuai et al. 2014
	O'ahu, Waianae (HI)	2’	1.5	32	14,000	2.3	None	Shuai et al. 2014
	Orange, San Pedro Shelf (CA)	Mixed	8	60	852,000	1.5	<500	Maurer et al. 1998, 2007; Diener et al. 1995
	San Diego, Point Loma (CA)	2’	8	98	713,000	1.4	<500	Zmarzly et al. 1994; City of San Diego 2009

[a] treatment level: 0 (untreated), pre (pretreated), 1’(primary treatment), 2’ (secondary treatment), mixed

[b] Mean significant wave height (Hsm) was used as a proxy for energy of the system, based on a global wave dataset simulated with the model WaveWatch III and driven by NCEP/NCAR reanalysis of winds and ice fields (Reguero et al., 2012).

[c] Magnitude of the impact of the outfall on benthic assemblages was based on the results and conclusions of reviewed studies, and categorized as no significant effects (None), effects detected near (<500 m), and effects detected far (>500 m).

Table 3-8. Summary of SPI parameters pre- and post-baseline years for all nearfield stations.

	Baseline Years 1992-2000 9-Year Interval	**Post-Baseline Years 2001-2014 13-Year Interval**
SS	Advanced from I to II-III	Bimodal: II-III tending to I
OSI - Low	4.8 (1997)	5.8 (2003)
OSI - High	7.2 (2000)	8.7 (2012)
RPD - Low	1.8 cm (1997 and 1998)	2.1 cm (2003)
RPD -High	3.0 cm (1995)	4.0 cm (2014)
Annual Mean RPD Measured	2.2 (0.49 SD) cm	3.4 (0.97 SD) cm
Annual Mean RPD All Values	2.4 (0.47 SD) cm	2.9 (0.58 SD) cm

aRPD has been variable but since 2010 it has trended deeper and increased in 2014 to the highest average over the 23 years of monitoring (Figure 3-26), which is an indication of continued high quality benthic habitat conditions. High diversity of benthos also confirms the presence of high quality benthic habitat (see infaunal discussion of diversity exceedence in 2014). The general nearfield pattern of increasing aRPD depth with time was observed at the six stations (NF07, NF08, NF10, NF12, NF21, and NF22) with measured aRPD layers measured every year (Figure 3-27). Comparison of SPI from these stations between 1999 and 2014 shows the deepening of the aRPD layer (Figure 3-28).

From 1995 to 2014, changes and trends in SPI variables appeared to be related to broader regional forcing factors. The dominance of hydrodynamic and physical factors, such as tidal and storm currents, turbulence, and sediment transport (Butman et al. 2008), along with high effluent quality (Taylor 2010) are the principal reasons that benthic habitat quality remains high in the nearfield area. The high-energy environment in the region of the outfall disperses effluents quickly and prevents degradation of soft bottom benthic infaunal habitat.

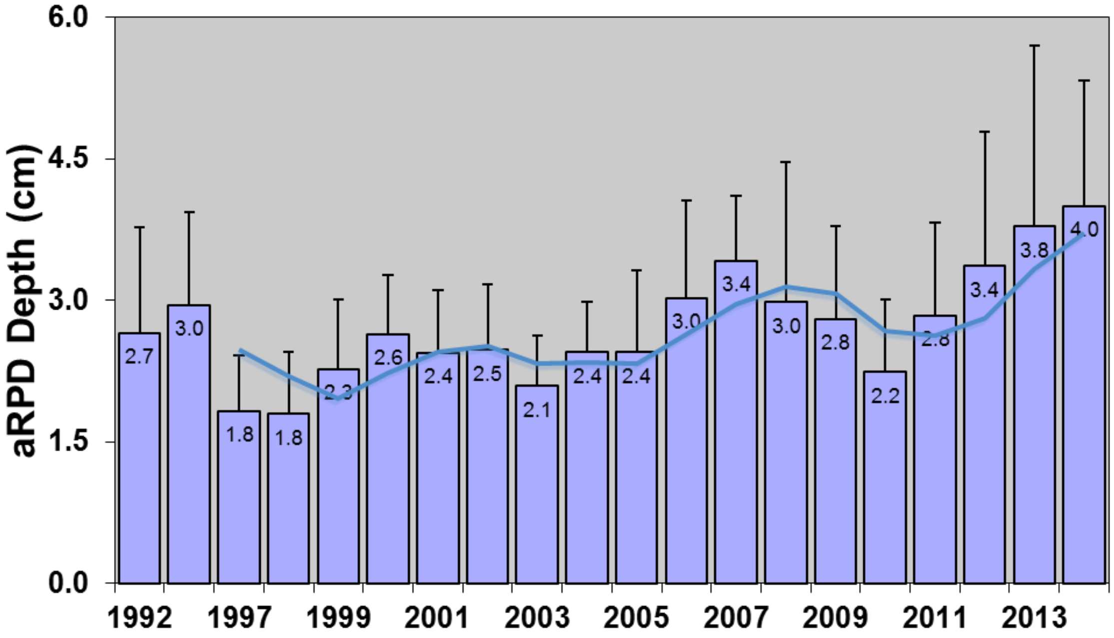


Figure 3-26. Average annual aRPD layer depth for all nearfield stations. Includes stations where aRPD layer was deeper than prism penetration. Bars are one standard deviation. Line is three-year moving average.

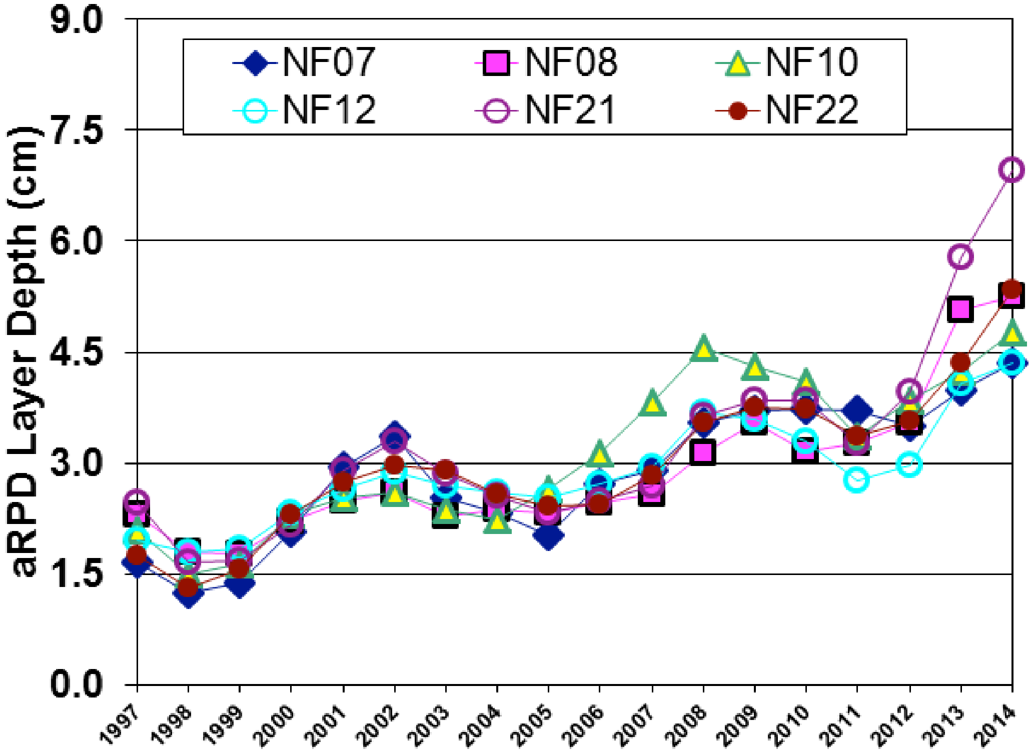


Figure 3-27. Average aRPD layer depth at nearfield stations for only stations that had measured aRPD layers every year.

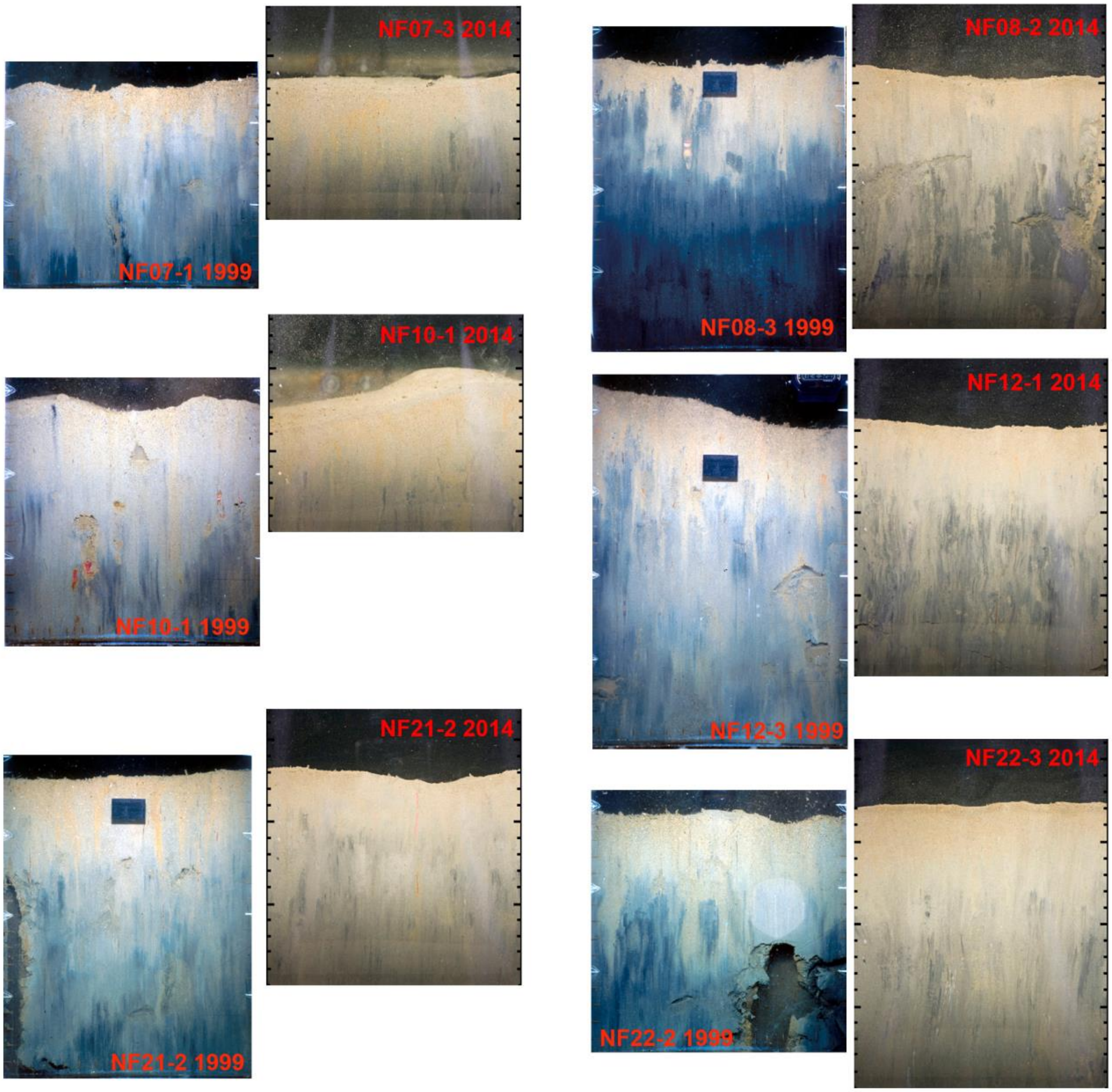


Figure 3-28. Comparison of aRPD layer depth between 1999 and 2014 at nearfield stations with measured values every year. In 1999 Fujichrome film was used and gave a green-blue tint to the images. In 2014 a Canon 7D digital camera was used and gave a less saturated view of the sediments. Scale on side of images is in cm.

3.4 Hard-Bottom Benthic Habitats and Fauna

2014 Results

Photographic coverage of the hard bottom habitat in the vicinity of the outfall in 2014 ranged from 13 to 28 minutes of video footage at each waypoint and a total of 488 minutes of video was viewed and analyzed. The video footage taken this year was generally similar to that taken in 2011, but differed in several ways. The vehicle used to survey most of the stations was a Benthos Mini-Rover, which is less powerful than the Outland 1000 used previously. The Benthos Mini-Rover is acoustically a noisier vehicle and may scare some mobile fauna away from the path of the survey. A GoPro Hero 3 camera was used to collect simultaneous HD video and still images along the dive track. A summary of the 2014 video analysis is included in Appendix B.

Data collected from the video taken during the 2014 survey was generally similar to data obtained from previous post-diversion surveys. The seafloor on the tops of drumlins consisted of a moderate to moderately high relief mix of glacial erratics in the boulder and cobble size categories, while the seafloor on the flanks of drumlins frequently consisted of a low to moderately low relief seafloor characterized by cobbles with occasional boulders. 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 2014 survey are shown in Appendix C. A total of fifty-one taxa, 4 algal species, 34 invertebrate species, 7 fish species, and 6 general categories were seen during the 2014 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 18 of the 23 waypoints. Two other algal species, *Palmaria palmata* (dulse) and *Ptilota serrata* (filamentous red algae) were also seen in numbers similar to those observed in previous years. In contrast, fewer of the fourth algal species *Agarum cribrosum* (shot-gun kelp) were seen than in previous years, with only a few fronds observed at one location. Many of the dulse observed in 2014 were small plants, while many dulse seen in 2011 were large plants that were being overgrown by the lacy bryozoan *Membranipora* sp. Common invertebrates seen in 2014 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 3-29 a & 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 3-29 c & 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, with very dense stands of the hydroid *Tubularia* sp. seen in the vicinity of the active diffuser.

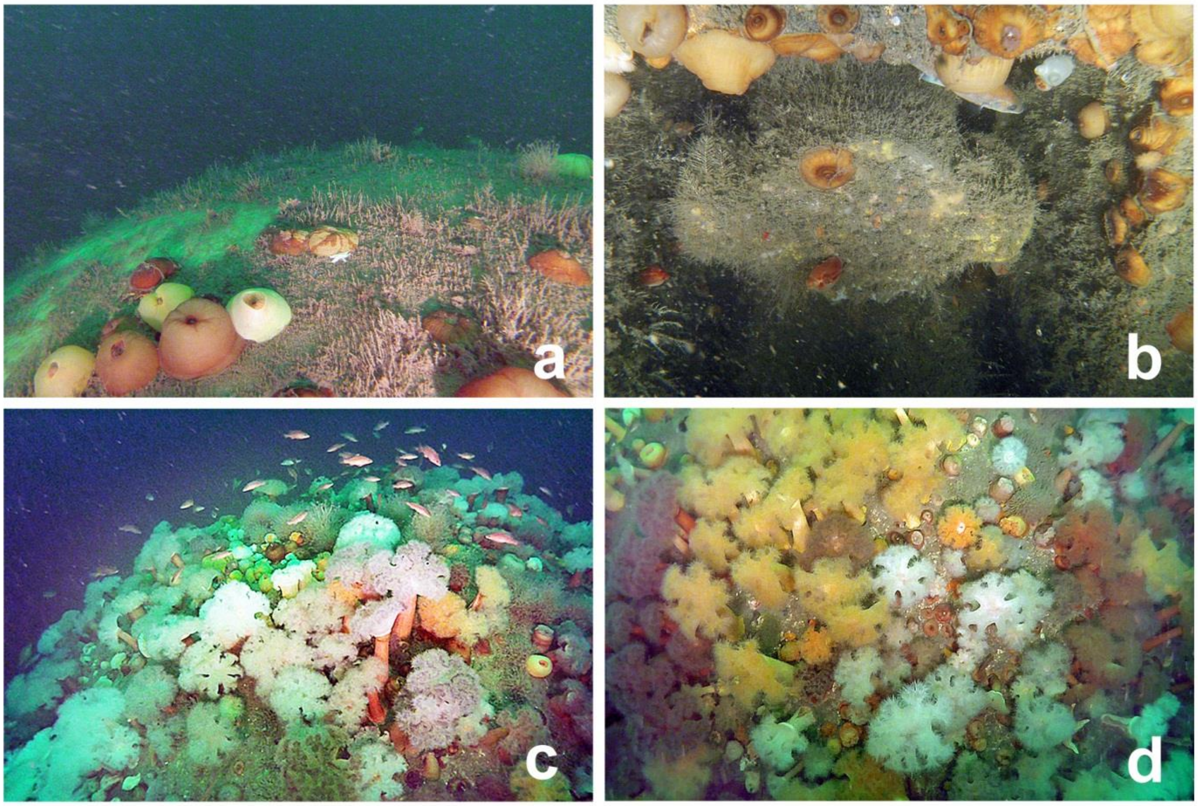


Figure 3-29. Still images taken at inactive diffuser head #44 (a & b) and active diffuser head #2 (c & d) during the 2014 hard-bottom survey. (a) A sparse population of frilled anemones *Metridium senile* colonizing the top of diffuser head #44, with several colonies of the hydroid *Tubularia* sp. and a juvenile *Asterias vulgaris* also visible. (b) *Metridium senile* and several sea peaches *Halocynthia pyriformis* colonizing a port of diffuser head #44. A cunner *Tautogolabrus adspersus* is also visible in the image. (c) Numerous frilled anemones *Metridium senile* colonizing the top of active diffuser head #2. Numerous cunner are also seen hovering over the top of the head. (d) Numerous *M. senile* colonizing the side of diffuser head #2. The arms of an adult *Asterias vulgaris* are also visible in the lower right corner of the image.

Comparison of 2014 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 2014. Encrusting coralline algae has historically been the most abundant and widely distributed taxon encountered during the hard-bottom surveys. Table 3-9 presents the relative cover of coralline algae observed in video footage taken during the 1996 through 2014 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 decrease in cover of coralline algae started at the northern reference sites in 2002 and has persisted; a similar reduction has been evident 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 have had less percent cover of coralline algae since 2001. The subsequent decrease in cover of coralline algae in 2005 and the spread of this decrease to the southern areas was observed in both the video and still images, although less pronounced in the data collected from video images.

The relative abundances of upright algae generally varied widely during both the pre- and post-diversion periods. Additionally, at many sites the upright algae have shown a general decrease over time. The observed variability appears to reflect both patchiness in the spatial distributions of the upright algae and natural cycles in the composition of algal communities. Table 3-10 shows the relative abundance of *Palmaria palmata* over the 1996 to 2014 time period. Dulse was consistently most abundant at the northern reference sites and common at two waypoints north of the outfall, during the pre-diversion period. The relative abundance of *P. palmata* has decreased at these five sites during most of the post-diversion years, and additionally it dropped to an area wide low in 2003 and 2004. In contrast, since 2005 dulse has been seen in modest abundances at stations where it had historically been largely absent, such as on the drumlin immediately north of the outfall, and at two of the southern reference sites. This pattern follows that observed in data collected from still images between 1996 and 2008.

Table 3-11 shows the relative abundance of *Ptilota serrata* over the 1996 to 2014 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 three of the sites. This alga does appear to occasionally rebound at the northern reference sites. It is also appearing in sizable abundances at several 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.

Table 3-9. Relative cover of coralline algae observed in video footage taken during the 1996 to 2014 hard-bottom surveys.

		Pre-diversion					Post diversion											
		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2014
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	f
	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	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	f-c
Northern transect	**T1-1**	va	c	c-a	c	c	f-c	f-c	f-c	c	f-c	f-c	f-c	f-c	f-c	f	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	c-a
	T1-3	a	va	a	va	a	va	a	a	a	a	c	c-a	c	c-a	c-a	c	c-a
	T1-4	va	va	a	a	a	a	a	a	c-a	c-a	c-a	c-a	c-a	c-a	c-a	c	c
	T1-5	a*	c	c	c	c-a	f-c	f-c	c	c	f	r-f	f	r-f	f	f	f	r-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	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	r
	T2-3	c	r	c	c	f*	f-c	f-c	f-c	f	f	f-c	r-f	f-c	f	f	f	r
	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	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	r
	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	c
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	f-c
	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	f-c
	T12-1								c-a	c-a	c	c-a		c	c-a	c	c	c
	T11-1								-	f	f	f	r-f		f	r-f	f	f
Diffusers	**T2-5**	-	-	r			-	-	-	-	-	-	-	-	-	-	-	-
	D44			-		-	-	-	-	-	-	-	-	-	-	-	-	-

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

Table 3-10. Relative abundance of *Palmaria palmata* (dulse) in videos taken during the 1996 to 2014 hard-bottom surveys.

		Pre-diversion					Post diversion											
		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2014
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	f-c
	T7-2	c	c	c-a	c-a	c	a	c-a	c-a	a	c	f-c	f-c	f	r-c	f-a	f-c	c
	T9-1		a-va	c	a	a	c-a	c	r-f	f	r-c	f	f	f	f-c	f-c	f	f-c
Northern transect	**T1-1**	a	a	c	c	f-c	f-c	c	f	f	c	f	r-f	f-c	c	f-c	f-c	f-c
	T1-2	f	-	r	f	-	r-f	-	r	r	r	f-c	f	f-c	f	c-a	c	f
	T1-3	-	-	r	-	r	f	f	f	r	f-c	f-c	f-c	c-a	f-a	c-a	c-a	c
	T1-4	-	-	-	-	-	r	-	f	r	f	f	f	f-c	f-c	f-a	f-c	c
	T1-5	r*	-	-	-	-	-	-	r	-	-	-	r	r	r	r	r	r
	T2-1	-	c	-	f	r	f	r	r	-	-	r	-	r-f	r-f	r	f	r
	T2-2	-	va	c	c	-	-	c	-	-	r-f	-	-	r	-	-	-	-
	T2-3	c	c	c	c	c	f-c	c	-	f	f	f-c	f	f	f-c	f-c	f	r-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	f
	T4-1	-	-	-	-	-	-	-										
	T4-2	-	-	-	-	-	-	-	-	-	-	f	r	-	-	-	r-f	-
	T4-3	-	-	-	-	-	-	-										
	T6-1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	T6-2	c*	-	r	-	-	-	-	-	-	-	-	-	-	r-f	r-f	-	r
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	r-f
	T8-2	-	-	-	-	-	-	-	-	-	r	f	r	r	r-f	r	f	r
	T12-1								f	f	f	f-c		f-a	f-c	f-c	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

Table 3-11. Relative abundance of *Ptilota serrata* (filamentous red alga) in videos during 1996 to 2014 hard-bottom surveys.

		Pre-diversion					Post diversion											
		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2014
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	f
	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	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	c
	T1-4	r-f	-	-	-	-	-	-	-	r-f	-	f	-	f-c	c-a	f-a	f-c	c-a
	T1-5	f-c*	-	-	-	-	-	-	-	-	-	r-f	-	-	r-f	-	-	-
	T2-1	f	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	T2-2	f	c	a*	c	-	-	-	-	-	-	-	-	-	-	-	-	-
	T2-3	a	-	c-a	f-c	f-c	-	r-f	-	-	-	r	-	-	-	-	-	-
	T2-4	a	r	c	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Southern transect	**T4/6-1**	c-va	c-a	f	f	-	-	-	-	-	-	-	-	r	r-f	r-f	f-c	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	a
	T11-1								-	-	-	-	-		-	-	-	-
Diffusers	**T2-5**	-	-	-			-	-	-	-	-	-	-	-	-	-	-	-
	D44			-		-	-	-	-	-	-	-	-	-	-	-	-	-

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

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 by the invasive bryozoan *Membranipora membranipora*. This decline was much less evident in the data collected from video images. In 2010 and 2011 this algae had also been seen at one site north of the outfall. In 2014, the number of *A. cribrosum* was at an all-time low, with only a few fronds being observed at one of the northern reference sites. Specifics of the abundance and distribution of shot-gun kelp over the time course of this study can be seen in Appendix A4.

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. Disturbed areas of the seafloor have been observed at all three northern reference sites at several instances during the post-diversion period. This may result in a seafloor that is a mosaic of areas in differing stages of recovery from physical disturbance.

Table 3-12 shows long-term trends that have been noted in the abundances of some of the larger mobile taxa over time. These trends appear to reflect widespread temporal changes in abundances throughout the survey area rather than changes related to the outfall. The numbers of *Cancer* crabs, cod (*Gadus morhua*), lobster (*Homarus americanus*), and winter flounder (*Pseudopleuronectes americanus*) observed during the surveys have generally increased over time. The number of *Cancer* crabs seen annually ranged from 0.6 to 3.6 individuals per 100 minutes of video between 1996 and 1999, to 6.3 to 39.1 individuals per 100 minutes of video between 2001 and 2014. The number of *Cancer* crabs seen during the 2014 survey was the highest it has been at any previous time during this study. The abundance of crabs varies widely and appears to undergo several-year cycles of higher and lower abundances, but the general trend has been towards more crabs over time. The number of lobsters seen during the surveys has also increased over time, ranging from 0.4 to 4.1 individuals per 100 minutes of video per year in the pre-diversion period to 2.1 to 17.6 individuals per 100 minutes of video per year in the post diversion period. Cod have shown a similar pattern with none to 5.2 individuals per 100 minutes of video seen annually during the pre-diversion years and 7.2 to 20.3 individuals per 100 minutes of video seen annually during all but two of the post diversion years. The low number of cod seen during the 2014 survey may in part reflect cod shying away from the acoustically noisier Benthos Mini-Rover and very high levels of suspended matter reducing visibility. Winter flounder appear to have increased in abundance since 2008, ranging from 2.5 to 8.1 individuals per 100 minutes of video seen during the pre-diversion period, 1.9 to 5.3 individuals per 100 minutes of video seen in the earlier part of the post-diversion period, and 8.9 to 17.1 individuals per 100 minutes of video seen in the later post-diversion period. Flounder are usually less skittish than cod, frequently allowing the ROV to closely approach them. Hence, their observed abundances might not be as easily influenced by the acoustic characteristics of the ROV.

Table 3-12. Number of several large mobile commercially important species observed in video footage taken during the 1996 to 2014 hard-bottom surveys (standardized to number seen per 100 minutes of video).

	Pre-discharge					Post-discharge											
	1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2014**
***Gadus morhua* (cod)**	0.0	1.2	2.7	5.2	2.5	9.2	10.7	2.1	11.5	13.7	14.1	9.1	14.4	20.3	7.2	9.2	2.0
***Pseudopleuronectes americanus* (winter flounder)**	4.6	2.9	6.8	8.1	2.5	4.0	3.8	1.9	5.3	3.6	2.6	3.6	10.6	8.9	17.1	12.9	9.4
***Cancer* spp. (rock crab)**	1.4	0.6	0.9	3.6	20.7	27.5	33.9	30.7	25.3	14.4	19.3	24.5	6.3	19.0	6.4	7.3	39.1
***Homarus americanus* (lobster)**	1.4	0.4	2.5	0.9	4.1	4.7	6.3	7.0	2.6	2.1	8.4	8.2	2.7	17.6	6.6	7.5	8.9

One noticeable difference seen during the 2014 survey was the widespread presence of dead or dying barnacle sets at many of the stations. Large areas of rock surfaces covered by dead or dying barnacles were observed at 15 of the stations spread throughout the survey area. An addition, 4 stations had smaller areas of dead or dying barnacles, while the southernmost reference site T11-1 had only a few. Live barnacles were only observed in high numbers at one site, T4/6-1, a drumlin top station located just south of the outfall. Similar instances of large areas of dead barnacle sets have been noted several times in previous years, but never as dominantly or as widely spread as those observed in 2014.

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

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 2014 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 2014 was greater than reported during the baseline period. The SPI results suggested a trend towards a predominance of a pioneering stage benthic community, a phenomenon that would suggest an increase in organic pollution. This was not supported by the infaunal study which found that the numbers of opportunistic species remained negligible in 2014. The trend seen in the SPI survey was likely an artifact of the coarsening of sediment grain-size that resulted in the decline in visible biogenic structures in the images. 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 (Nestler et al. 2014a, Maciolek et al. 2008). The outfall is located in an area dominated by hydrodynamic and physical factors, including tidal and storm currents, turbulence, and sediment transport (Butman et al. 2008). These physical factors, along with the high quality of the effluent discharged into the Bay (Taylor 2010), are the principal reasons that benthic habitat quality has remained high in the nearfield area.

Sediment contaminant monitoring in 2014 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 2014. 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 soft-bottom benthic communities continue to suggest that animals near the outfall have not been smothered by particulate matter from the wastewater discharge. As there were in each of the previous four years, there were threshold exceedances in 2014 for two infaunal diversity measures: (1) Shannon-Wiener Diversity (H′) and (2) Pielou’s Evenness (J′). Previous analyses of these parameters suggested that recent increases in H′ and J′ have been largely driven by relatively lower abundance in a small number of dominant species. Results of the 2014 infaunal survey confirmed these findings. Changes in faunal communities that resulted in threshold exceedances appear to be region-wide and unrelated to the discharge. Evaluations of the threshold exceedances suggest that it may be appropriate to revisit the need for upper diversity triggers for MWRA’s infaunal Contingency Plan thresholds. 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.

Hard-bottom benthic community monitoring in 2014 also found no evidence that particulate matter from the wastewater discharge has smothered benthic organisms. Although some modest changes in this community (e.g., coralline algae and upright algae cover) have been observed, comparisons between the post-diversion and baseline periods indicate that these changes are not substantial. Factors driving changes in the algal cover are unclear, but, 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.

Benthic monitoring results continue to indicate that the three potential impacts of primary concern (decreased oxygen; accumulation of contaminants; and particulate deposition that smothers the benthos) have not occurred at the MWRA stations. Results also continue to demonstrate that the benthic monitoring program comprises a sensitive suite of parameters that can detect both the influence of the outfall and the subtle natural changes in benthic communities. The spatial extent of particulate deposition from the wastewater discharge is measurable in the *Clostridium perfringens* concentrations in nearfield sediments. *C. perfringens* concentrations provide evidence of the discharge footprint at stations close to the outfall. Within this footprint, corresponding changes to sediment composition and infaunal communities have not been detected. Nonetheless, subtle variations in the species composition of infaunal assemblages clearly delineate natural spatial variation in the benthic community based on habitat (e.g., associated with different sediment grain sizes). Changes over time have also been detected. Diversity threshold exceedances highlight a region-wide shift towards higher diversity and lower dominance in the Massachusetts Bay infaunal assemblages during recent years. Detection of these spatial and temporal patterns in the benthos suggests that any ecologically significant adverse impacts from the outfall would be readily detected by the monitoring program if those impacts had occurred.

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Appendix A Annual Technical Meeting Presentations for Outfall Benthic Monitoring in 2014

Appendix A1. 2014 Harbor and Outfall Monitoring: Sediment conditions and contaminants
Appendix A2. 2014 Harbor and Outfall Monitoring: Benthic Infauna
Appendix A3. 2014 Harbor and Bay Sediment Profile Imaging
Appendix A4. 2014 Nearfield Hard-bottom Communities

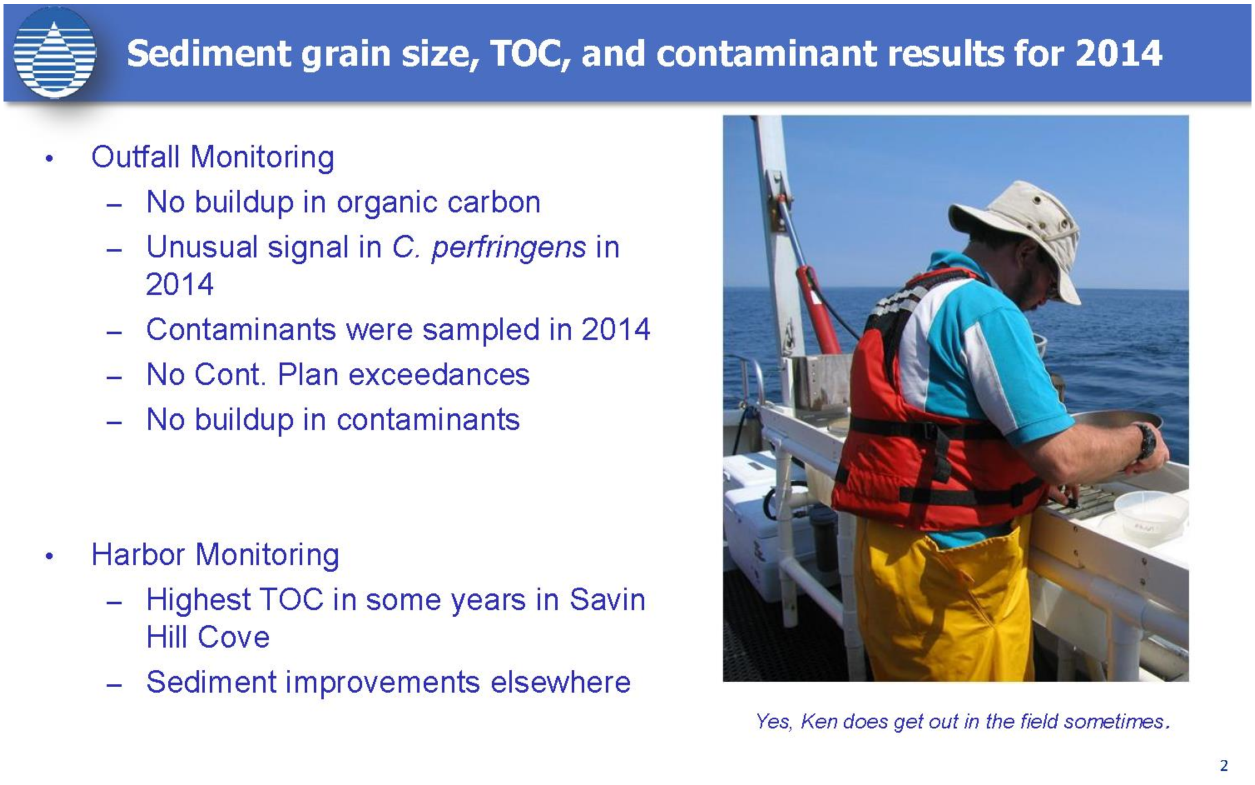
Appendix A1. 2014 Harbor and Outfall Monitoring: Sediment conditions and contaminants

Massachusetts Water Resources Authority

MWRA's Harbor and Outfall Monitoring 2014 Sediment conditions and contaminants

Ken Keay, MWRA
Eric Nestler, Normandeau

April 1, 2015



Sediment grain size, TOC, and contaminant results for 2014

- Outfall Monitoring
  - No buildup in organic carbon
  - Unusual signal in *C. perfringens* in 2014
  - Contaminants were sampled in 2014
  - No Cont. Plan exceedances
  - No buildup in contaminants
- Harbor Monitoring
  - Highest TOC in some years in Savin Hill Cove
  - Sediment improvements elsewhere

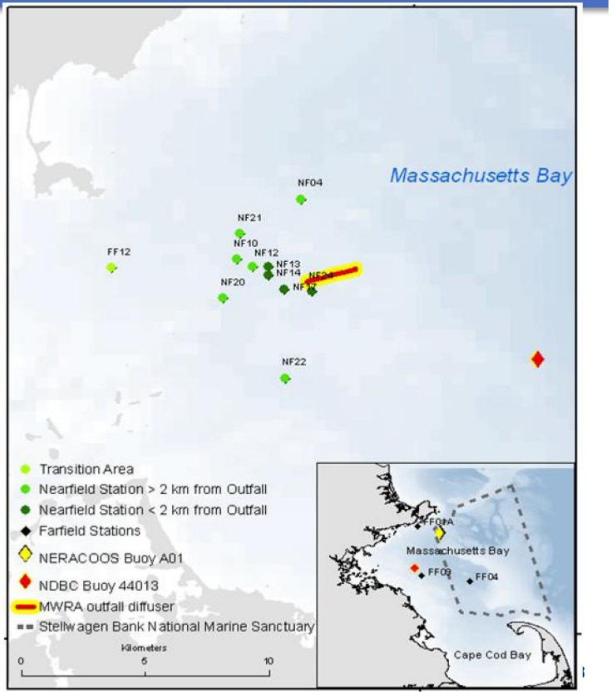
Yes, Ken does get out in the field sometimes.

Sediment sampling under Ambient Monitoring Plan

- 11 nearfield stations in W. Mass Bay.

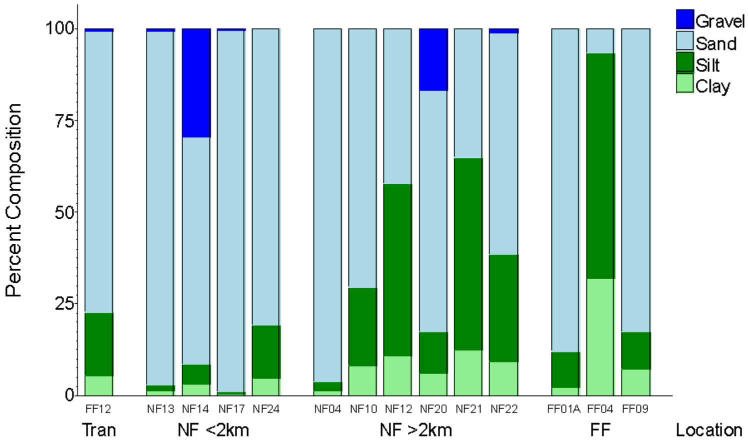
- 3 farfield reference stations -
  - Off Gloucester;
  - In Stellwagen Basin;
  - Between the nearfield and S Basin.

- Sampled annually for grain size, TOC, and *C. perfringens*.
- Sampled every third year (inc. 2014) for metals, PAHs, PCBs and Pesticides.



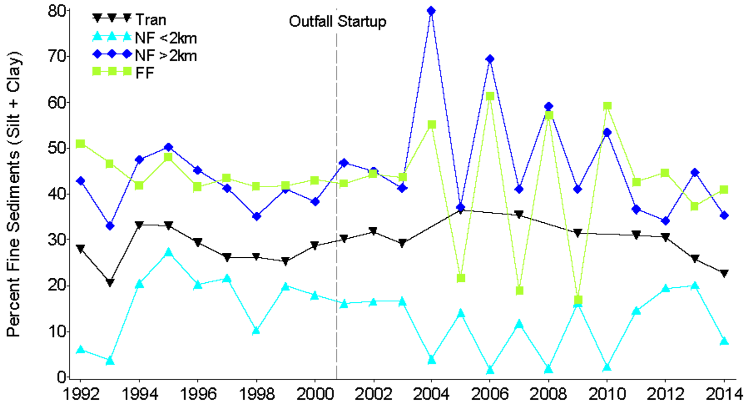
Grain size distribution

- 2014 results similar to most years.
- Nearfield sediments range from gravelly sands to sandy muds.
- Site NF24 near outfall unusually sandy in 2014
- Composition affects infaunal communities, contaminant accumulation.



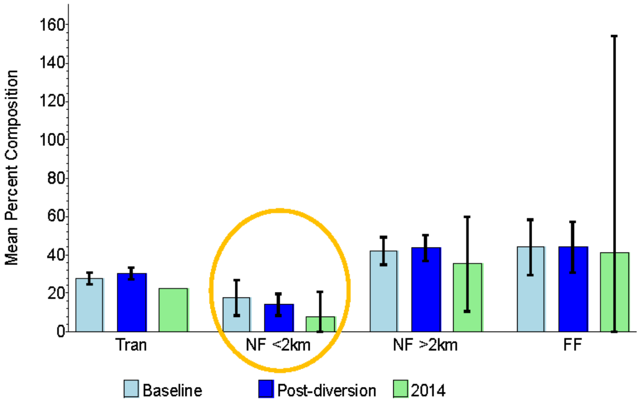
Percent fines in sediments

- Grain size was generally similar to previous years.
- Sawtooth pattern is an artifact.
- Percent fines at 0-2km stations is the lowest since NF24 was added in 1994.



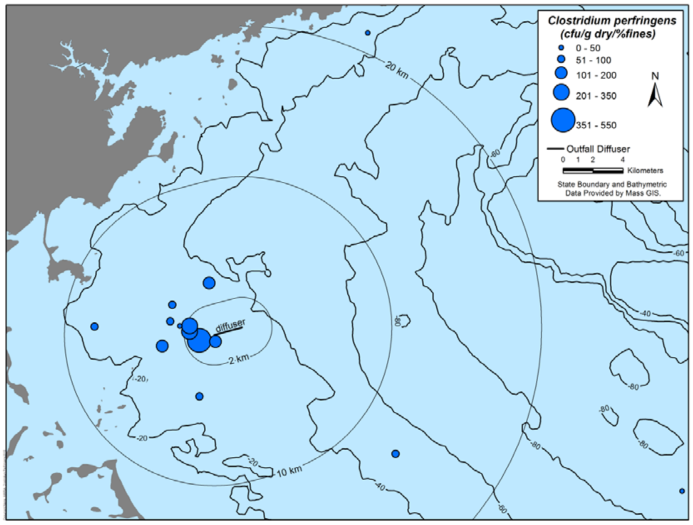
Percent fines in sediments

- At most stations grain size was similar to what was seen in previous years.
- 0-2 km stations.
    - NF13 – Sandy, commonly 2-6% fines.
    - NF14 – Sandy, commonly 5-13% fines.
    - NF17 – Sandy, commonly 1-4% fines.
    - NF24 – Silty, commonly 35-70+% fines
- 2014 data at all 4 stations lower % fines than most years, NF24 lowest yet observed.



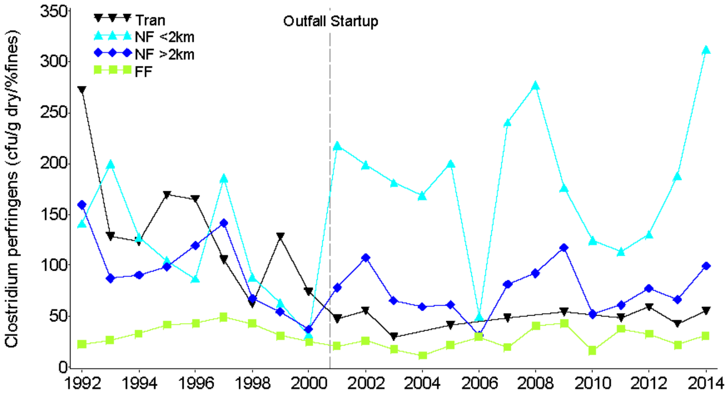
Why is that noteworthy?

- Map shows distribution of *Clostridium perfringens*
- Tracer of effluent solids.
- Spores are associated with fine particulates.
- Spore counts normalized to %fines are the **ONLY** confirmed effluent signature we've found in sediments.
- 2014 results w/in 2 km higher than usual.



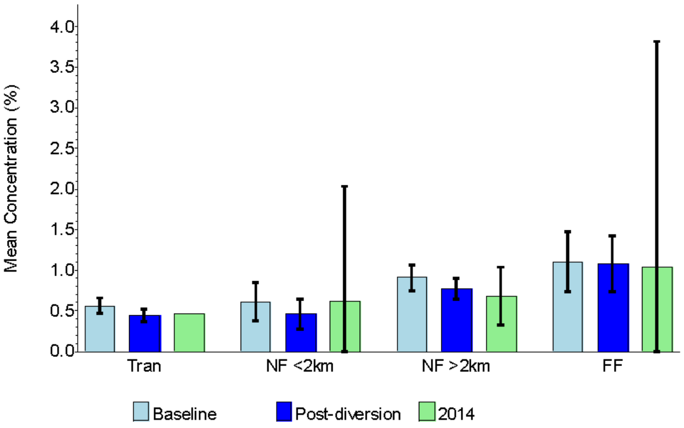
Clostridium perfringens, timeseries by region

- Recovery in Harbor (not shown), transition area.
- No change in farfield or at NF stations > 2 km from outfall.
- < 2 km highest yet observed.
- 2014 results, esp. w/in 2 km, higher than usual.
- Raw counts at 3 sand sites average –slightly above
- Raw counts at silty site lowest since startup.
- 2014 "signal" in part a result of normalizing to unusually low percent fines at the close-in sites.

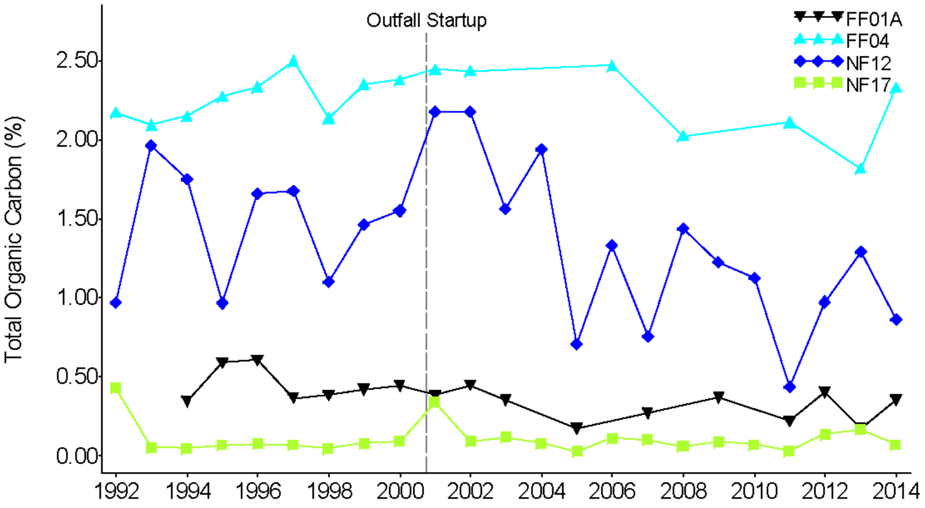


Total Organic Carbon

- Would expect to see increases if effluent solids accumulating in sediments.
- No change since baseline monitoring .
- 2014 results in range of discharge monitoring observations.
- Wide 2014 error bars result from small number of stations

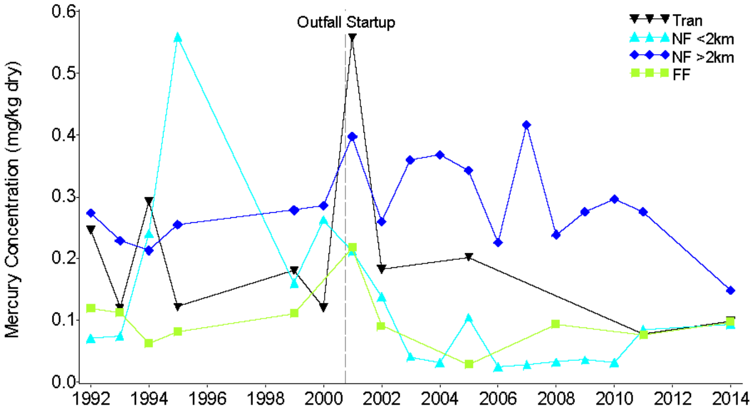


Total Organic Carbon (individual stations)

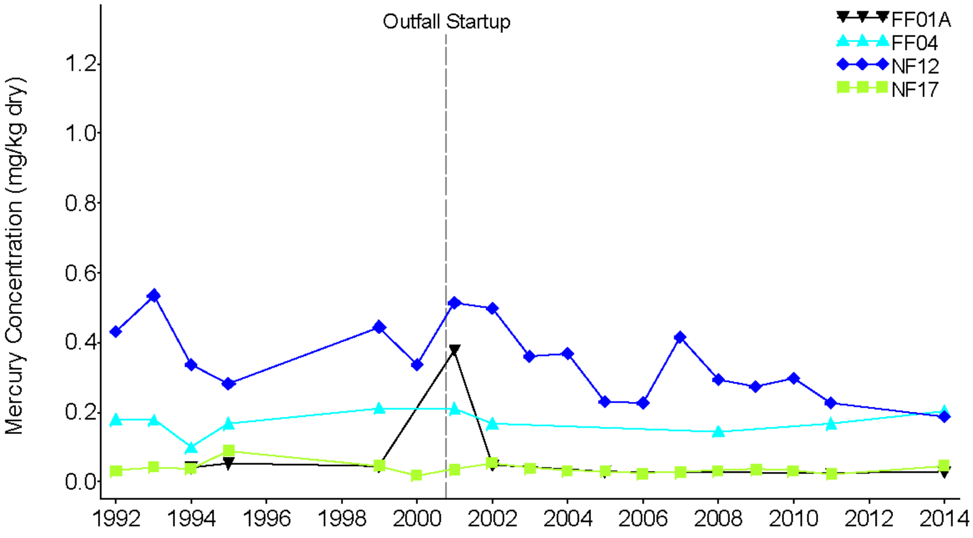


Mercury (by region)

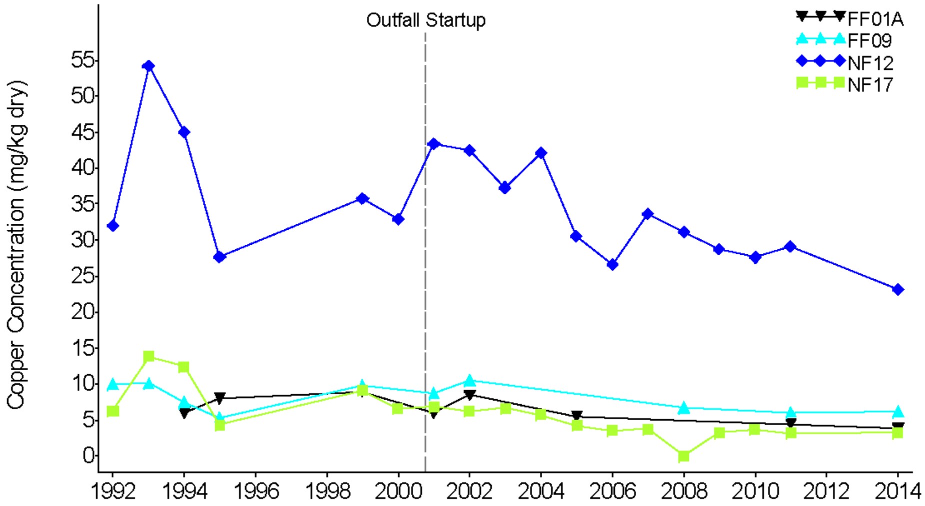
- No accumulation in nearfield sediments
- 2014 lower than many discharge years



Mercury (selected stations)

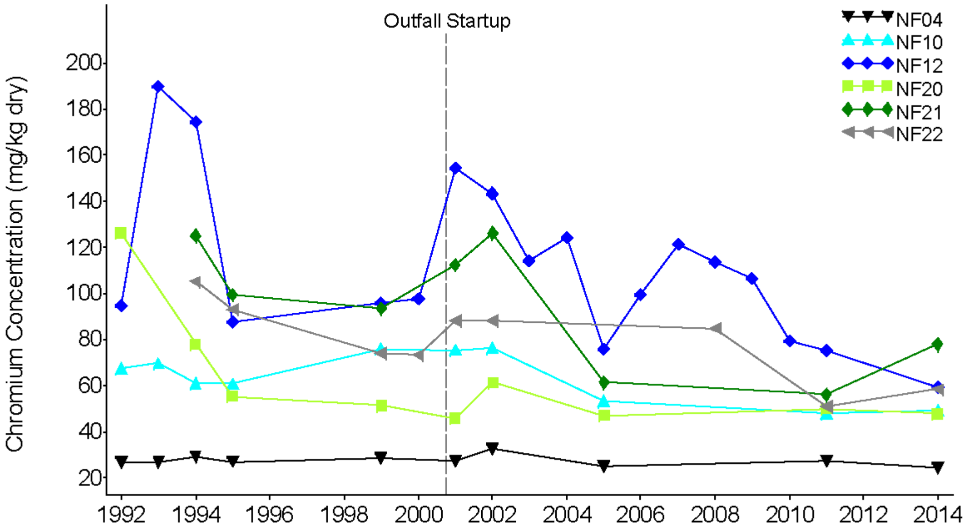


Copper (selected stations)



13

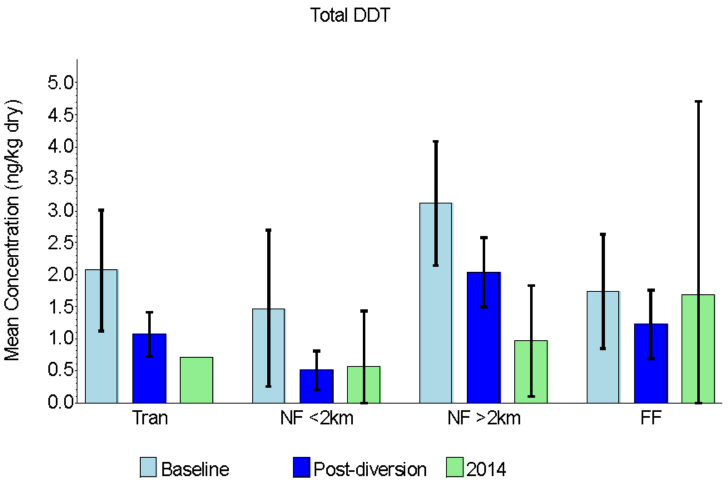
Chromium (selected NF stations)



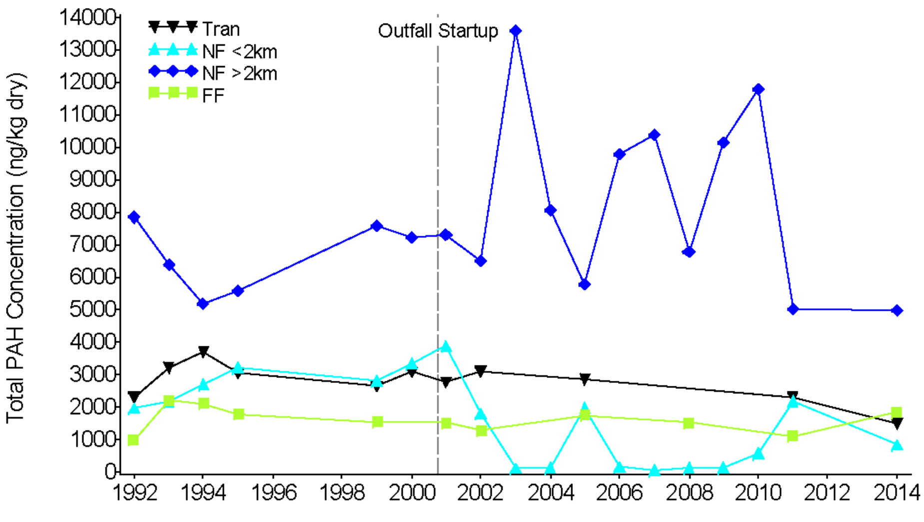
14

DDT by region (4-4′ DDT excluded from comparison)

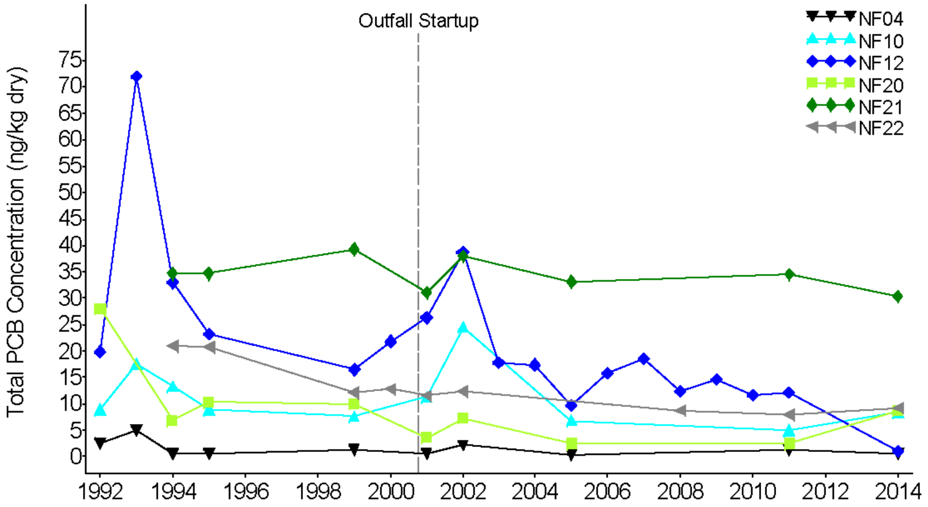
- DDT data are variable year-year and station-station.
- Nevertheless, reductions through time are apparent.



PAHs by region

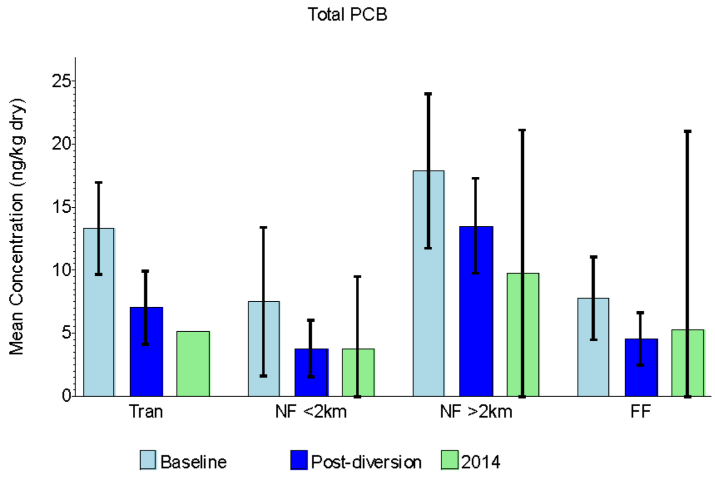


PCBs at selected NF stations



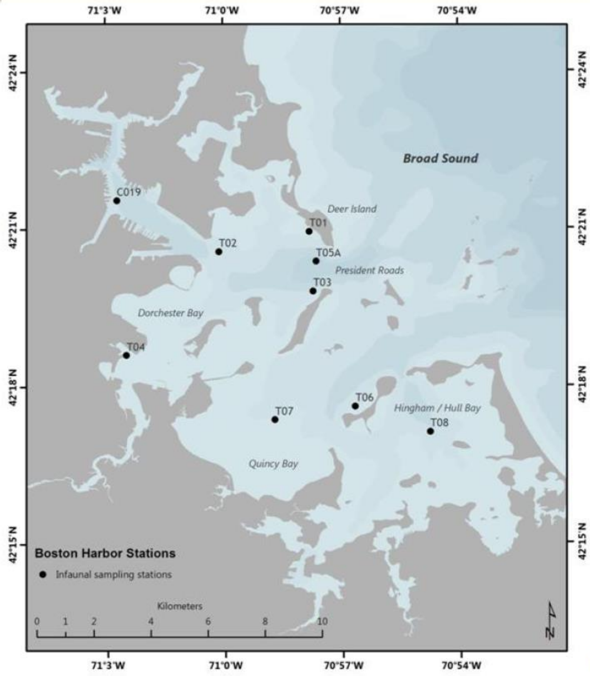
PCBs by region

- PCBs decreasing in sediments throughout system.
- Matches broad regional trends.

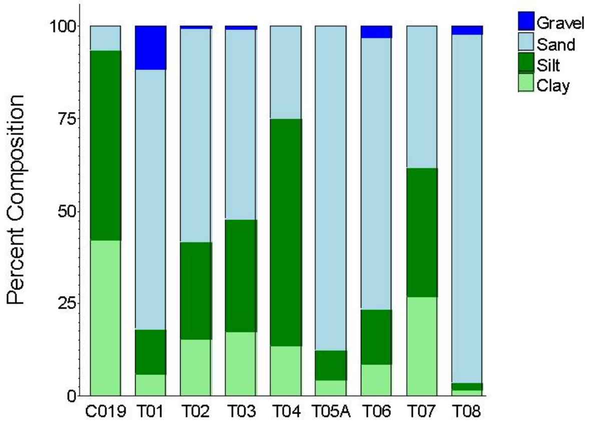


Boston Harbor sediment monitoring

- 8 “T” stations sampled annually since Sep. 1991.
- Sampled annually for grain size, TOC, and C. perfringens.
- Contaminants in some years, not since 2006.
- C019 sampled annually since 2004.
- Reductions in loading resulting in improvements at most stations.

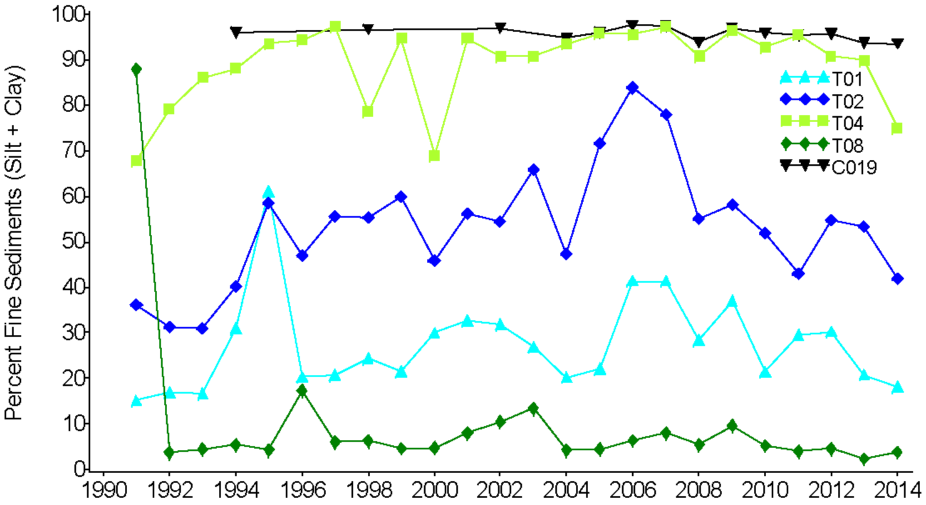


Grain size in 2014

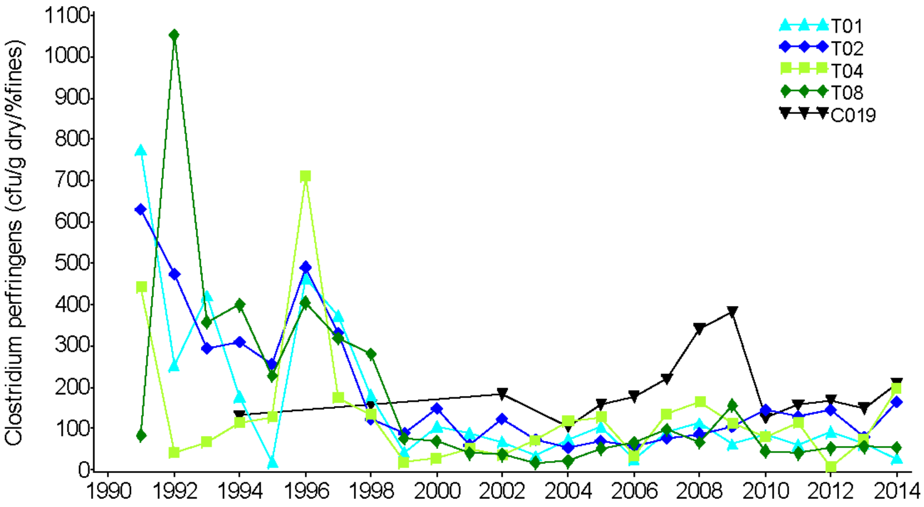


Collecting sea-floor sediments off of Deer Island

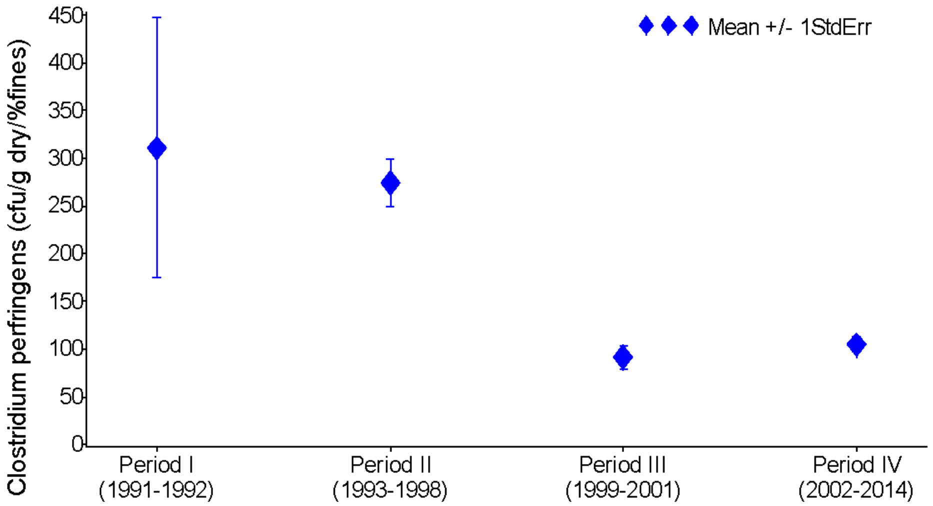
Percent fines at selected stations



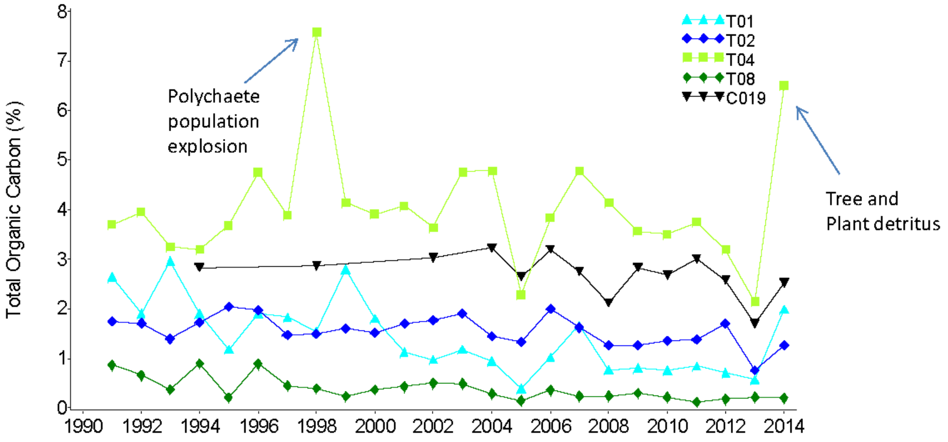
Clostridium perfringens by station



Clostridium perfringens through time

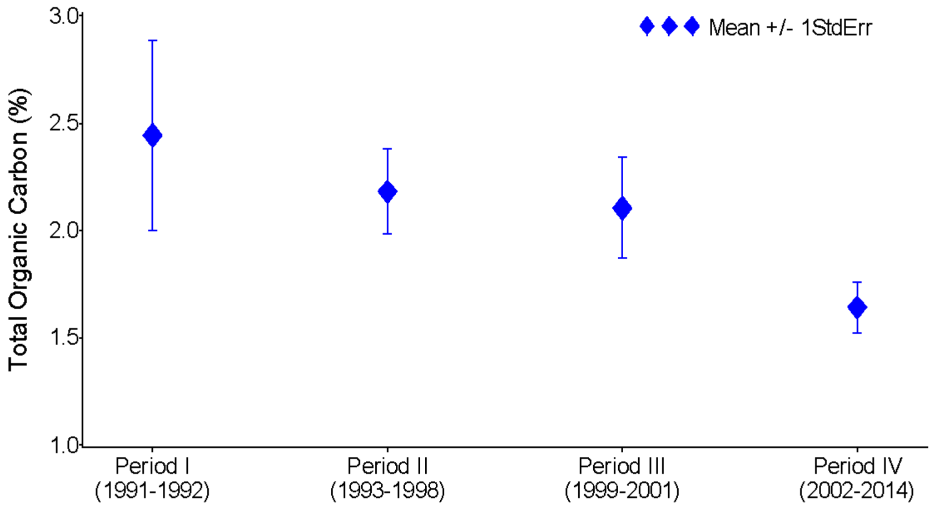


Total Organic Carbon



- TOC variable but decreases through time on average
- Spikes at station T04 in 1998 and 2014 appear to have discrete causes

Total Organic Carbon through time

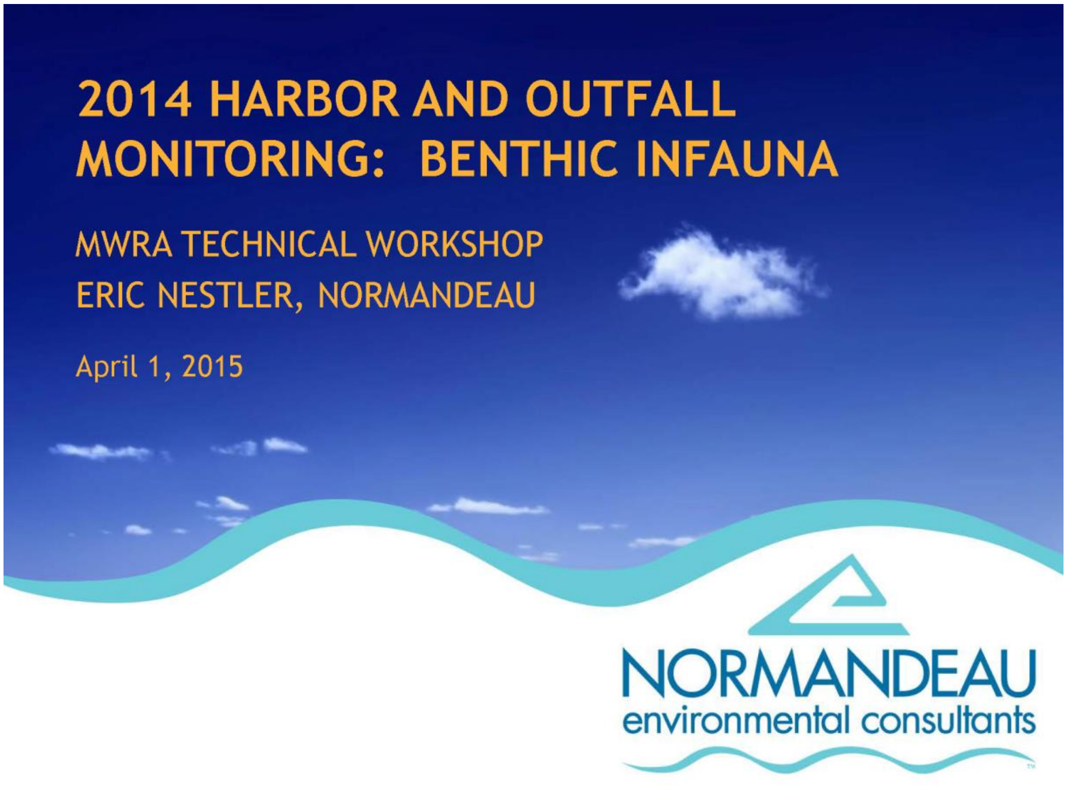


Next steps

- Combine Harbor and offshore data into similar format.
- Work towards manuscript on sediment contaminant monitoring?
- Consider additional Harbor sediment contaminant sampling?
- Get more photos of recent sampling team in the field.

See, the first picture of Ken in the field wasn't a fluke

Appendix A2. 2014 Harbor and Outfall Monitoring: Benthic Infauna

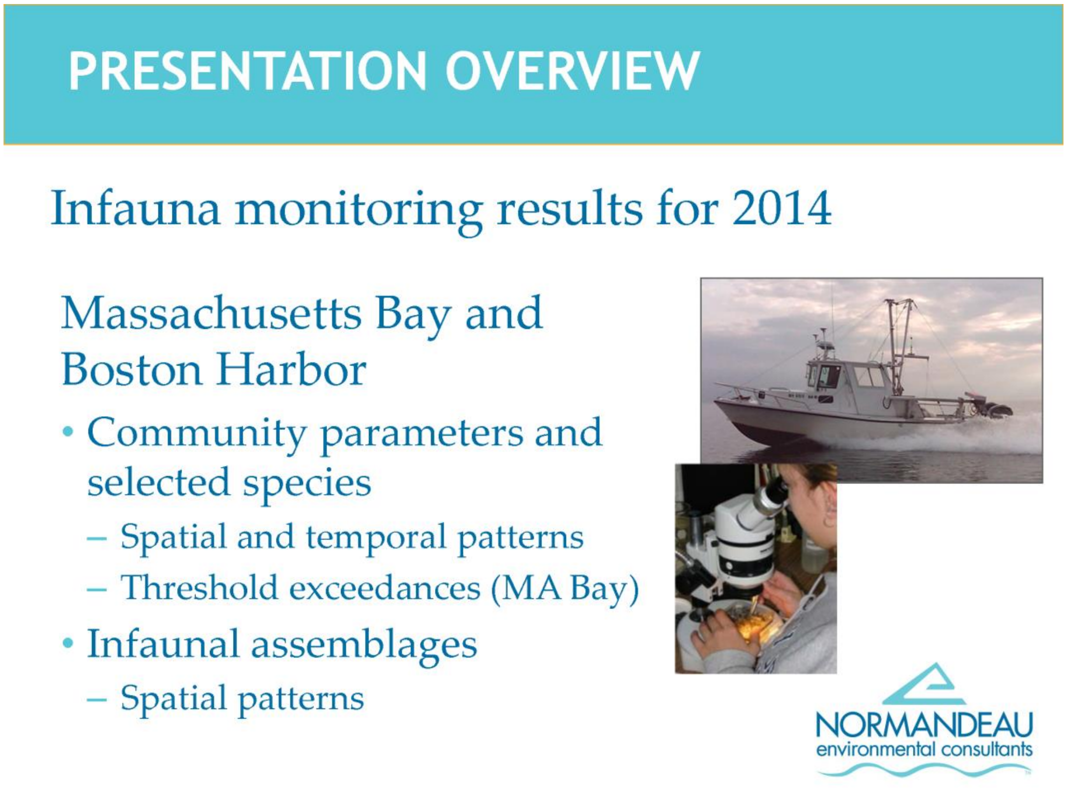


2014 HARBOR AND OUTFALL MONITORING: BENTHIC INFAUNA

MWRA TECHNICAL WORKSHOP
ERIC NESTLER, NORMANDEAU

April 1, 2015

NORMANDEAU
environmental consultants



PRESENTATION OVERVIEW

Infauna monitoring results for 2014

Massachusetts Bay and Boston Harbor

- Community parameters and selected species
  - Spatial and temporal patterns
  - Threshold exceedances (MA Bay)
- Infaunal assemblages
  - Spatial patterns

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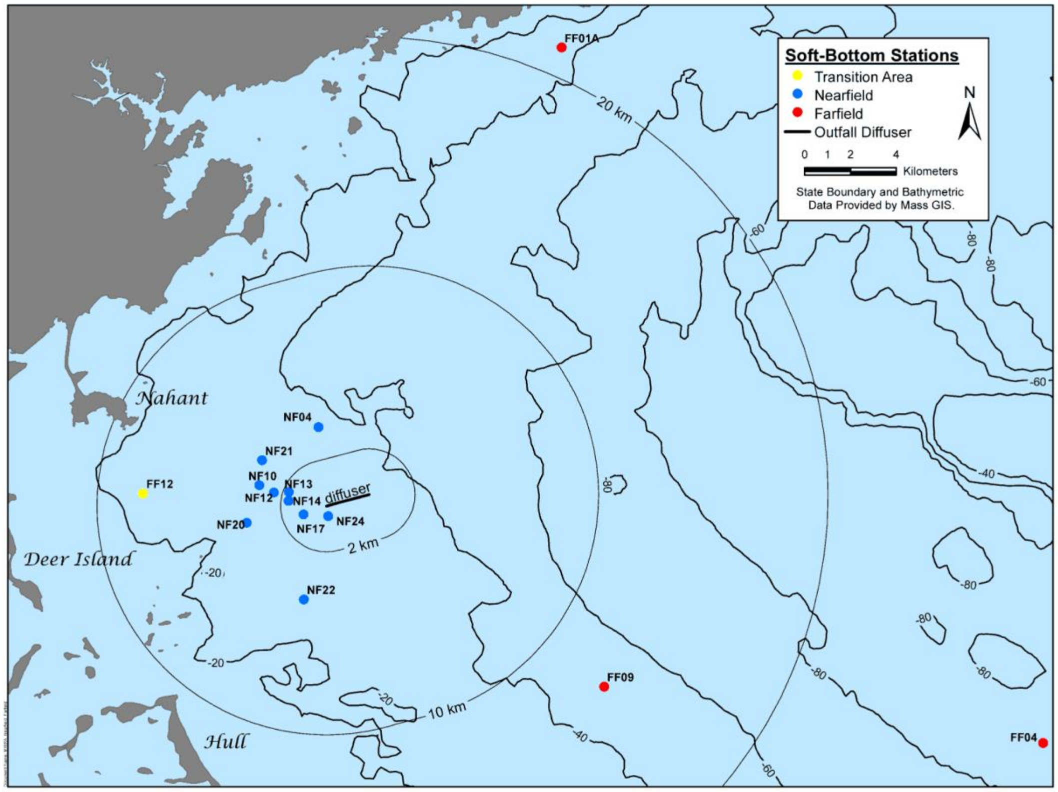

BENTHIC INFAUNA: MASSACHUSETTS BAY

- Summary for 14 samples in 2014:
  - 21,863 individual organisms (14,522 in 2013)
  - 210 taxa identified; 183 species and 27 higher taxonomic groups (207 taxa total and 183 species in 2013)
  - All counts used for abundance
  - Only species-level counts used for diversity measures and multivariate analyses

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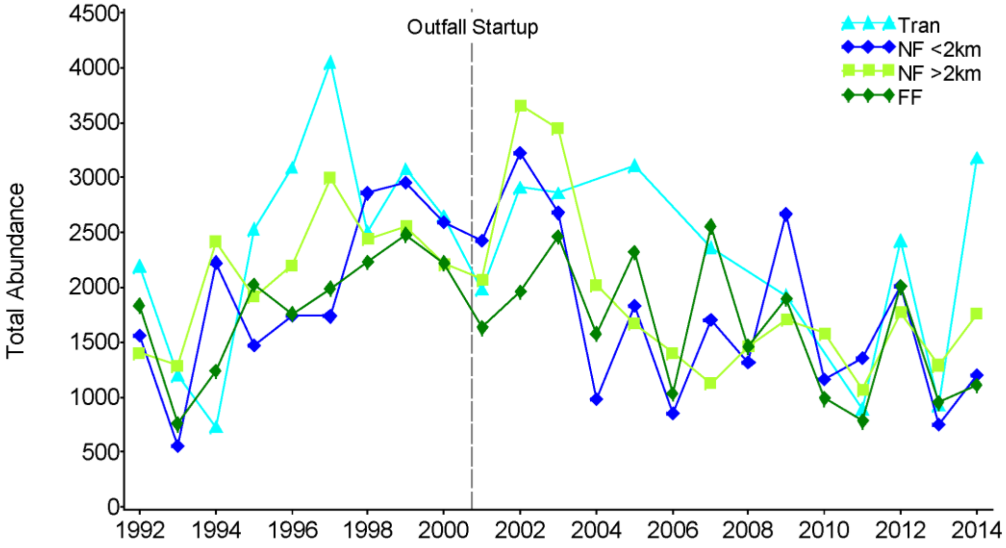
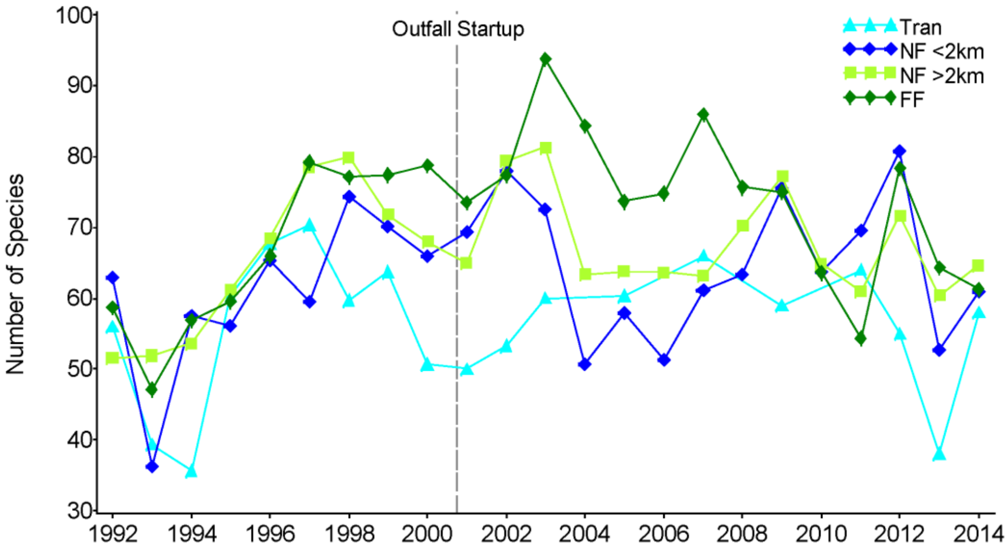
TOTAL ABUNDANCE: MASSACHUSETTS BAY



NUMBER OF SPECIES: MASSACHUSETTS BAY

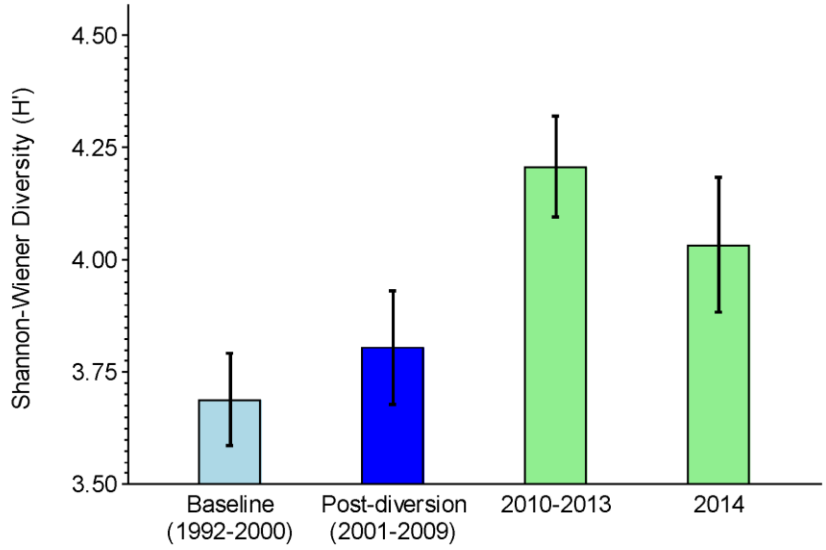


2014 THRESHOLD EXCEEDANCES

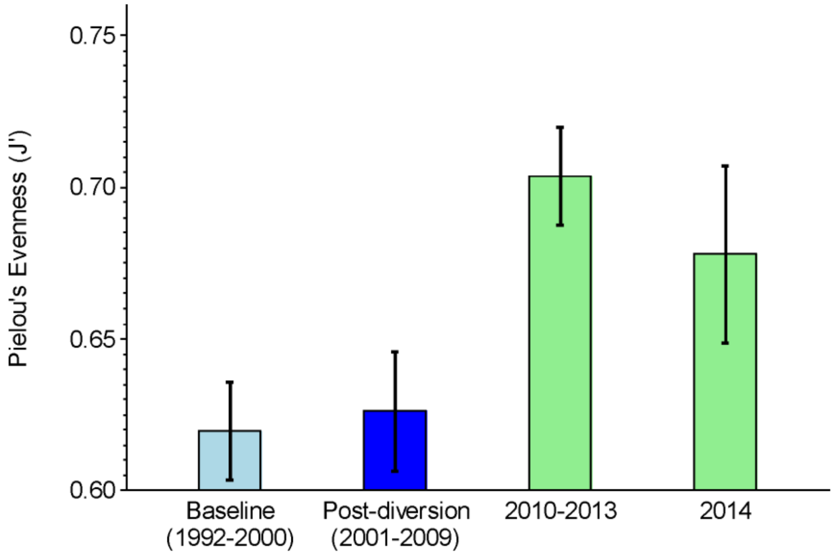
- Contingency Plan threshold exceedances for: Shannon-Wiener Diversity (H′) and Pielou’s Evenness (J′).
- Threshold exceedances for H′ and J′ have been reported each year since 2010.
- No exceedances for: Total species, log-series alpha, or percent opportunists.

Parameter	Threshold range		2014 Result	Exceedance?
	Low	High		
Shannon-Wiener (H')	3.37	3.99	4.03	Yes, Caution Level
Pielou’s (J')	0.57	0.67	0.68	Yes, Caution Level

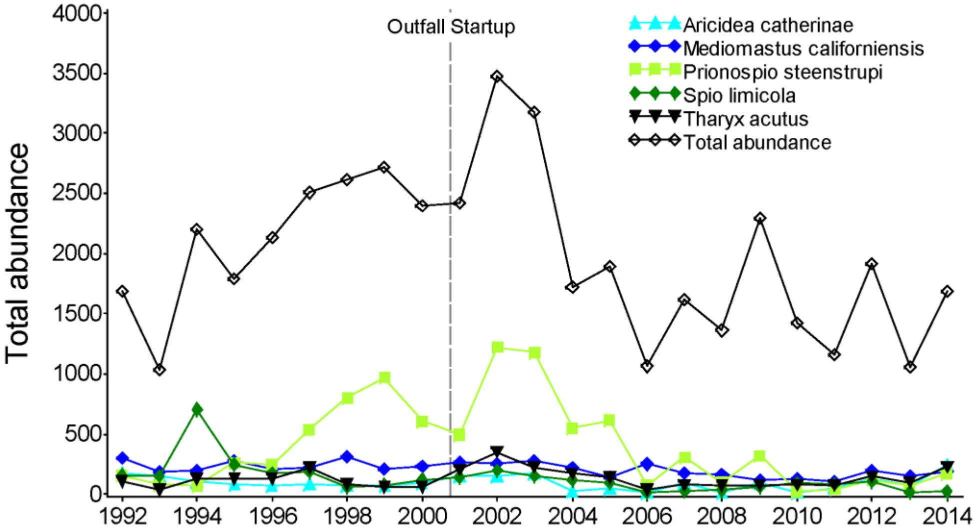
DIVERSITY (H’): NF STATIONS ONLY



EVENNESS (J'): NF STATIONS ONLY

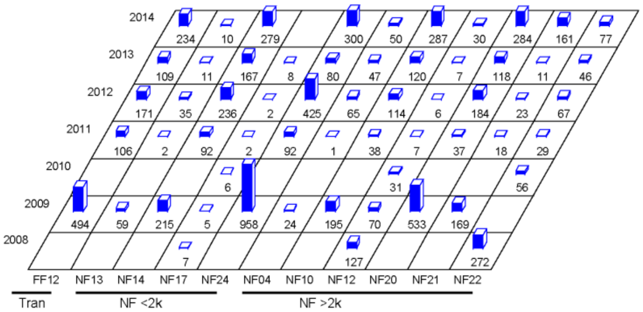


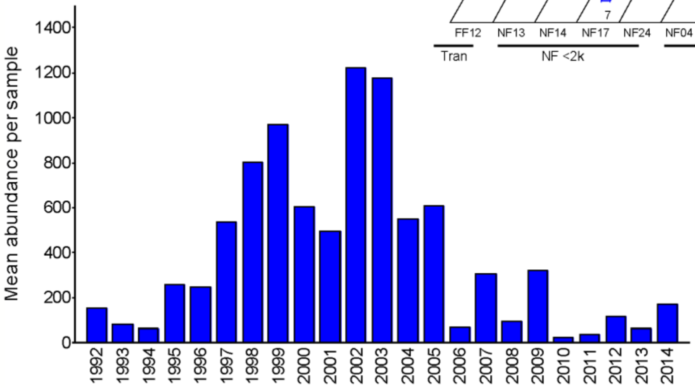
DOMINANT SPECIES: NF ONLY



PRIONOSPIO STEENSTRUPI

NF STATIONS ONLY





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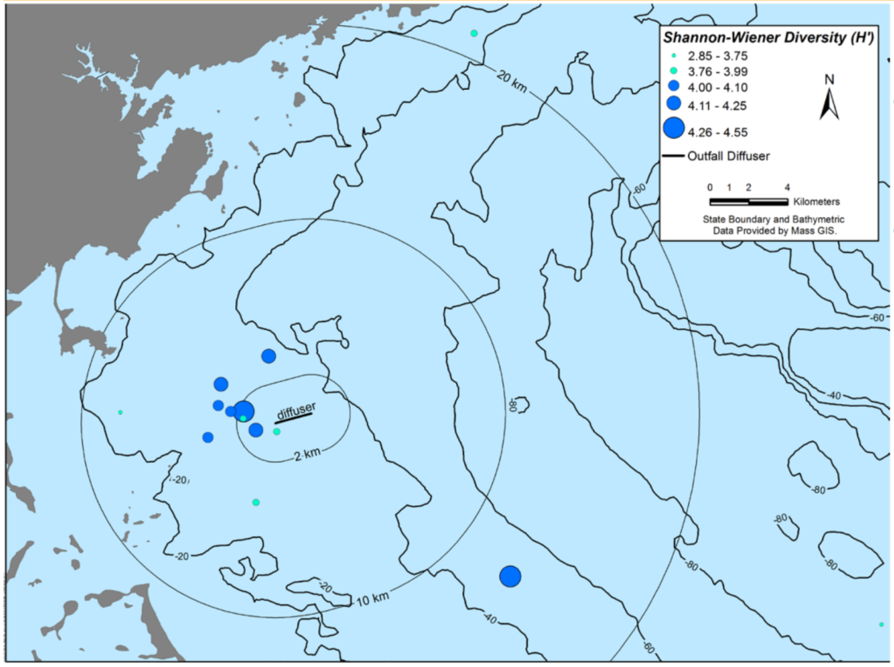
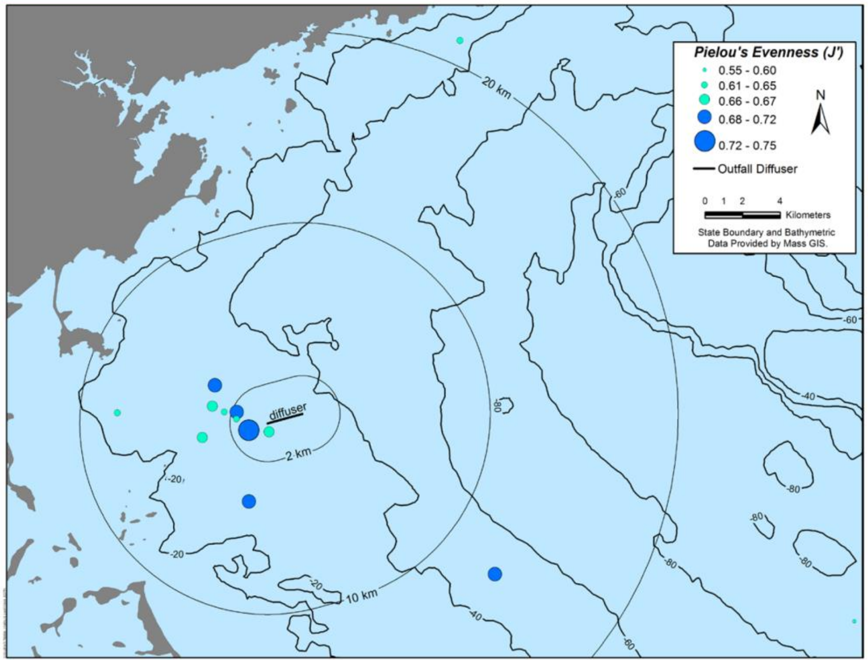
2014 DIVERSITY (H')



Light = below threshold

Dark = above threshold

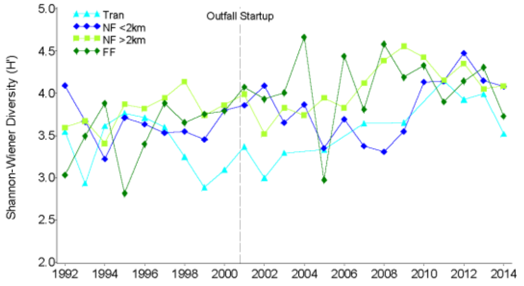
2014 EVENNESS (J')

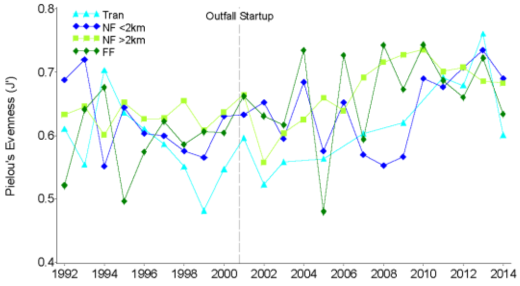


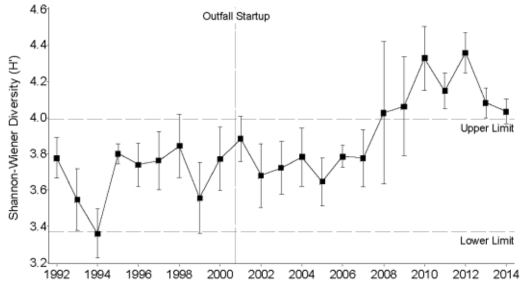
Light = below threshold

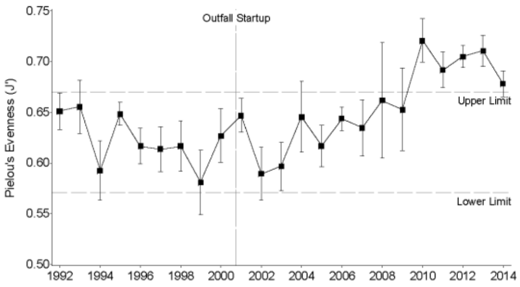
Dark = above threshold

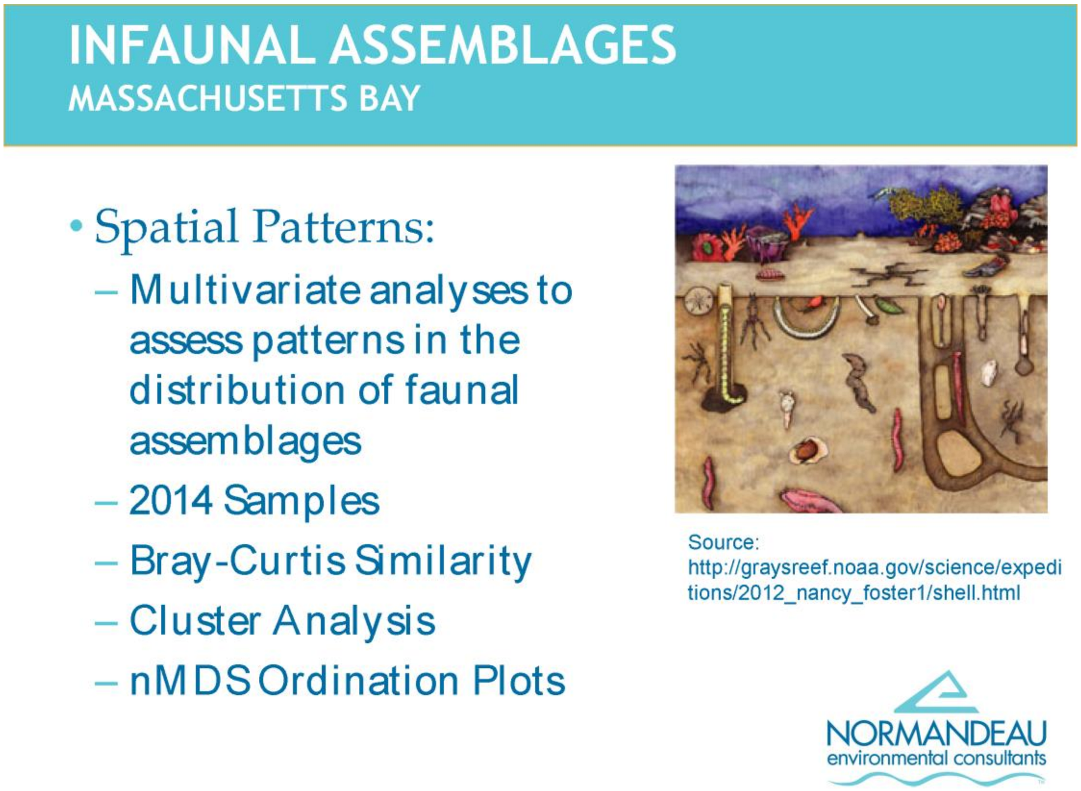
DIVERSITY (H') EVENNESS (J')











INFAUNAL ASSEMBLAGES
MASSACHUSETTS BAY

- Spatial Patterns:
  - Multivariate analyses to assess patterns in the distribution of faunal assemblages
  - 2014 Samples
  - Bray-Curtis Similarity
  - Cluster Analysis
  - nMDS Ordination Plots

Source: http://graysreef.noaa.gov/science/expeditions/2012_nancy_foster1/shell.html

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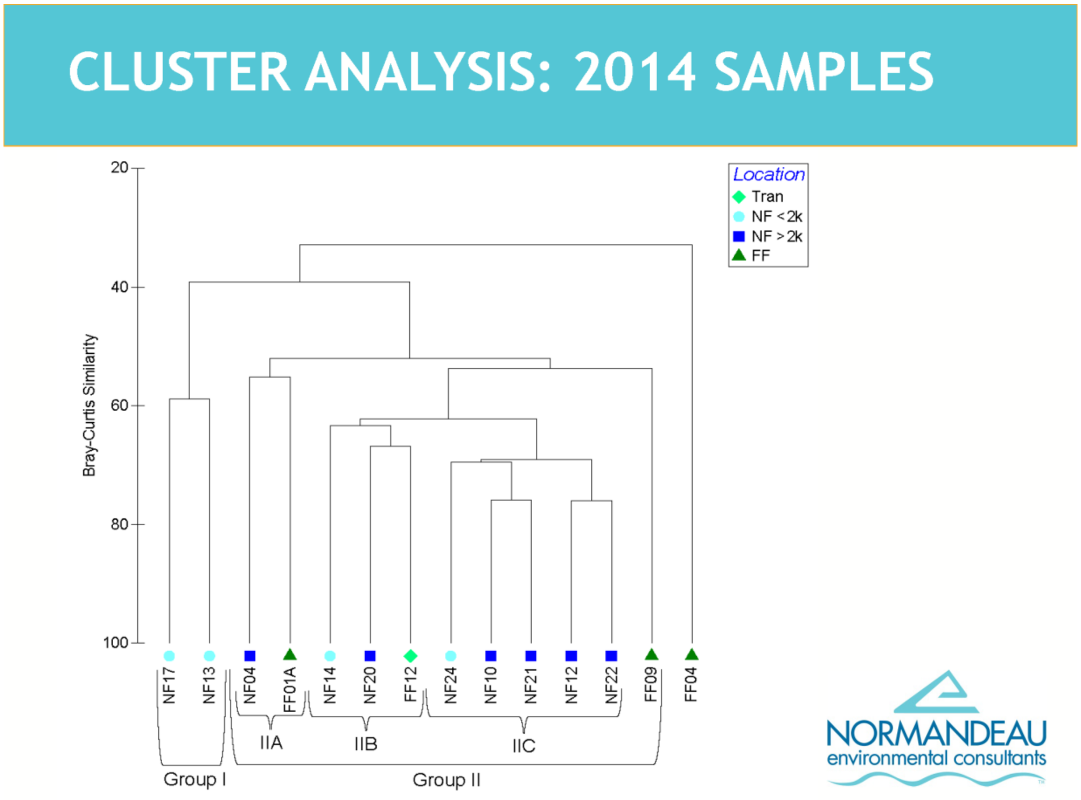

CLUSTER ANALYSIS: 2014 SAMPLES

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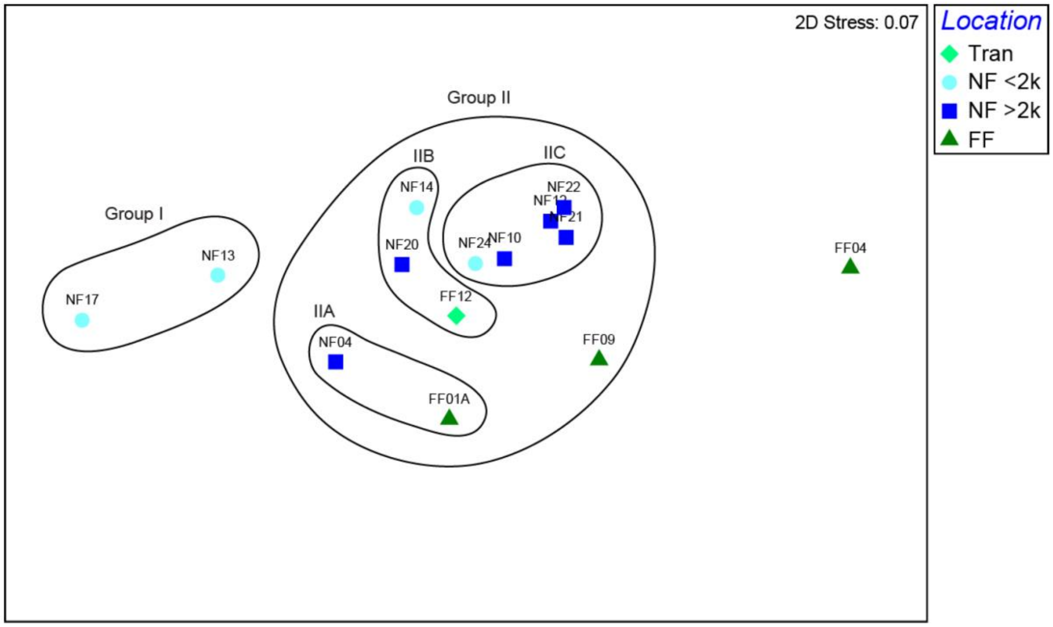
ORDINATION PLOT: 2014 SAMPLES LOCATION OVERLAY

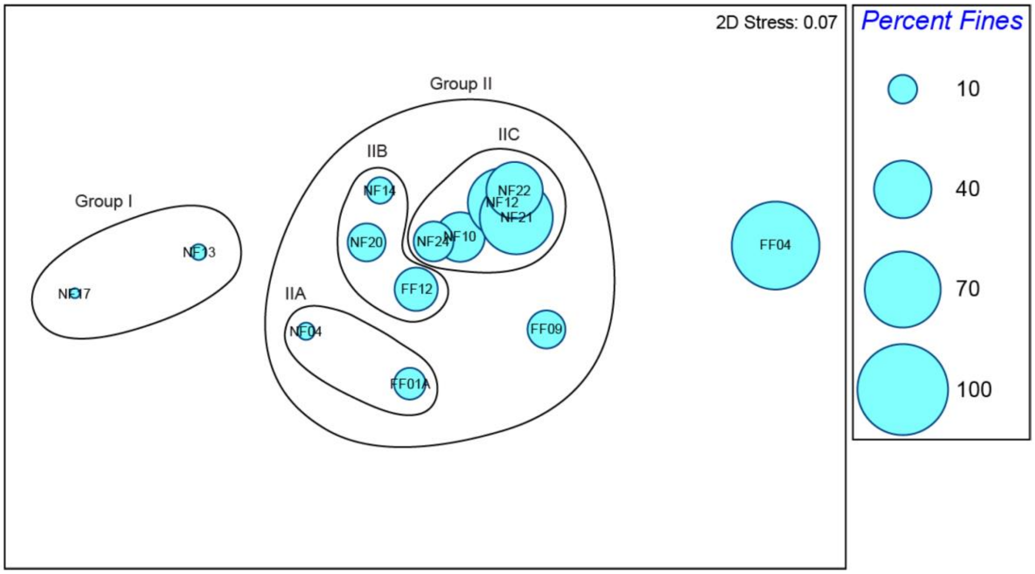


INFAUNAL ASSEMBLAGES

MASSACHUSETTS BAY

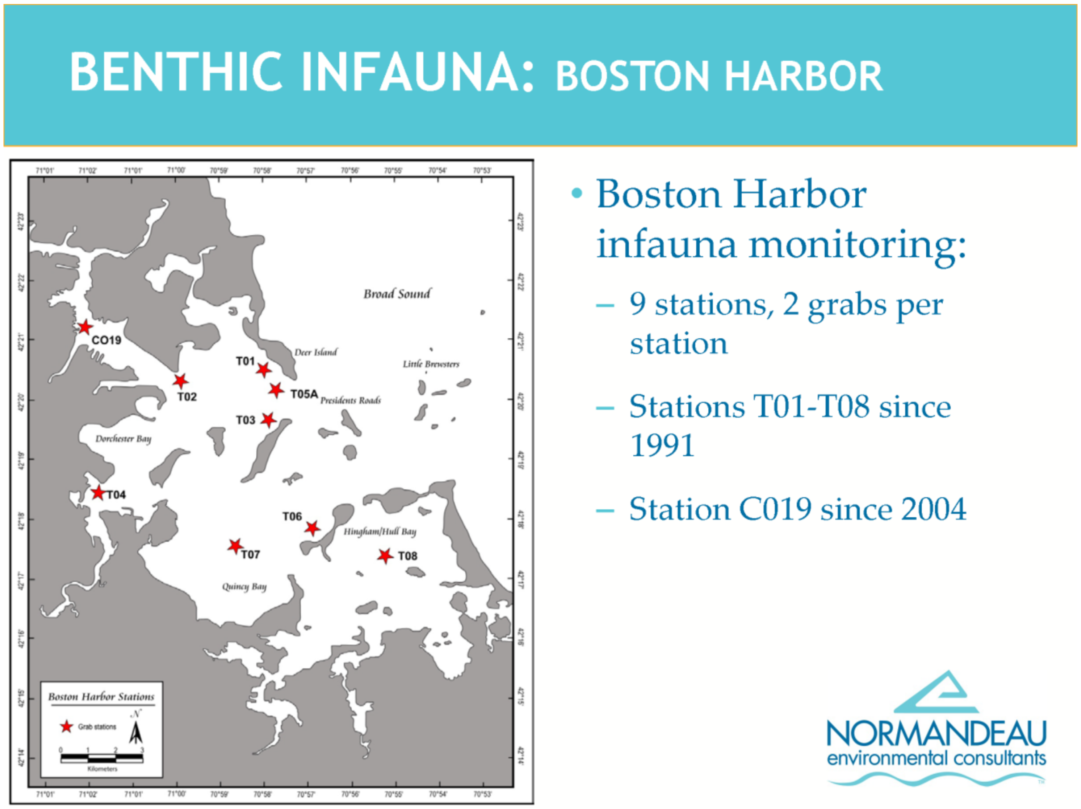
- Group I: NF17, NF13 (sand)
  - *Exogone hebes, Spiophanes bombyx, Aricidea catherinae, Molgula manhattensis, Orchomenella minuta*
- Group IIA: NF04, FF01A (sand, some fines)
  - *Nucula delphinodonta, Prionospio steenstrupi, A. catherinae*
- Group IIB: NF14, NF20, FF12 (sand with fines, gravel)
  - *A. catherinae, P. steenstrupi, Tharyx acutus*
- Group IIC: other NF stations (fines with sand)
  - *T. acutus, Mediomastus californiensis, P. steenstrupi*
- FF09 (sand with fines, deeper)
  - *Anobothrus gracilis, N. delphinodonta, Levinsenia gracilis*
- FF04 (fines)
  - *L. gracilis, Ninoe nigripes, Cossura longocirrata*

ORDINATION PLOT: 2014 SAMPLES PERCENT FINES OVERLAY



INFAUNA SUMMARY: MASSACHUSETTS BAY

- Faunal distributions reflect habitat (e.g., sediment grain size).
- Increased Diversity (H′) and Evenness (J′) since 2010 reflect reductions in numbers of dominant species (e.g., *Prionospio steenstrupi* and *Spio limicola*).
- No evidence of impacts to infauna from the discharge.



BENTHIC INFAUNA: BOSTON HARBOR

- Boston Harbor infauna monitoring:
  - 9 stations, 2 grabs per station
  - Stations T01-T08 since 1991
  - Station C019 since 2004

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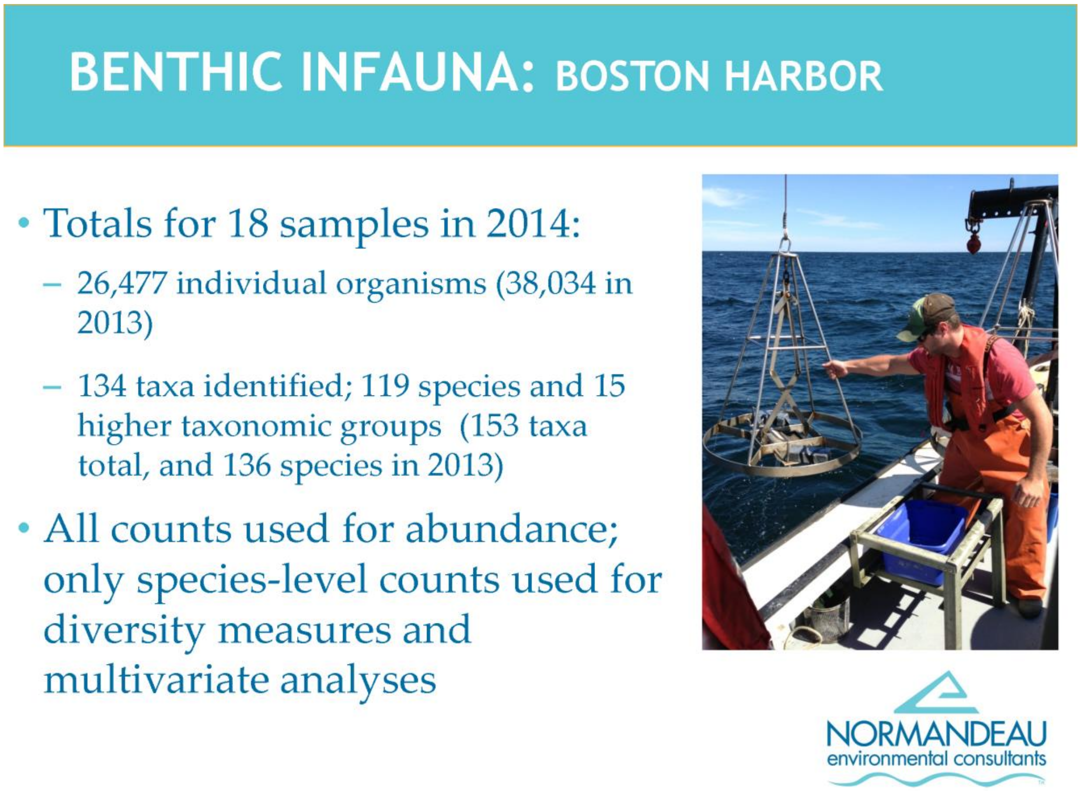

BENTHIC INFAUNA: BOSTON HARBOR

- Totals for 18 samples in 2014:
  - 26,477 individual organisms (38,034 in 2013)
  - 134 taxa identified; 119 species and 15 higher taxonomic groups (153 taxa total, and 136 species in 2013)
- All counts used for abundance; only species-level counts used for diversity measures and multivariate analyses

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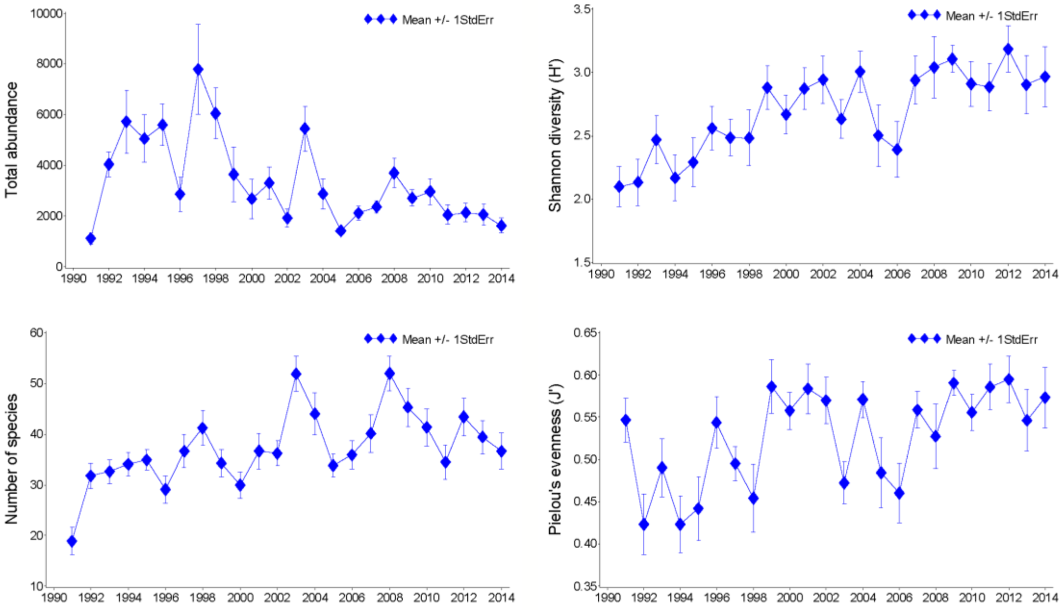
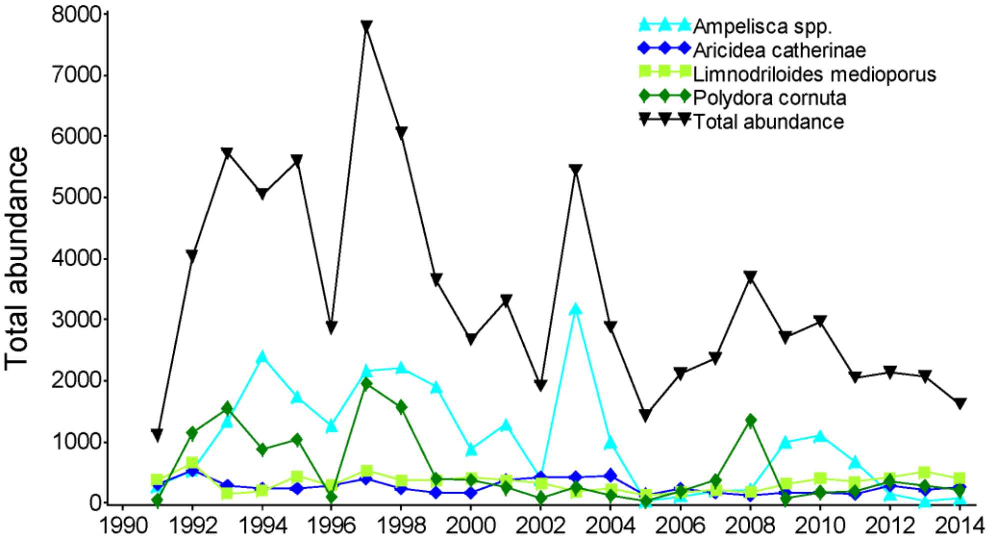
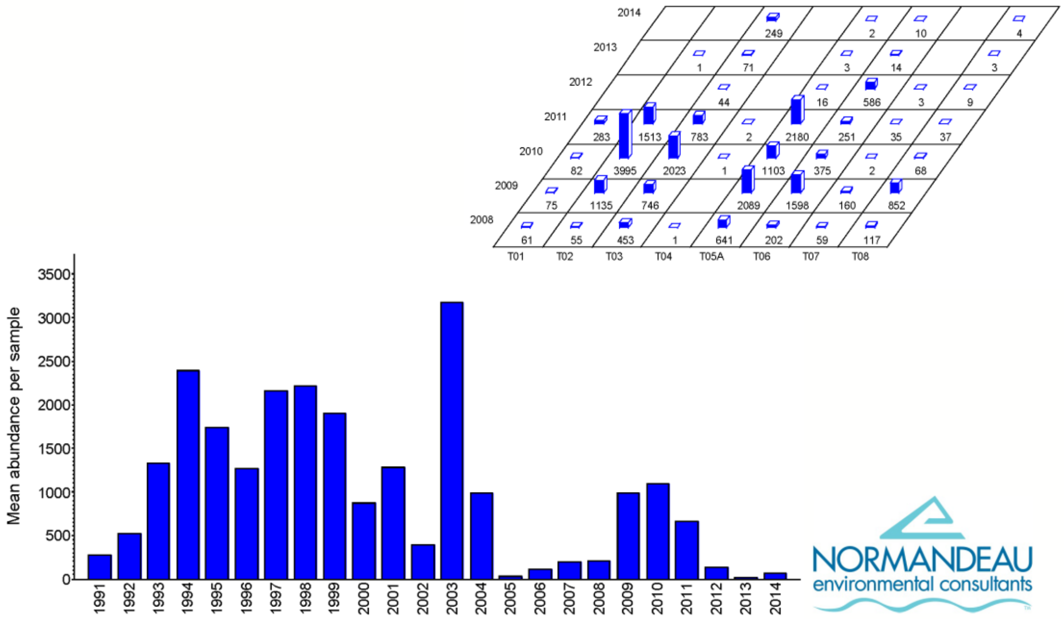
COMMUNITY PARAMETERS
HARBOR STATIONS T01-T08



DOMINANT SPECIES
HARBOR STATIONS T01-T08



AMPELISCA SPP.
HARBOR STATIONS T01-T08



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INFAUNAL ASSEMBLAGES
BOSTON HARBOR

- Spatial Patterns:
  - Multivariate analyses to assess patterns in the distribution of faunal assemblages
  - 2014 Samples; 9 stations, 2 reps
  - Bray-Curtis Similarity
  - Cluster Analysis
  - nMDS Ordination Plots

Source:
http://www.sardi.sa.gov.au/aquatic

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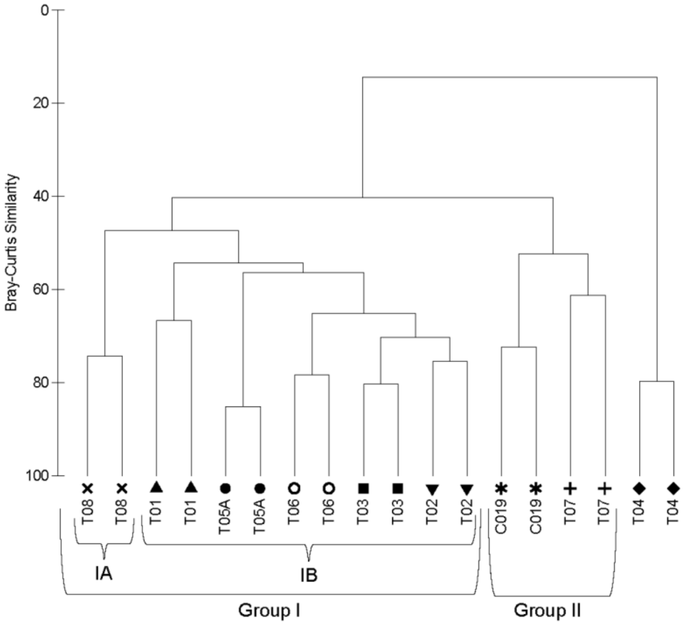
CLUSTER ANALYSIS: 2014 SAMPLES
BOSTON HARBOR



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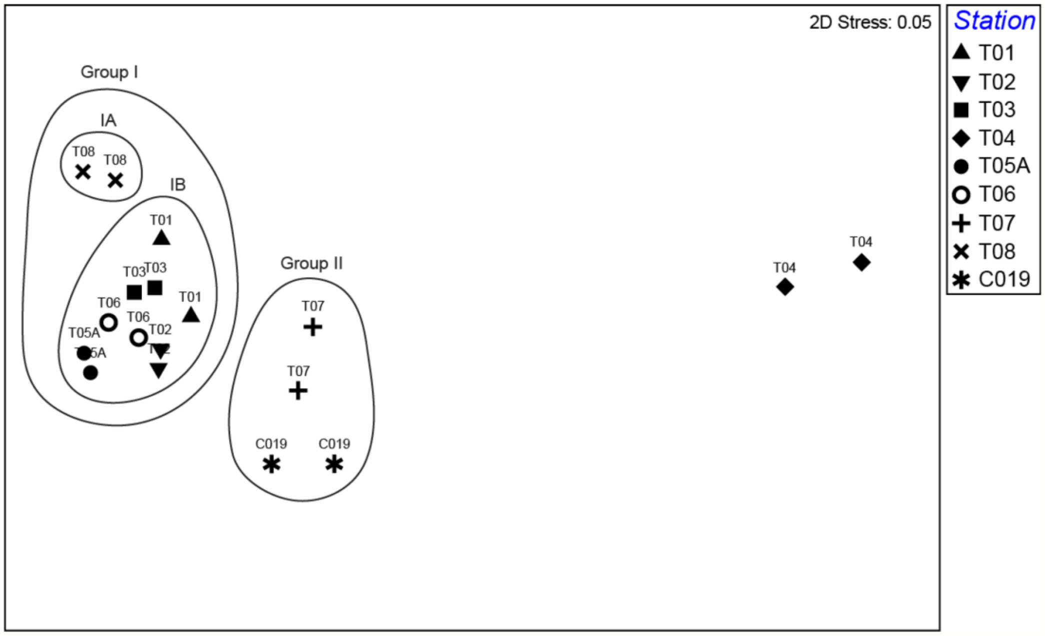
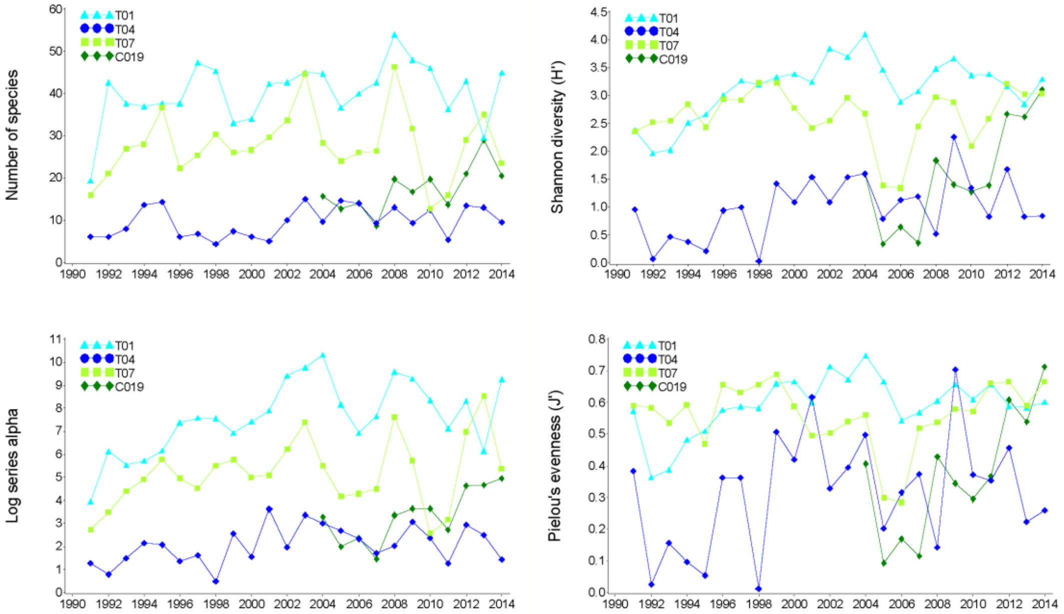
ORDINATION PLOT: 2014 SAMPLES
BOSTON HARBOR



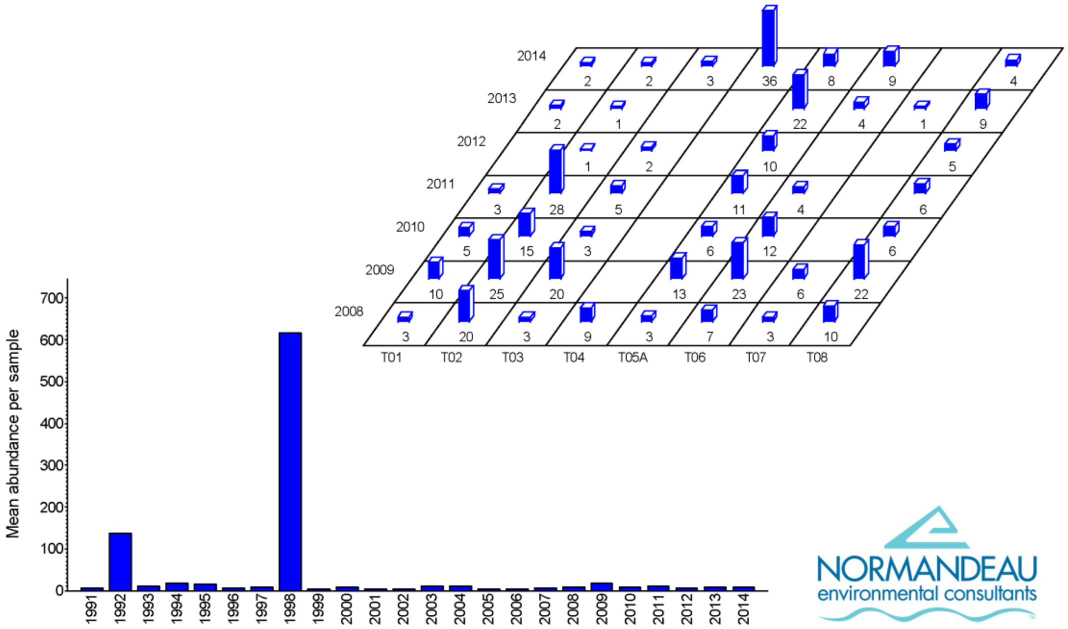
INFAUNAL ASSEMBLAGES
BOSTON HARBOR

- Group IA: T08 (outer Harbor, sand)
  - *Polygordius jouinae, Tharyx acutus, Clymenella torquata*
- Group IB: T01, T02, T03, T05A, T06 (outer Harbor, mixed sediments)
  - *Limnodriloides medioporus, Aricidea catherinae, Tubificoides intermedius*
- Group II: C019 and T07 (Inner Harbor and Quincy Bay, fines/ fines with sand)
  - *T. intermedius, Polydora cornuta, Bipalponephtys neotena*
- T04 (Savin Hill Cove, fines, organic enrichment, shallow – 4 meters)
  - *Streblospio benedicti, Tubificoides* sp.2, *Capitella capitata*

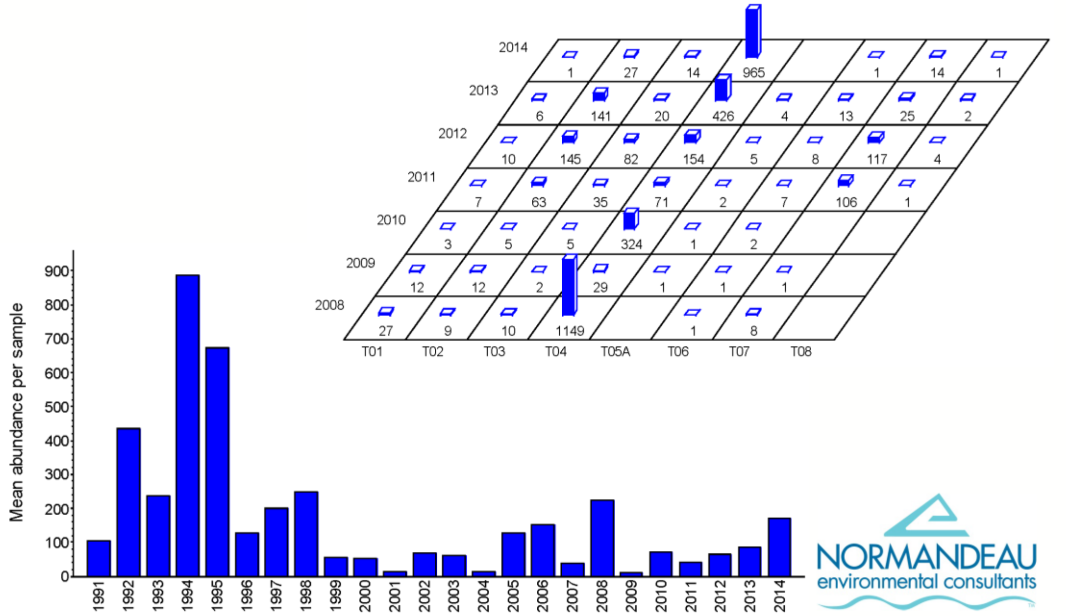
MEASURES OF DIVERSITY
HARBOR STATIONS T01, T04, T07, AND C019



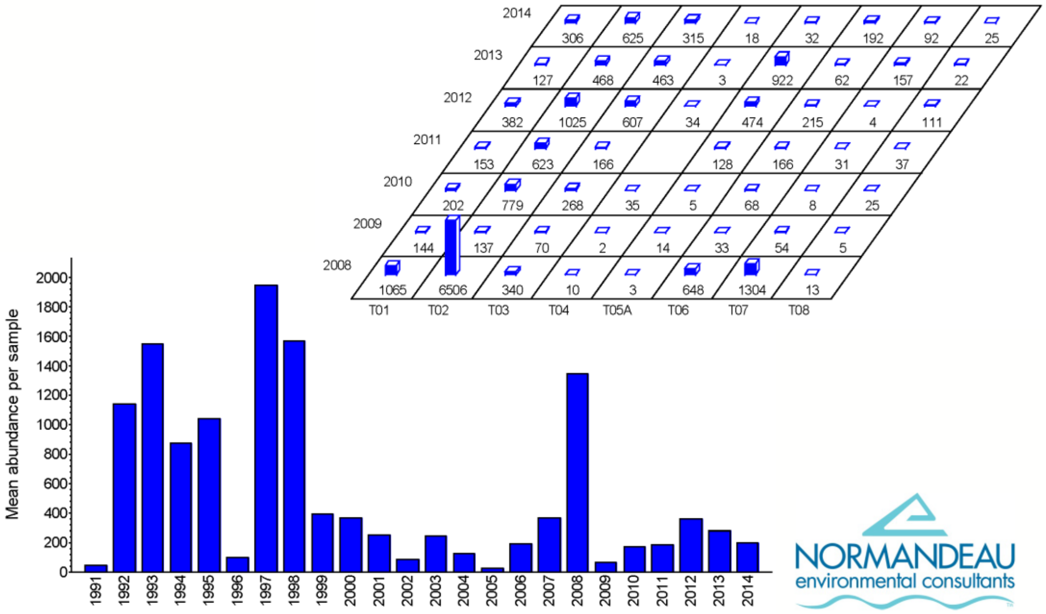
CAPITELLA CAPITATA
HARBOR STATIONS T01-T08



STREBLOSPIO BENEDICTI
HARBOR STATIONS T01-T08



POLYDORA CORNUTA
HARBOR STATIONS T01-T08



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INFAUNA SUMMARY: BOSTON HARBOR

- Faunal distributions reflect differences along an inner to outer-Harbor gradient:
  - Tidal flushing
  - Site-specific organic enrichment (station T04)
- Faunal communities at outer Harbor stations remain consistent with communities found during recent past years in the post-recovery period
- Continued improvement in faunal diversity at C019

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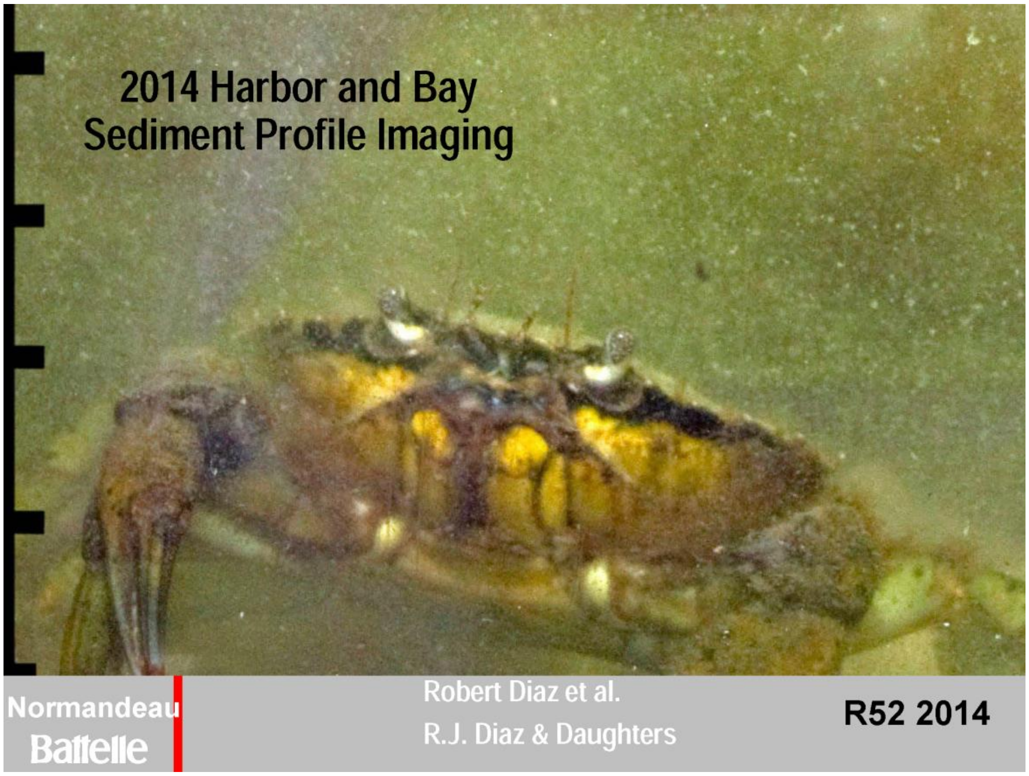
ACKNOWLEDGEMENTS

- Massachusetts Water Resources Authority
  - Ken Keay (Program Manager)
- Normandeau Associates, Inc.
  - Ann Pembroke (Project Manager),
    Hannah Proctor (Laboratory Manager),
    Erik Fel'Dotto (Field Manager)
- Cove Corporation
- Ocean's Taxonomic Services

NORMANDEAU
environmental consultants

Appendix A3. 2014 Harbor and Bay Sediment Profile Imaging

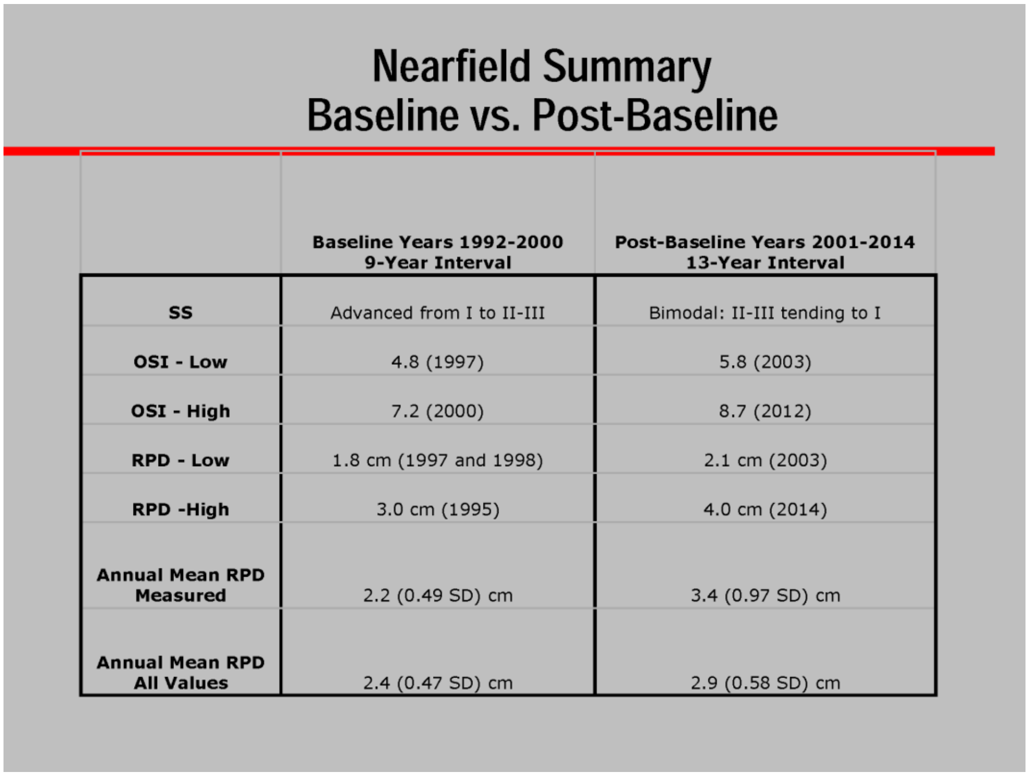


2014 Harbor and Bay Sediment Profile Imaging

Normandeau
Battelle

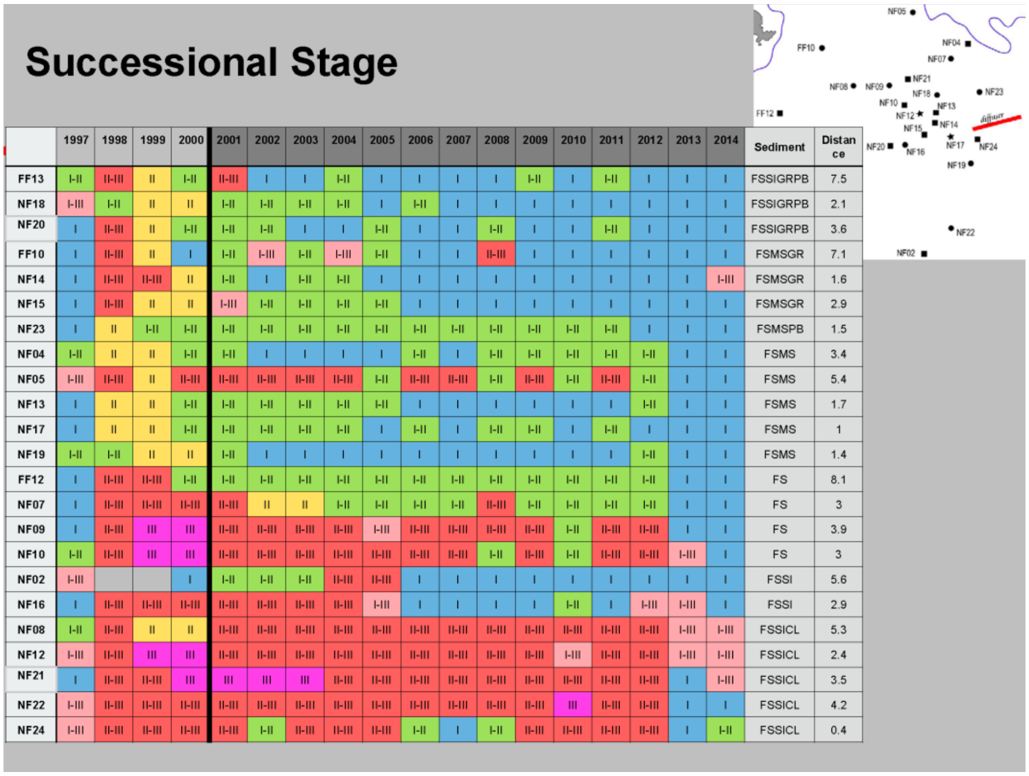
Robert Diaz et al.
R.J. Diaz & Daughters

R52 2014



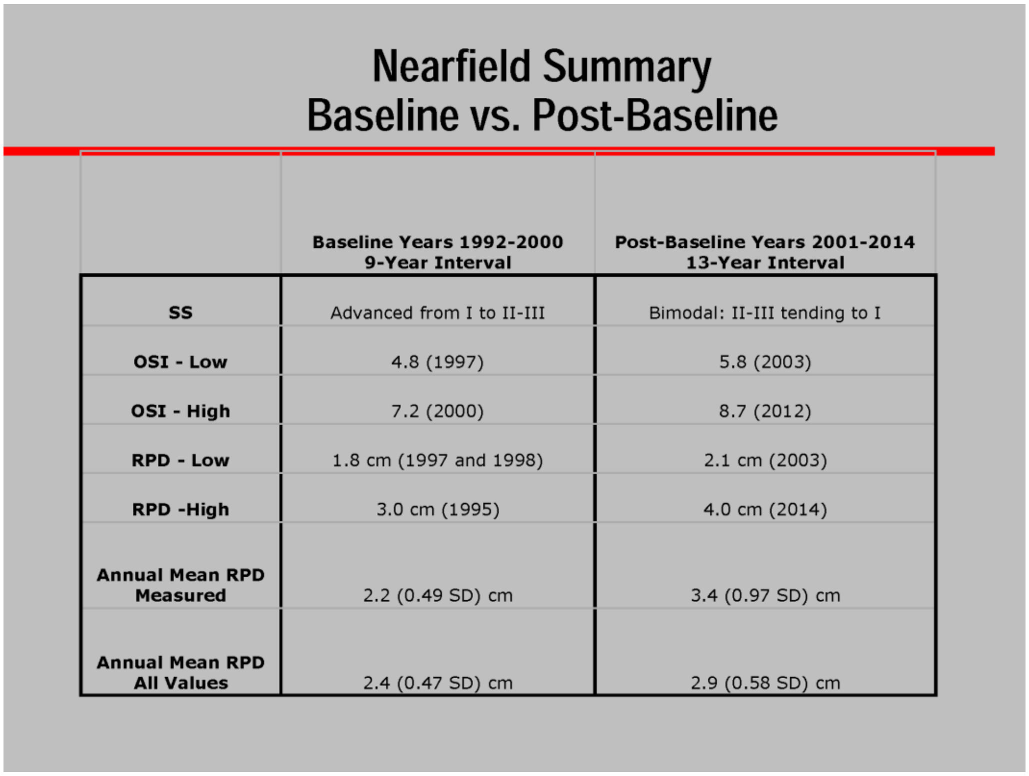
Nearfield Summary Baseline vs. Post-Baseline

	Baseline Years 1992-2000 9-Year Interval	**Post-Baseline Years 2001-2014 13-Year Interval**
SS	Advanced from I to II-III	Bimodal: II-III tending to I
OSI - Low	4.8 (1997)	5.8 (2003)
OSI - High	7.2 (2000)	8.7 (2012)
RPD - Low	1.8 cm (1997 and 1998)	2.1 cm (2003)
RPD -High	3.0 cm (1995)	4.0 cm (2014)
Annual Mean RPD Measured	2.2 (0.49 SD) cm	3.4 (0.97 SD) cm
Annual Mean RPD All Values	2.4 (0.47 SD) cm	2.9 (0.58 SD) cm



Successional Stage

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Sediment	Distance
FF13	I-II	II-III	II	I-II	II-III	I	I	I-II	I	I	I	I	I-II	I	I-II	I	I	I	FSSIGRPB	7.5
NF18	I-III	I-II	II	II	I-II	I-II	I-II	I-II	I	I-II	I	I	I	I	I	I	I	I	FSSIGRPB	2.1
NF20	I	II-III	II	I-II	I-II	I-II	I	I	I-II	I	I	I-II	I	I	I-II	I	I	I	FSSIGRPB	3.6
FF10	I	II-III	II	I	I-II	I-III	I-II	I-III	I-II	I	I	II-III	I	I	I	I	I	I	FSMSGR	7.1
NF14	I	II-III	II-III	II	I-II	I	I-II	I-II	I	I	I	I	I	I	I	I	I	I-III	FSMSGR	1.6
NF15	I	II-III	II	II	I-III	I-II	I-II	I-II	I-II	I	I	I	I	I	I	I	I	I	FSMSGR	2.9
NF23	I	II	I-II	I-II	I-II	I-II	I-II	I-II	I-II	I-II	I-II	I-II	I-II	I-II	I-II	I	I	I	FSMSPB	1.5
NF04	I-II	II	II	I-II	I-II	I	I	I	I	I-II	I	I-II	I-II	I-II	I-II	I-II	I	I	FSMS	3.4
NF05	I-III	II-III	II	II-III	II-III	II-III	II-III	II-III	I-II	II-III	II-III	I-II	II-III	I-II	II-III	I-II	I	I	FSMS	5.4
NF13	I	II	II	I-II	I-II	I-II	I-II	I-II	I-II	I	I	I	I	I	I	I-II	I	I	FSMS	1.7
NF17	I	II	II	I-II	I-II	I-II	I-II	I-II	I	I-II	I	I-II	I-II	I	I-II	I	I	I	FSMS	1
NF19	I-II	I-II	II	II	I-II	I	I	I	I	I	I	I	I	I	I	I-II	I	I	FSMS	1.4
FF12	I	II-III	II-III	I-II	I-II	I-II	I-II	I-II	I-II	I-II	I-II	I-II	I-II	I-II	I-II	I-II	I	I	FS	8.1
NF07	I	II-III	II-III	II-III	II-III	II	II	I-II	I-II	I-II	I-II	II-III	I-II	I-II	I-II	I-II	I	I	FS	3
NF09	I	II-III	III	III	II-III	II-III	II-III	II-III	I-III	II-III	II-III	II-III	II-III	I-II	II-III	II-III	I	I	FS	3.9
NF10	I-II	II-III	III	III	II-III	II-III	II-III	II-III	II-III	II-III	II-III	I-II	II-III	I-II	II-III	II-III	I-III	I	FS	3
NF02	I-III			I	I-II	I-II	I-II	II-III	II-III	I	I	I	I	I	I	I	I	I	FSSI	5.6
NF16	I	II-III	II-III	II-III	II-III	II-III	II-III	II-III	I-III	I	I	I	I	I-II	I	I-III	I-III	I	FSSI	2.9
NF08	I-II	II-III	II	II	II-III	II-III	II-III	II-III	II-III	II-III	II-III	II-III	II-III	II-III	II-III	II-III	I-III	I-III	FSSICL	5.3
NF12	I-III	II-III	III	III	II-III	II-III	II-III	II-III	II-III	II-III	II-III	II-III	II-III	I-III	II-III	II-III	I-III	I-III	FSSICL	2.4
NF21	I	II-III	II-III	III	III	III	III	II-III	II-III	II-III	II-III	II-III	II-III	II-III	II-III	II-III	I	I-III	FSSICL	3.5
NF22	I-III	II-III	II-III	II-III	II-III	II-III	II-III	II-III	II-III	II-III	II-III	II-III	II-III	III	II-III	II-III	I	I	FSSICL	4.2
NF24	I-III	II-III	II-III	II-III	II-III	I-II	II-III	II-III	II-III	I-II	I	I-II	II-III	II-III	II-III	II-III	I	I-II	FSSICL	0.4



Nearfield Summary
Baseline vs. Post-Baseline

	Baseline Years 1992-2000 9-Year Interval	**Post-Baseline Years 2001-2014 13-Year Interval**
SS	Advanced from I to II-III	Bimodal: II-III tending to I
OSI - Low	4.8 (1997)	5.8 (2003)
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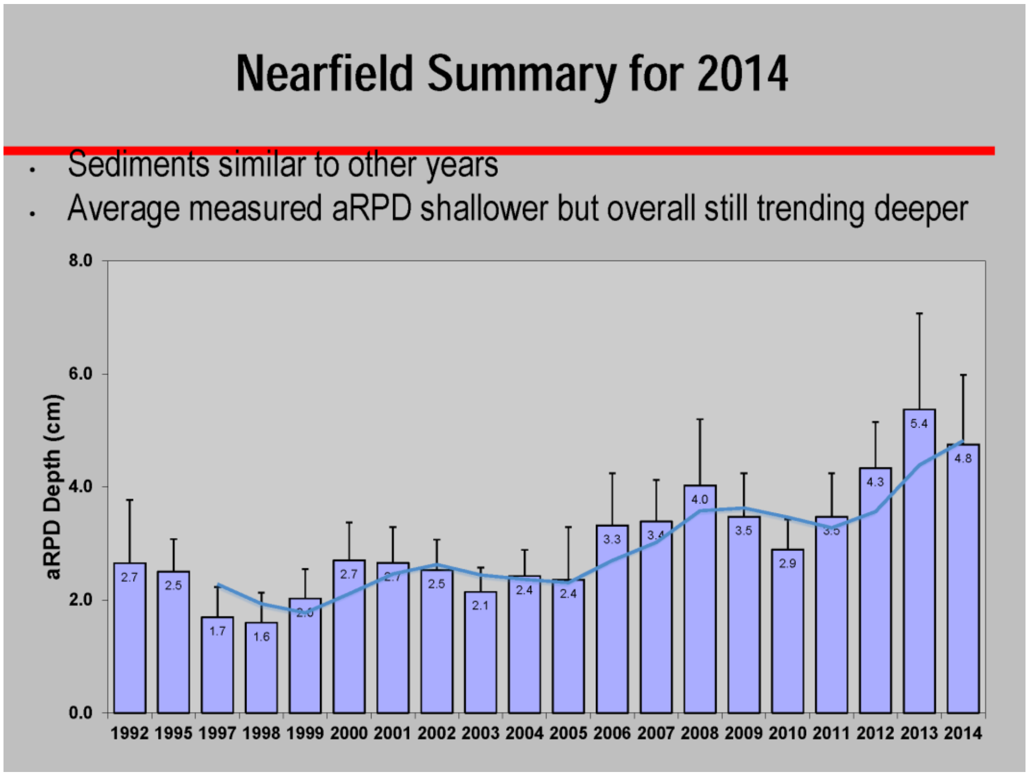
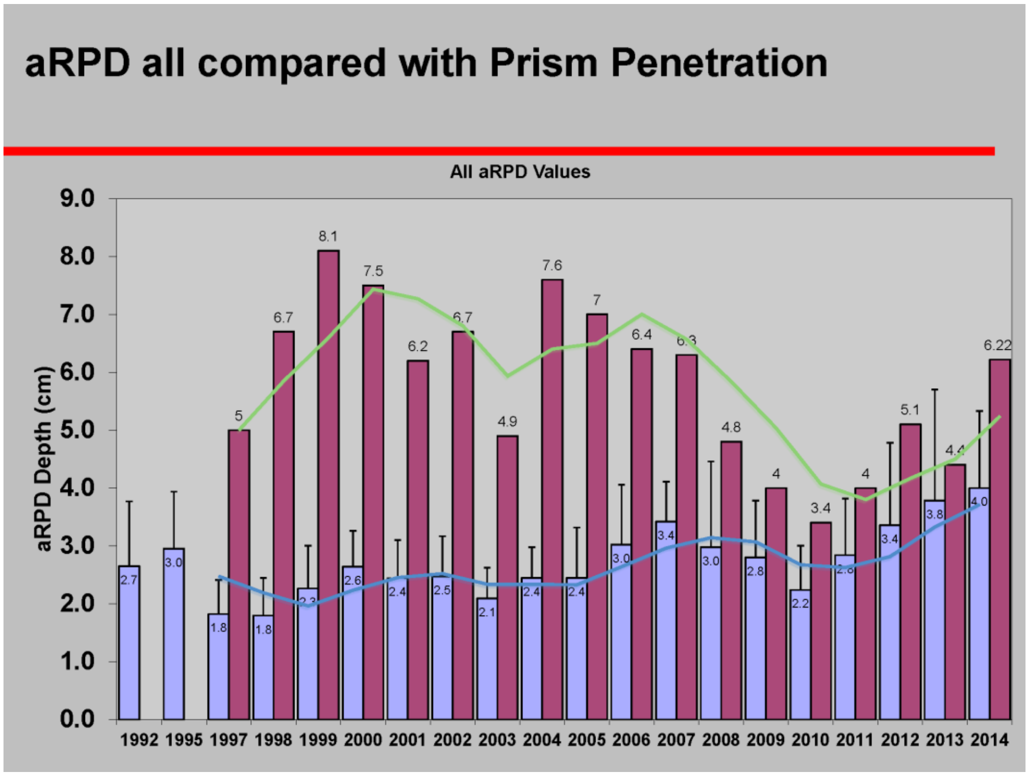
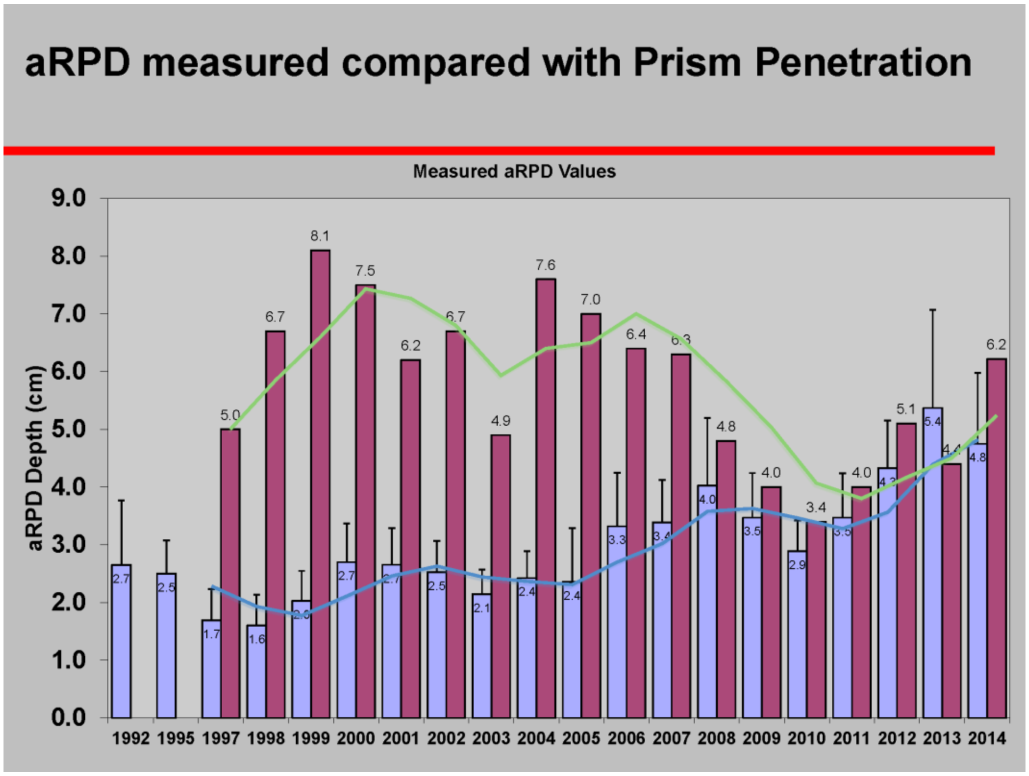


Nearfield Summary for 2014

- Sediments similar to other years
- Average measured aRPD shallower but overall still trending deeper

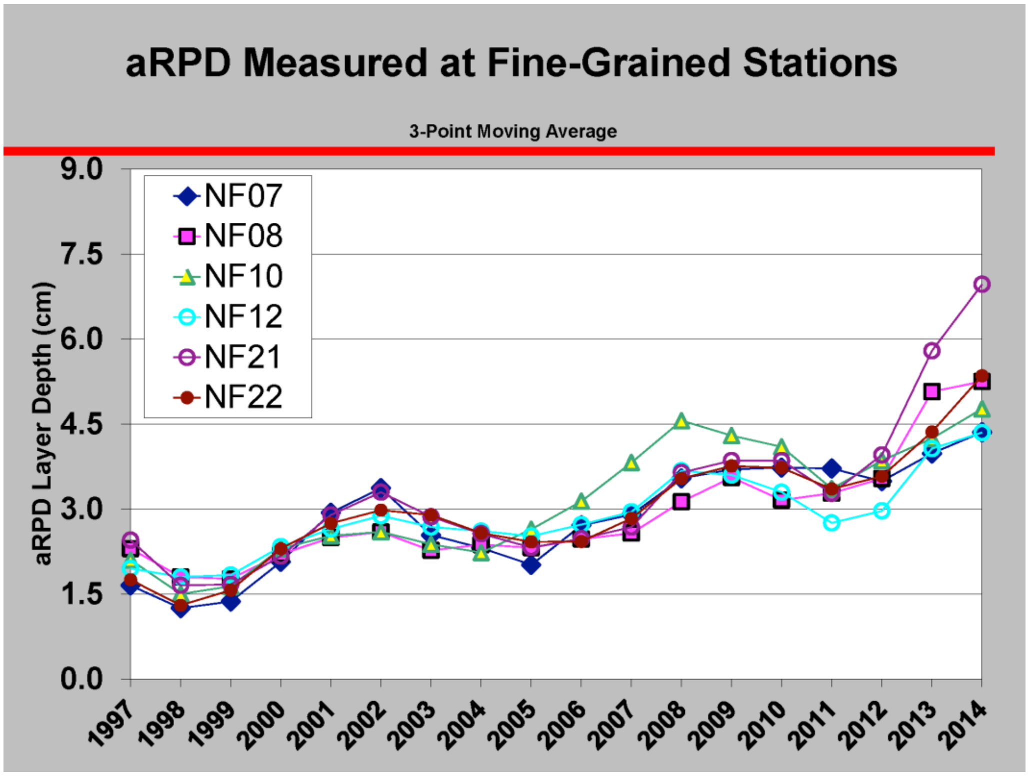


aRPD all compared with Prism Penetration



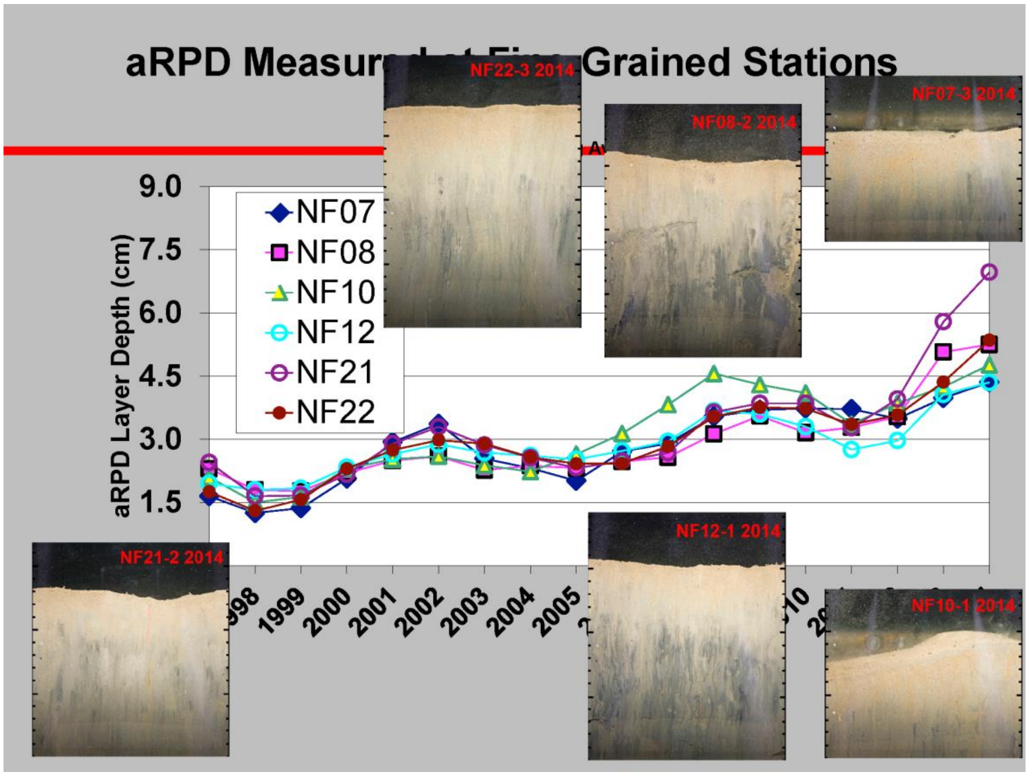
aRPD measured compared with Prism Penetration

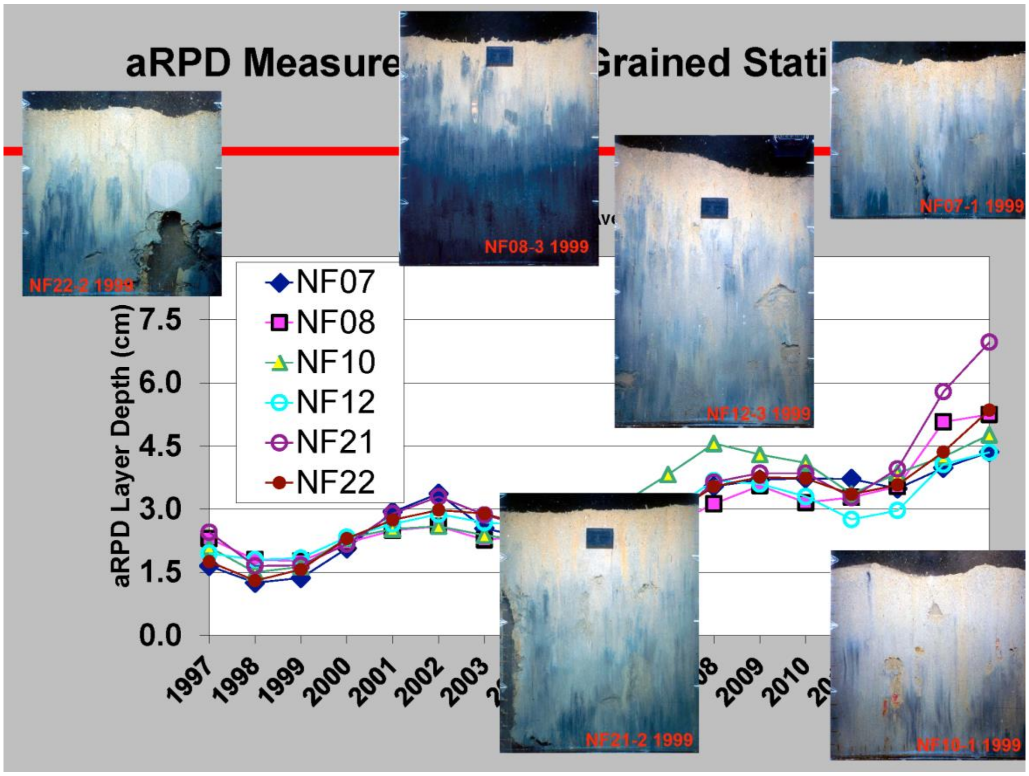
Measured aRPD Values

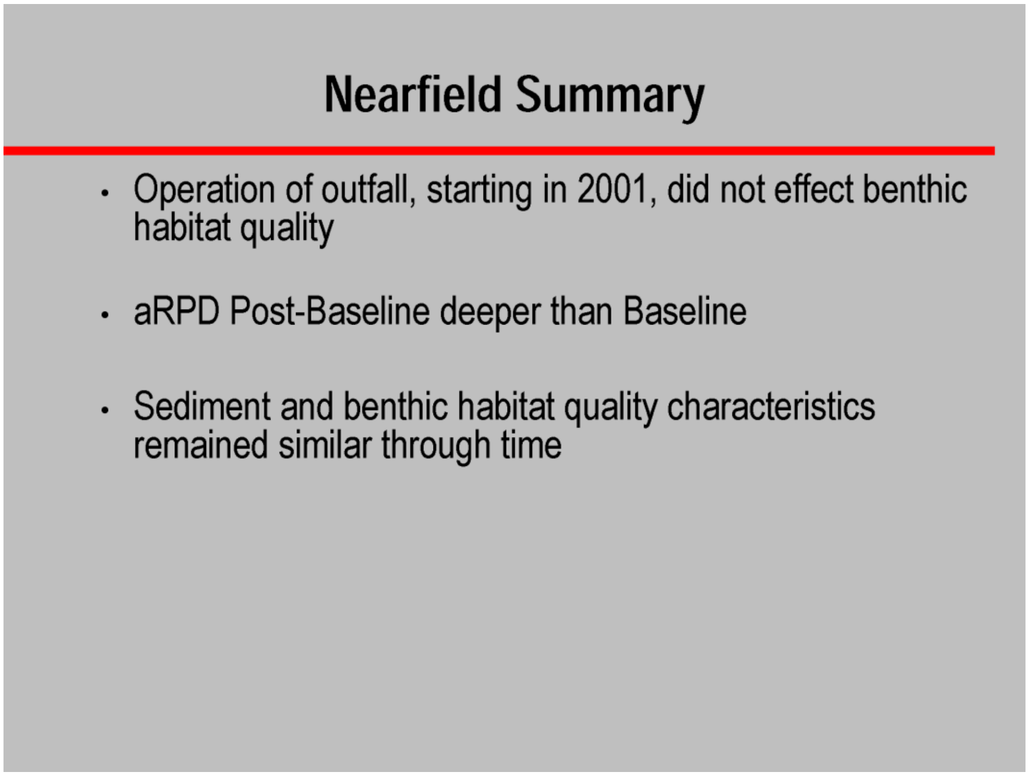


aRPD Measured at Fine-Grained Stations

3-Point Moving Average

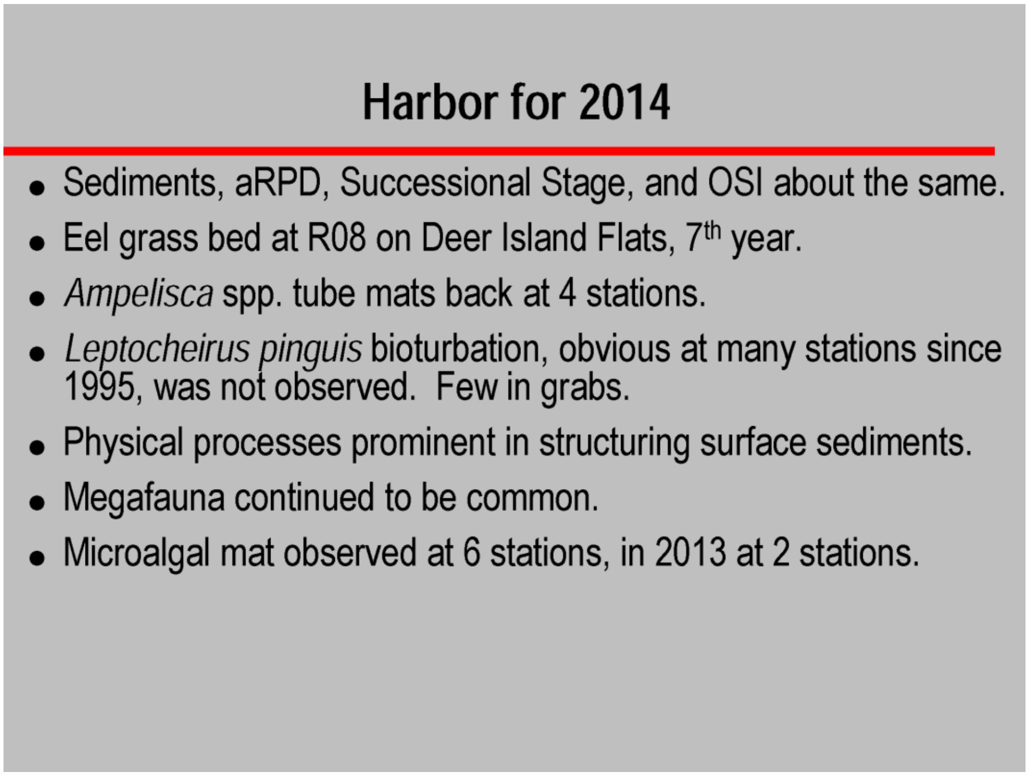

aRPD Measur
Grained Stations
NF22-3 2014
NF08-2 2014
NF07-3 2014
Av
9.0
7.5
6.0
4.5
3.0
1.5
aRPD Layer Depth (cm)
NF07
NF08
NF10
NF12
NF21
NF22
NF21-2 2014
NF12-1 2014
NF10-1 2014
1998
1999
2000
2001
2002
2003
2004
2005
10
20


aRPD Measure
Grained Stati
NF22-2 1999
NF08-3 1999
NF07-1 1999
NF12-3 1999
Av
7.5
6.0
4.5
3.0
1.5
0.0
aRPD Layer Depth (cm)
NF07
NF08
NF10
NF12
NF21
NF22
1997
1998
1999
2000
2001
2002
2003
08
2009
2010
20
NF21-2 1999
NF10-1 1999



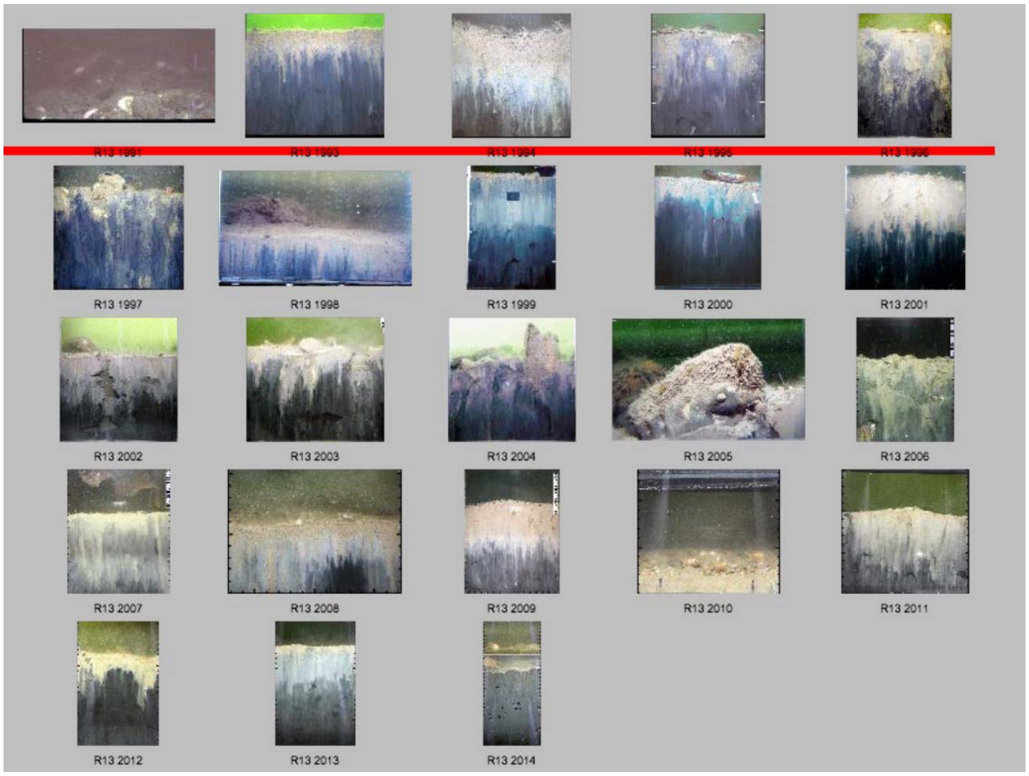
Nearfield Summary

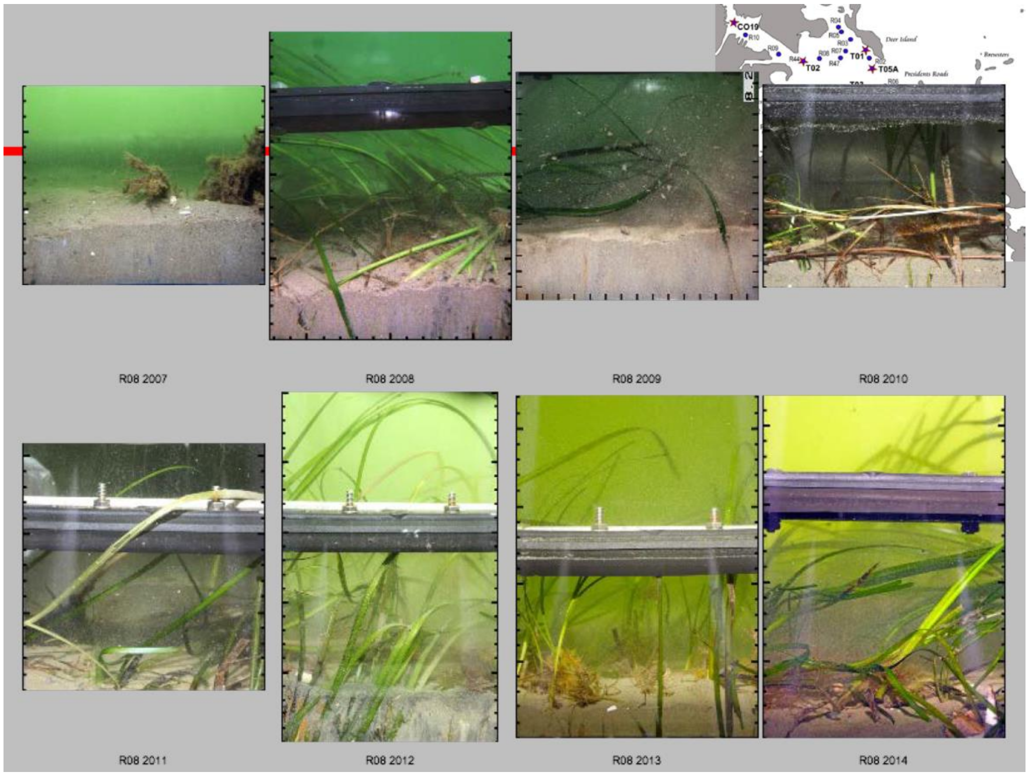
- Operation of outfall, starting in 2001, did not effect benthic habitat quality
- aRPD Post-Baseline deeper than Baseline
- Sediment and benthic habitat quality characteristics remained similar through time

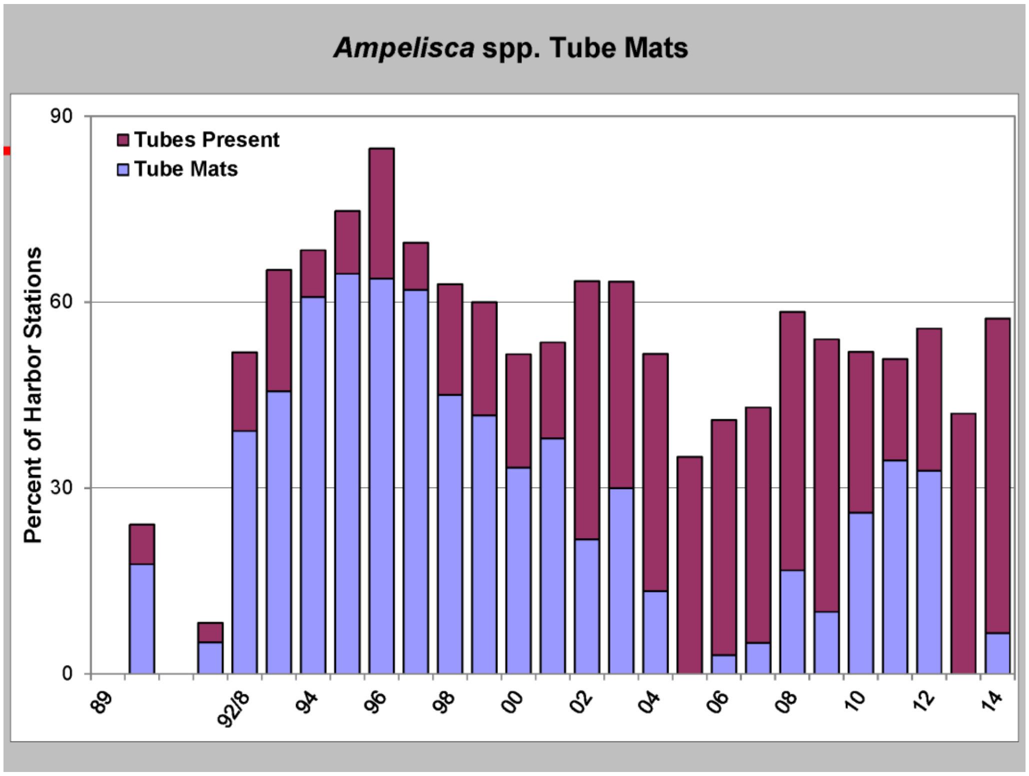


Harbor for 2014

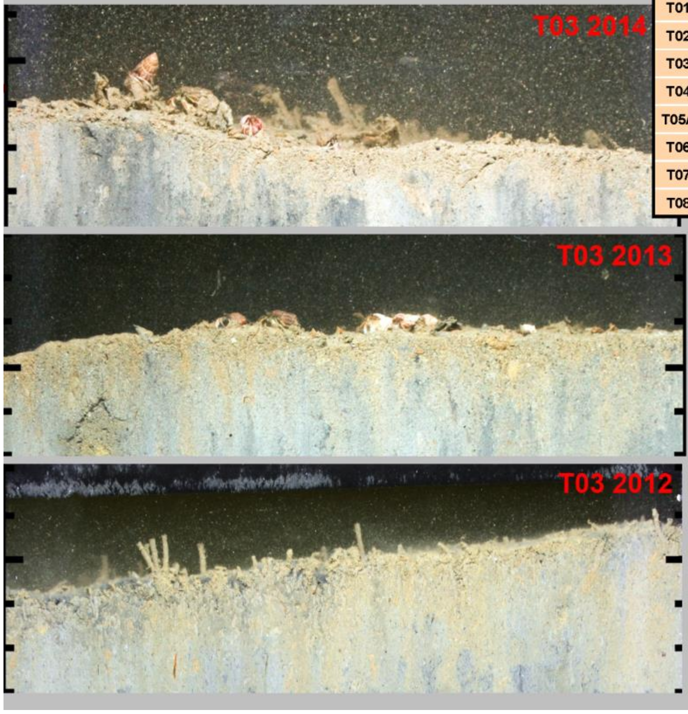
- Sediments, aRPD, Successional Stage, and OSI about the same.
- Eel grass bed at R08 on Deer Island Flats, 7th year.
- *Ampelisca* spp. tube mats back at 4 stations.
- *Leptocheirus pinguis* bioturbation, obvious at many stations since 1995, was not observed. Few in grabs.
- Physical processes prominent in structuring surface sediments.
- Megafauna continued to be common.
- Microalgal mat observed at 6 stations, in 2013 at 2 stations.


R13 1991
R13 1993
R13 1994
R13 1995
R13 1996
R13 1997
R13 1998
R13 1999
R13 2000
R13 2001
R13 2002
R13 2003
R13 2004
R13 2005
R13 2006
R13 2007
R13 2008
R13 2009
R13 2010
R13 2011
R13 2012
R13 2013
R13 2014

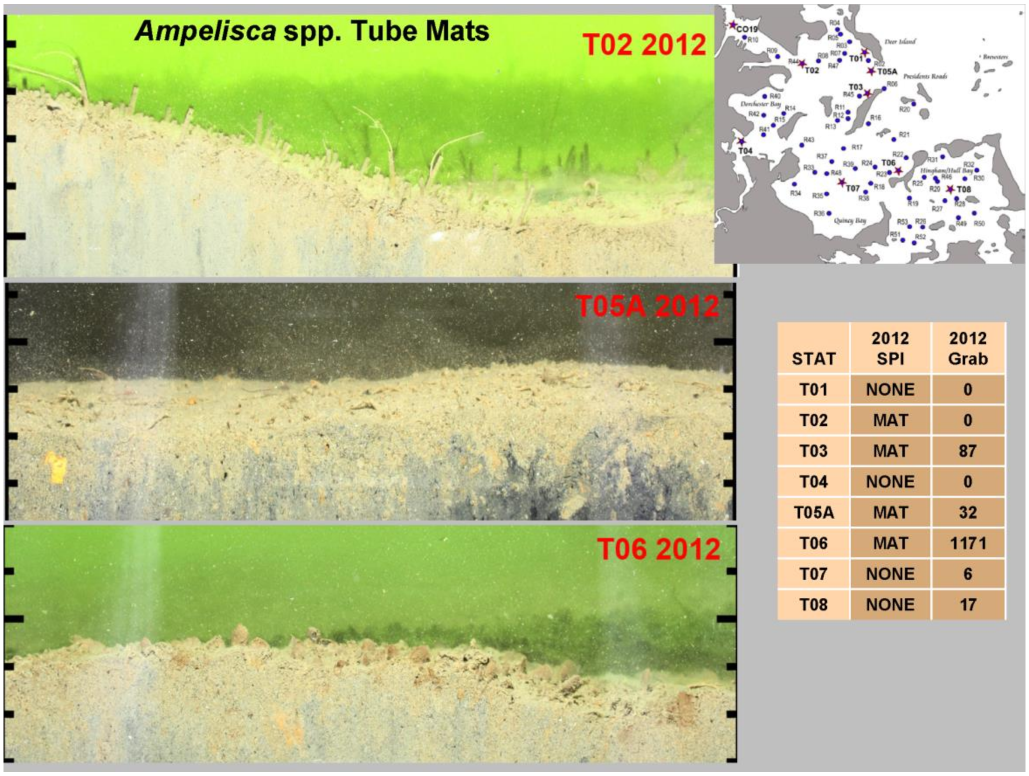

C019
R10
R04
R09
R05
R03
R08
R07
R02
R46
R47
T01
T02
T05A
R06
Deer Island
Brewsters
Presidents Roads
B-2
R08 2007
R08 2008
R08 2009
R08 2010
R08 2011
R08 2012
R08 2013
R08 2014



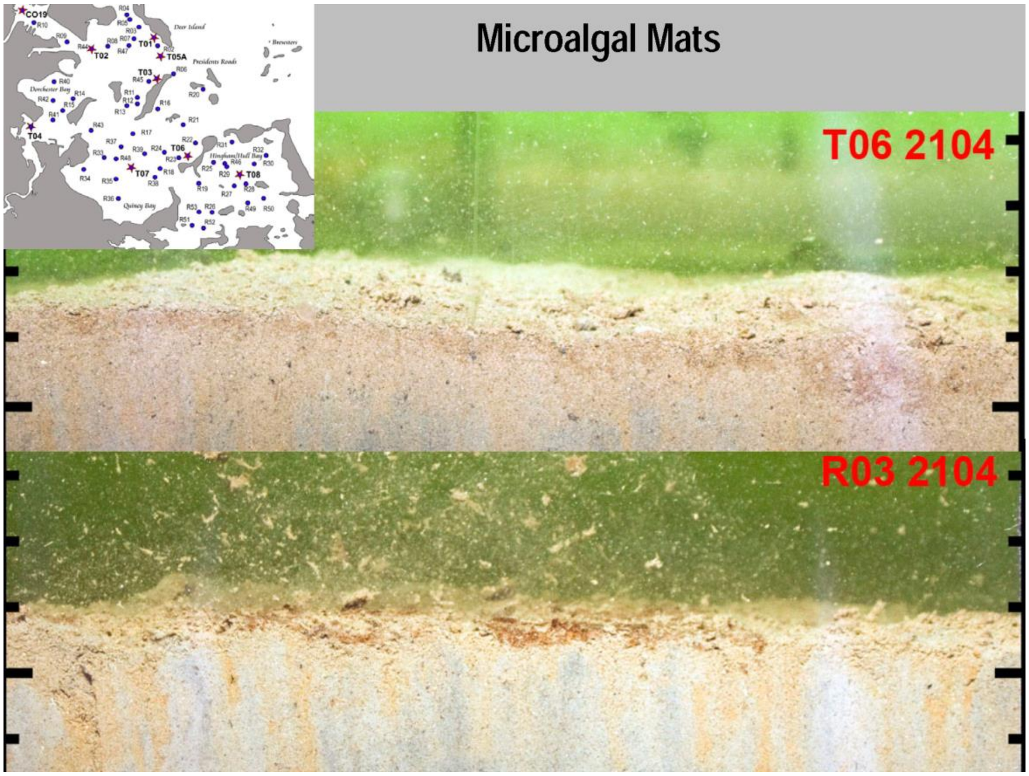
Ampelisca spp. Tube Mats

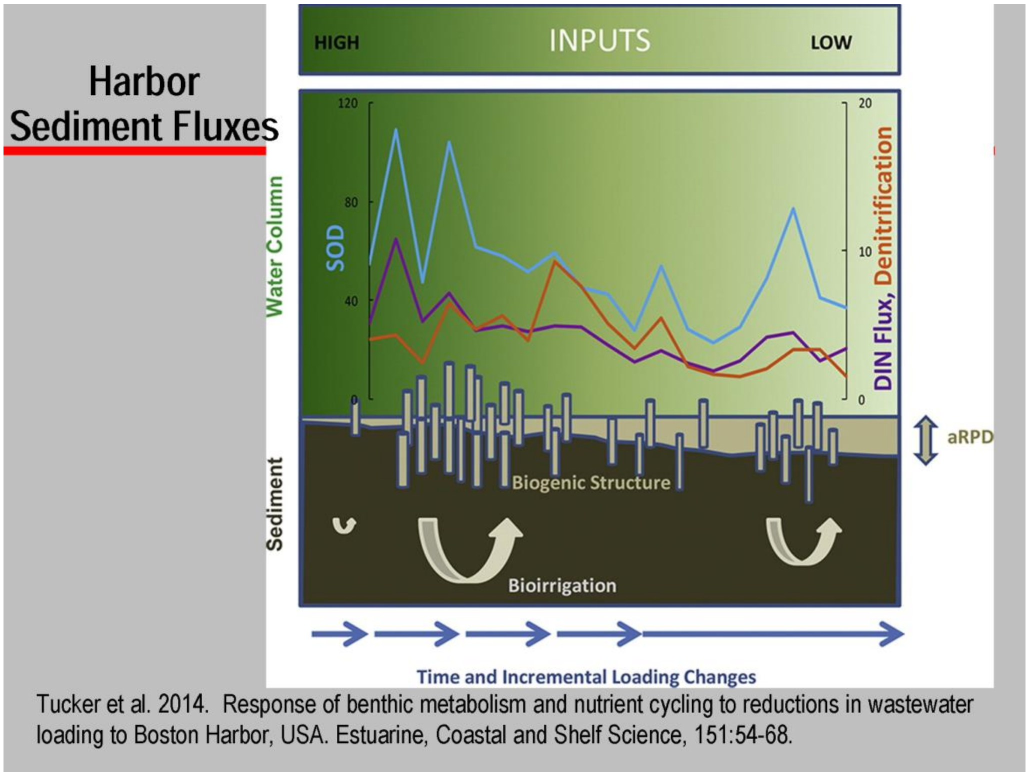


STAT	2012 SPI	2012 Grab	2013 SPI	2013 Grab	2014 SPI	2014 Grab
T01	NONE	0	NONE	0	NONE	0
T02	MAT	0	MANY	1	FEW	0
T03	MAT	87	MANY	141	MAT	498
T04	NONE	0	NONE	0	NONE	0
T05A	MAT	32	MANY	5	NONE	4
T06	MAT	1171	SOME	28	SOME	20
T07	NONE	6	NONE	0	NONE	0
T08	NONE	17	NONE	5	NONE	7



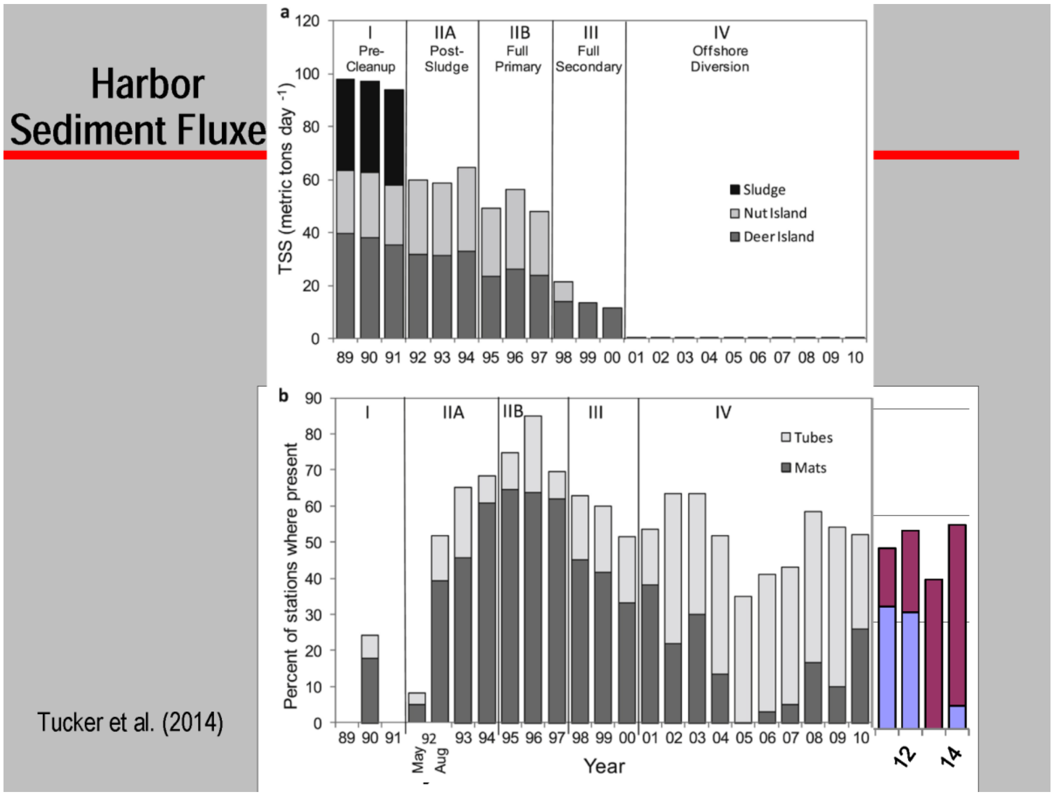
STAT	2012 SPI	2012 Grab
T01	NONE	0
T02	MAT	0
T03	MAT	87
T04	NONE	0
T05A	MAT	32
T06	MAT	1171
T07	NONE	6
T08	NONE	17





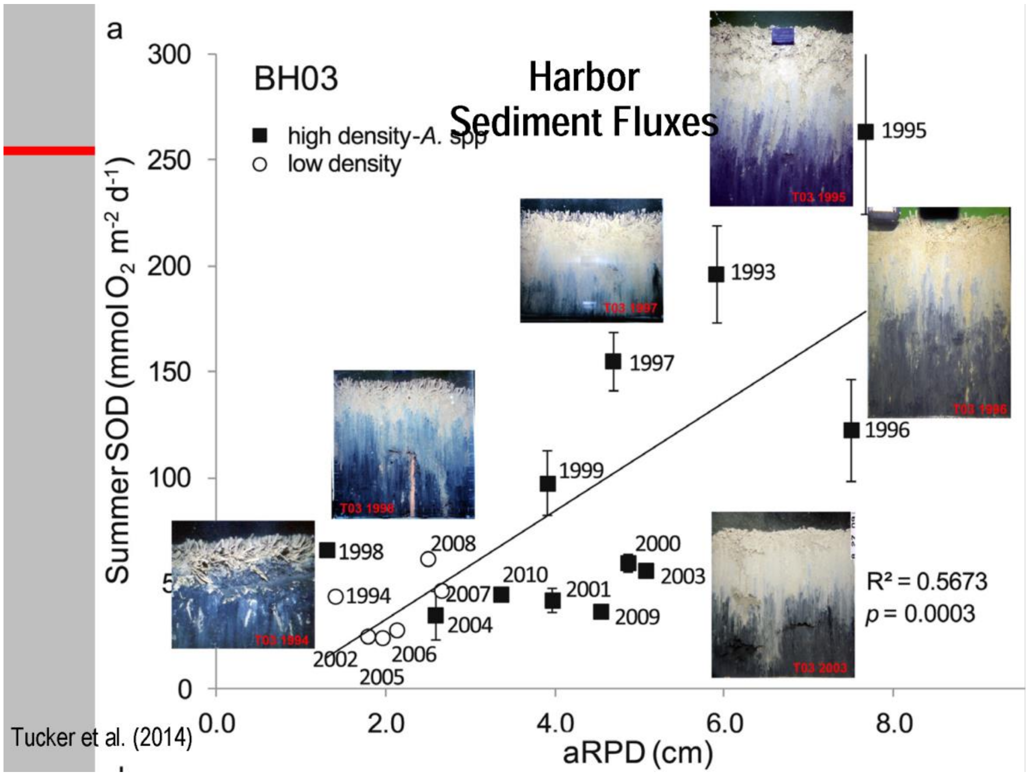
Harbor Sediment Fluxes

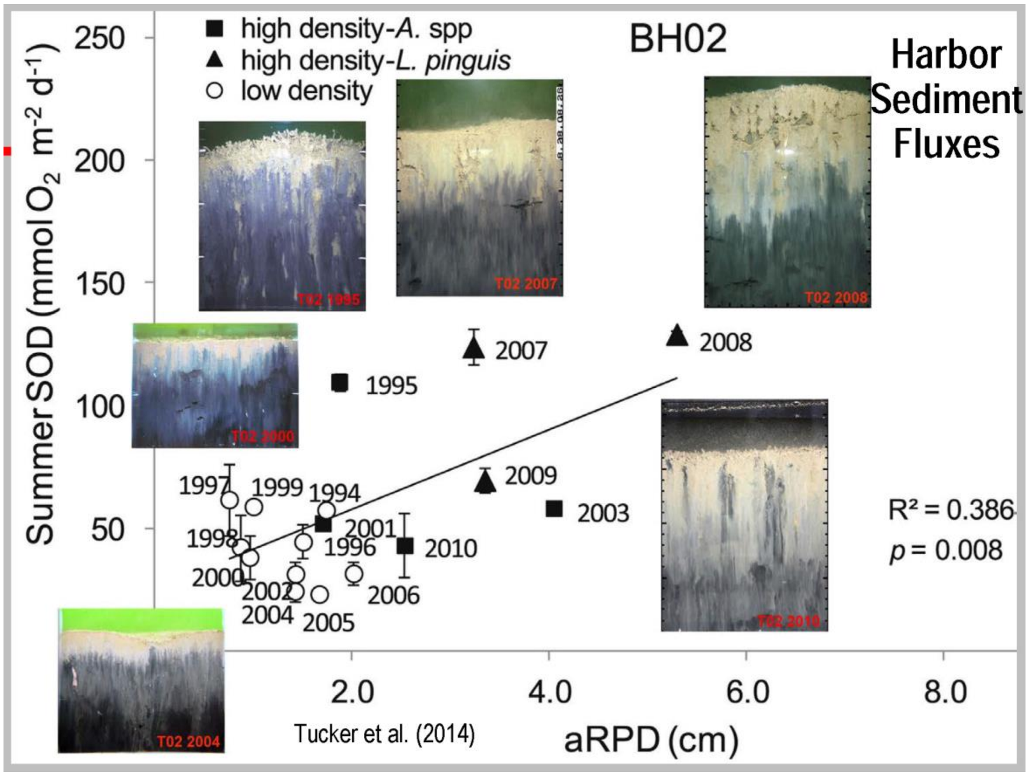
Tucker et al. 2014. Response of benthic metabolism and nutrient cycling to reductions in wastewater loading to Boston Harbor, USA. Estuarine, Coastal and Shelf Science, 151:54-68.



Harbor Sediment Fluxe

Tucker et al. (2014)


a
BH03
Harbor Sediment Fluxes
■ high density-A. spp
○ low density
Summer SOD (mmol O2 m-2 d-1)
300
250
200
150
100
5
0
0.0
2.0
4.0
6.0
8.0
aRPD (cm)
1995
1993
1997
1996
1999
1998
2008
1994
2010
2007
2004
2000
2003
2001
2009
2002
2005
2006
T03 1995
T03 1997
T03 1998
T03 1994
T03 1996
T03 2003
R² = 0.5673
p = 0.0003
Tucker et al. (2014)

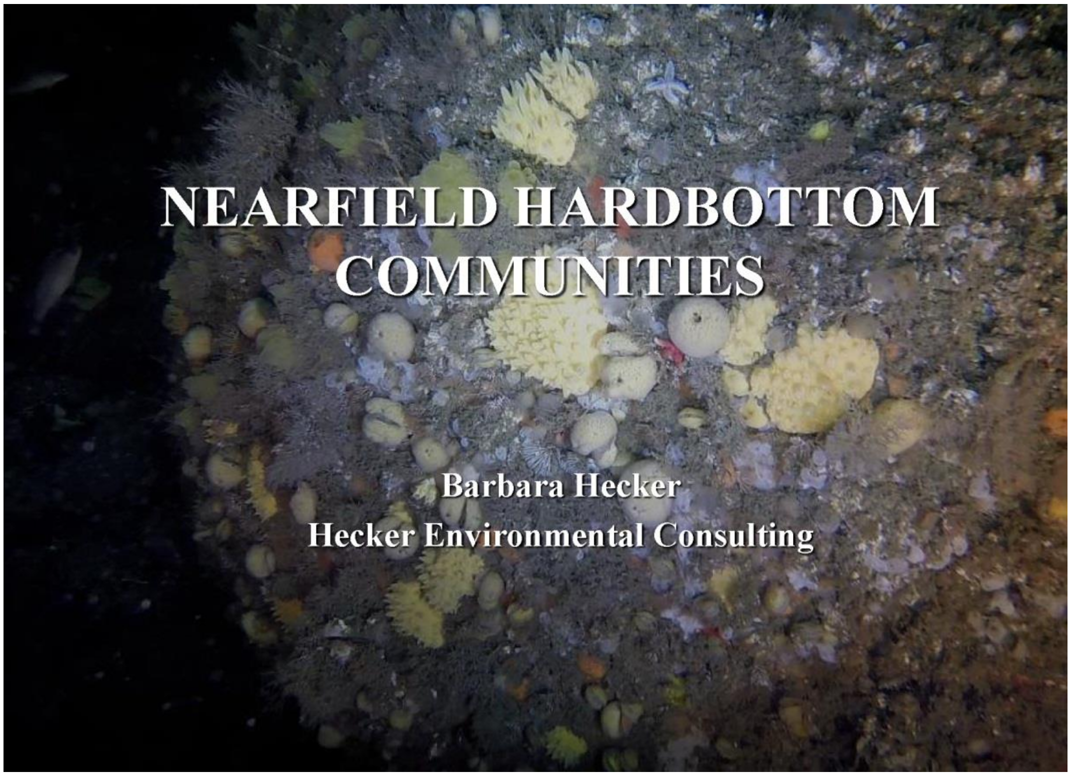

■ high density-A. spp
▲ high density-L. pinguis
○ low density
BH02
Harbor Sediment Fluxes
Summer SOD (mmol O2 m-2 d-1)
250
200
150
100
50
T02 1995
T02 2007
T02 2008
T02 2000
T02 2010
T02 2004
2007
2008
1995
2009
2003
1997
1999
1994
1998
2001
1996
2010
2000
2002
2006
2004
2005
R² = 0.386
p = 0.008
2.0
4.0
6.0
8.0
Tucker et al. (2014)
aRPD (cm)

Summary for Harbor

Benthic habitat quality for infauna has been about the same for last several years. Initial improvements in 1990s were related to changes in discharge and treatment.

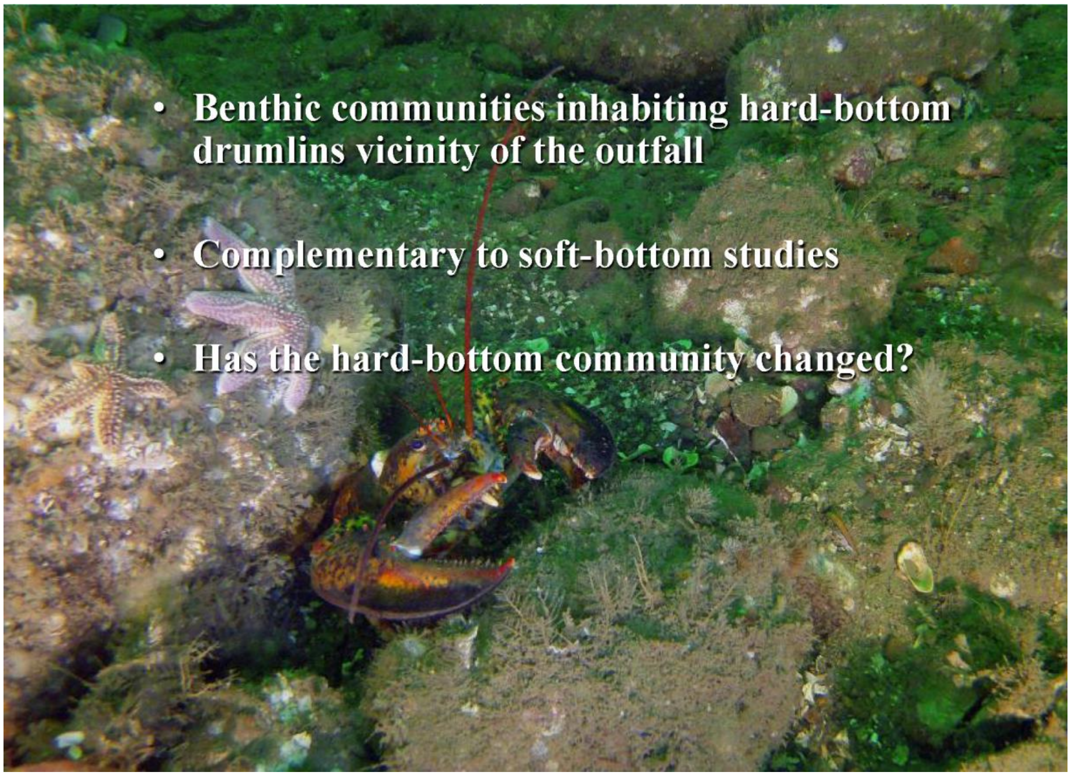
Inner to outer harbor gradient remains prominent and related to hydrodynamics.

Appendix A4. 2014 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?

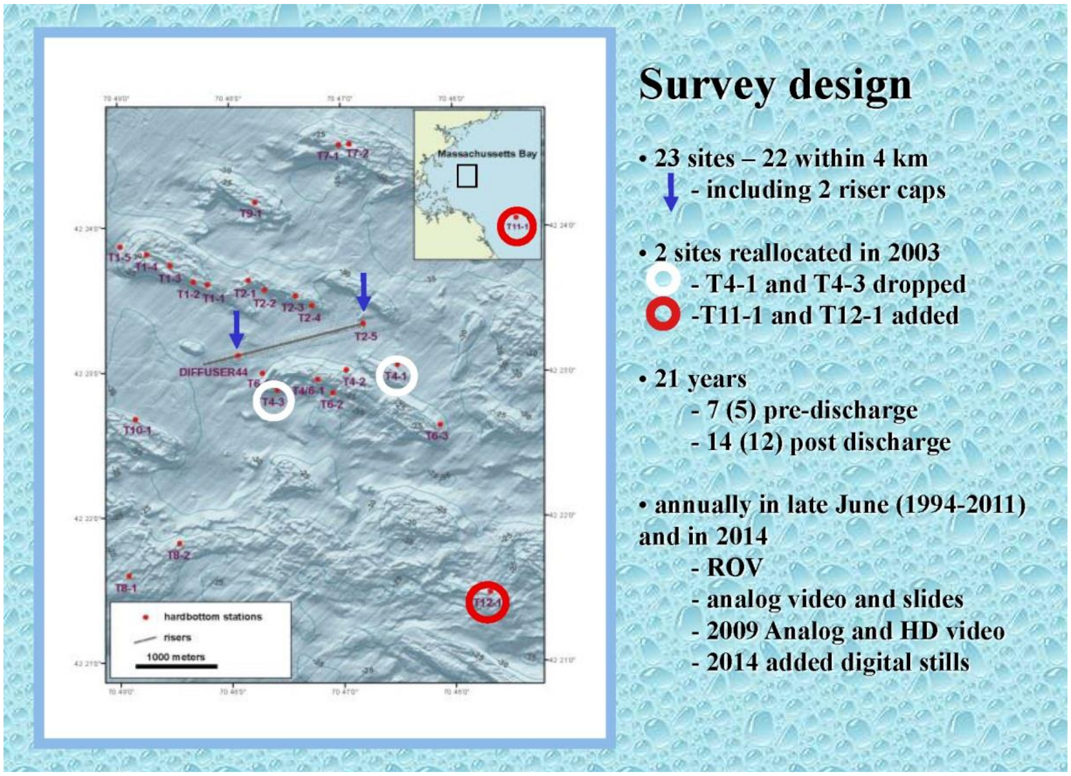
Acknowledgements

Field and Lab

Normandeau - Debbie Rutecki
Ocean Eye - Bill Campbell
Black Laser Learning - Vince Capone
CR Environmental - Chip Ryther, Eli Peron, Adrianna Ortiz, Joshua Goodwin
Boat Kathleen A. Mirarchi, Inc. - Frank Mirarchi
Battelle - Jeannine Boyle, Robert Mandiville
SAIC/ENSR/AECOM - Brigitte Hilbig, Pam Neubert, Paula Winchell

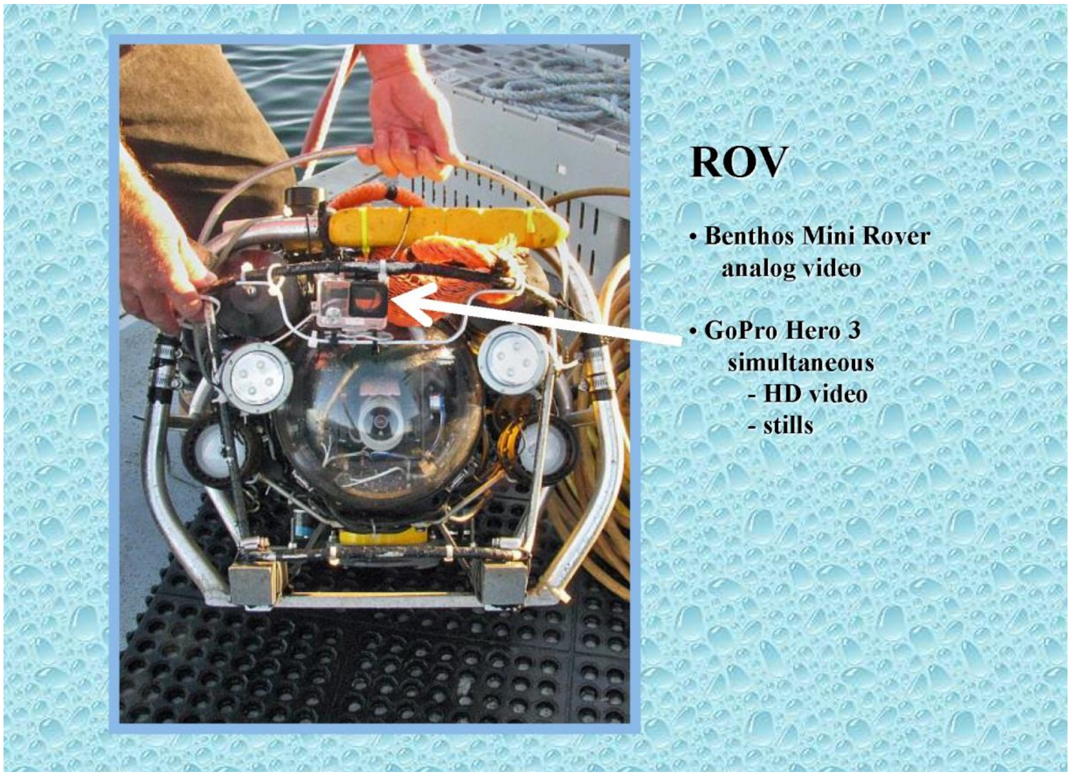
Other

MWRA - Ken Keay
Normandeau - Ann Pembroke, Eric Nestler
SAIC/ENSR/AECOM - James Blake, Nancy Maciolek
Battelle - Carlton Hunt, Ellie Baptiste-Carpenter



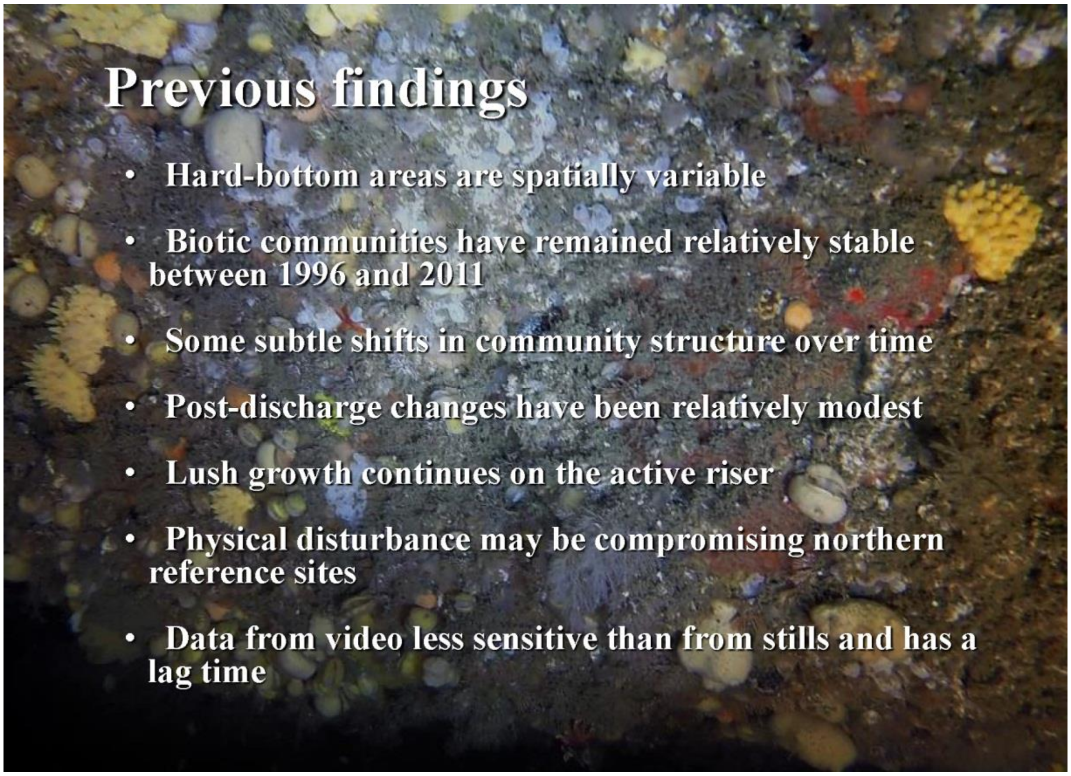
Survey design

- 23 sites – 22 within 4 km
  ↓ - including 2 riser caps
- 2 sites reallocated in 2003
  ○ - T4-1 and T4-3 dropped
  ⭕ -T11-1 and T12-1 added
- 21 years
  - 7 (5) pre-discharge
  - 14 (12) post discharge
- annually in late June (1994-2011) and in 2014
  - ROV
  - analog video and slides
  - 2009 Analog and HD video
  - 2014 added digital stills



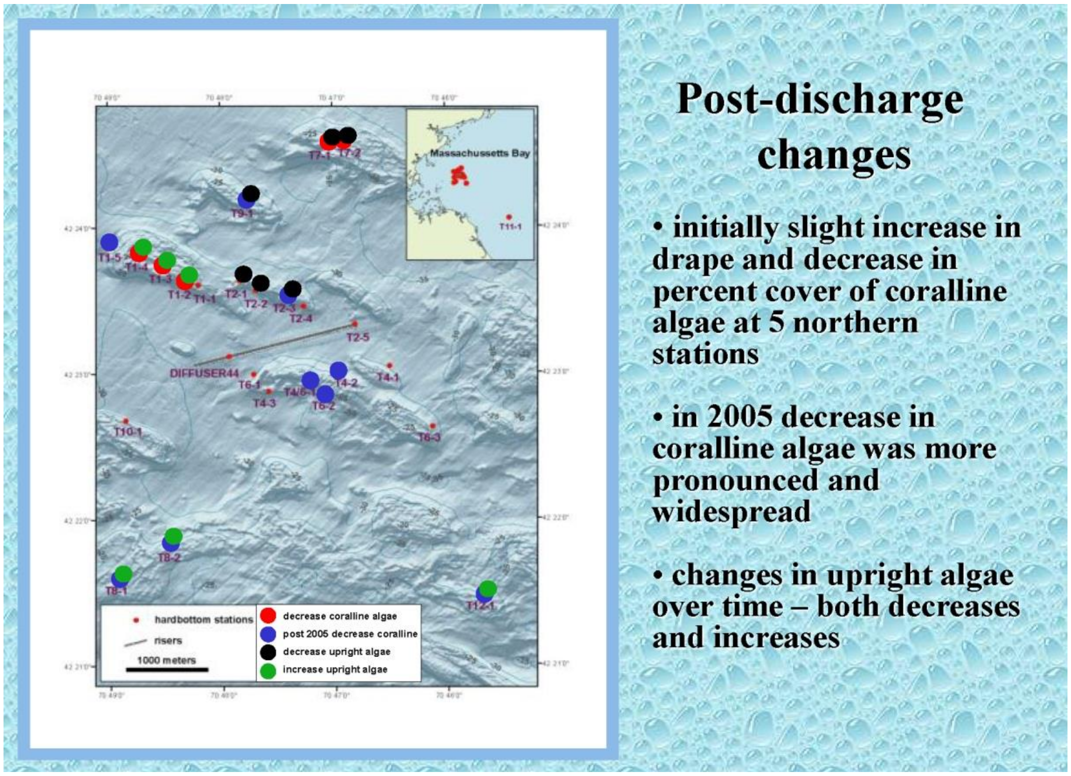
ROV

- Benthos Mini Rover analog video
- GoPro Hero 3 simultaneous
  - HD video
  - stills



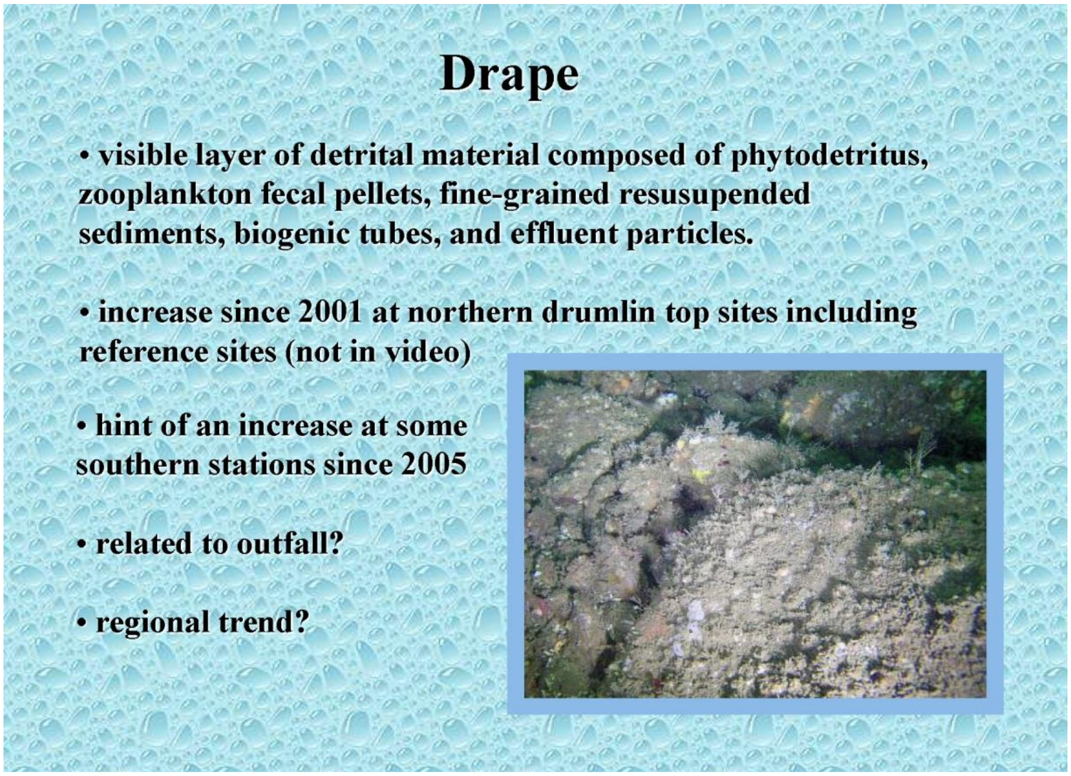
Previous findings

- Hard-bottom areas are spatially variable
- Biotic communities have remained relatively stable between 1996 and 2011
- 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

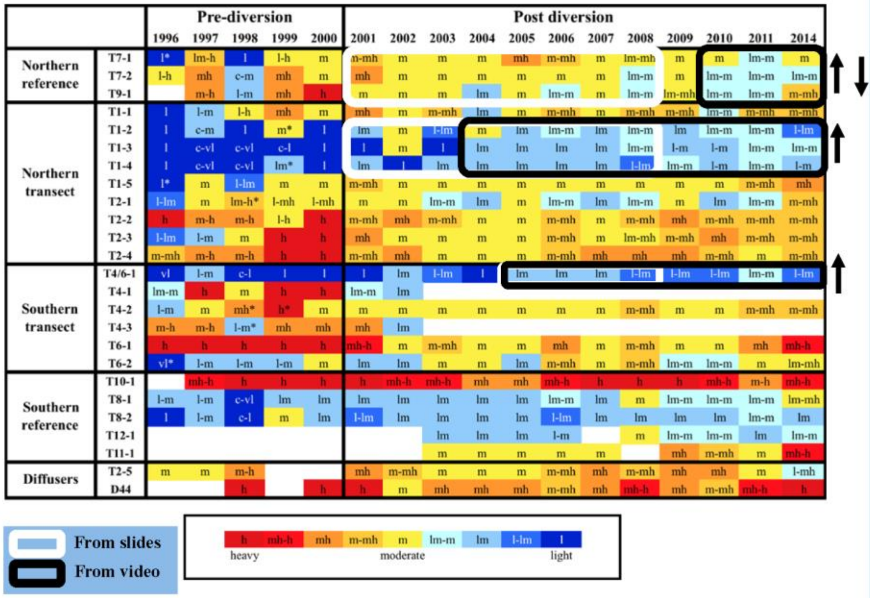
- initially slight increase in drape and decrease in percent cover of coralline algae at 5 northern stations
- in 2005 decrease in coralline algae was more pronounced and widespread
- changes in upright algae over time – both decreases and increases



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?

Drape



		Pre-diversion					Post diversion											
		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2014
Northern reference	T7-1	l*	lm-h	l	l-h	m	m-mh	m	m	m	mh	m-mh	m	lm-mh	m	m	lm-m	m
	T7-2	l-h	mh	c-m	mh	m	mh	m	m	m	m	m	m	lm-m	m	lm-m	lm-m	lm-m
	T9-1		m-h	l-m	mh	h	m	m	m	lm	m	lm-m	m	lm-m	lm-mh	lm-m	lm-m	m-mh
Northern transect	T1-1	l	l-m	l-h	mh	m	mh	m	m-mh	lm	m	m-mh	m	m-mh	m-mh	lm-m	m-mh	m-mh
	T1-2	l	c-m	l	m*	l	lm	m	l-lm	m	lm	lm-m	lm	lm-m	lm	lm-m	lm-m	l-lm
	T1-3	l	c-vl	c-vl	c-l	l	l	m	l	lm	lm	lm	lm	lm-m	l-m	l-m	lm-m	lm-m
	T1-4	l	c-vl	c-vl	lm*	l	lm	l	lm	lm	lm	lm	lm	l-lm	lm-m	l-m	lm-m	l-m
	T1-5	l*	m	l-lm	m	m	m-mh	m	m	m	m	m	m	m	m	m	m-mh	mh
	T2-1	l-lm	m	lm-h*	l-mh	l-mh	m	m	lm-m	lm	m	lm-m	lm	lm-m	m	lm	lm-m	m-mh
	T2-2	h	m-h	m-h	l-h	h	m-mh	mh	m-mh	m	m	m-mh	m	m-mh	mh	m-mh	m-mh	m-mh
	T2-3	l-lm	l-m	m	h	h	mh	m	m	m	m	m-mh	m	lm-mh	m-mh	mh	m-mh	m-mh
	T2-4	m-mh	m-h	m-h	h	h	m-mh	mh	m	m	m	m-mh	mh	mh	mh	m-mh	m	m-mh
Southern transect	T4/6-1	vl	l-m	c-l	l	l	l	lm	l-lm	l	lm	lm	lm	l-lm	l-lm	l-lm	lm-m	l-lm
	T4-1	lm-m	h	m	h	h	lm-m	lm										
	T4-2	l-m	m	mh*	h*	m	m	m	m	m	m	m	m	m-mh	m	m	m-mh	m-mh
	T4-3	m-h	m-h	l-m*	mh	mh	mh	lm										
	T6-1	h	h	h	h	h	mh-h	m	m-mh	m	m	mh	m	m-mh	m	m	mh	mh-h
	T6-2	vl*	l-m	l-m	l-m	m	lm	lm	m	m	lm	m-mh	m	m-mh	lm-m	lm-m	m	lm-mh
Southern reference	T10-1		mh-h	h	h	h	h	mh-h	mh-h	mh	mh	mh-h	h	h	h	mh-h	m-h	mh-h
	T8-1	l-m	l-m	c-vl	lm	lm	lm	lm	lm	lm	lm	lm-m	lm	m	lm-m	lm-m	lm-m	lm-mh
	T8-2	l	l-m	c-l	m	lm	l-lm	lm	lm	lm	lm	l-lm	lm	lm	lm	lm	lm-m	lm
	T12-1								lm	lm	lm	l-m		m	lm-m	lm-m	lm	lm-m
	T11-1								m	m	m	m	m		mh	m-mh	m	mh-h
Diffusers	T2-5	m	m	m-h			mh	m-mh	m	m	m	m-mh	mh	m-mh	mh	mh	m	l-mh
	D44			h		h	h	m	mh	mh	mh	m-mh	mh	mh-h	mh	m-mh	mh-h	h

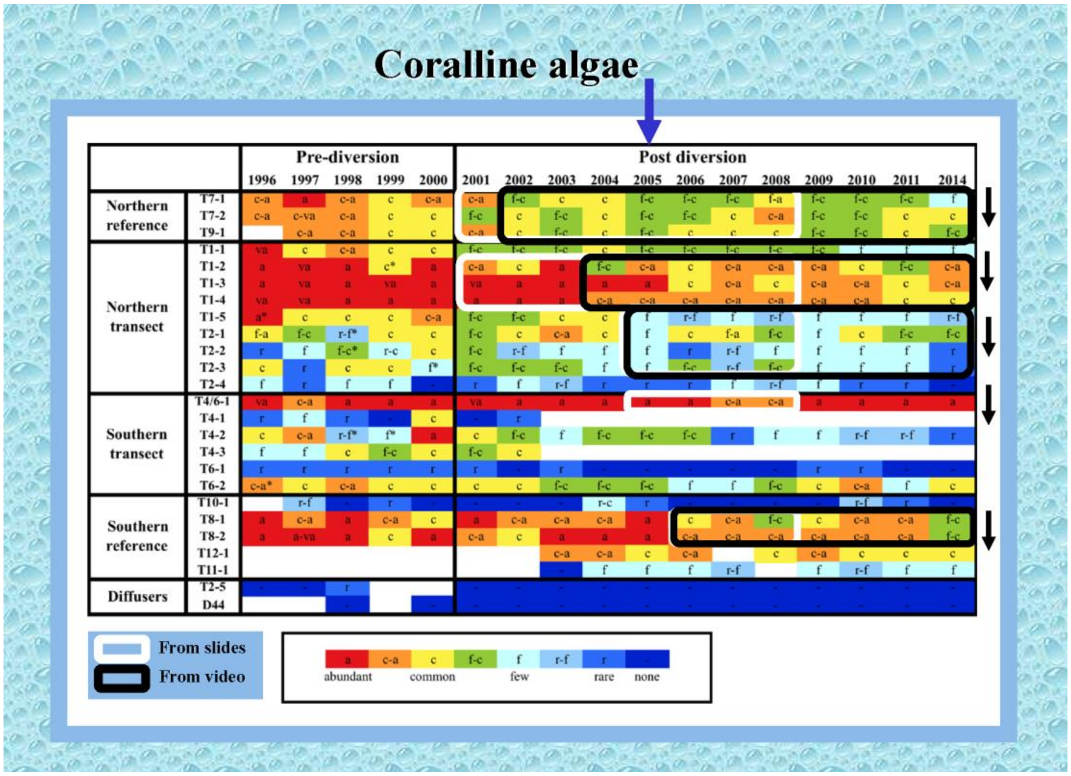
From slides

From video

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

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?



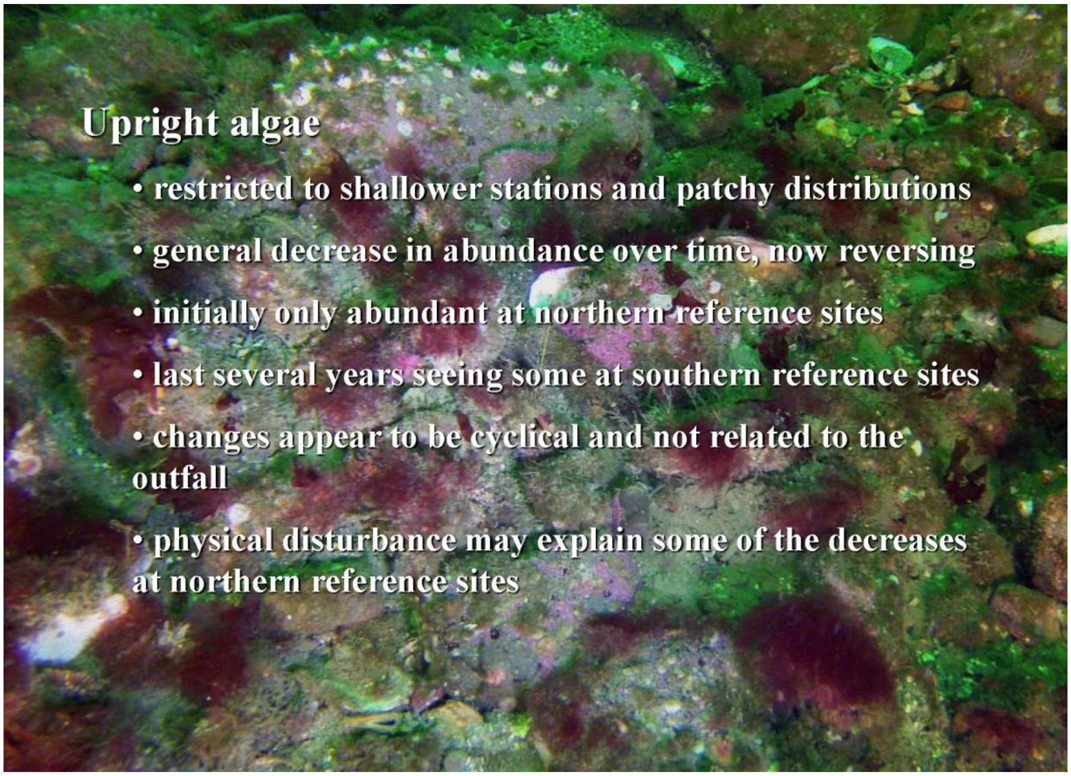
Coralline algae

		Pre-diversion					Post diversion											
		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2014
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	f
	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	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	f-c
Northern transect	T1-1	va	c	c-a	c	c	f-c	f-c	f-c	c	f-c	f-c	f-c	f-c	f-c	f	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	c-a
	T1-3	a	va	a	va	a	va	a	a	a	a	c	c-a	c	c-a	c-a	c	c-a
	T1-4	va	va	a	a	a	a	a	a	c-a	c-a	c-a	c-a	c-a	c-a	c-a	c	c
	T1-5	a*	c	c	c	c-a	f-c	f-c	c	c	f	r-f	f	r-f	f	f	f	r-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	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	r
	T2-3	c	r	c	c	f*	f-c	f-c	f-c	f	f	f-c	r-f	f-c	f	f	f	r
	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	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	r
	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	c
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	f-c
	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	f-c
	T12-1								c-a	c-a	c	c-a		c	c-a	c	c	c
	T11-1								-	f	f	f	r-f		f	r-f	f	f
Diffusers	T2-5	-	-	r			-	-	-	-	-	-	-	-	-	-	-	-
	D44			-		-	-	-	-	-	-	-	-	-	-	-	-	-

From slides

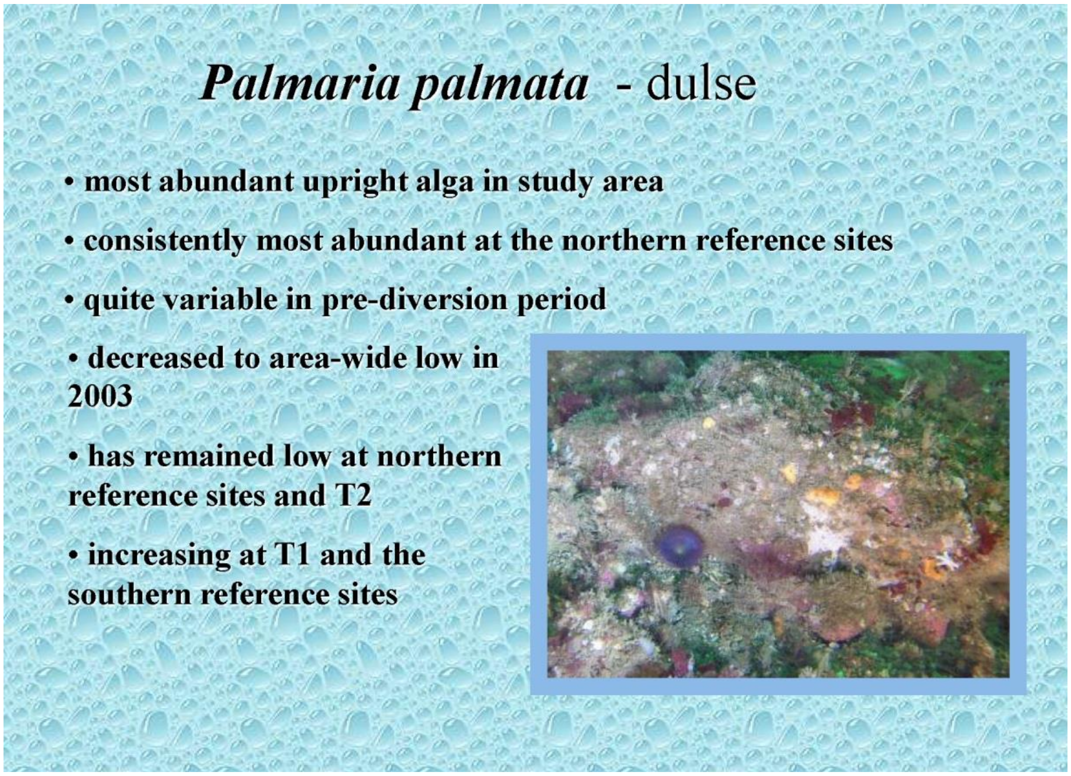
From video

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



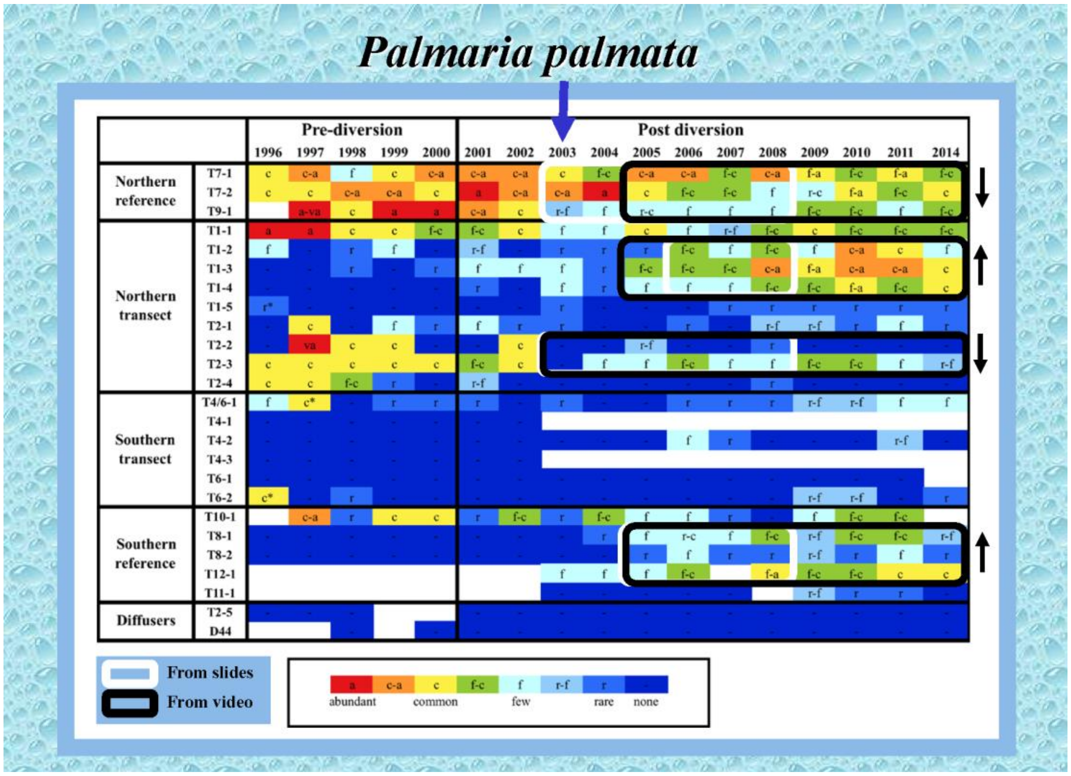
Upright algae

- 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



Palmaria palmata

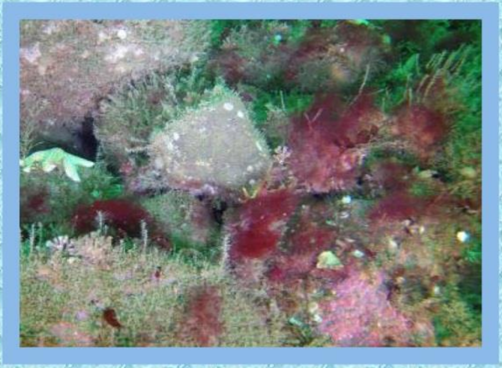
		Pre-diversion					Post diversion											
		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2014
Northern reference	T7-1	c	c-a	f	c	c-a	c-a	c-a	c	f-c	c-a	c-a	f-c	c-a	f-a	f-c	f-a	f-c
	T7-2	c	c	c-a	c-a	c	a	c-a	c-a	a	c	f-c	f-c	f	r-c	f-a	f-c	c
	T9-1		a-va	c	a	a	c-a	c	r-f	f	r-c	f	f	f	f-c	f-c	f	f-c
Northern transect	T1-1	a	a	c	c	f-c	f-c	c	f	f	c	f	r-f	f-c	c	f-c	f-c	f-c
	T1-2	f	-	r	f	-	r-f	-	r	r	r	f-c	f	f-c	f	c-a	c	f
	T1-3	-	-	r	-	r	f	f	f	r	f-c	f-c	f-c	c-a	f-a	c-a	c-a	c
	T1-4	-	-	-	-	-	r	-	f	r	f	f	f	f-c	f-c	f-a	f-c	c
	T1-5	r*	-	-	-	-	-	-	r	-	-	-	r	r	r	r	r	r
	T2-1	-	c	-	f	r	f	r	r	-	-	r	-	r-f	r-f	r	f	r
	T2-2	-	va	c	c	-	-	c	-	-	r-f	-	-	r	-	-	-	-
	T2-3	c	c	c	c	c	f-c	c	-	f	f	f-c	f	f	f-c	f-c	f	r-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	f
	T4-1	-	-	-	-	-	-	-										
	T4-2	-	-	-	-	-	-	-	-	-	-	f	r	-	-	-	r-f	-
	T4-3	-	-	-	-	-	-	-										
	T6-1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	T6-2	c*	-	r	-	-	-	-	-	-	-	-	-	-	r-f	r-f	-	r
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	r-f
	T8-2	-	-	-	-	-	-	-	-	-	r	f	r	r	r-f	r	f	r
	T12-1								f	f	f	f-c		f-a	f-c	f-c	c	c
	T11-1								-	-	-	-	-		r-f	r	r	-
Diffusers	T2-5	-	-	-			-	-	-	-	-	-	-	-	-	-	-	-
	D44			-		-	-	-	-	-	-	-	-	-	-	-	-	-

From slides
From video

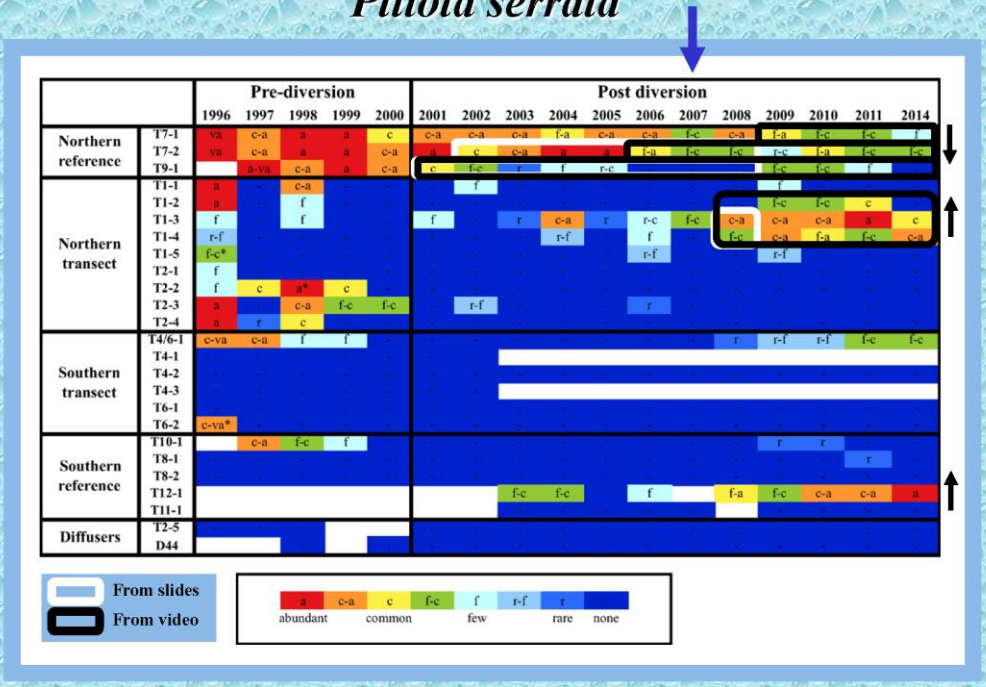
a	c-a	c	f-c	f	r-f	r	-
abundant		common		few		rare	none

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**



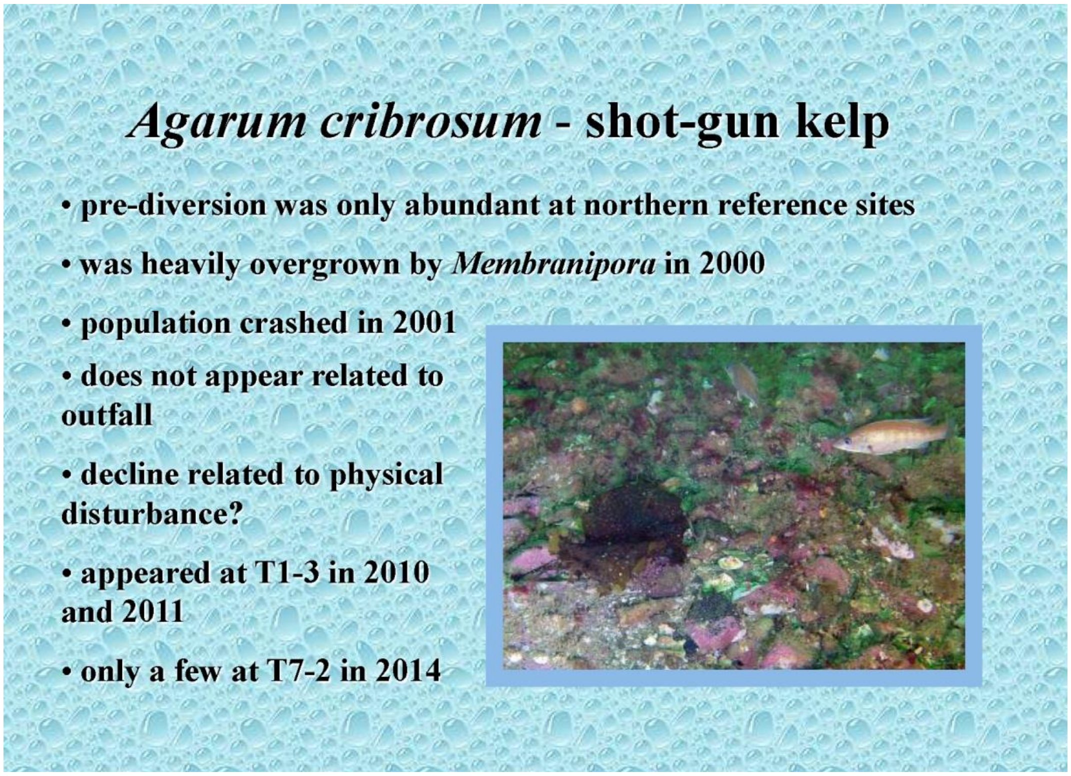
Ptilota serrata



		Pre-diversion					Post diversion											
		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2014
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	f
	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	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	c
	T1-4	r-f	-	-	-	-	-	-	-	r-f	-	f	-	f-c	c-a	f-a	f-c	c-a
	T1-5	f-c*	-	-	-	-	-	-	-	-	-	r-f	-	-	r-f	-	-	-
	T2-1	f	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	T2-2	f	c	a*	c	-	-	-	-	-	-	-	-	-	-	-	-	-
	T2-3	a	-	c-a	f-c	f-c	-	r-f	-	-	-	r	-	-	-	-	-	-
	T2-4	a	r	c	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Southern transect	**T4/6-1**	c-va	c-a	f	f	-	-	-	-	-	-	-	-	r	r-f	r-f	f-c	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	a
	T11-1								-	-	-	-	-		-	-	-	-
Diffusers	**T2-5**	-	-	-			-	-	-	-	-	-	-	-	-	-	-	-
	D44			-		-	-	-	-	-	-	-	-	-	-	-	-	-

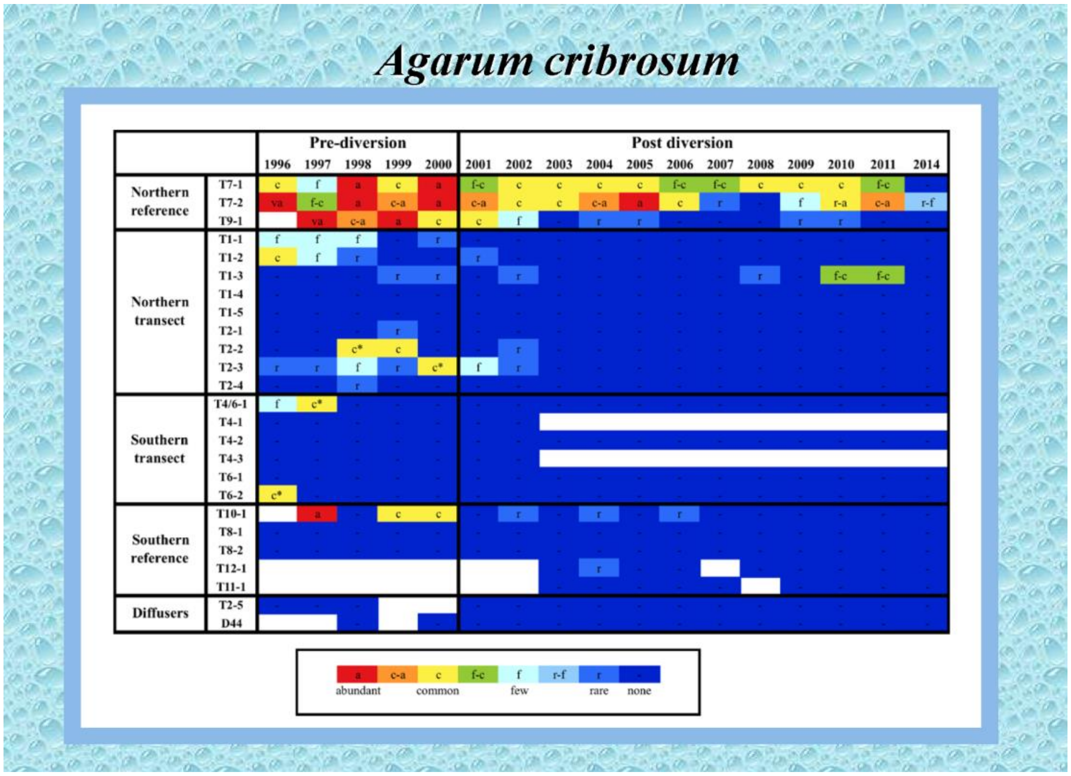
From slides
From video

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



Agarum cribrosum - shot-gun kelp

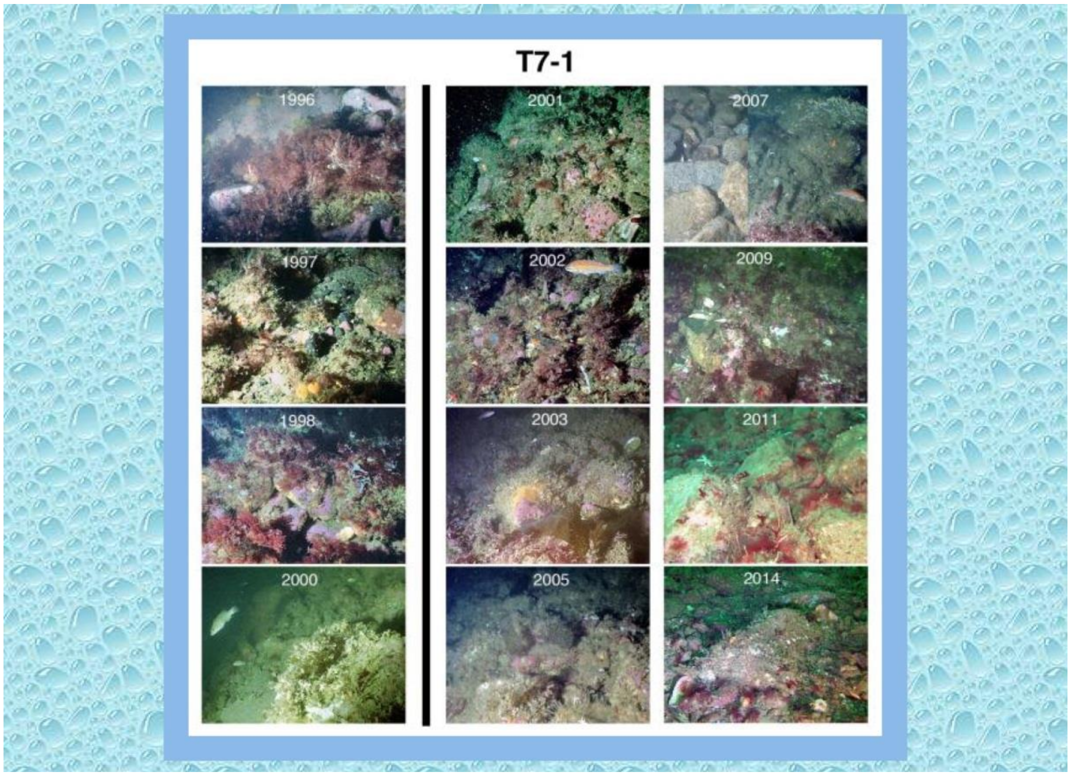
- pre-diversion was only abundant at northern reference sites
- was heavily overgrown by *Membranipora* in 2000
- population crashed in 2001
- does not appear related to outfall
- decline related to physical disturbance?
- appeared at T1-3 in 2010 and 2011
- only a few at T7-2 in 2014



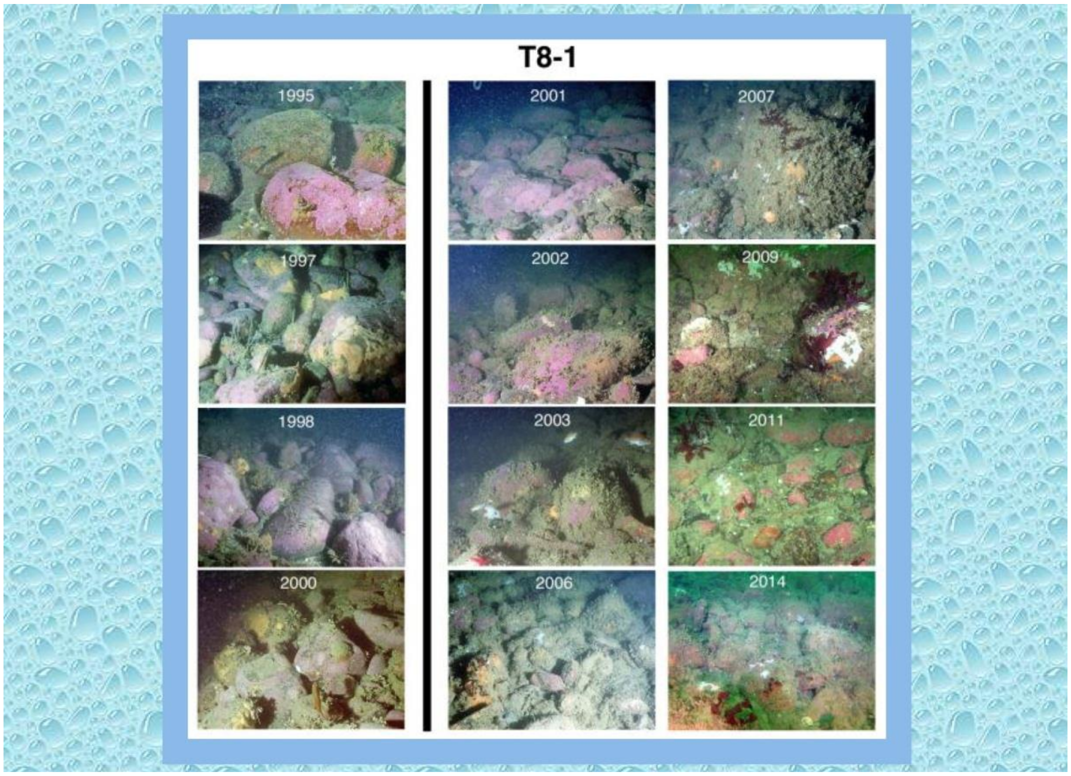
Agarum cribrosum

		Pre-diversion					Post diversion											
		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2014
Northern reference	T7-1	c	f	a	c	a	f-c	c	c	c	c	f-c	f-c	c	c	c	f-c	-
	T7-2	va	f-c	a	c-a	a	c-a	c	c	c-a	a	c	r	-	f	r-a	c-a	r-f
	T9-1		va	c-a	a	c	c	f	-	r	r	-	-	-	r	r	-	-
Northern transect	T1-1	f	f	f	-	r	-	-	-	-	-	-	-	-	-	-	-	-
	T1-2	c	f	r	-	-	r	-	-	-	-	-	-	-	-	-	-	-
	T1-3	-	-	-	r	r	-	r	-	-	-	-	-	r	-	f-c	f-c	-
	T1-4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	T1-5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	T2-1	-	-	-	r	-	-	-	-	-	-	-	-	-	-	-	-	-
	T2-2	-	-	c*	c	-	-	r	-	-	-	-	-	-	-	-	-	-
	T2-3	r	r	f	r	c*	f	r	-	-	-	-	-	-	-	-	-	-
	T2-4	-	-	r	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Southern transect	T4/6-1	f	c*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	T4-1	-	-	-	-	-	-	-										
	T4-2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	T4-3	-	-	-	-	-	-	-										
	T6-1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	T6-2	c*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Southern reference	T10-1		a	-	c	c	-	r	-	r	-	r	-	-	-	-	-	-
	T8-1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	T8-2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	T12-1								-	r	-	-		-	-	-	-	-
	T11-1								-	-	-	-	-		-	-	-	-
Diffusers	T2-5	-	-	-			-	-	-	-	-	-	-	-	-	-	-	-
	D44			-		-	-	-	-	-	-	-	-	-	-	-	-	-

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


T7-1
1996
2001
2007
1997
2002
2009
1998
2003
2011
2000
2005
2014

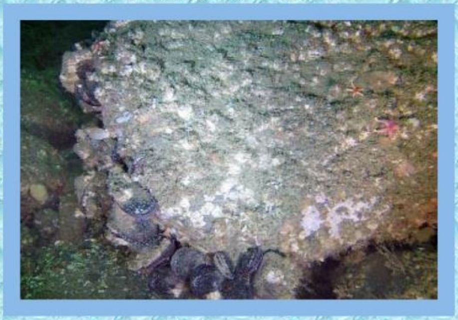

T1-3
1996
2001
2007
1997
2002
2009
1998
2003
2011
2000
2005
2014

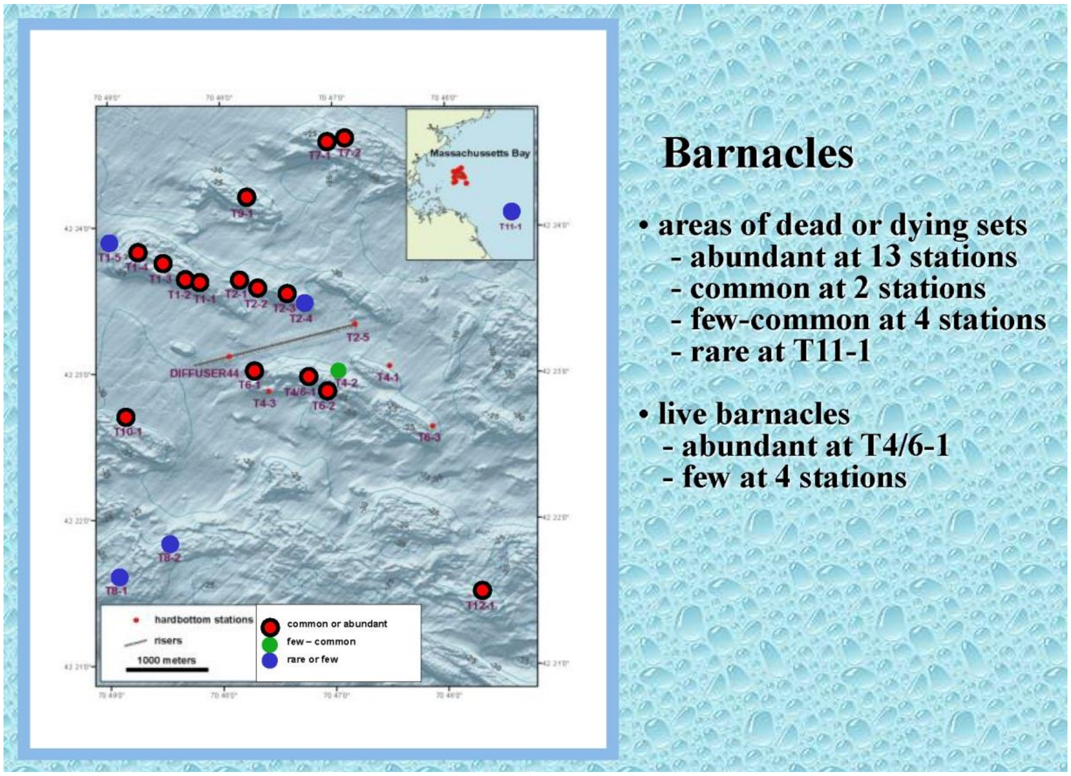


northern stations - disturbed area

encrusted dulse

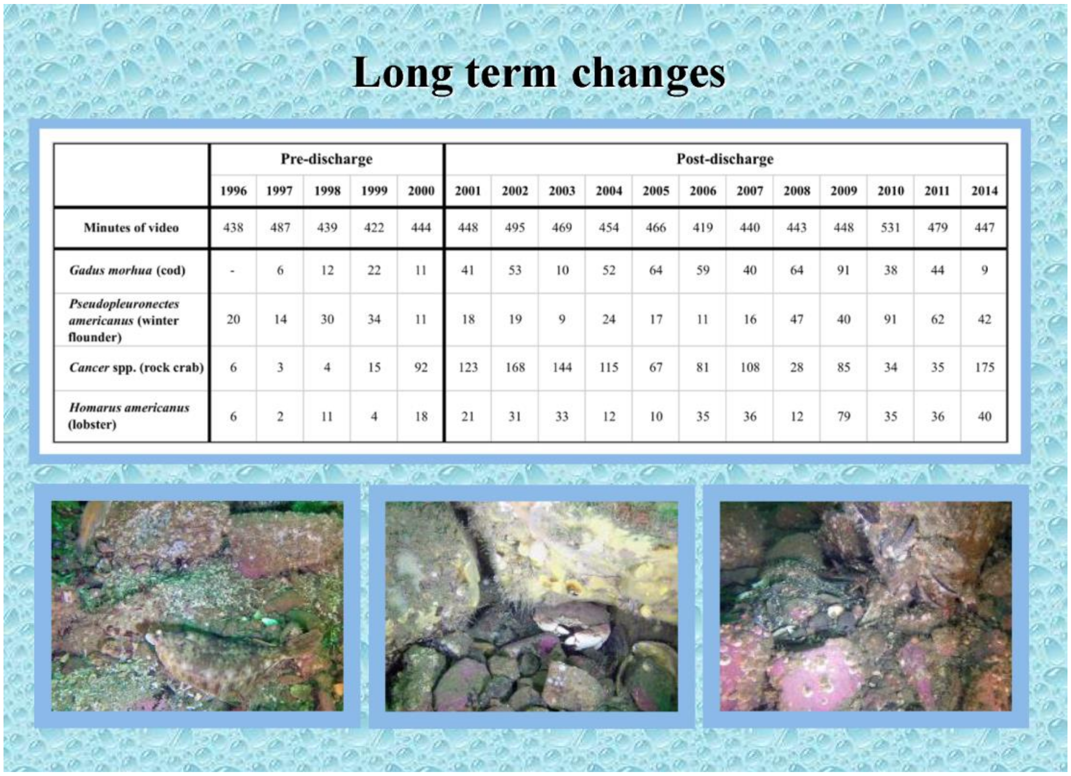
dead barnacle sets





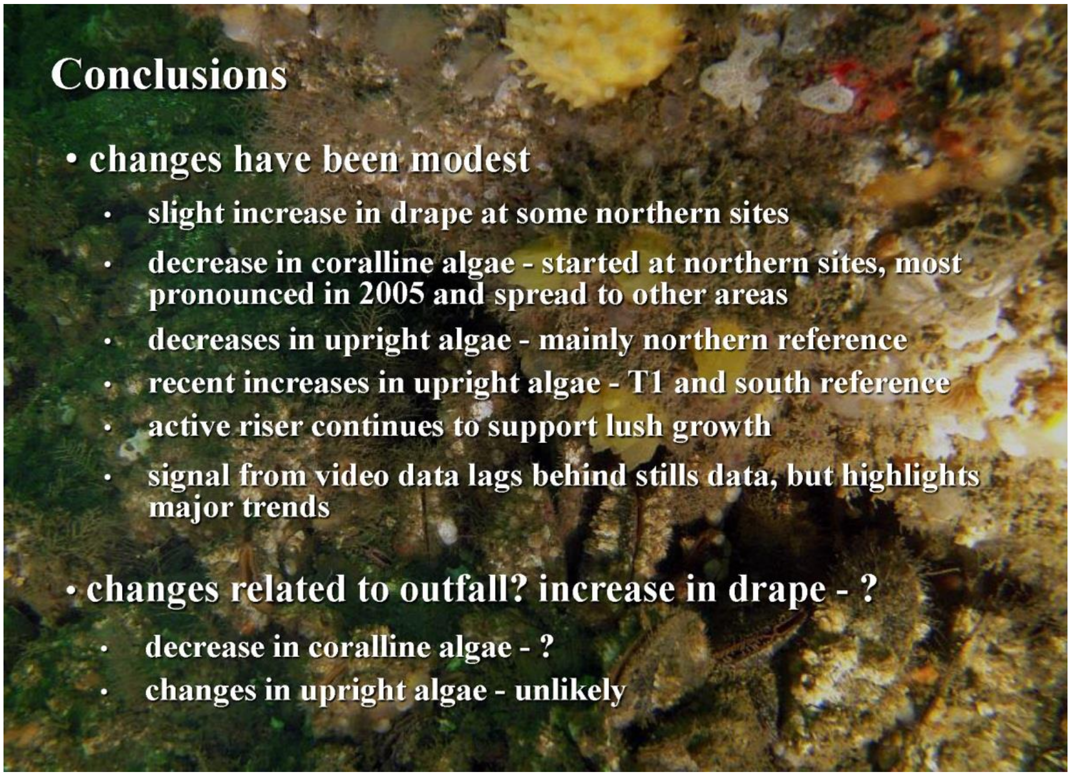
Barnacles

- areas of dead or dying sets
  - abundant at 13 stations
  - common at 2 stations
  - few-common at 4 stations
  - rare at T11-1
- live barnacles
  - abundant at T4/6-1
  - few at 4 stations



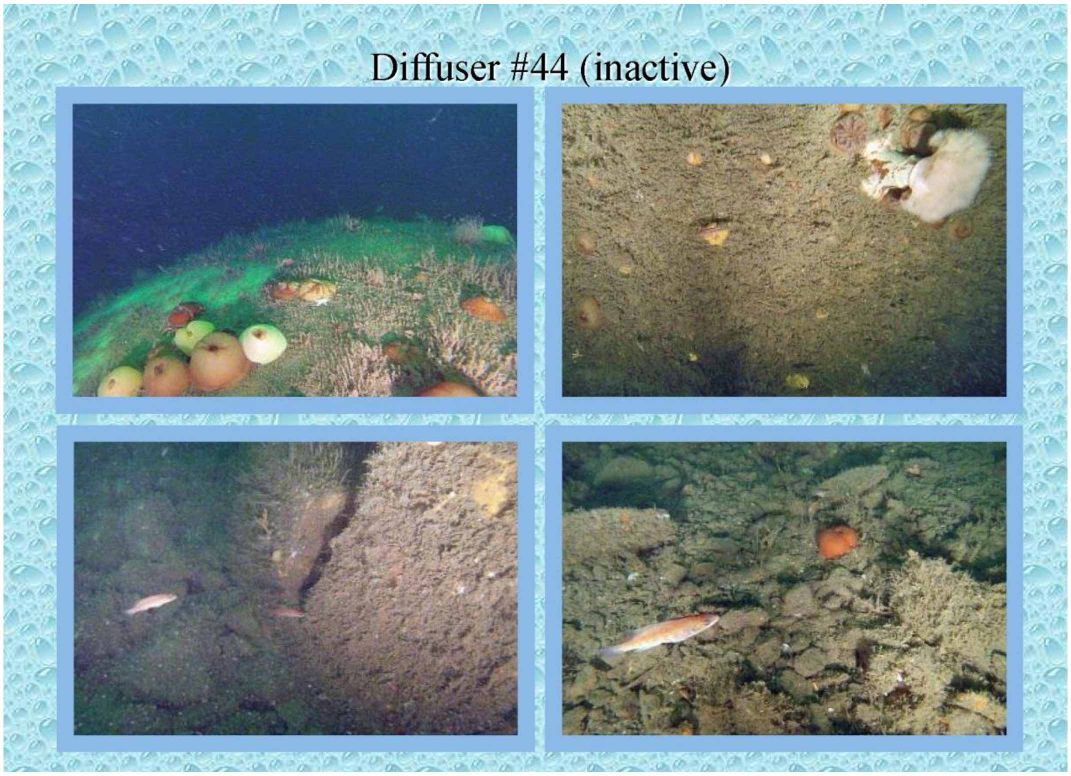
Long term changes

	Pre-discharge					Post-discharge											
	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2014
Minutes of video	438	487	439	422	444	448	495	469	454	466	419	440	443	448	531	479	447
***Gadus morhua* (cod)**	-	6	12	22	11	41	53	10	52	64	59	40	64	91	38	44	9
***Pseudopleuronectes americanus* (winter flounder)**	20	14	30	34	11	18	19	9	24	17	11	16	47	40	91	62	42
***Cancer* spp. (rock crab)**	6	3	4	15	92	123	168	144	115	67	81	108	28	85	34	35	175
***Homarus americanus* (lobster)**	6	2	11	4	18	21	31	33	12	10	35	36	12	79	35	36	40

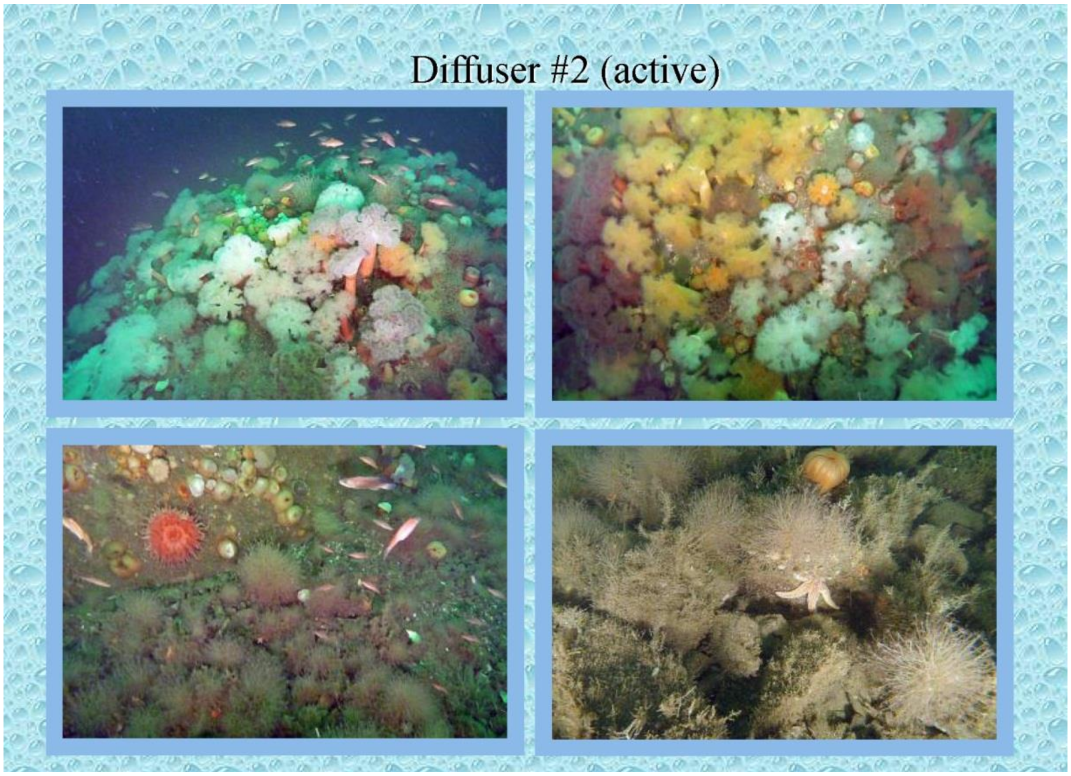


Conclusions

- **changes have been modest**
  - slight increase in drape at some northern sites
  - decrease in coralline algae - started at northern sites, most pronounced in 2005 and spread to other areas
  - decreases in upright algae - mainly northern reference
  - recent increases in upright algae - T1 and south reference
  - active riser continues to support lush growth
  - signal from video data lags behind stills data, but highlights major trends
- **changes related to outfall? increase in drape - ?**
  - decrease in coralline algae - ?
  - changes in upright algae - unlikely



Diffuser #44 (inactive)



Diffuser #2 (active)

Appendix B Summary of data recorded from video footage taken on the 2014 hard-bottom survey

Appendix B. Summary of data recorded from video footage taken on the 2014 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	28	13	23	21	21	21	21	22	21	23	21	20	21	22	23	19	19	20	24	22	19	23	21	488
Begin depth (m)	26	23	23	23	27	28	33	27	31	23	30	32	26	25	24	25	29	25	27	25	34	33	33	
End depth (m)	24	25	24	24	27	29	29	26	30	22	29	32	26	24	22	23	24	25	24	25	34	30	30	
Substrate [1]	cp+b	mx	b+c	cp+b	cp+ob	mx	cp+ob	b+c	c+b	b+c	cp+b	cp	mx	b+mx	b+c	b+c	b+c	cp+mx	cp+mx	c+b	cp+b	d+rr	d+rr	
Drape [2]	m-mh	l-lm	lm-m	l-m	mh	m-mh	m-mh	m-mh	m-mh	l-lm	m-mh	mh-h	lm-mh	m	lm-m	m-mh	mh-h	lm-mh	lm	lm-m	m-mh	l-mh	h	
Relief [3]	LM-MH	LM-MH	MH	LM-M	L-LM	L-M	L-M	LM-M	LM-M	M-MH	LM	L	LM-MH	M-MH	M-MH	M	MH-H	L-LM	L-LM	LM-MH	L-LM	LM-H	LM-H	
Suspended material[5]	h				h	h			h	h	h	h		h		h	h	h	h			h	h	
Coralline algae	f	c-a	c-a	c	r-f	f-c	r	r		a	r		c	f	c	f-c		f-c	f-c	c	f			
Ptilota serrata			c	c-a						f-c				f	f-c					a				
general hydroid	c	f-c	c	c	f	f-c	c	f	c-a	c	f-c	f	f-c	c	c	f-c	c-a	f-c	f-c	c	c-a	f	c-a	
barnacle/spirorbid complex	c			f					c	c	f			c	c	f-c	c	f-c	f	f	c		f	
Palmaria palmata	f-c	f	c	c	r	r		r-f		f			r	f-c	c	f-c		r-f	r	c				
Agarum cribosum															r-f									
general sponge	1				4	2	1	5	3						2	1			2	1	1			23
Haliclona oculata																						3	4	7
Haliclona spp. (encrusting)									1													1		2
Polymastia sp. A	f-c	f-c	r		r	c	c-a	f-c	c-a	r	c-a		f	f-c	c	f-c	c	r	f	f	f-c		f	
Suberites spp.	f		r		f	f	f	r	c		f		r			f	f-c	r	f		c			
cream sponge with projections																					f-c			
yellowish-cream encrusting sponge																					c			
white divided sponge	r-f					r	r-f	f-c	f-a		f-c			c	f	c	f			f	c			
Tubularia sp.								f		r				r	f	r	f			f		f-a	r-c	
general anemone																			1					1
Metridium senile								f									r			r		f-a	f-c	
Urticina felina	3		2	2		3	6	2	2	4	2		1	1	1		3			1	2	5	4	44
Cerianthus borealis												1												1
Gersemia rubiformis																	f							
gastropod																1								1
Crepidula plana												f						c-a		c	r-f			
Tonicella marmorea										3														3
Buccinum undatum				1																				1

(continued)

Appendix B. (Continued)

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
Nudibranch														2										2
Modiolus modiolus	c-a	c	c-a	c	r-f	f	f-c	c-a	c-a	a	c	f	c	c	a	c-a	c	r-f	c	f-c	c-a	r		
Mytilus edulis									r					f		r	f		r	c				
Placopecten magellanicus	1					2	2				4	16						1	1				3	30
Arctica islandica												r-f												
Balanus sp.	f		f							a						f				f				
Cancer spp.	17	3	10	5	10	16	21	11	10	6	9	14	3	5	5	4	14	5	6		3		1	178
Homarus americanus		1	1	1	1	2	5		3	4			4	4	2	4	3	1	2			1	1	40
Strongylocentrotus droebachiensis			c-a	f-c		r-c		r		c-a	r		f-c			f			c	r			r-f	
small white starfish	f	c	f	f-c	f	c	f-c	c	c	c	c	f	f-c	c	c	c	c	f	c	a	c-a		r-f	
Asterias vulgaris		f	c	c	r	c	f-c	f	f	r	c	c	c	f	f	r	f	f	c	a	c	f	r	
Henricia sanguinolenta	f-c	f-c	c	c	f-c	c	c	c	c	c	c	f	c	c	c	c	c	f	c	c	c	f	f	
Psolus fabricii		r						r	r	r									f	r				
Aplidium/Didemnum	c	c-a	c	c	f	f	c	c	c	f	f	f	f	f-c	c-a	c-a	c	f	f	f	f	r	r	
Boltenia ovifera								1												1	1	1		4
Botrylloides violaceus								2	14	2						1	5			3	11			38
Halocynthia pyriformis	r		r				r	r			r			f-c	r	r	f-c		r	f		r	c	
Myxicola infundibulum	f	f	f	r	r	f	f	c	f	f	c	r	c	c	c	f-c	f	r	r		r		r	
Terebratulina septentrionalis	r-f					r	r-f	f-c	f-a		f-c			c	f	c	f			f	c			
general fish				50+	1				1						1		1	1						5
Gadus morhua			1				2			2	1			1									2	9
Macrozoarces americanus					2																			2
Myoxocephalus spp.	8	1	5		12	2	2	1	2	2	4	5	1	1	3	1	2	3		2	2	4	2	65
Pholis gunnellus								1								1	1							3
Pseudopleuronectes americanus	1		5	1	1	1		1				15	1		1		1	14						42
Sebastes fasciatus																						8	1	9
Tautogolabrus adspersus	f-c	f-a	c	f-c	f	f-c	f-c	f-c	f-c	c-a	f-c	r	f-c	c	c-a	f-c	f-a	f-c	f	c	f	c-a	c	
egg case												1			1					1				3
nudibranch egg mass			4	4		10		1		2						2			1	6				30
ex barnacles	a	a	a	a	f	c	a	a	f	a	f-c	a	a	a	a	a	a	f	f	c	r			

[1] b=boulder, ob= ocassional 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 2014 nearfield hard-bottom video survey

Appendix Table C. Taxa observed during the 2014 nearfield hard-bottom video survey.

Name	Common Name	Name	Common Name
Algae			
Coralline algae	pink encrusting algae	**Crustaceans**	
Ptilota serrata	filamentous red algae	*Balanus* sp.	barnacle
Palmaria palmata	dulse	*Cancer* spp.	Jonah or rock crab
Agarum cribosum	shotgun kelp	*Homarus americanus*	lobster
Invertebrates		**Echinoderms**	
Sponges		*Strongylocentrotus droebachiensis*	green sea urchin
general sponge		small white starfish	juvenile *Asterias*
Haliclona oculata	finger sponge	*Asterias vulgaris*	northern sea star
Haliclona spp. (encrusting)	sponge	*Henricia sanguinolenta*	blood star
Polymastia sp. A	encrust yellow sponge	*Psolus fabricii*	scarlet holothurian
Suberites spp.	fig sponge		
cream sponge /projections	sponge	**Tunicates**	
yellow-cream encrust sp.	sponge	*Aplidium/Didemnum* spp.	cream encrust tunicate
white divided sponge	sponge on brachiopod	*Boltenia ovifera*	stalked tunicate
		Botrylloides violaceus	Pacific tunicate
Coelenterates		*Halocynthia pyriformis*	sea peach tunicate
hydroids			
Tubularia sp.	hydroid	**Miscellaneous**	
general anemone		*Myxicola infundibulum*	slime worm
Metridium senile	frilly anemone	barnacle/spirorbid complex	
Urticina felina	northern red anemone	*Terebratulina septentrionalis*	northern lamp shell
Cerianthus borealis	northern cerianthid		
Gersemia rubiformis	red soft coral	**Fishes**	
		general fish	
Molluscs		*Gadus morhua*	cod
gastropod		*Macrozoarces americanus*	ocean pout
Crepidula plana	flat slipper limpet	*Myoxocephalus* spp.	sculpin
Tonicella marmorea	chiton	*Pholis gunnellus*	rock gunnel
Buccinum undatum	waved whelk	*Pseudopleuronectes americanus*	winter flounder
nudibranch		*Sebastes fasciatus*	rosefish
Modiolus modiolus	horse mussel	*Tautogolabrus adspersus*	cunner
Mytilus edulis	blue mussel		
Placopecten magellanicus	sea scallop	**Other**	
Arctica islandica	ocean quahog	whelk egg case	
		nudibranch egg case	

Appendix D 2014 hard-bottom still images

Appendix D. 2011 hard-bottom still images

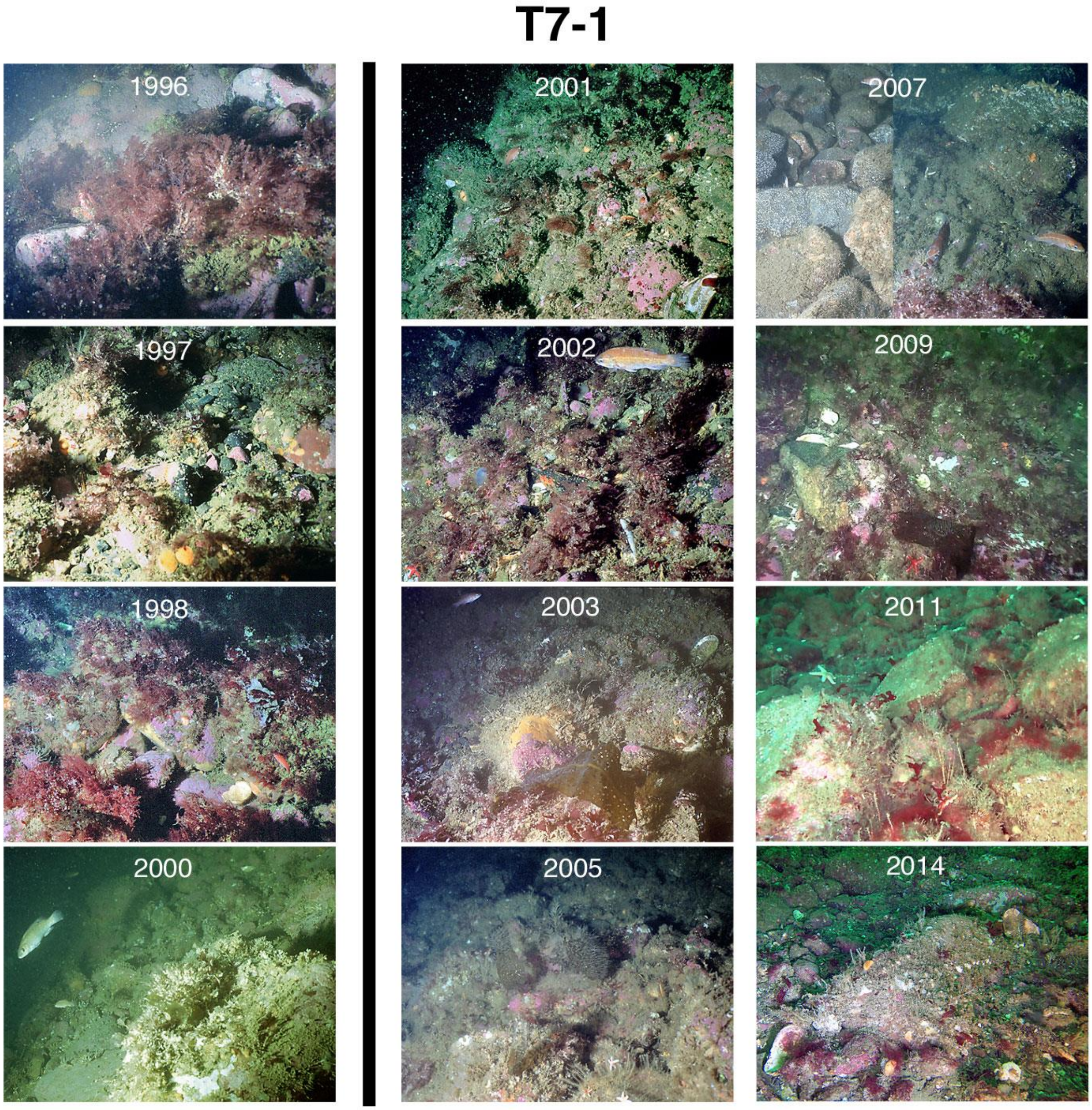


Plate 1. Representative images through time at T7-1 one of the northern reference sites. The four images on the left (1996, 1997, 1998 and 2000) show this site during the pre-diversion years. The benthic community was dominated by upright algae during this period. The eight images on the right show representative 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.

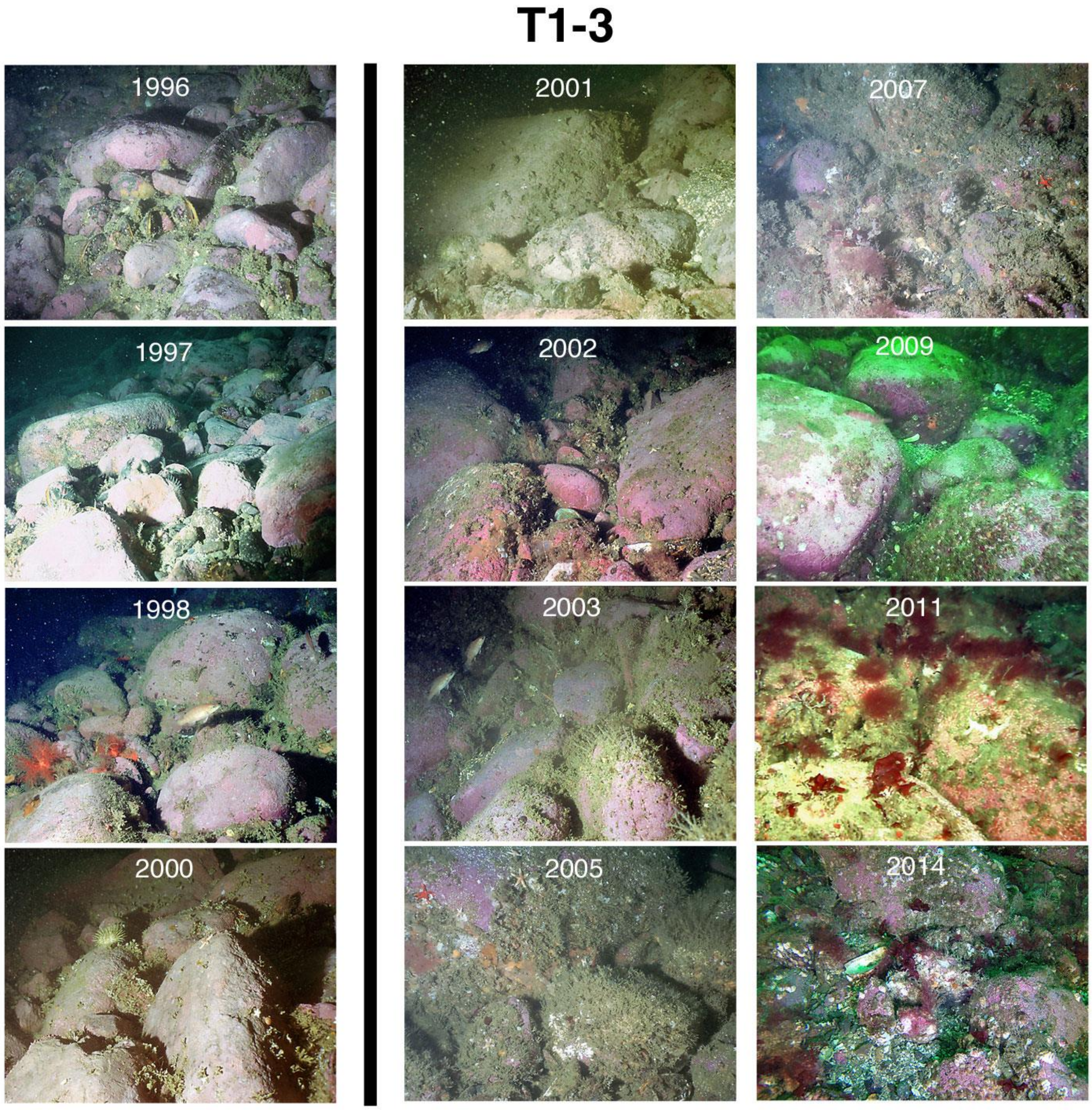


Plate 2. Representative images through time at T1-3 a drumlin top site north of the outfall. The four images on the left (1996, 1997, 1998 and 2000) show this site during the pre-diversion years. The benthic community was totally dominated by coralline algae and the rocks had very little drape during this period. The eight 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 have started to appear at this site in the last few years.

T8-1

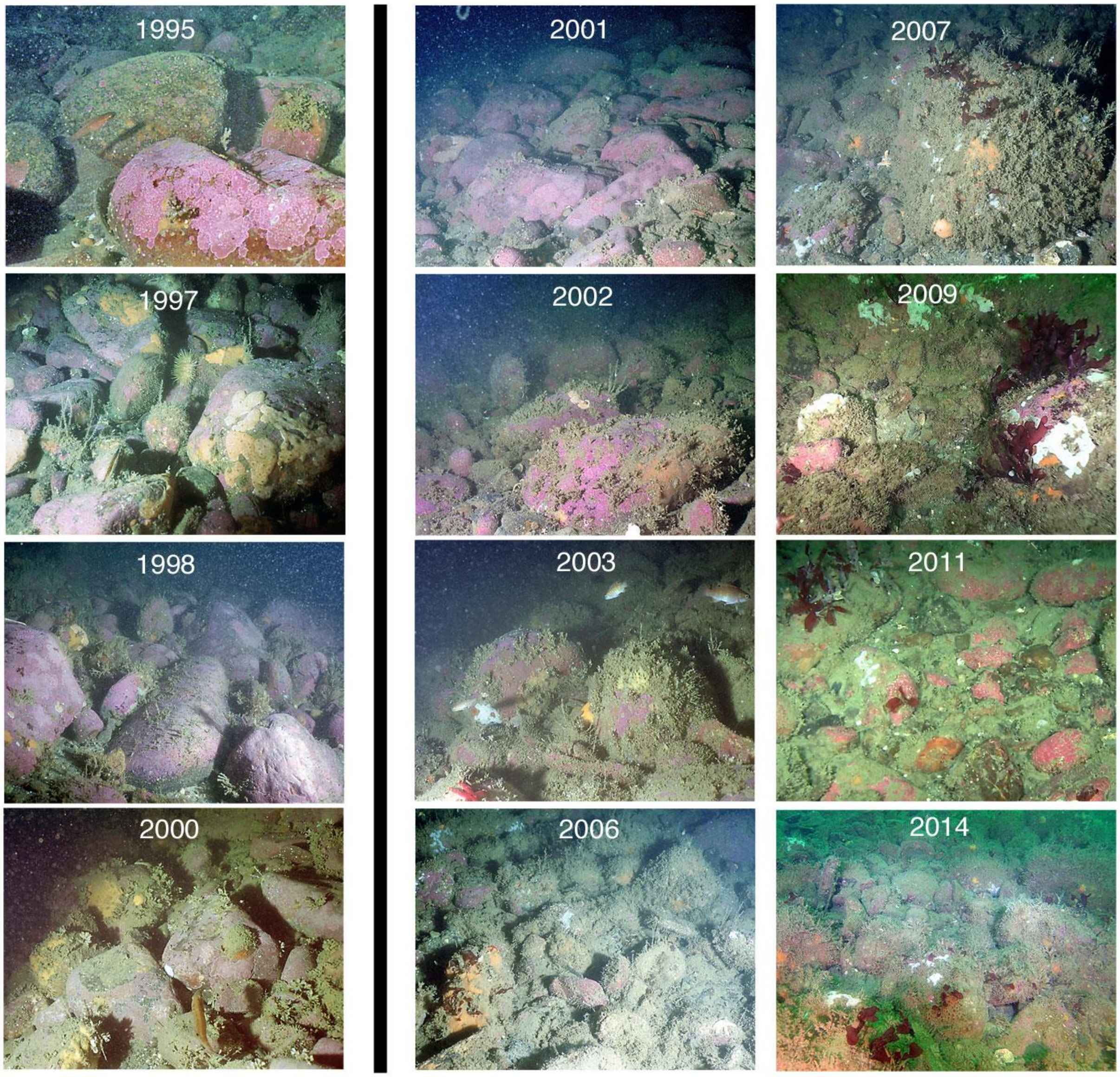


Plate 3. Representative images through time at T8-1 one of the southern reference sites. The four images on the left (1995, 1997, 1998 and 2000) show this site during the pre-diversion years. The benthic community was dominated by coralline algae during this period. The eight images on the right show 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.

Massachusetts Water Resources Authority
Charlestown Navy Yard
100 First Avenue
Boston, MA 02129
(617) 242-6000
www.mwra.com