Outfall Benthic Monitoring Report: 2016 Results

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Outfall Benthic Monitoring Report: 2016 Results

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EXECUTIVE SUMMARY

Benthic monitoring during 2016 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). Consistent with past observations during the post-diversion period, *C. perfringens* concentrations during 2016 were highest at sites closest to the discharge. Maciolek et al. (2007, 2008) documented this spatial pattern was statistically significant in previous years. The results for *C. perfringens*, therefore, 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 2016. These findings are also consistent with prior monitoring results (Nestler et al. 2016, Nestler et al. 2015, Maciolek et al. 2008).

Infaunal communities in Massachusetts Bay continued to exhibit no evidence of impacts from the offshore outfall in 2016. Monitoring results have consistently suggested that deposition of particulate organic matter from the wastewater discharge is not occurring at levels that disturb or smother animals near the outfall. There were no Contingency Plan threshold exceedances for any infaunal diversity measures in 2016. Exceedances had been reported for Shannon-Wiener Diversity (H') and Pielou's Evenness (J') each year from 2010 to 2014. Those previous exceedances for H' and J' were based on values that were above the upper threshold limits (higher than during the baseline period). Values for H' and J' in 2016 were below or at the upper threshold limits. MWRA requested the removal of the upper threshold limits for all Contingency Plan infaunal diversity parameters (total species, log-series Alpha, H', and J') based on detailed evaluation of the ecological significance of these measures (Nestler et al. 2015). The Outfall Monitoring Science Advisory Panel (OMSAP) has concurred with this recommendation. Multivariate analyses indicated that patterns in the distribution of faunal assemblages follow differences in habitat types at the sampling stations. Infaunal data in 2016 continue to suggest that the macrobenthic communities at sampling stations near the outfall have not been adversely impacted by the wastewater discharge.

The 2016 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 2016 was greater than during the baseline period, and among the highest reported during post-discharge years. These results support previous findings that organic loading and an associated decrease in oxygen levels have not been a problem at the nearfield benthic monitoring stations (Nestler et al. 2016, 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.

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1. INTRODUCTION

The Massachusetts Water Resources Authority (MWRA) has conducted long-term monitoring since 1992 in Massachusetts Bay and Cape Cod Bay to evaluate the potential effects of discharging secondary 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 sixteen-year post-diversion period (2001–2016). 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.

Benthic monitoring during 2016 was conducted following the current Ambient Monitoring Plan (MWRA 2010) which is required under MWRA's effluent discharge permit for the Deer Island Treatment Plant. 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, sediment contaminants are evaluated (at the same 14 stations where infauna and sediment condition samples are collected) and hard-bottom surveys are conducted (at 23 nearfield stations). The most recent sediment contaminant monitoring and hard-bottom surveys were conducted in 2014 (next sampling will be in 2017). Sediment contaminant monitoring in 2014 found no indication that toxic contaminants from the wastewater discharge are accumulating in depositional areas surrounding the outfall (Nestler et al. 2015). Monitoring results for 2014 also indicated that hard-bottom benthic communities near the outfall have not changed substantially during the post-diversion period as compared to the baseline period (Nestler et al. 2015).

The purpose of this report is to summarize key findings from the 2016 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 2016 benthic monitoring were presented at MWRA's Annual Technical Workshop on April 6, 2017. 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. 2016, 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. 2014b). 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 8, 2016 (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 (just less than 8 km from the offshore outfall)
- Nearfield stations NF13, NF14, NF17, and NF24, located in close proximity (less than 2 km) to the offshore outfall
- Nearfield stations NF04, NF10, NF12, NF20, NF21, and NF22, located in Massachusetts Bay but farther than 2 km (and less than 5 km) from the offshore outfall
- Farfield reference stations FF01A, FF04, and FF09, located in Massachusetts Bay but farther than 13 km from the offshore outfall

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*. 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 3, 2016 (Figure 2-2).
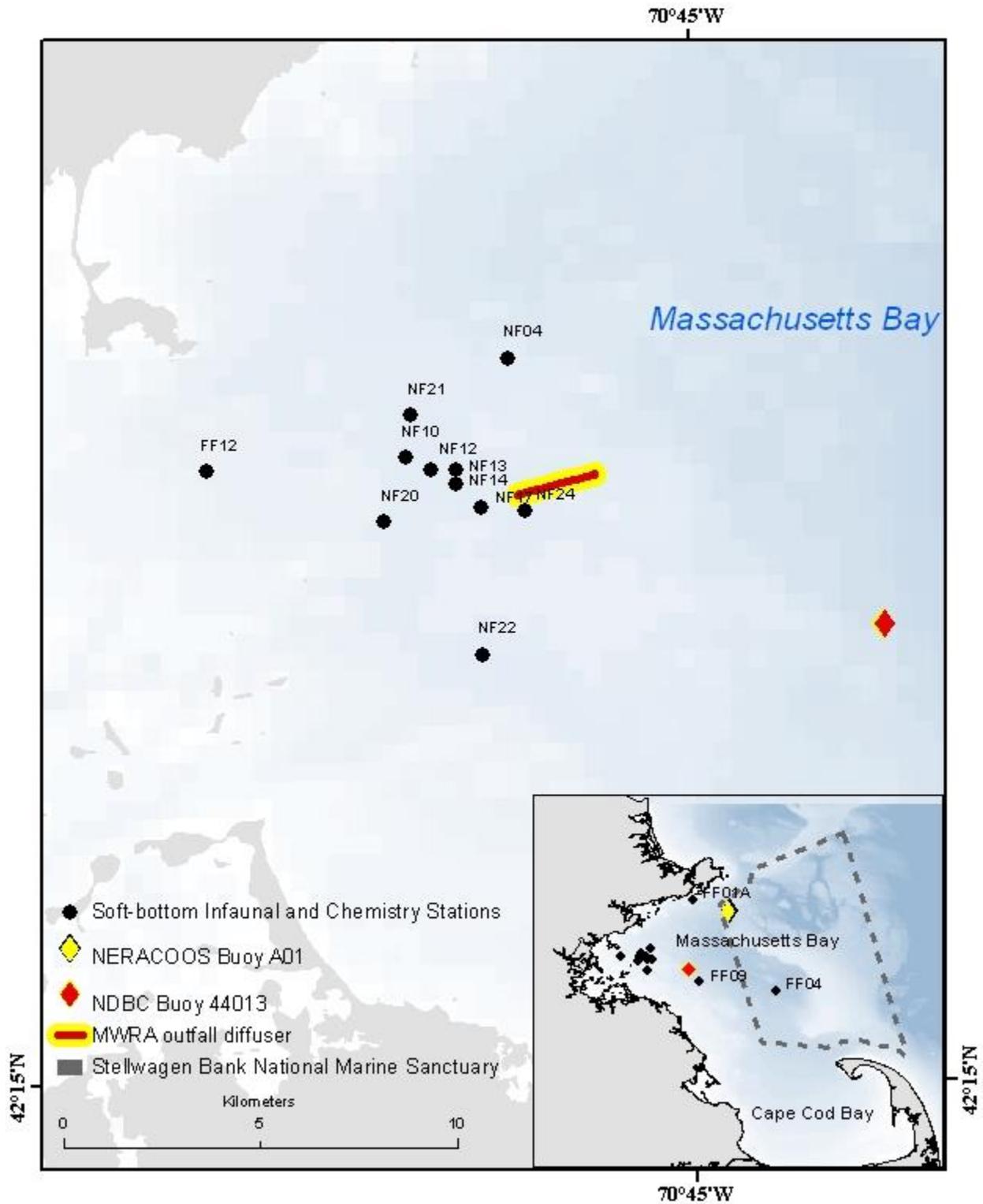
Figure 2-1.   Locations of soft-bottom sampling stations for 2016.
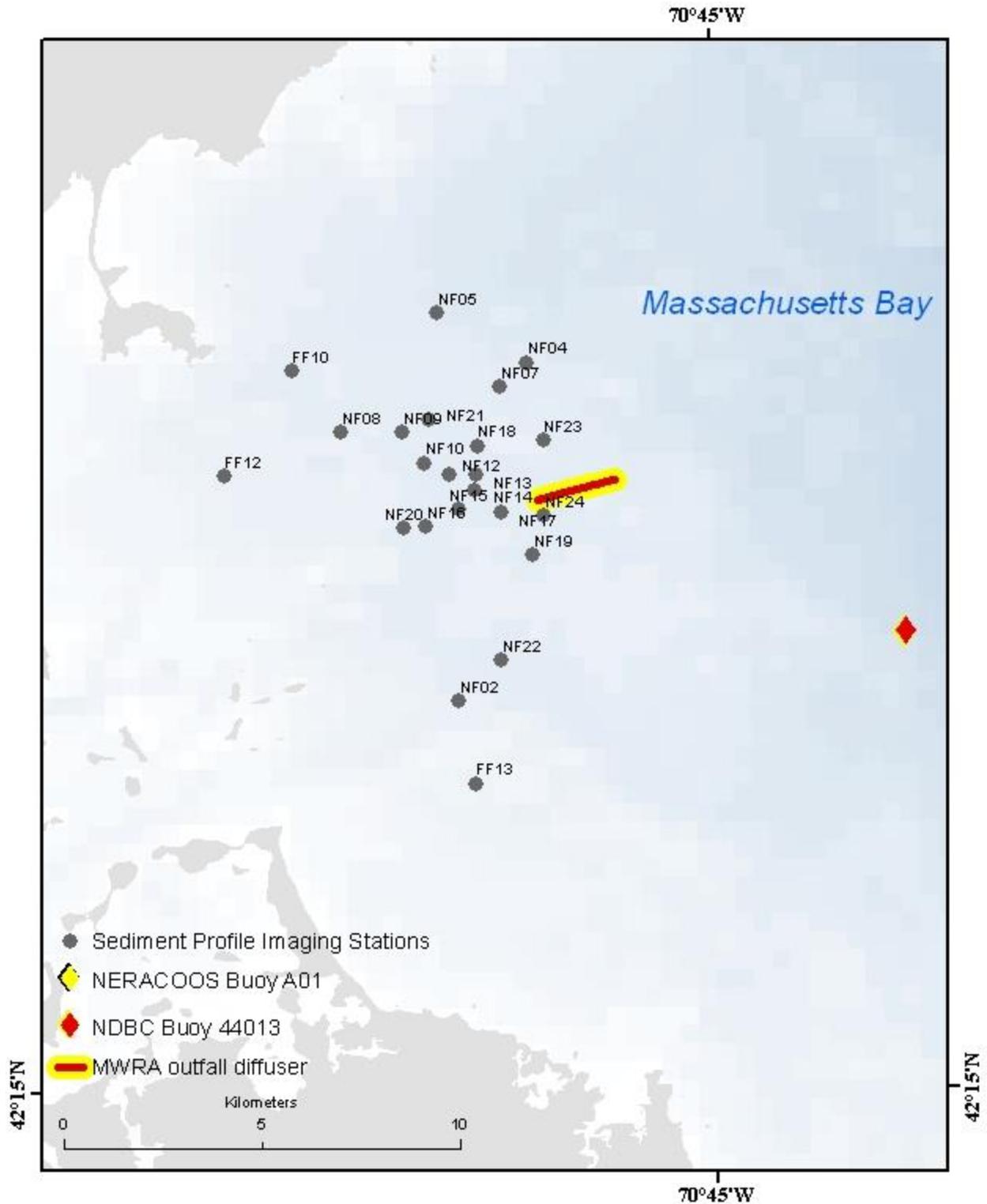
Figure 2-2.   Locations of sediment profile imaging stations for 2016.

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).

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.

To help with assessment of spatial patterns, stations have been grouped into regions according to distance from the outfall. The monitoring areas include nearfield stations <2 km from the outfall, nearfield stations > 2 km from the outfall, a transition station, and farfield stations (see Section 2.1).

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 2016 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 2016 were slightly lower than the previous year at all locations (Figure 3-1). As in past years during the post-diversion period, *C. perfringens* concentrations during 2016 continued to indicate a footprint of the effluent plume at sites closest to the discharge. Normalized *C. perfringens* spore counts in samples collected during 2016 were highest at stations NF17, NF14, and NF24 (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 statistically significant and consistent with an impact of the outfall discharge.

Sediment texture in 2016 varied considerably among the 14 stations, ranging from predominantly sand (e.g., NF17, NF04, and NF13) to mostly silt and clay (i.e., FF04), with many stations having mixed sediments (Table 3-1, Figure 3-3). Sediment texture has remained generally consistent over time, with relatively small year-to-year changes in the percent fine (silt + clay fractions) sediments at most stations (Figure 3-4). Interannual variability in sediment texture at the Massachusetts Bay stations has typically been associated with strong storms. 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.

 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 3-5.

As in past years during the post-diversion period, *Clostridium perfringens* concentrations during 2016 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 (Figure 3-6). Higher variability in 2016 at stations <2 km from the outfall and at farifield stations compared to other periods was due to the small numbers of samples in these two areas as

well as differences in sediments among the farifield stations. These findings are consistent with prior year monitoring results (Nestler et al. 2016, Maciolek et al. 2008).

Table 3-1.   2016 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	22.6	0.47	0.5	71.0	24.8	3.6	28.4
Nearfield (<2 km from outfall)	NF13	66.7	0.12	1.0	96.5	1.8	0.7	2.5
	NF14	214.7	1.36	43.4	50.4	5.0	1.3	6.2
	NF17	292.9	0.15	0.3	98.3	0.4	1.0	1.4
	NF24	108.3	0.37	0.8	79.9	15.0	4.4	19.3
Nearfield (>2 km from outfall)	NF04	95.6	0.09	1.1	96.7	1.8	0.5	2.3
	NF10	47.0	0.42	1.6	70.7	23.4	4.2	27.6
	NF12	59.6	1.04	0.5	37.2	52.7	9.5	62.3
	NF20	55.7	0.50	24.2	64.3	7.1	4.5	11.5
	NF21	38.3	0.80	0	47.5	41.5	11.1	52.5
	NF22	79.8	0.96	0	52.8	37.0	10.2	47.2
Farfield	FF01A	31.9	0.38	0.2	83.3	12.8	3.8	16.6
	FF04	23.2	2.32	0	6.5	53.1	40.4	93.5
	FF09	27.2	0.39	0.3	83.7	9.3	6.8	16.1
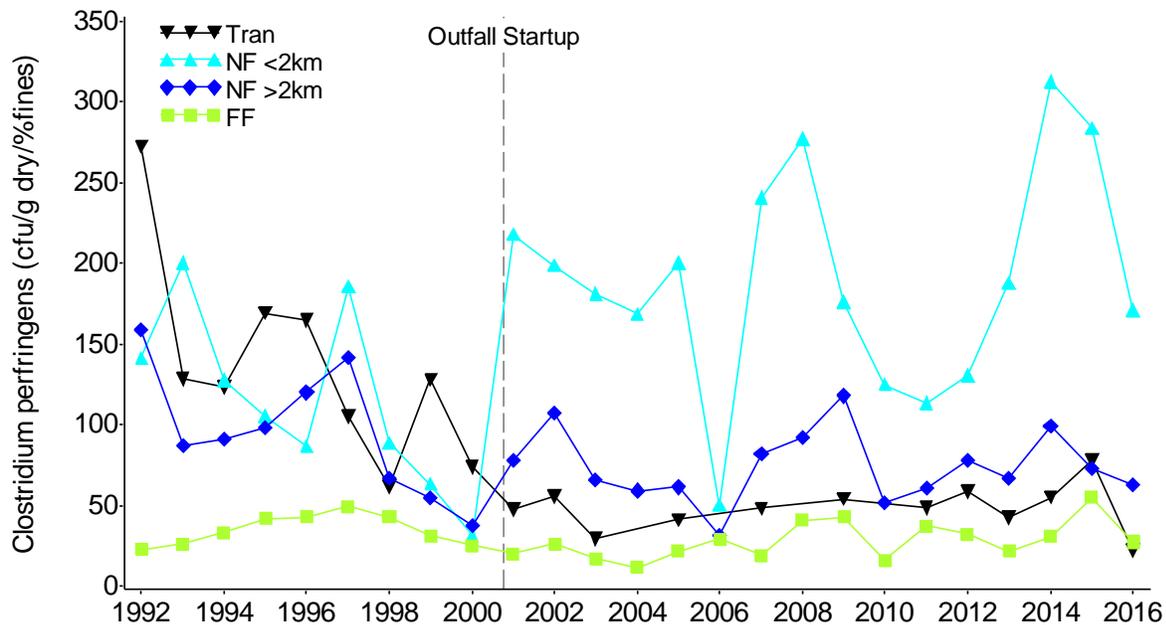
Figure 3-1.   Mean concentrations of *Clostridium perfringens* in four areas of Massachusetts Bay, 1992 to 2016. Tran=Transition area; NF<2km=nearfield, less than two kilometers from the outfall; NF>2km=nearfield, more than two kilometers from the outfall; FF=farfield.
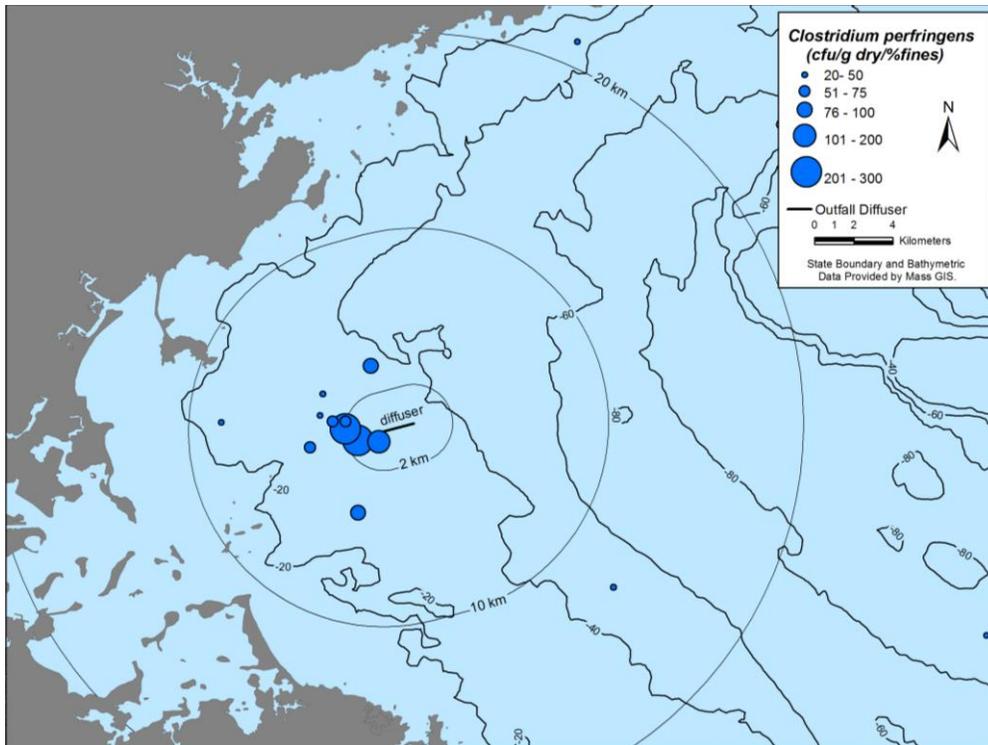
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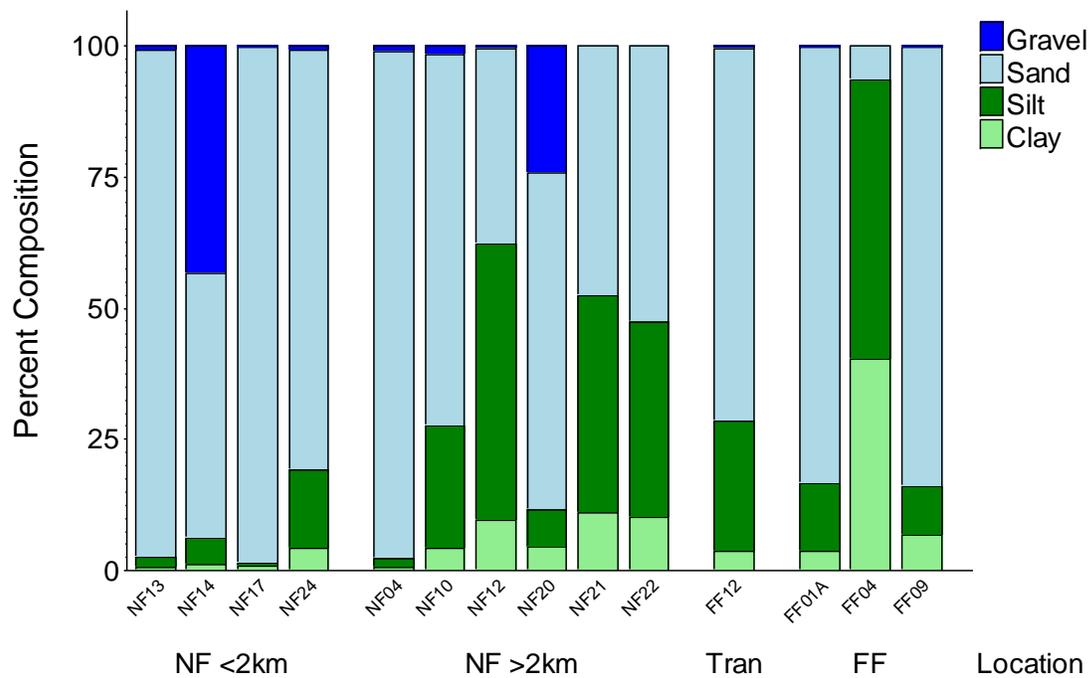
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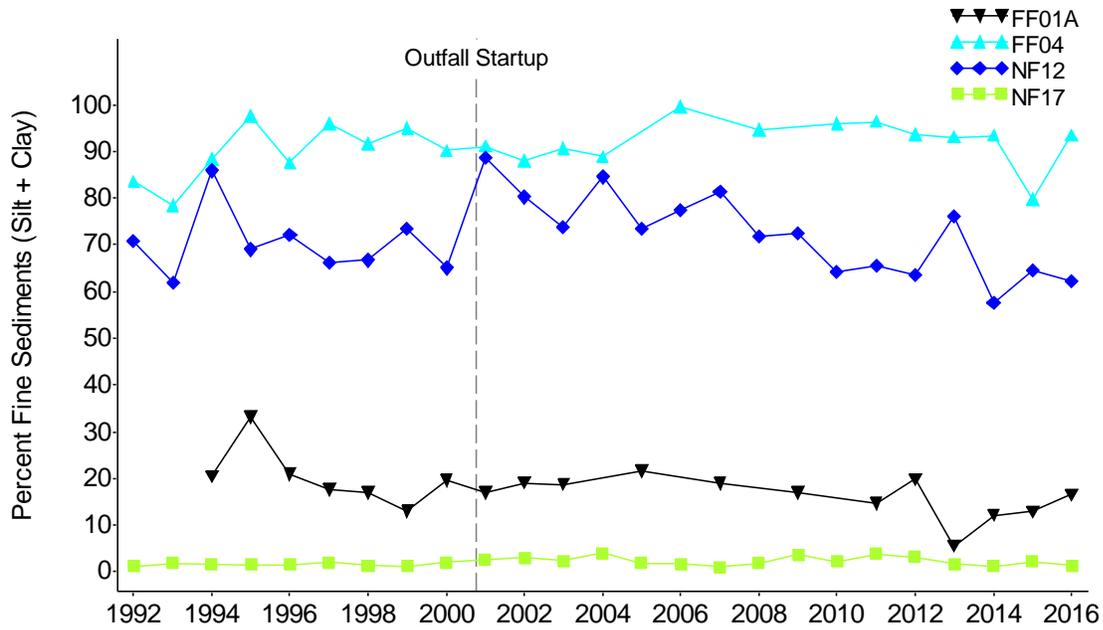
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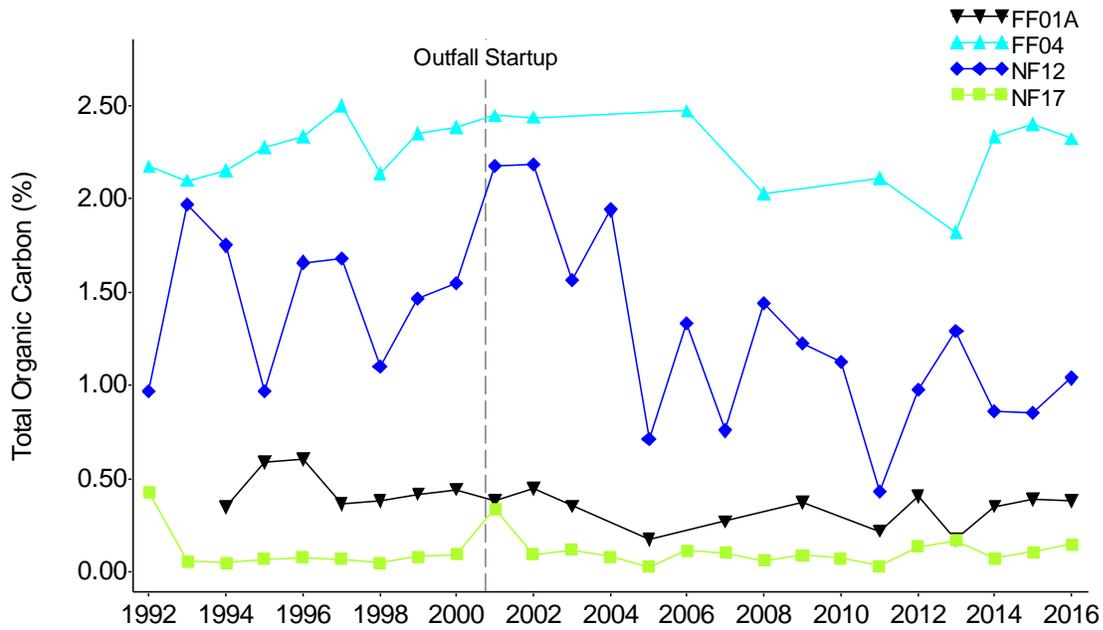
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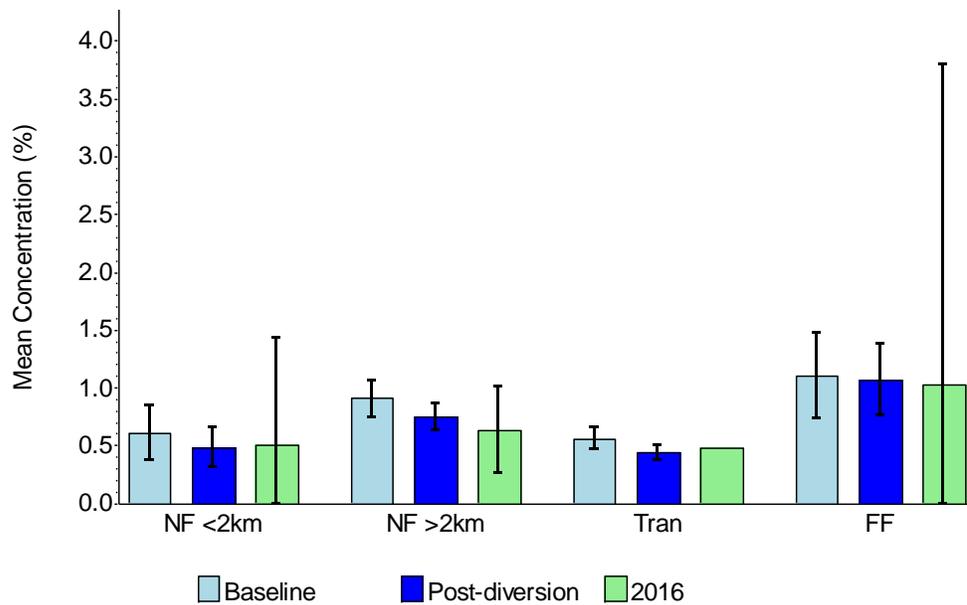
Figure 3-6.   Mean (with 95% confidence intervals) concentrations of TOC at four areas in Massachusetts Bay during the baseline (1992-2000) and post-diversion (2001 to 2015) compared to 2016.

3.2 Benthic Infauna

3.2.1 Community Parameters

A total of 18,077 infaunal organisms were counted from the 14 samples collected in 2016. Organisms were classified into 196 discrete taxa; 175 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 3-2).

Mean total abundance values in 2016 were comparable to the previous year at most nearfield stations in Massachusetts Bay (Figure 3-7). Although abundance declined for a second year at Station FF12 (the only station in the "Transition Area"), it remained higher than at other locations in the Bay (Figure 3-7, Table 3-2). Abundance at the farfield stations in 2016 was among the lowest values reported throughout the history of the monitoring program (Figure 3-7). The mean numbers of species per sample in 2016 were comparable to 2015 at all locations; values were nearly the same in all areas of the Bay except for the Transition Area (Figure 3-8).

There were no Contingency Plan threshold exceedances for any infaunal diversity measures in 2016 (Table 3-3) as in 2015. Exceedances had been reported for Shannon-Wiener Diversity (H') and Pielou's Evenness (J') each year from 2010 through 2014 (Nestler et al. 2015). The previous exceedances for H' and J' were upper limit exceedances, based on values that were higher than during the baseline period. In 2016 the values for H' were just below the upper threshold limit and for J' they were equal to the upper threshold limit (Figures 3-9 and 3-10, Table 3-3). Diversity thresholds are tested by comparing whether the annual nearfield station means fall within the central 95th percentiles (plus or minus) of the baseline means (see Appendix A, MWRA SOP-04 in Nestler et al. 2014b). The nearfield stations included in this

comparison are defined within MWRA's Ambient Monitoring Plan, which has been revised periodically over the years since monitoring began (e.g., MWRA 2004, 2010) resulting in changes of thresholds at times when the benthic sampling design has changed. Therefore, although mean H' values for 2008 and 2009 presented in Figure 3-8 are above the current threshold, these results did not exceed the thresholds applicable to the station sets that were sampled in those years. Results for H' in 2010 exceeded the threshold in effect that year; since 2011, monitoring has been conducted under the current Ambient Monitoring Plan (MWRA 2010) and tested against the current Contingency Plan thresholds.

In-depth evaluations of threshold exceedances for H' and J' were conducted in previous years (Nestler et al. 2014a). 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. Based on the detailed evaluations of the five consecutive years when exceedances occurred, the OMSAP has concurred with the conclusion that such exceedances are not indicative of an outfall effect and has recommended that the upper threshold criterion be dropped from further consideration for all Contingency Plan infaunal diversity parameters (total species, log-series Alpha, H', and J').

Spatial and temporal patterns of abundance, species richness, species diversity and evenness generally support the conclusion that there is no evidence of negative impacts caused by operation of the offshore outfall.

Table 3-2.   2016 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**	2,026	52	9.75	3.52	0.62
Nearfield (<2 km from outfall)	**NF13**	1,048	62	14.53	4.12	0.69
	NF14	1,393	59	12.51	4.22	0.72
	NF17	499	53	15.26	4.41	0.77
	NF24	2,333	66	12.66	3.74	0.62
Nearfield (>2 km from outfall)	**NF04**	517	41	10.48	3.94	0.74
	NF10	1,219	56	12.12	3.76	0.65
	NF12	1,391	57	11.97	3.75	0.64
	NF20	1,636	71	15.20	3.84	0.62
	NF21	1,830	68	13.93	4.22	0.69
	NF22	1,875	59	11.61	3.71	0.63
Farfield	**FF01A**	694	59	15.42	4.57	0.78
	FF04	558	33	7.70	3.25	0.64
	FF09	1,058	82	21.36	4.98	0.78

Table 3-3.   **Infaunal monitoring threshold results, August 2016 samples.**

Parameter	Threshold range		Result	Exceedance?
	Low	**High**		
Total species	43.0	81.9	58.6	No
Log-series Alpha	9.42	15.8	12.73	No
Shannon-Weiner H′	3.37	3.99	3.93	No
Pielou's J'	0.57	0.67	0.67	No
Apparent RPD	1.18	NA	4.8	No
Percent opportunists	10% (Caution) 25% (Warning)		0.2%	No
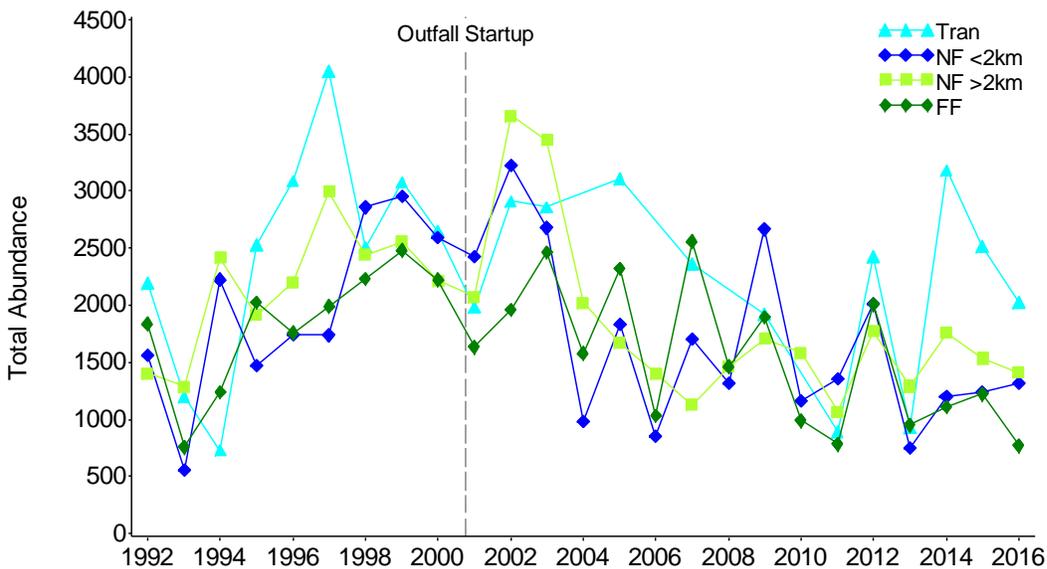
Figure 3-7.   **Mean infaunal abundance per sample at four areas of Massachusetts Bay, 1992 to 2016. Tran=Transition area; NF<2km=nearfield, less than two kilometers from the outfall; NF>2km=nearfield, more than two kilometers from the outfall; FF=farfield.**
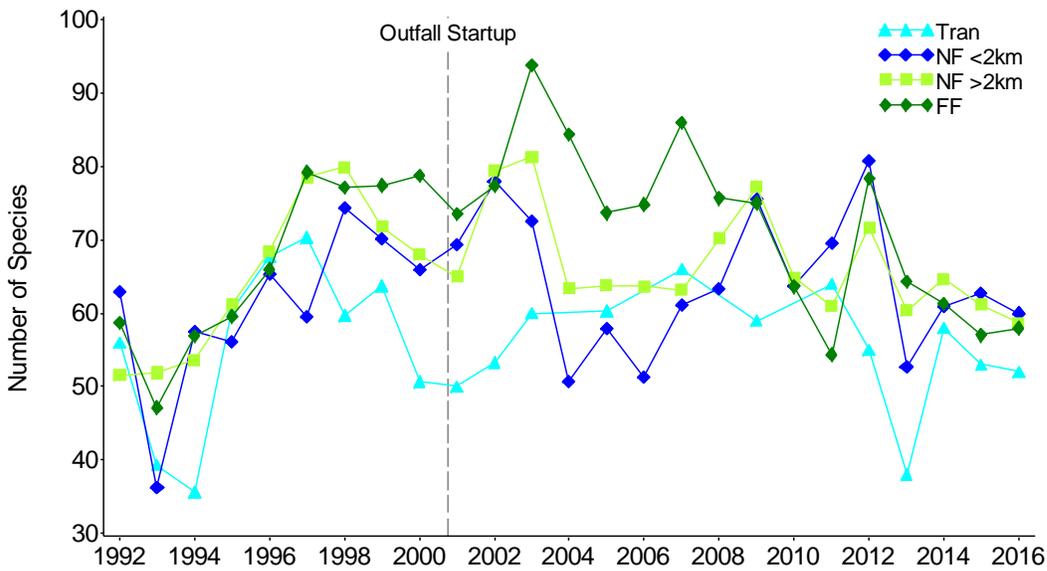
Figure 3-8. **Mean number of species per sample at four areas of Massachusetts Bay, 1992 to 2016. Tran=Transition area; NF<2km=nearfield, less than two kilometers from the outfall; NF>2km=nearfield, more than two kilometers from the outfall; FF=farfield.**
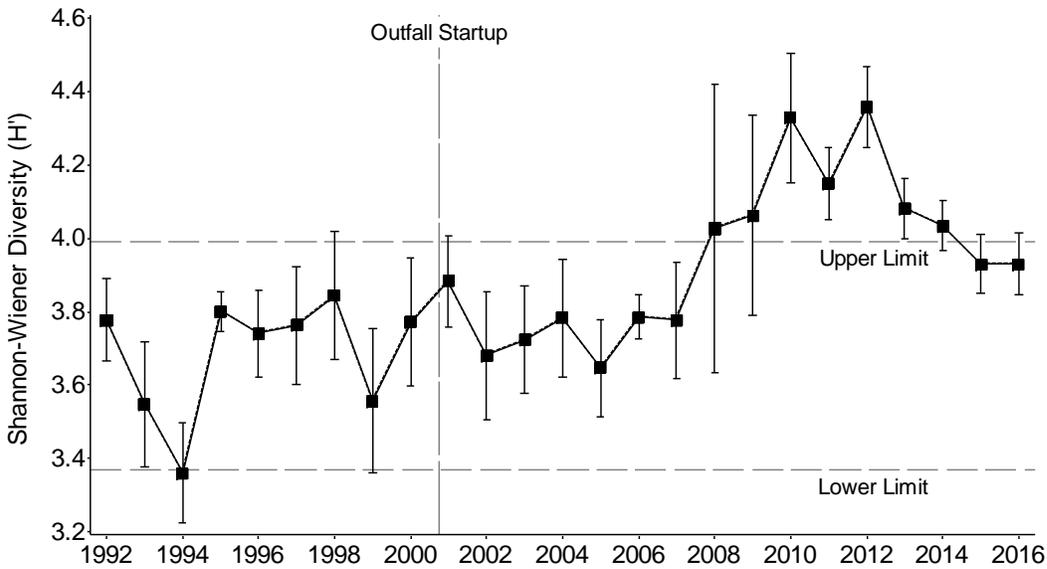
Figure 3-9. **Mean (and 95% confidence intervals) Shannon-Wiener Diversity (H′) at nearfield stations in comparison to threshold limits, 1992 to 2016. The nearfield stations and associated threshold limits are both based on the list of stations sampled following the 2010 revision to the Ambient Monitoring Plan (MWRA 2010).**
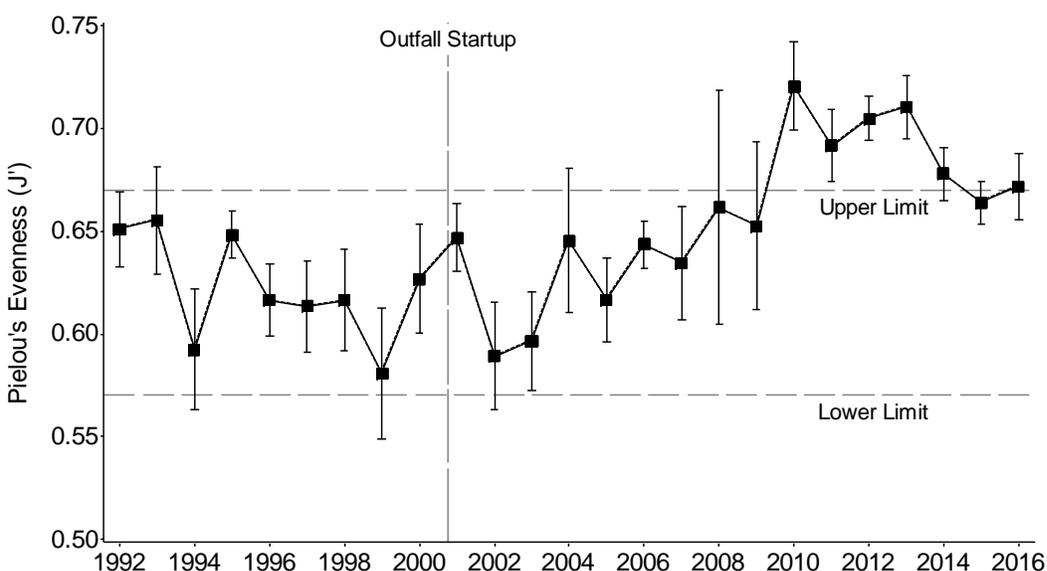
Figure 3-10.   Mean (and 95% confidence intervals) Pielou's Evenness (J′) at nearfield stations in comparison to threshold limits, 1992 to 2016. The nearfield stations and associated threshold limits are both based on the list of stations sampled following the 2010 revision to the Ambient Monitoring Plan (MWRA 2010).

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 (Groups I and II) were identified in a numerical classification of the 14 samples from 2016 (Figure 3-11). An outlier assemblage was found at Station FF04. The main groups were distinguished by total abundance, number of species, and numerically dominant species. The Group II assemblage, with higher abundances and numbers of species than Group I, contained four sub-assemblages (two of them, FF09 and FF01A, were single-sample outliers) that could be differentiated by species composition. All assemblages were mostly dominated by polychaetes (Table 3-4). Both main assemblages occurred at stations within two kilometers of the discharge and were also found at stations more than two kilometers from the discharge (Figure 3-11). Thus, stations closest to the discharge were not characterized by a unique faunal assemblage reflecting effluent impacts.   Station FF04 supported a low abundance, low species richness infaunal community dominated by polychaetes like *Levinsenia gracilis, Anobothrus gracilis,* and *Chaetozone anasimus* that were less abundant at other stations. This community structure reflected the high percent fines that differentiated habitat from other stations and was similar to that observed prior to 2011 at multiple sites in Stellwagen Basin and east of Cape Ann (Maciolek et al. 2008).

Comparisons of faunal distribution to habitat conditions indicated that stations with similar sediment types supported similar faunal assemblages (Figure 3-12). Figure 3-12 illustrates that much of the spatial pattern of association between faunal assemblages and sediment texture can be demonstrated by looking
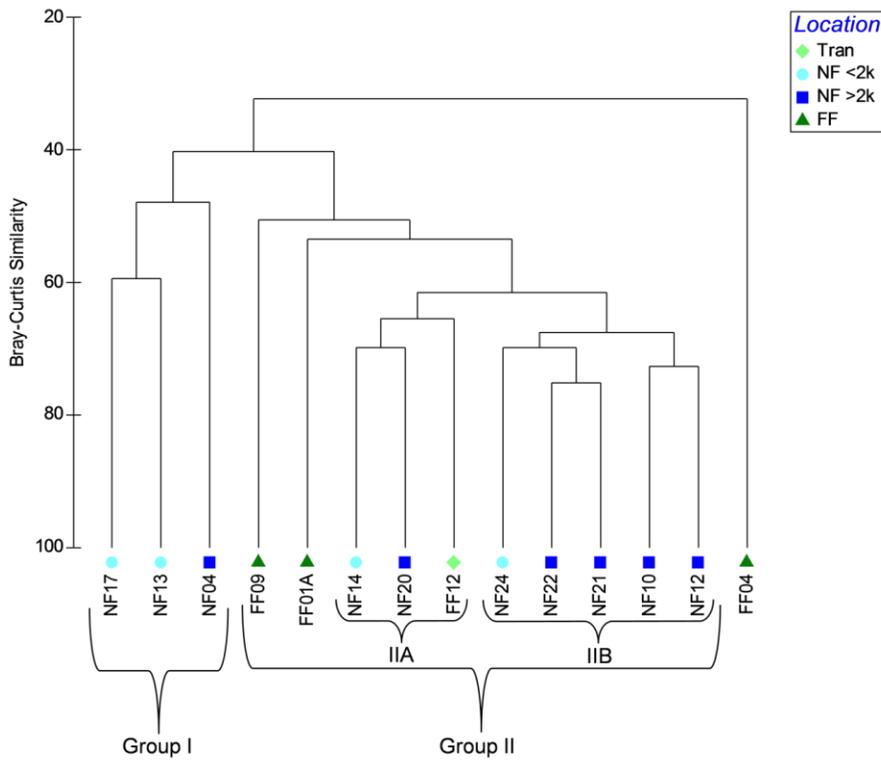
Figure 3-11.   Results of cluster analysis of the 2016 infauna samples.
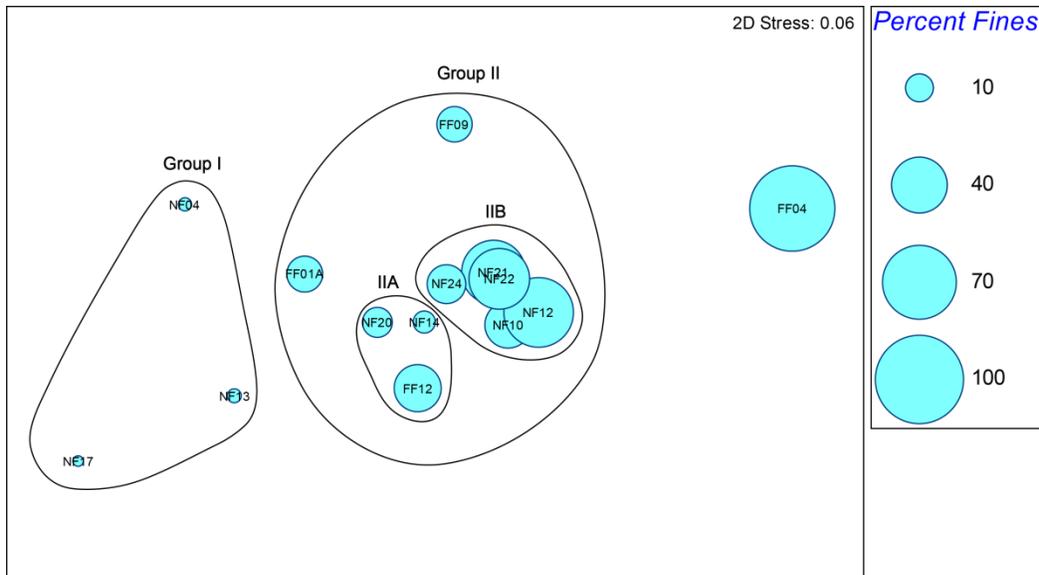
Figure 3-12.   Percent fine sediments superimposed on nMDS ordination plot of the 2016 infauna samples. Each point on the plot represents one of the 14 samples; similarity of species composition is indicated by proximity of points on the plot. Faunal assemblages (Groups I-II, and sub-groups) identified by cluster analysis are circled on the plot. The ordination and cluster analysis are both based on Bray-Curtis Similarity.

Table 3-4. **Abundance (mean # per grab) of numerically dominant taxa (10 most abundant per group) composing infaunal assemblages identified by cluster analysis of the 2016 samples.**

Family	Species	Group I	Group II				FF04
		I	FF09	FF01A	IIA	IIB	FF04
Nemertea							
	Nemertea sp. 12	2.7	43.0	-	9.7	18.0	1.0
Mollusca (Bivalvia)							
Mytilidae	*Crenella decussata*	0.3	47.0	-	-	-	-
Nuculidae	*Nucula delphinodonta*	12.3	80.0	36.0	29.0	13.8	1.0
Periplomatidae	*Periploma papyratium*	-	36.0	4.0	7.7	6.0	1.0
Annelida (Polychaeta)							
Ampharetidae	*Anobothrus gracilis*	0.7	40.0	1.0	3.0	1.6	65.0
Apistobranchidae	*Apistobranchus typicus*	-	2.0	10.0	0.7	4.8	24.0
Capitellidae	*Mediomastus californiensis*	21.7	45.0	52.0	204.7	368.2	24.0
Cirratulidae	*Chaetozone anasimus*	20.0	-	-	0.3	0.4	60.0
	Kirkegaardia baptisteae	9.0	-	82.0	81.0	72.0	-
	Kirkegaardia hampsoni	0.7	-	13.0	42.7	35.6	-
	Tharyx acutus	54.0	20.0	77.0	195.7	274.6	-
Cossuridae	*Cossura longocirrata*	-	2.0	-	0.3	7.0	37.0
Lumbrineridae	*Ninoe nigripes*	-	31.0	6.0	38.3	72.8	26.0
Maldanidae	*Rhodine loveni*	-	33.0	-	0.7	2.2	-
Nephtyidae	*Aglaophamus circinata*	15.7	3.0	41.0	4.3	0.8	-
Orbiniidae	*Leitoscoloplos acutus*	-	6.0	6.0	9.3	63.6	3.0
Oweniidae	*Owenia artifex*	0.7	7.0	20.0	15.0	1.4	-
Paraonidae	*Aricidea catherinae*	138.0	-	25.0	461.7	133.0	-
	Aricidea quadrilobata	0.3	19.0	-	-	4.6	24.0
	Levinsenia gracilis	17.3	78.0	10.0	83.0	226.0	216.0
Polygordiidae	*Polygordius jouinae*	60.7	5.0	23.0	9.3	3.2	-
Sabellidae	*Euchone incolor*	0.7	1.0	15.0	13.7	33.8	13.0
Spionidae	*Prionospio steenstrupi*	4.0	120.0	58.0	135.7	97.6	9.0
	Spio limicola	4.0	76.0	2.0	11.0	32.6	-
	Spiophanes bombyx	25.7	7.0	78.0	39.3	20.0	-
Syllidae	*Exogone hebes*	61.3	31.0	3.0	53.0	11.6	-
	Exogone verugera	19.0	30.0	-	10.3	9.4	-
Arthropoda (Amphipoda)							
Corophiidae	*Crassicorophium crassicorne*	30.0	-	-	-	0.2	-

only at the percent fine (i.e., silt and clay) fraction of the sediments. Although this association with sediment texture exemplifies the link between assemblages and habitat, other, often co-varying factors such as depth, hydrodynamic conditions, and biological factors, are known to influence faunal distributions (Diaz et al. 2004, Snelgrove and Butman 1994). Regardless of the dominant forcing factors, it is clear that patterns in the distribution of faunal assemblages follow differences in habitat types at the sampling stations, consistent with findings from previous years. Multivariate analyses of the 2016 data found no evidence of impacts from the offshore outfall on infaunal communities in Massachusetts Bay.

3.3 Sediment Profile Imaging

Starting in 1992, Sediment Profile Images (SPI) were collected at a set of unconsolidated sediment stations to gather baseline data around the nearfield region where the MWRA offshore outfall would be located (Figure 2-2). The primary reason was to collect data on benthic habitat conditions for infaunal communities and to measure the depth of the apparent color redox potential discontinuity (aRPD) layer as described in the MWRA's Contingency Plan (MWRA 2001). During baseline monitoring, SPI data were collected in six years, in August of 1992 and 1995, and annually from 1997 to 2000. In 2001 the offshore outfall went into operation and annual August SPI data collection continued to document post-diversion conditions in the nearfield region.

The region around the outfall has a complex bottom topography related to the presence of submerged drumlins, geological features produced by glacial drift deposits. Much of the bottom is covered with large boulders with limited areas consisting of unconsolidated pebble to silt-clay sediments (Butman et at. 1992, Nestler et al. 2015). The drumlins tops are at about 25 m depth and the bottoms at 30 to 40 m with nearfield SPI stations ranging in depth from 21 to 37 m. This topography is a major factor controlling wave-bottom stress, bottom stability, sediment transport, and the distribution of sediment types (Butman et al. 2008).

The dominance of physical processes in the nearfield is the principle reason there continues to be no evidence of an outfall effect on benthic habitat quality based on sediment profile imaging (SPI) data from 2001 to 2016. Comparisons between baseline habitat conditions (1992 through 2000) with post-baseline outfall operation conditions (2001 through 2016) showed there have not been any changes in benthic habitat quality within the nearfield region that can be attributed to outfall operation. Post-diversion changes that have occurred appeared to be regional and not associated with outfall operation, but were closely related to major physical disturbance events such as storms. For example, the August 1992 SPI sampling following the severe October 1991 "perfect storm", which was the highest bottom stress winter on record (Butman et al. 2008), documented that much of the nearfield was colonized by pioneering successional stage I species. Large numbers of tubes of spionid polychaetes assemblages were present at 19 of 20 nearfield stations in August 1992 with five stations having assemblages of spionids dense enough to form tube mats (Blake et al. 1993). Mat densities are defined as >5 tubes per linear cm of image or >50,000 tubes per m2. Polychaete tube mats were also observed in the nearfield in July 1984 and August 1987 SPI surveys conducted prior to start of MWRA monitoring, but not in winter surveys of those years (Shea et al. 1991). Shea et al. (1991) found that polychaete tube mats developed in the summer. After summer peaks in benthic populations, mats were broken down with the onset of winter

with declining temperature and increased storm activity. Over the baseline period (1992 to 2000) the occurrence of polychaete tube mats was sporadic. In 1992, 5 of 20 stations had tube mats; no mats were observed in 1995, 1997 or 1998; in 1999, 9 of 23 stations had mats (Figure 3-13); and none again in 2000. A scarcity of mats continued into the post-diversion period with mat densities of polychaetes observed at only four stations in 2001 and then none until a mat appeared at one station (NF16) in 2014. No tube mats were observed in 2015 or 2016 SPI. It also appeared that the species forming the tube mats differed from year to year. For example, distinctive medium-size twisted tubes were widespread at nearfield stations only from 2001 to 2003 (Figure 3-13).

Baseline to post-diversion comparisons showed increases in apparent color redox-potential discontinuity (aRPD) layer depth and Organism Sediment Index (OSI) across the 23 nearfield stations (Table 3-5). The grand average aRPD layer depth for 2016 was among the five highest years of all post-diversion years, extending the aRPD deepening trend that started in 2004 (Figure 3-14). Being among the highest annual averages for post outfall monitoring, the grand mean aRPD layer depth in 2016 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 2016 would be 4.8 cm (SD = 1.73 cm, 7 stations in mean). At 16 of the 23 stations, the aRPD was deeper than prism penetration due to coarse grain-size and high sediment compaction that limited prism penetration. If the depth of prism penetration is used as a proxy for aRPD at those stations, the mean for 2016 would be 3.8 cm (SD = 1.46 cm). From the start of SPI sampling in 1992, the aRPD has always been deeper than could be measured on the image at station NF17 and has only been observed once at NF13 (1992) and NF04 (2008). This was due to the coarseness sediments and high sediment porosity.

From the start of SPI monitoring in 1992 to 2003 the thickness of the measured annual mean aRPD layer remained unchanged with a grand average of 2.2 cm (breakpoint linear regression R2 = <0.01, p = 0.939). From 2004 to 2016 the measured aRPD layer depth was variable but trended deeper by about 0.2 cm per year (breakpoint linear regression R2 = 0.73, p = <0.001) (Figure 3-14). The general nearfield pattern of increasing aRPD depth with time was observed at the five stations (NF08, NF12, NF21, NF22, NF24) with measured aRPD layers every year from the start of annual SPI sampling in 1997 (Figure 3-15). Factors responsible for the depth of the aRPD layer in the nearfield appeared to be acting at regional scales with yearly patterns in aRPD depth reasonably consistent across these five stations. The deepening of the aRPD layer is an indication of continuing high quality benthic habitat conditions over the entire nearfield region. High diversity of benthos also confirms the presence of high quality benthic habitat (Section 3.2). Had outfall operation degraded benthic habitat quality both aRPD layer depth and diversity would had declined (Puente and Diaz 2015).

Sediments continued to be heterogeneous in 2016 ranging from fine-sand-silt-clay to cobble. Variation in grain-size had two components, small-scale heterogeneity within a station and large-scale regional trends. Both sources of variation were at play for baseline or post-diversion years. Year to year, individual stations varied little in modal grain-size patterns. For example, within station variation was consistently high at Station FF10 (Figure 3-16) and low at Station NF12 (Figure 3-17). Sediments appeared to change the most after periods with severe storms. Unfortunately there were no data to assess the effects of the October 1991 "perfect storm", but a May 2005 severe storm that had the second highest bottom stress on

record (Butman et al. 2008) did coincide with a general coarsening of modal grain-size in August 2005. In 2004 the grand average modal Phi for all nearfield stations was 4.4 and in 2005 it was 4.1. This is equivalent to the average nearfield grain-size coarsening from very-fine-silty-sand to very-fine-sand. For example, sediments at Station FF13 changed from fine-sand-silt sediments in 2004 to coarse pebble/cobble in 2005 and remaining so until 2008 when finer sediments occurred. Overall, 9 of 23 stations coarsened from 2004 to 2005 with pebbles more numerous in 2005 relative to 2004. Grain-size analysis also found coarsening of sediments between 2004 and 2005. For example, Station NF12 went from 15% to 26% sand with increased medium-sand and fine-sand fractions. Similarly, NF17 went from 96% to 98% sand with increased coarse-sand and medium-sand fractions (Maciolek et al. 2006). The coarsening of modal grain-size in 2005 was consistent with the higher bottom stress in 2005 from storms (Butman et al. 2008).

In contrast to years between 2006 and 2014 when within station variation in sediment grain-size was low, 2015 was a year of change. At 5 of the 23 nearfield stations sediments appeared to be sandier and coarser in 2015 relative to 2014. For example, modal grain-size at NF02 went from fine-sand-silt in 2014 to fine-medium-sand in 2015 (Figure 3-18). Similarly, NF17 went from fine-medium-sand to medium-sand (Figure 3-19). The overall slightly sandier appearance of sediments in 2015 is consistent with the stormy winter of 2014-2015 (R. Geyer, personal communication). Strong northeasters in October and February, a northwester in March, and a late northeaster in June all mixed the water column to depths greater than the nearfield stations and could have affected surficial sediments by redistributing fine-grained sediments. By August 2016, the coarser grained sands that occurred in 2015 at five nearfield stations (FF12, NF02, NF07, NF10, and NF17) had returned to 2014 estimates at four of those stations. For example, modal grain-size at NF02 went from fine-sand-silt in 2014 to fine-medium-sand in 2015 and back to fine-sand-silt in 2016 (Figure 3-18). Sediments appeared to remain coarser in 2016 only at NF17 which continued to be medium-sand (Figure 3-19). Based on grain-size analysis the average percent fines (silt+clay) at the 11 nearfield stations sampled, declined from 24.2% in 2014 to 22.2% in 2015 and increased again in 2016 to 26.0% (Section 3.1).

At the start of SPI monitoring in 1992, and perhaps even in the late 1980s, it appeared that biological processes were dominant over the nearfield region in structuring surficial sediments. Surficial sediments dominated by biological processes might contain, for example, polychaete tubes or fecal mounds, while physically dominated sediments might have a relatively featureless sediment surface, or show evidence of ripples caused by currents. From 1998 (the first year structuring processes were estimated) to 2000 the odds were in favor of surface sediments being biologically dominated by 10:1 to 22:1 (Figure 3-20). In 2000 only Station NF02 had a physically dominated surface, all other nearfield stations had varying degrees of biological dominance. The year of outfall startup (2001) coincided with a large decline in dominance by biological processes. The dominance of physical processes which started in 2001 was a shift away from the dominance of surficial biogenic structures such as feeding pits and mounds. For example, in 1998 surficial sediments at station FF13 were biologically dominated, from 1999 to 2001 a combination of physical and biological processes dominated, and from 2002 to 2016 physical processes dominated (Figure 3-21). By 2001 the odds biological dominance dropped to less than 2:1 as dominance of physical processes increased. From 2001 to 2014 surface sediments at nearfield stations tended to be dominated by a combination of biological and physical processes. In 2015 the odds shifted to about 3:1

in favor of physical dominance, likely related to the previous winter's storms. In 2016, sediments remained primarily physically dominated, though the odds of physical dominance dropped to about 2:1 (Figure 3-20).

The importance of biological processes continued to decline through time across the nearfield region. Fine-medium-sand Station NF05 provides a good example of this trend (Figure 3-22). The diversity of tube types and sizes remained high from 1995 to 2002. By 2005 tubes were smaller and declined in density as did other biogenic features, such as infaunal and oxic feeding voids, which led to a lowering of estimated successional stage by the early 2010s (Figure 3-23). Not all nearfield stations changed as much through time. At most fine-sand-silt-clay stations a combination of biological and physical processes consistently dominated after 2000, with fewer biogenic structures. Benthic habitat conditions at stations NF08, NF12 (Figure 3-17), NF21, and NF22 have remained the most consistent from 1998 to 2016.

During the baseline period mean aRPD layer depth, including stations where aRPD was deeper than prism penetration, varied from a low of 1.8 cm (SE = 0.13 to 0.14) in 1997 and 1998 to a high of 3.0 cm (SE = 0.22) in 1995 (Table 3-5). The largest deepening of the aRPD layer between successive samplings was 0.5 cm from 1998 to 1999 and appeared associated with an increase in the levels of biogenic activity. The increase in both successional Stage II and Stage III fauna at fine-grained stations in 1998 and 1999 was a key factor in the deepening of the aRPD at those stations. Most of the biogenic activity was related to burrowing organisms that created feeding mounds and pits in the sediment surface, subsurface feeding voids, and to small tube-building worms. Stage II and Stage III fauna were primarily related with the modal sediment grain-size of fine-sand-silt-clay that had the highest organic matter content of nearfield stations and is known to support a high diversity of bioturbating benthos (Rosenberg 2001). Biogenic structures associated with Stage III fauna were abundant from 1998 to 2004 with no downward trend (breakpoint linear regression R2 = 0.01, p = 0.858). Starting in 2005 there was a decline in biogenic structures (breakpoint linear regression R2 = 0.50, p = 0.010), which remained low through 2016, even at fine-sand-silt-clay stations (Figures 3-23 and 3-24). By 2013, evidence of Stage III fauna in SPI declined to a level similar to that found at the start of nearfield monitoring in 1992 (Figure 3-23).

When baseline conditions (1992 to 2000) are compared with post-diversion (2001 to 2016), SPI data exhibit no evidence of any outfall effect on benthic habitat quality (Table 3-5). The most likely change expected from outfall operation would have been an increase in sedimentary organic matter near the outfall, which would drive a shallowing of the aRPD layer. There has not been any increase in organic matter near the outfall or in the nearfield region (Section 3.1). The grand average apparent color redox-potential discontinuity layer (aRPD) for 2016 was the third deepest of all post-diversion years. 2013 was the deepest, 2015 the second deepest, and 2014 the fourth deepest year (Figure 3-14).

From 1992 to 2016, changes and trends in SPI variables at nearfield stations appeared to be related to broader regional forcing factors. 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. The high-energy environment in the region of the outfall disperses effluents quickly and prevents degradation of soft bottom benthic infaunal habitat. The lack of accumulation of organic matter in the sediments is the principle reason for lack of benthic impacts. In general, coastal

ocean sewage outfalls with low or no detectable impacts in benthic infauna are associated with low accumulation rates for organic matter and dominance of high energy physical processes (Puente and Diaz 2015).
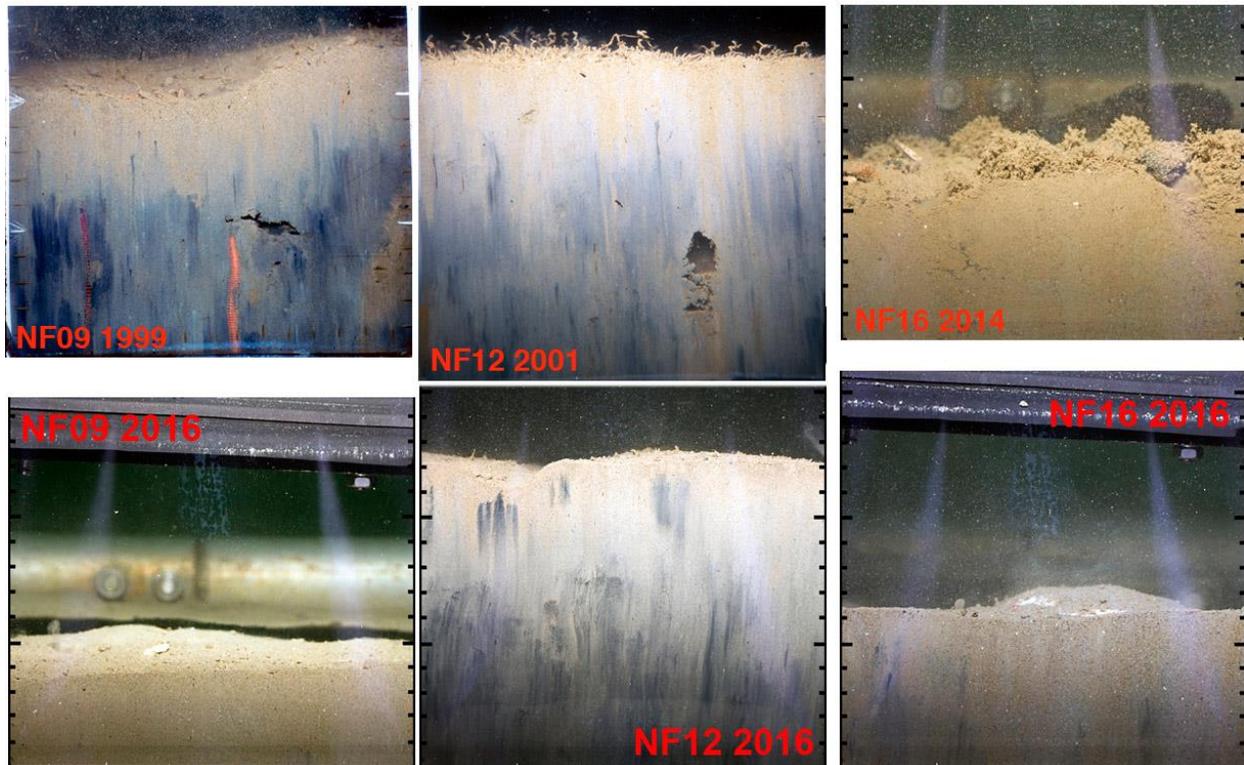
Figure 3-13. Tube mats on sediment surface pre- and post-diversion. Species of tube builders appeared to change through time. 1999 mats are likely similar to tube mats observed in 1992 images and represent the Stage I pioneering species. Medium-size twisted tube at NF12 were widespread at nearfield stations only in 2001 and 2002. Deeper dwelling species and biogenic structures can be seen at NF09 in 1999 and NF12 in 2001 that represent Stage III species. In 2016 surface sediments at these stations tended to be more physically dominated. 1992 images were not available. Scale on side of images is in cm.
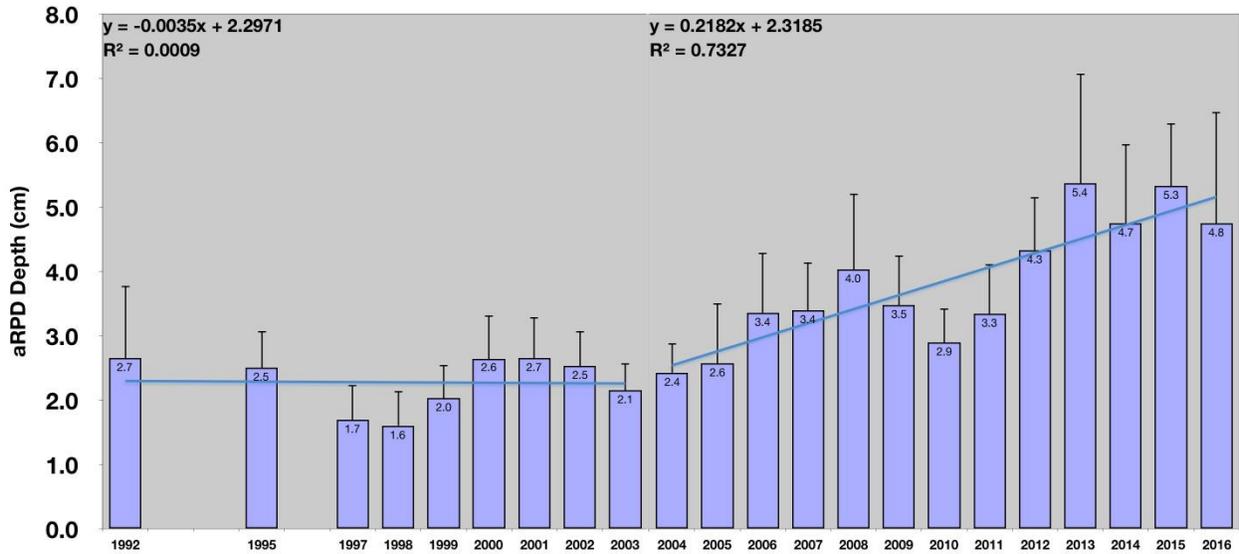
Figure 3-14.   **Average annual aRPD layer depth (cm) for nearfield stations with measured aRPD layers. Bars are one standard deviation. Lines are based on breakpoint linear regression.**
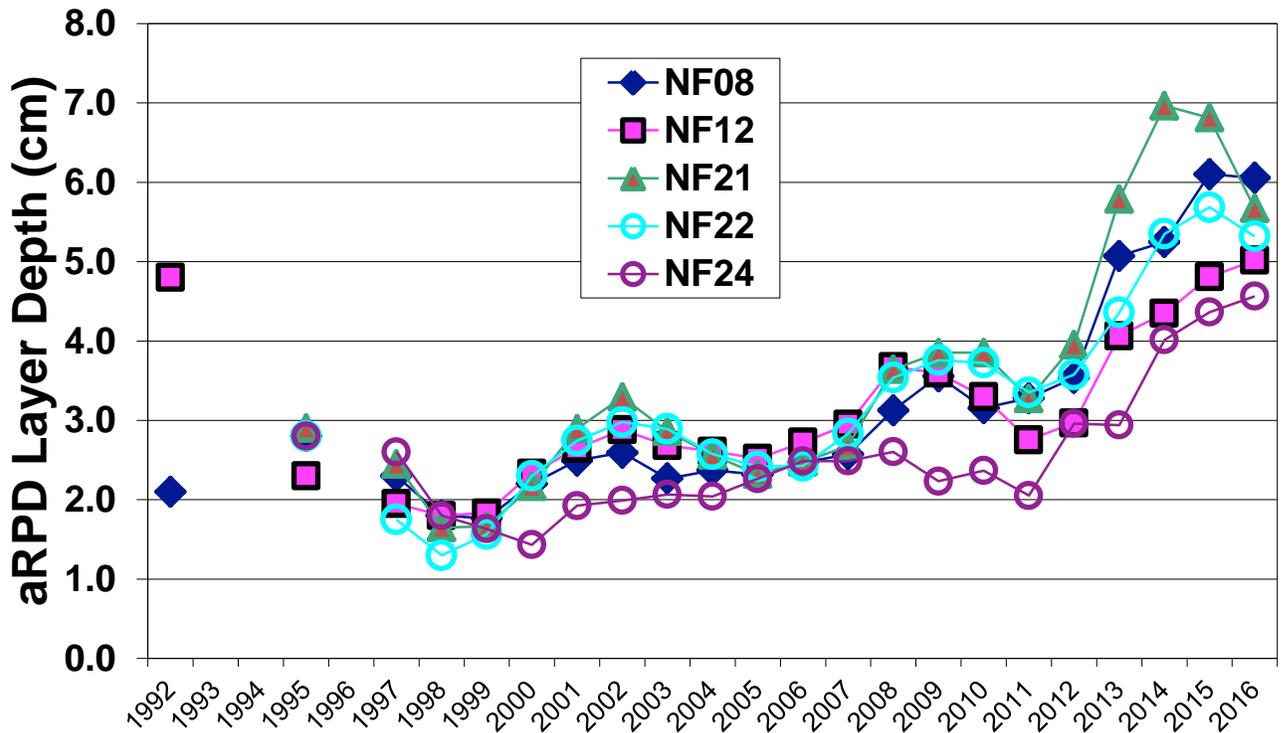
Figure 3-15.   **Average aRPD layer depth (cm) at nearfield stations that had measured aRPD layers every year. Data are annual averages of three images.**
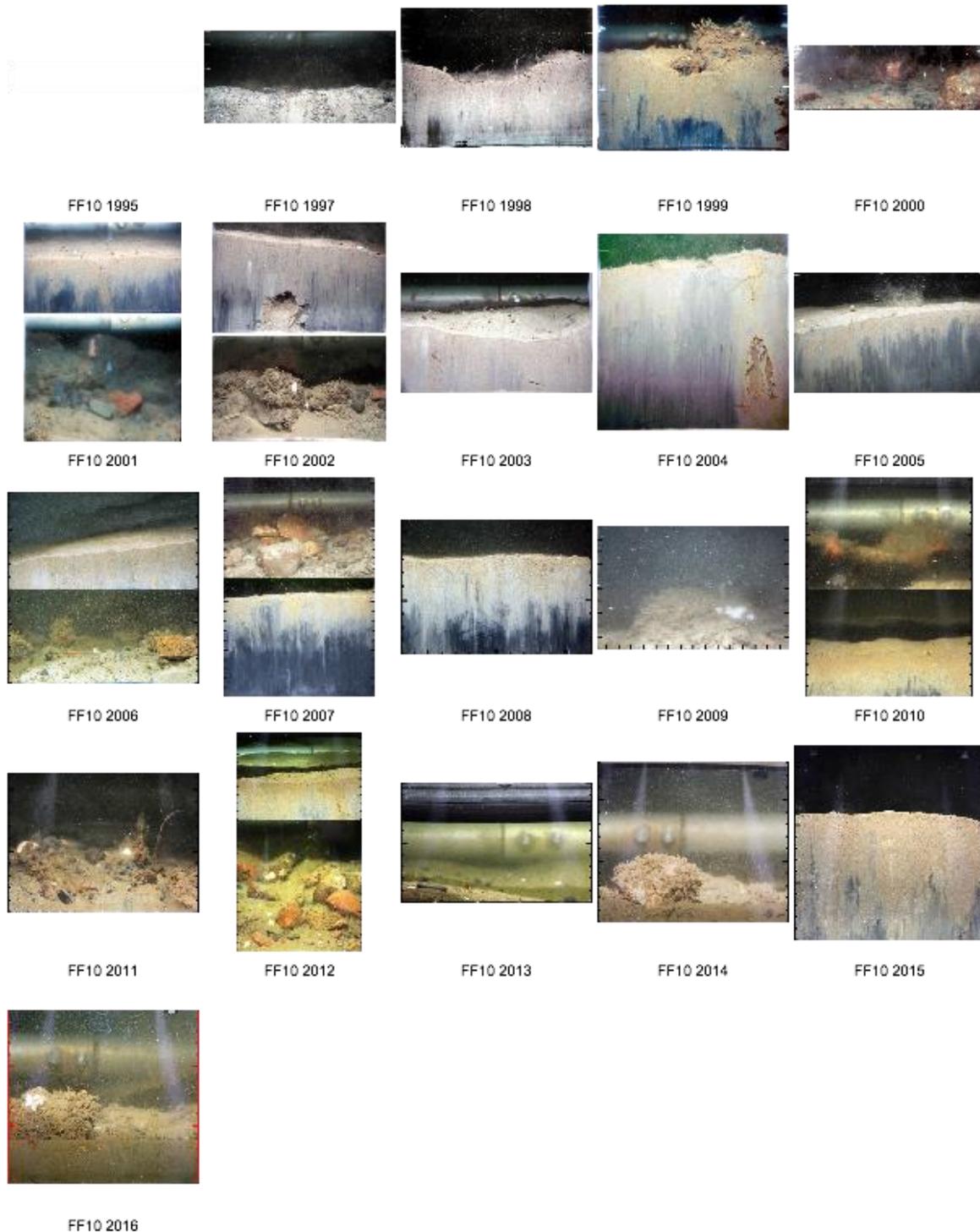
Figure 3-16.   Mosaic of SPI images for Station FF10 that had a high degree of temporal variation in grain-size. Scale on side of images is in cm.
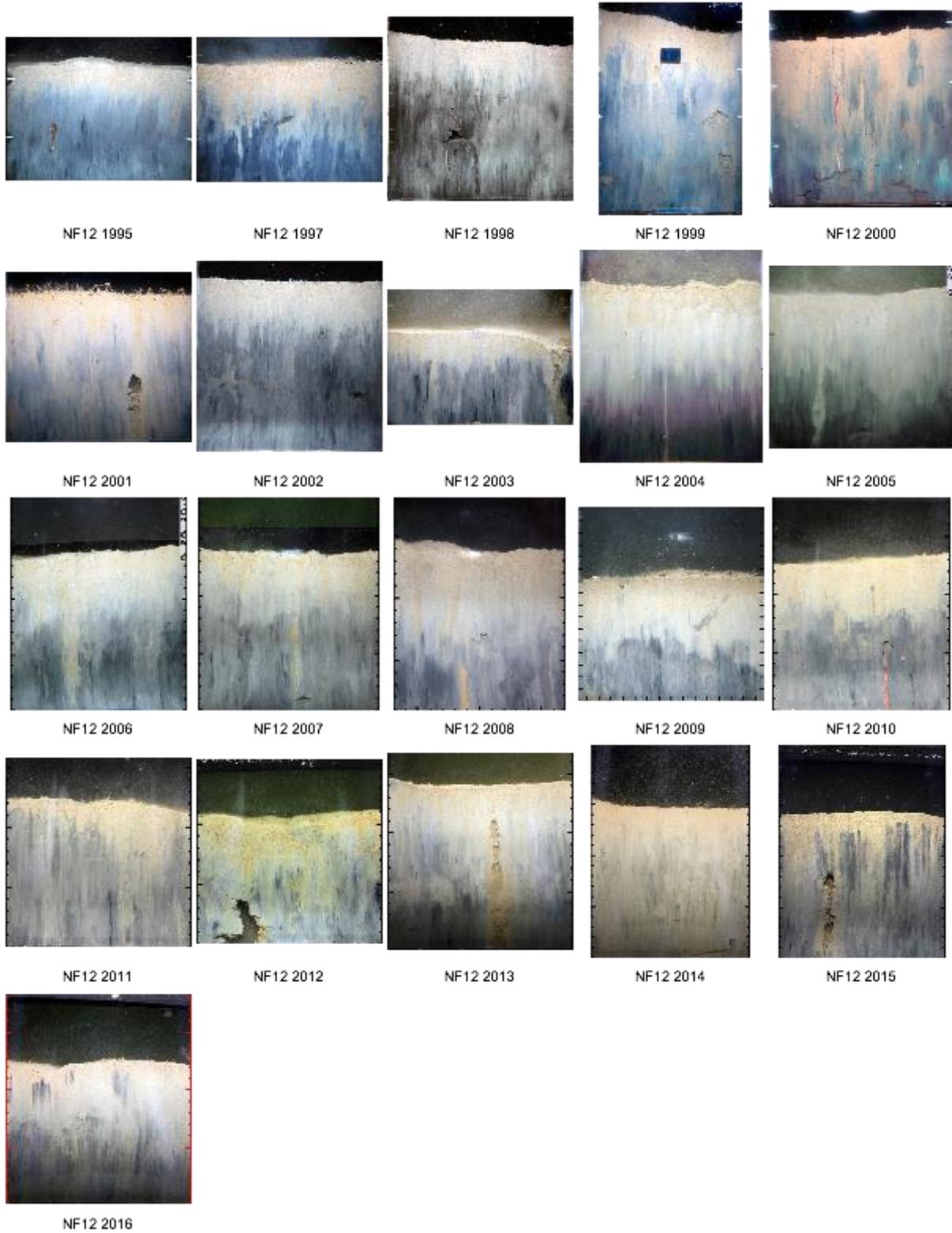
Figure 3-17.   **Mosaic of SPI images for Station NF12 that had little temporal variation in grain-size. Scale on side of images is in cm.**

	92	95	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16
%SI +CL	77	7	7	3	5	9	8	61	10		76		7		7							
Modal	VFS	CS	SI FS	PB GR	FS SI	MS FS	FS SI	FSS I	FS MS	SI F S	SI F S	FSV FS	F S	FS MS	PBGR	FS MS	PB GR	FSM S	FS SI	FS SI	FSM S	FS SI
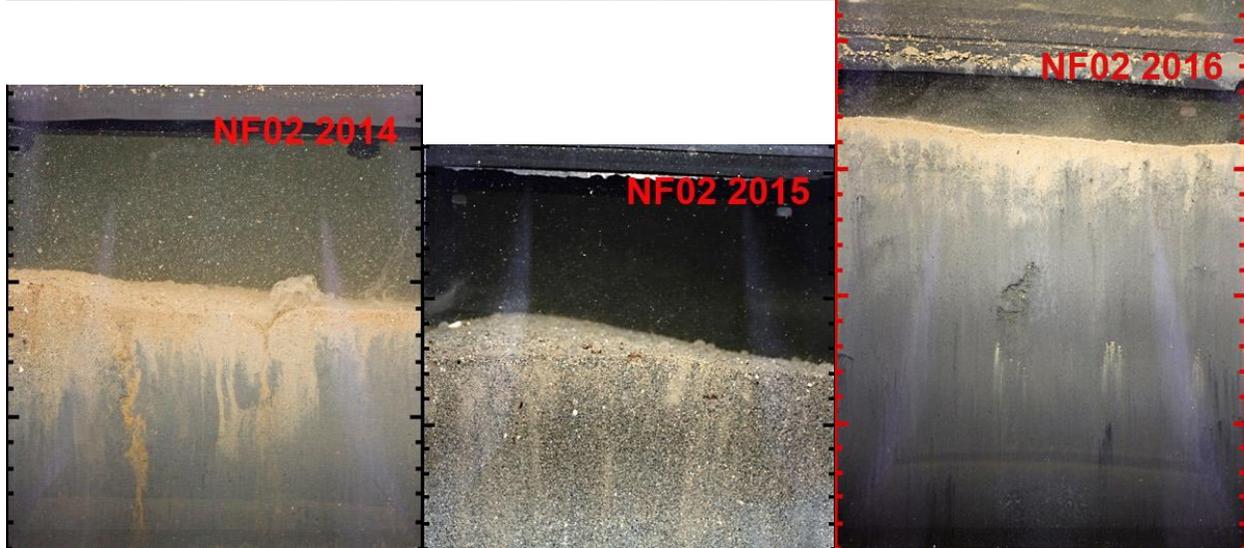
Figure 3-18.   Apparent change in modal sediment grain-size at NF02 from fine-sand-silt in 2014 to fine-medium-sand in 2015, and back to fine-sand-silt in 2016. Percent silt+clay data are from sediment analysis. Modal grain-size is from SPI analysis. CS = coarse-sand, FS = fine-sand, GR = gravel, MS = medium-sand, PB = pebble, SI = silt, and VFS = very-fine-sand. Scale on side of images is in cm.

	92	95	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16
% SI+CL	1	2	2	2	1	2	3	3	2	4	2	2	1	2	4	2	4	3	2	1	2	1
Modal	FS	FS	FS	FS	FSMS	FSMS	FSMS	FSMS	FSMS	FSMS	FSMS	FSMS	FSMS	FSMS	FSMS	FSMS	FSMS	FSMS	FSMS	FSMS	MSFS	MSFS
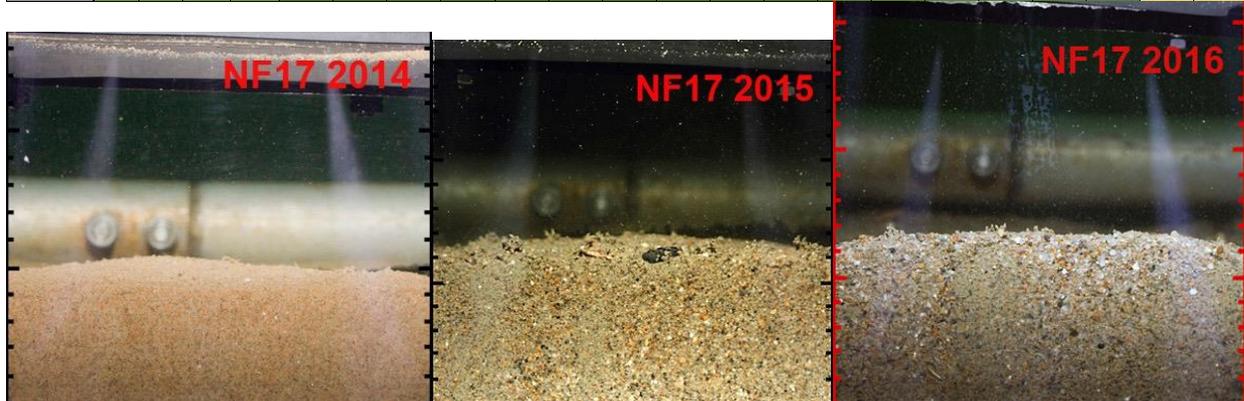
Figure 3-19.   Apparent change in modal sediment grain-size at NF17 from fine-medium-sand in 2014 to medium-fine-sand in 2015 and 2016. Percent silt+clay data are from sediment analysis. Modal grain-size is from SPI analysis. FS = fine-sand, MS = medium-sand. Scale on side of images is in cm.
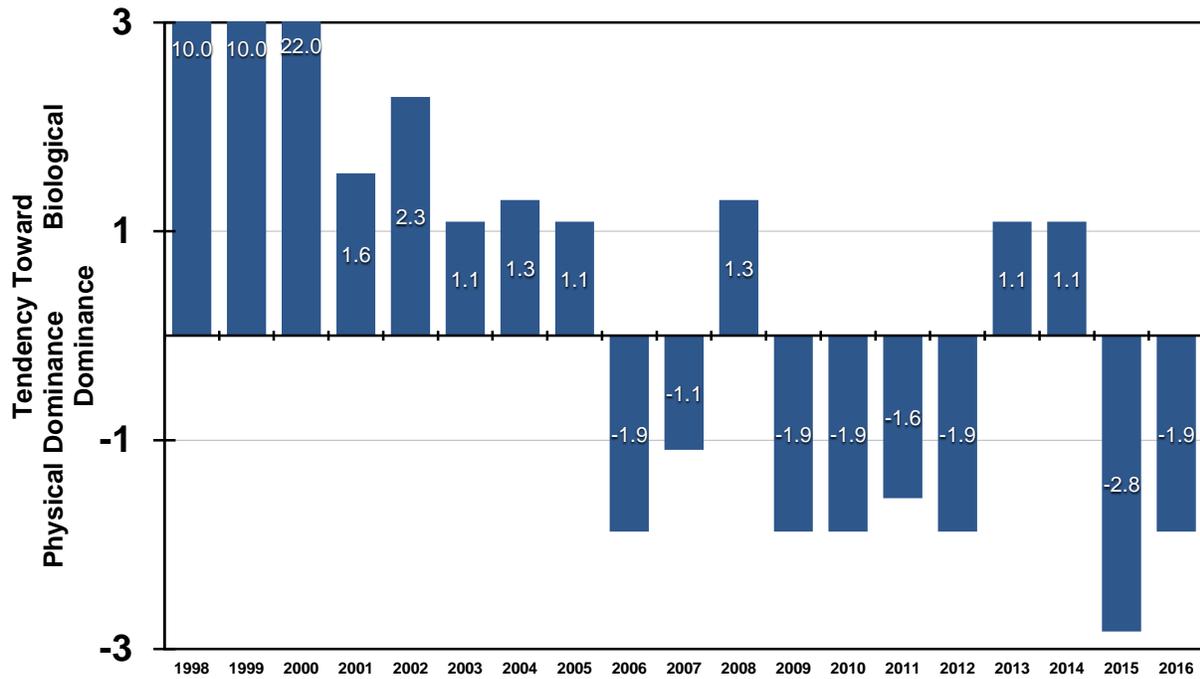
Figure 3-20. **Odds of biological versus physical processes dominance of surface sediments for nearfield stations from 1998 to 2016. Odds of 1 would be an even chance of either physics or biology dominating.**
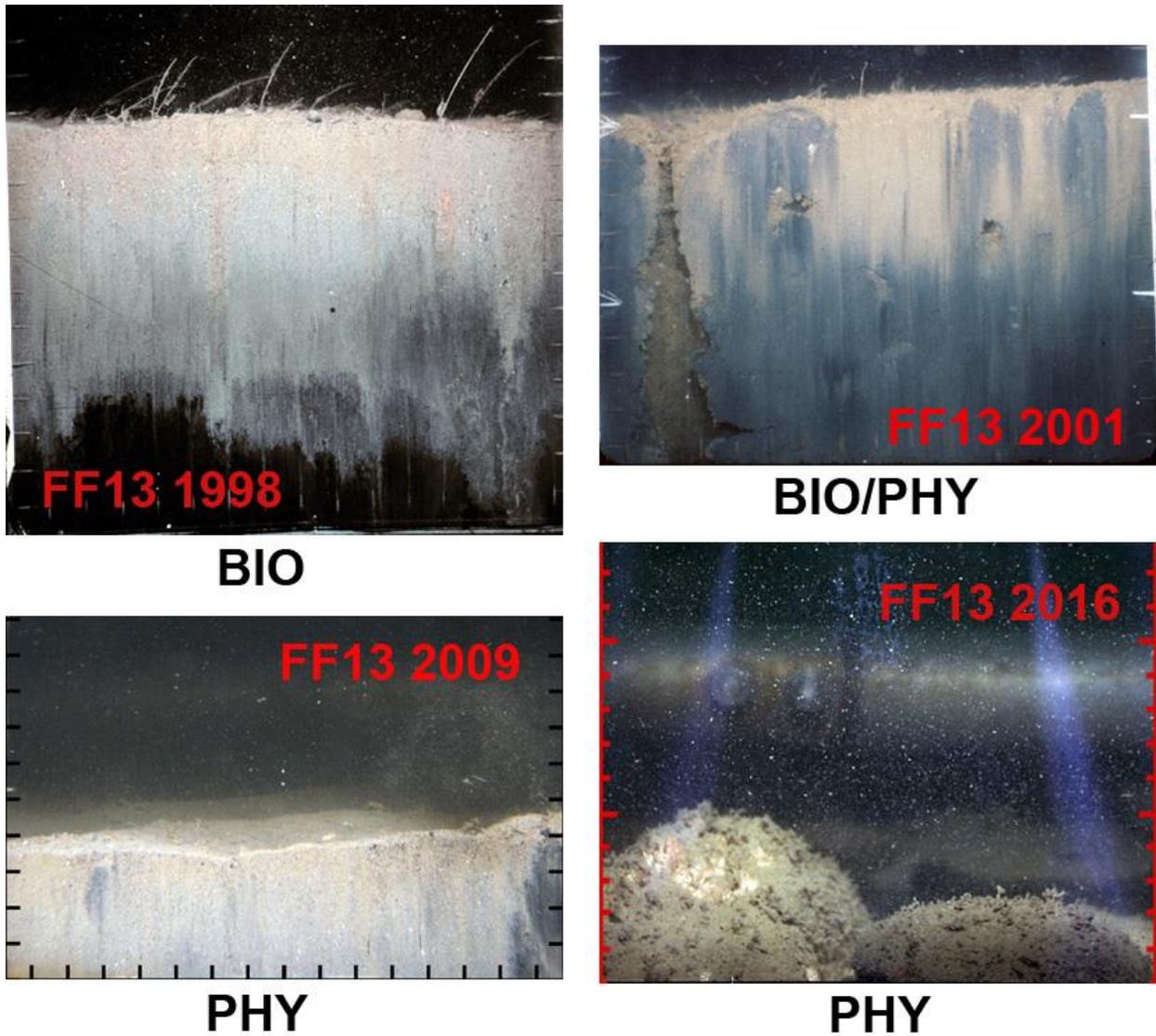
Figure 3-21. Shift in dominance of processes structuring surface sediments at station FF13 through time. BIO = biological dominance, BIO/PHY = combination of biological and physical dominance, PHY = physical dominance. Scale on side of images is in cm.
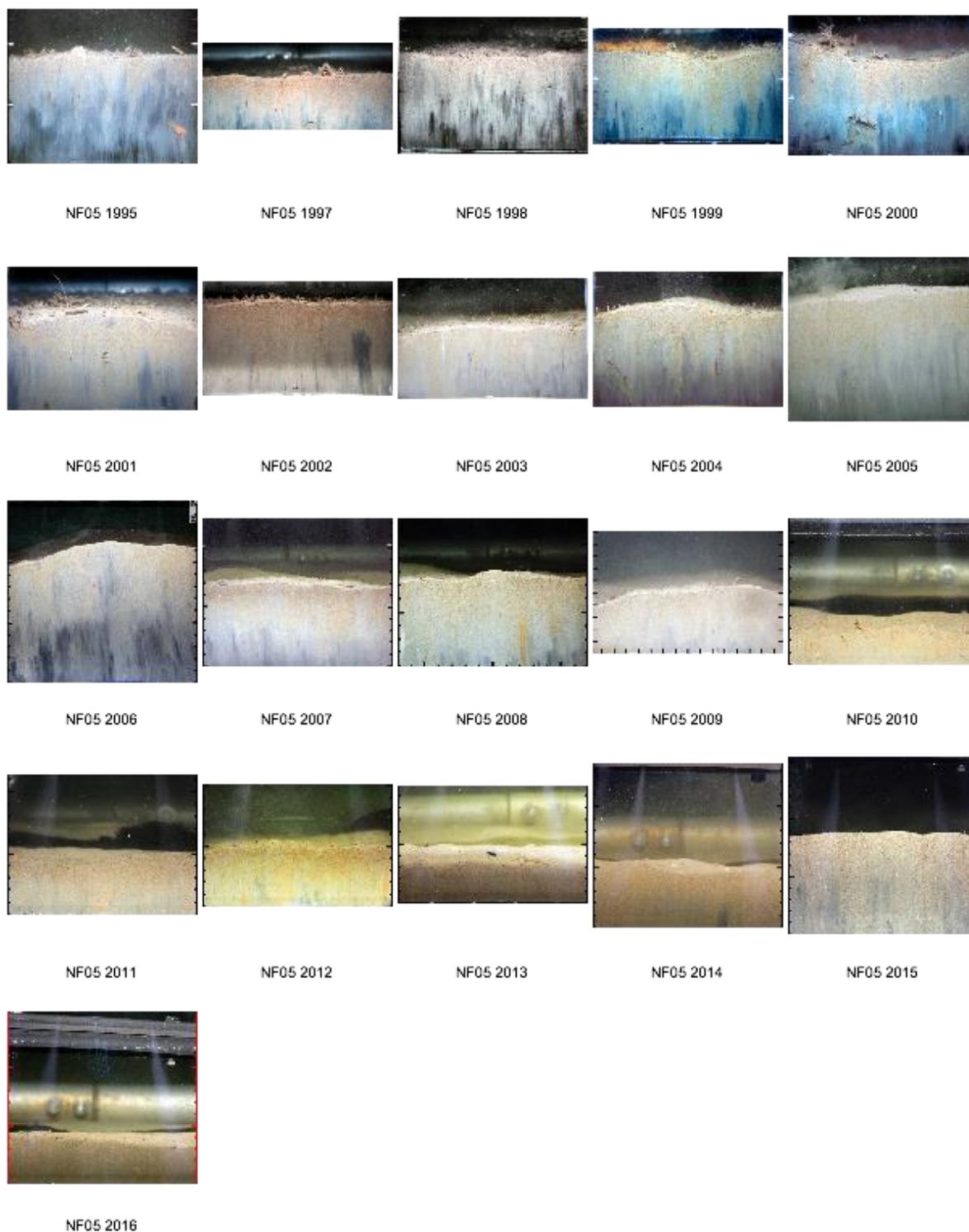
Figure 3-22.   Mosaic of SPI images for Station NF05 where surface sediments were increasingly dominated by physical processes through time. Scale on side of images is in cm.

	1992	1995	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Modal Grain-Size
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	I	I	FSSIGRPB
NF18	I	I	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	I-II	I	FSSIGRPB
NF20	I	I	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	I	I	FSSIGRPB
FF10	I-III		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	I-II	I	FSMSGR
NF14	I	I	I	II-III	II-III	II	I-II	I	I-II	I-II	I	I	I	I	I	I	I	I	I	I-III	I	I-II	FSMSGR
NF15	I	I	I	II-III	II	II	I-II	I-II	I-II	I-II	I-II	I	I	I	I	I	I	I	I	I	I-II	I-II	FSMSGR
NF23		I	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	I	I	FSMSPB
NF04	I	I-II	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	I	I	FSMS
NF05	I	I-II	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	I	I	FSMS
NF13	I	I	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	I	I-II	FSMS
NF17	I	I	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	I	I	FSMS
NF19		I	I-II	I-II	II	II	I-II	I	I	I	I	I	I	I	I	I	I	I-II	I	I	I-II	I-II	FSMS
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	I	I	FS
NF07	I-III	I	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	I-II	I-II	FS
NF09	I-III	I-III	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	I-II	I-II	FS
NF10	I	I-III	I-II	II-III	III	III	II-III	II-III	II-III	II-III	II-III	II-III	II-III	II-III	II-III	I-II	II-III	II-III	I-III	I	I	I-II	FS
NF02	I	I	I-III			I	I-II	I-II	I-II	II-III	II-III	I	I	I	I	I	I	I	I	I	I-II	I-III	FSSI
NF16	I	II-III	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	I	I	FSSI
NF08	I-III	I	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	I-III	I-II	FSSICL
NF12	II-III	I-III	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	I-II	I-III	FSSICL
NF21		II-III	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	I	I-III	FSSICL
NF22		I-III	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	I	I-II	FSSICL
NF24		I	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	I	I-II	FSSICL

Figure 3-23. **Estimated successional stage from nearfield SPI stations arranged from coarsest to finest sediment grain-size. Stage I is representative of a pioneering or opportunistic fauna, Stage II represents intermediate fauna, and Stage III is representative of equilibrium fauna. Combinations of Stages represent the presence of more than one successional stage. Sediment descriptors are: CL - clay, FS - fine-sand, GR - gravel, MS - medium-sand, PB - pebble, SI - silt. Vertical line separates baseline from post-diversion years.**
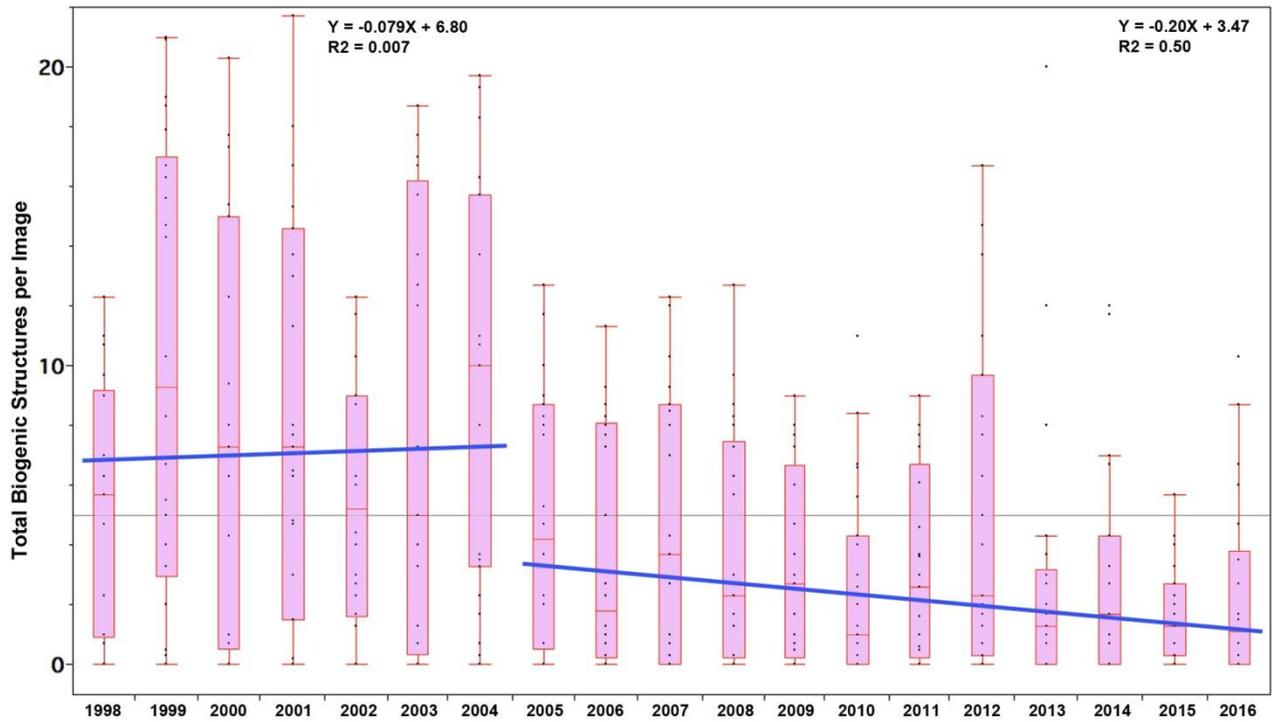
Figure 3-24. Box-plot of total biogenic structures (sum of infauna, burrows, oxic and anaerobic voids) observed in SPI for all nearfield stations. Box is interquartile range (IR = center 50% of observations), line in box is median, tails are 1.5xIR. Horizontal gray line is grand median for all years. Breakpoint regression lines are based on medians.

Table 3-5.   **Summary of SPI parameters for baseline and post-baseline years for all nearfield stations.**

	Baseline Years 1992-2000 9-Year Interval	Post-Baseline Years 2001-2016 16-Year Interval	Only 2016
SS	Advanced from I to II-III	Bimodal: II-III tending to I	Bimodal: I-II and I
OSI - Low	4.8 (1997)	5.8 (2003)	
OSI - High	7.2 (2000)	8.7 (2012)	8.3 (N = 19)
RPD - Low	1.8 cm (1997 and 1998)	2.1 cm (2003)	
RPD -High	3.0 cm (1995)	5.5 (1.33 SD) cm	
Annual Mean RPD Measured	2.2 (0.49 SD) cm	3.6 (1.06 SD) cm	4.8 (1.73 SD) cm N = 7
Annual Mean RPD All Values	2.4 (0.47 SD) cm	3.1 (0.88 SD) cm	3.8 (1.46 SD) cm N = 22

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 2016 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 2016 was greater than reported during the baseline period. The SPI results continued to suggest a trend towards a predominance of a pioneering stage benthic community, a result indicative of an increase in stress on the community. There is no evidence that this stress is caused by organic pollution; for example the infaunal study found that the numbers of opportunistic species remained negligible in 2016. 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. 2016, 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 loads were last monitored in 2014 when testing found no indication that toxic contaminants from the wastewater discharge are accumulating in depositional areas surrounding the outfall (Nestler et al. 2015). No Contingency Plan threshold exceedances for sediment contaminants have occurred to date, including 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 (Nestler et al. 2015). The hard-bottom community was also last monitored in 2014. 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 (Nestler et al. 2015).

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. There were no Contingency Plan threshold exceedances for any infaunal diversity measures in 2016. Exceedances had been reported for Shannon-Wiener Diversity (H') and Pielou's Evenness (J') each year from 2010 to 2014. The previous exceedances for H' and J' were upper limit exceedances, based on values that were higher than during the baseline period. Values for H' and J' in 2015 were just below the upper threshold limits for both parameters; in 2016 H' was below the upper threshold limit and J' was equal to the upper threshold limit. Previous analyses of these parameters suggested that recent increases in H′ and J′ were region-wide phenomena, unrelated to the discharge, which were largely driven by relatively lower abundance in a small number of dominant species. Based on these findings, MWRA received concurrence from the

OMSAP that upper diversity triggers were not necessary for inclusion in the infaunal Contingency Plan thresholds and a request for their removal has been submitted to the U.S. EPA. The numbers of dominant species in the 2016 samples remained relatively low.

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, no corresponding changes to sediment composition and infaunal communities have 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. A region-wide shift towards higher diversity and lower dominance in the Massachusetts Bay infaunal assemblages was highlighted by diversity threshold exceedances during 2010 to 2014. Although there were no threshold exceedances in 2016, diversity and evenness remained relatively high. 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 2016

Appendix A1. 2016 Harbor and Outfall Monitoring: Sediment Conditions and Benthic Infauna

Harbor and Outfall Monitoring: 2016 Sediment conditions and Benthic Infauna

MWRA Technical Workshop
Eric Nestler, Normandeau

April 6, 2017

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PRESENTATION OVERVIEW

Massachusetts Bay and Boston Harbor

- Sediment conditions
  - *Clostridium perfringens*, grain size, TOC
- Benthic infauna
  - Community parameters
  - Infaunal assemblages - spatial patterns

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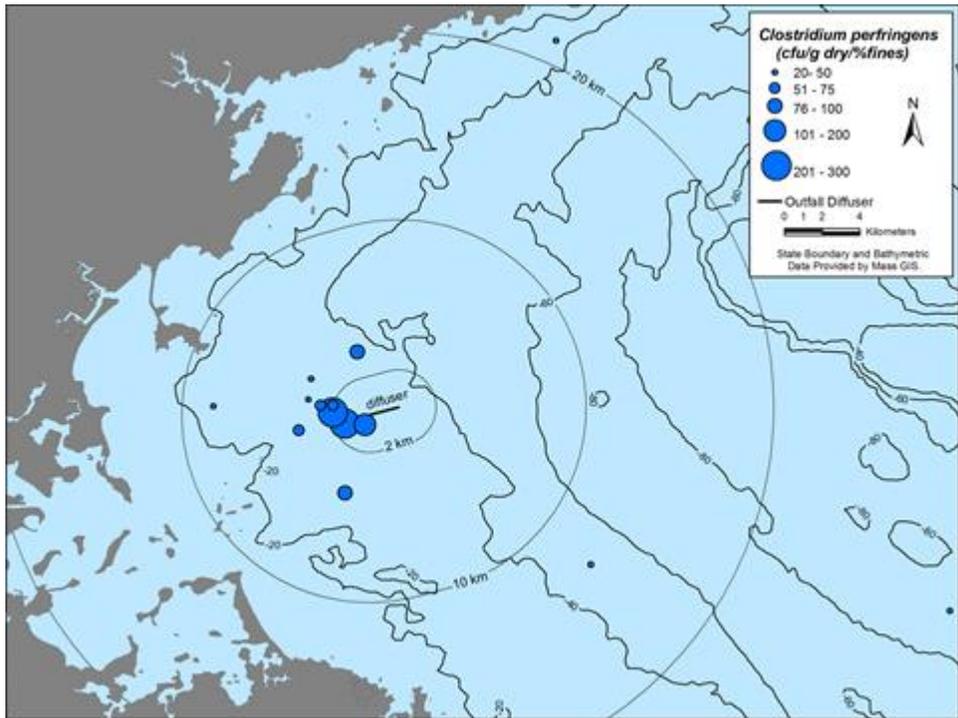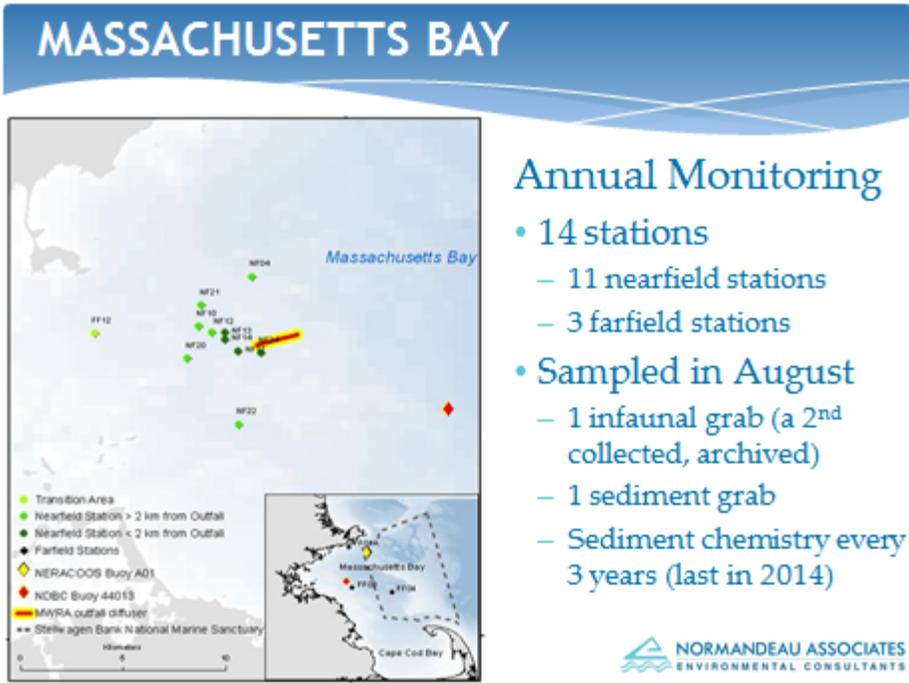
Clostridium perfringens (BY REGION)

2016 SEDIMENT GRAIN SIZE

PERCENT FINES (SELECTED STATIONS)

TOTAL ORGANIC CARBON (BY REGION)

TOTAL ORGANIC CARBON
(SELECTED STATIONS)
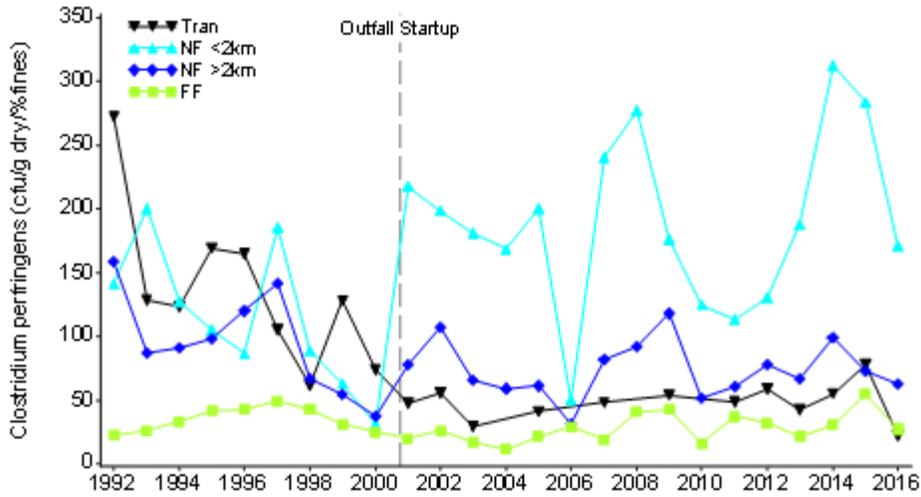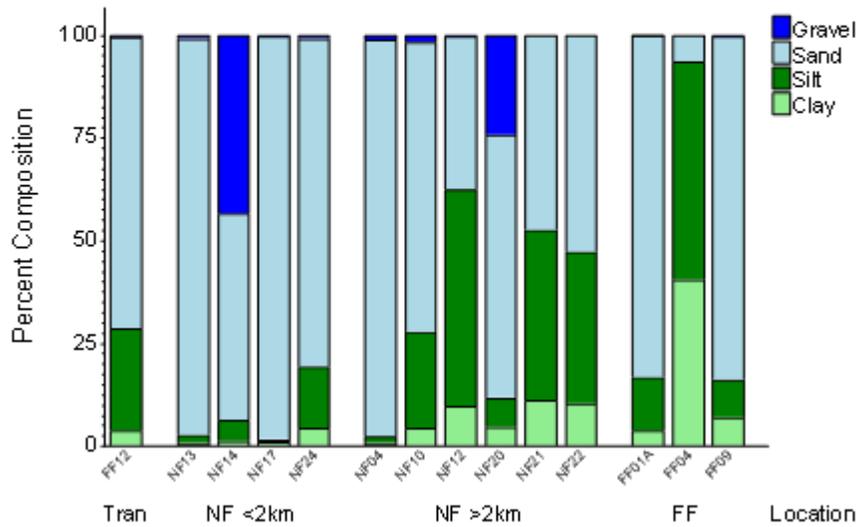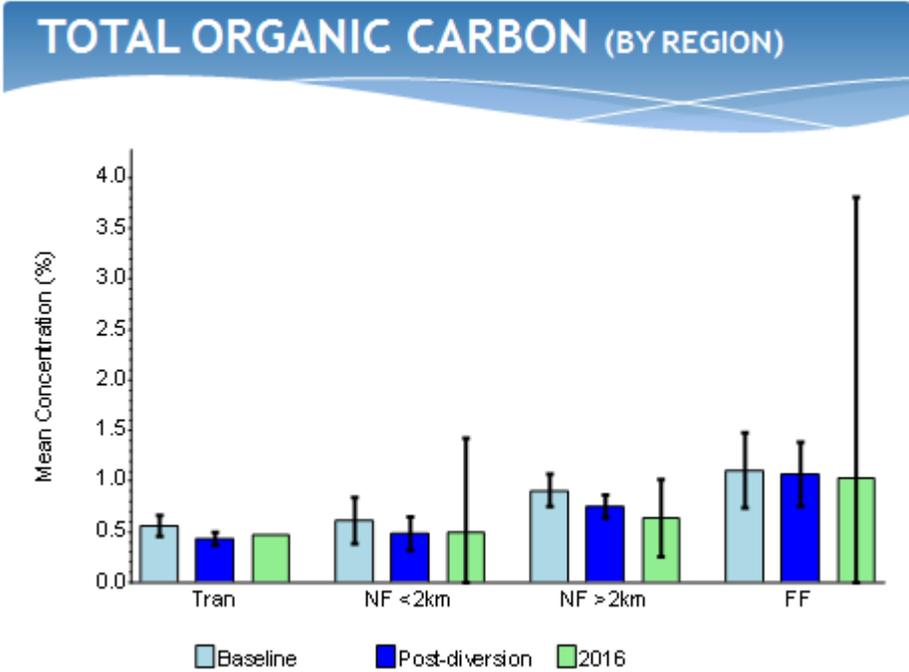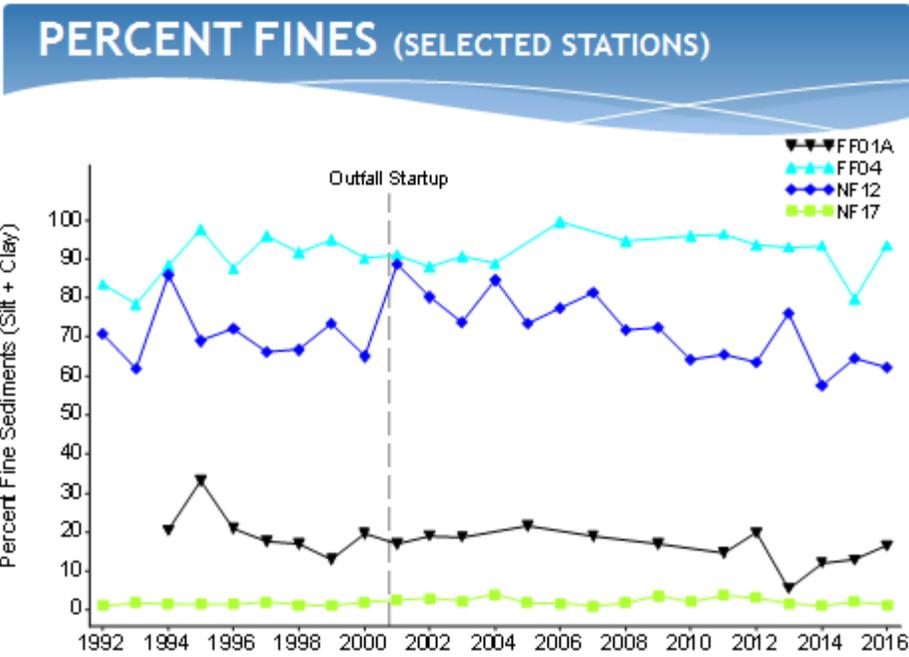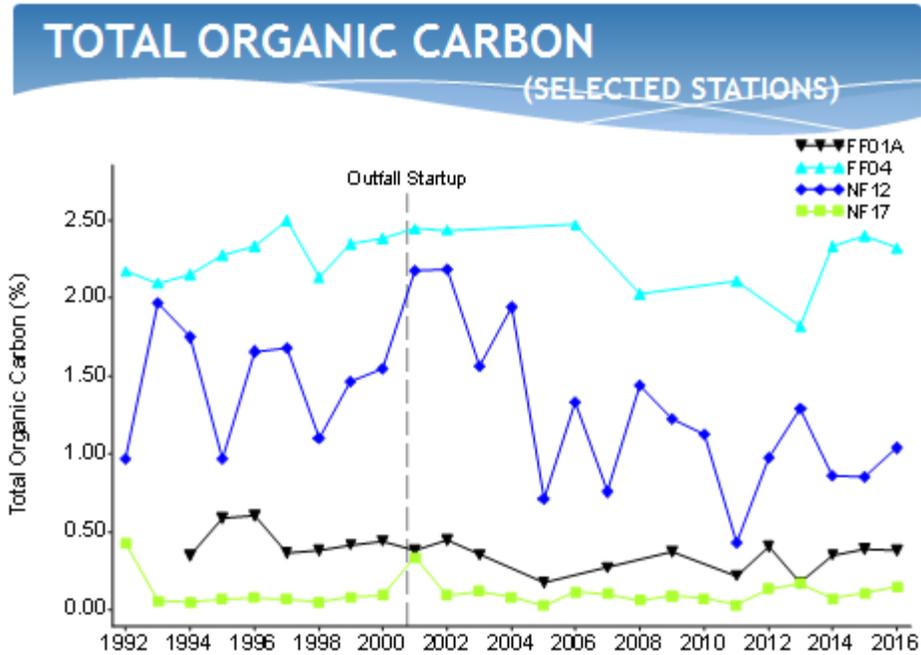
MASSACHUSETTS BAY: BENTHIC INFAUNA

- Totals for 14 samples in 2016:
  - 18,077 individual organisms (20,341 in 2015)
  - 196 taxa identified; 175 species and 21 higher taxonomic groups (186 taxa total and 164 species in 2015)
  - All counts used for abundance
  - Only species-level counts used for diversity measures and multivariate analyses

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

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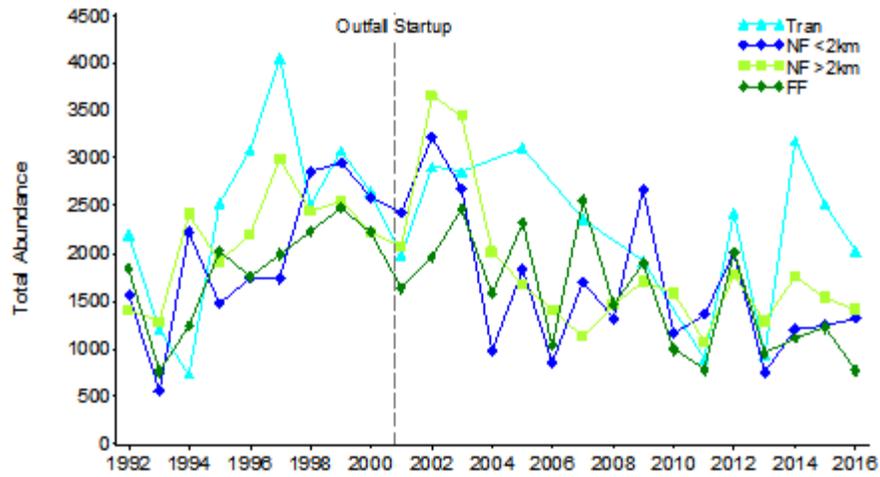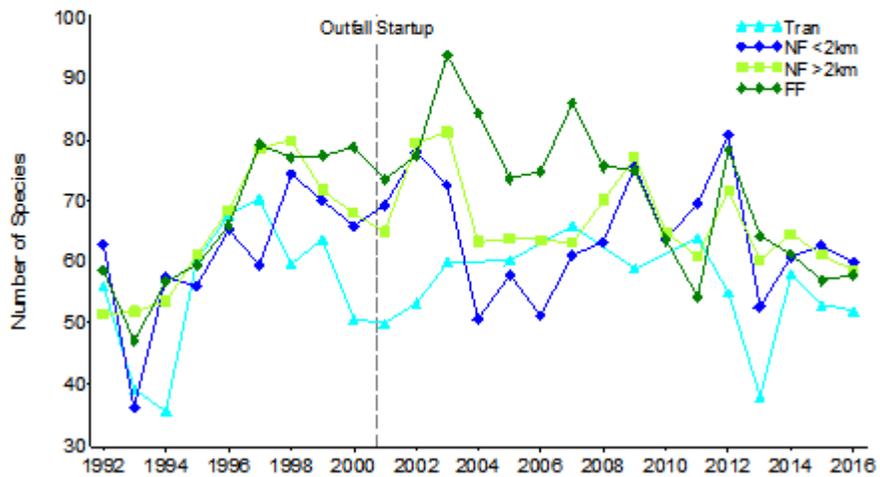
CONTINGENCY PLAN THRESHOLDS:
(NF STATIONS ONLY)

- No threshold exceedances in 2016.

- Exceedances for Shannon-Wiener Diversity (H′) and Pielou's Evenness (J′) were reported each year from 2010 to 2014.

- No exceedances in 2015 or 2016 for: H′, J′, total species, log-series alpha, or percent opportunists.
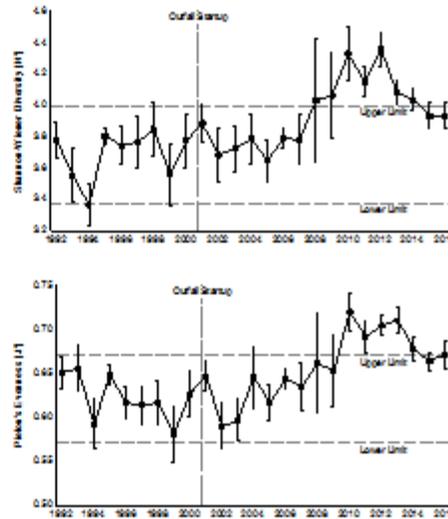
2016 INFAUNAL ASSEMBLAGES
MASSACHUSETTS BAY
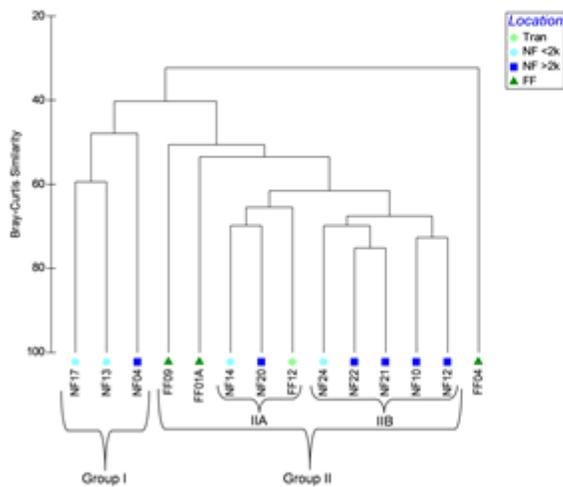
- Cluster Analysis:
  - Assess spatial patterns in the distribution of faunal assemblages
  - 2016 Samples
  - Bray-Curtis Similarity

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ORDINATION PLOT: 2016 SAMPLES
LOCATION OVERLAY

2D Stress: 0.06

Location
- ◆ Tran
- ● NF <2k
- ■ NF >2k
- ▲ FF

Group II

FF09

Group I

NF04

FF04

IIB

FF01A

NF24 NF21 NF22

IIA

NF20 NF14   NF10 NF12
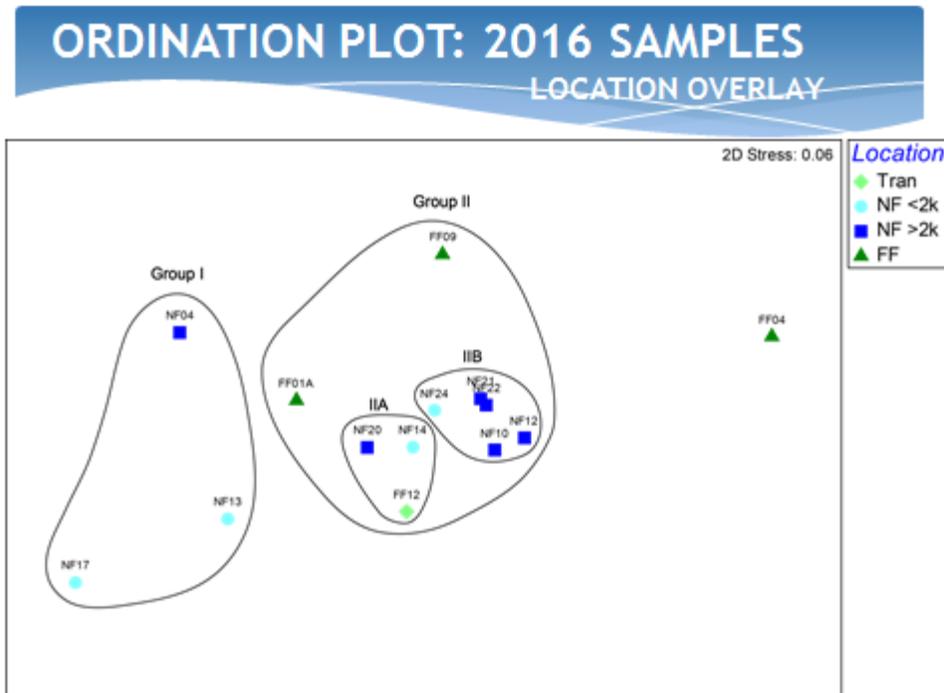
NF13

FF12

NF17

2016 INFAUNAL ASSEMBLAGES
MASSACHUSETTS BAY

- Group I: NF17, NF04, NF13 (sand)
  - *Aricidea catherinae, Exogone hebes, Polygordius jouinae*

- Group IIA: FF12, NF14, NF20 (sand with fines, gravel)
  - *A. catherinae, Mediomastus californiensis, Tharyx acutus*

- Group IIB: NF10, NF12, NF21, NF22, NF24 (fines with sand)
  - *M. californiensis, T. acutus, Levinsenia gracilis*

- FF09, FF01A (sand, some fines; FF09 is deeper)
  - *Prionospio steenstrupi, Nucula delphinodonta, Kirkegaardia baptisteae*

- FF04 (fines; deepest)
  - *L. gracilis, Anobothrus gracilis, Chaetozone anasimus*

TOTAL ORGANIC CARBON
(SELECTED STATIONS)

BOSTON HARBOR: BENTHIC INFAUNA

- Totals for 18 samples in 2016:
  - 32,348 individual organisms (33,058 in 2015)
  - 142 taxa identified; 129 species and 13 higher taxonomic groups (142 taxa total, and 129 species in 2015)

- All counts used for abundance; only species-level counts used for diversity measures and multivariate analyses

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CLUSTER ANALYSIS: 2016 SAMPLES
BOSTON HARBOR

ORDINATION PLOT: 2016 SAMPLES
BOSTON HARBOR

INFAUNAL ASSEMBLAGES

BOSTON HARBOR

– Group I: T08 (outer Harbor, sand)
  ▪ *Polygordius jouinae, Clymenella torquata, Angulus agilis*

– Group II: T01, T02, T03, T05A, T06 , T07 (outer and mid-Harbor, mixed sediments)
  ▪ *Aricidea catherinae, Polydora cornuta, Limnodriloides medioporus*

– Group III: C019 (Inner Harbor, fines)
  ▪ *P. cornuta, Tubificoides intermedius, Streblospio benedicti*

– Group IV: T04 (Savin Hill Cove, fines, organic enrichment, shallow – 4 meters)
  ▪ *S. benedicti, Tubificoides sp. 2*

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COMMUNITY PARAMETERS

HARBOR STATIONS T01, T08, T04, & C019
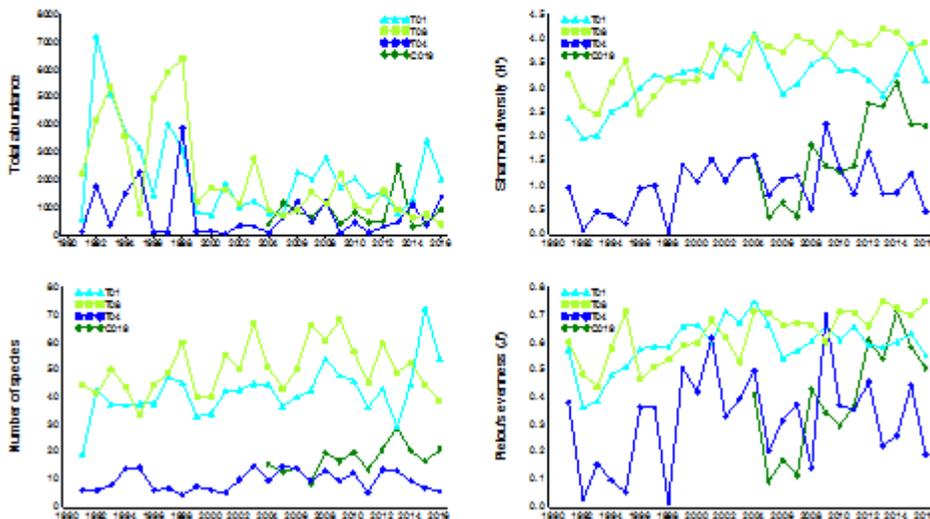
BOSTON HARBOR: SUMMARY

- Sediment conditions
  - Reductions in loading have resulted in improvements at most stations.

- Benthic infauna
  - Faunal communities remain consistent with communities found during recent past years in the post-recovery period.
  - Faunal distributions reflect differences along an inner to outer-Harbor gradient (tidal flushing).

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ACKNOWLEDGEMENTS

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  - 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

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Appendix A2.   2016 Harbor and Bay Sediment Profile Imaging
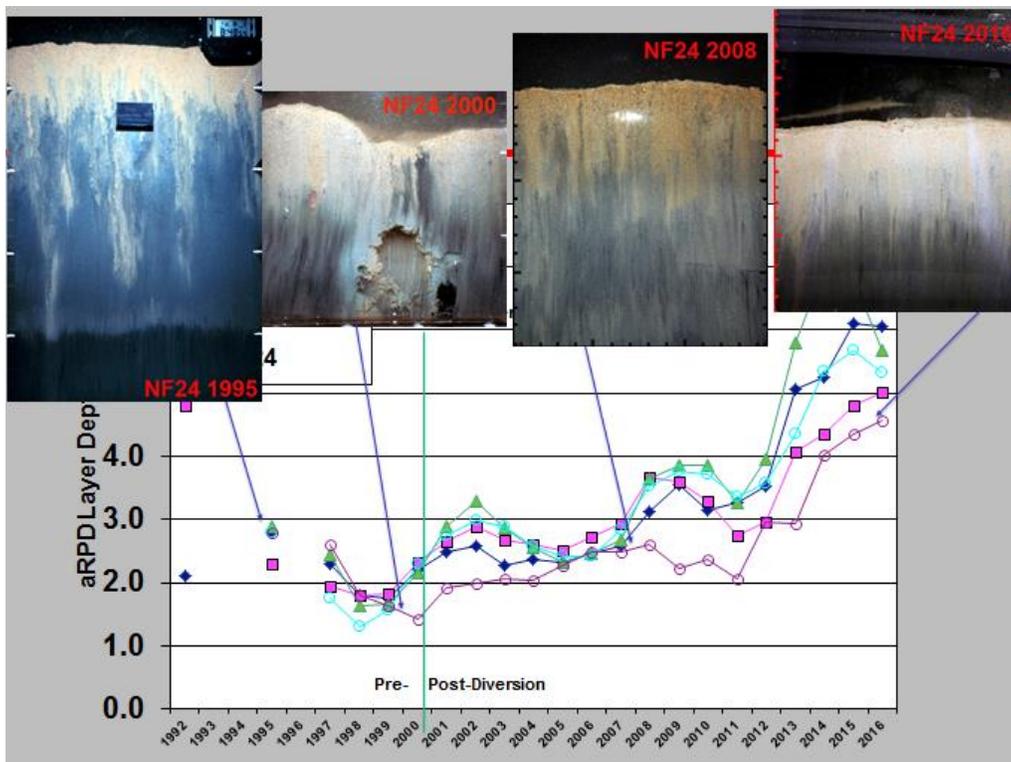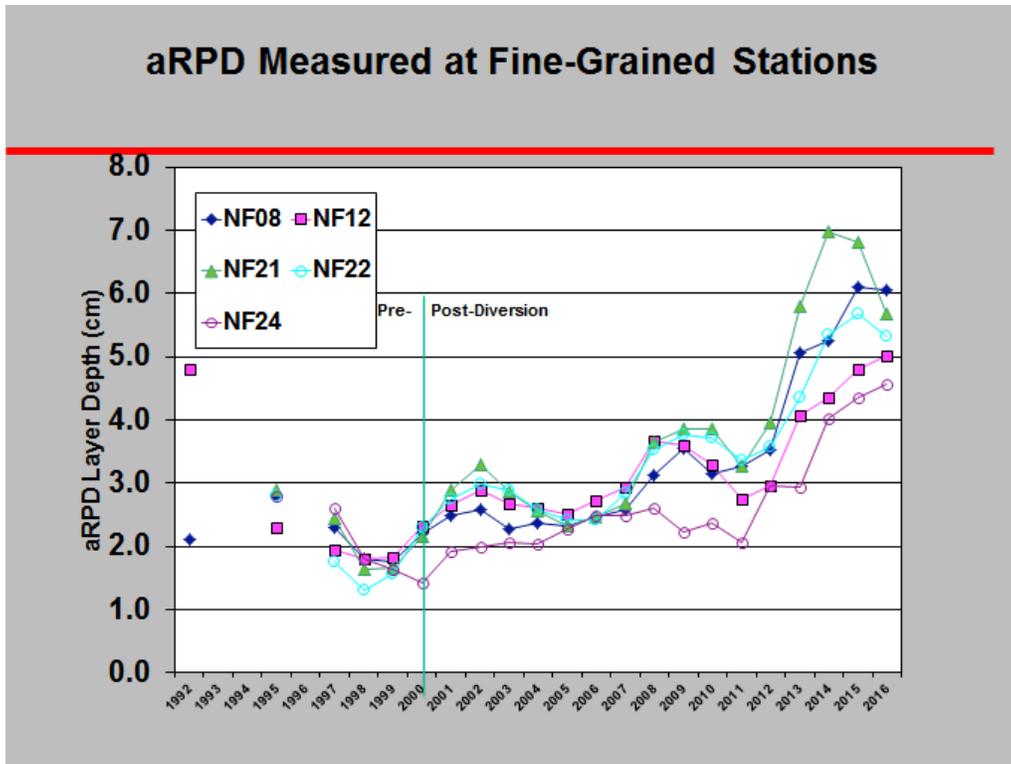
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