Outfall Benthic Monitoring Report: 2015 Results

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EXECUTIVE SUMMARY

Benthic monitoring during 2015 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, *Clostridium perfringens* concentrations during 2015 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. 2015, Maciolek et al. 2008).

Results of the 2015 monitoring provided no evidence of impacts from the offshore outfall on infaunal communities in Massachusetts Bay. These results continue to suggest 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 2015. 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 2015 were just below the upper threshold limits for both parameters. Previous analyses of threshold exceedances suggested that it may be appropriate to revisit the need for upper diversity triggers for MWRA’s infaunal Contingency Plan thresholds (Nestler et al. 2015). Multivariate analyses indicated that patterns in the distribution of faunal assemblages follow differences in habitat types at the sampling stations. Infaunal data in 2015 continue to suggest that the macrobenthic communities at sampling stations near the outfall have not been adversely impacted by the wastewater discharge.

The 2015 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 2015 was greater than during the baseline period, and 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. 2015, 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 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 fifteen-year post-diversion period (2001–2015). 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 2015 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). 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 2015 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 2015 benthic monitoring were presented at MWRA's Annual Technical Workshop on April 14, 2016. PowerPoint presentations from this workshop are provided in Appendix A.

2. METHODS

Methods used to collect, analyze, and evaluate all sample types remain consistent with those reported for previous monitoring years (Nestler et al. 2015, 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 12, 2015 (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, 2015 (Figure 2-2).

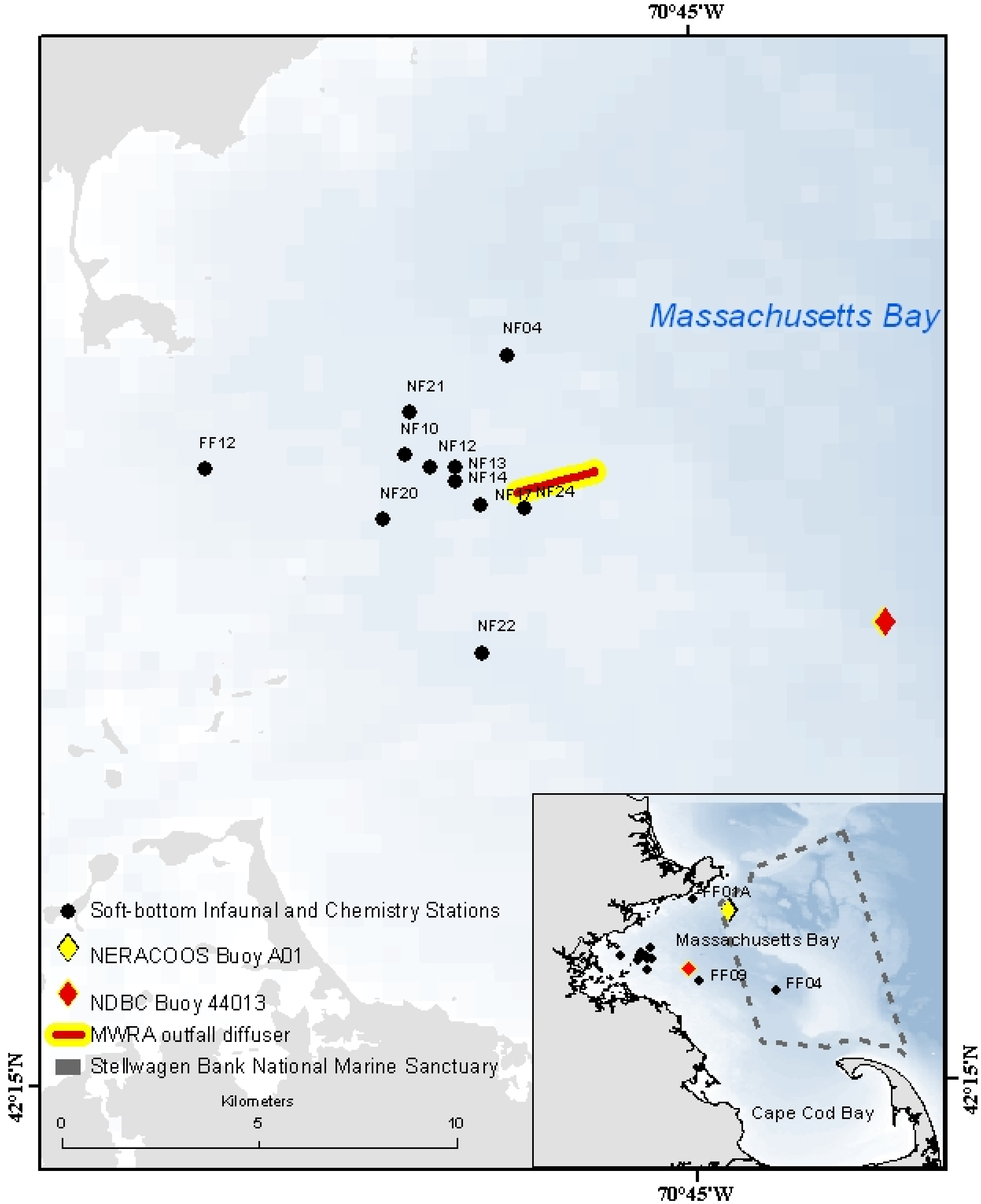


Figure 2-1. Locations of soft-bottom sampling stations for 2015.

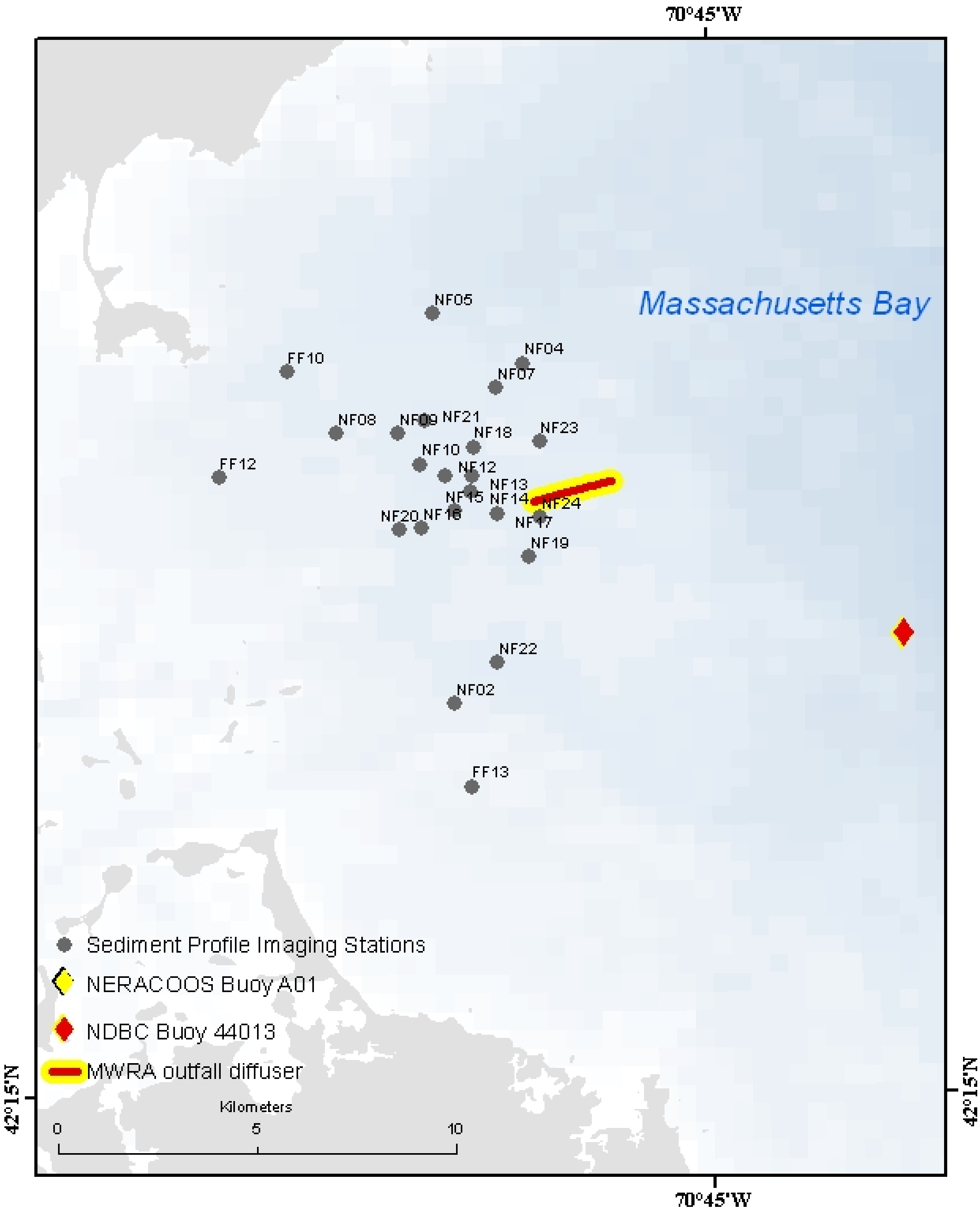


Figure 2-2. **Locations of sediment profile imaging stations for 2015.**

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 2015 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 2015 were highest at stations NF17, NF14, NF13, and NF24 (Table 3-1); the four 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., NF17, NF04, and NF13) to mostly silt and clay (i.e., FF04), with many stations having mixed sediments (Table 3-1, Figure 3-3). This variability in sediment composition reflects differences in habitat (e.g., hydrodynamic conditions and substrate) among the sampling locations, which have not changed substantially over time. Evidence of this is provided by the percent fine sediment, which has remained generally consistent over time within monitoring areas (Figure 3-4). Despite this consistency, year-to-year variability related to storm activity has been seen in some years (Nestler et al. 2015). 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 total organic carbon (TOC) in 2015 remained similar to values reported in prior years within monitoring areas (Figure 3-5). Concentrations of TOC track closely to percent fine sediments (i.e., silt + clay), with higher TOC values generally associated with higher percent fines (Maciolek et al. 2008). 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 2015 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. 2015, Maciolek et al. 2008).

Table 3-1. 2015 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**	77.8	0.35	0.9	80.9	13.5	4.8	18.3
Nearfield (<2 km from outfall)	**NF13**	258.5	0.18	0.4	95.7	2.0	1.9	3.9
	NF14	356.8	1.49	39.8	55.5	2.9	1.8	4.7
	NF17	386.3	0.11	0.1	97.7	0.7	1.5	2.2
	NF24	132.4	0.94	0.2	48.9	41.9	9.0	50.9
Nearfield (>2 km from outfall)	**NF04**	99.1	0.06	0.6	96.0	1.6	1.8	3.4
	NF10	71.6	0.38	0.5	79.4	15.2	4.9	20.1
	NF12	46.5	0.86	0	35.5	53.0	11.5	64.5
	NF20	92.5	0.74	41.6	55.7	1.2	1.5	2.7
	NF21	43.8	0.59	0	69.2	24.5	6.4	30.8
	NF22	85.0	1.13	0.7	56.3	34.0	9.1	43.1
Farfield	**FF01A**	68.2	0.39	0.2	86.9	9.3	3.6	12.9
	FF04	20.3	2.40	0	20.2	53.6	26.3	79.8
	FF09	76.4	0.27	0.3	91.4	5.1	3.1	8.2

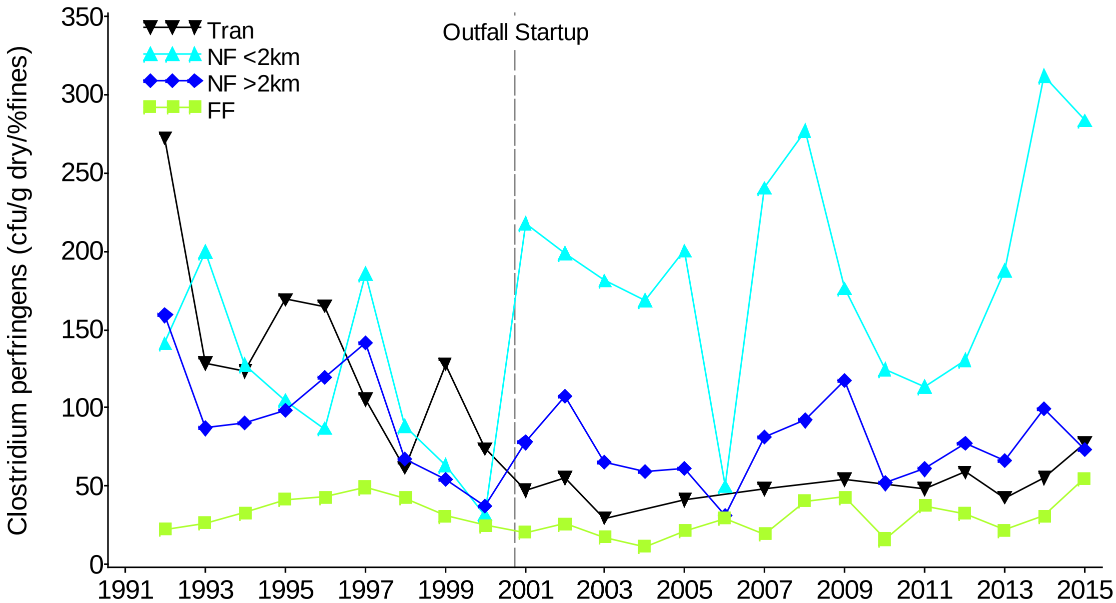


Figure 3-1. Mean concentrations of *Clostridium perfringens* in four areas of Massachusetts Bay, 1992 to 2015. Tran=Transition area; NF<2km=nearfield, less than two kilometers from the outfall; NF>2km=nearfield, more than two kilometers from the outfall; FF=farfield.

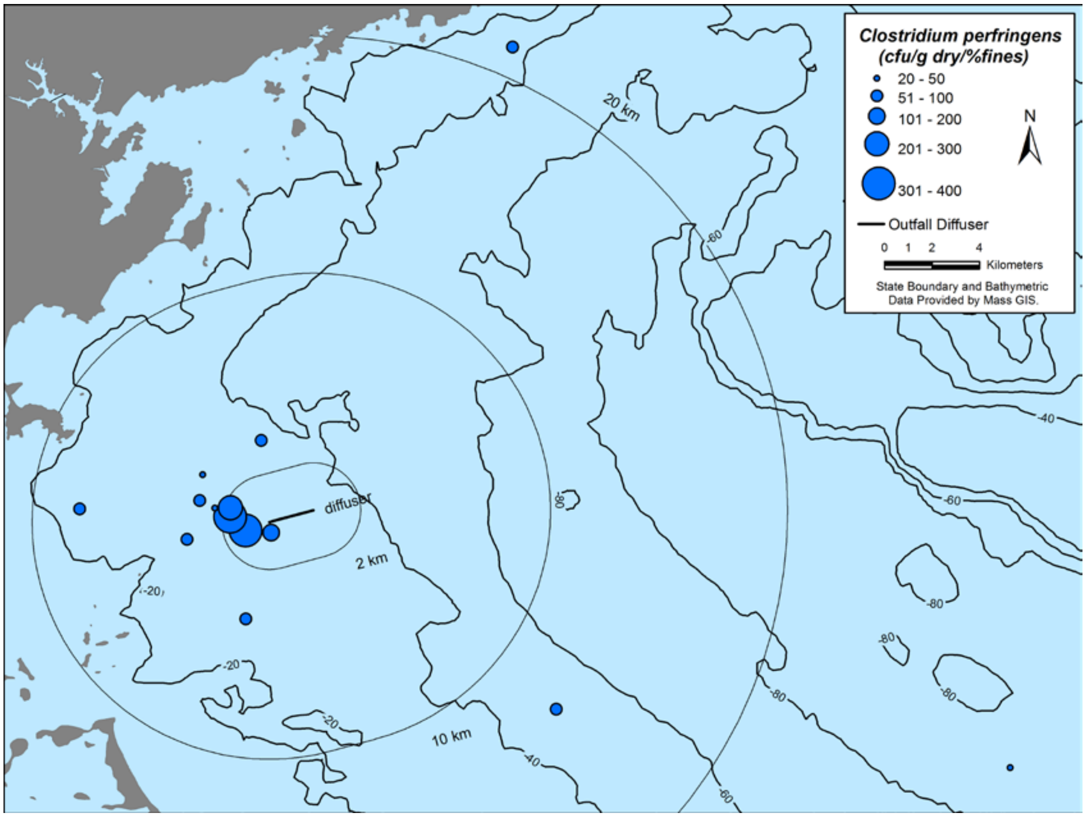


Figure 3-2. 2015 monitoring results for *Clostridium perfringens*.

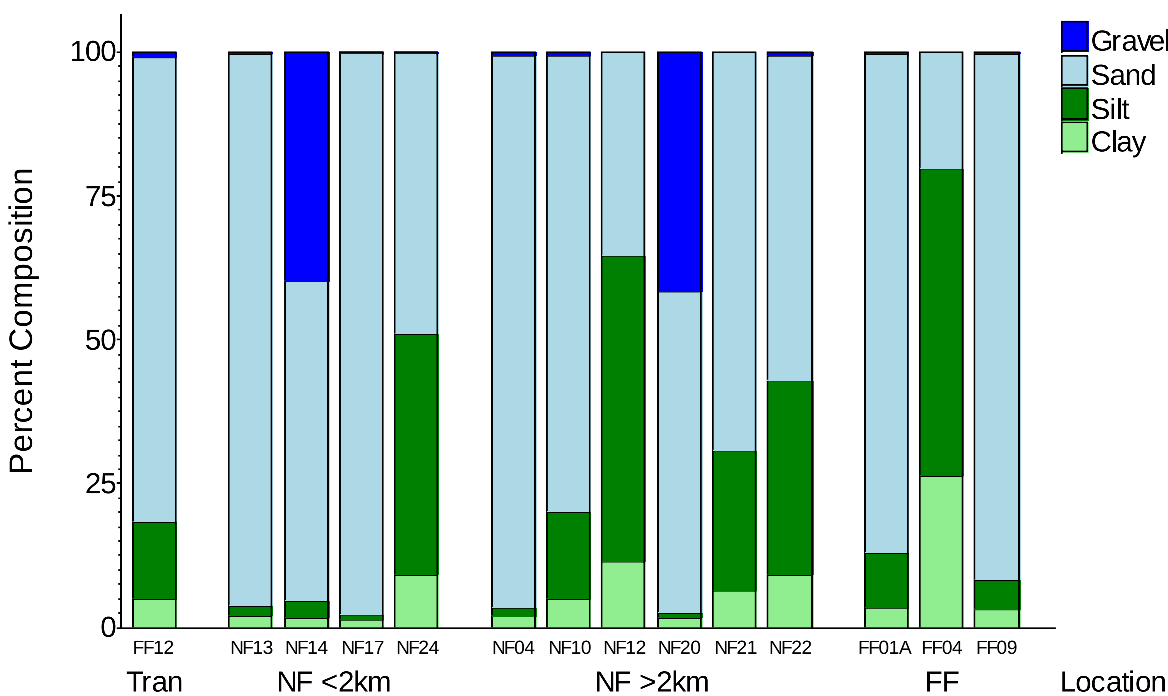


Figure 3-3. 2015 monitoring results for sediment grain size.

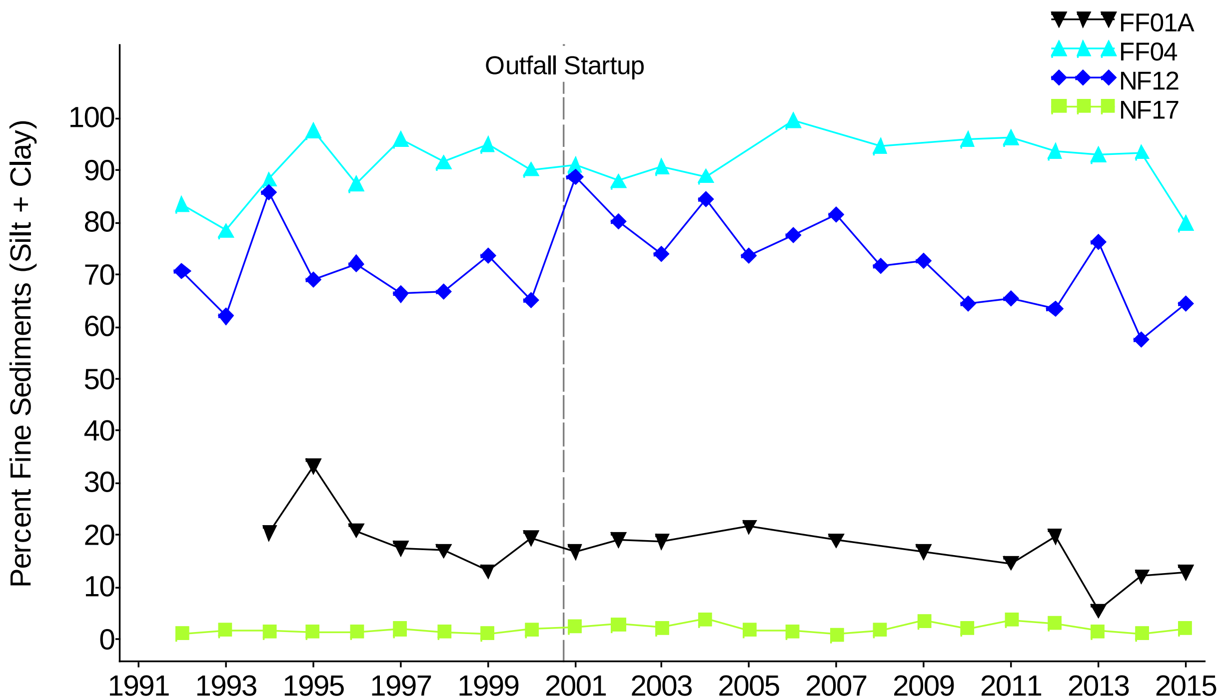


Figure 3-4. Mean percent fine sediments at FF01A, FF04, NF12 and NF17; 1992 to 2015.

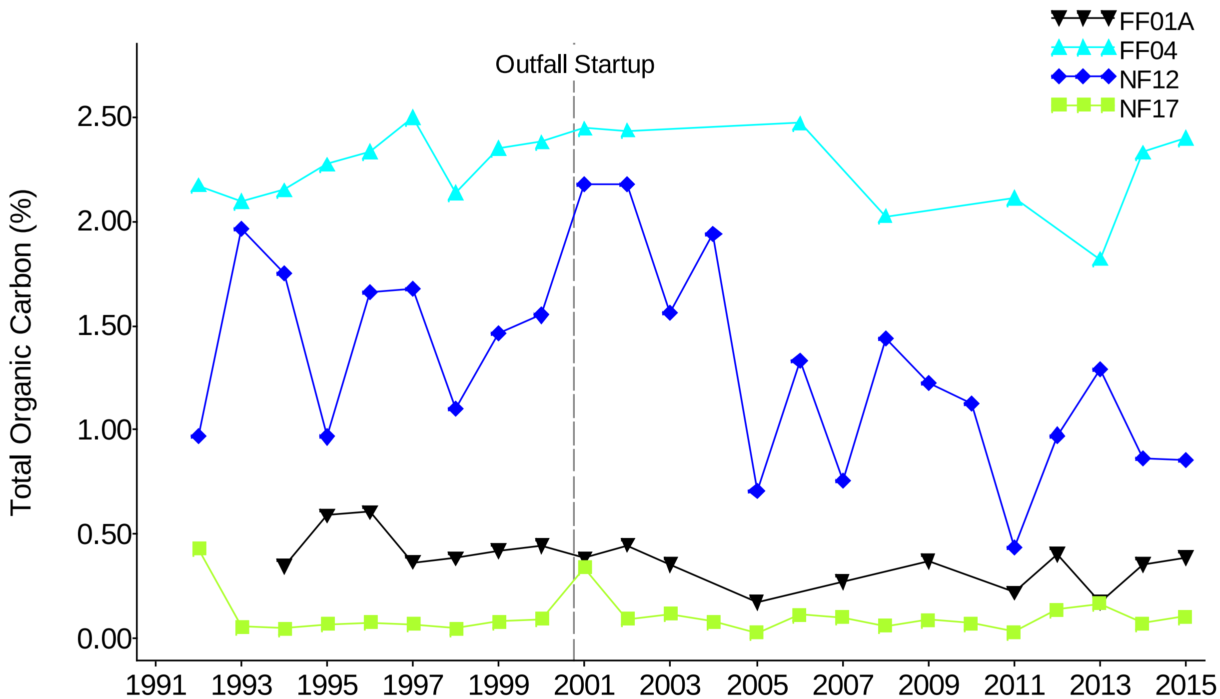


Figure 3-5. Mean concentrations of TOC at four stations in Massachusetts Bay, 1992 to 2015.

3.2 Benthic Infauna

3.2.1 Community Parameters

A total of 20,341 infaunal organisms were counted from the 14 samples in 2015. Organisms were classified into 186 discrete taxa; 164 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 2015 were comparable to the previous year within the four monitoring areas in Massachusetts Bay (Figure 3-6). Although abundance declined at Station FF12 (the only station in the "Transition Area"), it remained higher than at other locations in the Bay (Figure 3-6, Table 3-2). The mean numbers of species per sample in 2015 were also comparable to 2014 at all locations; values were marginally higher at the nearfield stations within two kilometers from the discharge, and slightly lower at all other locations (Figure 3-7).

There were no Contingency Plan threshold exceedances for any infaunal diversity measures in 2015 (Table 3-3). Exceedances were observed for Shannon-Wiener Diversity (H') and Pielou's Evenness (J') each year from 2010 to 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. Annual mean values for H′ and J′ at the nearfield stations, along with threshold limits under the current monitoring plan, are shown in Figures 3-8 and 3-9. Values for H' and J' in 2015 were just below the upper threshold limits for both parameters (Figures 3-8 and 3-9, 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. The spionid polychaete, *Prionospio steenstrupi*, was identified as the most influential species contributing to H' and J' exceedances (Nestler et al. 2014a). *P. steenstrupi*, was the most abundant species in the Massachusetts Bay samples from the mid 1990's to the mid 2000's (Nestler et al. 2014a). During 2015, *P. steenstrupi* was the third most abundant taxon in the samples from nearfield stations. Three other polychaetes, *Aricidea catherinae*, *Mediomastus californiensis,* and *Tharyx acutus*, were also among the top numerical dominants. Only these four species had mean abundances exceeding 100 individuals per sample at the nearfield stations; their abundances are compared over time in Figure 3-10. The paraonid polychaete, *A. catherinae*, was the most abundant species (mean abundance of 253 individuals per sample at the nearfield stations) in 2015. *A. catherinae* counts were highest in the sample from Station FF12 (1,031 individuals), accounting for the high total abundance at that station in 2015 (Figure 3-6, Table 3-2). Nonetheless, compared to years prior to 2010, relatively low abundance of dominant species was reported in 2015, and it is likely that these lower abundances contributed to the relatively high H' and J' values at the nearfield stations.

Table 3-2. 2015 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**	2,519	53	9.50	3.33	0.58
Nearfield (<2 km from outfall)	**NF13**	1,467	60	12.66	3.91	0.66
	NF14	1,163	72	17.04	4.17	0.68
	NF17	732	58	14.86	4.02	0.69
	NF24	1,574	61	12.63	3.78	0.64
Nearfield (>2 km from outfall)	**NF04**	1,104	49	10.57	3.94	0.70
	NF10	1,818	60	11.93	4.15	0.70
	NF12	985	50	11.14	3.72	0.66
	NF20	1,478	63	13.39	3.84	0.64
	NF21	1,669	75	16.23	4.29	0.69
	NF22	2,163	70	13.87	4.08	0.67
Farfield	**FF01A**	1,515	55	11.21	3.93	0.68
	FF04	711	30	6.41	3.20	0.65
	FF09	1,443	86	20.36	4.47	0.70

Table 3-3. Infaunal monitoring threshold results, August 2015 samples.

Parameter	Threshold range		Result	Exceedance?
	Low	High		
Total species	43.0	81.9	61.0	No
Log-series Alpha	9.42	15.8	13.1	No
Shannon-Weiner H′	3.37	3.99	3.93	No
Pielou's J'	0.57	0.67	0.66	No
Apparent RPD	1.18	NA	5.51	No
Percent opportunists	10% (Caution) 25% (Warning)		0.39%	No

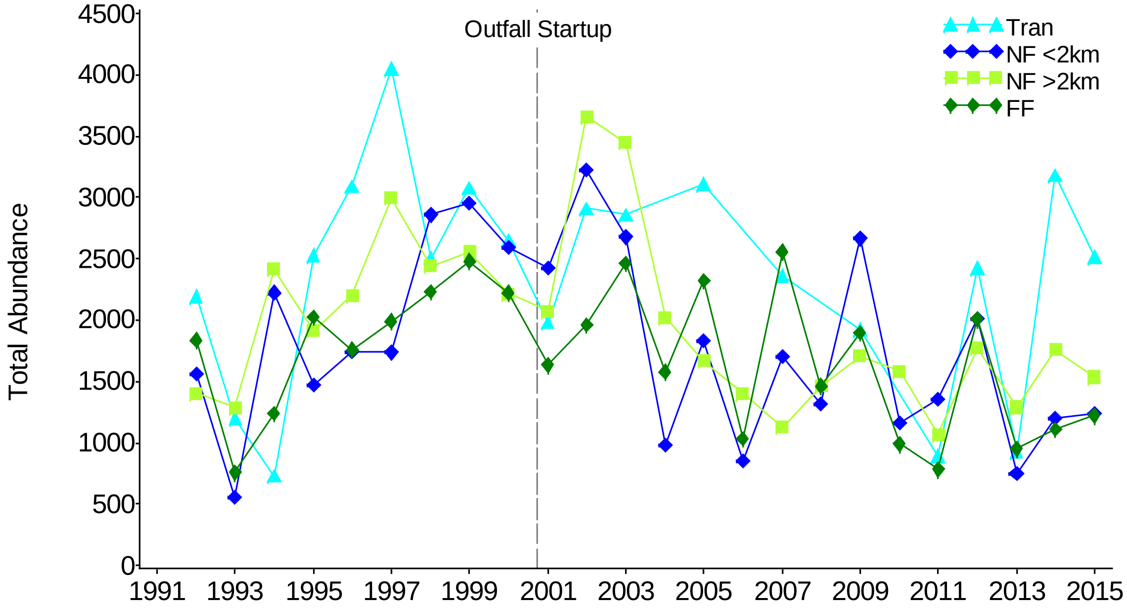


Figure 3-6. Mean infaunal abundance per sample at four areas of Massachusetts Bay, 1992 to 2015. Tran=Transition area; NF<2km=nearfield, less than two kilometers from the outfall; NF>2km=nearfield, more than two kilometers from the outfall; FF=farfield.

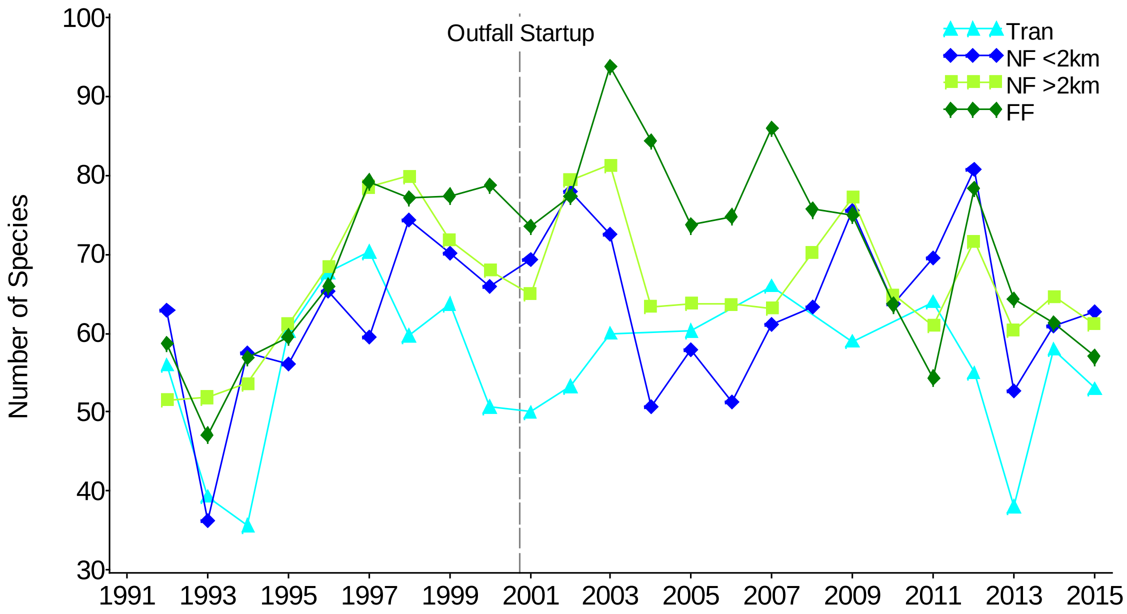


Figure 3-7. Mean number of species per sample at four areas of Massachusetts Bay, 1992 to 2015. Tran=Transition area; NF<2km=nearfield, less than two kilometers from the outfall; NF>2km=nearfield, more than two kilometers from the outfall; FF=farfield.

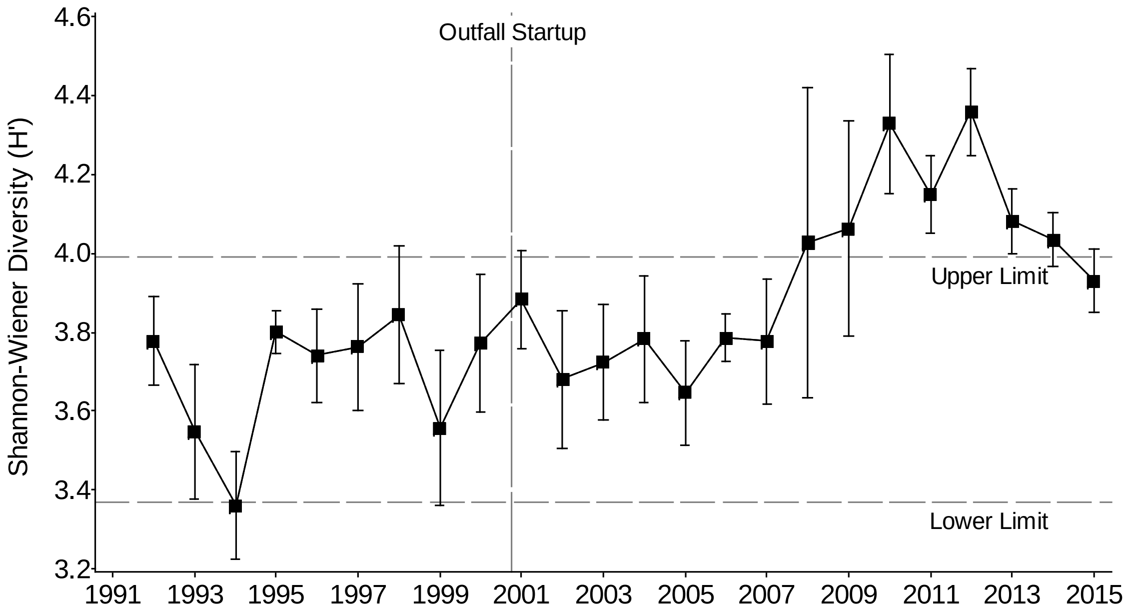


Figure 3-8. Mean Shannon-Wiener Diversity (H′) at nearfield stations in comparison to threshold limits, 1992 to 2015. The nearfield stations and associated threshold limits are both based on the list of stations sampled following the 2010 revision to the Ambient Monitoring Plan (MWRA 2010).

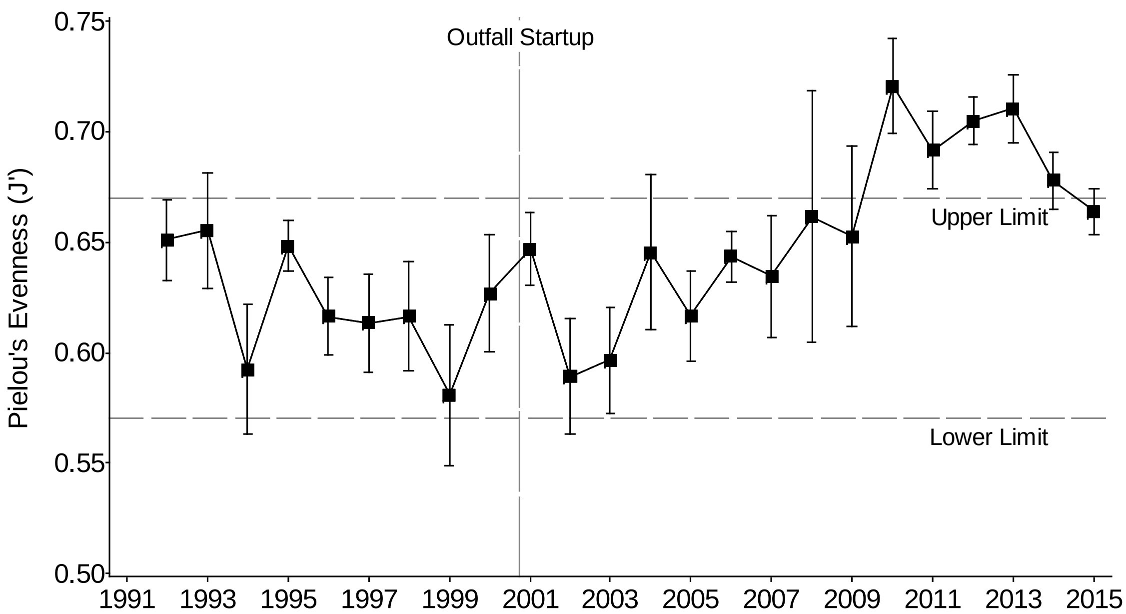


Figure 3-9. Mean Pielou's Evenness (J′) at nearfield stations in comparison to threshold limits, 1992 to 2015. The nearfield stations and associated threshold limits are both based on the list of stations sampled following the 2010 revision to the Ambient Monitoring Plan (MWRA 2010).

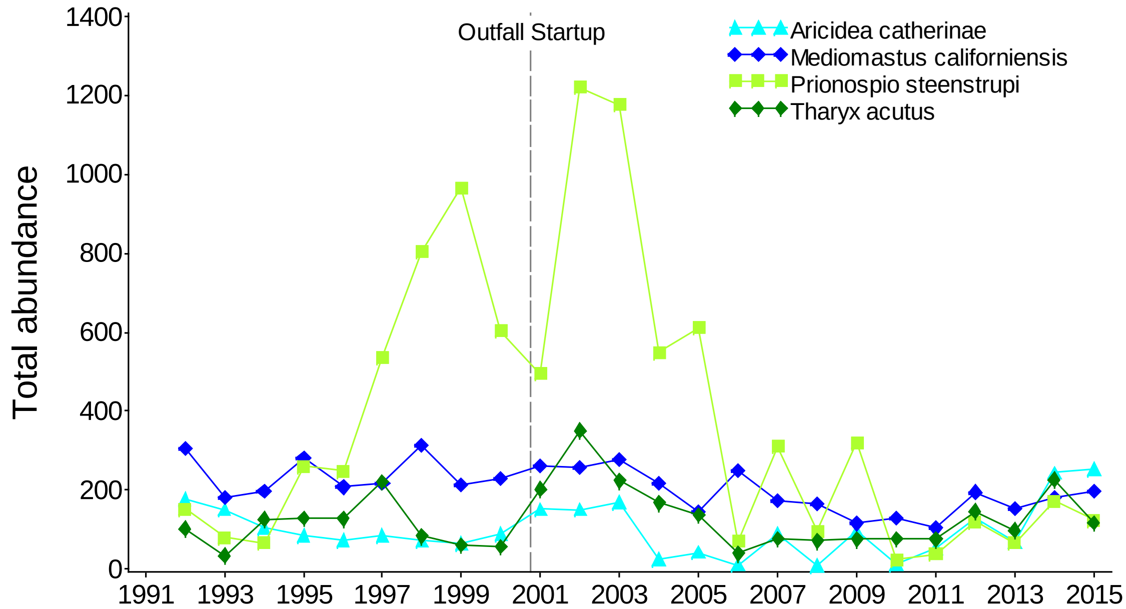


Figure 3-10. Mean abundance per sample, 1992 to 2015, of four top dominant species at nearfield stations in 2015.

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 cluster analysis of the 14 samples from 2015 (Figure 3-11). An outlier assemblage was found at Station FF04. The Group II assemblage contained three sub-assemblages that could be differentiated by species composition. Assemblages varied considerably in species composition, but were mostly dominated by polychaetes (Table 3-4). Both main assemblages occurred at the four stations within two kilometers of the discharge as well as 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 an infaunal community dominated by polychaetes like *Chaetozone assimilis*, *Cossura longicirrata*, and *Euchone incolor* 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 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

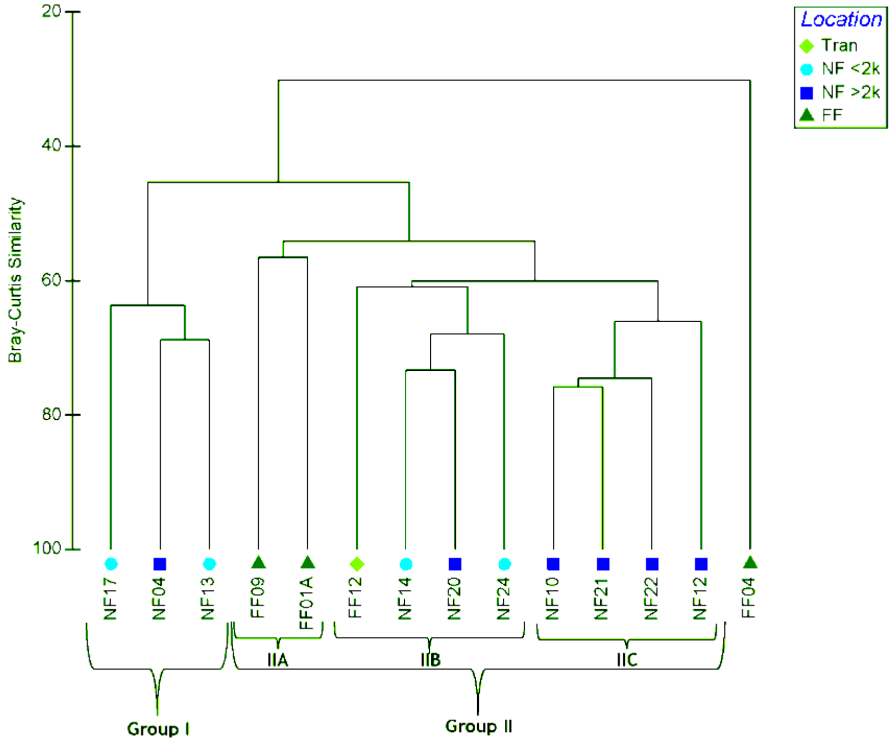


Figure 3-11. Results of cluster analysis of the 2015 infauna samples.

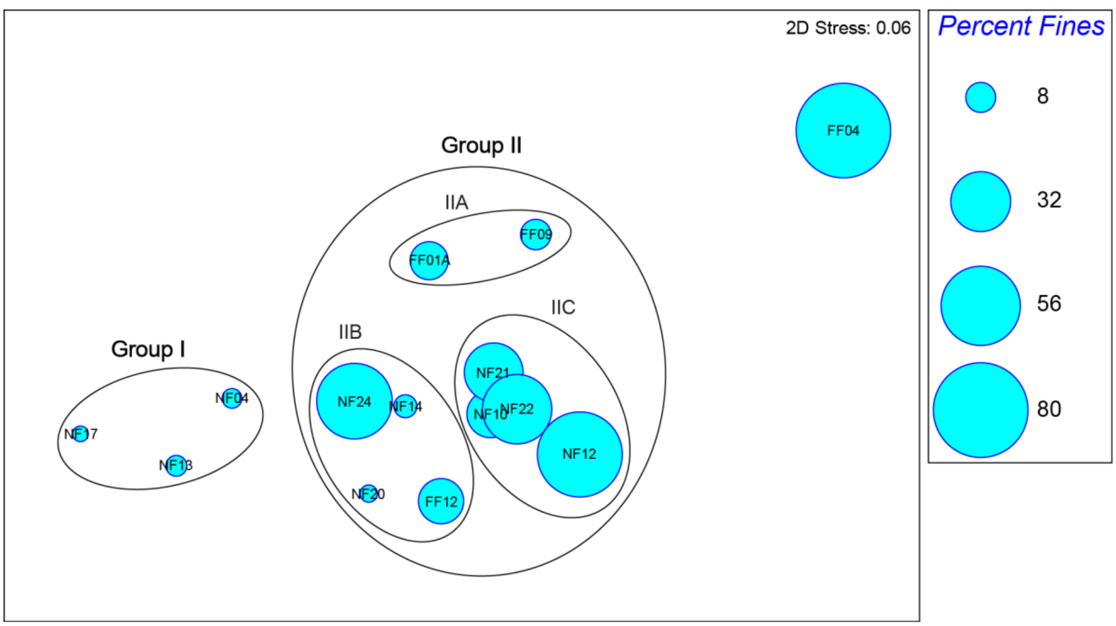


Figure 3-12. Percent fine sediments superimposed on nMDS ordination plot of the 2014 infauna samples. Each point on the plot represents one of the 14 samples; similarity of species composition is indicated by proximity of points on the plot. Faunal assemblages (Groups I-II, and sub-groups) identified by cluster analysis are circled on the plot. The ordination and cluster analysis are both based on Bray-Curtis Similarity.

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 2015 samples.

		Group I	Group II			
Family	**Species**	**NF17, NF04 & NF13**	**IIA (n=2)**	**IIB (n=4)**	**IIC (n=4)**	**FF04**
Mollusca (Bivalvia)						
Nuculidae	*Nucula delphinodonta*	12.3	172.0	14.8	27.8	1.0
Mollusca (Scaphopoda)						
Dentaliidae	*Dentalium entale*	-	1.0	-	0.5	9.0
Annelida (Polychaeta)						
Ampharetidae	*Anobothrus gracilis*	-	75.0	0.8	1.0	51.0
Amphinomidae	*Paramphinome jeffreysii*	-	-	-	-	11.0
Capitellidae	*Mediomastus californiensis*	29.7	29.0	185.8	330.5	24.0
Cirratulidae	*Chaetozone anasimus*	35.7	1.0	1.0	0.5	122.0
	Monticellina baptisteae	7.3	37.5	84.5	101.5	-
	Monticellina cf. dorsobranchialis	-	4.5	31.0	55.0	-
	Tharyx acutus	37.0	40.5	155.0	138.3	-
Cossuridae	*Cossura longocirrata*	-	2.0	0.3	6.8	93.0
Lumbrineridae	*Ninoe nigripes*	0.3	61.0	47.8	110.5	29.0
	Scoletoma hebes	-	-	34.8	13.8	-
Orbiniidae	*Leitoscoloplos acutus*	-	10.0	17.8	58.0	4.0
	Scoloplos armiger	31.7	-	0.5	0.3	-
Oweniidae	*Owenia artifex*	5.7	81.0	7.0	0.8	-
Paraonidae	*Aricidea catherinae*	189.7	13.5	485.8	67.0	-
	Levinsenia gracilis	0.7	104.5	60.8	213.5	215.0
Phyllodocidae	*Phyllodoce mucosa*	34.3	5.5	27.0	2.0	-
Polygordiidae	*Polygordius jouinae*	46.3	5.5	5.0	2.0	-
Sabellidae	*Euchone incolor*	2.7	43.5	6.0	18.3	69.0
Spionidae	*Prionospio steenstrupi*	6.3	289.5	196.0	141.3	9.0
	Spio limicola	8.3	111.0	24.0	61.3	4.0
	Spiophanes bombyx	84.7	36.5	53.5	8.3	-
Syllidae	*Exogone hebes*	230.7	23.0	40.3	9.8	-
Annelida (Oligochaeta)						
Enchytraeidae	*Marionina welchi*	89.3	-	-	-	-
Phorona (Phoronida)						
	Phoronis muelleri	39.3	6.0	11.5	7.8	-

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. Multivariate analyses of the 2015 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 the depth of the apparent color redox potential discontinuity (aRPD) layer as described in the MWRA's Contingency Plan (MWRA 2001). The baseline included six August collections in 1992, 1995, and annual collections from 1997 to 2000. In 2001 the offshore outfall went into operation as did annual August SPI data collection to document post-diversion conditions in the nearfield. The region where the outfall is located 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. The drumlins tops are at about 25 m depth and the bottoms at 30 to 40 m. All nearfield SPI stations were located in unconsolidated sediments and ranged 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 at. 1992, 2008)

Comparison of baseline and post-diversion benthic habitat conditions found that most of the changes within and between these two periods occurred over the entire nearfield area and were closely related to major regional events such as storms. Thus there was no evidence of any outfall effects. 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. Dense 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 being defined as >5 tubes per linear cm of image or >50,000 tubes per m^2. 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 by 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; none in 1995, 1997 or 1998; to 9 of 23 stations having mats in 1999; 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 one station (NF16) in 2014. It also appeared that the species forming the tube mats differed from year to year. For example, distinctive medium-size twisted tube were widespread at nearfield stations only 2001 to 2003 (Figure 3-13).

Variation in sediments 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. Overall, nearfield sediments were heterogeneous, consisting of cobble, pebble, gravel, and medium to fine sands mixed with silt and clay. Year to year, individual stations varied little in modal grain-size patterns. For example, within station variation was high at Station FF10 (Figure 3-14) and low at Station NF12 (Figure 3-15). Sediments appeared to change the most after periods with severe storms. Unfortunately there was no data to assess the effects of the October 1991 “perfect storm”, but a May 2005 severe storm that has 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 going 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. 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 components. Similarly, NF17 went from 96% to 98% sand with increased coarse-sand and medium-sand components (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 sediment variations were low, 2015 was a third year of change for sediment modal grain-size. While sediments at many stations continued to be heterogeneous, ranging from fine-sand-silt-clay to cobble, there was an apparent coarsening of sediments at many stations. At 5 of the 23 nearfield stations sediments appeared to be much 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. Similarly, NF17 went from fine-medium-sand to medium-sand (Figure 3-16). 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.

In addition to slightly coarser sediment in 2015, there was an increase in the dominance of physical processes structuring surficial sediments. In 2014 the odds were about even (1 to 1.1) that a nearfield station would be either physically dominated or dominated by a combination of biological and physical processes. In 2015 the odds shifted to 3.1 to 1 in favor of physical dominance. Not all nearfield stations changed in 2015. At most fine-sand-silt-clay stations a combination of biological and physical processes continued to dominate in 2015. Conditions at stations NF08, NF12 (Figure 3-15), and NF21 have remained relatively consistent from 1997 to 2015. 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 in structuring surficial sediments. From 1998 to 2002 the odds were in favor of sediments being biologically dominated. From 2003 on odds were about even or in favor of physical processes dominating (Figure 3-17). The year of outfall startup (2001) coincided with a large decline in dominance by biological processes. In 2000 only Station NF02 had a physically dominated surface, all other nearfield stations had varying degrees of biological dominance. The decline in the importance of biological processes through time occurred across the nearfield with Station NF05 providing a good example of this trend (Figure 3-18). 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 variables, such as infaunal and oxic feeding voids, visible in SPI images which led to a lowering of estimated successional stage by the early 2010s (Figure 3-19).

During the baseline period, the mean aRPD layer depth 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 (Figure 3-20). In 1997, due to technical problems, sampling occurred in both August and October, which may have contributed to the variation because the aRPD layer becomes seasonally shallower in the fall. 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 in 1998 and 1999 was a key factor in the deepening of the aRPD. Most of the biogenic activity was related to burrowing organisms that created feeding mounds and pits in the sediment surface, and to small tube-building worms. The predominance of Stage II and Stage III fauna was related to modal sediment grain-size and continued into the late 2000s. By 2102 biogenic structures associated with Stage III fauna had declined and remained low through to 2015 even at fine-sand-silt-clay stations (Figure 3-19).

The grand mean of the thickness of the aRPD layer in 2015 was the highest annual average of the post-diversion monitoring and 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 2015 would be 5.3 cm (SD = 0.97 cm, 9 stations in mean). At 14 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 2015 was 5.5 cm (SD = 1.33 cm). However, 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. Overall, post-diversion aRPD remained deeper than the baseline period (Table 3-5). Since 2001, the thickness of the annual grand mean aRPD has been variable but since 2011 it has tended deeper and increased in 2015 to the highest average over the 23 years of monitoring (Figure 3-20), which is an indication of continued high quality benthic habitat conditions. High diversity of benthos also confirms the presence of high quality benthic habitat (Section 3.2). 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 stations. From 1997 (start of annual sampling) to 2015 five stations had measurable aRPD layer depths for all years. There was a general concordance between these five stations and time with a deepening trend that started in baseline 1999 and continued to post-diversion 2002 for all five stations (Figure 3-21). Post-diversion, from 2003 to 2007 there were no trends in aRPD layer depth for these five stations. In 2008 there was an increase in aRPD and again little change until 2013 when aRPD trended deeper (Figure 3-21). While still trending deeper overall, the aRPD layer depth at station NF21 declined by about 2 cm in 2015 compared to 2014 (Figure 3-21). This decline may be associated with winter storms resuspending and removing fine silt-clay sediments. NF21 is still classified as fine-sand-silt-clay but the sand fraction appeared to be slightly coarser in 2015 compared to 2014 (Figure 3-22).

When baseline conditions (1992 to 2000) are compared with post-diversion (2001 to 2015) 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 regionally (Section 3.1). The grand average apparent color redox-potential discontinuity layer (aRPD) for 2015 was the highest of all the post-diversion years. The second highest year was 2014 and third highest 2013, continuing a deepening trend that started in 2011 (Figure 3-20).

From 1992 to 2015, changes and trends in SPI variables at nearfield stations appeared to be related to broader regional forcing factors. The dominance of hydrodynamic and physical factors (Butman et al. 2008) such as tidal and storm currents, turbulence, and sediment transport, is the principal reason that benthic habitat quality remains high in the nearfield area. The high-energy environment in the region of the outfall 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 the nearfield.

SPI and community analyses have been used in numerous coastal ocean sewage outfall monitoring programs to detect benthic impacts. In general, those outfalls with low or no detectable impacts in benthic infauna, appeared to have low accumulation rates for organic matter and to be dominated by high energy physical processes (Puente and Diaz 2015). Data compiled from other coastal ocean outfalls around the world indicated that when benthic impacts did occur they manifested primarily as changes in the ratio of opportunistic to sensitive species and secondarily as decrease in diversity or species richness (Figure 3-23). Neither of these community structure measures changed in these ways at the MRWA outfall (Section 3.2). The MWRA outfall was in a class with a few other ocean outfalls where diversity and richness increased, such as Point Loma, San Diego, and Honolulu, Hawaii (Puente and Diaz 2015).

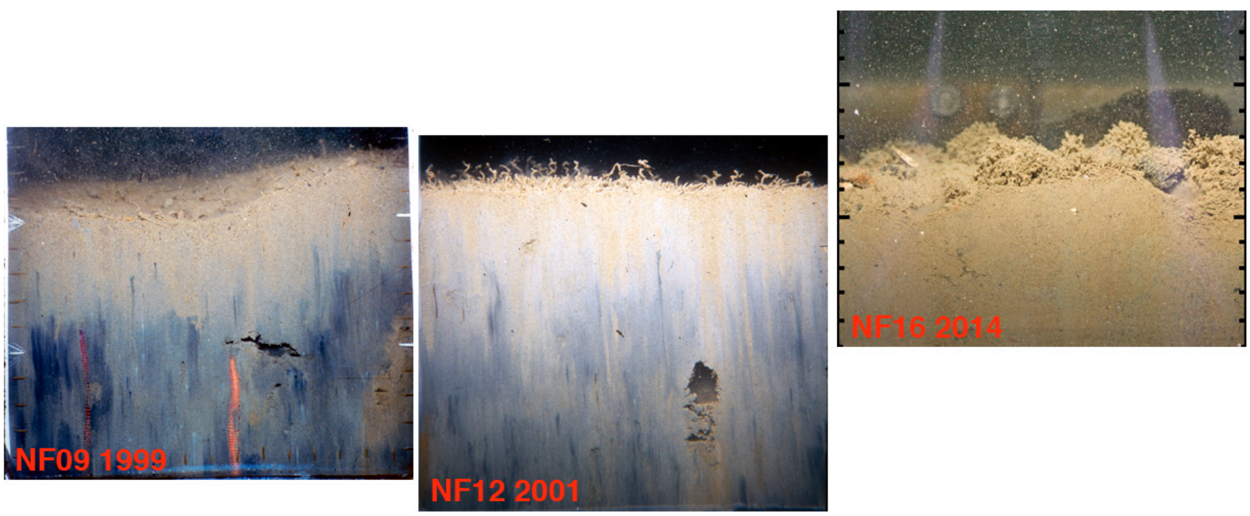


Figure 3-13. Tube mats on the sediment surface. Species of tube builders appeared to change from year to year. These mats are likely similar to tube mats observed in 1992 images and represent the Stage I pioneering species. Medium-size twisted tubes seen at NF12 were widespread at nearfield stations only in 2001 and 2002. Deeper dwelling species and biogenic structures can be seen at NF09 and NF12 that represent Stage III species. 1992 images were not available. Scale on side of images is in cm.

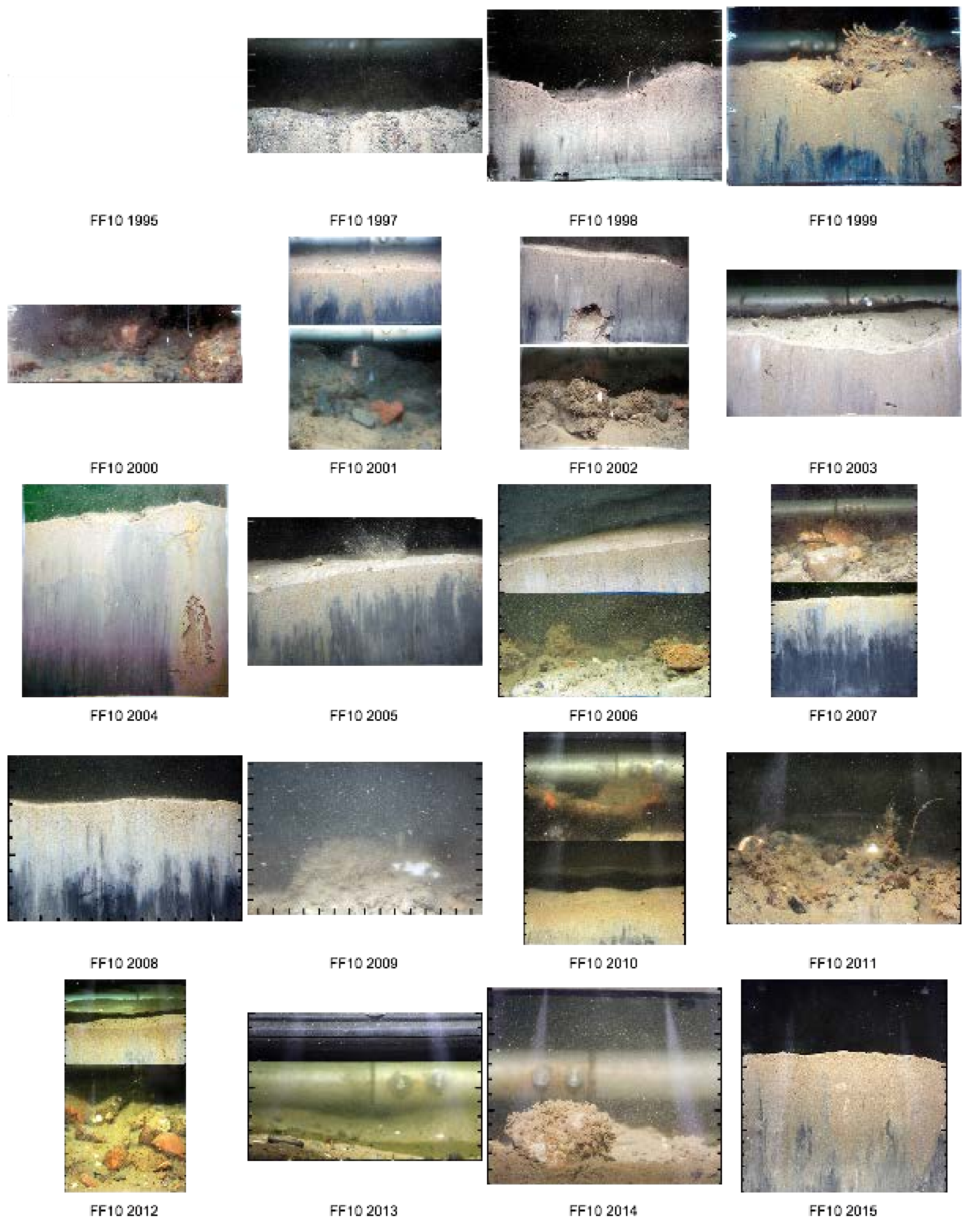


Figure 3-14. Mosaic of SPI images for Station FF10. Scale on side of images is in cm.

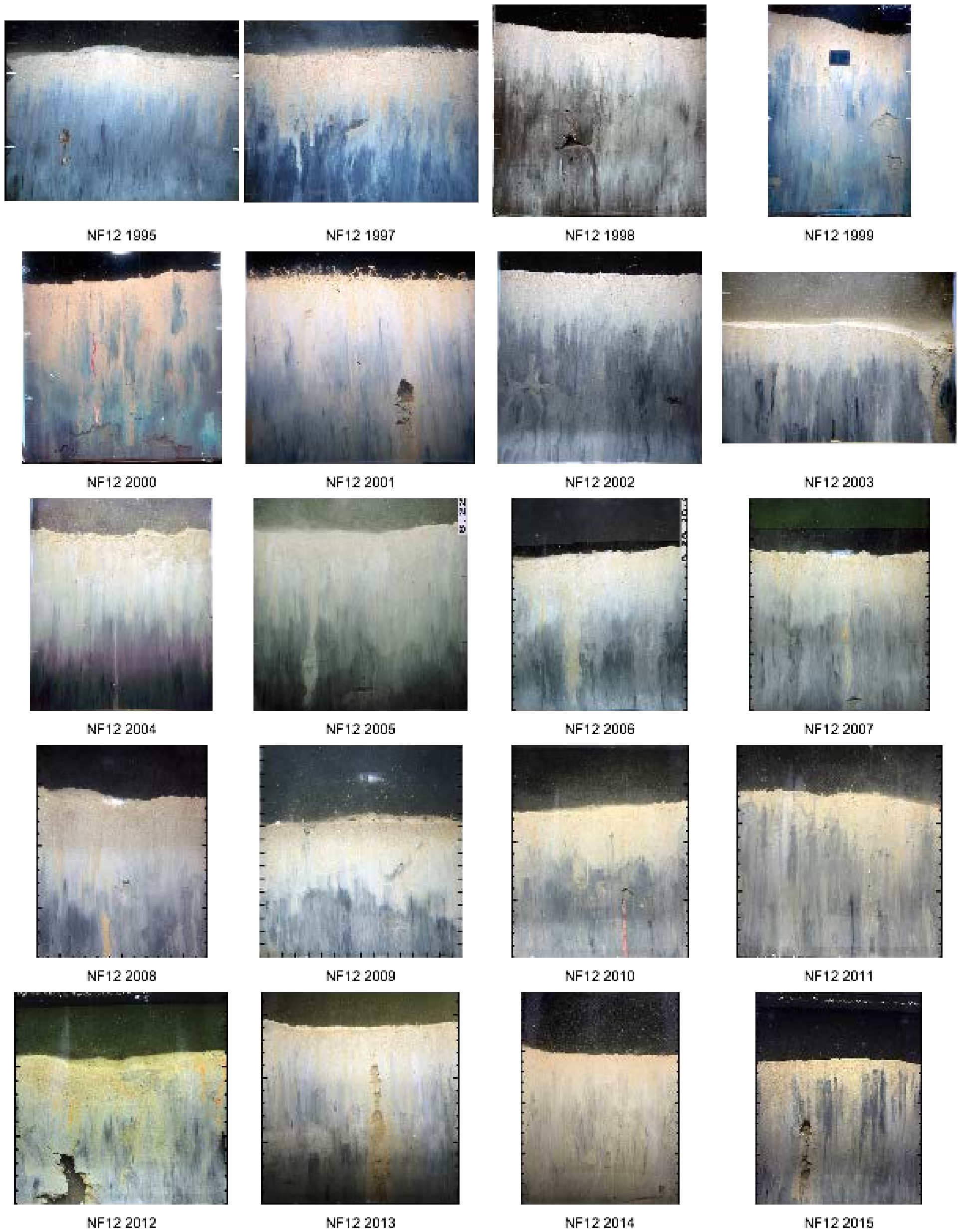


Figure 3-15. Mosaic of SPI images for Station NF12. Scale on side of images is in cm.

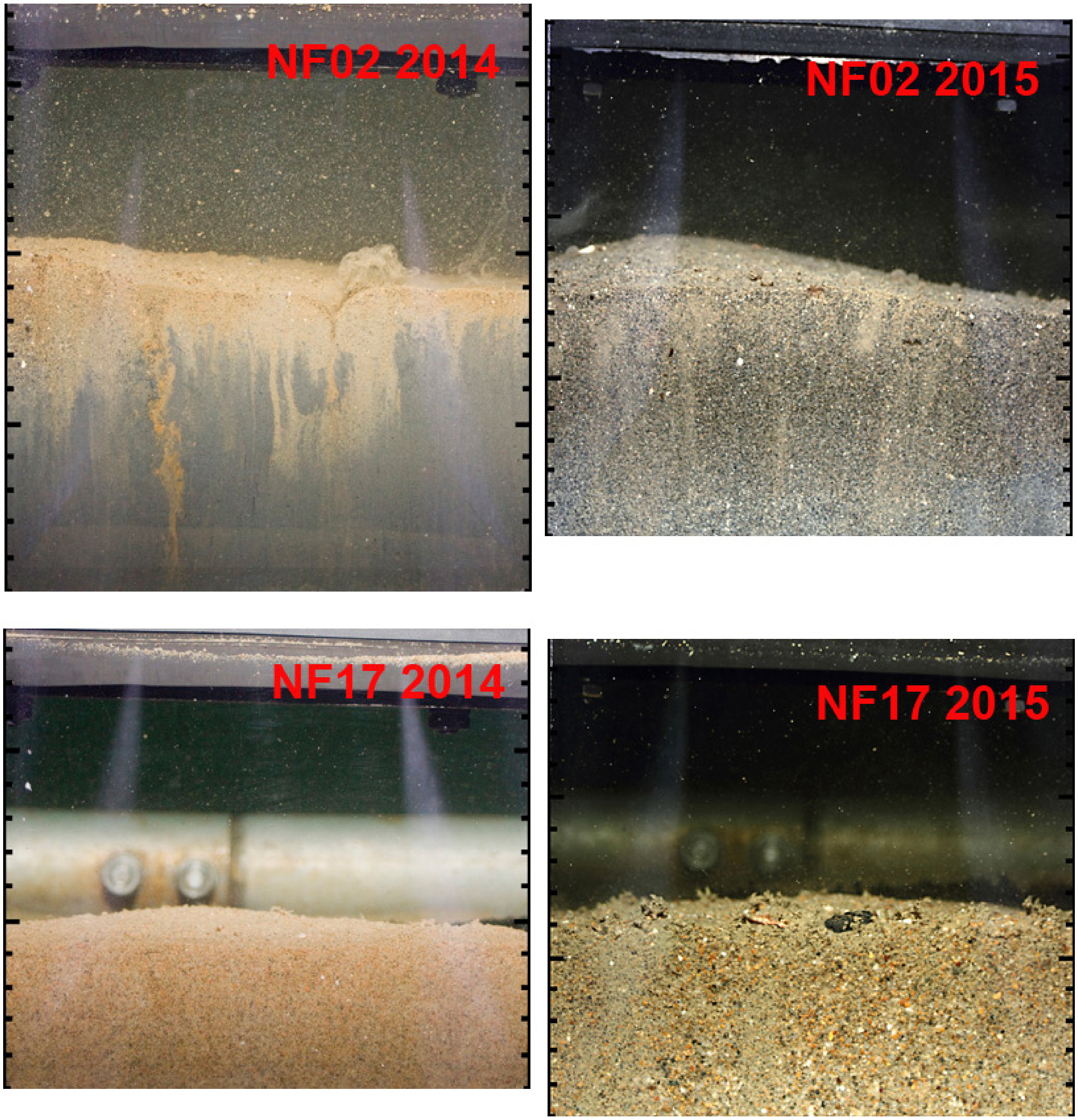


Figure 3-16. Apparent change in modal sediment grain-size at NF02 from fine-sand-silt in 2014 to fine-medium-sand in 2015, and at NF17 from fine-medium-sand to medium-sand. Scale on side of images is in cm.

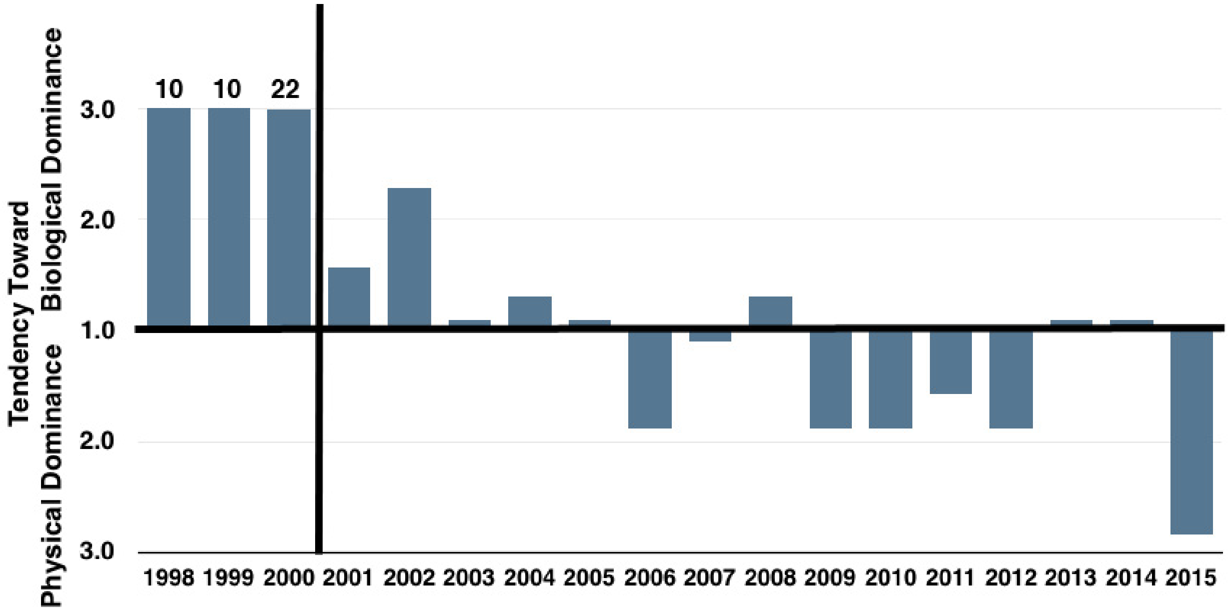


Figure 3-17. Odds of nearfield stations being dominated primarily by physical or biological processes. An odds of 1.0 would be even chance for either process to dominate. Vertical line separates baseline from post-diversion years.

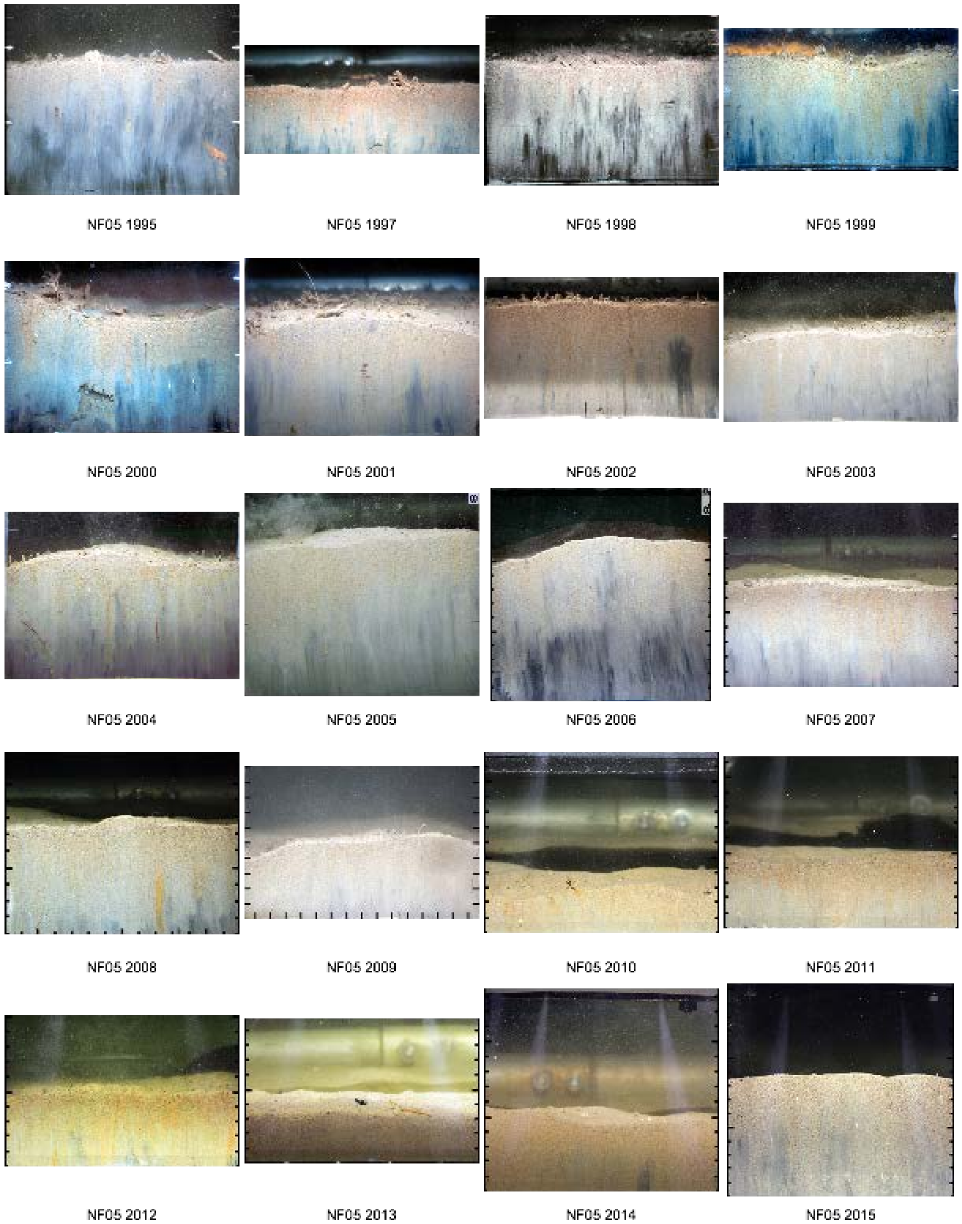


Figure 3-18. Mosaic of SPI images for Station NF05. Scale on side of images is in cm.

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Modal Grain-Size
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	I-II	FSSIGRPB
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	I	FSSIGRPB
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	FSSIGRPB
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	I	FSMSGR
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	I-II	FSMSGR
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	I-II	FSMSGR
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	I	FSMSPB
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	I	FSMS
NF19	I-II	I-II	II	II	I-II	I	I	I	I	I	I	I	I	I	I	I-II	I	I	I-II	FSMS
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	I	FSMS
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	I	FSMS
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	I	FSMS
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	I-II	FS
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	I	FS
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	I-II	FS
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	FS
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	I	FSSI
NF02	I-III			I	I-II	I-II	I-II	II-III	II-III	I	I	I	I	I	I	I	I	I	I-II	FSSI
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	I	FSSICL
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	I-II	FSSICL
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	I	FSSICL
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	I	FSSICL
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	I-III	FSSICL

Figure 3-19. Estimated successional stage from nearfield SPI. 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.

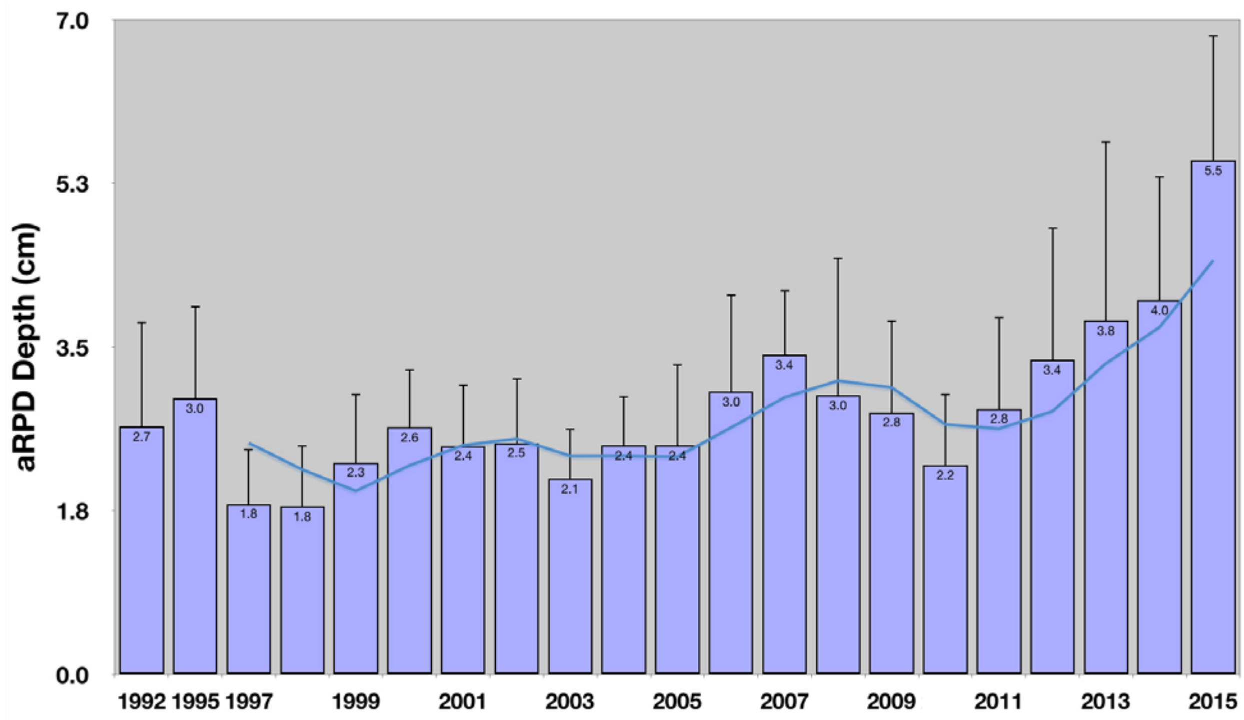


Figure 3-20. Average annual aRPD layer depth for all nearfield stations. Includes stations where aRPD layer was deeper than prism penetration. Error bars are one standard deviation. Line is three-year moving average.

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

	Baseline Years 1992-2000 9-Year Interval	**Post-Baseline Years 2001-2015 14-Year Interval**	**Only 2015**
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)	7.7 (2015)
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	3.5 (1.06 SD) cm	5.3 (0.97 SD) cm
Annual Mean RPD All Values	2.4 (0.47 SD) cm	3.1 (0.88 SD) cm	5.5 (1.33 SD) cm

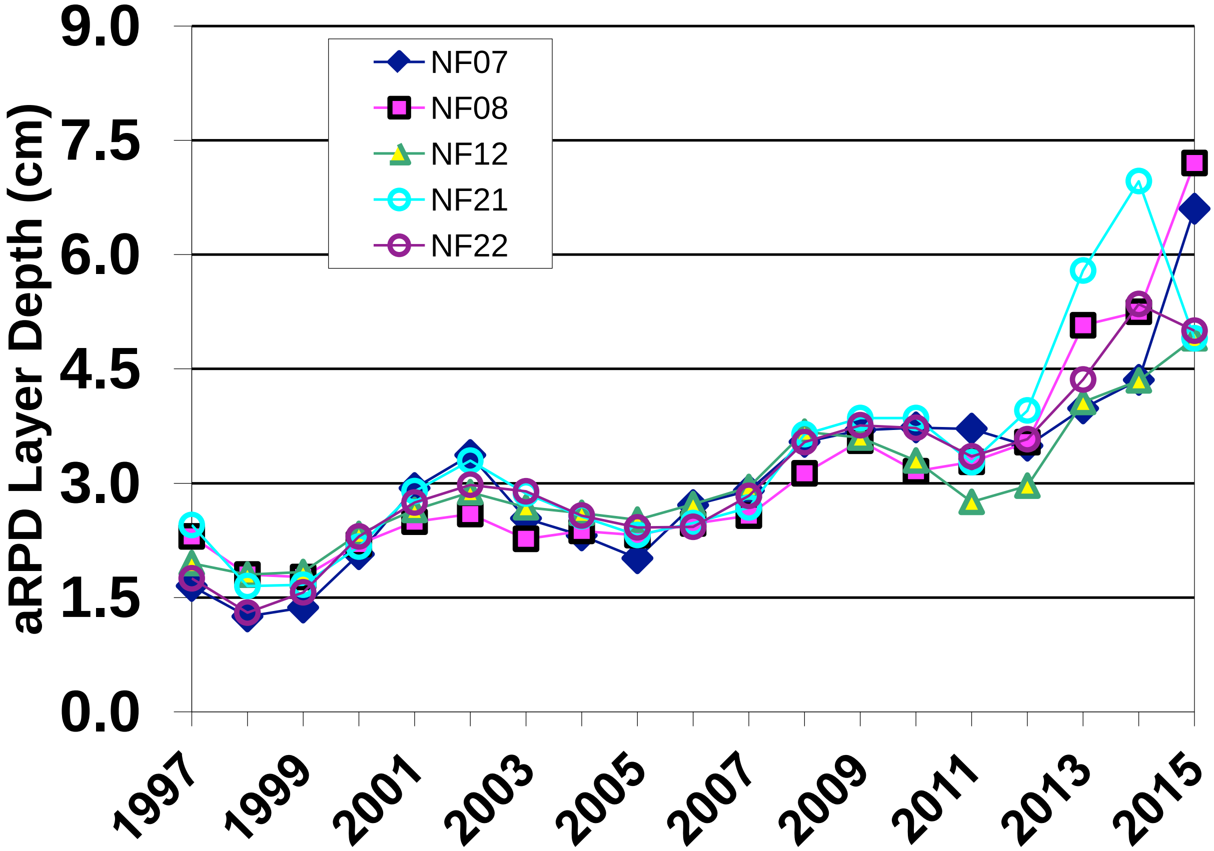


Figure 3-21. Average aRPD layer depth at nearfield stations for stations that had only measured aRPD layers every year. Lines are annual averages of three images.

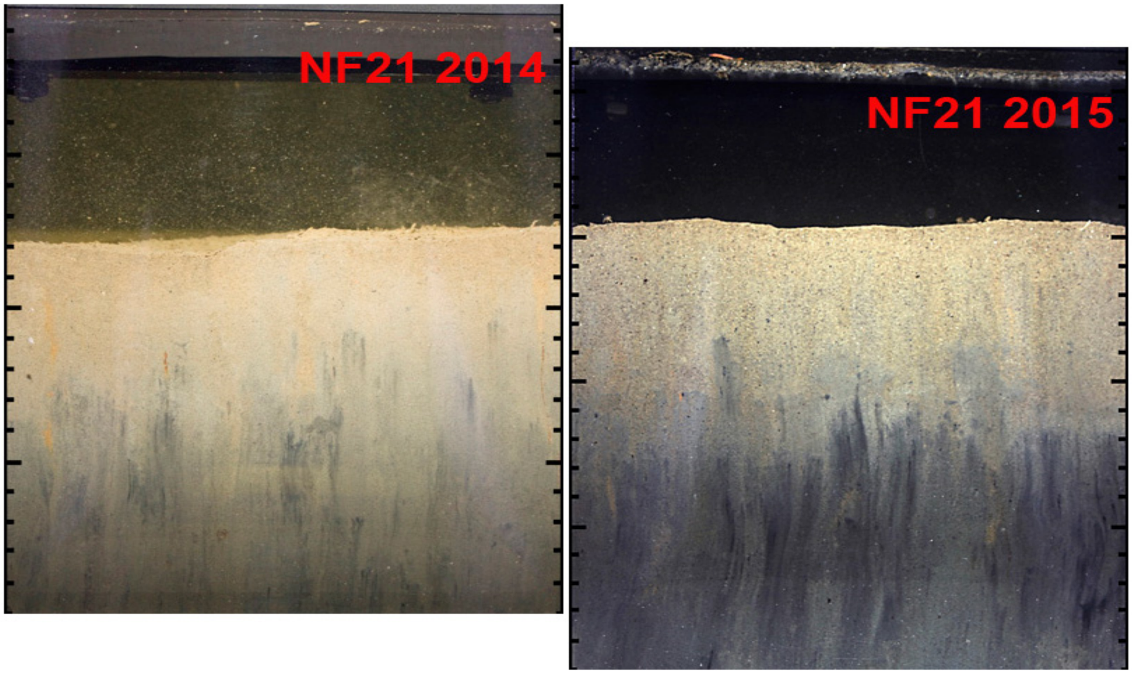


Figure 3-22. Comparison of aRPD layer depth at NF21 between 2014 and 2015. In 2014 aRPD averaged 7.0 cm in 2015 it was 4.9 cm. Sediments also appear to be slightly coarse in 2015 relative to 2014. Scale on side of images is in cm.

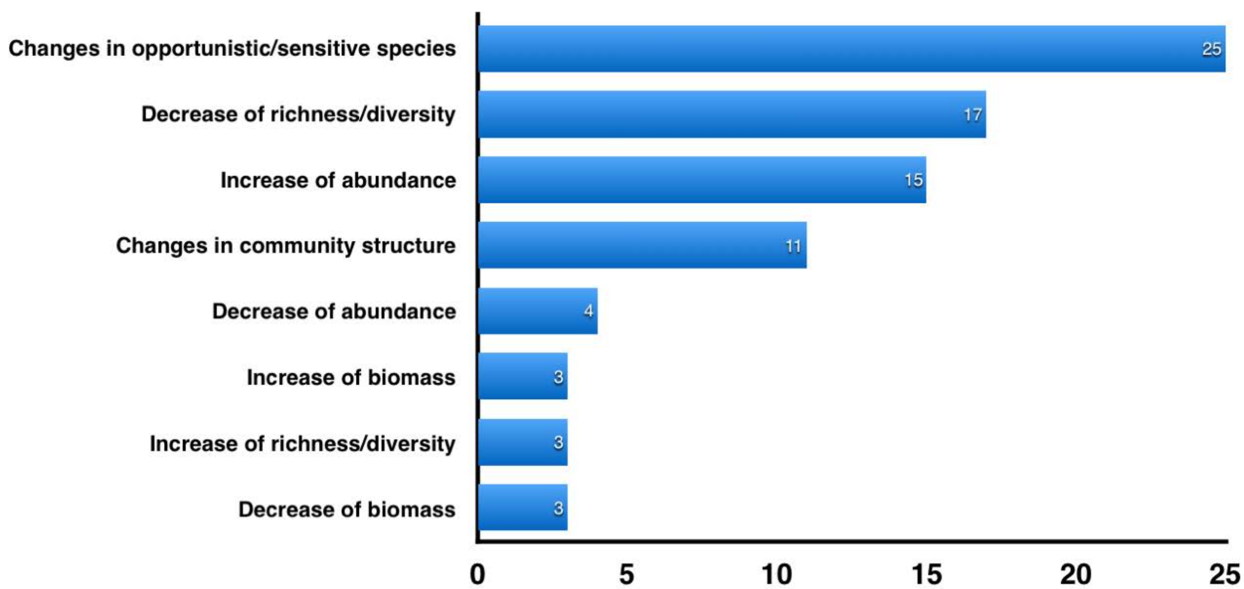


Figure 3-23. Types of benthic community changes observed at coastal ocean sewage outfalls around the world. MWRA's outfall is one of the three showing increased diversity. Graph based on data from a total of 44 outfalls (redrawn from Puente and Diaz 2105).

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 2015 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 2015 was greater than reported during the baseline period.. These results support previous findings that eutrophication and the associated decrease in oxygen levels have not been a problem at the nearfield benthic monitoring stations (Nestler et al. 2015, 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 2015. 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. 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. Those analyses also suggested that it may be appropriate to revisit the need for upper diversity triggers for MWRA’s infaunal Contingency Plan thresholds (Nestler et al. 2015). The numbers of dominant species in the 2015 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 2015, 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.

5. REFERENCES

Blake, JA, DC Rhoads, and B Hilbig. 1993. Massachusetts Bay outfall monitoring program: soft bottom benthic biology and sedimentology, 1992 baseline conditions in Massachusetts and Cape Cod Bays. MWRA Enviro. Quality Dept. Tech. Rpt. Series No. 93-10. Massachusetts Water Resources Authority, Boston, MA. 108 pp. + 4 appendices.

Bothner MH, Casso MA, Rendigs RR, and Lamothe PJ. 2002. The effect of the new Massachusetts Bay sewage outfall on the concentrations of metals and bacterial spores in nearby bottom and suspended sediments. Marine Pollution Bulletin. 44: 1063-1070.

Butman, B., M.H. Bothner, I.C. Hathaway, H.I. Jenter, H.I. Knebel, F.T. Manheim, and R.P. Signell. 1992. Contaminant Transport and Accumulation in Massachusetts Bay and Boston Harbor: A Summary of U.S. Geological Survey Studies. U.S. Geological Survey Open-File Report 92-202, Woods Hole, MA. 42 pages.

Butman B, Sherwood CR and Dalyander PS. 2008. Northeast storms ranked by wind stress and wave-generated bottom stress observed in Massachusetts Bay, 1990–2006. Continental Shelf Research 28:1231–1245.

Clarke KR. 1993. Non-parametric multivariate analyses of changes in community structure. Aust. J. Ecol., 18: 117-143.

Clarke KR and Green RH. 1988. Statistical design and analysis for a 'biological effects' study. Mar. Ecol. Prog. Ser., 46: 213-226.

Diaz, R. J., M. Solan, and R. M. Valente. 2004. A review of approaches for classifying benthic habitats and evaluating habitat quality. Journal of Environmental Management 73:165–181.

Maciolek, NJ, RJ Diaz, Dahlen DT, B Hecker, IP Williams, C Hunt, and WK Smith. 2006. 2005 Outfall Benthic Monitoring Report. Boston: Massachusetts Water Resources Authority. Report ENQUAD 2006-19. 166 pages plus appendices.

Maciolek NJ, Diaz RJ, Dahlen DT, Hecker B, Williams IP, Hunt CD and Smith W. 2007. 2006 Outfall benthic monitoring report. Boston: Massachusetts Water Resources Authority. Report 2007-08. 162 p.

Maciolek NJ, Doner SA, Diaz RJ, Dahlen DT, Hecker B, Williams IP, Hunt CD and Smith W. 2008. Outfall Benthic Monitoring Interpretive Report 1992–2007. Boston: Massachusetts Water Resources Authority. Report 2008-20. 149 pp.

MWRA. 1991. Massachusetts Water Resources Authority effluent outfall monitoring plan phase I: baseline studies. Boston: Massachusetts Water Resources Authority. Report 1991-ms-02. 95 pp.

MWRA. 1997. Massachusetts Water Resources Authority Contingency Plan. Boston: Massachusetts Water Resources Authority. Report 1997-ms-69. 41 pp.

MWRA. 2001. Massachusetts Water Resources Authority Contingency Plan Revision 1. Boston: Massachusetts Water Resources Authority. Report ENQUAD ms-071. 47 pp.

MWRA. 2004. Massachusetts Water Resources Authority Effluent Outfall Ambient Monitoring Plan Revision 1, March 2004. Boston: Massachusetts Water Resources Authority. Report 1-ms-092. 65 pp.

MWRA. 2010. Ambient monitoring plan for the Massachusetts Water Resources Authority effluent outfall revision 2. July 2010. Boston: Massachusetts Water Resources Authority. Report 2010-04. 107p.

Nestler EC, Diaz RJ, Hecker B, Pembroke AE, Keay KE. 2015. Outfall Benthic Monitoring Report: 2014 Results. Boston: Massachusetts Water Resources Authority. Report 2015-08. 49 pp. plus Appendices.

Nestler EC, Diaz RJ, Pembroke AE, Keay KE. 2014a. Outfall Benthic Monitoring Report: 2013 Results. Boston: Massachusetts Water Resources Authority. Report 2014-10. 35 pp. plus Appendices.

Nestler EC, Pembroke A and Hasevlat R. 2014b. Quality Assurance Project Plan for Benthic Monitoring 2014–2017. Boston: Massachusetts Water Resources Authority. Report 2014-03, 92 pp. plus Appendices.

Puente, A and RJ Diaz. 2015. Response of benthos to ocean outfall discharges: does a general pattern exist? Marine Pollution Bulletin 101:174-81.

Read PA, Anderson KJ, Matthews JE, Watson PG, Halliday MC and Shiells GM. 1983. Effects of Pollution on the Benthos of the Firth of Forth. Marine Pollution Bulletin 14:12-16. Shea D, Lewis DA, Buxton BE, Rhoads DC, and Blake JA. 1991. The sedimentary environment of Massachusetts Bay: physical, chemical and biological characteristics. Boston: Massachusetts Water Resources Authority. Report 1991-06. 139 p.

Snelgrove, P.V.R. and C.A. Butman. 1994. Animal sediment relationships revisited—Cause versus effect. Oceanography and Marine Biology 32:111-177.

Taylor DI. 2010. The Boston Harbor Project, and large decreases in loadings of eutrophication-related materials to Boston Harbor. Marine Pollution Bulletin 60:609–619.

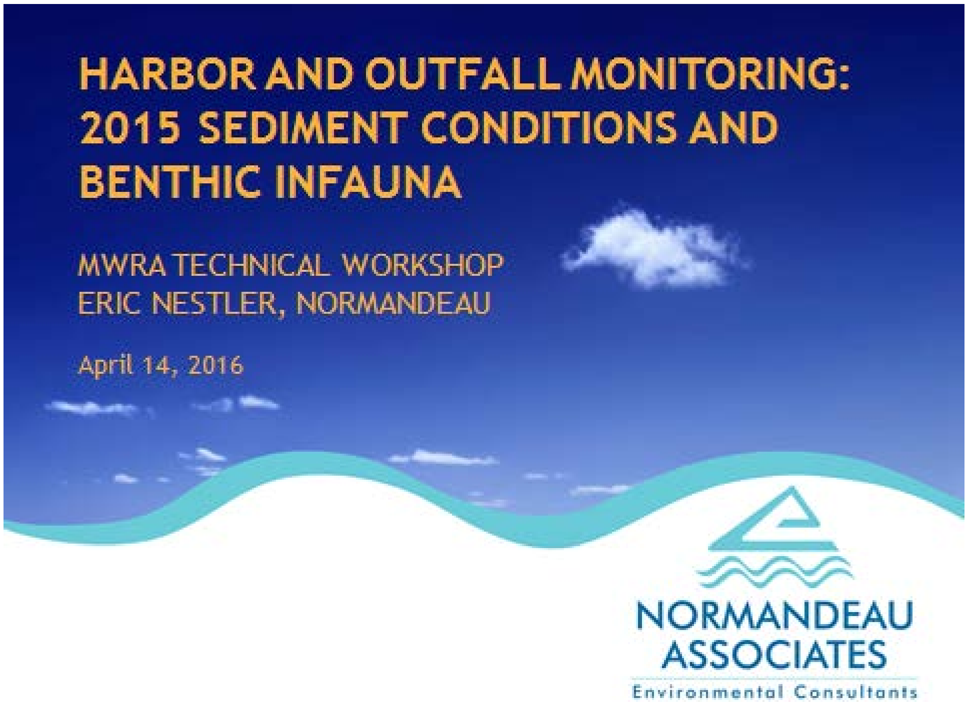
Warwick RM. 1993. Environmental impact studies on marine communities: pragmatical considerations. Aust. J. Ecol., 18: 63-80

Appendix A Annual Technical Meeting Presentations for Outfall Benthic Monitoring in 2015

Appendix A1. 2015 Harbor and Outfall Monitoring: Sediment Conditions and Benthic Infauna
Appendix A2. 2015 Harbor and Bay Sediment Profile Imaging

A2-1

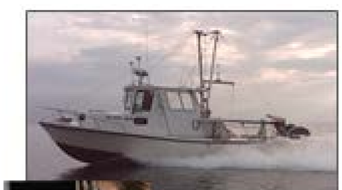
Appendix A1. 2015 Harbor and Outfall Monitoring: Sediment Conditions and Benthic Infauna



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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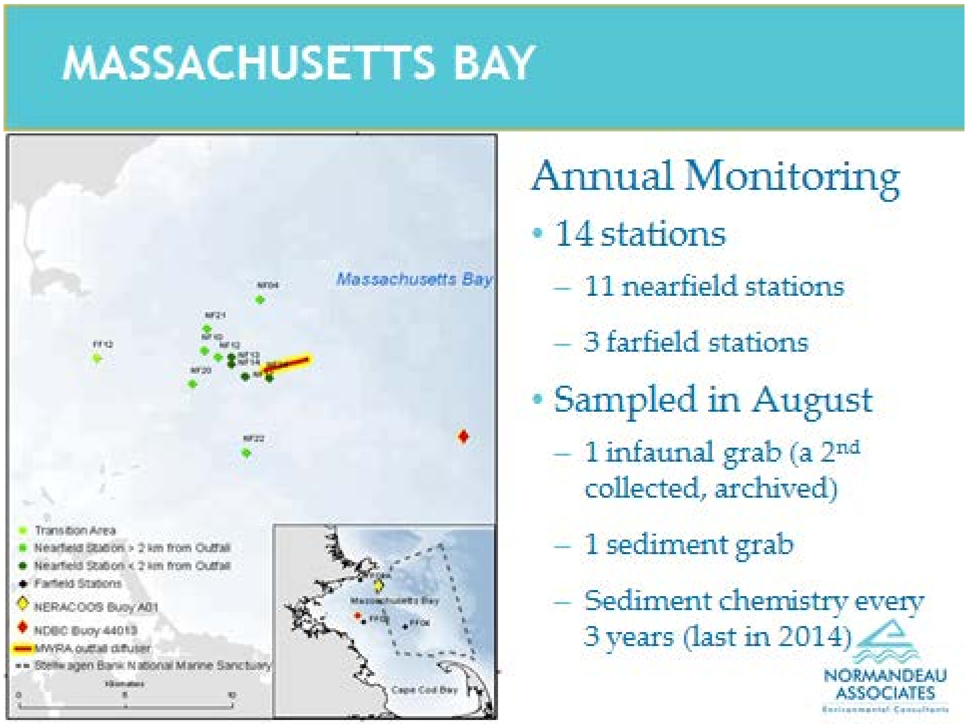
MASSACHUSETTS BAY
Massachusetts Bay
Transition Area
Nearfield Station > 2 km from Outfall
Nearfield Station < 2 km from Outfall
Farfield Stations
NERACOOS Buoy A01
NDBC Buoy 44013
MWRA outfall diffuser
Stellwagen Bank National Marine Sanctuary
Cape Cod Bay
Annual Monitoring
• 14 stations
– 11 nearfield stations
– 3 farfield stations
• Sampled in August
– 1 infaunal grab (a 2nd collected, archived)
– 1 sediment grab
– Sediment chemistry every 3 years (last in 2014)
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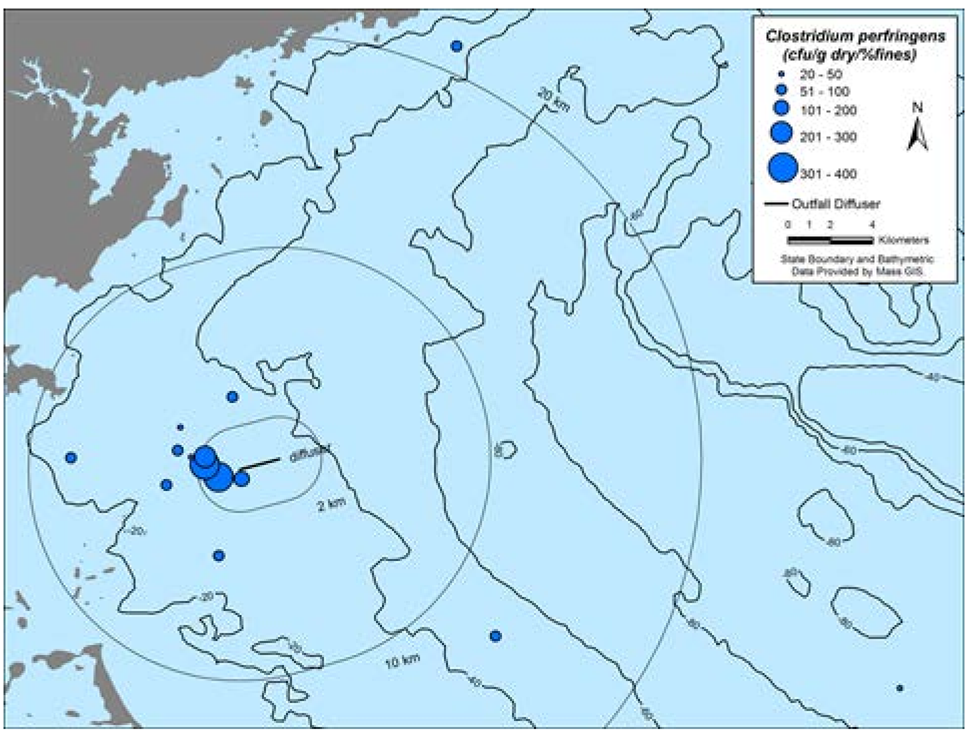
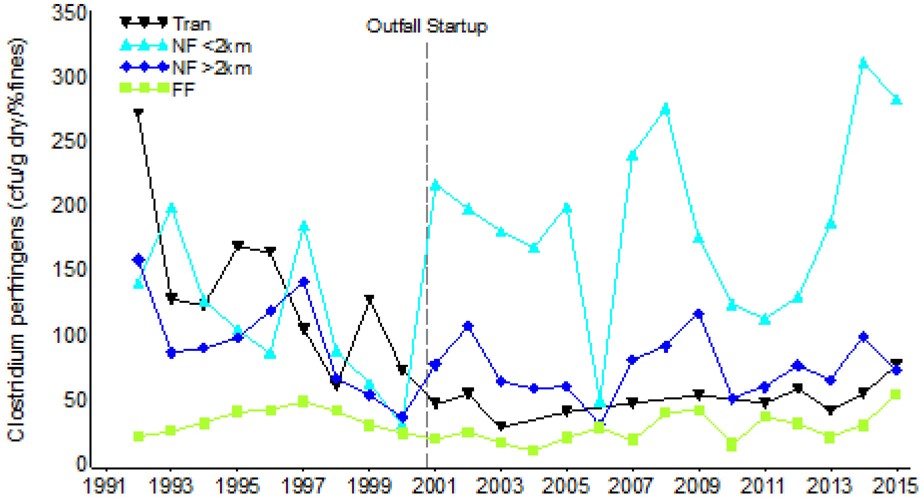
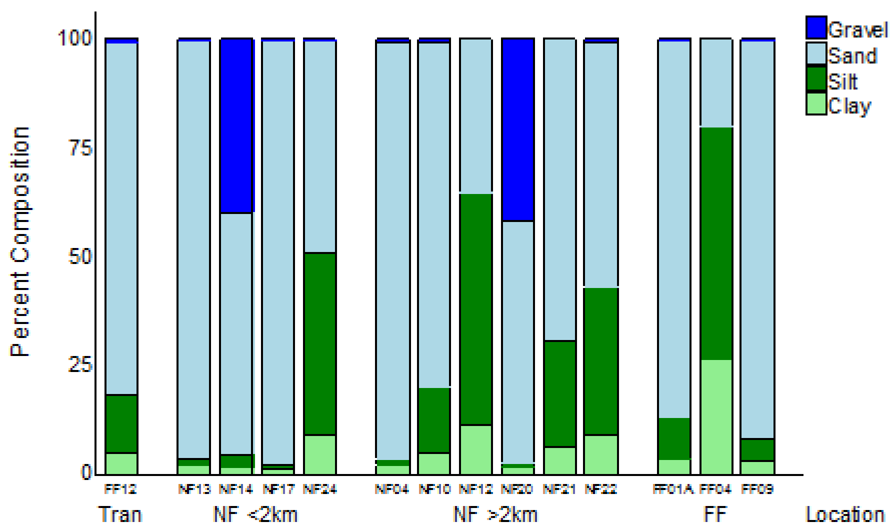

Clostridium perfringens (cfu/g dry/%fines)
20 - 50
51 - 100
101 - 200
201 - 300
301 - 400
N
Outfall Diffuser
0 1 2 4
Kilometers
State Boundary and Bathymetric Data Provided by Mass GIS
20 km
10 km
2 km
diffuser

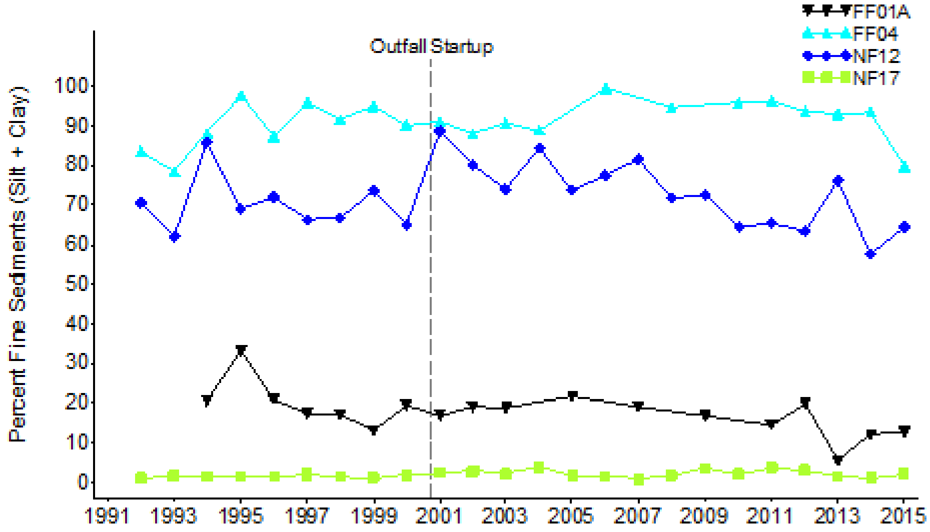
Clostridium perfringens (BY REGION)



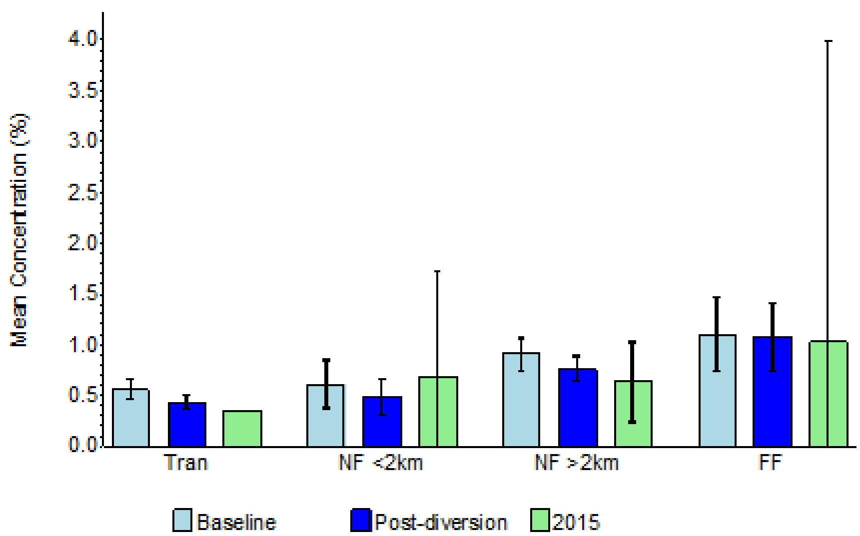
2015 SEDIMENT GRAIN SIZE



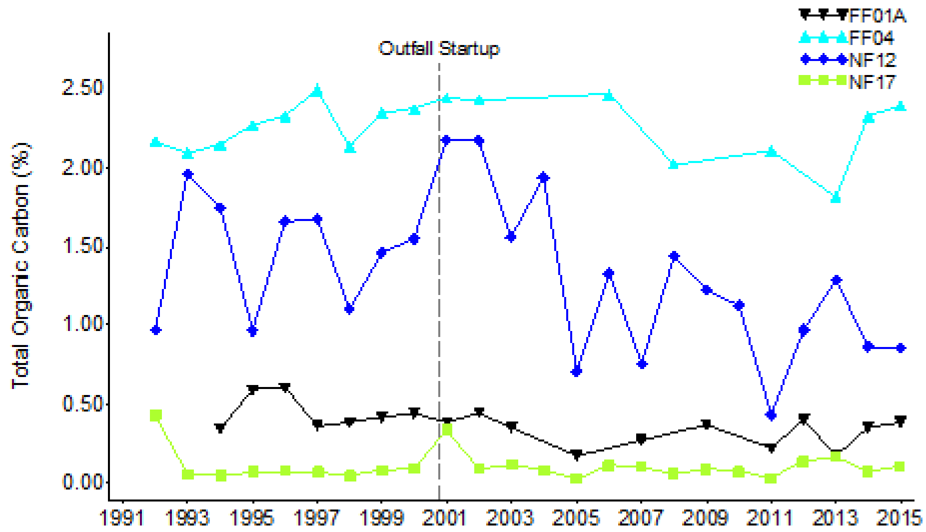
PERCENT FINES (SELECTED STATIONS)



TOTAL ORGANIC CARBON (BY REGION)



TOTAL ORGANIC CARBON
(SELECTED STATIONS)



MASSACHUSETTS BAY: BENTHIC INFAUNA

- Totals for 14 samples in 2015:
  - 20,341 individual organisms (21,863 in 2014)
  - 186 taxa identified; 164 species and 22 higher taxonomic groups (210 taxa total and 183 species in 2014)
  - 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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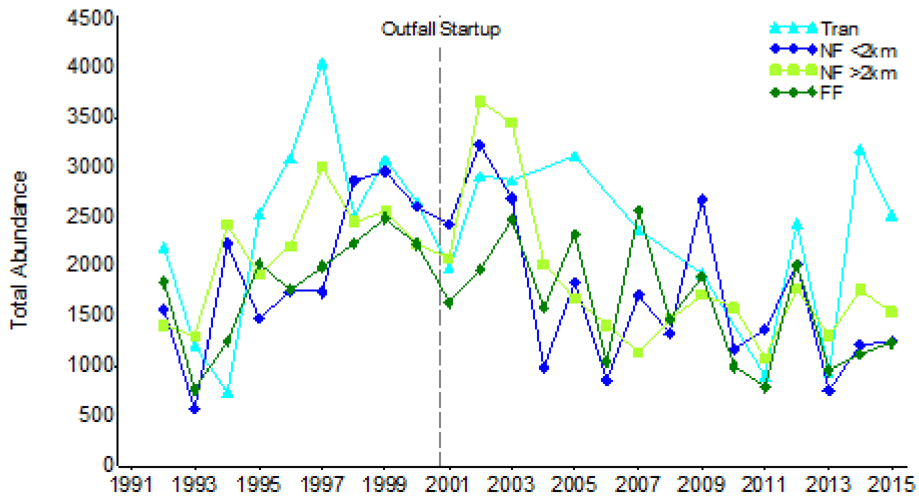
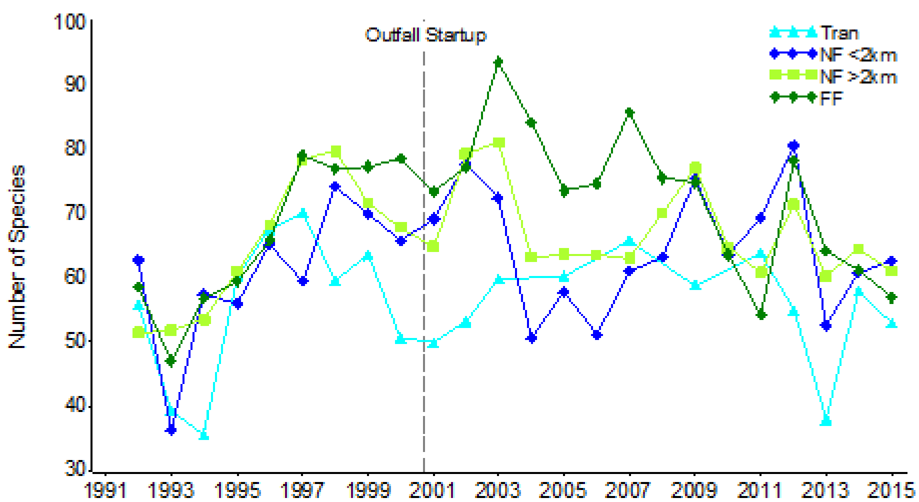
TOTAL ABUNDANCE (BY REGION)

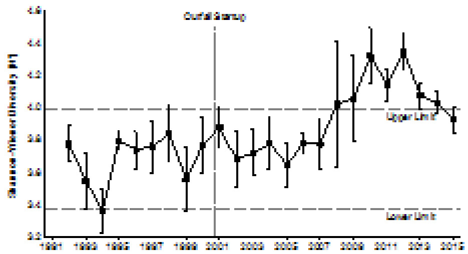


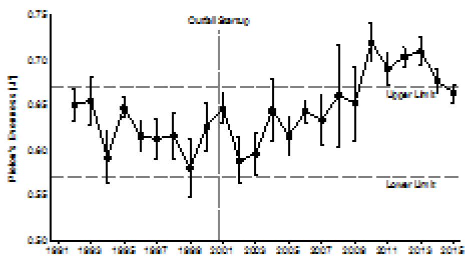
NUMBER OF SPECIES (BY REGION)



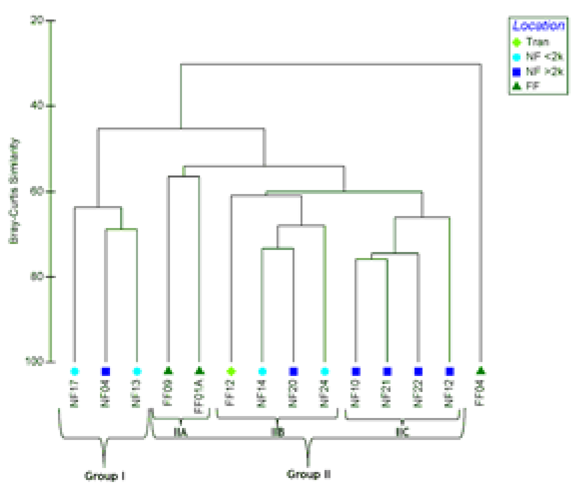
CONTINGENCY PLAN THRESHOLDS:
(NF STATIONS ONLY)

- No threshold exceedances!
- Exceedances for Shannon-Wiener Diversity (H′) and Pielou's Evenness (J′) were reported each year from 2010 to 2014.
- No exceedances in 2015 for: H′, J′, total species, log-series alpha, or percent opportunists.





2015 INFAUNAL ASSEMBLAGES
MASSACHUSETTS BAY



- Cluster Analysis:
  - Assess spatial patterns in the distribution of faunal assemblages
  - 2015 Samples
  - Bray-Curtis Similarity

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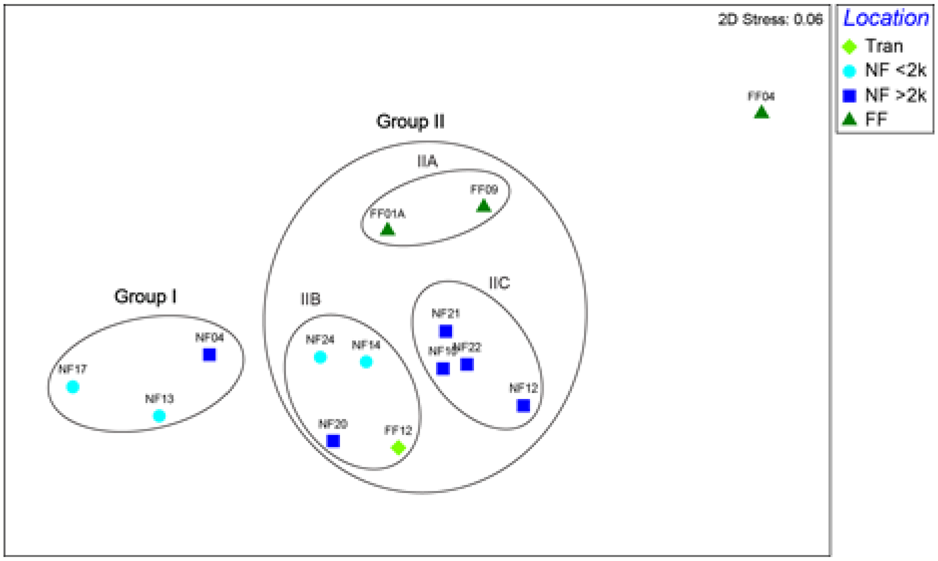
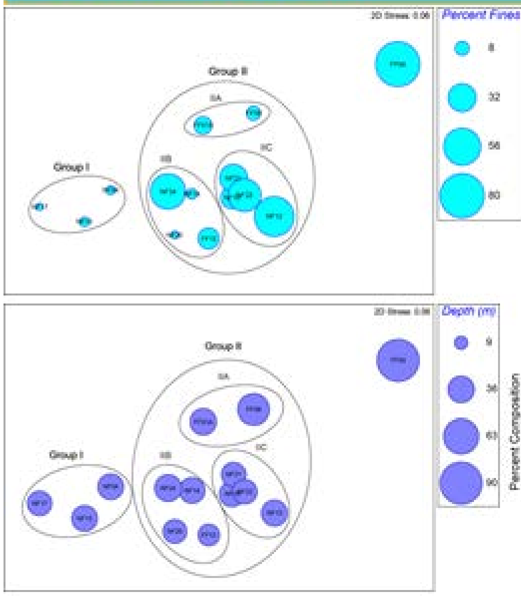
ORDINATION PLOT: 2015 SAMPLES
LOCATION OVERLAY



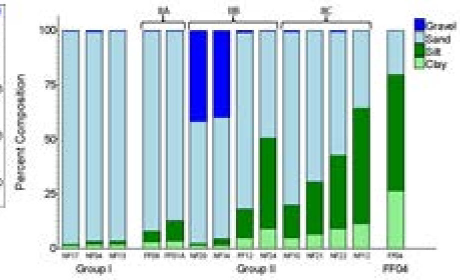
2015 INFAUNAL ASSEMBLAGES
MASSACHUSETTS BAY

- Group I: NF17, NF04, NF13 (sand)
  - *Exogone hebes, Aricidea catherinae, Marionina welchi*
- Group IIA: FF09, FF01A (sand, some fines; deeper)
  - *Prionospio steenstrupi, Nucula delphinodonta, Spio limicola*
- Group IIB: FF12, NF14, NF20, NF24 (sand with fines, gravel)
  - *A. catherinae, P. steenstrupi, Mediomastus californiensis*
- Group IIC: NF10, NF21, NF22, NF12 (fines with sand)
  - *M. californiensis, Levinsenia gracilis, P. steenstrupi*
- FF04 (fines; deepest)
  - *L. gracilis, Chaetozone anasimus, Cossura longocirrata*

2015 INFAUNAL ASSEMBLAGES
MASSACHUSETTS BAY



- Faunal distributions reflect habitat
  - Sediment grain size
  - Depth
  - Hydrodynamic conditions



MASSACHUSETTS BAY: SUMMARY

- Sediment conditions
  - Plume footprint indicated by *Clostridium perfringens*; only at stations closest to the outfall.
  - No evidence of change in grain size or TOC from the discharge.
- Benthic infauna
  - Faunal distributions reflect habitat (e.g., sediment grain size).
  - No infaunal diversity threshold exceedances in 2015.
  - No evidence of impacts to infauna from the discharge.

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BOSTON HARBOR

Annual Monitoring

- 9 stations
  - Stations T01-T08 since 1991
  - Station C019 since 2004
- Sampled in August
  - 2 infaunal grabs (a 3rd collected, archived)
  - 1 sediment grab

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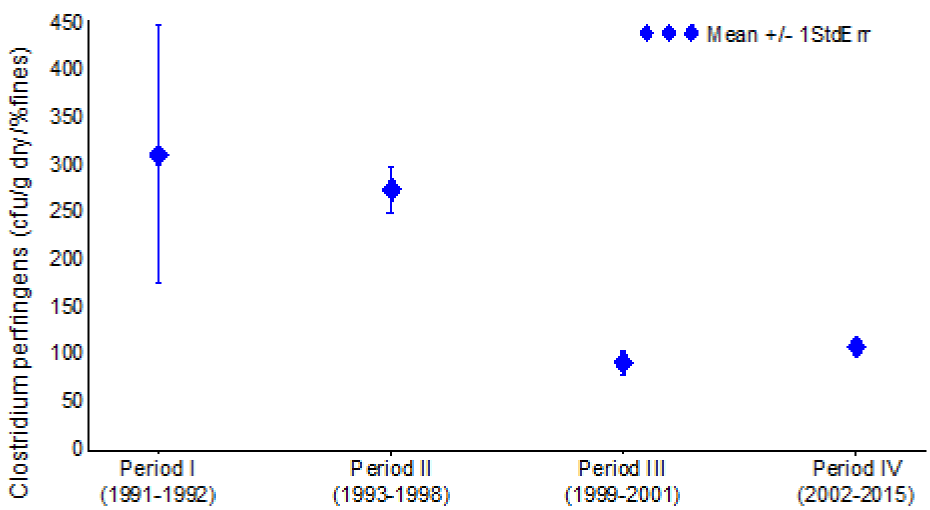
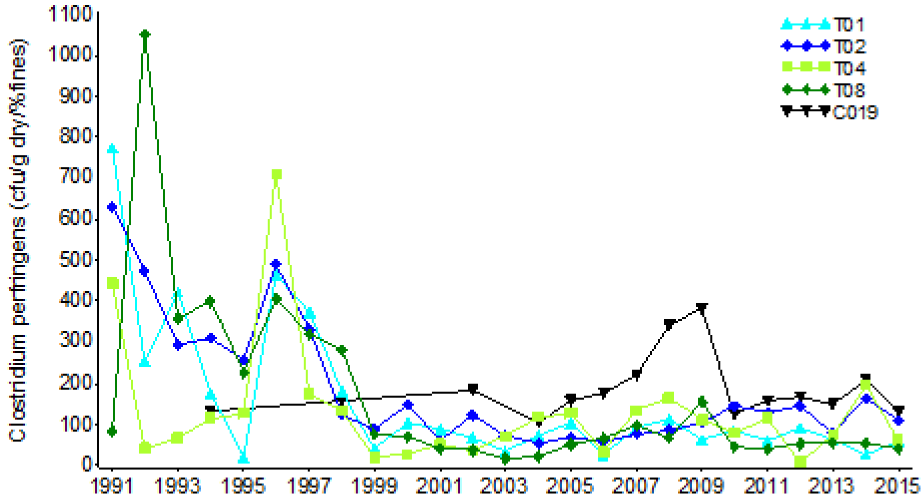
Clostridium perfringens (BY TIME PERIOD)

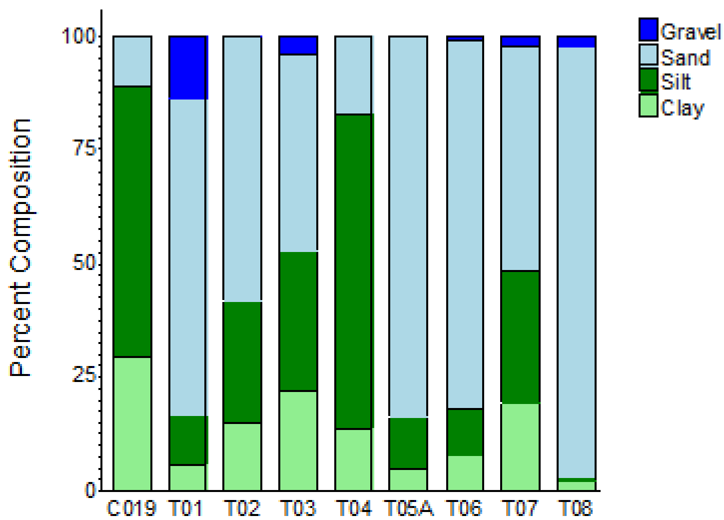
HARBOR STATIONS T01-T08



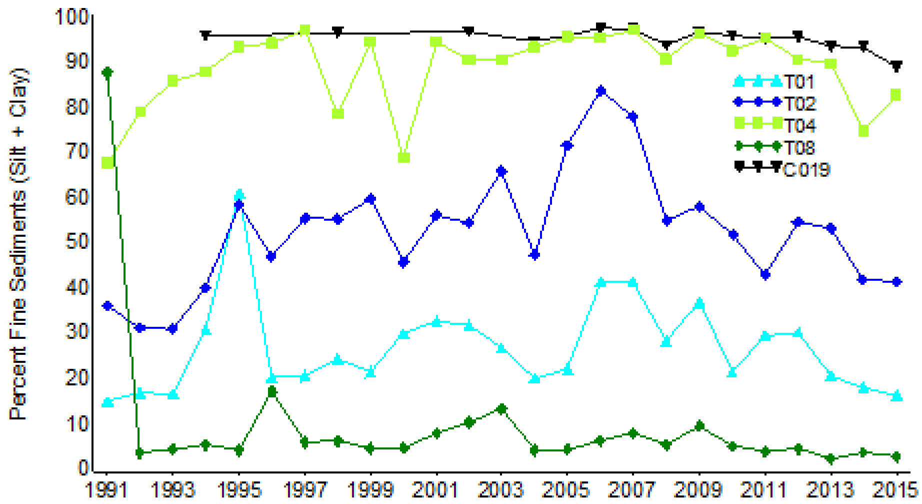
Clostridium perfringens
(SELECTED STATIONS)



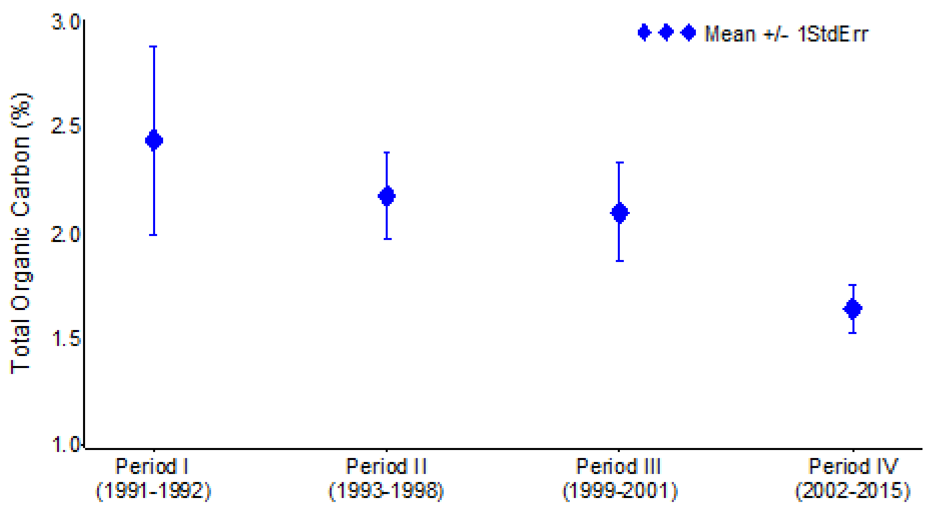
2015 SEDIMENT GRAIN SIZE



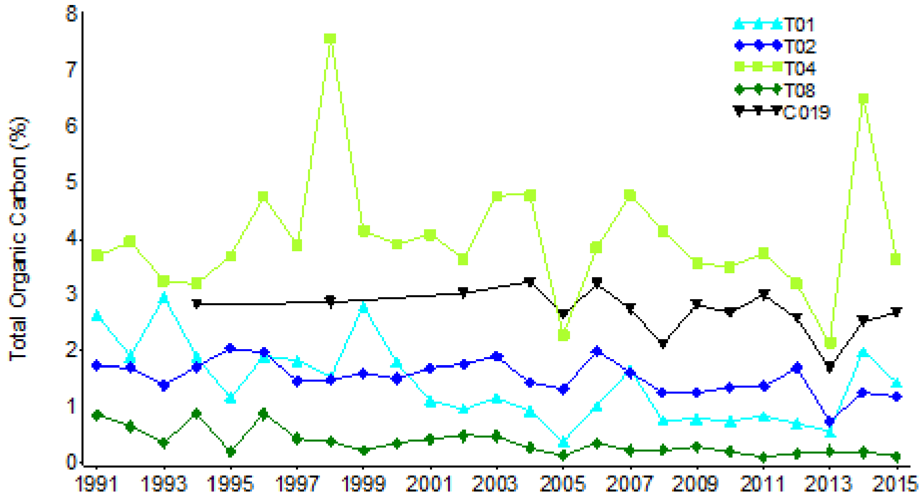
PERCENT FINES (SELECTED STATIONS)



TOTAL ORGANIC CARBON (BY TIME PERIOD)
HARBOR STATIONS T01-T08



TOTAL ORGANIC CARBON (SELECTED STATIONS)



BOSTON HARBOR: BENTHIC INFAUNA

- Totals for 18 samples in 2015:
  - 33,058 individual organisms (26,477 in 2014)
  - 142 taxa identified; 129 species and 13 higher taxonomic groups (134 taxa total, and 119 species in 2014)
- All counts used for abundance; only species-level counts used for diversity measures and multivariate analyses

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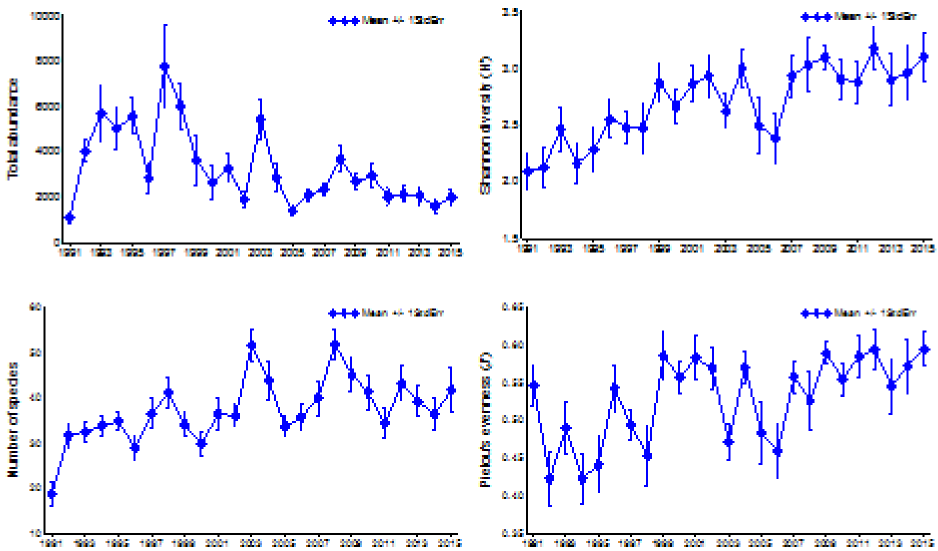
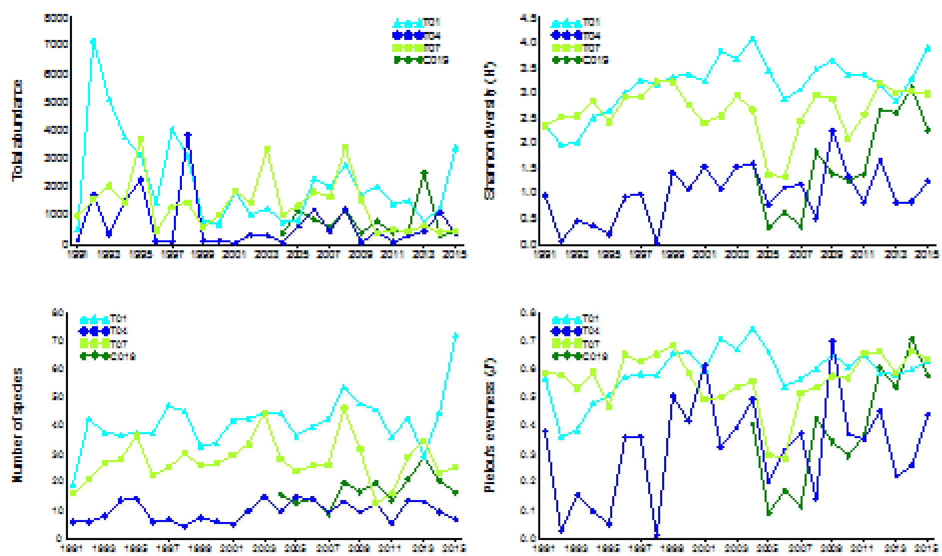
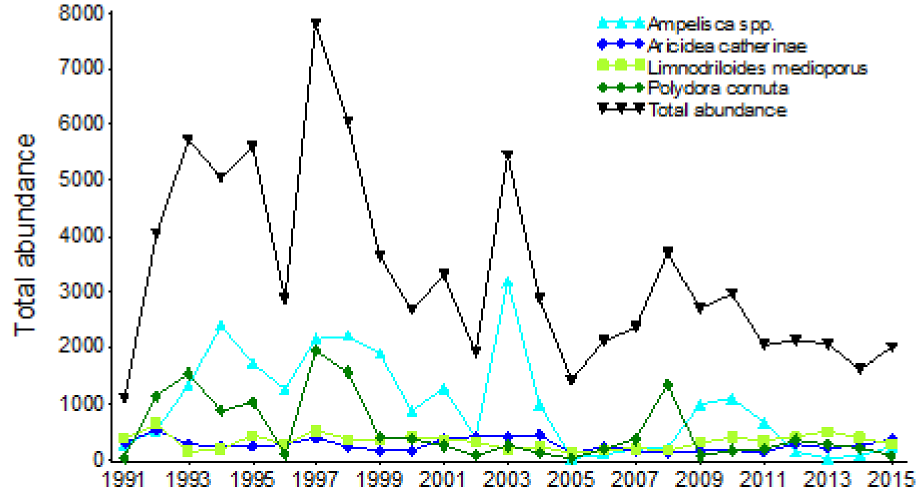
COMMUNITY PARAMETERS
HARBOR STATIONS T01-T08



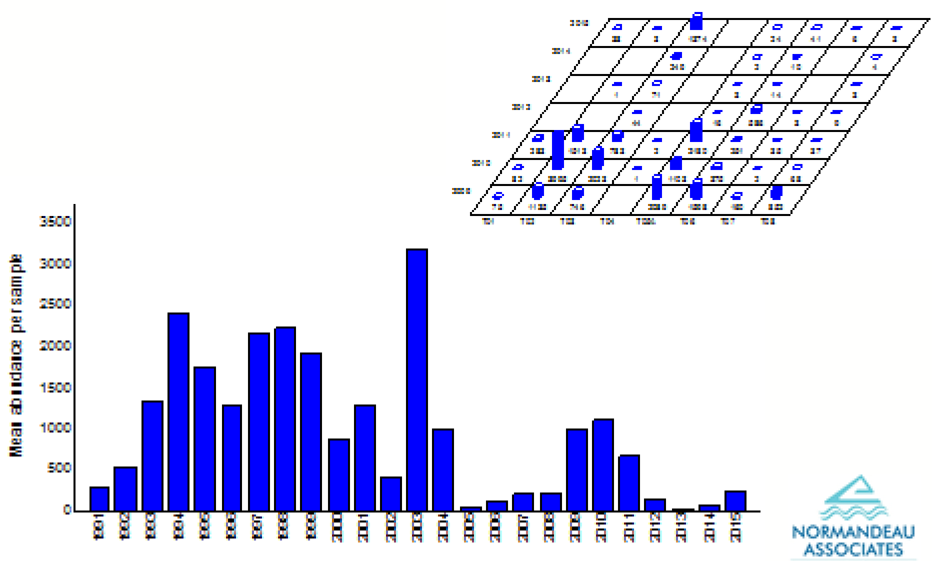
COMMUNITY PARAMETERS
HARBOR STATIONS T01, T04, T07, AND C019



DOMINANT SPECIES
HARBOR STATIONS T01-T08



AMPELISCA SPP.
HARBOR STATIONS T01-T08



INFAUNAL ASSEMBLAGES
BOSTON HARBOR

- Spatial Patterns:
  - Multivariate analyses to assess patterns in the distribution of faunal assemblages
  - 2015 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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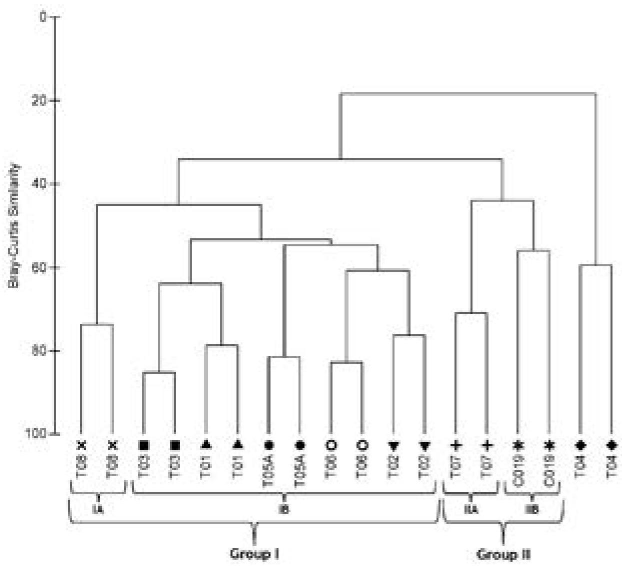
CLUSTER ANALYSIS: 2015 SAMPLES
BOSTON HARBOR



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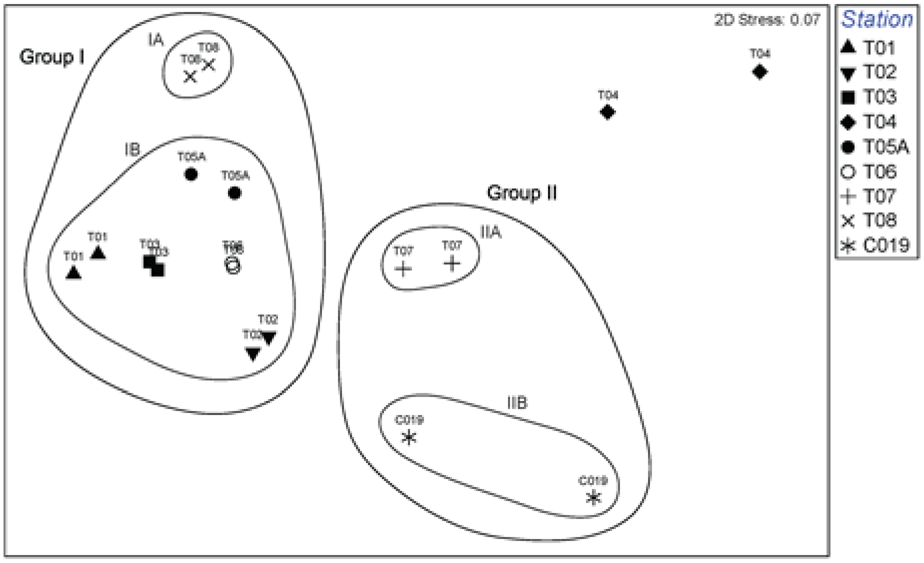
ORDINATION PLOT: 2015 SAMPLES
BOSTON HARBOR



INFAUNAL ASSEMBLAGES
BOSTON HARBOR

- Group IA: T08 (outer Harbor, sand)
  - *Polygordius jouinae, Tharyx acutus, Angulus agilis*
- Group IB: T01, T02, T03, T05A, T06 (outer Harbor, mixed sediments)
  - *Tubificoides intermedius, Aricidea catherinae, Limnodriloides medioporus*
- Group IIA: T07 (Quincy Bay, fines with sand)
  - *Bipalponephtys neotena, Streblospio benedicti, T. intermedius*
- Group IIB: C019 (Inner Harbor, fines)
  - *T. intermedius, B. neotena, Leptocheirus pinguis*
- T04 (Savin Hill Cove, fines, organic enrichment, shallow – 4 meters)
  - *S. benedicti, Tubificoides* sp. 2*, T. intermedius*

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).

NORMANDEAU ASSOCIATES

ACKNOWLEDGEMENTS

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- Normandeau Associates, Inc.
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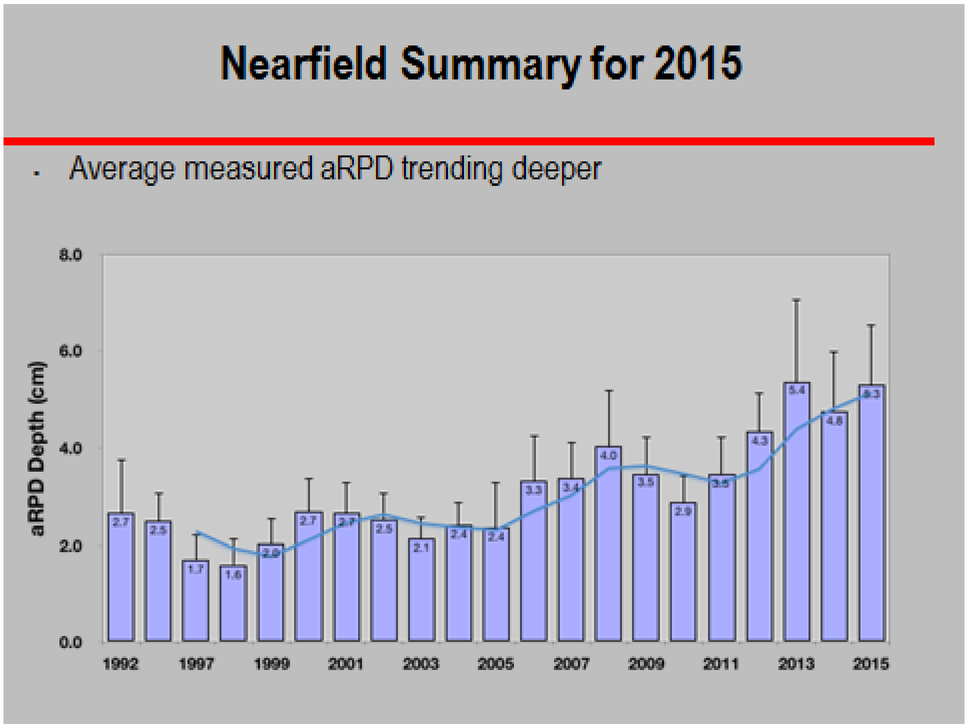
- Cove Corporation
- Ocean's Taxonomic Services

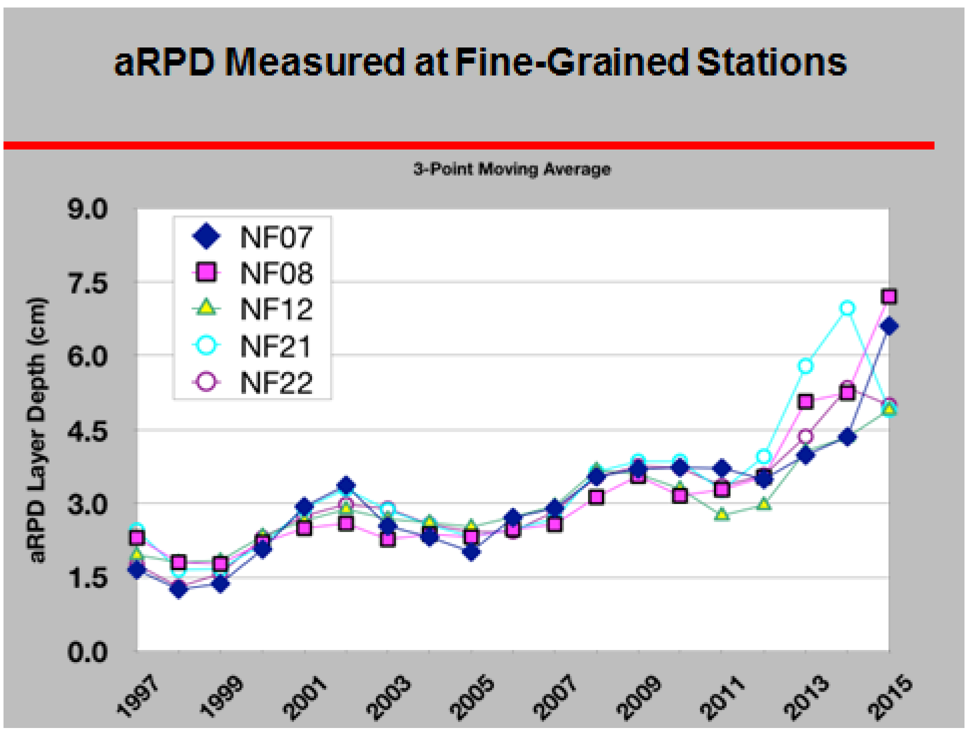
NORMANDEAU ASSOCIATES

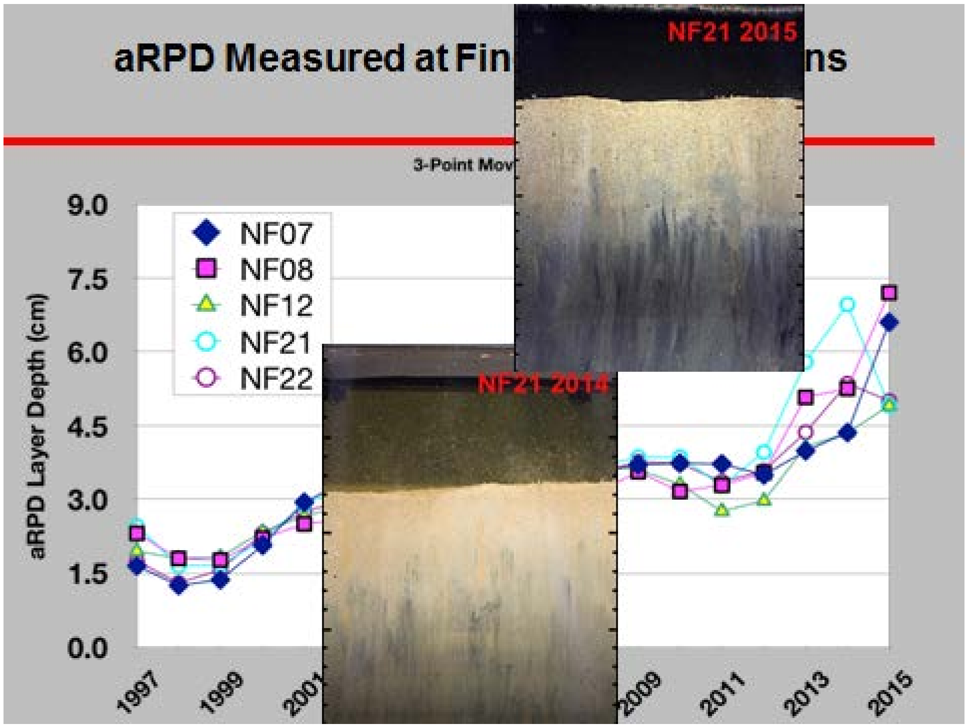
Appendix A2. 2015 Harbor and Bay Sediment Profile Imaging

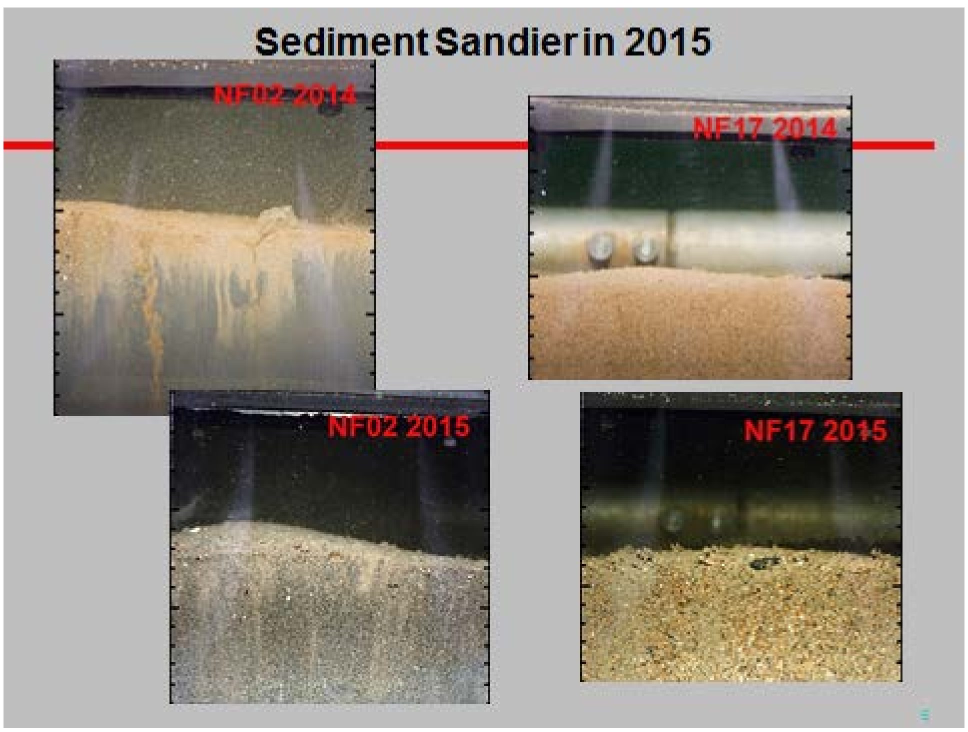
Nearfield Summary
Baseline vs. Post-Baseline

	Baseline Years 1992-2000 9-Year Interval	Post-Baseline Years 2001-2015 14-Year Interval	Only 2015
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)	7.7 (2015)
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	3.5 (1.06 SD) cm	5.3 (0.97 SD) cm
Annual Mean RPD All Values	2.4 (0.47 SD) cm	3.1 (0.88 SD) cm	5.5 (1.33 SD) cm


Nearfield Summary for 2015
Average measured aRPD trending deeper
aRPD Depth (cm)
8.0
6.0
4.0
2.0
0.0
1992
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2.7
2.5
1.7
1.6
2.0
2.7
2.7
2.5
2.1
2.4
2.4
3.3
3.4
4.0
3.5
2.9
3.5
4.3
5.4
4.8
5.3


aRPD Measured at Fine-Grained Stations
3-Point Moving Average
aRPD Layer Depth (cm)
9.0
7.5
6.0
4.5
3.0
1.5
0.0
NF07
NF08
NF12
NF21
NF22
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015


aRPD Measured at Fin
ns
3-Point Mov
NF21 2015
NF21 2014
aRPD Layer Depth (cm)
9.0
7.5
6.0
4.5
3.0
1.5
0.0
NF07
NF08
NF12
NF21
NF22
1997
1999
2001
2009
2011
2013
2015


Sediment Sandier in 2015
NF02 2014
NF17 2014
NF02 2015
NF17 2015

Nearfield 2015 Summary

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

MWRA Outfall vs. Other Ocean Outfalls

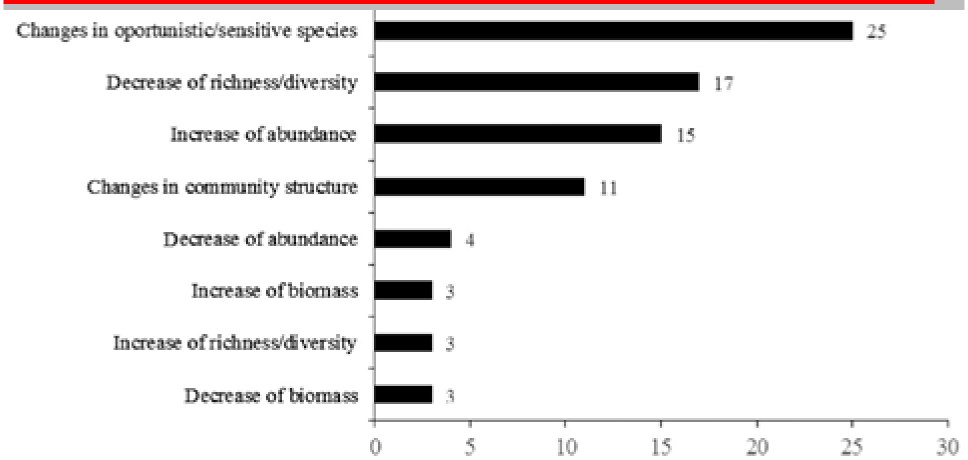
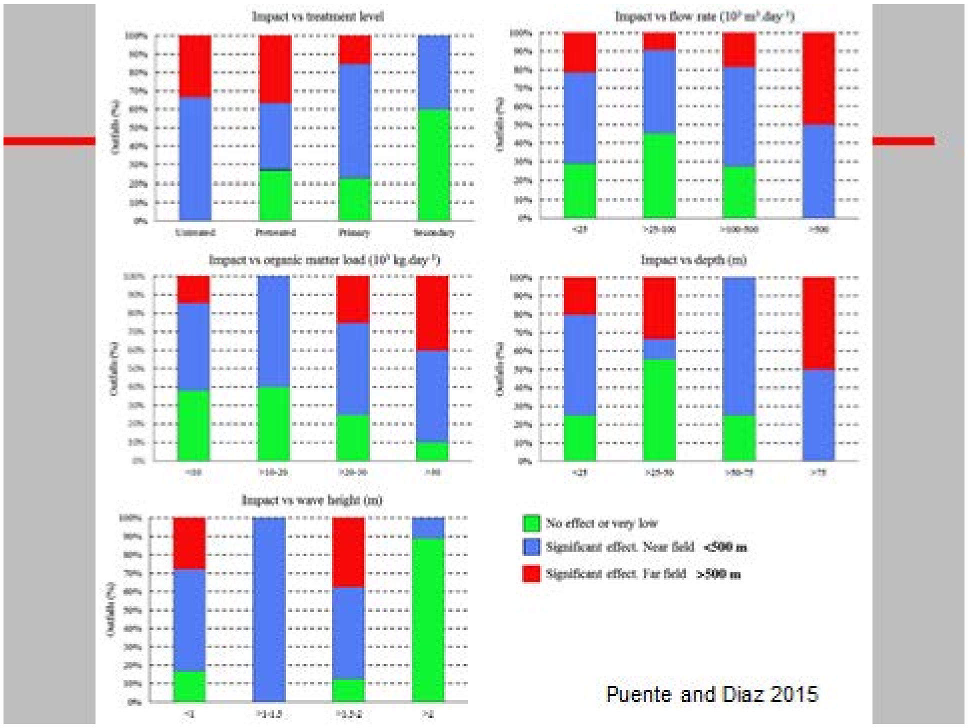
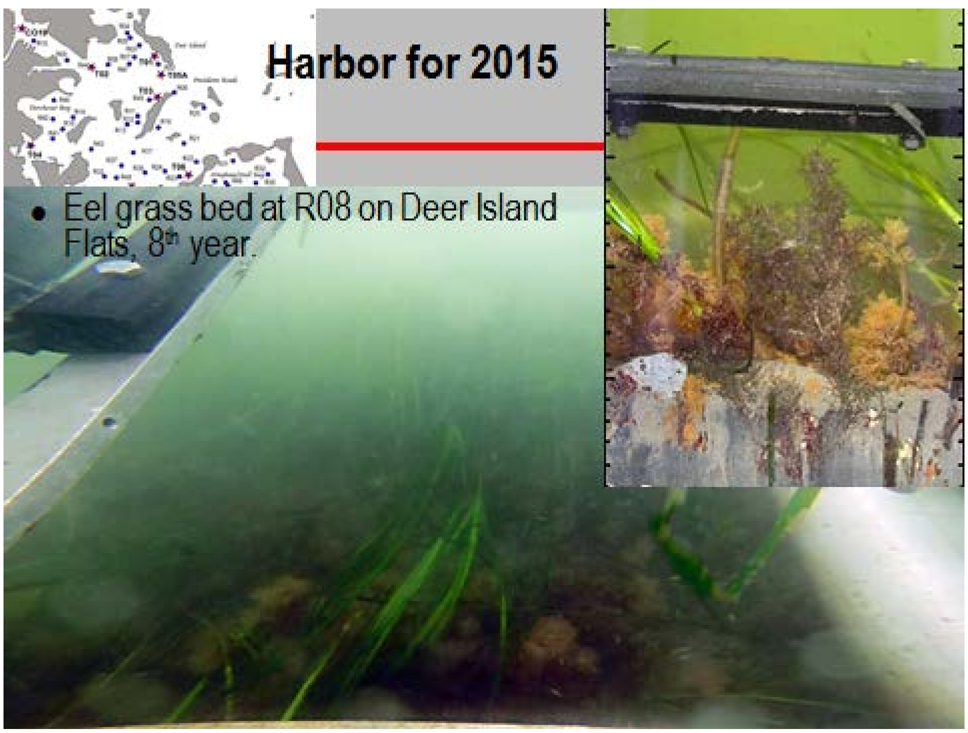
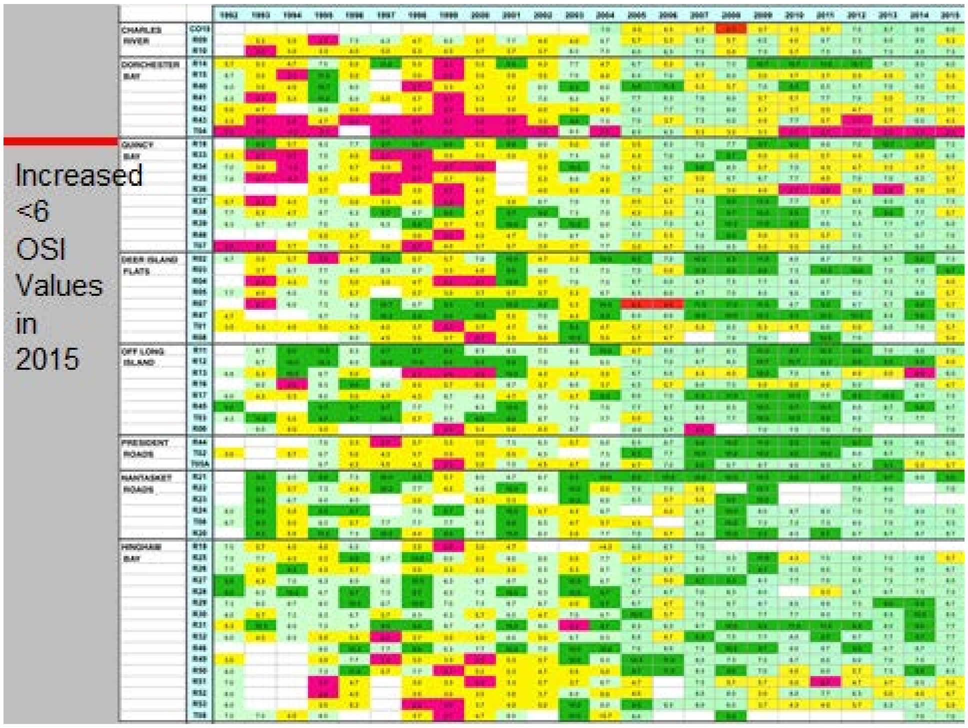


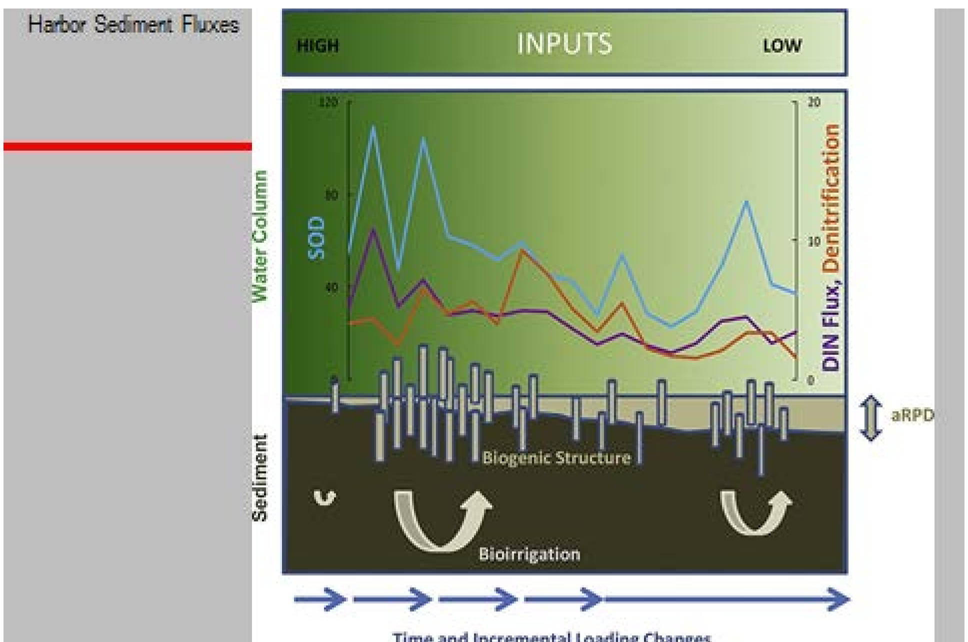
Fig. 1. Type of effects reported in the papers reviewed (number of outfalls).

Puente and Diaz (2015) Response of benthos to ocean outfall discharges: does a general pattern exist? Marine Pollution Bulletin 101(1):174-81.


Impact vs treatment level
Impact vs flow rate
Impact vs organic matter load
Impact vs depth (m)
Impact vs wave height (m)
No effect or very low
Significant effect. Near field <500 m
Significant effect. Far field >500 m
Puente and Diaz 2015


Harbor for 2015
• Eel grass bed at R08 on Deer Island Flats, 8th year.





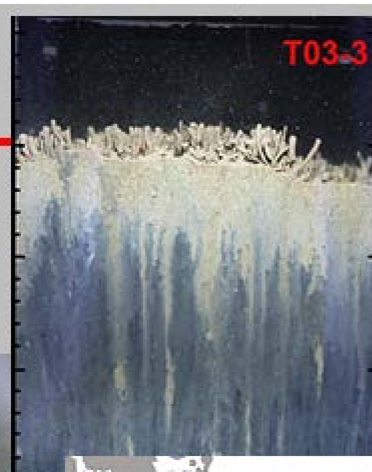
Tucker et al. 2014. Response of benthic metabolism and nutrient cycling to reductions in wastewater loading to Boston Harbor, USA. Estuarine, Coastal and Shelf Science, 151:54-68.

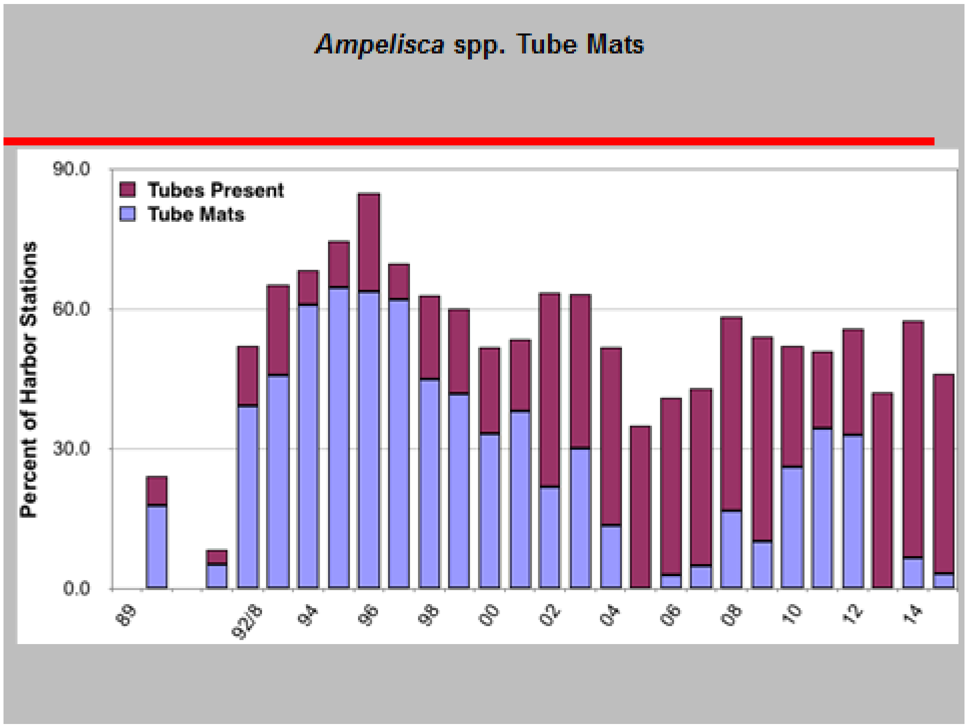
Harbor 2015 vs. 2014

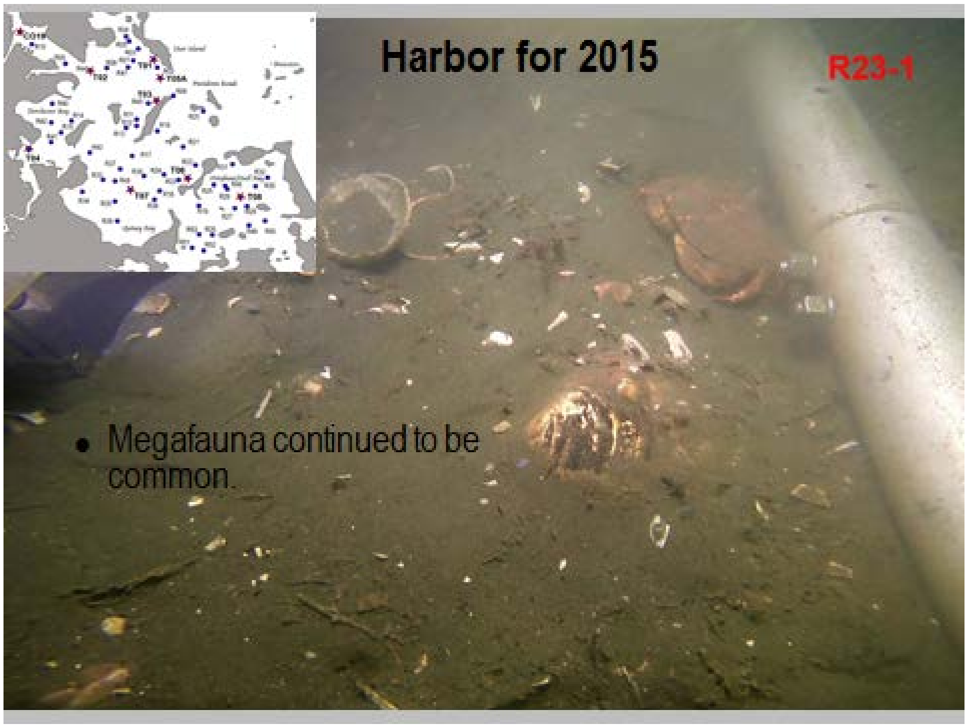
		[illegible] (cm)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]							
[illegible]	2015	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	2014	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	2015	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
BAY	2014	1.4	3.4	[illegible]	1.2	[illegible]	[illegible]	6.7
[illegible]	2015	1.2	1.2	[illegible]	1.1	[illegible]	[illegible]	6.7
BAY	2014	[illegible]	4.6	[illegible]	1.4	[illegible]	[illegible]	[illegible]
[illegible]	2015	2.1	[illegible]	[illegible]	1.1	[illegible]	[illegible]	[illegible]
FLATS	2014	2.7	[illegible]	1.2	[illegible]	[illegible]	[illegible]	[illegible]
OFF LONG	2015	1.7	1.4	[illegible]	1.3	[illegible]	[illegible]	[illegible]
ISLAND	2014	2.1	4.2	[illegible]	1.4	[illegible]	3.1	[illegible]
[illegible]	2015	1.4	2.2	[illegible]	1.4	[illegible]	[illegible]	[illegible]
ROADS	2014	2.4	7.7	[illegible]	2.2	[illegible]	[illegible]	[illegible]
[illegible]	2015	[illegible]	2.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ROADS	2014	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	2015	2.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6.7
BAY	2014	2.7	[illegible]	[illegible]	1.7	[illegible]	[illegible]	[illegible]

Harbor for 2015

- *Ampelisca* spp. tube mats at two stations.




Ampelisca spp. Tube Mats
Tubes Present
Tube Mats
Percent of Harbor Stations
90.0
60.0
30.0
0.0
89
92/8
94
96
98
00
02
04
06
08
10
12
14


Harbor for 2015
R23-1
• Megafauna continued to be common.

Summary for Harbor

Benthic habitat quality for infauna trended lower for 2015.

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

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