Outfall Benthic Monitoring Report: 2012 Results

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EXECUTIVE SUMMARY

Benthic monitoring during 2012 included soft-bottom sampling for sediment conditions and infauna at 14 nearfield and farfield stations, and sediment profile imaging (SPI) at 23 nearfield stations.

Sediment conditions were characterized based on spore counts of the anaerobic bacterium, *Clostridium perfringens*, and analyses of sediment grain size composition and total organic carbon (TOC). As in past years during the post-diversion period, *C. perfringens* concentrations during 2012 were highest at sites closest to the discharge. These *C. perfringens* results 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 evident in the monitoring results for sediment grain size or TOC during 2012. These findings are consistent with prior monitoring results (Nestler et al. 2012, Maciolek et al. 2008, 2011).

There were threshold exceedances in 2012 for two infaunal diversity measures: (1) Shannon-Wiener Diversity (H') and (2) Pielou's Evenness (J'). No exceedances were reported for other infaunal diversity measures or for the percent opportunistic species. Spatial comparisons of the 2012 values for H' and J' indicated that there was no association between high evenness or diversity values (or low values) and proximity to the outfall diffuser. Temporal comparisons of H' and J' values demonstrated no indication of increases in the post-diversion period compared to the baseline at stations closest to the outfall. Recent increases in H'and J' appear to be a region-wide occurrence, strongly influenced by relatively low abundance in a few dominant species, and unrelated to the discharge. Multivariate analyses found no evidence of impacts from the offshore outfall on infaunal communities in Massachusetts Bay. These results further support findings that increased H' and J' are a region-wide occurrence, unrelated to the discharge. Infaunal data in 2012 continue to suggest that animals near the outfall have not been smothered by particulate matter from the wastewater discharge.

The 2012 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 2012 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. 2012, Maciolek et al. 2008).

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1. INTRODUCTION

1.1 Background

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

Under its Ambient Monitoring Plan (MWRA (1991, 1997, 2001, 2004, 2010) the MWRA has collected extensive information over a nine-year baseline period (1992–2000) and a twelve-year post-diversion period (2001–2012). 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 2012 represented the second year of data collection following the 2010 revision to the Ambient Monitoring Plan (MWRA 2010). Under the current 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 2011 (next sampling will be in 2014). Sediment contaminant monitoring in 2011 found no indication that toxic contaminants from the wastewater discharge are accumulating in depositional areas surrounding the outfall (Nestler et al. 2012). Monitoring results for 2011 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. 2012).

Results of 2012 benthic monitoring were presented at MWRA's Annual Technical Workshop on March 6, 2013. PowerPoint presentations from this workshop are provided in Appendix A. The purpose of this report is to summarize key findings from the 2012 benthic surveys, with a focus on the most noteworthy observations relevant to understanding the potential effects of the discharge on the offshore benthic environment.

1.2 2012 Threshold Exceedance

Two infaunal biodiversity measures tracked by MWRA as Contingency Plan thresholds exceeded their caution level threshold ranges for samples collected in August 2012. The nearfield averages for both Shannon-Wiener diversity (H′) and Pielou's evenness (J′) were slightly higher than the upper threshold limit. These results were communicated to regulators and the public in December 2012 (MWRA 2012). Threshold exceedances for these two parameters were also reported for 2010 and 2011 monitoring (MWRA 2011a, MWRA 2011b).

A further evaluation of these findings was conducted and is described in section 3.2 of this report. The findings from this evaluation were consistent with those presented in the 2010 and 2011 Outfall Benthic Monitoring Reports (Nestler et al. 2012, Maciolek et al. 2011); i.e., there is no evidence that the threshold exceedances resulted from an impact of the outfall discharge on infaunal communities, but resulted from natural variability in the benthic communities monitored in the vicinity of MWRA's outfall.

2. METHODS

Methods used to collect, analyze, and evaluate all sample types remain largely consistent with those reported for previous monitoring years (Nestler et al. 2012, Maciolek et al. 2008). Detailed descriptions of the methods are contained in the Quality Assurance Project Plan (QAPP) for Benthic Monitoring (Nestler et al. 2013). 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 during August, 2012 (Figure 2-1):

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

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-2010-001.

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

SPI samples were collected in triplicate at 23 nearfield stations on August 13, 2012 (Figure 2-2).

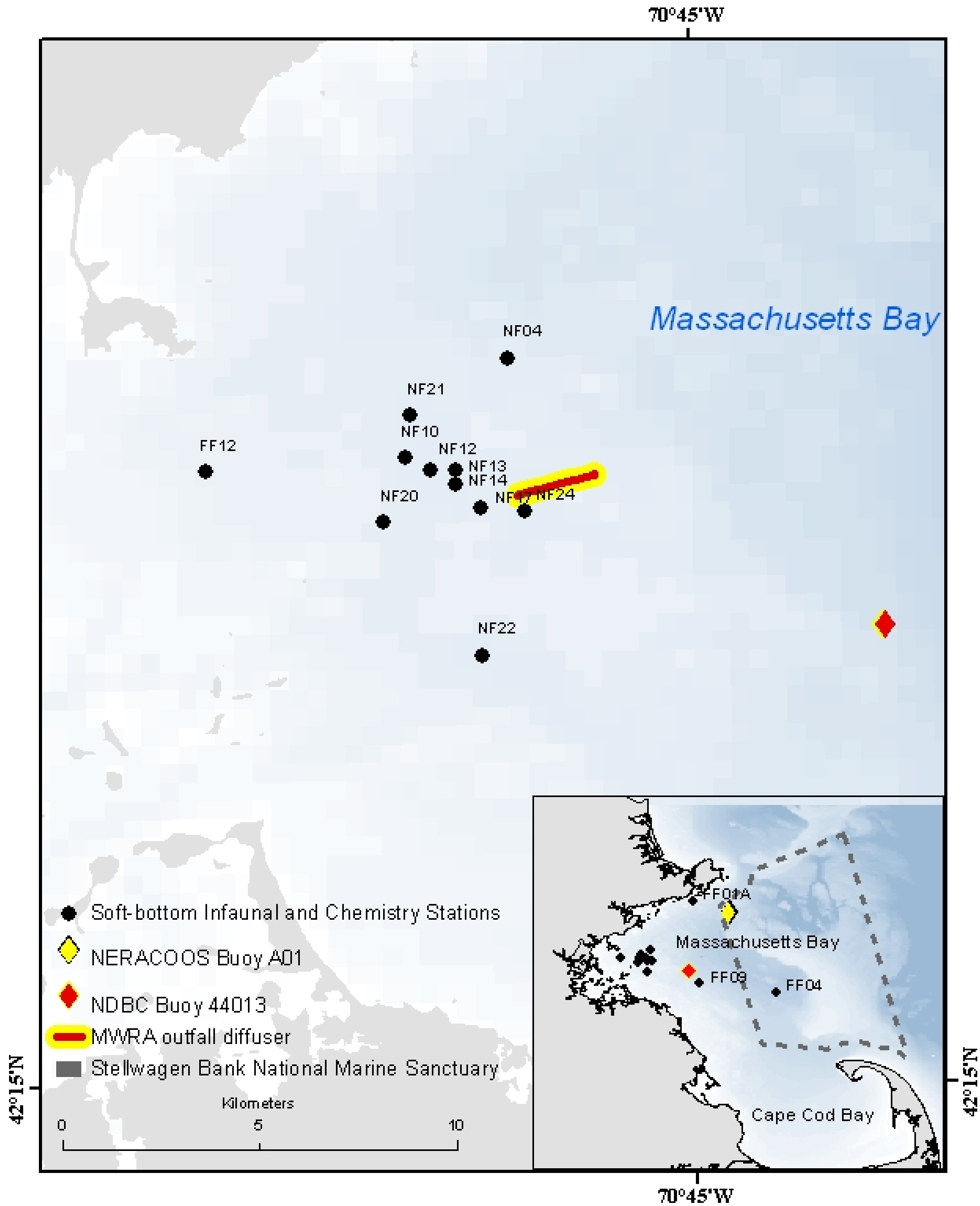

Figure 2-1. Locations of soft-bottom sampling stations for 2012.

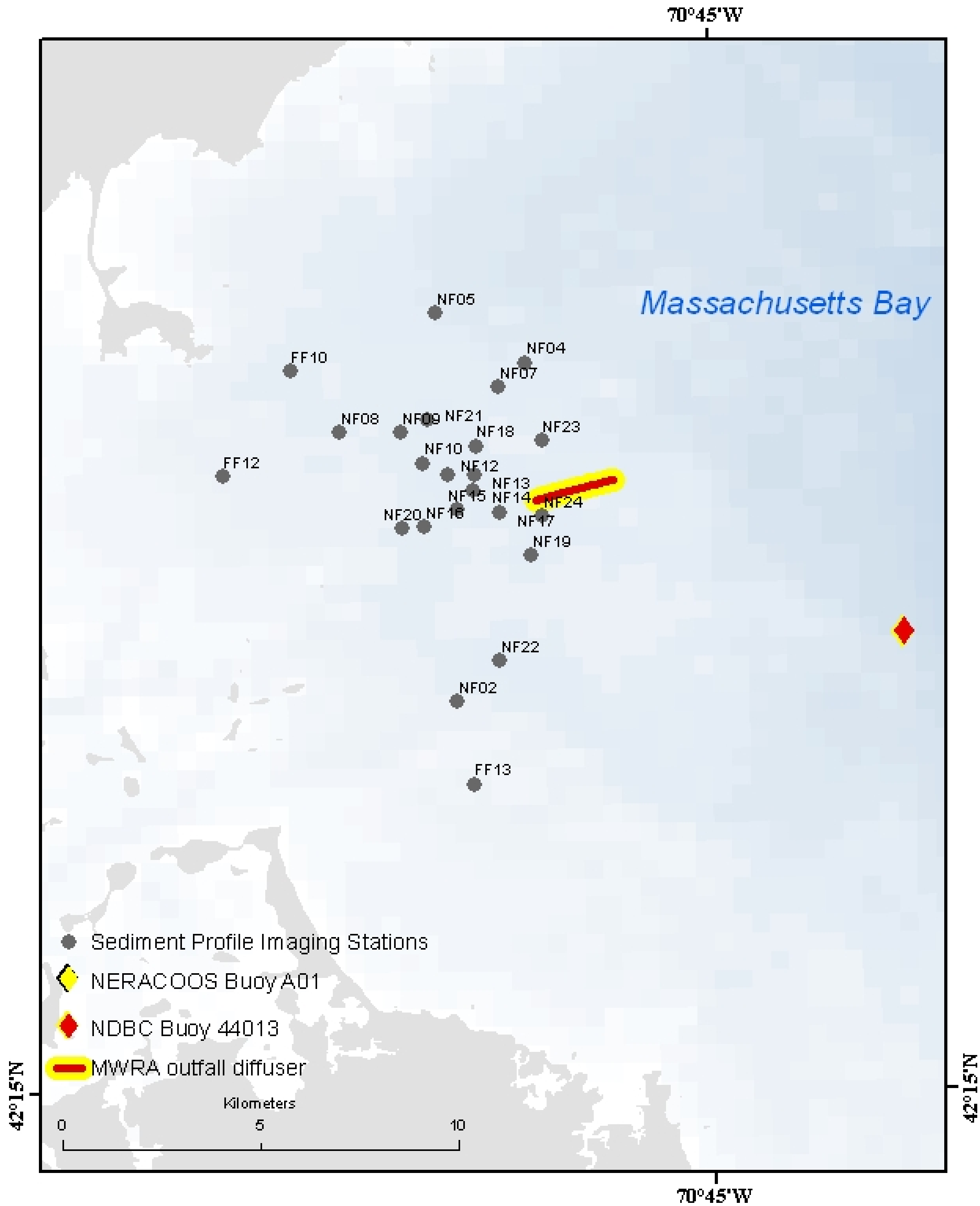

Figure 2-2. Locations of sediment profile imaging stations for 2012.

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. 2013).

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. 2013) or by Maciolek et al. (2008).

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

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

3. RESULTS AND DISCUSSION

3.1 Sediment Conditions

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

Sediment conditions were characterized by three parameters measured during 2012 at each of the 14 sampling stations: (1) *Clostridium perfringens*, (2) grain size (gravel, sand, silt, and clay), and (3) total organic carbon (Table 3-1).

Spores of the anaerobic bacterium *Clostridium perfringens* provide a sensitive tracer of effluent solids. Temporal analyses of *C. perfringens* at the 14 sampling sites demonstrated that a sharp increase occurred coincident with diversion of effluent to the offshore outfall at sites within two kilometers from the diffuser (Figure 3-1). *C. perfringens* concentrations have declined or remained comparable to the baseline at all other locations during the post-diversion period. *C. perfringens* counts (reported as colony forming units per gram dry weight, normalized to percent fines) in samples collected during 2012 were highest at stations NF13, NF24, and NF17 (Table 3-1); three stations located within two kilometers from the outfall (Figure 3-2).

The grain size composition of the sediments in 2012 remained consistent with results reported in prior years (Figure 3-3). There was considerable variability among the 14 stations with grain size profiles ranging from predominantly sand (e.g., NF13, NF17, and NF04) to almost entirely silt and clay (i.e., FF04), with most stations having mixed sediments (Table 3-1, Figure 3-4).

Concentrations of total organic carbon (TOC) in 2012 also remained similar to values reported in prior years at most stations (Figure 3-5). Concentrations of TOC track closely to percent fine sediments (i.e., silt + clay), with higher TOC values generally associated with higher percent fines (Maciolek et al. 2008). This pattern is evident in comparisons of Figures 3-3 and 3-5.

As in past years during the post-diversion period, *Clostridium perfringens* concentrations during 2012 continue to indicate a footprint of the effluent plume, but only at sites closest to the discharge. Although *C. perfingens* 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. 2012, Maciolek et al. 2008, 2011).

Table 3-1. 2012 monitoring results for sediment condition parameters.

Location	Station	*Clostridium perfringens* (cfu/g dry/%fines)	Total Organic Carbon (%)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Percent Fines (Silt + Clay)
Transition Area	**FF12**	59	0.38	5.2	64.2	24.5	6.1	30.6
Nearfield (<2 km from outfall)	**NF13**	155	0.15	1.3	93.2	2.8	2.7	5.5
	NF14	89	0.53	27.8	61.0	6.9	4.3	11.2
	NF17	132	0.14	0.0	96.8	1.2	2.0	3.2
	NF24	146	1.4	2.4	39.9	42.1	15.6	57.7
Nearfield (>2 km from outfall)	**NF04**	98	0.37	1.0	90.4	4.8	3.8	8.6
	NF10	54	0.62	0.2	61.2	29.6	9.0	38.6
	NF12	74	0.98	0.3	36.3	48.5	15.0	63.5
	NF20	110	0.29	42.1	51.8	3.3	2.8	6.1
	NF21	64	1.07	0.4	41.5	43.3	14.8	58.1
	NF22	66	0.66	2.5	67.2	22.1	8.3	30.3
Farfield	**FF01A**	16	0.41	1.3	78.9	17.1	2.7	19.8
	FF04	28	2.62	0.7	5.7	60.7	33.0	93.7
	FF09	53	0.54	0.0	79.4	13.1	7.5	20.6

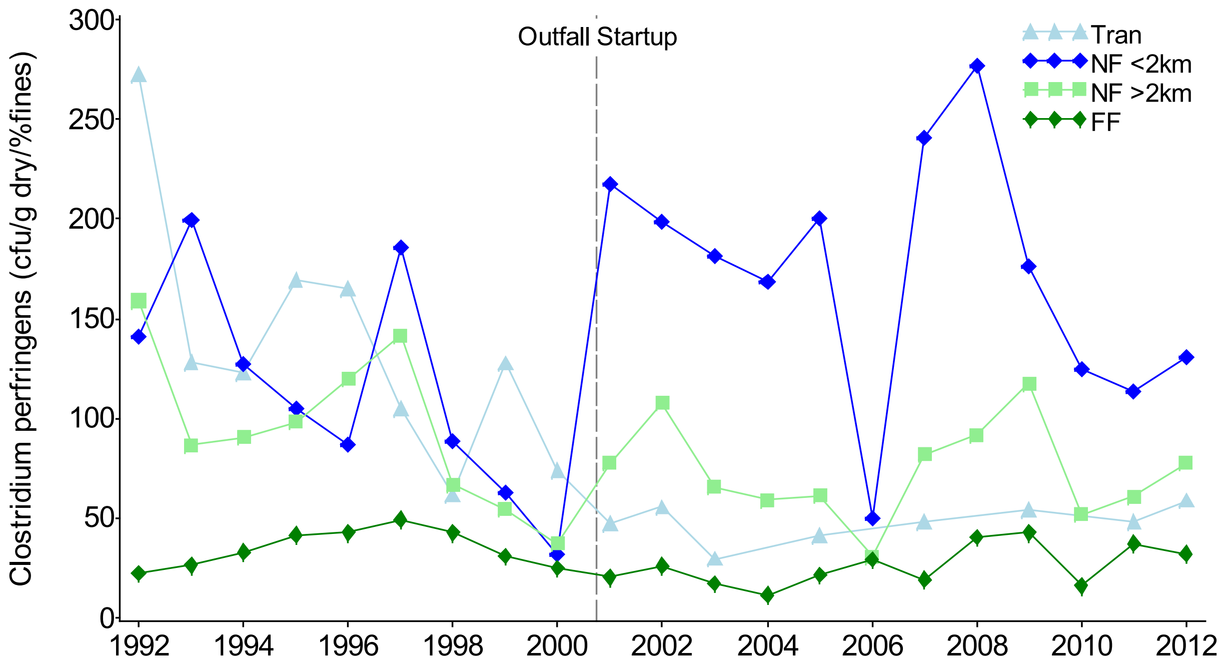

Figure 3-1. Mean concentrations of *Clostridium perfringens* in four areas of Massachusetts Bay, 1992 to 2012. Tran=Transition area; NF<2km=nearfield, less than two kilometers from the outfall; NF>2km=nearfield, more than two kilometers from the outfall; FF=farfield.

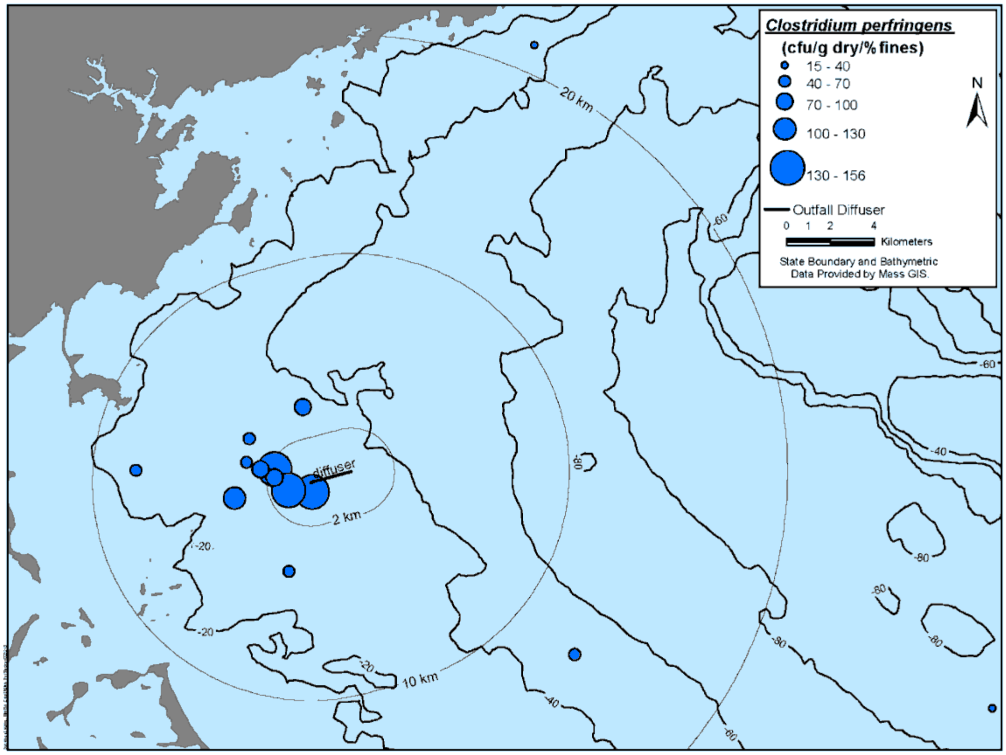

Figure 3-2. 2012 monitoring results for *Clostridium perfringens*.

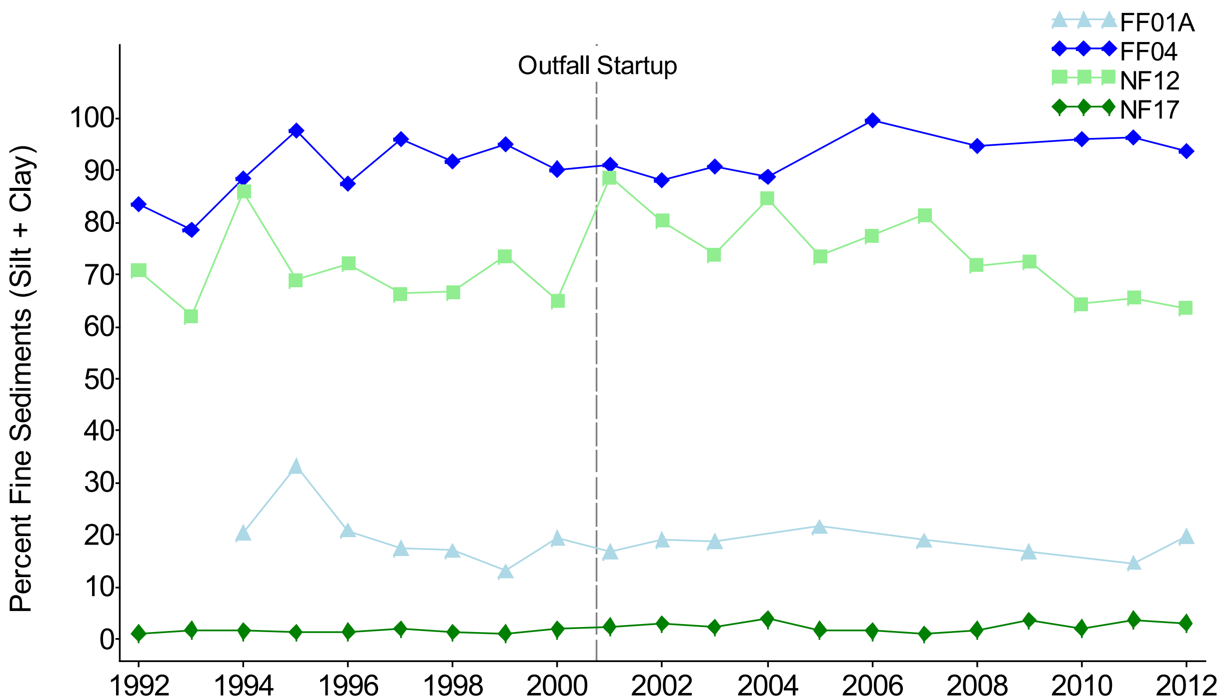

Figure 3-3. Mean percent fine sediments at four stations in Massachusetts Bay, 1992 to 2012.

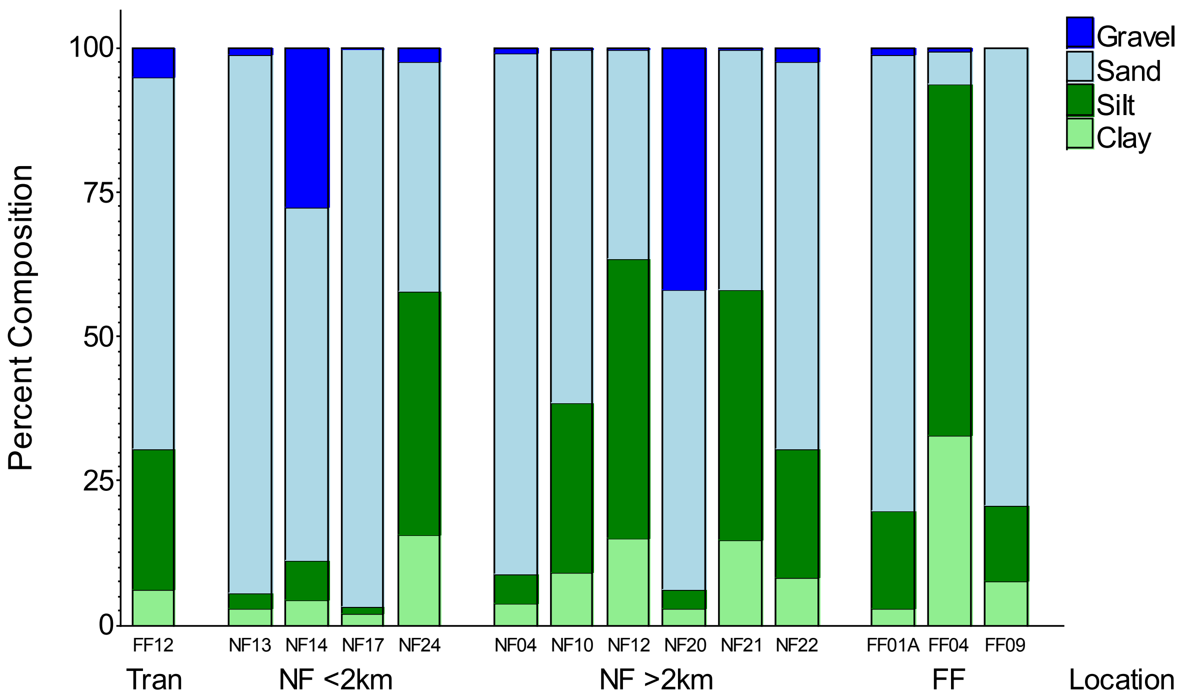

Figure 3-4. 2012 monitoring results for sediment grain size.

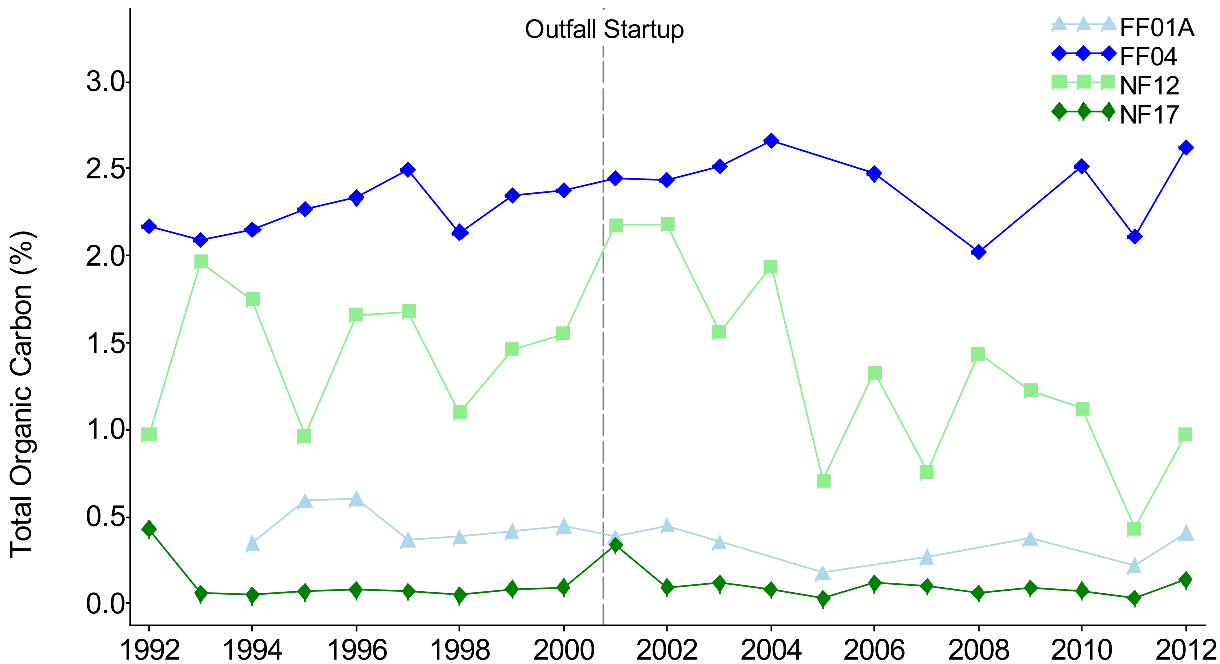

Figure 3-5. Mean concentrations of TOC at four stations in Massachusetts Bay, 1992 to 2012.

3.2 Benthic Infauna

3.2.1 Community Parameters

A total of 27,114 infaunal organisms were counted from the 14 samples in 2012. Organisms were classified into 240 discrete taxa; 210 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).

Abundance values reported for 2012 were higher than the previous two years at all four locations (i.e., spatial groups of stations classified by distance from the outfall) in Massachusetts Bay, and comparable to historical means throughout much of the time series (Figure 3-6). The numbers of species per sample were also generally higher than the previous two years, but within the range of historic variability reported for most locations (Figure 3-7). Note that sampling of different stations during even and odd years from 2004 to 2010 has likely influenced year to year variability in community parameters averaged by location during that time period (e.g. Figures 3-6 and 3-7; see Section 2.1).

There were threshold exceedances in 2012 for Shannon-Wiener Diversity (H') and Pielou's Evenness (J'); no exceedances were reported for other diversity measures or for the percent opportunistic species (Table 3-3). Contingency Plan threshold exceedances for the same parameters were observed in 2011 and 2010 (Nestler et al. 2012, Maciolek et al. 2011).

High diversity and high evenness are generally recognized as indications of healthy, undisturbed communities (Magurran 1988). Low diversity and evenness typically reflect stressed or impacted communities. Nonetheless, several studies of infaunal assemblages along gradients of organic enrichment have reported the highest levels of diversity and evenness under conditions of low-level enrichment (Pearson and Rosenberg 1978). Thus, threshold levels for infaunal diversity have both upper and lower limits. The exceedances for H' and J' were upper limit exceedances, based on higher values relative to the baseline range (Figures 3-8 and 3-9).

Analyses of infaunal data in 2012 were focused on answering two questions related to the threshold exceedances: (1) "What factors are driving the exceedances?" and (2) "Do the exceedances reflect an influence from the outfall, or region-wide changes in faunal assemblages, unrelated to the discharge?"

To answer the question of what factors are driving the exceedances, the parameters contributing to the computation of diversity and evenness were first considered. H' is a function of both the numbers of species in a sample (species richness) and the distribution of the total abundance among those species (evenness). Comparisons of species richness at the nearfield stations during the past three years, the baseline period (1992-2000), and the post-diversion period through 2009, suggested that the numbers of species have not changed enough to explain the exceedances (Figure 3-10). The same comparisons for total abundance indicated that the numbers of individuals per sample have been lower, on average, than previously reported (Figure 3-11). Since H' and J' are influenced not by total abundance, but by the distribution of abundance among species, the numerically dominant species were implicated. Dominant species were identified as those contributing at least 5% of total abundance during either the baseline period or the post-diversion period through 2009. Five dominant species were identified, and their abundances compared over time (Figure 3-12). The spionid polychaete, *Prionospio steenstrupi*, was the numerically dominant taxon in the Massachusetts Bay samples from the mid 1990's to the mid 2000's. During years in which *P. steenstrupi* numbers were relatively low, other dominants were often abundant (e.g., *Spio limicola* in 1994 and *Molgula manhattensis* in 2009). Relatively low abundance has been reported for all five dominants during the past three years (Figure 3-12). The influence of these five dominant species was demonstrated by excluding them from the database, then re-calculating the H' and J' values. A comparison of Figures 3-8 and 3-9 to Figures 3-13 and 3-14 demonstrates this influence of dominant taxa on diversity and evenness.

To answer the question of whether the exceedances are related to the discharge, spatial and temporal patterns in H' and J' were compared to the patterns expected if the discharge were influencing diversity and evenness. Spatial comparisons of the 2012 values for H' and J' indicated that there was no association between high diversity or evenness values (or low values) and proximity to the outfall diffuser (Figures 3-15 and 3-16). Temporal comparisons of H' and J' values demonstrated no indication of increases in the post-diversion period as compared to the baseline, at stations closest to the outfall (Figures 3-17 and 3-18). H' and J' have increased in both nearfield and farfield locations, suggesting region-wide changes, unrelated to the discharge.

Table 3-2. 2012 monitoring results for infaunal community parameters.

Location	Station	Total Abundance (per grab)	Number of Species (per grab)	Log-series alpha	Shannon-Wiener Diversity (H')	Pielou's Evenness (J')
Transition Area	**FF12**	2427	55	10.04	3.93	0.68
Nearfield (<2 km from outfall)	**NF13**	1944	99	22.35	4.82	0.73
	NF14	2293	78	15.69	4.49	0.71
	NF17	881	74	19.32	4.56	0.73
	NF24	2931	72	13.38	4.02	0.65
Nearfield (>2 km from outfall)	**NF04**	2217	90	19.11	4.81	0.74
	NF10	1690	77	16.73	4.47	0.71
	NF12	1579	66	14.35	4.25	0.70
	NF20	2096	77	15.98	4.75	0.76
	NF21	1070	58	13.28	3.9	0.67
	NF22	1964	62	12.25	3.95	0.66
Farfield	**FF01A**	3002	78	14.8	3.92	0.62
	FF04	1141	55	12.67	3.54	0.61
	FF09	1879	102	23.97	4.98	0.75

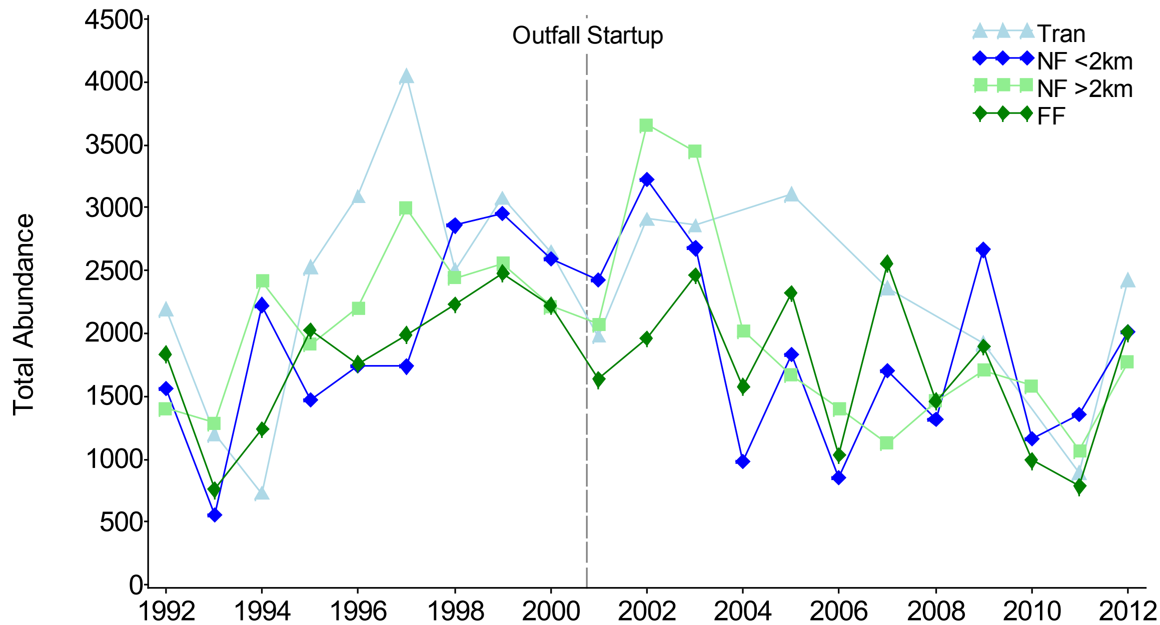

Figure 3-6. Mean infaunal abundance per sample at four areas of Massachusetts Bay, 1992 to 2012. Tran=Transition area; NF<2km=nearfield, less than two kilometers from the outfall; NF>2km=nearfield, more than two kilometers from the outfall; FF=farfield.

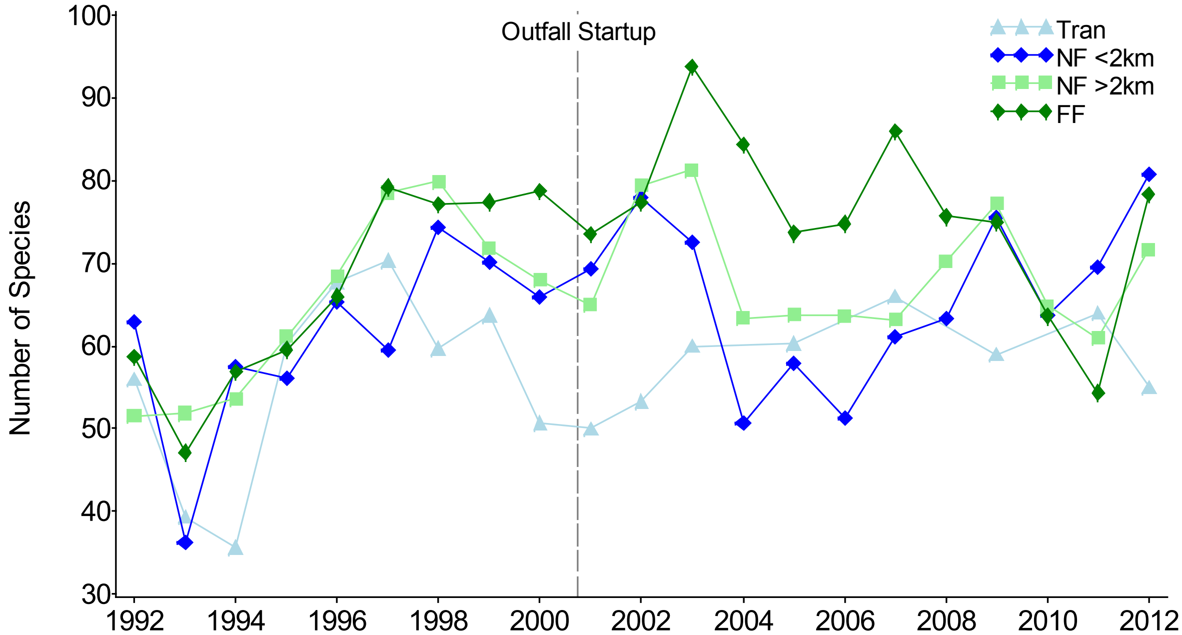

Figure 3-7. Mean number of species per sample at four areas of Massachusetts Bay, 1992 to 2012. Tran=Transition area; NF<2km=nearfield, less than two kilometers from the outfall; NF>2km=nearfield, more than two kilometers from the outfall; FF=farfield.

Table 3-3. Infaunal monitoring threshold results, August 2012 samples.

Parameter	Threshold range		Result	Exceedance?
	Low	High		
Total species	43	81.9	73.45	No
Log-series Alpha	9.42	15.8	15.68	No
Shannon-Weiner H'	3.37	3.99	4.36	Yes, Caution Level
Pielou's J'	0.57	0.67	0.70	Yes, Caution Level
Apparent RPD	1.18	NA	3.44	No
Percent opportunists		10%	0.16%	No

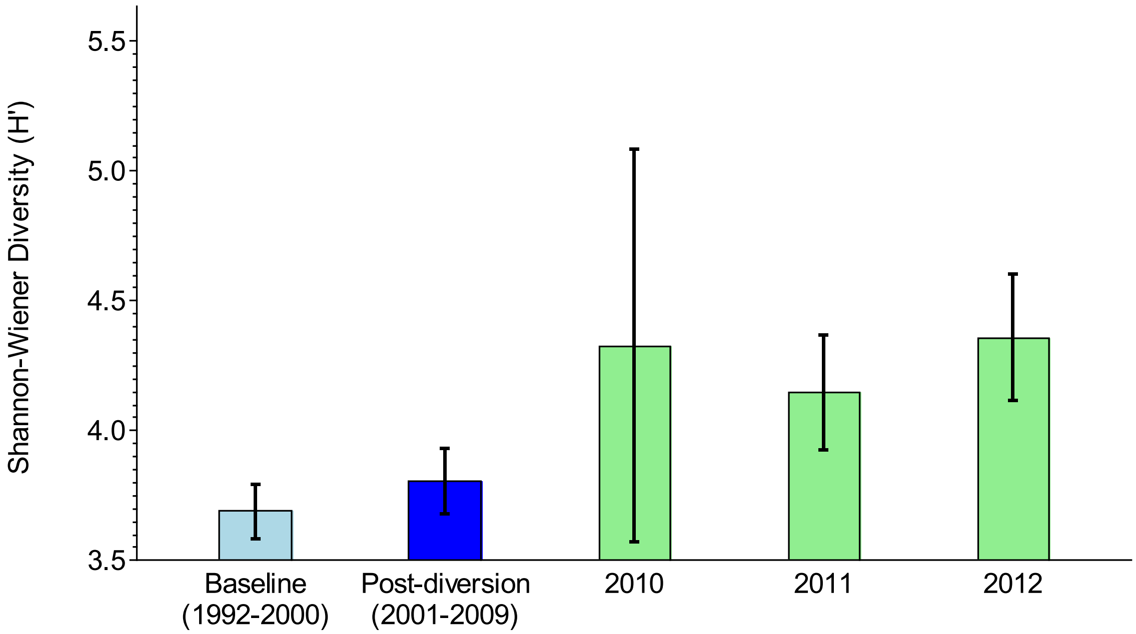

Figure 3-8. Mean H' per sample at nearfield stations in Massachusetts Bay during the baseline (1992 to 2000) and post-diversion (2001 to 2009) periods compared to 2010, 2011, and 2012. Error bars represent upper and lower 95% confidence limits.

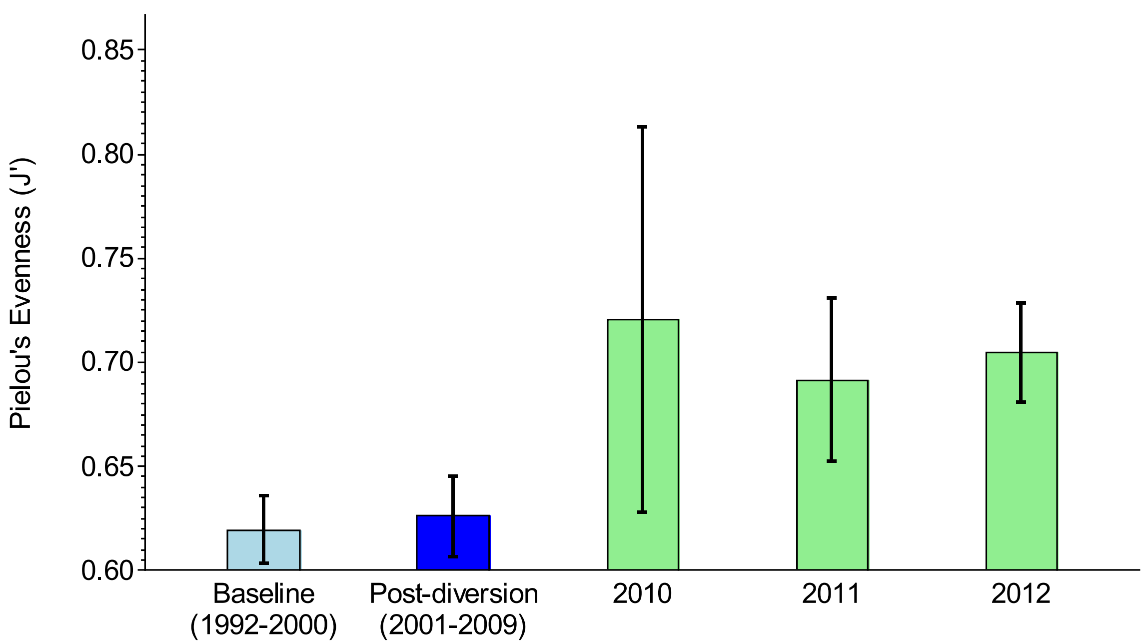

Figure 3-9. Mean J' per sample at nearfield stations in Massachusetts Bay during the baseline (1992 to 2000) and post-diversion (2001 to 2009) periods compared to 2010, 2011, and 2012. Error bars represent upper and lower 95% confidence limits.

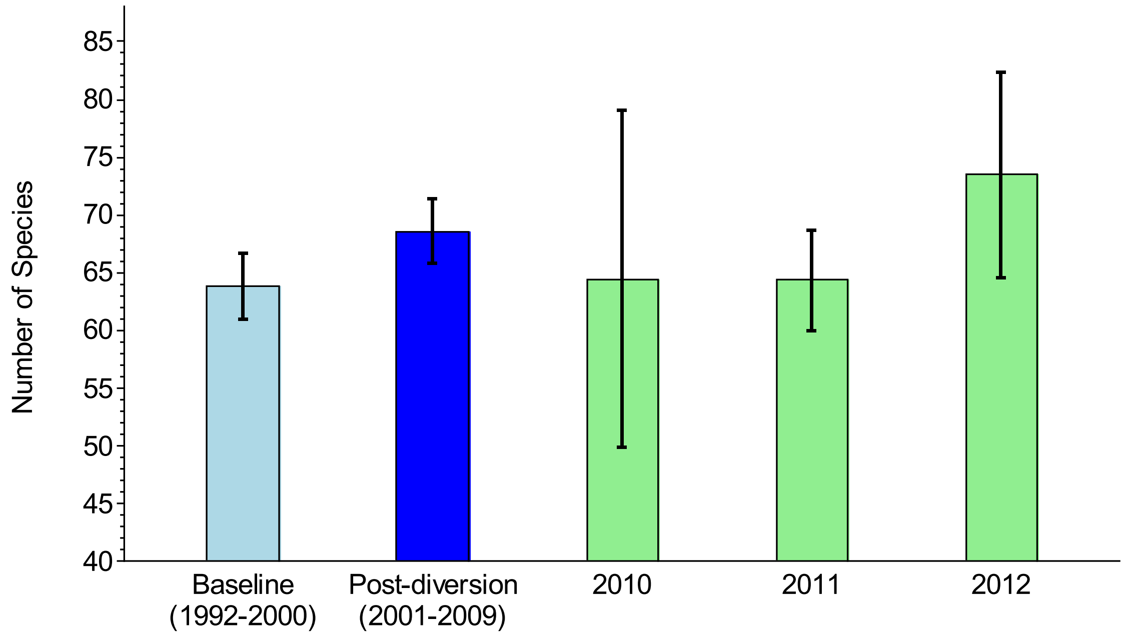

Figure 3-10. Mean number of species per sample at nearfield stations in Massachusetts Bay during the baseline (1992 to 2000) and post-diversion (2001 to 2009) periods compared to 2010, 2011, and 2012. Error bars represent upper and lower 95% confidence limits.

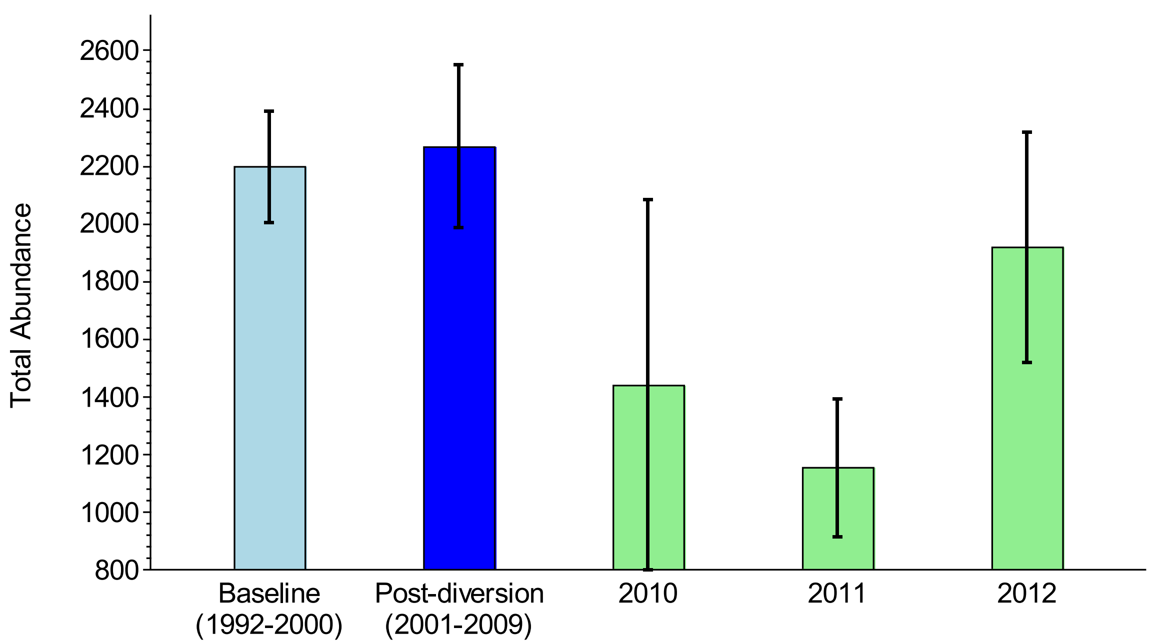

Figure 3-11. Mean total abundance per sample at nearfield stations in Massachusetts Bay during the baseline (1992 to 2000) and post-diversion (2001 to 2009) periods compared to 2010, 2011, and 2012. Error bars represent upper and lower 95% confidence limits.

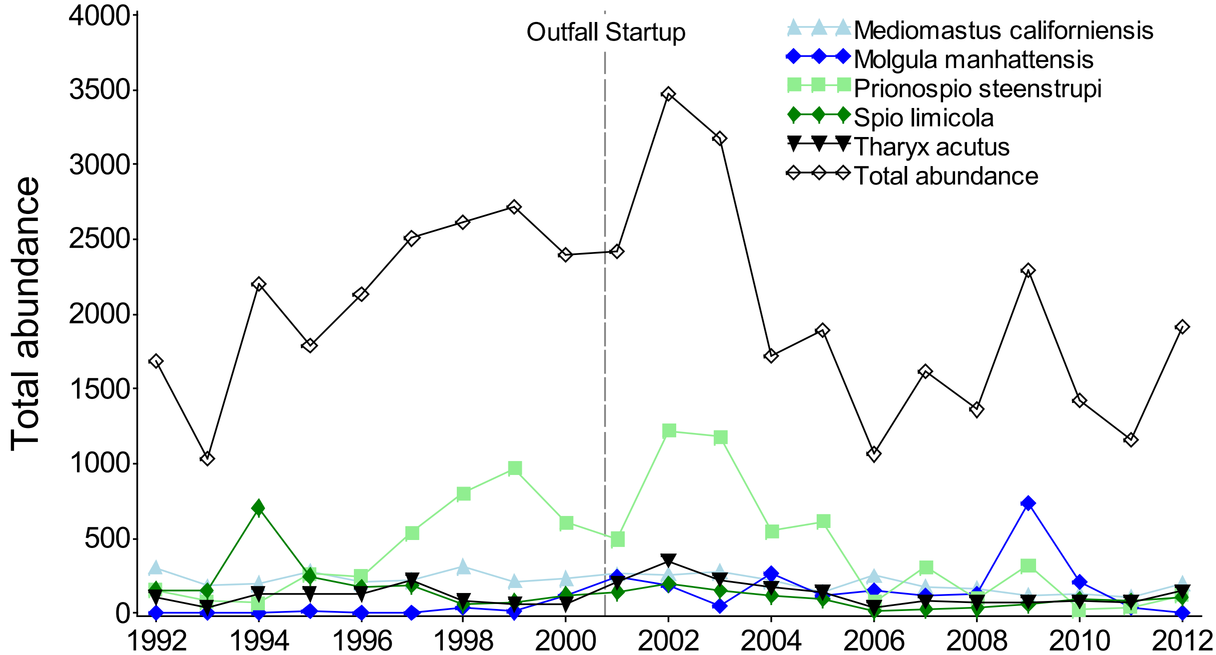

Figure 3-12. Mean abundance per sample of five dominant species compared to total abundance at nearfield stations in Massachusetts Bay, 1992 to 2012.

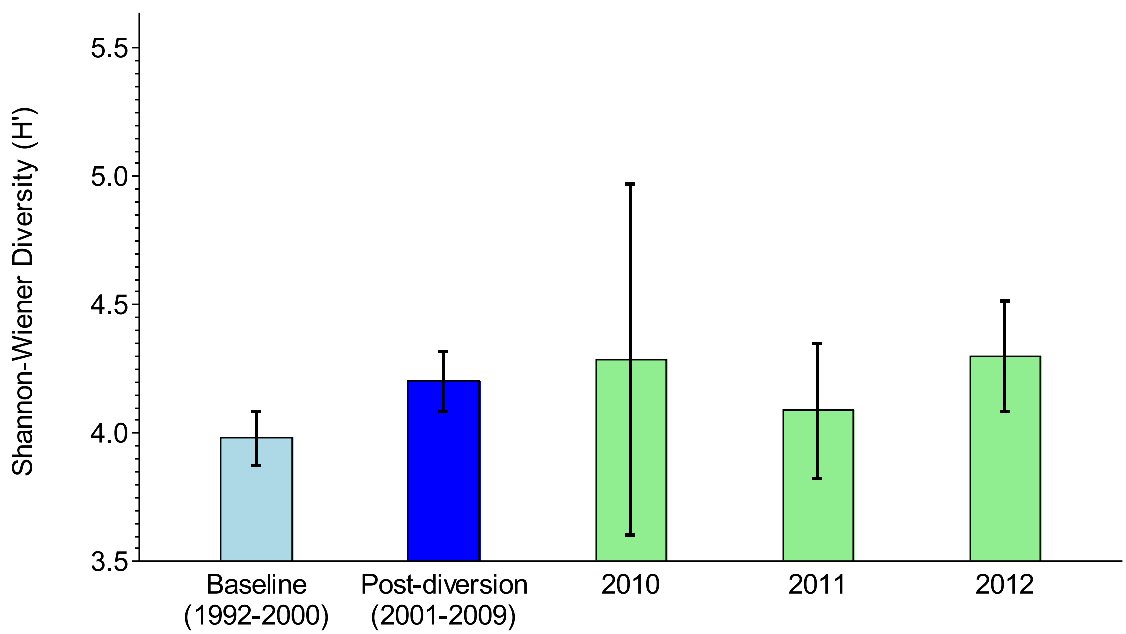

Figure 3-13. Mean H' per sample after excluding five dominant species from the data set. Nearfield stations in Massachusetts Bay during the baseline (1992 to 2000) and post-diversion (2001 to 2009) periods compared to 2010, 2011, and 2012. Error bars represent upper and lower 95% confidence limits.

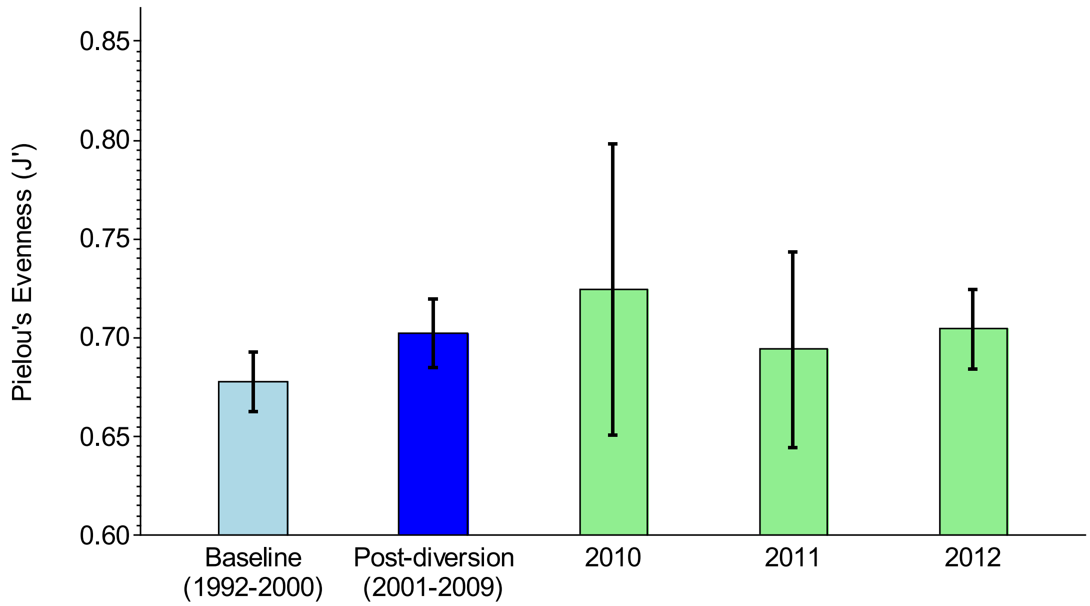

Figure 3-14. Mean J' per sample after excluding five dominant species from the data set. Nearfield stations in Massachusetts Bay during the baseline (1992 to 2000) and post-diversion (2001 to 2009) periods compared to 2010, 2011, and 2012. Error bars represent upper and lower 95% confidence limits.

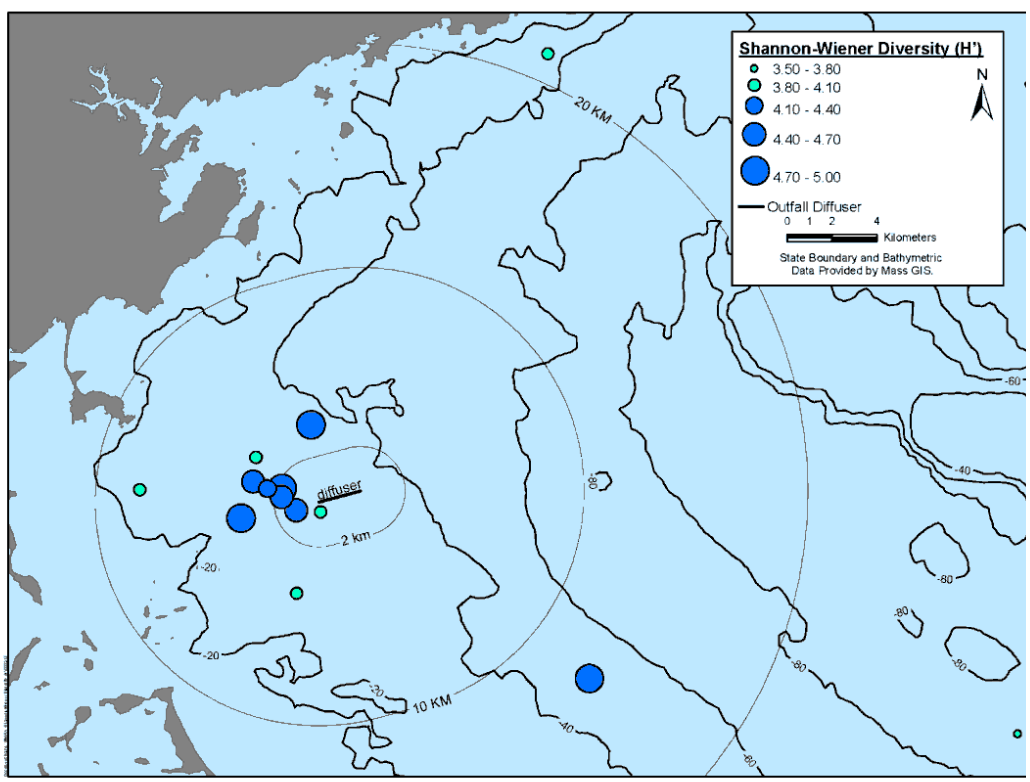

Figure 3-15. 2012 values for Shannon-Wiener diversity (H').

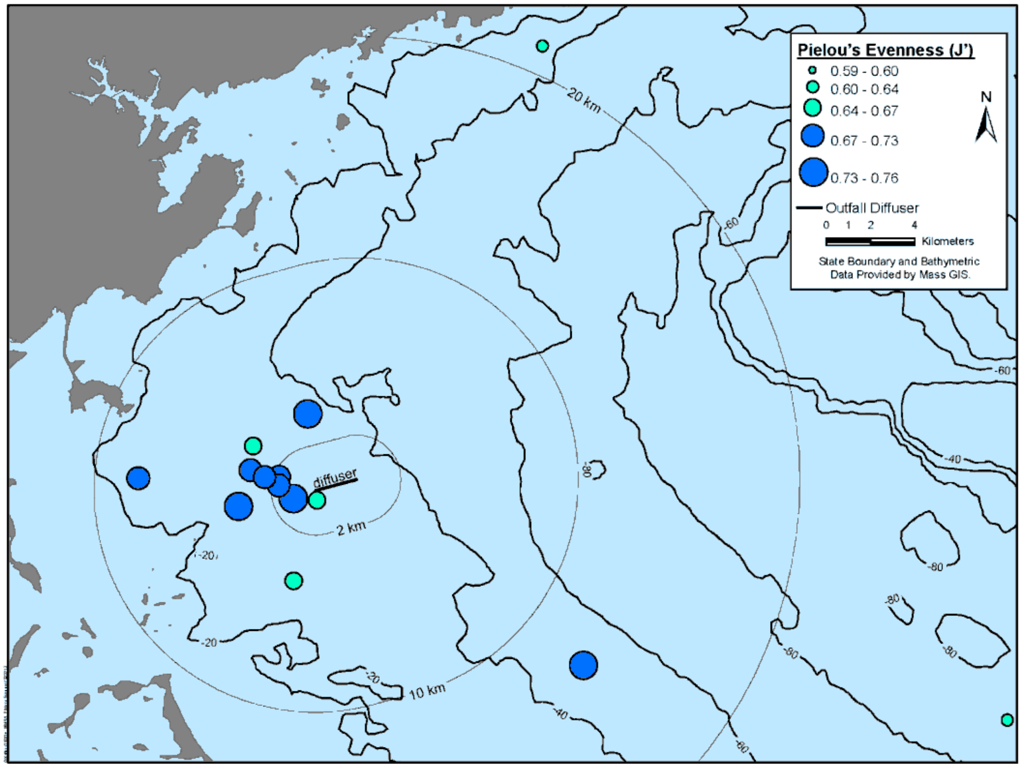

Figure 3-16. 2012 values for Pielou's evenness (J').

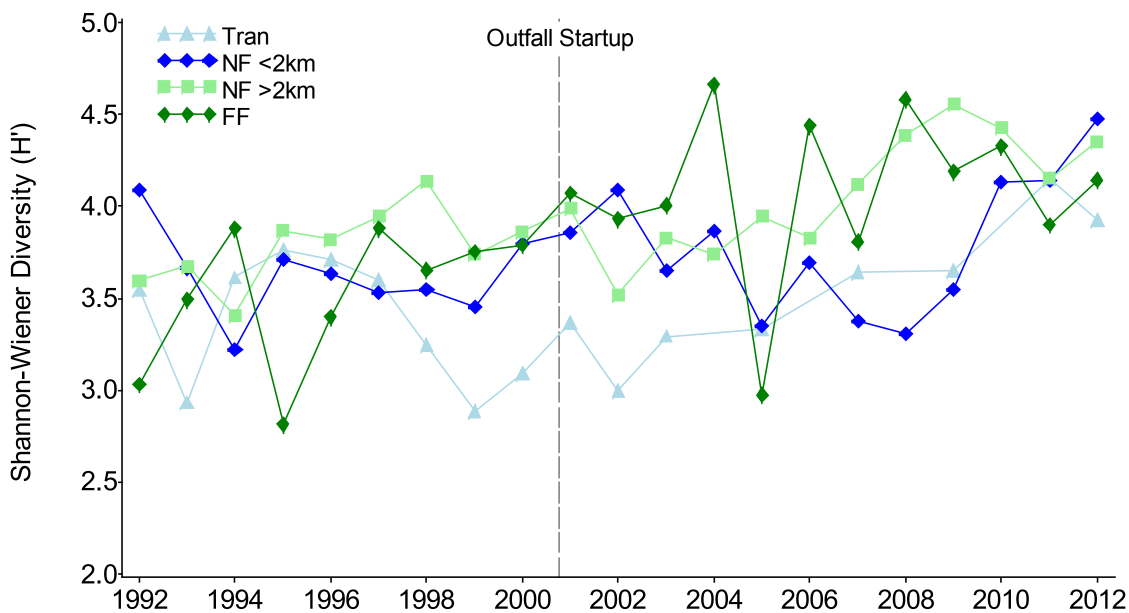

Figure 3-17. Mean H' per sample at four areas of Massachusetts Bay, 1992 to 2012. Tran=Transition area; NF<2km=nearfield, less than two kilometers of from the outfall; NF>2km=nearfield, more than two kilometers from the outfall; FF=farfield.

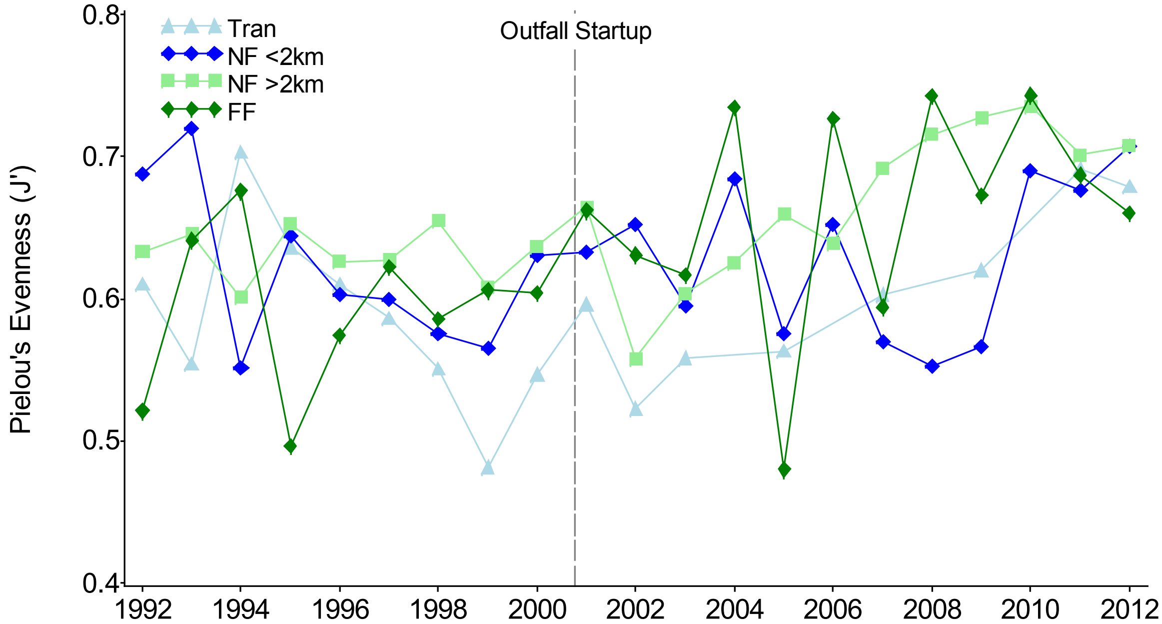

Figure 3-18. Mean J' per sample at four areas of Massachusetts Bay, 1992 to 2012. Tran=Transition area; NF<2km=nearfield, less than two kilometers of from the outfall; NF>2km=nearfield, more than two kilometers from the outfall; FF=farfield.

3.2.2 Infaunal Assemblages

Multivariate analyses based on Bray-Curtis Similarity were used to assess spatial and temporal patterns in the faunal assemblages at the Massachusetts Bay sampling stations. Six assemblages were identified in a cluster analysis of the 14 samples from 2012. Assemblages varied considerably in species composition, but were mostly dominated by polychaetes (Table 3-4). Three of the main assemblages occurred at stations within two kilometers of the discharge and also at stations more than two kilometers from the discharge (Figure 3-19). Thus, stations closest to the discharge are not characterized by a unique faunal assemblage reflecting effluent impacts. Comparisons of faunal distribution to habitat conditions indicated that patterns in the distribution of faunal assemblages follow differences in sediment types at the sampling stations (Figures 3-20 and 3-21). Figure 3-20 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. Nonetheless, the full composition of the sediments may help to further explain associations between benthic habitat and the infaunal community, which are not explained by percent fines alone. Figure 3-21 illustrates that the “Group IIB” assemblage is found at stations with the highest percent gravel in the sediments.

Temporal analyses of faunal assemblages at four stations during 1992 to 2012 indicated that assemblages varied little over time, and that samples were generally most similar to others collected at the same station over time (Figure 3-22). To the extent that an assemblage from one station was similar to the assemblage found at another station, the two most similar assemblages were found at a nearfield station within two kilometers from the outfall (NF24) and a farfield station (FF01A) (Figure 3-22).

Multivariate analyses found no evidence of impacts from the offshore outfall on infaunal communities in Massachusetts Bay. Recent increases in H’and J’ appear to be a region-wide occurrence, strongly influenced by a few dominant species, and unrelated to the discharge.

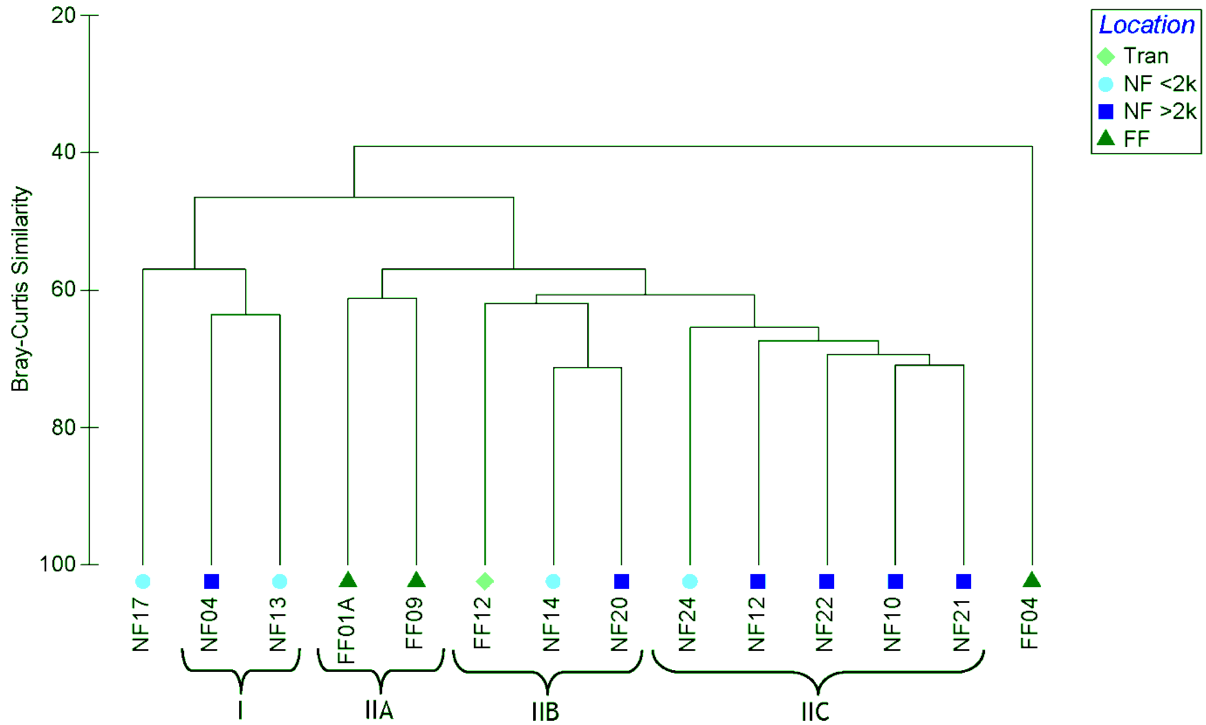

Figure 3-19. Results of cluster analysis of the 2012 infauna samples.

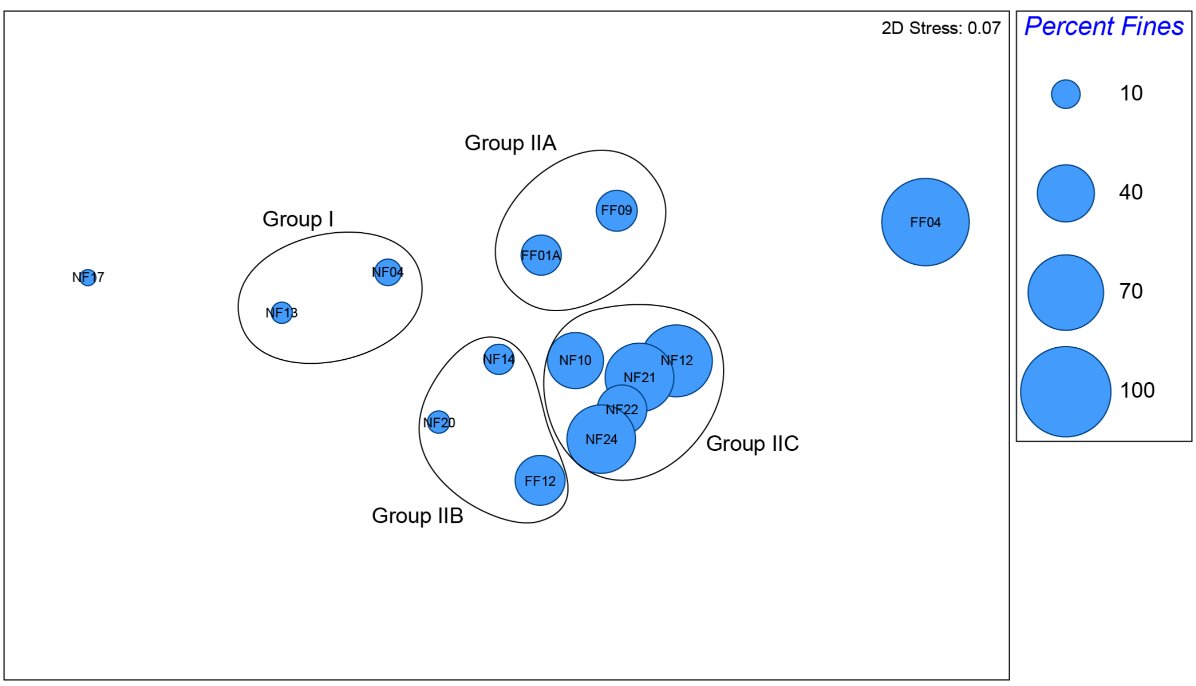

Figure 3-20. Percent fine sediments superimposed on nMDS ordination plot of the 2012 infauna samples. Each point on the plot represents one of the 14 samples; similarity of species composition is indicated by proximity of points on the plot. Faunal assemblages (Groups I-IIC) identified by cluster analysis 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 2012 samples.

Family	Species	NF17	I	IIA	IIB	IIC	FF04
Mollusca (Bivalvia)							
Nuculidae	*Nucula delphinodonta*	10.0	41.5	366.5	110.3	26.4	-
Annelida (Polychaeta)							
Ampharetidae	*Ampharete lindstroemi*	47.0	85.5	4.0	36.3	1.2	-
	Anobothrus gracilis	-	-	37.0	-	0.8	307.0
Apistobranchidae	*Apistobranchus typicus*	-	23.0	14.0	6.0	20.2	13.0
Capitellidae	*Mediomastus californiensis*	9.0	45.0	78.5	272.7	245.6	6.0
Cirratulidae	*Aphelochaeta* cf. *marioni*	-	40.0	7.0	2.3	55.8	3.0
	Chaetozone anasimus	7.0	33.5	4.0	-	0.8	15.0
	Monticellina baptisteae	-	4.5	42.0	118.0	119.0	2.0
	Monticellina cf. *dorsobranchialis*	1.0	4.5	20.5	77.0	31.6	-
	Tharyx acutus	14.0	86.5	100.0	69.3	213.8	-
Cossuridae	*Cossura longocirrata*	-	-	3.5	0.3	1.8	24.0
Lumbrineridae	*Ninoe nigripes*	-	14.5	48.5	91.3	87.4	49.0
	Scoletoma hebes	-	0.5	1.5	214.3	4.8	1.0
Maldanidae	*Euclymene collaris*	5.0	66.5	4.5	18.0	0.6	-
Nephtyidae	*Aglaophamus circinata*	19.0	6.5	1.5	1.0	0.4	1.0
Oweniidae	*Owenia fusiformis*	7.0	3.0	233.0	29.3	4.6	-
Paraonidae	*Aricidea catherinae*	21.0	170.0	20.5	248.0	62.8	-
	Aricidea quadrilobata	-	1.0	32.5	3.3	6.6	146.0
	Levinsenia gracilis	3.0	8.0	105.5	53.0	164.4	113.0
Polygordiidae	*Polygordius jouinae*	139.0	223.0	6.0	12.3	3.6	-
Sabellidae	*Euchone incolor*	1.0	65.0	163.0	113.3	128.0	72.0
Scalibregmatidae	*Scalibregma inflatum*	21.0	100.5	10.0	17.3	9.4	1.0
Spionidae	*Prionospio steenstrupi*	2.0	50.0	367.0	197.0	127.0	28.0
	Spio limicola	-	33.5	93.5	26.0	188.8	4.0
	Spiophanes bombyx	24.0	19.0	26.5	21.3	22.4	-
Syllidae	*Exogone hebes*	66.0	281.0	9.0	64.0	4.0	-
	Exogone verugera	3.0	50.0	14.5	49.0	1.8	-
Trichobranchidae	*Terebellides atlantis*	-	15.0	20.0	6.3	3.6	77.0
Ampharetidae	*Ampharete lindstroemi*	47.0	85.5	4.0	36.3	1.2	-
	Anobothrus gracilis	-	-	37.0	-	0.8	307.0
Arthropoda (Amphipoda)							
Corophiidae	*Crassicorophium crassicorne*	112.0	49.0	-	-	-	-
Arthropoda (Tanaidacea)							
Nototanaidae	*Tanaissus psammophilus*	129.0	26.5	-	-	-	-
Arthropoda (Cumacea)							
Diastylidae	*Diastylis sculpta*	49.0	13.0	-	3.3	0.2	-

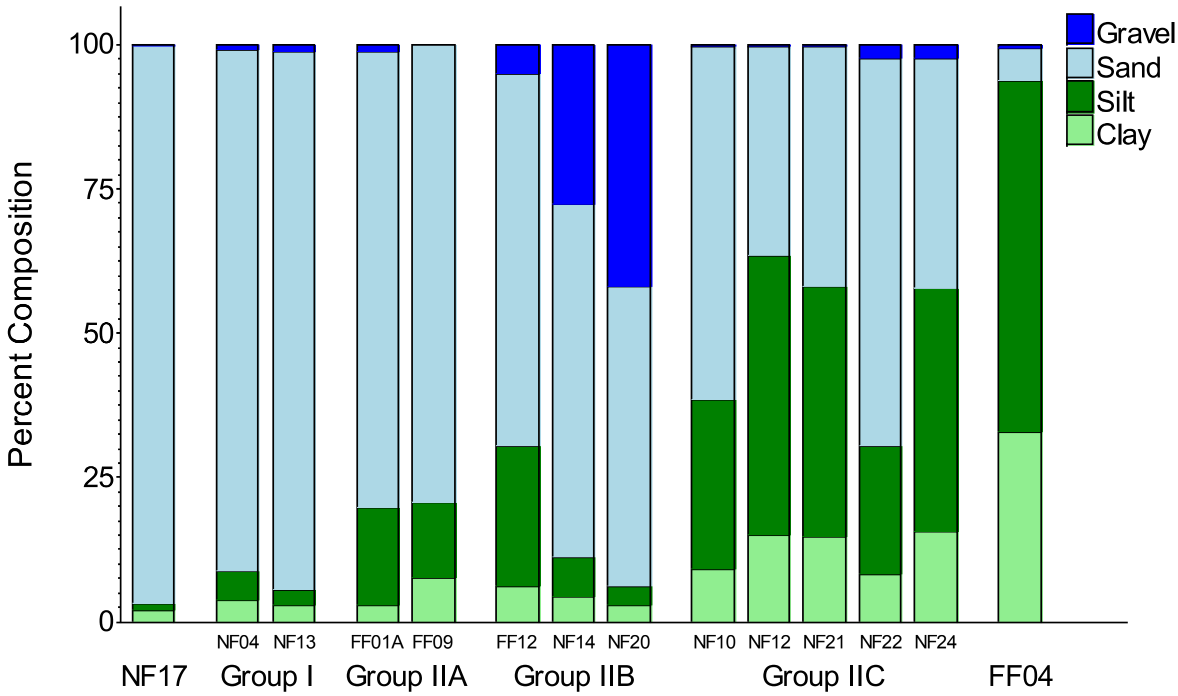

Figure 3-21. Monitoring results for sediment grain size with stations grouped by infaunal assemblages identified by cluster analysis of the 2012 samples.

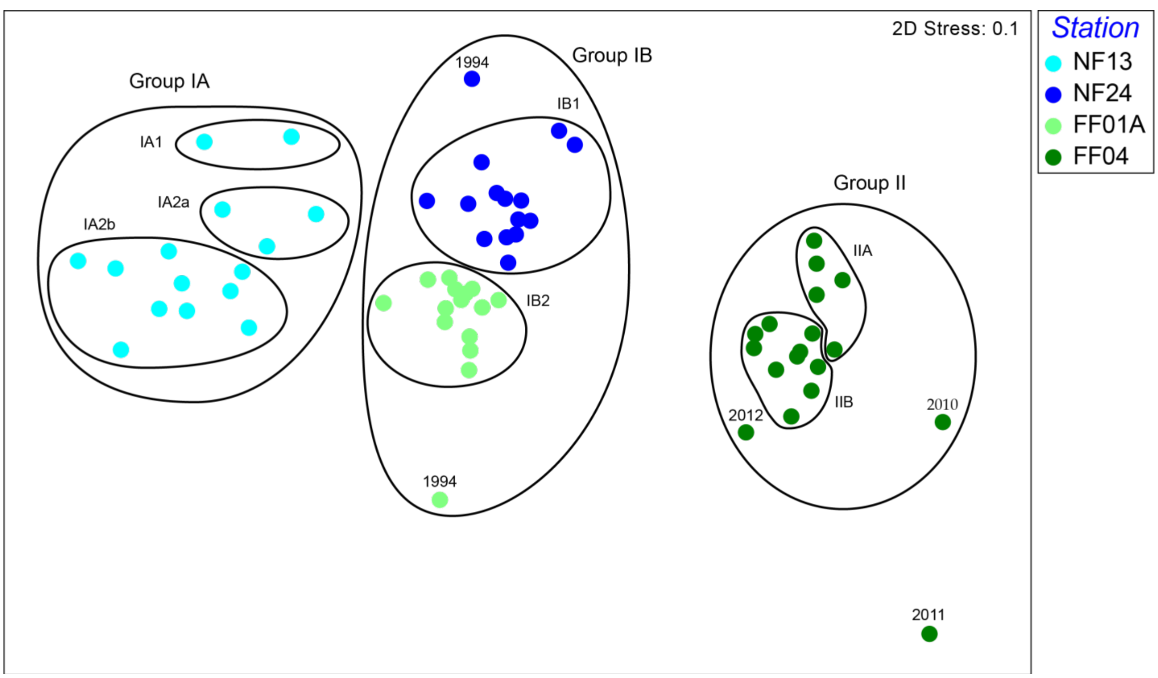

Figure 3-22. Cluster groups represented by colored dots superimposed on nMDS ordination plot of infauna samples from five stations, 1992 to 2012. Each point on the plot represents one sample; similarity of species composition is indicated by proximity of points on the plot. Each of the five stations is circled and labeled on the plot. The ordination and cluster analysis are both based on Bray-Curtis Similarity.

3.3 Sediment Profile Imaging

In 2012, there was little change in any of the sediment profile image parameters at the 23 nearfield monitoring stations. For sandy and silty bottom areas around the outfall, benthic habitat conditions in 2012 were similar to the previous ten years. When baseline conditions (1992 to 2000) are compared with post discharge (2001 to 2012) operation conditions there is no evidence of an outfall effect (Table 3-5). Values for SPI parameters in 2012 were within previously observed ranges. Sediments at many stations continued to be heterogeneous, ranging from sandy-silt-clay to cobble. Overall, the sediment surface appeared to be structured primarily by physical processes and secondarily by biological processes.

The grand mean of the thickness of the apparent color redox-potential discontinuity (aRPD) layer in 2012 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 2012 would be 4.3 cm (SD = 0.82 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 2012 was 3.4 cm (SD = 1.42 cm). From the start of annual SPI sampling in 1995, the aRPD has never been observed at stations N04 and N17. Overall, post-baseline period aRPD remained deeper than during the baseline period (Table 3-5). Although variable year to year, since 2006 the thickness of the annual grand mean aRPD has generally been deeper than in the baseline years and aRPD depth in 2012 was among the highest reported (Figure 3-23). This is an indication of continued high quality benthic habitat conditions. High diversity of benthos also confirms the presence of high quality benthic habitat (see discussion of infaunal diversity exceedance in 2012, Section 3.2.1).

There was also no indication of organic carbon accumulation in sediments for any of the pre- or post-baseline years. Image sequences from the mixed sand-silt-clay sediment stations, which had the finest sediments sampled in the nearfield, do not show a darkening of surface sediment that is typical for higher organic content sediments. See for example that NF24 (Figure 3-24), located within 2 km of the outfall, had on average 1.3% total organic carbon (TOC) and fine grained mixed sand-silt-clay sediments with about 55% fines (silt plus clay) on average. Sediment at five other stations averaged >50% fines (silt plus clay) over the years with no indication of increases in organic carbon content through time (NF08, NF12, NF16, NF21, NF22; Maciolek et al. 2011). The operation of the outfall did not appear to negatively affect benthic habitat quality for infauna.

Both the aRPD and TOC are important estimators of benthic habitat conditions, which relates directly to the quality of the habitat (Nilsson and Rosenberg 1997, Diaz et al. 2008, Germano et al. 2011). The aRPD provides an estimate of the depth to which sediments appear to be oxidized. The term "apparent" is used in describing this parameter because no actual measurement was made of the redox potential. The position of the RPD layer is determined by the depth in the sediments where the redox potential goes from positive to negative voltage (Figure 3-25). Given the complexities of iron and sulfate reduction-oxidation chemistry, the reddish-brown sediment color tones (Diaz and Trefry 2006) indicate sediments that contain oxygen or are in an oxidative geochemical state. This is in accordance with the classical concept of RPD layer depth, which associates it with sediment color (Fenchel 1969, Vismann 1991), and closely matches redox profiles measured by Tucker et al. (2009) at stations NF10, NF21, and NF22 (Figures 3-26, 3-27, and 3-28).

Based on the generally light color of sediments observed in the SPI from all stations, the true RPD layer was beyond prism penetration at all stations. Eh profiles measured by Tucker et al. (2009) in fine-sand-silt-clay sediments were positive to sediment depths of 18 cm. The light color of sediments in the SPI indicated low organic content and oxidized geochemical conditions with the aRPD measured from the SPI likely being an estimate of where sediment geochemistry shifts from oxic to suboxic processes (Fenchel and Riedl 1974, Seitzenger 1988). Reduced sediments are darker in color (mostly Fe and Mn sulfides) and a function of organic carbon content and geochemistry (Vismann 1991). Thus, the measurements of aRPD within the nearfield area relate more to the depth at which sediments shift from oxic to suboxic versus suboxic to anoxic (Seitzenger 1988). In higher organic content sediments, aRPD measurements are highly correlated with Eh profiles and the RPD layer depth (Rosenberg et al. 2001). The most important factors controlling aRPD throughout the nearfield appeared to be hydrodynamics at sandy stations and bioturbating infauna at finer grained stations.

From 1995 to 2012, changes and trends in SPI variables 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. This is a general characteristic of ocean outfalls, where benthic infaunal and epifaunal impacts are limited to the area immediately around the outfall (<100 to 500 meters) (Juanes and Canteras 1995).

The lack of accumulation of organic matter in the sediments is the principle reason for lack of benthic impacts in the nearfield. Pearson and Rosenberg (1978) generalized the response of benthic communities to organic loading, which appears to be similar in all marine systems. They found that as organic matter loading increases the benthic habitat conditions decline. The break point for benthos appears to be around 3% total organic carbon (Hyland et al. 2005). The only stations to have >3% TOC were NF08 in 1992 with 3.2% and NF14 in 2002 with 3.1% (Maciolek et al. 2011). If >3% TOC persisted at these stations, it is likely that changes would occur in benthic community structure. The grand average for nearfield stations is <1% TOC. It is likely that benthic habitat quality in the nearfield will remain high as the strong influence of hydrodynamics keeps sediment organic content low.

Table 3-5. Summary of SPI parameters pre- and post-baseline years for all nearfield stations. The year each table value occurred is in parentheses.

	Baseline Years 1992-2000 9-Year Interval	Post-Baseline Years 2001-2012 12-Year Interval
SS	Advanced from I to II-III	Bimodal: I-II and II-III
OSI - Low	4.8 (1997)	5.8 (2003)
OSI - High	7.2 (2000)	7.9 (2008)
RPD - Low	1.8 cm (1997 and 1998)	2.1 cm (2003)
RPD -High	3.0 cm (1995)	3.4 cm (2007)
Annual Mean RPD Measured	2.2 (0.49 SD) cm	3.1 (0.69 SD) cm
Annual Mean RPD All Values	2.4 (0.47 SD) cm	2.7 (0.43 SD) cm

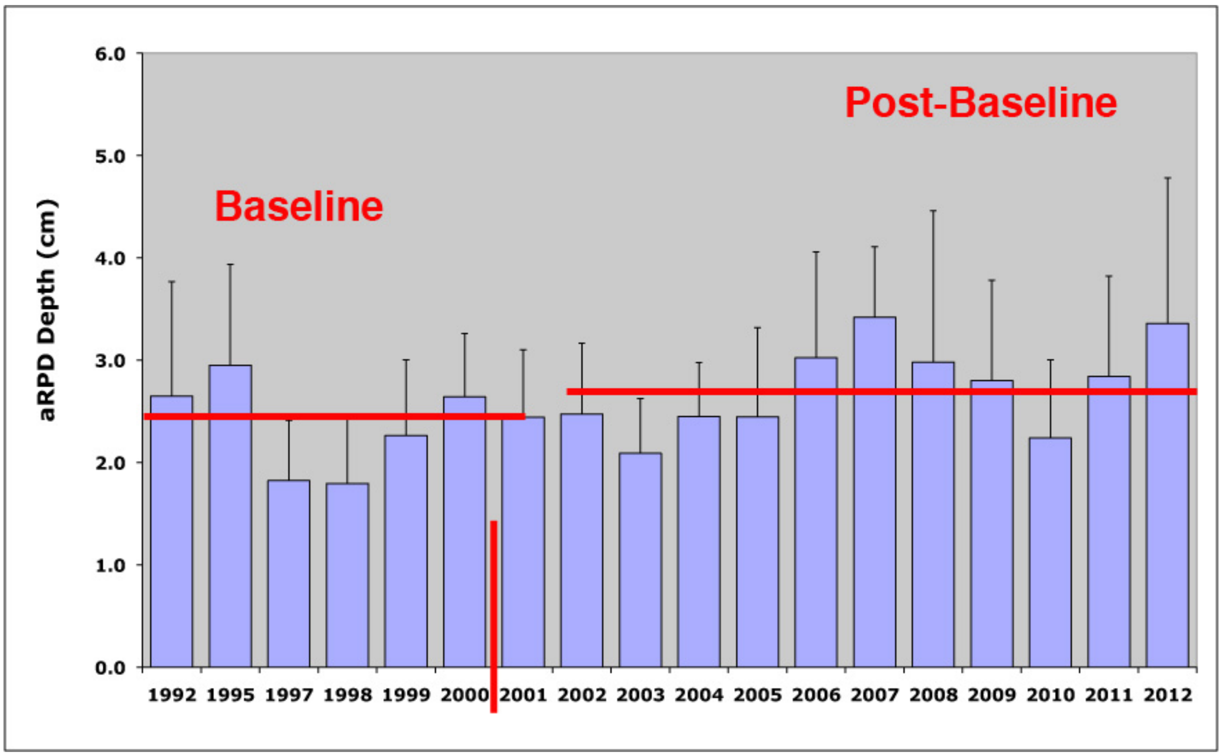

Figure 3-23. Average aRPD layer depth at nearfield stations by year for all 23 stations.

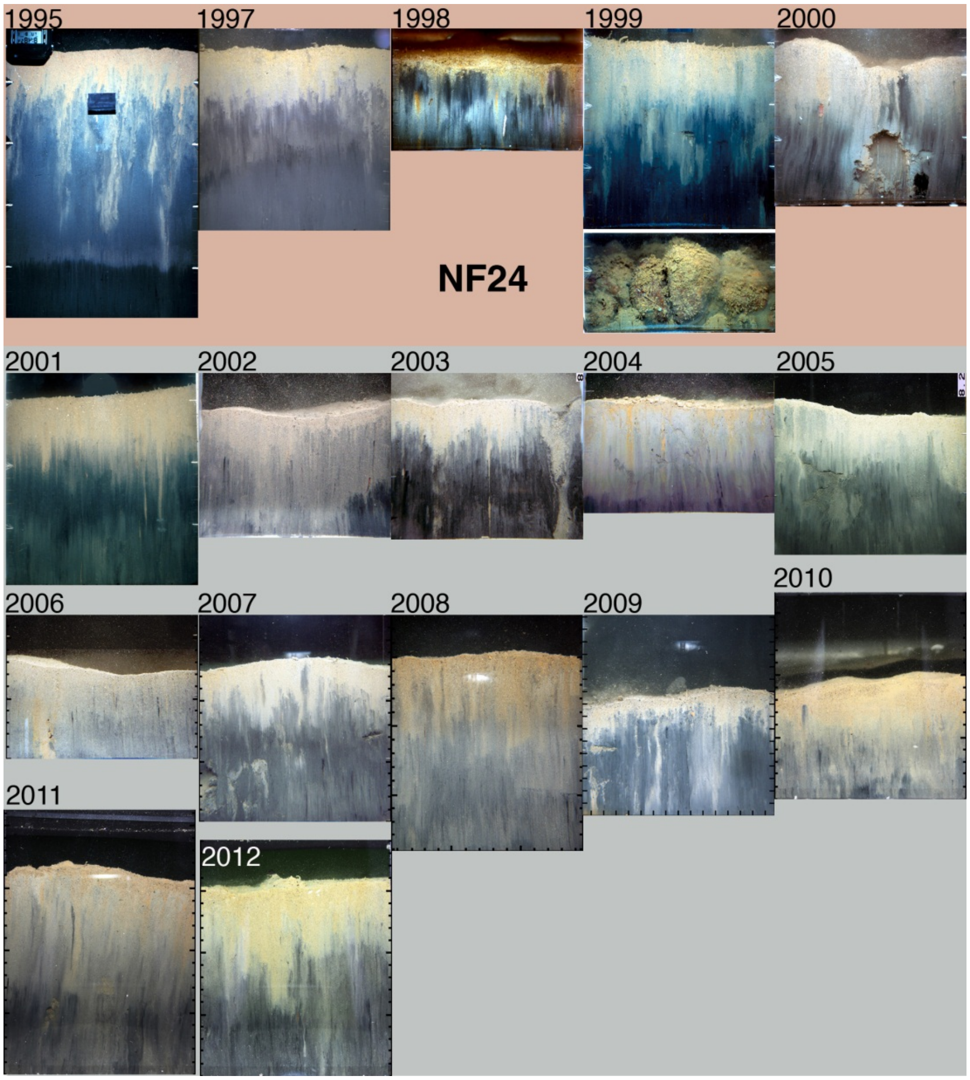

Figure 3-24. Thumbnail SPI images from NF24 for all years. Baseline years are up to 2000. Post-baseline years are from 2001. Sediment grain-size at NF24 is finest of all nearfield stations. It is also within 2 km of the outfall. Surface sediments are consistently light in color indicating there has been no accumulation of organic matter post-baseline. Scale along the side of each image is in cm.

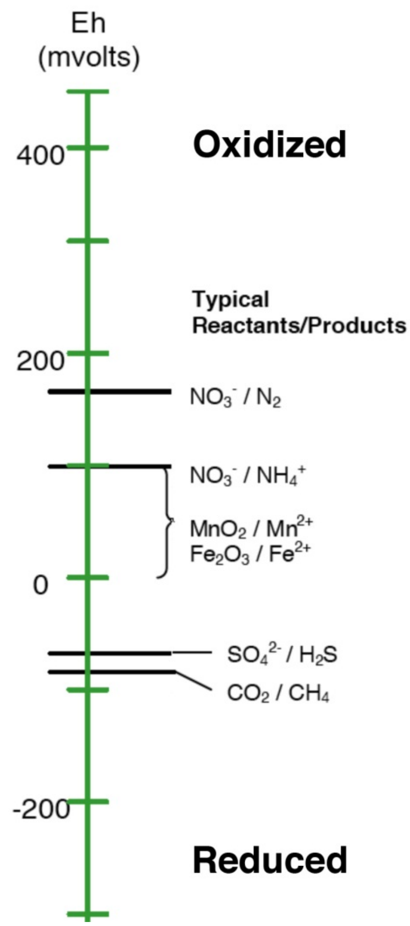

Figure 3-25. Redox scale with typical biogeochemical reactants and products. Aerobic processes dominate positive voltage and anaerobic processes dominate negative voltage.

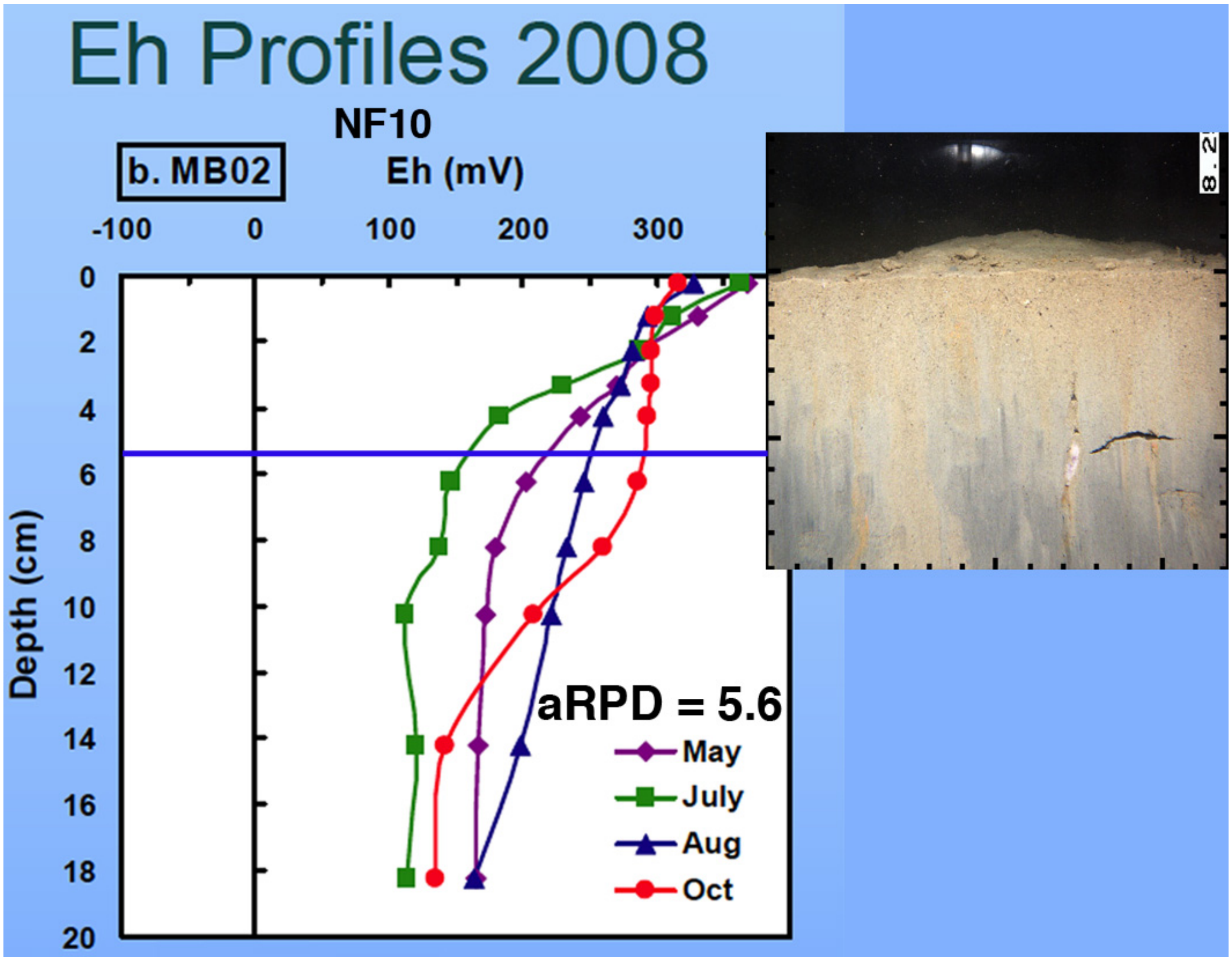

Figure 3-26. Comparison of August 2008 SPI from station NF10 with redox profiles measured by Tucker et al. (2009). aRPD depth was 5.6 cm. Eh indicates sediments were oxic to at least 18 cm.

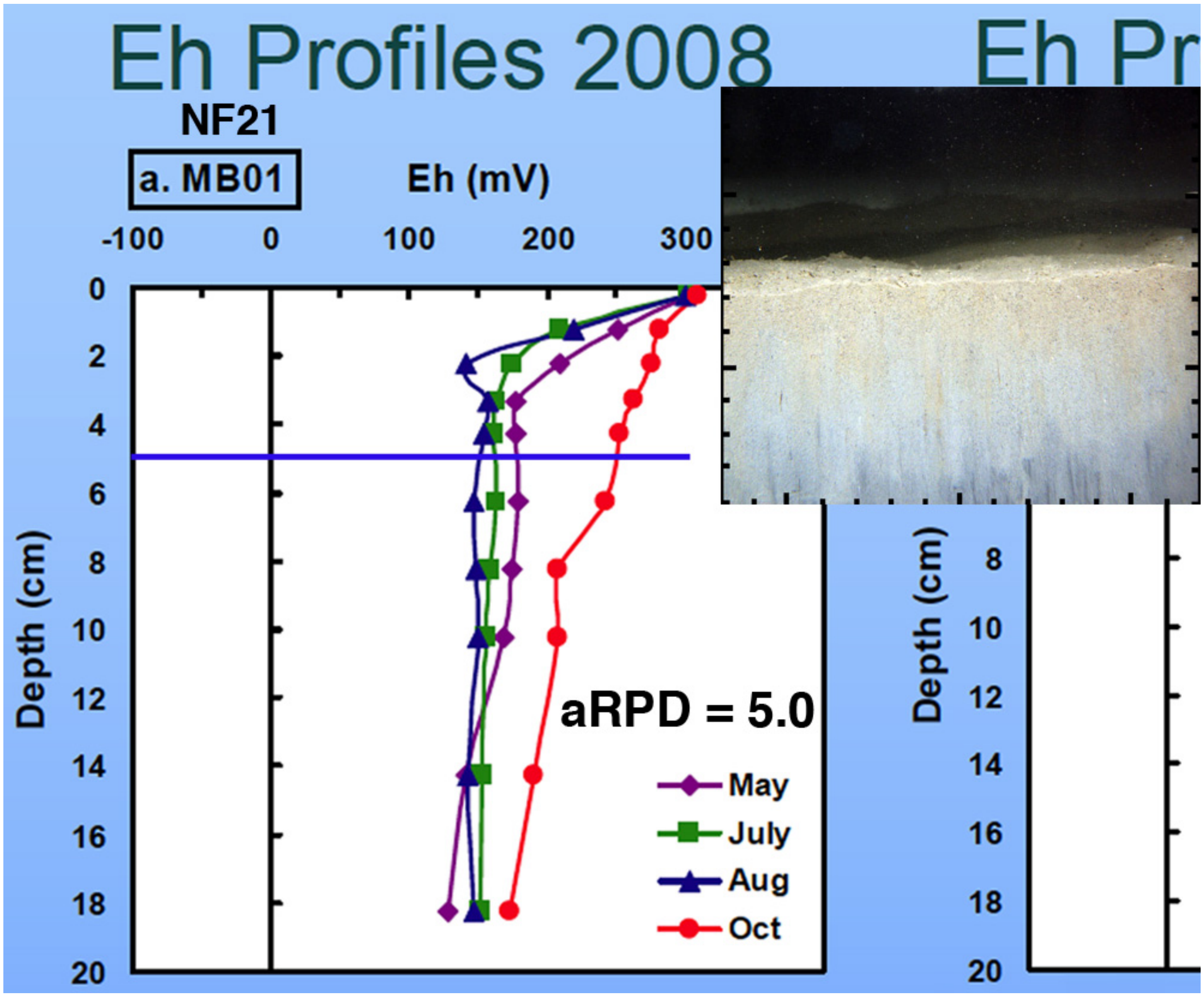

Figure 3-27. Comparison of August 2008 SPI from station NF21 with redox profiles measured by Tucker et al. (2009). aRPD depth was 5.0 cm. Eh indicates sediments were oxic to about 3 cm and suboxic to at least 18 cm.

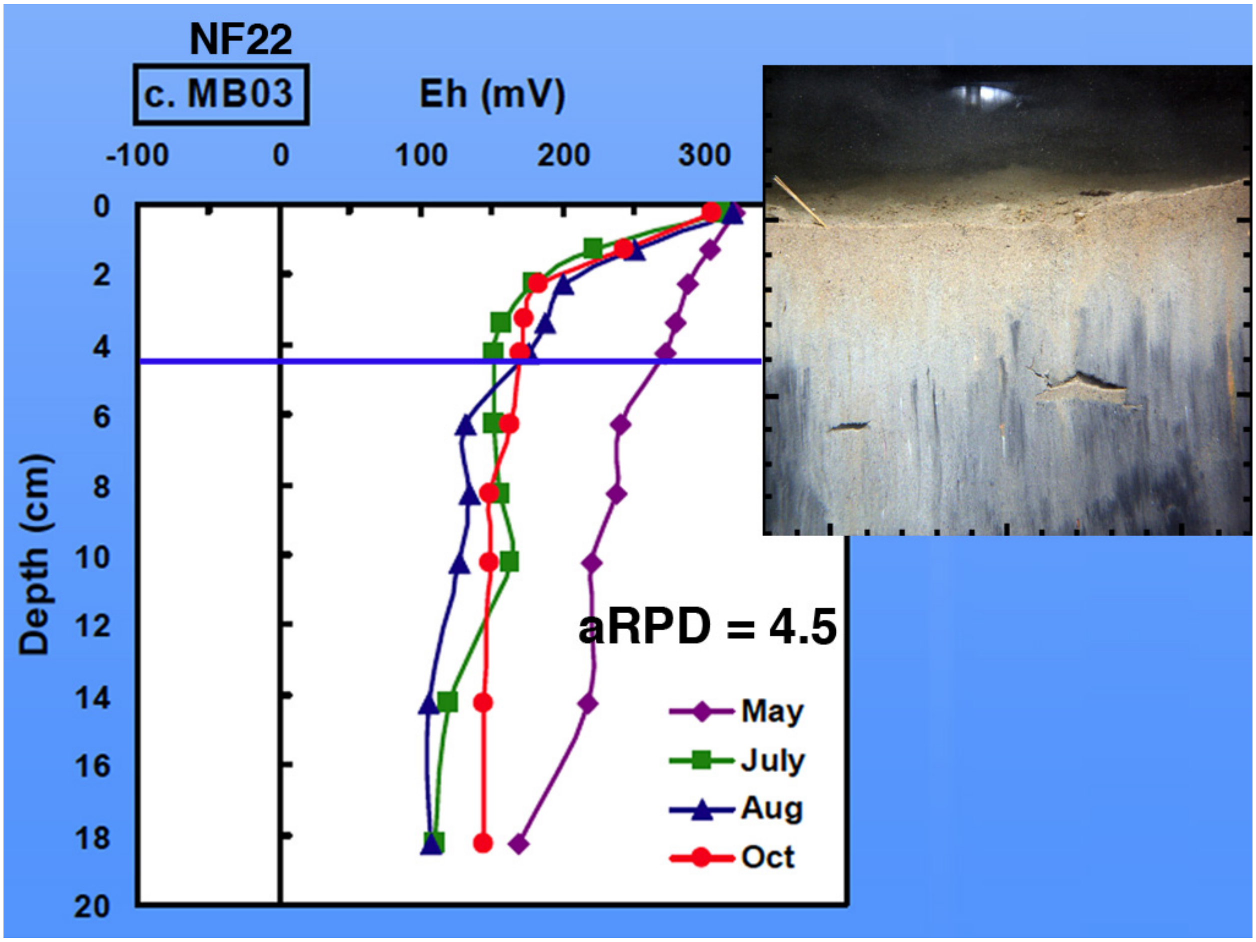

Figure 3-28. Comparison of August 2008 SPI from station NF22 with redox profiles measured by Tucker et al. (2009). aRPD depth was 4.5 cm. Eh indicates sediments were oxic to about 4 cm and suboxic to at least 18 cm.

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 2012 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 2012 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. 2012, Maciolek et al. 2008).

The most recent sediment contaminant monitoring and hard-bottom surveys were conducted in 2011 (next sampling will be in 2014). Sediment contaminant monitoring in 2011 found no indication that toxic contaminants from the wastewater discharge are accumulating in depositional areas surrounding the outfall (Nestler et al. 2012). No Contingency Plan threshold exceedances for sediment contaminants were reported in 2011. Patterns in the spatial distribution of higher contaminant concentrations primarily reflect both the percentage of fine particles in the sediment, and the proximity to historic sources of contaminants in Boston Harbor (Nestler et al. 2012). Monitoring in 2011 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. Some modest changes in hard-bottom communities (coralline algae and upright algae cover) have been observed; nonetheless, factors driving these changes are unclear. Since declines in upright algae started in the late 1990s (prior to wastewater diversion to the outfall), it is unlikely that the decrease was attributable to diversion of the outfall (Nestler et al. 2012).

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 threshold exceedances in 2012 for two infaunal diversity measures: (1) Shannon-Wiener Diversity (H’) and (2) Pielou’s Evenness (J’); however, analyses of these parameters suggest that recent increases in H’ and J’ have been largely driven by relatively lower abundance in a small number of dominant species. These changes in faunal communities appear to be region-wide and unrelated to the discharge. Both analyses of spatial and temporal patterns in community parameters and multivariate analyses, found no evidence of impacts to infaunal communities from the wastewater discharge in Massachusetts Bay.

5. REFERENCES

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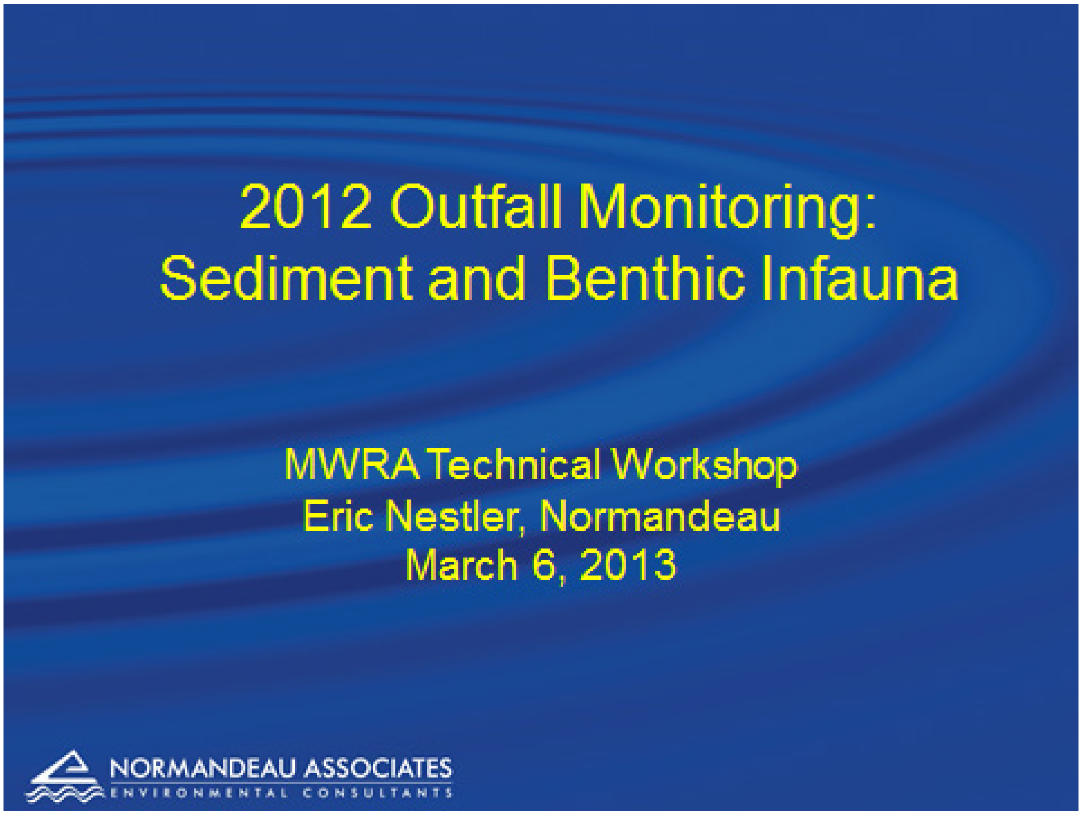
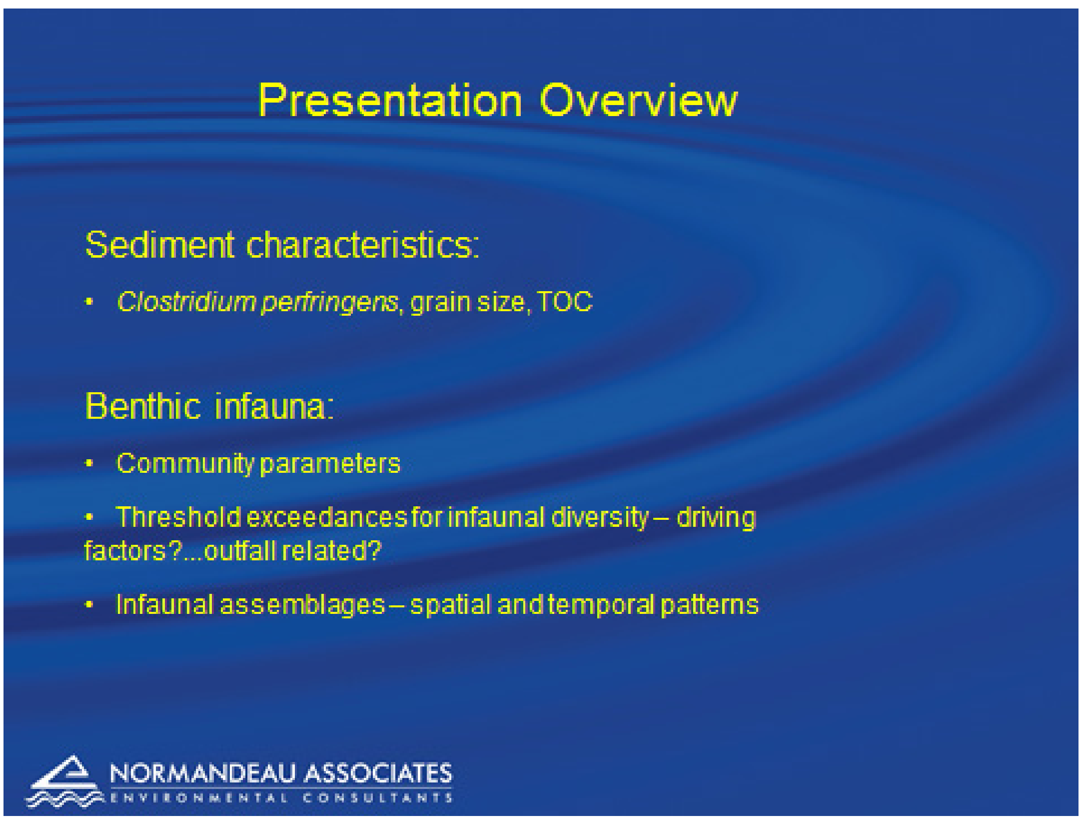
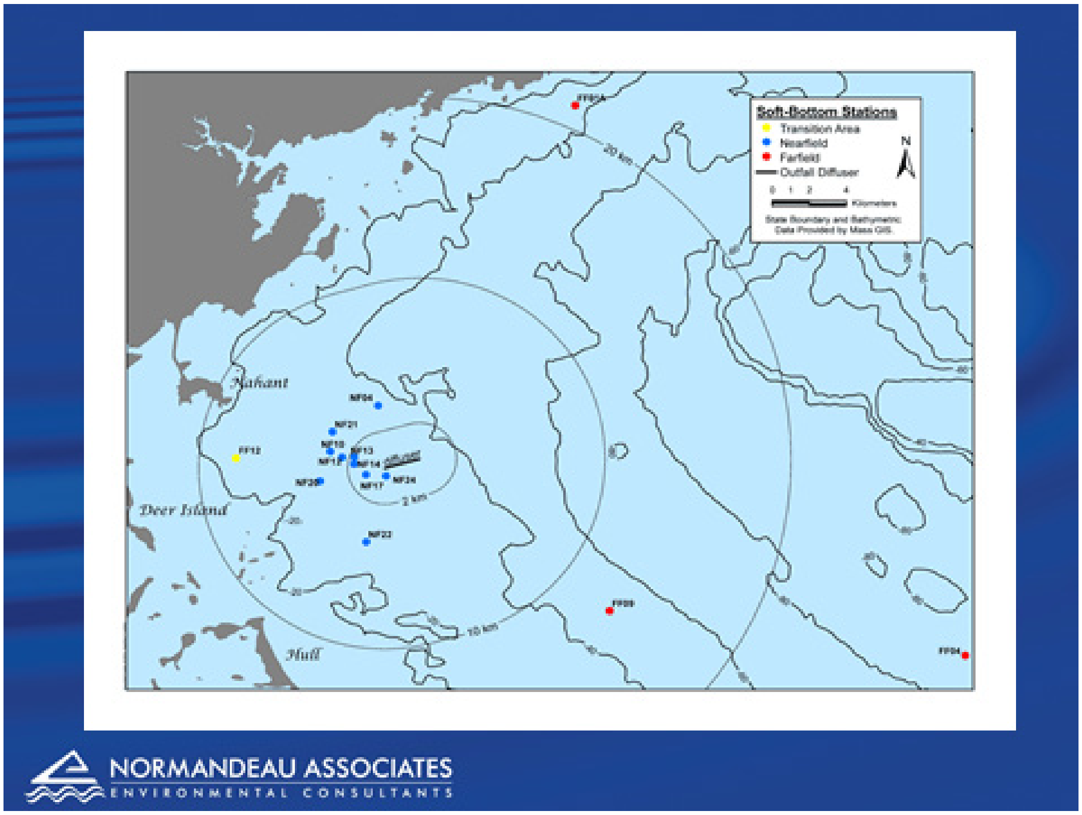
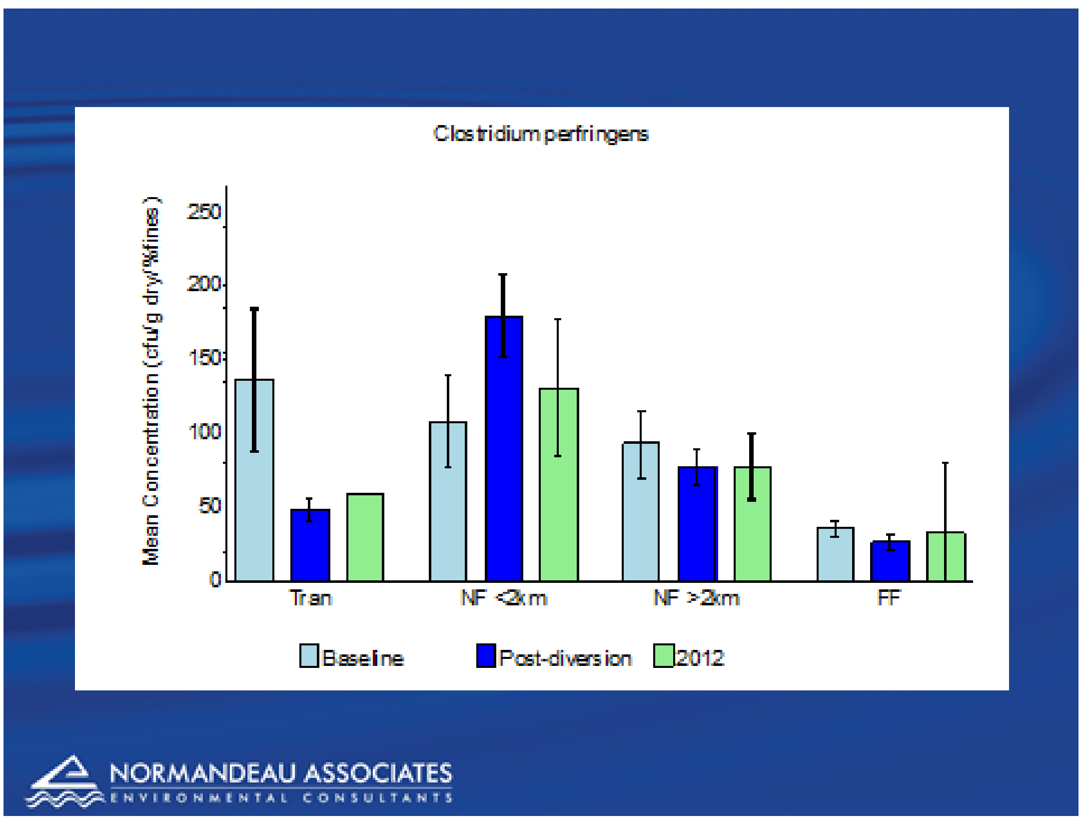
Appendix A Annual Technical Meeting Presentations for Outfall Benthic Monitoring in 2012

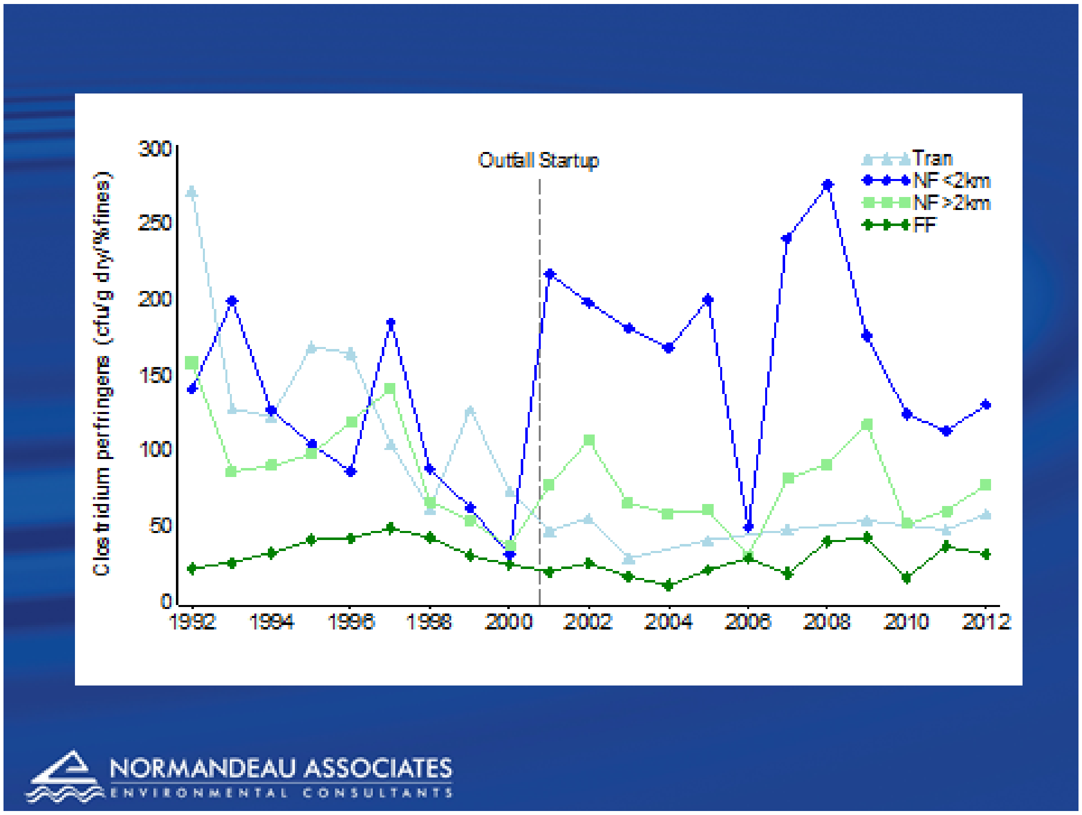
Appendix A1. 2012 Outfall Monitoring: Sediment and Benthic Infauna

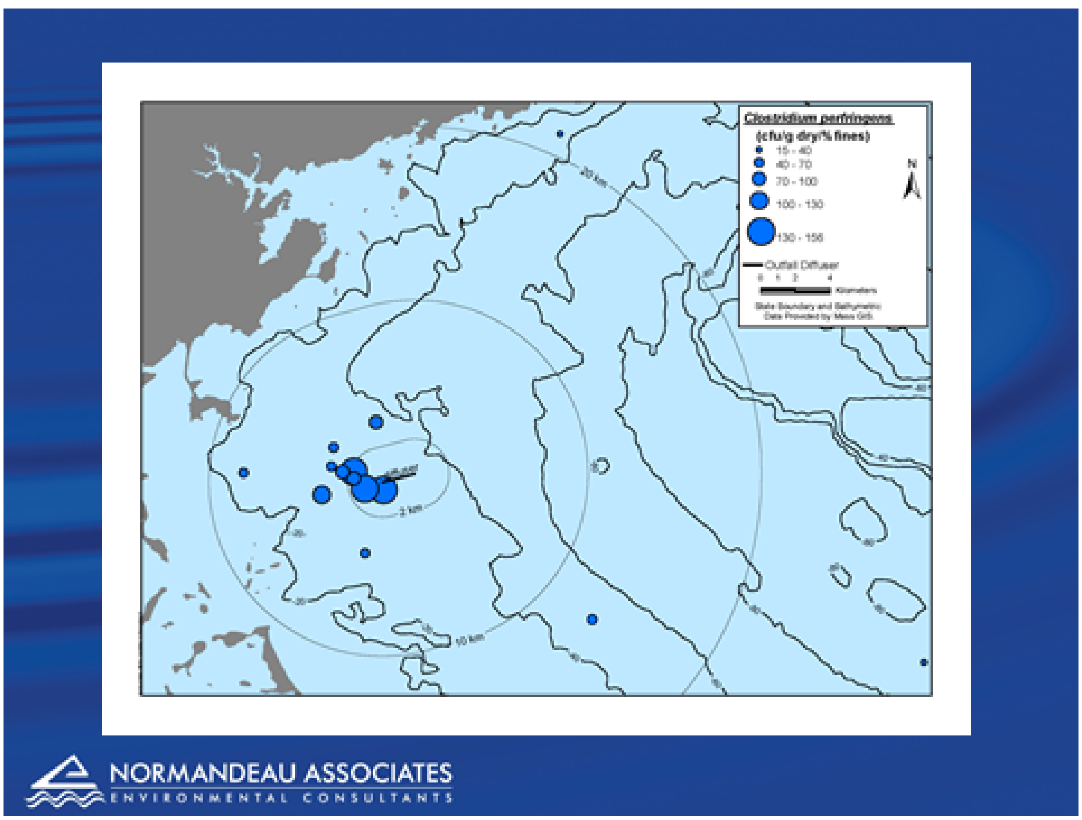

2012 Outfall Monitoring:
Sediment and Benthic Infauna
MWRA Technical Workshop
Eric Nestler, Normandeau
March 6, 2013
NORMANDEAU ASSOCIATES
ENVIRONMENTAL CONSULTANTS

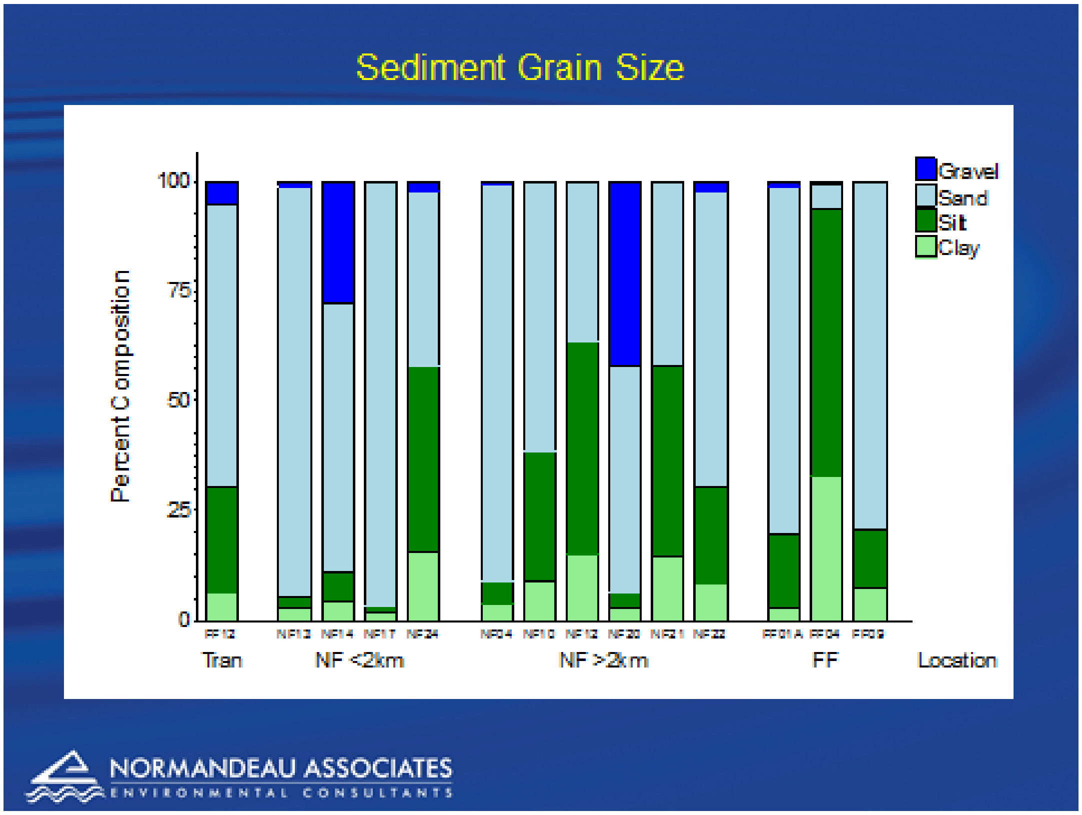

Presentation Overview
Sediment characteristics:
• *Clostridium perfringens*, grain size, TOC
Benthic infauna:
• Community parameters
• Threshold exceedances for infaunal diversity – driving factors?...outfall related?
• Infaunal assemblages – spatial and temporal patterns
NORMANDEAU ASSOCIATES
ENVIRONMENTAL CONSULTANTS

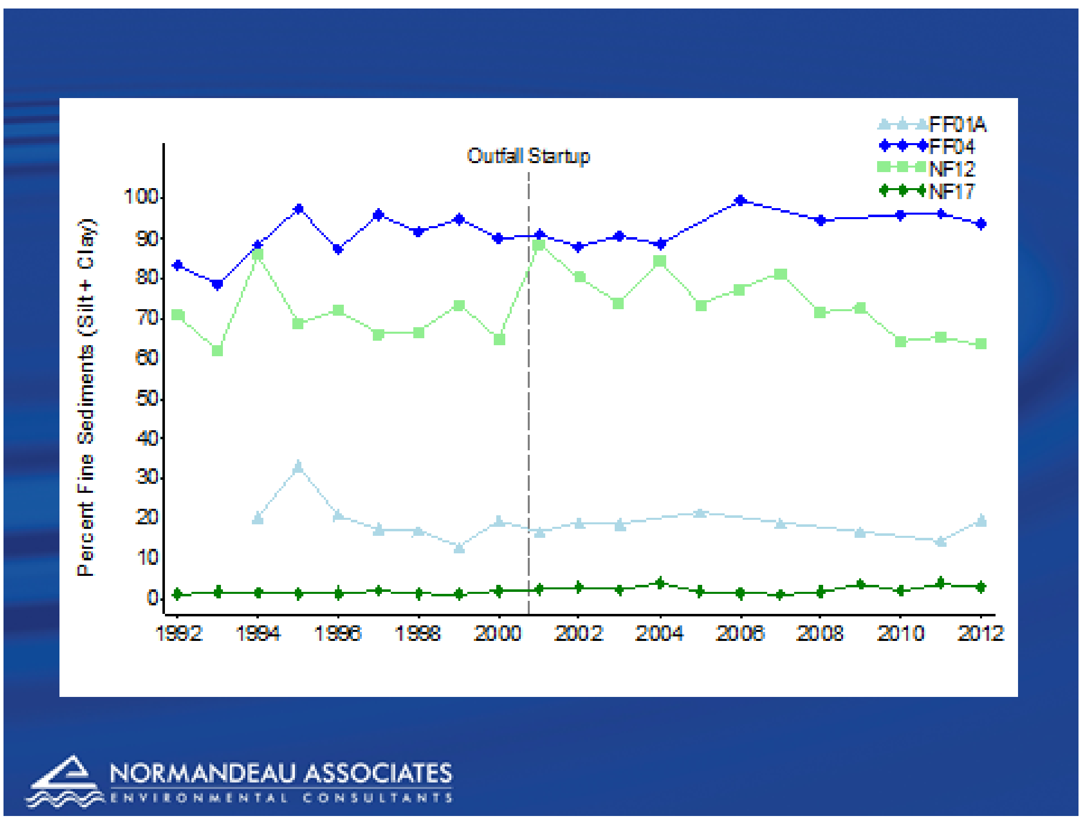

Soft-Bottom Stations
Transition Area
Nearfield
Farfield
Outfall Diffuser
Kilometers
Nahant
Deer Island
Hull
20 km
10 km
2 km
NORMANDEAU ASSOCIATES
ENVIRONMENTAL CONSULTANTS

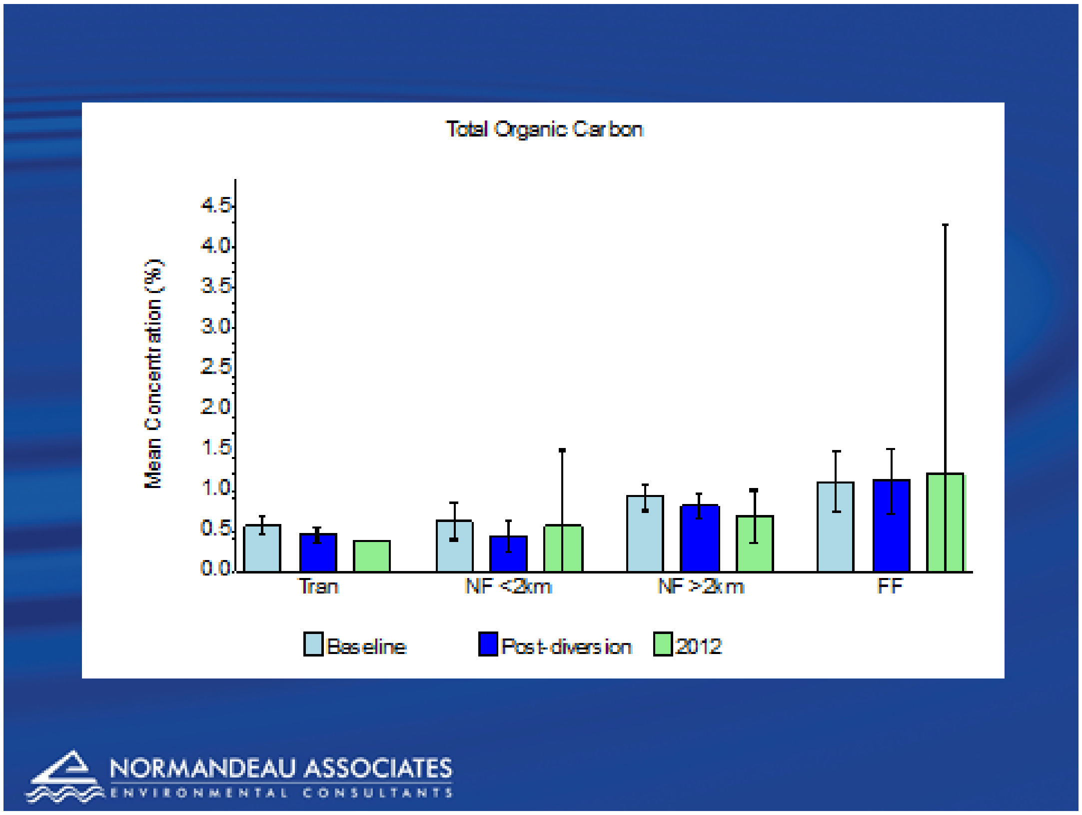

Clostridium perfringens
Mean Concentration (cfu/g dry/%fines)
250
200
150
100
50
0
Tran
NF <2km
NF >2km
FF
Baseline
Post-diversion
2012
NORMANDEAU ASSOCIATES
ENVIRONMENTAL CONSULTANTS


Clostridium perfringens (cfu/g dry/%fines)
300
250
200
150
100
50
0
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
Outfall Startup
Tran
NF <2km
NF >2km
FF
NORMANDEAU ASSOCIATES
ENVIRONMENTAL CONSULTANTS


Clostridium perfringens
(cfu/g dry/% fines)
N
Outfall Diffuser
NORMANDEAU ASSOCIATES
ENVIRONMENTAL CONSULTANTS


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


Outfall Startup
FF01A
FF04
NF12
NF17
Percent Fine Sediments (Silt + Clay)
100
90
80
70
60
50
40
30
20
10
0
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
NORMANDEAU ASSOCIATES
ENVIRONMENTAL CONSULTANTS


Total Organic Carbon
Mean Concentration (%)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Tran
NF <2km
NF >2km
FF
Baseline
Post-diversion
2012
NORMANDEAU ASSOCIATES
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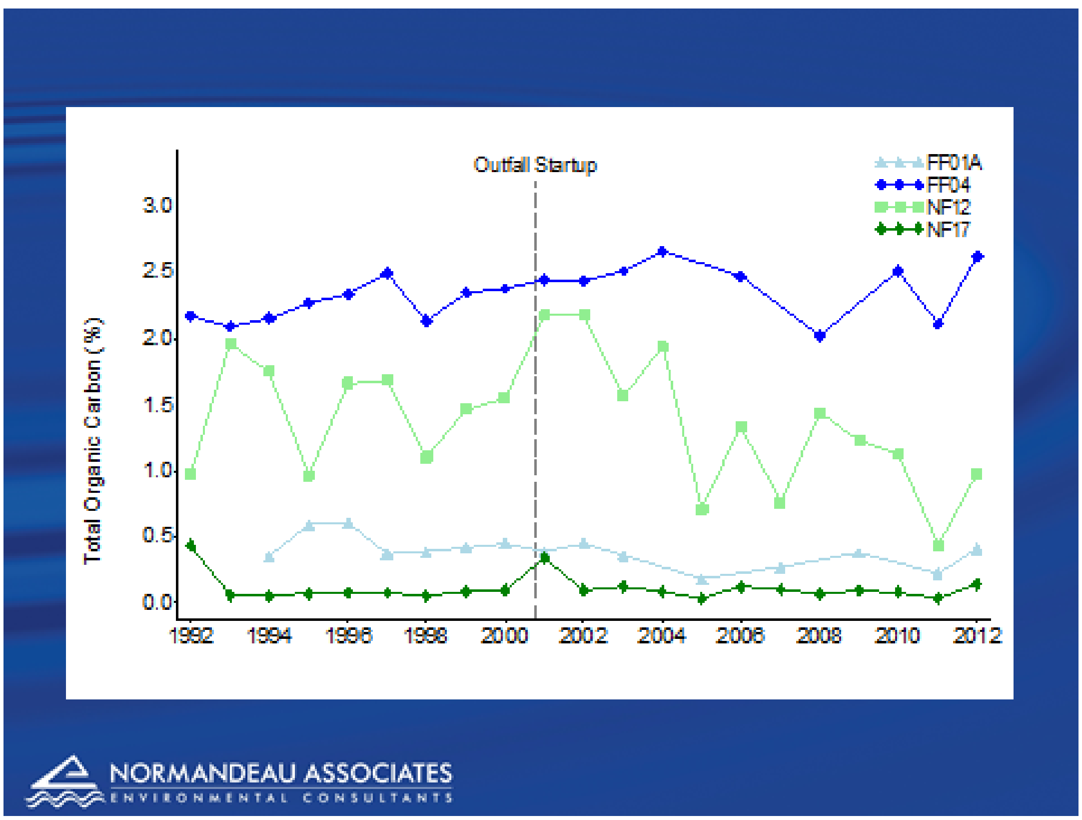
Outfall Startup
FF01A
FF04
NF12
NF17
Total Organic Carbon (%)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
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Sediment Summary:

- Plume footprint indicated by *Clostridium perfringens*; only at stations closest to the outfall.
- No changes in grain size from effluent discharge.
- No changes in TOC from effluent discharge.

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Benthic Infauna

Summary for 14 samples in 2012:

- 27,114 individual organisms (15,067 in 2011)
- 240 taxa identified; 210 species and 30 higher taxonomic groups (229 taxa total, and 199 species in 2011)
- All counts used for abundance
- Only species-level counts used for diversity measures and multivariate analyses

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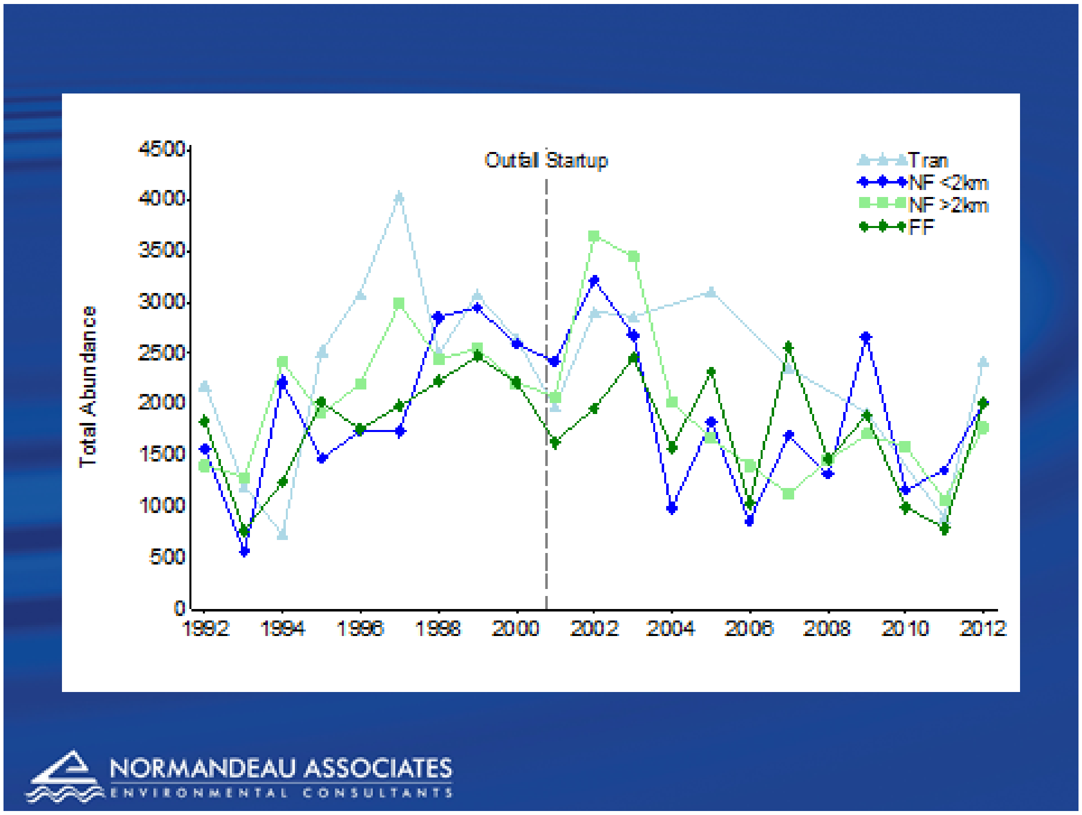
Outfall Startup
Tran
NF <2km
NF >2km
FF
Total Abundance
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
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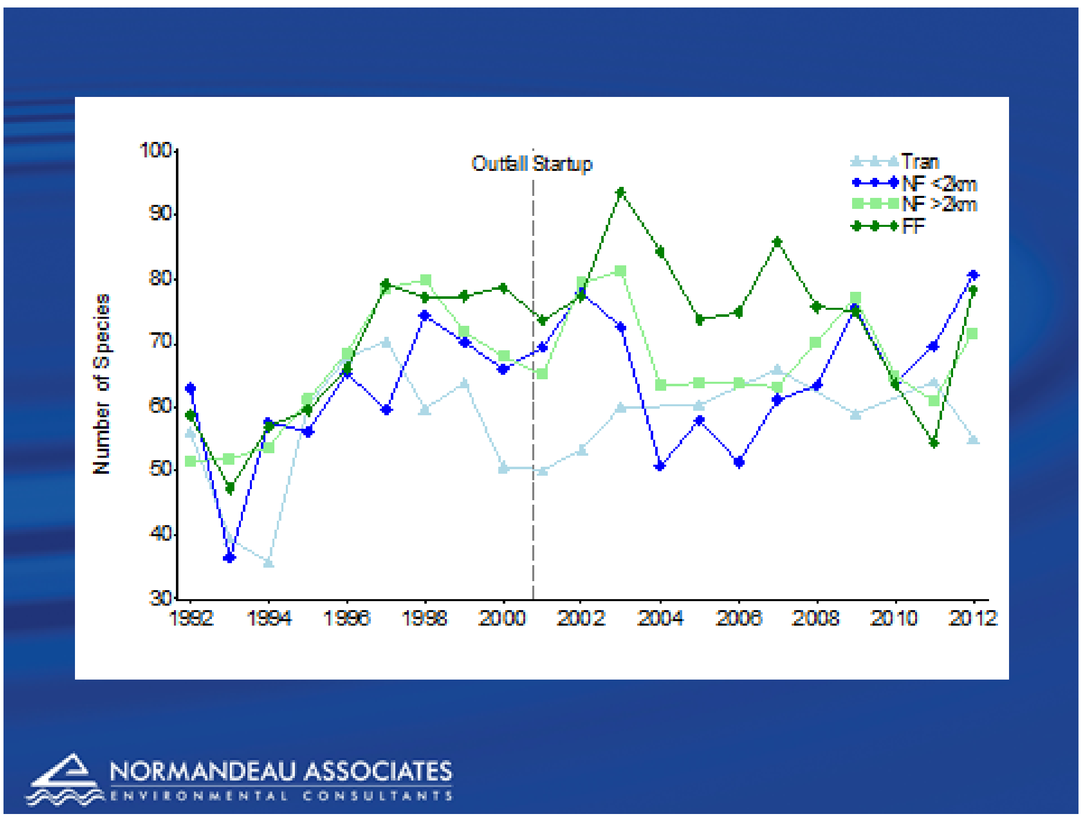
Outfall Startup
Tran
NF <2km
NF >2km
FF
Number of Species
100
90
80
70
60
50
40
30
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
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2012 Threshold Exceedances:

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

Parameter	Threshold range		2012 Result	Exceedance?
	Low	High		
Shannon-Weiner (H')	3.37	3.99	4.36	Yes, Caution Level
Pielou's (J')	0.57	0.67	0.7	Yes, Caution Level

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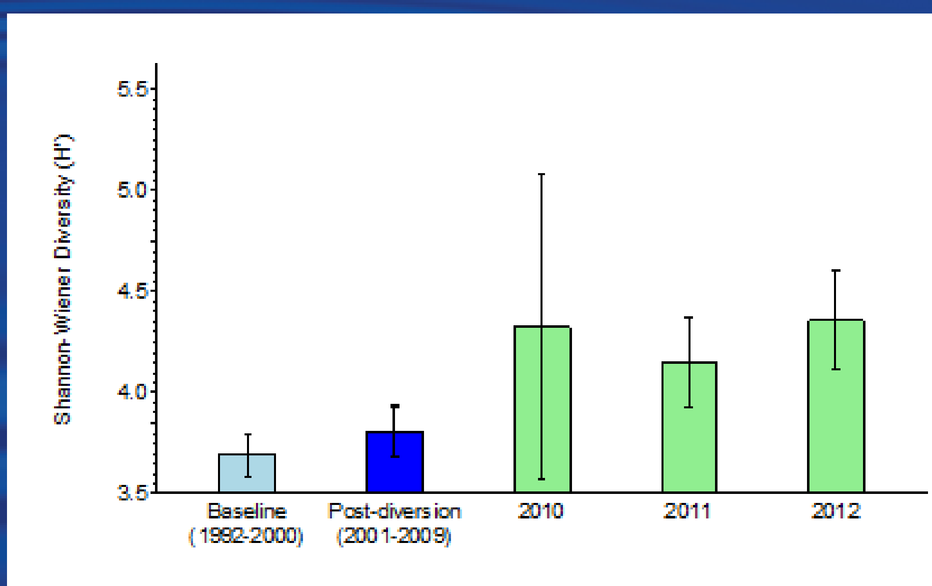
Nearfield Stations only



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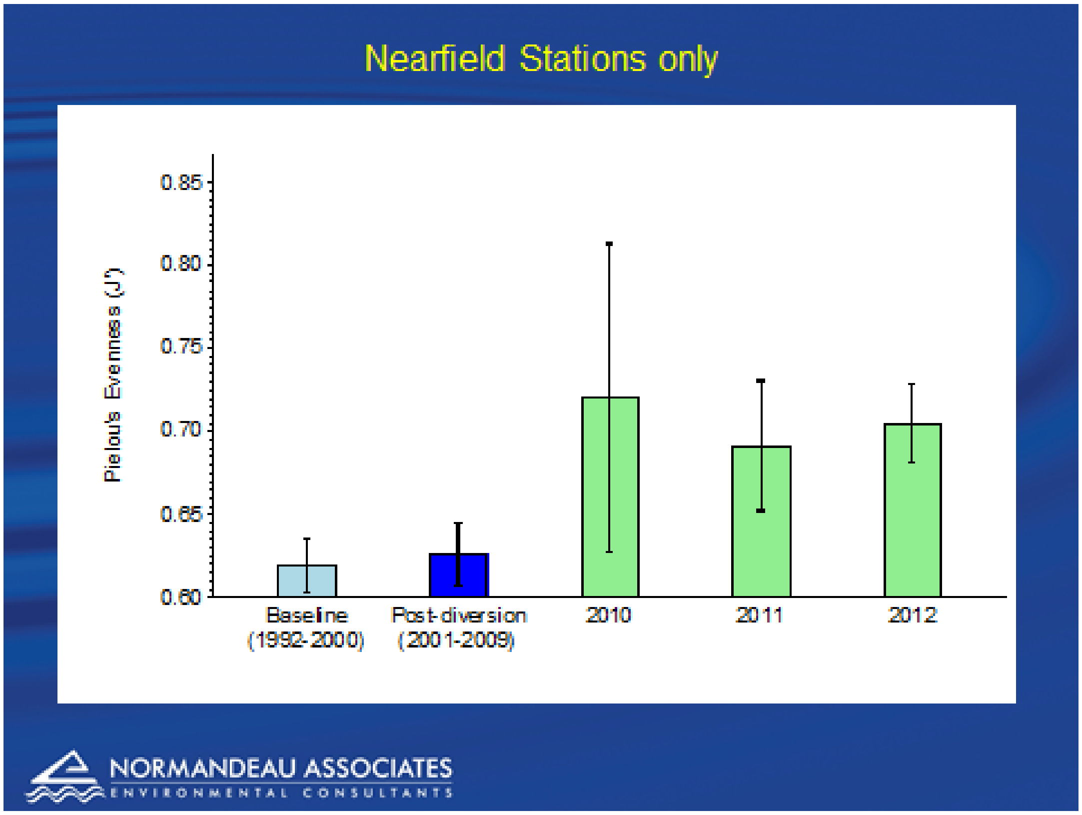
Nearfield Stations only
Pielou's Evenness (J')
0.85
0.80
0.75
0.70
0.65
0.60
Baseline (1992-2000)
Post-diversion (2001-2009)
2010
2011
2012
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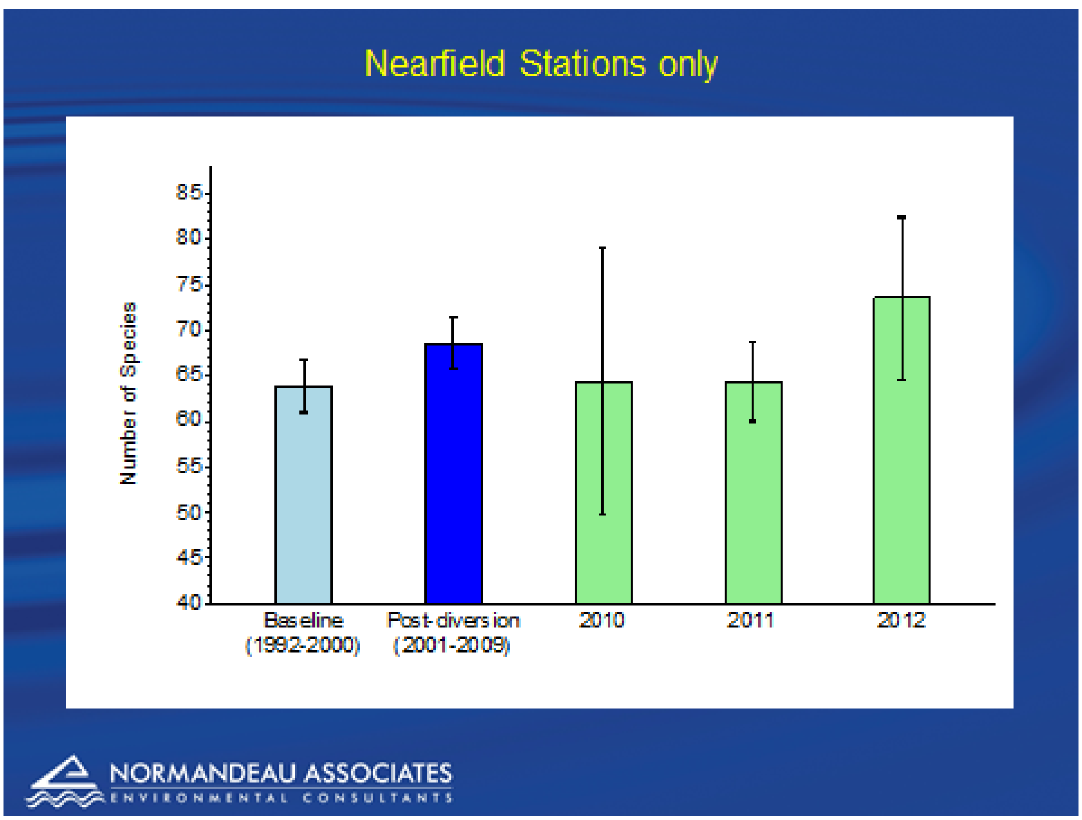
Nearfield Stations only
Number of Species
85
80
75
70
65
60
55
50
45
40
Baseline (1992-2000)
Post-diversion (2001-2009)
2010
2011
2012
NORMANDEAU ASSOCIATES
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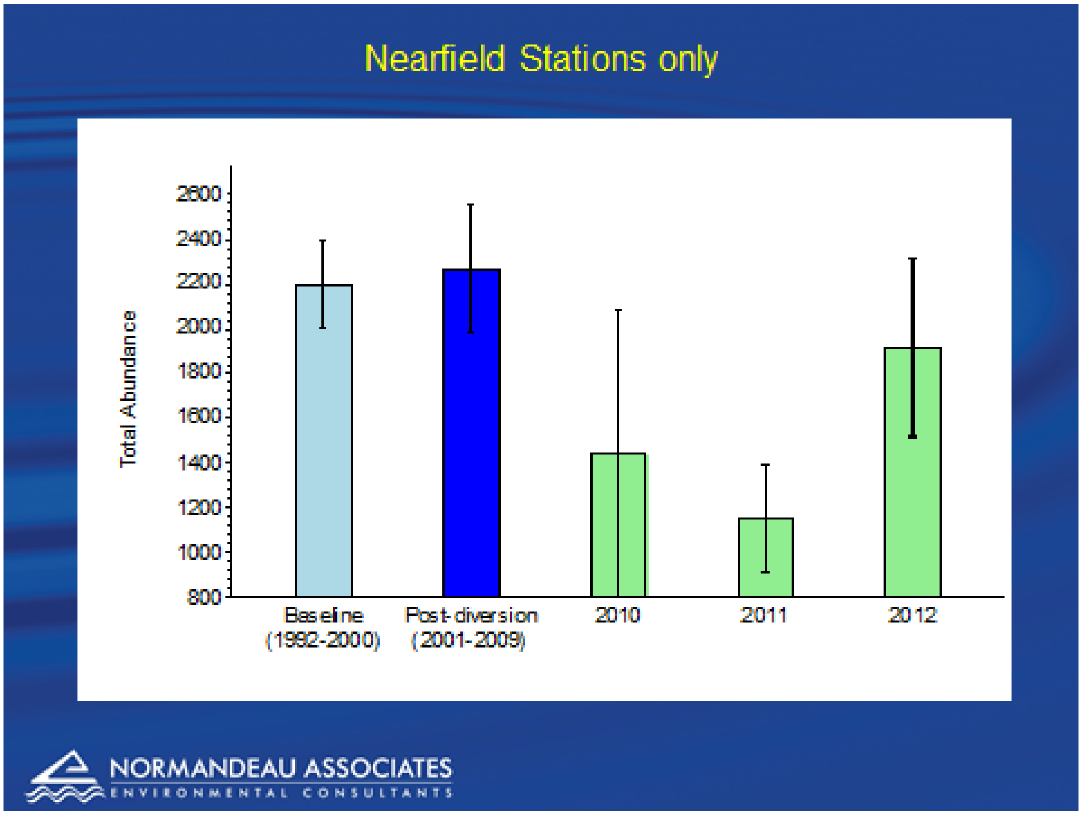
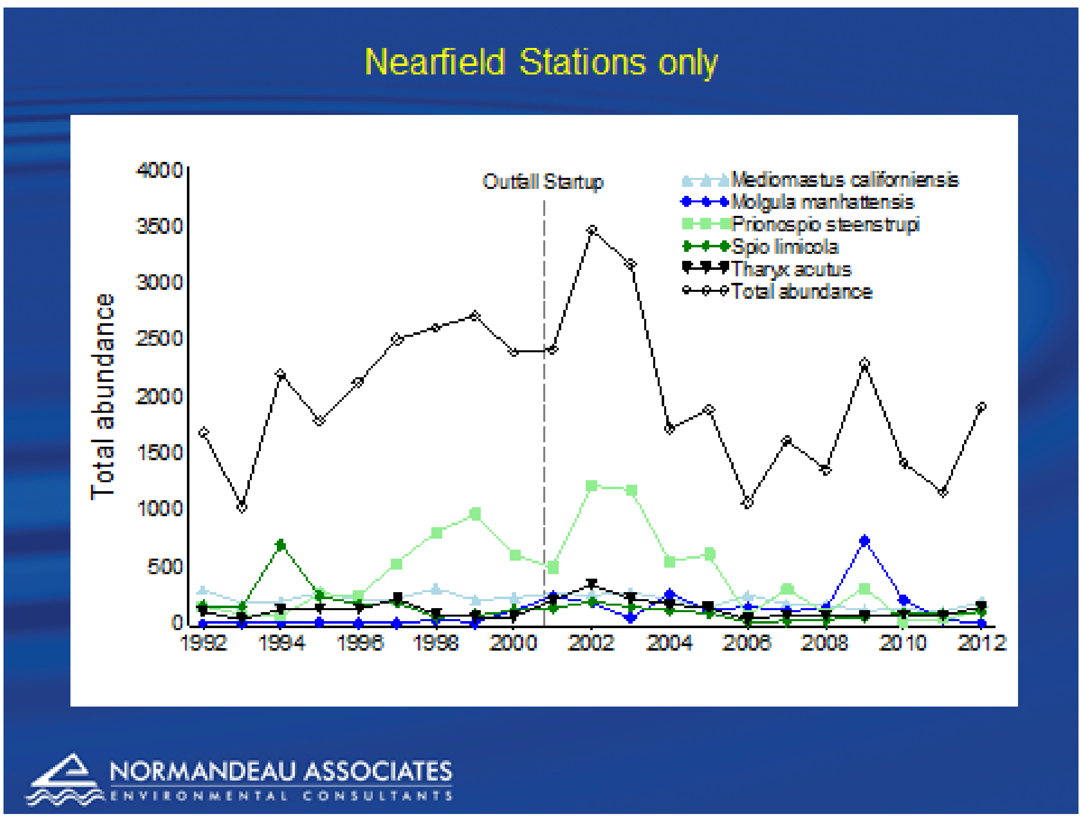

Nearfield Stations only
Total Abundance
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
Baseline (1992-2000)
Post-diversion (2001-2009)
2010
2011
2012
NORMANDEAU ASSOCIATES
ENVIRONMENTAL CONSULTANTS


Nearfield Stations only
Total abundance
4000
3500
3000
2500
2000
1500
1000
500
0
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
Outfall Startup
Mediomastus californiensis
Molgula manhattensis
Prionospio steenstrupi
Spio limicola
Tharyx acutus
Total abundance
NORMANDEAU ASSOCIATES
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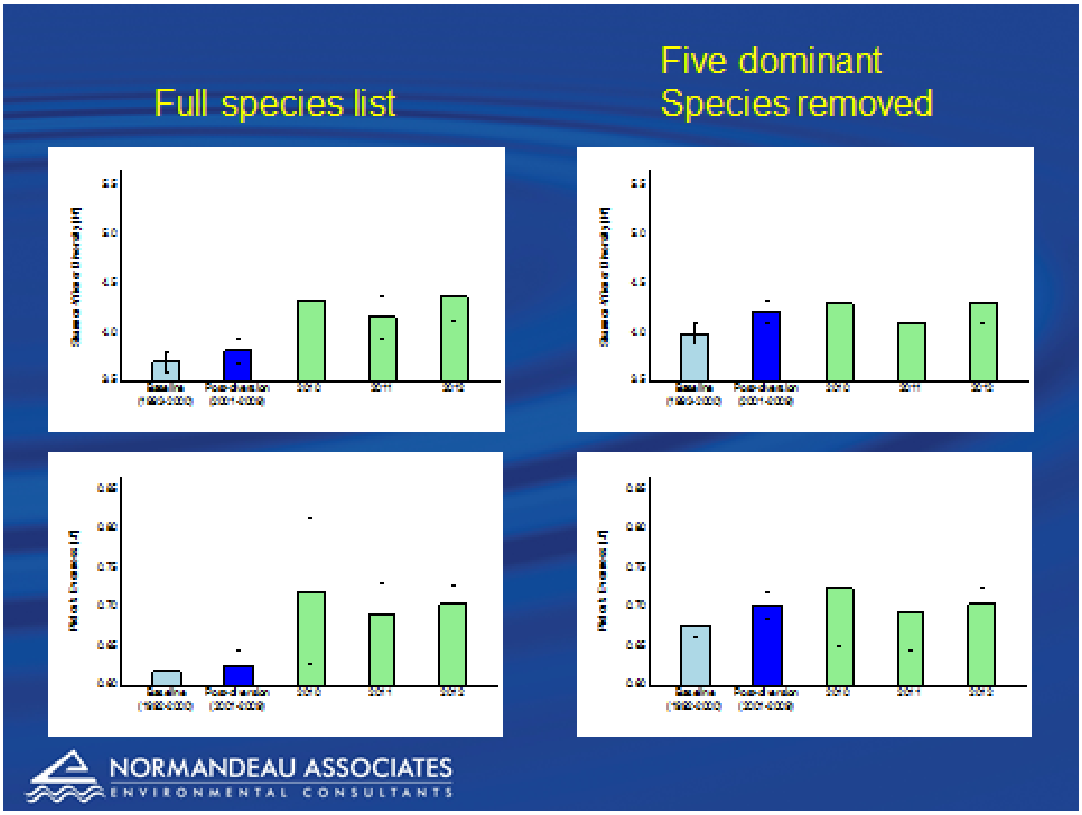
Full species list
Five dominant
Species removed
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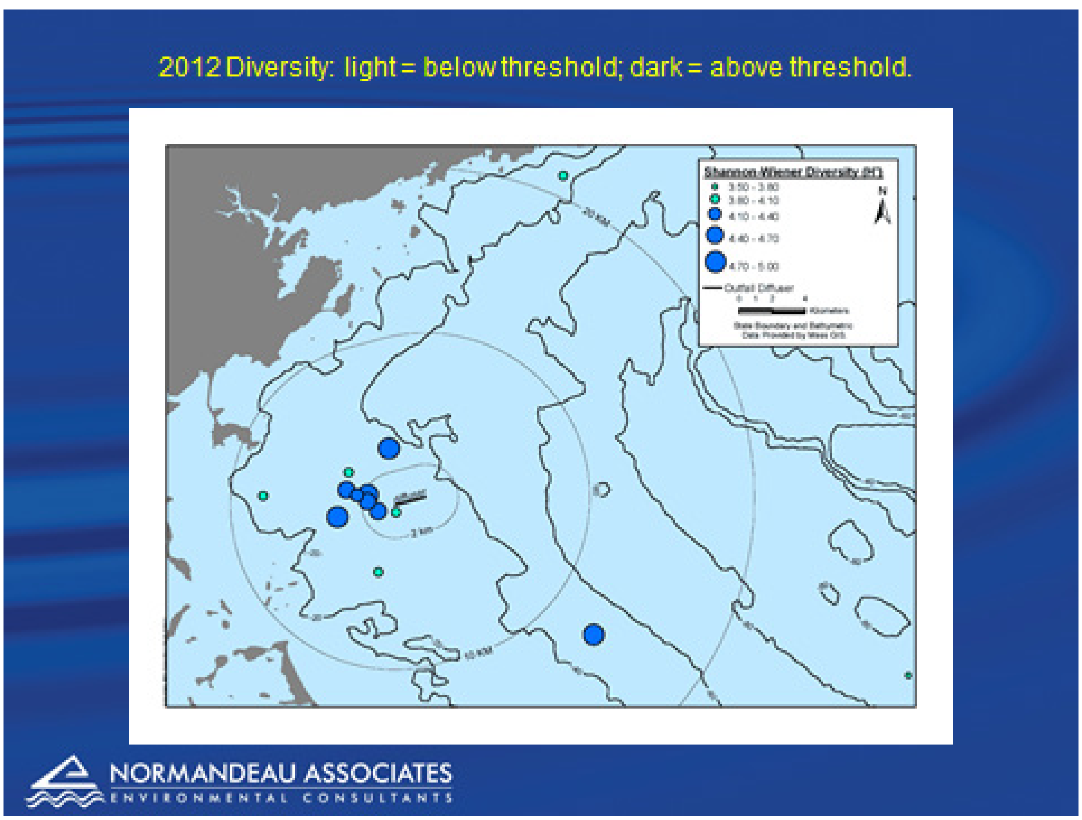
2012 Diversity: light = below threshold; dark = above threshold.
Shannon-Wiener Diversity (H')
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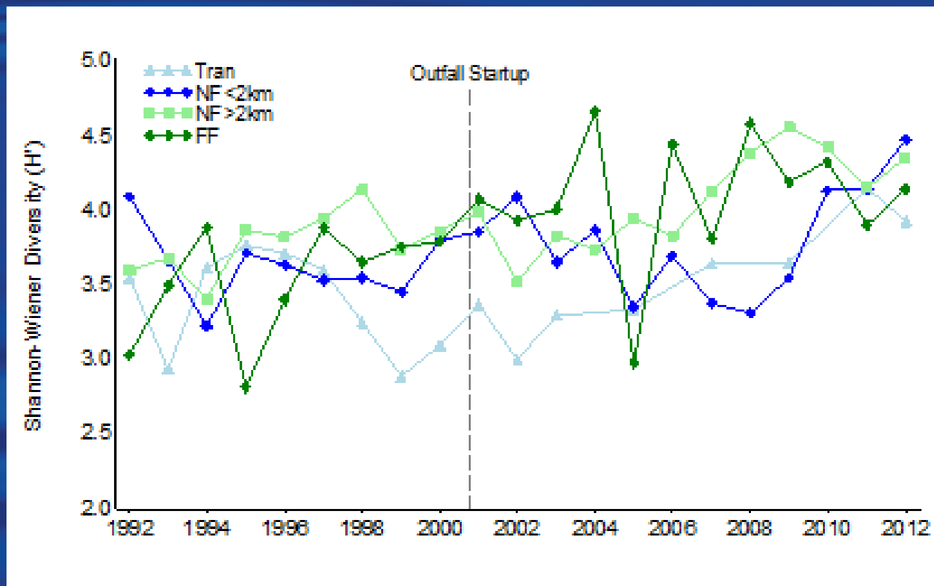

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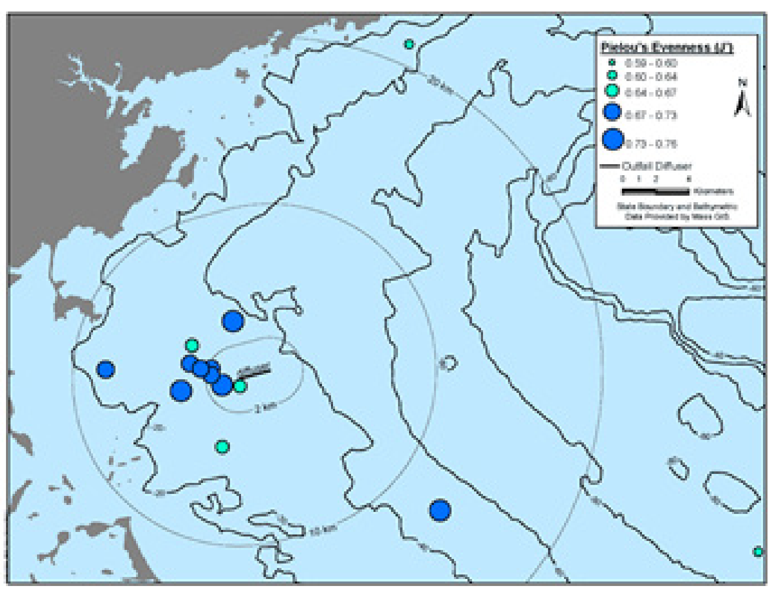
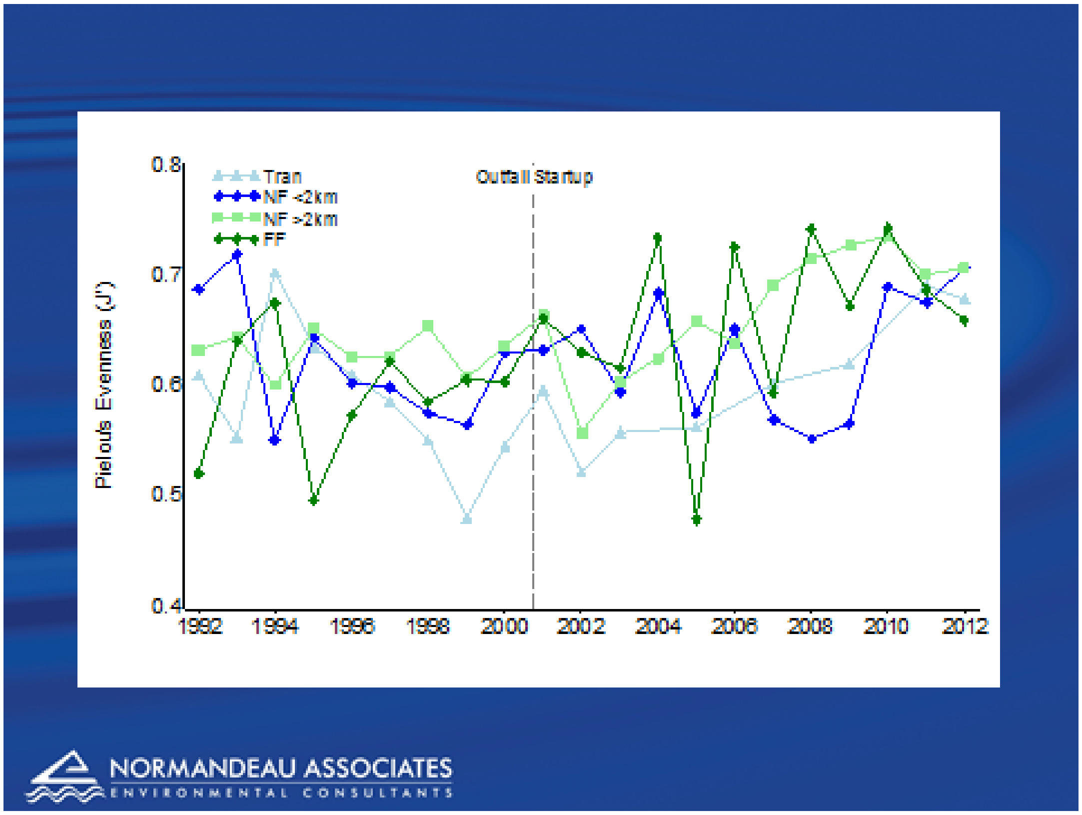
2012 Evenness: light = below threshold; dark = above threshold.



NORMANDEAU ASSOCIATES
ENVIRONMENTAL CONSULTANTS



Infaunal Assemblages Spatial Patterns:

- Multivariate analyses to assess patterns in the distribution of faunal assemblages
- 2012 Samples
- Bray-Curtis Similarity
- Cluster Analysis
- nMDS Ordination Plots

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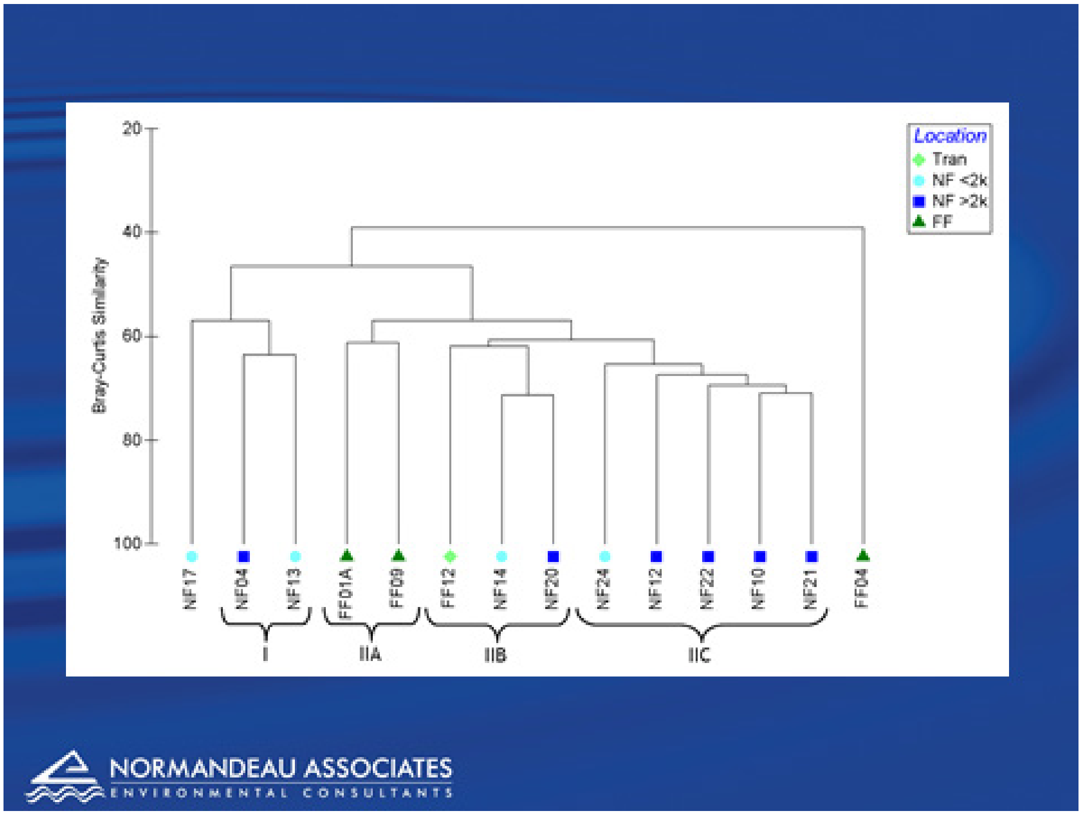

Bray-Curtis Similarity
20
40
60
80
100
Location
Tran
NF <2k
NF >2k
FF
NF17
NF04
NF13
FF01A
FF09
FF12
NF14
NF20
NF24
NF12
NF22
NF10
NF21
FF04
I
IIA
IIB
IIC
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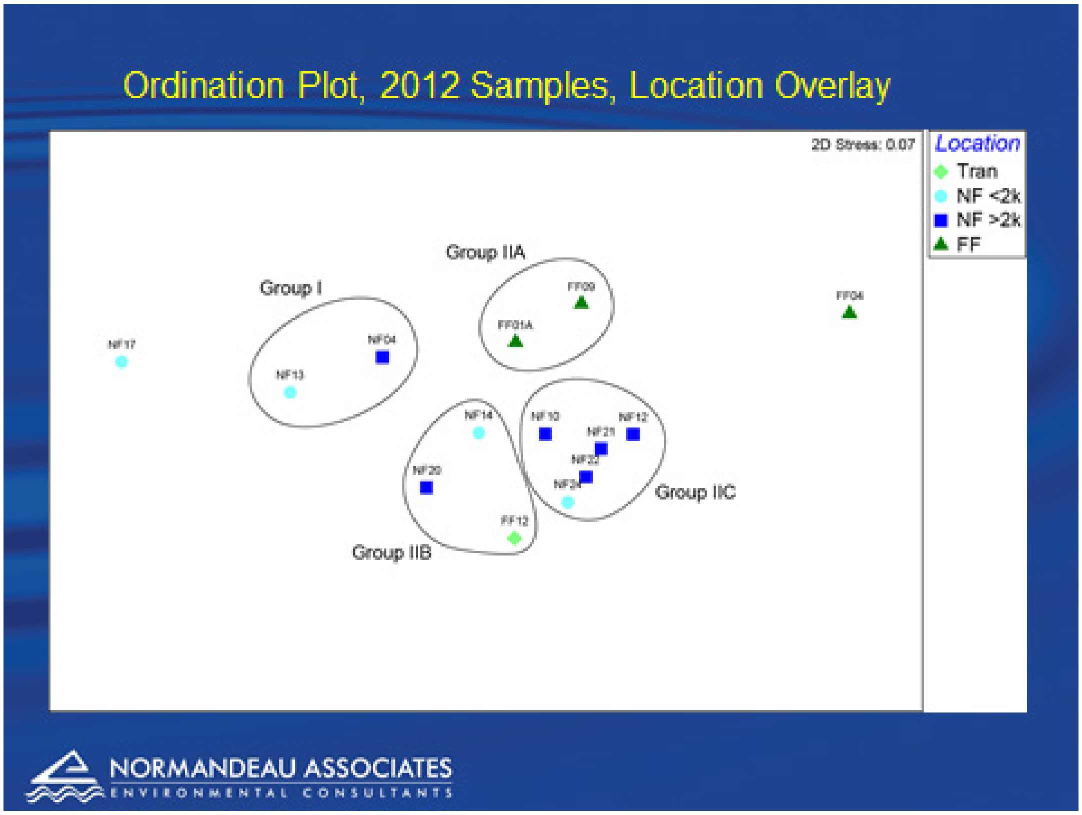

Ordination Plot, 2012 Samples, Location Overlay
2D Stress: 0.07
Location
Tran
NF <2k
NF >2k
FF
Group I
Group IIA
Group IIB
Group IIC
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2012 Infaunal Assemblages:

NF17 (sand)

- *Polygordius jouinae, Tanaissus psammophilus, Crassicorophium crassicorne*

Group I (sand, some fines)

- *Exogone hebes, Polygordius jouinae, Aricidea catherinae*

Group IIA (sand with fines)

- *Prionospio steenstrupi, Nucula delphinodonta, Owenia fusiformis*

Group IIB (sand with fines and gravel)

- *Mediomastus californiensis, Aricidea catherinae, Scoletoma hebes*

Group IIC (fines with sand)

- *Mediomastus californiensis, Tharyx acutus, Spio limicola*

FF04 (fines)

- *Anobothrus gracilis, Aricidea quadrilobata, Levinsenia gracilis*

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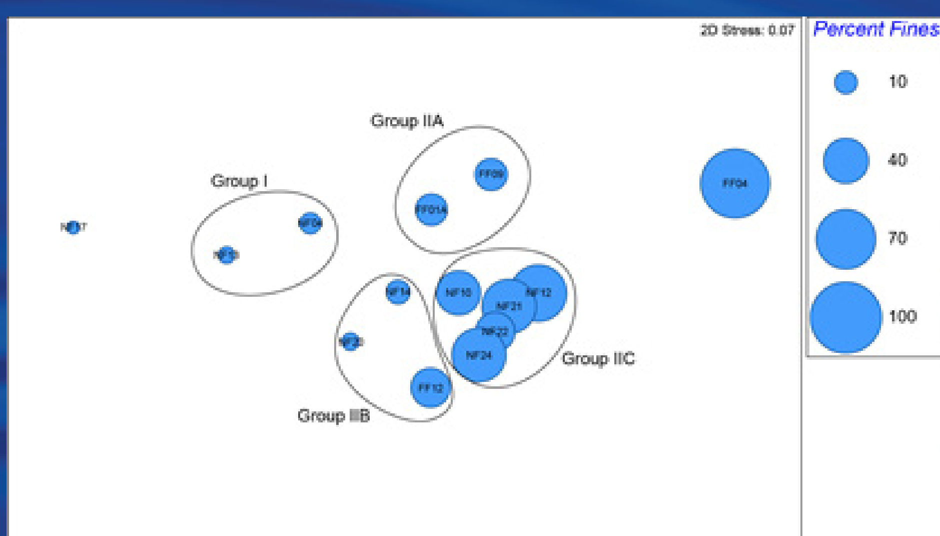
Ordination Plot, 2012 Samples, Percent Fines Overlay



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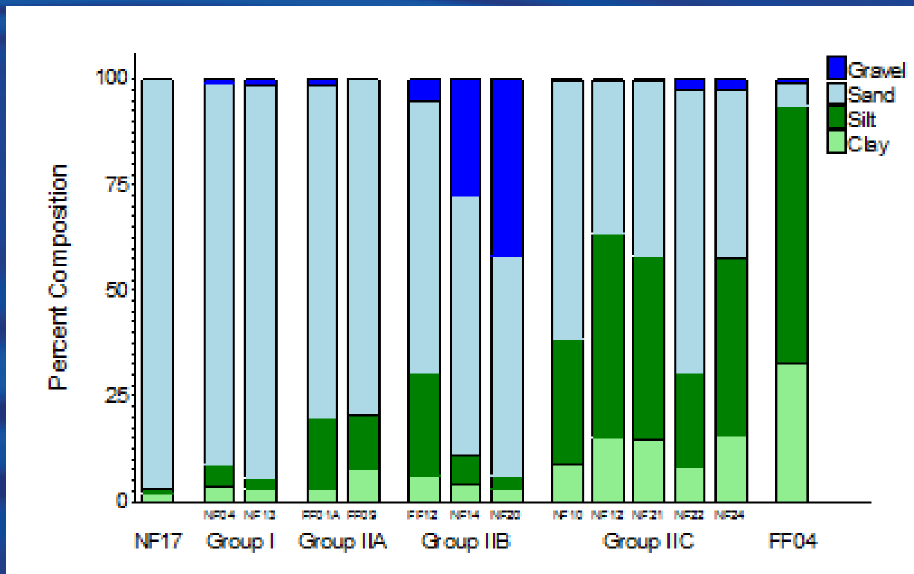
Sediment Grain Size Composition by Cluster Group



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Infaunal Assemblages Temporal Patterns:

- Multivariate analyses to assess changes in faunal assemblages over time
- Selected Stations: NF13, NF24, FF01A, FF04
- 1992-2012, Rep 1 only

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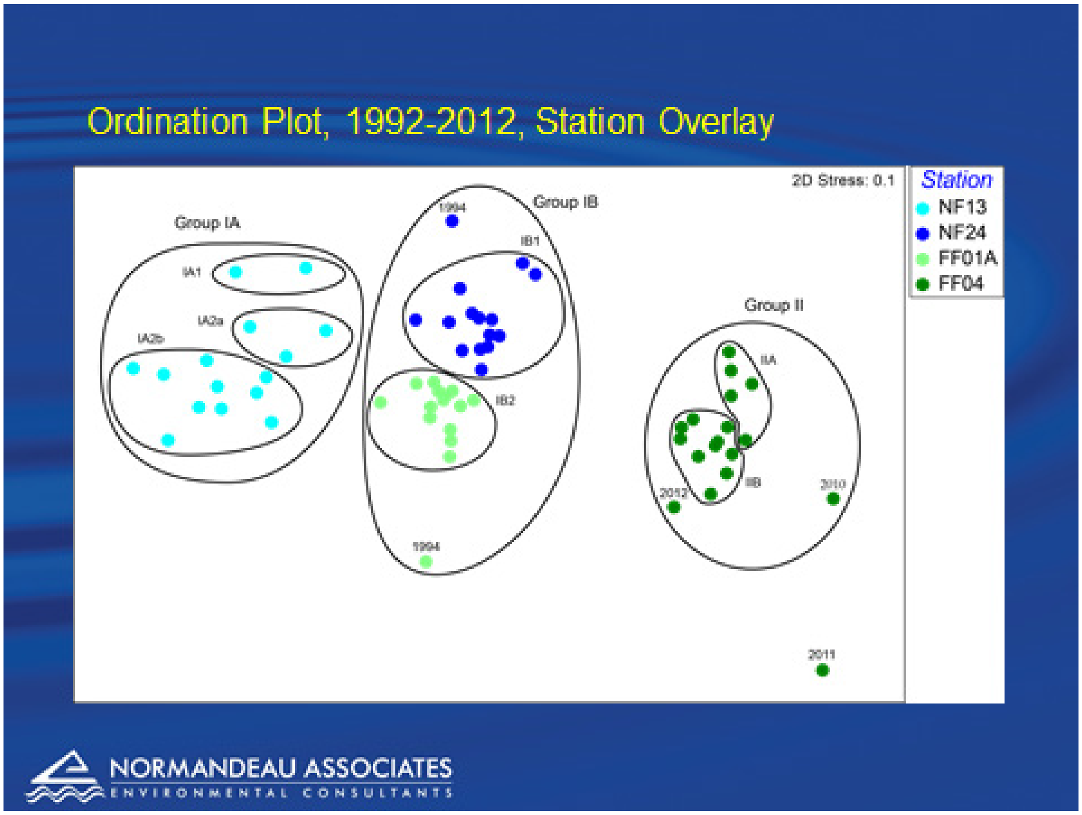
Ordination Plot, 1992-2012, Station Overlay
2D Stress: 0.1
Station
NF13
NF24
FF01A
FF04
Group IA
IA1
IA2a
IA2b
Group IB
1994
IB1
IB2
1994
Group II
IIA
IIB
2012
2010
2011
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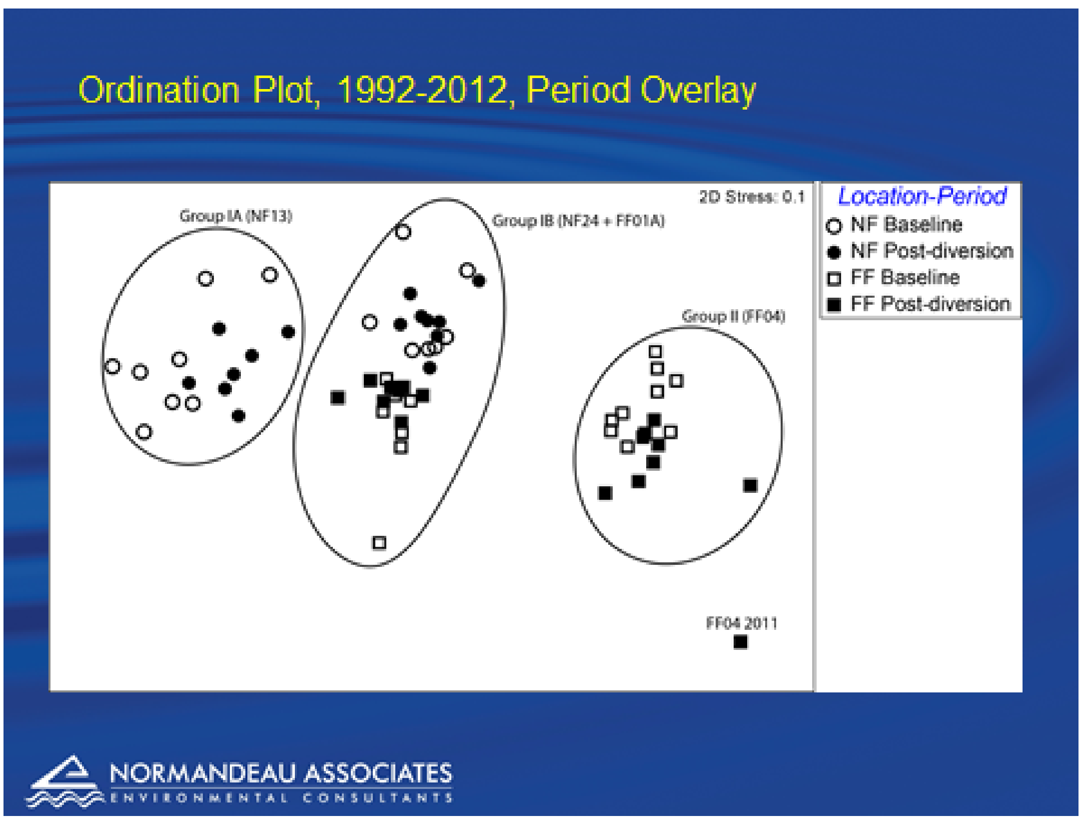
Ordination Plot, 1992-2012, Period Overlay
2D Stress: 0.1
Location-Period
NF Baseline
NF Post-diversion
FF Baseline
FF Post-diversion
Group IA (NF13)
Group IB (NF24 + FF01A)
Group II (FF04)
FF04 2011
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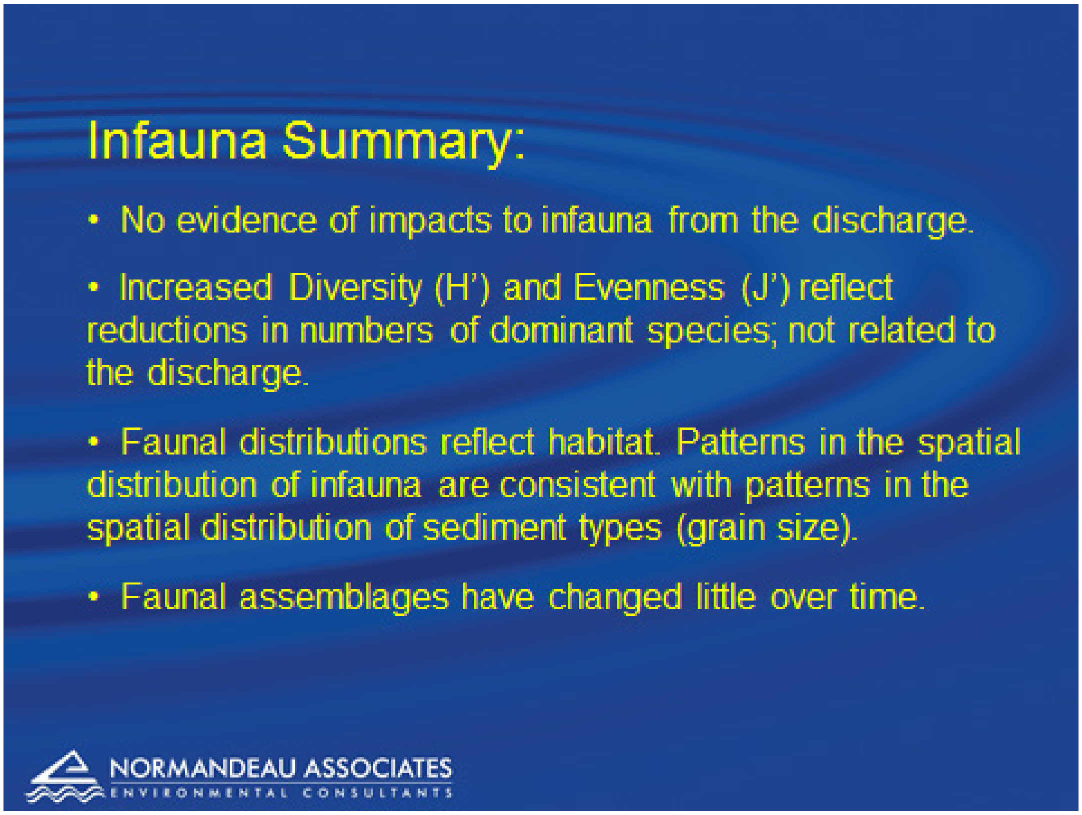
Infauna Summary:
• No evidence of impacts to infauna from the discharge.
• Increased Diversity (H') and Evenness (J') reflect reductions in numbers of dominant species; not related to the discharge.
• Faunal distributions reflect habitat. Patterns in the spatial distribution of infauna are consistent with patterns in the spatial distribution of sediment types (grain size).
• Faunal assemblages have changed little over time.
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Acknowledgements:
• Massachusetts Water Resources Authority
• Normandeau: Ann Pembroke, Program Manager; Hannah Proctor, Laboratory Manager; Erik Fel'Dotto, Field Manager
• Ocean's Taxonomic Services
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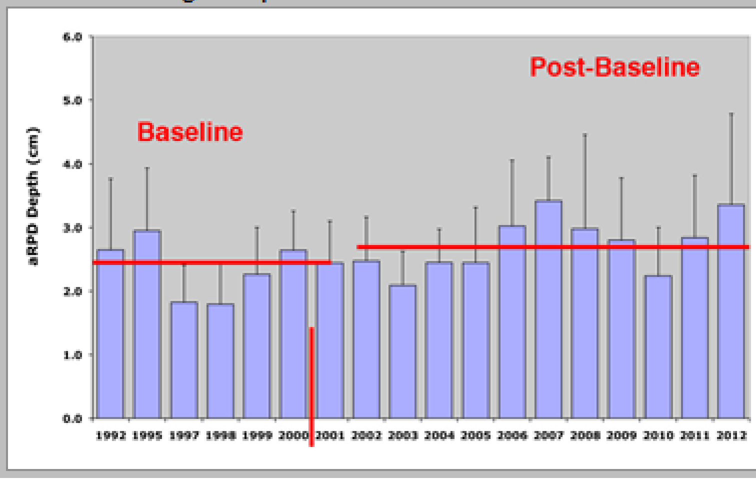
Appendix A2. 2012 Harbor and Bay Sediment Profile Imaging

Nearfield Summary
Baseline vs. Post-Baseline

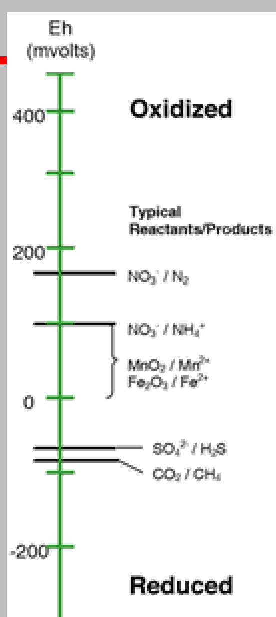
	Baseline Years 1992-2000 9-Year Interval	Post-Baseline Years 2001-2012 12-Year Interval
SS	Advanced from I to II-III	Bimodal: I-II and II-III
OSI - Low	4.8 (1997)	5.8 (2003)
OSI - High	7.2 (2000)	7.9 (2008)
RPD - Low	1.8 cm (1997 and 1998)	2.1 cm (2003)
RPD -High	3.0 cm (1995)	3.4 cm (2007)
Annual Mean RPD Measured	2.2 (0.49 SD) cm	3.1 (0.69 SD) cm
Annual Mean RPD All Values	2.4 (0.47 SD) cm	2.7 (0.43 SD) cm

Nearfield Summary for 2012

- Sediments similar to other years, but slightly sandier
- aRPD trending deeper



Apparent color RPD layer depth compared to Eh profiles



Summary of oxidation/reduction reactions:

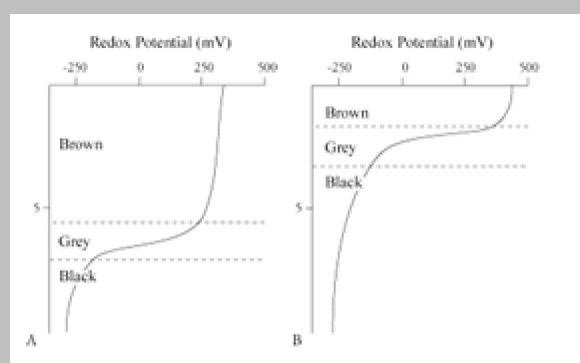
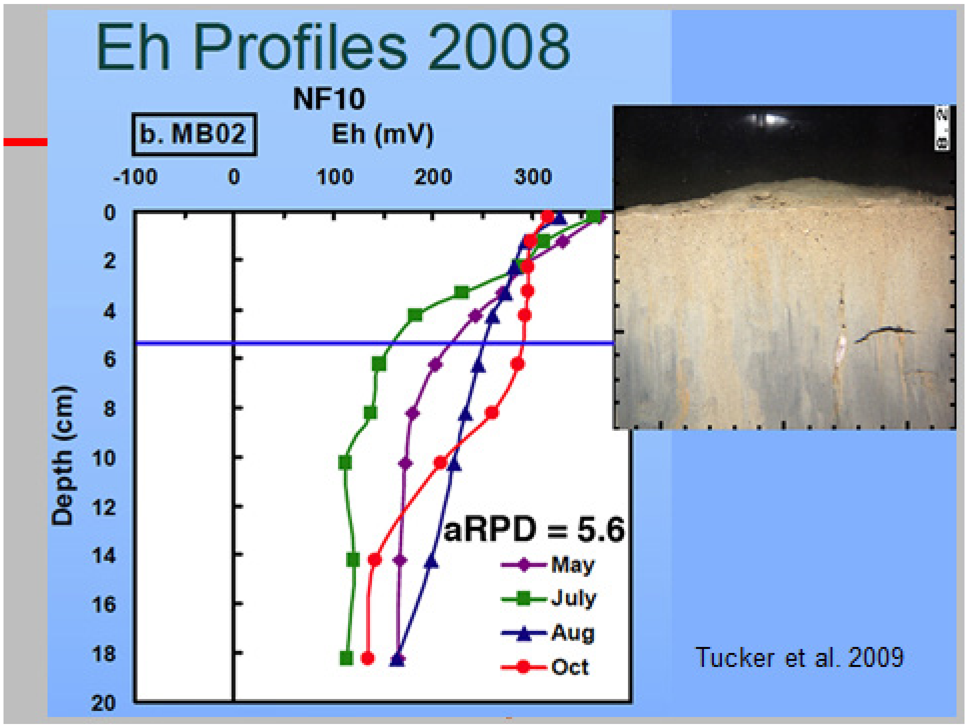
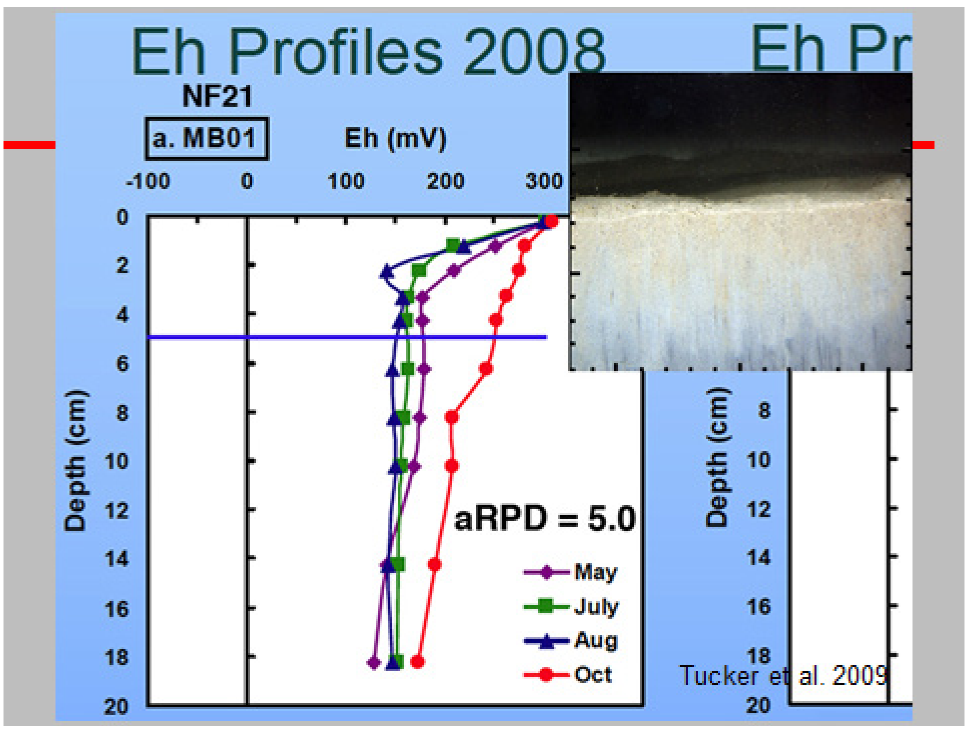
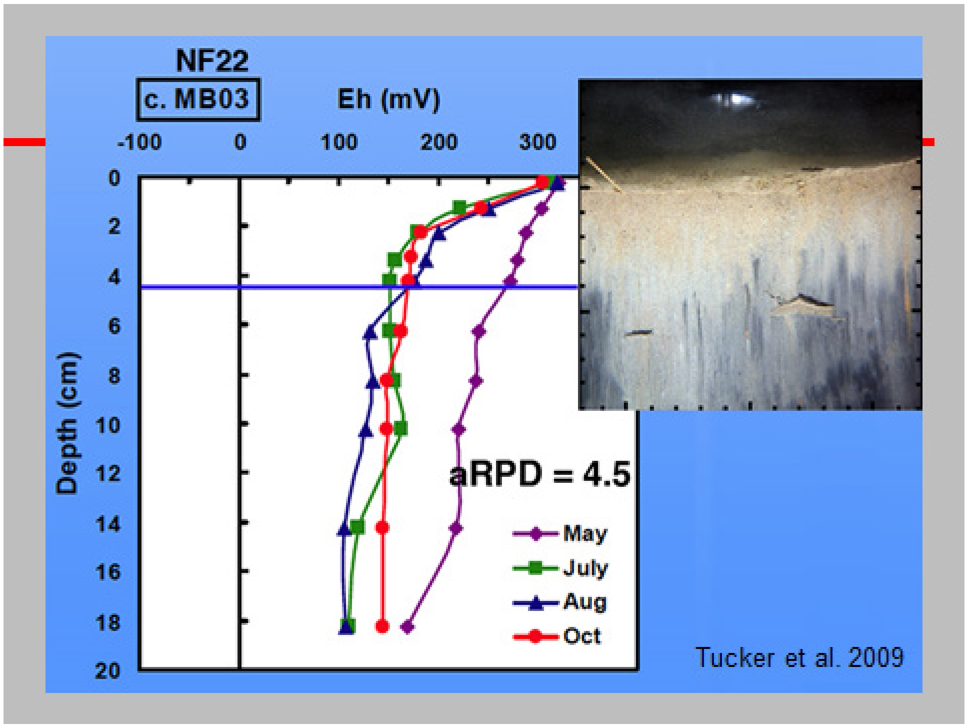
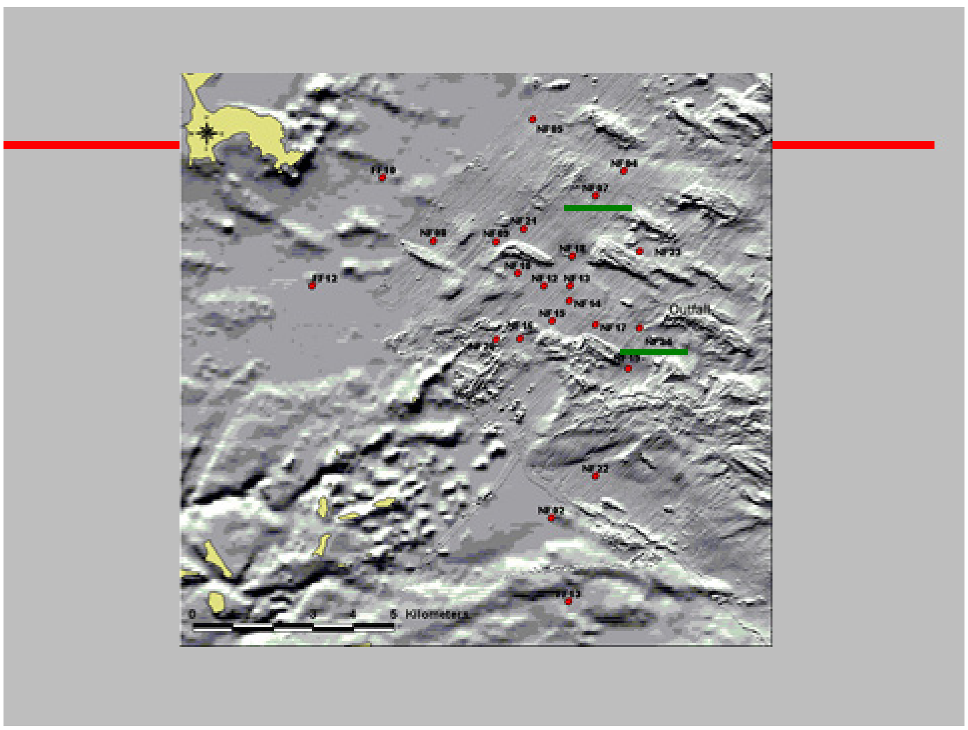


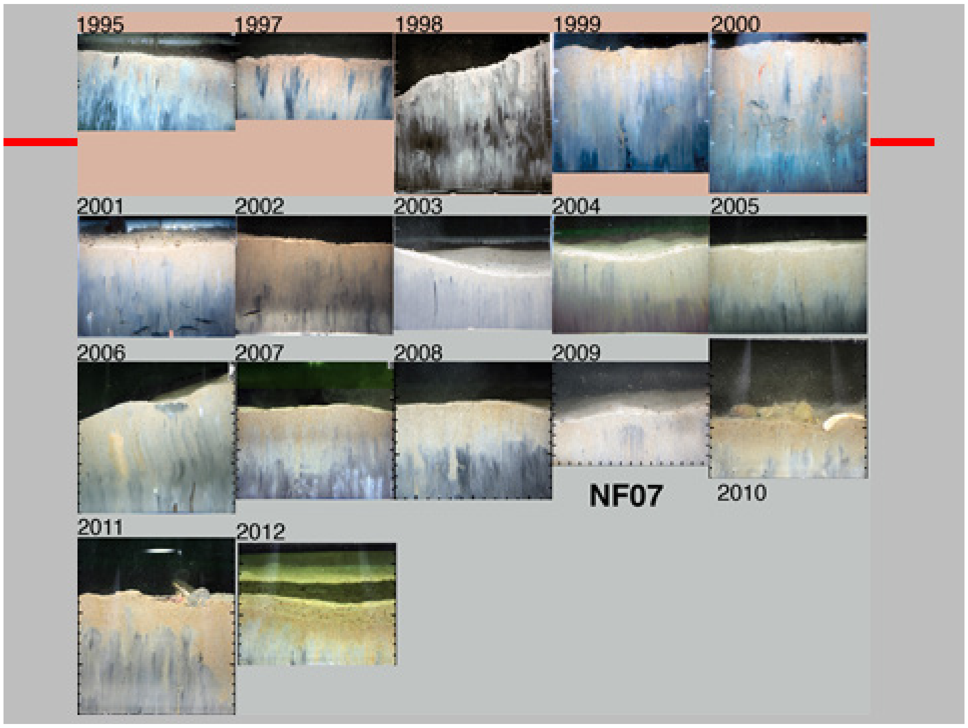
Figure 11. Typical redox potential profiles for two intertidal sediments: *A* medium sand, *B* fine sand

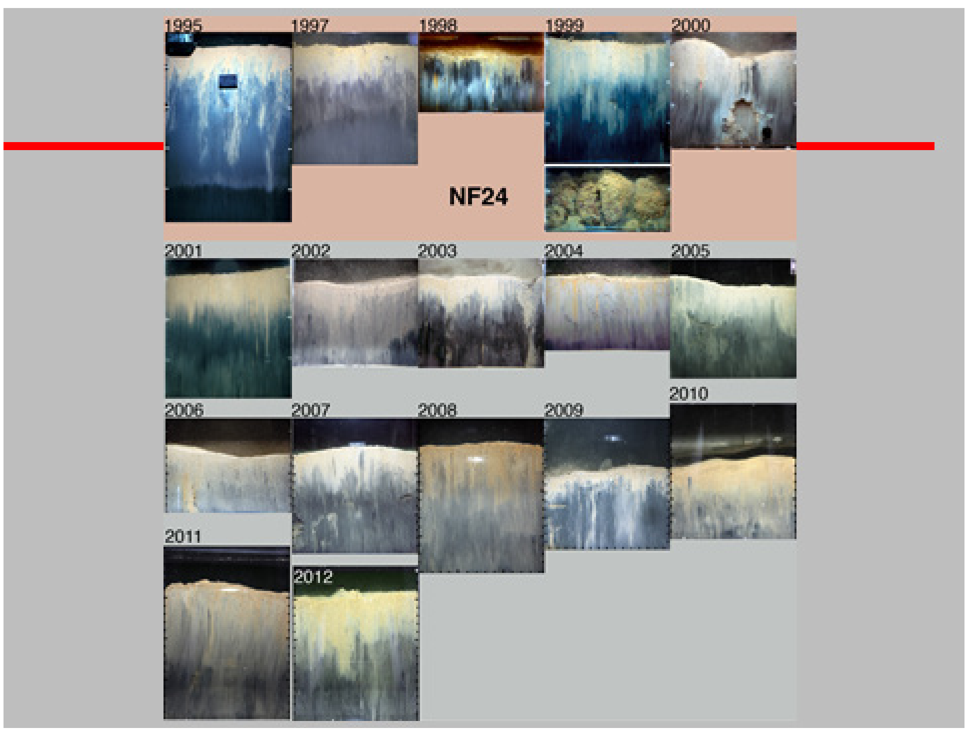

Eh Profiles 2008
NF10
b. MB02
Eh (mV)
-100 0 100 200 300
0 2 4 6 8 10 12 14 16 18 20
Depth (cm)
aRPD = 5.6
May
July
Aug
Oct
Tucker et al. 2009


Eh Profiles 2008
Eh Pr
NF21
a. MB01
Eh (mV)
-100 0 100 200 300
0 2 4 6 8 10 12 14 16 18 20
Depth (cm)
aRPD = 5.0
May
July
Aug
Oct
Tucker et al. 2009


NF22
c. MB03
Eh (mV)
-100
0
100
200
300
Depth (cm)
0
2
4
6
8
10
12
14
16
18
20
aRPD = 4.5
May
July
Aug
Oct
Tucker et al. 2009


Outfall
Kilometers


1995
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
NF07
2010
2011
2012

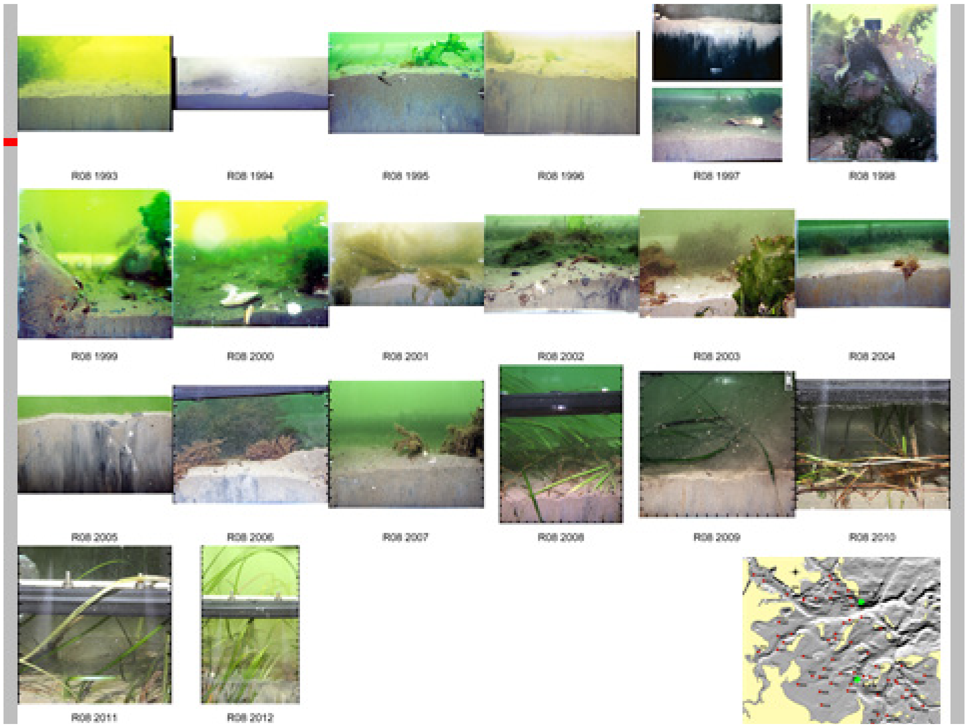

1995
1997
1998
1999
2000
NF24
2001
2002
2003
2004
2005
2010
2006
2007
2008
2009
2011
2012

Nearfield Summary

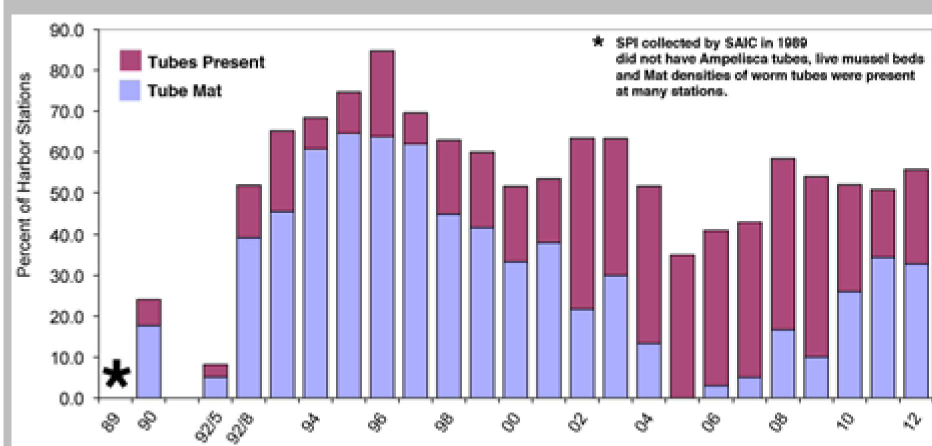
- Operation of outfall, starting in 2001, did not effect benthic habitat quality
- aRPD Post-Baseline deeper than Baseline
- aRPD is better estimate of highly oxidized sediments
- Sediment characteristics remained similar through time

Harbor for 2012

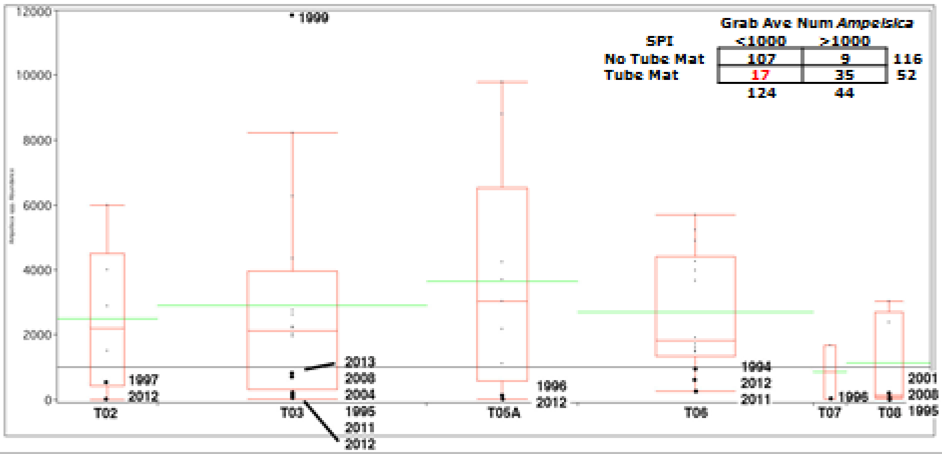
- Sediments, aRPD, Successional Stage, and OSI about the same.
- Eel grass bed at R08 on Deer Island Flats, 5th year.
- *Ampelisca* spp. tube mats 33% of stations and present 56% of stations.
- *Leptocheirus pinguis* bioturbation obvious at R05, R14, R20, and R30.
- Physical processes prominent in structuring surface sediments.
- Microalgal mat observed at T06.



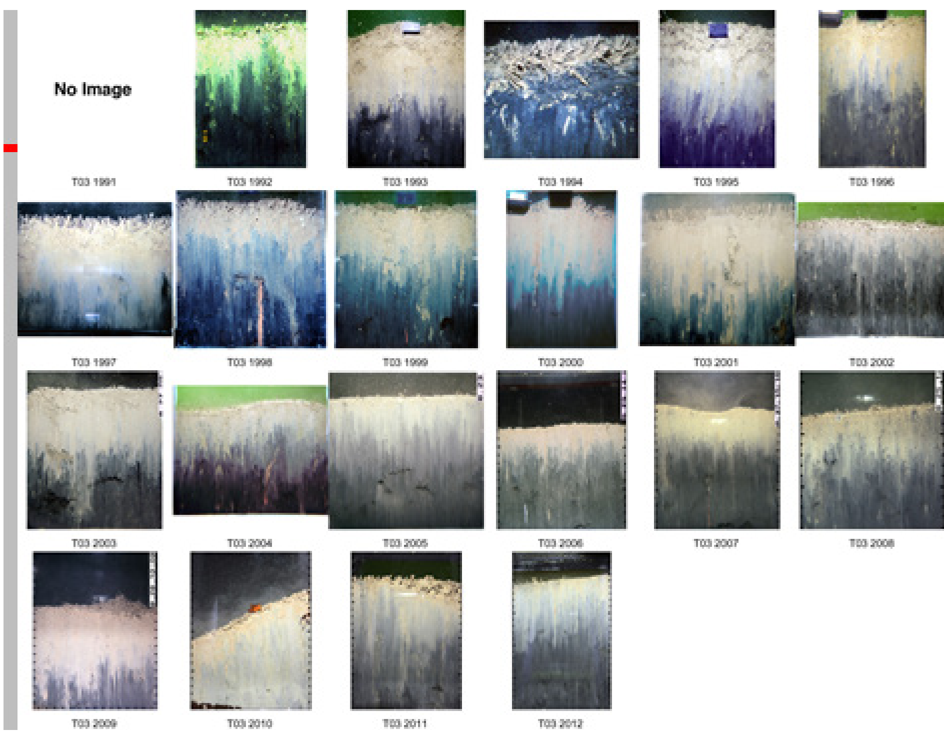
Ampelisca spp. Tube Mats



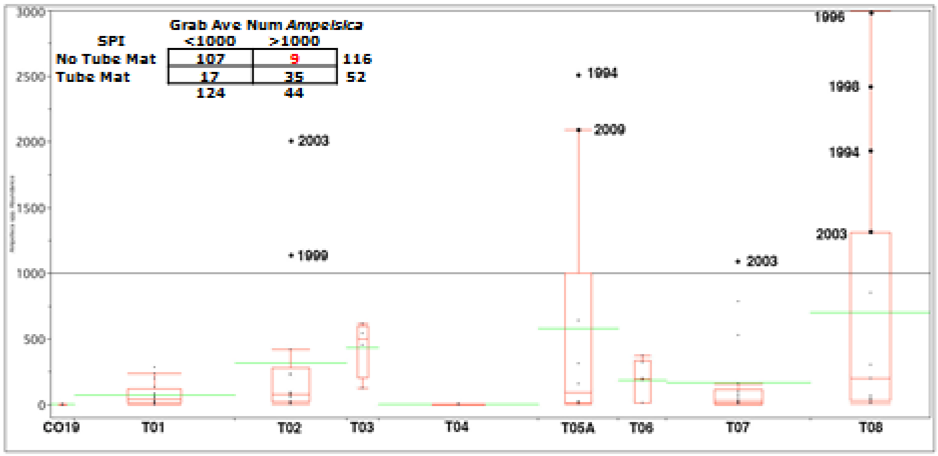
Ampelisca spp. Tube Mats vs. Grab Abundance



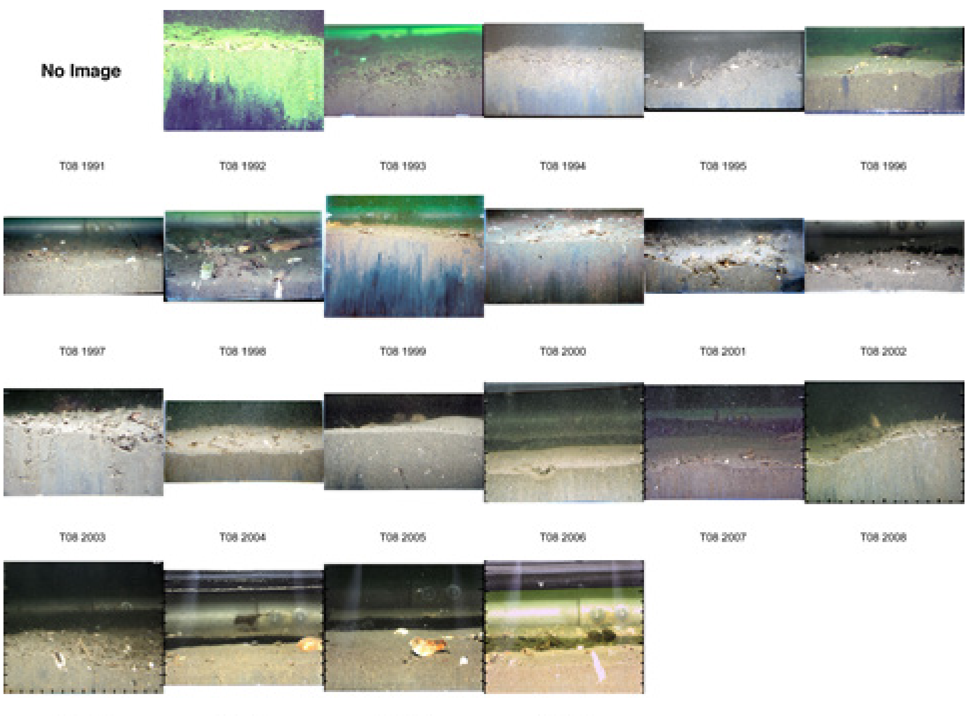
SPI says Mat present, Grab says no Mat

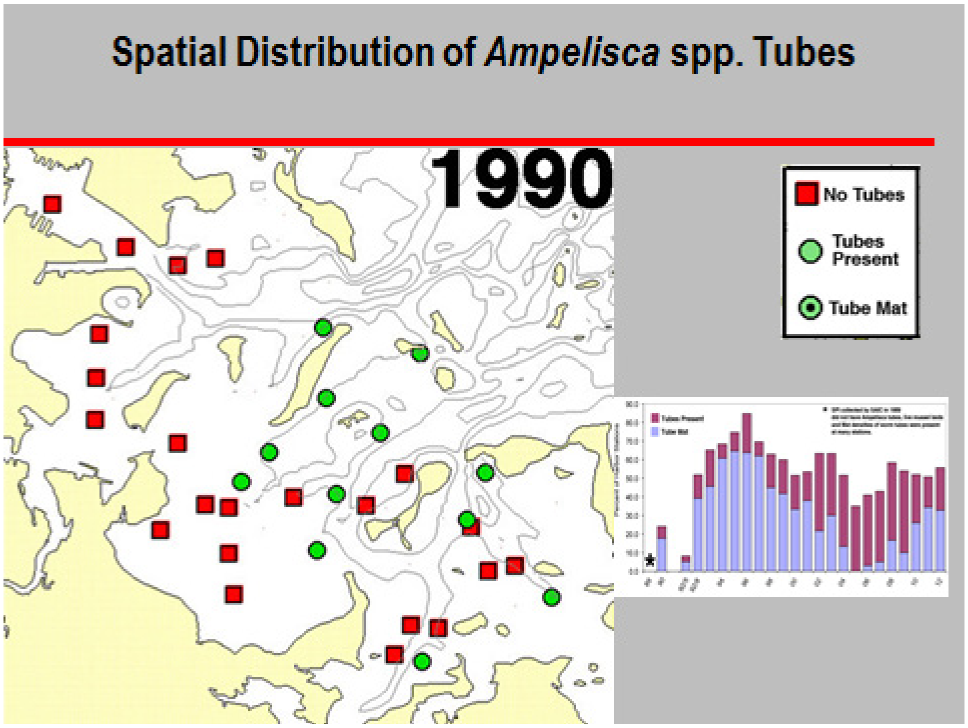


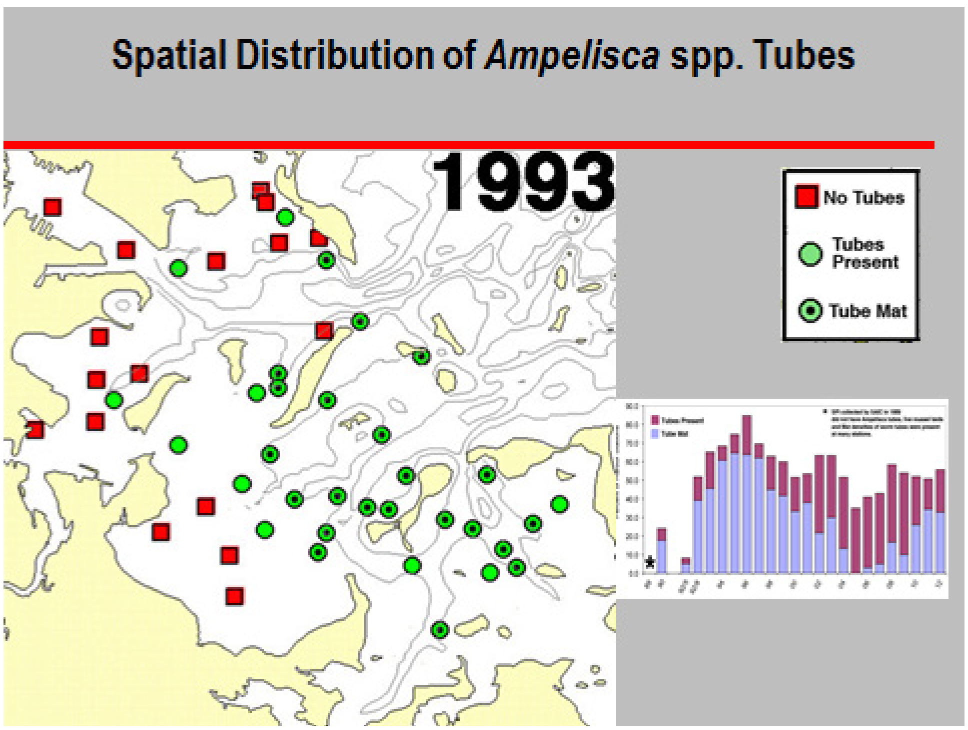
Ampelisca spp. Tubes Present vs. Grab Abundance

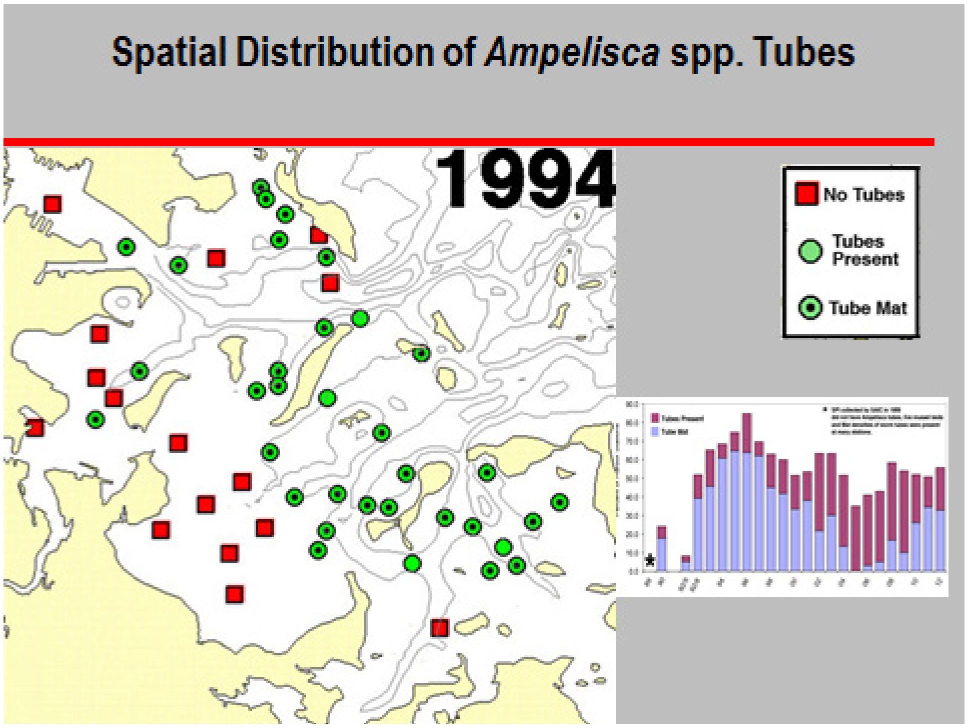


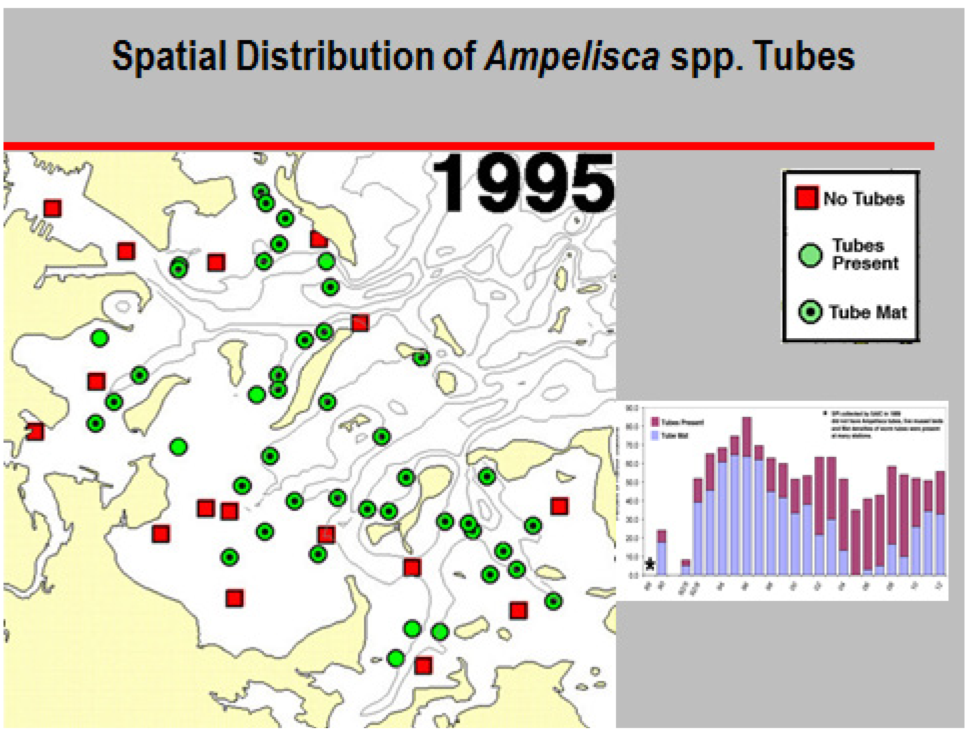
SPI says no Mat, Grab says Mat present

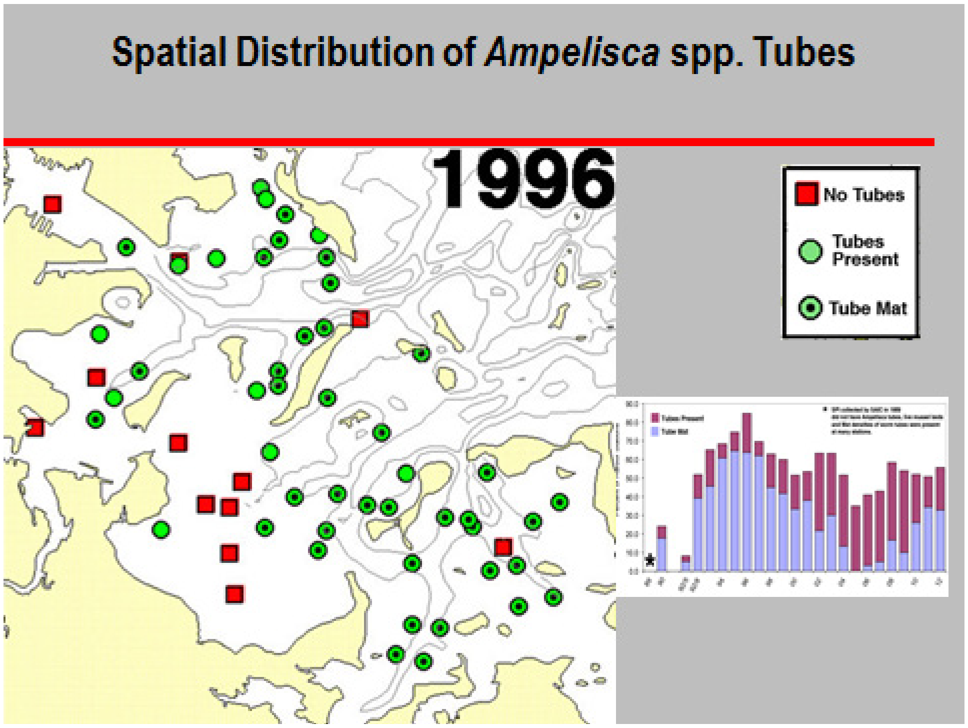


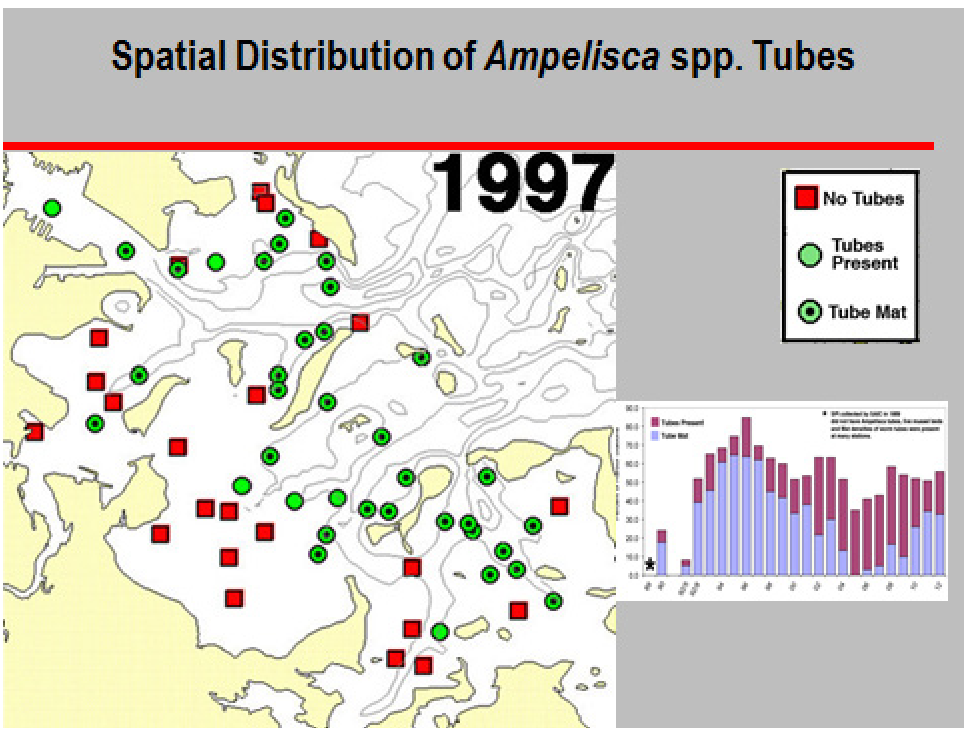

Spatial Distribution of *Ampelisca* spp. Tubes
1990
No Tubes
Tubes Present
Tube Mat

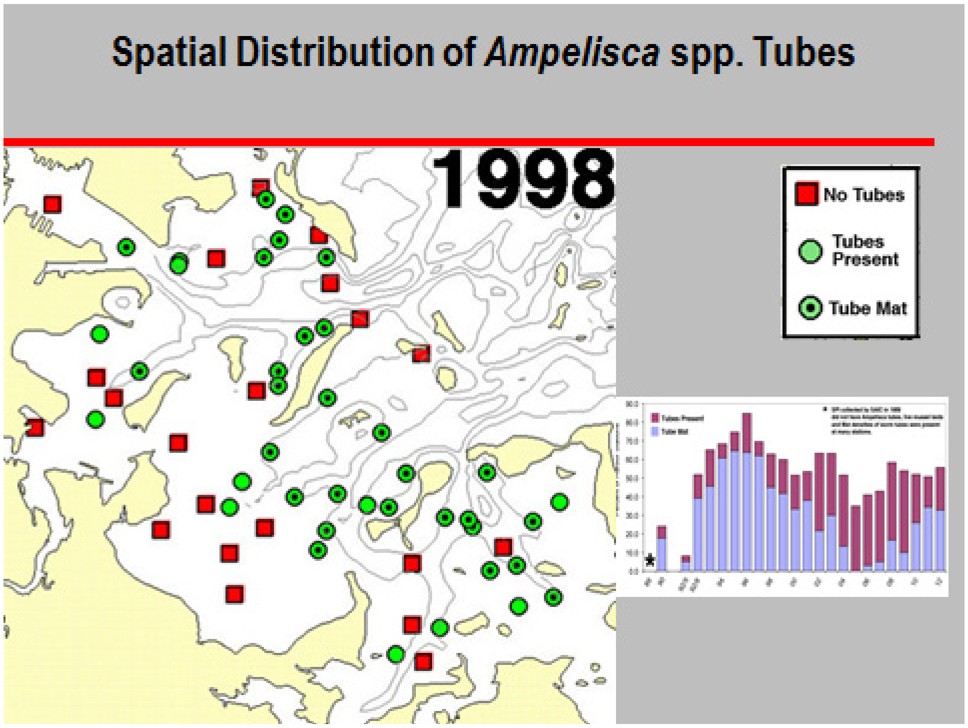

Spatial Distribution of *Ampelisca* spp. Tubes
1993
No Tubes
Tubes Present
Tube Mat

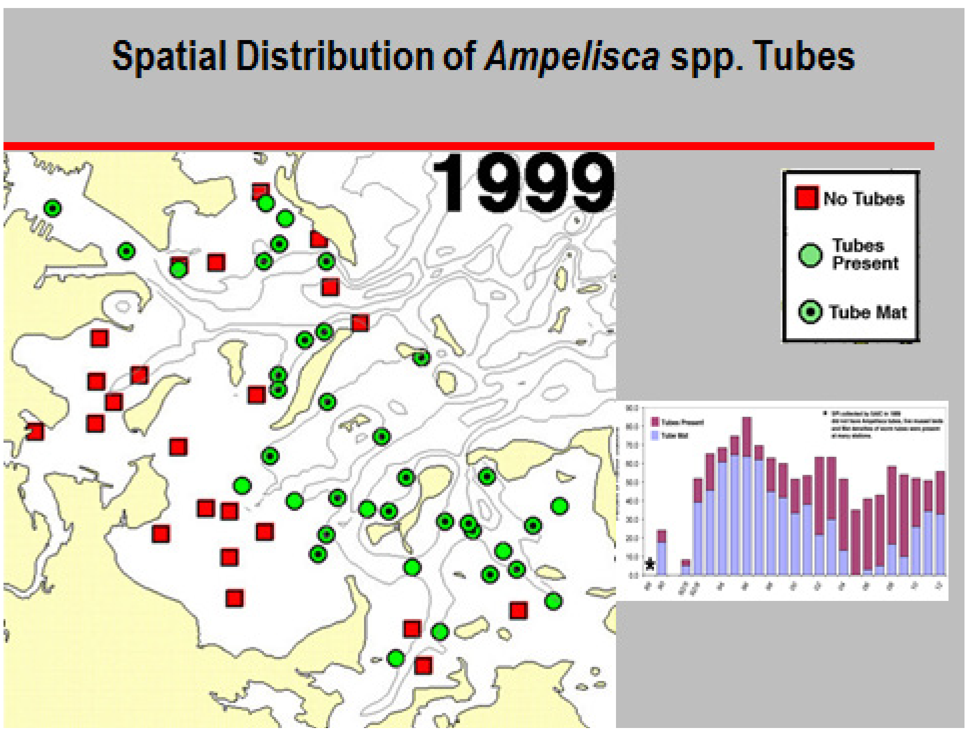

Spatial Distribution of *Ampelisca* spp. Tubes
1994
No Tubes
Tubes Present
Tube Mat

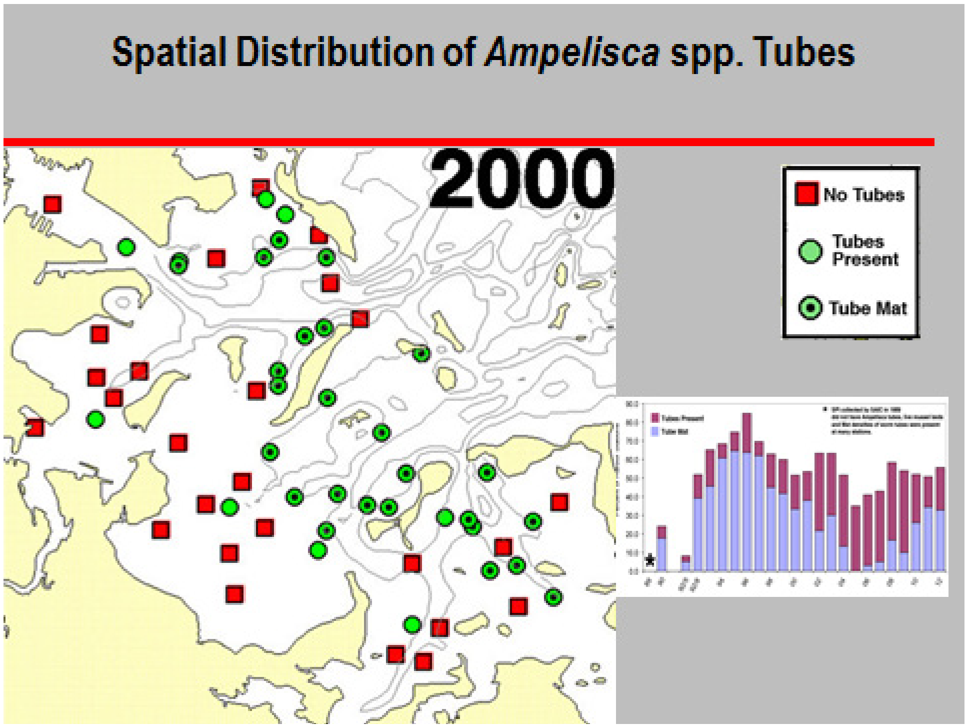

Spatial Distribution of *Ampelisca* spp. Tubes
1995
No Tubes
Tubes Present
Tube Mat

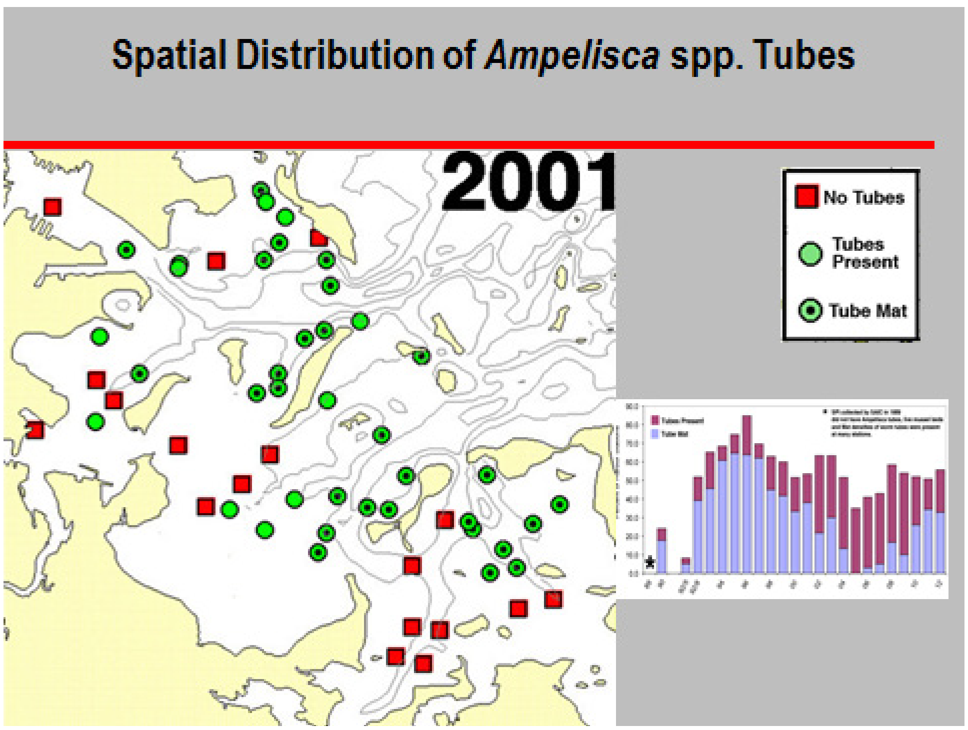

Spatial Distribution of Ampelisca spp. Tubes
1996
No Tubes
Tubes Present
Tube Mat

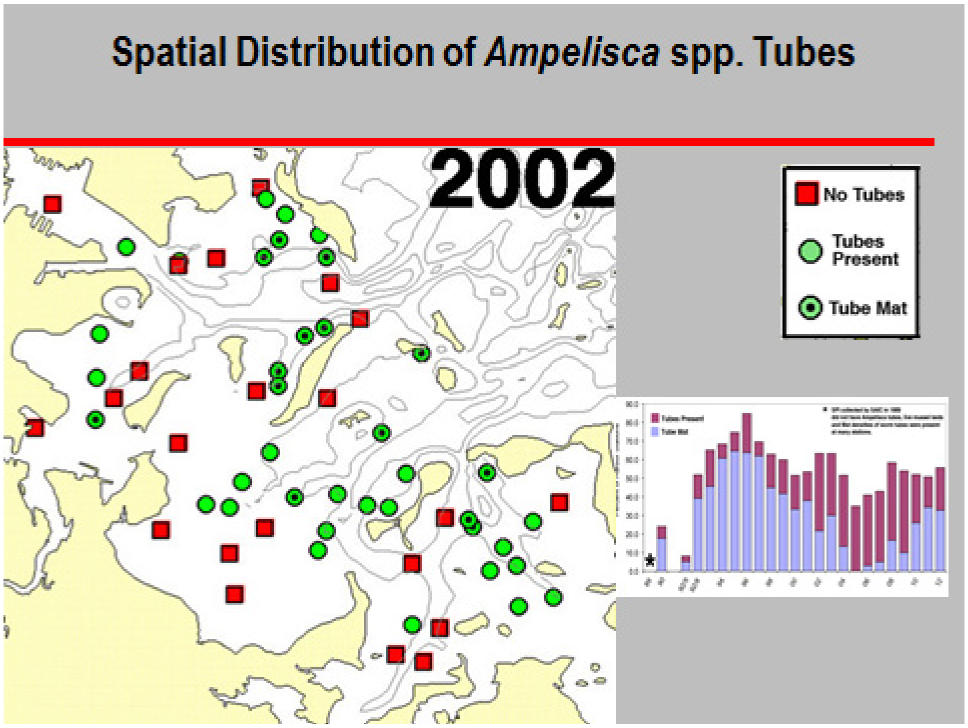

Spatial Distribution of Ampelisca spp. Tubes
1997
No Tubes
Tubes Present
Tube Mat

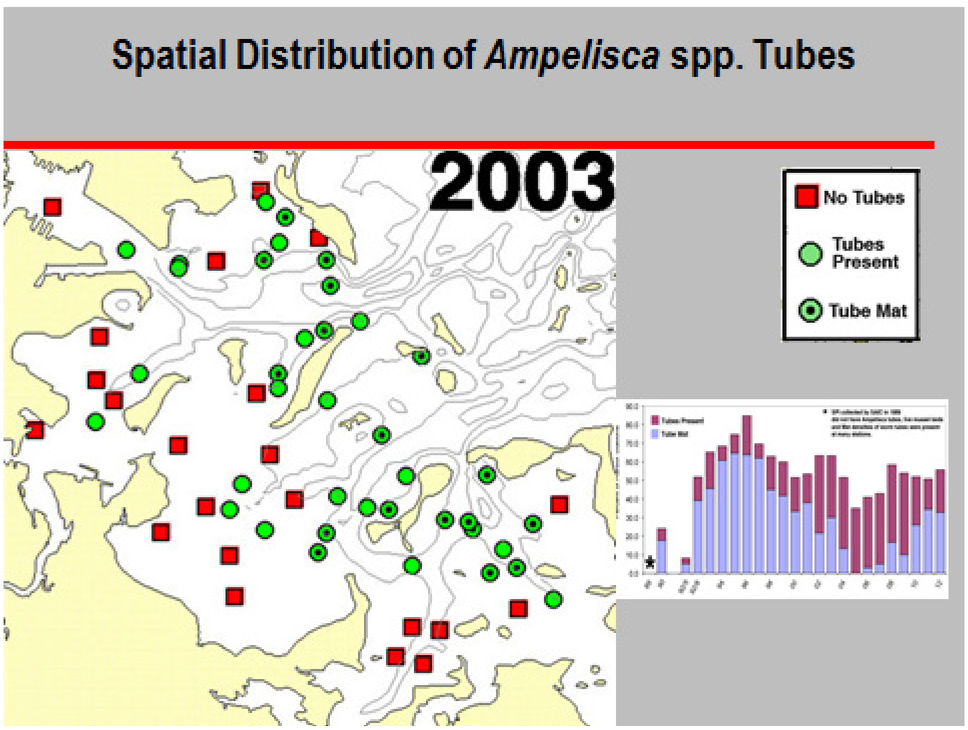

Spatial Distribution of *Ampelisca* spp. Tubes
1998
No Tubes
Tubes Present
Tube Mat

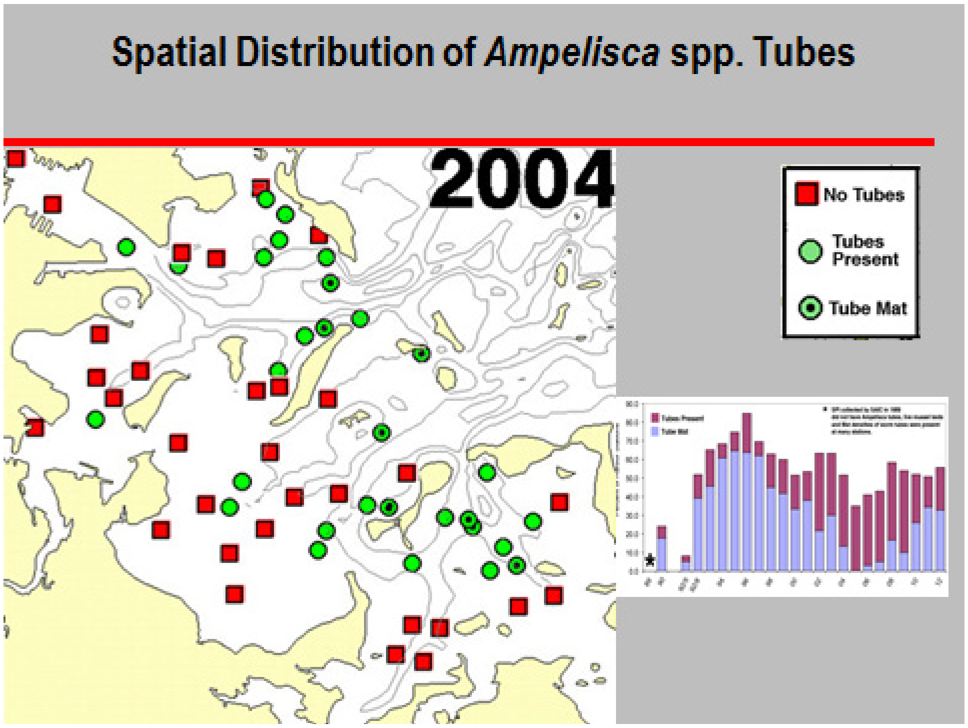

Spatial Distribution of *Ampelisca* spp. Tubes
1999
No Tubes
Tubes Present
Tube Mat

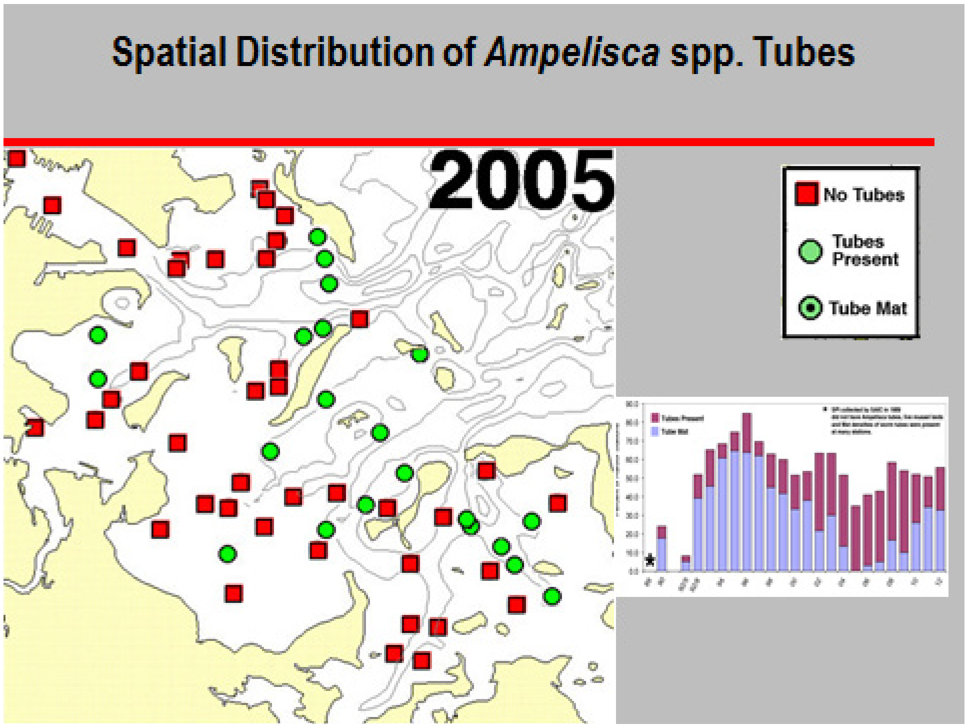

Spatial Distribution of *Ampelisca* spp. Tubes
2000
No Tubes
Tubes Present
Tube Mat

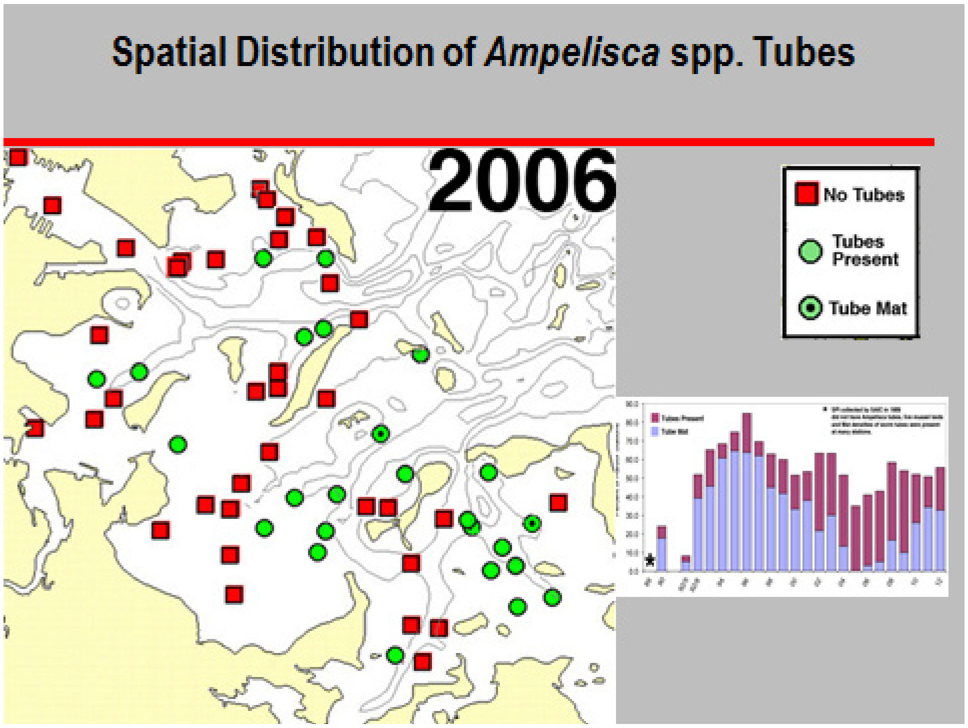

Spatial Distribution of *Ampelisca* spp. Tubes
2001
No Tubes
Tubes Present
Tube Mat

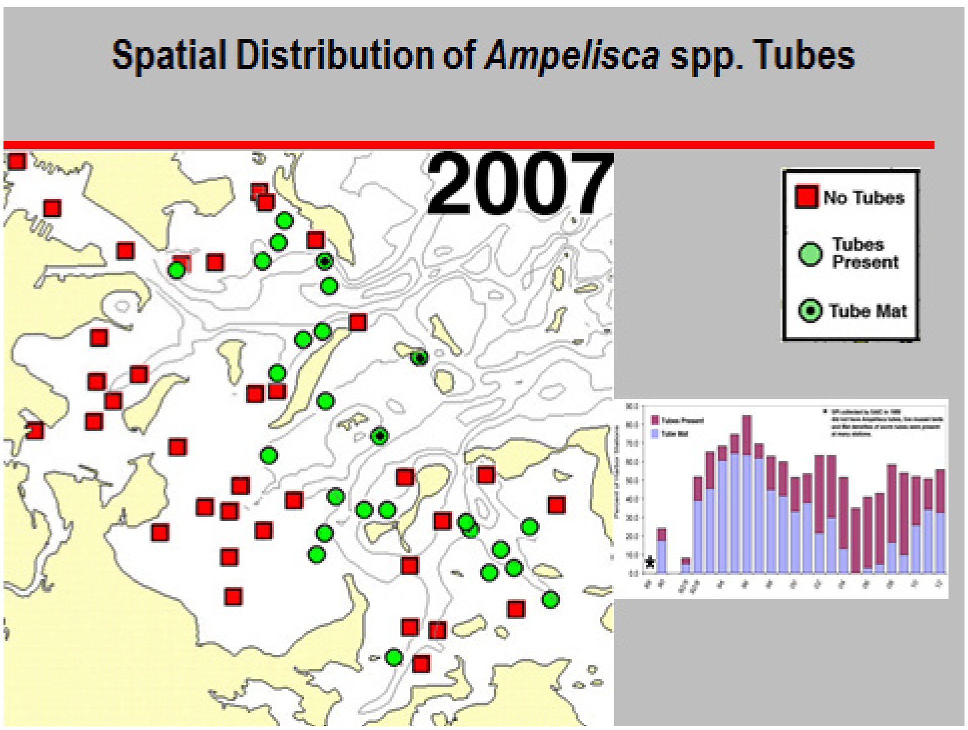

Spatial Distribution of *Ampelisca* spp. Tubes
2002
No Tubes
Tubes Present
Tube Mat

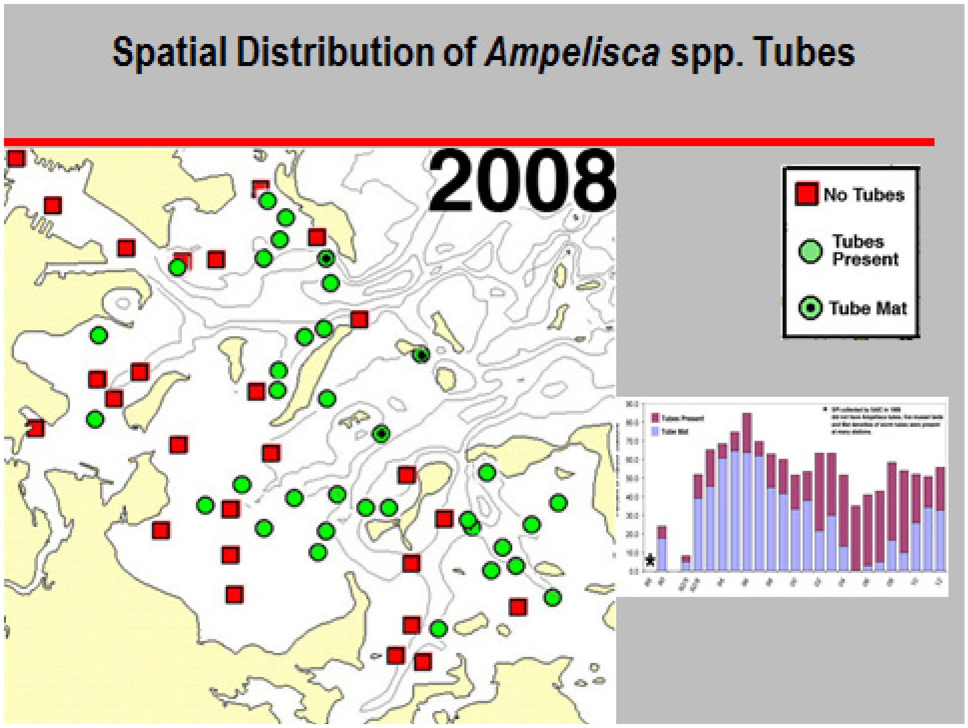

Spatial Distribution of *Ampelisca* spp. Tubes
2003
No Tubes
Tubes Present
Tube Mat

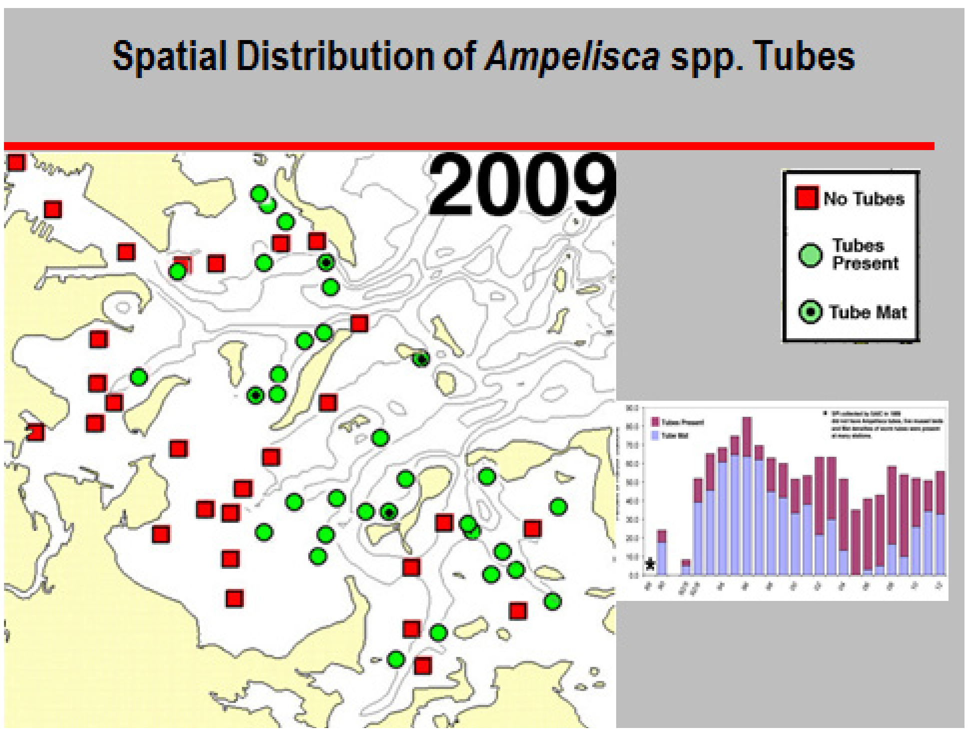

Spatial Distribution of *Ampelisca* spp. Tubes
2004
No Tubes
Tubes Present
Tube Mat

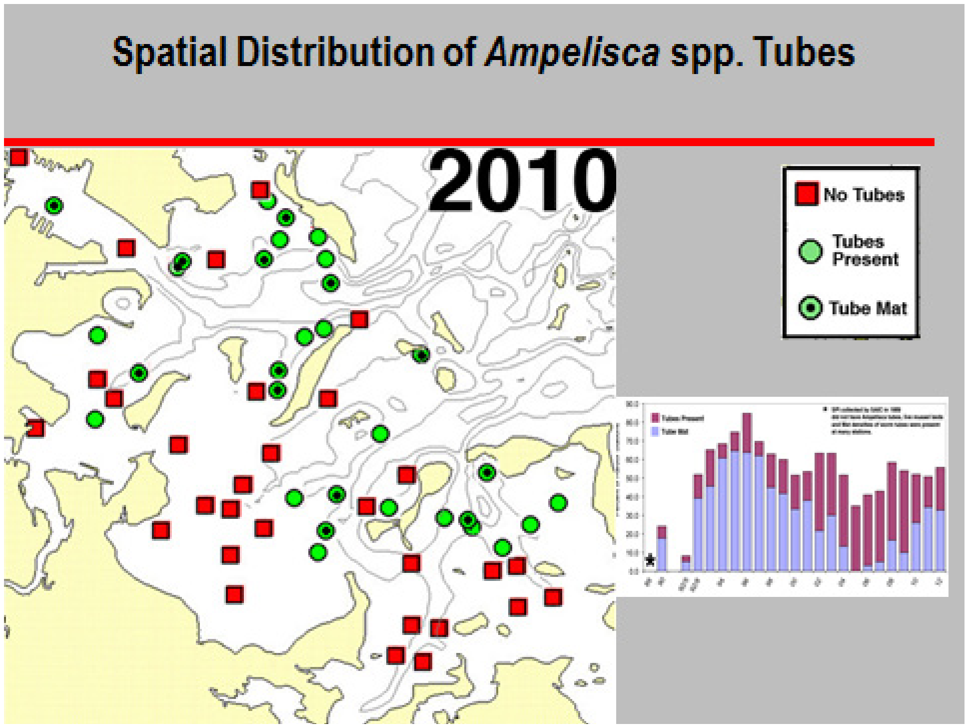

Spatial Distribution of *Ampelisca* spp. Tubes
2005
No Tubes
Tubes Present
Tube Mat

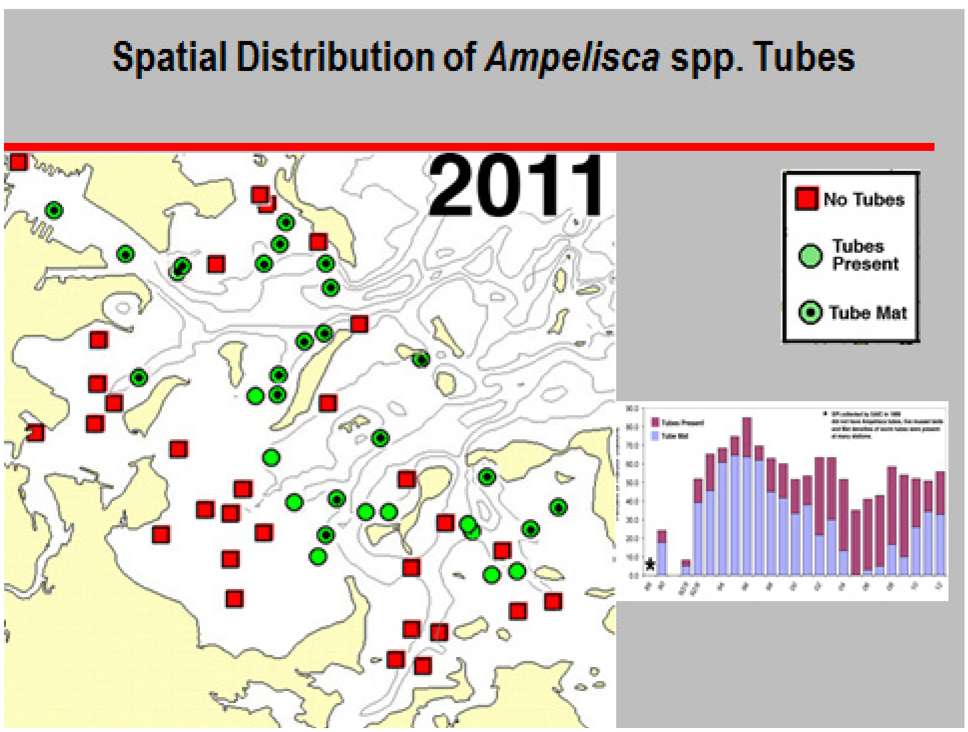

Spatial Distribution of *Ampelisca* spp. Tubes
2006
No Tubes
Tubes Present
Tube Mat

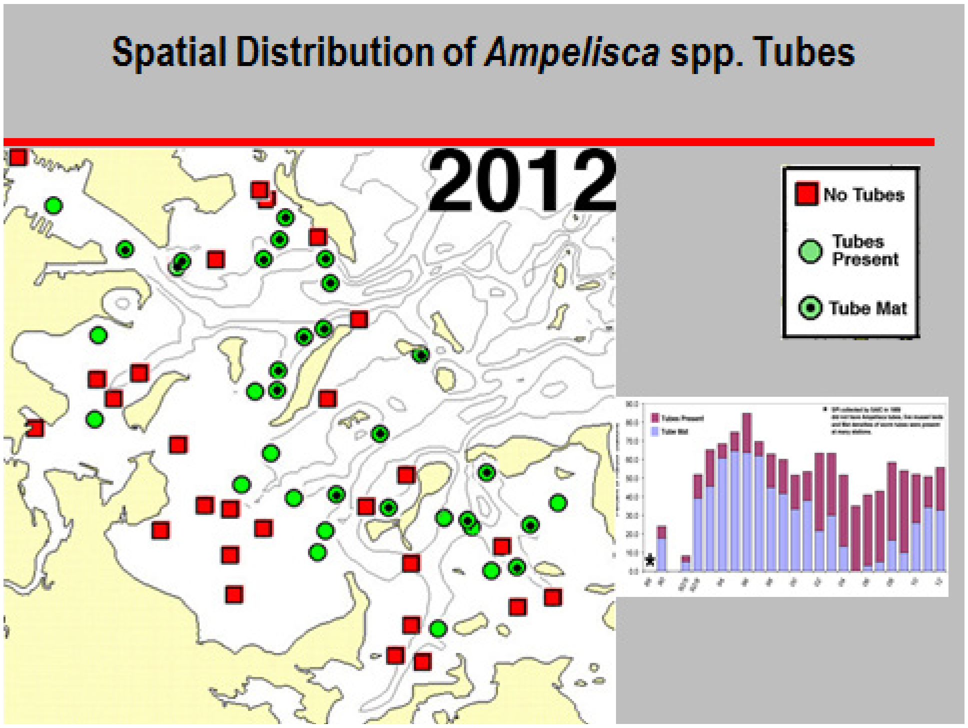

Spatial Distribution of *Ampelisca* spp. Tubes
2007
No Tubes
Tubes Present
Tube Mat

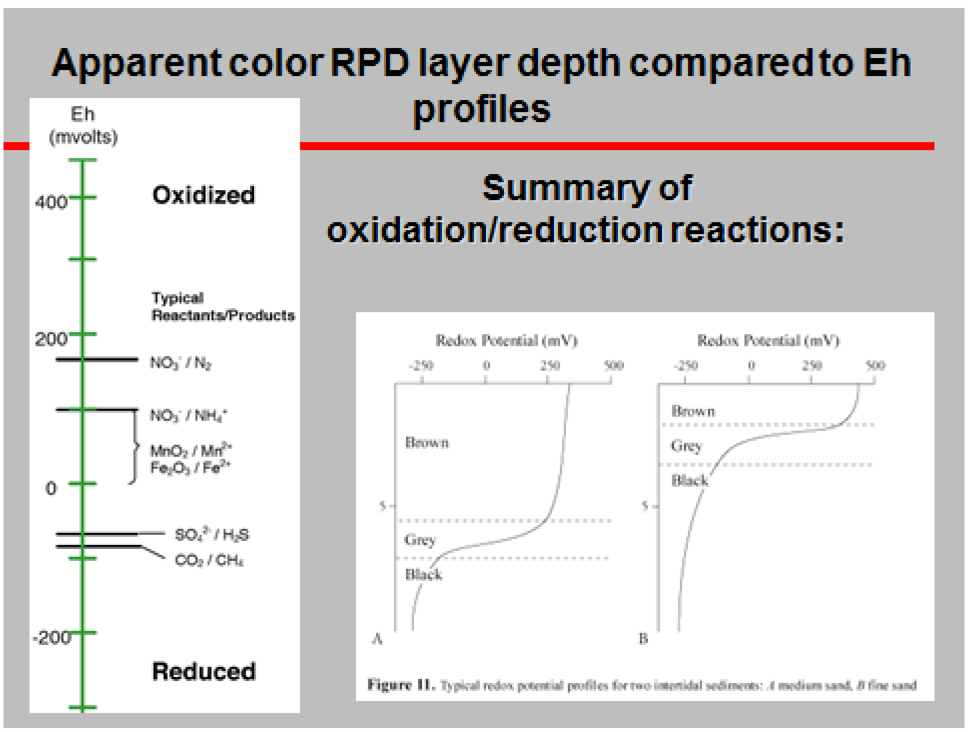

Spatial Distribution of Ampelisca spp. Tubes
2008
No Tubes
Tubes Present
Tube Mat

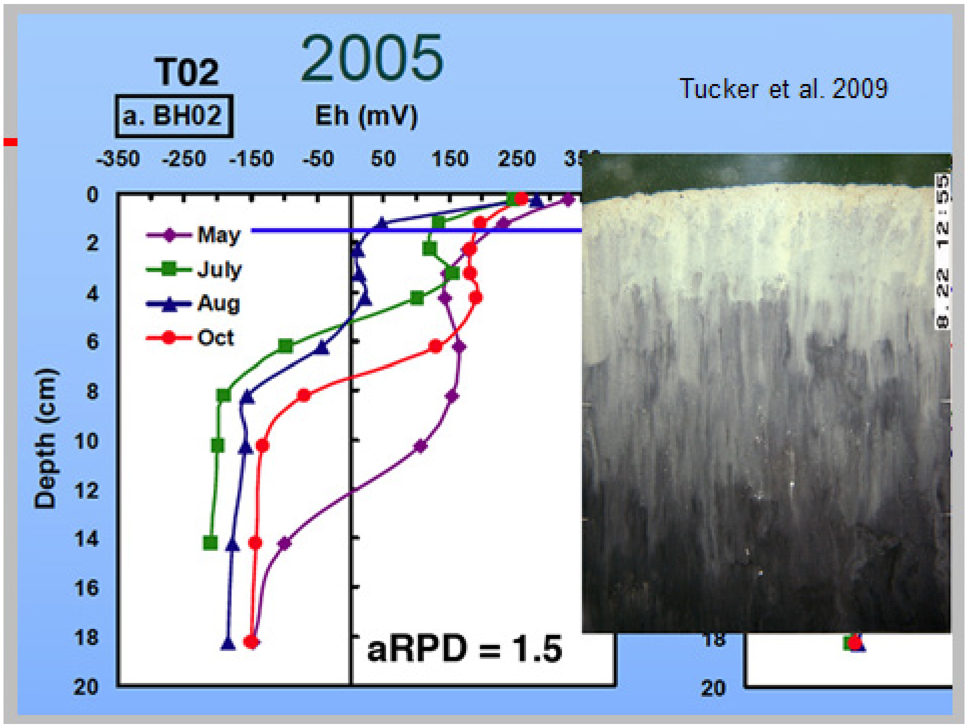

Spatial Distribution of Ampelisca spp. Tubes
2009
No Tubes
Tubes Present
Tube Mat

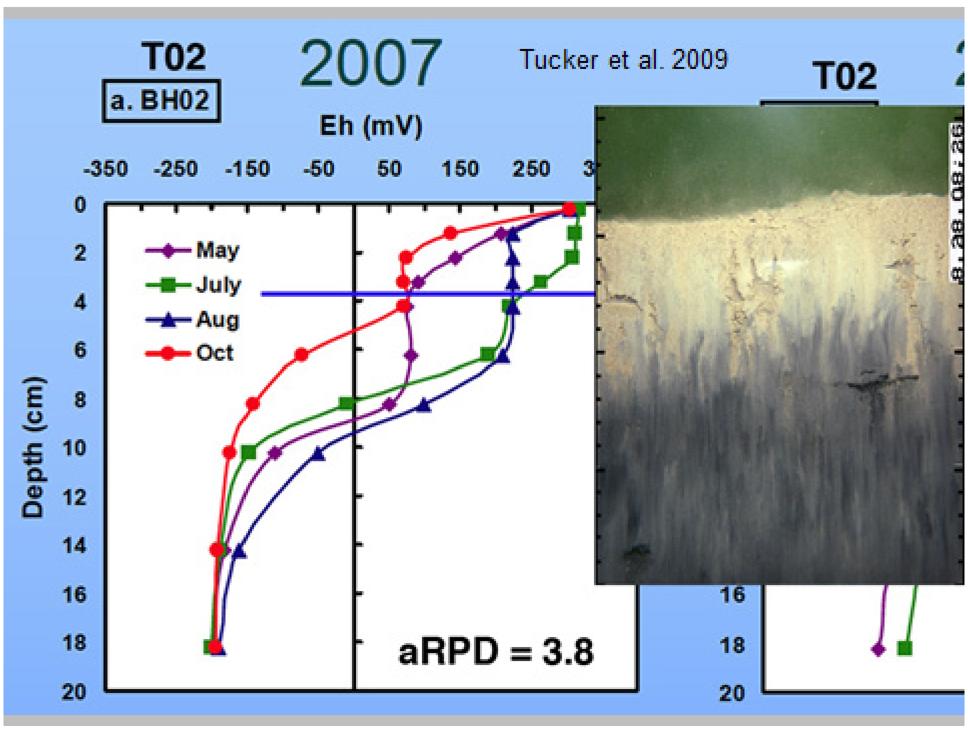

Spatial Distribution of *Ampelisca* spp. Tubes
2010
No Tubes
Tubes Present
Tube Mat

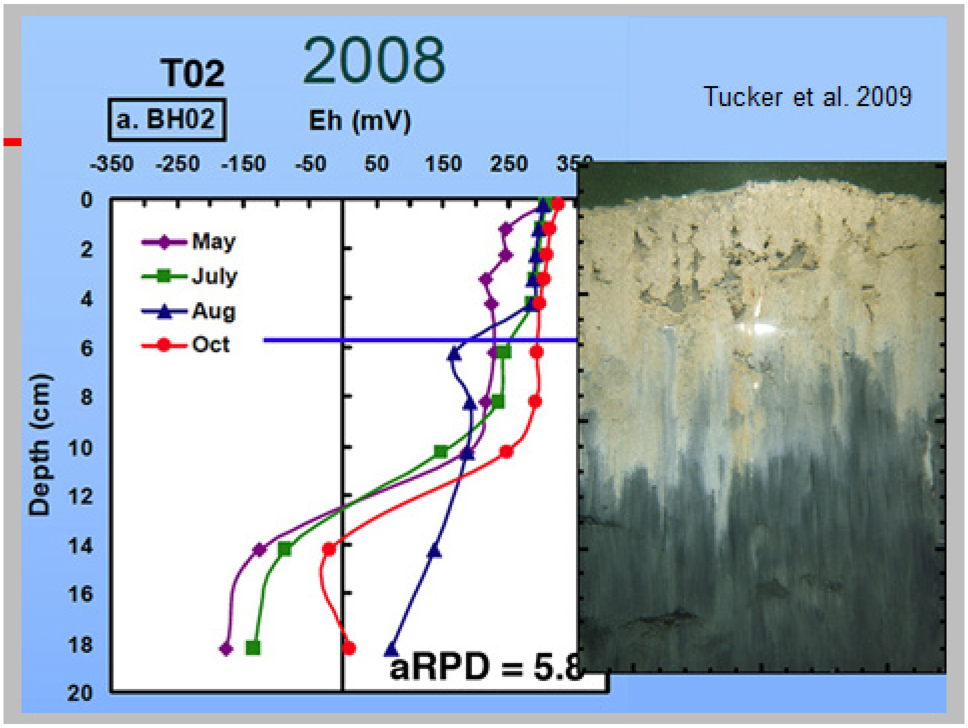

Spatial Distribution of *Ampelisca* spp. Tubes
2011
No Tubes
Tubes Present
Tube Mat


Spatial Distribution of *Ampelisca* spp. Tubes
2012
No Tubes
Tubes Present
Tube Mat


Apparent color RPD layer depth compared to Eh profiles
Eh (mvolts)
400
200
0
-200
Oxidized
Typical Reactants/Products
NO_3^- / N_2
NO_3^- / NH_4^+
MnO_2 / Mn^{2+}
Fe_2O_3 / Fe^{2+}
SO_4^{2-} / H_2S
CO_2 / CH_4
Reduced
Summary of oxidation/reduction reactions:
Redox Potential (mV)
-250 0 250 500
Brown
Grey
Black
A
B
Figure 11. Typical redox potential profiles for two intertidal sediments: A medium sand, B fine sand


T02
2005
Tucker et al. 2009
a. BH02
Eh (mV)
-350 -250 -150 -50 50 150 250
Depth (cm)
May
July
Aug
Oct
aRPD = 1.5


T02
2007
Tucker et al. 2009
a. BH02
Eh (mV)
-350 -250 -150 -50 50 150 250
Depth (cm)
May
July
Aug
Oct
aRPD = 3.8
T02



Summary for Harbor

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

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

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