Boston Harbor Benthic Monitoring Report: 2013 Results

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EXECUTIVE SUMMARY

Boston Harbor was once considered among the most degraded harbors in the country. Direct discharge of wastewater with limited treatment into the harbor had affected both water quality and biological conditions. Both the EPA and the Federal Court prevailed upon the Commonwealth of Massachusetts to take actions to improve these conditions substantially and the Massachusetts Water Resources Authority (MWRA) was created in response. In 1985, MWRA initiated a multi-faceted plan to meet these mandates, most significantly including an upgrade to secondary treatment, elimination of sludge disposal into the harbor, and relocation of wastewater discharge through an offshore diffuser located 9.3 mi off Deer Island in Massachusetts Bay. Subsequently, improvements have been made to numerous Combined Sewer Overflows (CSOs) reducing another source of water quality concern.

Sediments and associated benthic infauna reflect cumulative water quality conditions. In order to evaluate changes to the ecosystem, particularly the benthic community, resulting from reductions in contaminated discharges over time, MWRA has conducted benthic monitoring in Boston Harbor on an ongoing basis since 1991. This report provides a summary of the results of the benthic surveys that were conducted in 2013. These include sediment conditions, benthic infauna, and sediment profile imagery.

Overall, the improvements in wastewater treatment and moving the outfall offshore have led to improvements in water quality and benthic habitat quality within Boston Harbor by reducing organic and nutrient loading and favoring processes that enhance bioturbation or the mixing of sediment by organisms. At one time, the sediment organic matter in Boston Harbor was derived primarily from sewage but since changes in wastewater treatment and disposal were initiated, marine-derived organic material has been prevalent in the sediment. The infaunal community has responded to this change and subsequent biological activity has led to more aerobic and 'healthy' sediment conditions. Physical and biological properties of the soft substrate in Boston Harbor in 2013 exhibited minor changes from recent years but were consistent with longer-term trends (Pembroke et al. 2013). Concentrations of both TOC and *Clostridium perfringens*, indicators of organic enrichment and deposition from municipal wastewater discharge, have remained low compared to the levels occurring prior to the offshore diversion.

Community structure measures also continue to point to improving benthic conditions. Since municipal wastewater and sludge discharges have been eliminated from the harbor, total abundance has trended downward, particularly for opportunistic species such as *Capitella capitata*. Species richness, while variable, has trended upward as did evenness (J'), Shannon diversity (H'), and log series alpha diversity. Although abundances of individual taxa, such as the dominants *Ampelisca* spp. and *Polydora cornuta* have varied over time, the infaunal community structure and evidence from sediment profile imaging suggest that these changes relate more to normal physical disturbances than organic stress in the years since wastewater impacts to the Harbor have been reduced. The trends observed in previous years, including reduction of indicators of organic enrichment and increases in species diversity that continued in the 2013 survey are consistent with the recovery of benthic habitats from decades of inadequately treated sewage discharges.

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1. INTRODUCTION

Boston Harbor was once considered among the most degraded harbors in the country. Direct discharge of wastewater with limited treatment into the harbor had affected both water quality and biological conditions. Both the EPA and the Federal Court prevailed upon the Commonwealth of Massachusetts to take actions to improve these conditions substantially and the Massachusetts Water Resources Authority (MWRA) was created in response. In 1985, MWRA initiated a multi-faceted plan to meet these mandates, most significantly including an upgrade to secondary treatment, elimination of sludge disposal into the harbor, and relocation of wastewater discharge through an offshore diffuser located 9.3 mi off Deer Island in Massachusetts Bay. Subsequently, improvements have been made to numerous Combined Sewer Overflows (CSOs).

MWRA has conducted benthic monitoring in Boston Harbor on an ongoing basis since 1991 to evaluate changes to the ecosystem, in particular the benthic community, as contaminated discharges have been reduced over time. This report provides a summary of the results of the benthic surveys that were conducted in 201. These include sediment conditions, benthic infauna, and sediment profile imagery. A quantitative evaluation of the long-term sediment monitoring data collected since 1991 is provided in the 2007 harbor benthic monitoring report (Maciolek et al. 2008).

2. METHODS

Benthic monitoring in Boston Harbor continued at the same stations that have been surveyed since 1991. No changes were made to this program in the 2010 revision to the Ambient Monitoring Plan (MWRA 2010). This survey comprises three components: sediment conditions (grain size, total organic carbon, and *Clostridium perfringens*), benthic infauna, and sediment profile imaging (SPI).

Methods used to collect, analyze, and evaluate all sample types remain largely consistent with those reported by Pembroke et al. (2012) for previous monitoring years. Detailed descriptions of the methods are contained in the Quality Assurance Project Plan (QAPP) for Benthic Monitoring 2011–2014, Revision 1 (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 9 stations in August, 2013 (Figure 1). Soft-bottom stations were sampled for grain size composition, total organic carbon (TOC), the sewage tracer *Clostridium perfringens*, and benthic infauna. One sediment sample was collected at each station on August 9 and 10, and triplicate infauna samples (of which two were analyzed) were collected on August 28.

SPI samples were collected in triplicate at 61 stations on August 13-15, 2013 (Figure 1).

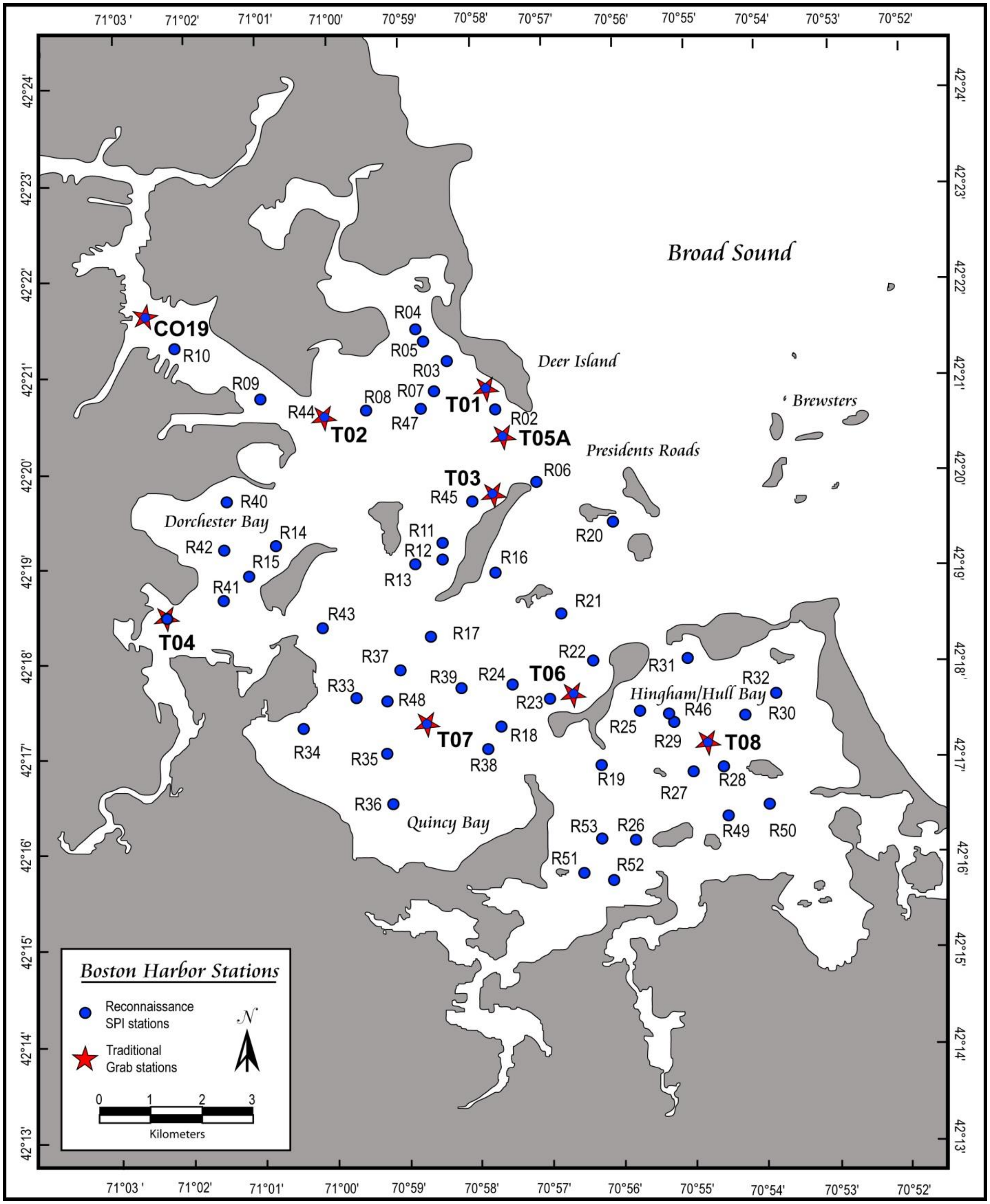

Figure 1. Locations of soft-bottom sampling and sediment profile imaging stations for 2013.

2.2 Laboratory Methods

Laboratory methods for benthic infauna and SPI image analyses were consistent with the QAPP (Nestler et al. 2013). Analytical methods for grain size, TOC, and *Clostridium perfringens* are described in (Constantino et al. 2012).

2.3 Data Handling, Reduction, and Analysis

All benthic data were extracted directly from the HOM database and imported into Excel. Data handling, reduction, and graphical presentations were performed in Excel or SAS (version 9.2), as described in the QAPP (Nestler et al. 2013) or in Maciolek et al. (2008). Data are presented graphically as means (averages per station) unless otherwise noted. Shannon-Weiner (H') was calculated using log base 2. 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.

Temporal patterns in the infaunal community and sediment chemistry were evaluated in the context of the four discharge periods described by Taylor (2006) offset by one year to allow for a lag in response time.

3. RESULTS AND DISCUSSION

3.1 Sediment Conditions

Sediment conditions in Boston Harbor were characterized by three parameters measured during 2013 at each of the nine sampling stations: (1) grain size (gravel, sand, silt, and clay), (2) total organic carbon, and (3) *Clostridium perfringens* (Table 1).

Grain Size. Surface sediments at the nine stations sampled during 2013 included a wide range of sediment types (Table 1, Figure 2). Grain size profiles ranged from predominantly sand (i.e., T08) to almost entirely silt and clay (i.e., C019 and T04); with most stations having mixed sediments ranging from silty-sand (i.e., T01, T05A) to sandy-silt (i.e., T03, T07). The grain size composition of the sediments in 2013 remained consistent with results reported in prior years, with T01 (just west of Deer Island) and T02 (at the mouth of the Inner Harbor) exhibiting the largest fluctuations in fine sediments over the years (Figure 3).

Table 1. 2013 monitoring results for sediment condition parameters.

Parameter	C019	T01	T02	T03	T04	T05A	T06	T07	T08
Clostridium perfringens, not normalized	14,000	1,300	4,200	5,900	6,700	800	2,300	11,000	130
*Clostridium perfringen*s (cfu/g dry/%fines)	149.46	62.59	78.61	89.99	74.5	32.87	67.63	171.53	56.28
Total Organic Carbon (%)	1.7	0.6	0.8	1.6	2.1	0.4	1.0	1.8	0.2
Gravel (%)	0.6	5.7	0	2.4	0	0	2.6	8.1	2.1
Sand (%)	5.7	73.5	46.6	32.1	10.1	75.7	63.4	27.8	95.6
Silt (%)	50.0	11.0	30.0	36.3	53.8	14.5	17.8	33.3	2.2
Clay (%)	43.7	9.8	23.4	29.3	36.1	9.8	16.3	30.8	0.1
Percent Fines (Silt + Clay)	93.7	20.8	53.4	65.6	89.9	24.3	34.0	64.1	2.3

Total Organic Carbon. Concentrations of total organic carbon (TOC) in 2013 also remained similar to values reported in prior years, although T01, T02, T04, and C019 have exhibited slight declines over the last few years (Figure 4). Concentrations of TOC track closely to percent fine sediments (silt + clay), with higher TOC values generally associated with higher percent fines (Figures 3 and 4). During 2013, Stations T04 and C019 had among the highest concentrations of TOC as has been typically observed, but Stations T03 and T07 (with percent fines of 64-66%) also had somewhat elevated TOC values (Table 1, Figure 4). Station T04 is located in a depositional area where contaminants entering Boston Harbor are known to accumulate (Wallace et al. 1991; Stolzenbach and Adams 1998). As in prior years, the lowest TOC concentrations for 2013 were reported at Station T08.

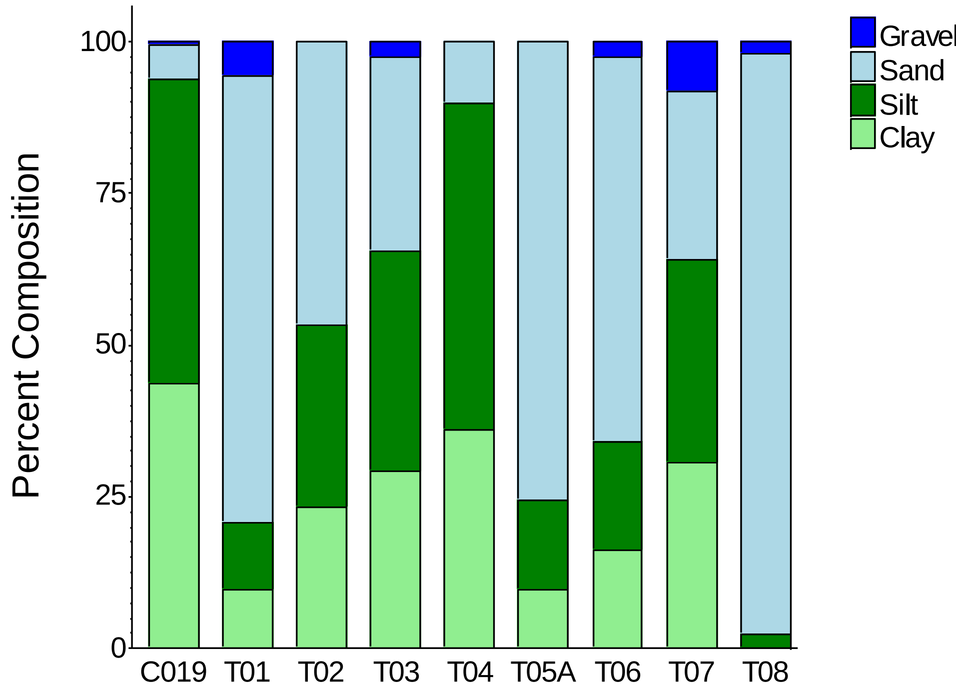

Figure 2. 2013 monitoring results for sediment grain size.

***Clostridium perfringens*.** Spores of *Clostridium perfringens*, an anaerobic bacterium found in the intestinal tract of mammals, provide a sensitive tracer of effluent solids. Abundances of *C. perfringens* (normalized to percent fines) during 2013 were highest at Station C019 in the Inner Harbor. The highest values in the Outer Harbor occurred at Station T07 and the lowest values were found at station T08 (Table 1). Abundances at T04, a depositional site in Savin Hill Cove, had declined for several years (2008-2012) but in 2013, abundances were about average of those observed in that time frame (Figure 5). *C. perfringens* concentrations were comparable to those reported from 2010 through 2012, and below the elevated levels at this station from 2007 through 2009. *C. perfringens* counts at other Harbor stations have remained consistently below historical averages since around 1999 (Figure 5).

Taylor (2006) defined time periods related to various changes in MWRA's management of wastewater and sludge treatment and discharges. Significant events that had a likelihood of affecting the harbor benthic community included ending the discharge of sludge in 1991 (end of Period I); opening of the new primary treatment plant at Deer Island (1995) and its upgrade to secondary treatment between 1997 and 2001 (Period II); implementation of the transfer of wastewater from Nut Island to Deer Island, ending the Nut Island discharge in 1998 (onset of Period III); and implementation of the offshore outfall in 2000 (onset of Period IV).

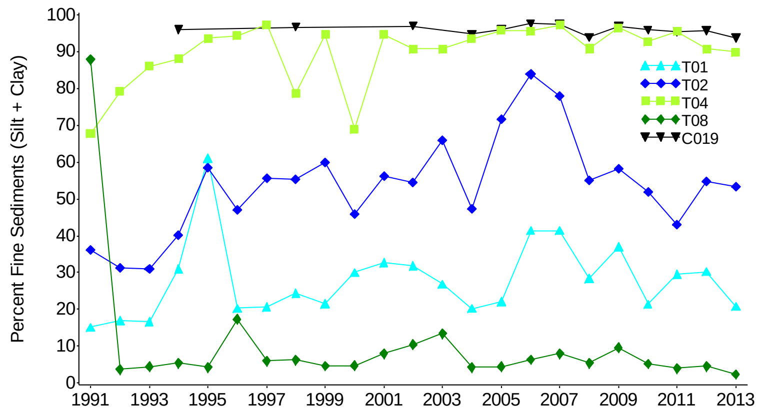

Figure 3. Mean percent fine sediments at five stations in Boston Harbor, 1991 to 2013.

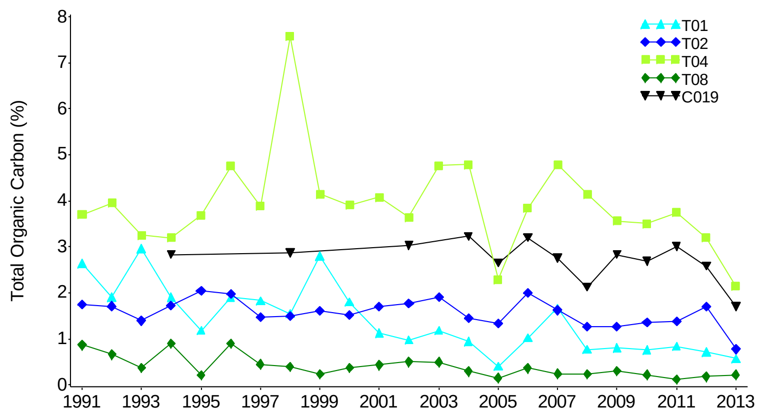

Figure 4. Mean concentrations of TOC at five stations in Boston Harbor, 1991 to 2013.

Results during 2013 for grain size, TOC, and *C. perfringens* in Boston Harbor sediments, are consistent with monitoring results from prior Period IV years (Maciolek et al. 2008, 2011; Pembroke et al. 2012, 2013). Concentrations of both TOC and *C. perfringens* at the traditional harbor stations (T01 to T08) have remained lower during the past decade, than those reported during the 1990s (Figures 6 and 7). These findings are consistent with changes documented in the Harbor following improvements to the collection, treatment and disposal of wastewater as part of the Boston Harbor Project (Maciolek et al. 2008, Taylor 2006).

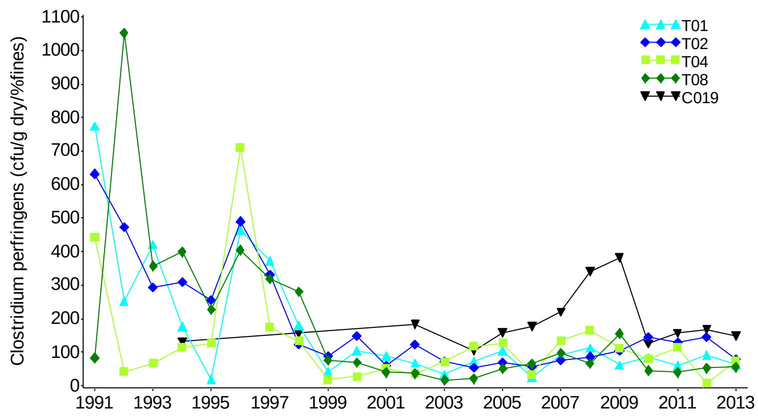

Figure 5. Mean concentrations of *Clostridium perfringens* at five stations in Boston Harbor, 1991 to 2013.

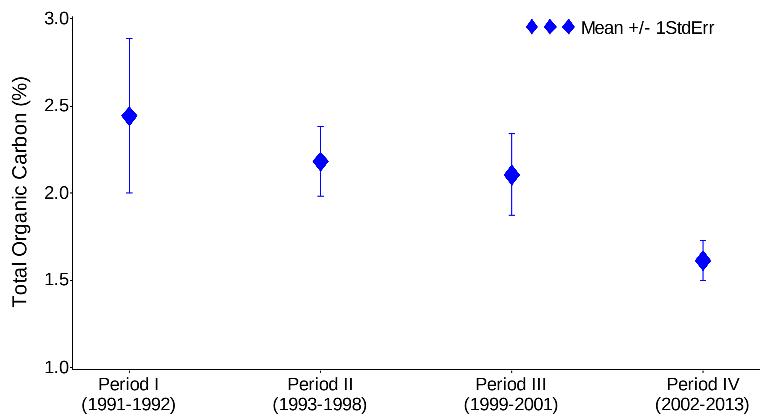

Figure 6. Comparison of TOC across four discharge periods (offset by one year) at Boston Harbor stations (T01-T08) from 1992 to 2013 (1991 excluded).

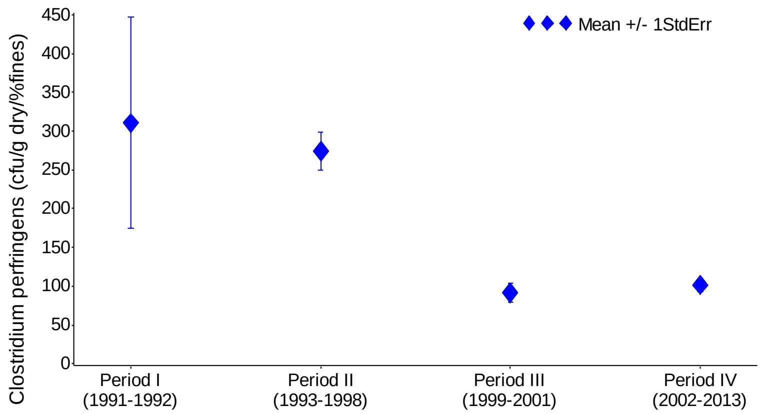

Figure 7. Comparison of *Clostridium perfringens* across four discharge periods (offset by one year) at Boston Harbor stations (T01-T08) from 1992 to 2013 (1991 excluded).

3.2 Benthic Infauna

3.2.1 Community Parameters

A total of 38,034 infaunal organisms were counted from the 18 samples in 2013. Organisms were classified into 147 discrete taxa; 128 of those taxa were species-level identifications, and these species richness values are consistent with values observed in the harbor in recent years. 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 2).

Table 2. 2013 mean infaunal community parameters by station.

Station	Total Abundance	Number of Species	Pielou's Evenness (J')	Shannon-Wiener Diversity (H')	Log-series alpha
C019	2,521.0	29	0.54	2.62	4.66
T01	783.5	29.5	0.58	2.85	6.14
T02	5,105.5	49	0.51	2.86	7.56
T03	3,292.5	49.5	0.52	2.94	8.28
T04	490.5	13	0.22	0.83	2.48
T05A	3,152.0	51	0.60	3.38	8.72
T06	2,085.0	39.5	0.59	3.12	6.96
T07	654.5	35	0.59	3.03	8.54
T08	932.5	49	0.75	4.22	11.44

Mean abundance values reported for 2013 varied from values in 2012 by 40% or more at more than half of the stations (Pembroke et al. 2012). Abundances in 2013 were about average for the post-offshore diversion period and relatively low (but within the range of abundances observed) compared to pre-diversion values (Figure 8). Most of the species that dominated (contributing ≥ 2.5% of the total abundance) the infauna at these stations in 2012 continued to do so in 2013 (Table 3) although the rank order changed and abundances of three notable taxa dropped below the 2.5% threshold (*Ampelisca* spp., *Mediomastus californiensis*, and *Tharyx* spp.). Two species of oligochaetes and five species of polychaetes were among the most abundant taxa in 2013. Abundance of amphipods in the genus *Ampelisca* declined dramatically compared to 2012 and they were no longer among the dominants. All dominant taxa in 2013 have previously been among the most abundant in the harbor. Certain spatial patterns of abundance appeared to be consistent with previous years; T04, T07, and C019 continued to support the lowest abundances (Table 2). As previously observed, Stations T02 and T03 supported the highest abundances among the harbor stations. Abundances at Station T05A, unusually low in 2012, increased again in 2013 to levels similar to those observed in 2011. High abundances at Station T06 in 2012 declined to more typical levels in 2013, largely as a result of reductions in *Ampelisca* abundances.

Temporally, benthic infaunal abundance in the harbor has been controlled by a handful of species (Table 4). Although these dominants have varied somewhat over the course of the surveys, four taxa have consistently been among the most abundant organisms. Annual abundances of these species are presented in Figure 9. *Aricidea catherinae* and *Limnodriloides medioporus* have exhibited little interannual variation in abundance whereas both *Polydora cornuta* and *Ampelisca* spp. have exhibited fluctuations of one to two orders of magnitude and abundances of both species are currently low. Both of these species reside in the upper substrate layer so variability could be related to many factors, including changes in organic enrichment, physical forces such as storm events, and reproductive success in a given year as was described in previous reports (Maciolek et al. 2006, 2011).

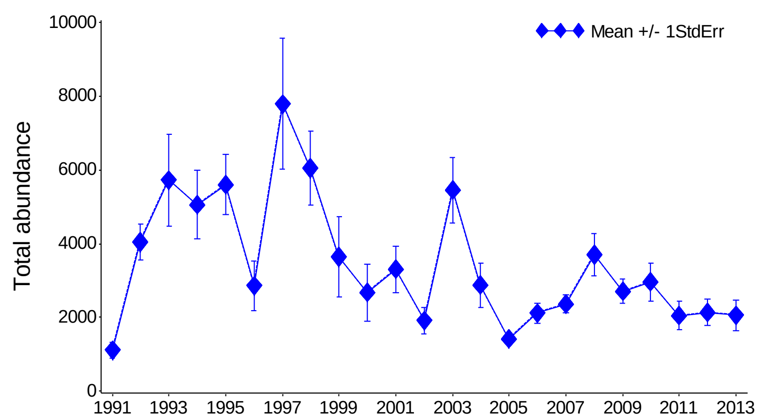

Figure 8. Mean abundance of benthic infauna at eight Boston Harbor stations, 1991-2013.

Table 3. Dominant taxa at eight grab stations in Boston Harbor in August 2013.

Taxon	Total 2013 Abundance (compared with 2012)[a]
Tubificoides intermedius[b]	5,062 (increase)
Polydora cornuta	4,444 (decrease)
Limnodriloides medioporus	4,266 (decrease)
Aricidea catherinae	3,270 (similar)
Scoletoma hebes	3,110 (similar)
Scolelepis bousfieldi	1,817 (double)
Streblospio benedicti	1,268 (similar)

[a] increase or decrease indicates ≥25% change from previous year

[b] previously identified as *T. apectinatus*

Table 4. Mean abundance per sample of dominant taxa during four discharge periods at eight Boston Harbor stations (T01-T08), 1992-2013.

Phylum	Higher Taxon	Family	Species	Period I	Period II	Period III	Period IV	2013
Annelida	Polychaeta	Capitellidae	*Capitella capitata* complex	65.2	88.8	3.4	5.9	4.7
		Cirratulidae	*Tharyx acutus*	50.6	111.8	52.4	59.3	23.9
		Lumbrineridae	*Scoletoma hebes*	3.4	10.5	4.2	62.7	194.4
		Nephtyidae	*Nephtys cornuta*	-	11.4	10.3	216.5	4.6
		Paraonidae	*Aricidea catherinae*	325.0	237.4	204.3	212.1	204.4
		Spionidae	*Polydora cornuta*	525.8	1,053.0	269.6	268.3	277.8
			Scolelepis bousfieldi	-	0.1	<0.1	14.0	113.6
			Streblospio benedicti	236.0	298.6	27.7	55.3	79.3
Annelida	Oligochaeta	Tubificidae	*Limnodriloides medioporus*	484.7	297.9	315.2	235.16	505.2
			Tubificoides intermedius	42.6	101.4	231.2	257.3	316.4
Arthropoda	Amphipoda	Ampeliscidae	*Ampelisca* spp.	354.3	1,698.3	1,205.9	641.1	11.3
		Aoridae	*Leptocheirus pinguis*	29.0	117.4	66.0	92.5	6.9
		Corophiidae	*Corophiidae* spp.	16.1	336.2	23.0	1.6	-
			Crassicorophium bonellii	7.9	217.3	37.3	8.7	0.1
		Isaeidae	*Photis pollex*	11.4	77.0	86.8	37.5	0.1
		Phoxocephalidae	*Phoxocephalus holbolli*	28.0	116.9	125.9	7.3	1.6

[a]Dominants identified as taxa composing 75% of total abundance in each period.

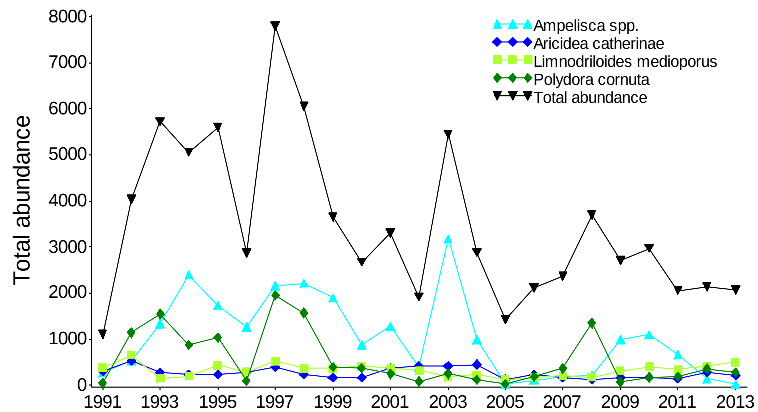

Figure 9. Total abundance of four dominant taxa at eight Boston Harbor stations, 1991-2013.

Patterns of abundance of *Ampelisca* spp. have been of particular interest throughout the past 23 years that Stations T01-T08 have been studied. Previous annual reports on the harbor surveys have related changes in the spatial extent of *Ampelisca* spp. beds and abundances of individual amphipods to changes in organic loading (the period from 1991 through about 1999) and storm events and subsequent recruitment (around 2005 through 2009; Maciolek et al. 2006, 2011). Following a period of low abundances (2005-2008), average abundances of *Ampelisca* at these stations reached moderately high levels from 2009 through 2011, declining in 2012 to levels comparable to those seen in 2005-2008, and in 2013 were similar to the historic lows observed in 2005 (Figure 10). Only three stations (T02, T03, and T05A), all located in the vicinity of the Main Ship Channel, accounted for most of the higher abundances in 2009-2011; however, all of these stations exhibited a decline in 2012 that continued in 2013 (Figure 11). Severe winter storms in 2004-2005 and 2012-2013 have been suggested as a major factor in disturbing *Ampelisca* mats. Maintenance dredging conducted in the nearby President Roads Anchorage and Main Ship Channel in 2004-2005 could also have resulted in disturbances (sedimentation or substrate contact from anchored vessels) to stations T03 and T05A.

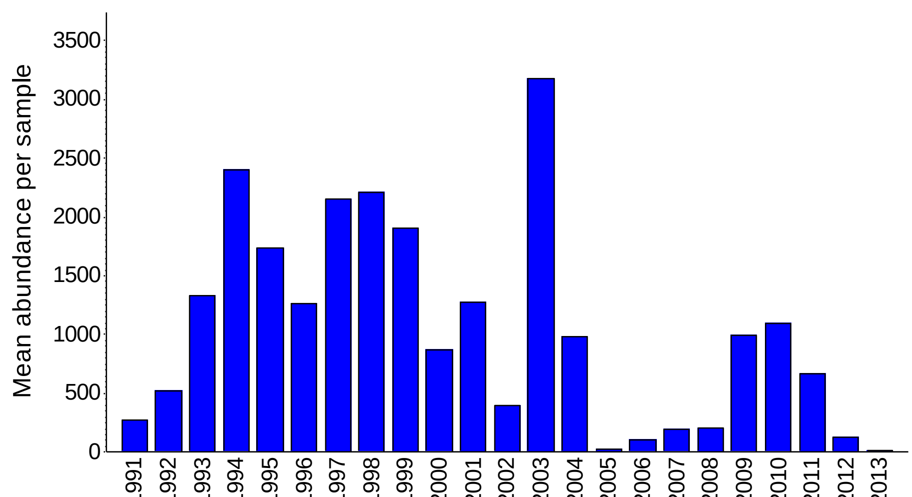

Figure 10. Mean annual abundance of *Ampelisca* spp. averaged over eight Boston Harbor stations, 1991-2013.

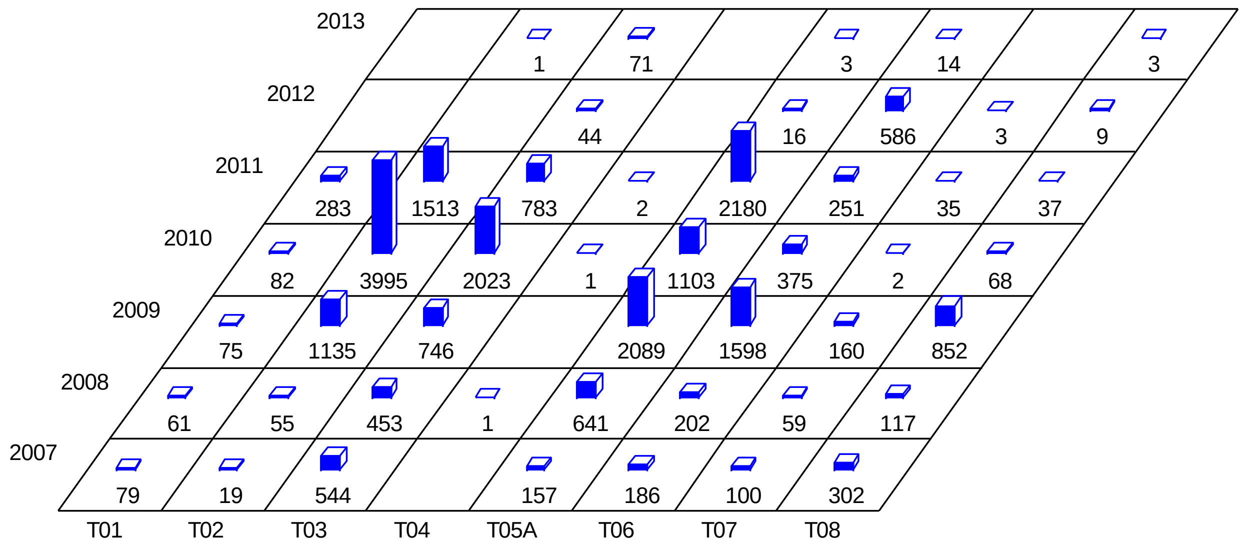

Figure 11. Spatial distribution of *Ampelisca* spp. at eight Boston Harbor stations, 2007-2013.

The numbers of species reported for 2012 ranged from 13 to 51 per station and averaged around 39 species per sample, higher than numbers reported in most years in the 1990s and about average for the 2000s, when species richness exhibited inter-annual variation (Figure 12). Species richness was slightly lower in 2013 than in 2012. As with abundance, species richness followed spatial patterns generally similar to those observed previously. Stations T02, T03, T05A, and T08 typically have exhibited the highest species richness from 2011 through 2013 (Pembroke et al. 2012, 2013). Station T04 has consistently supported the lowest species richness in this time frame. Species richness at T07 in Quincy Bay, which has historically been low, was double the 2011 value in 2013 (Pembroke et al. 2012, 2013).

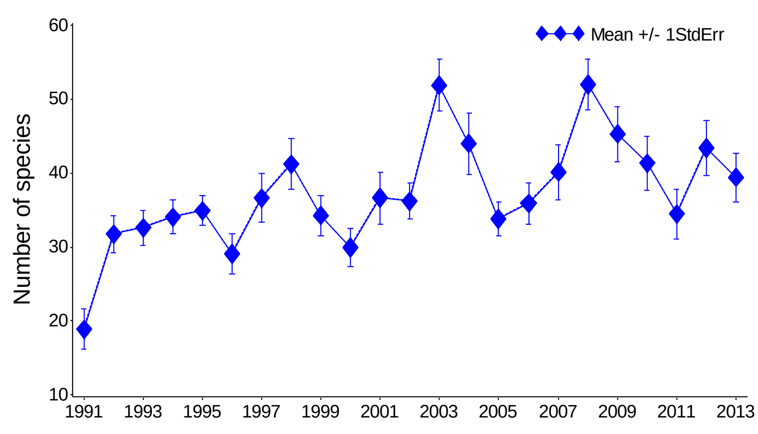

Figure 12. Mean species richness at eight Boston harbor stations, 1991-2013.

After reaching relatively high levels in 2012, measures of community structure including Pielou's evenness and Shannon-Weiner diversity dropped slightly 2013 when averaged across the harbor stations

(Figures 13 and 14). Across the eight stations in the outer harbor, values for these metrics remained within the high range of post-diversion values. In general, spatial patterns for these parameters were similar between the two years suggesting that the integrity of the benthic infaunal community had not changed. Average diversity for the harbor stations, as measured by log-series alpha, dropped in 2013 below the relatively high value seen in 2012 but still remained well above pre-diversion values (1991-2000; Figure 15). The spatial pattern observed in 2013 was generally consistent with that seen in 2010 through and 2012, with the most notable changes at Station T01 where diversity declined in 2013 and at Station T07 where diversity increased (Table 2; Pembroke et al. 2013).

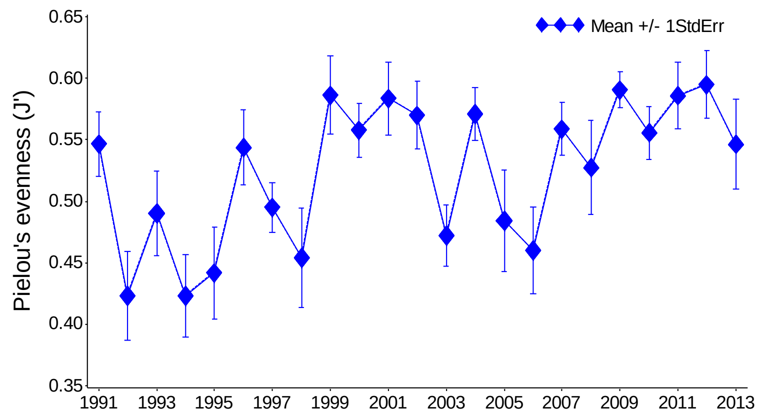

Figure 13. Mean community evenness at eight Boston Harbor stations, 1991-2013.

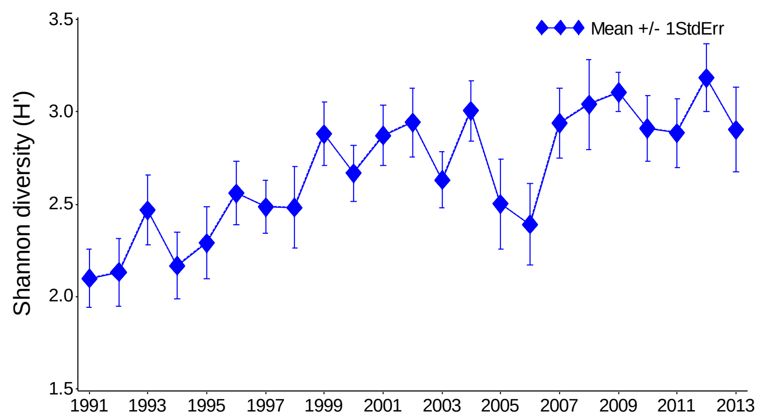

Figure 14. Mean Shannon-Weiner diversity at eight Boston harbor stations, 1991-2013.

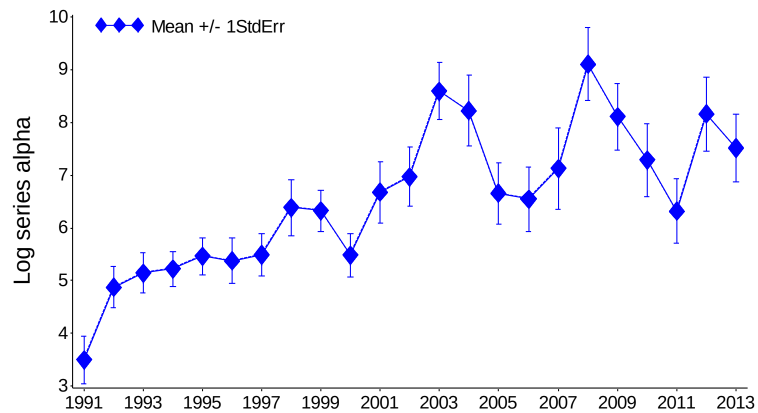

Figure 15. Mean log-series alpha diversity at eight Boston Harbor stations, 1991-2013.

3.2.2 Infaunal Assemblages

Multivariate analyses were used to assess spatial and temporal patterns in the faunal assemblages at the Boston Harbor sampling stations. Replicates within each station exhibited high similarities in community structure. One main assemblage was identified in a cluster analysis of the 18 samples from 2013 and included both replicates from each of 4 stations (Group I: T02, T03, T05A, and T06). Replicates from three other stations (T04, T07, and C019) also each formed their own discrete groups (Figure 16) as they had in 2011 and 2012 (Pembroke et al. 2012, 2013). In addition, community characteristics at stations T01 and T08 differed sufficiently in 2013 to cause their replicates to form discrete groups by station. Average community parameters, including total abundance, number of species, Shannon-Weiner and log-series alpha diversity, were all notably lowest at T04. Total abundance and number of species were highest in the main group. Evenness and the two diversity measures were highest at T08 (Table 2). Evenness and diversity values at the remaining stations exhibited little spatial variation. In Group I, abundance of the oligochaete *Limnodriloides medioporus* was nearly double that of the next most abundant species, but five other species (oligochaete *Tubificoides intermedius* and the polychaetes *Polydora cornuta*, *Aricidea catherinae*, *Scoletoma hebes*, and *Scolelepis bousfieldi*) were all relatively abundant (Table 5). Station T01was grouped with the main group in 2012 and did share several of the dominant species found in the main group in 2013. Low total abundance and species richness differentiated T01 in 2013 however. Station T08 supported a unique community in 2013. Although abundances at this station were low, numbers were fairly equally distributed among a high number of taxa (Table 5) so that Pielou's evenness value was the highest of all stations (Table 2). Species composition differed from Group I and numbers of oligochaetes were very low. Station T07 also supported low abundances with moderate species richness. The most abundant species were the oligochaete *Tubificoides intermedius* and the polychaetes *Polydora cornuta* and *Scoletoma hebes.* Evenness and diversity measures were moderate at T07 (Table 2). The Inner Harbor station C019 supported relatively high abundances, nearly half of which was contributed by the polychaete *Chaetozone anasimus*. Although evenness was moderate, both diversity measures were among the lowest observed in 2013 (Table 2). Station T04 exhibited the lowest similarity to other stations, as has been observed in past years. All community parameters were lowest at this station. One species, the opportunistic polychaete

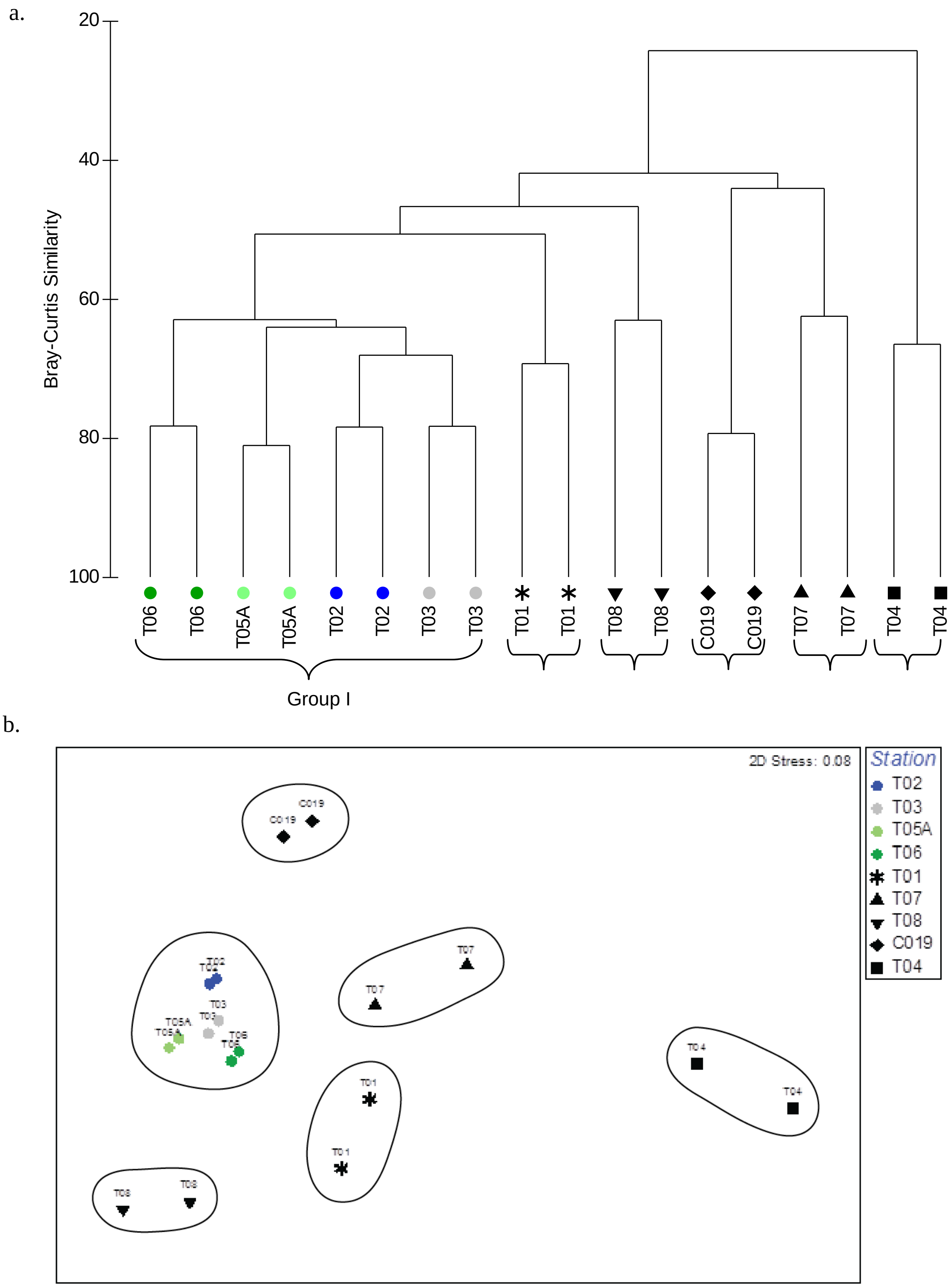

Figure 16. Results of (a) cluster analysis and (b) multidimensional scaling analysis of the 2013 infauna samples.

Table 5. Mean abundance of dominant taxa in 2013 Boston Harbor station groups defined by cluster analysis.

Phylum	Major Taxon	Family	Species	I	T01	T08	T07	C019	T04
Mollusca	Gastropoda	Nassariidae	*Ilyanassa trivittata*	12.9	12.5	5.5	1.5	2.0	-
	Bivalvia	Montacutidae	*Mysella planulata*	1.1	1.0	-	7.5	1.0	-
		Tellinidae	*Angulus agilis*	4.6	17.5	77.0	8.5	-	0.5
Annelida	Polychaeta	Capitellidae	*Mediomastus californiensis*	89.3	4.0	-	1.5	13.5	2.5
		Cirratulidae	*Chaetozone anasimus*	8.5	-	86.0	1.0	1,150.5	-
			Chaetozone cf. vivipara	0.1	-	-	-	96.5	-
			Monticellina cf. dorsobranchialis	18.5	1.0	25.0	2.0	2.5	-
			Tharyx acutus	26.0	9.5	70.0	6.0	422.0	1.5
			Tharyx sp. b	-	-	-	-	-	2.5
		Hesionidae	*Microphthalmus pettiboneae*	7.0	2.0	-	7.0	36.5	0.5
		Lumbrineridae	*Scoletoma hebes*	336.1	80.0	22.5	107.0	18.0	1.0
		Maldanidae	*Clymenella torquata*	6.1	8.5	41.0	0.5	-	-
		Nephtyidae	*Nephtys cornuta*	6.1	0.5	-	11.0	129.0	0.5
		Orbiniidae	*Leitoscoloplos robustus*	12.4	5.5	17.0	7.0	-	-
		Paraonidae	*Aricidea catherinae*	358.1	174.5	25.5	1.5	1.5	1.0
		Phyllodocidae	*Phyllodoce mucosa*	31.6	0.5	8.5	-	8.5	-
		Polygordiidae	*Polygordius jouinae*	26.8	-	151.0	-	-	-
		Spionidae	*Polydora cornuta*	478.5	127.0	21.5	157.0	269.0	2.5
			Scolelepis bousfieldi	214.5	0.5	48.0	1.5	11.0	0.5
			Spiophanes bombyx	25.8	-	30.0	-	-	-
			Streblospio benedicti	44.3	5.5	1.0	25.0	22.5	425.5
		Syllidae	*Exogone hebes*	13.8	6.5	51.0	1.5	-	-
		Terebellidae	*Polycirrus phosphoreus*	1.1	0.5	0.5	16.0	6.0	-
Annelida	Oligochaeta	Tubificidae	*Limnodriloides medioporus*	933.9	262.0	4.5	33.5	-	6.0
			Tubificoides intermedius	566.4	35.5	8.5	217.5	146.5	4.0
			Tubificoides sp. 2	-	-	-	-	-	38.0
Arthropoda	Amphipoda	Aoridae	*Leptocheirus pinguis*	13.4	-	-	2.0	28.0	-
		Lysianassidae	*Orchomenella minuta*	3.8	-	-	-	28.0	-

Streblospio benedicti contributed more than 85% of the total abundance at T04. Abundance of the tube-dwelling amphipod *Ampelisca* spp. (comprising *A. abdita* and *A. vadorum*) was lower than in 2012 and this species group was not among the dominants at any station in 2013. Low abundances of *Ampelisca* spp. at T04, T07, and C019 are consistent with recent patterns (Maciolek et al. 2011; Pembroke et al. 2012, 2013) whereas Group I included most of the stations where *Ampelisca* spp. has historically been abundant (Figure 11). Stations T04 (Dorchester Bay) and C019 (Inner Harbor) have long had the highest percentage of fine sediments of all harbor stations (see Section 3.1), and differences in the infaunal assemblages at these stations as compared to other harbor stations were identified and discussed by Maciolek et al. (2008). Maciolek et al. (2011) attributed an abrupt decline in the numbers of taxa at Station T07 (Quincy Bay) from 2009 (32 species) to 2010 (12.7 species) to a substantial reduction in the percent fines. Number of taxa remained relatively low in 2011 even though percent fines had increased to typical levels (Pembroke et al. 2012). In both 2012 and 2013, both the grain size distribution and the number of taxa returned to historic values.

3.2.3 Selected Stations

Station T01. Until 2013, infaunal community conditions at Station T01, located near Deer Island Flats north of President Roads, have exemplified conditions at most stations in the Harbor throughout the survey period. In 2013, total abundance at T01 was less than 60% of the eight-station average and, except for evenness, other community parameters at this station were lower than all of the other outer harbor stations except T04 (Table 2) and lower than the values in 2012. Mean abundance and species richness were lower in 2013 than in any year since 1991 (Figures 17 and 18). Similar to 2006, Shannon-Weiner diversity was depressed in 2013 and was one of the lowest values observed since the diversion of the outfall offshore in 2000 (Figure 19). Pielou's evenness also declined although it remained above the post-diversion low in 2006 (Figure 20). Mean log-series alpha decreased to a similar level to that observed in 1995 (Figure 21).

Station C019. Station C019 was initially included in the Harbor sampling program as part of the Sediment-Water Exchange (SWEX) study (Gallagher and Keay 1998). When first sampled in 1989, the benthic infauna consisted of only a few taxa and was overwhelmingly dominated by two polychaete species, *Streblospio benedicti* and *Chaetozone anasimus* (previously called *C. setosa*). There was a substantial increase in species richness in 2005-2010, a decline in 2011 and an increase in each of the last two years to record highs for the station (Figure 18). Mean abundance also increased in both 2012 and 2013, achieving the peak value seen thus far (Figure 17). Shannon-Weiner diversity and Pielou's evenness declined from the peak values observed in 2012 but remained above previous levels (Figures 19 and 20); log-series alpha remained at the same peak level seen in 2012 (Figure 21). The polychaete *Nepthys cornuta* had represented the majority of the infauna found at Station C019 from 2004-2011 (Figure 22) but the relative abundance of this species was substantially lower in 2012 (Pembroke et al. 2012) and 2013 when *C. anasimus* again dominated the infauna community (Table 5), coincident with a sharp decrease in TOC (Figure 4). The decrease in the relative contribution of a single species to the total abundance explains the relatively high evenness, Shannon-Weiner, and log-series alpha values.

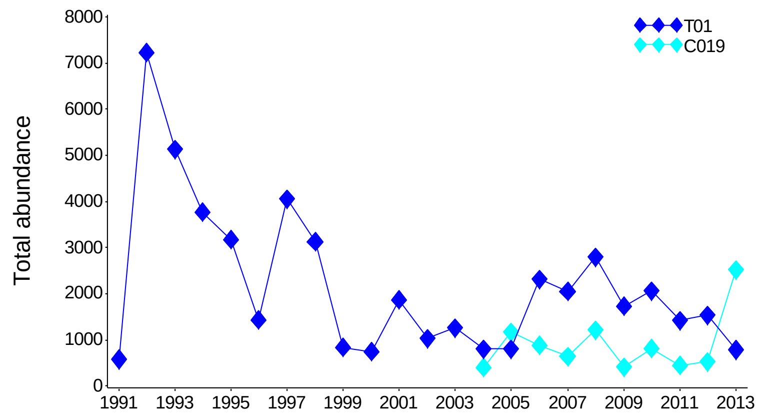

Figure 17. Mean total abundance at Boston Harbor Stations T01 and C019, 1991-2013.

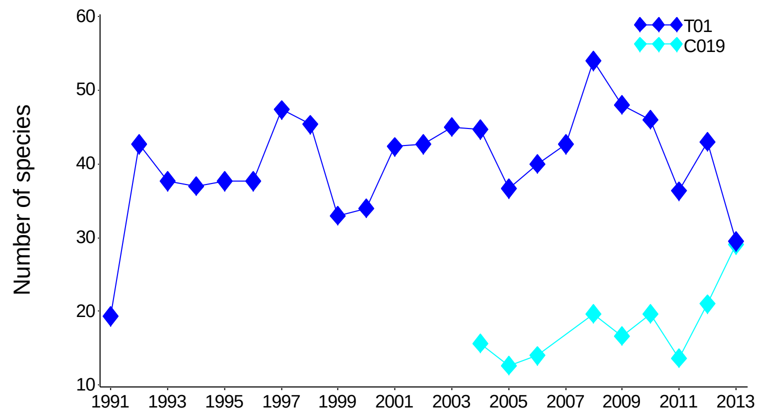

Figure 18. Mean species richness at Boston Harbor Stations T01 and C019, 1991-2013.

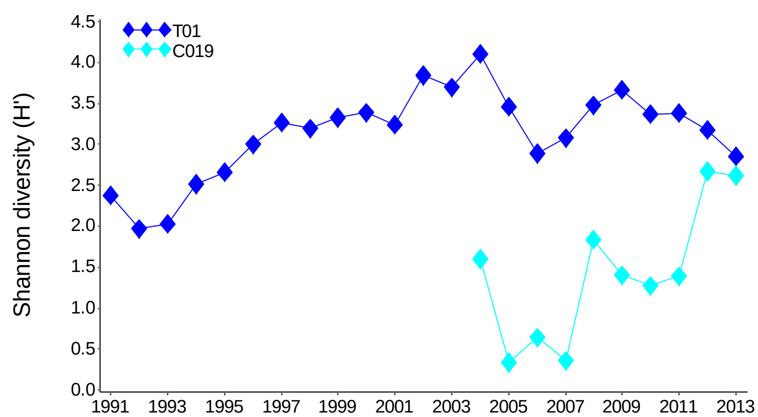

Figure 19. Mean Shannon-Weiner diversity at Boston Harbor Stations T01 and C019, 1991-2013.

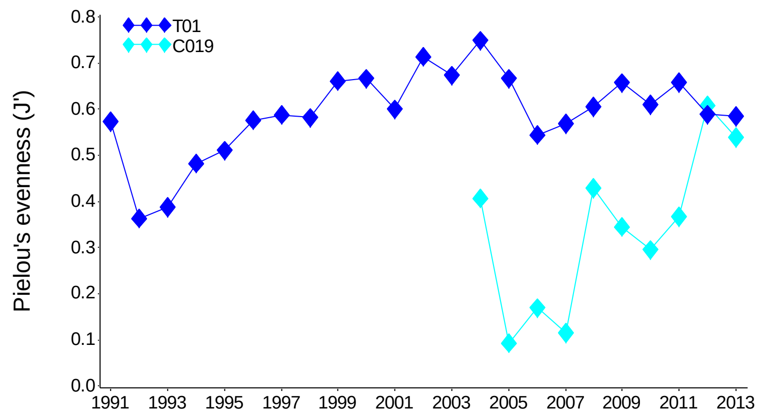

Figure 20. Mean evenness at Boston Harbor Stations T01 and C019, 1991-2013.

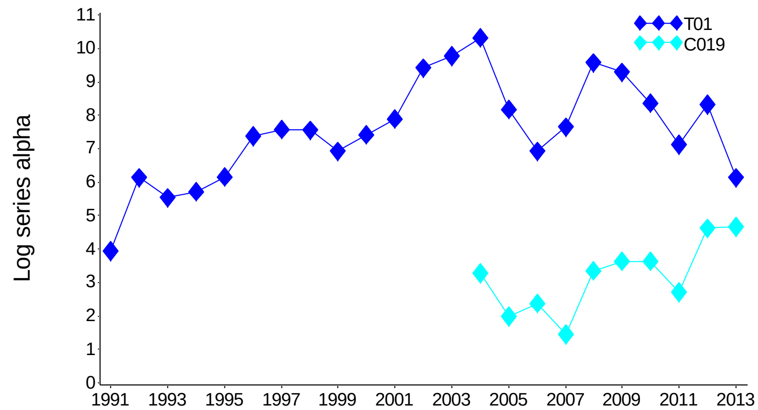

Figure 21. Mean log series alpha diversity at Boston Harbor stations T01 and C019, 1991-2013.

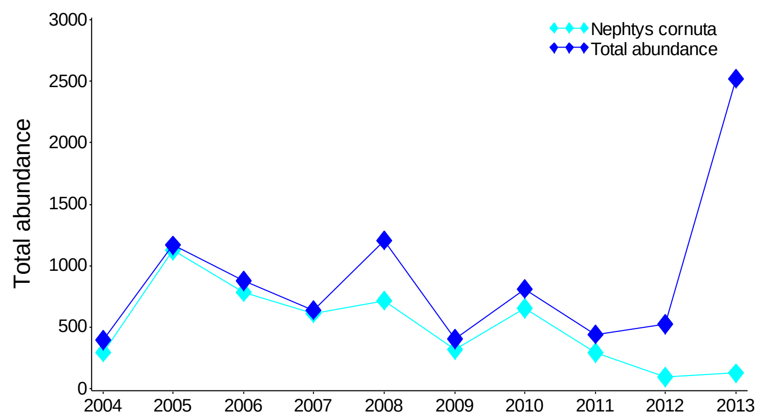

Figure 22. Mean abundance of *Nephtys cornuta* and total community abundance at Station C019, 2004-2013.

3.2.4 Temporal Trends

Benthic community parameters for the harbor have exhibited changes since 1991 that correspond well to the management changes defined by Taylor (2006) when a one-year offset is included to account a lag in benthic community response (Table 6). While mean total abundance has not changed dramatically through these periods, increases in species richness, evenness, and diversity between Periods I and IV have been notable and the trend in all of these parameters suggests a response to the reduction in pollutant loading into the harbor. Mean Period IV values for number of species, Shannon-Weiner diversity, and log-series alpha diversity for 2001-2013 were virtually the same as for 2001-2012 (Pembroke et al. 2013) so it is apparent that this trend has continued.

Table 6. Benthic community parameters for stations T01-T08, summarized by time periods defined by Taylor (2006).

Parameter	Period I (prior to Dec. 1991)[a]		Period II (Dec. 1991-mid 1998)		Period III (mid-1998-Sept. 2000)		Period IV (after Sept. 2000)	
	Mean	Std Err	Mean	Std Err	Mean	Std Err	Mean	Std Err
Total Abundance	2,606.4	343.64	5,513.4	469.00	3,213.4	492.66	2,679.0	148.2
Log-series alpha	4.2	0.31	5.51	0.17	6.16	0.27	7.53	0.19
Shannon-Wiener Diversity (H')	2.12	0.12	2.41	0.07	2.81	0.09	2.86	0.06
Pielou's Evenness (J')	0.48	0.02	0.47	0.01	0.58	0.02	0.54	0.01
Number of Species	25.45	2.06	34.74	1.14	33.61	1.70	41.5	1.0
Years included (with one year offset)	1991-1992		1993-1998		1999-2001		2002-2013	

[a]Years included in analysis (with one year offset): Period I 1991-1992; Period II 1993-1998; Period III 1999-2001; Period IV 2001-2013

3.3 Sediment Profile Imaging

In 2013, the annual sediment profile camera survey of soft bottom benthic habitat in Boston Harbor found conditions similar to the last few years. Largest improvements in benthic habitat quality were observed in the early 1990s after movement of outfalls from the inner harbor to outer harbor (Blake et al. 1993, Maciolek et al. 2008) and continued into the 2000s and 2010s after the startup of the ocean outfall in 2001, which ended sewage discharges within the harbor. Much if not all of the improvement in benthic habitat quality over the last 20 years can be attributed to upgrades in wastewater treatment and relocation of sewage outfalls from within the Harbor to Massachusetts Bay (Diaz et al. 2008, Taylor 2010). As a result, the nitrogen, phosphate, and organic carbon inputs to the harbor declined between 65% and 90% over this period, which has led to reversal of eutrophication in the Harbor (Taylor 2013). However, there are still problems with sediment associated contaminants (Bothner et al. 1998, Wang et al. 2001), which may be a factor in limiting improvements in benthic habitat quality at some stations, particularly those in the Dorchester Bay area (Gallagher and Keay 1998).

To characterize infaunal benthic habitat quality we used the organism–sediment index (OSI) developed by Rhoads and Germano (1986) from sediment profile image data. The OSI defines quality of benthic habitat for infauna by evaluating images for depth of the apparent color redox potential discontinuity (aRPD) layer, successional stage of macrofauna, the presence of gas bubbles in the sediment (an indication of high rates of methanogenisis), and the presence of reduced sediment at the sediment–water interface that would indicate current or recent low dissolved oxygen conditions. The OSI ranges from -10, describing highly disturbed benthic habitat with poorest quality, to +11, describing highest quality habitats with advanced successional stage fauna. In northeastern estuarine and coastal ecosystems where the OSI was developed, values >6 were associated with higher quality habitats with well-developed macrofaunal communities (Valente et al. 1992, Germano et al. 2011).

Based on the OSI, improvements in benthic habitat quality for infauna were observed at all seven Dorchester Bay stations from the 1990s to the 2000s (Figure 23). While some of the Dorchester Bay stations continued to improve into the 2010s, some like R41 and R42 declined. Station T04 improved the most from OSI values of -6 to about 2 by 2000. From 2000 on there has not been much change in benthic conditions at T04 (Figure 24). The lack of improvement in benthic habitat in Dorchester Bay is likely related to lingering effects of sediment contaminants. Inner Harbor stations showed improvements over time (Figure 23). In Quincy Bay, seven of 10 stations improved in benthic habitat quality with three stations (R36, R38, and R39) remaining about the same from 1993 to 2013 (Figure 25). R36 had poor habitat quality all years with an OSI between 2 and 4, but R36 was in a shelly/pebbly area and appeared to be good habitat for the epifauna that dominated (Figure 26). The OSI is not a good indicator of habitat conditions for epifauna.

Northern Harbor stations on Deer Island Flats all increased in habitat quality through time (Figure 27). The exception was R47, which had high habitat quality with a slight decline in the early 2000s (Figure 28). Stations off Long Island tended to have consistently high habitat values (Figure 29). Exceptions were low and variable OSI values at shelly/pebbly stations R06, R23, and R16, which favored epifauna. The largest increase in OSI was observed at station R17 that went from poor to very good infaunal habitat (Figure 30). The three stations in President Roads all increased in habitat quality going from poor to very good infaunal habitat (Figure 31). Stations in Nantasket Roads had consistently good habitat quality for infauna (Figures 31 and 32). The exception was R23, which had shelly/pebbly sediment.

The 16 Hingham Bay stations, in the southern Harbor, were divided into seven inner and nine outer stations. At inner Hingham Bay stations infaunal habitat quality was generally poor in the 1990s and increased into the 2000s and 2010s (Figure 33). Largest increases in OSI occurred at station R49 (Figures 33 and 34). At outer Hingham Bay stations was generally good from 1990s to 2010s but variable (Figure 35). Station R32 had the largest increase in OSI and went from poor to good habitat (Figure 36).

The increases in OSI from the 1990s appeared to be related to increases in bioturbation and other infaunal activity, which reflects recovery in infaunal communities. Recovery appeared to closely follow the classic Pearson-Rosenberg (1978) organic gradient model. A good example of this is seen at station T02 in President Roads, near Deer Island Flats (Figure 37). At three of the four harbor flux stations, T03, T07, and T08, there was a decline in total organic carbon (TOC) from 1995 to 2008 (Tucker et al. 2009). At the fourth flux station, T02, TOC was never higher than about 2% and remained about 1.5% up to

2012 (Pembroke et al. 2013). In 2013, TOC at T02 was 0.8%. Overall, TOC at harbor T-stations declined from about 2.5% in 1991-1992 to about 1.7% from 2002 to 2011, to 1.5% in 2012, and 1.1% in 2013 (Pembroke et al. 2013).

Much of the recovery in benthic habitat quality can be seen in the dynamics of the tube building amphipod *Ampelisca* spp., which can reach very high densities and form thick tube mats. Over the 23 years of SPI monitoring, biogenic activity associated with the presence of *Ampelisca* spp. had the most influence habitat quality. At some time between 1990 and 1992, when the SPI monitoring started, there was an increase in the occurrence of *Ampelisca* spp. tube mats (Figure 38). Prior to the dominance of *Ampelisca* spp. it appeared that blue mussels and polychaete tube mats were widely distributed (SAIC 1990, 1992). Amphipod tube mats peaked from 1994 to 1997 likely in response to the relocation of Nut Island outfalls to Deer Island. It is possible that prior to outfall relocation either organic or pollutant loading was too high for *Ampelisca* spp. to thrive. *Ampelisca* spp. have a life history that reflects a combination of opportunism in responding to organic matter (McCall 1977) and sensitivity to pollutants (Wolfe et al. 1996). As the organic and pollutant loading, and also primary production within the Harbor continued to decline, mat densities of *Ampelisca* spp. also declined. This started in 1998 and by 2005 no tube mats were observed. The loss of tube mats in 2005 may also have been associated with a strong storm in late 2004 (Butman et al. 2008) that disrupted tube mats. *Ampelisca* spp. tube mats reappeared 2006 and increased to levels seen in the late 1990s in 2011 and 2012, but in 2013 no tube mats were observed. *Ampelisca* spp. tubes were observed at less than mat densities at 25 of 61 Harbor stations. The abundance of *Ampelisca* spp. collected at the eight T-stations mirrored the occurrence of tube mats in SPI (Figure 38) with lowest number of *Ampelisca* spp. in 2005 and 2013.

While the occurrence of *Ampelisca* spp. tubes shifted from year to year, likely driven by physical factors such as storms and quality of organic matter, tube mats were observed every year in SPI monitoring except for 2005 and 2013. In the winter prior to the August SPI survey in both of these years strong storms occurred that could have seriously disturb *Ampelisca* spp. populations. The 2012-2013 storms were particularly strong and likely disturbed surficial sediments to water depths of 50 m (R. Geyer, personal communication). But the pattern of decline in tube mats between 2005 and 2013 was different (Figure 16). There was a gradual decline in tube mats from peak years of 1994 to 1997 when about 65% of stations had mats to 2004 when 13% of stations had mats. In 2005 there were no mats but *Ampelisca* spp. tubes were observed at 35% of stations. From 2006 to 2011-2012 there was a gradual buildup of tube mats to about 35% of stations; in 2013 there were no mats, but about 40% of harbor SPI stations had *Ampelisca* spp. tubes.

The harbor-wide decline in tube mats from 1998 to 2005 was primarily attributed to reduced primary production and nutrient loadings from 1992 to 2000 (Oviatt et al. 2007, Diaz et al. 2008, Taylor 2013). At the mouth of Boston Harbor, Oviatt et al. (2007) found 2005 to have the lowest primary production between 1992 and 2005. Diaz et al. (2008) estimated that it should take between 350 to 630 g C M^{-2} per year to maintain large areas of amphipod tube mats and that in 2005-2006 total organic matter loading was about 250 g C M^{-2} per year. The resurgence of tube mats in 2011 and 2012 with reduced organic loading in the Harbor relative to 2005 points to possibility that timing and severity of storms may be more important than gross organic matter as a determining factor for development of *Ampelisca* spp. tube mats. While overall carbon loading in Boston Harbor has declined greatly (Taylor 2013), the carbon that is produced may be of higher quality, arising from harbor phytoplankton and microalgal production.

Despite the outer Harbor stations (President Roads, Nantasket Roads, outer Hingham Bay) being more strongly influenced by hydrodynamic factors, they have always had higher habitat quality. Many outer Harbor stations also improved in infaunal habitat quality after the operation of the ocean outfall (Figures 31 and 35). From 1992 to the present there is strong evidence that benthic habitats within Boston Harbor shifted from a more anaerobic state to a more aerobic state and that these changes are directly related to changes in carbon loading associated with outfall placement and improvements in wastewater treatment. There were also corresponding decreases in primary production due to reduced nutrient loadings (Oviatt et al. 2007). The change in biogeochemistry, driven primarily by infaunal bioturbation, can be seen at station T02 (Figure 37). From 2005 to 2007 RPD measurements deepened from about 2 cm to 10 cm (Tucker et al. 2009). Over the same interval, SPI aRPD measurements went from 1.5 cm to 3.8 cm. By 2008, the sediments were oxic to about 6 cm and suboxic to at least 18 cm (Tucker et al. 2009). These changes corresponded with an increase in bioturbation, much of which can be attributed to the amphipod *Leptocheirus pinguis*. High levels of bioturbation from large numbers of this amphipod likely drove the changes in sediment biogeochemistry at station T02. Bioturbation by *L. pinguis*, that was obvious at many stations since 1995, was not observed in 2013.

Further evidence of improvement in benthic habitat quality is the eelgrass bed that has persisted at Station R08 since 2008 (Figure 39). Beds of eelgrass have also been reported in and around Nahant and Lynn Harbor, inside the northernmost breakwater in Winthrop, western and southwestern sides of Calf Island, off Long Island, and Whitehead Flats in Hull (P. Colarusso personal communication to K. Keay). Overall, the improvements in wastewater treatment and moving the outfall offshore have led to improvements in benthic habitats within Boston Harbor by favoring processes that enhance bioturbation or the mixing of sediment by organisms, which has led to more aerobic sediment conditions.

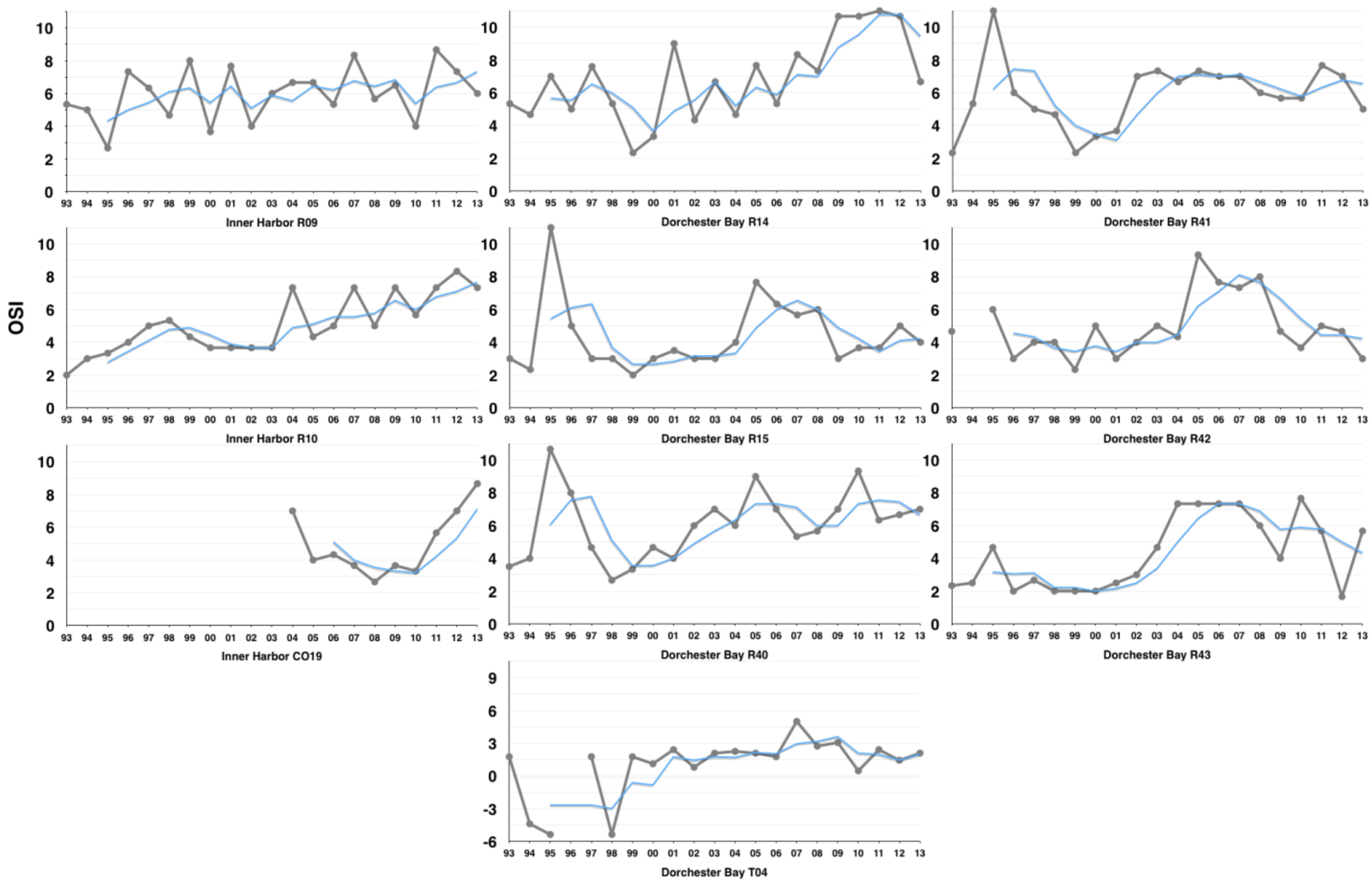

Figure 23. Trends in infaunal benthic habitat quality for Inner Harbor and Dorchester Bay as expressed by Organism Sediment Index (OSI). Poorest quality habitats have negative OSI. Good habitat quality is OSI over 6 with the best quality habitat 10 or 11. Gray line is annual average OSI. Blue line is three-year running average used to smooth annual variability.

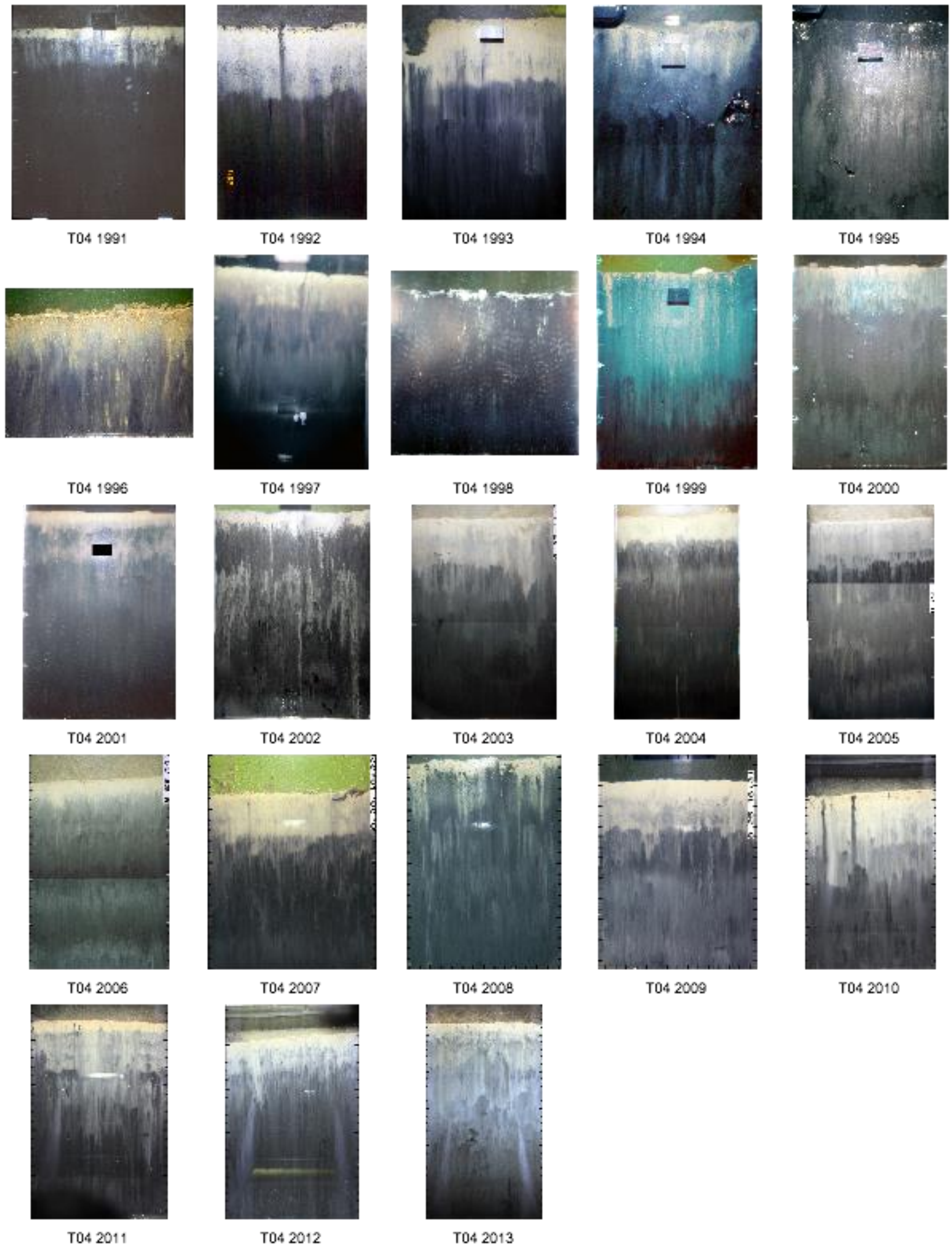

Figure 24. Thumbnail SPI images from station T04 located in inner Dorchester Bay, for all years. Baseline years are up to 2000. Post-baseline years are from 2001. This is an example of improved habitat conditions from very poor (-4 to -6 OSI) to poor (2 to 3 OSI). In 1994, 1995, and 1998 hypoxic conditions appear to be present. Traces of a bacterial mat are present on the surface in 1998. Scale along the side of each image is in cm.

Figure 25. Trends in infaunal benthic habitat quality for Quincy Bay as expressed by Organism Sediment Index (OSI). Poorest quality habitats have negative OSI. Good habitat quality is OSI over 6 with the best quality habitat 10 or 11. Gray line is annual average OSI. Blue line is three-year running average used to smooth annual variability.

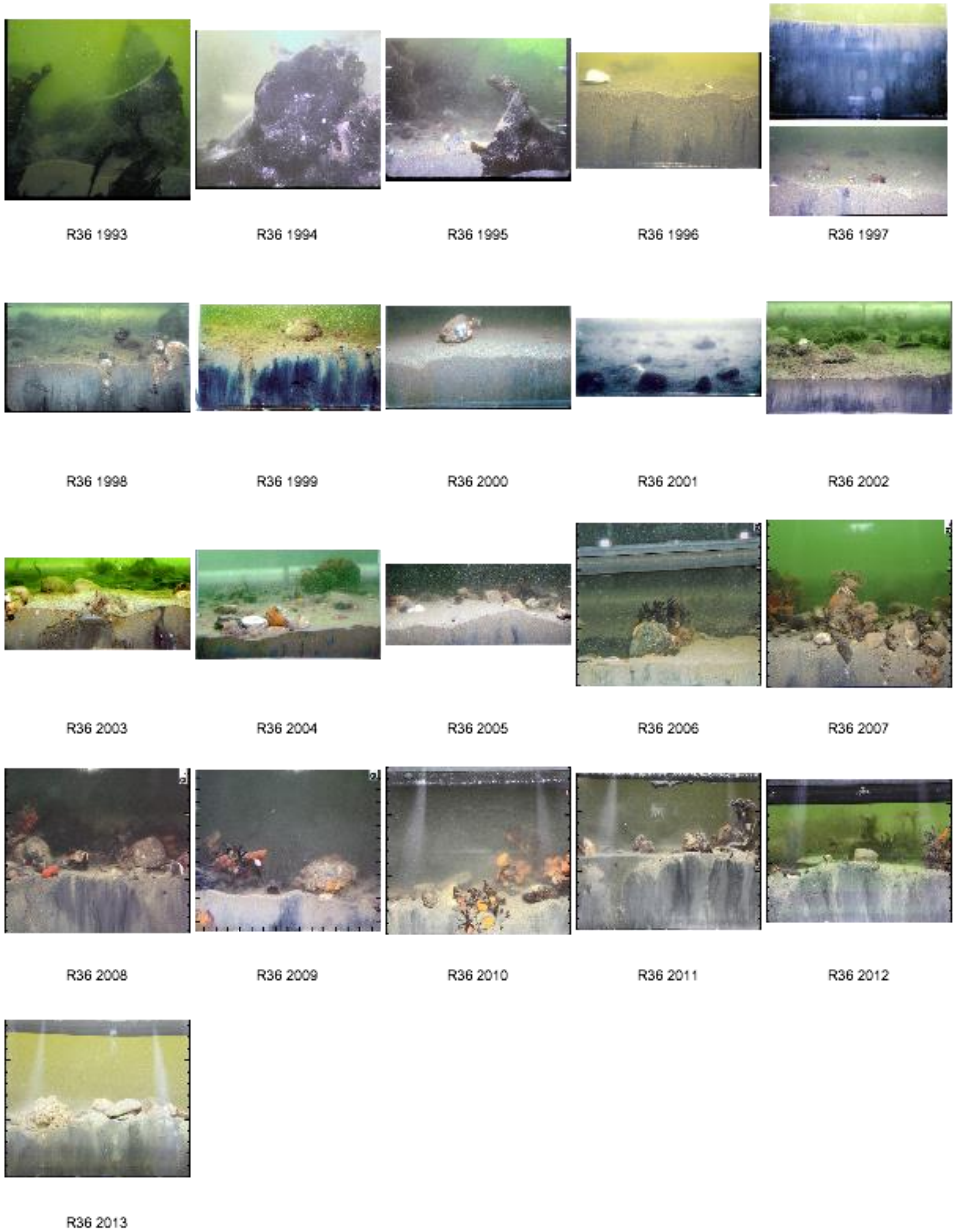

Figure 26. Thumbnail SPI images from station R36 located in Quincy Bay. Baseline years are up to 2000. Post-baseline years are from 2001. R36 is located in a shelly/pebbly area and appeared to be good habitat for epifauna but low OSI values point to its infaunal emphasis. Scale along the side of each image is in cm.

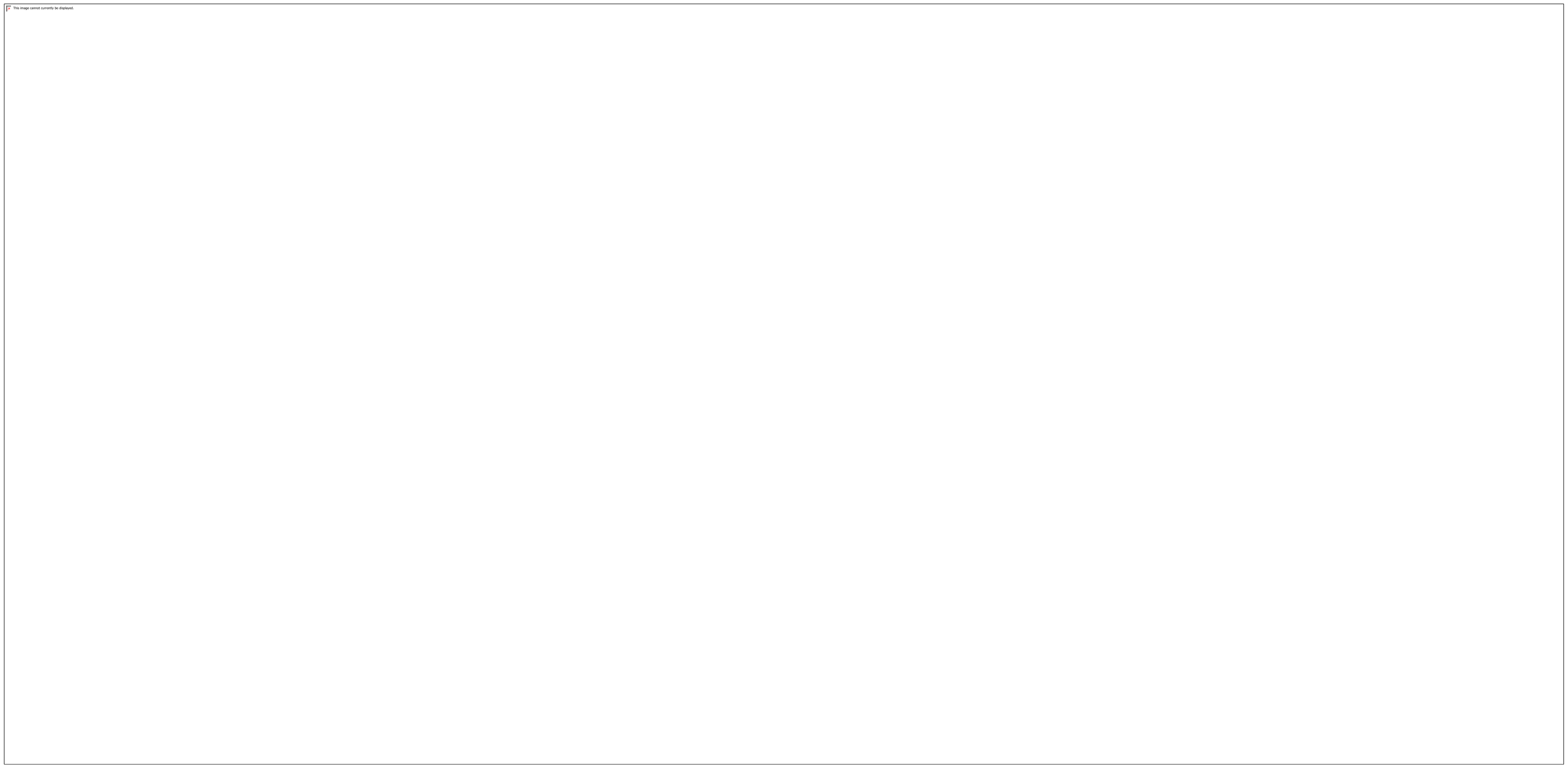

Figure 27. Trends in infaunal benthic habitat quality for Deer Island Flats as expressed by Organism Sediment Index (OSI). Poorest quality habitats have negative OSI. Good habitat quality is OSI over 6 with the best quality habitat 10 or 11. Gray line is annual average OSI. Blue line is three-year running average used to smooth annual variability.

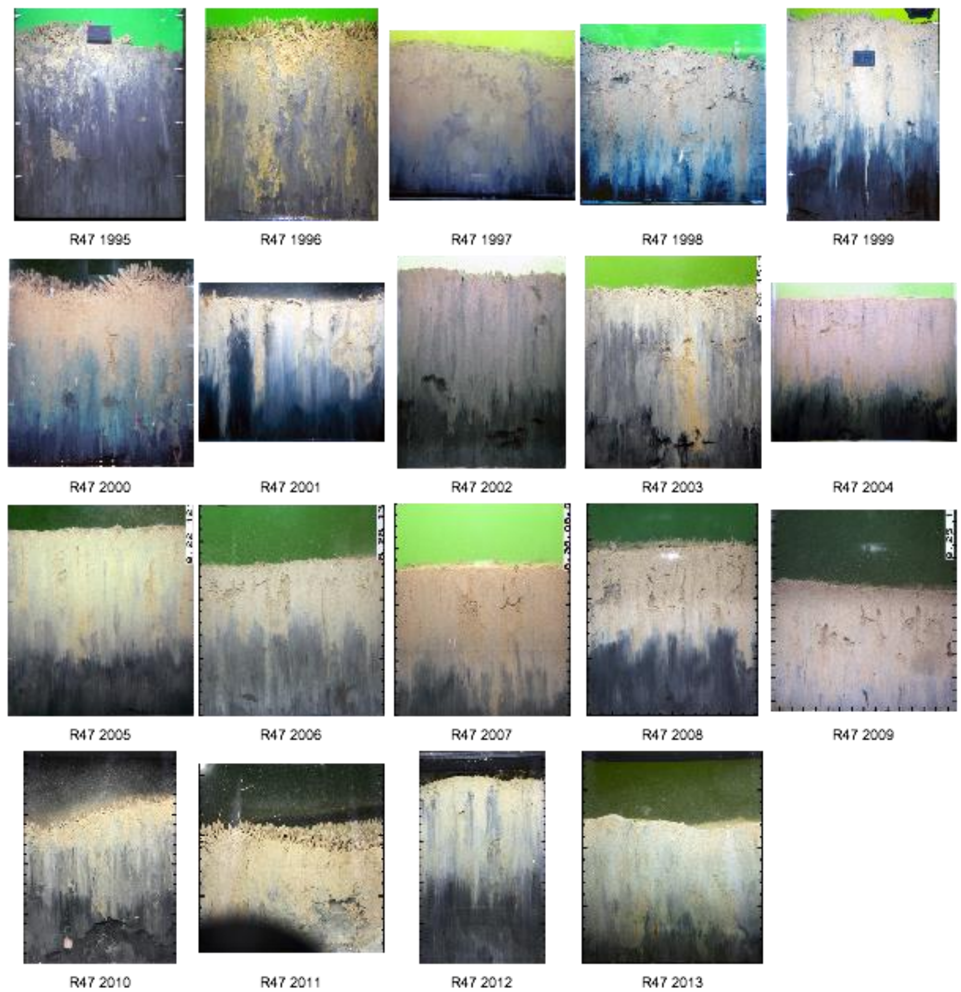

Figure 28. Thumbnail SPI images from station R47 located in Quincy Bay. Baseline years are up to 2000. Post-baseline years are from 2001. This is an example of good habitat conditions with deeper bioturbation prevalent through time. Scale along the side of each image is in cm.

Figure 29. Trends in infaunal benthic habitat quality for station off Long Island as expressed by Organisms Sediment Index (OSI). Poorest quality habitats have negative OSI. Good habitat quality is OSI over 6 with the best quality habitat 10 or 11. Gray line is annual average OSI. Blue line is three-year running average used to smooth annual variability.

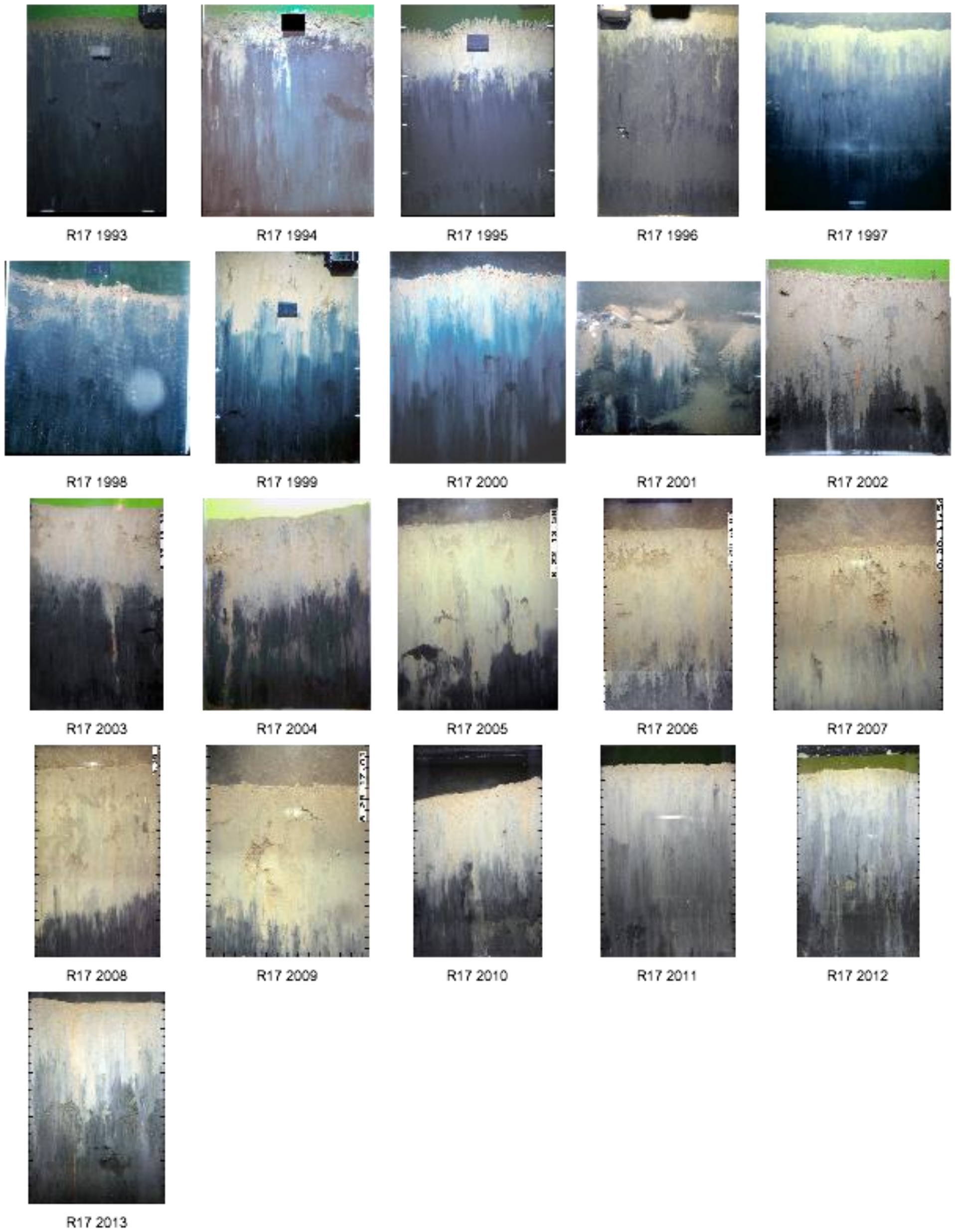

Figure 30. Thumbnail SPI images from station R17 located off Long Island. Baseline years are up to 2000. Post-baseline years are from 2001. This is an example of improved habitat conditions. By the mid-2000s sediments appear to be more bioturbated with the presence of deep-welling infauna and biogenic structures. Scale along the side of each image is in cm.

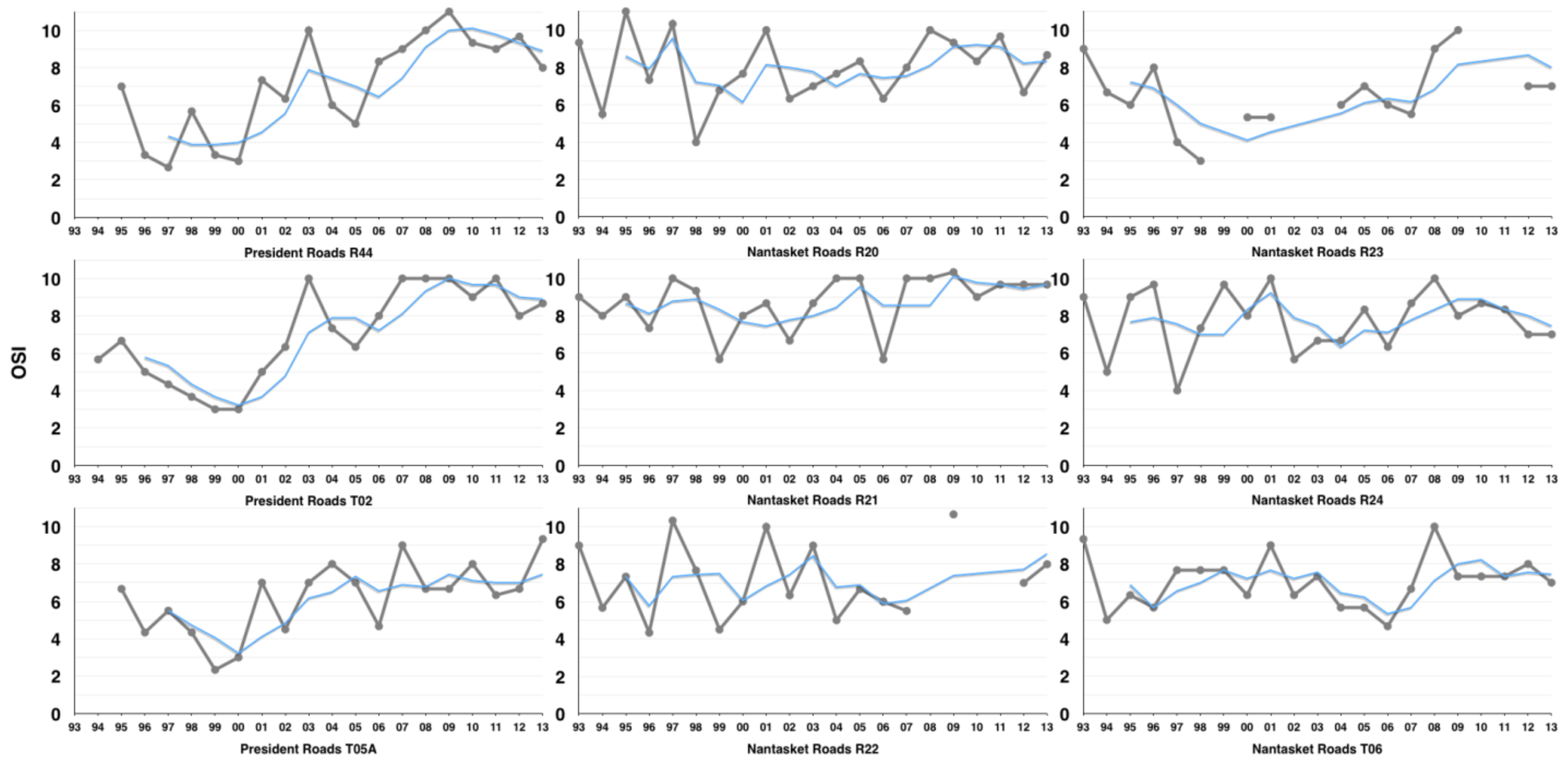

Figure 31. Trends in infaunal benthic habitat quality for President and Nantasket Roads as expressed by Organism Sediment Index (OSI). Poorest quality habitats have negative OSI. Good habitat quality is OSI over 6 with the best quality habitat 10 or 11. Gray line is annual average OSI. Blue line is three-year running average used to smooth annual variability.

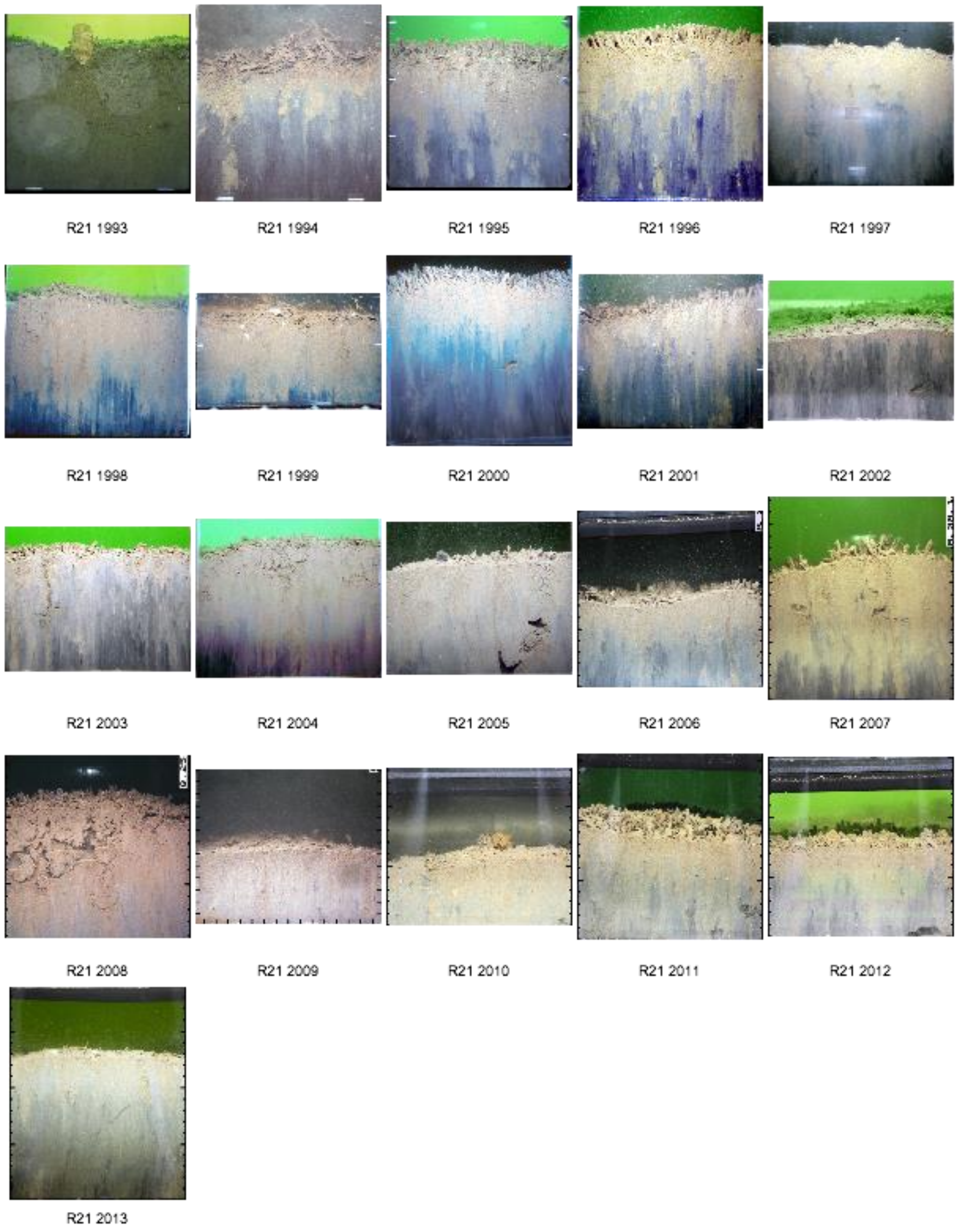

Figure 32. Thumbnail SPI images from station R21 located in Nantasket Roads. Baseline years are up to 2000. Post-baseline years are from 2001. This is an example of a station with consistently good habitat conditions. Ampelisca spp. tube mats were present in all years except 2005, 2009, 2010, and 2013. Scale along the side of each image is in cm.

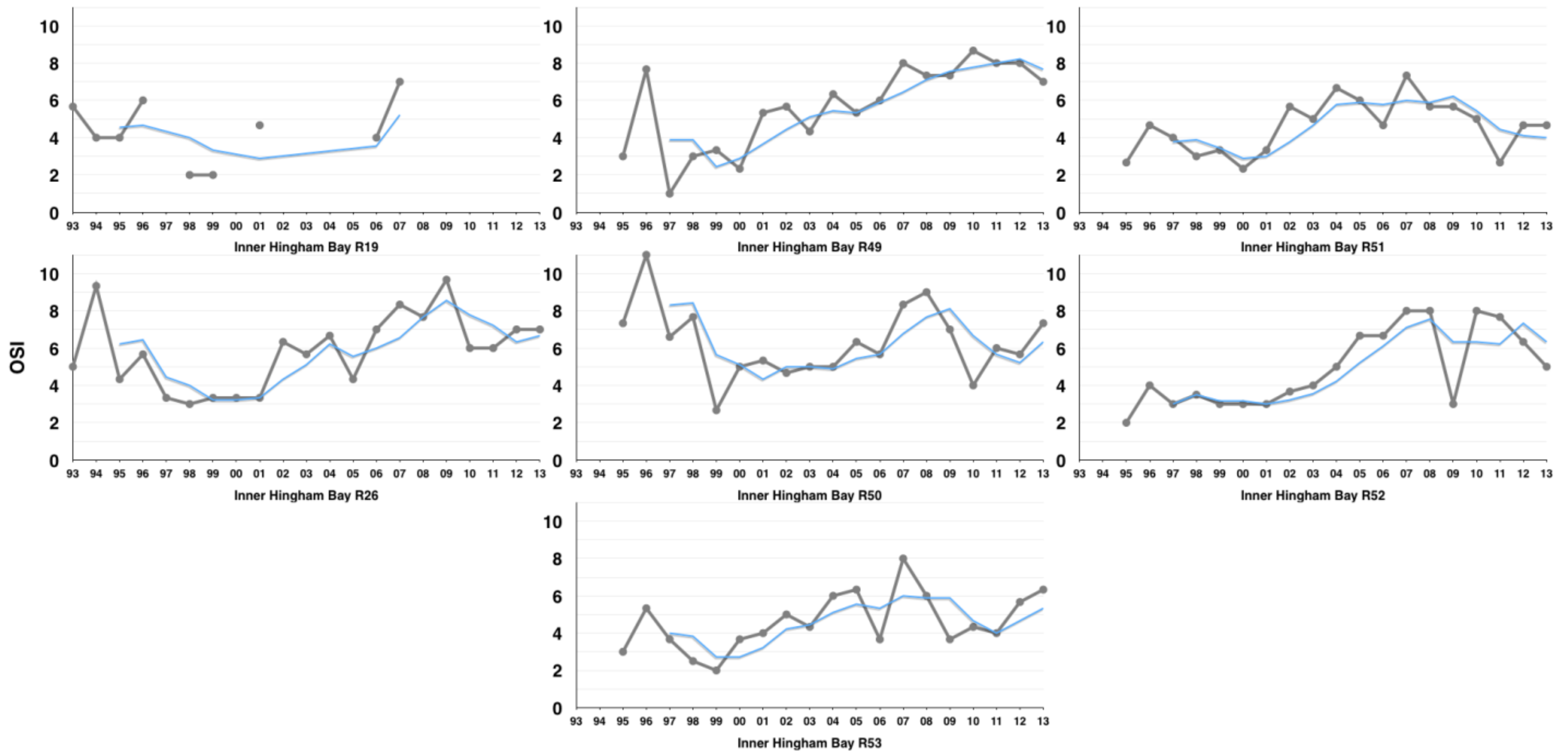

Figure 33. Trends in infaunal benthic habitat quality for inner Hingham Bay stations as expressed by Organism Sediment Index (OSI). Poorest quality habitats have negative OSI. Good habitat quality is OSI over 6 with the best quality habitat 10 or 11. Gray line is annual average OSI. Blue line is three-year running average used to smooth annual variability.

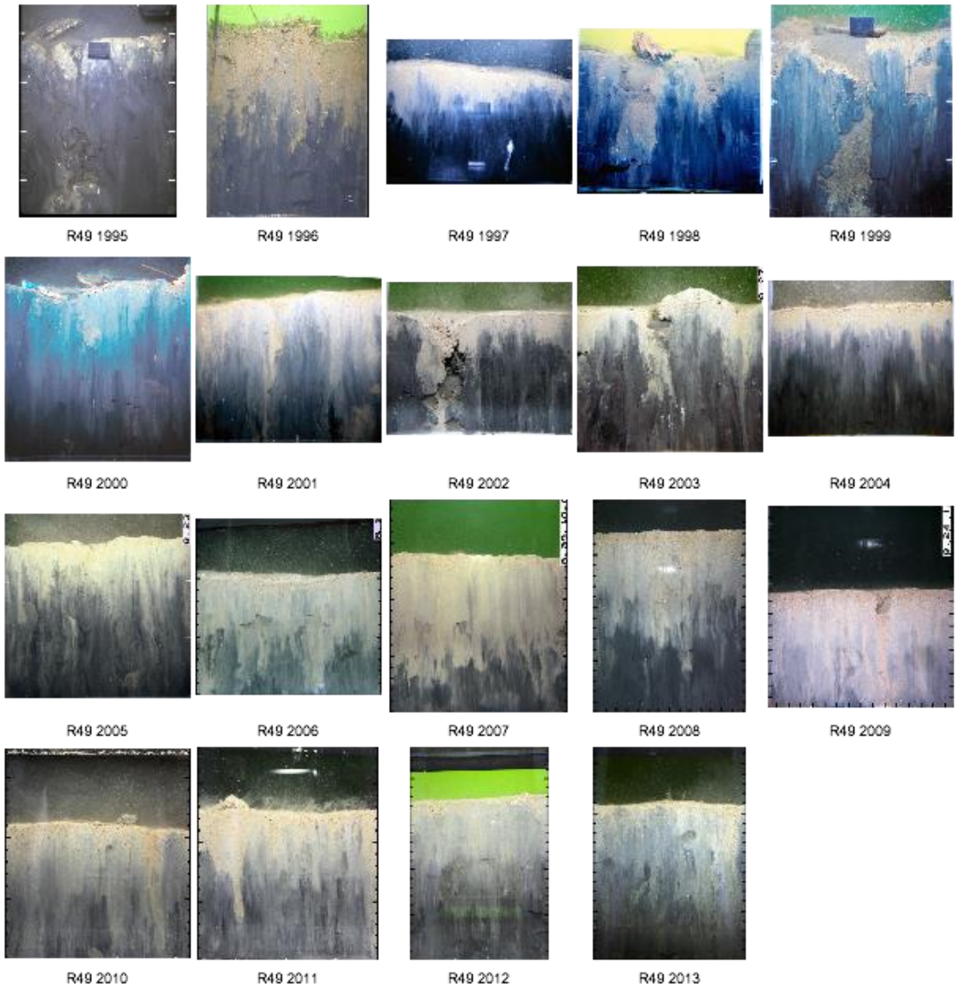

Figure 34. Thumbnail SPI images from station R49 located in inner Hingham Bay. Baseline years are up to 2000. Post-baseline years are from 2001. This is an example of greatly improved habitat conditions from very poor to good. 1996 was an exceptional year for the 1990s in that the OSI was high. By the mid-2000s the OSI consistently indicated good habitat conditions. Scale along the side of each image is in cm.

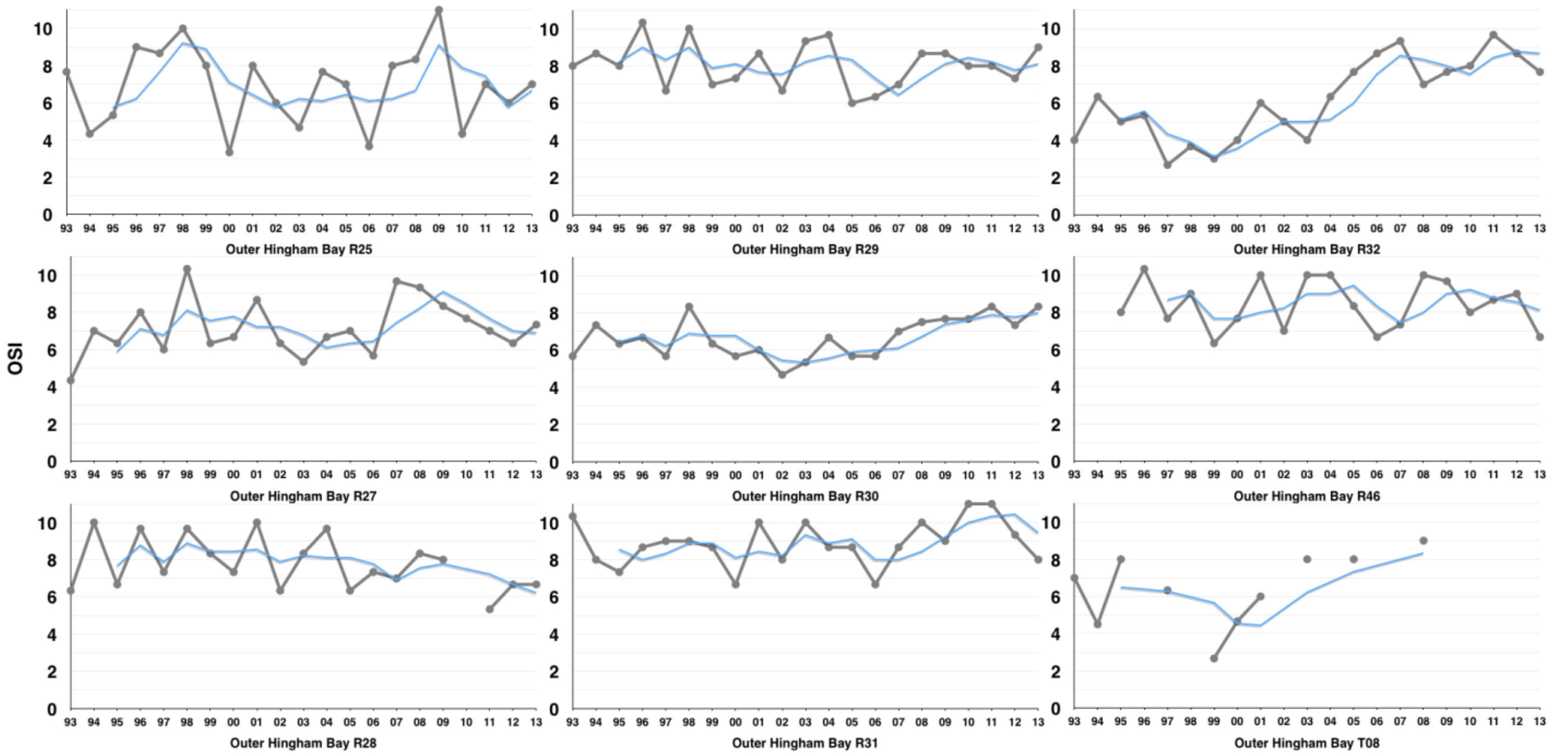

Figure 35. Trends in infaunal benthic habitat quality for outer Hingham Bay stations as expressed by Organism Sediment Index (OSI). Poorest quality habitats have negative OSI. Good habitat quality is OSI over 6 with the best quality habitat 10 or 11. Gray line is annual average OSI. Blue line is three-year running average used to smooth annual variability.

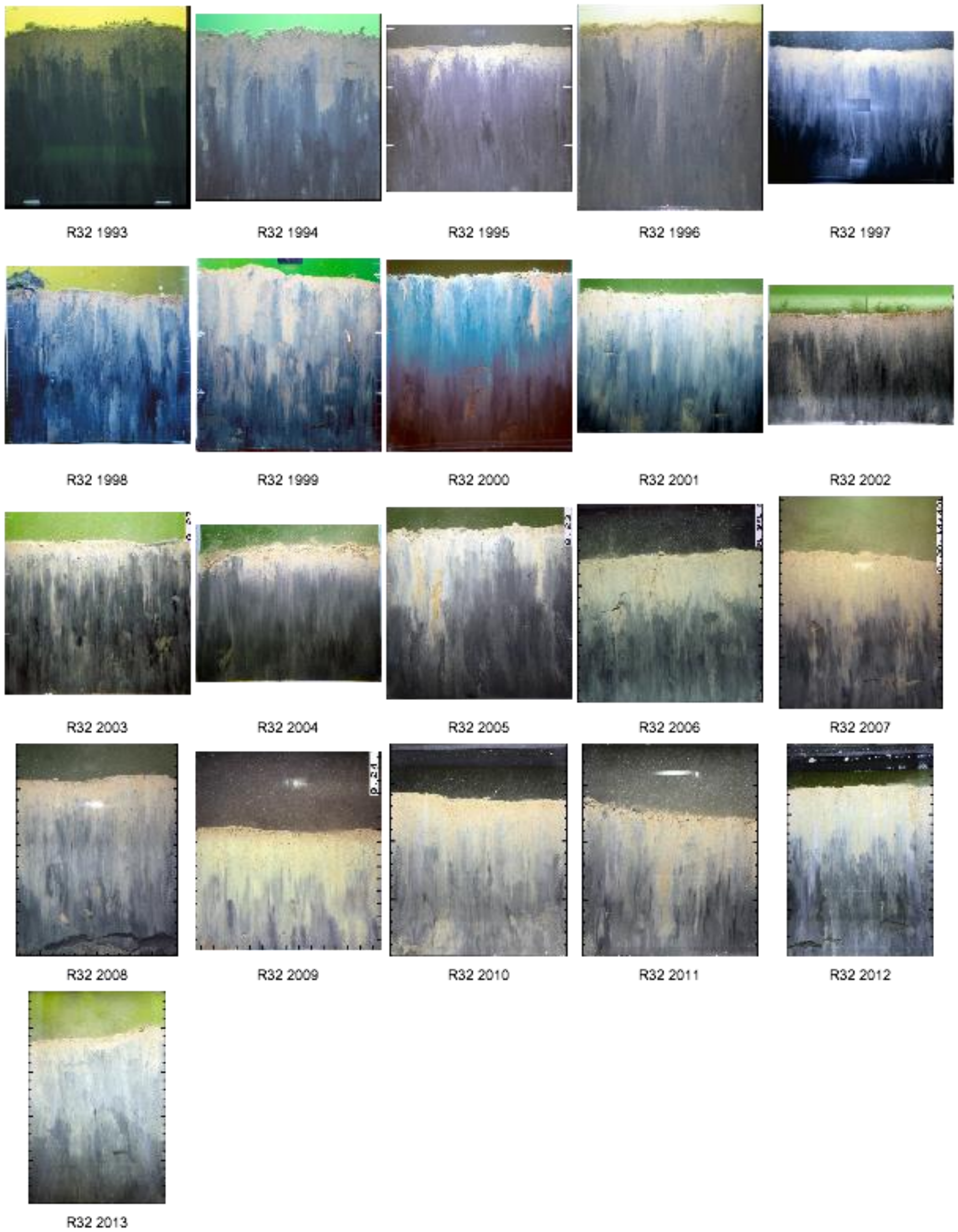

Figure 36. Thumbnail SPI images from station R32 located in outer Hingham Bay. Baseline years are up to 2000. Post-baseline years are from 2001. This is an example of greatly improved habitat conditions from very poor to good. By the mid-2000s the OSI consistently indicated good habitat conditions. Scale along the side of each image is in cm.

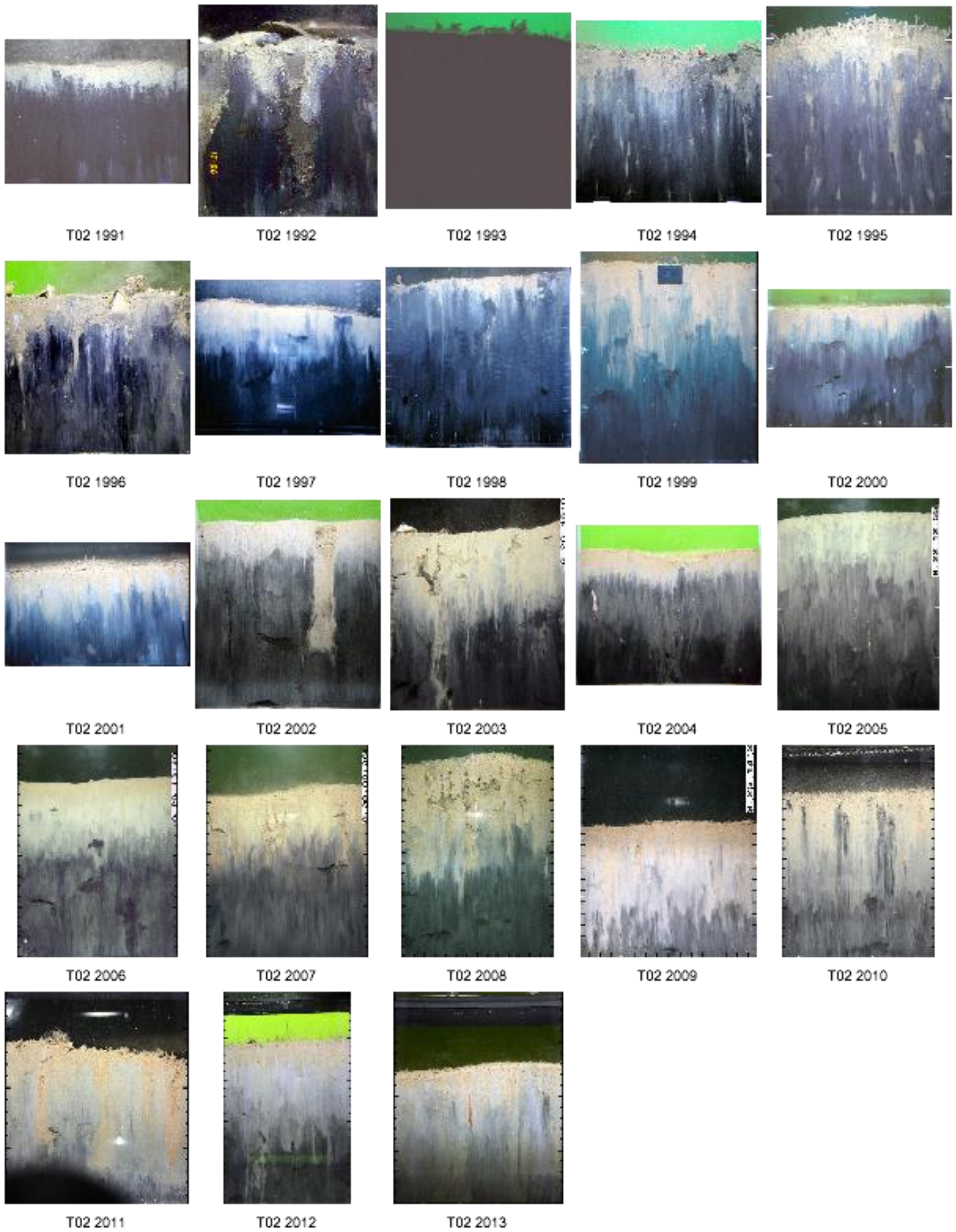

Figure 37. Thumbnail SPI images from station T02 located in President Roads, for all years. Baseline years are up to 2000. Post-baseline years are from 2001. This is an example of improved habitat conditions. By the mid-2000s sediments appear to becoming lighter in color with deeper bioturbation and the presence of deep-welling infauna and biogenic structures. These are the primary indicators of good benthic habitat. Scale along the side of each image is in cm.

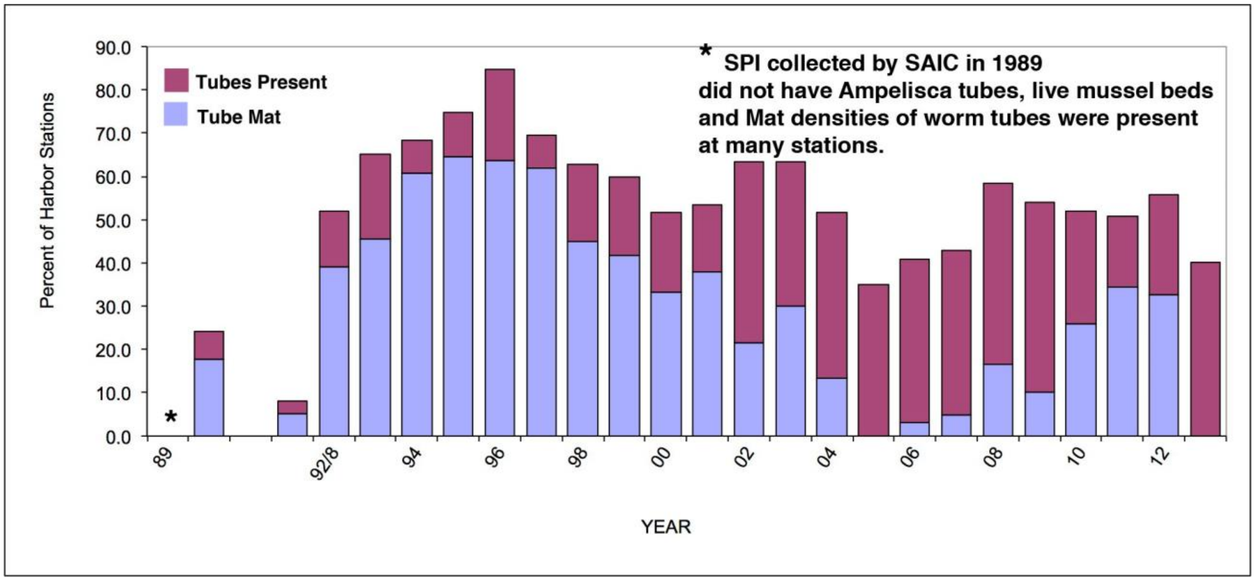

Figure 38. Histogram of *Ampelisca* spp. tubes present at harbor stations. Total bar represents percent of stations with tubes present. Mats densities of tubes are the bottom part of the bar in blue. There were two sample periods in 1992, spring and summer (92/8). Baseline years are up to 2000. Post-baseline years are from 2001.

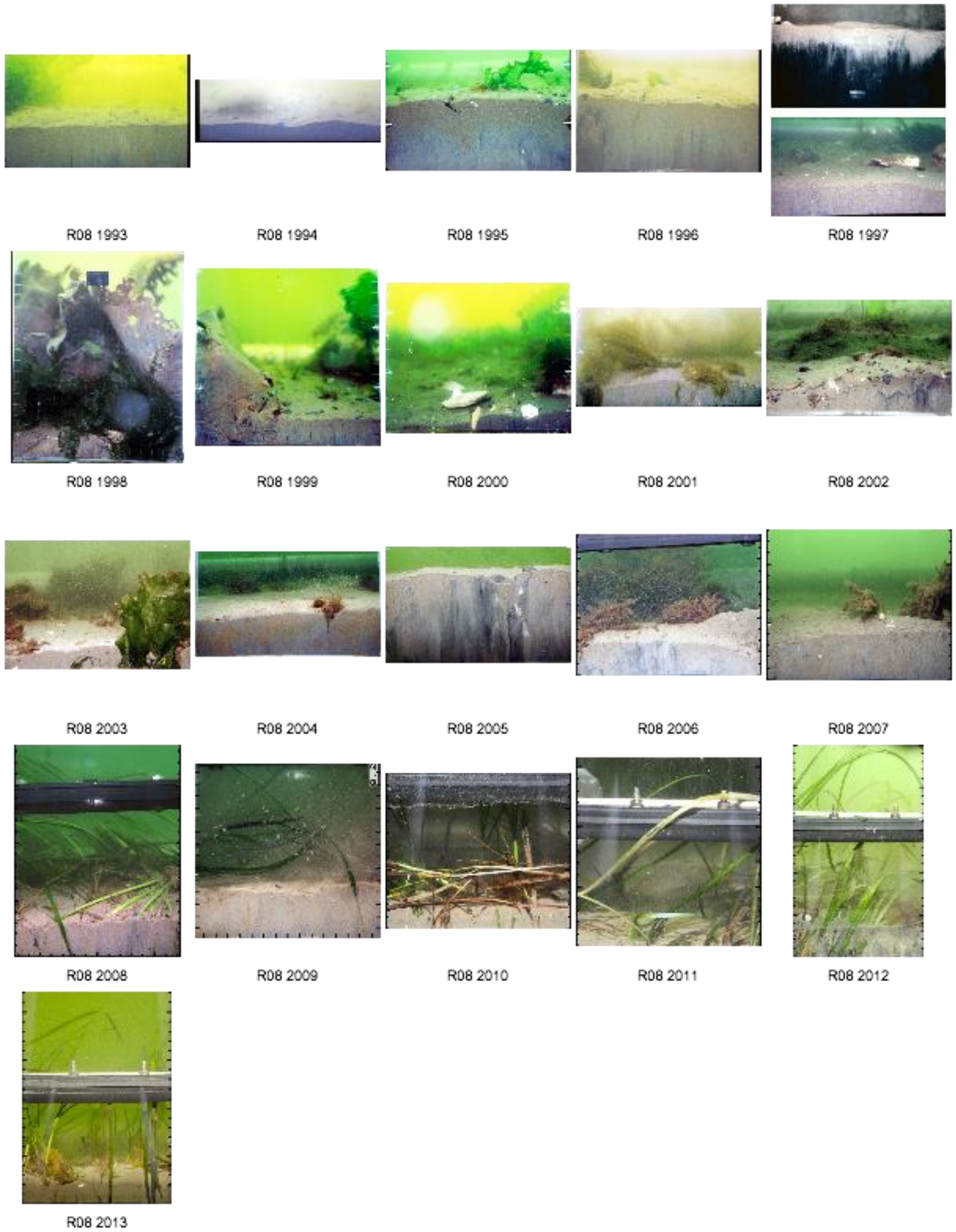

Figure 39. Eelgrass bed at Station R08 on Deer Island Flats persisted from 2008. Scale on sediment profile image is in cm.

4. CONCLUSION

Overall, the improvements in wastewater treatment and moving the outfall offshore have led to improvements in water quality and benthic habitat quality within Boston Harbor by reducing organic and nutrient loading and favoring processes that enhance bioturbation or the mixing of sediment by organisms. From 1990 to the present, the sediment organic matter in Boston Harbor has shifted from sewage to marine derived and infaunal activity has led to more aerobic and 'healthy' sediment conditions. Physical and biological properties of the soft substrate in Boston Harbor in 2013 exhibited minor changes from recent years but were consistent with longer-term trends (Pembroke et al. 2013). Concentrations of both TOC and *Clostridium perfringens*, indicators of organic enrichment and deposition from municipal wastewater discharge, have remained low compared to the levels occurring prior to the offshore diversion.

Community structure measures also continue to point to improving benthic conditions. Since municipal wastewater and sludge discharges have been eliminated from the harbor, total abundance has trended downward, particularly for opportunistic species such as *Capitella capitata*. Species richness, while variable, has trended upward as did evenness (J'), Shannon diversity (H'), and log series alpha diversity. Although abundances of individual taxa, such as the dominants *Ampelisca* spp. and *Polydora cornuta* have varied over time, the infaunal community structure and evidence from sediment profile imaging suggest that these changes relate more to normal physical disturbances than organic stress in the years since wastewater impacts to the Harbor have been reduced. The trends observed in previous years, including reduction of indicators of organic enrichment and increases in species diversity that continued in the 2013 survey are consistent with the recovery of benthic habitats from decades of inadequately treated sewage discharges.

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