# Harbor Benthic Monitoring Report: 2012 Results

Massachusetts Water Resources Authority

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# 1. INTRODUCTION

## 1.1 Background

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 in order 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 2012. 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 Maciolek et al. (2010 and 2011) 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. 2013b). 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, 2012 (Figure 1). Sediment samples were collected on August 9 and 10, and infauna samples were collected on August 28. Soft-bottom stations were sampled for grain size composition, total organic carbon (TOC), the sewage tracer *Clostridium perfringens*, and benthic infauna.

SPI samples were collected in triplicate at 61 stations on August 13-15, 2012 (Figure 1).

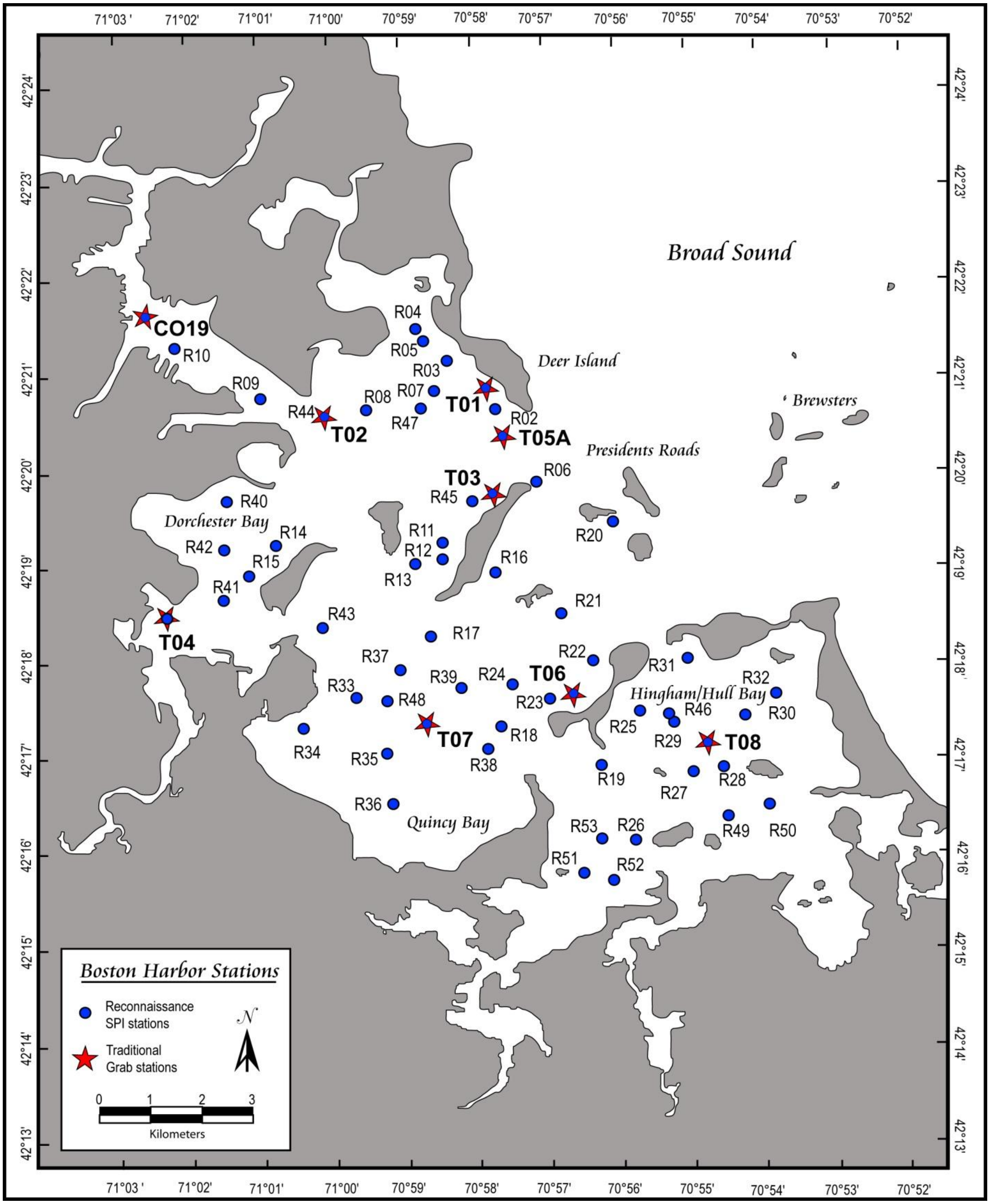



**Figure 1. Locations of soft-bottom sampling and sediment profile imaging stations for 2012.**

### 2.2 Laboratory Methods

Laboratory methods for benthic infauna and SPI image analyses were consistent with the QAPP (Nestler et al. 2013b). 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. 2013b) 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.

# 3. RESULTS AND DISCUSSION

## 3.1 Sediment Conditions

Sediment conditions in Boston Harbor were characterized by three parameters measured during 2012 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 2011 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 2012 remained consistent with results reported in prior years (Figure 3).

**Total Organic Carbon.** Concentrations of total organic carbon (TOC) in 2012 also remained similar to values reported in prior years (Figure 4). 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). A comparison of Figures 3 and 4 illustrates this association. During 2012, the highest concentrations of TOC were once again reported at Stations T04 and C019, two stations with the highest percent fine sediments. Nonetheless, although these stations have very similar grain size compositions, TOC concentrations remain higher at T04 than at C019 (Table 1, Figure 4). This 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 2012 were reported at Station T08.

***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 2012 were highest at Station T07 and lowest at station T04 (Table 1). Abundances at T04 were the lowest ever measured at this depositional site in Savin Hill Cove, continuing a general decrease observed since 2008 (Figure 5) after direct combined sewer overflow discharge to that area was ended. *C. perfringens* concentrations were second highest at C019 during 2012 but were comparable to those reported in 2011 at C019, 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).

Results during 2012 for grain size, TOC, and *C. perfringens* in Boston Harbor sediments, are consistent with prior year monitoring results (Maciolek et al. 2008, 2011; Pembroke et al. 2012). 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).

**Table 1. 2012 monitoring results for sediment condition parameters.**

| Parameter | C019 | T01 | T02 | T03 | T04 | T05A | T06 | T07 | T08 |
|---|---|---|---|---|---|---|---|---|---|
| ***Clostridium perfringens*** **(cfu/g dry/%fines)** | 167 | 93 | 146 | 151 | 7 | 47 | 63 | 268 | 53 |
| **Total Organic Carbon (%)** | 2.58 | 0.71 | 1.7 | 2.28 | 3.19 | 0.58 | 1.07 | 2.19 | 0.18 |
| **Gravel (%)** | 0 | 1.3 | 0.4 | 5.8 | 0 | 0.7 | 1.1 | 4.1 | 1.6 |
| **Sand (%)** | 4.2 | 68.5 | 44.8 | 21.5 | 9.3 | 76.1 | 67.1 | 32.6 | 93.9 |
| **Silt (%)** | 56.1 | 20.2 | 35.7 | 45.6 | 63.8 | 15.2 | 20.7 | 39.1 | 2.6 |
| **Clay (%)** | 39.7 | 10.1 | 19.2 | 27.1 | 26.9 | 8.0 | 11.1 | 24.2 | 1.9 |
| **Percent Fines (Silt + Clay)** | 95.8 | 30.2 | 54.9 | 72.7 | 90.7 | 23.2 | 31.8 | 63.3 | 4.5 |

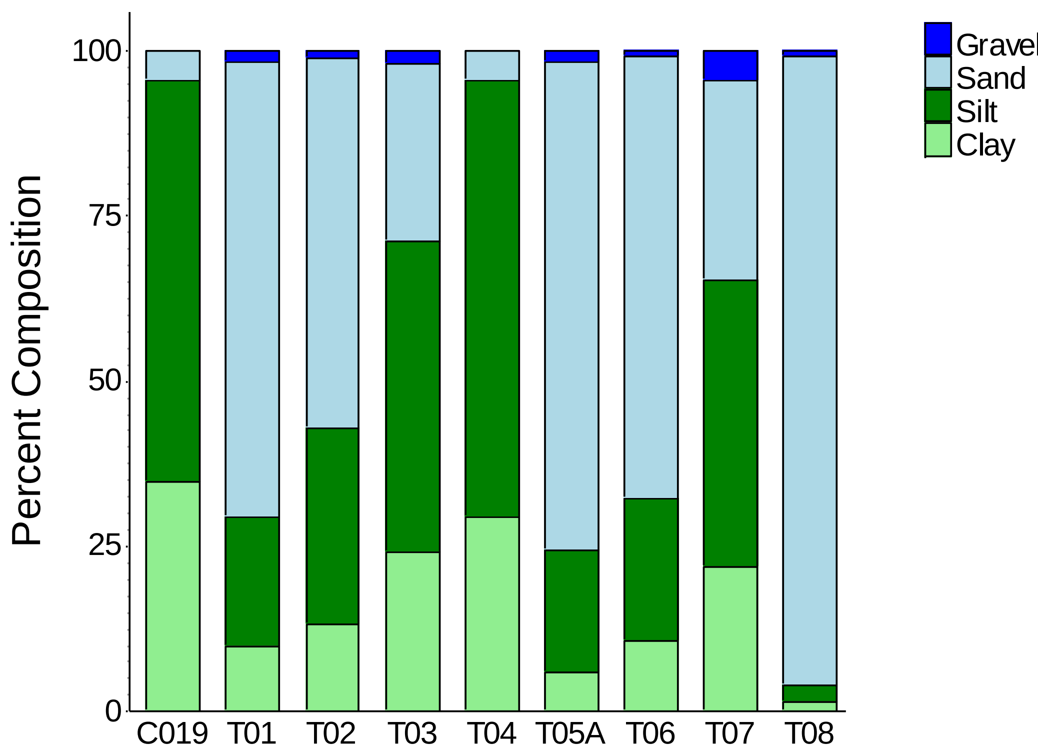



**Figure 2. 2012 monitoring results for sediment grain size.**

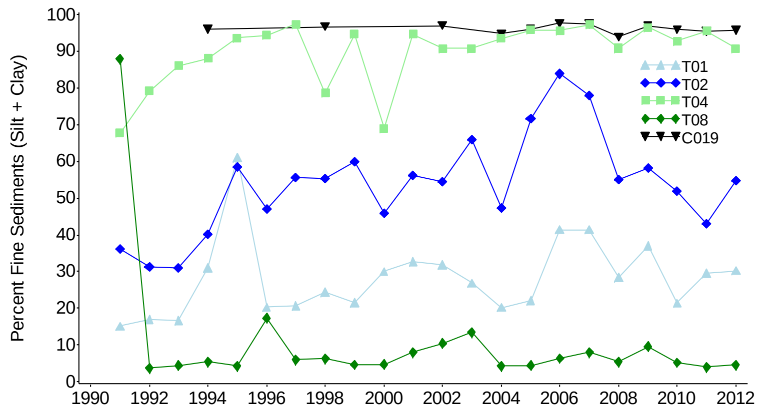



**Figure 3. Mean percent fine sediments at five stations in Boston Harbor, 1991 to 2012.**

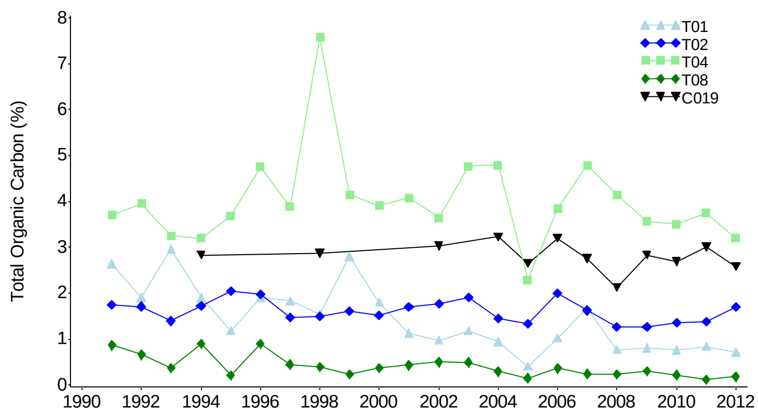



**Figure 4. Mean concentrations of TOC at five stations in Boston Harbor, 1991 to 2012.**

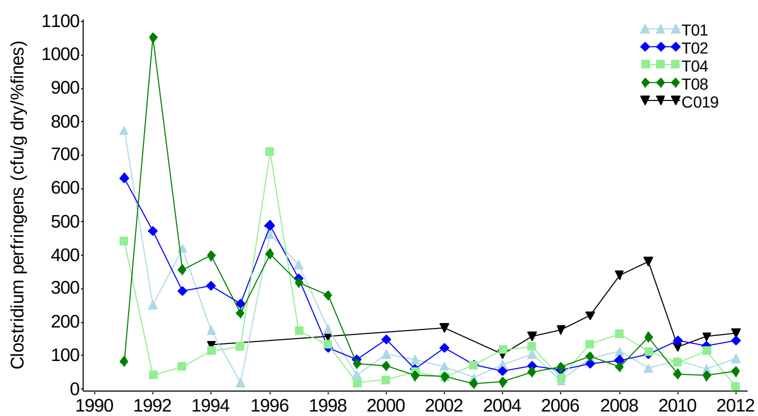



**Figure 5. Mean concentrations of *Clostridium perfringens* at five stations in Boston Harbor, 1991 to 2012.**

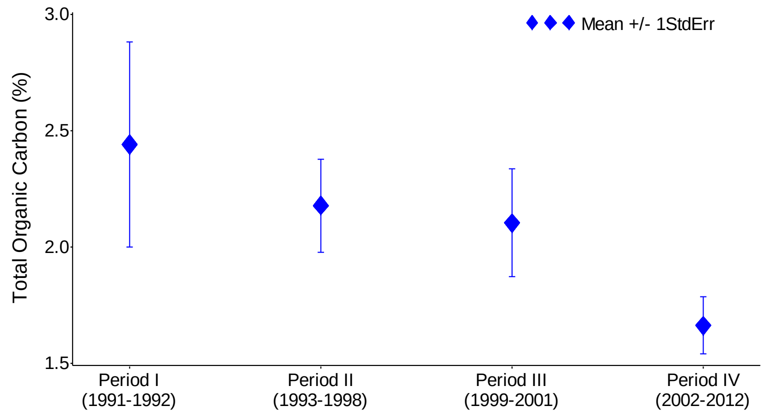



**Figure 6. Comparison of TOC across four discharge periods at Boston Harbor stations (T01-T08) from 1992 to 2012 (1991 excluded).**

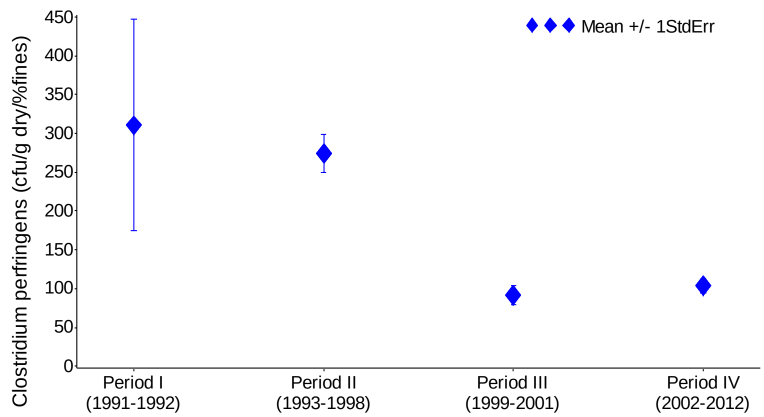



**Figure 7. Comparison of *Clostridium perfringens* across four discharge periods at Boston Harbor stations (T01-T08) from 1992 to 2012 (1991 excluded).**

## 3.2 Benthic Infauna

### 3.2.1 Community Parameters

A total of 35,121 infaunal organisms were counted from the 18 samples in 2012. Organisms were classified into 147 discrete taxa; 133 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. 2012 mean infaunal community parameters by station**

| Station | Total Abundance | Number of Species | Pielou's Evenness (J') | Shannon-Wiener Diversity (H') | Log-series alpha |
|---|---|---|---|---|---|
| C019 | 525.5 | 21.0 | 0.61 | 2.67 | 4.63 |
| T01 | 1528.5 | 43.0 | 0.59 | 3.17 | 8.32 |
| T02 | 4313.5 | 46.0 | 0.54 | 2.97 | 7.21 |
| T03 | 3954.0 | 51.5 | 0.57 | 3.26 | 8.40 |
| T04 | 307.5 | 13.5 | 0.46 | 1.67 | 2.94 |
| T05A | 1905.0 | 56.5 | 0.67 | 3.87 | 10.97 |
| T06 | 2984.0 | 48.0 | 0.61 | 3.41 | 8.15 |
| T07 | 467.0 | 29.0 | 0.67 | 3.22 | 6.97 |
| T08 | 1613.0 | 59.5 | 0.66 | 3.89 | 12.30 |

Mean abundance values reported for 2012 were generally similar or higher than in 2011 at individual stations (Pembroke et al. 2011). Abundances in 2012 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 $\geq$ 2.5% of the total abundance) the infauna at these stations in 2011 continued to do so in 2012 although the rank order changed (Table 3). Two species of oligochaetes and seven species of polychaetes were among the ten most abundant taxa in 2012.One change from 2011 was the substantial decline in abundance of amphipods in the genus *Ampelisca*, although they remained among the dominants. Other formerly dominant amphipods (*Orchomenella minuta* and *Photis pollex*) occurred at reduced abundances in 2012 as did the polychaete *Nepthys cornuta* so that none of these species were among the dominants. Abundance of the capitellid polychaete *Mediomastus californiensis* increased sufficiently to place it among the dominants. *M. californiensis* has commonly been among the dominants in fine-grained sediments in western Massachusetts Bay (Nestler et al. 2013a) but not 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. As previously observed, Stations T02 and T03 supported the highest abundances among the harbor stations. In 2011, Station T05A supported one of the most abundant infaunal communities but numbers in 2012 were less than half those in 2011 and abundances at Station T06 were higher in 2012 (double those seen in 2011).

Changes at Station T05A were largely driven by reductions in *Ampelisca* abundances. At Station T06, both *Ampelisca* and *M. californiensis* increased in abundance.

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. 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).

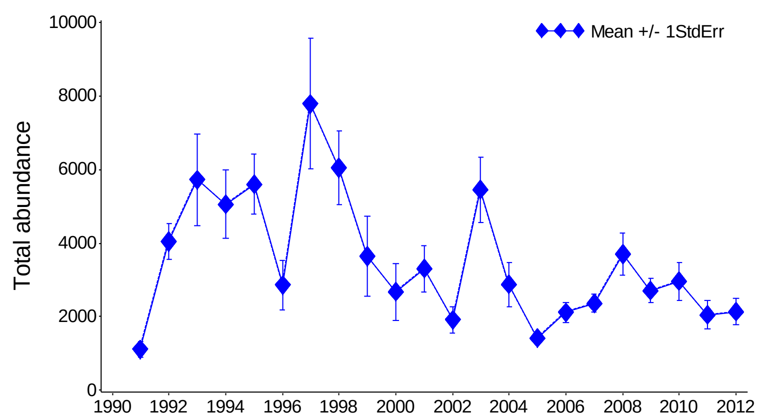



**Figure 8. Mean abundance of benthic infauna at eight Boston Harbor stations, 1991-2012.**

**Table 3. Dominant taxa at eight grab stations in Boston Harbor in August 2012.**

| Taxon | Total 2012 Abundance (compared with 2011[a]) |
|---|---|
| *Limnodriloides medioporus* | 5,785 (similar) |
| *Polydora cornuta* | 5,771 (increase) |
| *Aricidea catherinae* | 3,878 (double) |
| *Tubificoides intermedius*[b] | 3,736 (similar) |
| *Scoletoma hebes* | 2,530 (double) |
| *Ampelisca* spp. | 1,314 (90% decline) |
| *Mediomastus californiensis* | 1,172 (5-fold increase) |
| *Streblospio benedicti* | 1,053 (double) |
| *Tharyx* spp. | 925 (similar) |
| *Scolelepis bousfieldi* | 883 (increase) |

[a]2011 data adjusted to reflect 2 replicates rather than the 3 replicates reported in Pembroke et al. (2012)

[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), 1992-2012.**

| Phylum | Higher Taxon | Family | Species | Period I | Period II | Period III | Period IV | 2012 |
|---|---|---|---|---|---|---|---|---|
| Annelida | Polychaeta | Capitellidae | *Capitella capitata* complex | 65.2 | 88.8 | 3.4 | 6.0 | 1.9 |
| | | | *Mediomastus californiensis* | 7.0 | 7.6 | 7.7 | 20.5 | 72.4 |
| | | Cirratulidae | *Tharyx acutus* | 50.6 | 111.8 | 52.4 | 61.5 | 55.4 |
| | | Lumbrineridae | *Scoletoma hebes* | 3.4 | 10.5 | 4.2 | 54.4 | 158.1 |
| | | Nephtyidae | *Nephtys cornuta* | - | 11.4 | 10.3 | 229.7 | 3.3 |
| | | Paraonidae | *Aricidea catherinae* | 325.0 | 237.4 | 204.3 | 212.6 | 242.4 |
| | | Spionidae | *Polydora cornuta* | 525.8 | 1053.0 | 269.6 | 267.7 | 356.1 |
| | | | *Streblospio benedicti* | 236.0 | 298.6 | 27.7 | 53.8 | 65.4 |
| Annelida | Oligochaeta | Tubificidae | *Limnodriloides medioporus* | 484.7 | 297.9 | 315.2 | 218.3 | 361.4 |
| | | | *Tubificoides intermedius* | 42.6 | 101.4 | 231.2 | 253.6 | 232.4 |
| Arthropoda | Amphipoda | Ampeliscidae | *Ampelisca* spp. | 354.3 | 1698.3 | 1205.9 | 680.5 | 82.1 |
| | | Aoridae | *Leptocheirus pinguis* | 29.0 | 117.4 | 66.0 | 97.8 | 19.1 |
| | | Corophiidae | *Corophiidae* spp. | 16.1 | 336.2 | 23.0 | 1.6 | - |
| | | | *Crassicorophium bonellii* | 7.9 | 217.3 | 37.3 | 9.3 | - |
| | | Isaeidae | *Photis pollex* | 11.4 | 77.0 | 86.8 | 39.8 | 0.4 |
| | | Phoxocephalidae | *Phoxocephalus holbolli* | 28.0 | 116.9 | 125.9 | 7.8 | 5.4 |

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

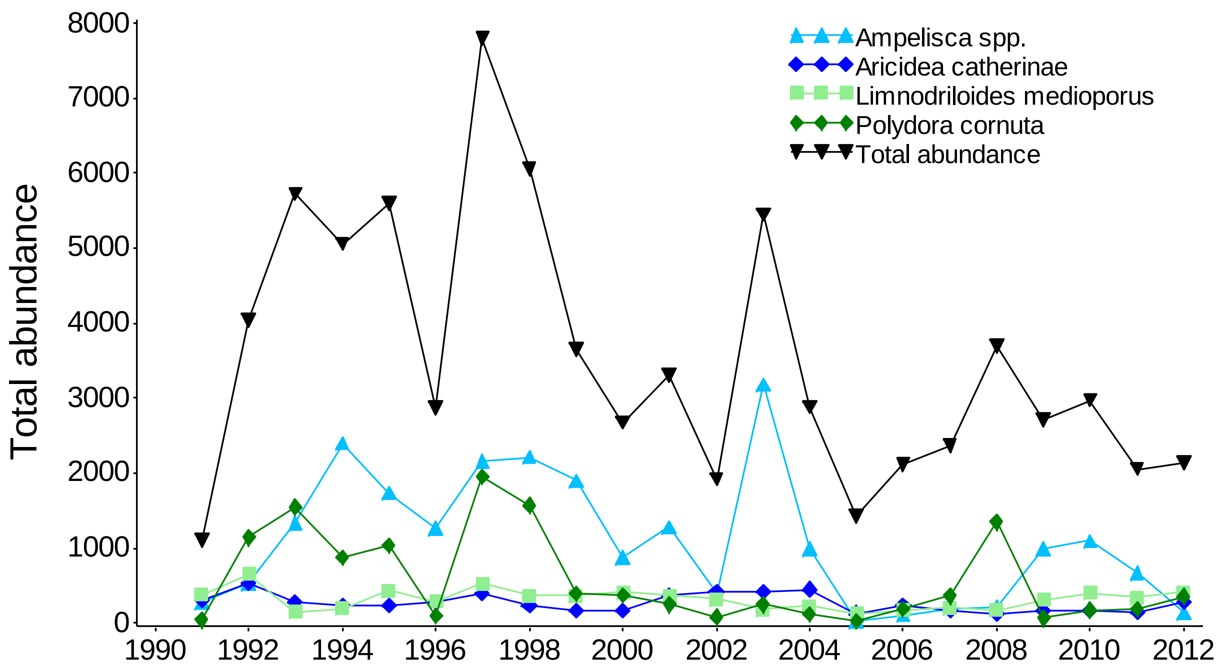



**Figure 9. Total abundance of four dominant taxa at eight Boston Harbor stations, 1991-2012.**

Patterns of abundance of *Ampelisca* spp. have been of particular interest throughout the past 21 years that Stations T01-T08 have been studied. Previous annual reports on the harbor surveys have related changes in the spatial extent of *Ampelisca* 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 average abundances of *Ampelisca* at these stations increased again in 2009, remaining at moderately high levels through 2011, and then declining in 2012 to levels comparable to those seen in 2005-2008 (Figure 10). Only three stations (T02, T03, and T05A) accounted for most of the higher abundances in 2009-2011; however, all of these stations exhibited a decline in 2012 (Figure 11). Each of these stations is located in the vicinity of the main shipping channel.

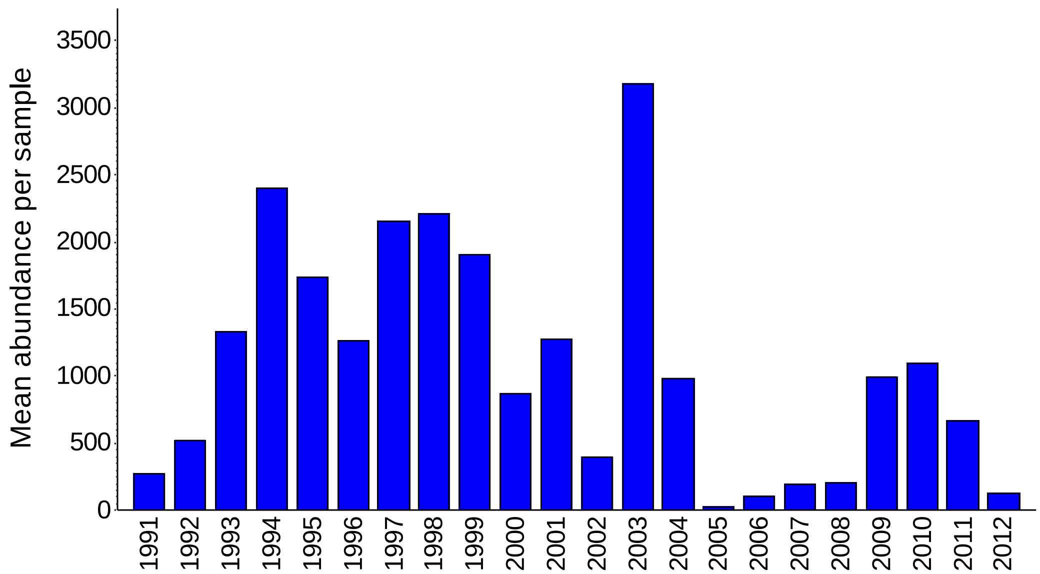



**Figure 10. Mean annual abundance of *Ampelisca* spp. averaged over eight Boston Harbor stations, 1991-2012.**

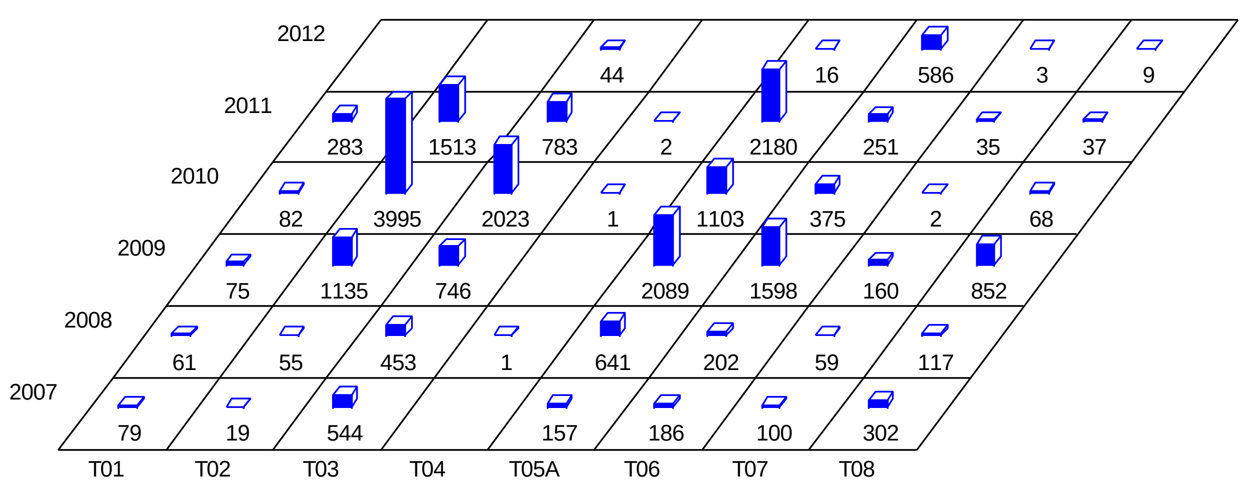



**Figure 11. Spatial distribution of *Ampelisca* spp. at eight Boston Harbor stations, 2007-2012.**

The numbers of species reported for 2012 ranged from 13 to 59 per station and averaged around 41 species per sample, higher than numbers reported in most years in the1990s and about average for the 2000s, when species richness exhibited inter-annual variation (Figure 12). The increase in species richness compared to 2011 appeared to reverse a decreasing trend that was observed in 2009 through 2011 (Maciolek et al. 2011; Pembroke et al. 2012). As with abundance, species richness followed similar spatial patterns to those observed previously. Stations T02, T03, T05A, and T08 exhibited the highest species richness and Stations C019, T07, and T04 supported the lowest species richness in both 2011 (Pembroke et al. 2012) and 2012.

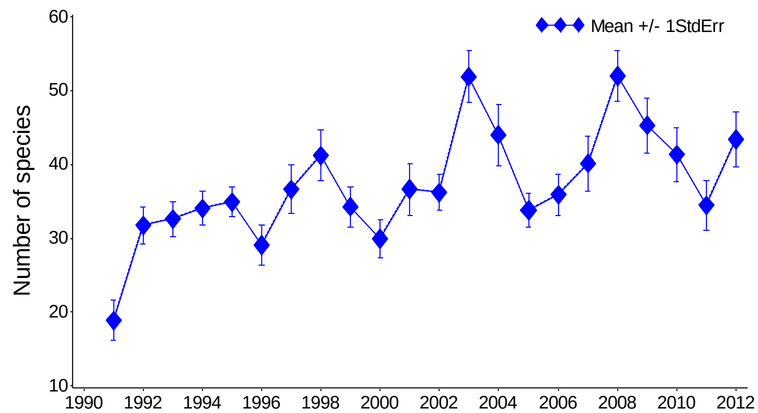



**Figure 12. Mean species richness at eight Boston harbor stations, 1991-2012.**

Measures of community structure including Pielou's evenness and Shannon-Weiner diversity were similar but slightly higher in 2012 compared to 2011 when averaged across the harbor stations (Figures 13 and 14). 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. Although there was a sharp increase in average diversity as measured by log-series alpha between 2011 and 2012 when values were among the highest observed during the program (Figure 15), the spatial pattern observed in 2012 was consistent with that seen in 2010 and 2011.

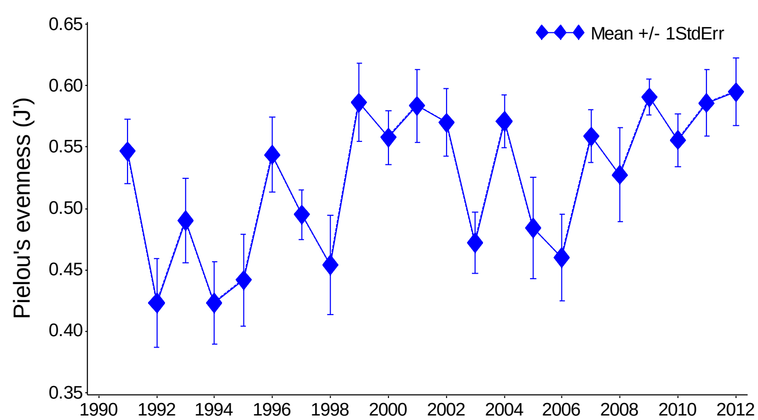



**Figure 13. Mean community evenness at eight Boston Harbor stations, 1991-2012.**

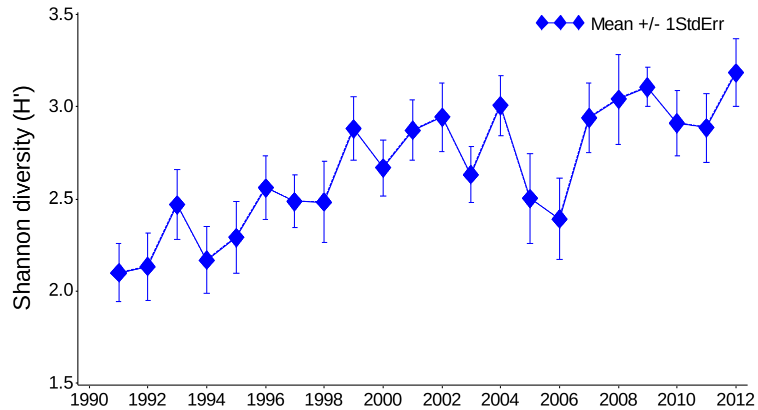



**Figure 14. Mean Shannon-Weiner diversity at eight Boston harbor stations, 1991-2012.**

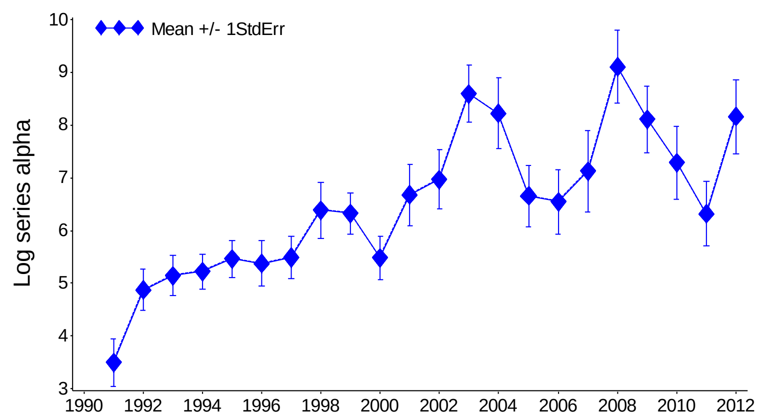



**Figure 15. Mean log-series alpha diversity at eight Boston Harbor stations, 1991-2012.**

### 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 2012 and included both replicates from each of 5 stations (T01, T02, T03, T05A, and T06); T08 was closely associated with the main group but species composition differed sufficiently to treat this station separately. Replicates from three other stations (T04, T07, and C019) also each formed their own discrete groups (Figure 16) as they had in 2011 (Pembroke et al. 2012). Average community parameters, including total abundance, number of species, Shannon-Weiner and log-series alpha diversity, were all notably higher at stations in the main group and at T08 than at T04, T07, or C019 (Table 2). The oligochaete *Limnodriloides medioporus* and the polychaete *Polydora cornuta* co-dominated in the main group and several other species (mostly polychaetes) were relatively abundant in this group (Table 5). With few exceptions, the dominants in the other stations differed from those in the main group. At T08, where total abundance was relatively high, oligochaetes occurred in very low numbers and the polychaete *Polygordius jouinae* was the dominant species, although several other species were relatively abundant.

Stations T04, T07, and C019 were each characterized by relatively low abundances and only one or two dominant species. The harbor benthic infaunal community differed from that observed in 2011 by the low abundance of the tube-dwelling amphipod *Ampelisca* spp. (comprising *A abdita* and *A. vadorum*) in 2012. Low abundances of *Ampelisca* spp. at T04, T07, and C019 are consistent with recent patterns (Maciolek et al. 2011; Pembroke et al. 2012) whereas Group I included most of the stations where *Ampelisca* spp. has historically been abundant (Figure 11). Stations T04 (Dorchester Bay) and C019

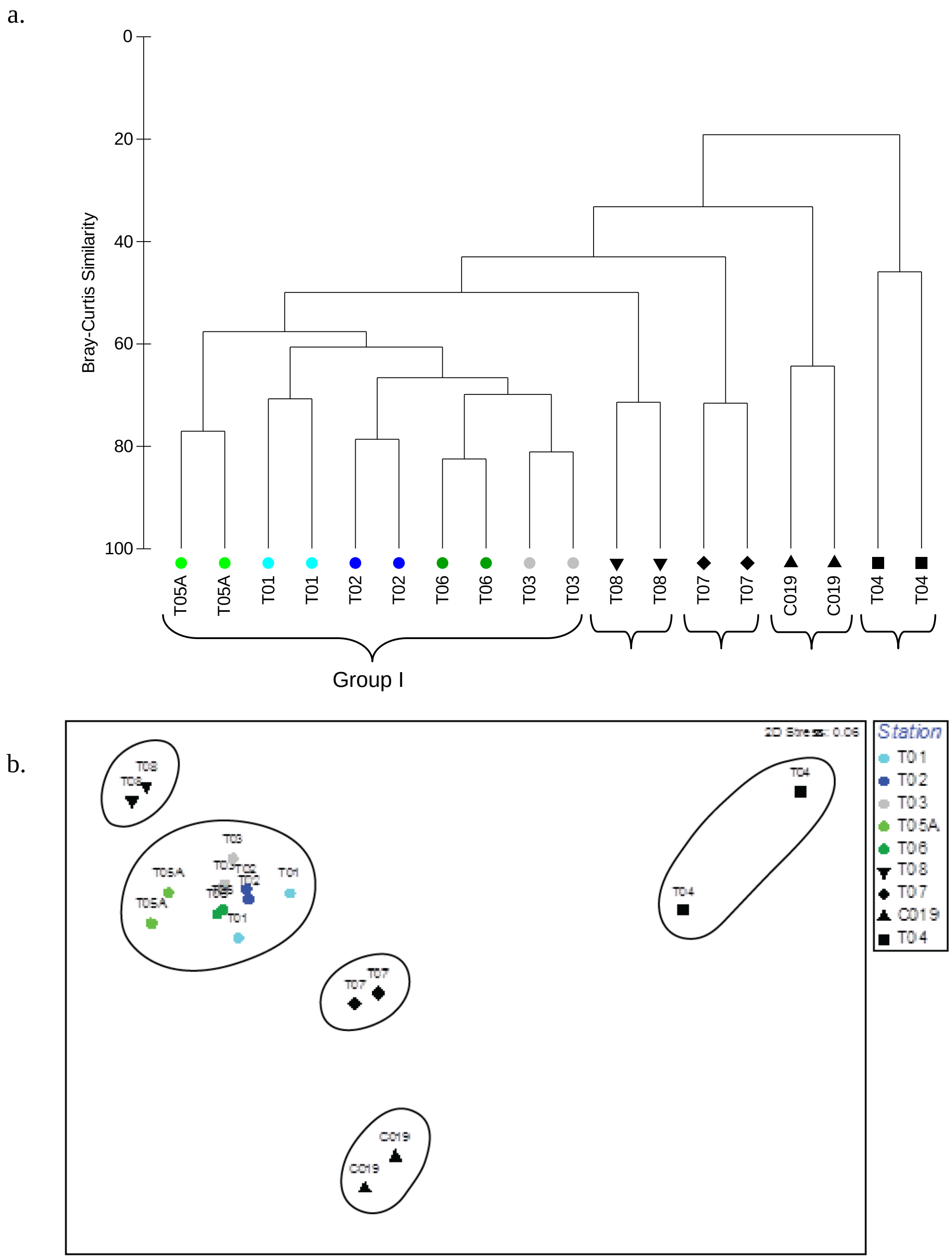



**Figure 16. Results of (a) cluster analysis and (b) multidimensional scaling analysis of the 2012 infauna samples.**

**Table 5. Mean abundance of dominant taxa in 2012 Boston Harbor station groups defined by cluster analysis.**

| Phylum | Major Taxon | Family | Species | I | T08 | T07 | C019 | T04 |
|---|---|---|---|---|---|---|---|---|
| Mollusca | Gastropoda | Nassariidae | *Ilyanassa trivittata* | 14.1 | 4.5 | 0.5 | 5.5 | - |
| | Bivalvia | Tellinidae | *Angulus agilis* | 20.4 | 113.5 | 1.0 | - | 0.5 |
| Annelida | Polychaeta | Capitellidae | *Mediomastus californiensis* | 114.5 | 3.5 | 3.0 | 7.0 | - |
| | | Cirratulidae | *Chaetozone anasimus* | 0.8 | 41.0 | - | - | - |
| | | | *Chaetozone cf. vivipara* | - | 1.0 | 6.0 | 172.5 | - |
| | | | *Monticellina baptisteae* | 5.1 | 55.0 | - | - | - |
| | | | *Tharyx acutus* | 62.1 | 117.0 | 15.0 | 19.5 | 0.5 |
| | | Lumbrineridae | *Scoletoma hebes* | 229.7 | 10.5 | 104.5 | 0.5 | 1.0 |
| | | Nephtyidae | *Nephtys cornuta* | 3.5 | - | 8.5 | 95.0 | 0.5 |
| | | Orbiniidae | *Leitoscoloplos robustus* | 12.8 | 20.0 | 7.0 | - | - |
| | | Paraonidae | *Aricidea catherinae* | 358.0 | 145.5 | 3.5 | - | - |
| | | Polygordiidae | *Polygordius jouinae* | 2.7 | 383.0 | - | - | - |
| | | Polynoidae | *Harmothoe imbricata* | 0.1 | - | - | - | 1.5 |
| | | Spionidae | *Dipolydora socialis* | 74.6 | 35.5 | - | 0.5 | 0.5 |
| | | | *Polydora cornuta* | 540.3 | 110.5 | 3.5 | 36.5 | 33.5 |
| | | | *Prionospio steenstrupi* | 9.7 | - | 2.0 | 0.5 | 1.0 |
| | | | *Scolelepis bousfieldi* | 84.8 | 15.5 | 1.5 | - | 0.5 |
| | | | *Spiophanes bombyx* | 5.9 | 158.5 | - | - | - |
| | | | *Streblospio benedicti* | 49.9 | 3.5 | 116.5 | 3.0 | 154.0 |
| | | Syllidae | *Exogone hebes* | 4.0 | 129.5 | - | - | - |
| | | Terebellidae | *Polycirrus phosphoreus* | 2.2 | - | 25.5 | 2.0 | - |
| Annelida | Oligochaeta | Naididae | *Naididae* sp. 5 | 28.7 | 12.0 | 38.5 | - | - |
| | | Tubificidae | *Limnodriloides medioporus* | 565.9 | 5.0 | 56.0 | 1.5 | 0.5 |
| | | | *Tubificoides intermedius* | 365.2 | 7.5 | 25.5 | 9.0 | - |
| | | | *Tubificoides sp. 2* | - | - | - | - | 3.5 |
| Arthropoda | Mysidacea | Mysidae | *Heteromysis formosa* | - | - | 1.5 | 1.0 | 7.5 |
| | Amphipoda | Ampeliscidae | *Ampelisca* spp. | 129.0 | 8.5 | 3.0 | 0.5 | - |
| | | Aoridae | *Leptocheirus pinguis* | 29.9 | 1.5 | 1.5 | 96.0 | - |
| | | | *Microdeutopus anomalus* | 0.1 | - | - | - | 16.5 |
| | | | *Unciola irrorata* | 8.9 | 1.0 | - | 9.0 | - |
| | | Corophiidae | *Monocorophium acherusicum* | 1.4 | 1.0 | - | - | 67.5 |
| | | Lysianassidae | *Orchomenella minuta* | 21.2 | - | - | 8.0 | - |
| | Decapoda | Portunidae | *Carcinus maenas* | - | - | - | - | 3.0 |

(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 2012, the number of taxa rose again, averaging 29 species per sample and sediment grain size distribution was similar to historical values.

### 3.2.3 Selected Stations

**Station T01.** 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 2012, total abundance at T01 was slightly below the eight-station average but other community parameters at this station were generally equal to or higher than the means for Stations T01-T08. Evenness decreased at T01 but the other parameters remained the same or increased in 2012 compared to 2011. Mean abundance was slightly lower in 2012 than from 2006 through 2010, but remained higher than 1999-2000 and 2002-2005 (Figure 17). Species richness rose to a level typical of that seen in most years since 1991 (Figure 18), and Shannon-Weiner diversity (Figure 19) and Pielou's evenness (Figure 20) remained at or above levels observed since the mid-1990s, indicating that the substrate at this station continued to support a benthic community with a varied species composition with relatively even distribution of abundances. Mean log-series alpha increased compared to 2011, attaining a similar level to that observed in 2010.

**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 setosa*. There was a substantial increase in species richness in 2008-2010 followed by a decline in 2011 (Figure 18). Species richness in 2012 was the highest observed to date. Mean abundance also increased in 2012 although it was only about half the peaks observed in 2005 and 2008 (Figure 17). All measures of diversity spiked in 2012 (Figures 19, 20, and 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 (Table 5). The decrease in the relative contribution of a single species to the total abundance explains the increase in the evenness, Shannon-Weiner, and log-series alpha indices.

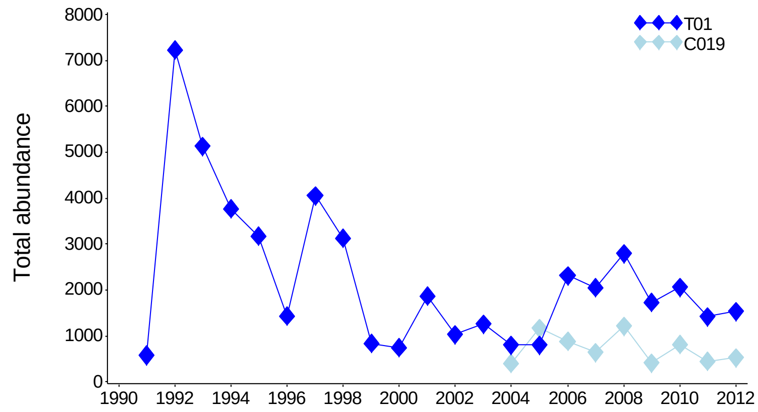



**Figure 17. Mean total abundance at Boston Harbor Stations T01 and C019, 1991-2012.**

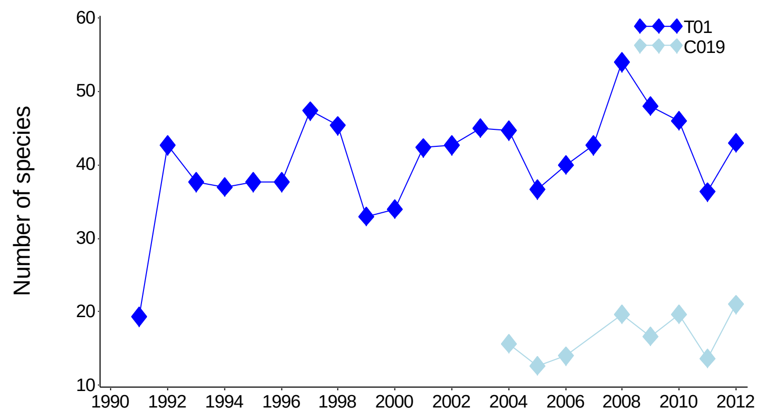



**Figure 18. Mean species richness at Boston Harbor Stations T01 and C019, 1991-2012.**

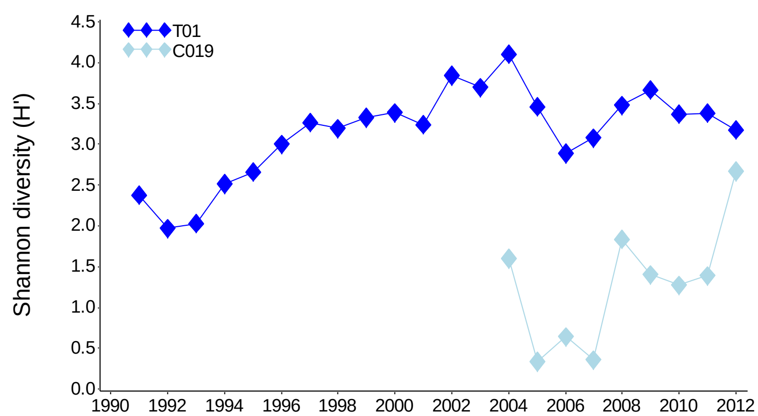



**Figure 19. Mean Shannon-Weiner diversity at Boston Harbor Stations T01 and C019, 1991-2012.**

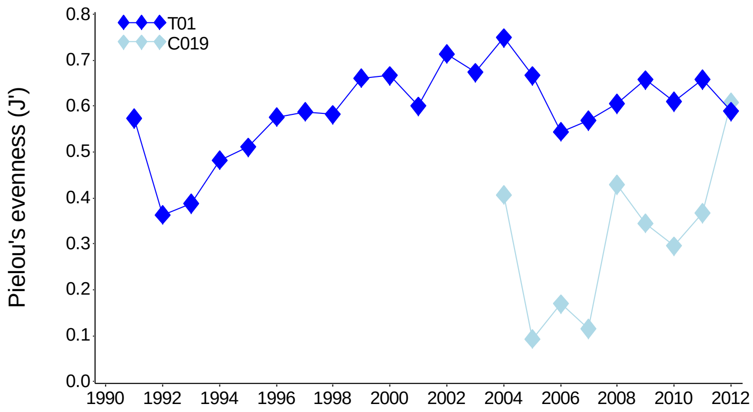



**Figure 20. Mean evenness at Boston Harbor Stations T01 and C019, 1991-2012.**

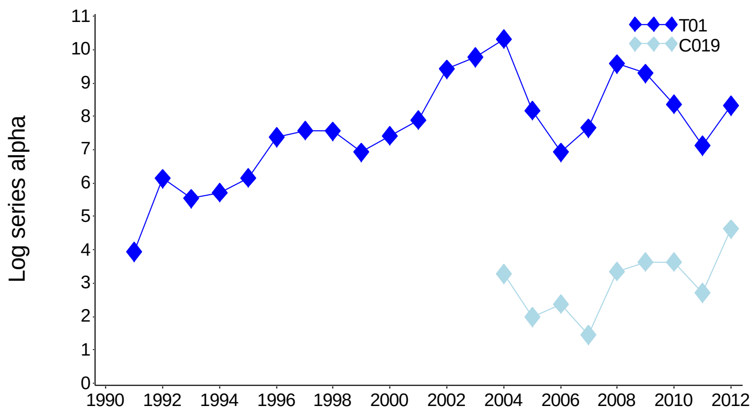



**Figure 21. Mean log series alpha diversity at Boston Harbor stations T01 and C019, 1991-2012.**

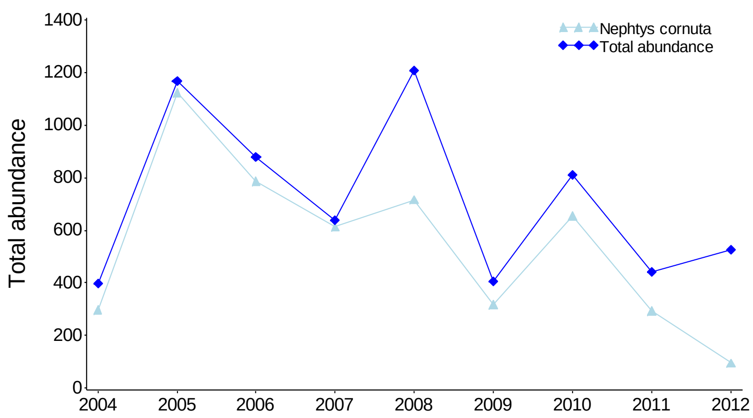



**Figure 22. Mean abundance of *Nephtys cornuta* and total community abundance at Station C019, 2004-2012.**

### 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) and described in Section 3.1 (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 2001-2012 were virtually the same as for 2001-2011 (Pembroke et al. 2012) 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 (1991-1992) | | Period II (1993-1998) | | Period III (1999-2001) | | Period IV (2001-2012) | |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std Err | Mean | Std Err | Mean | Std Err | Mean | Std Err |
| **Total Abundance** | 2606.4 | 343.64 | 5513.4 | 469.00 | 3213.4 | 492.66 | 2717.6 | 155.18 |
| **Log-series alpha** | 4.2 | 0.31 | 5.51 | 0.17 | 6.16 | 0.27 | 7.54 | 0.20 |
| **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 | 41.61 | 1.08 |

## 3.3 Sediment Profile Imaging

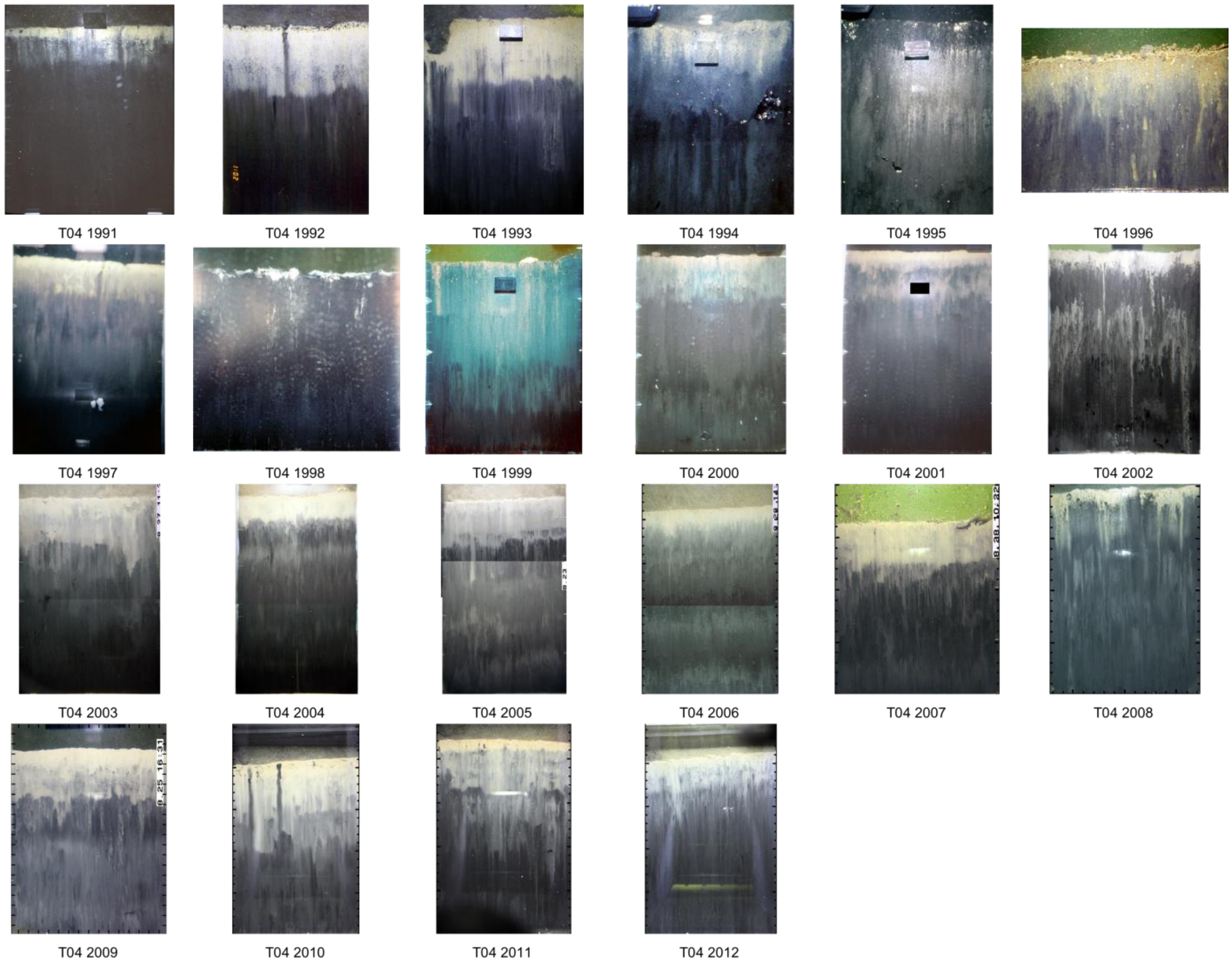
Within Boston Harbor there was little change in soft bottom benthic habitat conditions in 2012 relative to the last ten years. Much if not all of the improvement in water quality and benthic habitat quality over the last 25 years can be attributed to upgrades in wastewater treatment starting in the late 1980s, movement of outfalls from the inner harbor to outer harbor in the 1990s, and startup of the ocean outfall in the early 2000s, which ended sewage discharges within the harbor (Diaz et al. 2008, Taylor 2010, Taylor et al. 2011). Recovery of benthos at inner and mid harbor stations has closely followed the classic Pearson-Rosenberg (1978) organic gradient model. By 2000, northern and inner harbor stations, such as T04 in inner Dorchester Bay (Figure 23) and R43 in outer Dorchester Bay (Figure 24) had improved in habitat quality. As the legacy of excess organic and nutrient loading from sewage dissipated, the last year bacterial mats were observed at T04 was 1998 and at R43 evidence of increasing deeper bioturbation appeared in 1999. This closely follows the trends in sediment organic matter with a shift from more sewage derived to more marine derived organic matter between 1990 and 1998 (Tucker et al. 1999). Further evidence of improved conditions is the persistence of an eelgrass bed at Station R08 on Deer Island Flats since 2008 (Figure 25).

The four sediment flux stations also provide good examples of the recovery from organic loading and progression of improved benthic community structure and habitat quality. At three of the four harbor flux stations (T03 off Long Island, T07 in Quincy Bay, and T08 in Hingham Bay, Figures 26 to 28) there was a decline in total organic carbon (TOC) from 1995 to 2008 (Tucker et al. 2009). At the fourth flux station (T02 in President Roads near the Charles River mouth, Figure 29) TOC was never higher than about 2% and has slowly declined to about 1.5% over this period. High levels of bioturbation from large numbers of the amphipod *Leptocheirus pinguis* that recruited in 2007 and 2008 likely drove much of the change in sediment biogeochemistry at T02 (Figures 30 and 31). Overall, TOC at eight harbor T-stations declined from an average of about 2.5% in 1991-1992 to about 1.7% from 2002 to 2011 (Pembroke et al. 2012) and it continued to decline in 2012 (1.5%, Table 1). The range in TOC at these stations in 2012 was about 0.2% at T08 to about 3.2% at T04 (Table 1). These two stations consistently represented the broad range of soft bottom benthic habitats within Boston Harbor with T08 being the highest quality and T04 the lowest (Diaz et al. 2008).

Outer harbor stations were more strongly influenced by hydrodynamic and marine factors than inner harbor stations and always have had higher habitat quality from the beginning of SPI monitoring in 1991. Tucker et al. (1999) found a similar pattern for incorporation of sewage derived organic matter into the sediments with outer harbor locations having a greater marine influence. But outer harbor stations did show improvement from reductions in loadings and operation of the ocean outfall, following a combination of the Pearson-Rosenberg organic gradient model and the intermediate disturbance hypothesis (Pearson and Rosenberg 1978, Connell 1978). Pearson and Rosenberg predicted lower abundance, higher diversity, higher biomass, and an advanced successional stage at lower levels of organic loading, which would favor larger and long-lived species. Intermediate disturbance hypothesis predicts higher diversity at intermediate levels of disturbance, such as that provided by strong hydrodynamic influence near the mouth of Boston Harbor, which would favor both the short-lived opportunistic species and longer-lived equilibrium species. In 2012, the benthos at the T-stations followed this general pattern with higher diversity and moderate abundance at the outer harbor stations.

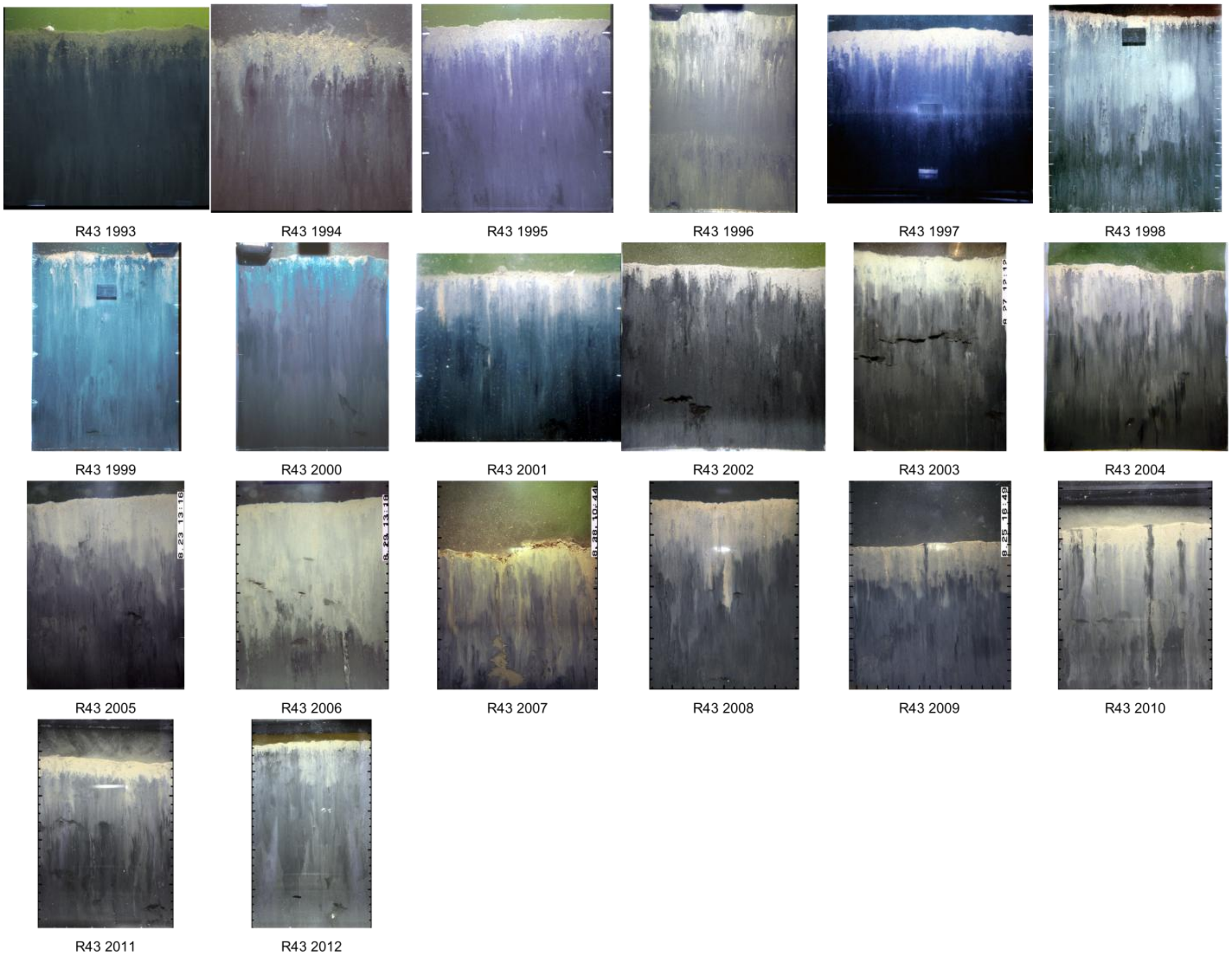
These changes in benthos and benthic habitat quality can be inferred from the changes in sediment color, and texture and fabric through time. Lighter colored sediments tend to contain less organic matter and are less sulphitic, as has been documented in Boston Harbor by Tucker et al. (2009). The burrowing lifestyle is important in geochemical processes and creates fine-scale sediment texture and fabric distinctive from physical processes that tend to produce larger structures such as laminations or repetitive pattern sediments (Rhoads 1967, Jones and Jago 1993, Bentley and Sheremet 2003). At station R31 in Hingham Bay (Figure 32), R02 on Deer Island Flats (Figure 33), R20 in Nantasket Roads (Figure 34), and T03 off Long Island (Figure 35), sediments tended to become lighter and develop more fabric through time. 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 (Tucker et al. 2002). There were also corresponding decreases in primary production due to reduced nutrient loadings, which would have also lessened carbon loading to the sediments (Oviatt et al. 2007). The change in biogeochemistry, driven primarily by infaunal bioturbation, can be seen at station T02 in both the SPI and redox profiles (Figure 31). From the early to late 1990s, measurements of the depth of the redox-potential discontinuity (RPD) layer were about 2 cm (Figure 30). In the early 2000s the RPD layer had deepened to about 6 cm and by 2008 to 10 cm. Over the same interval, the apparent color RPD layer (aRPD) measurements went from 1.5 cm to 3.8 cm. These changes corresponded with an increase in bioturbation and shift to a more oxic versus anoxic status of the sediments (Diaz et al. 2008, Tucker et al. 2002). By 2008, the sediments were oxic to about 6 cm and suboxic to at least 18 cm (Tucker et al. 2009).

Much of the recovery in benthic habitat quality can be attributed to the dynamics of the tube building amphipod *Ampelisca* spp., which can reach very high densities and form thick tube mats (Figure 36). Over the 21 years of SPI monitoring, biogenic activity associated with the presence of *Ampelisca* spp. tubemats, which included larger deep dwelling species such as nemerteans and maldanid polychaetes, had the most influence on habitat quality. At some time between 1990 and 1992, the start of SPI monitoring, there was an increase in the occurrence of *Ampelisca* spp. tube mats (Figure 37). 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 between 1994 and 1997, likely in response to 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 *Ampelsica* 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. *Ampelisca* spp. likely contributed to the relatively rapid shift in source of sediment organic matter from sewage derived to marine derived sources between 1990 and 1998 (Tucker et al. 1999). The decline in tube mats started in 1998 and by 2005 no tube mats were observed at the 63 SPI monitoring stations. This decline in *Ampelisca* spp. would be part of the benthic recovery as the dominant *Ampelisca* species, *A. vadorum* and *A. abdita*, are known to be intermediate successional species (McCall 1977). The loss of tube mats in 2005 may have also been associated with a strong storm in late 2004 (Butman et al. 2008) that disrupted tube mats or interfered with recruitment. During the period of low *Ampelisca* spp. abundance, benthic microalgal mats developed reaching a peak in 2007 at 18% of stations. *Ampelisca* spp. tube mats reappeared in 2006 and coincident with their spike in 2008, microalgal mats disappeared. *Ampelisca* spp. mats have now increased to levels seen in the late 1990s (Figure 37). Abundances of *Ampelisca* spp. averaged over the infaunal stations have roughly paralleled the pattern of mat prevalence. The occurrence of the *Ampelisca* spp. tube mats shifted from year to year likely driven by physical factors such as storms that control settlement success at the outer harbor stations and quality/quantity of organic matter that controls density at inner harbor stations (Figure 38). The widespread resurgence of tube mats was unexpected and may be linked to higher quality organic matter from harbor primary production or imported marine derived organic matter.



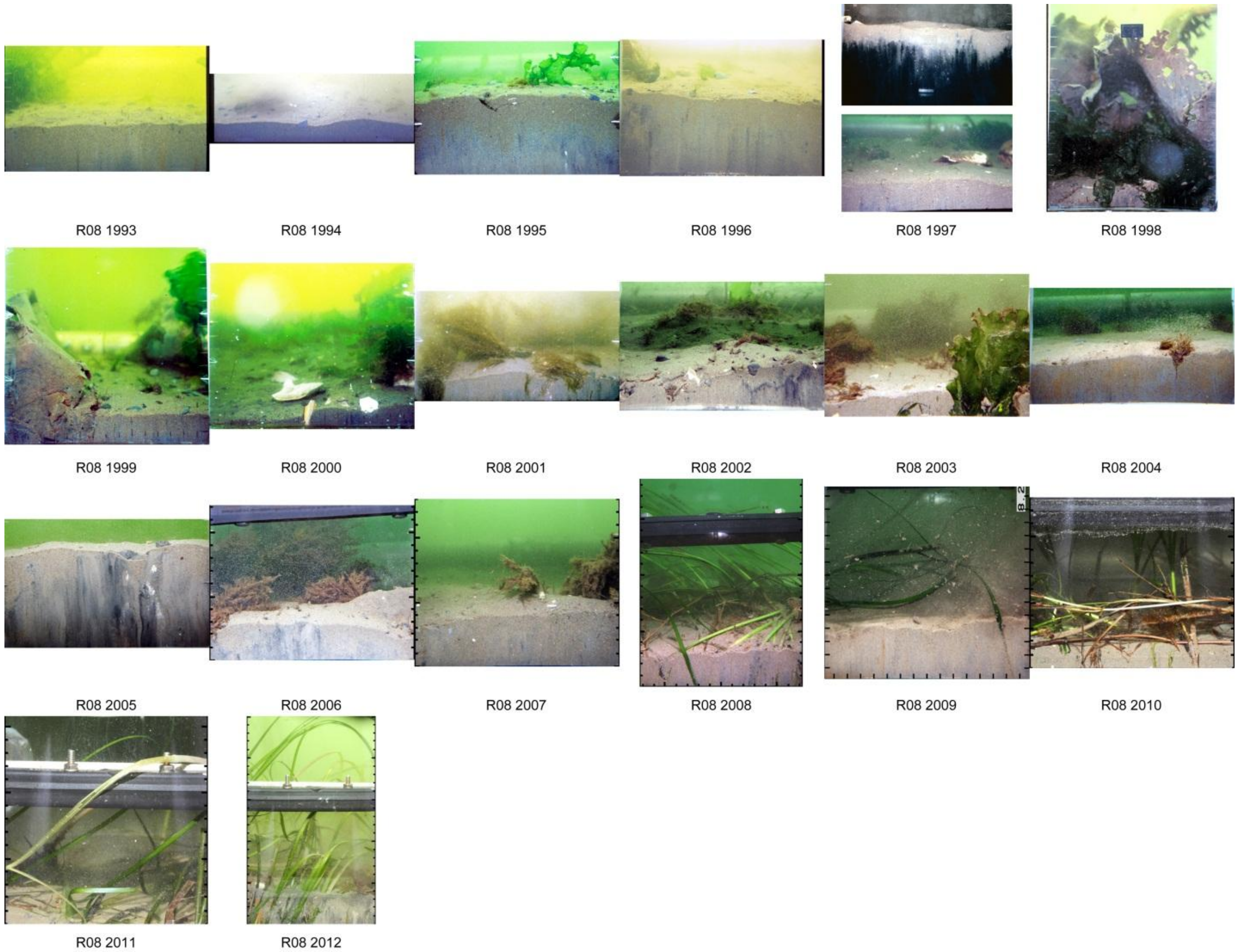

(Notes: baseline period is 1991-2000; scale along side of each image is in cm)

**Figure 23. Thumbnail SPI images from station T04 located in inner Dorchester Bay showing improved habitat conditions. In 1994, 1995, and 1998 hypoxic conditions appear to be present. Traces of a bacterial mat are present on the surface in 1998.**



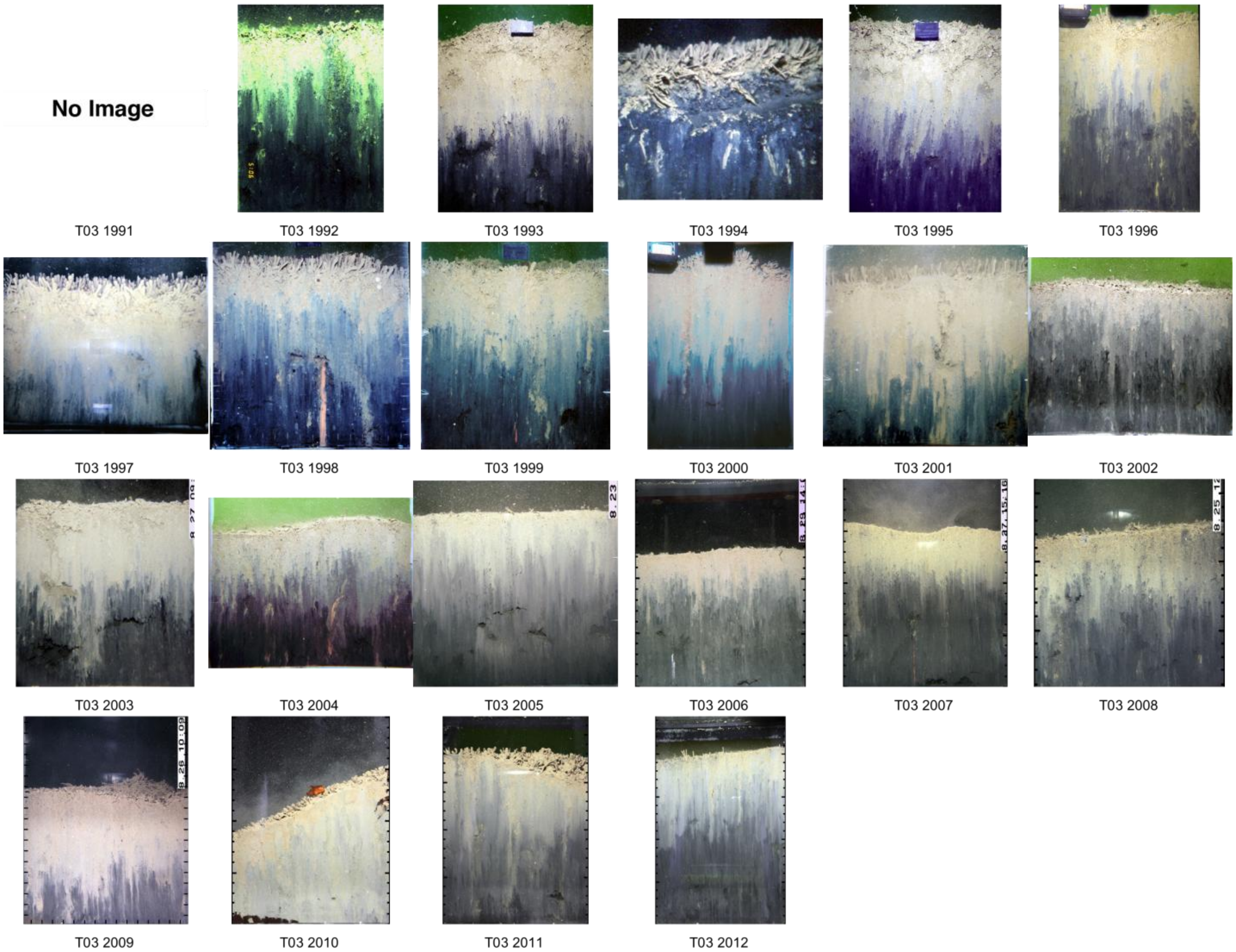

(Notes: baseline period is 1991-2000; scale along side of each image is in cm)

**Figure 24. Thumbnail SPI images from station R43 located in outer Dorchester Bay showing improved habitat conditions with deeper bioturbation being more prevalent through time starting in the mid 2000s.**



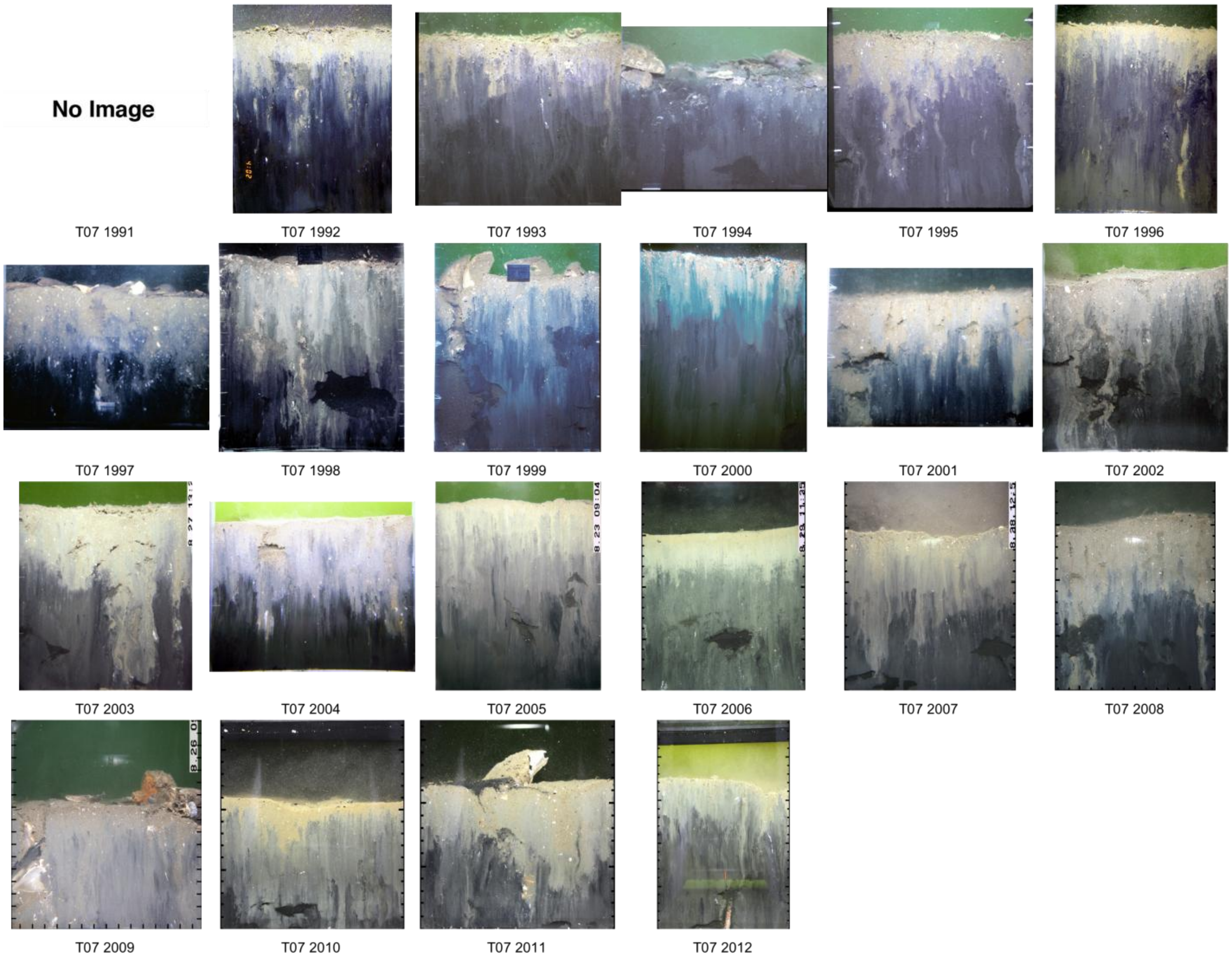

(Note: Scale on sediment profile image is in cm)

**Figure 25. Eelgrass bed at Station R08 on Deer Island Flats persisted from 2008.**



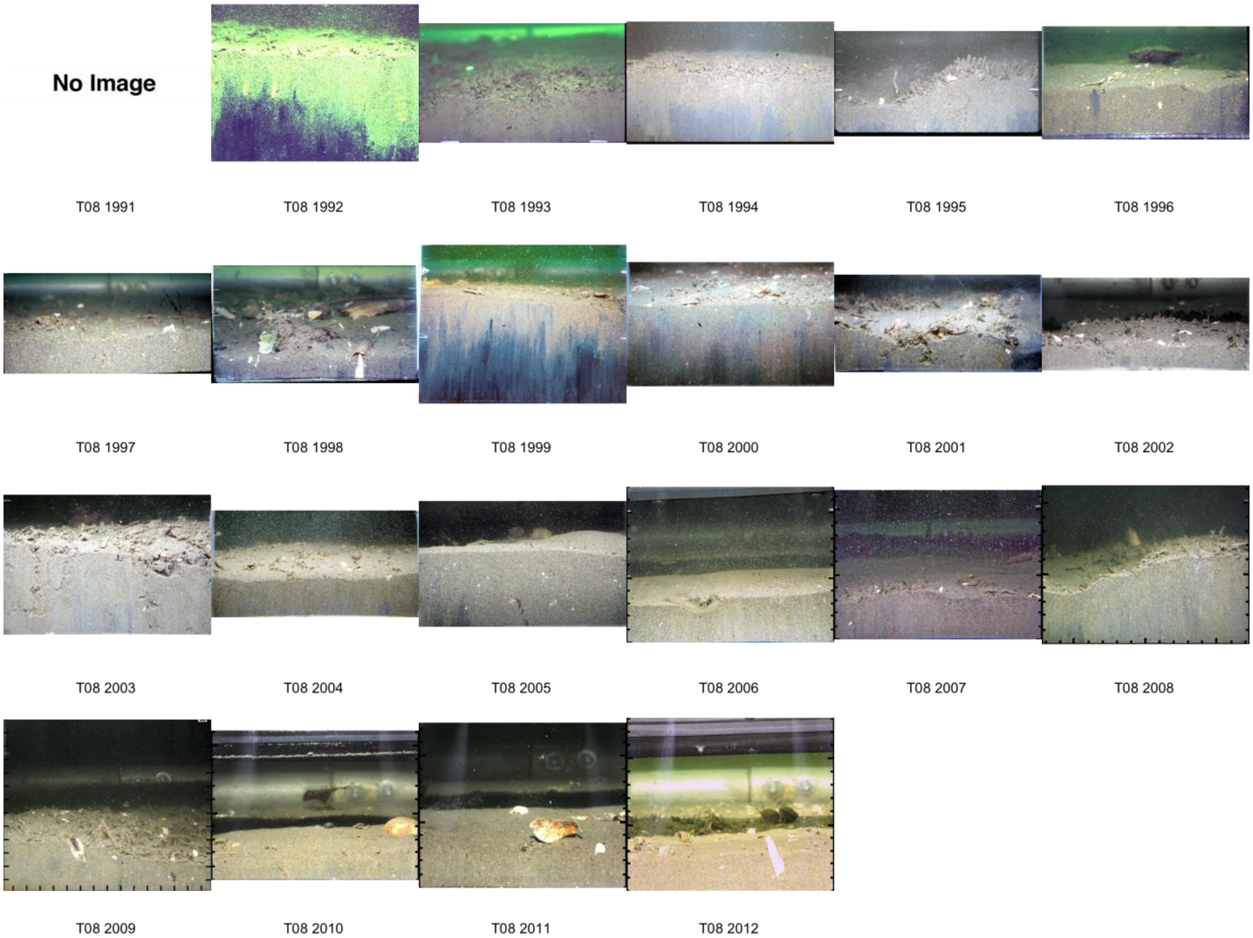

(Notes: baseline period is 1991-2000; scale along side of each image is in cm)

**Figure 26. Thumbnail SPI images from station T03 located off Long Island showing good habitat conditions during the baseline years and improved conditions with deeper bioturbation being more prevalent through time starting in the mid 2000s.**



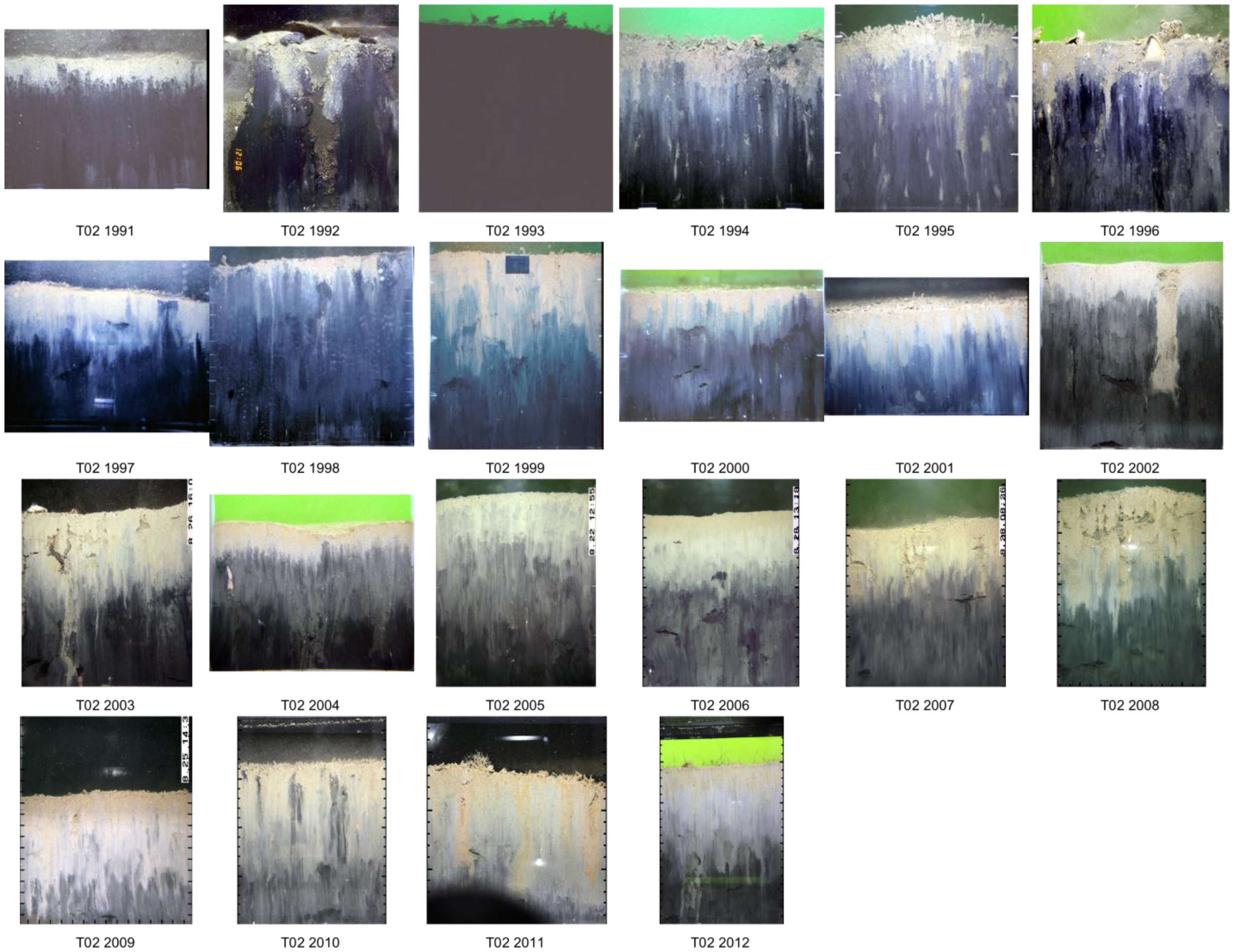

(Notes: baseline period is 1991-2000; scale along side of each image is in cm)

**Figure 27. Thumbnail SPI images from station T07 located in Quincy Bay showing improved habitat conditions with deeper bioturbation being more prevalent through time starting in the mid 2000s and declining sediment organic matter.**



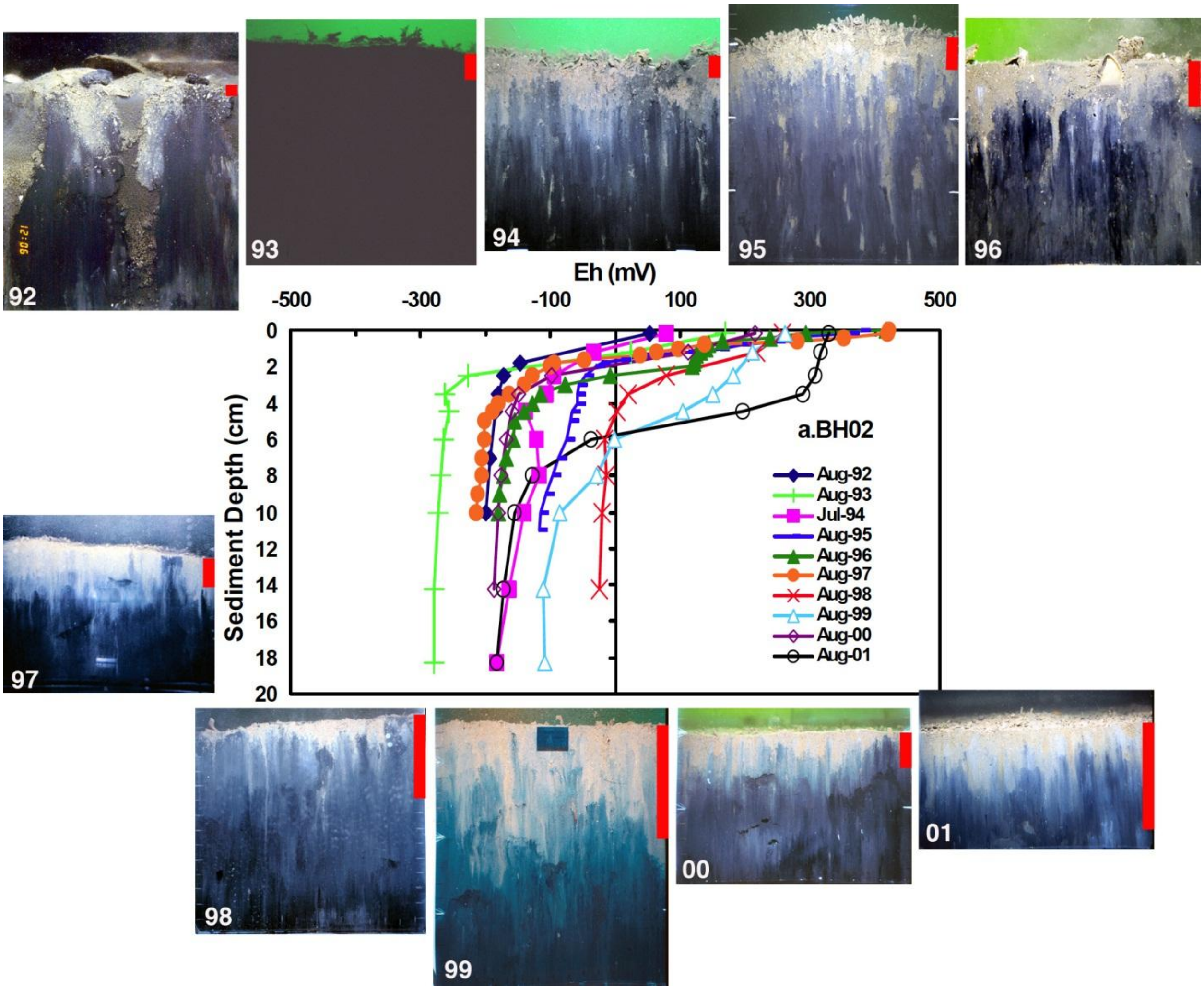

(Notes: baseline period is 1991-2000; scale along side of each image is in cm)

**Figure 28. Thumbnail SPI images from station T08 located in Hingham Bay showing improved habitat conditions with declining sediment organic matter through time.**



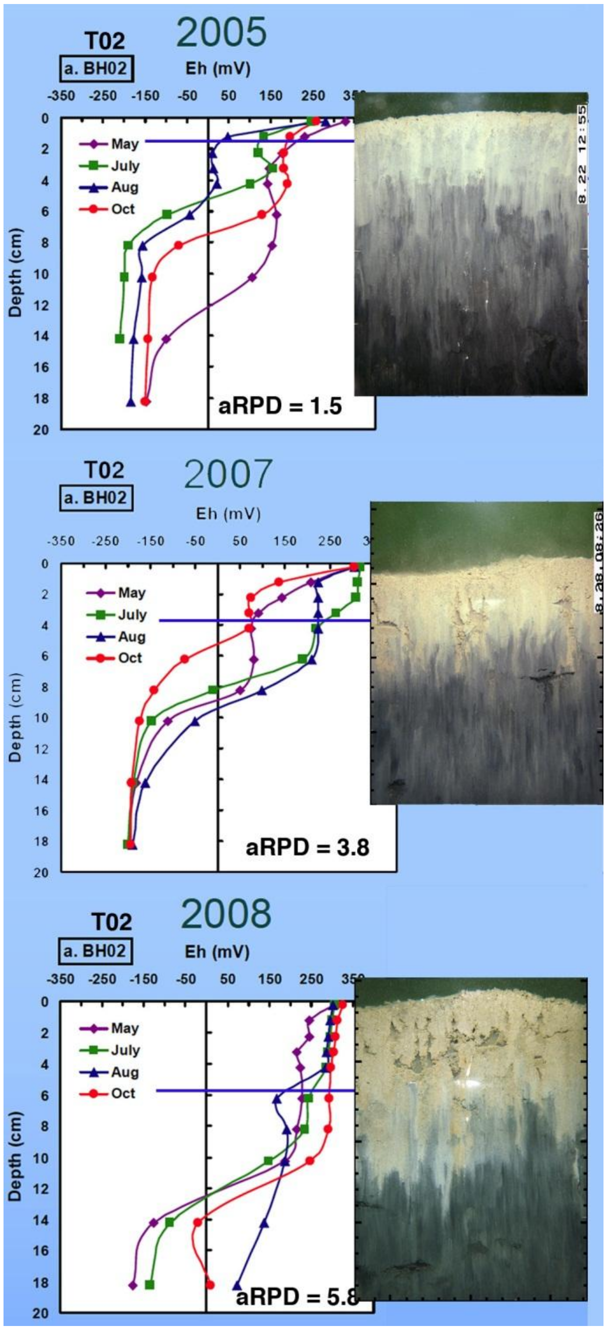

(Notes: baseline period is 1991-2000; scale along side of each image is in cm)

**Figure 29. Thumbnail SPI images from station T02 located in President Roads showing improved habitat conditions. By the mid 2000s sediments appear to becoming lighter in color and the presence of deep-welling infauna and biogenic structures increased, primary indicators of good benthic habitat.**



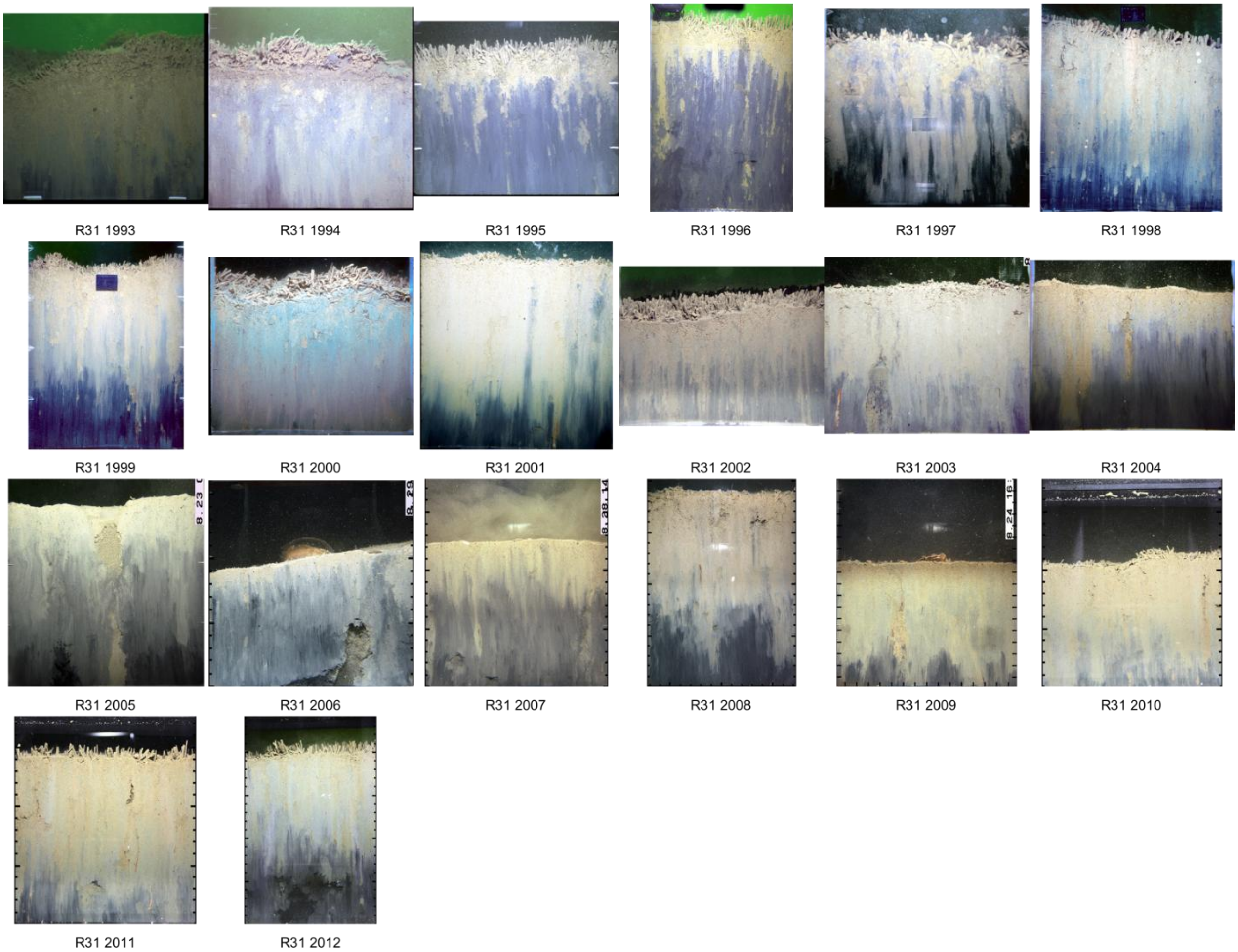

(Note: vertical red line on each SPI is measured RPD depth, defined as 0Eh; SPI are about 15 cm wide; SPI flash failed in 1993. Source of redox profiles is Tucker et al. [2002])

**Figure 30. Comparison of August SPI and redox Eh profiles from 1992 to 2001 from station T02 showing a general progression of deeper RPD layers from 1992 to 2001.**



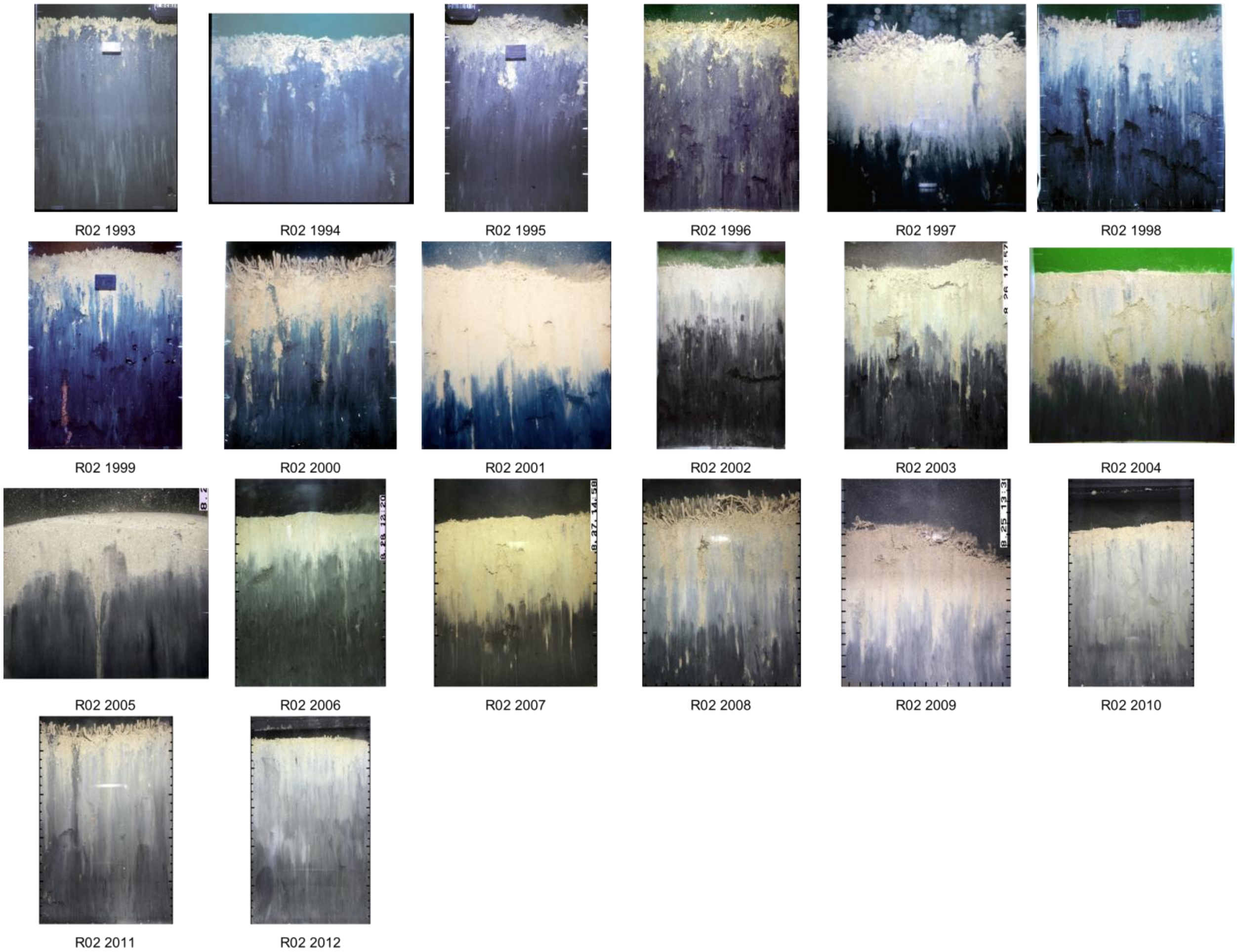

(Note: horizontal purple line is aRPD depth from SPI. Source of redox profiles is Tucker et al. [2009])

**Figure 31. Comparison of August 2005, 2007, and 2008 SPI from station T02 with redox profiles showing increase in bioturbation and redox depth over time. aRPD went from 1.5 cm with little evidence of bioturbation in 2005 to 5.8 cm with high levels of bioturbations and oxic feeding voids in 2008. Eh indicated that in 2005 RPD was about 2 cm and sediments below 8 cm were highly anaerobic and reduced, that both condition were deeper in 2007 (RPD at 10 cm, anaerobic sediments at 14 cm) and deeper still in 2008 (RPD at more than 18 cm, suboxic sediments to at least 18 cm).**



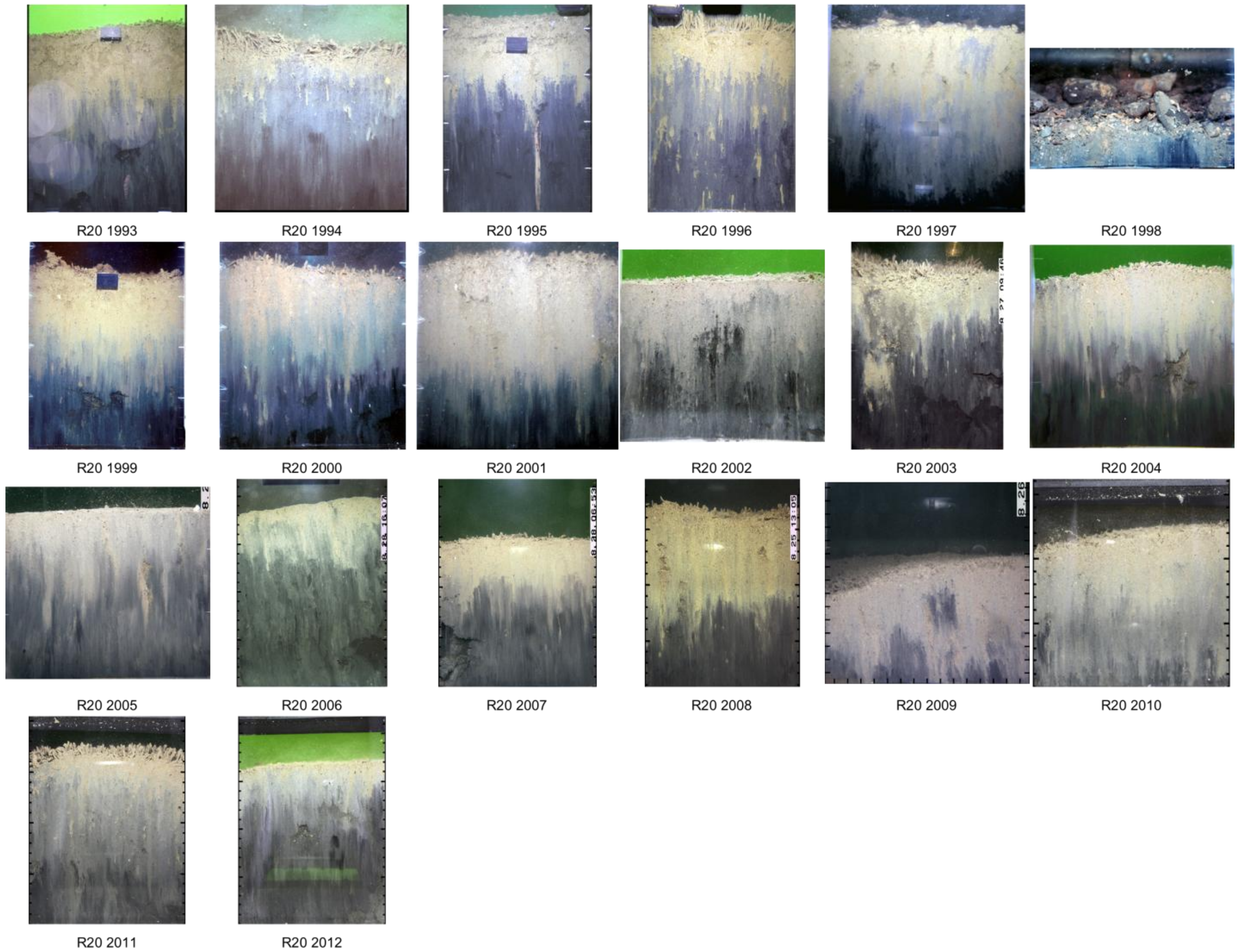

(Notes: baseline period is 1991-2000; scale along side of each image is in cm)

**Figure 32. Thumbnail SPI images from station R31 located in Hingham Bay showing improved habitat conditions. By the mid 2000s sediments appear to becoming lighter in color and the presence of deep-welling infauna and biogenic structures increased. the primary indicators of good benthic habitat.**



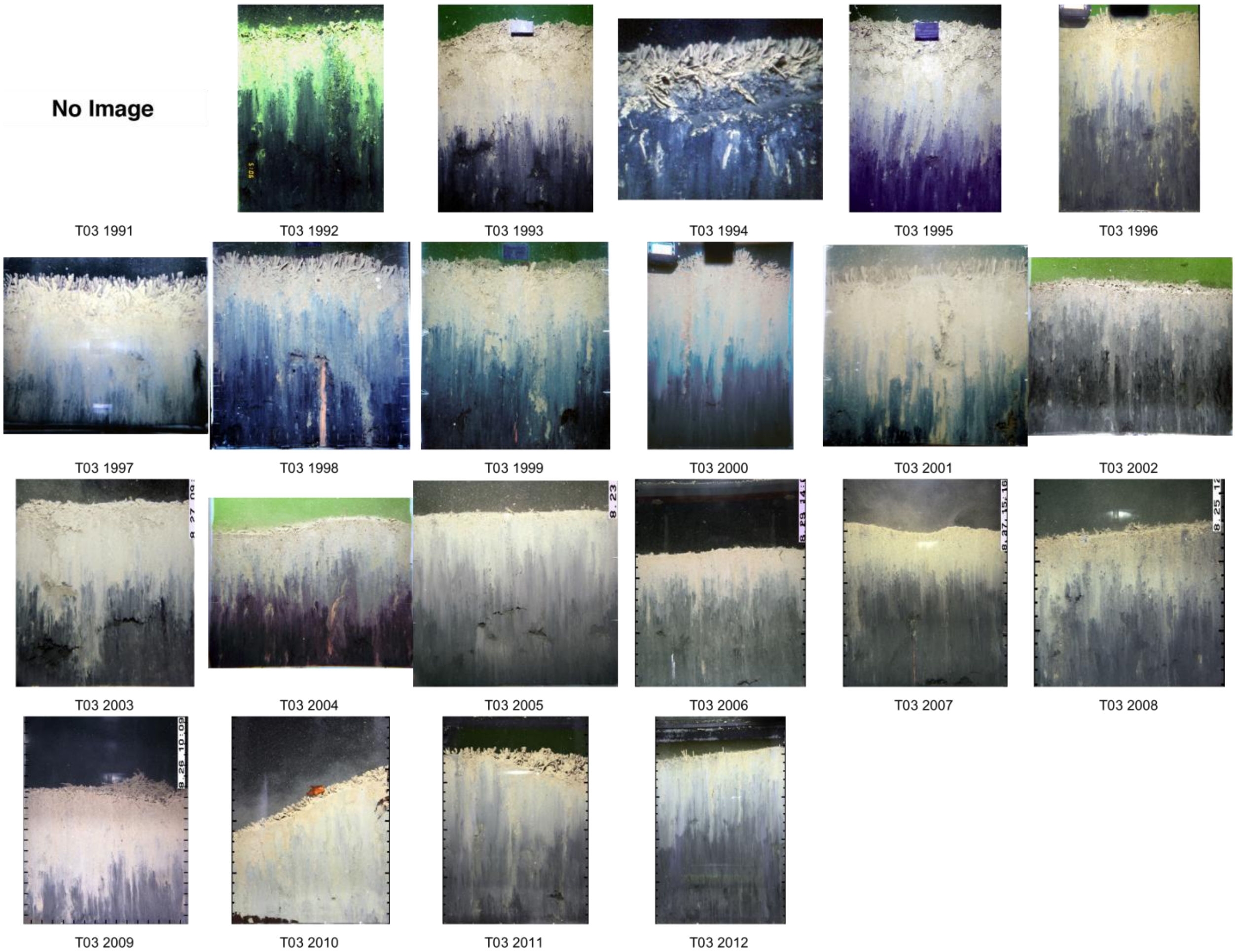

(Notes: baseline period is 1991-2000; scale along side of each image is in cm)

**Figure 33. Thumbnail SPI images from station R02 located off Deer Island showing improved habitat conditions. By the late 2000s sediments appear to becoming lighter in color, a primary indicator of good benthic habitat along with the *Ampelisca* spp. tube mats.**



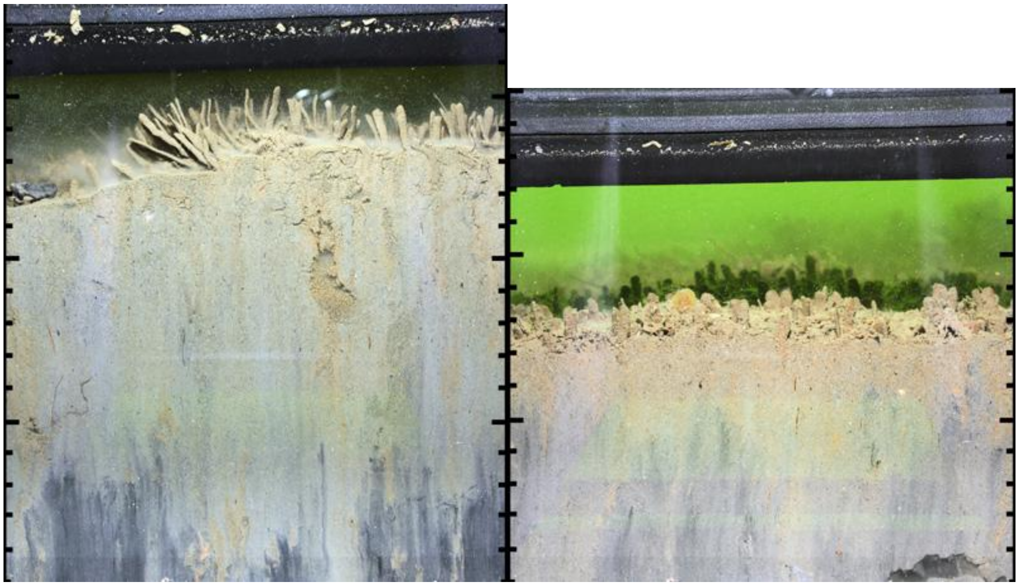

(Notes: baseline period is 1991-2000; scale along side of each image is in cm)

**Figure 34. Thumbnail SPI images from station R20 located in the outer harbor in Nantasket Roads showing good benthic habitat conditions throughout the monitoring period. *Ampelisca* spp. tube mats were present at this station all years except 1998, 2005, and 2006.**



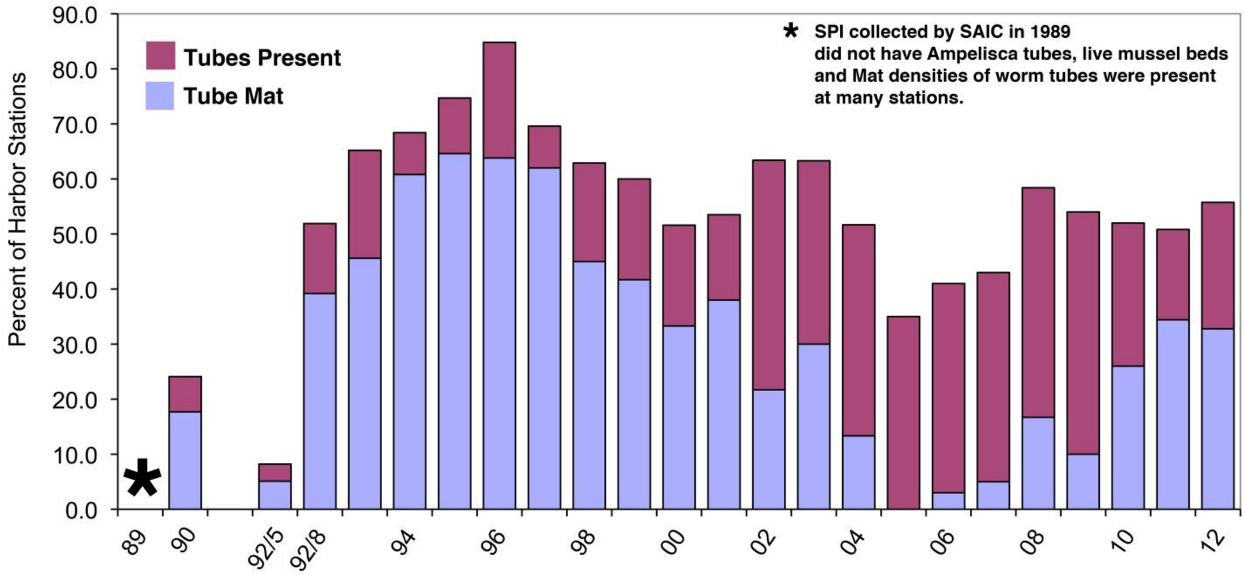

(Notes: baseline period is 1991-2000; scale along side of each image is in cm)

**Figure 35. Thumbnail SPI images from station T03 located off Long Island showing good benthic habitat conditions throughout the monitoring period and presence of *Ampelisca* spp. tube mats all years except 1993, 2005, 2006, and 2007.**



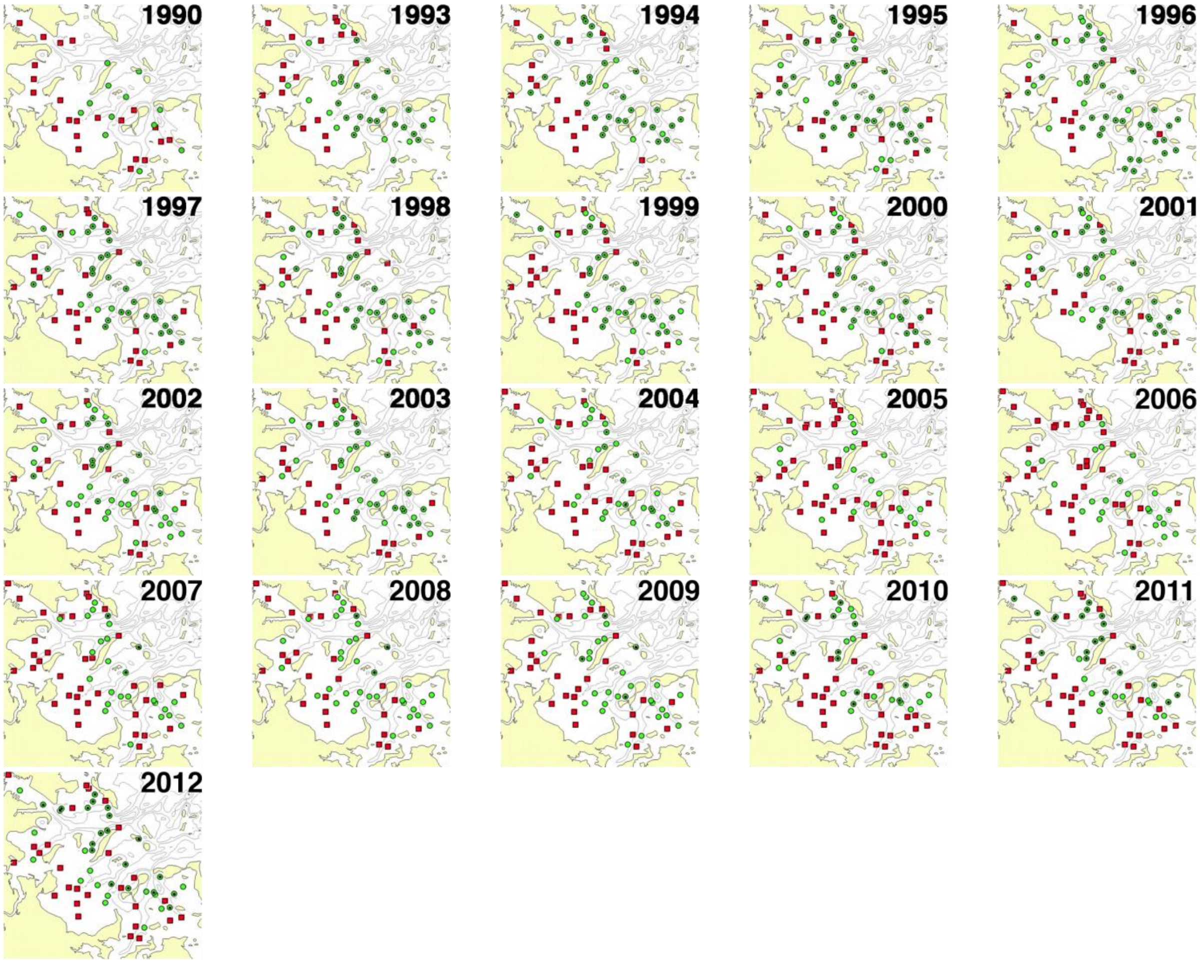
(Note: Scale on sediment profile image is in cm)

**Figure 36. Ampelisca spp. tube mats at stations R21, showing long thin tubes, and R31, with shorter fatter tubes, August 2012.**




(Notes: sampled in May and August 1992; baseline period through 2000)

**Figure 37. Percent of harbor SPI stations where *Ampelisca* spp. tubes were present.**




(Notes: baseline period is 1991-2000; presence of tubes is green circle, tubes at mat densities is black dot in green circle, no tubes present is red square)

**Figure 38. Occurrence of *Ampelisca* spp. tubes at harbor stations.**

# 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 2012 were consistent with trends observed in previous years (Pembroke et al. 2012). Concentrations of both TOC and *C. 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. Total abundance trends downward, particularly for opportunistic species such as *Capitella capitata*. Total species while variable trends upward as does 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 2012 survey are consistent with the recovery of benthic habitats from decades of inadequately treated sewage discharges.

## 5. REFERENCES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