2010 Boston Harbor Benthic Monitoring Report

Massachusetts Water Resources Authority

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1. INTRODUCTION

The direct discharge of waste products into Boston Harbor for several decades had a profound impact on the sedimentary environment of the harbor, including degradation of the communities of organisms associated with the sediments. In 1985, in response to both the EPA mandate to institute secondary treatment and a Federal Court order to improve the condition of Boston Harbor, the newly created Massachusetts Water Resources Authority (MWRA) instituted a multifaceted approach to upgrading the sewage treatment system, including an upgrade in the treatment facility itself and construction of a new outfall pipe to carry the treated effluent to a diffuser system located 9.5 mi offshore in Massachusetts Bay. Many of the Combined Sewer Overflows (CSOs) have been upgraded or discontinued, resulting in further improvements to the discharges to the harbor.

Starting in 1991, the MWRA has conducted monitoring in Boston Harbor to evaluate changes to the system as contaminated discharges into the harbor were reduced. Summaries of the pollution abatement activities and the impact on the harbor can be found in several technical reports maintained on the MWRA's website: http://www.mwra.state.ma.us/harbor/enquad/trlist.html.

The purpose of this summary report is to present key findings from the 2010 sampling season, including several chemical parameters and the evaluation of the soft-bottom benthic community through sediment profile images (SPI) and taxonomic evaluation of infauna collected by grab samples. A comprehensive 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

Methods used to collect, analyze, and evaluate all sample types are consistent with those reported by Maciolek et al. (2008) for previous monitoring years. Nine stations were sampled for grain size composition, total organic carbon (TOC), the sewage tracer *Clostridium perfringens*, sediment chemistry, and benthic infauna; SPI samples were collected in triplicate at 61 reconnaissance stations (Figure 1).

Sediment data (i.e., individual replicate and station mean values) were evaluated on a station- and harbor-wide basis to assess spatial and temporal trends, if any, among the data. Parametric and nonparametric regression analyses to evaluate temporal trends of sediment chemistry at individual harbor stations were conducted using Stata (version 11.1) rather than SAS as in earlier years (Maciolek et al. 2008).

In addition to a summary of harbor-wide temporal patterns in the benthic infaunal communities, the trends were examined in more detail for two stations, including station T01, which has seen substantial change over the course of the monitoring program, and station C019, which was added in the early 2000s to evaluate responses that may be associated with abatement of CSO discharges.

Harbor-wide data collected in summer (August or September) from 1991 to 2010 were also evaluated in context of the four discharge periods established by Taylor (2006). For benthic community and sediment chemical evaluations, the periods were offset by plus one year to allow for a lag in response time, as follows:

- Period I – includes data from 1991 and 1992
- Period II – includes data from 1993 through 1998
- Period III – includes data from 1999 through 2001
- Period IV – includes data from 2002 through 2010

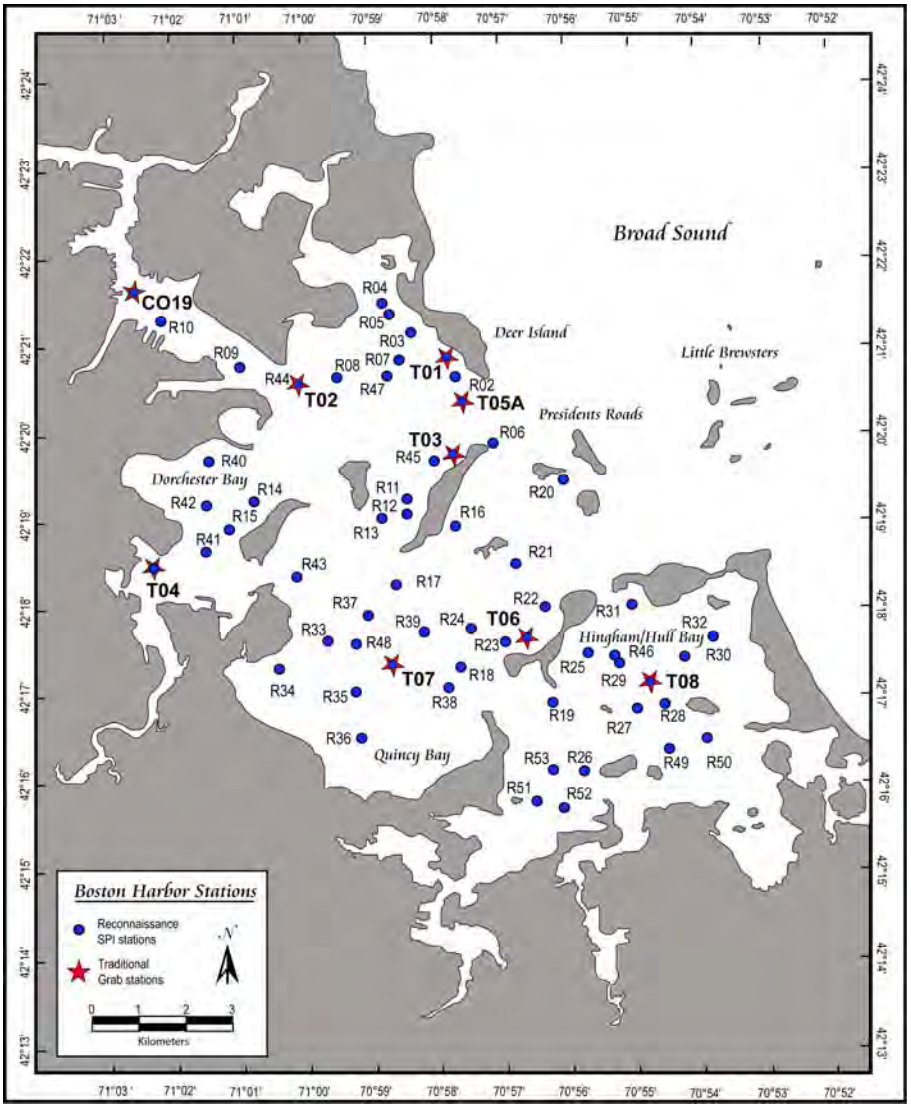


Figure 1. Locations of benthic stations in Boston Harbor sampled in August 2010. All stations were sampled by SPI and those denoted by star symbols were also sampled by grab.

3. RESULTS

3.1 2010 Sediment Chemistry

Grain Size. Results for 2010 are consistent with grain-size data from the larger monitoring period (1991–2008; Maciolek et al. 2009). Surface sediments in Boston Harbor include a wide range of sediment types, including coarse- and fine-grained sediments (Figure 2). Harbor Stations T01, T05A, and T08 generally have coarse-grained sediments; Stations T04 and CO19 have fine-grained (silty) sediment; and Stations T02, T03, T06, and T07 are comprised of sediments with roughly equal parts coarse- and fine-grained material (Figure 2 and Figure B1-1 in Maciolek et al. 2008).

Temporal changes in sediment environments at the harbor stations are difficult to discern because of the high variability among the data over time. However, there is evidence of a significant ($p < 0.05$) increase in percent fines at Stations T02 (positive parametric and nonparametric trends), T04 (positive nonparametric trend), and T08 (positive nonparametric trend) (Figure 3). Consistent with previous evaluations (Maciolek et al. 2008, 2009), sediment data from outlier years 1991 and 1996 were excluded from the statistical evaluations. However, sensitivity analyses using data from all years (including outlier years 1991 and 1996) revealed similar trend results, with the exception of percent fines for station T08 (and *C. perfringens* for stations T03 and T04) where the trend is slightly negative with the outlier years and slightly positive without the outlier years. As the monitoring program continues, outlier years (1996 in particular) could have less influence on the temporal trends.

Total Organic Carbon. Results for 2010 are within the range of data from the larger monitoring period (1991–2008; Maciolek et al. 2009). Fine-grained sediments (e.g., T04) typically have higher TOC compared to coarse-grained sediments (e.g., T05A and T08) (Figure 4A, B). Station T04, located in a depositional area considered to be a focus area for accumulation of sediment and contaminants entering Boston Harbor (Wallace et al. 1991; Stolzenbach and Adams 1998), consistently has the highest TOC (2010 mean = 3.5%; 1991–2010 mean = 4.1%) relative to other harbor stations (Figure 4A). The lowest TOC content is observed at Station T08 (2010 mean = 0.22%; 1991–2010 mean = 0.43%), followed by T05A (2010 mean = 0.68%; 1991–2010 mean = 0.78%) (Figure 4A).

TOC content in 2010 continues to be low or among the lowest levels measured in recent year at many of the harbor stations, and is lower than the grand station mean at all stations (Figure 4A)[1]. Stations T01, T03, T06, T07, and T08 all show evidence of a significant ($p < 0.05$) decrease in TOC over time (negative parametric and nonparametric trends; representative stations T01, T03, and T06 shown in Figure 5). TOC content and variability also appear to be decreasing harbor-wide over the four discharge periods (Figure 6A), albeit the decrease in mean concentrations is small.

Clostridium perfringens. Abundances of *C. perfringens* (normalized to percent fines) have decreased significantly ($p < 0.05$) over time at stations T02, T06, and T08 (representative stations T02 and T06 shown in Figure 7). Abundances also decreased at T01 and T05A (Station T05A shown in Figure 7), although the decrease is not significant at the 95% level of confidence (p values 0.05 to 0.09)[2]. The largest harbor-wide decrease in abundances of *C. perfringens* (normalized to percent fines) occurred between Periods I and III (Figure 6B), and a statistical analysis (one-way analysis of variance) indicated that harbor-wide abundances from the Period III and IV discharge periods are significantly lower than those measured in Periods I and II ($p < 0.001$). Abundances of *C. perfringens* (normalized to percent fines) at most stations have either leveled out or increased slightly (e.g., T02, T05A and T06, Figure 7) in recent years.

[1] 2010 station mean values for TOC are 5% to 49% different (lower) compared to the grand station mean for a given station. The largest differences (between grand station mean and 2010 station mean values) were observed at stations T01 and T08 (2010 station mean concentrations 49% different [lower] than grand station mean values), followed by T06 (2010 station mean concentration 39% different [lower] than grand station mean).

[2] The decrease in abundances of *C. perfringens* (normalized to percent fines) at stations T01 and T05A is significant at the 95% level of confidence ($p<0.05$) when data from the outlier years (1991 and 1996) are included in the analysis.

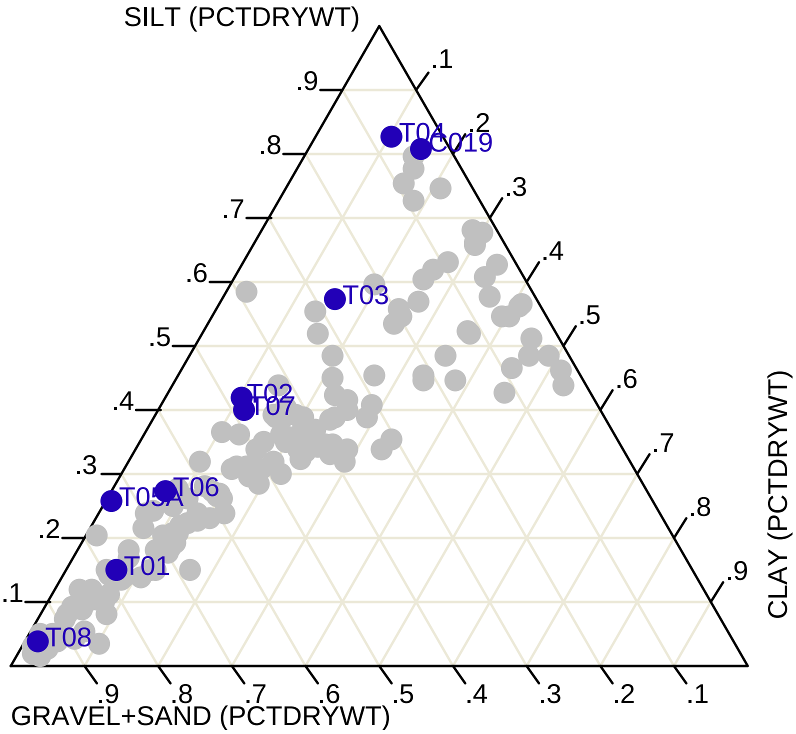


Figure 2. Distribution of percentages of gravel+sand, silt, and clay in surface sediment in Boston Harbor, 1991–2010. (Gray symbols represent 1991–2009 station mean values; blue symbols represent the 2010 station mean values, labeled with the station number).

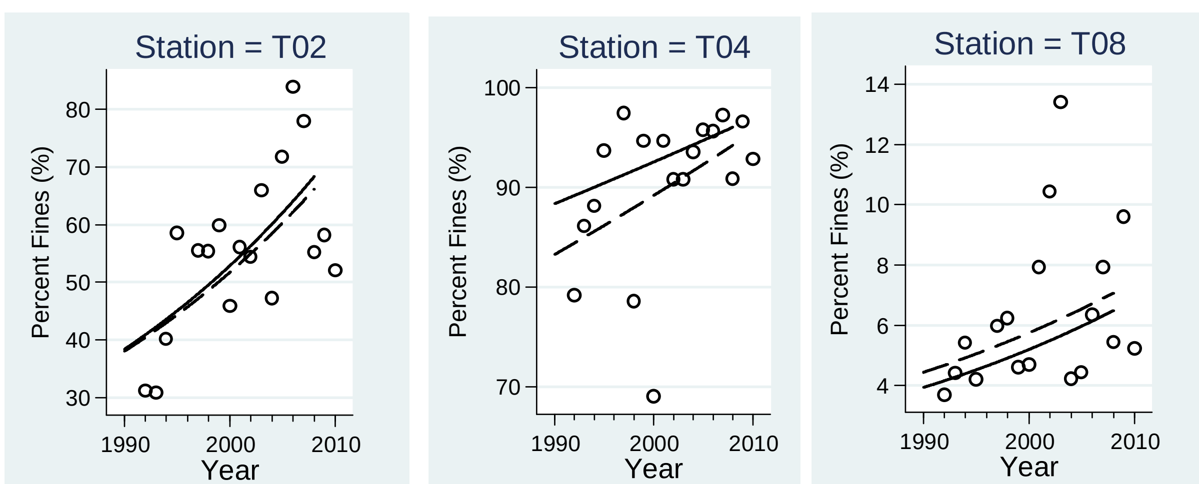


Figure 3. Increasing trends in percent fines in surface sediment at Stations T02, T04, and T08 from 1992 to 2010. (The solid line represents the nonparametric regression and the dashed line represents the parametric regression; outlier years 1991 and 1996 excluded).

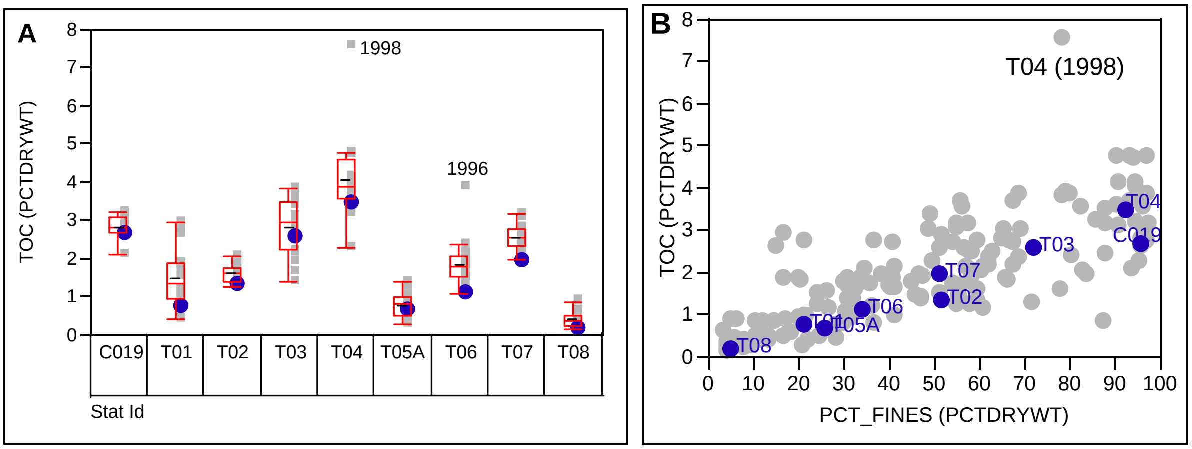


Figure 4. Distribution of TOC, by station (A) and in correspondence with percent fines (B), in surface sediment in Boston Harbor, 1991–2010. (Gray symbols represent 1991–2009 station mean values; blue symbols represent 2010 station mean values; red line across box plot (A) represents median value of 1991–2010 values and dash line within box plot (A) represents grand station mean of 1991–2010 values.)

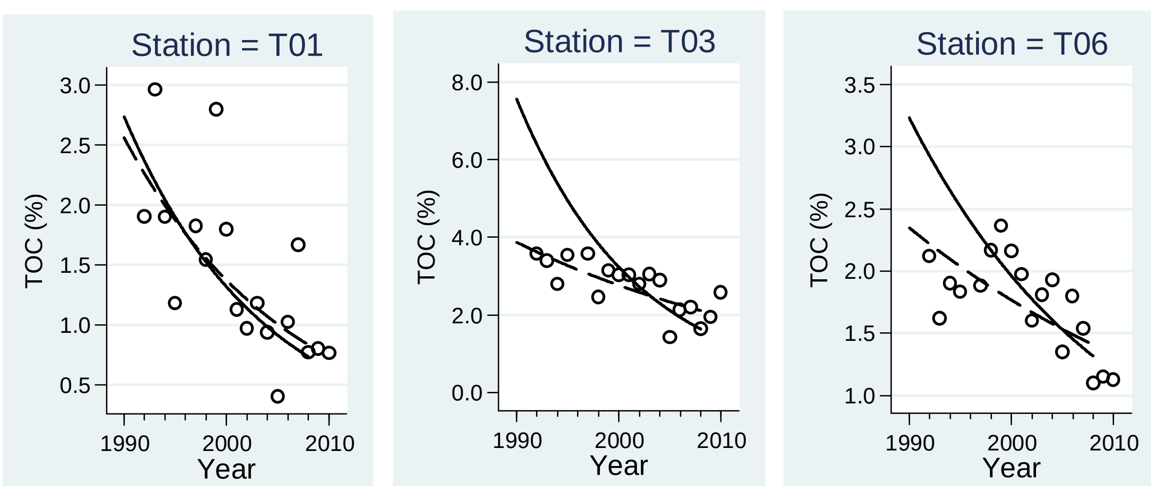
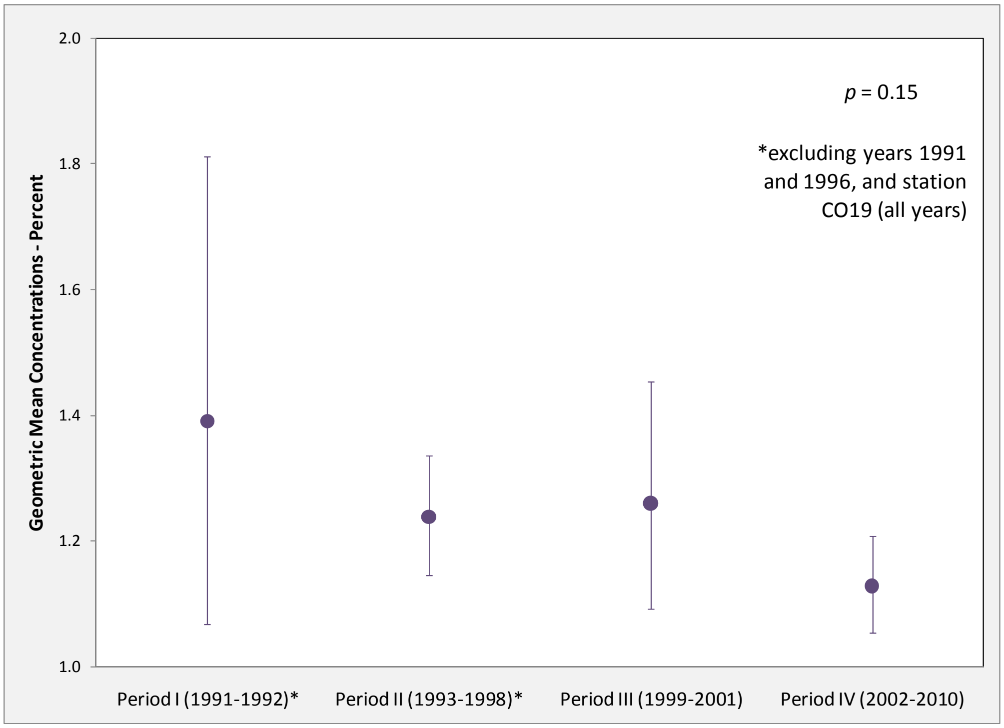


Figure 5. Decreasing trends in TOC ($p < 0.05$) at station T01, T03, and T06 from 1992 to 2010. (The solid line represents the nonparametric regression and the dashed line represents the parametric regression; outlier years 1991 and 1996 excluded).

A



B

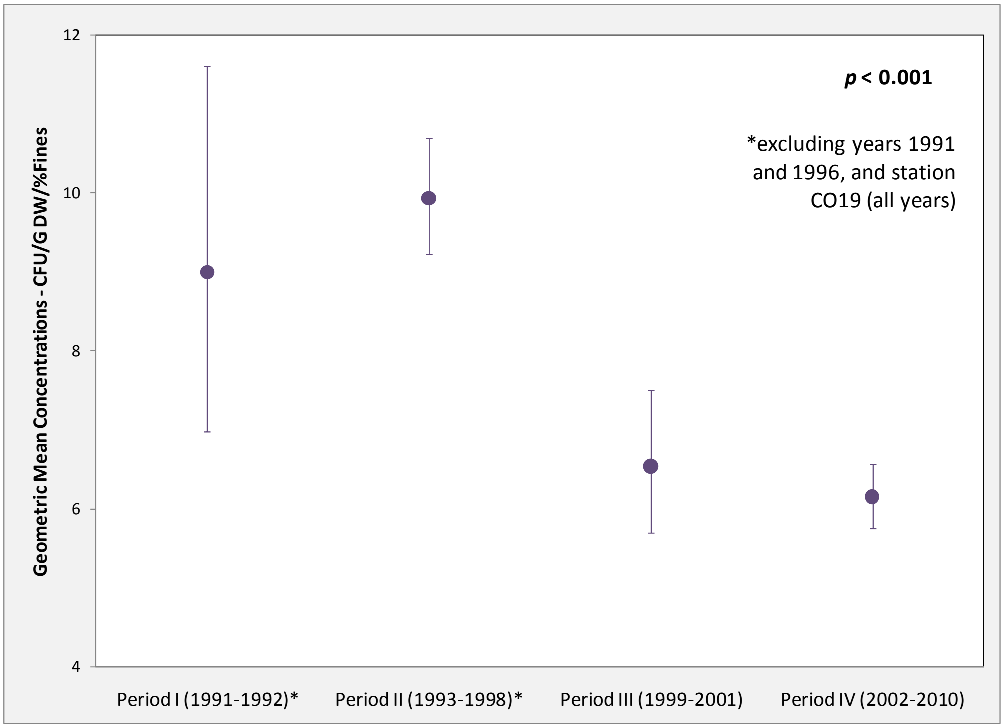


Figure 6. Trends in harbor-wide TOC (A) and normalized *C. perfringens* (B) from 1992 to 2010. Symbols represent the harbor-wide geometric mean and vertical bars represent the 95% confidence intervals around the mean. Outlier years 1991 and 1996 and station CO19 excluded.

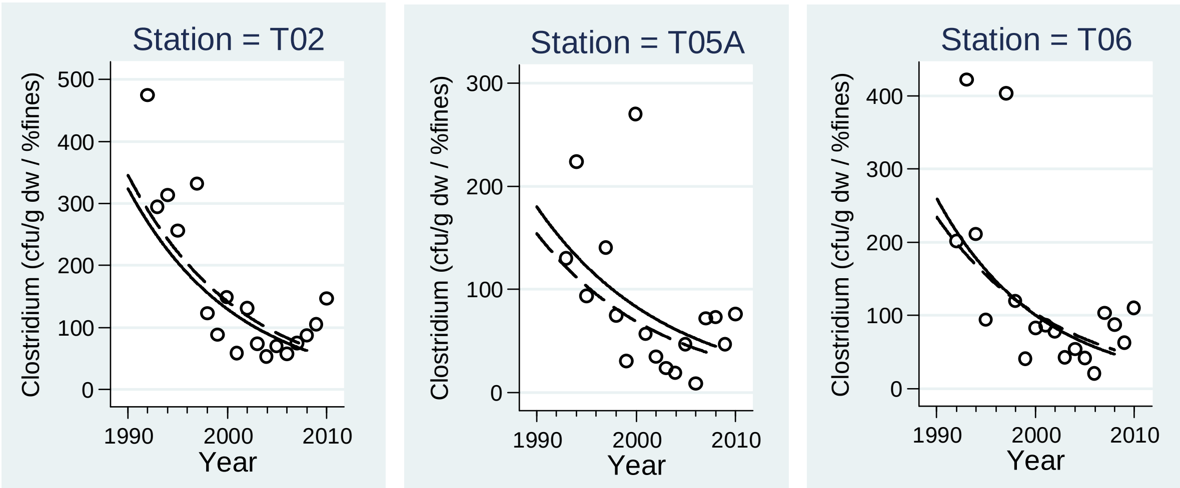


Figure 7. Decreasing trends in *C. perfringens* (normalized to percent fines) at stations T02 ($p < 0.05$), T05A ($p = 0.05$ for parametric and 0.09 for nonparametric), and T06 ($p < 0.05$) from 1992 to 2010. (The solid line represents the nonparametric regression and the dashed line represents the parametric regression; outlier years 1991 and 1996 excluded).

3.2 2010 Sediment Profile Imaging

From 1992 to 2010, there were large changes in organic inputs to the Harbor related to upgrades and relocation of outfalls that led to improvements in benthic habitat quality for infauna. There were increases in deeper, bioturbating species, which likely increased trophic complexity. An inner-to-outer Harbor gradient remains the prominent factor in controlling benthic habitat quality.

Overall, sediments in 2010 were similar to other years with physical processes prominent in structuring surface sediments. Estimated SS, OSI, and aRPD layer depth were about the same as in 2009. The eelgrass bed, first observed in 2008, was still present at station R08 on Deer Island Flats (Figure 8). No microalgal mats, which were observed at 18% of stations in 2007, were observed in 2010.

Figure 8. Eel grass bed at station R08 in 2010. Tic marks are in cm.

In 2010, *Ampelisca* spp. tubes at mat densities appeared at 25% of stations. *Ampelisca* spp. tubes at less than mat densities occurred at 50% of stations. This represents the fourth consecutive year for an increase in tube mats over 2005 when no station had mat densities (Figure 9). Over the ten-year period from 1993 to 2003, amphipod tube mats occurred in all regions of Boston Harbor (Figure 10). The following two years, 2004 and 2005, mat densities of *Ampelisca* spp. declined to zero. From 2006 on, there has been a rebound in amphipod mats with most occurring in the outer regions of the harbor. Mats persisted the longest in the outer harbor and southern harbor regions. Mats were never common in the inner harbor areas (Figure 11).

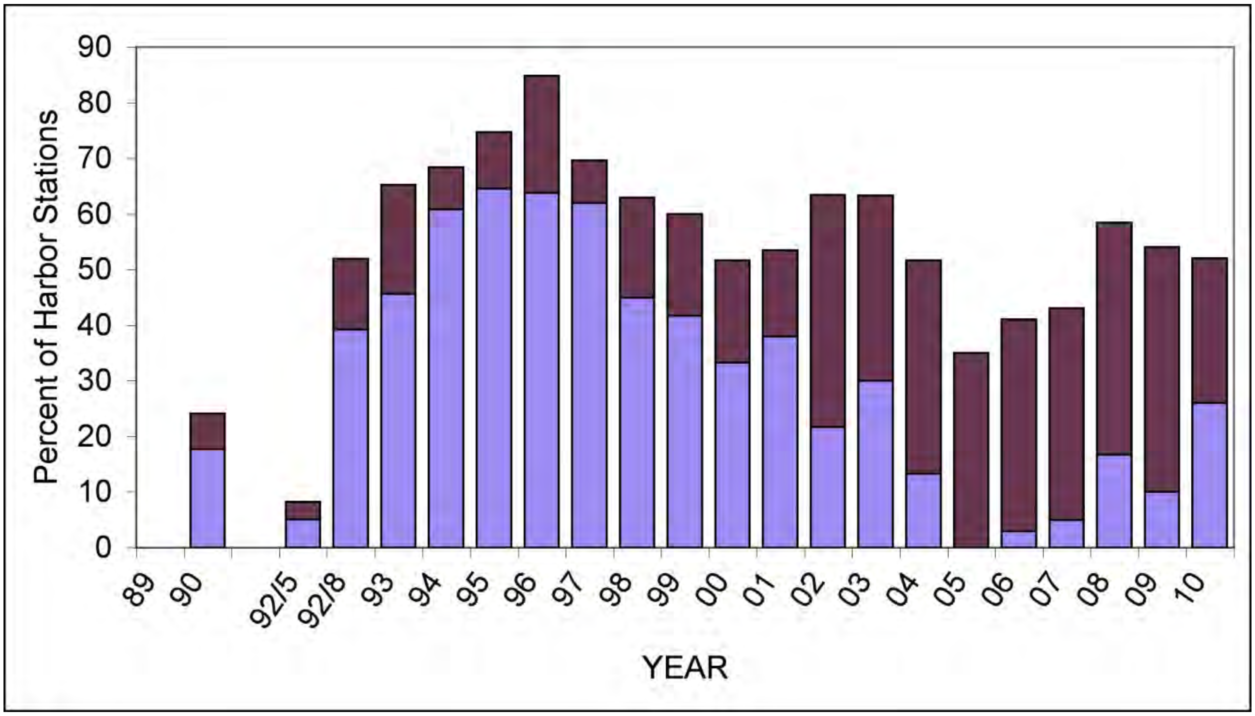


Figure 9. Histogram of *Ampelisca* spp. tubes present at harbor stations. Percent of stations with mats densities of tubes are in blue.

		1990	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
CHARLES RIVER	CO19	.	.	.	.	.	.	.	.	.	.	.	.	.	-	-	-	-	-	-	-
	R09	-	.	-	MAT	-	MAT	MAT	MAT	MAT	+	MAT	+	+	+	-	-	-	-	-	-
	R10	-	.	-	-	-	-	+	-	MAT	-	-	-	-	-	-	-	-	-	-	MAT
DORCHESTER BAY	R14	.	.	-	MAT	MAT	MAT	MAT	MAT	-	-	MAT	-	+	-	-	+	-	-	+	MAT
	R15	.	.	+	-	MAT	+	-	-	-	-	-	-	-	+	-	-	-	-	-	-
	R40	-	.	-	-	+	+	-	+	-	-	+	+	-	+	+	-	-	+	-	+
	R41	-	.	-	MAT	MAT	MAT	MAT	+	-	+	+	MAT	+	+	-	-	-	+	-	+
	R42	-	.	-	-	-	-	-	-	-	-	-	+	-	+	+	+	-	-	-	-
	R43	-	.	+	-	+	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-
	T04	.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
QUINCY BAY	R18	.	.	MAT	MAT	-	MAT	MAT	MAT	MAT	MAT	MAT	+	MAT	+	+	+	+	MAT	+	MAT
	R33	-	.	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	+	-	-
	R34	-	.	-	-	-	+	-	-	-	-	.	-	-	-	-	-	-	-	-	-
	R35	-	.	-	-	MAT	-	-	-	-	-	.	-	-	-	+	-	-	-	-	-
	R36	-	.	-	-	-	-	-	-	-	-	.	-	-	-	-	-	-	-	-	-
	R37	+	.	+	-	MAT	-	+	+	+	-	-	+	+	+	-	-	-	+	-	-
	R38	+	.	MAT	MAT	MAT	MAT	MAT	MAT	MAT	+	MAT	+	MAT	+	-	+	+	+	+	+
	R39	-	.	MAT	MAT	MAT	MAT	+	MAT	+	MAT	+	MAT	-	-	-	+	-	+	+	+
	R48	-	.	.	.	-	-	-	+	-	+	+	+	+	+	-	-	-	-	-	-
	T07	.	+	+	-	MAT	MAT	-	-	-	-	+	-	+	-	-	+	-	+	+	-
DEER ISLAND FLATS	R02	.	.	MAT	MAT	+	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	-	+	+	MAT	MAT	MAT	+
	R03	.	.	+	MAT	MAT	MAT	MAT	MAT	+	+	+	+	MAT	-	-	-	+	+	+	MAT
	R04	.	.	-	MAT	MAT	+	-	-	-	-	MAT	-	-	-	-	-	-	-	+	-
	R05	.	.	-	MAT	MAT	+	-	MAT	+	+	+	+	+	+	-	-	-	+	+	+
	R07	.	.	-	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	+	+	-	-	+	+	-	+
	R47	.	.	.	.	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	+	-	+	+	MAT	+	MAT
	T01	.	-	-	-	-	+	-	-	-	-	-	+	-	-	+	-	-	-	-	+
	R08	-	.	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-
OFF LONG ISLAND	R11	.	.	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	-	-	-	+	+	+	MAT
	R12	.	.	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	+	-	-	-	-	+	+	MAT
	R13	.	.	+	MAT	+	+	-	-	-	-	MAT	-	-	-	-	-	-	-	MAT	-
	R16	+	.	MAT	+	MAT	MAT	MAT	MAT	MAT	MAT	+	-	+	-	+	-	+	+	-	-
	R17	+	.	MAT	MAT	MAT	+	MAT	MAT	MAT	MAT	-	+	-	-	+	-	+	-	-	-
	R45	.	.	.	.	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	+	+	+	+	+	MAT	MAT	MAT
	T03	+	MAT	-	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	+	+	+	MAT	MAT	MAT
	R06	.	.	MAT	+	-	-	-	-	-	-	+	-	+	+	-	-	-	-	-	-
PRESIDENT ROADS	R44	.	.	.	.	MAT	-	-	MAT	-	+	MAT	+	+	-	-	-	-	-	-	MAT
	T02	-	-	+	MAT	MAT	+	MAT	+	+	MAT	+	-	+	+	-	-	+	+	+	MAT
	T05a	.	-	.	-	MAT	MAT	MAT	-	-	-	MAT	-	MAT	MAT	+	-	+	+	+	MAT
NANTASKET ROADS	R21	+	.	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	+	MAT	MAT	MAT	+	+
	R22	-	.	MAT	MAT	MAT	+	MAT	MAT	MAT	MAT	MAT	+	+	-	+	+	-	-	+	-
	R23	-	.	MAT	MAT	MAT	MAT	MAT	+	+	MAT	MAT	+	+	+	+	-	+	+	+	-
	R24	+	.	MAT	MAT	MAT	MAT	+	MAT	MAT	MAT	MAT	+	+	-	-	+	+	MAT	+	MAT
	T06	.	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	+	MAT	MAT	-	-	+	+	MAT	+
	R20	+	.	MAT	MAT	MAT	MAT	MAT	-	MAT	MAT	MAT	MAT	MAT	MAT	+	+	MAT	MAT	MAT	MAT
HINGHAM BAY	R19	.	.	+	+	-	MAT	-	-	+	-	-	-	+	+	-	-	-	-	-	-
	R25	.	.	MAT	MAT	MAT	MAT	MAT	MAT	MAT	+	-	-	MAT	-	-	-	-	-	-	+
	R26	-	.	MAT	-	+	MAT	+	+	+	-	-	-	-	-	-	-	-	+	+	-
	R27	-	-	+	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	+	MAT	+	-	+	+	+	+	-
	R28	-	.	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	+	MAT	MAT	+	+	+	+	+	-
	R29	-	.	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	+	+	+	+	+	+
	R30	.	+	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	+	MAT	+	+	MAT	+	MAT	-	+
	R31	+	.	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	+	-	+	-	+	+	MAT
	R32	.	+	+	MAT	-	MAT	-	+	+	-	MAT	-	-	+	-	-	-	+	+	+
	R46	+	.	.	.	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	+	+	+	+	+	MAT
	R49	.	.	.	.	-	MAT	-	+	-	-	-	+	-	+	-	+	-	-	-	-
	R50	+	.	.	.	MAT	MAT	MAT	MAT	+	MAT	-	+	+	-	+	+	+	+	+	-
	R51	-	.	.	.	+	MAT	-	+	+	-	-	-	-	-	-	+	+	-	+	-
	R52	+	.	.	.	-	MAT	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	R53	-	.	.	.	+	MAT	-	-	-	+	-	+	-	-	-	-	-	-	-	-
	T08	.	MAT	MAT	+	MAT	-	MAT	-	+	-	MAT	+	+	+	+	+	+	MAT	+	+

Figure 10. Pattern of *Ampelisca* spp. occurrence through time for all Harbor stations. MAT is mat densities, + is amphipods present, and – is no amphipod tubes present.

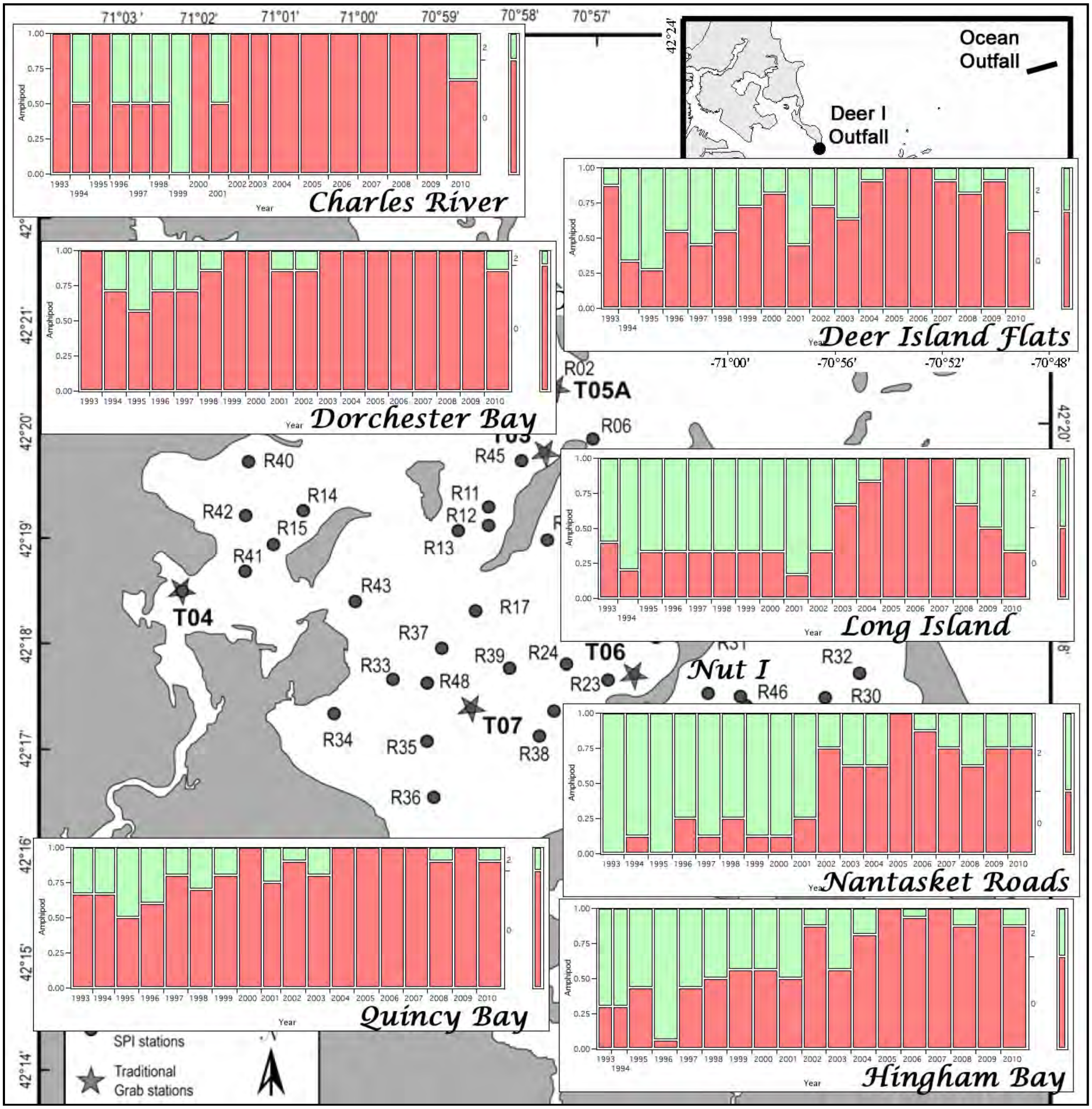


Figure 11. Proportion of stations with *Ampelisca* spp. tube mats by year and region (green color or upper portion of bars). Red or bottom of bar is all other stations.

In 2010, bioturbation by the amphipod *Leptocheirus pinguis* was not obvious. Enhanced levels of bioturbation that appeared to be related to the presence of *L. pinguis* amphipods were common in 2008 (Figure 12). The occurrence of epifaunal organisms in 2010 appeared to be similar to other year with most being hermit crabs. A small orange fish was seen at station T03 sitting on an amphipod tube mat (Figure 13).

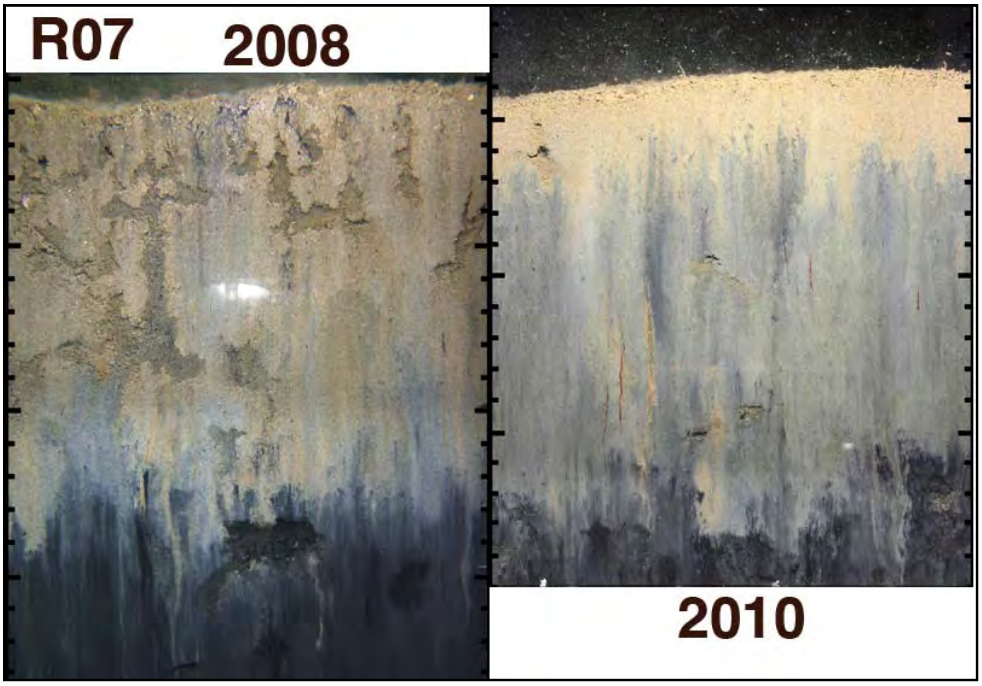


Figure 12. Comparisons of bioturbation at station R07 in 2008 and 2010. *Leptocheirus pinguis* was in high abundance in 2008. In 2010 there was little evidence of amphipod bioturbation. Scale is in cm.

Figure 13. Orange fish sitting on an amphipod tube mat at station T03. Scale is in cm.

3.3 2010 Soft-Bottom Benthic Infaunal Communities

Harbor-wide Results. Twenty-seven benthic grab samples were collected from Boston Harbor stations in August 2010; benthic community parameters were calculated for each of the samples (Appendix A) as in previous years (Maciolek et al., 2010).

Samples collected from the eight traditional grab stations yielded 139 valid taxa, a decline from the 146 reported for the 2009 samples. Mean species richness declined again in 2010 to 41.25±3.7 taxa, after a decline in 2009 (45.7 ± 3.8 taxa) from the record level of 52.1±3.4 taxa in 2008 (Figure 14). In 2010, the number of taxa decreased at five of the eight stations, most noticeably at T07, where the mean decreased from 32 species in 2009 to 12.7 species in 2010.

Mean total abundance increased slightly in 2010 compared with 2009 (2967.8 organisms per sample in 2010 vs. 2705.9 organisms per sample in 2009 (Figure 15). The large increase in 2008 of the polychaete *Polydora cornuta*, and to a lesser extent of the amphipod *Leptocheirus pinguis*, was followed in 2009 by a major decline in the abundance of these and other common species and this decline continued into 2010 (Figure 16). The total abundance of species of the amphipod genus *Ampelisca* was much higher in 2009 and 2010 than in 2008 (Figure 17), but this increase was not sufficient to offset the overall decline in the remaining fauna. In 2010, there was a large increase in *Ampelisca* spp. at Stations T02 and T03, whereas this taxon declined in numbers at Stations T05A, T06, T07, and T08 (Figure17).

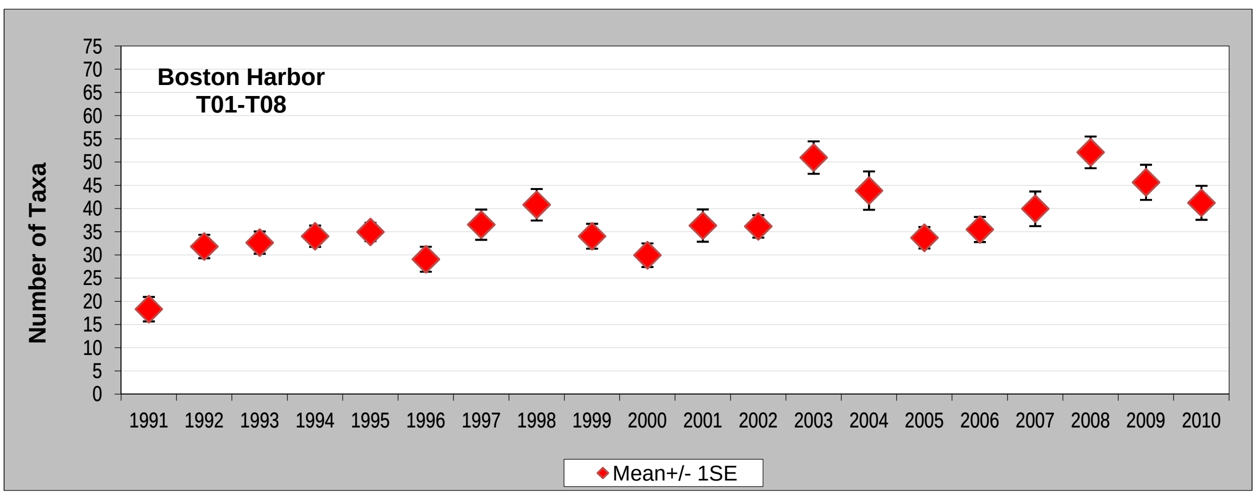


Figure 14. Mean species richness for eight Boston Harbor stations in August 1991–2010.

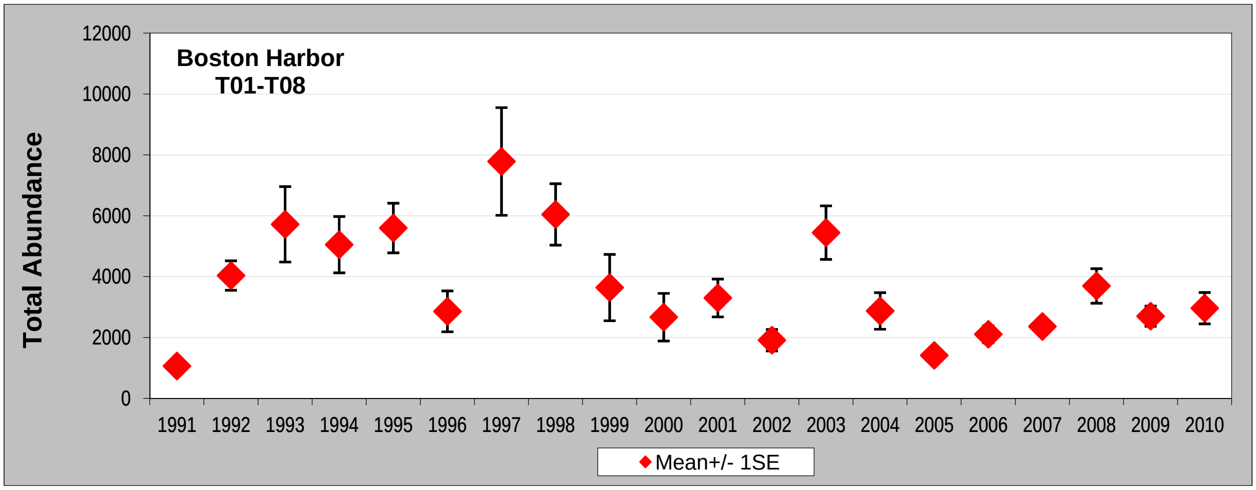


Figure 15. Mean total abundance for eight Boston Harbor stations in August 1991–2010.

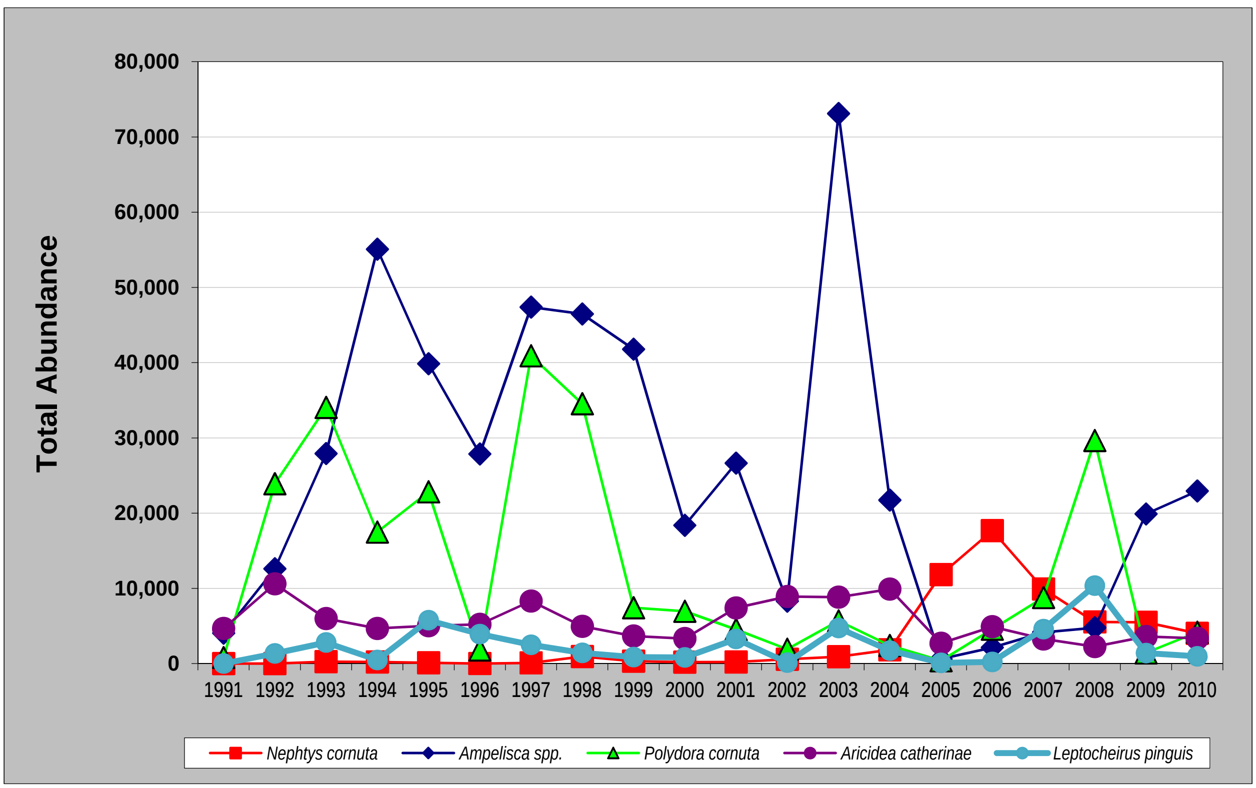


Figure 16. Annual density of five common species in Boston Harbor for the period 1991–2010.

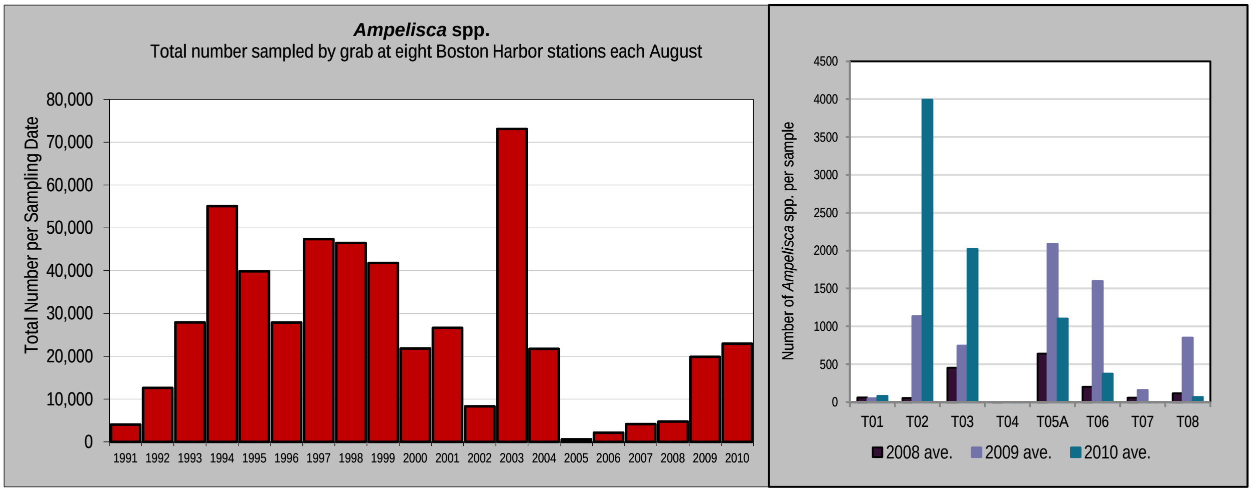


Figure 17. Left: Total number of *Ampelisca* at Boston Harbor stations in August 1991–2010. Right: Average number of *Ampelisca* spp. at each Boston Harbor station in August 2008–2010.

The numerically dominant species in the harbor (Table 1) reflect the large increase in numbers of ampeliscid amphipods and oligochaetes with the concomitant decrline of the amphipod *Leptocheirus pinguis,* which was not among the top dominants in 2010. *Polydora cornuta*, which was the top numerical dominant at four stations in 2008, and declined to less than 5% of its 2008 abundance in 2009, exhibited another cyclic increase in abundance (Table 1, Figure 16). *Nephtys cornuta*, a small polychaete that dominated most stations in 2005 and 2006 but declined in numbers thereafter, again declined between 2009 and 2010. The amphipod *L. pinguis*, which was among the top numerical dominants in 2009, was not as abundant in 2010; its absence was also noted in the SPI images for 2010.

Table 1. Dominant taxa at eight grab stations in Boston Harbor in August 2010.

Taxon	Total 2010 Abundance (compared with 2009)
Ampelisca spp.	22, 940 (increase)
Limnodriloides medioporus	8,429 (increase)
Tubificoides apectinatus	6,887 (minor increase)
Polydora cornuta	4,168 (increase)
Nephtys cornuta	4,026 (decrease)
Aricidea catherinae	3,373 (minor decrease)
Scoletoma hebes	2,829 (increase)
Phyllodoce mucosa	2,142 (increase)
Tharyx spp.	1,629 (half)
Orchomenella minuta	1,359 (increase)
Photis pollex	1,231 (minor decrese)
Streblospio benedicti	1,010 (increase)

Mean diversity declined slightly between 2009 and 2010 as measured by both Fisher's *alpha* and Shannon′ s H′(Figure 18); neither change was significant and diversities for the past three years remain higher than for the preceeding three years (2005–2007). Evenness (J′) was slightly lower than in 2009, but comparable to evenness in 2008 (Figure 18).

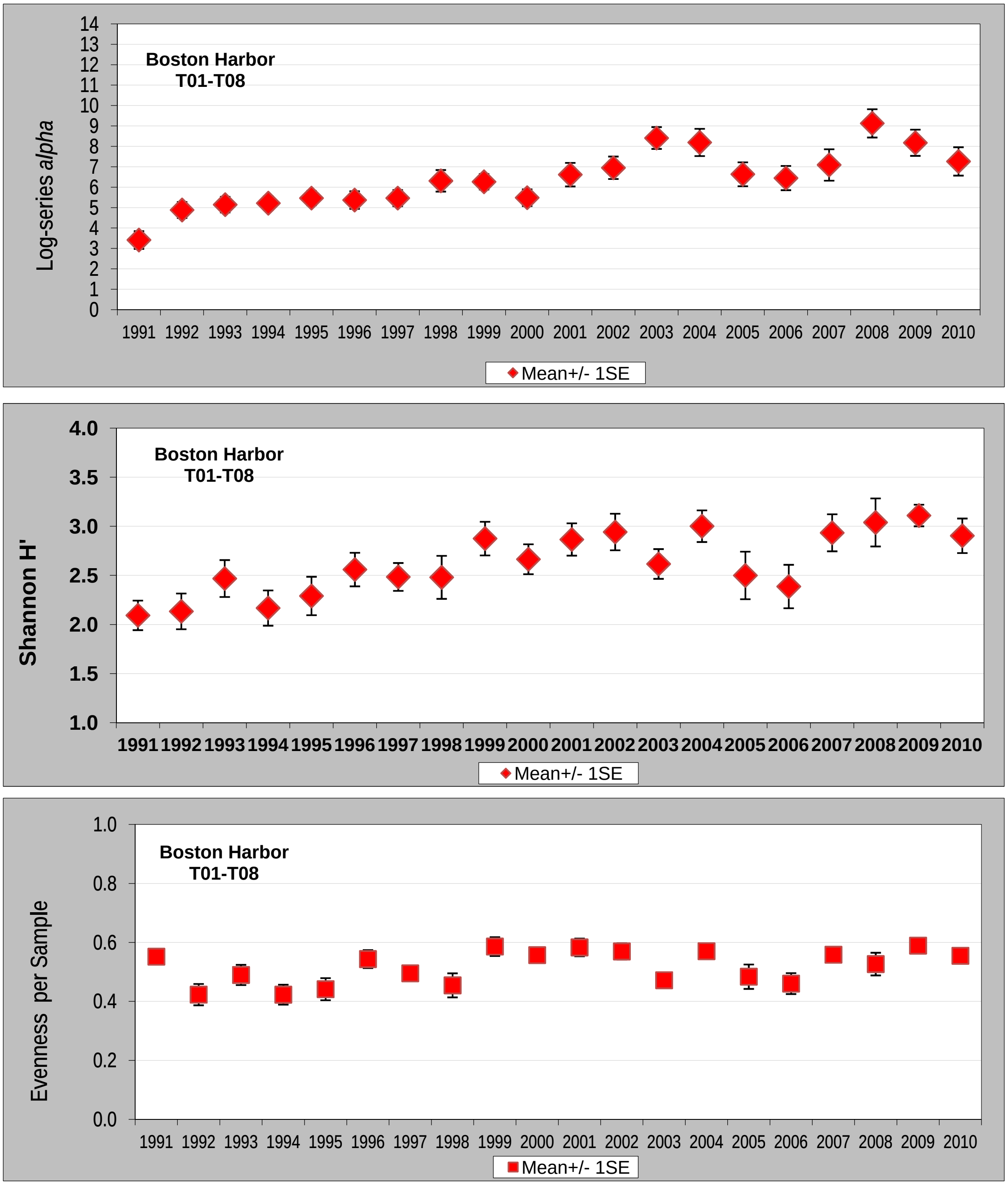


Figure 18. Mean species diversity and evenness for eight Boston Harbor stations in August 1991–2010.

T01. Changes over time in Boston Harbor are exemplified by the changes seen at T01, in the northern part of the harbor near Deer Island Flats (see Figure 1 for location). Community diversity, as represented by the rarefaction curves in Figure 19, increased after the divergence of the discharge from the habor in September 2000. The rarefaction curve for 2010 was lower than that for 2008 and 2009, but still higher thatn for the early years of the monitoring program. Only years 2002–2004 had higher diversity curves than 2008–2010.

Multivariate analysis indicated that 2010 and the years 2006–2009 were very different from all other years at T01 (Figure 20A): the increase in numbers of *Nephtys cornuta*, as well as *Limnodriloides medioporus* and *Tharyx* spp., accounted for this difference (Figure 20B). Similarly, the years before the divergence of the discharge (1991–2000), differ from the years immediately after the divergence (2001–2005) due to higher abundances of *Streblospio benedicti* in the earlier years, and higher abundances of species associated with cleaner, sandier sediments (e.g., *Exogone hebes* and *Leptocheirus pinguis*) in later years (Figure 20A, B).

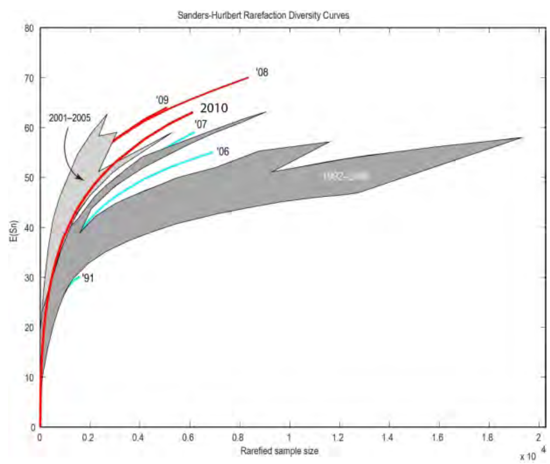


Figure 19. Rarefaction curves for station T01 off Deer Island flats in Boston Harbor, 1991–2010. All samples pooled within each year.

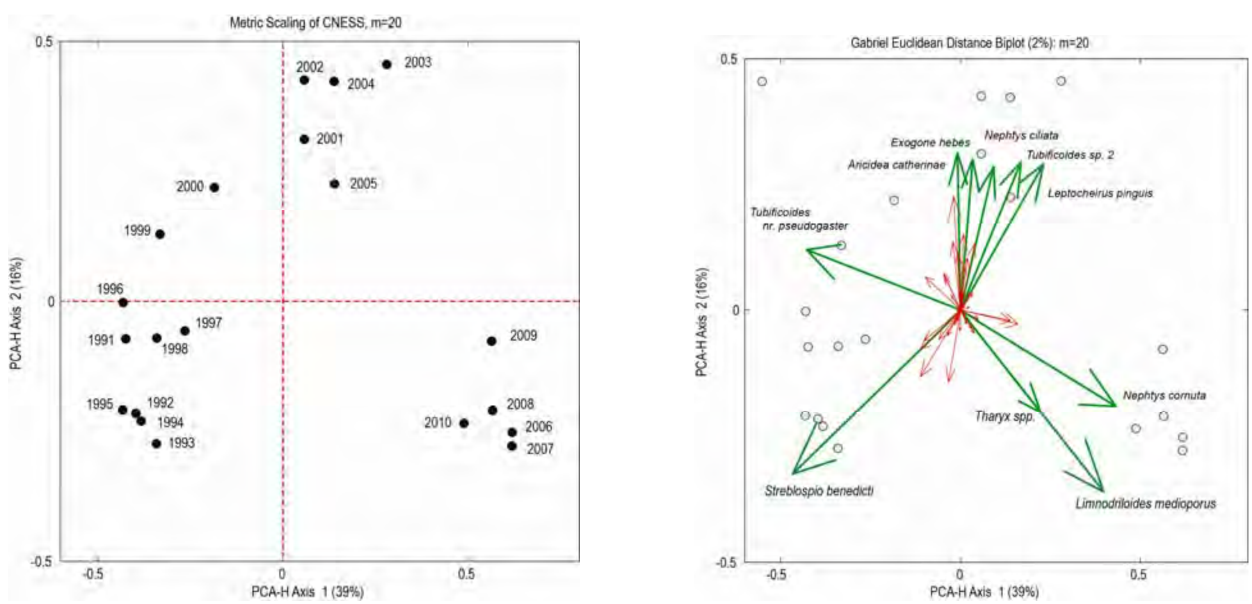


Figure 20. PCAH analyis for station T01 off Deer Island flats in Boston Harbor, 1991–2010. (A) metric scaling of annual samples, (B) Euclidean distance biplot showing the species responsible for at least 2% of the CNESS (*m* = 20) variation.

C019. This station was originally sampled in 1989 as part of the Sediment-Water Exchange (SWEX) study (Gallagher and Keay 1998). At that time, 94–96% of the fauna was comprised of *Streblospio benedicti* and a cirratulid identified as *Chaetozone setosa*; only a few individuals of four additional taxa were identified from the samples (oligochaetes, *Polydora* sp., *Mya arenaria*, and *Pectinaria gouldii*).

Over the past seven years of sampling (2004–2010), a total of 58 taxa have been recorded from this station, with the 2010 samples yielding 31 species. Taxa newly recorded from this station in 2010 included single specimens of the bivalve *Spisula solidissima*, the amphipod *Orchomenella minuta*, and the polychaete *Ophelina acuminata*, plus five specimens of the polychaete *Scoletoma hebes*. In 2010, as in the six preceding years, the fauna at C019 was dominated by *Nephtys cornuta* (Figure 21), which accounted for 80.8% of the total fauna at this station.

The increase in the number of taxa and reduced importance of *N. cornuta* starting in 2008 are reflected in the much higher diversity values compared with the three previous years. In 2010, diversity as measured with Fisher's *alpha* increased to the highest recorded at this station (3.71) while Shannon diversity dropped from 1.38 to 1.28 and evenness declined from 0.35 to 0.29 (Figure 22).

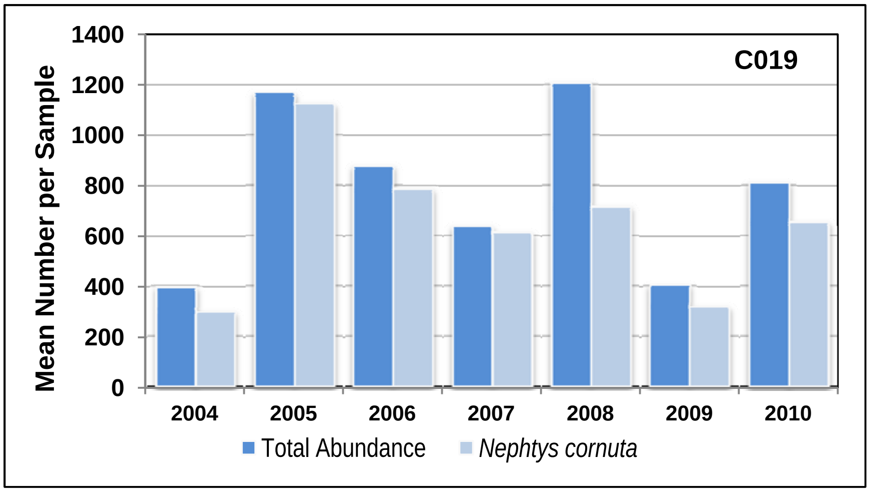


Figure 21. Total abundance and density of *Nephtys cornuta* at station C019.

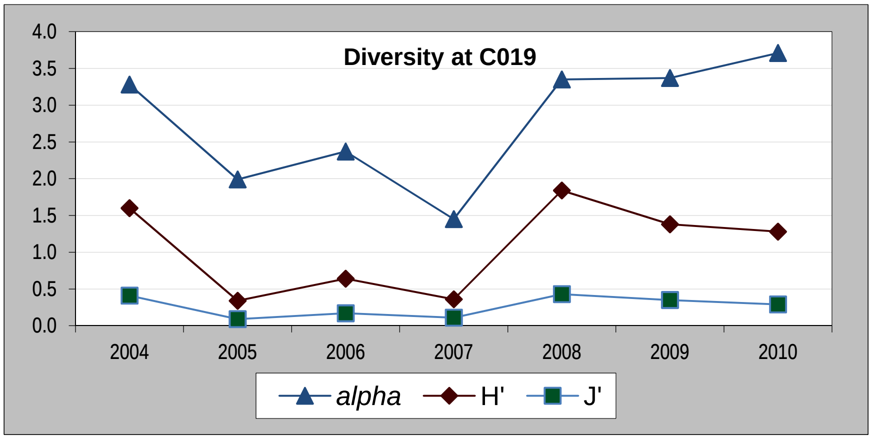


Figure 22. Mean annual diversity parameters at station C019.

Trends over time. Benthic community parameters for the harbor overall were summarized for Taylor (2006) time periods, offset by one year to allow for any lag time in the response of benthic populations to decreased pollutant loads (Table 2). Periods II and III appear the most similar for all parameters. Fisher's *alpha* shows a steady increase through all time periods, whereas the mean values of other parameters appear identical or decline between subsequent periods (e.g., number of species, periods II and III; Shannon diversity, periods III and IV), reflecting the increase and decline of amphipod populations, and, in the last two or three years, the irruption of *Nephtys cornuta*. Mean values for Period IV (2002–2010) were nearly identical to those reported last year for 2002–2009; there was a insignificant decline in numbers of species (42.1 for 2002–2010 vs. 42.2 for 2002–2009 and Fisher's *alpha* (7.59 for 2002–2010 vs. 7.64 for 2002–2009).

Table 2. Benthic community characteristics of Boston Harbor traditional stations summarized by discharge time periods defined by Taylor (2006).

Parameter	**Period**			
	I **before Dec. 1991**	**II** **Dec 1991–mid-1998**	**III** **mid-1998–Sep. 2000**	**IV** **after Sep. 2000** **(after outfall diversion)**
Groupings offset by one year	**n= 48** **(1991–1992)**	**n = 144** **(1993–1998)**	**n= 70** **(1999–2001)**	**n = 216** **(2002–2010)**
Number of Species	25.1 ± 14.25	34.7 ± 13.6	33.5 ±14.2	42.1 ± 17.3
H′	2.11 ± 0.81	2.41 ± 0.90	2.80 ±0.78	2.83 ± 0.95
log-series *alpha*	4.14 ± 2.13	5.50 ± 2.00	6.13 ± 2.24	7.59 ± 3.20
Rarefaction curves	1991 lowest	low	intermediate	highest
Fauna	highest abundances of opportunistic species such as *Streblospio benedicti* and *Polydora cornuta*	declining abundances of opportunistic species, some amphipod species numerous	fewer opportunists, more oligochaetes, some amphipod species numerous	some species from Massachusetts Bay, rise and decline of amphipods, irruption and decline of opportunistic polychaete *Nephtys cornuta*

4. CONCLUSION

Results obtained for biology and chemistry samples collected in Boston Harbor in 2010 were consistent with trends seen previously in the long-term monitoring data (Maciolek et al. 2009). The cyclic nature of population densities of, for example, ampeliscid amphipods and small polychaetes such as *Polydora cornuta* is typical of a near-coastal environment where physical as well as some level of contaminant stress is present. It is probable that the harbor benthos will continue to evidence episodic irruptions and declines of populations of amphipods and other species as has been documented over the past several years. However, the decrease in carbon loading and levels of *Clostridium perfringens* at several locations in the harbor, plus the concomitant increase in community parameters such as species richness and Fisher's *alpha*, as well as the deepening of the aRPD layer and continued presence of eelgrass on Deer Island Flats, all point towards a cleaner and healthier benthic environment brought about by minimizing wastewater impacts to Boston Harbor.

5. REFERENCES

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APPENDIX A

2010 Infaunal Community Parameters

Table A1. Benthic community parameters for all samples collected in August 2010.

Station	Replicate	Total Abundance	No. Species	H′ (base 2)	J′	Log-series *alpha*
T01	1	2374	48	3.69	0.66	8.54
	2	2037	46	2.96	0.54	8.37
	3	1758	42	3.39	0.63	7.75
	Mean ± SD	2056.3±251.9	45.3±2.5	3.35±0.30	0.61±0.05	8.22±0.34
T02	1	7735	53	2.95	0.52	7.66
	2	9125	52	2.89	0.51	7.38
	3	6950	54	2.67	0.46	7.98
	Mean ± SD	7936.7±899.3	53.0±0.8	2.84±0.12	0.50±0.02	7.67±0.25
T03	1	3179	40	2.95	0.55	6.45
	2	5844	49	2.67	0.48	7.34
	3	5268	49	2.88	0.51	7.47
	Mean ± SD	4763.7±1144.9	46.0±4.2	2.83±0.12	0.51±0.03	7.09±0.45
T04	1	412	13	1.26	0.34	2.56
	2	261	9	1.08	0.34	1.81
	3	711	14	1.68	0.44	2.48
	Mean ± SD	461.3±187.0	12.0±2.2	1.34±0.25	0.37±0.05	2.28±0.33
T05A	1	4152	58	3.70	0.63	9.55
	2	3780	52	3.55	0.62	8.54
	3	3693	61	3.56	0.60	10.38
	Mean ± SD	3875.0±199.1	57.0±3.7	3.61±0.07	0.62±0.01	9.49±0.75
T06	1	3853	49	3.00	0.53	7.92
	2	2486	43	2.86	0.53	7.39
	3	3291	50	3.27	0.58	8.37
	Mean ± SD	3210.0 ± 561.0	47.3±3.1	3.04±0.17	0.55±0.02	7.90±0.40
T07	1	354	10	1.67	0.50	1.91
	2	529	14	2.14	0.56	2.64
	3	264	14	2.49	0.65	3.16
	Mean ± SD	382.3 ± 110.0	12.7 ± 1.9	2.10 ± 0.34	0.57 ± 0.06	2.57 ± 0.51
T08	1	1292	62	3.84	0.64	13.66
	2	949	49	4.17	0.74	11.00
	3	931	59	4.37	0.74	14.17
	Mean ± SD	1057.3 ± 166.1	56.7 ± 5.6	4.13 ± 0.22	0.71 ± 0.05	12.94 ± 1.39
CO19	1	967	24	1.69	0.37	4.46
	2	738	19	1.03	0.24	3.56
	3	727	17	1.11	0.27	3.12
	Mean ± SD	810.7±135.5	20.0±3.61	1.28±0.36	0.29±0.07	3.71±0.68

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