2009 Boston Harbor
Benthic Monitoring Report

Massachusetts Water Resources Authority

Environmental Quality Department
Report 2010-18

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Benthic Monitoring Report

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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 2009 sampling season, including several chemical parameters and the evaluation of the soft-bottom benthic community through sediment profile images (SPI) and taxonomic evaluation of 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. SPI samples were collected in triplicate at 61 reconnaissance stations (Figure 1). Nine stations were sampled for grain size composition, total organic carbon (TOC), the sewage tracer *Clostridium perfringens*, sediment chemistry, and benthic infauna. 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. Harbor-wide data collected in summer (August or September) from 1991 to 2009 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 2009

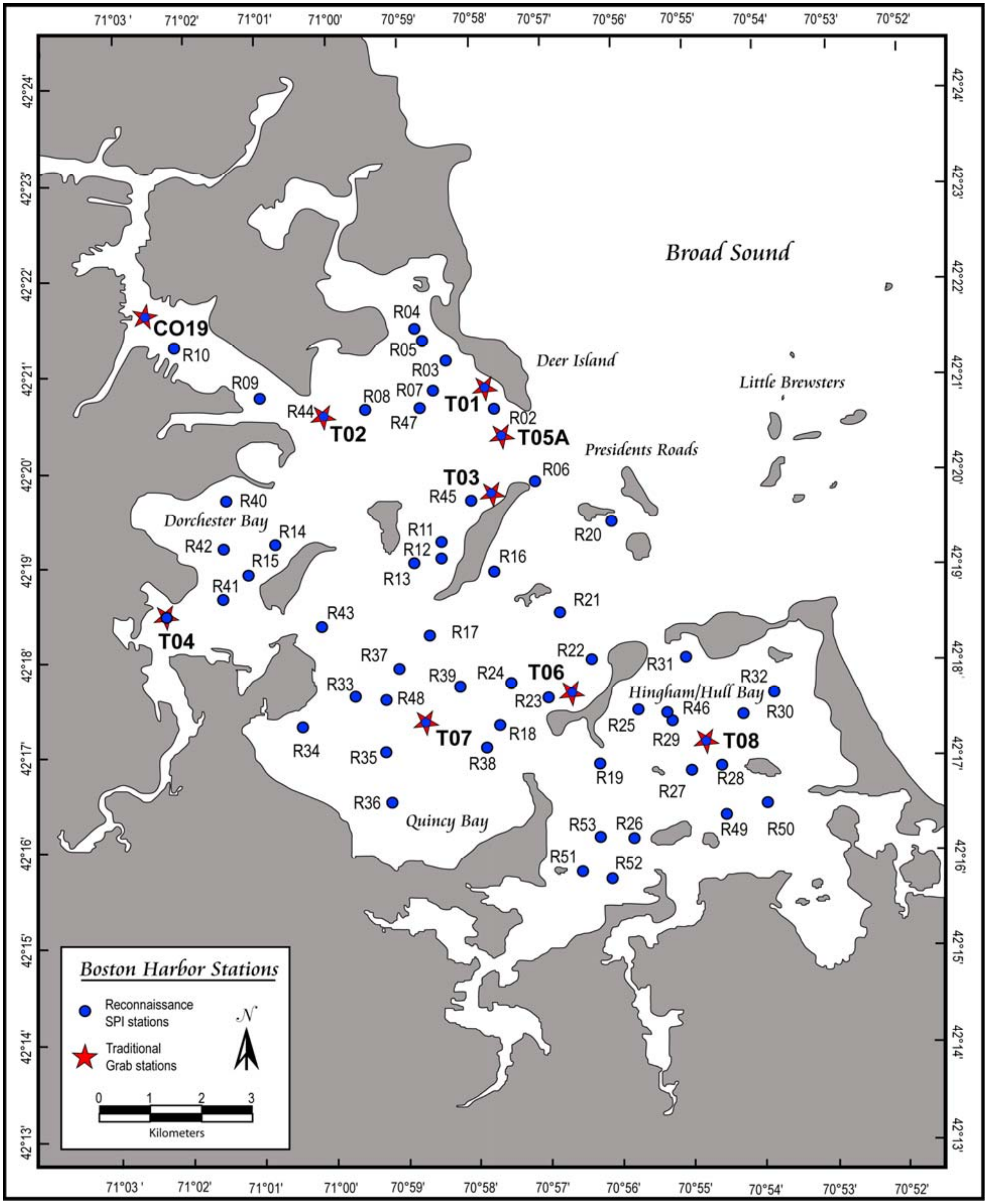

Figure 1. Locations of benthic stations in Boston Harbor sampled in August 2009. All stations were sampled by SPI and those denoted by star symbols were also sampled by grab.

3. RESULTS

3.1 2009 Sediment Chemistry

Grain Size. Results for 2009 were 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 were comprised of sediments with roughly equal parts coarse- and fine-grained material (Figure B1-1 in Maciolek et al. 2008).

Grain-size composition has changed significantly over time at stations T02 (Figure 3), T07, and T08, as evidenced by a significant increase in percent fines. Temporal changes in sediment environments at the other harbor stations have been difficult to discern because of the high variability among the data over time.

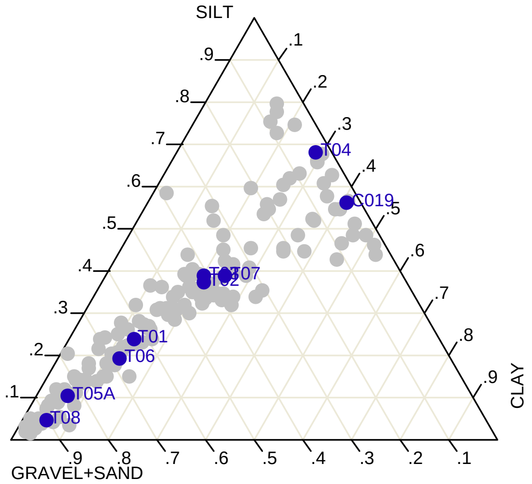

Figure 2. Distribution of percentages of gravel+sand, silt, and clay in surface sediment in Boston Harbor, 1991–2009. (Gray symbols represent 1991–2008 station mean values; blue symbols represent the 2009 station mean values, labeled with the station number).

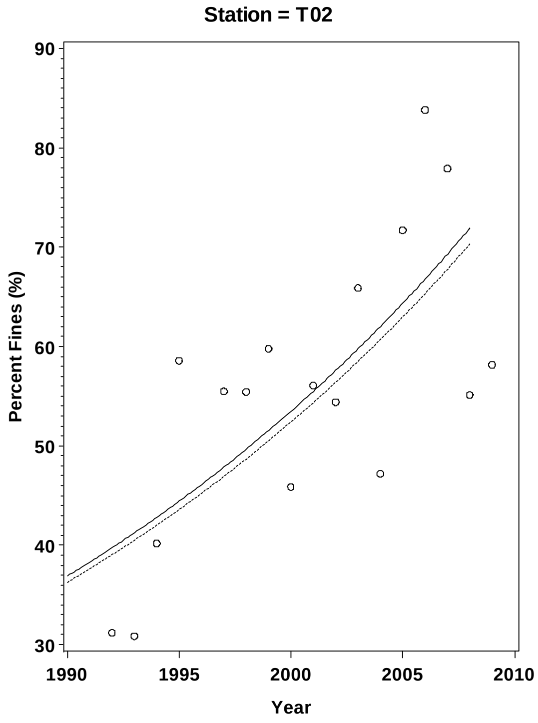

Figure 3. Increasing trends in percent fines in surface sediment at station T02, 1992–2009. (The solid line represents the nonparametric regression and the dashed line represents the parametric regression; outlier years 1991 and 1996 excluded).

Total Organic Carbon. Results for 2009 were consistent with data from the larger monitoring period (1991–2008; Maciolek et al. 2009). Fine-grained sediments (e.g., T04) typically had 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 had the highest TOC (2009 mean = 3.6%; 1991-2009 mean = 4.1%) relative to other harbor stations (Figure 4A). The lowest TOC content was measured at station T08 (2009 mean = 0.3%; 1991-2009 mean = 0.44%), followed by T05A (2009 mean = 0.50%; 1991-2009 mean = 0.78%) (Figure 4A).

Similar to 2008, TOC content in 2009 continued to be low or among the lowest levels measured in recent years at many of the harbor stations (Figure 4A). TOC decreased significantly over time at stations T01, T03, and T06[1] (representative station T01 shown in Figure 5). TOC content also decreased at T07 and T08, although the decrease was not significant at the 95% level of confidence (p values 0.06 to 0.08). TOC content and variability also appears to be decreasing harbor-wide over the four discharge periods (Figure 6), albeit the decrease in mean concentrations is small.

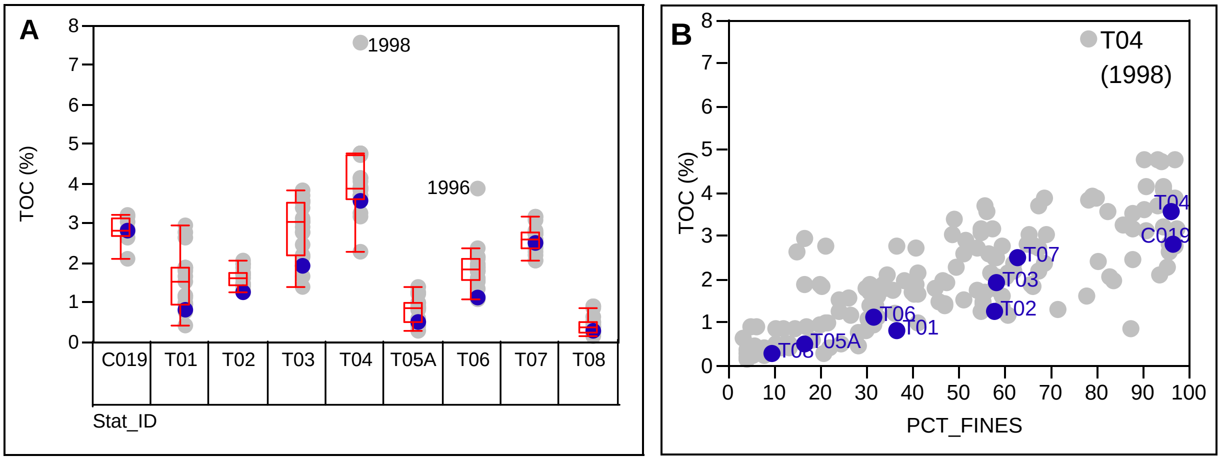

Figure 4. Distribution of TOC, by station (A) and in correspondence with percent fines (B), in surface sediment in Boston Harbor, 1991–2009. (Gray symbols represent 1991–2008 station mean values; blue symbols represent 2009 station mean values.)

Clostridium perfringens. There was a significant difference in the abundances of *C. perfringens* (normalized to percent fines) over time at many of the harbor stations. That is, abundances decreased significantly over time at stations T02, T05A, T06, and T08 and increased significantly over time at station CO19. Abundances also decreased at station T01 (Figure 5), although the decrease was not significant at the 95% level of confidence (p = 0.08). The largest harbor-wide decrease in abundances of *C. perfringens* (normalized to percent fines) occurred between Periods I and III (Figure 6), and a statistical analysis indicates that harbor-wide abundances from the Period III and IV discharge periods were significantly lower than those measured in Periods I and II (p = <0.001).

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[1] The significance of the decrease at T06 is influenced by the very low TOC content measured in 2008.

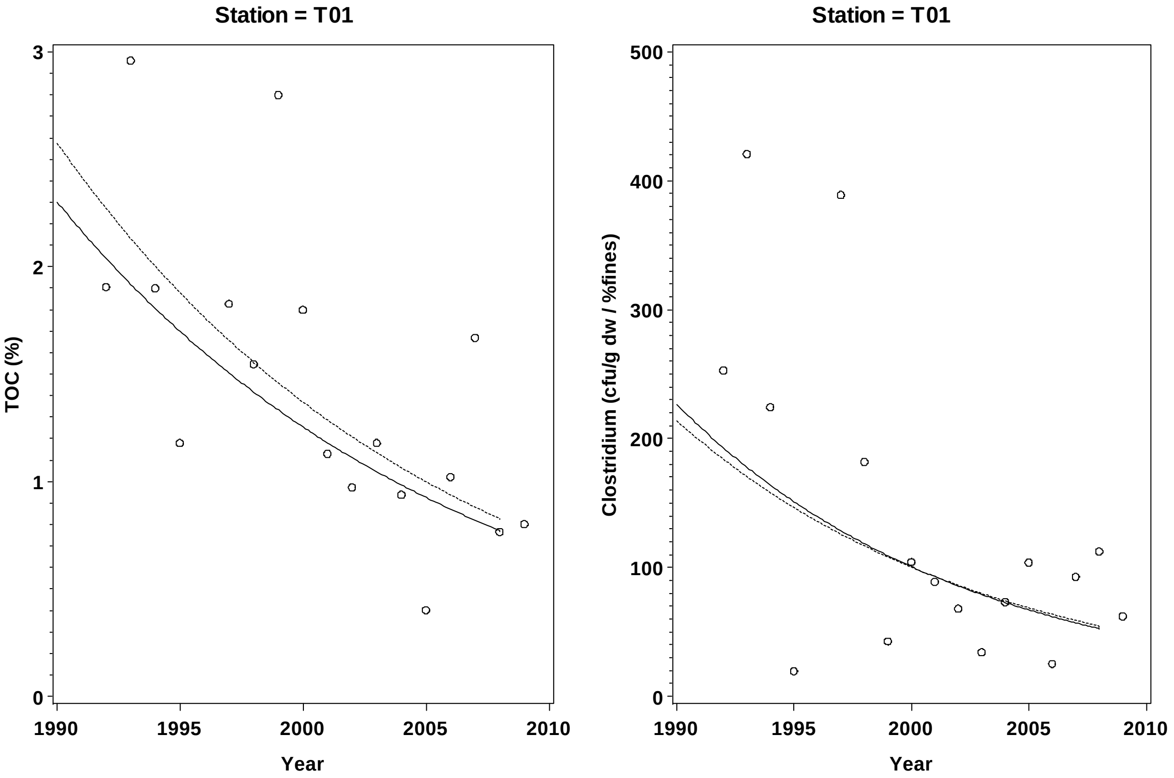


Figure 5. Decreasing trends in TOC (*p* = 0.06) and *C. perfringens* (normalized to percent fines, *p*<0.05) at Station T01 from 1992 to 2009. (The solid line represents the nonparametric regression and the dashed line represents the parametric regression; outlier years 1991 and 1996 excluded.)

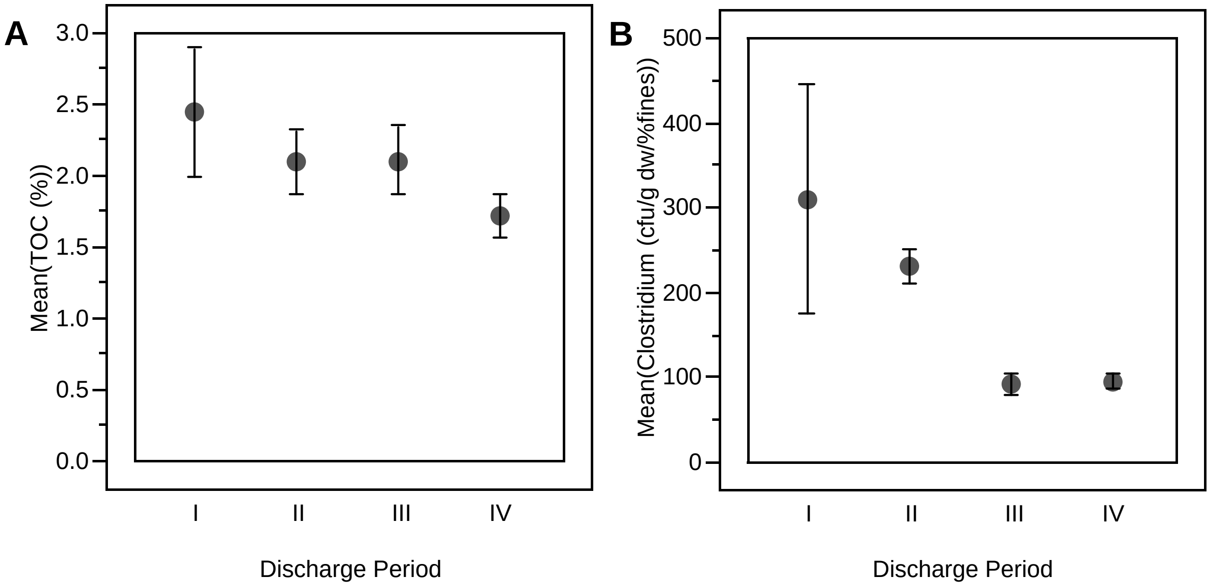


Figure 6. Trends in harbor-wide TOC (p = 0.24) and *C. perfringens* (normalized to percent fines, p< 0.001) from 1992 to 2009. Symbols represent the harbor-wide mean and vertical bars represent the standard error around the mean. (The solid line represents the nonparametric regression and the dashed line represents the parametric regression; outlier years 1991 and 1996 and station CO19 excluded.)

3.2 2009 Sediment Profile Imaging

This summary covers sediment profile images (SPI) collected at harbor stations from 1992 through 2009. Changes in the harbor up to 2006 were analyzed and summarized by Diaz et al. (2008). Based on the patterns of association between the sediment, infauna, and SPI variables, they found a cline of relative habitat quality in the harbor, from lower habitat quality at station T04 to higher habitat quality at T08 (Figure 7). This pattern has persisted to 2009. At higher levels of organic carbon, as seen at Station T04, the benthic habitat appeared characterized by anaerobic processes and carbon accumulation. At lower carbon levels, as seen at station T08, the benthic habitat appeared more aerobic with little carbon accumulation. The tipping point between these two habitat states appears to occur between sedimentary TOC of 2% to 3% with the state set by processes that control bioturbation and organic accumulation rates.

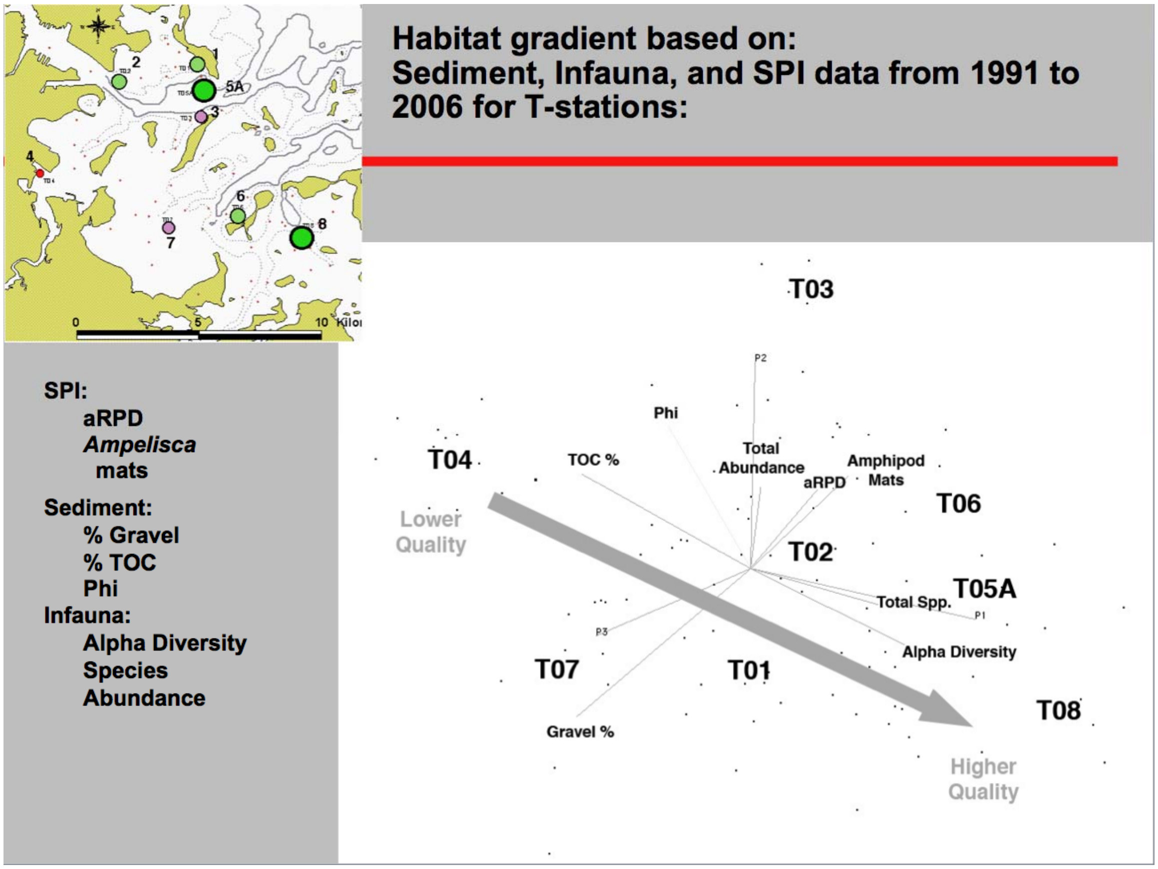


Figure 7. Biplot of eight sediment, infauna, and SPI variables from PCA of station-averaged data. Plot is arranged looking down on the first three principal component axes (P1, P2, and P3) at about a 45° angle. Arrow indicates general cline of habitat quality from lower at T04 to higher at T08. Location of stations is shown in the insert and variables used are listed.

In 2005, none of the 61 harbor stations had *Ampelisca* spp. tube mats (Figure 8). Organic carbon loading had declined and Diaz et al. (2008) associated the decline in amphipods with the reduced organic loading. However, in 2006 *Ampelisca* spp. tube mats started to reappear at two stations in the harbor and in 2008 there were 10 stations with mat densities. In 2009, there were six stations with amphipod tube mats. From 2006 to 2009, the organic carbon loading to the harbor did not increase. One possibility for the increase in *Ampelisca* spp. may be the blooms of the deep burrowing amphipod *Leptocheirus pinguis* that bioturbated sediment to at least 10 cm and likely stimulated increased organic carbon production (Figure 9).

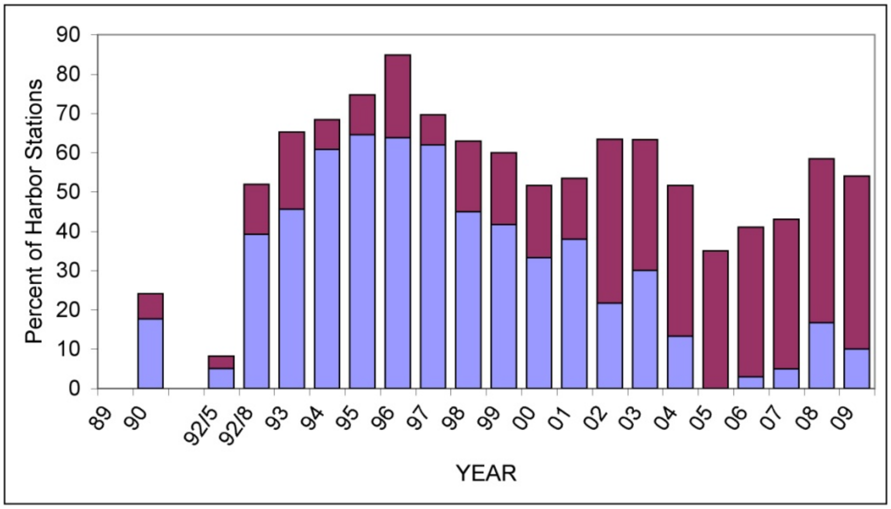


Figure 8. Histogram of *Ampelisca* spp. tubes present at harbor stations. Percent of stations with mat densities of tubes are in blue. Data from 1990 is based on benthic grabs.

Figure 9. Intense bioturbation by the amphipod *Leptocheirus pinguis* at R07 in 2008.

The optimal organic loading for maintaining large areas of amphipod tube mats seems to be around 500 g C per square meter per year. Above and below this level, the area of tube mats in Boston Harbor declined. The increase in tube mats in 2008 and 2009 likely points to an increase of *in situ* production or tightening of benthic-pelagic coupling.

The improvements in wastewater treatment and moving the outfall offshore have tipped the balance back to good benthic habitats within Boston Harbor by favoring processes that enhance bioturbation rates. Through time, the number of infauna and oxic voids seen in SPI increased (Figure 10). The exception remains portions of the harbor that have not had sufficient time to burn off stores of organic matter, for example, Station T04 in Dorchester Bay (Figure 11).

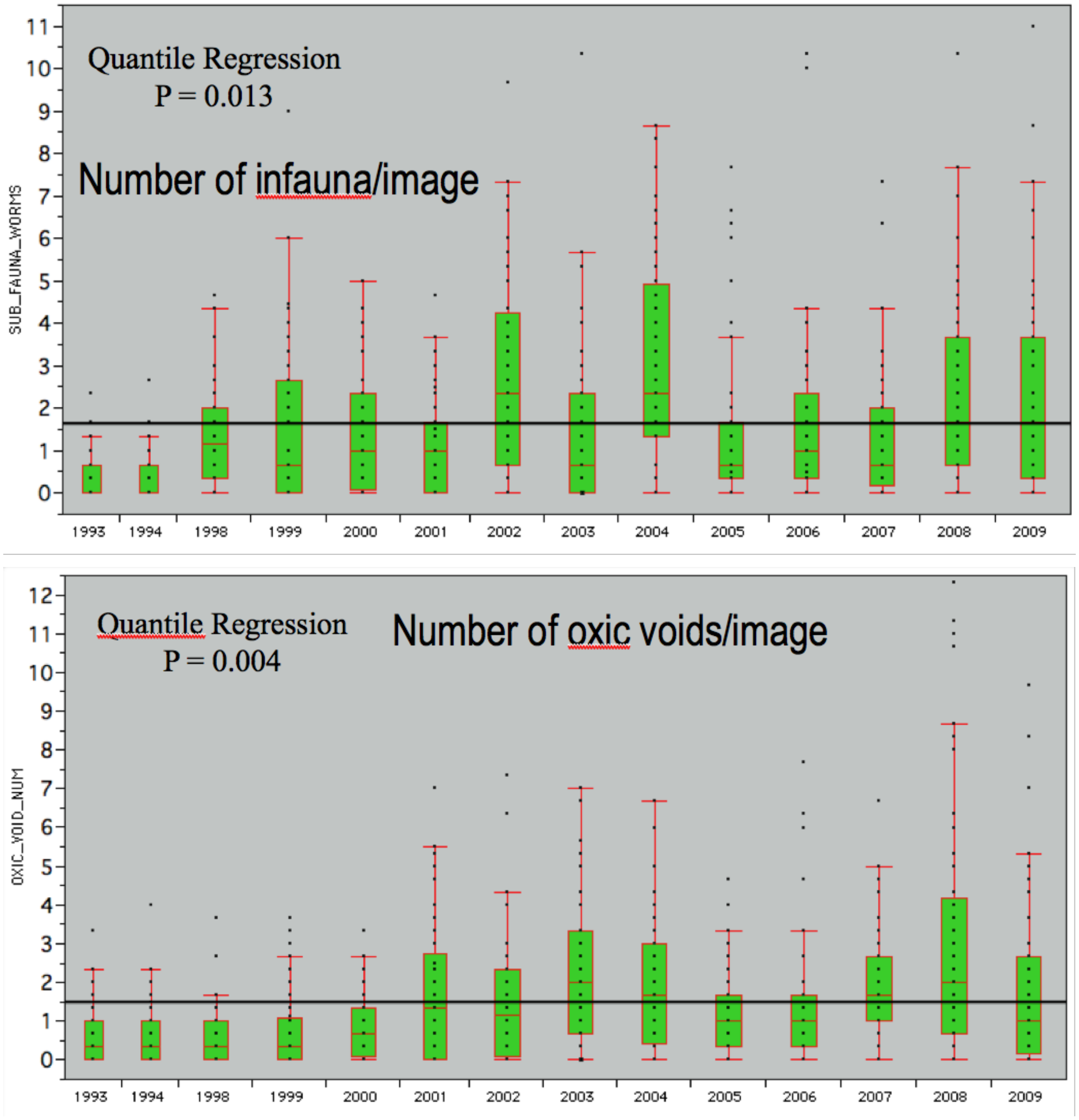


Figure 10. Trends in the number of infauna and oxic voids through time. While most images had low numbers of these features, regression using the 90th quantile revealed a significant increase.

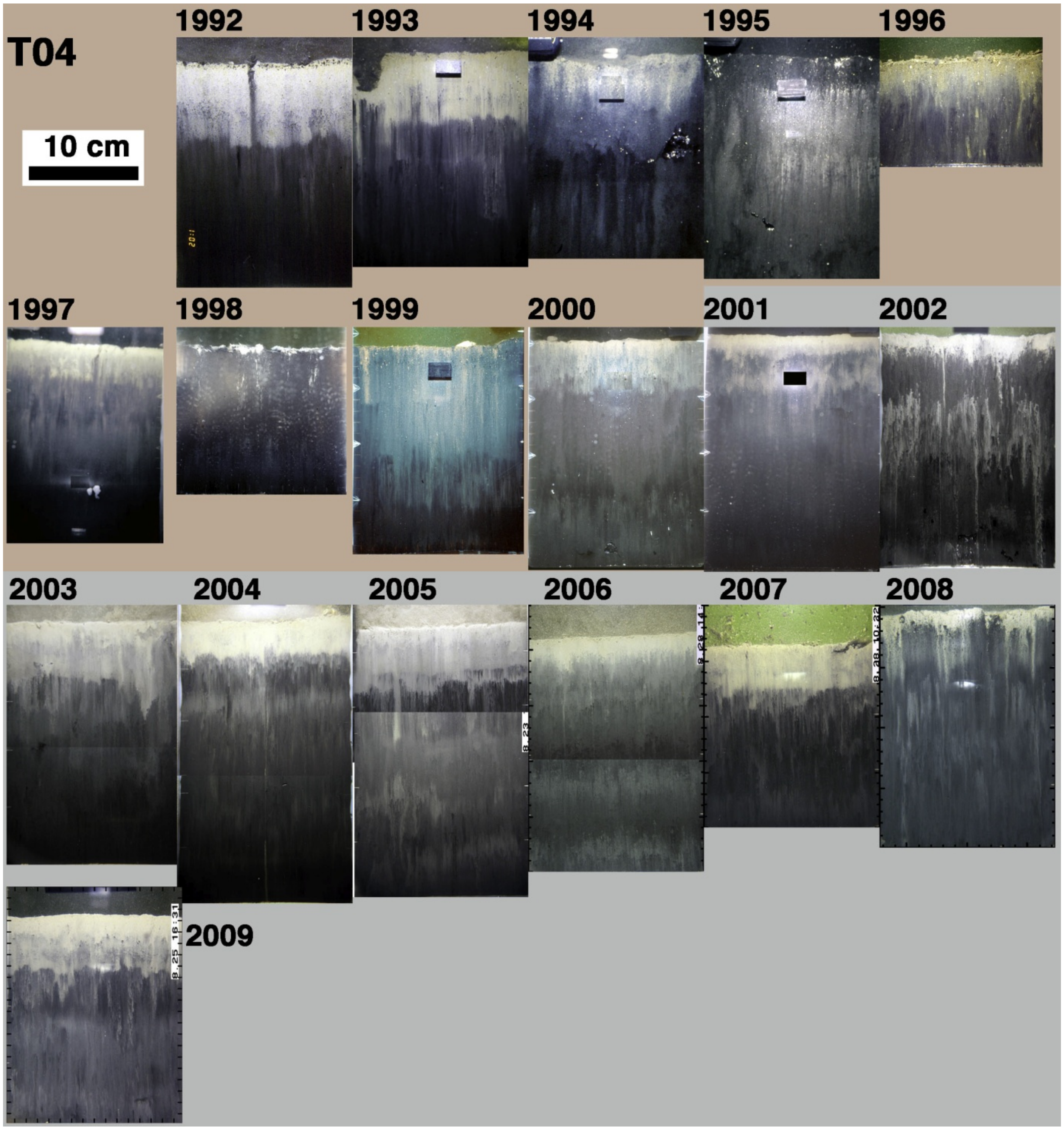
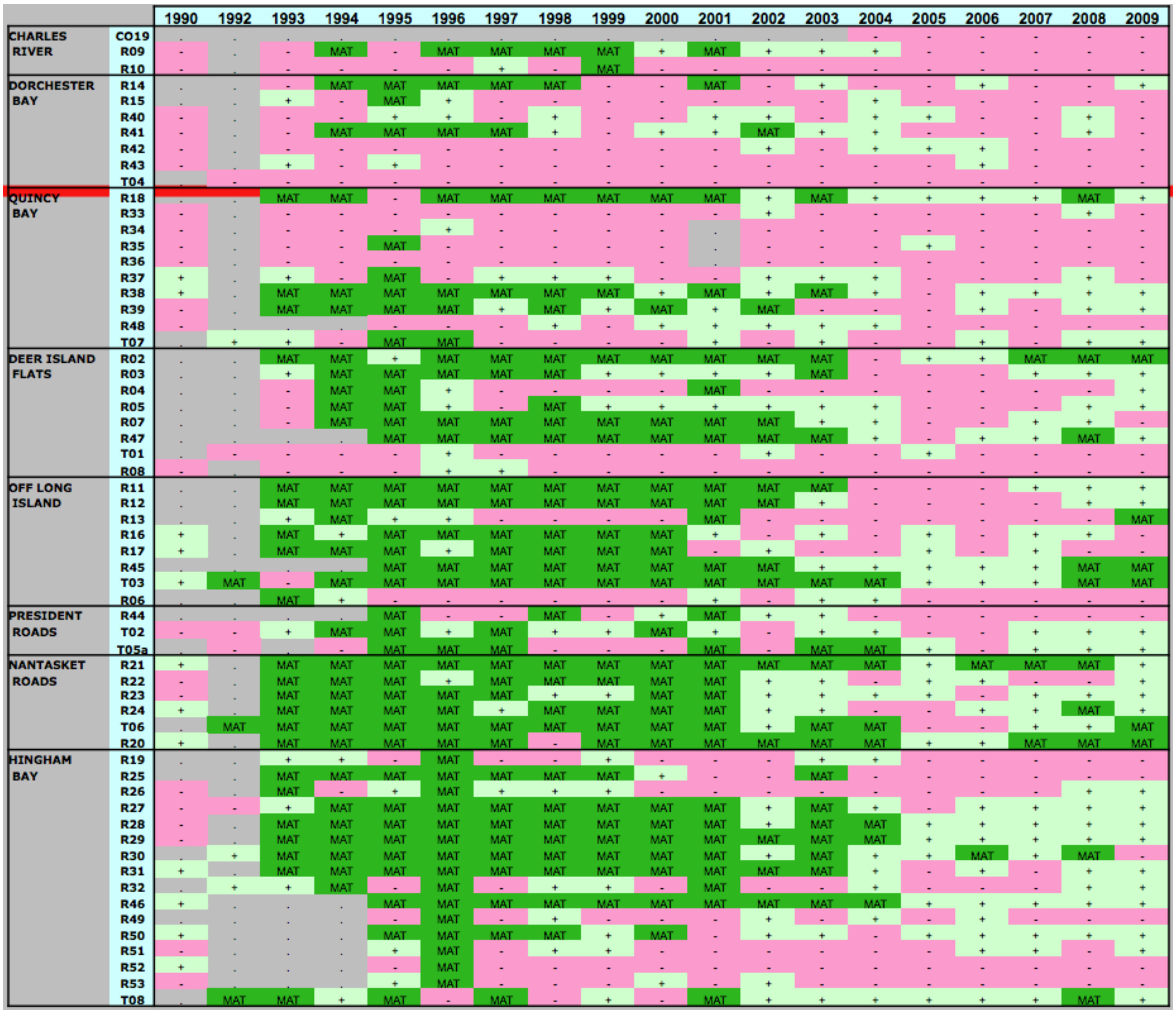


Figure 11. Thumbnail SPI images from T04. Baseline was 1992–2000. In 1998, there was a bacterial mat at the sediment surface. Scale along the side of each image is in cm.

2009 Harbor Details

In 2009, *Ampelisca* spp. tubes at mat densities appeared at six stations. *Ampelisca* spp. tubes at less than mat densities occurred at 27 stations. In total, 54% of the stations had *Ampelisca* spp. tubes. This is about the same as 2008 when 58% of the stations had *Ampelisca* spp. tubes (Figure 12). Over the 17 years of SPI monitoring (1993–2009), station R20 had amphipod mats all years except 1998, 2005 and 2006. Station R21 had mats all years except 2005 and 2009.



		1990	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
CHARLES RIVER	C019	.	.	.	.	.	.	.	.	.	.	.	.	.	-	-	-	-	-	-
	R09	-	.	-	MAT	-	MAT	MAT	MAT	MAT	+	MAT	+	+	+	-	-	-	-	-
	R10	-	.	-	-	-	-	+	-	MAT	-	-	-	-	-	-	-	-	-	-
DORCHESTER BAY	R14	.	.	-	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	+
	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	-	-	-	+	+	+
	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	+
	T01	.	-	-	-	-	+	-	-	-	-	-	+	-	-	+	-	-	-	-
	R08	-	.	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-
OFF LONG ISLAND	R11	.	.	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	-	-	-	+	+	+
	R12	.	.	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
	T03	+	MAT	-	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	+	+	+	MAT	MAT
	R06	.	.	MAT	+	-	-	-	-	-	-	+	-	+	+	-	-	-	-	-
PRESIDENT ROADS	R44	.	.	.	.	MAT	-	-	MAT	-	+	MAT	+	+	-	-	-	-	-	-
	T02	-	-	+	MAT	MAT	+	MAT	+	+	MAT	+	-	+	+	-	-	+	+	+
	T05a	.	-	.	-	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	+
	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
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	+	-	+	-	+	+
	R32	.	+	+	MAT	-	MAT	-	+	+	-	MAT	-	-	+	-	-	-	+	+
	R46	+	.	.	.	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 12. Occurrence of *Ampelisca* spp. tubes through time.

The occurrence of epifaunal organisms in 2009 appeared to be higher than in 2008. In addition to hermit crabs and snails, *Crangon* and mysids were seen at 17 stations. For the second consecutive year, eelgrass was seen at station R08 (Figure 13). Small fish were seen at two stations, R15 and R27, both over a soft sediment bottom. Sediments in 2009 were similar to 2008.

There appeared to be several changes in the average SPI parameters between 2009 and 2008. While the RPD layer depth was about the same between the two years, prism penetration was less in 2009. Average infauna and burrows per image were about the same, but oxic voids declined in 2009 and no gas voids were observed (Table 1). The decline in oxic voids was most likely related to a decline in bioturbation by *Leptocheirus pinguis*. Bioturbation that appeared to be related to the presence of *L. pinguis* amphipods was seen in 2009 but was not as widespread as in 2008.

Figure 13. Eel grass bed was present at R08 in 2008 and 2009.

Table 1. Summary of Harbor SPI variables for 2009 and 2008.

		Penetration (cm)	RPD (cm)	Infauna (#/image)	Burrow (#/image)	Oxic Voids (#/image)	Anaerobic Voids (#/image)	Gas Voids (#/image)	OSI
2009	Mean	9.4	3.0	2.3	0.6	1.8	0.4	0.0	7.8
	SD	4.23	1.75	2.34	0.61	2.14	0.65		2.51
2008	Mean	12.7	3.2	2.3	0.8	3.1	0.6	0.05	7.9
	SD	5.40	1.89	2.17	0.85	3.34	0.79	0.24	1.98

3.3 2009 Soft-Bottom Benthic Infaunal Communities

Harbor-wide Results. Twenty-seven benthic grab samples were collected from Boston Harbor stations in August 2009; benthic community parameters were calculated for each of the samples (Appendix A) as in previous years (Maciolek et al. 2008, 2009).

Samples collected from the eight traditional grab stations yielded 146 valid taxa. Mean species richness in 2009 (45.7 ± 3.8 taxa) was lower than in 2008, when the highest mean species richness (52.1 ± 3.4 taxa) in the program to date was recorded (Figure 14). In 2009, the number of taxa decreased at all stations except stations T05A and T08, which were the only two stations where species richness had not increased the previous year. Mean species richness in 2009 was similar to that recorded in 2004 (43.9 ± 4.1 taxa).

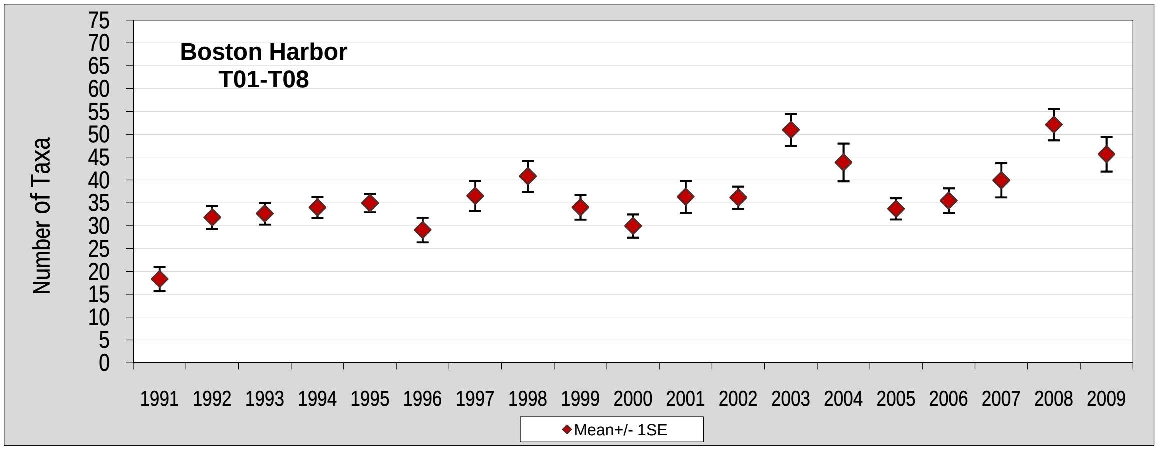


Figure 14. Mean species richness for eight Boston Harbor stations in August 1991–2009.

Total abundance declined in 2009 compared with 2008 (Figure 15). The large increases in 2008 of two species, the polychaete *Polydora cornuta* and the amphipod *Leptocheirus pinguis*, was followed in 2009 by major declines in the abundance of these and other common species (Figure 16). Although the total abundance of species of the amphipod genus *Ampelisca* was much higher in 2009 than in 2008 (Figure 17), this increase was not sufficient to offset the overall decline in the remaining fauna. Increases in *Ampelisca* spp. were greatest at stations T02, T05A, T06 and T08 (Figure17).

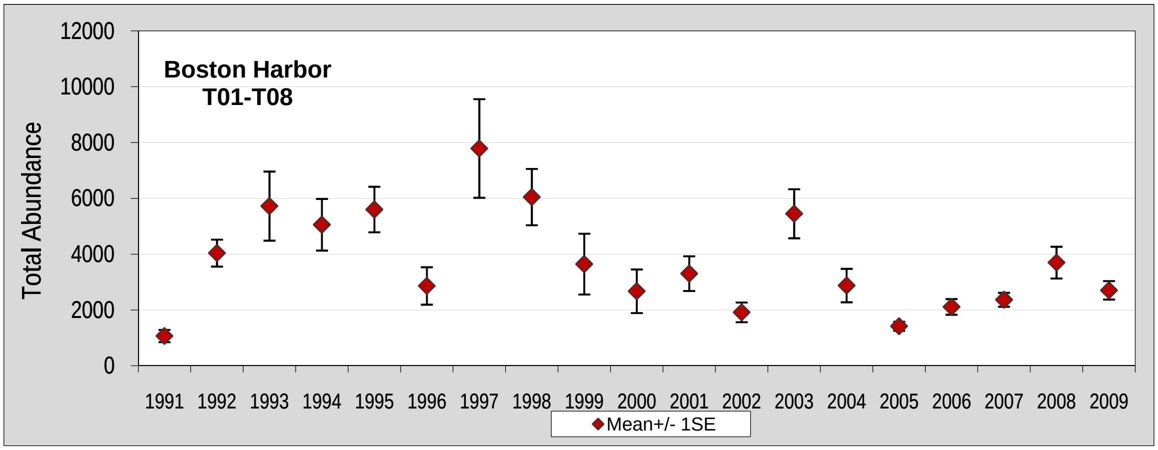


Figure 15. Mean total abundance for eight Boston Harbor stations in August 1991–2009.

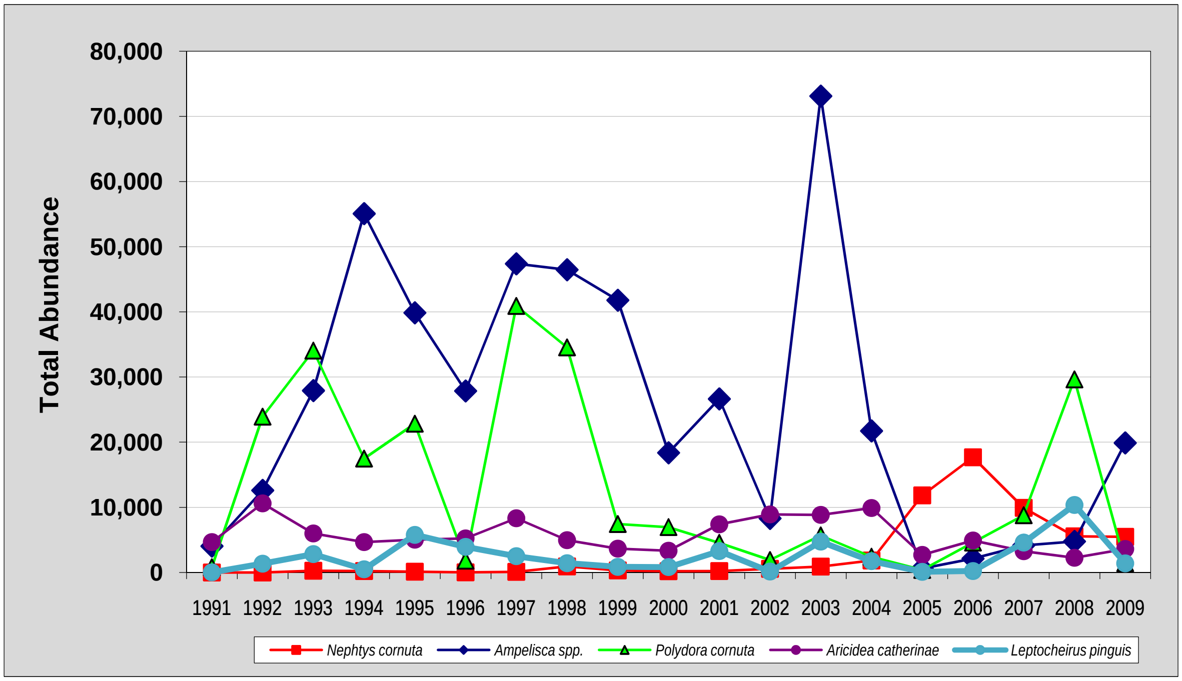


Figure 16. Annual density of five common species in Boston Harbor for the period 1991–2009.

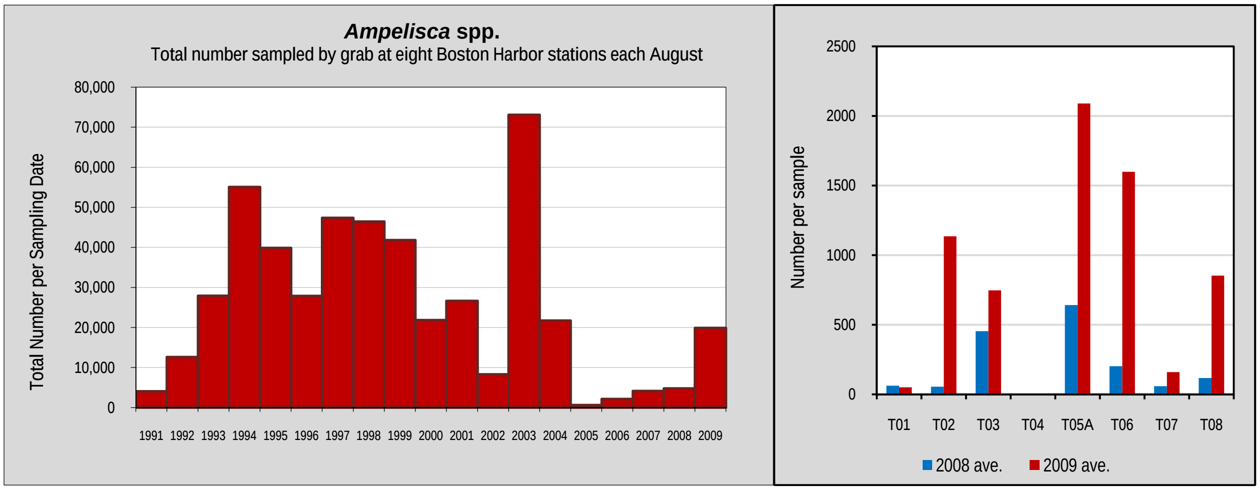


Figure 17. Left: Total number of *Ampelisca* at Boston Harbor stations in August 1991–2008. Right: Average number of *Ampelisca* spp. at each Boston Harbor station in August 2008 and 2009.

The numerically dominant species in the harbor (Table 2) reflect the large increase in numbers of ampeliscid amphipods and oligochaetes with the concomitant decrease in the polychaete *Polydora cornuta* and the amphipod *Leptocheirus pinguis*. *Polydora cornuta*, which was the top numerical dominant at four of eight stations last year, declined to less than 5% of its 2008 abundance, reflecting the patchiness and population fluctuations typical of this species (Table 2, Figure 16). *Nephtys cornuta*, a small polychaete that dominated most stations in 2005 and 2006 but declined in numbers thereafter, was present in about the same densities as in 2008.

Table 2. Dominant taxa at eight grab stations in Boston Harbor in August 2009.

Taxon	Total Abundance	Comparison with 2008
Ampelisca spp.	19,902	~400% increase
Limnodriloides medioporus	6,435	~75% increase
Tubificoides apectinatus	6,403	~ 50% increase
Nephtys cornuta	5,484	no change since 2007
Aricidea catherinae	3,600	~ 60% increase
Tharyx spp.	3,034	not among top dominants in 2008
Scoletoma hebes	1,765	~25% decrease
Spiophanes bombyx	1,543	not among top dominants in 2008
Photis pollex	1,493	not among top dominants in 2008
Polydora cornuta	1,424	4.8% of 2008 total
Leptocheirus pinguis	1,399	13.5% of 2008 total

Mean diversity as measured by Fisher's log-series *alpha* declined slightly between 2008 and 2009 but increased slightly as measured by Shannon's H′ (Figure 18); neither change was significant. Evenness (J′) was slightly higher in 2009, indicating a more equitable distribution of individuals among species (Figure 18).

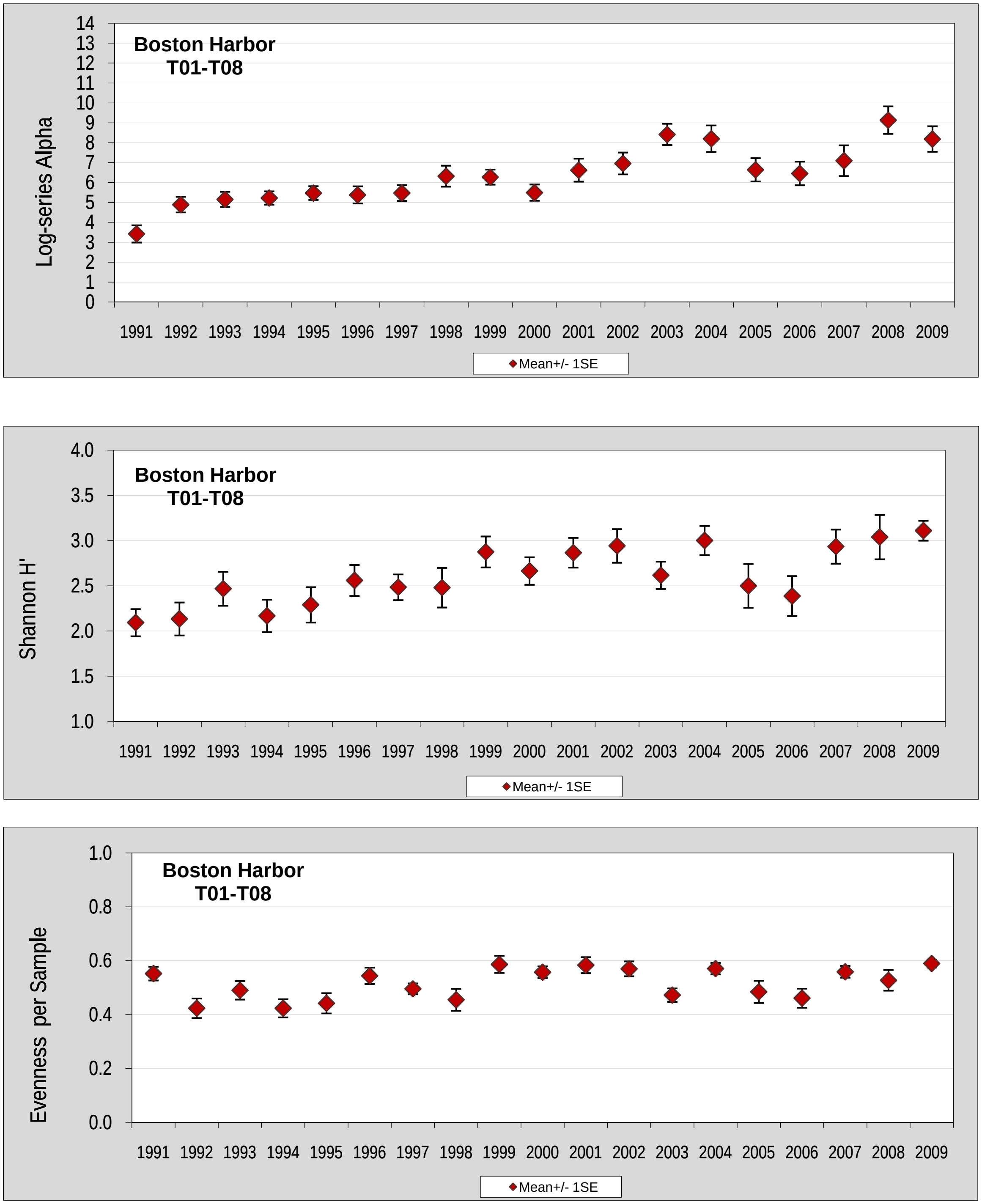


Figure 18. Mean species diversity and evenness for eight Boston Harbor stations in August 1991–2009.

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 2009 was slightly higher than that for 2008. Only years 2002–2004 had higher diversity curves than 2008 and 2009.

Multivariate analysis indicated that 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).

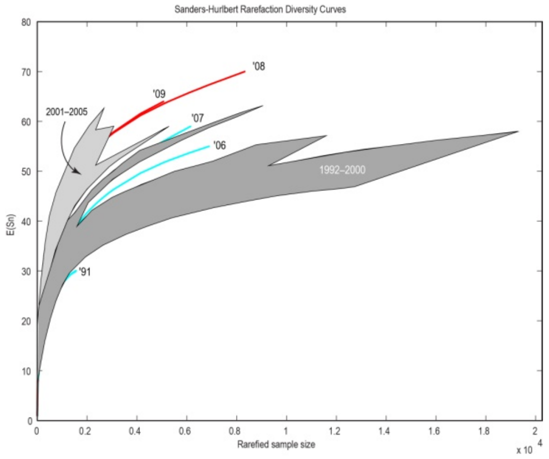


Figure 19. Rarefaction curves for station T01 off Deer Island flats in Boston Harbor, 1991–2009. All samples pooled within each year.

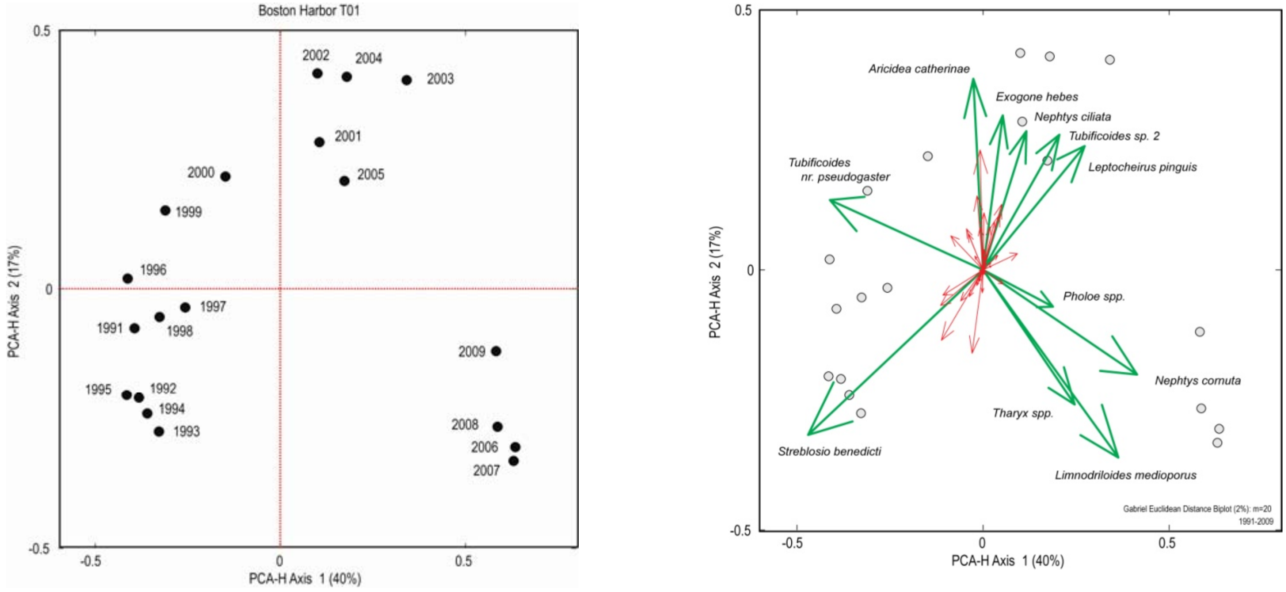


Figure 20. PCAH analyis for station T01 off Deer Island flats in Boston Harbor, 1991–2009. (A) metric scaling of annual samples, (B) Euclidean distance biplot showing the species responsible for at least 2% of the CNESS (*m* = 20) variation.

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 six years of sampling (2004–2009), a total of 54 taxa have been recorded from this station, with the 2009 samples yielding 24 species. Taxa newly recorded from this station in 2009 included single specimens of the polychaetes *Capitella capitata* complex, *Paranaitis speciosa*, *Pista cristata*, *Pygospio elegans*, and *Scolelepis bousfieldi*, and a single specimen of the amphipod *Microdeutopus anomalus*. In 2009, as in the five preceding years, the fauna at C019 was dominated by *Nephtys cornuta* (Figure 21), which accounted for 78.7% of the total fauna at this station.

The increase in number of taxa and reduced importance of *N. cornuta* in 2008 were reflected in the much higher diversity values in 2008 compared with the three previous years. In 2009, diversity as measured with Shannon H' decreased but Fisher's *alpha* remained high (Figure 22).

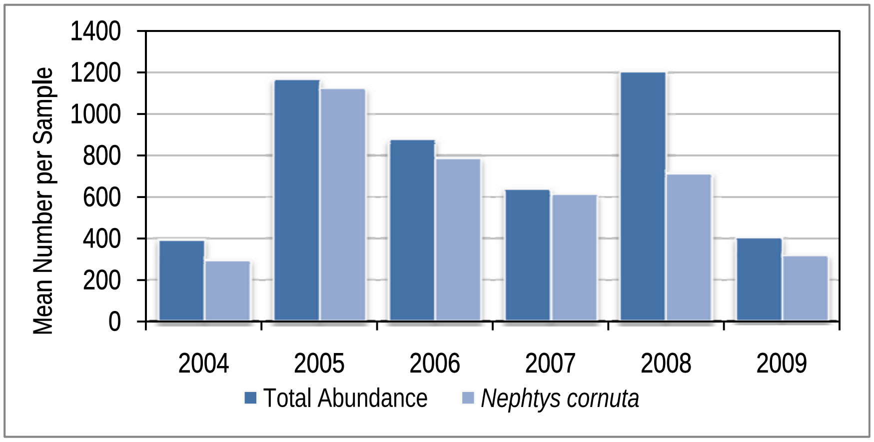


Figure 21. Total abundance and density of *Nephtys cornuta* at station C019.

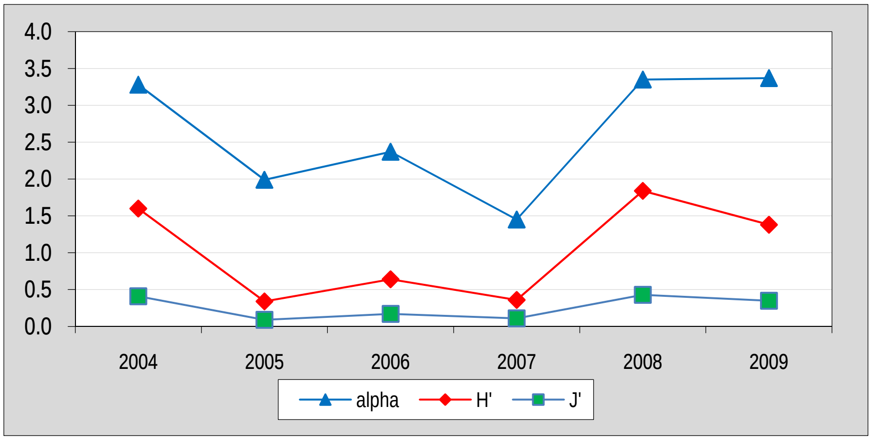


Figure 22. Mean annual diversity parameters at station C019.

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 3). 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 (2002–2009) increased slightly over the mean reported last year for 2002–2008.

Table 3. 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 = 192** **(2002–2009)**
Number of Species	25.1 ± 14.25	34.7 ± 13.6	33.5 ±14.2	42.2 ± 17.3
H′	2.11 ± 0.81	2.41 ± 0.90	2.80 ±0.78	2.82 ± 0.96
log-series *alpha*	4.14 ± 2.13	5.50 ± 2.00	6.13 ± 2.24	7.64 ± 3.18
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 2009 were consistent with trends seen previously in the long-term monitoring data (Maciolek et al. 2008). The cyclic nature of population densities of, for example, ampeliscid amphipods and small polychaetes 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, 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

2009 Infaunal Community Parameters

Table A1. Benthic community parameters for all samples collected in August 2009.

Station	Replicate	Total Abundance	No. Species	H′ (base 2)	J′	Log-series *alpha*
T01	1	1285	48	3.97	0.71	9.88
	2	2198	45	3.38	0.62	8.07
	3	1716	51	3.63	0.64	9.92
	Mean ± SD	1733.0 ± 456.7	48.0 ± 3.0	3.66 ± 0.29	0.66 ± 0.05	9.29 ± 1.06
T02	1	3252	46	3.18	0.58	7.59
	2	3198	43	2.68	0.49	7.03
	3	2982	39	2.94	0.56	6.34
	Mean ± SD	3144.0 ± 142.9	42.7 ± 3.5	2.93 ± 0.25	0.54 ± 0.04	6.98 ± 0.63
T03	1	3949	49	3.08	0.55	7.95
	2	2723	48	3.25	0.58	8.29
	3	3996	49	3.13	0.56	7.87
	Mean ± SD	3556.0 ± 721.8	48.7 ± 0.6	3.15 ± 0.09	0.56 ± 0.02	8.04 ± 0.22
T04	1	67	8	2.16	0.72	2.53
	2	95	10	2.26	0.68	2.82
	3	52	10	2.36	0.71	3.80
	Mean ± SD	71.3 ± 21.8	9.3 ± 1.2	2.26 ± 0.10	0.70 ± 0.02	3.05 ± 0.66
T05A	1	4695	71	3.83	0.62	11.88
	2	5509	73	3.46	0.56	11.89
	3	5784	57	3.19	0.55	8.79
	Mean ± SD	5329.3 ± 566.3	67.0 ± 8.7	3.49 ± 0.32	0.58 ± 0.04	10.86 ± 1.79
T06	1	3987	50	2.64	0.47	8.06
	2	3743	53	3.08	0.54	8.76
	3	4355	44	2.64	0.48	6.81
	Mean ± SD	4028.3 ± 308.1	49.0 ± 4.6	2.79 ± 0.26	0.50 ± 0.04	7.88 ± 0.99
T07	1	1899	36	3.25	0.63	6.36
	2	1823	30	2.85	0.58	5.11
	3	993	30	2.57	0.52	5.88
	Mean ± SD	1571.7 ± 502.6	32.0 ± 3.5	2.89 ± 0.34	0.60 ± 0.07	13.59 ± 0.27
T08	1	1764	65	3.84	0.64	13.46
	2	2845	74	3.26	0.53	13.91
	3	2032	67	3.89	0.64	13.42
	Mean ± SD	2213.7 ± 562.9	68.7 ± 4.7	3.67 ± 0.35	0.60 ± 0.07	13.59 ± 0.27
CO19	1	266	19	1.94	0.46	4.68
	2	376	12	1.13	0.32	2.36
	3	567	16	1.07	0.27	3.06
	Mean ± SD	403.0±152.3	15.67±3.5	1.38±0.48	0.35±0.10	3.37±1.19

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