Infaunal community changes in Boston Harbor, 1991-1994

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INFAUNAL COMMUNITY CHANGES IN BOSTON HARBOR, 1991–1994

THE 1994 ANNUAL HARBOR SOFT-BOTTOM BENTHIC MONITORING REPORT

by

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EXECUTIVE SUMMARY

In 1991, the Massachusetts Water Resources Authority (MWRA) began a long-term study to monitor environmental conditions in the bottom sediments of Boston Harbor. One of the primary purposes of the study is to document recovery of the Harbor ecosystem following the cessation of sludge discharge into the Harbor. Sludge generated at the Deer Island and Nut Island wastewater treatment facilities, until abatement in December 1991, was discharged from a point off the eastern tip of Long Island into Boston Harbor on outgoing tides. This report summarizes the data collected from 1991 through 1994 as part of the MWRA monitoring program and analyses the data for changes in biological and physical parameters that may be related to recovery of the Harbor benthos from sludge discharge activities. Included in this objective are comparisons of species-, community-, and habitat-level parameters measured from 1991 to 1994.

An initial survey was conducted in September 1991 prior to the abatement of sludge discharge into the Harbor. Subsequent surveys were conducted in April and August 1992 through 1994. On each survey, three replicate benthic grab samples were collected by using a 0.04-m2 Young-modified Van Veen grab sampler at eight traditional stations. Traditional samples were sorted in the laboratory to remove all infaunal organisms. In September 1991 and August 1993 1994, traditional infaunal sampling was supplemented with the collection of a single grab sample from 24 reconnaissance stations. Reconnaissance samples were subsampled and sorted for a finite amount of time. Also in late summer of each study year, sediment profile images were obtained at the traditional stations and at reconnaissance stations. Sediment profile images were analyzed to determine several sedimentary, benthic community, and organism/sediment qualities. Ancillary physicochemical analyses of sediment samples from traditional stations were particle size distribution (percent gravel, sand, silt, clay), total organic carbon content (TOC), and *Clostridium perfringens* spore counts.

Significant changes in the distribution of several taxa over the course of the study were detected. As highlighted by the reconnaissance survey grab-sample data, the tube-dwelling amphipod *Ampelisca* was predominant primarily in the southern and central parts of the Harbor in 1991, but by 1994 had expanded its area of numerical importance to include major portions of the northern Harbor. A polychaete worm, *Streblospio benedicti*, that was widespread in 1991 decreased in predominance by 1994. Interestingly, these changes were not necessarily related to changes in absolute abundance. Although the increased importance of Ampelisca was accompanied by increased abundance, the reduced importance of *Streblospio* was not accompanied by reductions in abundance. For example, at station T-2, the relative abundance of *Streblospio* was lower in 1994 than it was in 1991 although its absolute abundance was substantially higher. The abundances of other taxa fluctuated, but in ways difficult to characterize and that may reflect cyclic variation. For example, by late summer 1993, it appeared that the abundances of at least three species of amphipods other than Ampelisca had increased since 1991 and that these species, *Leptocheirus pinguis*, *Unciola irrorata*, and *Corophium bonelli*, were exhibiting changes parallel to those found for *Ampelisca*. However, data from the 1994 surveys countered this apparent trend as the abundances of all three species decreased substantially from those found in 1993. A polychaete worm, *Aricidea catherinae*, was very common at stations T-6 and T-8 through out the duration of the study and remained a consistent indicator of the southern Harbor community. *Polydora cornuta*, a spionid polychaete, showed apparently seasonal fluctuations in abundance, occurring at high abundances at some stations in August, but not in April, 1992, 1993, and 1994. The nutclam *Nucula delphinodonta* occurred in relatively large numbers only at station T-8, a pattern that did not change between 1991 and 1994.

Some community-level changes were detected. Total abundance increased at most stations over the course of the study. When the all August values were compared to the 1991 values, it appeared that abundance at stations in the northern part of the Harbor by August 1994 remained at least 4 x higher than that found in 1991. However, infaunal abundance at stations located in the central and southern part of the Harbor (except station T-4) was only slightly higher in August 1994 than in 1991. Species numbers per station appeared to show an increasing trend during the duration of the study. However, the total numbers of species per survey fluctuated seasonally to such an extent that the lowest values (April) were similar to those found in September 1991. Species diversity also fluctuated in an apparently seasonal manner, but over the three years remained reasonably similar.

Surprisingly few sedimentary changes were detected during the study. Sediment grain-size and total organic carbon content, with a few exceptions, generally were similar at each station throughout the four years. The sewage tracer, *Clostridium perfringens*, was substantially lower in 1992 1994 than in 1991. However, the largest change occurred between 1991 and August 1992, thereafter, spore counts fluctuated, but were essentially similar at each station.

Although it is tempting to attribute the substantial infaunal community changes observed during the study to the cessation of sludge discharge, the baseline data may not afford an adequate comparison. Qualitative comparisons with historical data show that the values obtained for benthic metrics after cessation often were within the range of variability found during earlier (1978 1982) studies. The considerable seasonal and annual variability encountered argue for the continuation of biannual sampling that will then provide the baseline data set necessary to evaluate change after the eventual cessation of effluent discharges into the Harbor.

Introduction

In 1991, the Massachusetts Water Resources Authority (MWRA) began a long-term study to monitor environmental conditions in the bottom sediments of Boston Harbor. One of the primary purposes of the study is to document recovery of the Harbor ecosystem following the cessation of sludge discharge into the Harbor. Sludge generated at the Deer Island and Nut Island wastewater treatment facilities, until abatement in December 1991, was discharged from sites off the harbor side of Deer Island and the eastern tip of Long Island into Boston Harbor on outgoing tides. Cessation of sludge discharge is part of a progression of changes in MWRA discharge practices that will eventually include construction of secondary treatment facilities and the diversion of treated-effluent discharge from the Harbor to deeper waters in Massachusetts Bay.

Of the many biological communities that could be studied in conjunction with environmental monitoring, those found on the bottom, i.e., the benthos, are particularly useful in the consideration of anthropogenic impacts. As stated by Bilyard (1987), study of the benthos affords a monitoring program with relatively easily obtained quantitative data, the variability of which can be estimated. Also, because most benthic animals do not migrate very much, the data are site-specific, which is important in assessing impacts caused by specific sources of disturbance. Many benthic community constituents are very sensitive to anthropogenic disturbance (Thomas, 1993; Conlan, 1994). The benthos also represents an important biological community that interacts not only with those in the overlying waters via food chains (e.g., Steimle *et al.*, 1994), but especially in the case of infaunal communities, also with the physical environment (e.g., Rhoads and Boyer, 1982).

This report is the fourth in a series describing the conditions of the benthos in the Harbor just prior to sludge abatement (Kelly and Kropp, 1992) and during the first three years after abatement (Kelly and Kropp, 1992; Blake *et al.*, 1993; Kropp and Diaz, 1994; this report). Conditions in the Harbor prior to 1991 have been described in a variety of reports primarily associated with the 301(h) waiver process. These were summarized by Blake *et al.* (1989). Other studies conducted prior to abatement used only sediment profile images to document conditions in the Harbor (SAIC, 1990; 1992).

The primary objective of this report is to examine data from all surveys conducted under the MWRA monitoring program and summarize changes in biological and physical parameters that may be related to recovery of the Harbor benthos from sludge discharge activities. Included in this objective are comparisons of species-, community-, and habitat-level parameters measured from 1991 to 1994. A cumulative species list/relative abundance table is presented in Appendix A. The results of the 1994 field sampling efforts are summarized in Appendices B and C of this report. A brief comparison of the infaunal communities to sediment chemistry at four monitoring stations occupied as part of a separate study of the effects of combined sewer overflows (CSOs) on sediment contaminants (Durell, 1995) appears as Appendix D.

Methods

A. Summary of 1991–1994 Field and Laboratory Activities

To examine the potential changes in the Boston Harbor infaunal communities in response to the abatement of sludge discharges into the Harbor, a series of surveys was undertaken at eight traditional stations in Boston Harbor (Figure 1). After a pre-abatement survey was completed in September 1991,

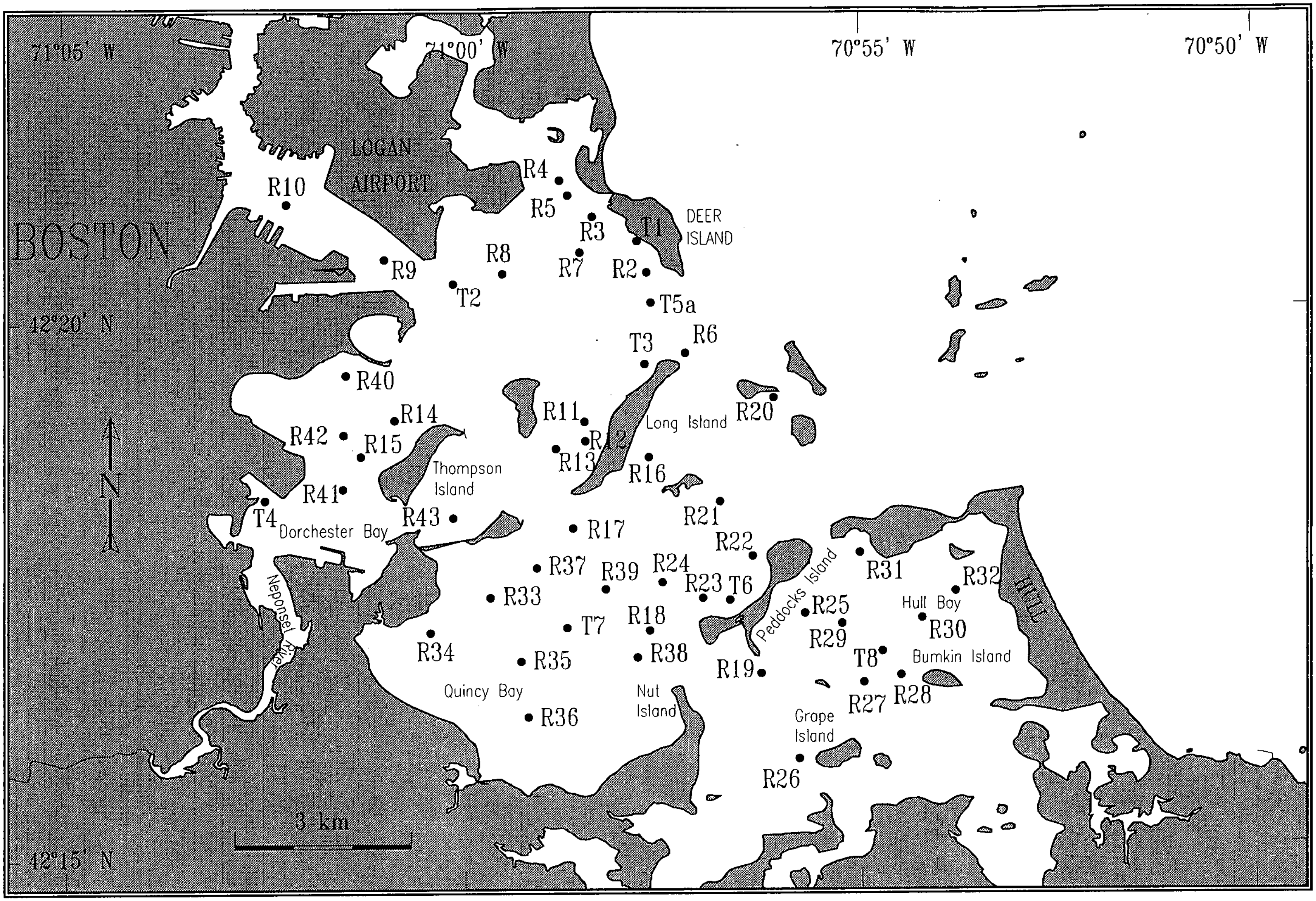


Figure 1. Traditional and reconnaissance stations sampled in Boston Harbor in 1993–1994.

biannual surveys were conducted in April and August 1992 1994. At each station, three replicate benthic grab samples were collected by using a 0.04-m^2 Young-modified Van Veen grab sampler. To support detailed infaunal analyses, a single grab sample was taken at each traditional station for sediment grain-size, total organic carbon (TOC), and *Clostridium perfringens* analyses. In late summer 1991 1994, sediment profile images (SPI) were collected from 4 61 reconnaissance stations (Table 1) in addition to the traditional stations. Locations of the reconnaissance stations sampled in 1993 1994 are indicated in Figure 1; stations sampled in 1991 1992 were illustrated in the reports presenting results of those efforts (Figures 1 and 2 in Kelly and Kropp, 1992; Figure 2 in Blake *et al.*, 1993). The late summer surveys conducted in 1991, 1993, and 1994 also included the collection from each reconnaissance station of a single 0.04-m^2 grab sample for analysis by a rapid sorting technique.

In general, field and laboratory activities conducted in 1991–1993 were comparable to those conducted in 1994 (see Kelly and Kropp, 1992; Blake *et al.*, 1992; Blake *et al.*, 1993; Kropp and Diaz, 1994; and Appendix B). However, a few procedural differences have occurred among the programs that make some comparisons of the data inappropriate. A summary of the various samples collected (including the survey dates) and those used for comparisons made in this report are provided in Table 1. In April 1992, the field crew was not able to sample at traditional station T-5 because suitable soft substrate could not be located. During the survey, a decision was made, in consultation with MWRA, to treat reconnaissance station R-6 as a traditional station. During the August 1992 survey, the field crew was able to sample successfully at station T-5. However, during preparations for the 1993 sampling program, station R-6 was redesignated as a traditional station, T-5a. A site near the original T-5 location was designated as a new reconnaissance station, R-6. Because of these differences in station locations, direct year-to-year comparisons of infaunal and sedimentary properties are not appropriate at those sites. In 1993 and 1994, the depth of the apparent redox potential discontinuity (RPD) was estimated for each macrofaunal grab sample by examining a clear core sample taken from the grab. This estimate was termed RPD_{VIS}.

Because of differences in field sieving techniques used in August 1992 as compared to those used for the other surveys, all analyses presented in this report refer to summed 0.3-mm and 0.5-mm fractions. No bulk sedimentary parameters (grain size, TOC, *Clostridium perfringens*) were measured on the April 1992 samples.

SPI analyses were available only for the late summer surveys. In August 1992, 61 reconnaissance stations were sampled with SPI. Of these, the locations of 18 were used as target coordinates for stations R-26 through R-43 that were sampled with SPI in August 1993 and 1994. Many of the additional 43 reconnaissance stations that were sampled in 1992 were near the locations of stations R-2 through R-25. However, a few areas of the Harbor that were sampled in 1992 were not sampled in 1993 and 1994. Included among these are the areas southeast of the Inner Harbor, southeast of Long Island, southeast of Nut Island, and northwest of Hull Bay.

B. Data Analysis

Sediment Profile Images, 1994 — The sediment profile images were first analyzed visually by projecting the images and recording all features viewed into a preformatted standardized spreadsheet file. The sediment profile images were then computer-image-analyzed using a Matrox color frame grabber and Image Pro analysis software on a 386 microcomputer. Computer analysis procedures for each image were standardized by executing a series of macro commands (Viles and Diaz, 1991). Data from each image were sequentially saved to an ASCII file for later analysis.

Table 1. Summary of Boston Harbor stations sampled, data collected, and data used for among-survey comparisons, 1991–1994. Boxes denote data used for among-survey comparisons.

	Survey													
	Sep 91		Apr 92		Aug 92		Apr 93		Aug 93		Apr 94		Aug 94	
	Trad	Recon	Trad	Recon	Trad	Recon	Trad	Recon	Trad	Recon	Trad	Recon	Trad	Recon
Survey Dates	16–21 Sept. 1991		23–24 April 1992		14–16 August 1992		19–21 April 1993		8–13 August 1993		12–14 April 1994		12–20 August 1994	
Infauna														
0.3-mm sieve	8	0	8	—	8	—	8	—	8	0	8	—	8	—
0.5-mm sieve	8	24	8	—	8	—	8	—	8	24	8	—	8	24
Total Sample	8	24	8		8		8		8	24	8		8	24
Sediment Measures														
Grain Size	8	24	0	—	8	—	8	—	8	0	8	—	11[c]	0
TOC	8	24	0	—	8	—	8	—	8	0	8	—	11[c]	0
C. perfringens	8	24	0	—	8	—	8	—	8	0	8	—	11[c]	0
Apparent RPD	nd	nd	nd	—	nd	—	8	—	8	24	8	—	11[c]	24
Sediment Chemistry	—	—	—	—	—	—	—	—	—	—	—	—	3[d]	—
Sediment Profiles														
Apparent RPD	3[a]	3[a]	—	—	8[b]	57[b]	—	—	6	40	—	—	8	42
Sediment Type	4[a]	4[a]	—	—	8[b]	61[b]	—	—	7	42	—	—	8	42
OSI	nd	nd	—	—	7[b]	55[b]	—	—	6	40	—	—	8	42
Succesional Stage	nd	nd	—	—	7[b]	56[b]	—	—	6	40	—	—	8	42
Report Reference	Kelly and Kropp, 1992		Kelly and Kropp, 1992		Blake *et al.*, 1993		Kropp and Diaz, 1995		Kropp and Diaz, 1995		This report		This report	

nd: Not determined.
[a] Four traditional and no reconnaissance stations in common with 1992; Four traditional and four reconnaissance stations in common with 1993.
[b] Seven traditional and 18 reconnaissance stations in common with 1993.
[c] Eight traditional and three CSO stations
[d] Three CSO stations

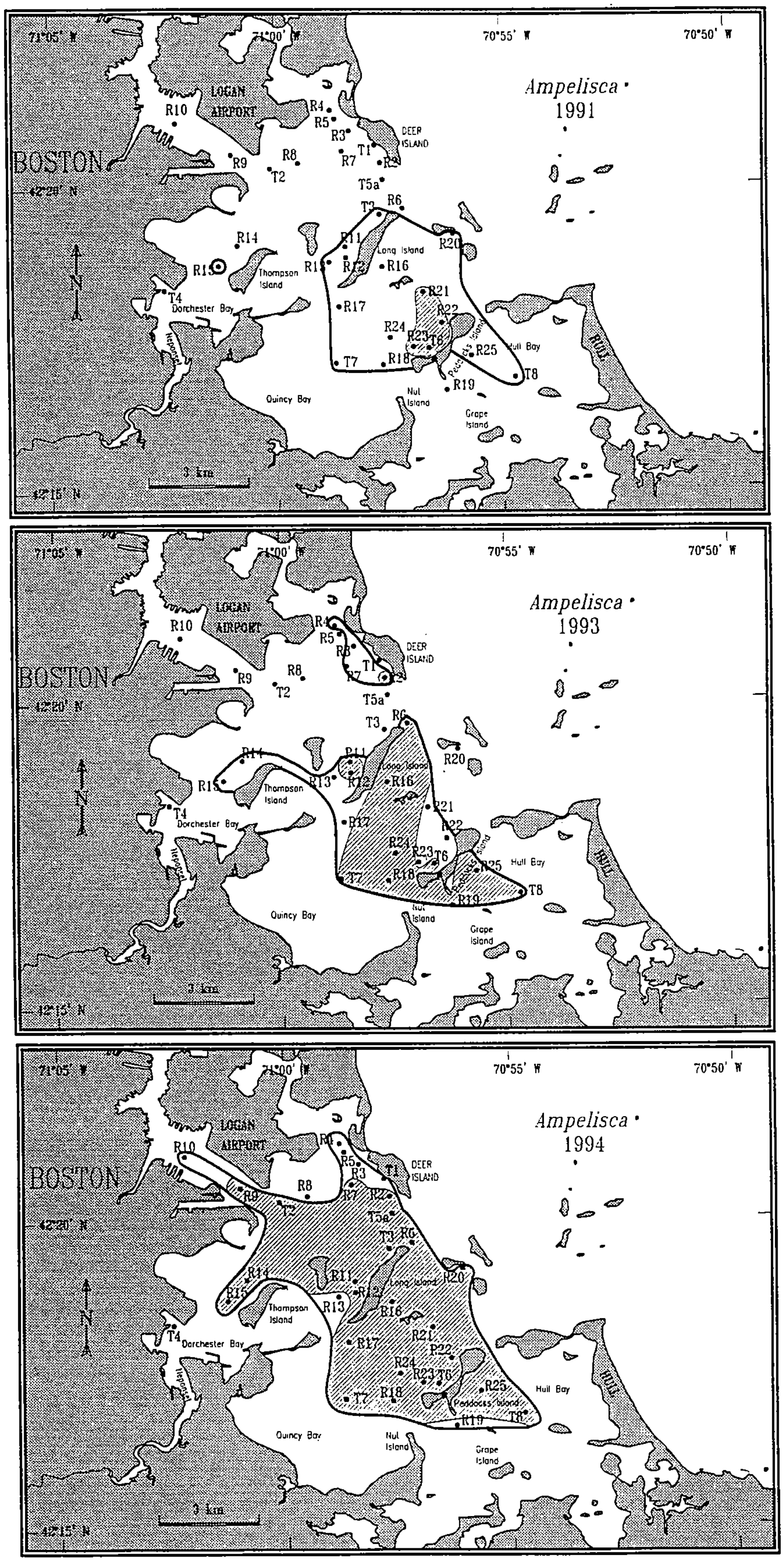


Figure 2. Map of Boston Harbor showing areas where *Ampelisca* was among the four most abundant taxa (bold lines) or the most abundant taxon (hatched areas) at Boston Harbor traditional or reconnaissance stations in September 1991, August 1993, and August 1994.

Sedimentary features measured by SPI included [1] Prism penetration (measured as the distance the sediment moves up the 20-cm length of the apparatus face plate), [2] surface relief (measured as the difference between the maximum and minimum distance the prism penetrated), [3] the apparent color redox potential discontinuity (RPD_{SPI}) layer (which estimates the boundary between oxic and anoxic sediments by analyzing the greenish-brown color tones characteristically associated with oxic sediment), [4] sediment grain size (estimated by comparing the sediment profile images with a set of standard images for which mean grain size had been determined in the laboratory). The sediment type was described following the Wentworth classification as described in Folk (1974), [5] surface and subsurface features (evaluated visually from each image and compiled by type and frequency of occurrence), and [6] the successional stage of the infaunal community at each station (estimated by visually examining images for characteristics associated with each stage—Rhoads and Germano, 1986; Valente *et al.*, 1992).

To characterize benthic habitat quality, data provided by the sediment profile images were used to calculate the multi-parameter organism-sediment index (OSI) developed by Rhoads and Germano (1982; 1986). SPI parameters incorporated in the OSI are depth of the apparent RPD_{SPI}, successional stage of macrofauna, the presence of gas bubbles in the sediment (an indication of high rates of methanogenesis), and the presence of reduced sediment at the sediment-water interface. The OSI ranges from -10, for poorest quality habitats, to +11, for highest quality habitats. More detailed information on these SPI techniques are presented in Diaz and Schaffner (1988) and Kropp and Diaz (1994).

Reconnaissance Grab Analysis, 1991, 1993 and 1994 — Numerical estimates of taxon abundance at each reconnaissance station were made by calculating the proportion of each sample that was sorted. The count for each taxon removed during the rapid sorting was divided by the proportion of the sample that was sorted to obtain an estimate of the abundance of that taxon in the whole sample. For example, if a sample was 25% sorted and a count of 15 was obtained for taxon "A", then that count was divided by 0.25 to derive 60 as the estimate of the abundance of taxon "A" in the entire sample.

Benthic Community Analyses, 1991 to 1994 — One of the primary purposes of the study is to document recovery of the Harbor ecosystem following the cessation of sludge discharge into the Harbor. To detect probable recovery-related changes, comparisons of infaunal communities before and after abatement were made. Among these comparisons were examination of community-level biological parameters (e.g., abundance, numbers of species) or indices (e.g., H') that would be expected to change predictably following abatement of sludge discharge. Also, comparisons were made of infaunal community constituents to look for changes in the relative contribution made by "enrichment" or "opportunistic" taxa.

For all infaunal analyses, data from the 0.3-mm and 0.5-mm fractions of each sample were pooled. Certain analyses included only taxa identified to species level. These analyses were (1) calculations of numbers of species per sample, (2) calculations of diversity, evenness, and dominance per sample, and (3) similarity analyses. Two taxa, although not identified to species, were included in these analyses: *Ampelisca* species complex (hereafter referred to as *Ampelisca*) and *Orchestia* species. Other analyses included all taxa collected. These analyses were (1) total and major taxon abundance, and (2) station taxon lists. Most analyses were performed on individual samples (i.e., replicates) although dominance and similarity analyses were conducted on combined replicates for each station.

Because of differences in taxonomic usage during various portions of the Harbor Studies program, some taxonomic assumptions were made to render the data more comparable. These assumptions are listed in Table 2. A list of all species collected from Boston Harbor during the Harbor studies program is given in

Table 2. Taxonomic changes and assumptions relevant to 1991–1994 comparisons.

Early Usage	Surveys Used	Present Usage	Comment
Photis sp.	9/91	*Photis pollex*	Assumption based on taxonomist opinion
Unciola sp.	9/91	*Unciola irrorata*	Assumption based on taxonomist opinion
Capitella spp. complex	9/91, 4/92	*Capitella capitata*	Assumption based on taxonomist opinion; probably represents a species complex
Polygordius sp.	9/91, 4/92	*Polygordius* sp. A	Assumption based on taxonomist opinion
Nassarius vibex	9/91, 4/92	*Ilyanassa trivitatta*	Corrected misidentification
Lumbrineris hebes	9/91, 4/92	*Scoletoma hebes*	Generic revision
Polydora ligni	9/91, 4/92, 8/92	*Polydora cornuta*	NODC code in 1991-1992 database is for *P. ligni*
Schistomeringos caeca	9/91, 4/92, 8/92	*Parougia caeca*	NODC code in 1991-1992 database is for *S. caeca;* name listed as *P. caeca*
Nassarius trivitattus	8/92	*Ilyanassa trivitatta*	Name change
Microphthalmus sczelkowii	4/93. 8/93	*M. aberrans*	Taxonomist examined specimens from all surveys
Crangon septemspinosa, *Mytilus edulis*, *Neomysis americana*, other Mysidaceans	9/91, 4/92, 8/92, 4/93. 8/93	Excluded from analyses	Taxa not considered infaunal

Appendix A. All calculations (e.g., *H'*) used in the year-to-year comparisons were made on the original data sets corrected as outlined in Table 2 (i.e., values were not taken from the various reports describing each set of sampling activities).

Descriptive community measures — the Shannon Diversity Index (*H'*), Pielou's evenness (*J'*), and Simpson's Dominance (*c*) — were calculated using standard formulae as presented in the Combined Work/Quality Assurance Project Plan (Kropp *et al.*, 1993). The program PRARE1, written in 1972 by George Power for H. Sanders and F. Grassle at Woods Hole Oceanographic Institute, and modified for the VAX in 1982 by T. Danforth, was used to calculate *H'* and *J'*. The spreadsheet program Quattro® Pro for Windows, version 5.0 (Borland, 1993) was used to perform calculations of some means, standard deviations, confidence intervals, and Pearson correlation coefficients (*r*).

After preliminary inspection of the data, several parameters were selected for in-depth comparisons. These parameters were total abundance, total number of species, species diversity (*H'*), and the abundance of selected taxa — Oligochaetes, *Streblospio benedicti, Capitella capitata, Ampelisca,* and *Ilyanassa trivittata.* The taxa chosen for statistical analyses were selected because they may be indicative of stressed conditions (Oligochaetes, *Streblospio,* and *Capitella*) or unstressed conditions (*Ampelisca* and, possibly, *Ilyanassa*). *Ilyanassa* also was chosen as a mollusc representative that occurs at several stations in the Harbor.

Similarity analyses were conducted on untransformed abundance data (with replicates for each station summed) by using the Chord-Normalized Expected Species Shared (CNESS: Trueblood *et al.*, 1994; Gallagher, 1994) algorithm, a modification of the original Normalized Expected Species Shared (NESS: Grassle and Smith, 1976). Gallagher (1994) provided a detailed derivation of CNESS and Coats (1995) succinctly summarized the modifications incorporated by the new measure. Because of low infaunal abundance at stations T-2 and T-5 in September 1991, CNESS was run at $m = 30$ to permit all samples to be included in the analysis. Clustering was accomplished with the unweighted pair-groups method using arithmetic averages (UPGMA; Sneath and Sokal, 1973; Gauch, 1982). The results were presented as a dendrogram.

RESULTS AND DISCUSSION

Many of the traditional ideas regarding the response of infaunal communities to sludge impacts are rooted in the model of response to organic input that predict a relatively rapid increase in abundance and numbers of species with decreasing level of enrichment (Pearson and Rosenberg, 1978). As the level of enrichment decreases further, the values for each metric also eventually decline. However, abundance typically increases and then decreases relatively quickly before reaching a fairly consistent level (see Figure 1 in Pearson and Rosenberg, 1978). Numbers of species, however, typically increase gradually with decreasing enrichment, reaching a maximum much later than abundance. Both model patterns have been supported, at least in part, by other recent spatial (Rees *et al.*, 1992; Maurer *et al.* 1993; Zmarzly *et al.*, 1994) or temporal (Swartz, *et al.*, 1986; Reid, *et al.*, 1991) studies. The model provides a useful context in which to present and discuss the benthic conditions in Boston Harbor during the first three years following the abatement of sludge discharge. Sewage sludge was released into Boston Harbor via the Deer Island Effluent Outfalls located on the harbor side of Deer Island and through the Nut Island Sludge Discharger located off the northeast tip of Long Island. Although only one of the sources of organic (and probably contaminant) input to the Harbor, the cessation of sludge discharge was a major step in reducing contaminant input into the Harbor (Alber and Chan, 1994). Therefore, it was expected that the major infaunal community changes would occur at stations closest to those sites, particularly stations T-3 and T-5, along with other stations in the northern Harbor (Battelle, 1991). The southern group of stations, two of which (stations T-6 and T-7) are located close to and likely to be influenced by the Nut Island effluent discharge (Signell and Butman, 1992), was not expected to show much response to sludge discharge abatement. Station T-8, located northwest of Bumkin Island, was expected to be relatively uninfluenced by either the sludge or effluent discharges.

A. Species-Level Changes

The previous reports in this series have shown that there have been substantial changes in the infaunal communities in Boston Harbor since the abatement of sludge discharge in December 1991. Noticeable were the dramatic increases in infaunal abundance observed in late 1992 and late 1993 (Blake *et al.*, 1993; Kropp and Diaz, 1994). However, some of the most striking changes among the Harbor infaunal communities were revealed by examination of the variation in the distribution patterns of certain taxa that might be indicative of benthic conditions in the Harbor. For these comparisons, only late summer data from traditional and reconnaissance stations sampled in 1991, 1993, and 1994 were used. One taxon in particular, the tube-dwelling amphipod *Ampelisca,* provided an interesting illustration of changing Harbor conditions. In 1991, *Ampelisca* was among the four most abundant taxa only in a relatively small part of the Harbor near Long Island and Peddocks Island (Figure 2, top). Furthermore, the species was numerically dominant at only four stations located northwest of Peddocks Island. By late summer 1993, the area within which *Ampelisca* was one of the four most common species expanded to include parts of the northern Harbor, including stations on Deer Island flats and to the northwest of Thompson Island (Figure 2, middle). At this time, *Ampelisca* was the most abundant species at 12 stations. By August 1994, the area where *Ampelisca* was one of the predominant species expanded to comprise all but two of the stations sampled, including parts of the inner Harbor to the south and east of Logan airport (Figure 2, bottom). *Ampelisca* was the most numerous species at 22 stations in August 1994.

A trend counter to that shown by *Ampelisca* was exhibited by the change in relative abundance of the spionid polychaete worm *Streblospio benedicti*. In late summer 1991, *S. benedicti* was among the four most abundant species throughout much of the northern Harbor, from Deer Island flats, to the inner harbor and extending southward to the mouth of Quincy Bay (Figure 3, top). At that time, *S. benedicti* was the numerically dominant species at six stations, five in the area described above and also at station T-4 in Dorchester Bay. By late summer 1993, the area where *S. benedicti* was numerically important was similar to that found for 1991 (Figure 3, middle). Although still the predominant species at six stations in 1993, those stations (except station T-4) differed from those found for 1991. In 1993, *S. benedicti* was the most abundant species at the northernmost stations along Deer Island flats, one station in the inner harbor, and at station T-4. By late summer 1994, the region where *S. benedicti* was among the four most abundant species was restricted to the northernmost parts of the Harbor and to three stations south of Spectacle Island (station R-13), at the mouth of Quincy Bay (station T-7), and at station T-4 in Dorchester Bay (Figure 3, bottom). *S. benedicti* was the most common species at only three stations in August 1994.

Oligochaete worms were clearly one of the predominant taxa throughout much of the Harbor in late summer 1991 (Figure 4, top), occurring among the most numerous taxa in most of the northern and central harbor, as well as at two stations in the southern harbor. Oligochaetes were the most abundant taxon at 13 stations in 1991, primarily surrounding the northeastern half of Long Island, near the Nut Island outfall, and off Deer Island. By late summer 1993, the region where oligochaetes were numerically important was restricted considerably (Figure 4, middle). At that time, oligochaetes were

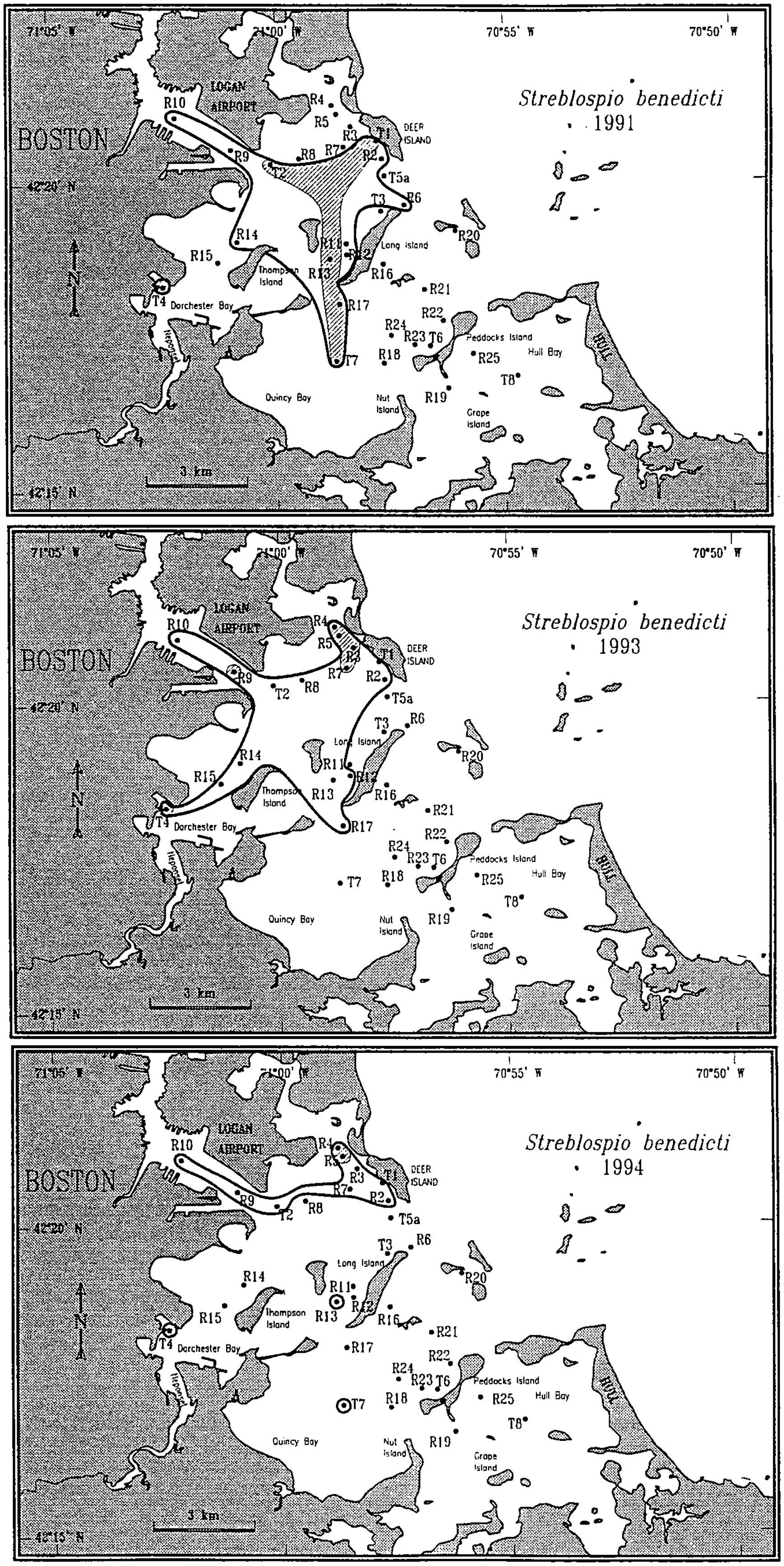


Figure 3. Map of Boston Harbor showing areas where *Streblospio benedicti* was among the four most abundant taxa (bold lines) or the most abundant taxon (hatched areas) at Boston Harbor traditional or reconnaissance stations in September 1991, August 1993, and August 1994.

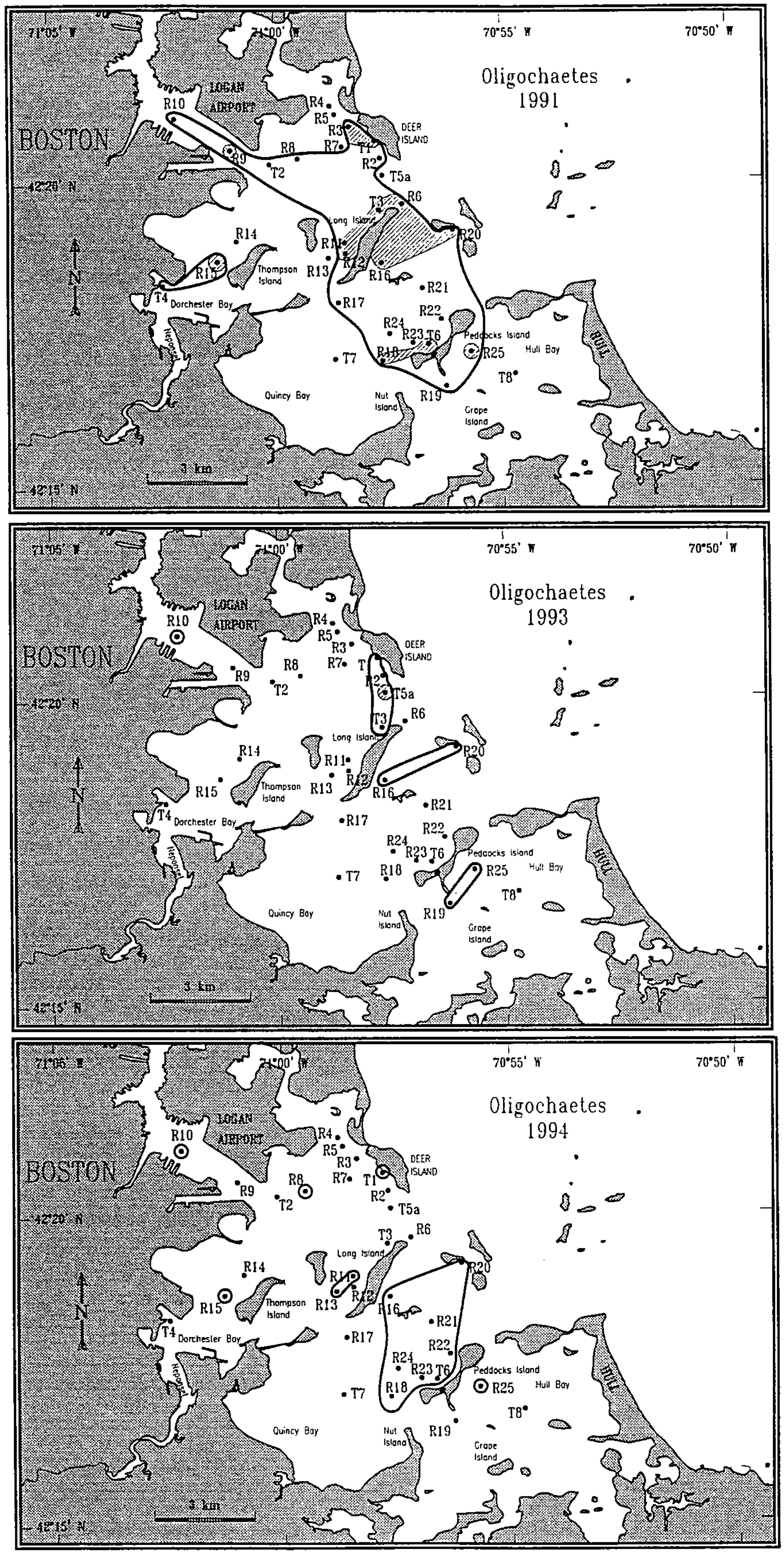


Figure 4. Map of Boston Harbor showing areas where oligochaetes were among the four most abundant taxa (bold lines) or the most abundant taxon (hatched areas) at Boston Harbor traditional or reconnaissance stations in September 1991, August 1993, and August 1994.

numerically dominant at only station T-5a. However, this trend in declining relative abundance did not continue in 1994. Oligochaetes where among the most common taxa throughout most of the central harbor in late summer 1994, and at scattered stations in the northern harbor (Figure 4, bottom).

All of the changes described above and illustrated in Figures 2–4 are indicative of changes in relative abundance and do not necessarily imply that the absolute abundance of each taxon changed in a similar manner. For example, the polychaete *Streblospio benedicti*, despite decreasing in relative abundance at two of the stations (stations T-1 and T-2) in 1993 and 1994, actually increased in absolute abundance (Figure 5). *S. benedicti* was the predominant species at four traditional stations in 1991, stations T-1, T-2, T-4, and T-7. *S. benedicti* abundance at the two stations was 2,700/m^2 and 600/m^2 in 1991, 6,900/m^2 and 13,600/m^2 in 1993, and 20,700/m^2 and 57,000/m^2 in 1994. However, the changes in relative abundance of *Ampelisca* from 1991 to 1994 were accompanied by very large increases in the absolute abundance that occurred at all traditional stations except station T-4 (Figure 6). In late summer 1991, *Ampelisca* abundance at the four traditional stations where it was among the predominant taxa (stations T-3, T-6, T-7, and T-8) ranged from about 900/m^2 to about 15,300/m^2. In August 1993 *Ampelisca* abundance at these four stations ranged from about 3,100/m^2 to about 131,000/m^2 and in August 1994, ranged from about 13,000/m^2 to about 157,000/m^2. Station T-2 showed tremendous change in *Ampelisca* abundance between 1991 (none present), August 1993 (1,800/m^2), and August 1994 (150,000/m^2). Furthermore, *Ampelisca* demonstrated strong temporal and small-scale variations in abundance. For example, large temporal variation occurred at station T-3 between August 1992 and August 1994. Mean (± 95% confidence intervals) abundance of *Ampelisca* in August 1992 was 24,358 (± 7,230)/m^2, declined to 3,100 (± 1,738)/m^2 by August 1993, but then increased to 156,725 (± 17,254)/m^2 in August 1994. Tremendous small-scale (i.e., among-replicate) variation was observed at station T-8 in 1994. *Ampelisca* abundance at station T-8 was 43,633 (± 40,869)/m^2 in April and 48,208 82,179)/m^2 in August.

The distributional changes observed for *Ampelisca* and *Streblospio* were not observed for other taxa that were examined. Some taxa seemingly did not change considerably in abundance or geographic extent between 1991 and 1994, whereas the abundances of others fluctuated, but in ways difficult to characterize and that may reflect cyclic variation. For example, by late summer 1993, it appeared that the abundances of at least three species of amphipods other than *Ampelisca* had increased since 1991 and that these species, *Leptocheirus pinguis*, *Unciola irrorata*, and *Corophium bonelli*, were exhibiting changes parallel to those found for *Ampelisca* (Kropp and Diaz, 1994; Figure 6). However, data from the 1994 surveys countered this apparent trend as the abundances of all three species decreased substantially from those found in 1993 (Figure 6). Note in the figure that the abundance of *Leptocheirus* and *Unciola* at station T-2 increased considerably by August 1994, a change that paralleled, albeit in less dramatic fashion, the changes seen at stations T-3 and T-6 in August 1992 or August 1993. A polychaete worm, *Aricidea catherinae*, was very common at stations T-6 and T-8 through out the duration of the study (Figure 5) and has remained a consistent indicator of the southern Harbor community. Other than periodic fluctuations, the abundance of *A. catherinae* has not changed in any noticeable pattern. Also, contrary to *Ampelisca*, *Aricidea catherinae* did not increase in abundance in the northern or central parts of the Harbor (Figure 5) during the study. The polychaete *Phyllodoce mucosa* was uncommon in 1991, increased in abundance and geographic coverage by August 1993, but then decreased at several stations by August 1994. *Polydora cornuta*, a spionid polychaete, showed apparently strong seasonal fluctuations in abundance (Figure 5), occurring at high abundances at some stations in August, but not in April, 1992, 1993, and 1994. Among the key molluscs, the mudsnail *Ilyanassa trivittata* and the tellinid clam *Tellina agilis* were usually more common at stations T-3 and T-8 than elsewhere in the Harbor, but were found throughout the Harbor (Figure 7). The nutclam *Nucula delphinodonta* occurred in relatively large numbers only at station T-8, a pattern that did not change between 1991 and 1994 (Figure 7).

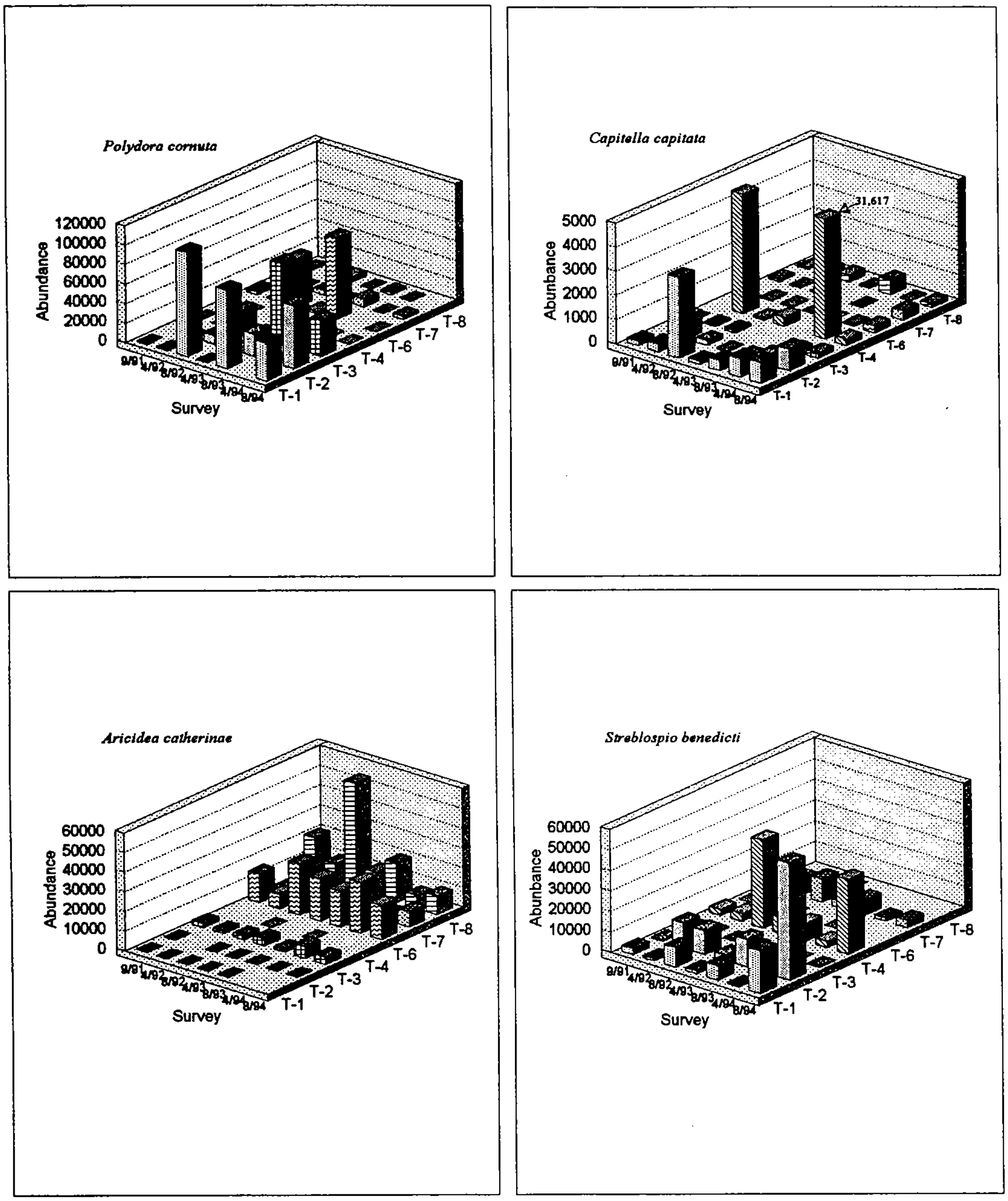


Figure 5. Mean abundance (#/m^2) of four species of polychaetes at Boston Harbor traditional stations (except T-5) across all surveys. Not that scales of Y-axes differ.

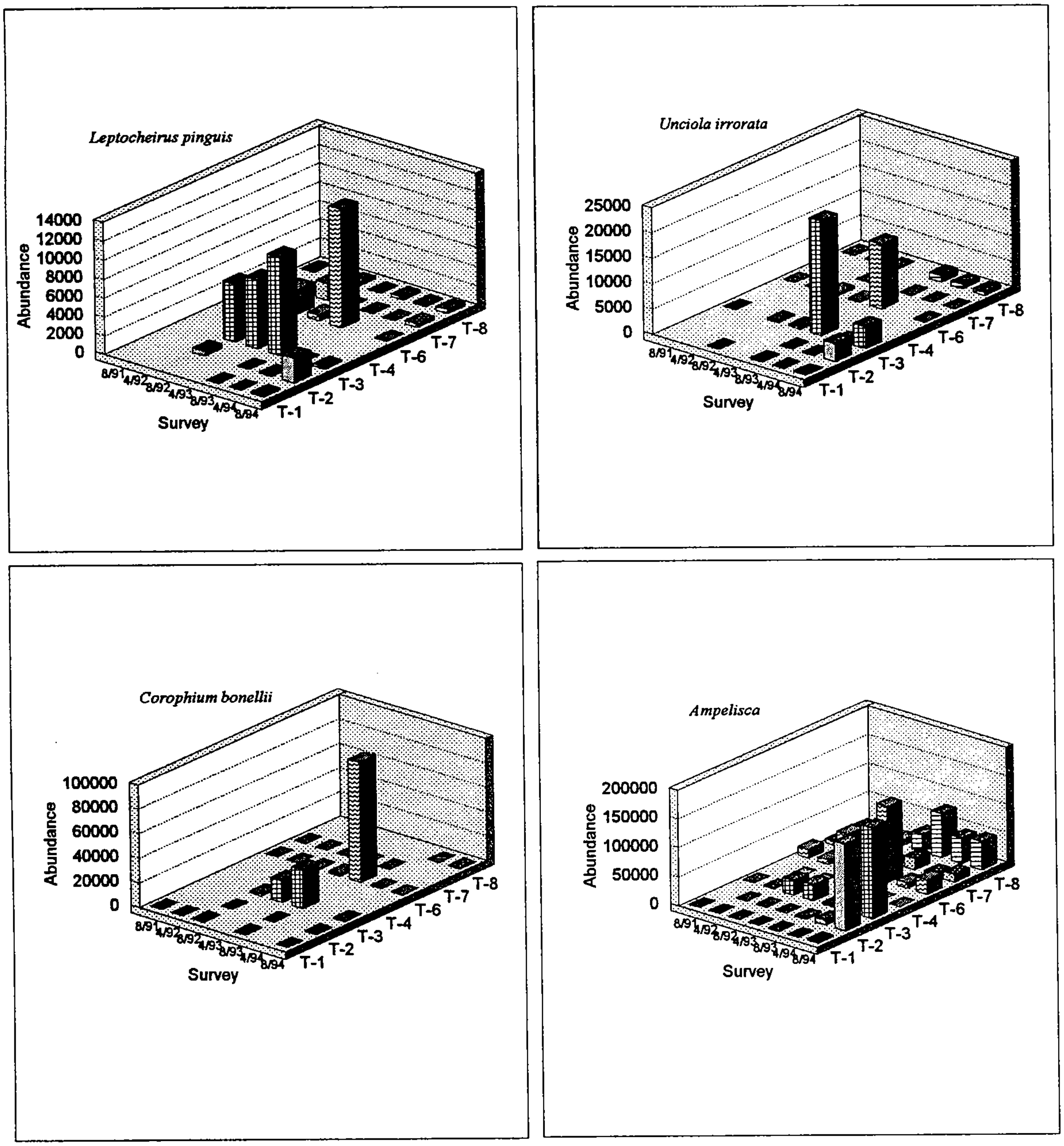


Figure 6. Mean abundance (#/m^2) of four crustacean taxa at Boston Harbor traditional stations (except T-5) across all surveys.

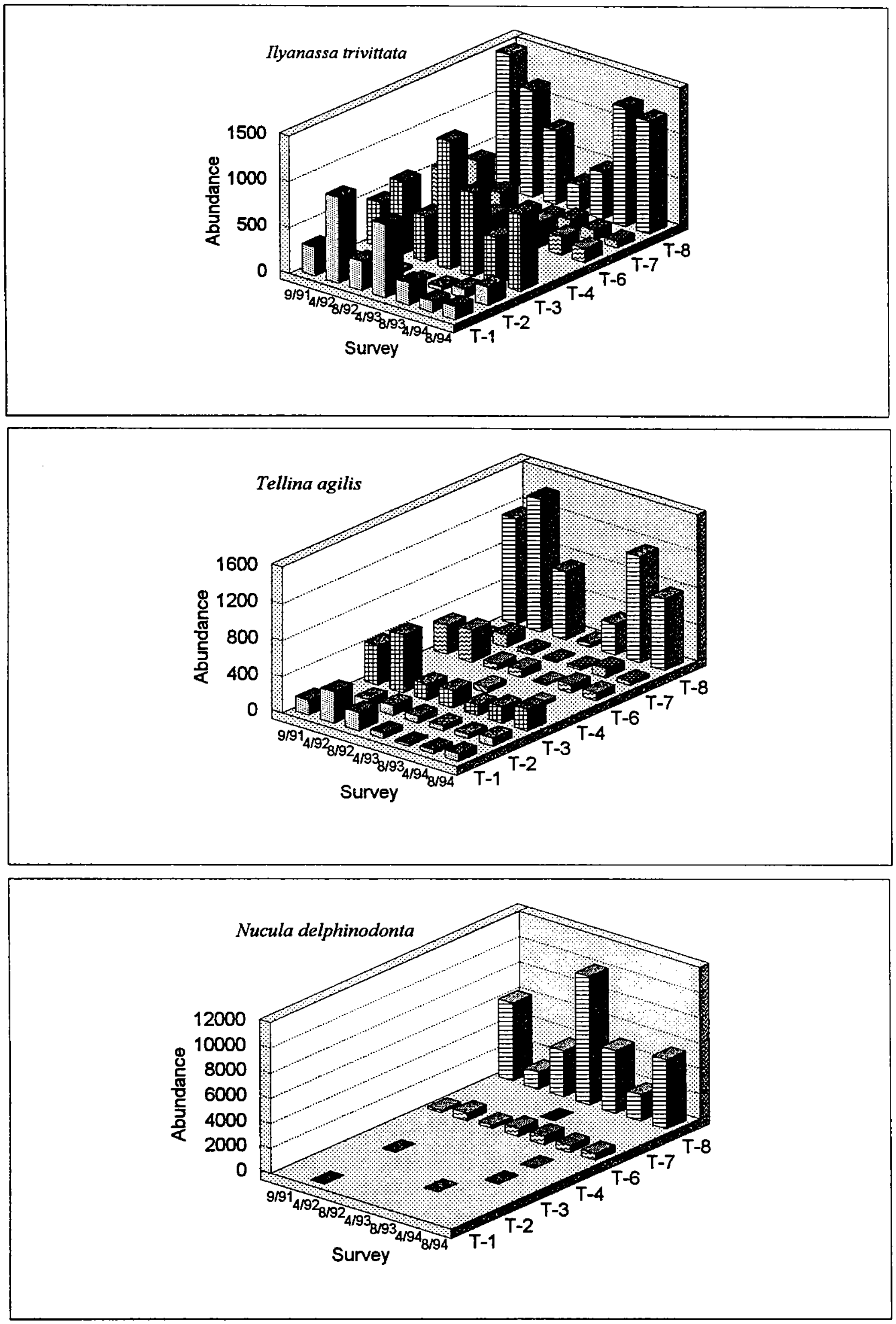


Figure 7. Mean abundance (#/m^2) of three species of molluscs at Boston Harbor traditional stations (except T-5) across all surveys. Note that scales of Y-axes differ.

Capitella capitata, an opportunistic polychaete worm traditionally used as an indicator of disturbed or polluted habitats (e.g., Pearson and Rosenberg, 1978), was relatively widespread throughout the Harbor (Figure 5), but typically was not abundant. Densities of *Capitella* exceeded 1,000 individuals/m^2 on only five occasions. Two of these occurrences were at the station T-5/T-5a area flanking the mouth of President Roads (not shown in Figure 5). In this area, *Capitella* was the first or second ranked taxon for each of the first three surveys, reaching a peak density of 21,000 individuals/m^2 in August 1992. In 1993 and 1994 the density of *Capitella* did not exceed 250 individuals/m^2 and the taxon ranked no higher than 12th. Twice *capitella* was relatively abundant at station T-4, most recently in April 1994 when it reached a density of about 31,600 individuals/m^2.

Previously, we remarked (Kropp and Diaz, 1994) that the species-level changes observed in 1993, greater relative importance of *Ampelisca* and lesser relative importance of certain annelid worms, were consistent to some degree with the transition of the Harbor infaunal communities to successional Stage II communities (*sensu* Rhoads and Germano, 1986). At least some of the data from 1994, especially the increased numerical importance of *Ampelisca* in the northern Harbor, extend that observation. As in 1993, the major changes in the relative abundance of key members of the Harbor infaunal communities in 1994 were the result of changes in the populations of species already present, rather than the import in large numbers of species not previously recorded. Zajac and Whitlach (1982) described a similar phenomenon during recovery from disturbance in a Connecticut estuary. Although still of lesser relative importance in 1994 than they were in 1991, the absolute abundances of several annelids (e.g., oligochaetes, *Streblospio benedicti*, and *Polydora cornuta*) have fluctuated temporally or have actually increased since 1991. As in 1994, the variation in *P. cornuta* abundance appeared to be primarily seasonal, consistent with what has been reported for the species (Zajac, 1991). Oligochaetes and *Streblospio benedicti* often have been associated with enriched or disturbed environments (Pearson and Rosenberg, 1978) and their increased abundance in 1994 may have been a response to some unobserved disturbance in the Harbor.

B. Community-Level Changes

Considering the species-level changes observed, it was reasonable to determine the effect, if any, of these changes on the larger-scale community measures. Previously, several changes in infaunal abundance were reported for several stations (Blake *et al.*, 1993; Kropp and Diaz, 1994). Across all surveys from 1991 to 1993, statistically significant differences in abundance were detected at all stations (station T-5a was excluded from the tests) tested (Kropp and Diaz, 1994). At all of these stations except station T-7, the trend was for increased abundances over time. That is, the abundances measured in August 1992 or 1993 were greater than those encountered in September 1991. Seasonal differences in abundance also were detected at all stations, except station T-4, with late summer values being greater than spring values (Kropp and Diaz, 1994). These patterns in abundance fluctuations, including data from 1994, are shown in Figure 8 (top). The seasonal shifts in abundance noticed earlier were still present in 1994. To reduce the effect of this seasonal variability on the overall abundance patterns, the August 1992–1994 abundance values were compared graphically to the September 1991 values (Figure 8 bottom). From this figure, in which the August values are shown relative to the 1991 value, it appeared that abundance at stations in the northern part of the Harbor by August 1994 remained at least 4 × higher than that found in 1991 (Figure 8, bottom). However, infaunal abundance at stations located in the central and southern part of the Harbor (except station T-4) was only slightly higher in August 1994 than in 1991 (Figure 8, bottom).

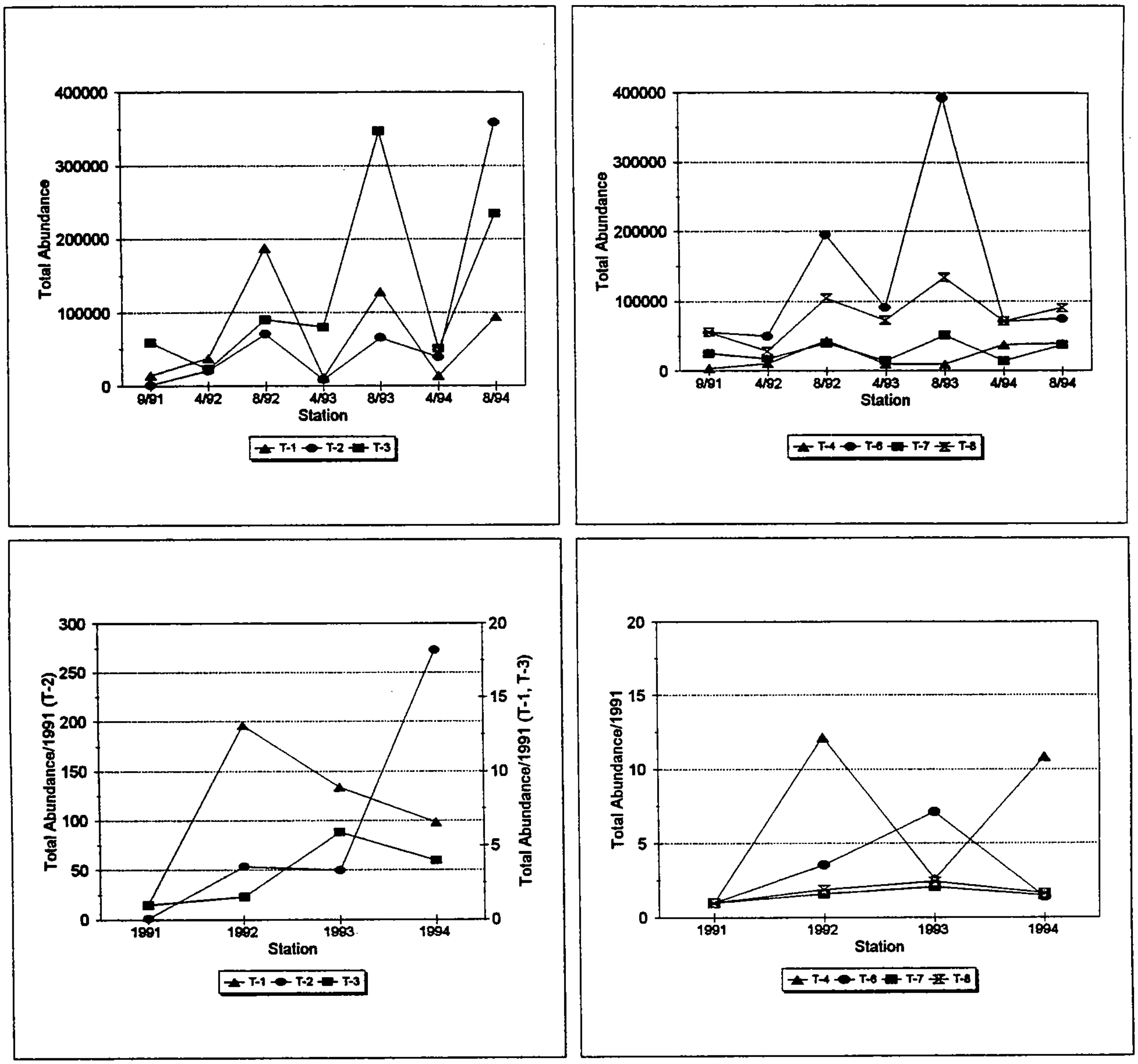


Figure 8. Actual mean infaunal abundance (#/m^2) at Boston Harbor traditional stations (except T-5) across all surveys (top) and August values relative to 1991 values (bottom).

One way to examine the number of species comprising the infaunal communities in the Harbor is to track the change in numbers at each station over the course of the study. This analysis seemed to indicate a generally increasing trend in species per station (Figure 9, top). This change was harborwide. Actually, station T-3, the station nearest the former Nut Island sludge outfall discharge, showed a relatively small increase in species numbers between 1991 and 1994 (2 ×; Figure 9, bottom). The overall change at station T-6, near the Nut Island effluent discharge site, also was relatively small (< 2 ×; Figure 9, bottom). Another approach is to look at the total species counts, in terms of numbers per survey and the cumulative species numbers. Before presenting these analyses, we point out that two taxa have been subjected to more intense taxonomic efforts as the study progressed. Both, oligochaetes and nemerteans, occurred in samples from 1991, but were only identified to phylum. Beginning with August 1992, oligochaetes were identified to species, and beginning with April 1993, nemerteans were identified to species. While we think that it is useful to keep these later identifications in the species counts, doing so biases comparisons with earlier data. To allow comparisons with early surveys we have estimated species counts that count each phylum as one "species" (termed comparable data) and have also estimated counts that include all species-level taxa (termed actual data). Comparable data across all surveys showed increasing total species numbers for the first three surveys, reaching a peak at 101 species in August 1992 (Figure 10, top). Following the August 1992 survey, total species numbers showed a strongly seasonal pattern, with lower numbers in April than in August. Also, no counts exceed those from August 1992. The cumulative number of species encountered during the study was based on the original species set (1991). For each successive survey, species were added to the cumulative list only if they had not been recorded previously. No correction was made for species that occurred once, then were not seen again. Examining the comparable data set showed that the greatest increase in cumulative species occurred in August 1992 (Figure 10, top). Since then the cumulative count has increased, albeit at a slower rate. The actual data sets for both comparisons generally showed the same patterns (Figure 10, bottom).

Species diversity (H') showed considerable survey-to-survey fluctuations in the northern Harbor, but exhibited much less in the southern Harbor (Figure 11, top). However, by the August 1994 survey, species diversity at all stations except stations T-2 and T-4 was generally similar to that calculated for samples collected in 1991 (Figure 11, bottom). Note that even with the large relative change in diversity at station T-4, the actual values calculated for the station were always low (Figure 11, top).

To some degree the species-level changes and differences in infaunal abundance also were reflected in changes in among-sample similarity as shown by the classification analysis. The dendrogram resulting from analysis of CNESS similarity revealed two primary, relatively dissimilar, groups of samples (Figure 12). One group of 28 samples consisted of all those collected from stations T-6 and T-8 throughout the study, those from station T-5a collected after August 1992, and those from stations T-3 and T-7 collected after April 1992. Within this group five subgroups consisting of three or more stations were recognized. Three of these subgroups consisted of samples from single stations (T-5a, T-7, T-8), whereas the two remaining subgroups were comprised primarily of samples from stations T-3 (collected after April 1992) and T-6. A second large group of 28 samples included all samples collected from stations T-1, T-2, T-4, and T-5 throughout the study, samples from T-5a collected in April 1992, and those from stations T-3 and T-7 collected before April 1992. Within this latter group of samples, three main subgroups were distinguished. One consisted of those collected from stations T-1 and T-2 after April 1992. A second subgroup consisted of all T-4 samples and those collected at station T-2 before August 1992. The third subgroup was comprised of a mix of stations sampled in September 1991 and April 1992. One main point illustrated by the classification analysis is that despite the numerous changes in various aspects of the infaunal communities in the Harbor, the only stations exhibiting substantial change in biological identity after the cessation of sludge discharge were stations T-3 and T-5a, the two

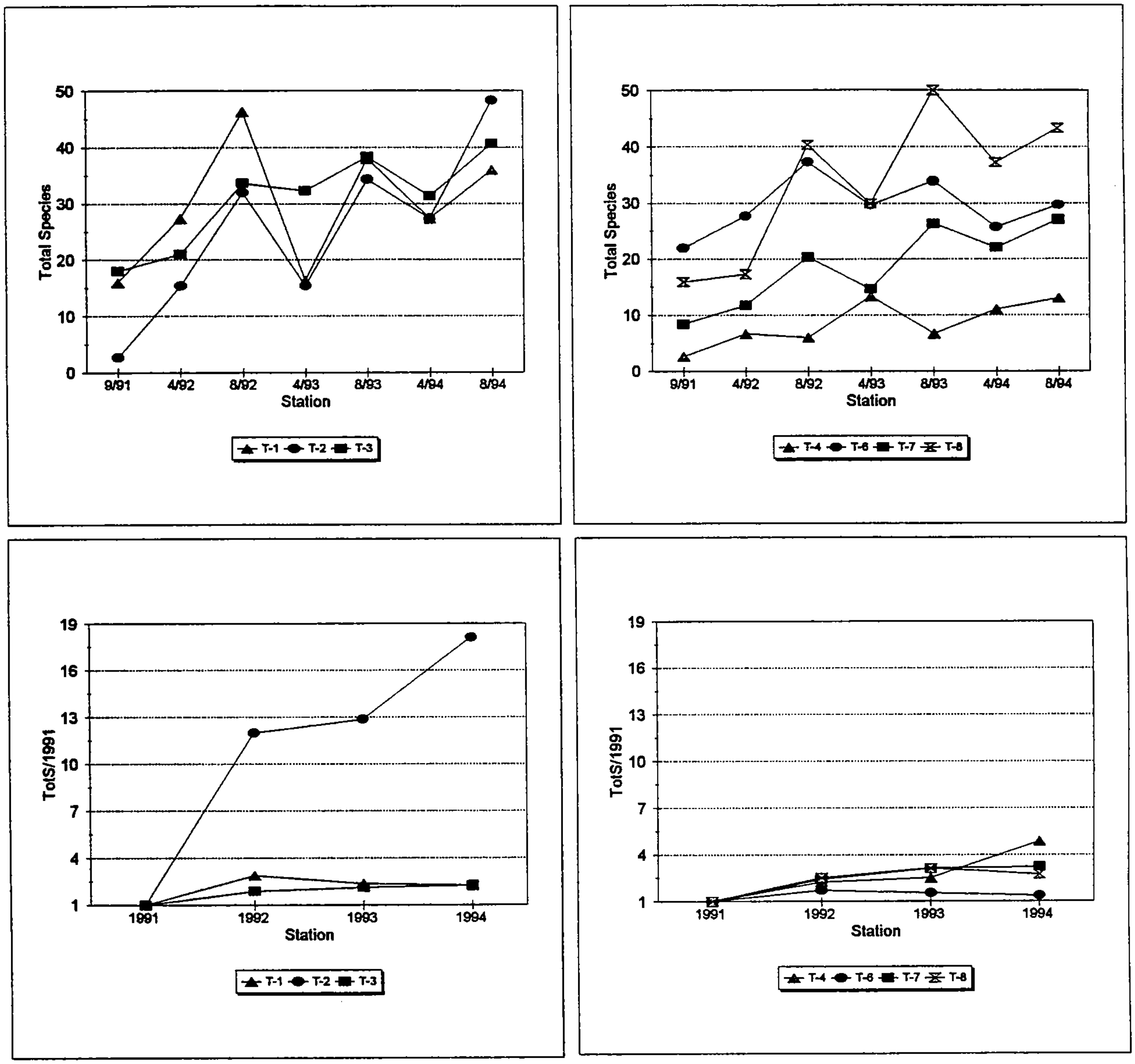
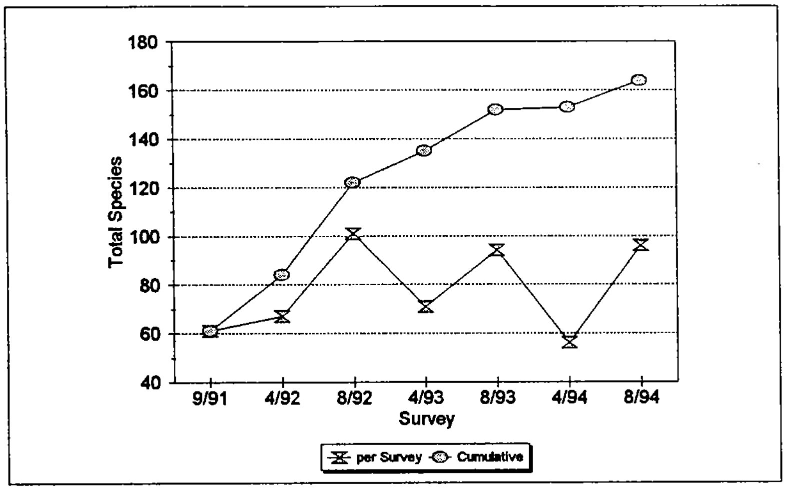


Figure 9. Actual mean number of species at Boston Harbor traditional stations (except T-5) across all surveys (top) and August values relative to 1991 values (bottom).



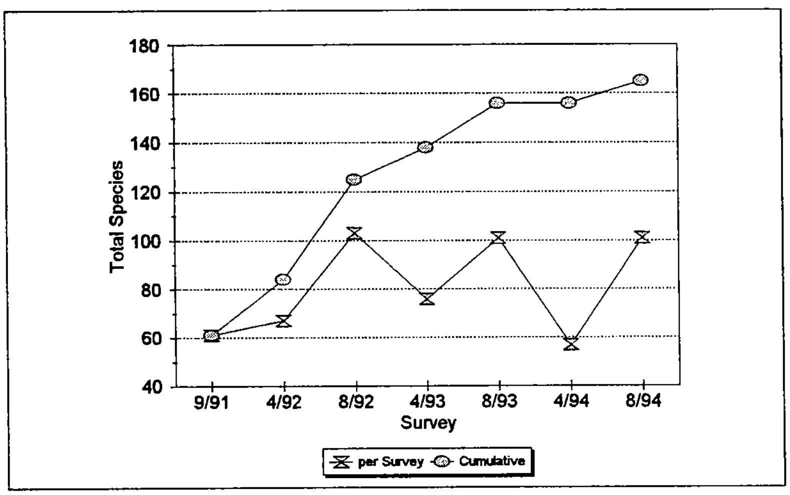


Figure 10. Total number of species per survey and cumulative species in Boston Harbor, 1991-1994 for comparable (top) and actual (bottom) data sets.

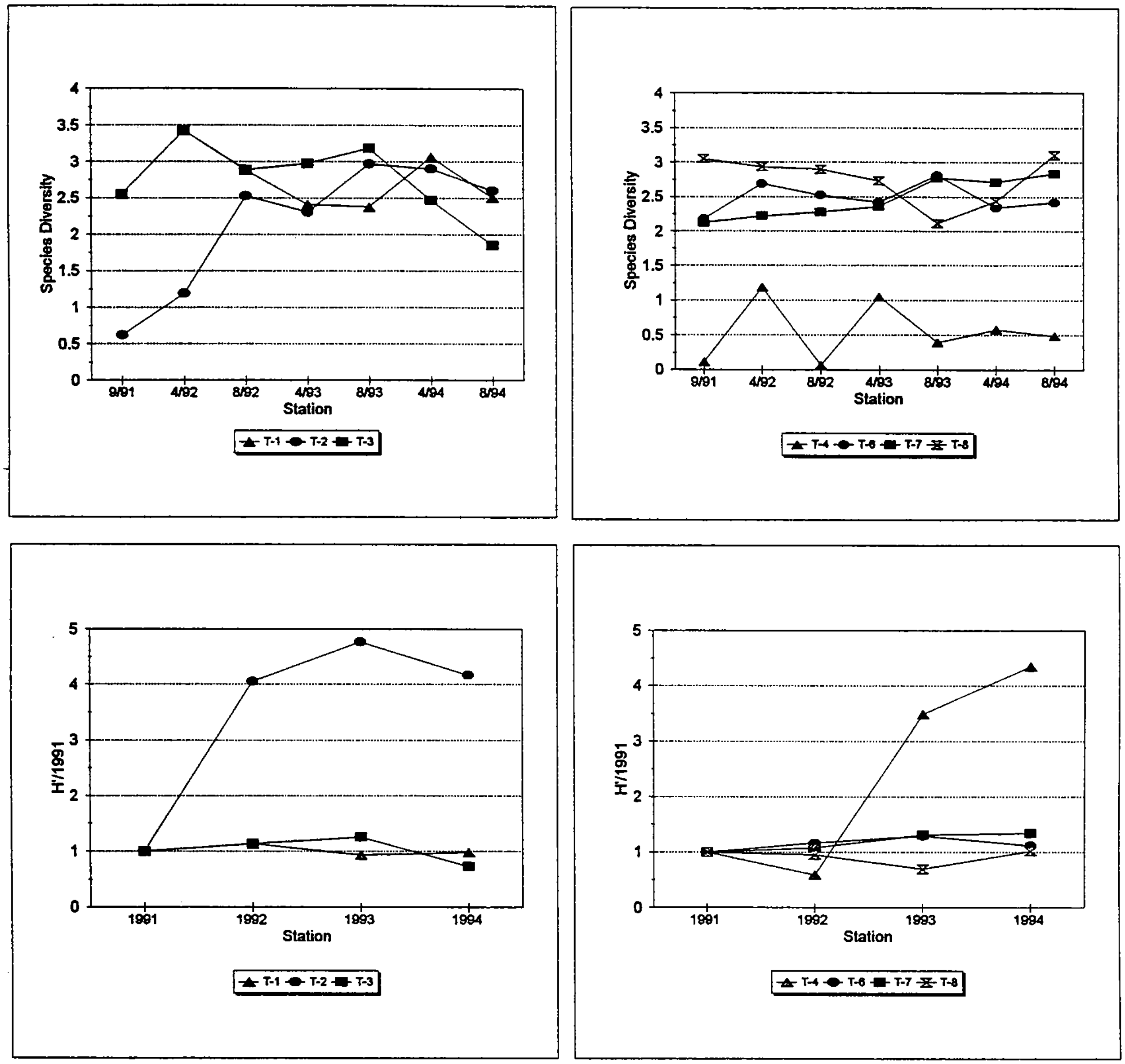


Figure 11. Actual mean species diversity (*H'*) at Boston Harbor traditional stations (except T-5) across all surveys (top) and August values relative to 1991 values (bottom).

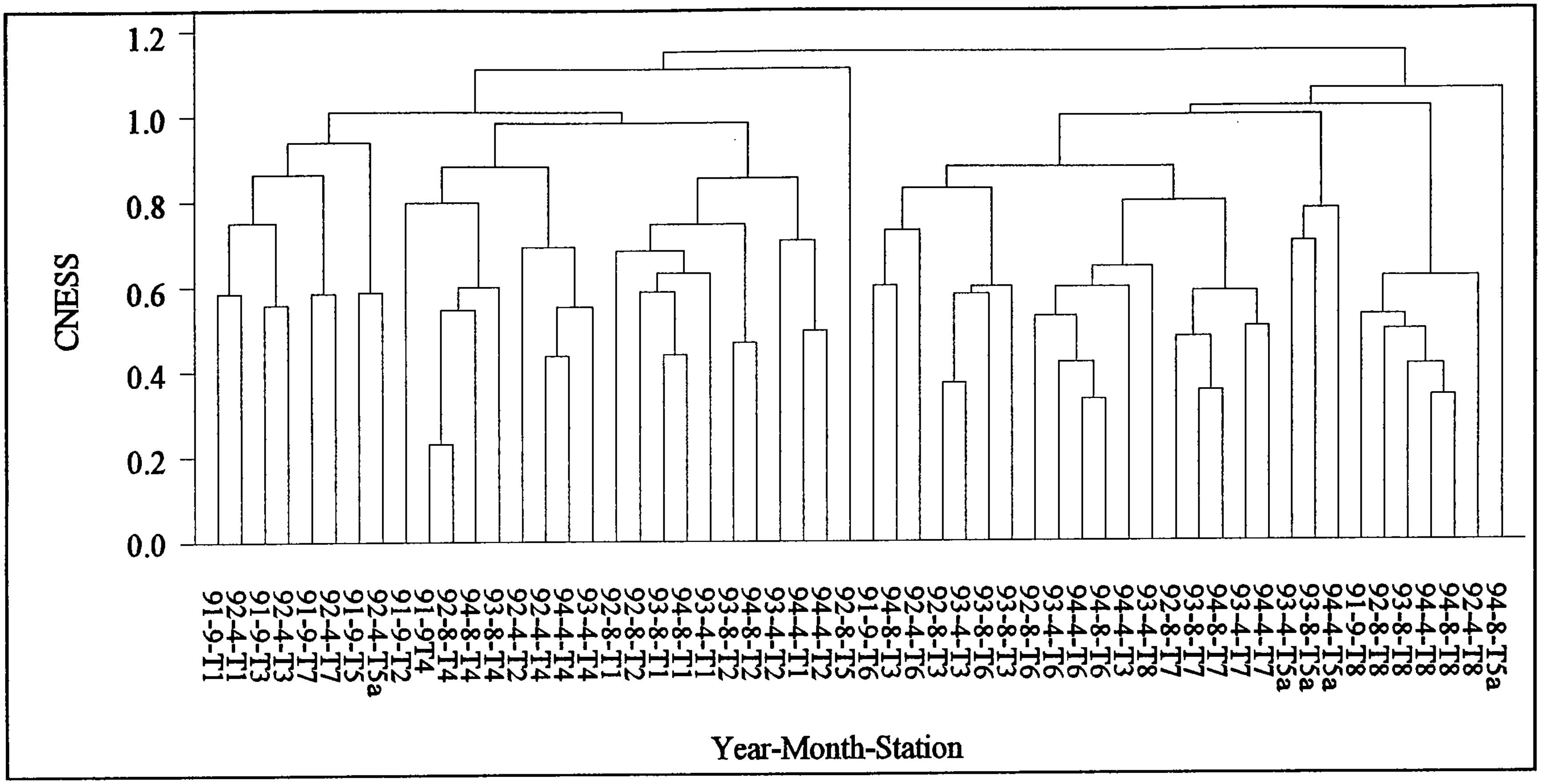


Figure 12. Dendrogram resulting from clustering of Boston Harbor traditional stations sampled in September "9" 1991, and April "4" and August "8" 1992–1994 based on the CNESS algorithm ($m = 30$).

stations closest to the former Nut Island sludge discharge site, and, paradoxically, station T-7. However, station T-5a was not sampled in 1991, nor in August 1992, so the comment regarding a change in its identity applies only to 1993 and 1994 relative to April 1992. Because it was not likely that sludge could have been transported to its location, station T-7, located in Quincy Bay, was not expected to be affected by the cessation of sludge discharge. Other stations that have experienced considerable change in various biological metrics, e.g. station T-2, have not changed substantially in biological identity. That is, station T-2, despite major changes in abundance and dominant species encountered there in August 1994, still clustered with other stations from the northern Harbor. Another point suggested by the classification analysis is that, with few exceptions, many stations have retained a distinct identity throughout the study. In particular, most samples from stations T-4 and T-8 belong to the same clusters. Also, there were relatively consistent pairs of stations throughout the study. Examples include stations T-1 and T-2 after April 1992 and two clusters of samples from stations T-3 and T-6.

C. Habitat-Level Changes

Bulk Sedimentary Measures — Given the observed changes in a variety of biological measures, it was appropriate to look for supporting or contradictory changes in the benthic sedimentary conditions. Three ancillary sedimentary parameters were measured throughout the program—sediment grain-size distribution and TOC content, and the concentration of *Clostridium perfringens* spores. As mentioned in previous studies (Blake *et al.*, 1993; Kropp and Diaz, 1994), changes in sediment texture at stations sampled within the Harbor have been relatively small with one or two exceptions. Sediments at station T-8 were characterized as fine (88% silt + clay) in late 1991 (Kelly and Kropp, 1992), but since have been coarse with relatively little change between sampling periods (>90% sand + gravel, Table 3, Figure 13). Several other stations have shown variation in sediment texture, but without revealing an overall trend. For example, at station T-1 sediments have been 15 18% silt + clay for all surveys except April 1993 and August 1994. At station T-1, even for survey periods that had sediments with relatively consistent fine fractions, there was variation within the coarse fraction. For example, the August 1992 samples were predominantly gravel (65%) as compared to primarily sand (75 90%) for the other periods (Table 3). Blake *et al.* (1993) attributed the variation at station T-1 to sedimentary patchiness. Sediments at a station close to the former Nut Island sludge discharge site, station T-3, possibly showed a trend for increasing coarseness (Table 3, Figures 13 and 14). With the exception of April 1993, sediments collected on each survey after September 1991 were coarser, albeit slightly, than those of the previous survey. These gradual changes amounted to about a 34% change between 1991 and August 1994 (Figure 14). Two other stations showed possible trends in changing sediment texture. Station T-4 gradually increased in percent fines until sediments there were about 1.4 times muddier in late 1994 than in 1991. Sediments at station T-7 were 22 97% finer for 1992 1994 surveys than they were in 1991. Without a better idea of the degree of spatial variation on the scale of the sampling scheme, it seems reasonable to view such possible trends with caution.

Sedimentary TOC content, often used as an approximate indicator of organic enrichment (e.g., Maurer, *et al.*, 1993) would be expected to decrease temporally after the elimination of a major input source. TOC might be expected to change most dramatically at stations near to the former source of organic input, in this case stations T-3 and T-5/5a. At most stations, sediment TOC content, although fluctuating somewhat, was about the same in late 1994 as in late 1991 (Table 3, Figure 13). Late 1994 values differed from the late 1991 values by no more than 16% at 5 stations. At the stations that differed by more than 16% in 1994, only station T-3 showed a possible trend (Figure 14). However, much of the observed variation in TOC values were as likely to have reflected sampling or seasonal variation as they were annual trends. For example, during studies measuring the benthic processes Giblin *et al.* (1995)

Table 3. Bulk sedimentary parameters from samples collected in Boston Harbor between 1991 and 1994. No samples were collected in April 1992.

Station		Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Silt+Clay (%)	TOC (%)	*Clostridium* s/gdw[a]
T-1	Sep 91	1.3	83.6	11.9	3.2	15.1	2.64	11,700
	Aug 92	65.3	17.8	8.0	9.0	17.0	1.91	4,300
	Apr 93	3.2	90.5	6.0	0.3	6.3	1.38	3,870
	Aug 93	8.0	75.3	11.7	5.1	16.7	2.96	7,030
	Apr 94	3.7	77.8	13.7	4.7	18.4	1.38	6,180
	Aug 94	8.2	60.8	24.0	7.0	31.1	1.90	5,490
T-2	Sep 91	0.2	63.6	27.8	8.5	36.3	1.75	22,900
	Aug 92	21.3	47.6	19.1	12.1	31.2	1.71	14,800
	Apr 93	0.0	38.6	48.2	13.2	61.4	2.20	3,690
	Aug 93	3.1	66.0	20.4	10.5	30.9	1.39	9,090
	Apr 94	0.7	69.6	18.9	10.9	29.8	2.20	18,500
	Aug 94	2.1	57.7	28.0	12.3	40.2	1.73	12,475
T-3	Sep 91	0.0	44.1	39.1	16.8	55.9	3.69	207,000
	Aug 92	0.0	43.5	39.0	17.5	56.5	3.57	938
	Apr 93	0.0	38.4	41.0	20.6	61.6	2.89	12,500
	Aug 93	0.5	50.3	30.7	18.6	49.2	3.41	20,200
	Apr 94	0.2	52.0	43.8	4.0	47.8	2.64	14,600
	Aug 94	6.2	57.0	26.2	10.6	36.8	2.80	20,300
T-4	Sep 91	0.0	32.3	48.6	19.1	67.7	3.70	30,000
	Aug 92	0.0	20.8	59.8	19.4	79.2	3.95	3,330
	Apr 93	0.0	16.4	64.3	19.3	83.6	3.58	10,500
	Aug 93	0.0	13.9	60.4	25.6	86.1	3.25	5,750
	Apr 94	0.0	28.0	63.1	8.9	72.0	5.35	12,000
	Aug 94	0.0	4.8	70.4	24.8	95.2	3.10	9,080
T-6	Sep 91	0.1	65.6	25.1	9.2	34.3	1.81	29,400
	Aug 92	0.4	64.8	22.2	12.6	34.8	2.12	7,000
	Apr 93	0.0	37.1	43.2	19.7	62.9	2.51	10,300
	Aug 93	0.2	67.1	20.6	12.1	32.7	1.62	13,800
	Apr 94	5.4	63.5	28.1	3.0	31.1	1.82	11,900
	Aug 94	1.4	64.7	21.8	12.0	33.8	1.90	7,110
T-7	Sep 91	1.8	57.3	27.3	13.6	40.9	2.73	13,700
	Aug 92	4.5	40.2	38.8	16.5	55.3	3.18	7,500
	Apr 93	0.0	19.6	59.9	20.5	80.4	2.87	13,700
	Aug 93	10.3	39.7	33.7	16.3	50.0	2.31	7,100
	Apr 94	8.9	39.1	46.1	6.0	52.1	2.18	10,600
	Aug 94	3.0	38.9	43.8	14.3	58.1	2.50	7,290
T-8	Sep 91	0.0	12.1	52.2	35.7	87.9	0.87	7,330
	Aug 92	2.9	93.4	1.7	2.0	3.7	0.66	3,890
	Apr 93	11.4	79.8	6.1	2.7	8.8	0.84	3,420
	Aug 93	1.9	93.7	1.9	2.5	4.4	0.37	1,580
	Apr 94	5.0	92.9	1.8	0.3	2.1	0.22	5,230
	Aug 94	3.1	91.5	3.1	2.3	5.4	0.90	2,158

[a] spores/gram dry weight

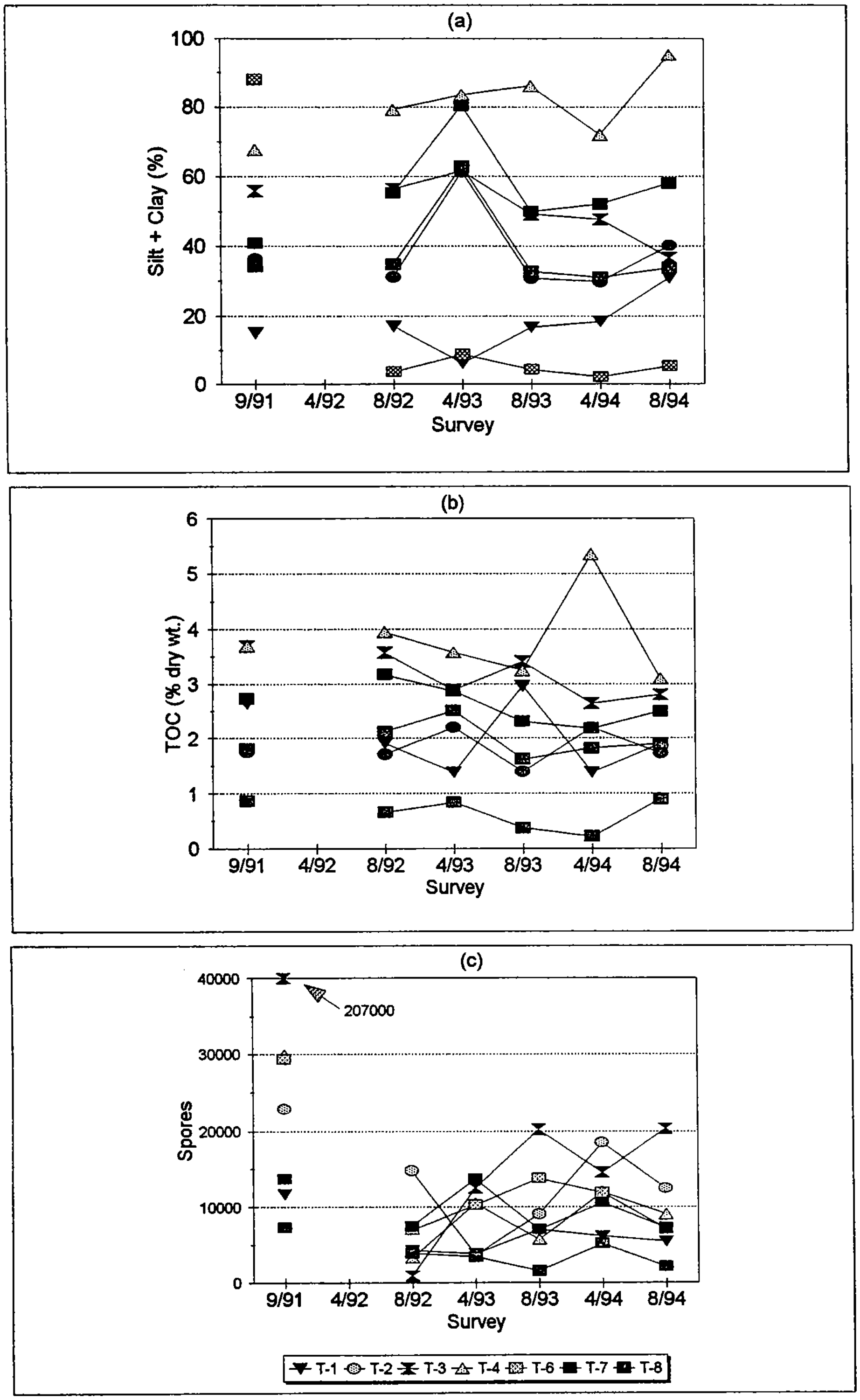


Figure 13. Sediment silt + clay (a), total organic carbon (b), and *Clostridium perfringens* spore counts/g dry weight (c) at Boston Harbor traditional stations (except T-5) across all surveys.

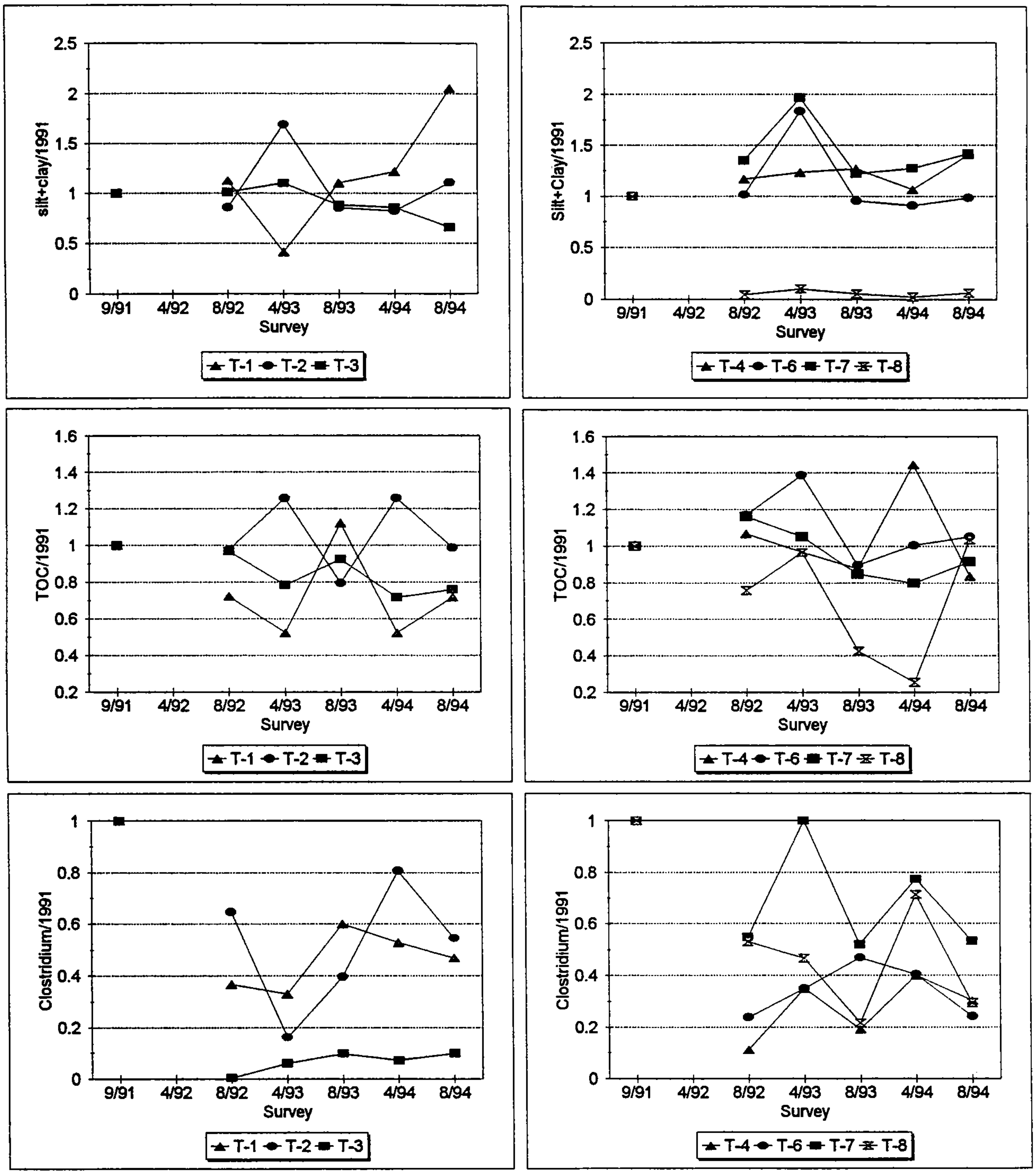


Figure 14. Values for sediment percent silt + clay (top), TOC (middle), and *Clostridium perfringens* spore counts at Boston Harbor traditional stations (except T-5) relative to 1991 values.

found seasonal TOC concentrations at station T-3 (their station BH03) in 1994 (2.7% 3.5%) similar to those recorded over the course of the infaunal studies (2.6% 3.7%).

Spore counts of the sewage sludge tracer, *Clostridium perfringens*, decreased at all stations between 1991 and 1994. The largest decreases, ranging from 35 to >99%, occurred between 1991 and August 1992 (Table 3, Figures 13 and 14). Station T-3, which had the highest spore counts in late 1991, had the lowest counts in late 1992 (Table 3). However, all stations monitored in the Harbor showed the sharp decreases in spore counts. Durell (1995), reporting on data collected as part of a study of combined sewer overflow impacts, also noted lower values in 1994 than at comparable sites sampled prior (1990) to the present study. The relatively rapid decrease in spore counts in Boston Harbor following the 1991 survey was similar to that observed for the New York Bight Apex after sludge dumping was stopped in 1987. Davis and Watkins (1991) reported a 100-fold decrease in *C. perfringens* spores at stations closest to the former 12-mile sludge dump site in the Christiaensen Basin. Davis and Watkins speculated that the decrease in the New York Bight may have resulted from sediment resuspension activity.

Although subject to periodic fluctuations, most spore counts made in the Harbor subsequent to 1992 remained <60% of what they were in late 1991. At some stations these fluctuations seemed to show seasonal patterns, either higher (station T-3) or lower (stations T-4, T-7) in August than the preceding April. Others showed no apparent seasonal trend. Whether the observed fluctuations reflected actual seasonal variation or not is unknown. The distribution of *C. perfringens* spores in the sediment has been shown to exhibit significant small-scale patchiness. Hill *et al.* (1993) found that variation in *C. perfringens* spore counts among individual subcores within single 0.25-m^2 box-core samples ranged from 70 89%. This suggests the possibility that at least some of the variation observed among Boston Harbor samples, which were collected from a small portion of a grab sample, might have reflected inherent small-scale patchiness in spore distribution.

Despite substantial harborwide decreases in *C. perfringens* spore counts since 1991, the absolute spore counts were still relatively high, usually exceeding 5,000/gdw at all stations except station T-8. The spore counts found in the Harbor in late 1994 were similar to those found at an offshore sewage sludge dump site, the Deepwater Municipal Sewage Sludge [106-mile] dumpsite off the New York Bight, where counts have been reported to range up to about 10^4/gdw (Hill *et al.*, 1993; White *et al.*, 1993). The Boston Harbor spore counts also were higher than those reported for an inshore environment, Narragansett Bay, Rhode Island, where at least some untreated sewage entered the Bay. Valente *et al.* (1992) reported *C. perfringens* spore counts to range up to about 3,000/g wet weight in sediments close to treatment facilities.

The apparent lack of correspondence between the biological and sedimentary changes observed in the Harbor was supported by Pearson correlation analyses. Few significant correlations were found between biological parameters and sediment grain-size distribution, TOC content or *C. perfringens* spore counts (Table 4). However, significant correlations were found between several infaunal abundance measures, at either low (e.g., species) or high taxonomic (e.g., phylum) levels, and the RPD_{VIS} depth (Table 4). The lack of correspondence between biology and sediment character in Boston Harbor conflicts with the typically-cited notion of an intimate relationship between the two (e.g., Gray, 1974; Rhoads, 1974). However, as nicely pointed out in a recent review (Snelgrove and Butman, 1994), the disconnect between infauna and bulk sedimentary characteristics should be expected. As Snelgrove and Butman mention, the scale on which the two types of data are collected often differ substantially, even when both are extracted from the same sediment sample. Even when studies have presented evidence for correlation between sediment character and infauna, there has not been demonstration of a causative mechanism, and, as Snelgrove and Butman point out, the two factors may each be responding to another factor or factors

Table 4. Pearson correlation coefficients (r) between biological and abiotic parameters using all survey data (except April 1992). Critical values of r: [$n = 48$, 0.285 at $\alpha = 0.05$, 0.366 at $\alpha = 0.01$; $n = 32$, 0.339 at $\alpha = 0.05$, 0.437 at $\alpha = 0.01$ (from Table Y in Rohlf and Sokal, 1969)].

	Silt +Clay	TOC	*C. perfringens*	RPD_{vis} [a]
n	48	48	48	32
Abundance				
Total	-0.1020	-0.1405	-0.1188	0.6444**
Polychaete	-0.1244	-0.0472	-0.0768	0.5108**
Arthropod	-0.0948	-0.2219	-0.1360	0.5280**
Mollusc	-0.1913	-0.3415*	-0.1144	0.3329
Species				
Total	-0.2464	-0.2725	-0.3252*	0.1603
Polychaete	-0.2416	-0.2714	-0.3833**	-0.0096
Arthropod	-0.1938	-0.2350	-0.2295	0.3317
Mollusc	-0.2868*	-0.2680	-0.1147	0.2338
Diversity (*H'*)	-0.2569	-0.2351	-0.1537	0.0743
Evenness (*J'*)	-0.2380	-0.1431	-0.0291	-0.0671
Selected Taxa				
Oligochaeta	-0.2079	-0.0810	0.1143	0.1514
Polydora cornuta	-0.2318	-0.0926	-0.0655	0.5359**
Phyllodoce mucosa	-0.2520	-0.3184*	-0.1539	0.5113**
Streblospio benedicti	0.0245	0.1534	-0.0203	-0.3832*
Aricidea catherinae	0.1442	-0.0044	-0.0034	0.4167*
Microphthalmus aberrans	-0.2219	-0.0353	0.0197	-0.1329
Ampelisca	0.0215	-0.1757	-0.1070	0.5077**
Leptocheirus pinguis	0.0292	0.0112	-0.0636	0.7044**
Photis pollex	-0.0820	-0.1173	-0.2184	0.3378
Corophium bonellii	0.0559	0.1825	0.0562	0.6949**
Unciola irrorata	-0.1203	-0.2293	-0.1294	0.5479**
Ilyanassa trivittata	-0.2395	-0.2401	-0.0350	0.2462
Tellina agilis	0.0431	-0.1675	-0.0405	0.0993
Nucula delphinodonta	0.0367	-0.2085	-0.1067	0.3945*
Sediment Parameters				
Silt + Clay	—	0.6514**	0.2031	-0.0671
TOC		—	0.4575**	0.1376
C. perfringens			—	0.3381

* Significant correlation at $\alpha = 0.05$.
** Significant correlation at $\alpha = 0.01$.
[a] Redox potential discontinuity as estimated from grab samples; 1993–1994 data only.

(e.g., near-bottom flow regimes). Furthermore, bulk measures of organic carbon content may not explain infaunal distributions because the measures may not be indicative of the nature of the carbon available for use by organisms (reviewed in Snelgrove and Butman, 1994). The 1991 1994 Boston Harbor data make it apparent that the infaunal communities have responded to changing conditions at a rate considerably different from that at which the measured bulk sedimentary parameters responded.

Sediment Profile Measures — Of the 50 stations sampled for SPI in August 1994, about half were sampled with REMOTS® in1989/90, prior to the cessation of sludge discharge, and in August 1992 (SAIC, 1992; Blake *et al.*, 1993). At these stations, modal sediment grain size remained the same from 1990 1992 to 1993, except at station R-33 where sediments became coarser (Table 5). From 1993 to 1994 sediments appeared to become finer (Tables 5 and 6). However, this latter observation may, in part, have resulted from an analytical artifact. Categorization of sediment type placed many of the 1993 stations into the fine sand category whereas in 1994 they were classified as silty fine sand. The distinction between fine sand and silty fine sand is difficult to see in the SPI images when the percentage of fine sediments exceeds 10 15%. A direct comparison of the 1993 and 1994 images indicated that most of the fine sand stations in 1993 also had appreciable levels of fine sediments and actually could be thought to have the border-line silty fine sand sediments. Thus, the change to a finer sediment category may not be a significant change. None of the stations that were pure fine sand changed in sediment type between 1993 and 1994. Surface relief was relatively unchanged through time, with most of the change occurring in 1994 when about a quarter of the stations increased in surface relief. The conclusion based on these two SPI parameters is that through time the physical conditions of the sediments in the Harbor did not change significantly, which supports conclusion based on bulk sedimentary measures.

One of the most striking biological observations was the change in the distributional importance of the tube-dwelling amphipod *Ampelisca*. Because the tubes constructed by *Ampelisca* are visible on SPI, it is possible to evaluate directly any changes in the relative abundance the taxon since 1989/90 (Figure 15). The 1989/90 distribution of *Ampelisca* spp. tube mats, as seen in REMOTS® images, was centered around Long and Peddocks Islands. A total of 18 of 98 (18%) REMOTS® stations had evidence of *Ampelisca* spp. tubes (SAIC 1992, their Figure 12). By May 1992 *Ampelisca* spp. had declined in abundance with no tube mats seen in REMOTS® images, except at station T3 where a number of tubes were observed. By August 1992, *Ampelisca* spp. tube mats appeared at 21 of 50 (42%) sediment profile camera stations and were centered around the Long and Peddocks Islands areas (Blake et al. 1993). In August 1993, *Ampelisca* spp. tube mats again were present at 22 of 49 (45%) stations in these areas. By August 1994 the spatial extent of tube mats had increased further, occurring at 30 of 50 (60%) stations.

Other measures furnished by SPI that are indicative of habitat quality (RPD_{SPI}, OSI, successional stage) showed some change since 1989/90. Blake *et al.* (1993) documented improvement of benthic habitat conditions near the former sludge discharge sites off Deer and Long Islands (stations T-1, T-2, T-3, T-5) between 1989 and 1992. This trend of improved benthic habitat conditions continued into 1993, with RPD_{SPI}, OSI, and successional stage tending to increase at these traditional stations (Table 5). However, the trend in improving habitat condition at these and the other traditional stations did not continue into 1994 (Tables 5 and 6). Decreased RPD_{SPI}, OSI, and successional stage values were seen at almost all of the traditional stations. The exceptions were an increase in successional stage from Stage I to Stage II at station T-1, and at station T-7, which did not change between 1993 and 1994.

Similar improvement of habitat conditions from 1989 through 1992 at many of the outer reconnaissance stations were not observed. By August 1993, at the 17 reconnaissance stations sampled with profile cameras in previous years, there were no changes in either RPD_{SPI}, OSI, or successional stage at a little

Table 5. Comparison of 1990-1992 (SAIC, 1992, Blake et al., 1993), 1993 (Kropp and Diaz, 1994), and 1994 (this report) sediment profile image data. Comparisons between 1990/2 with 1993 were based on range of parameters from all replicate images. Comparisons between 1993 and 1994 are discussed in the text.

1993-94 Station	1992 Station	Sediment Type 90/2-93	Sediment Type 93-94	Surface Relief 90/2-93	Surface Relief 93-94	RPD 90/2-93	RPD 93-94	OSI 90/2-93	OSI 93-94	Successional Stage 90/2-93	Successional Stage 93-94
T1	T1	0	0	-	+	+	-	+	-	0	+
T2	T2	0	0	0	0	nd	nd	nd	nd	nd	nd
T3	T3	0	F	0	0	+	-	+	-	+	-
T4	T4	0	0	0	+	+	-	0	-	0	-
T6	T6	0	F	0	0	+	-	+	-	+	0
T7	T7	0	0	0	0	0	0	+	0	-	0
T8	T8	0	F	0	0	+	-	0	0	0	0
R26	5	0	F	0	0	0	+	-	+	0	+
R27	8	0	F	0	0	-	0	-	+	0	0
R28	15	0	F	0	0	-	+	-	+	0	+
R29	18	0	F	0	0	+	0	0	0	0	0
R30	67	0	F	0	+	0	+	-	+	0	0
R31	21	0	F	0	0	+	-	+	-	0	0
R32	23	0	F	+	0	0	0	0	+	0	0
R33	34	C	F	0	+	0	0	0	0	-	0
R34	27	0	F	0	0	0	0	-	0	-	0
R35	29	0	F	0	0	-	0	-	0	-	0
R36	26	0	0	nd	nd	nd	nd	nd	nd	nd	nd
R37	40	0	F	0	0	0	0	0	+	-	+
R38	38	0	0	0	0	-	0	0	0	0	0
R39	41	0	0	0	0	0	0	-	+	0	+
R40	59	0	0	0	0	0	0	0	0	-	0
R41	57	0	F	0	+	-	+	0	0	-	0
R42	58	0	0	+	0	+	-	0	nd	-	nd
R43	16	0	F	0	+	0	0	0	0	0	0

0: No Change, overlapping range for parameter or difference less than critical (see text for specific parameter values),
-: Reduction, lower non-overlapping range or critical value for years compared,
+: Increase, higher non-overlapping range or critical value for years compared.
nd: No data for comparison.
F: Finer in later year than in previous year.
C: Coarser in later year than in previous year.

Table 6. Comparison of August 1993–1994 SPI data based on the range of parameters from all replicate images.

Station	RPD[a]	Penetration[a]	Surface Relief[a]	Sediment[b]	Amphipods[c]	Polychaetes[c]	Burrows[c]	Infauna[c]	Successional Stage[d]	OSI[d]
T1	–	0	+	0	0–	0	·	·	+II	–
T2	·	0	0	0	+M	0	·	·	·	·
T3	–	–	0	F	+M	–	–	–	–II	–
T4	–	0	–	0	0–	0	–	0	–0	–
T5a	·	0	0	·	·	·	·	·	·	·
T6	–	0	0	F	0M	0	–	–	0	–
T7	0	0	0	0	–	0	0	0	0	0
T8	–	0	0	F	–M	0	+	0	0	0
R2	+	–	0	0	0M	0	+	+	0	+
R3	0	0	0	F	+M	–	0	+	0	+
R4	0	0	0	F	+M	–	0	0	0	0
R5	+	–	0	F	+M	–	+	+	0	+
R6	0	–	0	C	–M	+	·	·	0	–
R7	+	0	0	F	+M	–	+	0	+II	+
R8	·	0	0	0	0–	–	·	·	·	·
R9	0	0	0	F	+M	–	–	0	0	0
R10	+	0	0	0	0–	–	0	0	0	0
R11	0	0	0	F	0M	0	–	–	0	0
R12	+	0	0	F	0M	–	0	+	0	+
R13	+	0	+	0	+M	–	0	0	0	+
R14	0	0	+	F	+M	+	–	–	0	0
R15	0	0	0	F	–	0	–	0	0	0
R16	–	–	+	F	–M	+	–	0	0	–
R17	+	0	0	F	0M	+	0	+	0	0
R18	–	–	0	0	0M	–	0	0	0	–
R19	0	0	+	0	0+	+	·	·	0	0
R20	–	0	0	0	0M	0	0	0	0	–
R21	–	0	+	F	0M	0	0	–	0	–
R22	–	0	0	0	0M	0	+	0	0	–
R23	–	0	0	0	0M	+	0	0	0	–
R24	–	–	0	0	0M	+	–	–	0	–
R25	–	–	0	0	0M	+	0	0	0	–
R26	+	0	0	F	–M	+	+	0	+III	+
R27	0	0	0	F	+M	–	+	0	0	+
R28	+	0	0	F	0M	+	+	+	+III	+
R29	0	0	0	F	0M	0	0	–	0	0
R30	+	0	+	F	0M	+	+	0	0	+
R31	–	0	0	F	0M	0	0	0	0	–
R32	0	0	0	F	+M	–	0	+	0	+
R33	0	–	+	F	0–	0	0	0	0	0
R34	0	0	0	F	0–	+	0	0	0	0
R35	0	0	0	F	0–	–	0	0	0	0
R36	·	0	·	0	0–		·	·	·	·
R37	0	0	0	F	–	+	0	+	+II	+
R38	0	0	0	0	0M	0	–	–	0	0
R39	0	0	0	0	0M	+	0	0	+III	+
R40	0	0	0	0	0–	+	·	·	0	0
R41	+	0	+	F	+M	+	+	+	0	0
R42	–	0	0	0	0–	0	·	·	·	·
R43	0	0	+	F	–	+	+	0	0	0

[a] Criteria for increase (+) or decrease (–) were: RPD and Surface Relief >1 cm, Penetration >5 cm change between years; no change (0) = less than the critical value.

[b] F = finer in 1994; C = coarser in 1994; 0 = no change between years.

[c] Amphipods, Polychaetes, Burrows, and Infauna: + indicates present in 94 but absent in 93; – indicates absent in 94 but present in 93; and 0 indicates no change between years with the value following the 0 indicating the variable state for both years (for example: +M is mat present in 1994 but not 1993).

[d] Successional Stage and OSI increased (+) or decreased (–) if the range of values did not overlap between years. Overlapping ranges were scored as no change (0). The value following the change in successional stage indicates the 1994 value.

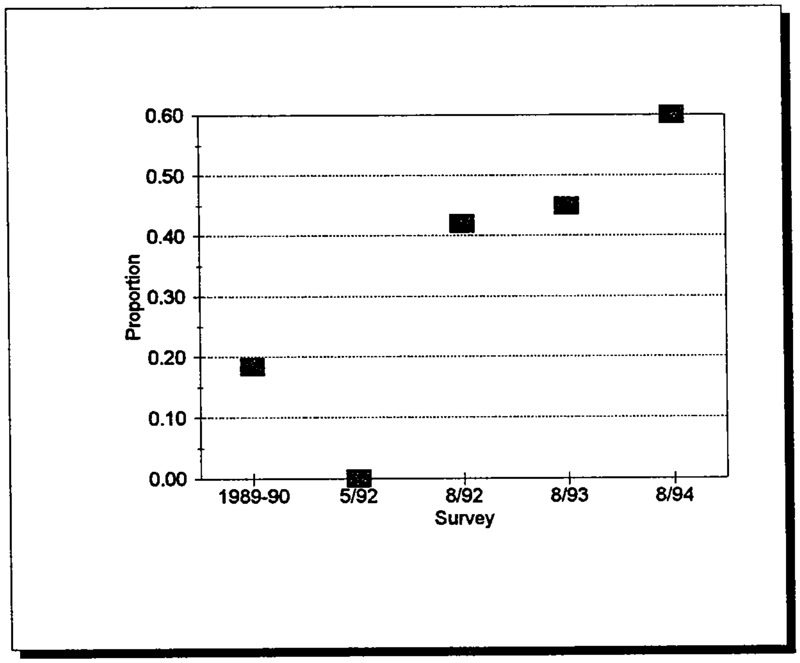


Figure 15. Proportion of stations having *Ampelisca* tube mats as determined from sediment profile images.

more than half of these stations (Table 5). These parameters declined at five to seven of these reconnaissance stations. Only three stations increased in RPD_{SPI}, one in OSI, and none in successional stage. Overall, there appeared to be a slight negative trend in benthic habitat quality from 1992 to 1993. From 1993 to 1994 this trend at the reconnaissance stations was reversed to an improving trend, with more stations showing increases in parameters than decreases (Table 5).

CODA: WAS CHANGE RELATED TO SLUDGE DISCHARGE ABATEMENT?

Although the data from 1994 appeared to follow two of the main tenets of the general model described by Pearson and Rosenberg, it is data aren't sufficient to conclude that infaunal community changes fit the model's expectations. Total abundance showed a possible downward trend in 1994 (e.g., Figure 8), which followed rapid increases in 1992 and 1993. Species numbers continued to increase at some stations in 1994 and generally have appeared to increase since 1991 (Figure 9). These observations, especially when considered along with apparent reductions in the sewage tracer *Clostridium perfringens* and general habitat improvements revealed during SPI analyses that have occurred since 1989/90, make it tempting to ascribe the changes in the benthos to the cessation of sludge discharge. However, relating infaunal community change and sludge discharge abatement is more complex than these simple observations allow. One complicating factor is the cessation of sludge discharge was not the only step taken to reduce contaminant loads into the Harbor. Since the 1980s, when Boston Harbor was given the appellation as "dirtiest harbor" in the country, many contaminant reduction measures have been instituted. Among these were the removal of scum (grease and trash) from wastewater discharge and major improvements to CSOs. Certainly the stoppage of sludge discharge, and its organic input, into the Harbor also was important. Although these measures appeared to result in improvements in water quality, reduced sedimentary contaminants, and reduced incidence of disease in fish populations (e.g., Alber *et al.*, 1993; Durell, 1995; Leo *et al.*, 1995), it is difficult to associate any single step to a specific result. Some of the difficulty undoubtedly relates to nature of the Harbor as a dynamic, well-mixed, well-flushed water mass where local conditions often blend into the broader milieu.

As tempting as it might be to fit the observed general infaunal community changes in Boston Harbor to the Pearson-Rosenberg model, the Harbor data may differ from the model when specific details are highlighted. First, the model predicts that changes would be greatest near the former sites of organic input, in this case stations T-3 and T-5/T-5a. One noticeable difference at these areas was the change in the identity of the two stations , as measured by the CNESS analysis, after sludge discharge stopped. Even this evidence is equivocal because a station that was not expected to be affected by sludge discharges, station T-7, changed identity in a way similar to that shown at the other two stations. As mentioned previously, most of the changes in abundance and species numbers observed in Boston Harbor have been Harbor-wide, not restricted to the localized vicinity of the former source of organic enrichment. Also, there has not been a demonstrated change in the organic content of the sediments (Figure 14). Thus, the infaunal community changes observed since 1991 have happened without a corresponding detectable change in organic content. Of course it is possible that the community changes have occurred in response to a sedimentary property that was not measured. Thompson and Dorsey (1989) found that species in the benthos responded differently to changes in various contaminant levels following sludge discharge abatement in Santa Monica Bay, California. In the Boston Harbor case, sludge contained many contaminants and cessation of sludge discharge curtailed toxic as well as organic input.

The ability to associate benthic community changes with sludge discharge abatement is contingent upon separating the observed changes from typical cyclic fluctuations. To understand such typical cycles, the ideal study design would include a reasonable period of temporally replicated sampling (e.g., Morrisy *et al.*, 1992; Underwood, 1992). Here, the study includes only one directly-comparable sampling period prior to the event hypothesized to affect the benthos. Without an understanding of earlier cyclic variation, it is difficult to know whether or not the September 1991 data reflect true baseline conditions in the Harbor. Qualitative comparison of the 1991 data with historical data may indicate that 1991 was not an entirely accurate pres-cessation baseline. It is also possible that, without data to the contrary, some of the differences detected between 1991 and August of other years may reflect typical August-September variation. The data collected during 1992–1994, which showed considerable spring and summer variability, emphasize the difficulty of the situation. Although we identified what may be important trends in the data, we point out that at many stations the values measured in 1991 for community-level metrics occurred within the range of seasonal variability encountered during 1992–1994 (see Figures 8, 9, and 11).

Historical data were available that allowed some qualitative comparisons that further underscored the possibility that the fluctuations observed during the present study may have been part of typical long-term cycles within the Harbor. Blake *et al.* (1989) summarized studies conducted in the Harbor between 1978 and 1982 in support of 301(h) waiver applications. Although not directly comparable to the present data because of sampling and methodological differences, the earlier data do allow insights into the nature of the communities at a time well before the cessation of sludge discharges. We established four regions in the Harbor that were sampled in 1978–1982 and again in 1991–1994 (Table 7). Among the notable observations from this comparison are that values for community-level metrics for the area approximately northwest of Long Island, i.e., close to the Nut Island sludge discharge sites, that were sampled after abatement (1994) were within the historical range for the area (Table 7). Similar observations could be made for each of the other three Harbor regions indicated in Table 7. Among the community changes emphasized in the present study were striking changes in the distributions of certain taxa, especially *Ampelisca*. One 1992–1994 trend involved the increased importance of *Ampelisca* in the northern Harbor. Yet, even this observation has historical precedent as *Ampelisca* was among the most abundant taxa at two stations in the northern Harbor in 1978 even though it was not predominant during subsequent surveys (1979, 1982). In contrast, consistency in the predominant taxa of other regions like Hingham Bay and the northwest side of Peddocks Island, was apparent. *Ampelisca*, *Aricidea catherinae*, and oligochaete worms were among the key taxa in this area from 1978 to 1994.

In summary, in the absence of a better understanding of "baseline" conditions prior to sludge abatement caution should be exercised in attributing the infaunal community changes observed in the present study to the cessation of sludge discharge into the Harbor. The data collected as part of the Harbor Studies program demonstrate the need for long-term temporally-replicated studies. However, it is reasonable to say that they will provide, if continued, the required quantitative *baseline* information about the nature of variability in the Harbor prior to the eventual termination of effluent discharges.

Conclusions

Major results from the 1991–1994 studies of infaunal communities in Boston Harbor include:

(1) Grab-sample analyses revealed substantial changes in the relative importance of several species within the Harbor. *Ampelisca,* a pollution sensitive amphipod (Thomas, 1993), increased in relative importance within the Harbor. In 1991, *Ampelisca* was numerically important primarily in the southern parts of the Harbor, but by 1994 had expanded its range of importance to include much of

Table. 7. Comparison of 1991 and 1994 infaunal parameters for geographic regions of Boston Harbor with those from past [301(h)] studies summarized in Blake *et al.* (1989). Abundance is given in 1000s/m^2. Key taxa are listed alphabetically

Year Month	1978 July	1979 June	1982 June	1991 September	1994 April, August
Sample size	0.05 m^2	0.05 m^2	0.1 m^2	0.04 m^2	0.04 m^2
Sieve size	0.5 mm	0.5 mm	0.5 mm	0.3 mm	0.3 mm
Deer Island Flats north of President Roads					
Stations	T4–T9	B6, DW	B3–B6	T-1, T-2	T-1, T-2, T-5a
Abundance	2.2–54.5	5.4–35.9	1.4–8.5	1.3–14.4	13.4–359.3
Species Numbers	8–39	19–21	8–70	3–16	26–48
H'	1.6–3.3	1.5–2.6	1.8–5.0	0.6–2.6	1.6–3.3
Key Taxa[a]	Ap, Cp, Ol, Ph	Cp, Et, Pd	Cp, Et, Pd	Ol, St	Ap, Pd, St, Th,
Northwest of Long Island south of President Roads					
Stations	T10–T12	None	None	T-3	T-3
Abundance	11.8–54.4	—	—	58.9	50.6–234.2
Species Numbers	27–36	—	—	18	31–41
H'	1.7–3.3	—	—	2.6	1.9–2.5
Key Taxa[a]	Et, Ol, Ph, Th	—	—	Ap, Ar, Mi, Ol	Am, Ap, Ar, Ol, Pd
Northwest side of Peddocks Island					
Stations	T13–T21	NI	B10–B12	T-6, T-7	T-6, T-7
Abundance	17.0–41.6	61.6	39.8–45.1	25.1–55.2	14.3–74.9
Species Numbers	25–71	43	87–105	8–22	22–31
H'	1.6–5.0	3.5	3.7–4.0	2.1–2.2	2.3–2.8
Key Taxa[a]	Ap, Ar, Ol, Ph	Ap, Ar, Ol	Ap, Ar, Ol	Ap, Ar, Ol, St	Ap, Ar, Ol, St
Hingham Bay					
Stations	None	B9	B9	T-8	T-8
Abundance	—	81.8	29.1	55.9	71.4–90.3
Species Numbers	—	45	65	16	37–54
H'	—	3.8	3.8	3.1	2.4–3.1
Key Taxa[a]	—	Ap, Ol	Ap, Ar, Ol	Ap, Ar, Nu	Ap, Ar, Nu

[a] Am: amphipods; Ap: *Ampelisca*; Ar: *Aricidea catherinae*; Cp: *Capitella capitata*; Et: *Eteone longa*; Mi: *Microphthalmus aberrans*; Nu: *Nucula delphinodonta*; Ol: oligochaetes; Pd: *Polydora cornuta*; Ph: *Pholoe minuta*; St: *Streblospio benedicti*; Th: *Tharyx acutus*

the northern Harbor. This change was necessarily accompanied by reduced relative importance of several annelid worms, notably oligochaetes, *Streblospio benedicti*, and *Polydora cornuta*.

(2) Infaunal abundance increased substantially throughout the Harbor by 1992 and 1993, but then showed a slight decrease by 1994. Abundance in 1994 at some stations was still much higher than it was in 1991. Strong temporal, some of which were probably seasonal, differences in abundance also were detected. Such variation argues for continued semi-annual sampling. The mean number of species per station has increased steadily since the cessation of sludge discharge. Species diversity (*H'*) did not change substantially during the course of the study.

(3) In general the changes in community-level infaunal measures, e.g., abundance and species numbers, were observed Harbor-wide and were not restricted to the areas presumably affected most by sludge discharges (stations T-3 and T-5a). However, the character of these two stations may have changed. Classification analysis showed that prior to the cessation of sludge discharge each aligned with stations in the northern, and presumably more impacted, stations, whereas after discharge of sludge ceased, each eventually was allied with stations from the southern, and presumably less impacted, stations.

(4) Little change in the sedimentary environment, with the exception of *Clostridium perfringens* spore counts, occurred following the abatement of sludge discharge. Habitat quality, as indicated by several SPI-measured parameters, increased following discharge stoppage through 1993, but may have regressed slightly by 1994.

(5) Most of the changes observed in the infaunal communities of Boston Harbor following sludge-discharge abatement appeared consistent with those predicted by the Pearson-Rosenberg model. However, these changes have occurred without concomitant apparent changes in the organic content of the sediments. Because of this and the possibility that the observed data fall within the range of variability historically encountered in the Harbor, it is difficult to associate the community changes with the cessation of sludge discharges.

(6) The present Harbor Studies program will provide the valuable quantitative baseline data on temporal and annual variability that will facilitate analysis of community changes that occur after the cessation of effluent discharge.

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APPENDIX A
List of Species Collected 1991–1994

The typical presentation of a species list for a sampling program,which provides only the names of the taxa identified, does not allow one to evaluate the relative numerical importance the taxa listed. This appendix is an attempt to provide information on the relative numerical importance of the various taxa encountered during the four years of sampling in Boston Harbor. The goal was to concisely summarize the abundance of each taxon in a manner that would allow the abundance of each to be tracked at each station for each survey. To permit the data for each taxon to fit on one page, a coding system for numerical abundance was required. It was decided that presentation of the data in log-normal format would meet this need and provide unbiased breakpoints between each abundance category. Typically the geometric classes are represented by Roman numerals, but here it was necessary to substitute Arabic numerals to allow the data to fit within the confines of Table A-1. Note that because abundance data were presented as mean #/m^2, geometric class 4 was the smallest possible for this study. The geometric classes and their respective arithmetic abundances used in Table A-1 are:

Geometric Class	Arithmetic Class (#/m^2)
1	1
2	2–3
3	4–7
4	8–15
5	16–31
6	32–63
7	64–127
8	128–255
9	256–511
10	512–1023
11	1024–2047
12	2048–4095
13	4096–8191
14	8192–16383
15	16384–32767
16	32768–65535
17	65536–131071
18	131072–262143

Survey–	Station T-1							Station T-2						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Cnidaria														
Actinaria sp. 2														
Platyhelminthes														
Turbellaria sp. 1														
Nemertea														
Nemertea sp. 2					7							7	7	10
Nemertea sp. 4														
Amphiporus angulatus														
Amphiporus cruentatus														
Amphiporus sp. 1													4	
Cerebratulus lacteus						4								
Tetrastemma vittatum														4
Oligochaeta	13	15	14	13	12	11	12	9	11	15	11	12	13	13
Enchytraeidae sp. 1														
Enchytraeidae sp. 2														
Enchytraeidae sp. 3														
Tubificoides apectinatus			8		5					10	5			5
Tubificoides benedeni			5	4	6	6					4	4		
Tubificoides nr. pseudogaste			14	13	12	11	12			15	11	12	13	13
Tubificoides sp. A														
Polychaeta														
Ampharete arctica										4				4
Ampharete lindstromi													4	
Asabellides oculata			7	4	9	4	10		4	5	4	11	9	12
Capitella capitata	8	9	12	8	9	10	10		10	8	6	7	9	10
Heteromastus filiformis			4											
Mediomastus californiensis	6	7	7	6	8	5	9			9		6	6	11
Aphelochaeta monilaris														
Aphelochaeta sp. A					8		12					14		15
Chaetozone setosa							5					6		
Chaetozone sp. A														
Cirratulus cirratus														
Cirriformia grandis														
Monticellina baptisteae														
Monticellina dorsobranchialis														
Tharyx acutus	10	11	11	11	15	13	14	4	11	14	12	12	14	14

Survey–	Station T-3							Station T-4						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Cnidaria														
Actinaria sp. 2														
Platyhelminthes														
Turbellaria sp. 1														
Nemertea														
Nemertea sp. 2						5	4						10	6
Nemertea sp. 4					8									
Amphiporus angulatus					4									
Amphiporus cruentatus					6		6							
Amphiporus sp. 1						4								
Cerebratulus lacteus						5								
Tetrastemma vittatum							4							
Oligochaeta	16	14	14	13	15	15	13	4	11	7	8	6	10	7
Enchytraeidae sp. 1														
Enchytraeidae sp. 2														
Enchytraeidae sp. 3													5	
Tubificoides apectinatus			10	12	12	13	11						6	
Tubificoides benedeni				4		8				4	6		7	
Tubificoides nr. pseudogaste			14	13	15	15	12			7	8	6	7	7
Tubificoides sp. A														
Polychaeta														
Ampharete arctica														
Ampharete lindstromi														
Asabellides oculata	4	6	7	8	6	4	9				5	4	7	6
Capitella capitata	5	6	7			6	8		13	7	9		15	9
Heteromastus filiformis														
Mediomastus californiensis	6	4	7	5	6	8	8						4	
Aphelochaeta monilaris														
Aphelochaeta sp. A					9		8							
Chaetozone setosa														
Chaetozone sp. A														
Cirratulus cirratus				4										
Cirriformia grandis														
Monticellina baptisteae														
Monticellina dorsobranchialis														
Tharyx acutus	7	10	8	11	12	12	10	5	7	5	5	5	6	7

Survey–	Station T-5							Station T-6						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Cnidaria														
Actinaria sp. 2												4		
Platyhelminthes														
Turbellaria sp. 1														
Nemertea														
Nemertea sp. 2														
Nemertea sp. 4												5		
Amphiporus angulatus							5							4
Amphiporus cruentatus														
Amphiporus sp. 1														
Cerebratulus lacteus						4						5		4
Tetrastemma vittatum														
Oligochaeta	11	10	16	13	13	12	11	15	15	16	14	11	15	15
Enchytraeidae sp. 1				4										
Enchytraeidae sp. 2														
Enchytraeidae sp. 3														
Tubificoides apectinatus			6	12	12	11	11			11	13	10	11	10
Tubificoides benedeni			12	10	10	10	7				4			
Tubificoides nr. pseudogaste			16	12	11	9	9			16	14	10	15	15
Tubificoides sp. A				8	5									
Polychaeta														
Ampharete arctica														
Ampharete lindstromi														
Asabellides oculata					4				5	7	6	5		5
Capitella capitata	8	13	15	8	8	7	8		6	6	4	5	7	9
Heteromastus filiformis														
Mediomastus californiensis		4	7	6		6	6	10	9	11	9	7	8	10
Aphelochaeta monilaris				4										
Aphelochaeta sp. A					10		9							
Chaetozone setosa					7									
Chaetozone sp. A				8										
Cirratulus cirratus														
Cirriformia grandis		5												
Monticellina baptisteae								7	5	7				
Monticellina dorsobranchialis													7	5
Tharyx acutus	5	9	7	14	12	12	10	5	5	4	7	4		

Survey–	Station T-7							Station T-8						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Cnidaria														
Actinaria sp. 2														
Platyhelminthes														
Turbellaria sp. 1												4		
Nemertea														
Nemertea sp. 2							6							7
Nemertea sp. 4												4		
Amphiporus angulatus														
Amphiporus cruentatus												4		8
Amphiporus sp. 1														
Cerebratulus lacteus												5		4
Tetrastemma vittatum														
Oligochaeta	10	11	13	13	12	12	12	11	11	11	14	10	7	11
Enchytraeidae sp. 1														
Enchytraeidae sp. 2											4			
Enchytraeidae sp. 3														
Tubificoides apectinatus			11	12	11	11	12			9	13	8	6	9
Tubificoides benedeni				4										4
Tubificoides nr. pseudogaste			12	12	11	9	9			11	13	9		11
Tubificoides sp. A														
Polychaeta														
Ampharete arctica								4	4					
Ampharete lindstromi													4	
Asabellides oculata		6	8	5	8	7	6	4		7	6	8	6	6
Capitella capitata	7	5	5		6		9	6	8	9	5	10	5	8
Heteromastus filiformis														
Mediomastus californiensis			7	4	6	4	8	7	5	8	9	6	4	9
Aphelochaeta monilaris														
Aphelochaeta sp. A					9									
Chaetozone setosa					4		4			6	8		8	
Chaetozone sp. A														
Cirratulus cirratus														
Cirriformia grandis														
Monticellina baptisteae								9	8	8	4			
Monticellina dorsobranchialis											5	6		6
Tharyx acutus	8	8	7	9	10	10	10	10	11	10	9	12	10	10

	Station T-1							Station T-2							Station T-3							Station T-4						
Survey--	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Tharyx sp. 1														10														
Cossura longicirrata					7		8																					
Dorvilleidae sp. A																												
Parougia caeca			4			4																						
Pherusa affinis			5		4		5			6				8			7		4		6							
Glycera dibranchiata			4																		4							
Microphthalmus aberrans	11	12	13	7	11	10	9			11	7	10	11	11	12	10	9	6	8	11	7		5	5	6			7
Scoletoma aciculatum																												
Scoletoma fragilis														5														
Scoletoma hebes		6	7	4	5		5																					
Ninoe nigripes	5	6	4				4			6	5		4	6	6	5	5		4	5	4							
Clymenella torquata	6	8	14	9	12	9	12					4		7		4		4	4	4								
Maldane glebifex																			4									
Sabaco elongata																		4										
Aglaophamus circinata			4														4											
Nephtys caeca	8	6	6	5	8	8	9			5		7	5	9		4			4		6							
Nephtys ciliata													4	9				5		4	7							4
Nephtys cornuta							5																					
Nephtys incisa																												
Nephtys longosetosa													4															
Nephtys neotena					9						5	9	8	7												7		7
Neanthes virens			7		8	6	6			8		7	4	5	5		8	5	7	5					4			
Ophelina acuminata										4																		
Leitoscoloplos robustus							4							5											5			
Scoloplos armiger							5					4	5							4								
Aricidea catherinae	5	5	6	5	8	6	9	4		5	6	6	4	6	12	11	12	12	11	13	12			4		4		
Aricidea cerrutii																												
Aricidea quadrilobata					5																							
Levinsenia gracilis					6					4																4		
Pectinaria granulata	5		5		5		5			5				4														
Pholoe minuta	6	5	8		6	5	8			8		9	4	11	5		7	5	4		6							
Eteone flava			4							4																		
Eteone heteropoda					5		5							5					4				6		5		6	
Eteone longa			9		9	4	9			10		11		10		4	9	7	8	4	8						7	
Eulalia viridis					4																							
Eumida sanguinea																												
Paranaitis speciosa	5	5							5				5	6								4						4
Phyllodoce maculata					10		4					8						6	10		6							
Phyllodoce mucosa			7	5	11	7	7			10		12	7	12			8	8	12	6	10							
Polygordius sp. A		5	7				4																					

	Station T-5							Station T-6							Station T-7							Station T-8						
Survey--	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Tharyx sp. 1																												
Cossura longicirrata																												
Dorvilleidae sp. A																							4					
Parougia caeca			4							4												8	6	5	6	5		6
Pherusa affinis			4							5		4										4					4	
Glycera dibranchiata																4						4	4					4
Microphthalmus aberrans	4		10	5	7	5			4	8	6		6		6	6	7	6	7	6	10	10		8	5	5		
Scoletoma aciculatum									4														4					
Scoletoma fragilis																												
Scoletoma hebes								9	8	9	9	10	10	10	4		5	7	8	8	10	8	8	9	11	11	9	11
Ninoe nigripes								8	5	8	6	5	7	8					5	4	6	5	5	5	6	6		5
Clymenella torquata																						11	8	4		7	5	9
Maldane glebifex																												
Sabaco elongata																												
Aglaophamus circinata			4															4						4		4	4	
Nephtys caeca		4	4	5	9	7	11			5		4		5			4		5		7	7	5	6		9	7	9
Nephtys ciliata				4	5	6	8				4		5	9						4	7						6	7
Nephtys cornuta																												
Nephtys incisa										4											4							
Nephtys longosetosa						4																					4	
Nephtys neotena				7		5								7				6	11	10	11							
Neanthes virens	4		9			4	5		4	8	6	7	6	7			6			5	4				4			
Ophelina acuminata																												
Leitoscoloplos robustus																	5	4								6	5	5
Scoloplos armiger					4																					4	4	
Aricidea catherinae		5	8	12	11	10	5	14	13	15	15	15	15	15	11	10	13	12	13	12	13	15	14	16	14	15	13	14
Aricidea cerrutii				6		4																			4			
Aricidea quadrilobata																												
Levinsenia gracilis																										6		
Pectinaria granulata			6				4			4											4							4
Pholoe minuta			6				5	5	5	5			5	4					6		7	5				4	5	7
Eteone flava																												
Eteone heteropoda					4																							
Eteone longa			9		5		4	4		5		5		7		6	5	5	8		6	4				7		7
Eulalia viridis																												
Eumida sanguinea			5																									
Paranaitis speciosa				4												5	4			5	5							4
Phyllodoce maculata											9	12							4							8	7	7
Phyllodoce mucosa			8		7	5	10	7	6	11	10	13	5	10			5		6	4	5	8	5	10	8	12	10	11
Polygordius sp. A							6		4						4		4					11	13	13		11	11	12

	Station T-1							Station T-2							Station T-3							Station T-4						
Survey--	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Gattyana cirrosa																			5		4							
Harmothoe imbricata			6		4					6				5			8	5	7		5							5
Hartmania moorei							4																					
Lepidonotus squamatus						4																						
Euchone incolor									5																			
Fabricia stellaris						4															4				6			
Polydora aggregata			11		12					8		9																
Polydora caulleryi																												
Polydora cornuta	10	10	17	9	17		16		7	14		15	8	16	6	8	15	13	17	5	16		7		10	4	11	8
Polydora quadrilobata		7	8			9	4		7	4	6		9	9		7				5	6		4		5			
Polydora socialis		9	10		6	9	7		8	6			10	11		8	7			9	8							
Polydora websteri			8			5				10																		
Prionospio steenstrupi	4						5			5		6	5	8		4	5	4	5	4	7							
Pygospio elegans			7	4	5	5	6				6									5								
Scolelepis texana																												
Spio filicornis		4	5						6	5				7			4				6							
Spio limicola	6	8	4		5	12	6						11	11		6				8	8							
Spio setosa		9	9	5					5	4																		
Spio thulini	5	7	12	6	9	5	8			11	4	10	6	11	4		10	8	9	5	11				7			
Spiophanes bombyx		4	5			6	4							6		4				4	5							
Streblospio benedicti	12	11	14	11	13	10	15	10	14	14	12	14	14	16	7	10	7	6	5	6	9	12	12	16	13	14	12	16
Autolytus cornutus						5																						
Autolytus fasciatus																												
Exogone arenosa																						4						
Exogone hebes	4	7	8	4	6	4	7			5		4		4	5	4	5	4	4						4		5	
Exogone verugera																	4		4									
Procerea cornuta			8		7	5	4			7		5		5					4		5							7
Procerea fasciatus																												
Sphaerosyllis longicauda																		4										
Syllides longocirrata																												
Typosyllis sp. 1																												
Nicolea zostericola																												
Polycirrus eximius																												
Polycirrus medusa												4																
Polycirrus sp. A																												
Trochochaeta multisetosa														5														
Sipuncula																												
Nephasoma diaphanes																												

	Station T-5							Station T-6							Station T-7							Station T-8						
Survey--	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Gattyana cirrosa												6																
Harmothoe imbricata			8				4					7		4								4				4		7
Hartmania moorei																												
Lepidonotus squamatus			4			4																						
Euchone incolor																												
Fabricia stellaris				5																								
Polydora aggregata																												
Polydora caulleryi			5																									
Polydora cornuta			12		10	4	9	12	10	16	11	17		10	10	11	13	7	13	7	12	11		13	7	12	7	
Polydora quadrilobata		6	5			4			7	4	4		7			5		4		6			6	6	6	4	4	6
Polydora socialis			4			8	5		10				9	4		9	4			7	6		9	7	4		8	7
Polydora websteri			10																									
Prionospio steenstrupi			7	5	6	4		4	5	5	5	4	5	9			4				5	8	4	9	7	7	6	5
Pygospio elegans				8	6	5		4	5	4												9	9	11	4	9	9	5
Scolelepis texana																				4								
Spio filicornis			7							4														7		5		4
Spio limicola		7	6		4	12	8		10	6			10	7		9	6			8			6	6			5	
Spio setosa		5			5											4								4				
Spio thulini			12	5	4			8	5	11	8	8	4	8			7	4	6		4	7	4	11	6	7		6
Spiophanes bombyx				5	8	7	6															11	10	13		14	13	13
Streblospio benedicti	5	8	9	9	6	6	6	6	7	7		5			14	14	14	12	13	11	12	4	5	5				
Autolytus cornutus																												
Autolytus fasciatus			5																									
Exogone arenosa																												
Exogone hebes		4	4	6	6	5	4			4					5							11	12	13	8	12	12	13
Exogone verugera																												
Procerea cornuta			8							4		6												5				4
Procerea fasciatus			5																									
Sphaerosyllis longicauda																									5			
Syllides longocirrata																				4								
Typosyllis sp. 1																											4	
Nicolea zostericola			6																									
Polycirrus eximius																										4		
Polycirrus medusa																			4									5
Polycirrus sp. A																						5						
Trochochaeta multisetosa																												
Sipuncula																												
Nephasoma diaphanes																				4								

	Station T-1							Station T-2							Station T-3							Station T-4							Station T-5							Station T-6							Station T-7							Station T-8						
Survey--	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Arthropoda																																																								
Ampelisca	9	5	10	5	11	9	12		5	7	6	11	14	18	10	10	15	15	12	13	18		6	5		8	5	5		5	8	5		12	16	14	13	16	16	17	14	15	13	12	14	8	15	12	14	14	9	14	15	17	16	16
Cymadusa compta			5																																																					
Leptocheirus pinguis					4	5	8			10		6	7	12			8	8	14	4	8										5				6	4	5	12	10	14		5	4	7	11		7	5	9	7		9	4	9	8	9
Microdeutopus anomalus																																								9																
Unciola irrorata			7		9	6	8					7	5	12			9	9	16	7	13										6		7		13		5	9	8	14		7			4		6	4	4		6	7		11	10	10
Argissa hamatipes																4																																					4			
Aeginina longicornis			10		4					5																		8			4																									
Caprella linearis			4																																																					
Paracaprella tenuis			5																									10			7																									
Corophium bonellii		5	10		9		6			5		6		9			6	15	16		9										6							10	11	17	5	6					6								8	9
Corophium crassicorne						5								4			7	10	13		5																													7	5	7		12	9	9
Corophium insidiosum		4																										8																4												
Corophium tuberculatum																																					4	5												5						
Gammarus lawrencianus		4																	4											5		6																						5		
Photis pollex	5	7	9	7	10	7	10	4	5	4	9	10	10	12	7	8	12	11	14	10	13	4								4	5	5	6	7	12	7	7	11	7	13	9	11					4	5	5	6		9	6	9	7	8
Erichthonius brasiliensis						4																																																		
Ischyrocerus anguipes		7	8																											7	7						6														4					
Jassa marmorata		4																																																						
Orchomenella minuta		6				4								6			9	9	7	6	9												4				6	5	9	7	6	5		4			4			7	4	4			4	8
Phoxocephalus holbolli			7				5			7		5		8	9	6	12	12	14	12	14						4				12		5		7	11	10	12	12	14	12	12					5		6	9	4	9	9	9	7	10
Rhepoxynius hudsoni																																																				4				
Pleusymptes subglaber																															4																									
Dyopedos monacanthus		6		5	4	5			4		5	5	9	4		8	5	7	4	8							4							6			10		8	5	4			7		6		6			6		5	4		5
Pontogeneia inermis																					5										4							7																		
Metopella angusta			4			4													4												5									5										6		5	6	6		7
Proboloides holmesi																															7																4					4				
Monoculodes sp. 1																																																								5
Stenthoe minuta																												7																						4						
Diastylis polita																				5													9		9																			4		
Diastylis sculpta					4						5	6	6	4		6		8		8	5										4	8	9	7	9		6		5		4					9	7								8	6
Lamprops quadriplicata																																	5																							
Eudorella pusilla																																																						4		
Cancer irroratus	4	4	6				5			4				6			4		6		4							6			6					4		7	4	10					5				6			5		5		6
Crangon septemspinosa	6		4			4	7	7				4	4	5	5		4			4	6	6	4			5		5					4		4	6						5	8				5		6	8		5			4	6
Pagurus longicarpus		5	5															4																		4		4	5					4						5		4	4			
Ptilanthura tenuis																																													5											
Cirolana polita																																																					4			
Edotia tribola	6	5	7		8	4	7		5	5	5	7		10	7	6	10	9	11	8	12									6	6	6	12	10	12	6	6	6	7	8	4	5			4			4		9	5	7	7	9	8	9
Limnoria lignorum													4																																						4					

	Station T-1							Station T-2							Station T-3							Station T-4						
Survey--	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Pleurogonium inerme																	5		5									
Neomysis americana		6						4									6				7					7		
Phoxichilidium femoratum																												4
Tanaissus psammophilus										4																		
Mollusca																												
Anomia simplex																												
Arctica islandica																					4							
Astarte undata																												
Cerastoderma pinnulatum										5		5		5				6										
Hiatella arctica			6		5									4				5	10		7							
Lyonsia arenosa														5							9							
Lyonsia hyalina	5		5			6		5							5	6	5	9	8									
Mulinia lateralis																												5
Spissula solidissima		4																										
Mysella planulata										4															5			
Mya arenaria	7	8	5	5		7	4		6	8	9		9	7	6	6	4		7	6			4		5		6	7
Crenella decussata																												
Musculus niger						4											4		5									
Mytilus edulis		12	10	4	9	9	6	5	10	9	7	8	8	8	8	10	6	7	11	9	9		8	6		6	6	4
Yoldia limatula																4												
Nucula delphinodonta		5										4				4				6							5	
Pandora gouldiana																												
Petricola pholadiformis										4				5														
Periploma papyratium																												
Ensis directus	5		5		6		4			5		7			4											6		
Macoma balthica	4																											
Tellina agilis	8	9	8	6	5	6	7		7	7	7	6	6	7	9	10	8	8	7	8	8				6			6
Asthenotherus hemphilli																												
Thyasira gouldii																												
Turtonia minuta																												
Pitar morrhuanus																												
Doridacea sp. A			4																									
Crepidula fornicata			4							6																		
Crepidula plana			4							4																		
Euspira heros																												
Ilyanassa trivittata	9	10	9	10	8	7	8	4	5	6	5	6	7	8	9	10	9	11	11	9	10							
Phoronida																												
Phoronis architecta																												

	Station T-5							Station T-6							Station T-7							Station T-8						
Survey--	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Pleurogonium inerme																												
Neomysis americana			5							5							5							4				
Phoxichilidium femoratum																												
Tanaissus psammophilus			4																				4	6	4	6		5
Mollusca																												
Anomia simplex			5																									
Arctica islandica							4			4																		5
Astarte undata																						5		4				
Cerastoderma pinnulatum												4										4			4	5	5	
Hiatella arctica			7		4					4	7	8										5		4	6	5	9	
Lyonsia arenosa																												
Lyonsia hyalina			5					6							6				4			11	5	7	7	7	10	5
Mulinia lateralis															5													
Spissula solidissima																4						4						
Mysella planulata																												
Mya arenaria		8		7	4	9		6	5		7	5	9	4	11	9	5			4		6	4		4	4	4	4
Crenella decussata																												4
Musculus niger			4																					4		5		5
Mytilus edulis	4	10	11	8	7	10	8	6	10	8	7	8	9	9		6	4	5		7		7	9	7	8	11	11	11
Yoldia limatula																												
Nucula delphinodonta						6		8	10	9	10	10	10	10				4				13	11	12	14	13	12	13
Pandora gouldiana																											4	
Petricola pholadiformis									6			5	10	4									4				6	4
Periploma papyratium																											4	6
Ensis directus			6	5	8	4	6								11				4		4	7		5		9	5	6
Macoma balthica				8																								
Tellina agilis	6	7	9	9	9	9	9	9	9	7	7	5	7	7	6	7	6	5	5	7	6	11	11	10	6	9	11	10
Asthenotherus hemphilli																								5	5			
Thyasira gouldii												4																
Turtonia minuta								4														4	4					
Pitar morrhuanus																							4					4
Doridacea sp. A			7																									
Crepidula fornicata			6																									
Crepidula plana																												
Euspira heros																					4							
Ilyanassa trivittata	9	10	10	9	7	11	10	10	9	8	7	9	8	8	9	8	7	7	8	7	7	11	11	10	9	9	11	11
Phoronida																												
Phoronis architecta										7			4											7		6	5	5

	Station T-1							Station T-2							Station T-3							Station T-4						
Survey–	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Echinodermata																												
Strongylocent. droebachiensi																												
Ophiura robusta																												
Chordata																												
Bostrichobranchus pilularis																			6									

	Station T-5							Station T-6							Station T-7							Station T-8						
Survey–	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Echinodermata																												
Strongylocent. droebachiensi										5																		
Ophiura robusta																										5		
Chordata																												
Bostrichobranchus pilularis																										4		

Surveys:
1 = September 1991   3 = August 1992   5 = August 1993   7 = August 1994
2 = April 1992   4 = April 1993   6 = April 1994

Appendix B
1994 Sampling Results — Grab Sample Data

Field and Laboratory Methods — The April 12–14, 1994 and August 12–20, 1994 field sampling programs are summarized in Campbell (1994 a, b). During each survey, all eight traditional stations (T-1 to T-8; Kropp *et al.*, 1993) were successfully occupied (Figure 1). Coordinates and water depth for each replicate are given in Appendix A. At each traditional station, a 0.04-m^2 Young-modified Van Veen grab was used to collect three samples for infaunal analysis. Each sample was rinsed with filtered seawater over nested 0.3-mm and 0.5-mm-mesh sieves. Each fraction was fixed with buffered 10% formalin. Also at each traditional station, a single grab sample was obtained for sediment grain size, total organic carbon (TOC), and *Clostridium perfringens* analysis. Details of the sampling procedures are provided in the soft-bottom monitoring Combined Work/Quality Assurance Project Plan (CW/QAPP; Kropp *et al.*, 1993).

In the laboratory, infaunal samples were rinsed with fresh water and transferred to 70% ethanol for storage. All intact macrofaunal species and body fragments identifiable to species level were removed from each sample. Identification of all specimens was to the species level whenever possible. Juveniles or damaged specimens lacking the characters necessary for identification to species were identified to the next highest taxonomic level. Specimens that were counted had a critical part of its body present; for example, polychaetes and arthropods had the head, and bivalves the umbo. Animals lacking these parts were considered fragments and not counted as part of the sample. Epifauna attached to shell fragments, pelagic contaminants, and pieces of colonial organisms were not counted.

Sediment grain size analysis was performed according to methods presented in Folk (1974). Briefly, coarse and fine fractions were separated by wet-sieving through a 62 µm-mesh sieve. The fine fraction (silt and clay) was further separated by suspending the sediment in a deflocculant solution and taking aliquots of the settling sediment at timed intervals after the solution is thoroughly mixed. The coarse fraction (sand and gravel) was dried and then separated by sieving through a 2-mm screen. Grain size was reported as percentage (based on dry weight) of each fraction of the total sample weight.

The sediment subsample to be analyzed for TOC content was treated with 6N HCl to remove inorganic carbon, dried, and finely ground. A LECO model 761-100 carbon analyzer then was used to determine the TOC content of the samples. Data were reported as percent dry weight.

Clostridium perfringens analysis was performed on sediment samples using methods developed by Emerson and Cabelli (1982) and modified by Saad (D. Saad, MTH Environmental Associates, personal communication). The enumeration of *C. perfringens* spore densities was performed by membrane filtration, using serial half-log dilutions of the extract and the procedure developed by Bisson and Cabelli (1979). All final data were reported in units of spores per gram dry weight.

During the August survey, an additional 42 reconnaissance stations (R-2 to R-43; Kropp *et al.*, 1993) were sampled (Figure 1). At reconnaissance stations R-2 to R-25, a single grab sample was collected with the 0.04-m^2 Van Veen grab sampler for analysis by a rapid sorting technique. Each sample was rinsed over a 0.5-mm-mesh sieve and fixed with 10% formalin.

To facilitate sorting, reconnaissance grab samples were stained heavily in a saturated solution of Rose Bengal. Laboratory processing started with a visual inspection of the sample to determine the presence or absence of mollusc shells or rocks. If shells or rocks were present, they were removed from the sample and rinsed over a stack of nested 3.35-, 1.0-, and 0.5-mm-mesh sieves. The material remaining on the sieves was placed in separate, labeled jars and covered with 70% ethanol. Each fraction was named after the mesh size of the sieve on which it was retained. If no heavy fraction was present, the sample was washed over nested 1.0- and 0.5-mm-mesh sieves as described above.

All organisms in the 3.35-mm fraction were removed and identified to the lowest practical taxonomic level (usually species). Sediment in the 1.0- and 0.5-mm fractions of each replicate was sorted by two experienced taxonomists who removed all organisms encountered. The maximum time allowed to sort a fraction was 15 min. After expiration of the time limit, the sorted residue and any material not sorted was placed in separate labeled jars and covered with 70% ethanol. All organisms removed during sorting were identified to the lowest practical taxonomic level (usually species) and counted. To estimate the proportion of the sample that was sorted, the volume of each of the sorted and unsorted residues was obtained by pouring the residues into separate graduated cylinders and allowing them to settle for 3 min.

Reconnaissance Grab Analysis — Numerical estimates of taxon abundance at each reconnaissance station were made by calculating the proportion of each sample that was sorted. The count for each taxon removed during the rapid sorting was divided by the proportion of the sample that was sorted to obtain an estimate of the abundance of that taxon in the whole sample. For example, if a sample was 25% sorted and a count of 15 was obtained for taxon "A", then that count was divided by 0.25 to derive 60 as the estimate of the abundance of taxon "A" in the entire sample.

Benthic Community Analyses — For all infaunal analyses, data from the 0.3-mm and 0.5-mm fractions of each sample were pooled. Certain analyses included only taxa identified to species level. These analyses were (1) calculations of numbers of species per sample, (2) calculations of diversity, evenness, and dominance per sample, and (3) similarity analyses. Two taxa, although not identified to species, were included in these analyses: *Ampelisca* species complex (hereafter referred to as *Ampelisca*) and *Orchestia* species. Other analyses included all taxa collected. These analyses were (1) total and major taxon abundance, and (2) station taxon lists. Most analyses were performed on individual samples (i.e., replicates) although dominance and similarity analyses were conducted on combined replicates for each station.

Descriptive community measures — the Shannon Diversity Index (H'), Pielou's evenness (J'), and Simpson's Dominance (c) — were calculated using formulae as presented in CW/QAPP (Kropp *et al.*, 1993). The program PRARE1, written in 1972 by George Power for H. Sanders and F. Grassle at Woods Hole Oceanographic Institute, and modified for the VAX in 1982 by T. Danforth, was used to calculate H' and J'. The spreadsheet program Quattro® Pro for Windows, version 5.0 (Borland, 1993) was used to perform calculations of some means, standard deviations, confidence intervals, and Pearson correlation coefficients (r). Similarity analyses were conducted on untransformed abundance data by using the Chord-Normalized Expected Species Shared (CNESS: Trueblood *et al.*, 1994; Gallagher, 1995) algorithm, a modification of the original Normalized Expected Species Shared (NESS: Grassle and Smith, 1976). Coats (1995) provided a succinct discussion of the modifications incorporated by the new measure. CNESS was run at $m = 100$. Two similarity comparisons were run on the 1994 data, one with the replicates for each station summed and one with the replicates for each station separate. Clustering was accomplished with the unweighted pair-groups method using arithmetic averages (UPGMA; Sneath and Sokal, 1973; Gauch, 1982). The results were presented as dendrograms.

RESULTS

The results of the 1994 grab sampling activities are presented in Tables B-1 through B-8 and Figures B-1 through B-5.

REFERENCES

Campbell, J.F. 1994a. Boston Harbor Traditional Survey S9401 Report forSoft-Bottom Benthic Monitoring: 1994. Report to Massachusetts Water Resources Authority, Boston, MA. 9 pp.

Campbell, J.F. 1994b. Boston Harbor Traditional Survey S9402 Report forSoft-Bottom Benthic Monitoring: 1993–1994. Report to Massachusetts Water Resources Authority, Boston, MA. 21 pp.

Other references cited above are listed in the main text section.

Table B-1. Summary of Grab Sample Collections for the Boston Harbor Traditional Survey S9401

Station	Protocol	Latitude	Longitude	Depth (m)
T1	CHE	42°20.95'N	70°57.83'W	4
T1	MAC/1	42°20.93'N	70°57.84'W	4
T1	MAC/2	42°20.93'N	70°57.84'W	4
T1	MAC/3	42°20.91'N	70°57.84'W	4
T2	CHE	42°20.57'N	71° 00.12'W	6
T2	MAC/1	42°20.57'N	71° 00.11'W	6
T2	MAC/2	42°20.56'N	71° 00.13'W	6
T2	MAC/3	42°20.58'N	71° 00.09'W	6
T3	CHE	42°19.80'N	70°57.77'W	9
T3	MAC/1	42°19.82'N	70°57.74'W	9
T3	MAC/2	42°19.80'N	70°57.77'W	9
T3	MAC/3	42°19.80'N	70°57.74'W	9
T4	CHE	42°18.59'N	71° 02.48'W	3.5
T4	MAC/1	42°18.60'N	71° 02.50'W	3.5
T4	MAC/2	42°18.60'N	71° 02.49'W	3.5
T4	MAC/3	42°18.61'N	71° 02.50'W	3.5
T5A	CHE	42°20.34'N	70°57.61'W	19
T5A	MAC/1	42°20.35'N	70°57.61'W	15
T5A	MAC/2	42°20.41'N	70°57.65'W	13
T5A	MAC/3	42°20.43'N	70°57.63'W	13
T6	CHE	42°17.60'N	70°56.65'W	6
T6	MAC/1	42°17.61'N	70°56.68'W	6
T6	MAC/2	42°17.60'N	70°56.65'W	6
T6	MAC/3	42°17.61'N	70°56.65'W	6
T7	CHE	42°17.37'N	70°58.68'W	7
T7	MAC/1	42°17.38'N	70°58.67'W	7
T7	MAC/2	42°17.37'N	70°58.71'W	7
T7	MAC/3	42°17.38'N	70°58.69'W	7
T8	CHE	42°17.11'N	70°54.72'W	10
T8	MAC/1	42°17.14'N	70°54.76'W	11
T8	MAC/2	42°17.11'N	70°54.75'W	11
T8	MAC/3	42°17.14'N	70°54.73'W	11

CHE: Sediment chemistry sample.
MAC: Infaunal sample; /1 = replicate 1, etc.

Table B-2. Summary of Benthic Grab Sample Collections for the Boston Harbor Traditional/Reconnaissance Survey S9402.

Station	Protocol/ Replicate	Latitude	Longitude	Depth (m)	Station	Protocol/ Replicate	Latitude	Longitude	Depth (m)
T1	CHE	42°20.89'N	70°57.78'W	6	R2	MAC	42°20.65'N	70°57.67'W	13
T1	MAC/1	42°20.94'N	70°57.79'W	5	R3	MAC	42°21.18'N	70°58.36'W	3
T1	MAC/2	42°20.92'N	70°57.77'W	5	R4	MAC	42°21.51'N	70°58.79'W	6
T1	MAC/3	42°20.94'N	70°57.81'W	5	R5	MAC	42°21.38'N	70°58.67'W	5
					R6	MAC	42°19.91'N	70°57.12'W	7
T2	CHE	42°20.55'N	71°00.11'W	6	R7	MAC	42°20.84'N	70°58.52'W	5
T2	MAC/1	42°20.58'N	71°00.11'W	6	R8	MAC	42°20.67'N	70°59.49'W	2
T2	MAC/2	42°20.58'N	71°00.11'W	6	R9	MAC	42°20.79'N	71°00.97'W	12
T2	MAC/3	42°20.55'N	71°00.12'W	6	R10	MAC	42°21.32'N	71°02.21'W	13
					R11	MAC	42°19.31'N	70°58.48'W	9
T3	CHE	42°19.80'N	70°57.72'W	10	R12	MAC	42°19.10'N	70°58.45'W	7
T3	MAC/1	42°19.83'N	70°57.70'W	10	R13	MAC	42°19.08'N	70°58.85'W	8
T3	MAC/2	42°19.84'N	70°57.74'W	10	R14	MAC	42°19.25'N	71°00.77'W	7
T3	MAC/3	42°19.82'N	70°57.72'W	10	R15	MAC	42°18.92'N	71°01.15'W	4
					R16	MAC	42°18.95'N	70°57.66'W	9
T4	CHE	42°18.57'N	71°02.49'W	3	R17	MAC	42°18.28'N	70°58.66'W	7
T4	MAC/1	42°18.56'N	71°02.50'W	3	R18	MAC	42°17.26'N	70°57.68'W	7
T4	MAC/2	42°18.58'N	71°02.50'W	3	R19	MAC	42°16.94'N	70°56.32'W	9
T4	MAC/3	42°18.57'N	71°02.49'W	3	R20	MAC	42°19.51'N	70°56.11'W	12
					R21	MAC	42°18.52'N	70°56.78'W	10
T5A	CHE	42°20.38'N	70°57.61'W	20	R22	MAC	42°18.04'N	70°56.35'W	10
T5A	MAC/1	42°20.37'N	70°57.62'W	19	R23	MAC	42°17.61'N	70°57.02'W	11
T5A	MAC/2	42°20.37'N	70°57.62'W	19	R24	MAC	42°17.77'N	70°57.52'W	6
T5A	MAC/3	42°20.38'N	70°57.66'W	19	R25	MAC	42°17.47'N	70°55.71'W	5
T6	CHE	42°17.60'N	70°56.68'W	11					
T6	MAC/1	42°17.60'N	70°56.65'W	5					
T6	MAC/2	42°17.60'N	70°56.67'W	5					
T6	MAC/3	42°17.60'N	70°56.65'W	5					
T7	CHE	42°17.35'N	70°58.71'W	5					
T7	MAC/1	42°17.36'N	70°58.73'W	5					
T7	MAC/2	42°17.37'N	70°58.73'W	5					
T7	MAC/3	42°17.35'N	70°58.74'W	5					
T8	CHE	42°17.12'N	70°54.72'W	10					
T8	MAC/1	42°17.10'N	70°54.75'W	10					
T8	MAC/2	42°17.11'N	70°54.73'W	11					
T8	MAC/3	42°17.12'N	70°54.72'W	11					

CHE: Sediment chemistry sample. MAC: Infaunal sample; /1 = replicate 1, etc.

Table B-3. Sediment characteristics for Boston Harbor soft-bottom stations sampled in April and August 1994.

Survey Station	*Clostridium perfringens* (spores/gdw[a])	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Silt + Clay (%)	TOC (%)	RPD[b]
April								
T-1	6180	3.7	77.8	13.7	4.7	18.4	1.38	0.8
T-2	18500	0.7	69.6	18.9	10.9	29.8	2.20	2.8
T-3	14600	0.2	52.0	43.8	4.0	47.8	2.64	0.7
T-4	12000	0.0	28.0	63.1	8.9	72.0	5.35	0.0
T-5a	2460	0.4	74.3	22.2	3.1	25.3	0.28	0.7
T-6	11900	5.4	63.5	28.1	3.0	31.1	1.82	2.5
T-7	10600	8.9	39.1	46.1	6.0	52.1	2.18	2.3
T-8	5230	5.0	92.9	1.8	0.3	2.1	0.22	>
August								
T-1	5490	8.2	60.8	24.0	7.0	31.1	1.90	1.3
T-2	12475	2.1	57.7	28.0	12.3	40.2	1.73	1.3
T-3	20300	6.2	57.0	26.2	10.6	36.8	2.80	2.7
T-4	9080	0.0	4.8	70.4	24.8	95.2	3.10	1.5
T-5a	2840	0.3	87.1	9.1	3.6	12.7	0.50	0.5
T-6	7110	1.4	64.7	21.8	12.0	33.8	1.90	1.0
T-7	7290	3.0	38.9	43.8	14.3	58.1	2.50	0.7
T-8	2158	3.1	91.5	3.1	2.3	5.4	0.90	2.2

[a] grams dry weight.
[b] Apparent redox potential discontinuity depth, estimated visually by core taken from macrofaunal grab sample; average of three replicates.
> Apparent redox potential discontinuity layer was deeper than the grab penetration depth.

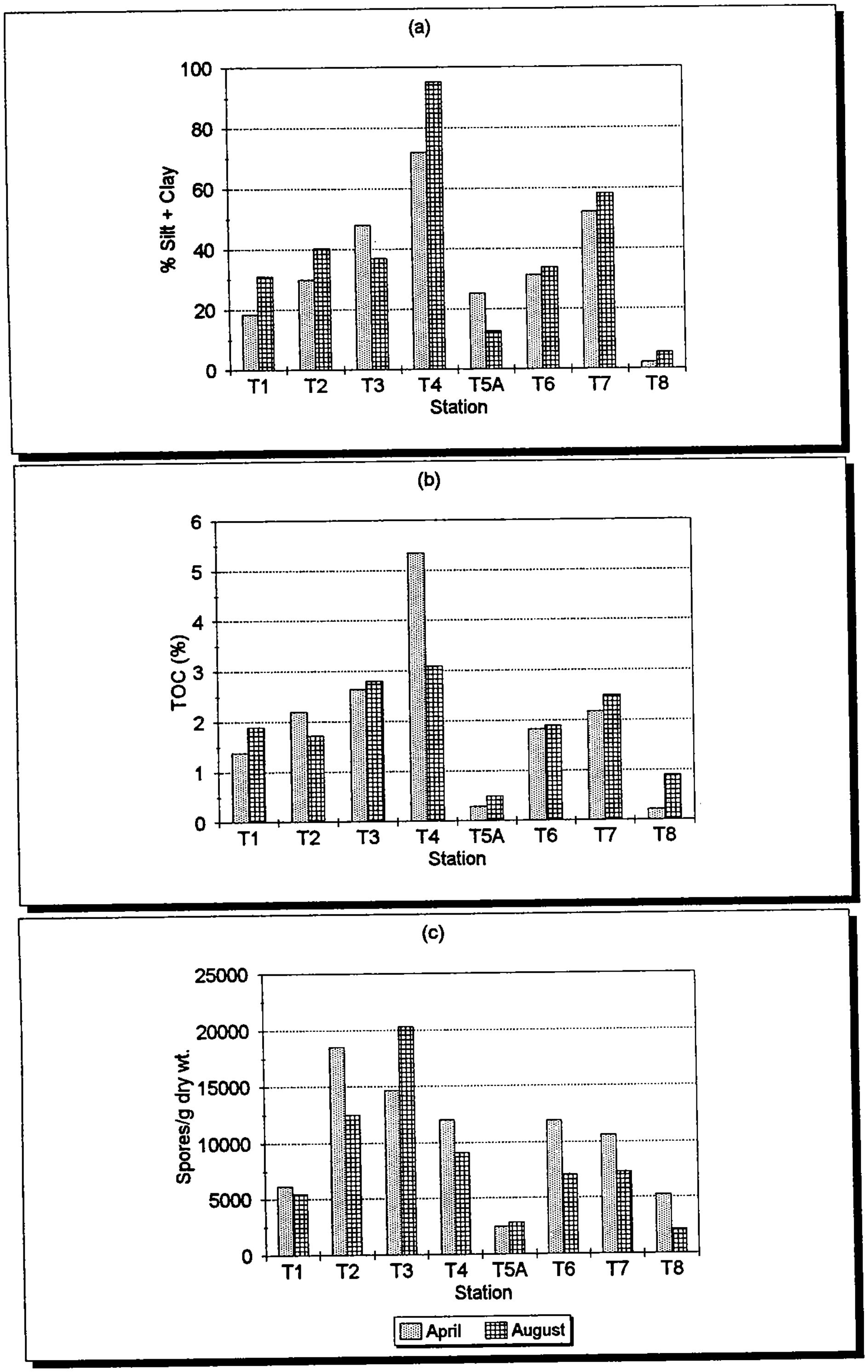


Figure B-1. Sediment percent silt + clay (a), total organic carbon (b), and *Clostridium perfringens* spore counts (c), at Boston Harbor traditional stations in 1994.

Table B-4. Mean (m) infaunal abundance (#/m²) found at each Boston Harbor traditional station sampled in April and August 1994. The 95% confidence intervals (ci) are provided.

		Total	Annelids	Crustaceans	Molluscs	Other
April						
T-1	m	13,441.7	12,183.3	633.3	375.0	250.0
	ci	2,273.8	2,159.9	390.3	347.6	198.0
T-2	m	38,608.3	28,133.3	9,475.0	691.7	308.3
	ci	11,620.2	4,961.8	6,326.6	397.4	290.3
T-3	m	50,616.7	40,991.7	8,250.0	1,333.3	41.7
	ci	21,251.3	26,196.6	5,769.7	71.2	58.9
T-4	m	37,550.0	36,641.7	33.3	116.7	758.3
	ci	28,304.1	27,187.3	43.2	32.7	1,182.2
T5a	m	16,733.3	9,683.3	3,966.7	3,075.0	8.3
	ci	10,645.4	5,935.6	4,246.7	542.0	16.3
T-6	m	70,550.0	53,008.3	13,008.3	4,525.0	8.3
	ci	25,122.8	20,890.0	4,225.7	2,360.3	16.3
T-7	m	14,325.0	10,016.7	4,000.0	250.0	58.3
	ci	3,933.5	6,012.2	3,104.5	172.1	65.3
T-8	m	71,408.3	19,100.0	45,891.7	6,291.7	125.0
	ci	45,747.5	1,722.9	47,902.4	2,827.5	84.9
August						
T-1	m	94,150.0	88,966.7	4,383.3	391.7	408.3
	ci	17,355.4	13,583.0	3,651.2	214.2	155.8
T-2	m	359,325.0	195,408.3	161,191.7	1,991.7	733.3
	ci	30,750.1	13,163.7	18,144.3	756.1	228.7
T-3	m	234,183.3	51,291.7	180,841.7	2,000.0	50.0
	ci	20,437.0	8,178.5	13,014.7	129.6	49.0
T-4	m	39,016.7	37,308.3	1,416.7	241.7	50.0
	ci	28,769.0	29,278.7	2,727.6	86.4	98.0
T5a	m	82,891.7	6,383.3	75,216.7	1,266.7	25.0
	ci	23,909.4	2,728.4	20,602.8	694.3	
T-6	m	74,883.3	44,816.7	29,000.0	1,016.7	50.0
	ci	9,009.1	759.3	8,114.5	163.3	28.3
T-7	m	37,075.0	23,066.7	13,758.3	166.7	83.3
	ci	5,672.1	6,371.5	1,018.6	127.6	81.7
T-8	m	90,325.0	29,608.3	52,000.0	8,308.3	408.3
	ci	126,601.0	24,400.7	97,266.0	5,393.3	580.0

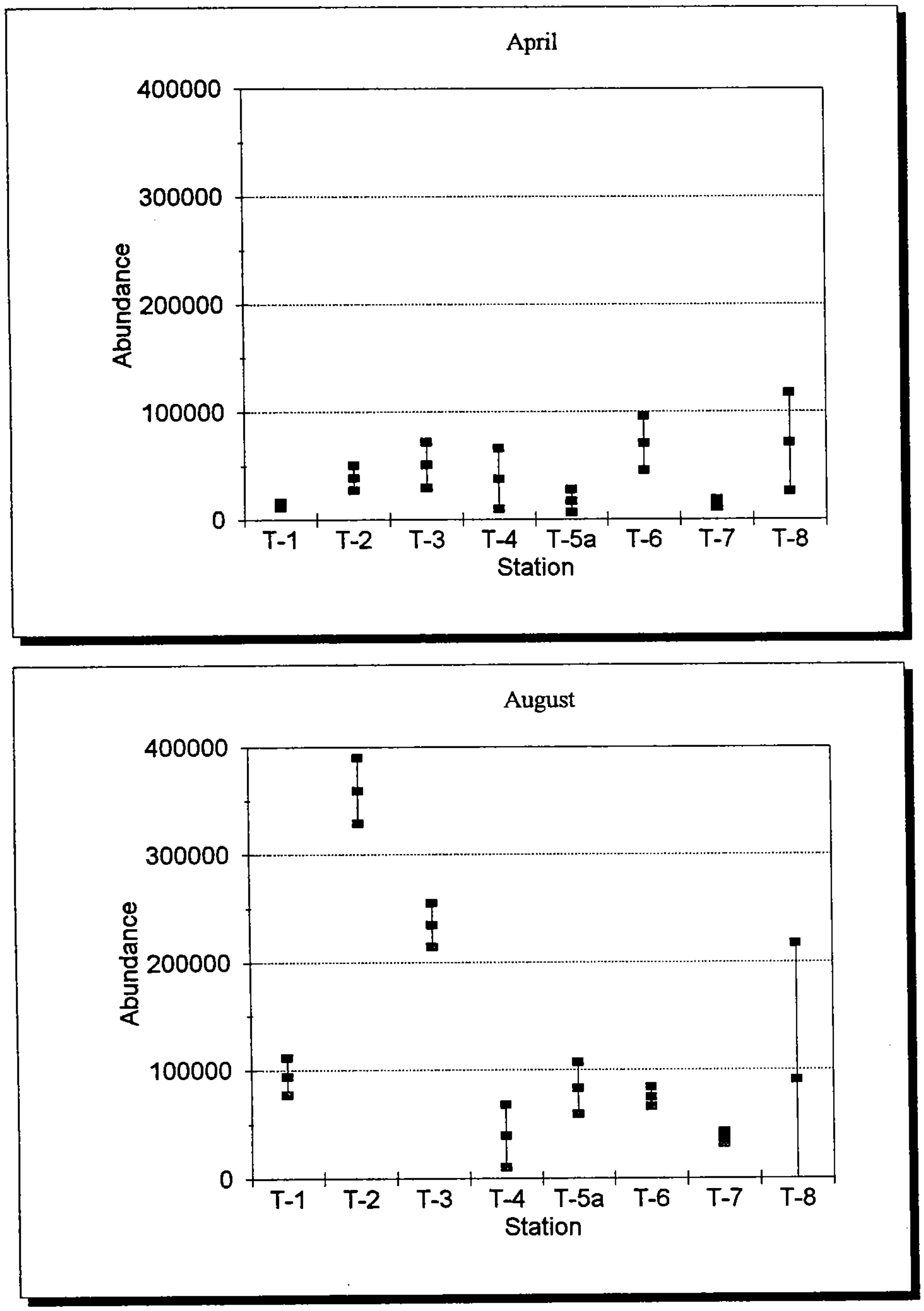
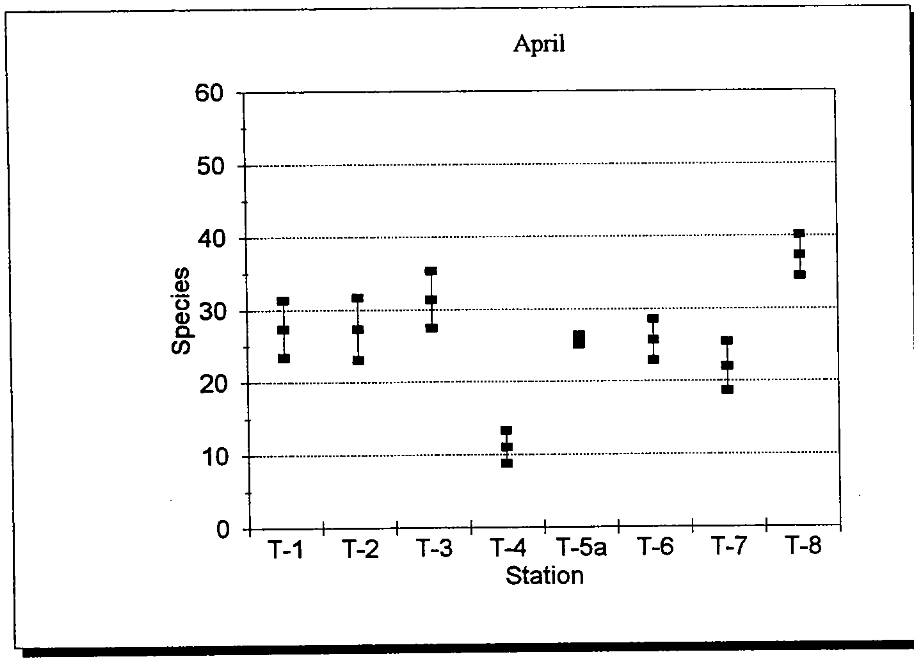


Figure B-2. Mean (± 95% confidence intervals) total infaunal abundance (#/m^2) at Boston Harbor traditional stations in April and August 1994.

Table B-5. Mean (m) numbers of species found at each Boston Harbor traditional station sampled in April and August 1994. The 95% confidence intervals (ci) are provided.

		Total	Annelids	Crustaceans	Molluscs	Other
April						
T-1	m	27.3	18.0	6.0	3.0	0.3
	ci	4.0	3.9	2.0	–	0.7
T-2	m	27.3	17.3	5.7	3.3	1.0
	ci	4.3	2.4	0.7	0.7	1.1
T-3	m	31.3	16.7	8.7	4.7	1.3
	ci	4.0	2.6	0.7	0.7	1.7
T-4	m	11.0	8.0	1.0	1.3	0.7
	ci	2.3	1.1	1.1	0.7	0.7
T5a	m	25.7	17.0	4.3	4.0	0.3
	ci	0.7	1.1	1.3	1.1	0.7
T-6	m	25.7	15.7	4.7	5.0	0.3
	ci	2.8	1.3	1.3	1.1	0.7
T-7	m	22.0	15.7	3.7	2.3	0.3
	ci	3.4	1.7	1.3	0.7	0.7
T-8	m	37.3	21.0	8.0	7.7	0.7
	ci	2.8	1.1	3.0	1.3	0.7
August						
T-1	m	36.0	26.7	6.3	3.0	0.0
	ci	2.0	2.4	1.3	2.0	–
T-2	m	48.3	32.7	10.0	4.3	1.3
	ci	3.5	2.4	1.1	1.7	0.7
T-3	m	40.7	25.0	10.0	4.3	1.3
	ci	3.6	2.3	1.1	0.7	1.7
T-4	m	13.0	7.7	2.7	2.3	0.3
	ci	7.1	2.8	3.3	0.7	0.7
T5a	m	28.7	17.0	7.3	3.7	0.7
	ci	1.3	1.1	0.7	1.3	0.7
T-6	m	29.7	19.0	6.3	3.7	0.7
	ci	1.7	1.1	0.7	0.7	0.7
T-7	m	27.0	20.0	4.7	1.7	0.7
	ci	2.0	2.0	1.7	1.7	0.7
T-8	m	43.3	24.3	10.7	7.0	1.3
	ci	10.7	5.1	3.5	1.1	1.7



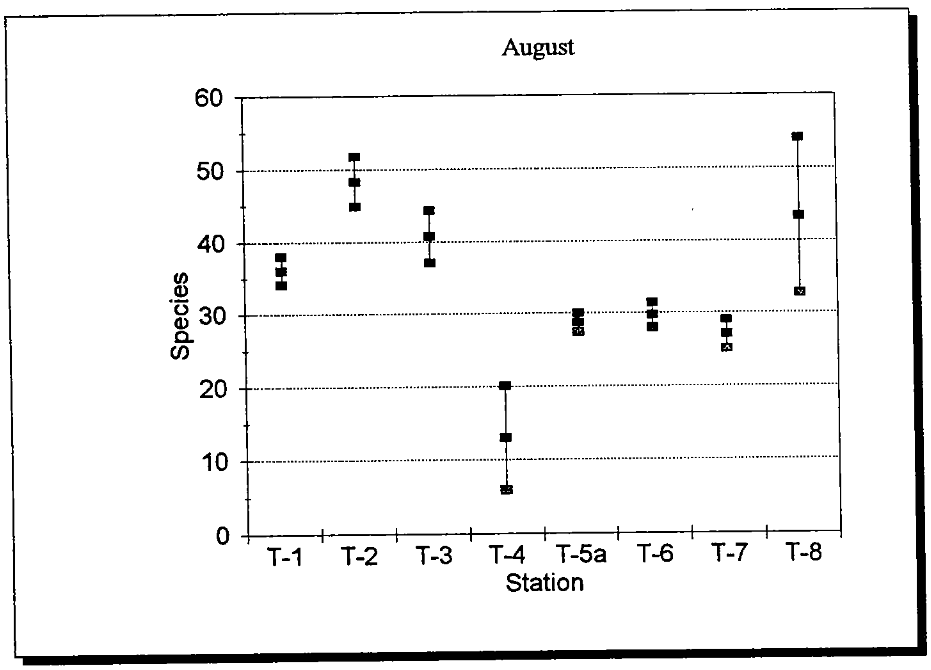


Figure B-3. Mean (± 95% confidence intervals) total numbers of species at Boston Harbor traditional stations in April and August 1994.

Table B-6. Mean (m) species diversity (*H'*), evenness (*J'*), and dominance (*c*) at Boston Harbor traditional stations sampled in April and August 1994. The 95% confidence intervals (ci) are provided.

		April			August		
		H'	*J'*	*c*	*H'*	*J'*	*c*
T-1	m	3.07	0.64	0.207	2.51	0.48	0.266
	ci	0.25	0.05	0.064	0.33	0.06	0.051
T-2	m	2.90	0.61	0.189	2.60	0.47	0.261
	ci	0.08	0.03	0.010	0.11	0.03	0.018
T-3	m	2.47	0.50	0.323	1.85	0.35	0.479
	ci	0.67	0.15	0.196	0.06	0.01	0.030
T-4	m	0.58	0.17	0.829	0.49	0.12	0.873
	ci	0.58	0.17	0.218	0.56	0.12	0.156
T-5a	m	3.28	0.70	0.148	1.62	0.34	0.583
	ci	0.30	0.06	0.042	0.04	0.01	0.015
T-6	m	2.34	0.50	0.278	2.42	0.49	0.260
	ci	0.21	0.06	0.043	0.14	0.04	0.026
T-7	m	2.71	0.61	0.234	2.84	0.60	0.213
	ci	0.16	0.03	0.048	0.27	0.05	0.049
T-8	m	2.44	0.47	0.378	3.10	0.58	0.232
	ci	1.05	0.21	0.270	0.90	0.20	0.216

Table B-7. Mean abundance (#/m^2) of the 10 most abundant species found at each Boston Harbor traditional stations in April 1994. The standard deviation (sd) and cumulative percent (%) are provided.

Species	#/m^2	sd	%	Species	#/m^2	sd	%
Station T-1				**Station T-2**			
Tharyx acutus (P)	4,841.7	1,757.9	37.8%	*Streblospio benedicti* (P)	9,641.7	355.6	25.2%
Spio limicola (P)	2,058.3	355.6	53.9%	*Tharyx acutus* (P)	8,516.7	3,866.1	47.5%
Tubificoides nr. *pseudogaster* (O)	1,158.3	820.2	63.0%	*Ampelisca* (A)	8,416.7	5,151.0	69.5%
Capitella capitata (P)	783.3	824.0	69.1%	*Tubificoides* nr. *pseudogaster* (O)	4,250.0	687.4	80.7%
Streblospio benedicti (P)	700.0	375.0	74.5%	*Spio limicola* (P)	1,933.3	774.7	85.7%
Microphthalmus aberrans (P)	558.3	773.1	78.9%	*Microphthalmus aberrans* (P)	1,033.3	849.4	88.4%
Polydora socialis (P)	500.0	175.0	82.8%	*Polydora socialis* (P)	591.7	256.6	90.0%
Clymenella torquata (P)	391.7	296.2	85.9%	*Photis pollex* (A)	583.3	340.3	91.5%
Ampelisca (A)	341.7	310.6	88.5%	*Polydora quadrilobata* (P)	466.7	101.0	92.7%
Polydora quadrilobata (P)	308.3	87.8	91.0%	*Asabellides oculata* (P)	425.0	114.6	93.8%
Total N	**12,800.0**			**Total N**	**38,216.7**		
Station T-3				**Station T-4**			
Tubificoides nr. *pseudogaster* (O)	26,241.7	21,606.8	52.4%	*Capitella capitata* (P)	31,616.7	17,629.1	85.5%
Aricidea catherinae (P)	5,850.0	854.4	64.1%	*Streblospio benedicti* (P)	2,900.0	4,915.1	93.3%
Ampelisca (A)	4,566.7	4,905.2	73.2%	*Polydora cornuta* (P)	1,125.0	1,926.9	96.4%
Tubificoides apectinatus (O)	4,425.0	1,280.4	82.1%	Nemertea sp. 2 (N)	733.3	1,021.4	98.4%
Phoxocephalus holbolli (A)	2,108.3	312.6	86.3%	*Eteone longa* (P)	125.0	109.0	98.7%
Tharyx acutus (P)	2,083.3	1,616.8	90.5%	*Asabellides oculata* (P)	75.0	50.0	98.9%
Microphthalmus aberrans (P)	1,075.0	1,333.2	92.6%	*Tubificoides benedeni* (O)	66.7	14.4	99.1%
Photis pollex (A)	866.7	444.6	94.3%	*Tubificoides* nr. *pseudogaster* (O)	66.7	94.6	99.3%
Ilyanassa trivittata (G)	500.0	253.7	95.3%	*Tharyx acutus* (P)	58.3	101.0	99.4%
Polydora socialis (P)	266.7	265.0	95.9%	*Eteone heteropoda* (P)	50.0	86.6	99.5%
Total N	**50,050.0**			**Total N**	**36,983.3**		

Table B-7. Mean abundance (#/m^2) of the 10 most abundant species found at each Boston Harbor traditional stations in April 1994. The standard deviation (sd) and cumulative percent (%) are provided. (*continued*).

Species	#/m	sd	%
Station T-5a			
Ampelisca (A)	3,075.0	3,602.7	19.8%
Tharyx acutus (P)	2,850.0	2,985.3	38.2%
Spio limicola (P)	2,533.3	1,365.7	54.6%
Tubificoides apectinatus (O)	2,008.3	893.1	67.5%
Ilyanassa trivittata (G)	1,058.3	625.7	74.4%
Tubificoides benedeni (O)	600.0	475.0	78.2%
Edotia triloba (I)	583.3	321.5	82.0%
Aricidea catherinae (P)	558.3	118.1	85.6%
Tellina agilis (B)	508.3	482.4	88.9%
Tubificoides nr. *pseudogaster* (O)	358.3	246.6	91.2%
Total N	15,500.0		

Species	#/m	sd	%
Station T-6			
Aricidea catherinae (P)	25,950.0	9,794.0	38.1%
Tubificoides nr. *pseudogaster* (O)	22,808.3	9,171.9	71.7%
Ampelisca (A)	9,416.7	1,780.9	85.5%
Phoxocephalus holbolli (A)	3,016.7	1,740.0	89.9%
Tubificoides apectinatus (O)	1,475.0	347.3	92.1%
Petricola pholadiformis (B)	833.3	1,134.2	93.3%
Spio limicola (P)	791.7	341.3	94.5%
Scoletoma hebes (P)	716.7	256.6	95.6%
Nucula delphinodonta (B)	558.3	353.8	96.4%
Photis pollex (A)	483.3	477.2	97.1%
Total N	68,033.3		

Species	#/m	sd	%
Station T-7			
Ampelisca (A)	3,916.7	2,739.3	27.8%
Aricidea catherinae (P)	3,600.0	2,264.3	53.4%
Tubificoides apectinatus (O)	1,833.3	2,114.9	66.4%
Streblospio benedicti (P)	1,683.3	104.1	78.3%
Nephtys neotena (P)	1,016.7	152.8	85.6%
Tharyx acutus (P)	566.7	340.3	89.6%
Tubificoides nr. *pseudogaster* (O)	408.3	426.0	92.5%
Spio limicola (P)	200.0	129.9	93.9%
Scoletoma hebes (P)	141.7	94.6	94.9%
Ilyanassa trivittata (G)	116.7	101.0	95.7%
Total N	**14,083.3**		

Species	#/m	sd	%
Station T-8			
Ampelisca (A)	43,633.3	40,869.3	62.0%
Aricidea catherinae (P)	6,691.7	1,607.9	71.5%
Spiophanes bombyx (P)	5,108.3	1,463.4	78.7%
Exogone hebes (P)	2,333.3	1,270.9	82.0%
Nucula delphinodonta (B)	2,058.3	1,313.5	85.0%
Polygordius sp. A (P)	1,783.3	3,088.8	87.5%
Ilyanassa trivittata (G)	1,300.0	725.0	89.3%
Tellina agilis (B)	1,166.7	669.1	91.0%
Unciola irrorata (A)	875.0	646.6	92.2%
Tharyx acutus (P)	791.7	496.4	93.4%
Total N	**70,416.7**		

A: Amphipod G: Gastropod N: Nemertean P:Polychaete
B: Bivalve I: Isopod O: Oligochaete

Table B-8. Mean abundance (#/m^2) of the 10 most abundant species found at each Boston Harbor traditional stations in August 1994. The standard deviation (sd) and cumulative percent (%) are provided.

Species	#/m^2	sd	%	Species	#/m^2	sd	%
Station T-1				**Station T-2**			
Polydora cornuta (P)	39,008.3	3,988.2	42.0%	*Ampelisca* (A)	150,016.7	16,422.6	43.6%
Streblospio benedicti (P)	20,741.7	2,204.7	64.3%	*Polydora cornuta* (P)	64,566.7	13,040.3	62.4%
Tharyx acutus (P)	15,300.0	2,869.8	80.8%	*Streblospio benedicti* (P)	57,058.3	3,828.9	79.0%
Tubificoides nr. *pseudogaster* (O)	3,616.7	2,008.8	84.7%	*Aphelochaeta* sp. A (P)	26,883.3	5,469.9	86.8%
Ampelisca (A)	3,341.7	2,520.2	88.3%	*Tharyx acutus* (P)	9,800.0	3,482.0	89.6%
Aphelochaeta sp. A (P)	2,600.0	665.7	91.1%	*Tubificoides* nr. *pseudogaster* (O)	5,666.7	2,352.8	91.3%
Clymenella torquata (P)	2,483.3	2,394.8	93.8%	*Unciola irrorata* (A)	3,708.3	388.4	92.4%
Capitella capitata (P)	875.0	912.8	94.7%	*Photis pollex* (A)	3,350.0	894.8	93.3%
Asabellides oculata (P)	566.7	300.3	95.3%	*Phyllodoce mucosa* (P)	3,016.7	137.7	94.2%
Photis pollex (A)	516.7	382.7	95.9%	*Asabellides oculata* (P)	2,941.7	724.7	95.1%
Total N	**92,891.7**			**Total N**	**343,966.7**		
Station T-3				**Station T-4**			
Ampelisca (A)	156,725.0	15,247.4	67.1%	*Streblospio benedicti* (P)	36,366.7	25,333.0	93.5%
Polydora cornuta (P)	36,800.0	2,858.2	82.8%	*Paracaprella tenuis* (A)	916.7	1,587.7	95.9%
Phoxocephalus holbolli (A)	10,650.0	2,627.6	87.4%	*Capitella capitata* (P)	258.3	190.9	96.6%
Photis pollex (A)	4,966.7	1,855.8	89.5%	*Polydora cornuta* (P)	241.7	281.0	97.2%
Unciola irrorata (A)	4,375.0	1,050.9	91.4%	*Corophium insidiosum* (A)	150.0	259.8	97.6%
Aricidea catherinae (P)	3,783.3	2,368.3	93.0%	*Aeginina longicornis* (A)	141.7	245.4	97.9%
Tubificoides nr. *pseudogaster* (O)	3,433.3	1,504.2	94.5%	*Stenothoe minuta* (A)	91.7	158.8	98.2%
Edotia triloba (I)	2,966.7	1,502.6	95.8%	*Nephtys neotena* (P)	83.3	144.3	98.4%
Spio thulini (P)	1,600.0	614.4	96.5%	*Mya arenaria* (B)	75.0	50.0	98.6%
Tubificoides apectinatus (O)	1,258.3	513.8	97.0%	Four species @	66.7	115.5	99.3%
Total N	**233,587.5**			**Total N**	**38,875.0**		

Table B-8. Mean abundance (#/m^2) of the 10 most abundant species found at each Boston Harbor traditional stations in August 1994. The standard deviation (SD) and cumulative percent (%) are provided. (*continued*).

Species	#/m^2	sd	%
Station T-5a			
Ampelisca (A)	62,791.7	16,554.9	75.9%
Unciola irrorata (A)	5,141.7	585.9	82.1%
Edotia triloba (I)	3,166.7	963.2	86.0%
Photis pollex (A)	3,166.7	1,091.5	89.8%
Tubificoides apectinatus (O)	1,333.3	562.0	91.4%
Nephtys caeca (P)	1,108.3	202.1	92.8%
Phyllodoce mucosa (P)	883.3	208.2	93.8%
Tharyx acutus (P)	791.7	559.2	94.8%
Ilyanassa trivittata (G)	750.0	606.7	95.7%
Polydora cornuta (P)	483.3	455.8	96.3%
Total N	**82,700.0**		

Species	#/m^2	sd	%
Station T-6			
Ampelisca (A)	24,691.7	5,518.9	33.1%
Tubificoides nr. *pseudogaster* (O)	22,200.0	3,823.4	62.9%
Aricidea catherinae (P)	17,366.7	4,368.2	86.1%
Phoxocephalus holbolli (A)	2,766.7	1,672.3	89.8%
Photis pollex (A)	1,341.7	926.8	91.6%
Scoletoma hebes (P)	808.3	202.1	92.7%
Polydora cornuta (P)	775.0	326.9	93.8%
Tubificoides apectinatus (O)	758.3	444.6	94.8%
Mediomastus californiensis (P)	608.3	137.7	95.6%
Phyllodoce mucosa (P)	541.7	62.9	96.3%
Total N	**74,608.3**		

Species	#/m^2	sd	%
Station T-7			
Ampelisca (A)	13,158.3	1,400.1	35.8%
Aricidea catherinae (P)	7,841.7	2,640.7	57.1%
Streblospio benedicti (P)	3,741.7	364.3	67.2%
Polydora cornuta (P)	3,533.3	537.5	76.9%
Tubificoides apectinatus (O)	2,650.0	2,304.8	84.1%
Nephtys neotena (P)	1,525.0	463.0	88.2%
Tharyx acutus (P)	883.3	118.1	90.6%
Scoletoma hebes (P)	600.0	352.7	92.2%
Microphthalmus aberrans (P)	533.3	224.1	93.7%
Tubificoides nr. *pseudogaster* (O)	483.3	524.6	95.0%
Total N	**36,791.7**		

Species	#/m^2	sd	%
Station T-8			
Ampelisca (A)	48,208.3	82,178.7	54.1%
Aricidea catherinae (P)	9,425.0	11,082.8	64.6%
Nucula delphinodonta (B)	5,508.3	4,798.5	70.8%
Spiophanes bombyx (P)	4,575.0	544.9	75.9%
Exogone hebes (P)	4,550.0	2,827.0	81.0%
Polygordius sp. A (P)	3,516.7	3,514.8	85.0%
Tubificoides nr. *pseudogaster* (O)	1,358.3	2,224.1	86.5%
Phyllodoce mucosa (P)	1,283.3	1,724.9	87.9%
Scoletoma hebes (P)	1,241.7	1,999.4	89.3%
Ilyanassa trivittata (G)	1,233.3	287.6	90.7%
Total N	**89,175.0**		

A: Amphipod   G: Gastropod   O: Oligochaete
B: Bivalve   I: Isopod   P: Polychaete

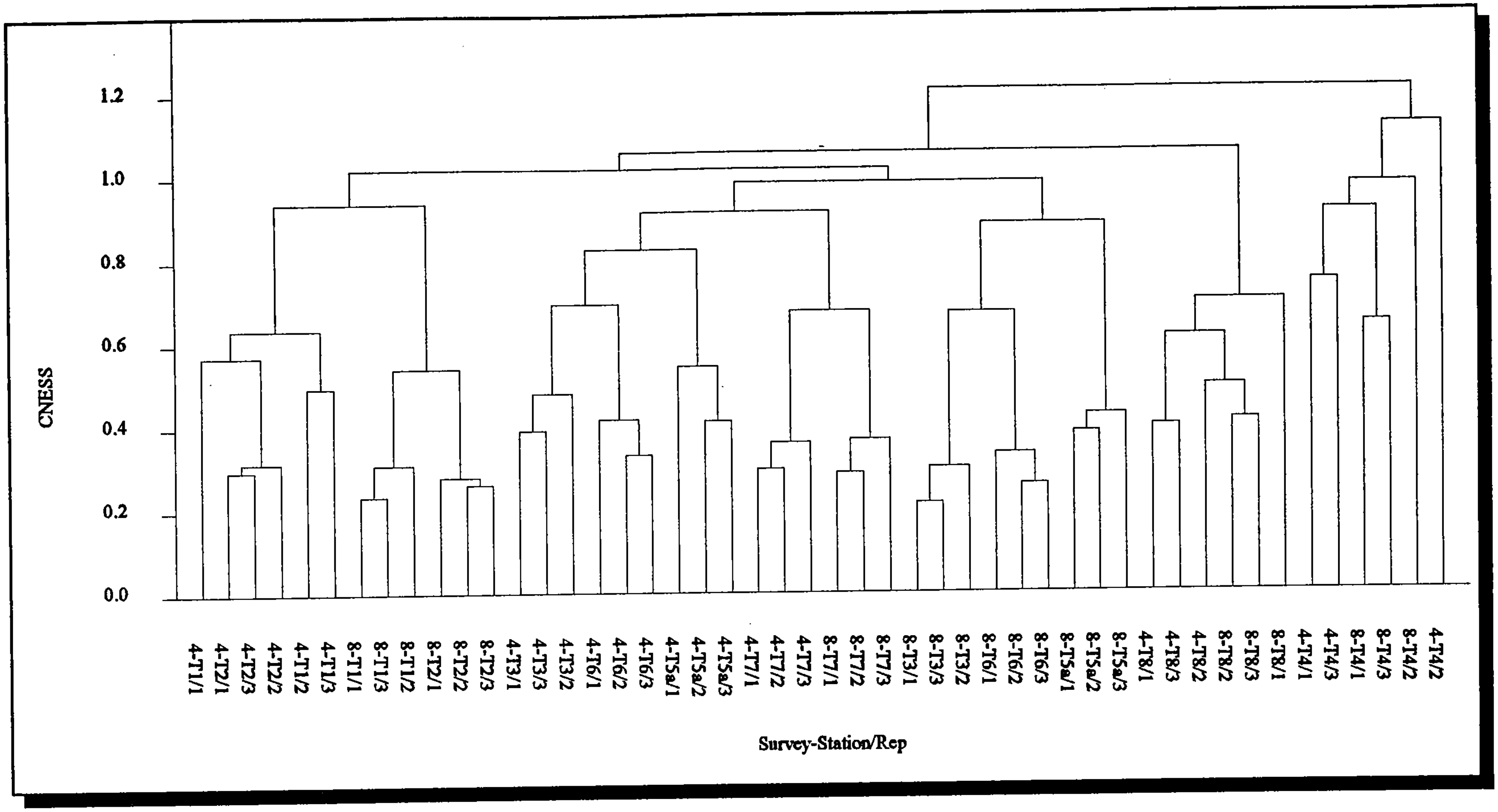


Figure B-4. Dendrogram resulting from clustering of traditional station replicates collected from Boston Harbor in April (4) and August (8) 1994 based on the CNESS algorithm (m = 100).

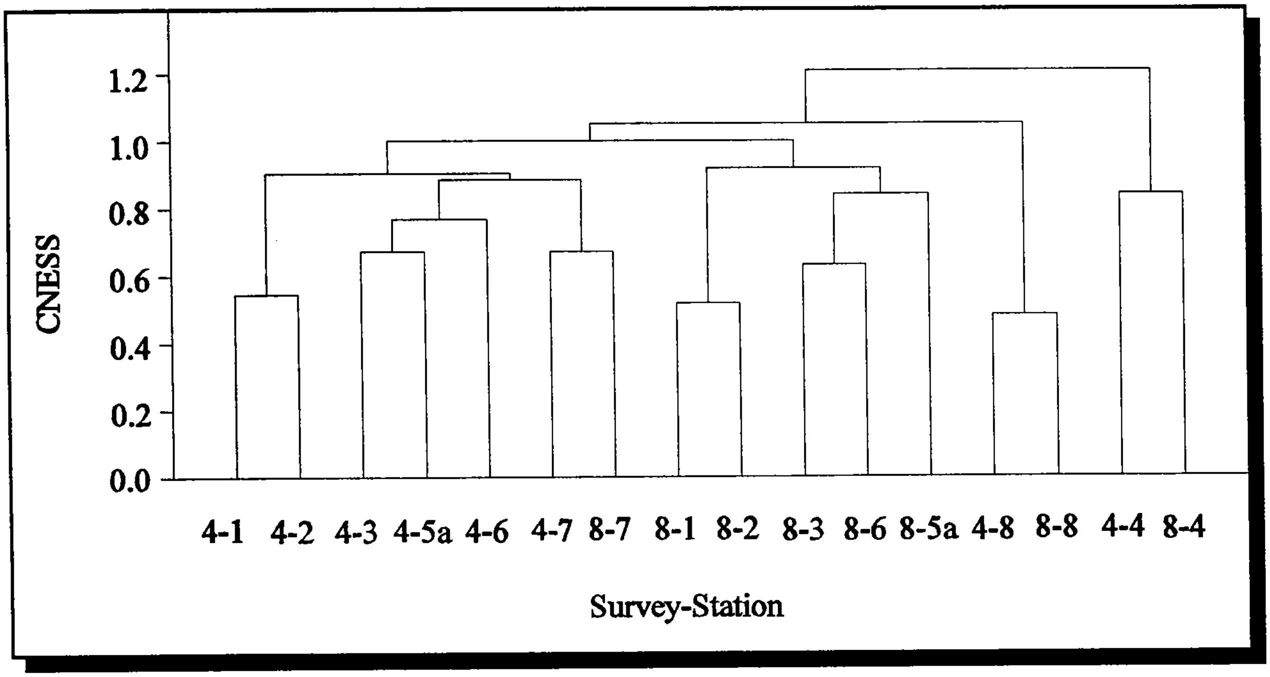


Figure B-5. Dendrogram resulting from clustering of traditional stations (with replicates summed) from Boston Harbor in April (4) and August (8) 1994 based on the CNESS algorithm (*m* = 100).

Appendix C
1994 Sampling Results — SPI Data

SUMMARY OF 1994 FIELD AND LABORATORY ACTIVITIES: SEDIMENT PROFILE IMAGES

During the August 1994 survey, a Hulcher Model Minnie sediment profile camera was used to obtain four sediment profile images (SPI) at each traditional and reconnaissance station (Campbell, 1994). On each deployment, the profile camera was set to record two images at 2 and 10 sec after the camera apparatus contacted the bottom. Images, recorded on Fujichrome 100P slide film, were obtained at all 50 stations. Laboratory processing of all biological samples, ancillary physicochemical samples, and SPI proceeded as presented in the CW/QAPP (Kropp *et al.*, 1993).

The sediment profile images were first analyzed visually by projecting the images and recording all features viewed into a preformatted standardized spreadsheet file. The sediment profile images were then computer-image-analyzed using a Matrox color frame grabber and Image Pro analysis software on a 386 microcomputer. Computer analysis procedures for each image were standardized by executing a series of macro commands (Viles and Diaz, 1991). Data from each image were sequentially saved to an ASCII file for later analysis.

Prism penetration, measured as the distance the sediment moves up the 20-cm length of the apparatus face plate, provides a geotechnical estimate of sediment compaction. The further the prism enters into the sediment, the softer the sediments and the higher the water content. If the camera frame weight is not changed during field image collection, then prism penetration provides a means for assessing the relative compaction between stations or different habitat types. Because prism penetration is a function of the equipment used to capture SPI, comparisons of this parameter between the 1992 and 1993–1994 surveys, on which different equipment was used, are not appropriate. In addition, for each deployment, two exposures were taken at 8-sec intervals, allowing the camera to record overlapping photographs of the sediment.

Surface relief, measured as the difference between the maximum and minimum distance the prism penetrated, provided an estimate of small-scale bed roughness, on the order of the prism face plate width (15 cm). The causes of surface roughness can often be determined from visual analysis of the images. Surface relief provided qualitative and quantitative data on habitat characteristics that were used to evaluate sedimentary conditions at the time the image was recorded.

The apparent color redox potential discontinuity (RPD) layer was determined to provide an estimate of the depth to which sediments were oxidized. Because no direct measurements were made of the redox potential discontinuity, the apparent RPD only approximates the actual boundary between oxic and anoxic sediments. Because of the complexities of iron and sulfate reduction-oxidation chemistry, reddish-brown sediment color tones (Diaz and Schaffner, 1988) or, in black-and-white images, the whiter or lighter areas of the image (Rhoads and Germano, 1986) were assumed to indicate that the sediments were oxic, or at least were not intensely reducing. The area of the image distinguished as being oxidized was obtained by digitally manipulating the image to enhance characteristics associated with oxic sediment (greenish-brown color tones). The enhanced area was then determined from a density slice of the image. The depth of the apparent RPD then was determined by dividing the area of the image having oxic sediments by the width of the digitized image. This study used two methods to estimate apparent RPD depth: SPI and visual analysis of grab-sample cores (Kropp *et al.*, 1993). Estimates obtained from SPI analysis were termed RPD_{SPI} to distinguish them from estimates obtained from grab samples. The latter were termed RPD_{VIS}.

Sediment grain size was estimated by comparing the sediment profile images with a set of standard images for which mean grain size had been determined in the laboratory. The sediment type was described following the Wentworth classification as described in Folk (1974) and represents the major modal class for each layer identified in an image. Surface and subsurface features were evaluated visually from each image and compiled by type and frequency of occurrence. Examples of surface features are amphipod and worm tubes, amphipod tube mats, shells, and mud clasts. Subsurface features include active infaunal burrows, back-filled burrows, water filled voids, gas voids, infaunal organisms, and shell debris.

The successional stage of the infaunal community at each station was estimated by visually examining images for characteristics associated with each stage (Rhoads and Germano, 1986; Valente *et al.*, 1992). Sediments having pioneering or colonizing (Stage I) assemblages (in the sense of Odum, 1969), were characterized by shallow apparent RPD_{SPI} layers and dense aggregations of small tube-dwelling polychaete worms at the surface. Sediments with advanced or equilibrium (Stage III) assemblages were characterized by deep apparent RPD_{SPI} layers and the presence of larger deposit-feeding organisms, the presence of which typically was indicated only by the presence of subsurface feeding voids. Sediments with assemblages (Stage II) transitional to Stages I and III were characterized by shallow to deep RPD_{SPI} depths and dense groupings of tube-dwelling amphipods such as *Ampelisca*.

Using data provided by the sediment profile images, Rhoads and Germano (1982; 1986) developed the multi-parameter organism-sediment index (OSI) to characterize benthic habitat quality. SPI parameters incorporated in the OSI are depth of the apparent RPD_{SPI}, successional stage of macrofauna, the presence of gas bubbles in the sediment (an indication of high rates of methanogenesis), and the presence of reduced sediment at the sediment-water interface. The OSI ranges from - 10, for poorest quality habitats, to +11, for highest quality habitats.

RESULTS

The data from the 1994 SPI activities are presented in Tables C-1 through C-3 and Figures C-1 and C-2.

REFERENCES

Campbell, J.F. 1994. Boston Harbor Traditional Survey S9402 Report forSoft-Bottom Benthic Monitoring: 1993–1994. Report to Massachusetts Water Resources Authority, Boston, MA. 21 pp.

Other references cited above are listed in the main text section.

Table C-1. Summary of Benthic SPI Collections for the Boston Harbor Traditional/Reconnaissance Survey S9402.

Station	Protocol/ Replicate	Latitude	Longitude	Depth (m)
T1	SPI/1	42°20.95'N	70°57.81'W	5
T1	SPI/2	42°20.95'N	70°57.80'W	5
T1	SPI/3	42°20.97'N	70°57.80'W	5
T2	SPI/1	42°20.59'N	71°00.09'W	6
T2	SPI/2	42°20.58'N	71°00.12'W	6
T2	SPI/3	42°20.58'N	71°00.12'W	6
T3	SPI/1	42°19.84'N	70°57.73'W	8
T3	SPI/2	42°19.84'N	70°57.75'W	8
T3	SPI/3	42°19.79'N	70°57.72'W	8
T4	SPI/1	42°18.59'N	71°02.51'W	2
T4	SPI/2	42°18.58'N	71°02.52'W	2
T4	SPI/3	42°18.59'N	71°02.51'W	2
T5A	SPI/1	42°20.38'N	70°57.61'W	18
T5A	SPI/2	42°20.37'N	70°57.63'W	18
T5A	SPI/3	42°20.35'N	70°57.59'W	18
T6	SPI/1	42°17.60'N	70°56.64'W	6
T6	SPI/2	42°17.60'N	70°56.63'W	6
T6	SPI/3	42°17.61'N	70°56.63'W	6
T7	SPI/1	42°17.36'N	70°58.71'W	7
T7	SPI/2	42°17.36'N	70°58.70'W	7
T7	SPI/3	42°17.35'N	70°58.70'W	7
T8	SPI/1	42°17.08'N	70°54.71'W	11
T8	SPI/2	42°17.12'N	70°54.74'W	11
T8	SPI/3	42°17.12'N	70°54.76'W	11
T8	SPI/4	42°17.12'N	70°54.76'W	11
R2	SPI/1	42°20.64'N	70°57.67'W	14
R2	SPI/2	42°20.65'N	70°57.69'W	14
R2	SPI/3	42°20.64'N	70°57.70'W	14
R3	SPI/1	42°21.19'N	70°58.37'W	5
R3	SPI/2	42°21.20'N	70°58.38'W	5
R3	SPI/3	42°21.20'N	70°58.38'W	5
R4	SPI/1	42°21.53'N	70°58.77'W	7
R4	SPI/2	42°21.54'N	70°58.79'W	7
R4	SPI/3	42°21.53'N	70°58.77'W	7

Station	Protocol/ Replicate	Latitude	Longitude	Depth (m)
R5	SPI/1	42°21.37'N	70°58.66'W	5
R5	SPI/2	42°21.36'N	70°58.67'W	5
R5	SPI/3	42°21.36'N	70°58.68'W	5
R6	SPI/1	42°19.88'N	70°57.11'W	5
R6	SPI/2	42°19.91'N	70°57.12'W	5
R6	SPI/3	42°19.92'N	70°57.13'W	5
R6	SPI/4	42°19.91'N	70°57.16'W	5
R7	SPI/1	42°20.84'N	70°58.53'W	6
R7	SPI/2	42°20.83'N	70°58.54'W	6
R7	SPI/3	42°20.84'N	70°58.56'W	6
R8	SPI/1	42°20.66'N	70°59.52'W	3
R8	SPI/2	42°20.67'N	70°59.53'W	3
R8	SPI/3	42°20.67'N	70°59.54'W	3
R9	SPI/1	42°20.79'N	71°00.95'W	11
R9	SPI/2	42°20.79'N	71°00.94'W	11
R9	SPI/3	42°20.79'N	71°00.94'W	11
R10	SPI/1	42°21.34'N	71°02.17'W	12
R10	SPI/2	42°21.32'N	71°02.19'W	12
R10	SPI/3	42°21.32'N	71°02.18'W	12
R11	SPI/1	42°19.26'N	70°58.50'W	6
R11	SPI/2	42°19.26'N	70°58.51'W	6
R11	SPI/3	42°19.27'N	70°58.51'W	6
R12	SPI/1	42°19.08'N	70°58.49'W	5
R12	SPI/2	42°19.09'N	70°58.47'W	5
R12	SPI/3	42°19.12'N	70°58.45'W	5
R13	SPI/1	42°19.04'N	70°58.83'W	5
R13	SPI/2	42°19.05'N	70°58.82'W	5
R13	SPI/3	42°19.06'N	70°58.82'W	5
R14	SPI/1	42°19.25'N	71°00.78'W	6
R14	SPI/2	42°19.27'N	71°00.79'W	6
R14	SPI/3	42°19.29'N	71°00.79'W	6
R15	SPI/1	42°18.91'N	71°01.15'W	2
R15	SPI/2	42°18.93'N	71°01.15'W	2
R15	SPI/3	42°18.96'N	71°01.16'W	2
R16	SPI/1	42°18.97'N	70°57.67'W	8
R16	SPI/2	42°18.95'N	70°57.68'W	8
R16	SPI/3	42°18.97'N	70°57.66'W	8

Station	Protocol/ Replicate	Latitude	Longitude	Depth (m)
R17	SPI/1	42°18.30'N	70°58.62'W	9
R17	SPI/2	42°18.29'N	70°58.62'W	9
R17	SPI/3	42°18.30'N	70°58.61'W	9
R18	SPI/1	42°17.33'N	70°57.65'W	9
R18	SPI/2	42°17.35'N	70°57.66'W	9
R18	SPI/3	42°17.37'N	70°57.67'W	9
R19	SPI/1	42°16.93'N	70°56.25'W	9
R19	SPI/2	42°16.94'N	70°56.24'W	9
R19	SPI/3	42°16.92'N	70°56.24'W	9
R20	SPI/1	42°19.49'N	70°56.11'W	12
R20	SPI/2	42°19.50'N	70°56.11'W	12
R20	SPI/3	42°19.50'N	70°56.10'W	12
R21	SPI/1	42°18.54'N	70°56.75'W	9
R21	SPI/2	42°18.56'N	70°56.73'W	9
R21	SPI/3	42°18.57'N	70°56.70'W	9
R22	SPI/1	42°18.02'N	70°56.39'W	10
R22	SPI/2	42°18.01'N	70°56.38'W	10
R22	SPI/3	42°18.01'N	70°56.37'W	10
R22	SPI/4	42°18.03'N	70°56.37'W	10
R23	SPI/1	42°17.60'N	70°56.99'W	11
R23	SPI/2	42°17.60'N	70°56.97'W	11
R23	SPI/3	42°17.63'N	70°57.01'W	11
R23	SPI/4	42°17.65'N	70°57.01'W	11
R24	SPI/1	42°17.76'N	70°57.50'W	8
R24	SPI/2	42°17.76'N	70°57.52'W	8
R24	SPI/3	42°17.77'N	70°57.51'W	8
R24	SPI/4	42°17.78'N	70°57.51'W	8
R25	SPI/1	42°17.48'N	70°55.72'W	10
R25	SPI/2	42°17.48'N	70°55.73'W	10
R25	SPI/3	42°17.48'N	70°55.73'W	10
R26	SPI/1	42°16.14'N	70°55.78'W	7
R26	SPI/2	42°16.14'N	70°55.78'W	7
R26	SPI/3	42°16.13'N	70°55.79'W	7
R27	SPI/1	42°16.84'N	70°55.01'W	6
R27	SPI/2	42°16.85'N	70°55.00'W	6
R27	SPI/3	42°16.82'N	70°54.97'W	6
R27	SPI/4	42°16.84'N	70°54.96'W	6

Station	Protocol/ Replicate	Latitude	Longitude	Depth (m)
R28	SPI/1	42°16.90'N	70°54.52'W	7
R28	SPI/2	42°16.90'N	70°54.52'W	8
R28	SPI/3	42°16.91'N	70°54.55'W	8
R29	SPI/1	42°17.39'N	70°55.28'W	11
R29	SPI/2	42°17.39'N	70°55.25'W	11
R29	SPI/3	42°17.39'N	70°55.24'W	11
R30	SPI/1	42°17.44'N	70°54.24'W	5
R30	SPI/2	42°17.43'N	70°54.23'W	5
R30	SPI/3	42°17.42'N	70°54.23'W	5
R31	SPI/1	42°18.04'N	70°55.00'W	10
R31	SPI/2	42°18.05'N	70°55.05'W	10
R31	SPI/3	42°18.05'N	70°55.06'W	10
R32	SPI/1	42°17.68'N	70°53.82'W	5
R32	SPI/2	42°17.70'N	70°53.83'W	5
R32	SPI/3	42°17.66'N	70°53.84'W	5
R33	SPI/1	42°17.64'N	70°59.69'W	5
R33	SPI/2	42°17.64'N	70°59.69'W	5
R33	SPI/3	42°17.65'N	70°59.66'W	5
R34	SPI/1	42°17.33'N	71°00.42'W	4
R34	SPI/2	42°17.34'N	71°00.41'W	5
R34	SPI/3	42°17.35'N	71°00.40'W	5
R35	SPI/1	42°17.03'N	70°59.25'W	6
R35	SPI/2	42°17.05'N	70°59.29'W	6
R35	SPI/3	42°17.05'N	70°59.29'W	6
R36	SPI/1	42°16.52'N	70°59.21'W	5
R36	SPI/2	42°16.52'N	70°59.20'W	5
R36	SPI/3	42°16.52'N	70°59.21'W	5
R37	SPI/1	42°17.92'N	70°59.08'W	6
R37	SPI/2	42°17.92'N	70°59.08'W	6
R37	SPI/3	42°17.96'N	70°59.04'W	6
R38	SPI/1	42°17.08'N	70°57.84'W	7
R38	SPI/2	42°17.08'N	70°57.83'W	7
R38	SPI/3	42°17.07'N	70°57.83'W	7
R39	SPI/1	42°17.74'N	70°58.21'W	8
R39	SPI/2	42°17.74'N	70°58.21'W	8
R39	SPI/3	42°17.75'N	70°58.21'W	8
R40	SPI/1	42°19.71'N	71°01.44'W	2

Station	Protocol/ Replicate	Latitude	Longitude	Depth (m)
R40	SPI/2	42°19.72'N	71°01.46'W	2
R40	SPI/3	42°19.72'N	71°01.46'W	2
R41	SPI/1	42°18.67'N	71°01.52'W	4
R41	SPI/2	42°18.67'N	71°01.52'W	4
R41	SPI/3	42°18.68'N	71°01.52'W	4
R42	SPI/1	42°19.20'N	71°01.50'W	2
R42	SPI/2	42°19.20'N	71°01.49'W	2
R42	SPI/3	42°19.19'N	71°01.49'W	2
R42	SPI/4	42°19.21'N	71°01.49'W	2
R43	SPI/1	42°18.40'N	71°00.12'W	3
R43	SPI/2	42°18.41'N	71°00.12'W	3
R43	SPI/3	42°18.40'N	71°00.14'W	3

Table C-2. Summary of SPI parameters by station for the August 1994 survey of the Boston Harbor area. Data from all three replicates were averaged for quantitative parameters and summed for the qualitative parameters (for example, the presence of infauna in one of the three replicates results in a + for the station).

					Epifauna and Surface Features				Subsurface Features				
Station	RPD (cm)	Prism Penetration (cm)	Surface Relief (cm)	Sediment Type	Amphipods	Polychaetes	Pellet Layer	Clast	Burrows	Infauna	Voids	Successional Stage	Range for OSI
T1	0.5	3.1	2.7	FS/SH/GR?	-	-	-	-	NA	NA	NA	II	4
T2	1.7	14.4	0.9	SI/FS	MAT	-	-	-	+	+	A	II	5–6
T3	1.4	10.0	1.6	SI	MAT	-	-	-	-	-	-	II	5–6
T4	0.8	>22.8	0.9	SI	-	-	-	-	-	-	G	0?	-6–2
T5a	>1.6	1.6	0.8	FS	-	-	-	-	-	-	-	IND	IND
T6	1.2	6.6	1.2	SI/FS	MAT	-	-	-	-	-	-	I/II–II	4–6
T7	0.9	9.1	1.0	SI/FS/SH	-	-	-	-	+	-	-	I/II	3–4
T8	1.1	3.2	1.5	FS/MS/ST	+	-	-	-	+	-	-	I–II	2–7
R2	1.6	14.1	0.9	SI	MAT	-	-	-	+	+	A	II	5–6
R3	1.9	15.1	1.2	SI/FS	MAT	-	-	-	+	+	O	II–III	6–8
R4	1.0	12.0	1.2	SI/FS	MAT	-	-	-	-	+	A	I/II–II	3–5
R5	2.1	11.1	1.2	SI/FS	MAT	-	-	-	+	+	A, O	II	5–7
R6	1.1	1.1	1.0	MS/ST/SH	+	+	-	-	NA	NA	NA	I/II	4
R7	1.8	14.6	1.6	SI/FS	MAT	-	-	-	+	+	A	II	6
R8	>1.4	0.9	0.7	FS	-	-	-	-	NA′	NA	NA	IND	IND
R9	1.3	10.3	1.4	SI	MAT	-	-	-	-	+	-	II	5
R10	1.8	19.0	1.4	SI	-	-	-	-	-	-	G	I?	2–4
R11	4.1	20.0	1.6	SI	MAT	-	-	-	-	-	-	II	9
R12	6.4	20.1	0.9	SI	MAT	-	-	-	+	+	O	II/III	10
R13	5.5	13.1	2.2	SI/FS	MAT	-	-	-	+	+	A	II/III	10
R14	1.2	6.4	1.9	SI/FS	MAT	MAT	-	-	-	-	-	II	4–6
R15	0.6	7.1	1.7	SI/SH	-	+	-	-	-	-	O	I–I/II	1–4
R16	1.0	7.8	2.2	SI/SH	+	MAT	-	-	-	-	-	I–II	2–3
R17	2.1	19.6	1.0	SI	MAT	MAT	-	-	+	+	-	I–II	4–6
R18	1.6	13.5	1.3	SI/FS	MAT	-	-	-	+	+	-	II	5–6
R19	0.7	5.2	1.7	MS/SI/SH	+	MAT	-	-	+	+	-	I/II–II	3–5
R20	1.5	11.6	1.3	FS/SI	MAT	+	--	-	+	+	-	II	5–6
R21	3.4	9.0	2.2	SI/FS	MAT	+	-	-	+	-	O	II	8
R22	1.6	6.0	1.1	FS	MAT	-	-	-	+	+	-	II	4–7
R23	>2.4	4.7	2.0	FS	MAT	+	-	-	-	-	-	II	6–7
R24	1.3	3.7	0.9	FS	MAT	+	-	-	-	-	-	II	5
R25	0.8	14.2	1.2	SI/FS	MAT	+	-	-	+	+	A	II–III	4–5
R26	2.9	11.6	1.0	SI/FS	-	MAT	-	-	+	-	O	III	9–10
R27	2.0	5.5	1.4	SI/FS	MAT	-	-	-	+	-	-	II–III	6–9
R28	3.4	8.5	1.4	SI/FS	MAT	+	-	-	+	+	O	III	10
R29	3.3	10.3	1.0	SI/FS	MAT	-	-	-	+	-	O	II–III	7–11
R30	3.1	7.6	2.3	SI/FS	MAT	+	-	-	+	+	O	II	7–8
R31	1.6	10.4	1.7	SI/FS	MAT	+	-	-	+	+	O	III	8
R32	2.1	11.6	1.5	SI/FS	MAT	-	-	-	+	+	O	II	5–7
R33	0.6	8.8	2.2	SI/FS	-	+	-	+	+	-	A	0–I	-3–3
R34	0.7	9.9	1.1	SI/FS	-	+	-	-	+	-	-	0–I?	-3–3
R35	0.6	9.6	1.6	SI/FS	-	-	-	+	-	-	A	0–I?	-3–3
R36		0		SA?	-	-	-	-	NA	NA	NA	IND	IND
R37	0.7	7.7	1.1	SI/FS/SH	-	+	-	-	+	+	A, O	II	4–5
R38	1.0	11.7	1.2	SI/FS	MAT	-	-	+	-	-	A	II	4–5
R39	2.5	14.9	0.9	SI/FS	MAT	+	-	-	+	+	A, O	III	8–9
R40	>1.6	2.8	0.8	FS	-	+	-	-	-	-	-	I	4
R41	1.8	9.5	2.1	SI/FS	MAT	+	-	-	+	+	A	I/II–II	3–7
R42	>1.7	4.0	2.0	FS/SH	-	-	-	-	+	-	-	IND	IND
R43	0.9	14.2	1.8	SI	-	+	-	-	+	-	-	I	2–3

[a] Prism penetration too shallow to accurately see these features.
[b] At least one of the three station replicates had an RPD layer deeper than the prism penetration.
+: present; - absent
Sediment Type: FS—Fine sand; MS—Medium sand; SI—Silt; ST—Stone; GR—Gravel; SH—Shell
MAT: Tube mat.
Voids: Water or gas filled inclusions in sediment, A—Anoxic, G—Gas, O—Oxic

Table C-3. Cross classification of August 1994 SPI parameters by sediment type.

Parameter (n)	Silt (11)	Silt/Fine Sand (27)	Fine Sand (8)	Medium Sand (4)	Total (50)
Penetration (cm)[a]	>15.0±5.6	10.7±2.7	3.4±1.6	2.4±2.3	
RPD (cm)[a]	2.0±1.7	1.9±1.1	>1.5±0.5	>1.0±0.2[c]	
Surface Relief (cm)[a]	1.4±0.4	1.4±0.4	1.4±0.8	1.4±0.4[c]	
OSI[b]	−6 to 10, 5	−3 to 11, 6	4 to 7, 5	2 to 7, 4[c]	
Ampelisca[d]					
Tube Mat	6	21	3	0	30
Present	1	0	0	3	4
Absent	4	6	5	1	16
Worm Tubes[d]					
Tube Mat	2	2	0	0	5
Present	2	13	4	2	21
Absent	7	12	4	1	24
Pelletal Layer Present[d]	0	0	0	0	0
Burrows[d]					
Present	4	22	2	2	30
Absent	7	5	4	0	16
Indeterminate	0	0	2	2	4
Infauna[d]					
Present	4	16	1	1	22
Absent	7	11	5	1	24
Indeterminate	0	0	2	2	4
Voids[e]					
Oxic	2	11	0	0	13
Anoxic	1	12	0	0	13
Gas	2	0	0	0	2
Absent	6	7	6	2	21
Indeterminate	0	0	2	2	4
Successional Stage[d]					
0	1	0	0	0	1
0–I	0	3	0	0	3
I	2	0	1	0	3
I–II	3	4	0	3	10
II	4	11	4	0	19
II–III	1	5	0	0	6
III	0	4	0	0	4
Indeterminate	0	0	3	1	4

[a] Mean±standard error.
[b] Range, median.
[c] $n = 3$.
[d] Number of occurrences.
[e] Number of occurrences; total may exceed number of stations when more than one type of void present.

Appendix D
1994 Sampling Results — CSO:Biology Comparison

Summary of 1994 Field and Analytical Activities: CSO-Infaunal Comparisons

During the August 1994 survey, 14 stations (Table D-1) in Boston Harbor were sampled for full chemical analysis as part of the CSO studies program. Full details on the sampling methods can be found in Campbell (1994). The chemical analytical methods and results are presented in Durell (1995). Because three of the stations sampled under the CSO priogram were traditional stations sampled for infaunal analysis (T-1, T-2, and T-8) and a fourth (DB14) was very near a traditional station (T-4), a simple Pearson correlation analysis (Sokal and Rohlf, 1981) was run comparing selected biological and chemical parameters. Quantitative infaunal and chemical data were log-transformed (n+1) and percent data were arc-sine transformed prior to the analysis. The spreadsheet program Quattro® Pro for Windows, version 5.0 (Borland, 1993) was used to perform the calculations.

Results

The results of the analysis are presented in Table C-2. A strong word of caution is required. The sample size for this analysis was very small (n = 4), therefore any statistically significant relationships between chemical and biological parameters should be viewed with caution. Interpretations that try to explain cause:effect are not feasible, especially in light of a recent review emphasizing that a correlative relationship between bulk sedimentary features and infauna may reflect the response of each to the same factor, e.g., bottom boundary layer current flow (Snelgrove and Butman, 1994). We further note that there were strong intercorrelations among many of the abiotic parameters at the four stations compared (Table C-3). No normalizations to correct for these intercorrelations were performed. Given these caveats, we also note that the three ecological indices (diversity, evenness, and dominance) did show statistically significant correlation with several environmental measures. Few other statistically significant correlations were detected.

References

Campbell, J.F. 1994. Boston Harbor Traditional Survey S9402 Report forSoft-Bottom Benthic Monitoring: 1993–1994. Report to Massachusetts Water Resources Authority, Boston, MA. 21 pp.

Durell, G. 1995. Concentrations of contaminants in Dorchester Bay and Boston Harbor sediments collected in the vicinity of CSO discharges and comparison to 1990 concentrations. MWRA Environmental Quality Technical Report Series No. 95-14. Massachusetts Water Resources Authority, Boston, MA. 128 pp.

Other references cited above are listed in the main text section.

Table D-1. Summary of Benthic Grab Sample Collections for the Boston Harbor CSO Survey S9402.

Station	Protocol/ Replicate	Latitude	Longitude	Depth (m)
T1	CSO/CHE/1	42°20.96'N	70°57.79'W	7
T1	CSO/CHE/2	42°20.95'N	70°57.78'W	7
T1	CSO/CHE/3	42°20.94'N	70°57.81'W	7
T2	CSO/CHE/1	42°20.56'N	71°00.10'W	6
T2	CSO/CHE/2	42°20.57'N	71°00.12'W	6
T2	CSO/CHE/3	42°20.57'N	71°00.12'W	6
T8	CSO/CHE/1	42°17.11'N	70°54.74'W	10
T8	CSO/CHE/2	42°17.12'N	70°54.75'W	10
T8	CSO/CHE/3	42°17.13'N	70°54.72'W	11
SWEX 3	CSO/CHE/1	42°19.73'N	70°59.57'W	8
SWEX 3	CSO/CHE/2	42°19.74'N	70°59.55'W	8
SWEX 3	CSO/CHE/3	42°19.76'N	70°59.53'W	8
C019	CSO/CHE/1	42°21.55'N	71°02.68'W	12
C019	CSO/CHE/2	42°21.55'N	71°02.73'W	9
C019	CSO/CHE/3	42°21.55'N	71°02.71'W	9
DB01	CSO/CHE/1	42°19.48'N	71°02.75'W	3
DB01	CSO/CHE/2	42°19.47'N	71°02.76'W	3
DB01	CSO/CHE/3	42°19.47'N	71°02.76'W	3
DB03	CSO/CHE/1	42°19.30'N	71°00.87'W	5
DB03	CSO/CHE/2	42°19.31'N	71°00.85'W	5
DB03	CSO/CHE/3	42°19.32'N	71°00.87'W	5
DB04	CSO/CHE/1	42°19.68'N	71°02.23'W	4
DB04	CSO/CHE/2	42°19.68'N	71°02.22'W	4
DB04	CSO/CHE/3	42°19.68'N	71°02.23'W	4
DB06	CSO/CHE/1	42°19.40'N	71°02.24'W	2
DB06	CSO/CHE/2	42°19.41'N	71°02.23'W	2
DB06	CSO/CHE/3	42°19.41'N	71°02.24'W	2
DB10	CSO/CHE/1	42°17.49'N	71°02.33'W	2
DB10	CSO/CHE/2	42°17.51'N	71°02.34'W	2

Station	Protocol/ Replicate	Latitude	Longitude	Depth (m)
DB10	CSO/CHE/3	42°17.50'N	71°02.32'W	2
DB11	CSO/CHE/1	42°17.32'N	71°02.05'W	2
DB11	CSO/CHE/2	42°17.30'N	71°02.07'W	2
DB11	CSO/CHE/3	42°17.32'N	71°02.06'W	2
DB12	CSO/CHE/1	42°18.97'N	71°01.28'W	5
DB12	CSO/CHE/2	42°18.97'N	71°01.29'W	5
DB12	CSO/CHE/3	42°18.96'N	71°01.28'W	5
DB13	CSO/CHE/1	42°18.58'N	71°02.49'W	4
DB13	CSO/CHE/2	42°18.56'N	71°02.50'W	4
DB13	CSO/CHE/3	42°18.58'N	71°02.51'W	3
DB14	CSO/CHE/1	42°17.93'N	71°02.73'W	2
DB14	CSO/CHE/2	42°17.91'N	71°02.73'W	2
DB14	CSO/CHE/3	42°17.92'N	71°02.74'W	2

Table D-2. Pearson correlation coefficients between selected abiotic or chemical parameters and infaunal parameters at four Boston Harbor stations, August 1994. Critical value = 0.950 ($n = 4, p = 0.05$; from Rohlf and Sokal, 1969).

	Mud %	TOC (mg)	TPAH	Dieldrin	TPCB	TDDT	2,4-DD	Coprost	LAB	Ag	Al %	Cd	Cr	Cu	Fe %	Hg	Ni	Pb	Zn
Abundance																			
Total	-0.434	-0.578	-0.442	-0.516	-0.368	-0.401	-0.500	0.182	-0.117	-0.242	-0.088	-0.537	-0.263	-0.256	-0.341	-0.520	-0.324	-0.375	-0.393
Annelid	0.019	-0.128	0.019	-0.168	0.037	0.036	-0.123	0.545	0.107	0.071	0.438	-0.189	0.116	0.096	0.151	-0.162	0.125	-0.061	-0.035
Arthropod	-0.687	-0.792	-0.702	-0.645	-0.591	-0.646	-0.662	-0.157	-0.233	-0.408	-0.519	-0.659	-0.489	-0.456	-0.660	-0.657	-0.603	-0.506	-0.562
Mollusc	-0.863	-0.879	-0.876	-0.723	-0.783	-0.834	-0.764	-0.606	-0.462	-0.622	-0.896	-0.724	-0.726	-0.683	-0.902	-0.737	-0.840	-0.647	-0.717
Species																			
Total	-0.930	-0.976	-0.932	-0.948	-0.902	-0.918	-0.951	-0.537	-0.702	-0.814	-0.689	-0.955	-0.845	-0.834	-0.878	-0.952	-0.881	-0.879	-0.903
Annelid	-0.857	-0.916	-0.855	-0.931	-0.845	-0.849	-0.919	-0.431	-0.697	-0.786	-0.534	-0.939	-0.790	-0.791	-0.775	-0.931	-0.799	-0.865	-0.870
Arthropod	-0.953	-0.986	-0.959	-0.907	-0.904	-0.934	-0.926	-0.605	-0.650	-0.785	-0.814	-0.912	-0.847	-0.823	-0.936	-0.916	-0.914	-0.835	-0.878
Mollusc	-0.900	-0.891	-0.910	-0.758	-0.837	-0.879	-0.800	-0.722	-0.560	-0.702	-0.954	-0.756	-0.797	-0.758	-0.945	-0.771	-0.893	-0.708	-0.772
H'	-0.934	-0.964	-0.932	-0.982	-0.931	-0.932	-0.977	-0.594	-0.800	-0.882	-0.666	-0.986	-0.891	-0.890	-0.871	-0.983	-0.896	-0.938	-0.947
J'	-0.958	-0.972	-0.954	-0.995	-0.960	-0.958	-0.992	-0.664	-0.843	-0.919	-0.716	-0.997	-0.929	-0.927	-0.902	-0.995	-0.929	-0.963	-0.972
D	0.900	0.937	0.896	0.971	0.903	0.899	0.960	0.542	0.789	0.864	0.598	0.976	0.862	0.865	0.824	0.970	0.857	0.926	0.928
Oligochaeta	-0.744	-0.817	-0.740	-0.866	-0.745	-0.740	-0.841	-0.292	-0.641	-0.709	-0.357	-0.876	-0.689	-0.700	-0.637	-0.863	-0.677	-0.800	-0.790
P. cornuta	0.335	0.227	0.344	0.098	0.301	0.332	0.159	0.654	0.189	0.241	0.732	0.082	0.336	0.295	0.473	0.111	0.411	0.143	0.204
P. mucosa	-0.837	-0.917	-0.844	-0.836	-0.776	-0.810	-0.843	-0.350	-0.498	-0.642	-0.605	-0.848	-0.694	-0.674	-0.789	-0.844	-0.766	-0.730	-0.767
S. benedicti	0.753	0.665	0.758	0.573	0.729	0.752	0.623	0.891	0.588	0.664	0.969	0.561	0.746	0.712	0.842	0.585	0.805	0.601	0.654
A. catherinae	-0.976	-0.931	-0.971	-0.956	-0.995	-0.987	-0.967	-0.894	-0.928	-0.980	-0.877	-0.949	-0.999	-0.993	-0.965	-0.957	-0.991	-0.972	-0.985
M. aberrans	0.469	0.356	0.475	0.251	0.447	0.470	0.308	0.770	0.349	0.398	0.819	0.234	0.484	0.447	0.594	0.263	0.545	0.302	0.358
Ampelisca	-0.837	-0.917	-0.843	-0.854	-0.785	-0.814	-0.857	-0.349	-0.528	-0.663	-0.580	-0.865	-0.706	-0.690	-0.780	-0.860	-0.766	-0.752	-0.783
L. pinguis	-0.781	-0.870	-0.784	-0.844	-0.744	-0.762	-0.835	-0.271	-0.532	-0.647	-0.457	-0.857	-0.667	-0.661	-0.700	-0.847	-0.704	-0.746	-0.762
C. bonellii	-0.885	-0.951	-0.890	-0.896	-0.840	-0.865	-0.900	-0.437	-0.598	-0.728	-0.644	-0.905	-0.769	-0.754	-0.834	-0.901	-0.824	-0.806	-0.837
U. irrorata	-0.797	-0.885	-0.801	-0.844	-0.753	-0.776	-0.839	-0.288	-0.522	-0.645	-0.495	-0.856	-0.674	-0.664	-0.724	-0.848	-0.720	-0.742	-0.764
I. trivittata	-0.979	-0.994	-0.978	-0.984	-0.966	-0.974	-0.989	-0.681	-0.806	-0.901	-0.779	-0.986	-0.929	-0.919	-0.939	-0.987	-0.950	-0.943	-0.963
T. agilis	-0.901	-0.849	-0.906	-0.758	-0.868	-0.894	-0.800	-0.872	-0.677	-0.780	-0.999	-0.751	-0.860	-0.827	-0.957	-0.769	-0.924	-0.753	-0.806

Table D-3. Pearson correlation coefficients between selected abiotic and chemical parameters at four Boston Harbor stations, August 1994. Critical value = 0.950 ($n = 4, p = 0.05$; from Rohlf and Sokal, 1969).

	Mud %	TOC (mg)	TPAH	Dieldrin	TPCB	TDDT	2,4-DDT	Coprost	LAB	Ag	Al %	Cd	Cr	Cu	Fe %	Hg	Ni	Pb
TOC	0.986																	
TPAH	1.000	0.987																
Dield	0.964	0.962	0.959															
TPCB	0.989	0.960	0.985	0.978														
TDDT	0.998	0.977	0.996	0.970	0.996													
2,4-DDT	0.980	0.975	0.976	0.998	0.987	0.984												
Coprost	0.805	0.693	0.797	0.728	0.845	0.828	0.752											
LAB	0.837	0.767	0.823	0.892	0.908	0.868	0.883	0.867										
Ag	0.928	0.876	0.918	0.954	0.973	0.949	0.954	0.874	0.981									
Al%	0.887	0.828	0.891	0.741	0.857	0.881	0.783	0.886	0.679	0.776								
Cd	0.962	0.964	0.957	1.000	0.974	0.967	0.997	0.712	0.882	0.947	0.732							
Cr	0.967	0.919	0.961	0.959	0.993	0.980	0.967	0.893	0.945	0.989	0.854	0.952						
Cu	0.953	0.903	0.945	0.960	0.987	0.969	0.964	0.887	0.963	0.997	0.822	0.953	0.998					
Fe%	0.988	0.961	0.990	0.914	0.969	0.984	0.939	0.845	0.798	0.896	0.947	0.910	0.951	0.929				
Hg	0.969	0.968	0.964	1.000	0.980	0.974	0.999	0.729	0.886	0.952	0.751	1.000	0.959	0.959	0.921			
Ni	0.993	0.959	0.991	0.948	0.992	0.996	0.965	0.870	0.870	0.947	0.915	0.943	0.983	0.970	0.991	0.952		
Pb	0.943	0.915	0.935	0.985	0.979	0.959	0.981	0.804	0.956	0.990	0.742	0.981	0.980	0.987	0.897	0.983	0.945	
Zn	0.971	0.945	0.964	0.990	0.993	0.982	0.992	0.816	0.934	0.984	0.795	0.986	0.989	0.990	0.935	0.990	0.971	0.995

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