1993 Annual Soft-Bottom Benthic Monitoring Report:

Boston Harbor Studies

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1993 ANNUAL SOFT-BOTTOM BENTHIC MONITORING REPORT: BOSTON HARBOR STUDIES

by

Roy K. Kropp
Battelle Ocean Sciences
397 Washington Street
Duxbury, MA 02332

and
Robert J. Diaz
R.J. Diaz & Daughters
6198 Driftwood Lane
Ware Neck, VA 23178

prepared for:

Massachusetts Water Resources Authority
Charlestown Navy Yard
100 First Avenue
Boston, MA 02129
(617) 242-6000

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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. A primary purpose 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 results of the 1993 field sampling efforts. Data from all surveys conducted under the program were examined for changes in biological and physical parameters that may indicate recovery of the Harbor benthos from sludge discharge activities. Several other topics, tangential to the 1993 study (e.g., a comparison of two methods of estimating the apparent redox potential discontinuity depth), also were evaluated.

In April and August 1993, a 0.04 m^2 modified van Veen grab sampler was used to collect three samples for infaunal analysis and one sample for ancillary physicochemical analyses from each of eight traditional stations. These traditional infaunal samples were rinsed in the field over nested 0.3- and 0.5-mm-mesh sieves. In August, traditional infaunal sampling was supplemented with the collection of a single grab sample from 24 reconnaissance stations. These reconnaissance infaunal samples were rinsed in the field over a 0.5-mm-mesh sieve. Also in August, sediment profile images were obtained at the 6 of the traditional stations and at 42 reconnaissance stations.

Traditional samples were sorted in the laboratory to remove all infaunal organisms. These organisms were identified to the lowest practical taxonomic level (usually species) and counted. Reconnaissance samples were subsampled and sorted for a finite amount of time (1 h total/sample) to remove all infaunal organisms. These organisms were identified and counted. 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.

1993 Results

In 1993, sediment grain size ranged from predominantly sand at stations T-1 (Deer Island flats), T-5a (SW tip of Deer Island), and T-8 (Hull Bay) to primarily silt + clay at station T-4 (Dorchester Bay). Sediment TOC was generally low (~1%) at sandy stations and high (>3%) at stations having a high percentage of fine material (silt + clay). *Clostridium perfringens* spore counts ranged from ~1,200 to ~20,000 spores/g dry weight and were slightly higher in August than in April.

The average apparent RPD depth ranged from <1.0 cm to >8.0 cm as estimated by visual examination of cores taken from grab samples in April and August or by analysis of sediment profile images taken in August. The deepest values, found primarily in the central and southern Harbor, were associated with *Ampelisca* tube mats in fine sand and silty fine-sand sediments.

In April, infaunal abundances in the Harbor showed two basic patterns. At stations T-3 (North tip of Long Island), T-6 (North side of Peddocks Island), and T-8, mean abundances were relatively high, ~3000 individuals/0.04 m^2, whereas abundances at the remaining stations were relatively low, usually <1000 individuals/0.04 m^2. By August, mean abundance increased at all stations, except at stations T-4 and T-5a, including dramatic increases at stations T-3 and T-6 where densities reached 13,932 and 15,725 individuals/0.04 m^2, respectively.

Species numbers were low at station T-4 (~10), but ranged up to ~50 elsewhere (station T-8, August). Species diversity (*H'*) was lowest at station T-4 (≤1.0) but, ranged from ~2.0 to ~3.7 at the remaining stations.

In April, the most common taxa in the northern part of the Harbor (stations T-1, T-2, and T-5a), in Dorchester Bay (station T-4), and in Quincy Bay (station T-7) were annelid worms, such as *Streblospio benedicti, Tharyx acutus,* and *Tubificoides* nr. *pseudogaster*. Amphipods were most common at stations T-3, T-6, and T-8. Most noticeable in August was the appearance, in parts of the Harbor, of the polychaete *Polydora cornuta* as the predominant taxon (stations T-1, T-2, and T-3) or the third-ranked species (stations T-6 and T-7). Analysis of grab samples collected at reconnaissance stations in August showed that *Polydora cornuta* was the predominant species in much of the northern Harbor, whereas the amphipod *Ampelisca* was the predominant species in much of the southern Harbor.

Comparisons of 1991–1993 Data

Sediment grain size composition at individuals stations, with few exceptions, was consistent during the study period. Sedimentary TOC also was consistent over all surveys. *Clostridium perfringens* spore counts were lower at all stations in August 1992 than in September 1991, but then increased slightly at some stations by August 1993. At all stations, the August 1993 counts were less than those obtained for September 1991. For example, spore counts at station T-3, near the former sludge outfall, dropped from 207,000 spores/g dry weight in 1991 to 20,200 spores/g dry weight in August 1993.

Statistically significant differences in the mean total infaunal abundance across surveys at each station tested were found. At all stations except station T-7, the August 1993 and/or the August 1992 values were higher than those from all other surveys. Furthermore, total infaunal abundance in August 1993 was significantly greater than that in September 1991 at all stations except station T-7. August 1993 total infaunal abundance was greater than that found in August 1992 at stations T-3 and T-6, but was significantly less at station T-4. Seasonal differences in patterns of infaunal abundance were apparent at each station, except station T-4. In 1992 and 1993, abundance was greater in the late summer than in the spring.

Each station tested showed significant among-survey variation in the mean number of species per sample. In general, the mean number of species per sample increased between the September 1991 and August 1993 surveys. Comparisons between spring and late summer revealed significant differences in number of species at all stations tested, except stations T-3 and T-6. The number of species was higher in the late summer than in the spring at all stations except station T-4.

Significant among-survey variation in species diversity (H') was found for five of the seven stations tested. No significant differences in H' among surveys were found at stations T-7 and T-8. Species diversity in August 1993 (the most recent survey) was significantly greater than that in September 1991 (the pre-abatement survey) at only stations T-2 and T-6. Late summer values were lower than spring values at stations T-1, T-3, T-4, and T-6, but were higher at station T-2.

Changes in the relative abundance of several key taxa during the study period were observed. Oligochaete worms declined in abundance relative to other taxa at all stations. In 1991, oligochaetes were among the most common taxa at many stations in the Harbor but, by 1993, were among the most common taxa only at a few stations. *Ampelisca,* an amphipod that was not identified to species, increased in predominance and abundance during the study. The abundance of *Ampelisca* at station T-6 increased from ~600 individuals/0.04 m^2 in 1991 to ~2,500 individuals/0.04 m^2 in August 1992 and to ~5,200 individuals/0.04 m^2 in August 1993.

Periodically, several other taxa were predominant at various stations. Among the most striking examples were the polychaete *Polydora cornuta* and the amphipod *Corophium bonellii*. *P. cornuta* was common only during late summer and was the predominant taxon in the northern Harbor in August 1993. *Corophium bonellii,* which first appeared in April 1992, increased in abundance dramatically at stations T-3 and T-6 during the study, reaching densities of ~1300 individuals/0.04 m^2 at station T-3 and ~3900 individuals/0.04 m^2 at station T-6. Relatively large amphipods, *Leptocheirus pinguis* and *Unciola irrorata,* also increased in abundance at stations T-3 and T-6. *Phyllodoce mucosa,* a polychaete that was uncommon in 1991, increased in abundance and geographic coverage by August 1993. *Aricidea catherinae*, a polychaete, was consistently common in the southern Harbor, but was not yet a major part of the northern Harbor fauna.

Classification based on NESS similarity analysis conducted on all stations (with replicates pooled) for all surveys revealed three major, relatively dissimilar, groups of stations.

The first group consisted of station T-4 collections from all three late summer surveys. The second cluster contained all station T-6 and station T-8 collections, as well as the station T-3 samples collected after April 1992. The third group consisted of the April station T-4 samples, the station T-3 samples collected before August 1992, all station T-7 samples, and all stations in the northern Harbor (including the station T-5, R-6, T-5a complex). This pattern of station clusters generally showed consistent linkage of stations from year to year. The notable exception to this consistency was the placement of samples from station T-3. Collections made at station T-3 during September 1991 and April 1992 were linked to stations located primarily in the northern region of the Harbor. However, samples from station T-3 collected after April 1992 clustered with stations located toward the southern region of the Harbor (station T-6 and T-8).

Data collected during the study period indicated that infaunal communities in Boston Harbor have changed considerably since the cessation of sludge discharge in late 1991. Because many of the changes are in the direction that would be predicted by the Pearson-Rosenberg model of organic enrichment, it is tempting, to attribute these changes to the process of recovery from the impacts of sludge disposal. However, many of the observed changes may be part of cycles (e.g., shifts in *Polydora cornuta* and amphipod densities) previously documented in the Harbor (although much exaggerated since 1991) or part of a response to natural disturbance. One natural event that may complicate interpretation of the Boston Harbor data are the severe storms that occurred in late October 1991 and in mid-December 1992. If the apparent recovery of the infaunal community was a result of reduced pollution, then further infaunal recovery (as predicted by Pearson-Rosenberg) or possibly no community change might be expected. However, if the changes in the infaunal community were caused by a natural phenomenon (e.g., the severe storms), then the community would be expected to gradually regress to the state found during polluted conditions. Continued monitoring of the Harbor should provide data to permit separation of these possible causes of community change.

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 a point off 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 diversion of treated-effluent discharge from the Harbor to deeper waters in Massachusetts Bay.

This report is the third 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 two years after abatement (Kelly and Kropp, 1992; Blake *et al.*, 1993). 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 first objective of this report is to summarize the results of the 1993 field sampling efforts. In particular, spatial patterns of large-scale biological parameters (e.g., abundance and numbers of species of major taxa), overall infaunal similarity among stations, and the distribution of certain taxa are explored. Also, several other tangential topics (e.g., a comparison two methods of estimating the apparent redox potential discontinuity depth) are included. The second objective of this report is to examine data from all surveys conducted under the program for changes in biological and physical parameters that may be related to recovery of the Harbor benthos from sludge discharge activities. Included in the latter objective are statistical and/or qualitative comparisons of large-scale biological parameters and species distributions from 1991 to 1993.

METHODS

A. Summary of 1993 Field and Laboratory Activities

The April 19-21, 1993 and August 8-13, 1993 field sampling programs are summarized in Campbell (1993 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

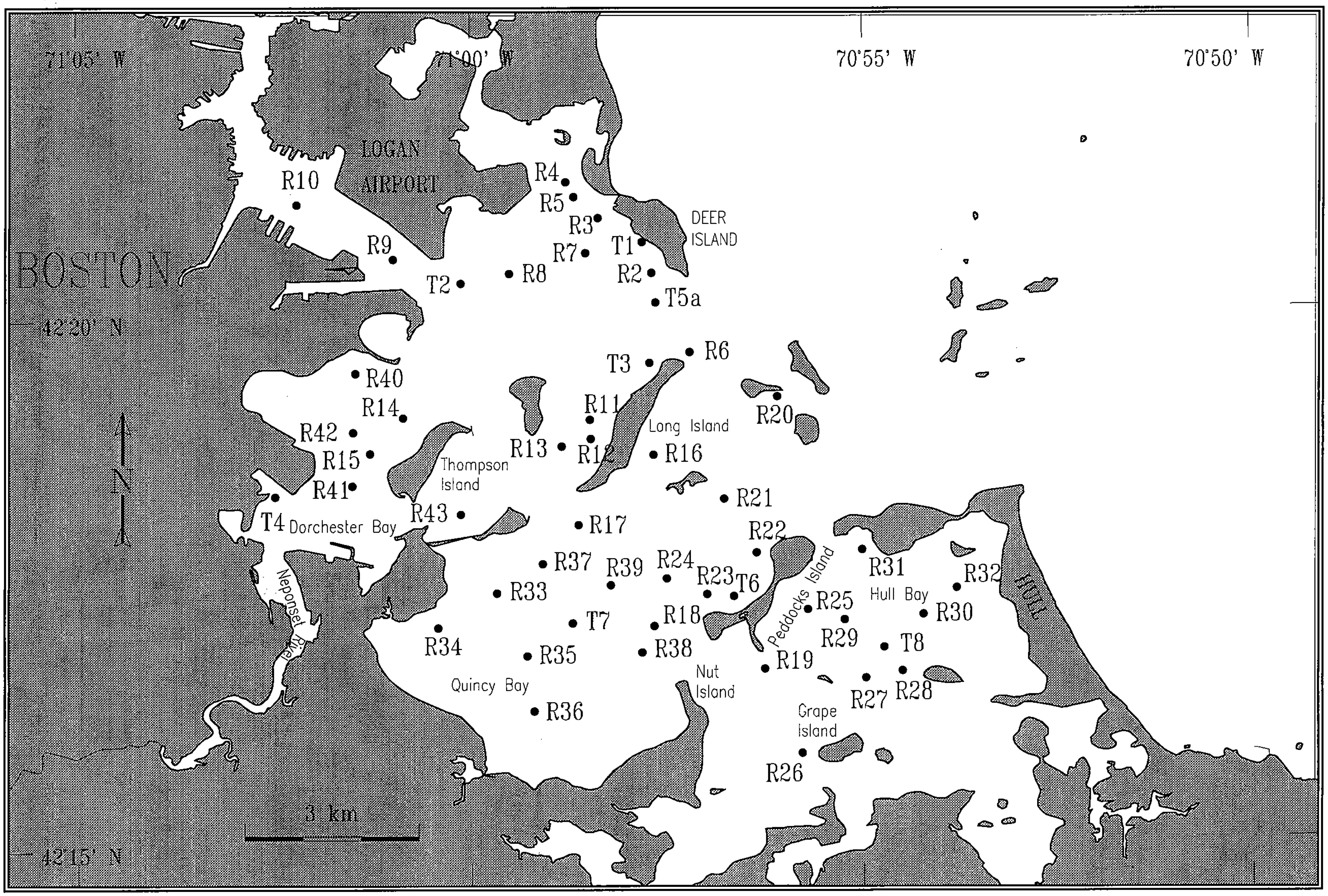


Figure 1. **Traditional and reconnaissance stations sampled in Boston Harbor in 1993.**

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.

During the August survey, a Hulcher Model Minnie sediment profile camera was used to obtain four sediment profile images (SPI) at each traditional and reconnaissance station. 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 48 of the 50 stations. At two stations (T-2 and T-5a), the magnetic switch that turns on the strobe failed. However, ambient light at station T-2 allowed for measurement of several parameters. Laboratory processing of all biological samples, ancillary physicochemical samples, and SPI proceeded as presented in the CW/QAPP (Kropp *et al.*, 1993).

B. Summary of 1991–1992 Field and Laboratory Activities

In general, field and laboratory activities conducted in 1991–1992 were comparable to those conducted in 1993 (see Kelly and Kropp, 1992; Blake *et al.*, 1992; and Blake *et al.*, 1993). 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

Table 1. **Summary of Boston Harbor stations for which data were used for among-survey comparisons, 1991–1993. Boxes denote data used for among-survey comparisons.**

	Survey									
	Sep 91		Apr 92		Aug 92		Apr 93		Aug 93	
	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	
INFAUNA										
0.3-mm sieve	8	0	8	—	8	—	8	—	8	0
0.5-mm sieve	8	24	8	—	8	—	8	—	8	24
Total Sample	8	24	8		8		8		8	24
SEDIMENT MEASURES										
Grain Size	8	24	0	—	8	—	8	—	8	0
TOC	8	24	0	—	8	—	8	—	8	0
Clostridium perfringens	8	24	0	—	8	—	8	—	8	0
Apparent RPD	nd	nd	nd	—	nd	—	24	—	24	24
SEDIMENT PROFILES										
Image Data										
Apparent RPD	3[a]	3[a]	—	—	8[b]	57[b]	—	—	6	40
Sediment Type	4[a]	4[a]	—	—	8[b]	61[b]	—	—	7	42
OSI	nd	nd	—	—	7[b]	55[b]	—	—	6	40
Successional Stage	nd	nd	—	—	7[b]	56[b]	—	—	6	40
REPORT REFERENCE	Kelly and Kropp, 1992		Kelly and Kropp, 1992		Blake *et al.*, 1993		This report		This report	

nd: Not determined.

Four traditional and no reconnaissance stations in common with 1992; Four traditional and four reconnaissance 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.

All samples collected for infaunal analysis, except those collected in August 1992, were rinsed in the field over nested 0.3-mm and 0.5-mm-mesh sieves prior to being fixed. The August 1992 samples were rinsed in the field over a 0.3-mm-mesh sieve and fixed. These samples subsequently were rinsed over nested 0.3-mm and 0.5-mm-mesh sieves in the laboratory. The fractions resulting from these two different sieving activities are not directly comparable because live animals often can "worm" through sieves (e.g., Ohwada, 1988). Therefore, the 0.5-mm fraction resulting from sieving *after* fixation will likely contain more animals than the 0.5-mm fraction resulting from sieving *before* fixation. As a result, 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. 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. Included among these are the areas southeast of the Inner Harbor, southeast of Long Island, southeast of Nut Island, and northwest of Hull Bay.

C. Data Analysis

Sediment Profile Images, 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 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.

Reconnaissance Grab Analysis, 1991 and 1993 — 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, 1993 — 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 (with replicates for each station summed) using the Bray-Curtis (Bray and Curtis, 1957) and Normalized Expected Species Shared (NESS: Grassle and Smith, 1976) algorithms. The two similarity measures were used because the Bray-Curtis measure is strongly influenced by very abundant taxa (Boesch, 1977), whereas NESS is more sensitive to the contribution made by rare taxa (Grassle and Smith, 1976). NESS was run at $m = 100$. 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.

Benthic Community Analyses, 1991 to 1993 — 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 large-scale 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.

In general, data used for year-to-year comparisons were examined as were those used to describe benthic conditions found during 1993. However, 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 taxa collected from Boston Harbor during the Harbor studies program is given in Appendix B. All calculations (e.g., H') used in the year-to-year comparisons were made on the original data sets (i.e., values were not taken from the various reports describing each set of sampling activities).

After preliminary graphical inspection of the data, several parameters were selected for statistical analyses. 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. A preliminary examination of the data was performed using the Proc Univariate protocols of the statistical program SAS® for Windows, version 6.08 (SAS, 1989). These protocols include tests for normality and generate stem-leaf diagrams that allow visual inspection of the data. Based on the results of this preliminary examination of the data, a log transformation was applied to the total abundance data, whereas no transformations were required for the total species and diversity data. The preliminary tests also showed that the abundance data for the selected taxa were extremely skewed and not appropriate for parametric analysis.

Table 2. Taxonomic changes and assumptions relevant to 1991–1993 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
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
Microphthalmus aberrans	9/91, 4/92, 8/92	*M. sczelkowii*	Assumption based on taxonomist opinion
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*
Edotea triloba	9/91, 4/92, 8/92	*Edotia triloba*	Corrected spelling
Nassarius trivitattus	8/92	*Ilyanassa trivitatta*	Name change

A preliminary two-way Analysis of Variance (ANOVA; Sokal and Rohlf, 1981) to compare across stations and surveys was performed on the total abundance, species number, and diversity data. This ANOVA showed that, for each parameter, there was a significant station × survey interaction that precluded making an overall statement about the survey effects across all stations because those effects differed from station to station. Therefore, series of one-way ANOVAs were run to analyze survey effects station by station. Following the ANOVAs, unplanned multiple comparisons of the treatment means were run using the Tukey method (Sokal and Rohlf, 1981). The Tukey procedure was used because it is a powerful test that controls the experiment-wise error rate across all pair-wise comparisons (Day and Quinn, 1989). Following the one-way ANOVAs, series of linear contrasts were run to compare the average spring (April) versus the average late summer (August/ September) values at each station. The null hypothesis — that the difference between spring and late summer values was not significantly different from zero — was tested with *t*-tests (Sokal and Rohlf, 1981). For the selected taxa, survey effects were tested station by station using the Kruskal-Wallace nonparametric ANOVA (Sokal and Rohlf, 1981). SAS® for Windows, version 6.08 (SAS, 1989) was used to run these tests.

Descriptive community measures and Pearson correlation coefficients were calculated as discussed for the 1993 data. Classification analysis was performed on station data (i.e., replicates summed) from all surveys using NESS as the similarity measure. As for the 1993 analyses, NESS was run at m = 100 and UPGMA served as the clustering method and the results were presented as a dendrogram.

PRÉCIS OF 1993 RESULTS

A. Sedimentary Parameters

Grain Size — In April, sediment grain size (determined by sieve analysis) varied considerably among the Harbor stations (Table 3), ranging from predominantly sand at stations T-1 (90.5%) and T-8 (79.8%) to primarily silt + clay at stations T-4 (83.6%) and T-7 (80.4%).

In August, sieve analysis showed that the sand fraction at five of the eight traditional stations exceeded 65% (Table 3). Stations T-8 (93.7%) and T-5a (85.3%) were the two sandiest stations. The percent fine fraction (silt + clay) was quite a bit higher at station T-4 (86.1%) than elsewhere in the Harbor. Five stations showed somewhat sandier sediments in August as compared to April; two stations (T-4 and -8) showed little change between months (Figure 2). Data from the SPI analysis showed that the predominant sediment type throughout the study area was fine sand (Wentworth scale, Folk, 1974), which occurred at 29 (59%) stations, including stations T-1 and T-6. Stations having fine sands were located northwest of Peddocks Island, along Deer Island,

Table 3. **Sediment characteristics for April and August 1993 Boston Harbor soft-bottom stations.**

Survey / Station	*Clostridium perfringens* (spores/gdw[a])	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	TOC (%)	RPD[b] (cm)
April							
T-1	3,870	3.2[c]	90.5[c]	6.0[c]	0.3[c]	1.38	0.7
T-2	3,690	0.0	38.6	48.2	13.2	2.20	0.5
T-3	12,500	0.0	38.4	41.0	20.6	2.89	7.0
T-4	10,500	0.0	16.4	64.3	19.3	3.58	1.3
T-5a	2,610	0.4	62.4	31.1	6.2	1.14[c]	<0.5[d]
T-6	10,300	0.0	37.1	43.2	19.7	2.51	3.8
T-7	13,700	0.0	19.6	59.9	20.5	2.87	0.6
T-8	3,420	11.4	79.8	6.1	2.7	0.84	3.7
August							
T-1	7,030	8.0	75.3	11.7	5.0	2.96	2.8
T-2	9,090	3.1	66.0	20.4	10.4	1.39	0.7
T-3	20,200	0.5	50.3	30.7	18.6	3.41	>8.2[e]
T-4	5,750	0.0	13.9	60.4	25.6	3.25	1.0
T-5a	1,190	0.0	85.3	9.4	5.2	0.88	<0.5[d]
T-6	13,800	0.2	67.1	20.6	12.1	1.62	>7.8[e]
T-7	7,100	10.3	39.7	33.7	16.2	2.31	2.0
T-8	1,580	1.9	93.7	1.9	2.5	0.37	>6.8[e]

[a] Spores/gram dry weight
[b] Apparent RPD depth, estimated visually by core taken from macrofaunal grab sample; average of three replicates.
[c] Mean of triplicate analyses (grain size) or mean of duplicate analyses (TOC).
[d] Actual estimate of the apparent RPD depth was < 0.5 cm for each replicate.
[e] For each replicate (only two replicates at T-8), the apparent RPD depth was greater than grab penetration depth. In these cases the penetration depth was used to estimate the average RPD.

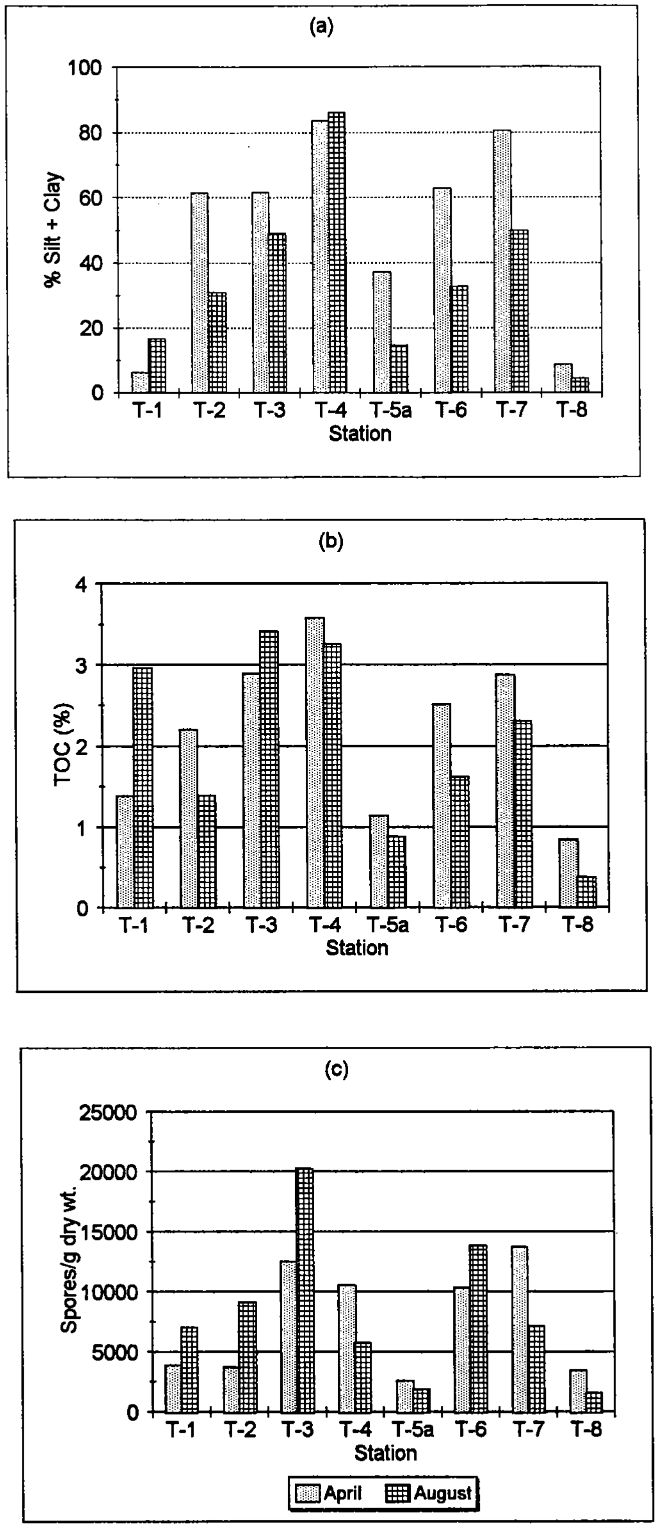


Figure 2. **Sediment percent silt + clay (a), total organic carbon (b), and *Clostridium perfringens* spore counts (c) at Boston Harbor traditional stations in April and August 1993.**

and in Hull Bay. Medium sand characterized three stations (T-8, R-19, and R-36) scattered over the southern end of the study area. Silty fine sand sediments occurred at 14 stations (29%), predominantly in Quincy Bay and around Long Island. Shell hash was mixed into the sediments and occurred sporadically within the study area at five stations. Predominantly silty sediments occurred at three stations (Table 4): off Deer Island (station R-2), in the Inner Harbor (station R-10), and near the mouth of the Neponset River (station T-4).

The depth of penetration into the substrate by the sediment profile camera prism, which acts as a dead-weight penetrometer, was related to sediment type. The depth of penetration by the prism averaged 9.7 cm in fine sand and 15.7 cm in silty fine sand sediments (Table 4). The prism penetration depth averaged 22.4 cm (±1.7) in low-compaction silty sediments. The deepest penetration depth for a single replicate was 25.1 cm at station T-4.

***TOC and* Clostridium perfringens** — In April, TOC was low at the sandiest stations (T-1 = 1.38%; T-8 = 0.84%; Table 3) and high at the stations having the highest fine (silt + clay) fraction (T-4 = 3.58%; T-7 = 2.87%). *Clostridium perfringens* values ranged from 2,610 spores/g dry weight at station T-5a to 13,700 spores/g dry weight at station T-7 (Table 3).

In August, TOC was lowest at the two sandiest stations, T-8 (0.37%) and T-5a (0.88%) and highest at stations T-3 (3.41%) and T-4 (3.25%). TOC values for six stations sampled in August were slightly lower than in April (Figure 2). *Clostridium perfringens* values ranged from 1,190 spores/g dry weight at station T-5a to 20,200 spores/g dry weight at station T-3 (Table 3). *C. perfringens* spore counts were lower at four stations in August than in April (Figure 2). Stations with higher spore counts in August were T-1, T-2, and T-3 in the northern Harbor and T-6 off Peddocks Island.

Surface and Subsurface Features — Based on SPI analysis, the average small-scale surface relief at stations in the study area ranged from 0.5 to 2.7 cm in height. At most stations, surface relief was predominantly biogenic and was caused by varying thicknesses of *Ampelisca* tube mats (Figures 3 and 4). At stations having silty sediments, surface relief resulted from the presence of biogenic mounds and pits or depressions in the sediment surface. The average height of the surface relief was 1.2 cm in fine sand, 1.0 cm in silty sand, 1.0 cm in medium sand, and 1.3 cm in silt (Table 4).

Ampelisca tube mats, which occurred at 22 (45%) stations (Table 4) represented the most prominent surface feature revealed by SPI. The distribution of *Ampelisca* tubes appeared to be related to sediment grain size. Tube mats were proportionately higher at stations characterized by silty fine sands (9 of 14 = 64%) than by fine sands (11 of 29 = 38%). *Ampelisca* occurred at 13 of 14 silty fine-sand stations and 16 of 29 fine-sand stations. Other surface features included worm tubes and fecal pellet layers

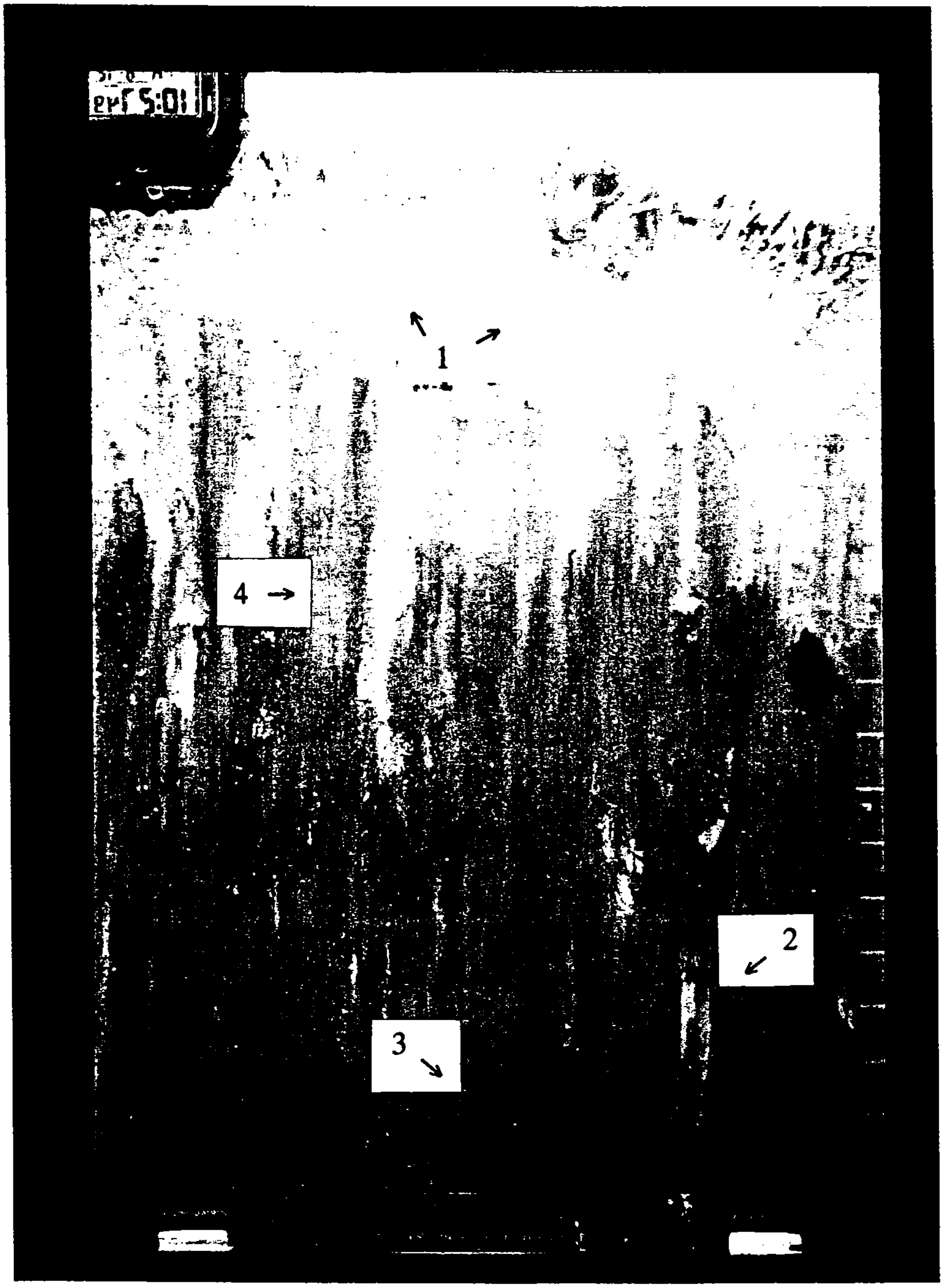


Figure 3. Sediment profile image from station R-25 sampled in August 1993. Image shows (1) dense *Ampelisca* tube mat on the sediment surface and (2) a large reddish worm—possibly a nemertean; (3), anoxic, water-filled voids; (4), a small worm—probably a polychaete. Scale marks = 1 cm.

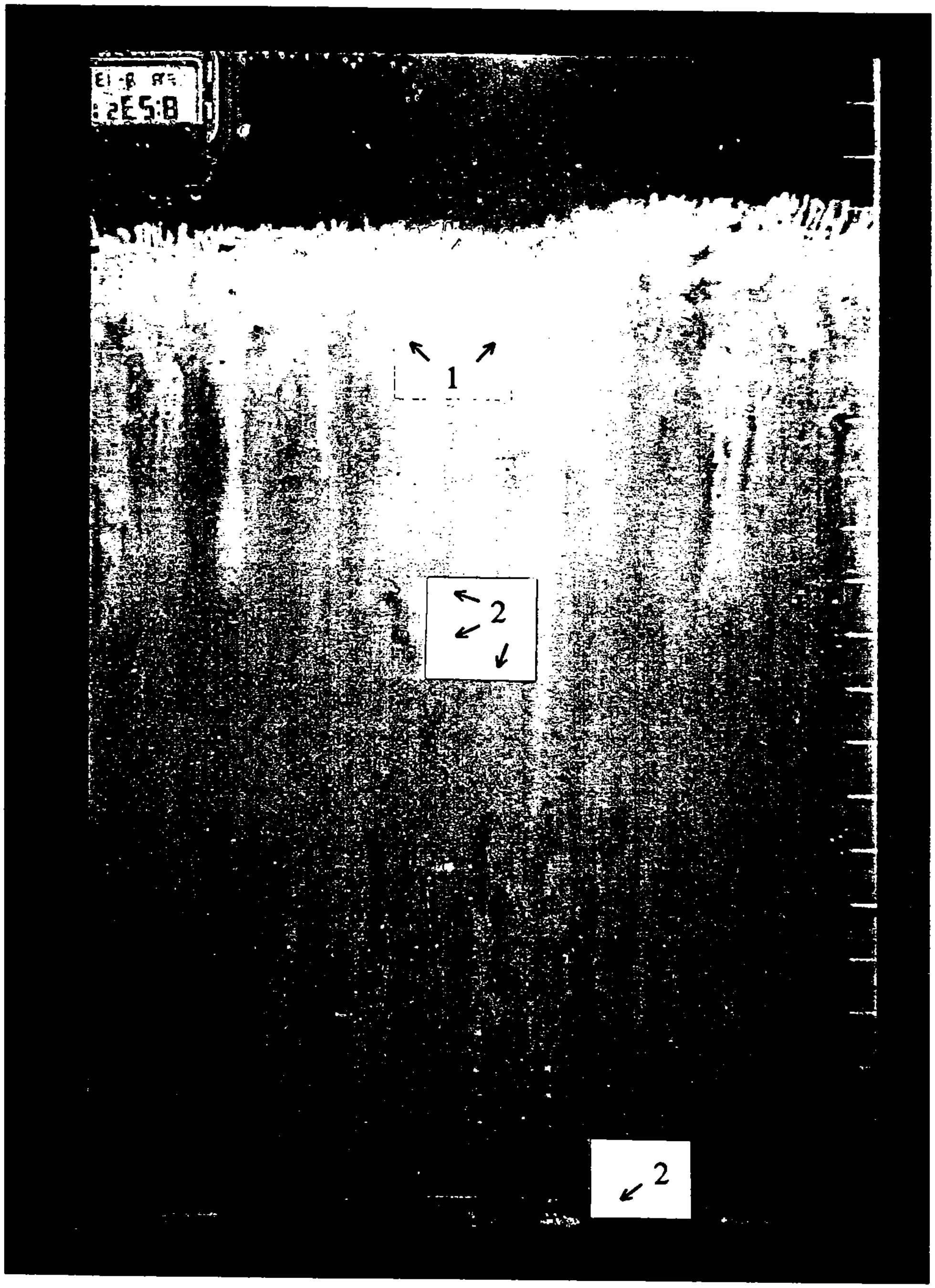


Figure 4. **Sediment profile image from station R-2, replicate 2 sampled in August 1993. Image shows (1), dense *Ampelisca* tube mat on the sediment surface; (2), gas-filled voids indicative of high rates of methanogenesis. Scale marks = 1 cm.**

Table 4. **Summary of SPI parameters by station for the August 1993 survey of Boston Harbor.**

Stat.	Ave. RPD Depth (cm)	Ave. Prism Penetration (cm)	Ave. Surface Relief (cm)	Sediment Type	Epifauna and Surface Features				Subsurface			Successional Stage	Range for OSI
					Amphipods	Polychaetes	Pellet Layer	Clast	Burrows	Infauna	Voids		
T-1	>3.0[a]	3.0	1.2	FS	-	+	+	-	NA	NA	NA	1	5-6
T-2		12.2	0.7	SIFS?	+?	+?	-	-	NA	NA	NA	IND	IND
T-3	5.9	16.0	1.1	SIFS	-	+	+	-	+	+	A,O	3	11
T-4	2.0	24.8	2.2	SI	-	-	+	-	-	-	G	1?	2
T-5a	Magnetic Switch Problems												
T-6	4.6	10.7	1.6	FS	MAT	-	-	-	+	+	O	2/3	9-10
T-7	1.1	11.1	0.9	SIFS/SH	+	+	+	+	+	-	-	1	2-3
T-8	>4.4[a]	4.4	1.3	MS/SH	MAT	+	+	-	-	-	-	1/2	5-9
R-2	0.6	19.1	0.8	SI	MAT	-	-	-	-	-	A,G	2ON0	2-4
R-3	1.4	11.0	1.1	FS	+	+	+	-	+	-	O,A	1/2	3-4
R-4	0.8	14.6	0.7	FS	-	+	+	-	-	+	A	1/2	2-4
R-5	0.9	15.9	0.6	FS	-	+	+	-	-	-	A	1/2	4
R-6	1.8	6.7	1.5	FS	MAT	-	-	-	-	-	-	2	5-7
R-7	0.7	18.1	0.8	FS	-	+	+	-	-	+	A	1	2-3
R-8		2.0	0.5	FS/ST	-	+	-	-	NA[a]	NA	NA	IND	IND
R-9	1.1	9.0	0.5	FS	-	+	+	-	+	+	O,A	2/3	5-6
R-10	0.4	23.3	1.0	SI	-	+	-	-	-	-	O	1	2
R-11	4.0	18.7	0.9	SIFS	MAT	-	+	-	+	+	A	2/3	8-9
R-12	2.5	18.6	1.5	SIFS	MAT	+	+	-	+	-	O,A	1/2	3-9
R-13	1.9	15.8	0.5	SIFS	+	+	-	-	+	+	A	1/2	5-6
R-14	1.4	8.4	0.7	FS	-	+	+	-	+	+	A	2	5-6
R-15	0.9	7.8	1.6	SIFS/SH	+	+	-	-	+	-	A,O	1	3
R-16	3.3	16.1	0.7	SIFS	MAT	-	-	-	+	-	-	2	8
R-17	0.8	18.9	0.7	SIFS	MAT	+	-	-	+	-	A	2	4-5
R-18	3.8	19.4	1.2	SIFS	MAT	+	+	-	+	+	A,O	2/3	8-10
R-19	>2.2[a]	2.2	0.6	MS	+	+	-	-	NA	NA	NA	1/2	4-7
R-20	4.4	15.3	1.0	SIFS	MAT	+	-	-	+	+	O,A	2/3	9-10
R-21	>10.5[a]	10.5	2.4	FS	MAT	+	+	-	+	+	O	2	9
R-22	4.8	9.5	1.0	FS	MAT	-	+	-	-	+	-	2	9
R-23	>5.0[a]	6.5	2.7	FS	MAT	-	-	-	-	-	-	2	9
R-24	>4.7[a]	9.6	1.4	FS	MAT	-	+	-	+	+	-	2	9
R-25	2.2	19.7	0.9	SIFS	MAT	-	+	-	+	+	A	2/3	7-9
R-26	1.2	13.1	1.0	FS	MAT	+	+	-	-	-	-	2	5
R-27	1.2	5.7	0.8	FS	+	+	+	-	-	-	-	1/2	4-5
R-28	2.3	6.4	1.3	FS	MAT	-	+	-	-	-	-	2	6-7
R-29	3.5	13.0	0.8	FS	MAT	-	+	-	+	+	-	2	8
R-30	1.7	6.8	0.8	FS	MAT	-	+	-	-	+	-	2	5-6
R-31	4.0	10.7	2.6	FS	MAT	+	+	-	+	+	O	2/3	10-11
R-32	1.3	13.8	1.3	FS	+	+	+	-	+	-	-	1/2	4
R-33	0.8	14.5	1.1	FS	-	+	-	-	+	-	A	1	2-3
R-34	1.2	11.3	1.5	FS	-	-	+	-	+	-	A	1?	3
R-35	1.0	11.8	0.7	FS	-	+	+	+	-	-	A	1?	2-4
R-36		1.0	.	MS	-	NA	-	-	NA	NA	NA	IND	IND
R-37	0.9	9.4	0.9	FS	+	-	+	-	+	-	A	1?	2-3
R-38	1.3	16.3	0.8	SIFS	MAT	-	+	-	+	+	A	2	5-6
R-39	2.1	13.5	1.1	SIFS/SH	MAT	-	+	-	+	+	-	2	6-7
R-40	1.4	2.6	1.2	FS	-	-	-	-	NA	NA	NA	1	3-4
R-41	0.7	11.6	0.8	FS	-	-	+	-	-	-	A	1	2-3
R-42	>2.3[a]	3.1	1.9	FS/SH	-	-	-	-	NA	NA	NA	1?	4-5
R-43	0.8	13.1	0.7	FS	+	-	+	-	-	-	A	1	2-3

[a] At least one of the three station replicates had an RPD layer deeper than the prism penetration.

NA: Not available, prism penetration too shallow.
IND: Indeterminant
ST: Stones or pebbles
FS: Fine Sand
-: Absent
SIFS: Silty fine sand
MS: Medium Sand
+: Present
SI: Silt
SH: Shell hash or pieces
MAT: Tube mat on sediment surface
G: Gas filled void
A: Anoxic
O: Oxic sediment
?: Unclear

(Table 4). Worm tubes were observed at 26 or 27 relatively scattered stations, although most records appeared to be for stations in the northern region of the Harbor. A fecal pellet layer was observed at 32 stations, located primarily in the southern Harbor, northwest of Peddocks Island, and along Deer Island.

The most prominent subsurface features were burrow structures, infaunal organisms, and water- and gas-filled voids (Figures 3 and 4). The distribution of subsurface features was related to sediment texture. Gas-filled voids only occurred at stations R-2 and T-4, both of which had silty sediments. The distribution of the 23 stations at which water-filled voids were observed did not show any pattern. Burrow structures were found at all silty fine-sand stations and at half of the fine-sand stations. Infaunal organisms also occurred more frequently at stations with fine sands.

Apparent Redox Potential Discontinuity Depth — As estimated by visual examination of cores from grab samples collected in April 1993, the average apparent RPD depth ranged from < 0.5 cm at station T-5a to 7.0 cm at station T-3 (Table 3). At stations T-3 and T-6, the average RPD_{VIS} depth was 7.0 cm and 3.8 cm, respectively.

In August 1993, the average apparent RPD depth, estimated from grab samples, ranged from < 0.5 cm at station T-5a to >8.2 cm at station T-3 (Table 3). The average apparent RPD_{VIS} depth estimated in August increased substantially over that estimated in April at stations T-1, T-6, and T-8 (Figure 5). At stations T-3 and T-7, the RPD_{VIS} depth was also greater in August than the estimate for April. However, at the remaining three stations the RPD_{VIS} depth estimated in August was similar to the estimate for April. In August, the estimated RPD_{VIS} depth was greater than the grab penetration at stations T-3, T-6, and T-8 (2 replicates only).

As determined by analysis of SPI, the average depth of the apparent color RPD layer in August 1993 ranged from 0.4 to 5.9 cm (Table 4), with the deepest RPD_{SPI} layers associated with *Ampelisca* tube mats in fine-sand and silty fine-sand sediments (Figure 3). The average RPD_{SPI} depth was 2.0 cm in fine-sand sediments, 2.6 cm in silty sand, >3.3 cm in medium sand, and 1.0 cm in silt. Areas with shallow (<1.0 cm) RPD_{SPI} depths were west Deer Island, off the southern tip of Long Island, and around Thompson Island. The deepest RPD_{SPI} depths, shown in the RPD_{SPI} contour plot (Figure 6), occurred at the northwest tip of Long Island (station T-3) and northwest of Peddocks Island (stations T-6, R-21, R-22, R-23, and R-24).

During the August survey, parallel measurements of the apparent RPD depth were made at 29 stations. One set of measurements was obtained from the SPI analyses; the second set was from estimates made by examination of grab samples collected for infaunal analyses. No SPI estimates were obtained at stations T-2 and R-8. One comparison was made using all data collected. For this comparison, the mean RPD depth estimated by the grab sample method was significantly greater than that estimated by SPI (t = 2.83903, n = 29, α <0.05). However, no indication of the apparent

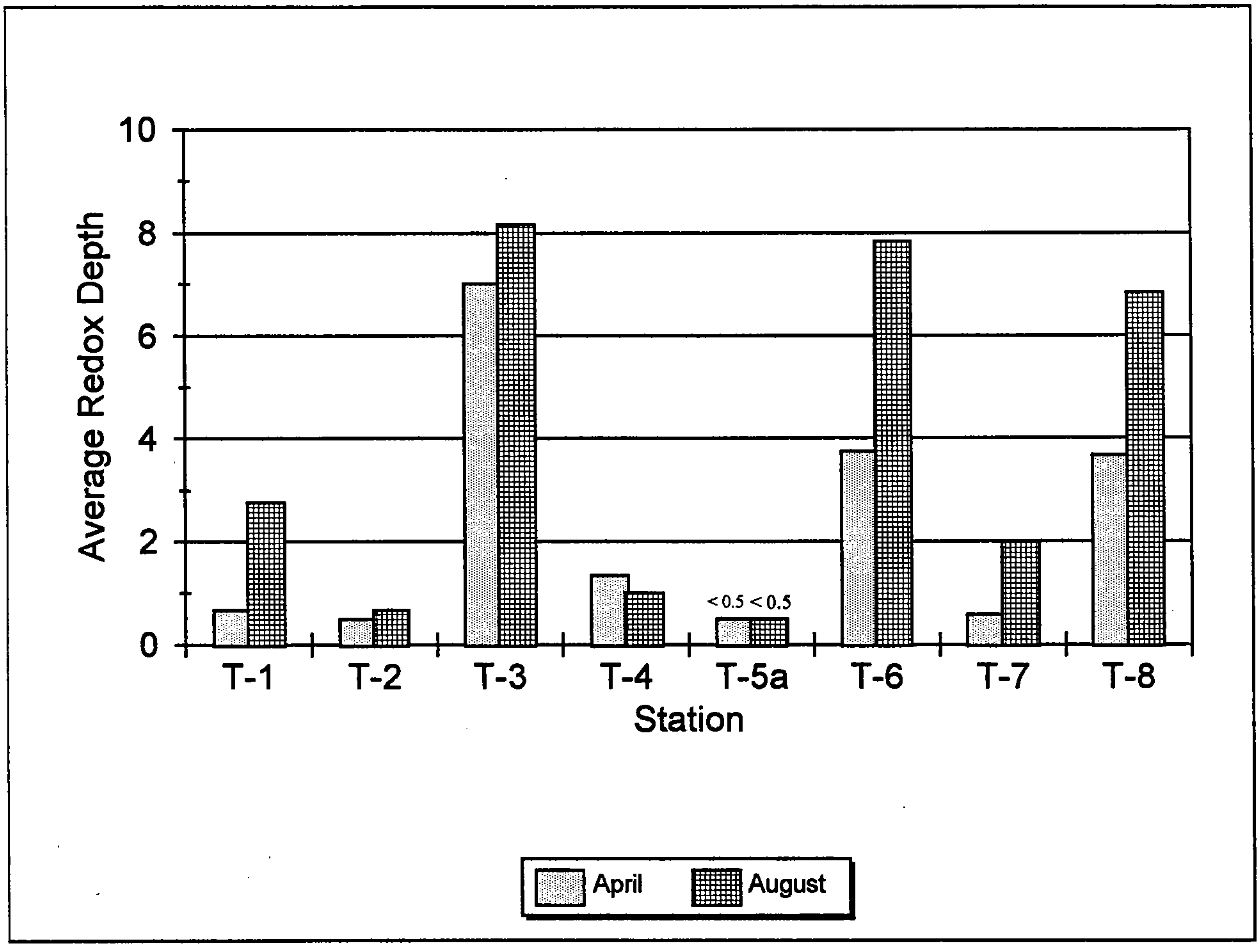


Figure 5. **Comparison of apparent RPD depth as estimated by the grab sample method in April and August 1993.**

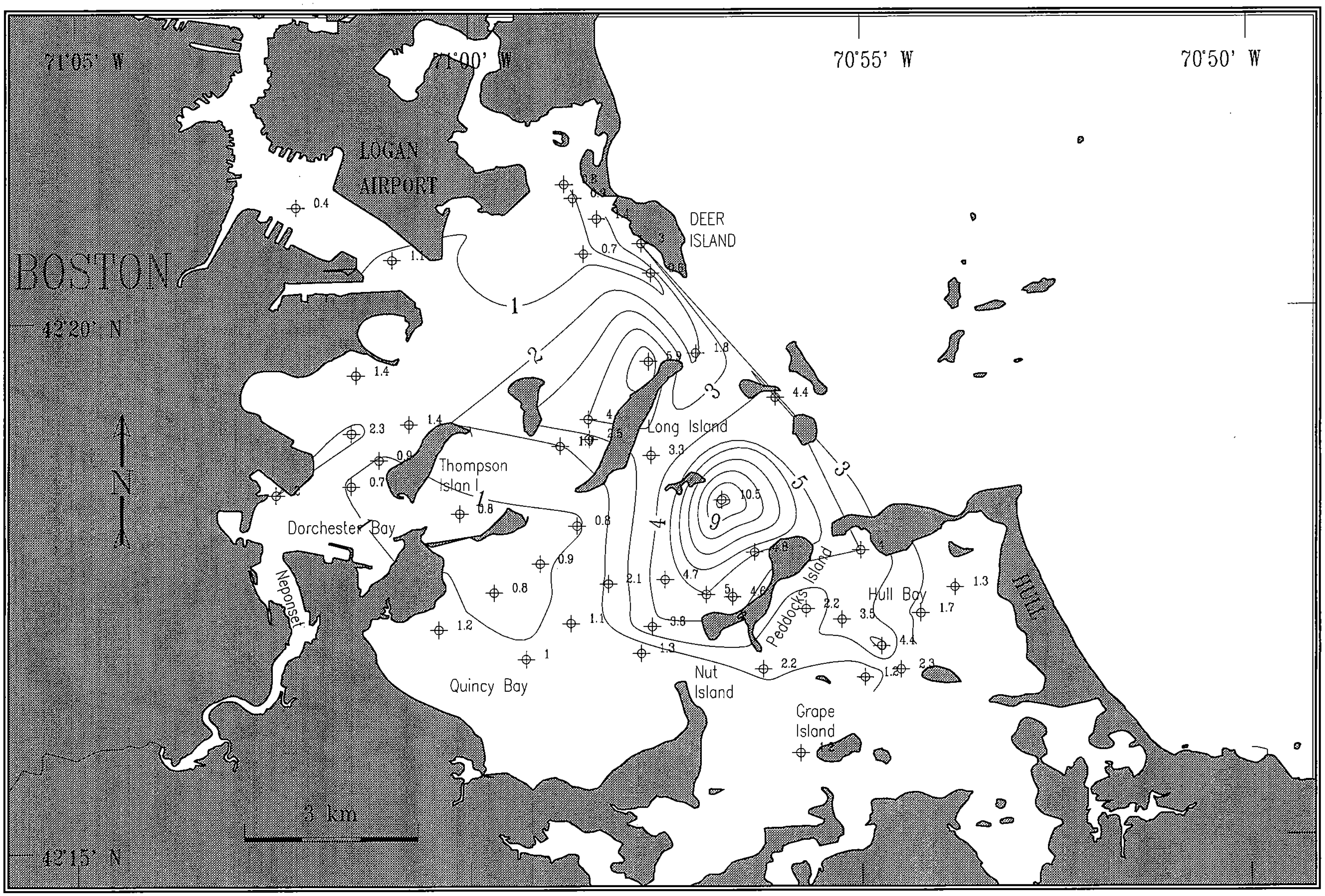


Figure 6. Contour map of Boston Harbor showing average RPD depths based on the sediment profile image method in August 1993. Contour interval is 1 cm.

RPD boundary was visible at six stations. Therefore, it was likely that the apparent RPD_{VIS} depth was greater than the sediment depth sampled by the grab. A second comparison was made excluding data from these stations because no estimate of the apparent RPD_{VIS} could be made (Figure 7). For this restricted comparison, the mean RPD depth estimated by the grab sample method was not significantly different from the depth estimated by SPI (t = 1.92861, n = 23, α = 0.05). This suggests that visual estimates of the RPD depth (when that depth does not exceed the depth of the sediment sampled by the grab) may be used to compare surveys on which no SPI was available to those where SPI was used.

B. Infaunal Communities

Total Abundance — A table of 1993 infaunal data (by replicate) is given in Appendix C. In April, the traditional stations showed two patterns of abundance (Figure 8, Table 5). Stations T-3, T-6, and T-8 had similar mean abundances, ranging around 3000 individuals/0.04 m^2, whereas the remaining stations had abundances at or well below 1000 individuals/0.04 m^2. At stations T-3, T-6, and T-8, arthropods were the predominant major taxon, respectively accounting for about 76%, 54%, and 42% of the mean total abundance at those stations. Polychaetes accounted for most of the individuals present at the remaining stations.

Total abundance values were as much as 8 × greater in August than in April. Three patterns were noticeable (Figure 8, Table 5). Stations T-3 and T-6 had mean abundances around 15,000 individuals/0.04 m^2, stations T-1 and T-8 had abundances just greater than 5,000 individuals/0.04 m^2, and the remaining stations had abundances at or less than 2,500 individuals/0.04 m^2. Again, arthropods were predominant at stations T-3, T-6, and T-8, respectively accounting for about 66%, 71%, and 60% of the mean total abundance at those stations. Polychaetes again accounted for most of the individuals present at the remaining stations. At stations T-1, T-2, and T-4, polychaetes accounted for more than 94% of the individuals present.

Numbers of Species — Stations sampled in April were grouped into two categories based on mean number of species per replicate (Figure 9, Table 5). Stations T-3, T-5a, T-6, and T-8 had about 25 or more species/0.04 m^2, whereas the remaining stations had fewer than 18 species/0.04 m^2. Polychaetes accounted for 48% or more of the species identified at each station. Arthropods accounted for about 32% of the species present at stations T-3 and T-6.

In August, species numbers were generally similar at six of the traditional stations, ranging from about 27 to 39 species/0.04 m^2 (Figure 9, Table 5). Stations T-8 and T-4, respectively had the greatest and fewest numbers of species/0.04 m^2. Polychaetes again predominated at each station.

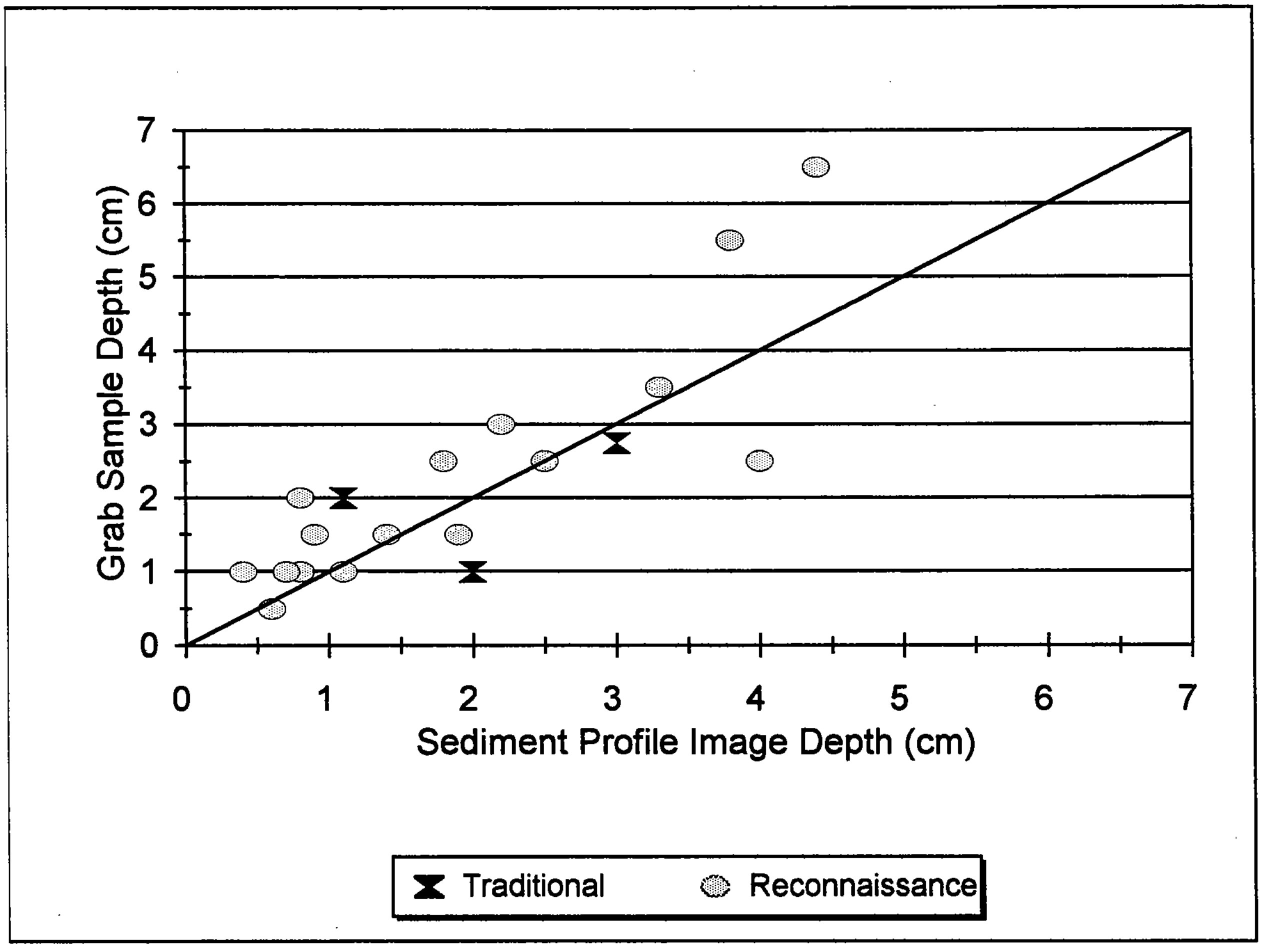
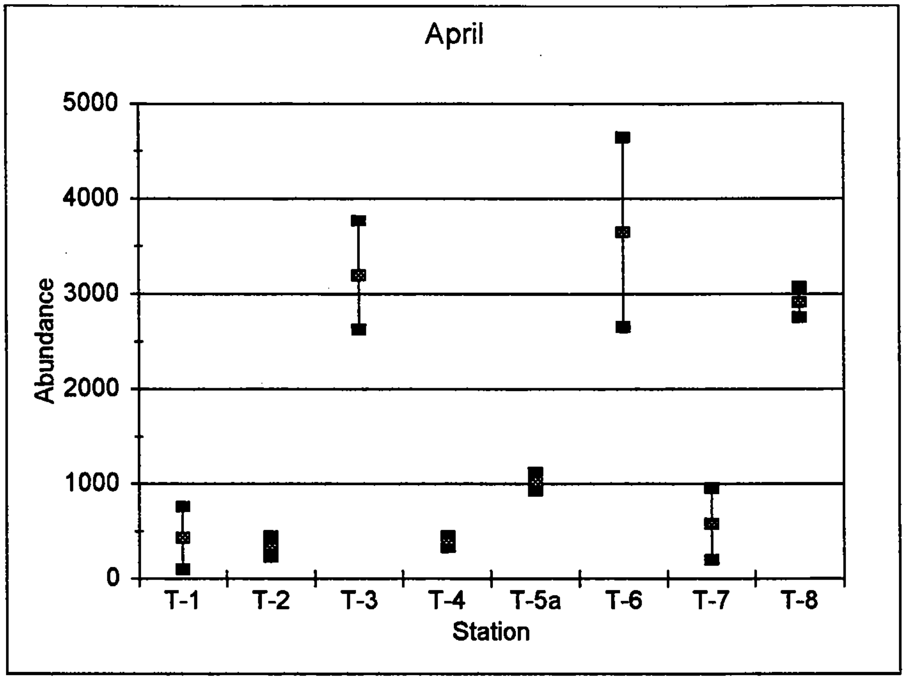


Figure 7. **Comparison of average RPD depth as estimated by SPI and grab sample methods in August 1993. Excluded are data where the apparent RPD exceeded grab penetration depth. Dashed line indicates a 1:1 correspondence between methods.**



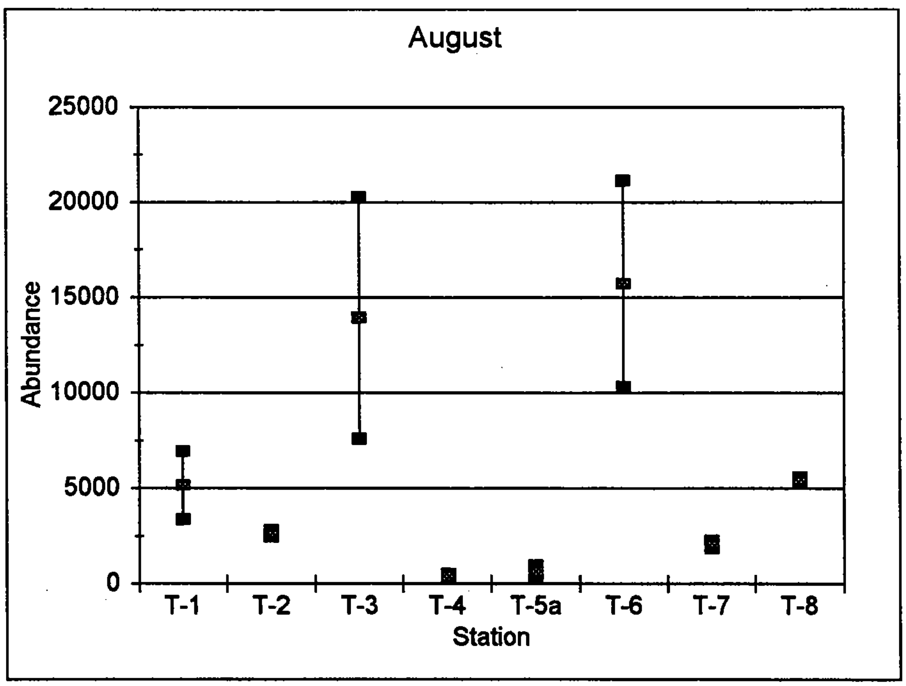


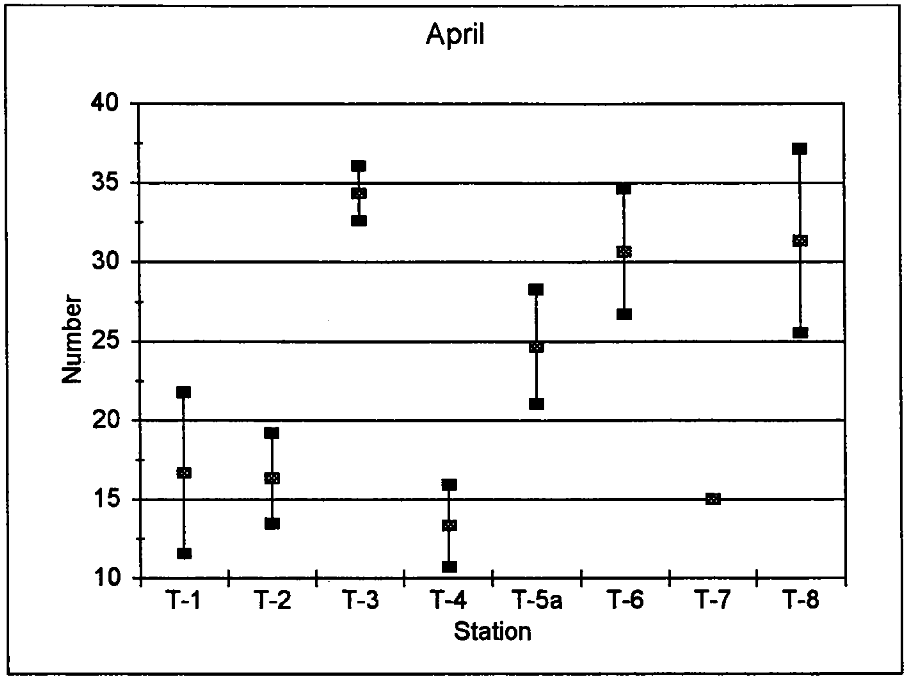
Figure 8. Mean (± 95% confidence intervals) total infaunal abundance (#/0.04 m^2) at Boston Harbor traditional stations in April and August 1993. Note that scales of Y-axes differ.

Table 5. Mean (± 95% confidence intervals) infaunal abundance (#/0.04 m^2) and numbers of species at each traditional station in April and August 1993.

	Abundance per Sample					Species per Sample				
Station	Annelids	Arthropods	Molluscs	Other	Total	Annelids	Arthropods	Molluscs	Other	Total
April 1993										
T-1	389.0	4.3	35.3	0.3	429.0	12.0	2.0	2.7	0	16.7
	(306.5)	(0.7)	(25.3)	(0.6)	(329.3)	(4.5)	(1.1)	(1.3)		(5.1)
T-2	295.7	20.3	19.0	0.7	335.7	9.3	3.3	3.7	0	16.3
	(92.1)	(18.4)	(1.1)	(1.3)	(108.0)	(2.4)	(2.4)	(0.7)		(2.8)
T-3	666.0	2413.0	111.3	5.0	3195.3	17.0	11.0	6.3	0	34.3
	(29.4)	(595.0)	(46.6)	(3.4)	(572.7)	(2.3)	(1.1)	(0.7)		(1.7)
T-4	382.7	0	4.3	0.3	387.3	11.3	0	2.0	0	13.3
	(60.1)		(1.7)	(0.7)	(60.1)	(2.6)		(0)		(2.6)
T-5a	955.0	10.3	53.3	2.3	1021.0	17.3	2.5	5.7	0	24.7
	(112.6)	(11.3)	(16.0)	(2.4)	(93.8)	(1.7)	(2.4)	(0.7)		(3.6)
T-6	1630.3	1966.7	46.3	5.7	3649.0	15.0	10.3	5.3	0	30.7
	(272.2)	(1236.8)	(22.4)	(5.8)	(995.9)	(1.1)	(1.7)	(1.3)		(4.0)
T-7	562.0	11.0	6.0	0	579.0	11.3	1.7	2.0	0	15.0
	(377.9)	(7.9)	(4.1)		(376.8)	(0.7)	(0.7)	(0)		(0)
T-8	1175.3	1213.0	438.3	87.7	2914.3	16.7	8.0	6.7	0	31.3
	(189.7)	(139.8)	(48.8)	(60.8)	(160.6)	(3.3)	(2.3)	(0.7)		(5.8)

Table 5. **Mean (± 95% confidence intervals) infaunal abundance (#/0.04 m^2) and numbers of species at each traditional station in April and August 1993. *(continued)***

	Abundance per Sample					Species per Sample				
Station	**Annelids**	**Arthropods**	**Molluscs**	**Other**	**Total**	**Annelids**	**Arthropods**	**Molluscs**	**Other**	**Total**
August 1993										
T-1	4972.7	129.3	45.0	4.7	5151.7	28.0	6.3	4.0	1.0	39.0
	(1763.4)	(58.7)	(10.8)	(2.6)	(1786.6)	(3.0)	(0.7)	(1.1)	(0)	(3.0)
T-2	2462.7	126.3	27.7	4.3	2621.0	23.0	7.3	5.0	1.0	36.0
	(206.8)	(25.5)	(4.3)	(4.0)	(182.5)	(1.1)	(2.8)	(1.1)	(0)	(3.0)
T-3	4518.7	9251.3	149.7	12.7	13,932.3	18.7	11.3	6.3	3.0	39.3
	(2607.4)	(3739.1)	(60.6)	(1.7)	(6338.7)	(4.7)	(0.7)	(0.7)	(1.1)	(5.1)
T-4	355.7	11.7	10.3	0.7	378.3	5.0	2.3	1.3	0	8.7
	(145.8)	(13.3)	(1.3)	(1.3)	(157.8)	(2.0)	(0.7)	(0.7)		(1.7)
T-5a	468.7	137.3	35.0	0.3	641.3	20.0	7.3	4.7	0	32.0
	(294.0)	(52.4)	(7.1)	(0.7)	(335.7)	(3.0)	(0.7)	(0.7)		(3.9)
T-6	4537.3	11,094.7	90.7	2.7	15,725.3	16.7	10.3	6.3	1.7	35.0
	(2030.5)	(3350.7)	(52.7)	(0.7)	(5407.8)	(1.3)	(0.7)	(2.8)	(0.7)	(4.1)
T-7	1243.0	797.3	11.3	1.0	2052.7	18.3	6.0	2.7	0	27.0
	(313.0)	(105.3)	(1.7)	(0)	(208.2)	(0.7)	(0)	(0.7)		(1.1)
T-8	1824.7	3260.0	330.0	15.7	5430.3	28.3	11.7	7.3	3.7	51.0
	(417.9)	(345.5)	(27.2)	(5.1)	(151.5)	(1.7)	(1.7)	(1.7)	(1.7)	(3.4)



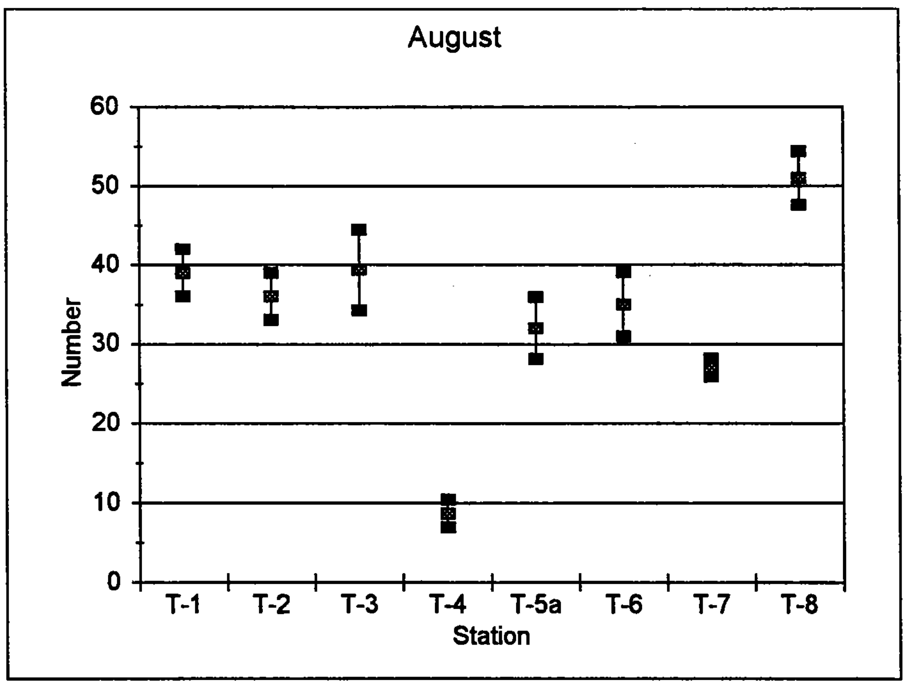


Figure 9. **Mean (± 95% confidence intervals) total numbers of species per sample at Boston Harbor traditional stations in April and August 1993. Note that scales of Y-axes differ.**

Indices — Mean species diversity (H') during April was similar at all stations except station T-4 (Table 6). Mean diversity at station T-4 was just above 1.0, whereas mean values of H' at the remaining stations ranged from about 2.4 to 3.0. As expected, evenness (J') showed a pattern that was similar to the pattern for diversity (Table 6). Evenness was lowest at station T-4 (~0.3) and relatively similar at the remaining stations (~0.5-0.6). Simpson's dominance values, although calculated for summed replicates at each station rather than as the mean of replicates, reflected the general patterns shown by diversity. Generally, when H' values were high, dominance values were low. Dominance values ranged from 0.19 at station T-3 to 0.70 at station T-4 (Table 6).

In August, H' was lowest at station T-4 and highest at station T-5a, with the remaining stations showing approximately similar diversity values (Table 6). J' values dropped at stations T-1 and T-4 as compared to those in April, whereas values for the remaining stations were similar in April and August (Table 6). Dominance values ranged from 0.20 at stations T-2 and T-3 to 0.87 at station T-4 (Table 6).

Predominant Species — The 10 most abundant species identified at each station (replicates summed) in April are listed in Table 7. At station T-1 and T-2, three annelids — *Streblospio benedicti, Tharyx* acutus, and *Tubificoides* nr. *pseudogaster* — comprised more than 79% of the individuals identified to species. Note that, except for *Tharyx acutus,* the ranks of the taxa differed between the two stations. Stations T-4 and T-5a could be classified as polychaete-dominated stations. *Streblospio benedicti* accounted for about 83% of the individuals at station T-4. Three oligochaete species and the polychaetes *Tharyx acutus, Aricidea catherinae,* and *Streblospio benedicti* accounted for about 89% of the individuals identified to species at station T-5a. Those taxa, excluding the oligochaete *Tubificoides benedeni*, accounted for about 95% of the individuals identified to species at station T-7. An amphipod taxon, *Ampelisca,* was the predominant taxon at stations T-3, T-6, and T-8. However, polychaetes were still important components of the 10 most abundant taxa at all three stations.

The 10 most abundant species identified at each station (replicates summed) in August are listed in Table 8. Most noticeable in August was the appearance, in parts of the Harbor, of the polychaete, *Polydora cornuta,* as the predominant taxon (stations T-1, T-2, and T-3) or the third-ranked species (stations T-6 and T-7). Indeed, the only station at which *Polydora cornuta* was not among the top 10 ranked species was station T-4. *Streblospio benedicti, Tharyx acutus,* and *Tubificoides* nr. *pseudogaster* again were significant at stations T-1 and T-2, although the latter two dropped in rank at station T-2. Stations T-4 and T-5a again could be classified as polychaete-predominated stations, although an isopod crustacean, *Edotia triloba,* was the third-ranked species at station T-5a. *Streblospio benedicti* accounted for about 93% of the individuals at station T-4. As in April, *Ampelisca* was the predominant taxon at stations T-6, T-7, and T-8. Noticeable was the rise to predominance of several crustacean species at stations T-3 and T-6. Seven crustaceans ranked among the top 10 species at station T-3 and six

Table 6. Species diversity (*H'*), Evenness (*J'*), and Dominance (D) at traditional stations in April and August 1993. 95% confidence intervals are enclosed within parentheses.

		H'		*J'*		D[a]
April						
	T-1	2.42	(0.13)	0.61	(0.10)	0.28
	T-2	2.37	(0.06)	0.59	(0.02)	0.25
	T-3	3.04	(0.27)	0.60	(0.05)	0.19
	T-4	1.05	(0.26)	0.28	(0.08)	0.70
	T-5a	2.59	(0.23)	0.56	(0.03)	0.28
	T-6	2.35	(0.08)	0.48	(0.01)	0.29
	T-7	2.35	(0.08)	0.60	(0.02)	0.21
	T-8	2.52	(0.23)	0.51	(0.03)	0.24
August						
	T-1	2.06	(0.05)	0.39	(0.01)	0.43
	T-2	3.00	(0.16)	0.58	(0.02)	0.20
	T-3	3.08	(0.24)	0.58	(0.07)	0.20
	T-4	0.52	(0.07)	0.17	(0.03)	0.87
	T-5a	3.73	(0.05)	0.75	(0.03)	0.10
	T-6	2.53	(0.01)	0.49	(0.01)	0.23
	T-7	2.55	(0.25)	0.54	(0.05)	0.23
	T-8	2.50	(0.35)	0.44	(0.05)	0.35

[a] Calculated for pooled replicates

Table 7. **The 10 most abundant species found at each station in April 1993. Total N represents only organisms identified to species. Abundance (#) is the mean number of individuals/0.04 m^2 at each station; % is the cumulative percentage.**

Station T-1			Station T-2			Station T-3			Station T-4		
Species	**#**	**%**	**Species**	**#**	**%**	**Species**	**#**	**%**	**Species**	**#**	**%**
Tubificoides nr. *pseudogaster* (O)	198.0	46.19	*Streblospio benedicti* (P)	111.7	33.77	*Ampelisca* (A)	1101.0	35.22	*Streblospio benedicti* (P)	320.7	83.43
Tharyx acutus (P)	80.3	64.93	*Tharyx acutus* (P)	97.7	63.31	*Corophium bonelli* (A)	695.0	57.45	*Polydora cornuta* (P)	23.0	89.42
Streblospio benedicti (P)	62.3	79.47	*Tubificoides* nr. *pseudogaster* (O)	68.0	83.87	*Leptocheirus pinguis* (A)	291.7	66.78	*Capitella capitata* (P)	15.3	93.41
Ilyanassa trivittata (G)	32.0	86.94	*Photis pollex* (A)	15.7	88.61	*Tubificoides* nr. *pseudogaster* (O)	189.7	72.85	*Tubificoides* nr. *pseudogaster* (O)	7.0	95.23
Clymenella torquata (P)	17.0	90.90	*Mya arenaria* (B)	11.3	92.04	*Polydora cornuta* (P)	165.0	78.13	*Spio thulini* (P)	3.3	96.10
Polydora cornuta (P)	13.0	93.93	*Microphthalmus sczelkowii* (P)	4.7	93.45	*Phoxocephalus holbolli* (A)	142.3	82.68	*Microphthalmus sczelkowii* (P)	2.3	96.70
Capitella capitata (P)	6.3	95.41	*Mytilus edulis* (B)	4.0	94.66	*Aricidea catherinae* (P)	141.7	87.21	*Tellina agilis* (B)	2.3	97.31
Microphthalmus sczelkowii (P)	3.7	96.27	*Tellina agilis* (B)	3.0	95.56	*Tubificoides apectinatus* (O)	84.3	89.91	*Tubificoides benedeni* (O)	2.0	97.83
Photis pollex (A)	2.7	96.89	*Ampelisca* (A)	2.3	96.27	*Ilyanassa trivittata* (G)	55.7	91.69	*Fabricia stellaris* (P)	1.7	98.27
Mediomastus californiensis (P)	2.3	97.43	*Capitella capitata* (P)	2.0	96.88	*Photis pollex* (A)	49.7	93.28	Four taxa, each with	1.0	99.31
Tellina agilis (B)	2.3	97.98									
Total N	**428.7**		**Total N**	**330.7**		**Total N**	**3126.0**		**Total N**	**383.6**	

Table 7. **The 10 most abundant species found at each station in April 1993. Total N represents only organisms identified to species. Abundance (#) is the mean number of individuals/0.04 m^2 at each station; % is the cumulative percentage. *(continued)*.**

Station T-5a			Station T-6			Station T-7			Station T-8		
Species	#	%	Species	#	%	Species	#	%	Species	#	%
Tharyx acutus (P)	493.0	48.92	*Ampelisca* (A)	1677.7	46.12	*Tubificoides* nr. *pseudogaster* (O)	140.3	24.29	*Ampelisca* (A)	1175.7	41.71
Tubificoides apectinatus (O)	136.0	62.42	*Aricidea catherinae* (P)	855.0	69.63	*Aricidea catherinae* (P)	129.3	46.68	*Aricidea catherinae* (P)	485.0	58.92
Aricidea catherinae (P)	121.7	74.50	*Tubificoides* nr. *pseudogaster* (O)	429.0	81.42	*Streblospio benedicti* (P)	129.3	69.07	*Nucula delphinodonta* (B)	406.7	73.35
Tubificoides nr. *pseudogaster* (O)	104.7	84.88	*Tubificoides apectinatus* (O)	165.0	85.96	*Tubificoides apectinatus* (O)	128.7	91.34	*Tubificoides* nr. *pseudogaster* (O)	291.3	83.69
Tubificoides benedeni (O)	21.7	87.03	*Phoxocephalus holbolli* (A)	162.0	90.41	*Tharyx acutus* (P)	19.0	94.63	*Tubificoides apectinatus* (O)	256.3	92.79
Streblospio benedicti (P)	20.3	89.05	*Polydora cornuta* (P)	78.7	92.58	*Ampelisca* (A)	9.3	96.25	*Scoletoma hebes* (P)	75.0	95.45
Tellina agilis (B)	16.3	90.67	*Corophium bonellii* (A)	58.7	94.19	*Ilyanassa trivittata* (G)	4.0	96.94	*Tharyx acutus* (P)	18.3	96.10
Ilyanassa trivittata (G)	11.3	91.80	*Phyllodoce mucosa* (P)	34.0	95.12	*Scoletoma hebes* (P)	3.7	97.58	*Mediomastus californiensis* (P)	14.3	96.61
Chaetozone sp. A (P)	10.0	92.79	*Nucula delphinodonta* (B)	26.3	95.85	*Polydora cornuta* (P)	3.3	98.15	*Phoxocephalus holbolli* (A)	14.0	97.10
Macoma balthica (B)	9.7	93.75	*Leptocheirus pinguis* (A)	24.0	96.51	*Microphthalmus sczelkowii* (P)	2.0	98.50	*Diastylis sculpta* (C)	12.3	97.54
Total N	**1007.7**		**Total N**	**3637.3**		**Total N**	**577.7**		**Total N**	**2818.3**	

A: Amphipod C: Cumacean P: Polychaete
B: Bivalve G: Gastropod O: Oligochaete

Table 8. **The 10 most abundant species found at each station in August 1993. Total N represents only organisms identified to species. Abundance (#) is the mean number of individuals/0.04 m^2 at each station; % is the cumulative percentage.**

Station T-1			Station T-2			Station T-3			Station T-4		
Species	#	%	Species	#	%	Species	#	%	Species	#	%
Polydora cornuta (P)	3210.3	62.91	*Polydora cornuta* (P)	917.0	35.45	*Polydora cornuta* (P)	3307.0	38.54	*Streblospio benedicti* (P)	346.3	93.44
Tharyx acutus (P)	868.0	79.92	*Streblospio benedicti* (P)	544.3	56.49	*Corophium bonelli* (A)	1265.0	53.29	*Ampelisca* (A)	7.3	95.41
Streblospio benedicti (P)	278.0	85.37	*Aphelochaeta* sp. A (P)	336.7	69.51	*Unciola irrorata* (A)	903.7	63.82	*Nephtys neotena* (P)	5.0	96.76
Tubificoides nr. *pseudogaster* (O)	122.3	87.77	*Phyllodoce mucosa* (P)	153.3	75.44	*Tubificoides* nr. *pseudogaster* (O)	770.7	72.80	*Neomysis americana* (M)	2.7	97.48
Clymenella torquata (P)	106.3	89.85	*Tharyx acutus* (P)	131.0	80.50	*Phoxocephalus holbolli* (A)	541.3	79.11	*Ensis directus* (B)	2.3	98.11
Polydora aggregata (P)	101.3	91.83	*Tubificoides* nr. *pseudogaster* (O)	112.7	84.86	*Leptocheirus pinguis* (A)	417.0	83.97	*Tubificoides* nr. *pseudogaster* (O)	2.0	98.65
Ampelisca (A)	58.7	92.98	*Ampelisca* (A)	70.7	87.59	*Photis pollex* (A)	347.3	88.02	*Mytilus edulis* (B)	2.0	99.19
Phyllodoce mucosa (P)	52.7	94.02	*Asabellides oculata* (P)	63.7	90.05	*Corophium crassicorne* (A)	170.3	90.00	*Tharyx acutus* (P)	1.0	99.46
Microphthalmus sczelkowii (P)	50.3	95.00	*Eteone longa* (P)	48.7	91.93	*Ampelisca* (A)	124.0	91.45	*Crangon septemspinosa* (D)	0.7	99.64
Phyllodoce maculata (P)	32.0	95.63	*Photis pollex* (A)	37.7	93.39	*Phyllodoce mucosa* (P)	115.0	92.79			
Total N	**5103.0**		**Total N**	**2586.7**		**Total N**	**8580.0**		**Total N**	**370.7**	

Table 8. **The 10 most abundant species found at each station in August 1993. Total N represents only organisms identified to species. Abundance (#) is the mean number of individuals/0.04 m^2 at each station; % is the cumulative percentage. *(continued)*.**

Station T-5a			Station T-6			Station T-7			Station T-8		
Species	#	%	Species	#	%	Species	#	%	Species	#	%
Tharyx acutus (P)	107.3	17.06	*Ampelisca* (A)	5227.7	33.80	*Ampelisca* (A)	787.0	38.82	*Ampelisca* (A)	3030.3	56.74
Tubificoides apectinatus (O)	106.3	33.97	*Corophium bonelli* (A)	3932.7	59.23	*Aricidea catherinae* (P)	324.7	54.83	*Aricidea catherinae* (P)	794.0	71.60
Edotia triloba (I)	88.3	48.01	*Polydora cornuta* (P)	3345.3	80.86	*Polydora cornuta* (P)	323.0	70.77	*Spiophanes bombyx* (P)	328.3	77.75
Aricidea catherinae (P)	74.3	59.83	*Aricidea catherinae* (P)	733.0	85.60	*Streblospio benedicti* (P)	315.3	86.32	*Nucula delphinodonta* (B)	198.3	81.46
Tubificoides nr. *pseudogaster* (O)	41.0	66.35	*Unciola irrorata* (A)	509.7	88.89	*Tubificoides* nr. *pseudogaster* (O)	80.7	90.30	*Exogone hebes* (P)	136.0	84.01
Tubificoides benedeni (O)	30.3	71.17	*Leptocheirus pinguis* (A)	503.7	92.15	*Nephytys neotena* (P)	53.3	92.93	*Phyllodoce mucosa* (P)	113.7	86.14
Polydora cornuta (P)	26.0	75.30	*Phoxocephalus holbolli* (A)	449.0	95.05	*Tubificoides apectinatus* (O)	43.7	95.08	*Polydora cornuta* (P)	94.0	87.90
Aphelochaeta sp. A (P)	23.3	79.01	*Photis pollex* (A)	228.7	96.53	*Tharyx acutus* (P)	36.3	96.88	*Corophium crassicorne* (A)	90.7	89.60
Nephytys caeca (P)	20.3	82.25	*Phyllodoce mucosa* (P)	200.7	97.83	*Aphelochaeta* sp. A (P)	13.7	97.55	*Tharyx acutus* (P)	82.3	91.14
Diastylis sculpta (C)	18.7	85.21	*Phyllodoce maculata* (P)	96.7	98.45	*Scoletoma hebes* (P)	8.7	97.98	*Scoletoma hebes* (P)	63.0	92.32
Total N	629.0		Total N	15466.3		Total N	2027.3		Total N	5341.0	

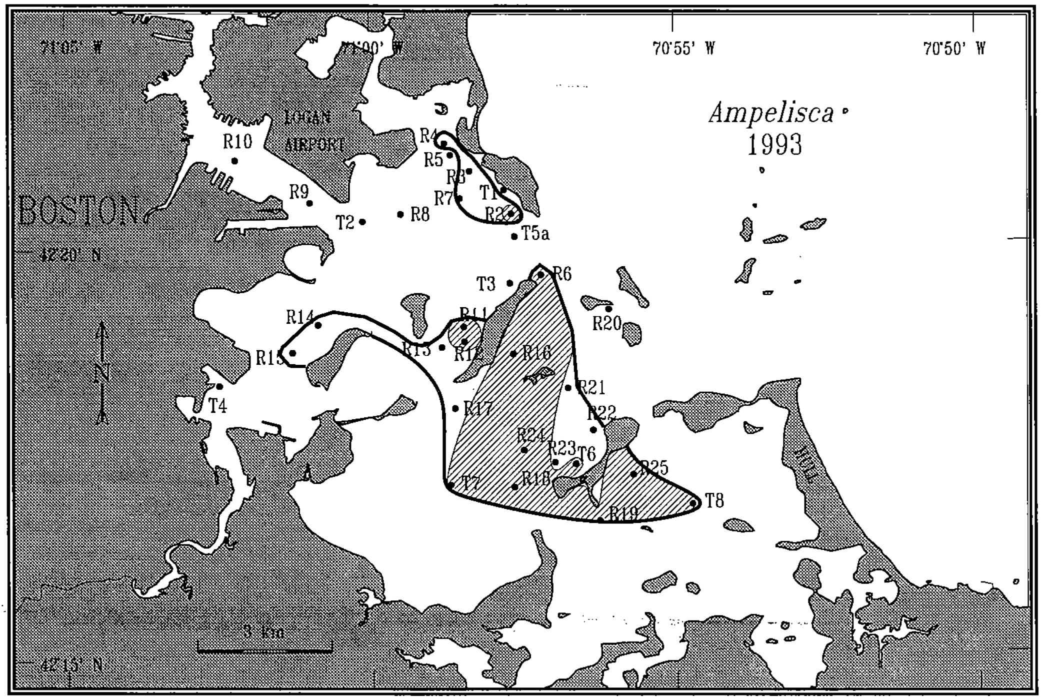
A: Amphipod C: Cumacean G: Gastropod M: Mysid P: Polychaete
B: Bivalve D: Decapod I: Isopod O: Oligochaete

ranked among the top 10 at station T-6, accounting for about 70% of the individuals identified to species at that station.

The rapid-sorting method of analysis of the reconnaissance grab samples allowed estimates of the most common infaunal taxa to be made for a much larger portion of the Harbor than covered by the traditional stations. Studies in progress compare the estimates derived by rapid-sorting to those obtained by processing the entire sample, and have shown that rapid sorting tends to underestimate the abundance of common taxa and may overestimate the abundance of uncommon taxa. However, the method provides reasonable estimates of the relative ranking of species by their abundance. By using this relative-rank information about the most common taxa, the rapid-sorting method can be used to obtain a relatively broad-scale picture of infaunal communities in the Harbor.

In the context of the 1993 reconnaissance surveys, taxa were ranked in order of the estimated abundance of each in the sample taken at each reconnaissance station. The top four ranked taxa from each reconnaissance station, as well as those from each traditional station, were used to map the distribution of the predominant taxa in the Harbor. Three general patterns emerged. The distribution of the "area of relative numerical importance" of the amphipod *Ampelisca* provided evidence for the utility of the rapid-sorting method in mapping predominant infaunal taxa. If only data from traditional stations are considered, *Ampelisca* would be numerically important only in the southeast area of the Harbor near Nut Island and in a portion of the central region of the Harbor. However, data from reconnaissance stations showed that *Ampelisca* was the predominant (i.e., top ranked) taxon as far north as the tip of Long Island and at one station (R-2) off Deer Island (Figure 10). Using secondary predominance information (ranks 2, 3, or 4), the area of relative numerical importance of *Ampelisca* was shown to extend north of the Deer Island flats and into Dorchester Bay. Data gathered from analysis of SPI showed that the area of relative numerical importance of *Ampelisca* extended north of station T-8 toward Hull (stations R-30, R-31) and south of T-8 toward Grape Island (stations R-26, R-27, R-28).

Similarly, better understanding of the area of relative numerical importance of *Polydora cornuta*, a polychaete worm, was gained by combining data from reconnaissance stations with those from traditional stations (Figure 10). Considering only data from traditional stations, *P. cornuta* was numerically dominant only in the portion of the Northwest Harbor bounded by stations T-1, T-2, and T-3. However, data from the reconnaissance stations showed that the primary area of relative numerical importance of *P. cornuta* extended into Dorchester Bay. *P. cornuta* was secondarily important in the outer portion of the central region of the Harbor and just southeast of Peddocks Island. Note that the regions where either *Ampelisca* or *Polydora cornuta* is the predominant taxon do not overlap; the former predominates to the south, the latter predominates to the north (Figure 10).



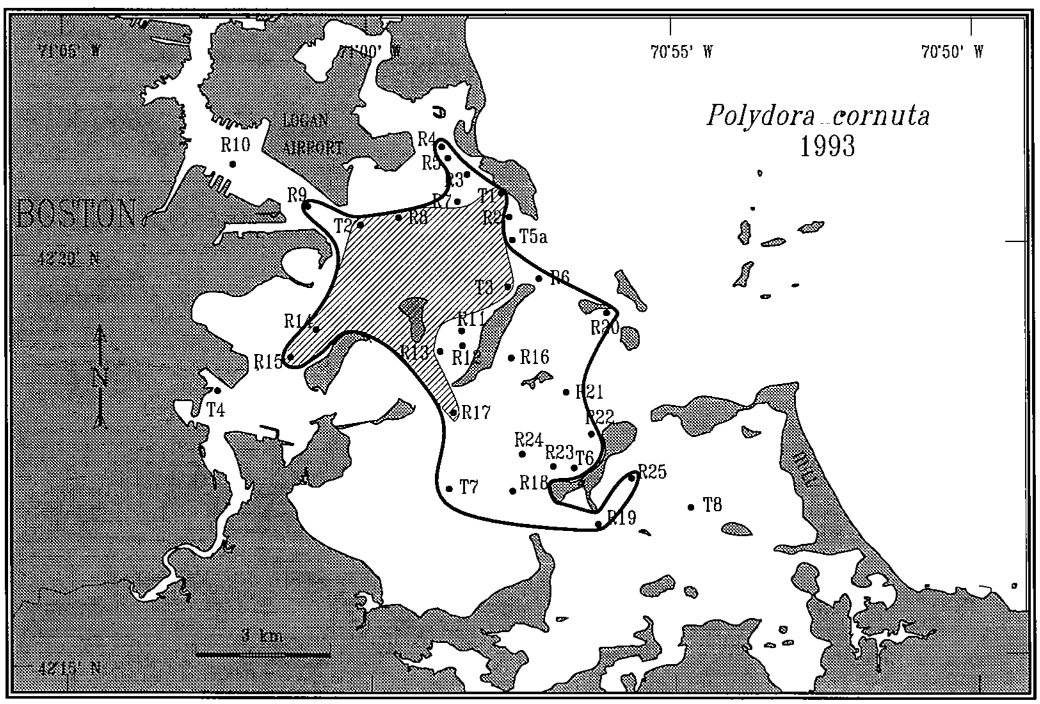


Figure 10. **Map of Boston Harbor showing areas where either *Ampelisca* or *Polydora cornuta* was among the four most abundant taxa (bold lines) or the most abundant taxon (hatched areas) at Boston Harbor traditional or reconnaissance stations in August 1993.**

The third pattern evident from this analysis was the restricted predominance of the polychaete *Streblospio benedicti* (Figure 11). *Streblospio* was the predominant species at station T-4 in inner Dorchester Bay, accounting for about 93% of the individuals identified there (Table 8). Reconnaissance data showed that its area of influence was generally restricted to pockets of the Northwest Harbor. Also, although *Streblospio* was the predominant taxon at several reconnaissance stations in the Northwest Harbor, its relative importance was less than at station T-4 because it accounted for more than 60% of the infaunal abundance only at station R-4.

Successional Stages and the Organism-Sediment Index — Overall, the apparent successional stage of the benthos, as determined by SPI analysis, was bimodal with stages I and II being the predominate categories. Within the Harbor, silty fine-sand habitats generally had the highest successional stages. Some evidence of stage III communities was found at about 38% (5 of 13) of the stations having silty fine-sand sediments, whereas about 11% of the fine-sand stations (3 of 28) showed some evidence of stage III succession (Table 4). Seven of these stations also showed evidence of stage II development, whereas only stage III development was found for station T-3. Stations showing stage II/III development were located primarily around the southern part of Peddocks Island. The 14 stations having only stage I communities were located primarily in Dorchester Bay and in Quincy Bay, but also included stations T-1 and T-7. Mixed stage I/II communities were found primarily along Deer Island and southeast of Peddocks Island. Station T-8 was classified as having stage I/II development. Stage II communities were found in the Central Harbor between Peddocks Island and Long Island.

By sediment type, the average OSI value was lowest (2.3) for silty stations. The average OSI at stations characterized by other sediment types was higher, ranging from 5.2 to 6.7 (Table 4). For each station, the midpoint values of the OSI ranges presented in Table 4 were used to characterize the geographic distribution of OSI in the Harbor. High OSI values ($> +6$) were found at 15 stations in the Central Harbor between Peddocks Island and Long Island, southeast of Peddocks Island, and along the northwest shore of Long Island (Figure 12). The highest OSI value determined for the Harbor stations was 11 (maximum value) at station T-3. OSI values at the remaining stations were relatively low ($\leq +6$).

Sediment: Infauna Correlations — April and August 1993 data were considered together to evaluate potential correlations between the bulk sedimentary parameters and a selection of biological parameters. Among the major biological parameters, mean total abundance and mean arthropod abundance showed very significant correlation ($p < 0.01$) with the average apparent RPD depth, as estimated by visual examination of grab samples (Table 9). Annelid abundance, the total number of species, and the mean number of arthropod species were all significantly correlated ($p < 0.05$) with the apparent RPD_{VIS} depth. The abundances of all selected arthropod taxa, *Polydora cornuta*, and *Nucula delphinodonta* were significantly correlated with the apparent

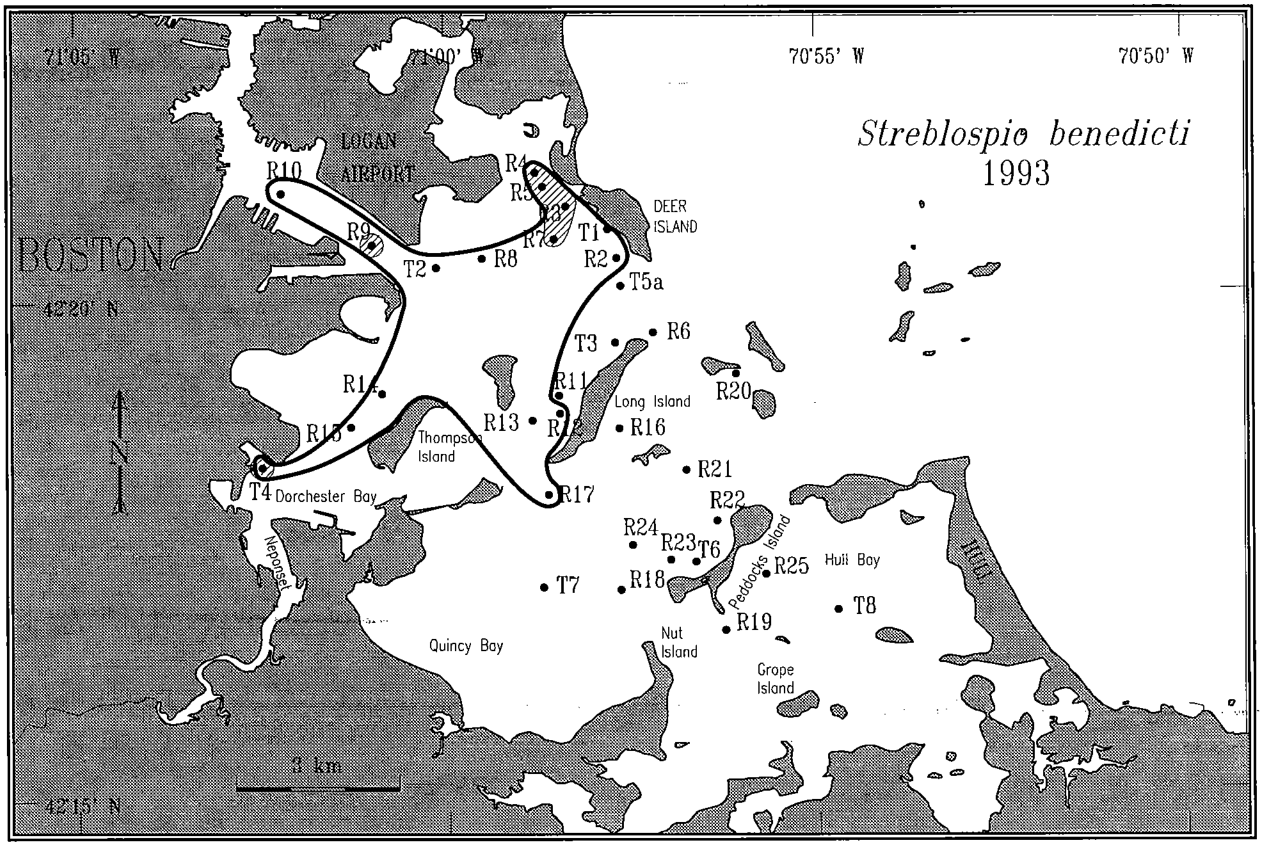


Figure 11. Map of Boston Harbor showing areas where *Streblospio benedicti* was among the four most abundant taxa (bold lines) or the most abundant taxon (hatched areas) at Boston Harbor traditional or reconnaissance stations in August 1993.

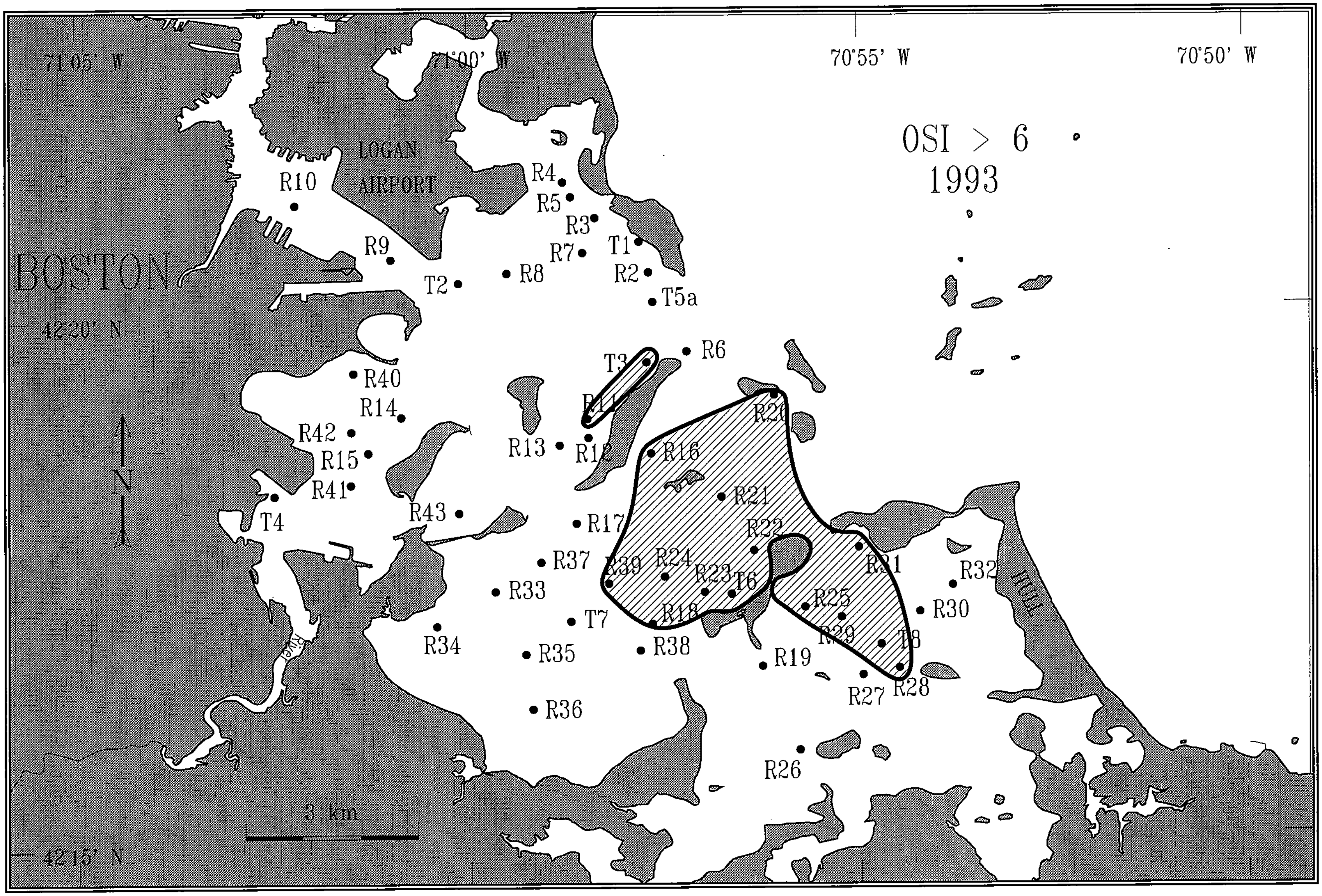


Figure 12. **Map of Boston Harbor showing areas (hatched where organism-sediment index values were > 6 in August 1993.**

Table 9. Pearson correlation coefficients (*r*) between biological and abiotic parameters using only 1993 data. Critical limits of *r* for n = 16 are 0.497 at α = 0.05 and 0.623 at α = 0.01 (from Table Y in Rohlf and Sokal, 1969)

	Silt+Clay	TOC	*C. perfringens*	RPD[a]
Abundance				
Total	-0.19360	0.05674	0.60859*	0.83108**
Annelids	-0.30822	0.11097	0.48167	0.58859*
Arthropods	-0.04463	0.11310	0.64925*	0.84143**
Species				
Total	-0.62380**	-0.40398	0.07988	0.66745**
Annelids	-0.69133**	-0.41276	-0.08281	0.37848
Arthropods	-0.38931	-0.26473	0.26156	0.82414*
Diversity (*H'*)	-0.53160*	-0.49370	0.04937	0.22733
Selected Taxa				
Oligochaetes	-0.03683	0.13355	0.46774	0.38695
Capitella capitata	-0.39359	-0.24574	-0.40942	0.00092
Polydora cornuta	-0.19400	0.24679	0.56720*	0.55497*
Tharyx acutus	-0.33734	-0.00136	-0.22251	-0.15948
Streblospio benedicti	0.28724	0.31769	0.00680	-0.47486
Ampelisca	-0.24850	-0.32999	0.13856	0.68654**
Leptocheirus pinguis	0.04182	0.20612	0.71139**	0.80596**
Photis pollex	-0.02348	0.22734	0.72396**	0.71390**
Corophium bonellii	-0.04404	0.02314	0.52239*	0.64781**
Ilyanassa trivittata	-0.21277	0.03802	0.30172	0.60954*
Nucula delphinodonta	0.46207	-0.51242*	-0.33237	0.25291
Sediment Parameters				
Silt+Clay	—	0.78932**	0.47072	-0.14672
TOC	—	—	0.65998**	0.05415
Clostridium perfringens	—	—	—	0.51909*

* Significant correlation at α = 0.05
** Significant correlation at α = 0.01
[a] Apparent RPD depth, visually estimated by core taken from grab sample.

RPD_{VIS} depth (Table 9). Also, the mean total species and mean polychaete species showed high negative correlation with fine sediments (% silt + % clay; Table 9). Mean arthropod abundance and mean total abundance showed high positive correlation with *Clostridium perfringens* spore counts (Table 9). Note that, as might be expected, sediment TOC was highly correlated with fine sediments and also with *Clostridium perfringens* spore counts. Among selected taxa, the bivalve *Nucula delphinodonta* was negatively correlated with sediment TOC. Several taxa were positively correlated with *Clostridium perfringens* spore counts (Table 9).

Numerical Classification — Results of the similarity analysis performed on the data from April showed that stations could be classified into two primary groups (Figure 13). The Bray-Curtis and NESS similarity measures each showed one group to consist of stations from the southern (station T-8) and central (stations T-3 and T-6) regions of the Harbor. For each similarity measure, a second group consisted of stations from the northern (stations T-1 and T-5a) or inner (stations T-2 and T-4) regions of the Harbor. The two similarity measures differed primarily in the alignment of station T-7, which clustered with the south/central harbor stations in the NESS analysis, but aligned with the north/inner harbor stations in the Bray-Curtis analysis (Figure 13). Similarity between the two major groups determined by the NESS analysis was 0.45, whereas Bray-Curtis similarity between the two major groups was 0.13.

For the August data, NESS similarity analysis again separated the stations into two major groups (Figure 14). However, stations T-5a and T-7 switched group affinities from those determined for the April data. Station T-5a now clustered with the south/central Harbor stations, whereas station T-7 was aligned with the north/inner Harbor stations. Station groups determined by the Bray-Curtis analysis differed from those determined by NESS. Two stations each showed low similarity to the remaining six stations (Figure 14). Station T-5a, just off the tip of Deer Island, was the most distinct, joining the remaining stations at a Bray-Curtis similarity of 0.10. Station T-4 clustered with the remaining stations at a Bray-Curtis value of 0.11. The remaining six stations were classified into three pairs of geographically related stations (Figure 14).

Boston Harbor Benthos: 1991–1993 Comparisons

A. Sedimentary Parameters

Grain Size — Data from sieve analysis of samples collected during all years of the program indicated that, with only a few exceptions, sediment composition has been consistent (Table 10). This consistency is evident in the general pattern shown in Figure 15. Noticeable differences in sediment type have been observed at station T-8, which was about 88% silt + clay in September 1991, but has been consistently sandy (>80% sand) since. Although the fine sediment fraction remained relatively consistent at station T-1, a larger fraction of gravel was noted in August 1992 (Table 10). Three

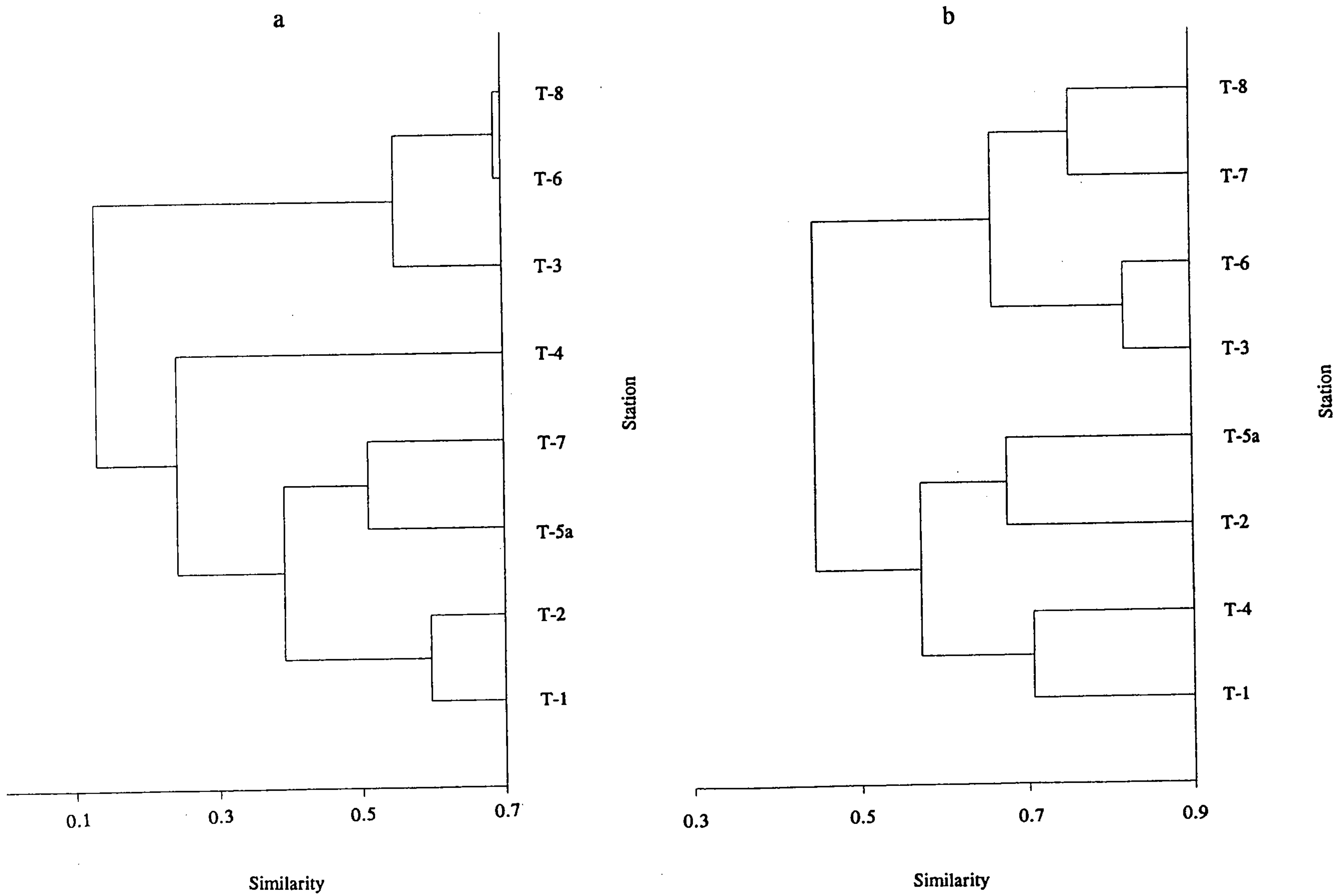


Figure 13. **Dendrograms resulting from similarity analysis of Boston Harbor traditional stations sampled in April 1993 based on the Bray-Curtis (a) and NESS (b) algorithms.**

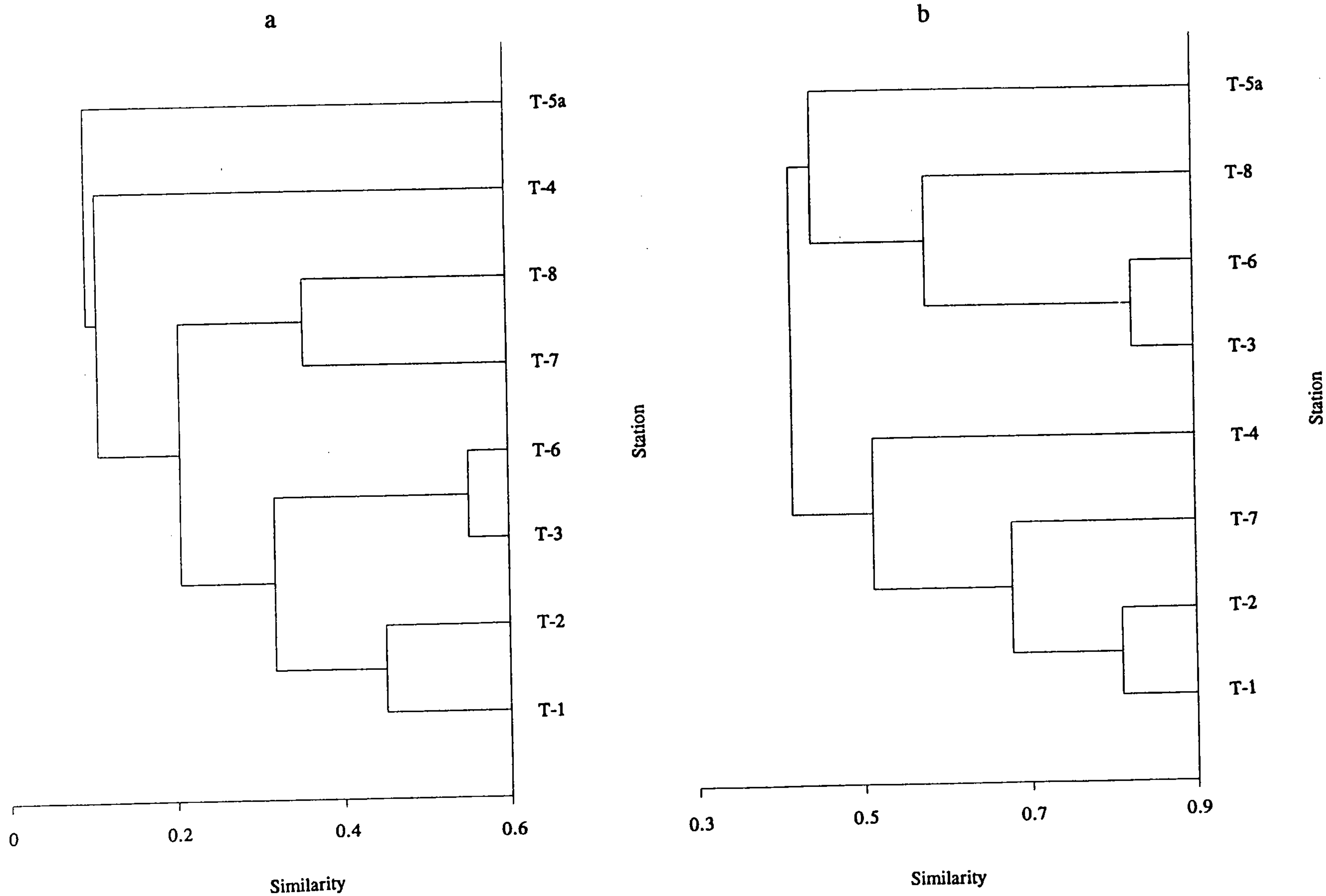


Figure 14. **Dendrograms resulting from similarity analysis of Boston Harbor traditional stations sampled in August 1993 based on the Bray-Curtis (a) and NESS (b) algorithms.**

Table 10. **Bulk sedimentary parameters from samples collected in Boston Harbor between 1991 and 1993. No samples were collected in April 1992.**

	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Silt+Clay (%)	TOC (%)	*C. perfringens* s/gdw[a]
Station T-1							
Sep 91	1.3	83.6	11.9	3.2	15.1	2.64	11700
Aug 92	65.3	17.8	8.0	9.0	17.0	1.91	4300
Apr 93	3.2	90.5	6.0	0.3	6.3	1.38	3870
Aug 93	8.0	75.3	11.7	5.1	16.7	2.96	7030
Station T-2							
Sep 91	0.2	63.6	27.8	8.5	36.3	1.75	22900
Aug 92	21.3	47.6	19.1	12.1	31.2	1.71	14800
Apr 93	0.0	38.6	48.2	13.2	61.4	2.20	3690
Aug 93	3.1	66.0	20.4	10.5	30.9	1.39	9090
Station T-3							
Sep 91	0.0	44.1	39.1	16.8	55.9	3.69	207000
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	12500
Aug 93	0.5	50.3	30.7	18.6	49.2	3.41	20200
Station T-4							
Sep 91	0.0	32.3	48.6	19.1	67.7	3.70	30000
Aug 92	0.0	20.8	59.8	19.4	79.2	3.95	3330
Apr 93	0.0	16.4	64.3	19.3	83.6	3.58	10500
Aug 93	0.0	13.9	60.4	25.6	86.1	3.25	5750
Station T-6							
Sep 91	0.1	65.6	25.1	9.2	34.3	1.81	29400
Aug 92	0.4	64.8	22.2	12.6	34.8	2.12	7000
Apr 93	0.0	37.1	43.2	19.7	62.9	2.51	10300
Aug 93	0.2	67.1	20.6	12.1	32.7	1.62	13800
Station T-7							
Sep 91	1.8	57.3	27.3	13.6	40.9	2.73	13700
Aug 92	4.5	40.2	38.8	16.5	55.3	3.18	7500
Apr 93	0.0	19.6	59.9	20.5	80.4	2.87	13700
Aug 93	10.3	39.7	33.7	16.3	50.0	2.31	7100
Station T-8							
Sep 91	0.0	12.1	52.2	35.7	87.9	0.87	7330
Aug 92	2.9	93.4	1.7	2.0	3.7	0.66	3890
Apr 93	11.4	79.8	6.1	2.7	8.8	0.84	3420
Aug 93	1.9	93.7	1.9	2.5	4.4	0.37	1580

[a] Spores/gram dry weight

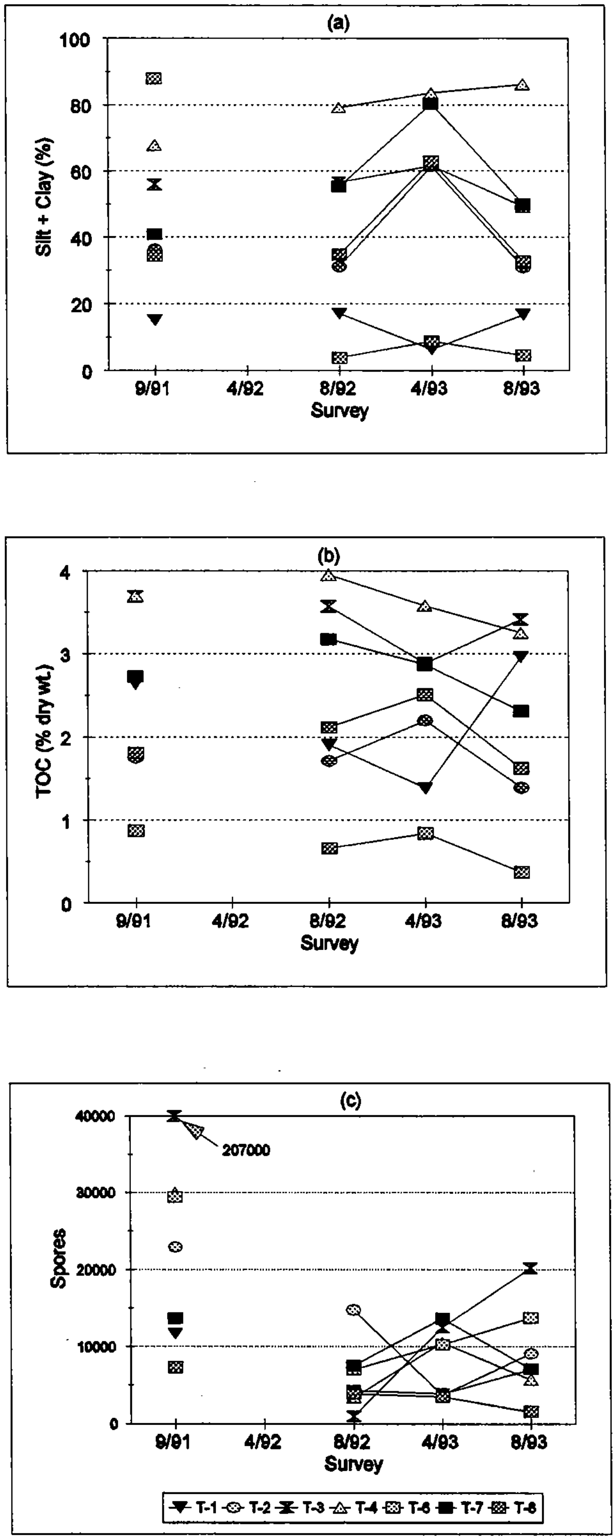


Figure 15. **Sediment percent silt + clay (a), total organic carbon (b), and *Clostridium perfringens* spore counts (c) at Boston Harbor traditional stations (except T-5) across all surveys. No data for April 1992 were collected.**

stations (T-2, T-6, and T-7) had a much higher silt + clay fraction than at late summer sampling periods (Figure 15, Table 10).

Of the 50 stations sampled for SPI in August 1993, 25 were sampled with REMOTS® on previous surveys in 1989/90 (Table 11). [See SAIC (1992) and Blake *et al.* (1993) for details of 1990 and 1992 sediment profile camera surveys]. For the 18 reconnaissance and 7 traditional stations with comparable data, modal sediment grain size remained the same from 1990-1992 to 1993, except for station R-33 at which the sediments were coarser in 1993 (Table 11). Surface relief was also relatively unchanged, with only three stations (stations T-1, R-32, R-42) differing between years. The constancy of both of these parameters through time indicated that physical conditions generally did not change.

***TOC and* Clostridium perfringens** — Sediment TOC has been remarkably consistent station-by-station over all surveys (Table 10; Figure 15). For any particular survey, TOC content was generally highest at stations T-3, T-4, and T-7, and lowest at station T-8.

Clostridium perfringens spore counts were much lower at all stations in August 1992 than in September 1991. Although there has been some variation since August 1992, station-by-station spore counts were still lower in August 1993 than they were in September 1991 (Figure 15, Table 10). At some stations, these differences have been large. For example, spore counts at station T-3 have dropped from 207,000 spores/g dry weight in 1991 to 20,200 spores/g dry weight in August 1993. Spore counts obtained in August 1993 were higher than those in April 1993 at stations T-1, T-2, T-3, and T-6 (Table 10), although in each case the August 1993 counts were less than those obtained for September 1991.

Apparent Redox Potential Discontinuity Depth — In September 1991, RPD depth estimates (from SPI analyses) were obtained for only three traditional (T-2, T-3, and T-4) and three reconnaissance (R-4, R-7, and R-11) stations. Among these stations, station R-11 was not sampled in August 1992 and station T-2 was not sampled adequately in August 1993. Among the four stations for which data were collected in all three years, stations R-4 and R-7 showed no net change in RPD_{SPI} depth from 1991 to 1993, although the RPD_{SPI} depth at each of these two stations was greater in 1992 (Figure 16). Stations T-3 and T-4 had greater RPD_{SPI} depths in 1993 than in 1991 or 1992 (Figure 16).

A more extensive comparison of RPD depth estimates obtained from SPI analyses was possible between August 1992 and August 1993. Six of the traditional stations were comparable (station T-2 was not sampled adequately in 1993 and the location of station T-5/T-5a has not been consistent among years). Among the six comparable stations, five had greater (i.e., the ranges were nonoverlapping) RPD_{SPI} depths in 1993 than in 1992. Therefore, increases in RPD_{SPI} depths were probably Harbor-wide, rather than

Table 11. **Comparison of 1990 and 1992 (SAIC 1992, Blake et al. 1993) with 1993 sediment profile image data. Comparisons were based on range of parameters from all replicate images.**

1993 Station	1992 Station	Sediment Type	Surface Relief	RPD	OSI	Success. Stage
T-1	T-1	0	-	+	+	0
T-2	T-2	0	0	nd	nd	nd
T-3	T-3	0	0	+	+	+
T-4	T-4	0	0	+	0	0
T-6	T-6	0	0	+	+	+
T-7	T-7	0	0	0	+	-
T-8	T-8	0	0	+	0	0
R-26	5	0	0	0	-	0
R-27	8	0	0	-	-	0
R-28	15	0	0	-	-	0
R-29	18	0	0	+	0	0
R-30	67	0	0	0	-	0
R-31	21	0	0	+	+	0
R-32	23	0	+	0	0	0
R-33	34	Coarser	0	0	0	-
R-34	27	0	0	0	-	-
R-35	29	0	0	-	-	-
R-36	26	0	nd	nd	nd	nd
R-37	40	0	0	0	0	-
R-38	38	0	0	-	0	0
R-39	41	0	0	0	-	0
R-40	59	0	0	0	0	-
R-41	57	0	0	-	0	-
R-42	58	0	+	+	0	-
R-43	16	0	0	0	0	0

0: No Change, overlapping range for parameter.
-: Reduction, lower non-overlapping range for 1993 data.
+: Increase, higher non-overlapping range for 1993 data.
nd: No data for comparison.

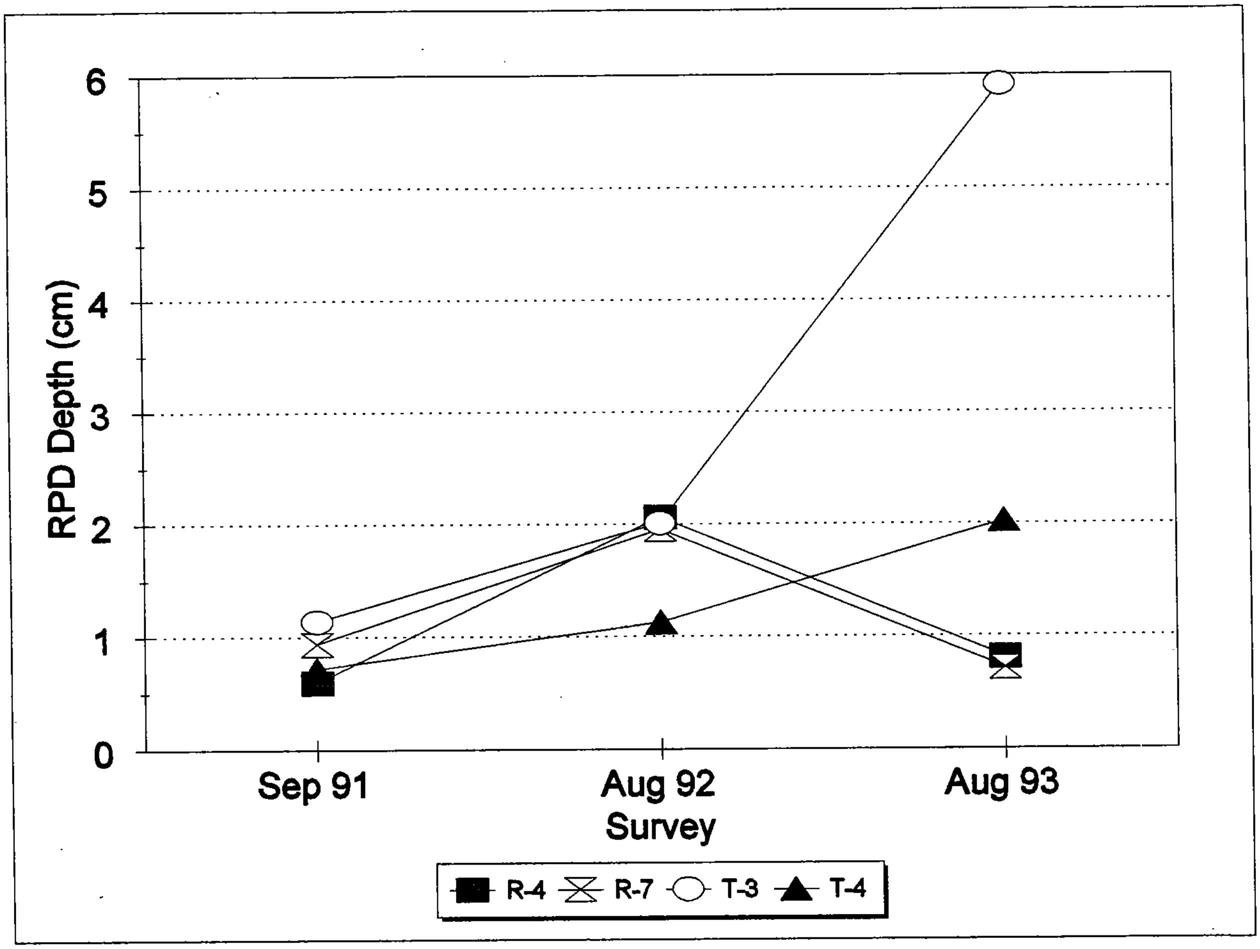


Figure 16. RPD depth as estimated by sediment profile image methods at the four stations sampled during each late summer survey between 1991 and 1993.

just at stations near the sludge discharge site. At station T-7 there was no difference between 1992 and 1993 RPD_{SPI} depth ranges. Eighteen of the reconnaissance stations that were sampled in 1992 were sampled again in 1993. Of the 17 with comparable data, 5 had shallower RPD_{SPI} depths in 1993 than in 1992, 3 had greater RPD_{SPI} depths in 1993, and 9 showed no difference between the two years. A comparison of RPD_{SPI} depth classes between 1992 and 1993 showed that no values greater than the 3-4 cm class were obtained in 1992, whereas the 4-5 cm, 5-6 cm, and 10-11 cm classes were represented in 1993 (Figure 17). The mean (± standard deviation) RPD_{SPI} depth (by station) in 1992 was 1.94 ± 0.79 cm (Blake *et al.*, 1993), compared to 2.37 ± 1.91 cm for 1993.

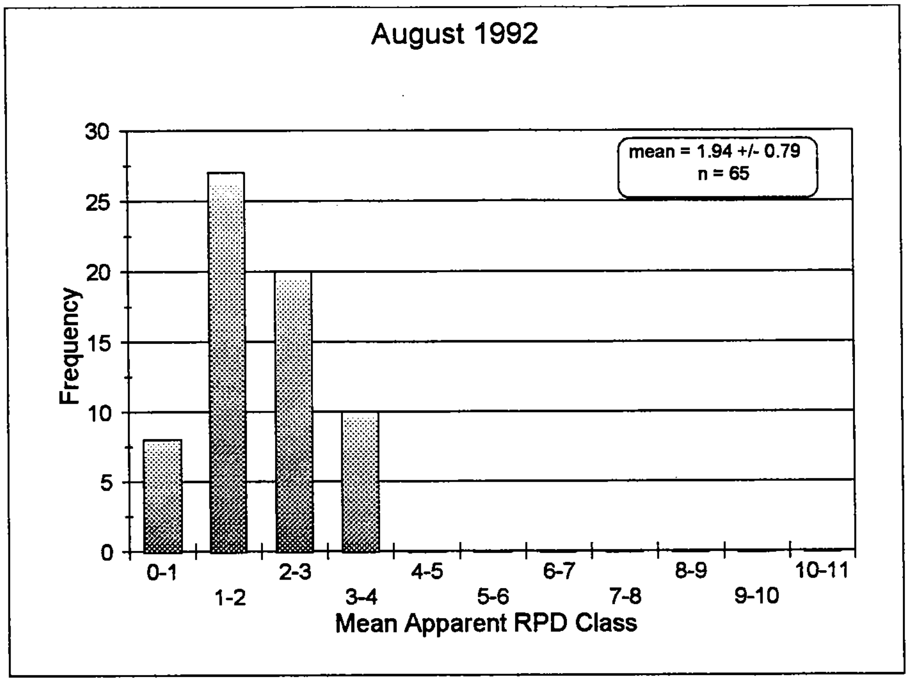
B. Infaunal Communities

Total Abundance — In 1991, late summer data were collected in mid-September, whereas in 1992 and 1993 they were collected in mid-August. For statistical comparisons across surveys, it was assumed that samples collected in September or August would be equivalent in representing late summer conditions. Without data to the contrary, the possibility that some of the statistical differences detected between 1991 and other years resulted from normal August–September changes cannot be rejected.

Across surveys, statistically significant differences were discovered in the mean total infaunal abundance at each station tested (Table 12). At six of the stations, these differences were highly significant ($p < 0.001$). At all stations except station T-7, the August 1993 and/or the August 1992 values were higher than those from all other surveys. Furthermore, total infaunal abundance was significantly greater in August 1993 than in September 1991 at all stations except station T-7. At stations T-3 and T-6, total infaunal abundance in August 1993 was greater than in August 1992, but at station T-4, it was significantly less in August 1993.

Compared to changes in abundance at other stations (e.g., stations T-1 and T-8), the changes in abundance at stations T-3 and T-6 have been dramatic (Figure 18). Mean (± 95% confidence intervals) total abundance at station T-3 was 2,360 (± 1,486.5) individuals/0.04 m^2 in September 1991, but increased to 13,932 (± 6,338.7) individuals/0.04 m^2 by August 1993. Station T-6 has shown a similar change in abundance, increasing from 2,214 (± 482.9) individuals/0.04 m^2 in September 1991 to 15,725 (± 5,407.8) individuals/0.04 m^2 in August 1993. Although these two examples were the most spectacular, it should be pointed out that infaunal abundances for the August 1993 survey were greater than those for the September 1991 survey at all stations except station T-7.

Seasonal differences in patterns of infaunal abundance were apparent. Significant differences between spring and late summer abundances were found at all stations tested



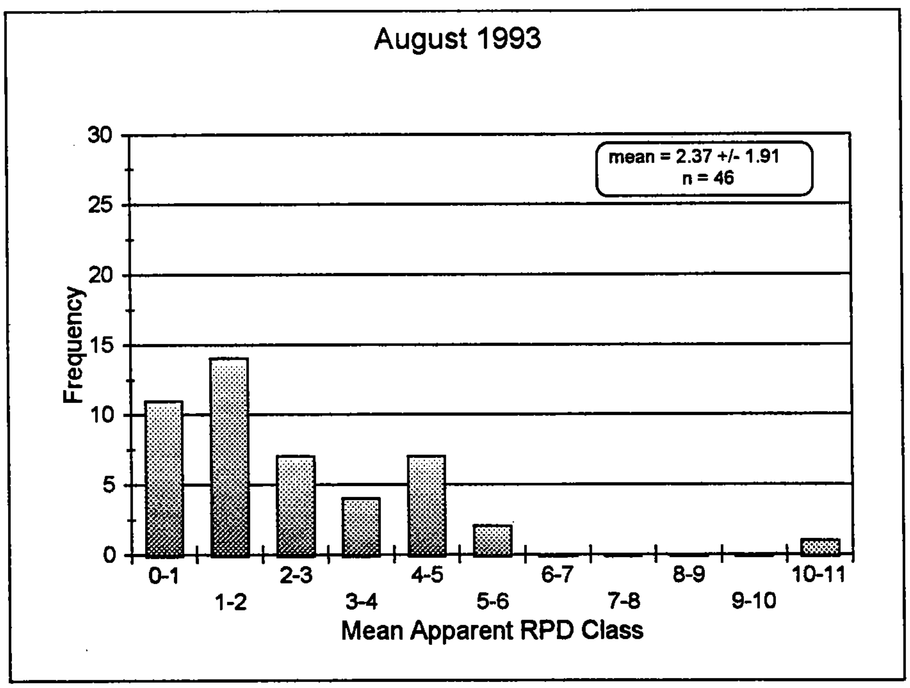


Figure 17. Histograms of mean apparent RPD depth class (cm) in Boston Harbor from August 1992 and August 1993. August 1992 data are from Blake *et al.* (1993).

Table 12. **Results of one-way ANOVA and associated Tukey test to show significant differences in abundance, number of species, and diversity among surveys at selected Boston Harbor stations (df=4,10).**

Factors are ordered by decreasing average values. Those connected by straight lines have differences not significantly different from zero (α=0.05).

Parameters	ANOVA *F*	ANOVA *P*	Tukey Grouping				
Abundance							
T-1	22.89	<0.001	8/92	8/93	4/92	9/91	4/93
T-2	119.26	<0.001	8/92	8/93	4/92	4/93	9/91
T-3	16.64	<0.001	8/93	8/92	4/93	9/91	4/92
T-4	36.09	<0.001	8/92	4/92	4/93	8/93	9/91
T-6	38.50	<0.001	8/93	8/92	4/93	9/91	4/92
T-7	4.45	0.025	8/93	8/92	9/91	4/92	4/93
T-8	27.71	<0.001	8/93	8/92	4/93	9/91	4/92
Species							
T-1	23.64	<0.001	8/92	8/93	4/92	9/91	4/93
T-2	66.36	<0.001	8/93	8/92	4/93	4/92	9/91
T-3	27.44	<0.001	8/93	8/92	4/93	4/92	9/91
T-4	11.15	0.001	4/93	8/93	4/92	8/92	9/91
T-6	7.61	0.004	8/92	8/93	4/93	4/92	9/91
T-7	7.65	0.004	8/93	8/92	4/92	4/93	9/91
T-8	13.78	<0.001	8/93	8/92	9/91	4/93	4/92
Diversity (*H'*)							
T-1	11.10	0.001	4/92	9/91	4/93	8/92	8/93
T-2	14.54	<0.001	8/93	8/92	4/93	4/92	9/91
T-3	9.25	0.002	4/92	8/93	4/93	8/92	9/91
T-4	61.68	<0.001	4/92	4/93	8/93	9/91	8/92
T-6	26.65	<0.001	4/92	8/93	8/92	4/93	9/91
T-7	2.97	0.074	NA				
T-8	2.55	0.105	NA				

NA: Not applicable (ANOVA showed no significant differences among surveys at α=0.05).

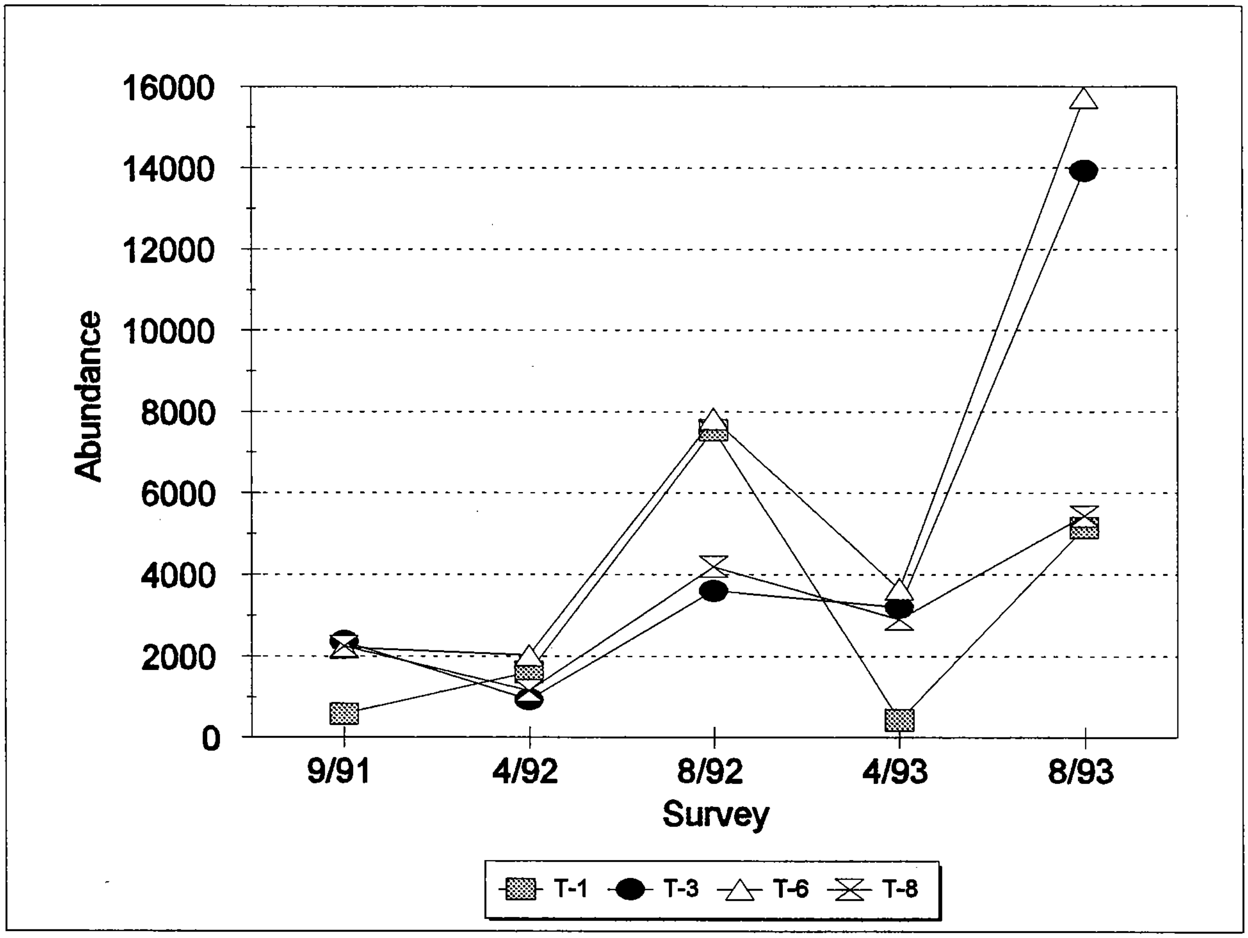


Figure 18. **Mean total infaunal abundance (#/0.04 m^2) at four Boston Harbor traditional stations (1991–1993).**

except station T-4 (Table 13). In each case, abundance was greater in the late summer than in the spring.

The proportion of polychaetes and arthropods to total infaunal abundance at all stations has usually exceeded 0.90 for each survey. However, the proportions of the two taxa have differed at some stations across surveys. At stations T-3, T-6, and T-8, the proportion of polychaetes has decreased from about 0.60–0.94 in September 1991 to about 0.29–0.34 in August 1993. Conversely, the proportion of arthropods at these three stations has changed from about 0.03–0.30 in September 1991 to about 0.60–0.71 in August 1993. The switch from predominantly polychaete communities to predominantly arthropod communities apparently occurred after the August 1992 survey (Figure 19). The relative contribution of the two taxa has remained fairly consistent at stations T-1 (Figure 19), T-2, and T-4.

Numbers of Species — Each station tested showed significant variation among surveys in the mean number of species per sample (Table 12). In general, the mean number of species per sample has increased since the September 1991 survey. For example, at stations T-1, T-2, and T-8, the mean number of species found in August 1992 and August 1993 was greater than for other surveys. Furthermore, at each station, the August 1992 and 1993 samples contained more species than the September 1991 samples. Comparisons between spring and late summer revealed significant differences in the number of species at all stations tested, except stations T-3 and T-6 (Table 13). The number of species was higher in the late summer than in the spring at all stations except station T-4.

The relative contribution of polychaetes and arthropods to the total number of species at stations T-1, T-3, T-6, and T-8 has not changed dramatically since 1991 (Figure 19). Polychaetes typically have accounted for about 50–70% of the species at any particular station. The percentage of arthropod species at most stations usually has ranged from about 15–25%.

Indices — Significant among-survey variation in species diversity (H') was found for five of the seven stations tested (Table 12). No significant differences in H' among surveys were found at stations T-7 and T-8. At two stations (T-1 and T-6), average species diversity was highest in April 1992. At two other stations (T-3 and T-4), average diversity was numerically higher, though not significantly different from either the April 1993 (T-3 and T-4) or August 1993 (T-3) values. Examination of the most recent survey and the pre-abatement survey showed that species diversity in August 1993 was significantly greater than that in September 1991 only at stations T-2 and T-6. Comparisons of H' between seasons revealed significant variation at four of the stations tested (Table 13). Late summer values were lower than spring values at stations T-1, T-3, T-4, and T-6, but the values were higher at station T-2. As might be expected, dominance values generally mirrored diversity values, being low where diversity was

Table 13. **Results of t-tests comparing average late summer and average spring values for abundance, number of species, and diversity (H') at selected Boston Harbor stations.**

Positive differences indicate the late summer values were greater than the spring values. Differences in abundance are based on ln-transformed means; differences in species numbers and diversity are based on untransformed means.

Parameter	Station	Difference	Standard Error of Difference	t	$p>\|t\|$[a]
Abundance					
	T-1	1.249	0.257	4.86	<0.001
	T-2	0.329	0.137	2.41	0.040
	T-3	1.022	0.221	4.63	<0.001
	T-4	0.105	0.136	0.77	0.458ns
	T-6	0.869	0.128	6.80	<0.001
	T-7	0.868	0.237	3.66	0.004
	T-8	0.698	0.106	6.57	<0.001
Species					
	T-1	12.389	2.550	4.86	<0.001
	T-2	8.111	1.472	5.51	<0.001
	T-3	3.278	1.575	2.08	0.064ns
	T-4	-4.167	0.962	-4.33	0.002
	T-6	2.667	1.948	1.37	0.201ns
	T-7	4.000	1.764	2.27	0.047
	T-8	14.667	2.281	6.43	<0.001
H'					
	T-1	-0.640	0.149	-4.29	0.002
	T-2	0.297	0.205	1.45	0.178ns
	T-3	-0.042	0.100	-4.18	0.002
	T-4	-0.904	0.061	-14.74	<0.001
	T-6	-0.240	0.050	-4.79	<0.001
	T-7	0.136	0.081	1.68	0.124ns
	T-8	-0.016	0.164	-0.10	0.926ns

ns: no significant difference

[a] Probability associated with the absolute value of t.

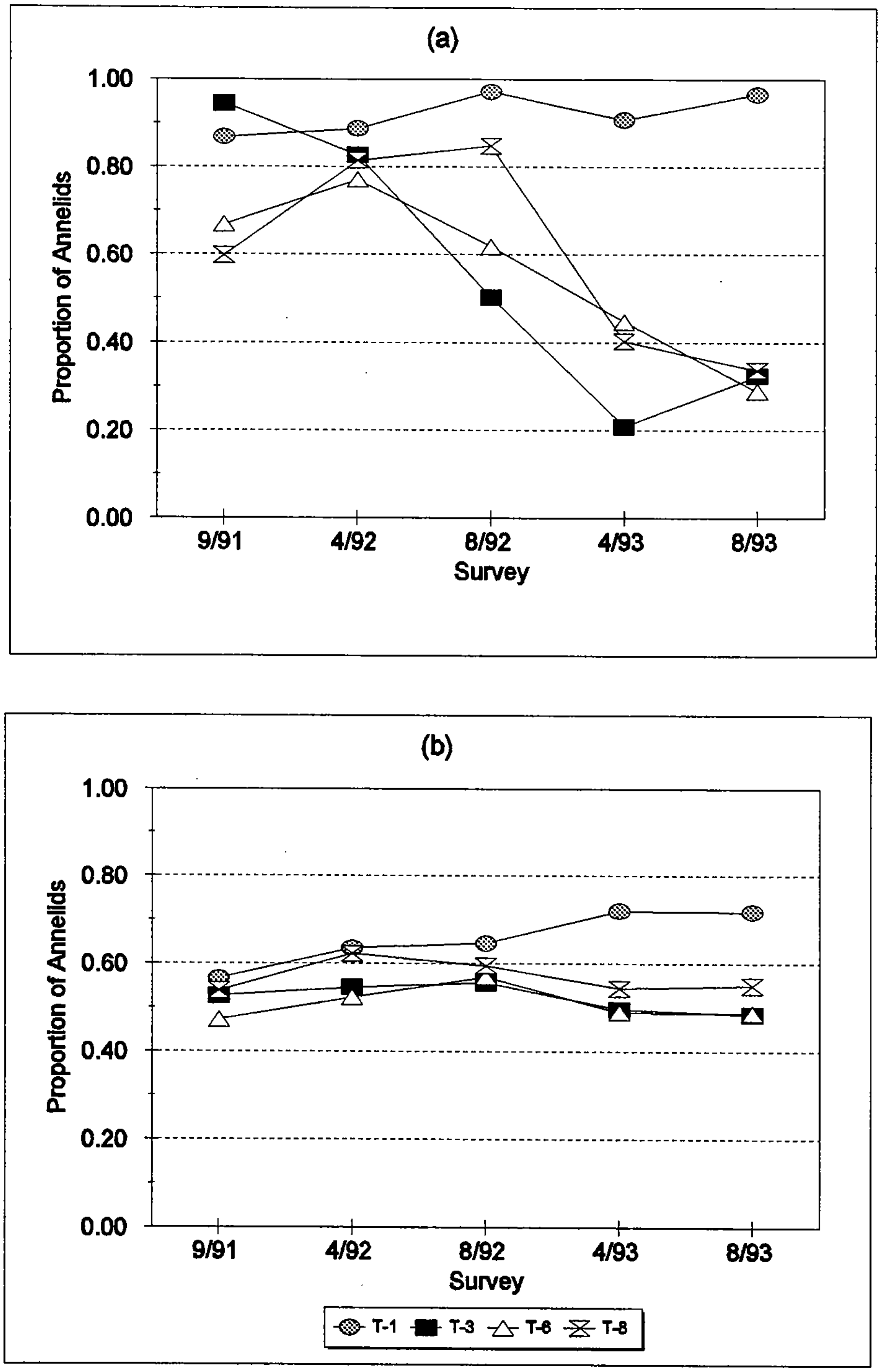


Figure 19. **Proportion of infaunal abundance (a) or numbers of species (b) attributable to annelids at four Boston Harbor traditional stations (1991–1993).**

high and vice versa. The highest dominance values (0.87–0.99) have been found in late summer samples from station T-4. Dominance values have been lowest (0.10–0.20) at station T-3.

Predominant Species — In the Harbor, several differences related to the predominant taxa present in 1991 and those present in late summer 1993 were detected. Oligochaete worms apparently declined in abundance relative to other taxa at each station. Although not identified to species, oligochaetes were the predominant taxon at stations T-1, T-3, and T-6 in 1991 and in April 1992. When the September 1991 data from traditional stations are coupled with data from the analysis of reconnaissance grab samples, the overall predominance of oligochaetes in the Harbor is clear (Figure 20). Oligochaetes were among the four predominant taxa from the Inner Harbor to Deer Island, and south around Peddocks Island. By August 1993, oligochaetes were predominant only at station T-5a. Furthermore, the overall importance of the group was restricted to small areas between Deer Island and Long Island, south of Long Island, south of Peddocks Island, and at station R-10 in the Inner Harbor (Figure 20). Absolute oligochaete abundance also has changed across surveys. The Kruskal-Wallace analysis detected significant differences across surveys in the mean abundance of oligochaetes at all stations except T-3 and T-7 (Table 14). Oligochaete densities ranged up to 2024.3 individuals/0.04 m^2 at station T-3 in 1991, but declined to a maximum density of 874.7 individuals/0.04 m^2 in 1993.

Oligochaete abundance at station T-6 showed an interesting pattern of change, increasing in abundance from 661.3 individuals/0.04 m^2 in 1991 to 1411.3 individuals/0.04 m^2 in August 1992, then decreasing to 72.3 individuals/0.04 m^2 in August 1993. Species identification of oligochaetes since April 1992 may have detected a change in the relative contribution of the two major oligochaete species present at some stations (Figure 21). In a comparison of the relative abundance of the two primary oligochaete species, *Tubificoides* nr. *pseudogaster* and *T. apectinatus,* the former was found to be the predominant oligochaete present at all stations in August 1992, comprising from 64% (station T-7) to 99% (station T-1) of the combined abundance of the two species. The relative abundance of *T.* nr. *pseudogaster* at stations T-1 and T-2 has not changed since August 1992, although the total number of oligochaetes has decreased at those two stations. No net change in relative abundance of the two species was found at station T-7, although the proportion of *T.* nr. *pseudogaster* was lower at station T-7 than elsewhere in the Harbor. At stations T-3 and T-8, there may have been a slight change in the relative proportions of the two species (Figure 21). A strong shift in the relative contribution of the two species has occurred at station T-6, where the percentage of *T. apectinatus* increased from 4% in 1992 to 54% in August 1993. The ecological significance of this apparent shift is not clear.

For comparisons of the predominance of several other species, oligochaetes (because they were not identified to species) were excluded. *Streblospio benedicti,* a polychaete worm, was the predominant species at stations T-1, T-2, T-4, and T-7 in 1991. In

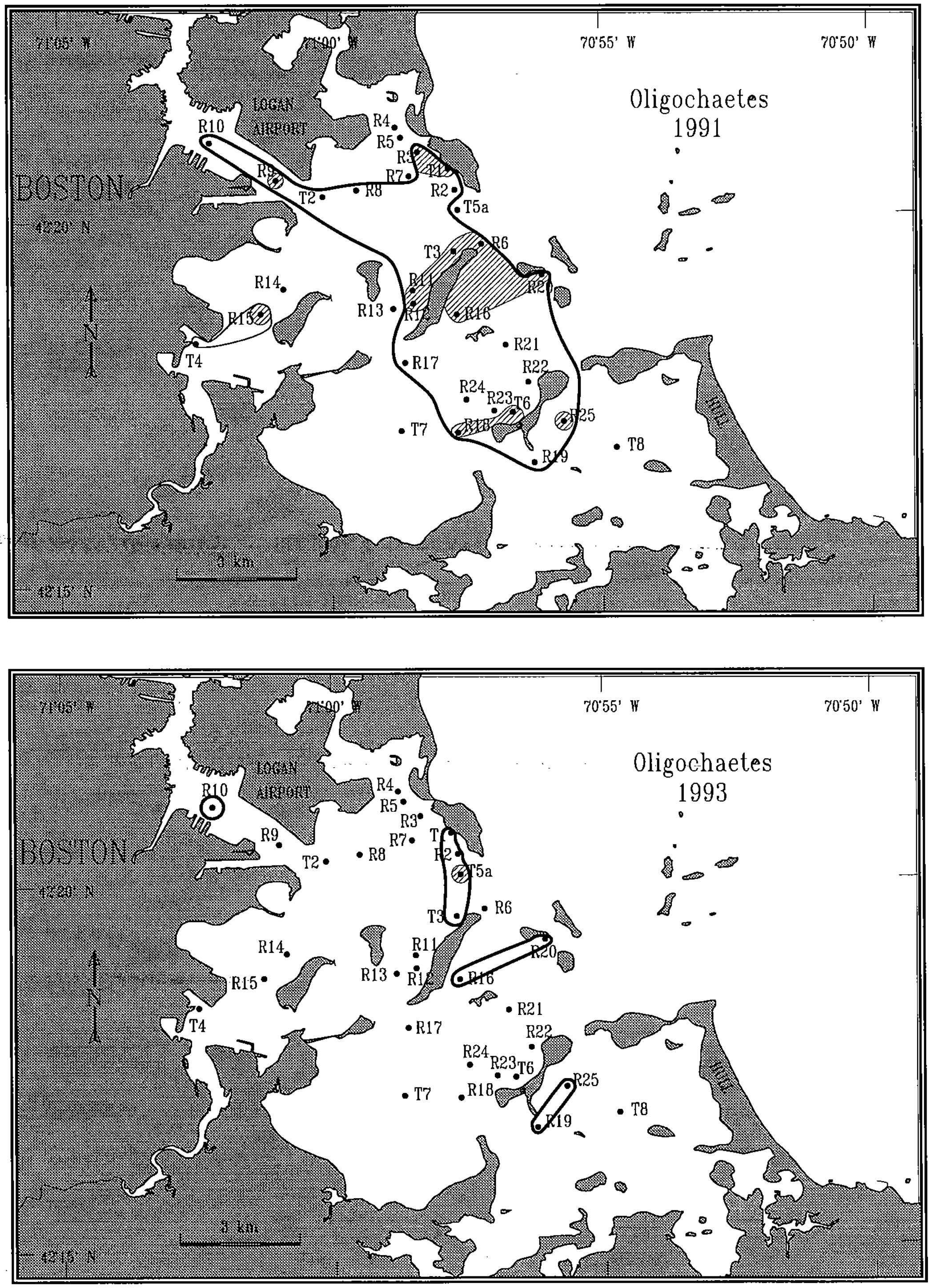


Figure 20. Map of Boston Harbor showing areas where oligochaetes were among the four most abundant taxa (bold lines) or the most abundant taxon (hatched areas) at Boston Harbor traditional or reconnaissance stations in September 1991 and August 1993.

Table 14. **Results of nonparametric Kruskal-Wallace tests comparing the abundances of selected taxa at Boston Harbor stations (except T-5) among surveys. Taxa were selected as representatives of each major phylum contributing to infaunal communities in Boston Harbor.**

Station	Oligochaetes		*Capitella capitata*		*Streblospio benedicti*		*Ampelisca*		*Ilyanassa trivittata*	
	X^2	p	X^2	p	X^2	p	X^2	p	X^2	p
T-1	11.23	0.024	4.53	0.339_{ns}	11.73	0.019	11.18	0.025	8.99	0.061_{ns}
T-2	11.73	0.019	10.39	0.034	9.63	0.047	10.69	0.030	4.09	0.394_{ns}
T-3	8.43	0.077_{ns}	9.79	0.044	8.04	0.090_{ns}	12.32	0.015	5.37	0.252_{ns}
T-4	13.41	0.010	13.78	0.008	12.90	0.012	12.82	0.012	NA	
T-6	11.17	0.025	8.38	0.079_{ns}	11.02	0.026	12.10	0.017	6.17	0.187_{ns}
T-7	7.10	0.131_{ns}	4.51	0.341_{ns}	6.53	0.163_{ns}	12.90	0.012	10.36	0.035
T-8	10.70	0.030	10.92	0.027	2.37	0.668_{ns}	12.28	0.015	9.78	0.044

ns: No significant differences among surveys at $\alpha = 0.05$
NA: Not applicable, no individuals present at station T-4

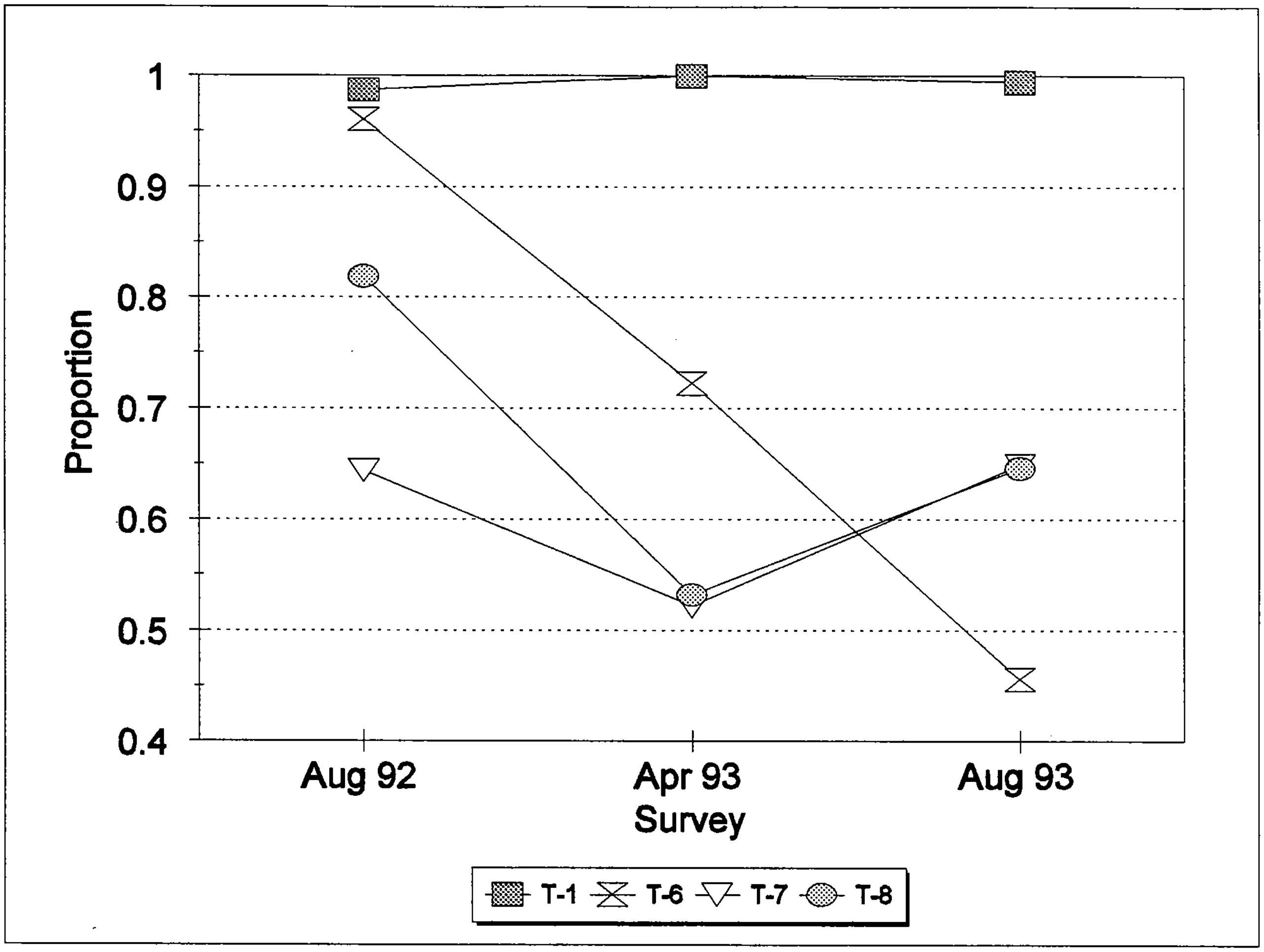


Figure 21. Proportion of individuals of the oligochaete genus *Tubificoides* identified as *T.* nr. *pseudogaster* at four Boston Harbor traditional stations (1992–1993).

addition, reconnaissance samples showed that *S. benedicti* was among the four predominant taxa across much of the northern Harbor (Figure 22). By August 1993, the species predominated only at station T-4, although reconnaissance samples still showed *S. benedicti* to be important across much of the northern Harbor (Figure 22).

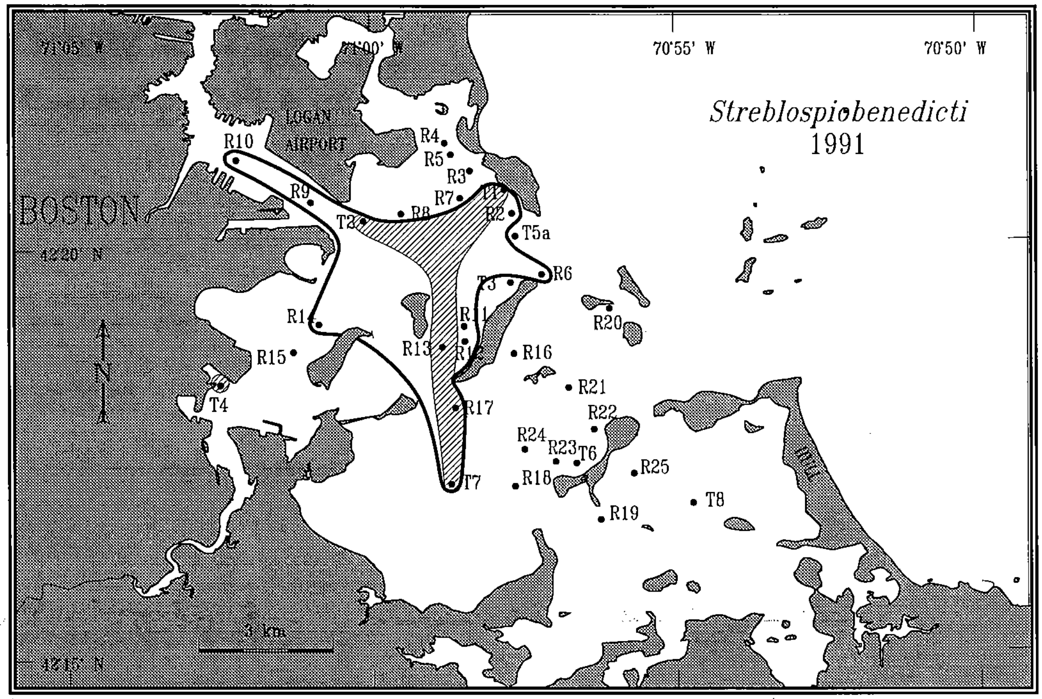
Significant across-survey differences in the abundance of *S. benedicti* at stations T-1, T-2, T-4, and T-6 were found (Table 14). These differences do not necessarily represent decreases in abundance. For example, at station T-2, the density of *S. benedicti* has increased from 24.0 individuals/0.04 m^2 in 1991 to 544.3 individuals/0.04 m^2 in August 1993.

Significant across-survey differences were found in the abundance of another polychaete worm, *Capitella capitata,* at stations T-2, T-3, T-4, and T-8 (Table 14). *Capitella* has consistently been among the 10 most numerous species at station T-1, although it has not been very numerous anywhere else in the study area.

Ampelisca, an amphipod that was not identified to species, increased in predominance and abundance during the study period (Figure 23). In 1991, *Ampelisca* was the predominant species only at stations T-6, R-21, R-22, and R-23. This species complex was among the four predominant taxa from the north side of Long Island, the middle Harbor, and southeast of Peddocks Island (Figure 24). In August 1993, it was the predominant taxon at traditional stations T-6, T-7, and T-8, as well as at nine reconnaissance stations (Figure 24). *Ampelisca* also showed increased importance along Deer Island in 1993. Significant differences were detected in the abundance of *Ampelisca* at all stations across surveys (Table 14). The increase in numbers of *Ampelisca* at station T-6 was dramatic, increasing from 612.7 individuals/0.04 m^2 in 1991 to 2,485.3 individuals/0.04 m^2 in August 1992, and to 5,227.7 individuals/0.04 m^2 in August 1993. In August 1993, *Ampelisca* was ranked among the top 10 taxa at all stations except station T-5a.

Although the predominant taxon only at stations T-5, R-2, and R-3 in September 1991, the gastropod *Ilyanassa trivittata* was among the four predominant taxa in much of the northern Harbor (Figure 25). In August 1993, *I. trivittata* was not among the predominant taxa at any station. Significant differences in the numbers of *I. trivittata* across surveys were detected only at stations T-7 and T-8 (Table 14). Although these differences were not partitioned statistically, it appeared that the abundance of *Ilyanassa* has decreased since 1991.

Periodically, several other taxa were predominant at various stations. Among the most striking examples were the polychaete, *Polydora cornuta,* and the amphipod, *Corophium bonellii. P. cornuta* was the predominant taxon in the northern Harbor in August 1993. However, it was common only during late summer (Figure 23). *Corophium bonellii,* which first appeared in April 1992, increased in abundance dramatically at stations T-3 and T-6 by August 1993 (Figure 23). *C. bonellii* reached a density of



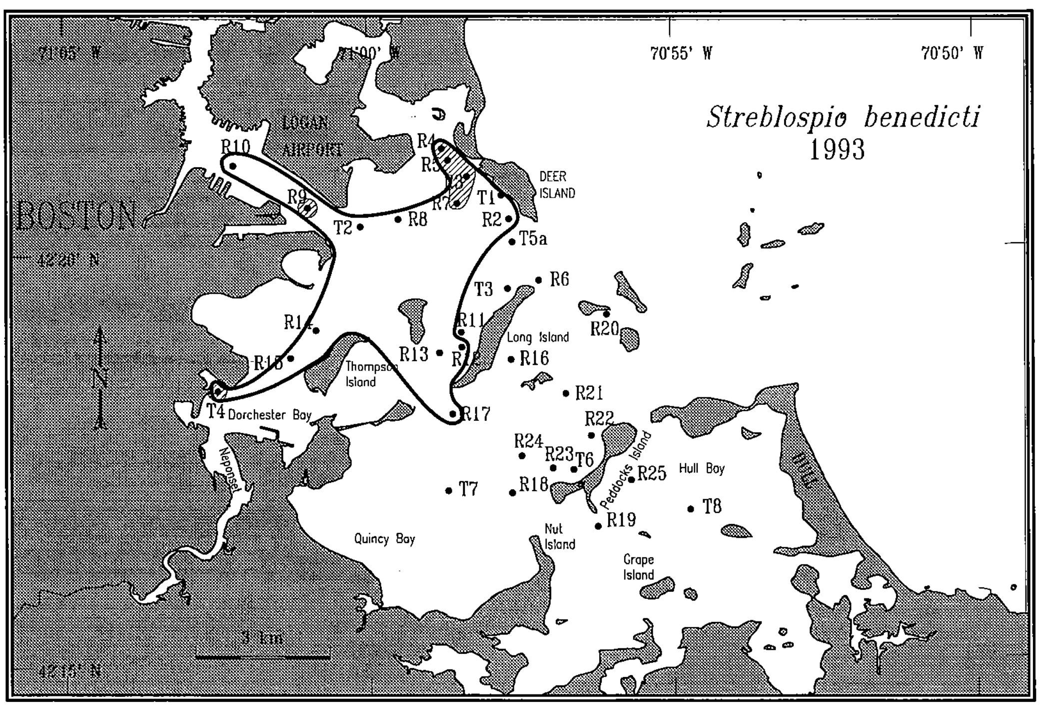


Figure 22. Map of Boston Harbor showing areas where *Streblospio benedicti* was among the four most abundant taxa (bold lines) or the most abundant taxon (hatched areas) at Boston Harbor traditional or reconnaissance stations in September 1991 and August 1993.

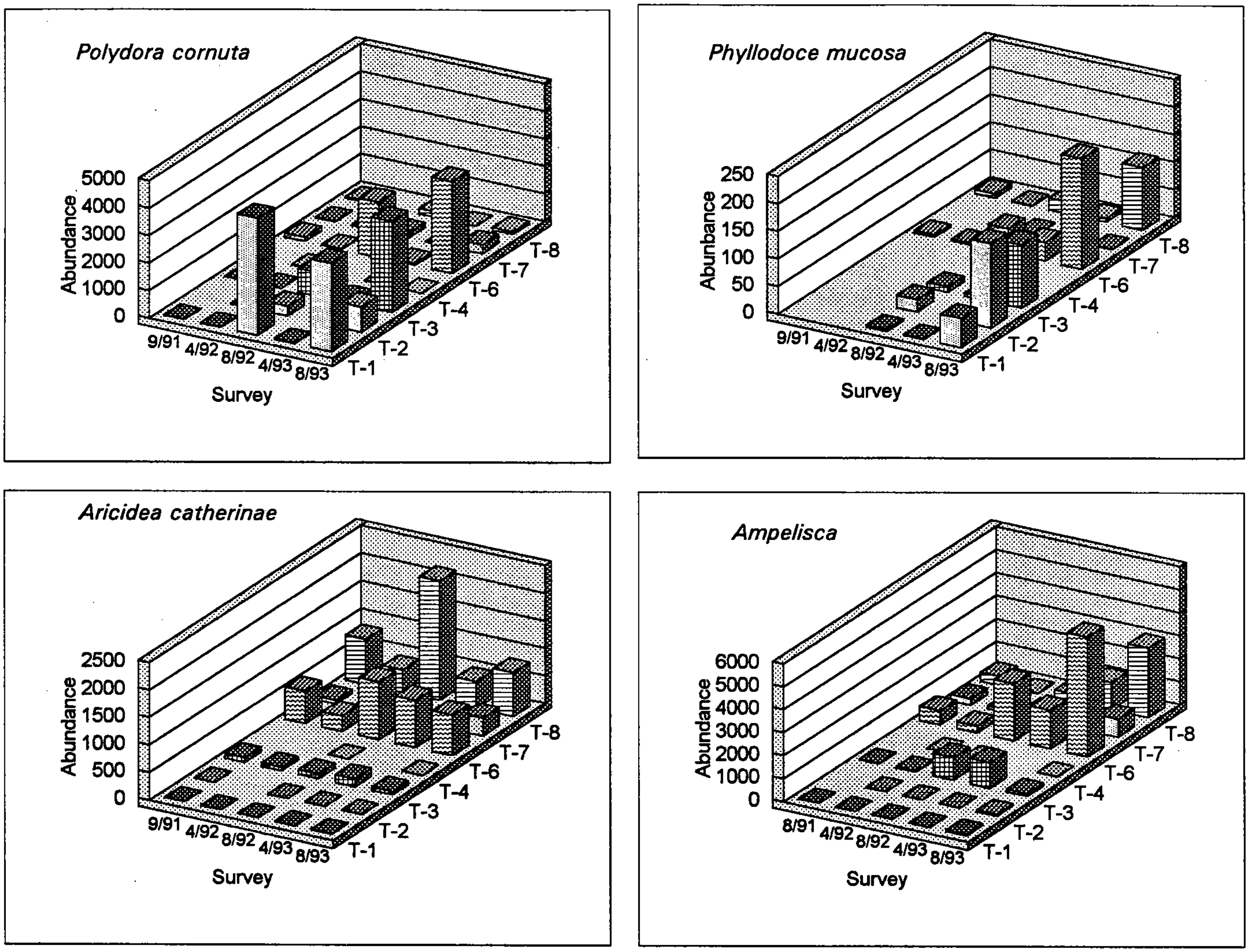


Figure 23. **Abundance (#/0.04 m²) of *Polydora cornuta*, *Phyllodoce mucosa*, *Aricidea catherinae*, and *Ampelisca* at Boston Harbor traditional stations (except T-5) across all surveys. Note that scales of Y-axes differ.**

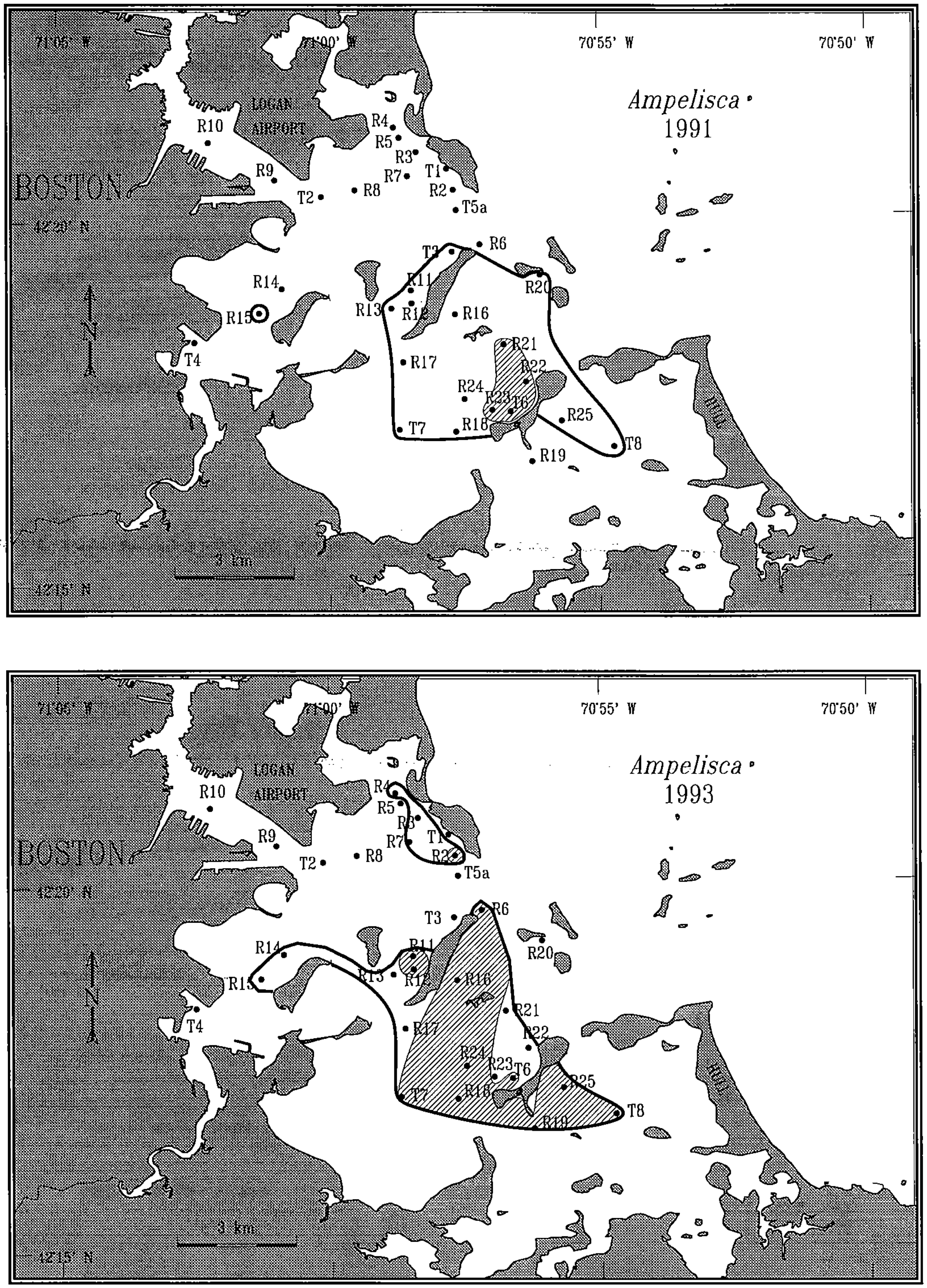


Figure 24. **Map of Boston Harbor showing areas where *Ampelisca* was among the four most abundant taxa (bold lines) or the most abundant taxon (hatched areas) at Boston Harbor traditional or reconnaissance stations in September 1991 and August 1993.**

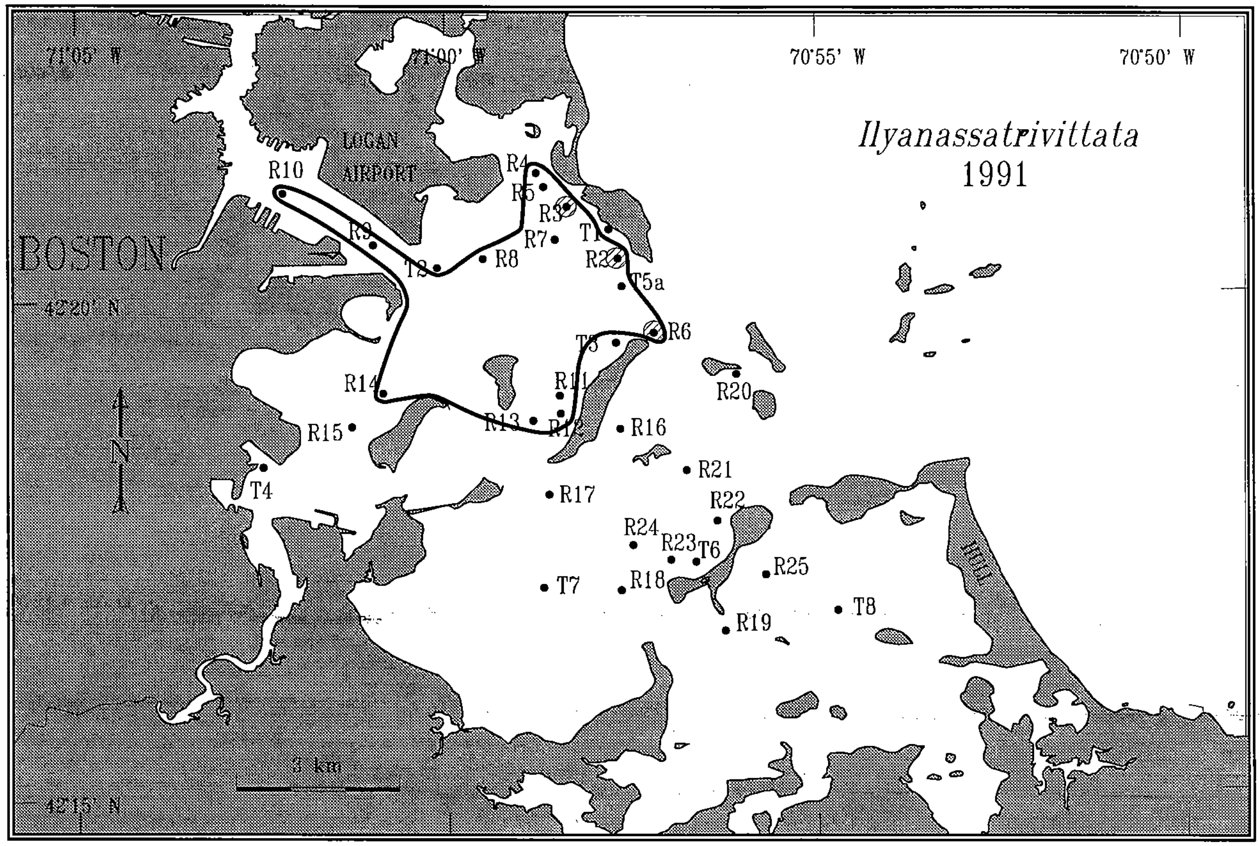


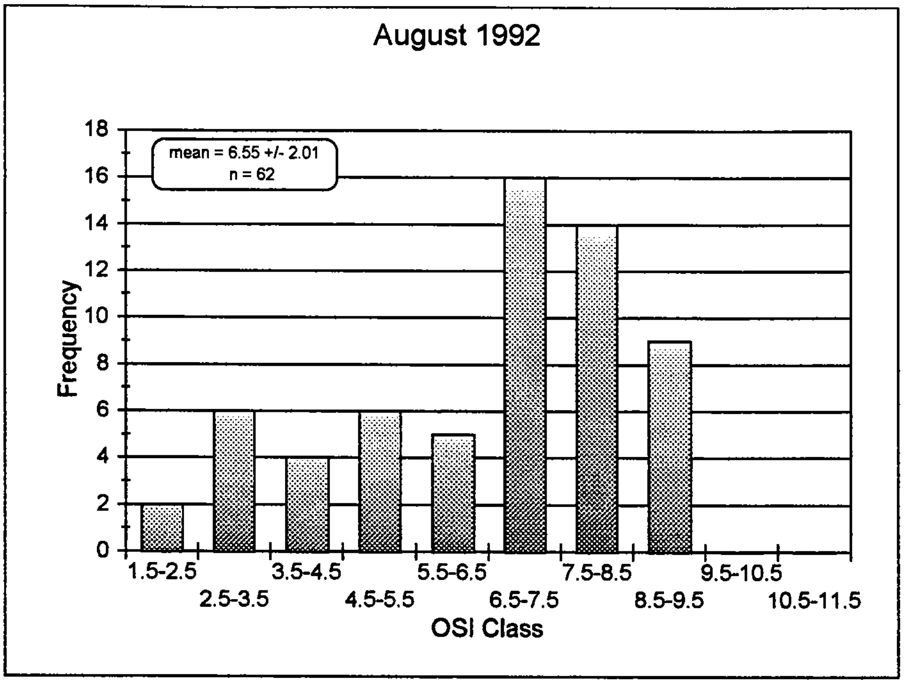
Figure 25. Map of Boston Harbor showing areas where *Ilyanassa trivittata* was among the four most abundant taxa (bold lines) or the most abundant taxon (hatched areas) at Boston Harbor traditional or reconnaissance stations in September 1991.

1,265.0 individuals/0.04 m^2 at station T-3 and 3,932.7 individuals/0.04 m^2 at station T-6. Relatively large amphipods, *Leptocheirus pinguis* and *Unciola irrorata,* also increased in abundance at stations T-3 and T-6 (Tables 7 and 8). *Phyllodoce mucosa,* a polychaete that was uncommon in 1991, increased in abundance and geographic coverage by August 1993 (Figure 23). *Aricidea catherinae*, a polychaete, consistently was common in the southern Harbor during the study period, but did not become a major part of the northern Harbor fauna (Figure 23).

Successional Stages and the Organism-Sediment Index — Community successional stage was determined for 23 of the 25 stations sampled in common between 1992 and 1993. No overall change (i.e., the ranges overlapped) in successional stage was detected between years for 13 of the stations (Table 11). Eight stations showed earlier successional stages in 1993 than in 1992; three were located in Dorchester Bay (stations R-40, R-41, R-42) and five were located in Quincy Bay (stations T-7, R-33, R-34, R-35, R-37). Stations T-3 and T-6 had later successional stages in 1993 than in 1992.

Between 1992 and 1993, no differences were detected in the ranges of OSI values at 11 of the commonly sampled stations (Table 11). OSI values were lower at seven stations (three in Quincy Bay and four adjacent to station T-8). At five stations (T-1, T-3, T-6, T-7, and R-31), OSI values were higher in 1993 than in 1992. A histogram of OSI classes, similar to that found in Figure 8 of Blake *et al.* (1993), was generated. Although mean OSI values were generally similar between the two years, two higher classes were represented in 1993 (Figure 26). However, note that the 1992 data include stations that were not sampled in 1993, and the effect of these additional data on the comparison was not estimated.

Numerical Classification — Classification (based on NESS similarity analysis) conducted on all stations (with replicates pooled) for all surveys revealed several interesting clusters (Figure 27). Three major, relatively dissimilar, groups of stations were apparent. The first group, which joined the remaining stations at a NESS similarity of 0.24, consisted of station T-4 collections from all three late summer surveys. The second large group, linked to the remaining stations at a NESS similarity of 0.42, was composed of all station T-6 and station T-8 collections, as well as the station T-3 samples collected after April 1992. The third major group consisted of the April station T-4 samples, the station T-3 samples collected before August 1992, all station T-7 samples, and all stations in the northern Harbor (including the station T-5, R-6, T-5a complex). This grouping of stations generally showed consistent linkage of stations from year to year. The notable exception to this consistency was the placement of samples from station T-3. Collections made at station T-3 during September 1991 and April 1992 were linked to stations located primarily in the northern region of the Harbor. However, samples collected from station T-3 after April 1992 clustered with stations located toward the southern region of the Harbor (station T-6 and T-8).



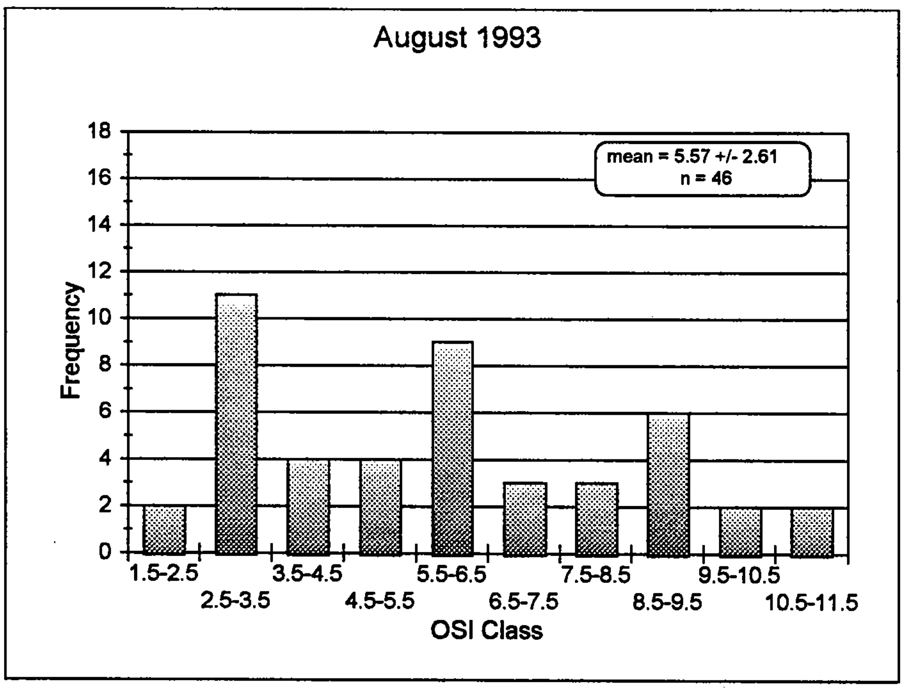


Figure 26. Histograms of mean organism-sediment index (OSI) class in Boston Harbor from August 1992 and August 1993. August 1992 data are from Blake *et al.* (1993).

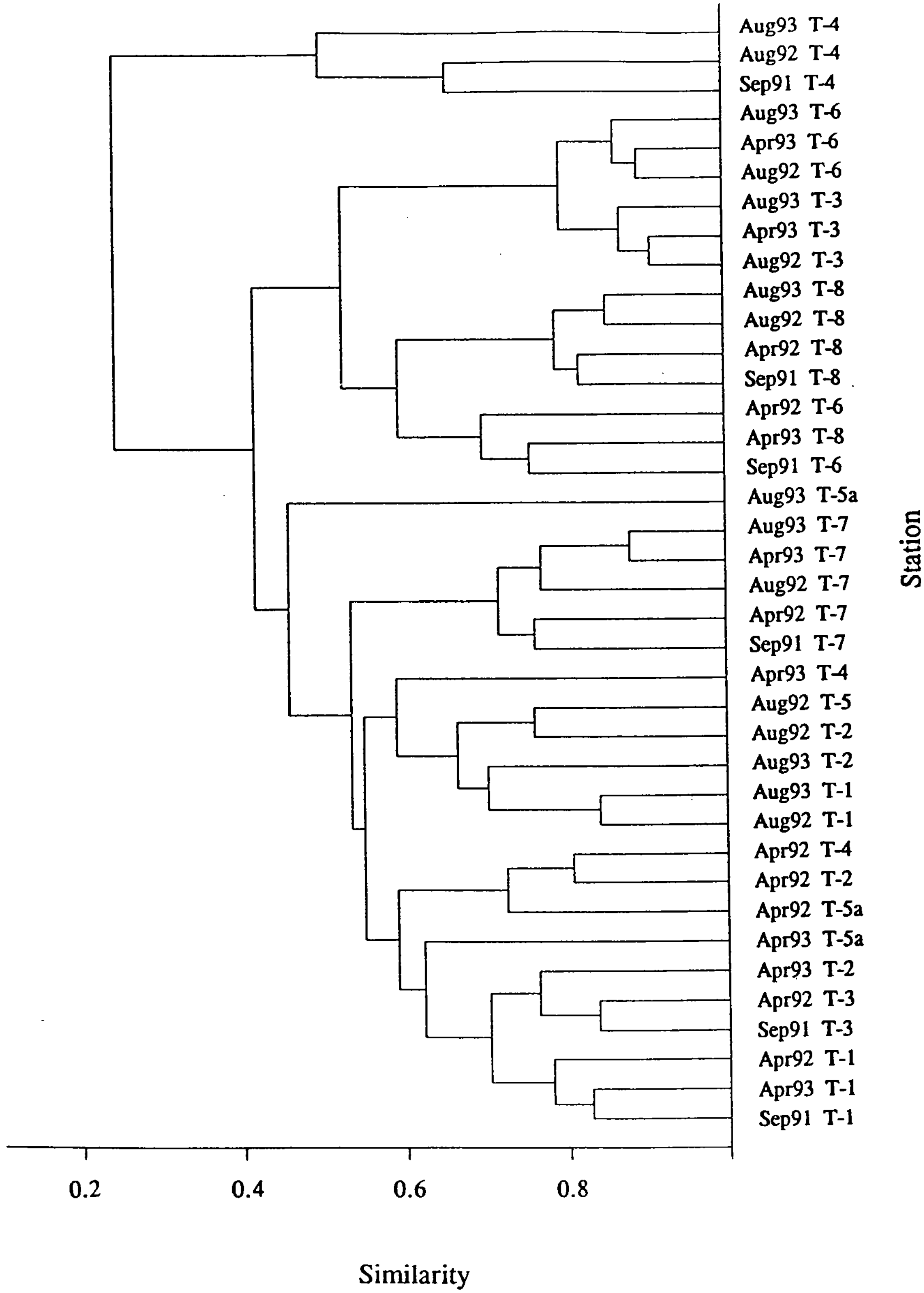


Figure 27. Dendrogram resulting from NESS similarity analysis of all Boston Harbor traditional stations across all surveys (1991–1993).

Sediment: Infauna Correlations — Data from all surveys (except April 1992) were used to calculate Pearson correlation coefficients between the bulk sedimentary parameters and several biological measurements. Few of the comparisons were significantly correlated (Table 15), which probably reflects the dramatic fluctuations in biological parameters that have not been observed in the physical parameters.

DISCUSSION

Sediment Quality — Although there has been some variation in sediment grain size composition at some stations, in general the observed sedimentary environments appeared to be as previously described for Boston Harbor (Knebel, 1993; Knebel and Circe', ms.). The large-scale differences observed at station T-8 between September 1991 and the subsequent surveys, as well as the differences at the station T-5/R-6/T-5a complex, probably reflect substrate patchiness within the Harbor.

Sediment TOC content, which has been used as an approximate measure of organic enrichment (e.g., Maurer *et al.*, 1993), is generally expected to decrease temporally after cessation of a major source of organic input to the Harbor. This decrease is also expected to be most noticeable at station T-3, which was probably most affected by sludge discharge. However, decreases in sediment TOC have not been observed. It is possible that sediment TOC content may be a bulk sedimentary parameter that is slow to change after cessation of organic inputs. Alternatively, organic input (e.g., effluent discharge and plankton production/deposition) may still be strong enough to maintain the elevated sediment TOC levels.

Sedimentary concentrations of spores of the enteric bacterium *Clostridium perfringens,* a parameter used by MWRA as a sewage tracer (Conner *et al.*, 1994), are expected to decrease following the cessation of sludge discharge into the Harbor. Quantitative predictions of the decrease in *Clostridium* spore counts are not available. However, the process may be slow because decreased sedimentary spore counts result primarily from deposition of new material that has low numbers of spores, and such new deposition is probably very small relative to background spore levels present in the Harbor sediments. However, a 100-fold decrease in *Clostridium* spores, six months after sludge discharge abatement, was observed in the Christiaensen Basin (New York Bight Apex) near the former sludge discharge site (Davis and Watkins, 1991). Davis and Watkins suggested that resuspension activity may have contributed to these decreased spore counts. Although spore concentrations at some stations (e.g., T-1, T-2, T-3, and T-6) were higher in August 1993 than in April 1993, spore counts at all stations were lower in 1993 than in September 1991. The slight increases in the August 1993 spore counts at the four stations mentioned may have resulted from continuing nearby effluent discharge that may serve as a source of *Clostridium* spores (Valente *et al.*, 1992).

Table 15. **Pearson correlation coefficients (*r*) between biological and abiotic parameters using all survey (except April 1992) data. Critical limits of *r* for n = 32 are 0.349 at α = 0.05 and 0.449 at α = 0.01 (from Table Y in Rohlf and Sokal, 1969)**

	Silt+Clay	TOC	*C. perfringens*
Abundance			
Total	-0.18106	-0.05195	-0.03967
Annelids	-0.31132	-0.06951	0.01041
Arthropods	-0.01018	0.02000	-0.06359
Species			
Total	-0.40586*	-0.44495*	-0.17403
Annelids	-0.42816*	-0.43172*	-0.21749
Arthropods	-0.28972	-0.29968	-0.18501
Diversity (*H'*)	-0.33545*	-0.43756*	0.00474
Selected Taxa			
Oligochaetes	-0.17425	0.08447	0.60674**
Capitella capitata	-0.30343	-0.12743	0.04720
Polydora cornuta	-0.19618	0.07165	-0.10620
Tharyx acutus	-0.22148	-0.10058	-0.11915
Streblospio benedicti	0.30109	0.38773*	-0.14603
Ampelisca	-0.12658	-0.23954	-0.11801
Leptocheirus pinguis	0.08544	0.18291	-0.05824
Photis pollex	0.01486	0.15599	-0.03305
Corophium bonellii	-0.01166	-0.01203	-0.01896
Ilyanassa trivittata	-0.09742	-0.23719	0.06927
Nucula delphinodonta	-0.18575	-0.52441**	-0.13415
Sediment Parameters			
Silt+Clay	—	0.64478**	0.08416
TOC	—	—	0.28657

* Significant correlation at α = 0.05
** Significant correlation at α = 0.01

As habitat quality improves following sludge discharge abatement, the apparent depth of the RPD should increase (Diaz and Shaffner, 1988; Valente *et al.*, 1992). In Boston Harbor, it was expected that the changes in RPD depth would occur earlier and be greater in outer Boston Harbor and Dorchester Bay than elsewhere (Blake *et al.*, 1993). However, Blake *et al.* (1993) found that RPD_{SPI} depths measured in August 1992 had increased Harbor-wide from the depths measured before cessation of sludge discharge (June 1990). In August 1993, this Harbor-wide pattern of increasing RPD_{SPI} depths continued. This improvement was indicated by the increased overall mean RPD_{SPI} depth and the presence of depth size classes greater than those found previously [compare Figure 17 to Figure 19 in Blake *et al.* (1993)].

Infaunal Communities — The various responses of infaunal communities to increasing "distance" (either spatial or temporal) from a source of organic input have been presented conceptually by Pearson and Rosenberg (1978). The Pearson-Rosenberg model predicts dramatic increases in infaunal density along the organic gradient until a maximum abundance, coinciding with a peak in numbers of opportunist organisms relatively removed from the source, is achieved, followed by a steady reduction in abundance until some stable level is reached at low levels of enrichment. Among recent empirical studies, this pattern has been demonstrated along spatial gradients (Rees *et al.*, 1992; Maurer *et al.*, 1993; Zmarzly *et al.*, 1994). However, along temporal gradients the pattern has not been clear (e.g., Swartz *et al.*, 1986; Moore and Rodger, 1991). The dramatic increases in infaunal abundances observed in Boston Harbor were consistent with the prediction of the model. However, as in the case of increased RPD depth, the changes in infaunal abundance have not been restricted to the area presumably most affected by the former sludge discharge (i.e., station T-3). Indeed, tremendous increases in density also occurred at station T-6, near the present Nut Island effluent discharge.

Another prediction of the Pearson-Rosenberg model is the gradual increase in species richness along the gradient of organic enrichment. This prediction has been supported by recent studies of spatial (Rees *et al.*, 1992; Maurer *et al.*, 1993; Zmarzly *et al.*, 1994) or temporal (Swartz, *et al.* 1986; Reid *et al.*, 1991) trends. The observed increase in numbers of species in Boston Harbor since 1991 is consistent with the prediction of the model. Again the observed phenomenon was Harbor-wide.

In addition to the changes in the "bulk" biological measurements described above, differences in the faunal composition of the Harbor between September 1991 and August 1993 have occurred. In September 1991, the predominant taxa included oligochaete worms (not identified to species), the polychaete *Streblospio benedicti,* the gastropod *Ilyanassa trivittata,* and ampeliscid amphipods. Oligochaetes, *Streblospio*, and *Ilyanassa* were predominant in the northern Harbor, whereas oligochaetes and ampeliscids were predominant in the central and southern Harbor. Oligochaetes and *Streblospio* are among the many taxa that typically occur in organically enriched habitats, although the latter is also counted among those opportunistic taxa that may colonize an area in response to habitat disturbance (Pearson and Rosenberg, 1978). *Ilyanassa* is a scavenging gastropod that has been associated with low organic sediments (Caracciolo and Steimle, 1983); ampeliscids are suspension-feeding amphipods typically considered sensitive to toxicants and pollution (Thomas, 1993). By August 1993, the character of the infaunal communities had changed considerably. This change appeared to result primarily from the increased "importance" in 1993 of several taxa, rather than a decrease in numbers of the taxa that were predominant in 1991. For example, the relative abundance of oligochaetes was considerably reduced, although they were still numerically abundant. No significant differences in abundance of *Ilyanassa* among surveys was found, but in 1993, the snail was no longer among the predominant taxa at any station. Responsible for the change in the infaunal character of the Harbor by 1993, were dramatically increased abundances of the polychaete *Polydora cornuta,* and the suspension-feeding amphipods *Corophium bonellii, Leptocheirus pinguis,* and *Unciola irrorata*. *Ampelisca* increased in abundance at stations were it was common in 1991 and also expanded its area of importance into parts of the northern Harbor. *Polydora cornuta* has been regarded as an enrichment species (Pearson and Rosenberg, 1978); it is also an opportunistic taxon that may be one of the early colonizers of disturbed nearshore habitats (references in Zajac, 1991). Populations of *Polydora cornuta* are known to experience marked seasonal fluctuations in abundance typically peaking in early or mid-summer (Zajac, 1991 and other references therein). Although not common in Boston Harbor in September 1991, *Polydora cornuta* was locally abundant at other times prior to sludge abatement, notably in the Inner Harbor in 1979 and off Deer Island in 1982 (Blake *et al.*, 1989). While the dramatic increases since 1991 in suspension-feeding amphipods might be interpreted as marking a shift to a Stage II community (*sensu* Rhoads and Germano, 1986), Blake *et al.* (1989) pointed out that populations of *Ampelisca* have experienced "...periodic explosions" in the past (e.g., 1979). That the shifts in character of the Harbor communities have resulted from increases in importance of taxa already present in the Harbor, agrees with observations made on infaunal response to disturbance in other areas (e.g., Zajac and Whitlach, 1982).

Similarity analysis conducted on all stations over all surveys showed an interesting change in "affiliation" of the station most likely to be affected by sludge discharge abatement — station T-3. As mentioned earlier, the NESS analysis (see Figure 27) revealed three main, relatively dissimilar clusters: one comprised of late-summer station T-4 samples, one consisting primarily of station T-6 and T-8 samples, and one containing the remaining samples (primarily from the northern Harbor). Samples collected from station T-3 in 1991 and April 1992 clustered with the group containing the northern Harbor samples, whereas samples collected from station T-3 after April 1992 clustered with samples from stations T-6 and T-8. The implication is that when all stations and surveys are compared, samples from station T-3 collected more than seven months after-abatement were more similar to samples from stations in the southern Harbor (regardless of survey) than to station T-3 samples collected prior to or just after abatement. However, station T-3 samples collected in late summer previously have shown affinity with southern Harbor stations. For example, in September 1991, station

T-3 allied with stations T-6 and T-8 (Kelly and Kropp, 1992), but in August 1992, the same three stations were part of a cluster that also included station T-7 (Blake *et al.*, 1993).

An interesting result of the study to date is that relative lack of correlation between the bulk biological parameters (abundance, species numbers, diversity) and the bulk sedimentary parameters (TOC, grain size, *Clostridium* spores). One implication of this finding is that the biological features of a particular sedimentary regime change at a rate that differs substantially from that at which the sedimentary parameters change. It is likely that infaunal organisms respond more rapidly to relatively fine-scale habitat changes, such as changes in pore-water chemistry. Among the pore-water properties that may affect infaunal communities are food quality and RPD depth (Watling, 1991), dissolved oxygen (Hyland *et al.*, 1991) or, in the case of pollution-related studies, presumably pore-water toxicant levels. It is notable that, in the present study, several infaunal measurements were significantly correlated with the apparent RPD depth estimated during grab-sampling activities. In spite of this correlation, the RPD depth may not be an adequate indication of sediment oxygenation (Watling, 1991).

Infaunal communities in Boston Harbor have undergone considerable change since the cessation of sludge discharge in late 1991. It is particularly tempting, because many of the changes are in the direction that would be predicted by the Pearson-Rosenberg model of organic enrichment, to attribute these changes to the process of recovery from the impacts of sludge disposal. However, many of the observed changes may be part of cycles (e.g., shifts in *Polydora cornuta* and amphipod densities) previously documented in the Harbor (although much exaggerated since 1991) or part of a response to disturbance. Natural events often complicate interpretation of data collected to document pollution impacts or recovery from such impacts (Ferraro *et al.*, 1991; Zmarzly *et al.*, 1994). Severe storms are one kind of regionally-occurring natural event that has been mentioned as possibly complicating interpretation of the Boston Harbor data. Two major storms, one in late October 1991 and one in mid-December 1992, have occurred since the first survey conducted during this program. Turbulence from such storms may disturb sediments in the Harbor, rendering them suitable to recolonization by a variety of opportunists (Blake *et al.*, 1993) but in reality storm effects are not known. Ferraro *et al.* (1991) suggest that such natural events may be separated from recovery from pollution by temporal monitoring the direction of community changes. In their study, and in the case of Boston Harbor, if the apparent recovery of the infaunal community was a result of reduced pollution, then further infaunal recovery (as predicted by Pearson-Rosenberg) or possibly no community change might be expected. However, if the changes in the infaunal community resulted from a natural phenomenon (e.g., the late October 1991 storm), then the community would be expected to gradually regress to the state found during polluted conditions.

CONCLUSIONS

Major results from the 1993 sampling program include the following:

(1) Sediment grain size ranged from predominantly sand at stations T-1, T-5a, and T-8 to primarily silt + clay at station T-4. Sediment total organic carbon (TOC) was generally low at the sandy stations and high at stations having a high percentage of fine material (silt + clay) and ranged from <1% to ~3.5%. *Clostridium perfringens* spore counts ranged up to 13,700 spores/g dry weight in April and up to 20,200 spores/g dry weight in August.

(2) As estimated by visual examination of cores taken from grab samples, the average apparent RPD depth ranged from 0.5 cm at station T-5a to 7.0 cm at station T-3 in April and from < 0.5 cm at station T-5a to >8.2 cm at station T-3 (where the grab penetration depth was shallower than the apparent RPD depth) in August. As determined from analysis of sediment profile images taken in August, the apparent RPD depth ranged from 0.4 to 5.9 cm; the deepest values were associated with *Ampelisca* tube mats in fine sand and silty fine-sand sediments.

(3) In April, infaunal abundances in the Harbor showed two basic patterns. At stations T-3, T-6, and T-8, mean abundances were relatively high, around 3000 individuals/0.04 m^2; arthropods were the predominant major taxon. Mean abundances at the remaining stations were relatively low, usually <1000 individuals/0.04 m^2. By August, mean abundance had increased at all stations, except at stations T-4 and T-5a. Mean abundance increased dramatically at stations T-3 and T-6, reaching 13,932 and 15,725 individuals/0.04 m^2, respectively. Species numbers ranged from about 13 (station T-4) to about 31 (stations T-6 and T-8) in April and from about 9 (station T-4) to about 51 (station T-8) in August. The number of annelid species at each station was greater than that of any other major taxon. In April and August, species diversity (H') was lowest at station T-4 (1.05 and 0.52, respectively) but, at the remaining stations, ranged from 2.35 to 3.04 in April and from 2.06 to 3.73 in August.

(4) In April, the most common taxa in the northern part of the Harbor (stations T-1, T-2, and T-5a), in Dorchester Bay (station T-4), and in Quincy Bay (station T-7) were annelid worms, such as *Streblospio benedicti, Tharyx acutus,* and *Tubificoides* nr. *pseudogaster*. Amphipods were most common at stations T-3, T-6, and T-8. Most noticeable in August was the appearance, in parts of the Harbor, of the polychaete *Polydora cornuta* as the predominant taxon (stations T-1, T-2, and T-3) or the third-ranked species (stations T-6 and T-7). Also noticeable was the rise to predominance of several crustacean species at stations T-3 and T-6. Analysis of grab samples collected at reconnaissance stations in August showed that *Polydora cornuta* was the predominant species in much of the northern Harbor, whereas the amphipod *Ampelisca* was the predominant species in much of the southern Harbor.

Furthermore, *Polydora cornuta* was one of the most common species at many other sites. *Ampelisca* was among the most common species at stations west of Deer Island and northeast of Thompson Island.

Major results from the 1991-1993 comparisons include:

(1) Data from sieve analysis of sediments from grab samples indicated that, with only a few exceptions, sediment composition was consistent during all years of the program. Data from SPI analysis also showed this consistency, at all but 1 of the 25 stations sampled in 1992; there was no change in grain size in 1993. Sedimentary TOC remained consistent over all surveys. *Clostridium perfringens* spore counts were lower at all stations in August 1992 than in September 1991, but increased slightly at some stations by August 1993. At all stations, the August 1993 counts were less than those obtained for September 1991. At some stations, the decrease was large. For example, spore counts at station T-3 dropped from 207,000 spores/g dry weight in 1991 to 20,200 spores/g dry weight in August 1993.

(2) Statistically significant differences were discovered across surveys in the mean total infaunal abundance at each station tested. At all stations except station T-7, the August 1993 and/or the August 1992 values were higher than those from all other surveys. Furthermore, total infaunal abundance in August 1993 was significantly greater than that in September 1991 at all stations except station T-7. August 1993 total infaunal abundance was greater than that found in August 1992 at stations T-3 and T-6, but was significantly less at station T-4. Seasonal differences in patterns of infaunal abundance were apparent at each station, except station T-4. In both years, abundance was greater in the late summer than in the spring.

(3) Each station tested showed significant variation among surveys in the mean number of species per sample. In general, the mean number of species per sample has increased since the September 1991 survey. For example, at stations T-1, T-2, and T-8, the mean number of species found in August 1992 and August 1993 was greater than for other surveys. Furthermore, at each station, the August 1992 and 1993 samples had more species than the September 1991 samples. Comparisons between spring and late summer revealed significant differences in number of species at all stations tested, except stations T-3 and T-6. The number of species was higher in the late summer than in the spring at all stations except station T-4.

(4) Significant among-survey variation in species diversity (H') was found for five of the seven stations tested. No significant differences in H' among surveys were found at stations T-7 and T-8. Species diversity in August 1993 (the most recent survey) was significantly greater than that in September 1991 (the pre-abatement survey) only at stations T-2 and T-6. Seasonal variation in H' was found at four

of the stations tested. Late summer values were lower than spring values at stations T-1, T-3, T-4, and T-6, but were higher at station T-2.

(5) Oligochaete worms apparently declined in abundance relative to other taxa at all stations. In 1991, oligochaetes were among the most common taxa at many stations in the Harbor but, by 1993, were among the most common taxa only at a few stations. Across surveys, significant differences in the mean abundance of oligochaetes were found at all stations except stations T-3 and T-7.

(6) *Ampelisca,* an amphipod that was not identified to species, increased in predominance and abundance during the study period. Significant differences were detected in the abundance of *Ampelisca* at all stations across surveys. The change in numbers of *Ampelisca* at station T-6 was dramatic, where abundance increased from ~613 individuals/0.04 m^2 in 1991 to ~2485 individuals/0.04 m^2 in August 1992 and to ~5228 individuals/0.04 m^2 in August 1993.

(7) Periodically, several other taxa were predominant at various stations. Among the most striking examples were the polychaete *Polydora cornuta* and the amphipod *Corophium bonellii. P. cornuta* was the predominant taxon in the northern Harbor in August 1993. However, it was common only during late summer. *Corophium bonellii,* which first appeared in April 1992, increased in abundance dramatically at stations T-3 and T-6 by August 1993. *C. bonellii* reached a density of 3,795 individuals/0.12 m^2 at station T-3 and 11,798 individuals/0.12 m^2 at station T-6. Relatively large amphipods, *Leptocheirus pinguis* and *Unciola irrorata,* also increased in abundance at stations T-3 and T-6. *Phyllodoce mucosa,* a polychaete that was uncommon in 1991, increased in abundance and geographic coverage by August 1993. *Aricidea catherinae*, a polychaete, consistently was common in the southern Harbor during the study period, but did not become a major part of the northern Harbor fauna.

(8) Classification based on NESS similarity analysis conducted on all stations (with replicates pooled) for all surveys revealed three major, relatively dissimilar, groups of stations. The first group consisted of station T-4 collections from all three late summer surveys. The second large group was composed of all station T-6 and station T-8 collections, as well as the station T-3 samples collected after April 1992. The third major group consisted of the April station T-4 samples, the station T-3 samples collected before August 1992, all station T-7 samples, and all stations in the northern Harbor (including the station T-5, R-6, T-5a complex). This grouping of stations generally showed consistent linkage of stations from year to year. The notable exception to this consistency was the placement of samples from station T-3. Collections made at station T-3 during September 1991 and April 1992 were linked to stations located primarily in the northern region of the Harbor. However, samples from station T-3 collected after April 1992 clustered

with stations located toward the southern region of the Harbor (station T-6 and T-8).

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APPENDIX A

Coordinates and depths for infaunal replicates (rep 1, etc.) and sediment chemistry samples (chem) at Boston harbor Traditional stations, 1993.

Station		April 1993 Latitude	April 1993 Longitude	April 1993 Depth[a] (m)	August 1993 Latitude	August 1993 Longitude	August 1993 Depth[a] (m)
T-1	rep 1	42°20.94'N	70°57.84'W	6.9	42°20.95'N	70°57.82'W	4.0
	rep 2	42°20.93'N	70°57.84'W	7.0	42°20.95'N	70°57.82'W	4.0
	rep 3	42°20.92'N	70°57.84'W	6.9	42°20.96'N	70°57.81'W	4.0
	chem	42°20.94'N	70°57.84'W	6.6	42°20.95'N	70°57.81'W	3.0
T-2	rep 1	42°20.56'N	71°00.08'W	10.7	42°20.54'N	71°00.12'W	8.0
	rep 2	42°20.56'N	71°00.07'W	10.9	42°20.58'N	71°00.11'W	8.0
	rep 3	42°20.56'N	71°00.05'W	10.9	42°20.57'N	71°00.11'W	8.0
	chem	42°20.56'N	71°00.06'W	9.7	42°20.57'N	71°00.15'W	8.0
T-3	rep 1	42°19.83'N	70°57.74'W	10.7	42°19.84'N	70°57.73'W	7.0
	rep 2	42°19.84'N	70°57.72'W	10.3	42°19.84'N	70°57.73'W	7.0
	rep 3	42°19.85'N	70°57.74'W	10.8	42°19.84'N	70°57.74'W	7.0
	chem	42°19.84'N	70°57.71'W	10.9	42°19.83'N	70°57.73'W	7.0
T-4	rep 1	42°18.62'N	71°02.47'W	5.5	42°18.59'N	71°02.45'W	3.0
	rep 2	42°18.62'N	71°02.46'W	5.5	42°18.59'N	71°02.45'W	3.0
	rep 3	42°18.62'N	71°02.46'W	5.6	42°18.61'N	71°02.46'W	3.0
	chem	42°18.62'N	71°02.46'W	5.5	42°18.57'N	71°02.47'W	3.0
T-5a	rep 1	42°20.40'N	70°57.65'W	15.7	42°20.36'N	70°57.62'W	18.0
	rep 2	42°20.38'N	70°57.65'W	17.7	42°20.38'N	70°57.62'W	18.0
	rep 3	42°20.38'N	70°57.65'W	18.4	42°20.37'N	70°57.59'W	18.0
	chem	42°20.40'N	70°57.64'W	15.9	42°20.38'N	70°57.63'W	18.0
T-6	rep 1	42°17.66'N	70°56.68'W	–	42°17.60'N	70°56.67'W	5.0
	rep 2	42°17.67'N	70°56.68'W	–	42°17.59'N	70°56.64'W	5.0
	rep 3	42°17.66'N	70°56.69'W	6.3	42°17.62'N	70°56.64'W	5.0
	chem	42°17.66'N	70°56.69'W	6.2	42°17.59'N	70°56.66'W	6.0
T-7	rep 1	42°17.38'N	70°58.72'W	5.2	42°17.36'N	70°58.70'W	4.0
	rep 2	42°17.38'N	70°58.71'W	5.4	42°17.34'N	70°58.70'W	4.0
	rep 3	42°17.38'N	70°58.69'W	5.5	42°17.35'N	70°58.73'W	4.0
	chem	42°17.40'N	70°58.70'W	5.7	42°17.36'N	70°58.69'W	4.0
T-8	rep 1	42°17.13'N	70°54.80'W	11.7	42°17.12'N	70°54.76'W	12.0
	rep 2	42°17.13'N	70°54.82'W	10.9	42°17.12'N	70°54.76'W	13.0
	rep 3	42°17.09'N	70°54.79'W	11.0	42°17.12'N	70°54.76'W	13.0
	chem	42°17.13'N	70°54.76'W	11.9	42°17.15'N	70°54.75'W	13.0

[a] Depths were not tidally rectified.

APPENDIX B

List of taxa collected from Boston Harbor during MWRA-sponsored benthic studies, 1991-1993.

		9/91	4/92	8/92	4/93	8/93
CNIDARIA						
	Hydrozoa					✗
	Anthozoa				✗	
	Actiniaria sp. 2					✗
PLATYHELMINTHES						
	Turbellaria	✗	✗			
	Turbellaria sp. 1					✗
NEMERTEA		✗	✗	✗	✗	
	Nemertea sp. 2					✗
	Nemertea sp. 4					✗
	Amphiporidae					
	Amphiporus angulatus (Fabricius, 1774)					✗
	Amphiporus cruentatus Verrill, 1879					✗
	Lineidae					
	Cerebratulus lacteus (Leidy, 1851)					✗
	Tetrastemmatidae					
	Tetrastemma vittatum Verrill, 1874					✗
ANNELIDA						
OLIGOCHAETA		✗	✗			
	Enchytraeidae					
	Enchytraeidae sp. 1				✗	
	Enchytraeidae sp. 2				✗	
	Tubificidae					
	Tubificoides apectinatus Brinkhurst, 1965			✗	✗	✗
	Tubificoides benedeni Udekem, 1855			✗	✗	✗
	Tubificoides nr. *pseudogaster* Dahl, 1960			✗	✗	✗
	Tubificoides sp. A				✗	✗
POLYCHAETA						
	Ampharetidae					
	Ampharete arctica Malmgren, 1866	✗		✗		
	Asabellides oculata (Webster, 1879)	✗	✗	✗	✗	✗

	9/91	4/92	8/92	4/93	8/93
Capitellidae					
Capitella capitata (Fabricius, 1780)	✗	✗	✗	✗	✗
Heteromastus filiformis (Claparède, 1864)			✗		
Mediomastus californiensis Hartman, 1944	✗	✗	✗	✗	✗
Cirratulidae					
Aphelochaeta monilaris (Hartman, 1960)				✗	
Aphelochaeta sp. A					✗
Chaetozone setosa Malmgren, 1867			✗		✗
Chaetozone sp. A				✗	
Cirratulus cirratus (O.F. Müller, 1776)				✗	
Cirriformia grandis (Verrill, 1873)			✗		
Dodecaceria		✗			
Monticellina baptisteae Blake, 1991	✗	✗	✗	✗	
Monticellina dorsobranchialis (Kirkegaard, 1959)				✗	✗
Tharyx acutus Webster & Benedict, 1887	✗	✗	✗	✗	✗
Cossuridae					
Cossura longicirrata Webster & Benedict, 1887					✗
Dorvilleidae					
Dorvilleidae sp. A		✗			
Ophryotrocha					✗
Parougia caeca (Webster & Benedict, 1884)	✗	✗	✗	✗	✗
Flabelligeridae					
Pherusa affinis (Leidy, 1855)	✗		✗		✗
Glyceridae					
Glycera dibranchiata Ehlers, 1868	✗	✗	✗		
Hesionidae					
Microphthalmus aberrans (Webster & Benedict, 1887)	✗	✗	✗		
Microphthalmus sczelkowii Mecznikow, 1865				✗	✗
Lumbrineridae					
Scoletoma acicularum (Webster & Benedict, 1887)		✗			
Scoletoma hebes (Verrill, 1880)	✗	✗	✗		✗
Ninoe nigripes Verrill, 1873	✗	✗	✗	✗	✗

	9/91	4/92	8/92	4/93	8/93
Maldanidae					
Euclymeninae	✗	✗			✗
Clymenella torquata (Leidy, 1855)	✗	✗	✗	✗	✗
Maldane glebifex Grube, 1860					✗
Sabaco elongatus (Verrill, 1873)				✗	
Nephtyidae					
Aglaophamus circinata (Verrill, 1874)			✗	✗	✗
Nephtys caeca (Fabricius, 1780)	✗	✗	✗	✗	✗
Nephtys ciliata (O.F. Müller, 1776)				✗	✗
Nephtys incisa Malmgren, 1865			✗		
Nephtys neotena (Noyes, 1980)				✗	✗
Nereididae					
Neanthes virens Sars, 1835	✗	✗	✗	✗	✗
Opheliidae					
Ophelina acuminata Oersted, 1843			✗		
Orbiniidae					
Leitoscoloplos robustus (Verrill, 1873)			✗	✗	✗
Scoloplos armiger (O.F. Müller, 1776)					✗
Paraonidae					
Aricidea catherinae Laubier, 1967	✗	✗	✗	✗	✗
Aricidea cerrutii Laubier, 1967				✗	
Aricidea quadrilobata Webster & Benedict, 1887					✗
Levinsenia gracilis (Tauber, 1879)			✗		✗
Pectinariidae					
Pectinaria granulata (Linnaeus, 1767)	✗		✗		✗
Pholoidae					
Pholoe minuta (Fabricius, 1780)	✗	✗	✗	✗	✗
Phyllodocidae					
Eteone flava (Fabricius, 1780)			✗		
Eteone heteropoda Hartman, 1951		✗		✗	✗
Eteone longa (Fabricius, 1780)	✗	✗	✗	✗	✗
Eulalia viridis (Linnaeus, 1767)					✗
Eumida sanguinea (Oersted, 1843)			✗		

	9/91	4/92	8/92	4/93	8/93
Paranaitis speciosa (Webster, 1870)	✗	✗	✗	✗	
Phyllodoce maculata (Linnaeus, 1767)				✗	✗
Phyllodoce mucosa Oersted, 1843	✗	✗	✗	✗	✗
Polygordiidae					
Polygordius	✗	✗			
Polygordius sp. A			✗		✗
Polynoidae					
Gattyana cirrosa (Pallas, 1766)					✗
Harmothoe imbricata (Linnaeus, 1767)	✗		✗	✗	✗
Lepidonotus squamatus (Linnaeus, 1767)			✗		
Sabellidae					
Euchone incolor Hartman, 1978		✗			
Fabricia stellaris stellaris (Müller, 1774)				✗	
Spionidae					
Polydora aggregata Blake, 1969			✗		✗
Polydora caulleryi Mesnil, 1897			✗		
Polydora cornuta Bosc, 1802	✗	✗	✗	✗	✗
Polydora quadrilobata Jacobi, 1883		✗	✗	✗	✗
Polydora socialis (Schmarda, 1861)		✗	✗		✗
Polydora websteri Hartman, 1943			✗		
Prionospio steenstrupi Malmgren, 1867	✗	✗	✗	✗	✗
Pygospio elegans Claperède, 1863	✗	✗	✗	✗	✗
Spio filicornis (O.F. Müller, 1776)		✗	✗		✗
Spio limicola Verrill, 1880		✗	✗		✗
Spio setosa Verrill, 1873		✗	✗	✗	✗
Spio thulini Maciolek, 1990	✗	✗	✗	✗	✗
Spiophanes bombyx Claperède, 1870	✗	✗	✗	✗	✗
Streblospio benedicti Webster, 1879	✗	✗	✗	✗	✗
Syllidae					
Autolytus fasciatus (Bosc, 1802)			✗		
Exogone arenosa Perkins, 1981	✗				
Exogone hebes (Webster & Benedict, 1884)	✗	✗	✗	✗	✗
Exogone verugera (Claperède, 1868)			✗		✗

	9/91	4/92	8/92	4/93	8/93
Pionosyllis		✗			
Procerea cornuta Agassiz, 1863			✗		✗
Sphaerosyllis longicauda Webster & Benedict, 1887				✗	
Typosyllis	✗		✗	✗	
Terebellidae					
Amphitritinae					✗
Nicolea zostericola (Oersted, 1844)			✗		
Polycirrus eximius (Leidy, 1855)					✗
Polycirrus medusa Grube, 1850					✗
Polycirrus sp. A	✗				
SIPUNCULA				✗	
CRUSTACEA					
AMPHIPODA					
Ampeliscidae					
Ampelisca	✗	✗	✗	✗	✗
Ampithoidae					
Cymadusa compta (Smith, 1873)			✗		
Aoridae					
Leptocheirus pinguis (Stimpson, 1853)	✗	✗	✗	✗	✗
Microdeutopus anomalus (Rathke, 1843)					✗
Unciola	✗				
Unciola irrorata Say, 1818		✗	✗	✗	✗
Argissidae					
Argissa hamatipes (Norman, 1869)		✗		✗	
Caprellidae		✗		✗	
Aeginina longicornis (Krøyer, 1842-43)			✗		✗
Caprella linearis (Linnaeus, 1767)			✗		
Paracaprella tenuis Mayer, 1903			✗		
Corophiidae					
Corophium bonellii (Milne Edwards, 1830)		✗	✗	✗	✗
Corophium crassicorne Bruzelius, 1859	✗	✗	✗	✗	✗
Corophium insidiosum Crawford, 1937		✗			
Corophium tuberculatum Shoemaker, 1934	✗	✗	✗		

		9/91	4/92	8/92	4/93	8/93
	Gammaridae					
	Gammarus	✗				
	Gammarus lawrencianus Bousfield, 1956		✗			✗
	Isaeidae					
	Photis	✗				
	Photis pollex Walker, 1895		✗	✗	✗	✗
	Ischyroceridae					
	Ischyrocerus anguipes (Krøyer, 1842)		✗	✗		
	Jassa marmorata Holmes, 1903		✗			
	Lysianassidae					
	Orchomenella minuta (Krøyer, 1842)	✗	✗	✗	✗	✗
	Phoxocephalidae					
	Phoxocephalus holbolli (Krøyer, 1842)	✗	✗	✗	✗	✗
	Rhepoxynius hudsoni Barnard & Barnard, 1982			✗		
	Pleustidae					
	Pleusymptes glaber (Boeck, 1861)			✗		
	Podoceridae					
	Dyopedos monacanthus (Metzger, 1875)		✗	✗	✗	✗
	Pontogeneiidae					
	Pontogeneia inermis (Krøyer, 1842)			✗		
	Stenothoidae					
	Metopella angusta Shoemaker, 1949	✗		✗	✗	✗
	Proboloides holmesi Bousfield, 1973			✗		✗
	Stenthoe minuta Holmes, 1905	✗				
	Talitridae					
	Orchestia				✗	
CIRRIPEDIA						
	Balanidae					
	Balanus crenatus Bruguiere, 1789	✗				
CUMACEA						
	Diastylidae	✗				
	Diastylis polita (Smith, 1879)					✗
	Diastylis sculpta Sars, 1871		✗	✗	✗	✗

		9/91	4/92	8/92	4/93	8/93
	Lampropidae					
	Lamprops quadriplicata Smith, 1879					✗
	Leuconidae					
	Eudorella pusilla Sars, 1871					✗
DECAPODA						
	Cancridae					
	Cancer irroratus Say, 1817	✗	✗	✗	✗	✗
	Crangonidae					
	Crangon septemspinosa Say, 1818	✗	✗	✗		✗
	Paguridae					
	Pagurus	✗	✗	✗		✗
	Pagurus longicarpus Say, 1817	✗	✗	✗	✗	
ISOPODA						
	Anthuridae					
	Ptilanthura tenuis Harger, 1879			✗		
	Cirolanidae					
	Politolana polita (Stimpson, 1853)				✗	
	Idoteidae					
	Edotia tribola (Say, 1818)	✗	✗	✗	✗	✗
	Erichsonella			✗		
	Limnoriidae					
	Limnoria lignorum (Rathke, 1799)		✗			
	Munnidae					
	Munna		✗			
	Paramunnidae					
	Pleurogonium inerme Sars, 1882			✗		✗
MYSIDACEA						
	Mysidae					
	Neomysis americana (Smith, 1873)	✗		✗		✗
TANAIDACEA						
	Nototanaidae					
	Tanaissus psammophilus (Wallace, 1919)		✗	✗	✗	✗

	9/91	4/92	8/92	4/93	8/93
MOLLUSCA					
BIVALVIA					
Anomiidae					
Anomia simplex Orbigny, 1842			✗		
Arcticidae					
Arctica islandica (Linnaeus, 1767)			✗		
Astartidae					
Astarte undata Gould, 1841	✗		✗		
Cardiidae					
Cerastoderma pinnulatum (Conrad, 1831)	✗		✗	✗	✗
Hiatellidae					
Hiatella arctica (Linnaeus, 1767)	✗		✗	✗	✗
Lyonsiidae					
Lyonsia hyalina Conrad, 1831	✗	✗	✗	✗	✗
Mactridae					
Mulinia lateralis (Say, 1822)	✗				
Spissula solidissima (Dillwyn, 1817)	✗	✗			
Montacutidae					
Mysella planulata (Stimpson, 1857)			✗	✗	
Myidae					
Mya arenaria Linnaeus, 1758	✗	✗	✗	✗	✗
Mytilidae					
Musculus	✗				
Musculus niger (Gray, 1824)			✗		✗
Mytilus edulis Linnaeus, 1758	✗	✗	✗	✗	✗
Nuculanidae					
Yoldia limatula (Say, 1822)		✗			
Nuculidae					
Nucula delphinodonta Mighels & Adams, 1842	✗	✗	✗	✗	✗
Pandoridae					
Pandora	✗	✗			
Petricolidae					
Petricola pholadiformis (Lamarck, 1818)		✗	✗		✗

		9/91	4/92	8/92	4/93	8/93
	Solenidae					
	Ensis directus Conrad, 1843	✗		✗	✗	✗
	Tellinidae					
	Macoma balthica (Linnaeus, 1758)	✗			✗	
	Tellina agilis Stimpson, 1857	✗	✗	✗	✗	✗
	Thraciidae					
	Asthenotherus hemphilli Dall, 1886			✗	✗	
	Thracia	✗	✗			✗
	Thyasiridae					
	Thyasira gouldii (Philippi, 1845)					✗
	Turtoniidae					
	Turtonia minuta (Fabricius, 1780)	✗	✗			
	Veneridae					
	Pitar morrhuanus Linsley, 1848		✗			
GASTROPODA						
Opisthobranchia			✗			
	Doridacea sp. A			✗		
	Pyramidellidae					
	Odostomia					✗
Prosobranchia						
	Acmaeidae			✗		
	Calyptraeidae					
	Crepidula	✗	✗			
	Crepidula fornicata (Linnaeus, 1758)			✗		
	Crepidula plana Say, 1822			✗		
	Nassariidae					
	Ilyanassa trivittata (Say, 1822)	✗	✗	✗	✗	✗
PHORONIDA						
	Phoronis	✗	✗			
	Phoronis architecta Andrews, 1890			✗		✗

	9/91	4/92	8/92	4/93	8/93
ECHINODERMATA					
ECHINOIDEA		✗			
Strongylocentrotidae					
Strongylocentrotus droebachiensis (Müller, 1776)			✗		
OPHIUROIDEA			✗		
Ophiuridae					
Ophiura robusta (Ayres, 1851)					✗
HEMICHORDATA					
ENTEROPNEUSTA		✗	✗		
CHORDATA					
ASCIDIACEA	✗	✗	✗		✗
Molgulidae					
Bostrichobranchus pilularis					✗

APPENDIX C

Raw infaunal abundance data (#/0.04 m²) for samples collected from Boston Harbor in April and August 1993. The values represent summed 0.3-mm and 0.5-mm fraction data.

April 1993	Station/Replicate																							
	T1			T2			T3			T4			T5a			T6			T7			T8		
Species	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Cnidaria																								
Anthozoa																		3						
Platyhelminthes																								
Turbellaria			1								1			4			7	4						
Nemertea							2	8	5				2					3					2	2
Annelida																								
Oligochaeta																								
Enchytraeidae																								
Enchytraeidae sp. 1															1									
Enchytraeidae sp. 2																						1		
Tubificidae															7									
Tubificoides apectinatus				1	1		93	39	121				92	130	186	159	175	161	328	35	23	223	290	256
Tubificoides benedeni		1				1	1				3	3	23	19	23	1					1			
Tubificoides nr. *pseudogaster*	175	359	60	37	98	69	274	114	181	9	8	4	109	118	87	650	311	326	236	170	15	246	274	354
Tubificoides sp. A													11	4	11									
Polychaeta																								
Ampharetidae																								
Asabellides oculata		1				1	4	11	9	1		2					5	2	1	1	1	1	2	1
Capitellidae																								
Capitella capitata	12	7		2	3	1				26	5	15	6	9	11			1					1	1
Mediomastus californiensis	1	4	2				1		2				4	1		8	21	32		1		6	8	29

April 1993	Station/Replicate																							
	T1			T2			T3			T4			T5a			T6			T7			T8		
Species	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Cirratulidae																				1				
Aphelochaeta															6									
Aphelochaeta monilaris													1											
Chaetozone sp. A													9	13	8									
Cirratulus																								1
Cirratulus cirratus								1																
Monticellina baptisteae																								1
Monticellina dorsobranchialis																								2
Tharyx acutus	55	152	34	45	138	110	32	62	42			3	417	567	495	4	4	1	24	26	7	8	14	33
Dorvilleidae																								
Parougia caeca																						5		
Hesionidae																								
Microphthalmus sczelkowii		9	2	11	2	1	3	1	1	3	2	2	1		2	1		4			6		2	
Lumbrineridae				1																				
Ninoe nigripes						2											3	4				1		6
Scoletoma hebes		1														4	18	20	5	4	2	54	21	150
Maldanidae																								
Clymenella torquata	3	36	12				1																	
Sabaco elongata								1																
Nephtyidae																								
Aglaophamus circinata																				1				
Nephtys caeca	1	1											2											
Nephtys ciliata							2								1		1							
Nephtys neotena					1	1							1	2	5					1	4			

April 1993	Station/Replicate																							
	T1			T2			T3			T4			T5a			T6			T7			T8		
Species	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Nereididae																								
Neanthes virens								2	1	1						3	2	1						1
Orbiniidae																								
Leitoscoloplos				1							1		2	1	3									
Leitoscoloplos robustus										1	1	1							1					
Paraonidae																								
Aricidea catherinae		2		1	3		180	94	151				132	147	86	1006	684	875	125	174	89	463	496	496
Aricidea cerrutii													3	1	3							1		
Pholoidae																								
Pholoe minuta							1	1																
Phyllodocidae																								
Eteone heteropoda											2	1												
Eteone longa							5	3	2										1		1			
Paranaitis speciosa															1									
Phyllodoce maculata							1	1	2							6	15	17						
Phyllodoce mucosa	1	2					7	7	4							13	36	53					17	3
Polynoidae							1																	
Harmothoinae				1	3			3	2									1						
Harmothoe imbricata								2																
Sabellidae				1																				
Fabricia stellaris stellaris										1		4		2										
Spionidae																								
Polydora								1				3			1				1					
Polydora cornuta	23	16					85	291	119	49	10	10				23	139	74	9	1			9	1
Polydora quadrilobata						4					1	1				1			1				2	2

April 1993	Station/Replicate																							
	T1			T2			T3			T4			T5a			T6			T7			T8		
Species	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Prionospio steenstrupi									1					3			1	2				1	3	4
Pygospio elegans	1				3	2							8	15	5									1
Spio				1	4	1						2								1				
Spio setosa	1	1																						
Spio thulini	2	1	1		1		4	13	10	7	2	1	1	1		12	2	9	1			2	3	2
Spiophanes bombyx													2											
Streblospio benedicti	65	88	34	117	124	94	1	3	2	340	297	325	30	22	9				182	104	102			
Syllidae																								
Exogone hebes			1					1				1	2		3							6	11	8
Sphaerosyllis longicauda								1														1		1
Typosyllis																						1		
Sipuncula				2									1									37	80	142
Crustacea																								
Amphipoda							12	92	28				1			3	1	2				1		1
Ampeliscidae																								
Ampelisca		2		2		5	1430	1269	604						3	615	2371	2047	6	15	7	1292	1187	1048
Aoridae																								
Leptocheirus pinguis							370	288	217							9	26	37						1
Unciola irrorata							13	17	16							1	14	9						
Argissidae																								
Argissa hamatipes																						1		
Caprellidae																							1	
Corophiidae																								
Corophium																						2		
Corophium bonellii							658	753	674							7	97	72						
Corophium crassicorne							23	39	17															

April 1993	Station/Replicate																							
	T1			T2			T3			T4			T5a			T6			T7			T8		
Species	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Isaeidae																								
Photis pollex	4	2	2	2	39	6	61	64	24						2	5	2	4				4	1	1
Lysianassidae																								
Orchomenella minuta							24	17	9								35	25						1
Phoxocephalidae																								
Phoxocephalus holbolli							116	127	184							75	216	195				14	11	17
Podoceridae																								
Dyopedos monacanthus		1	2	2		1		9	6							4	4	8		4	1		1	1
Stenothoidae																								
Metopella angusta																						2		3
Talitridae																								
Orchestia																		1						
Cumacea																								
Diastylidae																								
Diastylis sculpta				1		1	7	9	3				10		8	2		1				15	8	14
Decapoda																								
Cancridae																								
Cancer irroratus																	1							
Paguridae																								
Pagurus longicarpus									1									2				1		
Isopoda																								
Cirolanidae																								
Politolana polita																								1
Idoteidae																								
Edotia tribola				2			16	19	23						7	1	3	5				4	5	

April 1993	Station/Replicate																							
	T1			T2			T3			T4			T5a			T6			T7			T8		
Species	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Tanaidacea																								
Nototanaidae																								
Tanaissus psammophilus																								1
Mollusca																								
Bivalvia							13	13	28			2	5	3	4	5	3	3		1		7	6	5
Cardiidae																								
Cerastoderma pinnulatum							1	2	1														1	
Hiatellidae																								
Hiatella arctica									3								3	5				2		2
Lyonsiidae																								
Lyonsia hyalina							16	21	19													3	2	7
Montacutidae																								
Mysella planulata											2													
Myidae																								
Mya arenaria	2			14	10	10	6	5	5	1		1	4	6	5		3	7				1		
Mytilidae																								
Mytilus edulis	1			2	7	3	5	3	3				11	4	4	2	3	6	2			6	3	8
Nuculidae																								
Nucula delphinodonta																10	30	39			1	362	420	438
Solenidae																								
Ensis directus													1		1									
Tellinidae																								
Macoma balthica													12	8	9									
Tellina agilis	3	2	2	2	1	6	5	6	12	3	1	3	19	11	19	2	6	3		2		1	2	2

April 1993	Station/Replicate																							
	T1			T2			T3			T4			T5a			T6			T7			T8		
Species	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Thraciidae																								
Asthenotherus hemphilli																								2
Gastropoda																								
Prosobranchia																								
Nassariidae																								
Ilyanassa trivittata	14	59	23	1		1	22	66	79				10	5	19	6	2	1	3	7	2	15	1	19

August 1993	Station/Replicate																							
	T1			T2			T3			T4			T5a			T6			T7			T8		
Species	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Cnidaria																								
Hydrozoa	6					1	3		3						1					1	1	1	1	
Anthozoa																								
Actiniaria sp. 2																1								
Platyhelminthes																								
Turbellaria																								
Turbellaria sp. 1																								1
Nemertea				1	3				1	2												10	17	3
Nemertea sp. 2		2	6	3	5																			
Nemertea sp. 4							5	9	6							2	1							1
Amphiporidae																								
Amphiporus angulatus							1																	
Amphiporus cruentatus							3	2	1													1		
Lineidae																								
Cerebratulus lacteus																		2					1	1
Tetrastemmatidae																								
Tetrastemma vittatum																	2						1	
Annelida																								
Oligochaeta																								
Tubificidae																								
Tubificoides apectinatus	1		1				20	209	83				181	76	62	9	26	83	43	11	77	1	8	19
Tubificoides benedeni	2	2	1			1							62	15	14									
Tubificoides nr. *pseudogaster*	110	117	140	97	78	163	427	1361	524	2	1	3	81	18	24	15	8	76	17	19	206	8	16	27
Tubificoides sp. A													1	1										
Polychaeta																								
Ampharetidae																								
Asabellides oculata	20	5	18	61	69	61	2	2			1				1		2	1	6	7	3	5	7	5
Capitellidae																								
Capitella capitata	13	21	17	1	4	8							10	3	4			2	1	3		20	46	6
Mediomastus californiensis	10	8	7	1		4		5									3	9			4	1	3	3

August 1993	Station/Replicate																							
	T1			T2			T3			T4			T5a			T6			T7			T8		
Species	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Cirratulidae																								
Aphelochaeta sp. A	6	9	10	237	329	444	5	13	17				35	23	12				18	16	7			
Chaetozone setosa					1	3							10	3	2				1			11	8	2
Monticellina dorsobranchialis																						1	3	2
Tharyx acutus	1288	670	646	120	146	127	34	110	80		2	1	178	97	47		1		31	34	44	102	129	16
Cossuridae																								
Cossura longicirrata	14																							
Dorvilleidae																								
Ophryotrocha																							1	
Parougia caeca																							2	1
Flabelligeridae																								
Pherusa affinis	1							1								1								
Hesionidae																								
Microphthalmus sczelkowii	98	50	3	20	78	13		15	2				6	2					1	3	4	1		2
Lumbrineridae													1			1						12		9
Ninoe nigripes									1									2		2	1	1	2	2
Scoletoma hebes	2															36	52		7	5	14	68	46	75
Maldanidae																								
Euclymeninae																							1	
Clymenella torquata	175	65	79			1		1														3	3	9
Maldane glebifex									1															
Nephtyidae																								
Aglaophamus circinata																								
Nephtys caeca	8	7	3	3	1	5		1					19	17	25	1			1	1	1	14	14	10
Nephtys ciliata													1		2									
Nephtys neotena	18	4	10	26	12	13				6	3	6							66	41	53			
Nereididae			1															1						
Neanthes virens	10	4	12	6	3	2		5	3							4	6	3						
Orbiniidae																								
Leitoscoloplos							1		1															
Leitoscoloplos robustus																							2	2
Scoloplos armiger				3											1							1		

August 1993	Station/Replicate																							
	T1			T2			T3			T4			T5a			T6			T7			T8		
Species	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Paraonidae																								
Aricidea catherinae	15	2	2	2	2		61	79	42		1		109	62	52	628	482	1089	339	212	423	876	826	680
Aricidea quadrilobata	2																							
Levinsenia gracilis	3	1										1										2	2	
Pectinariidae																								
Pectinaria granulata		1	1																					
Pholoidae																								
Pholoe minuta	4			27	9	12			1											1	4			1
Phyllodocidae																								
Eteone heteropoda		2							1								1							
Eteone longa	21	9	18	57	59	30	5	9	3				1	1		2	1		7	1	10	5	2	3
Eulalia viridis	1																							
Phyllodoce maculata	55	16	25	13	6	6	27	30	30							62	142	86	1			5	6	11
Phyllodoce mucosa	86	38	34	181	166	113	81	144	120				6	5	1	124	274	204	1	2	1	98	105	138
Polygordiidae																								
Polygordius sp. A																						9	129	
Polynoidae																								
Gattyana cirrosa								1	1							2	2							
Harmothoe imbricata		1					2	2	8							2	4	6					1	
Spionidae															1				2	1	1			
Polydora	13	27	29	16	14	24	3	2	8				3	2	1	2	46	43	15	25	15	36	50	7
Polydora aggregata	139	65	100	1	13	22																		
Polydora cornuta	4275	2500	2856	1058	869	824	1443	4709	3769			1	39	27	12	1768	5180	3088	348	277	344	106	75	101
Polydora quadrilobata																		1				1		
Polydora socialis		5	2																			1		
Prionospio steenstrupi				2	3	2	1		2				2	1	1			1				3	4	2
Pygospio elegans	1		2										4	3								24	20	2
Spio filicornis																							1	1
Spio limicola				1		2								1										
Spio setosa													2	1										
Spio thulini	18	5	9	26	8	37	6	13	21					1		3	4	15	1	2	1	7	4	4
Spiophanes bombyx													6	11	7							375	384	226
Streblospio benedicti	347	253	234	654	384	595	2	1		437	200	402	5	1		1	1	1	308	318	320			

August 1993	Station/Replicate																							
	T1			T2			T3			T4			T5a			T6			T7			T8		
Species	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Syllidae																								
Exogone hebes	1	4	2		1				1				1	1	2							153	213	42
Exogone verugera									1															
Procerea cornuta	2	1	5	1	2				1							1	3							
Terebellidae								1										1						1
Amphitritinae								1																
Polycirrus					2	1																		
Polycirrus eximius																							1	
Polycirrus medusa				1																1				
Crustacea																								
Amphipoda	2	17	2	2	2	1	241	1237	901	3			1	3	2	15	465	100			2	3	9	10
Ampeliscidae																								
Ampelisca	80	17	79	71	80	61	79	194	99	18	2	2				4465	5575	5643	796	875	690	2851	2829	3411
Aoridae																								
Leptocheirus pinguis		1		4	2		208	623	420							393	741	377	4	5	1	10	12	10
Microdeutopus anomalus																	52							
Unciola irrorata	11	11	12		6	6	628	1192	891				9		4	303	653	573	2	1	3	56	67	40
Caprellidae					1																			
Aeginina longicornis			1																					
Corophiidae																								
Corophium							3414	5968	4203				1	1								12		
Corophium bonellii	31	8	18		2	2	644	2106	1045							2136	5355	4307	3	1	1			
Corophium crassicorne							166	182	163													59	142	71
Gammaridae																								
Gammarus							1																	
Gammarus lawrencianus								1					2	1	3							1	1	
Isaeidae																								
Photis pollex	19	12	45	24	39	50	284	432	326				2	2	2	173	395	118	1			13	15	30
Lysianassidae																								
Orchomenella minuta							112	154	68				1			3	2	5			1		1	
Oedicerotidae															1									
Phoxocephalidae																								
Phoxocephalus holbolli					3		537	704	383					2		386	462	499	2			11	21	8

August 1993	Station/Replicate																							
	T1			T2			T3			T4			T5a			T6			T7			T8		
Species	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Podoceridae																								
Dyopedos monacanthus	1				2				1									2					1	
Stenothoidae																								
Metopella angusta							1									1		1				4		1
Proboloides holmesi																				1				
Cumacea																								
Diastylidae																								
Diastylis polita													23	12	16									1
Diastylis sculpta			1	2	2	1							25	8	23							2	5	6
Lampropidae																								
Lamprops quadriplicata													1		1									
Leuconidae																								
Eudorella pusilla																						1		
Decapoda																								
Cancridae																								
Cancer irroratus							1	1	3							17	32	17					2	
Crangonidae																								
Crangon septemspinosa					1	1				2				1						1	1			
Paguridae																								
Pagurus																	1						1	
Isopoda																								
Idoteidae																								
Edotia tribola	8	4	8	1	9	4	46	60	33				113	57	95	5	9	3				12	27	20
Paramunnidae																								
Pleurogonium inerme									2															
Mysidacea																			1					
Mysidae																								
Neomysis americana										2	1	5												
Tanaidacea																								
Nototanaidae																								
Tanaissus psammophilus																						2	2	

August 1993	Station/Replicate																							
	T1			T2			T3			T4			T5a			T6			T7			T8		
Species	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Mollusca																								
Bivalvia	9	16	23	17	5	11	11	23	28	7	4	7	4	2	2	25	62	15	6	1	4	20	22	27
Cardiidae																								
Cerastoderma pinnulatum				1	1												1						3	
Hiatellidae																								
Hiatella arctica	1	1					10	36	27				1			2	12	4					2	
Lyonsiidae																								
Lyonsia hyalina							11	7	10											1		5	3	
Myidae																								
Mya arenaria							2	2	8					1			1	1				1		
Mytilidae																								
Musculus niger									2														2	1
Mytilus edulis	13	11	24	6	12	6	30	61	52		5	1	7	2	2	12	10	7				32	58	58
Nuculidae																								
Nucula delphinodonta					1											23	40	18				197	149	249
Petricolidae																								
Petricola pholadiformis																	1	2						
Solenidae																								
Ensis directus	1		3	5	3	2				4		3	6	11	3						1	9	30	6
Tellinidae																								
Tellina agilis	2	1		2	1	4	8	3	3				14	10	14		2		1	1	1	20	16	5
Thraciidae																								
Thracia																								3
Thyasiridae																								
Thyasira gouldii																	1							
Gastropoda		1						6					4	2	5							4	5	1
Opisthobranchia																								
Pyramidellidae																								
Odostomia						1																1		
Prosobranchia																								
Nassariidae																								
Ilyanassa trivittata	10	14	5	1	2	2	16	38	55				6	5	4	17	12	4	6	7	5	33	21	7

August 1993	Station/Replicate																							
	T1			T2			T3			T4			T5a			T6			T7			T8		
Species	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Phoronida																								
Phoronis architecta																						1		3
Echinodermata																								
Ophiuroidea																			1					
Ophiura robusta																						1		2
Chordata																								
Ascidiacea																								
Molgulidae																								
Bostrichobranchus pilularis							1		3													1		

The Massachusetts Water Resources Authority
Charlestown Navy Yard
100 First Avenue
Charlestown, MA 02129
(617) 242-6000