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BOSTON HARBOR SLUDGE ABATEMENT MONITORING PROGRAM:

Soft Bottom Benthic Biology & Sedimentology 1991-1992 Monitoring Surveys

Massachusetts Water
Resources Authority

Environmental Quality Department
Technical Report No. 93-11

Final Report

for

BOSTON HARBOR SLUDGE ABATEMENT MONITORING PROGRAM

Soft-Bottom Benthic Biology and Sedimentology 1991-1992 Monitoring Surveys

prepared for

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1.0 INTRODUCTION

1.1 Background of the MWRA Monitoring Program

The Massachusetts Water Resources Authority (MWRA) has instituted a long-term monitoring program in Boston Harbor (Figure 1) in order to assess the recovery of the benthos following the abatement of sludge discharges in December 1991. Previously, sludge that had been generated at the Deer Island and Nut Island sewage treatment facilities was discharged from the Deer Island outfalls (Deer Island sludge) and a point off Long Island (Nut Island sludge) into Boston Harbor on out-going tides. The abatement of sludge disposal is part of the long-term effort to clean up Boston Harbor that will eventually include secondary treatment and a new offshore outfall.

Pre-abatement baseline surveys using sediment profile imaging were conducted in 1989, 1990, and 1991; the infauna was sampled only in September 1991. Post-abatement surveys were conducted in April-May and August 1992. Preliminary reports on these activities have been prepared (SAIC, 1989, 1990, 1992; Kelly and Kropp, 1992; see Table 1). The current report presents results of the second (August 1992) post-abatement survey and provides a retrospective analysis of pre- and post-abatement conditions in the Boston Harbor benthos. This analysis considers natural temporal patterns as well as possible changes due to sludge abatement.

1.2 Historical Overview of Benthic Studies in Boston Harbor

The most extensive studies of the infaunal benthos of Boston Harbor were associated with an application for a waiver from secondary treatment [301(h) waiver] in the late 1970s and early 1980s. Surveys were conducted in the summers of 1978, 1979, and 1982. The results of these surveys were reviewed by Blake *et al.* (1989), who identified some year-to-year patterns at those few stations that were resampled in subsequent years.

It was found that the benthic communities of Boston Harbor fell into two groups, based on their proximity either to the more oceanic conditions of Massachusetts Bay or to known sources of pollution or stress. The southern region of the outer harbor was found to be relatively healthy, with species richness and faunal composition similar to those of offshore locations. Periodic population explosions of ampeliscid amphipods alternated with assemblages dominated by spionid and capitellid polychaetes. These results suggested to Blake *et al.* (1989) that benthic communities in Boston Harbor were continuously shifting between the Stage I and II successional seres of Rhoads and Germano (1986). There was little evidence for the development of communities having deep-burrowing deposit feeders (Stage III).

Studies initiated in 1991 by the MWRA were intended to characterize the infauna of Boston Harbor so that changes due to sludge abatement in December of 1991 could be documented. Stations were selected near known sludge discharges and in key control locations. The present report summarizes the results of this program to date. It includes a detailed analysis of all quantitative benthic infaunal data collected as part of surveys in August 1991, April 1992, and August 1992.

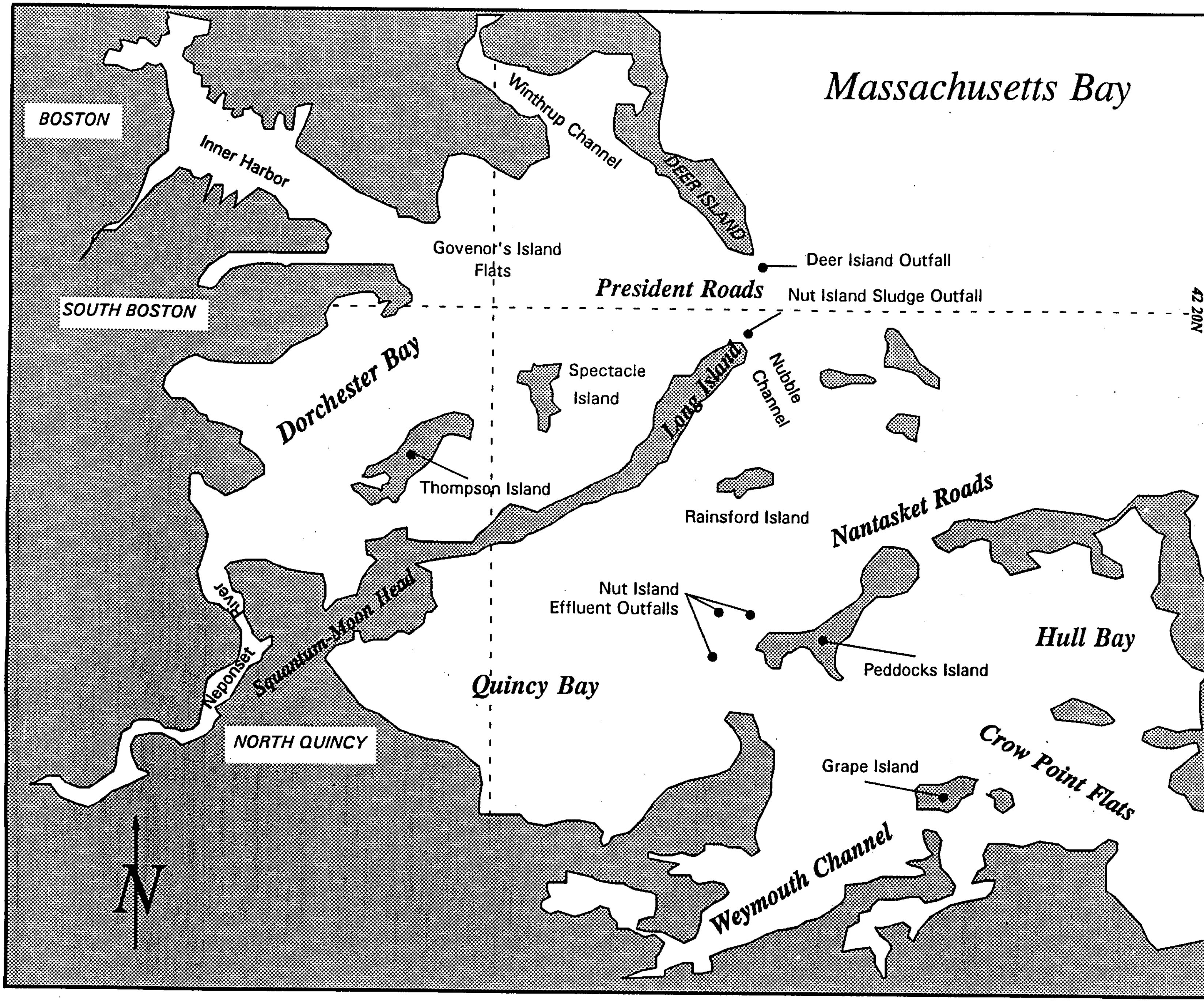

Figure 1. **Boston Harbor Map Indicating Sewage Outfalls and Place Names.**

Table 1. **Studies Relevant to Assessment of Benthic Conditions in Boston Harbor in Relation to Sludge Abatement.**

Type of Study	Date of Sampling	Reference
301(h)	1978	Summarized in Blake, Maciolek, and Rosen (1989)
	1979	
	1982	
Pre-abatement	June 1989	SAIC (1989, 1990)
	May 1990	SAIC (1990)
	September 1991	Kelly and Kropp (1992)
Post-abatement	April 1992	Kelly and Kropp (1992)
	May 1992	SAIC (1992)
	August 1992	This report

1.3 Overview of the Present Study

A total of 69 stations were sampled with the REMOTS® sediment profile camera. Eight of these stations were also sampled using traditional grabs for biology, sediment grain-size, total organic carbon (TOC), and spores of *Clostridium perfringens*. The station design for August 1992 was based upon the same pattern used in May 1992, which was modified from earlier surveys in 1989 and 1990. The REMOTS® stations provide the means to assess benthic conditions over most of the outer Boston Harbor and Dorchester, Quincy, Hingham, and Hull Bays. The "traditional" stations (those sampled with grabs) cover the same areas, but are more limited in scope. The actual station selection was originally based upon an assessment of Harbor circulation and location of historical sampling sites. At least five of the eight traditional stations correspond to stations that were sampled during the 301(h) waiver surveys. Although the station coordinates are not always exactly the same, it is possible to compare current biological results with those taken between the late 1970s and early 1980s.

2.0 METHODS

2.1 Field Operations

Details of the August 1992 sampling program were presented in Blake *et al.* (1992a).

2.1.1 Sampling Design and Location of Stations

All stations sampled in August 1992 are shown in Figure 2. Stations sampled with the REMOTS® camera are indicated with open circles; the traditional stations are indicated with closed circles. Table 2 provides exact coordinates for each station. All traditional stations except T5 were sampled in September 1991, April 1992, and August 1992. Station T5 was moved to an adjacent location in the April survey and designated R6 (Kelly and Kropp, 1992).

2.1.2 Navigation

Vessel positioning was achieved with the SAIC Portable Integrated Navigation and Survey System (PINSS). This system consisted of Northstar 800 Loran-C and MX4200 Global Positioning System (GPS) receivers interfaced to an 80486 portable computer and a Hewlett-Packard Thinkjet printer. The system provided accurate vessel position and a visual plot of the position in relation to the station location. This information was relayed to the helmsman through a remote CRT display. Position fixes showing date, local time, latitude and longitude were recorded on magnetic disk and sent to the printer as hard-copy backup. Position fixes were recorded manually when samples were taken as well as automatically at specified intervals (5 min for this survey).

2.1.3 Grab Sampling

Benthic Infauna

For analysis of benthic infauna, three 0.04-m^2 grabs were taken at all stations sampled in August 1992. After retrieval of the grab, the sample was examined for quality and integrity. The grab was then placed on a stand so that the jaws could be opened and the sample washed into a bucket positioned below the grab. The entire sample was gently washed into the bucket with seawater filtered through a 5-μm filter cartridge. The sample was then sieved through a 300-μm-mesh screen; the portion retained on the screen was transferred to a prelabeled 1-L plastic jar and fixed in 10% buffered formalin in seawater for two to three days. Any anemones found were preserved separately in small jars to prevent mucus, exuded by the anemones even after fixation, from contaminating the entire sample, making it difficult to sort. To prevent decalcification of molluscs, all samples were transferred to 70–80% ethanol, preceded by a freshwater rinse to avoid formation of a precipitate, as soon as practical after collection.

Sediment

A single grab for sediment analysis was obtained at each station with a 0.1-m^2 Kynar-coated grab whose doors were lined with Teflon panels. Subsamples were taken for determination of grain size,

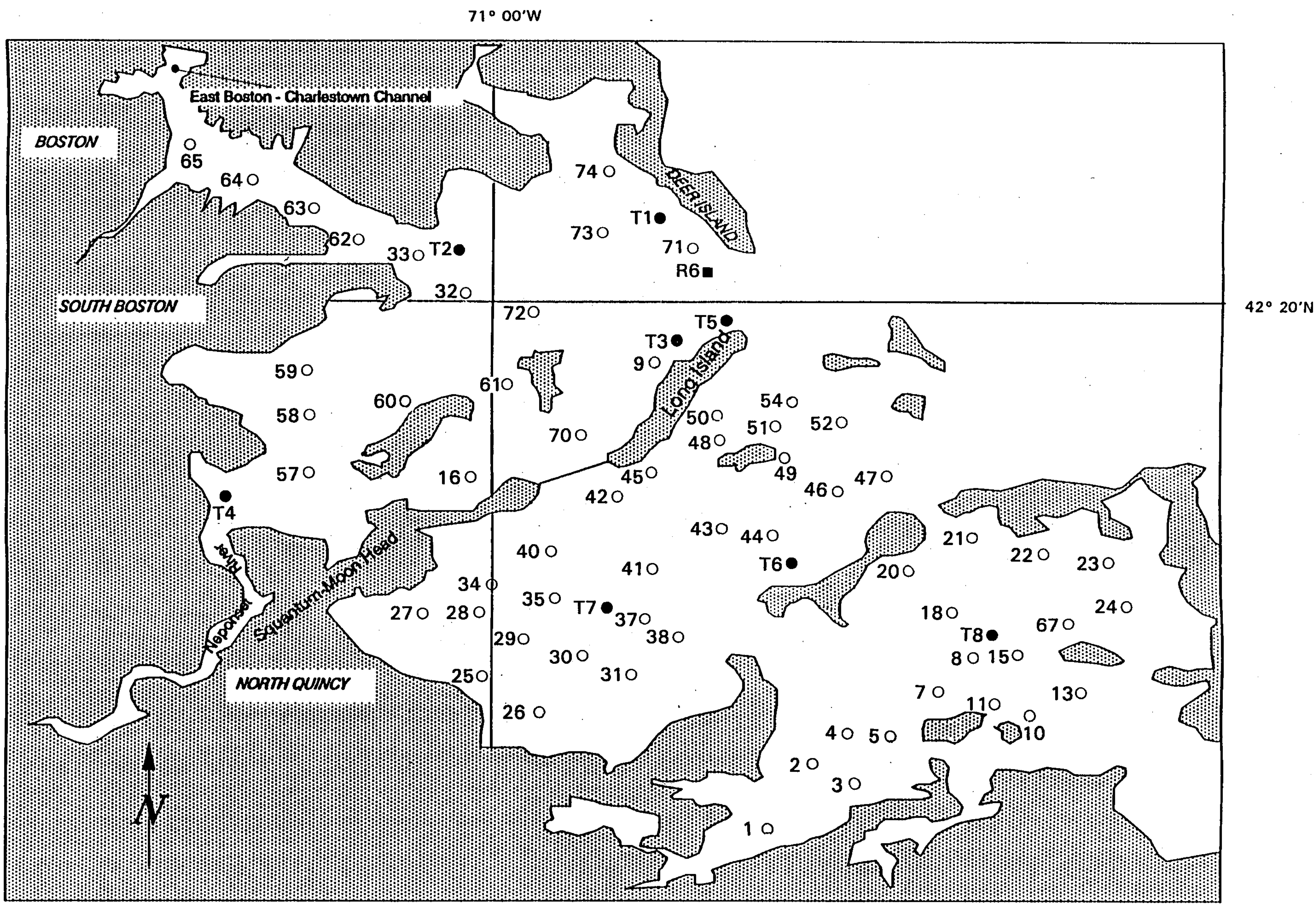

Figure 2. Stations Sampled for the August 1992 Boston Harbor Survey. Open circles are REMOTS® stations; filled circles are stations where biology and sediment samples were collected in addition to the REMOTS® pictures; filled square is Station R6, a station that substituted for T5 during the April 1992 survey.

Table 2. Summary of Station Data for August 1992 Boston Harbor Survey.

Station	Latitude	Longitude	Loran-C TDs	Depth (feet)
Boston Harbor Stations - REMOTS® and Sediment Samples				
T1	42° 20.95'N	70° 57.81'W	14021.78, 25844.06	10
T2	42° 20.57'N	71° 00.12'W	14038.71, 25858.52	22
T3	42° 19.81'N	70° 57.72'W	14026.53, 25836.60	25
T4	42° 18.60'N	71° 02.49'W	14063.26, 25863.72	5
T5	42° 19.91'N	70° 57.21'W	14022.69, 25833.44	22
T6	42° 17.61'N	70° 56.66'W	14030.34, 25816.18	21
T7	42° 17.36'N	70° 58.71'W	14044.94, 25829.66	18
T8	42° 17.12'N	70° 54.75'W	14020.51, 25799.80	38
Boston Harbor Stations - REMOTS® Samples only				
1-90	42° 15' 17"N	70° 56' 53"W	14042.95, 25804.16	6
2-90	42° 15' 47"N	70° 56' 31"W	14038.38, 25804.51	8
3-90	42° 15' 42"N	70° 56' 05"W	14035.82, 25800.92	7
4-90	42° 16' 09"N	70° 56' 16"W	14035.07, 25804.86	10
5-90	42° 16' 08"N	70° 55' 48"W	14031.95, 25801.44	19
7-90	42° 16' 34"N	70° 55' 24"W	14027.19, 25801.02	13
8-90	42° 16' 50"N	70° 54' 59"W	14023.46, 25799.72	12
9-89/90	42° 19' 38"N	70° 58' 06"W	14030.04, 25838.46	23
10-90	42° 16' 23"N	70° 54' 29"W	14022.28, 25793.42	28
11-90	42° 16' 28"N	70° 54' 50"W	14024.10, 25796.38	14
13-90	42° 16' 30"N	70° 53' 54"W	14018.01, 25789.93	25
15-90	42° 16' 54"N	70° 54' 31"W	14020.13, 25796.68	27
16-89/90	42° 18' 24"N	71° 00' 08"W	14049.17, 25846.06	13
18-90	42° 17' 23"N	70° 55' 15"W	14022.47, 25804.78	29
20-90	42° 17' 44"N	70° 55' 39"W	14023.49, 25809.74	20
21-90	42° 18' 03"N	70° 55' 02"W	14017.83, 25807.08	32
22-92	42° 17' 46"N	70° 54' 18"W	14014.85, 25800.40	21
23-92	42° 17' 41"N	70° 53' 49"W	14012.05, 27596.31	18
24-92	42° 17' 13"N	70° 53' 39"W	14012.66, 25792.49	17
25-90	42° 16' 45"N	70° 59' 45"W	14054.47, 25833.74	11

Table 2 (Continued).

Station	Latitude	Longitude	Loran-C TDs	Depth (feet)
Boston Harbor Stations - REMOTS® Samples only				
26-92	42° 16' 32"N	70° 59' 12"W	14052.16, 25828.53	9
27-90	42° 17' 20"N	71° 00' 25"W	14056.07, 25841.89	11
28-90	42° 17' 14"N	70° 59' 45"W	14052.45, 25836.54	13
29-90	42° 17' 03"N	70° 59' 17"W	14050.39, 25832.24	14
30-90	42° 16' 50"N	70° 58' 47"W	14047.96, 25827.21	13
31-90	42° 16' 41"N	70° 58' 13"W	14044.86, 25822.36	13
32-89/90	42° 20' 11"N	71° 00' 06"W	14040.67, 25856.11	41
33-89/90	42° 20' 31"N	71° 00' 40"W	14042.52, 25861.89	12
34-90	42° 17' 39"N	70° 59' 40"W	14049.90, 25838.43	13
35-90	42° 17' 26"N	70° 59' 03"W	14046.87, 25832.69	13
37-90	42° 17' 12"N	70° 58' 12"W	14042.61, 25824.99	14
38-90	42° 17' 05"N	70° 57' 50"W	14040.68, 25821.86	15
40-90	42° 17' 56"N	70° 59' 05"W	14044.70, 25835.93	13
41-90	42° 17' 44"N	70° 58' 13"W	14040.09, 25828.32	21
42-90	42° 18' 18"N	70° 58' 25"W	14038.33, 25832.88	31
43-90	42° 18' 13"N	70° 57' 38"W	14033.76, 25826.90	30
44-92	42° 18' 02"N	70° 57' 07"W	14031.30, 25822.04	40
45-90	42° 18' 37"N	70° 58' 04"W	14034.76, 25832.32	32
46-92	42° 18' 36"N	70° 56' 22"W	14023.77, 25819.94	37
47-92	42° 18' 42"N	70° 55' 57"W	14020.57, 25817.33	43
48-90	42° 18' 55"N	70° 57' 37"W	14030.33, 25830.79	23
49-90	42° 18' 45"N	70° 56' 46"W	14025.57, 25823.73	29
50-90	42° 19' 10"N	70° 57' 20"W	14027.23, 25830.15	22
51-90	42° 19' 04"N	70° 56' 49"W	14024.38, 25825.80	31
52-90	42° 19' 05"N	70° 56' 12"W	14020.16, 25821.48	27
54-90	42° 19' 20"N	70° 56' 38"W	14021.83, 25826.05	25
57-90	42° 18' 40"N	71° 01' 30"W	14056.63, 25857.60	18
58-90	42° 19' 11"N	71° 01' 30"W	14054.18, 25860.50	12
59-90	42° 19' 44"N	71° 01' 27"W	14051.25, 25863.20	15

Table 2 (Continued).

Station	Latitude	Longitude	Loran-C TDs	Depth (feet)
Boston Harbor Stations - REMOTS® Samples only				
60-90	42° 19' 13"N	71° 00' 47"W	14049.50, 25855.50	25
61-90	42° 19' 18"N	70° 59' 42"W	14042.23, 25848.11	18
62-90	42° 20' 48"N	71° 00' 59"W	14043.19, 25866.16	37
63-90	42° 21' 03"N	71° 01' 28"W	14045.09, 25870.86	37
64-90	42° 21' 21"N	71° 02' 02"W	14047.51, 25876.89	39
65-90	42° 21' 42"N	71° 02' 41"W	14050.04, 25833.38	39
67-92	42° 17' 26"N	70° 54' 15"W	14015.98, 25797.97	17
70-92	42° 18' 55"N	70° 58' 44"W	14037.36, 25838.88	11
71-92	42° 20' 34"N	70° 58' 00"W	14025.07, 25843.21	36
72-92	42° 20' 02"N	70° 59' 31"W	14037.56, 25850.92	41
73-92	42° 20' 39"N	70° 58' 42"W	14029.04, 25848.76	12
74-92	42° 21' 19"N	70° 58' 35"W	14025.06, 25851.69	12

TOC, and enumeration of *Clostridium perfringens* spores. Procedures used to obtain these samples conformed to methods used in the NOAA National Status and Trends program, whereby the top 1 cm of sediment, except that adjacent to the grab walls or doors, was removed with a Teflon scoop and quickly transferred to a 1-L Teflon-lined jar, which was immediately capped.

Homogenization of the sample was carried out in the ship laboratory to avoid contamination by stack gases. The sample was thoroughly stirred with a Teflon spatula and then subsampled, using the same spatula, into three prelabeled containers.

1. For *C. perfringens* analysis, sterile, prelabeled 4-oz Whirl-Paks (unopened bags are sterile) were two-thirds filled with sediment. The laboratory needed 30 g (1 oz) of sample for analysis. The samples were frozen and stored on dry ice covered with a layer of bubble-wrap in a cooler. All *C. perfringens* samples were kept together in a zipper-closure plastic bag.
2. The second subsample was for grain-size analysis. Clean, prelabeled 4-oz Whirl-Paks were two-thirds filled with sediment. The laboratory needed 30 g (1 oz) of dry sediment, excluding sand and water, for analysis. For very watery or sandy sediments, a second sample was collected. The samples were stored cold in a cooler with wet or blue ice to prevent the growth of mold. All grain-size samples were kept together in a zipper-closure plastic bag.
3. The third subsample was for TOC analysis. Clean, prelabeled 4-oz Whirl-Paks were two-thirds filled with sediment. The laboratory needed 10 g (⅓ oz) of sample for analysis. The samples were stored cold in a cooler with wet or blue ice. All TOC samples were kept together in a zipper-closure plastic bag.

2.1.4 Sediment Profile Imaging (REMOTS®)

A Benthos Model 3731 Sediment Profile Camera was used in this study (Benthos, Inc., North Falmouth, MA). The camera is designed to obtain *in situ* profile images of the top 15-20 cm of sediment. Functioning like an inverted periscope, the camera consists of a wedge-shaped prism with a front face plate and a back mirror mounted at a 45° angle to reflect the profile of the sediment-water interface up to the camera. The camera is mounted horizontally on top of the prism. The prism assembly is moved up and down by producing tension or slack on the winch wire. Tension on the wire keeps the prism in the up position.

The camera frame was lowered to the seafloor at a rate of about 1 m s^{-1}. Slack on the winch wire allowed the prism to penetrate the sediment vertically when the frame settled onto the bottom. A passive hydraulic piston ensured that the prism entered the sediment slowly (about 6 cm s^{-1}) and did not disturb the sediment-water interface. On impact with the bottom, a trigger activated a 13-s time delay on the shutter release; once the prism came to rest in the sediment, a photograph was taken. When the camera was raised, a wiper blade cleaned off the faceplate, the film was advanced by a motor drive, the strobe was recharged, and the camera was then ready to be lowered for another image.

Three replicate photographs were taken at each station. Ektachrome 100 ASA color slide film was used for all photographs. Film was developed, using a JOBO E6 rotary processor, at the end of each sampling day to determine the success of the REMOTS® sampling for that day.

2.1.5 Sample Documentation, Custody, and Quality Assurance/Quality Control

Standard SAIC procedures for sample tracking and custody were followed. In preparation for the field surveys, a checklist of all samples to be collected was prepared and sample containers were prelabeled in indelible ink. Benthic infauna samples had inside labels, written in pencil on plasticized paper, as well as outside labels. Label information included month and year; station number; sample type; and replicate number.

All pertinent information on field activities and sampling efforts was recorded in a bound logbook. The chief scientist was responsible for ensuring that sufficient detail was recorded. Entries were recorded in indelible ink and included, at a minimum:

- Date and time of starting work
- Names of field supervisor and team members
- Sampling site and activities
- Details of sampling effort, particularly deviations from standard operating procedures
- Field observations
- Field measurements made
- Sample identification
- Type and number of samples collected
- Sample handling and labeling information.

Chain-of-custody forms were also prepared for each type of sample so that a paper trail could be established to track the samples from the time of collection through the laboratory process.

2.2 Laboratory Methods: Sample Processing and Analysis

2.2.1 Benthic Infauna

Samples for taxonomic analysis of benthic infauna were taken to the SAIC office in Woods Hole where they were transferred from formalin to 70-80% ethanol and shipped to Cove Corporation for sorting, identification, and enumeration. Prior to sorting, each sample was resieved through nested 300-μm and 500-μm mesh screens, and the two resulting fractions were sorted separately. The sorters removed all organisms from the samples and separated them into major taxonomic groups. All residual material was labeled and stored for QC analysis. The first five samples processed by a sorter were resorted by a second technician. If fewer than 5% of the total number of organisms had been missed by the first sorter, only a random selection of that sorter's samples were rechecked. If more than 5% of the total organisms had been missed, the first sorter was required to resort all subsequent samples until five consecutive samples passed the QC check. SAIC personnel intercalibrated with Cove Corporation on the taxonomy and confirmed or changed some of the identifications.

2.2.2 Sediment Grain-Size

Samples for analysis of grain size were shipped to GEO/PLAN for analysis by Dr. Peter Rosen according to a standard method (Folk, 1974) for measuring weight percent gravel, sand, silt, and clay.

2.2.3 Total Organic Carbon

Samples for determination of TOC were shipped on ice to GERG (Geochemical and Environmental Research Group of Texas A&M University). The samples were analyzed according to standard methods used in the NOAA Status and Trends program. Details of the procedures were presented in the Work/Quality Assurance Project Plan for this project (Blake *et al.*, 1992b).

2.2.4 Clostridium perfringens

Samples for *C. perfringens* spore analysis were processed by the SAIC Environmental Testing Center in Narragansett, Rhode Island. Spores were extracted from the sediment according to the sonicate-and-settle method (Emerson and Cabelli, 1982) and enumerated by the mCP membrane filtration method (Bisson and Cabelli, 1979).

2.2.5 Sediment Profile Imaging Analysis

Replicate photographs were analyzed with the SAIC REMOTS® image analysis system. This system uses a SPARCstation 1+ Sun WorkStation integrated with a PULNIX TMC-50 video camera and frame grabber. Color slides are digitally recorded as color images on computer disk. The image analysis software is a menu-driven program that incorporates user commands via keyboard and trackball. This system displays each color slide on the CRT while measurements of all physical and biological parameters are obtained.

Up to 21 variables can be obtained for each REMOTS® image. All parameters were stored on computer disk and printed out on data sheets for editing by a senior-level scientist before being approved for final data synthesis, statistical analyses, and interpretation. A separate data sheet was generated for each REMOTS® image. Automatic disk storage of all parameters measured allow data from any variables of interest to be compiled, sorted, displayed graphically, contoured, or compared statistically.

REMOTS® photographs were analyzed for sediment type, surface boundary roughness, mud clasts, apparent redox potential discontinuity depth, sedimentary methane, and infaunal successional stages following procedures used for previous Boston Harbor surveys (SAIC, 1989, 1990).

2.2.6 Archived Sediment

For the benthic infauna samples, residues will be archived at SAIC for one year, and the identified collections will be kept for a period to be specified by MWRA.

2.3 Data Management and Analysis

Upon completion of the infaunal identifications, each taxon was assigned a code composed of a letter and three digits and keypunched into a spreadsheet on a personal computer. Preliminary data summaries were performed on this spreadsheet and the data were then converted into a database format that could be entered into a VAX 11/780 computer for further analysis. Data quality was verified by SAIC personnel. The database included counts of organisms for which the identification was uncertain (juveniles, anterior fragments, etc.); these were used for density and rank order tabulations but were not included in calculations of similarity or diversity indices. Animals, such as barnacles and hydroids, that are normally known to be attached to hard surfaces, were excluded from all analyses, as were parasitic and pelagic species.

Statistical treatment of the infaunal data set included an agglomerative clustering technique to determine similarity between samples. The similarity measures used were the Normalized Expected Species Shared (NESS) (Grassle and Smith, 1976) and the Bray-Curtis Similarity Coefficient (Boesch, 1977). For NESS, the number of individuals (m) was set at 200. The clustering strategy used was group average sorting for both NESS and Bray-Curtis (Boesch, 1977) and data used with the Bray-Curtis coefficient was square root transformed to alleviate bias caused by some of the very abundant dominant species.

Ordination using reciprocal averaging or correspondence analysis was also used. The first step in this analysis included reducing the data to the 50 most abundant species. These data were then clustered using the Bray-Curtis Similarity Coefficient with group average sorting. Ordination was used to analyze the individual cluster groups along axes 1 through 3 in an effort to explain the distribution of the cluster groups.

Benthic community parameters, including Shannon-Wiener diversity (H') and its associated evenness value (J'), were calculated along with the rarefaction method (Sanders, 1968) as modified by Hurlbert (1971). The Shannon-Wiener index was calculated using the base $\log_e$. For the rarefaction analyses, the number of individuals was set at defined points ranging between 500 and 9000.

To test for the significance of benthic parameters in the pre- and post-abatement samples at selected stations, analysis of variance (ANOVA) and appropriate multiple comparison tests were used. Comparison of means in a single classification Model I ANOVA (Sokal and Rohlf, 1969), for each station separately, were performed to determine whether there were any differences among sampling periods (September 1991, April 1992, and August 1992) in number of species or total densities. Sources of variation were among sampling periods (df = 2) and within sampling periods (df = 6); $F_{.05[2,6]} = 5.14$. Planned comparisons among means were limited to examining differences between pre- and post-abatement of sludge (September 1991 vs August 1992) and seasonal variation (cruise 2 vs 3). When the ANOVA determined a significant difference in number of species or total densities among sampling periods, *a posteriori* the Student Newman-Keuls (SNK) test (Sokal and Rohlf, 1969) and Scheffé test (Sokal and Rohlf, 1981, p. 256) were performed to determine where the difference occurred. The Student Newman-Keuls test uses the range as the statistic to measure differences among means. Scheffé's test allows comparison between a pair of sampling periods, for example, cruise 1 versus cruise 3, or between one sampling period and the mean of the other two, for example, cruise 1 versus cruises 2 and 3.

Where practical, maps were prepared depicting the distribution of individual species, communities, or benthic parameters.

3.1. Sedimentology

3.1.1 Distribution of Sediment Types

The dominant grain-size mode, as determined from REMOTS® images, for each station is shown in the grain-size map (Figure 3) along with information on the presence of imaged sedimentary methane gas, active ripples, hard bottom, and sand layering over mud. Sediment grain-size data from the sieve analyses of grab samples are presented in Table 3; a complete list of REMOTS® raw data is presented in Appendix A.

As noted in baseline survey reports (SAIC, 1989 and 1990; Kelly and Kropp, 1992), the overall sedimentary pattern is complex, consisting of a patchy mosaic of different grain-size distributions. Most stations consist of 4-3 phi very fine sands mixed with variable proportions of organic mud. Slight variations in station position and sampling can result in very different textures, making it difficult to assess spatial versus temporal changes in sediment type (see discussion).

Figure 3 underestimates the overall distribution of erosional bottom consisting of coarse sand and gravel sediments (see, for example, Figure 4). Some station locations have, over time, been repositioned from hard bottoms to softer bottoms. For example, those stations which showed shallow or no penetration of sampling gear in the 1989 and 1990 REMOTS® surveys were either dropped or moved to softer bottom types for the 1991 and 1992 surveys. This adjustment in some station locations was necessary to facilitate both camera prism penetration and core/grab sampling.

The mapped patterns of texture reflect the influence of source inputs of organic-rich silt + clays, water depth, and kinetic energy of the overlying water column. Nineteen stations show a distinct sand-over-mud layering (Figure 3). This layering suggests that the average kinetic energy at these stations increased in the recent past, perhaps related to storm activity. This textural layering comes about when shoaling storm waves move sand from shoals and the strand line out into deeper water to cover muds that accumulate in low kinetic areas of the bottom. Stations with sand-over-mud layering are located at the mouth of inner Boston Harbor, at the mouth of the Neponset River, in the inner part of Quincy Bay, at the mouth of Weymouth Channel, and on the Crow Point Flats of Hull Bay. Rippled bottom was observed in profile images at Stations 1 and T8, which are fine sands experiencing bed-load transport. Station T5, a medium sand, is also a relatively high kinetic energy bottom (Figure 3).

The lowest kinetic energy bottoms consist of methane containing very fine sand or silt + clay. Station 32 at the mouth of inner Boston Harbor has consistently shown the presence of methane in the sediment column. Nearby Station T2 also contained methane gas in the September 1991 sediment profile survey (Kelly and Kropp, 1992). Station T4, located at the mouth of the Neponset River, contains methane. Station T4 also showed the presence of methane in the September 1991 survey (Kelly and Kropp, 1992). Significantly, Station T4 has the highest TOC (4%) measured at the eight traditional (T) stations. The above stations are apparently experiencing high rates of sedimentation of reactive organic matter, resulting in anaerobic production of methane gas. Other stations may also contain methane, but the REMOTS® analysis can only detect bubbles that are >1 mm in diameter.

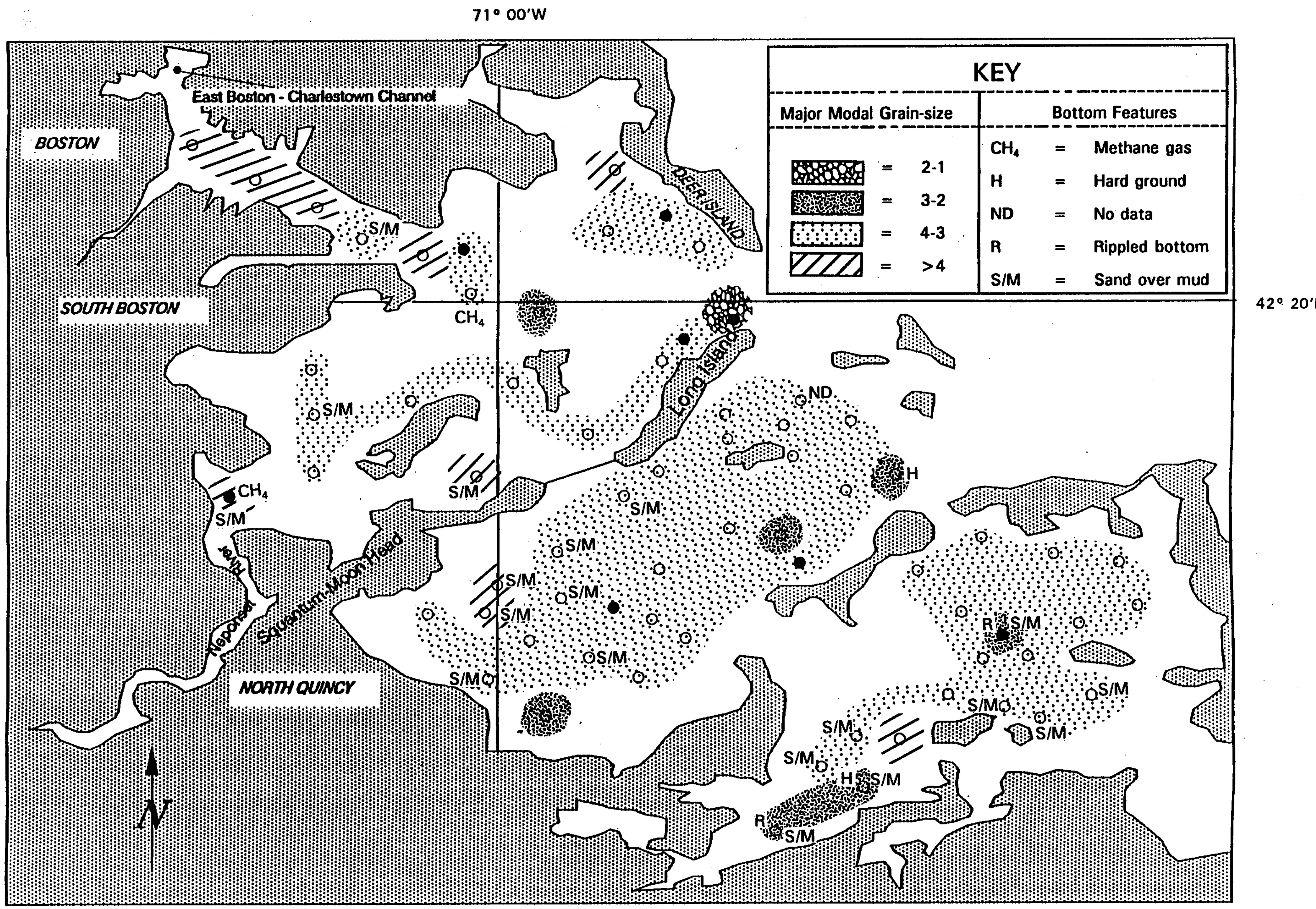

Figure 3. **Distribution of Major Modal Grain-Size and Sedimentary Structures.**

Table 3. **Sediment Grain-size Data for August 1992 Boston Harbor Survey.**

Station	% Gravel	% Sand	% Silt	% Clay
T1	65.3	17.8	8.0	9.0
T2	21.3	47.6	19.1	12.1
T3	0.0	43.5	39.0	17.5
T4	0.0	20.8	59.8	19.4
T5	92.5	5.6	1.0	0.9
T6	0.4	64.8	22.2	12.6
T7	4.5	40.2	38.8	16.5
T8	2.9	93.4	1.7	2.0

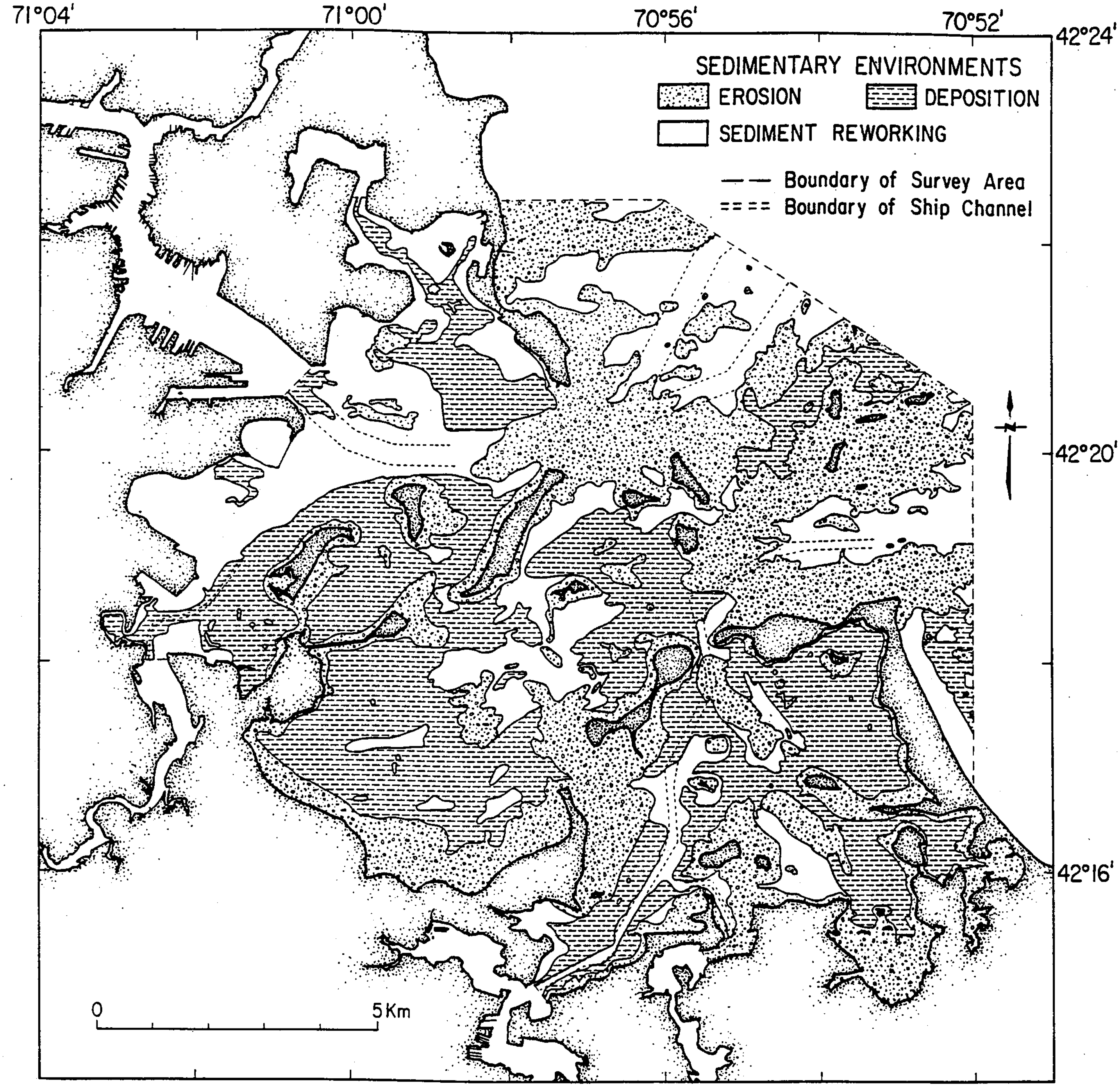

Figure 4. **Distribution of Sedimentary Environments Inferred from Sidescan Sonographs, Bathymetry, Sediment Type, Subbottom Acoustics, and Bottom-Current Data (Knebel et al., 1992). Note that most of the stations occupied in the MWRA study are located within depositional or reworked areas.**

3.1.2 Total Organic Carbon and Clostridium Spores

Spatial gradients in sediment TOC can serve to identify sources and sinks for organic matter. Counts of *C. perfringens* spores, in turn, can identify enrichment areas that are receiving high inputs of sewage-derived organic matter. The values for TOC and *C. perfringens* spore counts at the eight traditional stations are shown in Figure 5. The highest TOC contents (>3%) are located at Station T4 at the entrance to the Neponset River (4.0%), Station T3 near the former sludge discharge (3.6%), and Station T7 in the center of Quincy Bay (3.2%). These values are comparable to those recorded in September 1991 (T4 = 3.7%, T3 = 3.7%, and T7 = 2.7%). The major difference between these years is noted at Station T1 on the Deer Island Flats. In 1991, this station had a TOC content of 2.6%, whereas in 1992 a mean of three replicates yielded a value of 1.9%.

Figure 5 also shows the exponent of concentration for *C. perfringens* spores. Most traditional stations have a density of several thousand spores per gram of dry sediment (10^3). Stations T2 and T5 have the highest counts (10^4) and Station T3 has the lowest concentration (10^2). In 1991, counts were generally higher by an order of magnitude; most traditional stations had a concentration of several ten thousands (10^4). The exceptions were Station T3 (10^5) and Station T8 (10^3).

3.1.3 Mean Apparent RPD Depths

The spatial pattern of mean station RPD depths is shown in Figure 6. The lowest values are clustered near the mouth of inner Boston Harbor (Stations T2, 32, and 33) and at Stations T5, 61, 34, and T7. The major mode for the frequency distribution of apparent RPD depths falls into the depth class of 1.0-2.2 cm (Figure 6, inset). Baseline (pre-abatement of sludge) RPD depth classes fell into a major mode of 0-1.5 cm. This apparent increase in the RPD depth between pre- and post-abatement must be interpreted with care (see discussion). Most of the baseline data come from the spring months (June 1989 and May 1990); the post-abatement 1992 data were obtained in May and August.

3.1.4 Infaunal Successional Stages

Figure 7 shows the distribution of stations represented by Stage I seres only, stations where Stage II (*Ampelisca* sp.) are well developed, and stations where Stage III species are present together with mixtures of Stage I and/or II. No azoic stations were recorded although one replicate at Station T7 appeared to be devoid of macrofauna. Stations containing only Stage I seres are limited to nearshore locations in outer Boston Harbor in the vicinity of the Deer Island Flats (T1 and 73); at the mouth of inner Boston Harbor (Stations T2 and 33); Dorchester Bay (Stations T4 and 16); Quincy Bay (Station 25); Weymouth Channel (Station 1); and west of Hull (Station 47). Stations well represented by Stage II seres are located north of Long Island (9 and T3) and the outer reaches of Quincy Bay and Hull Bay. Stage III seres are broadly distributed throughout the surveyed area with the exception of the Stage I stations mentioned above and Stations T-8 and 44 where only Stage II seres were observed.

3.1.5 Organism-Sediment Indices (OSI)

The distribution of mean station OSI values is given in Figure 8. OSI values of $\leq +6$ tend to represent organically enriched or physically disturbed stations. Negative values identify severely

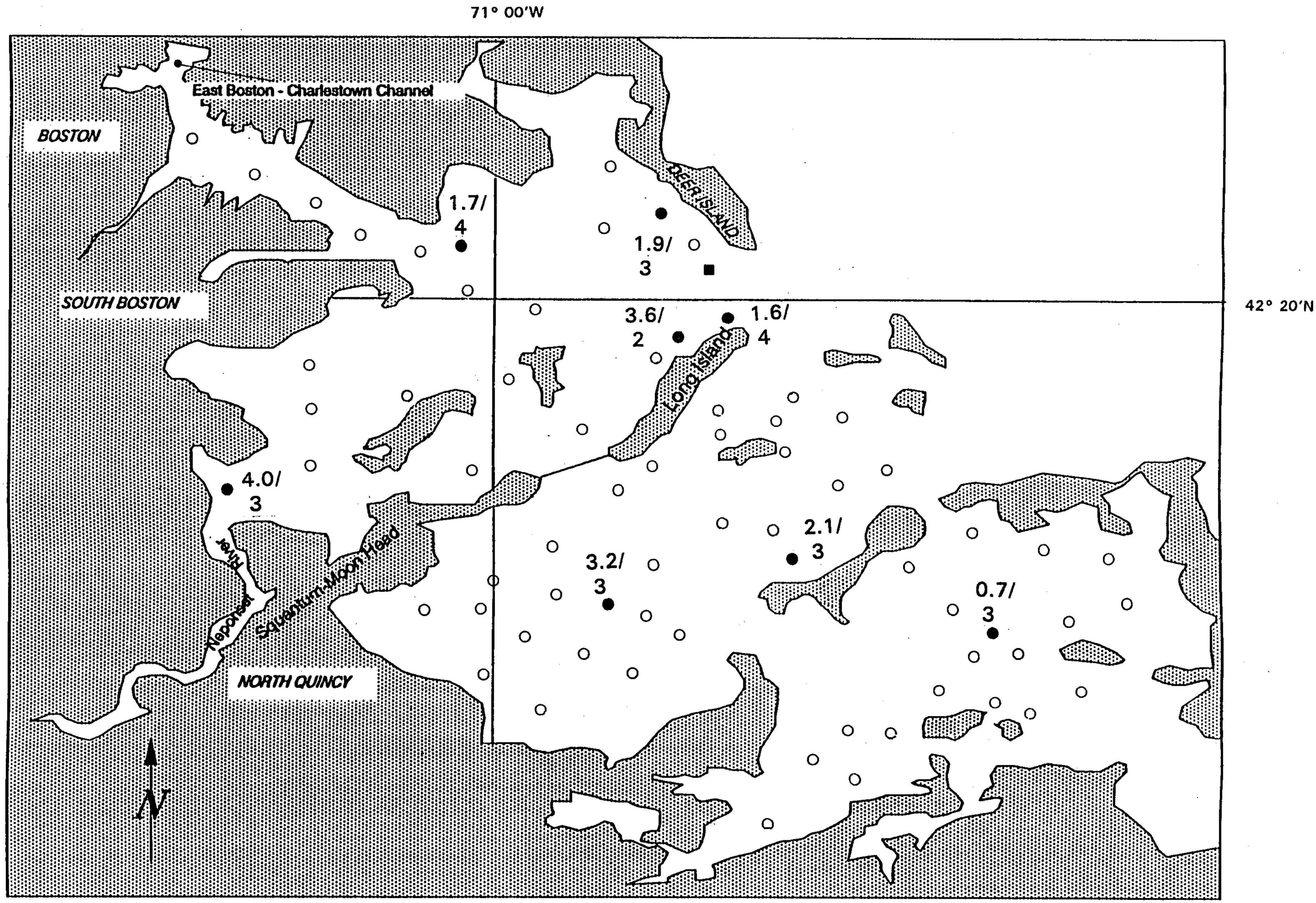

Figure 5. Total Organic Carbon (Dry Weight Percent) and *Clostridium perfringens* Spores (Colony Forming Units/g Dry Wt. of Sediment) at the Eight Traditional Stations. The first value by each station is the TOC and the second value is the exponent (base 10) of the spore counts.

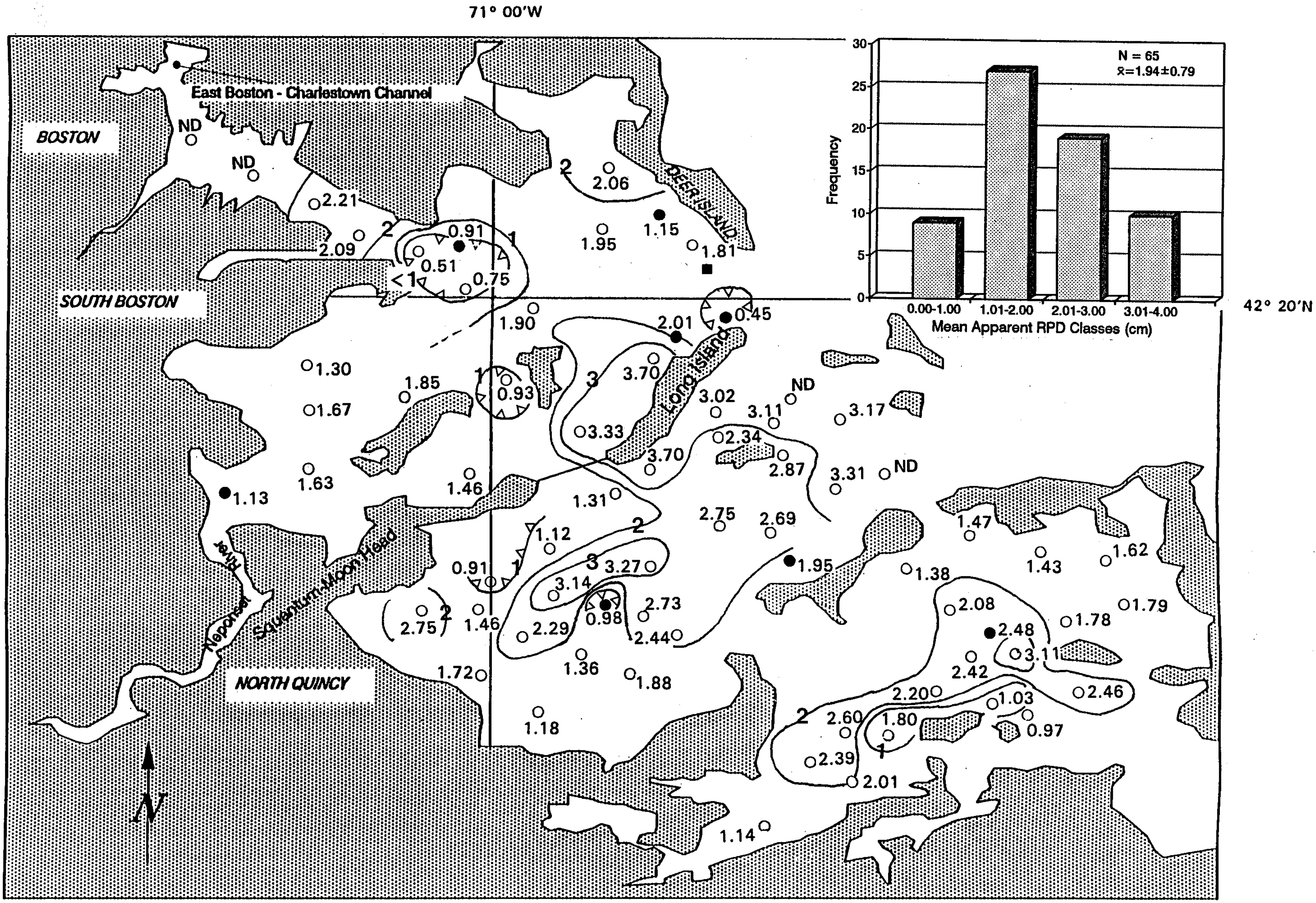

Figure 6. Mean Depth of the Apparent Redox Potential Discontinuity (RPD) Contoured on 1-cm Intervals. ND = no data. Inset shows frequency distribution of apparent RPD depths for all stations.

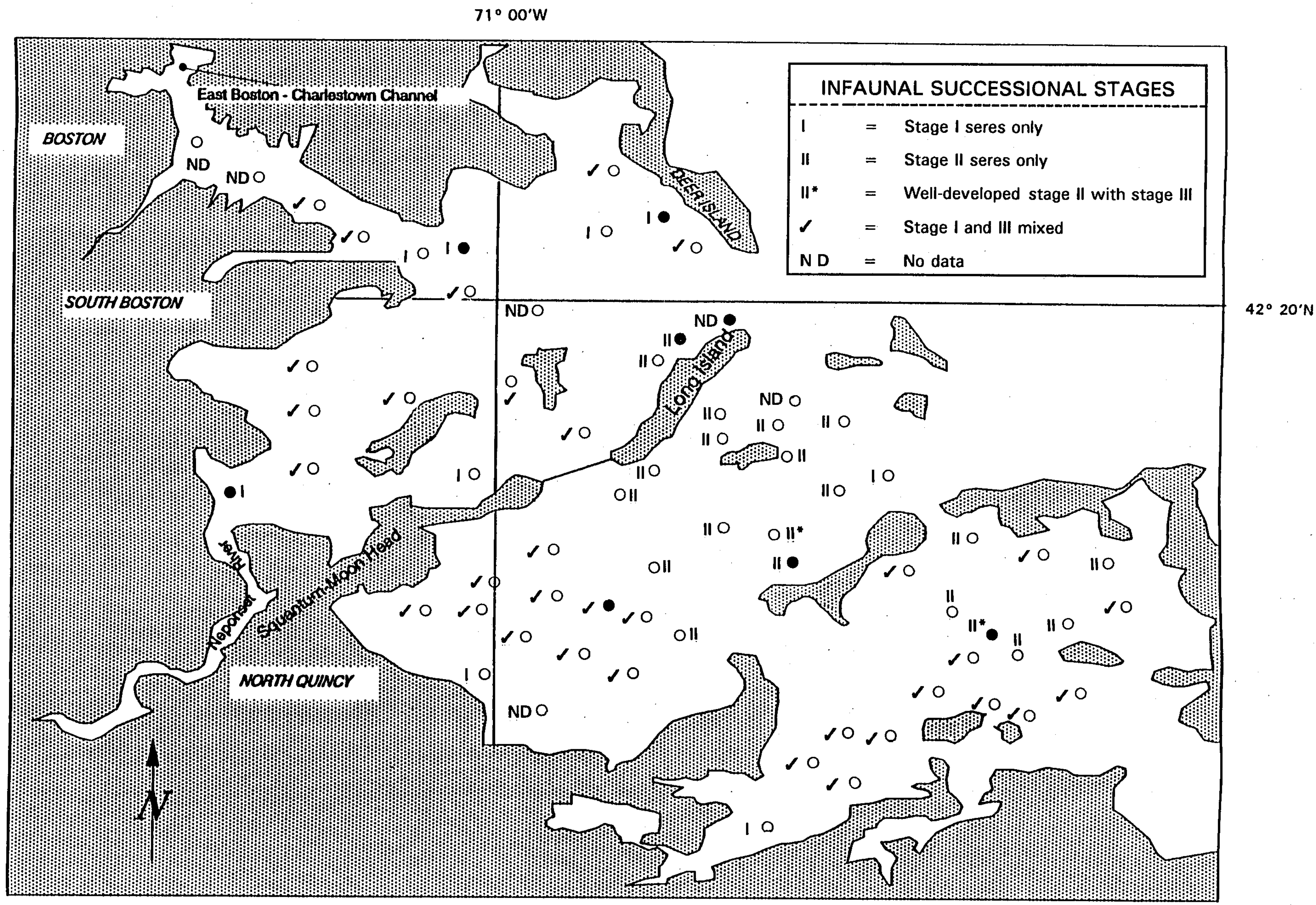

Figure 7. Infaunal Successional Stages as Inferred from REMOTS® Images.

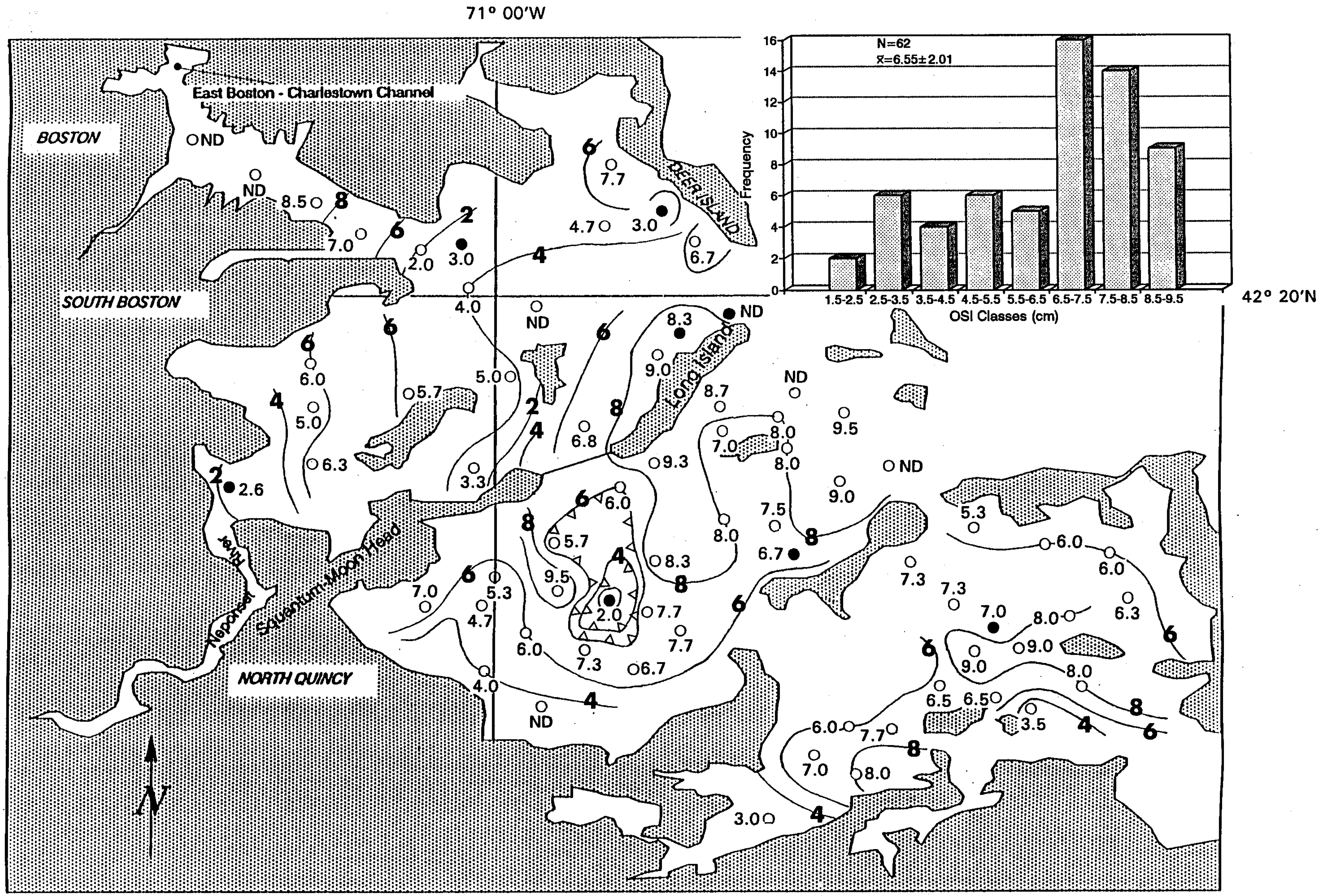

Figure 8. Mean Organism-Sediment Index (OSI) for each Station and Contoured on Intervals of 2 (Nondimensional) Units. ND = no data. Inset shows frequency distribution of OSI values at all stations.

impacted sites. No negative station OSIs were encountered in this survey. Quincy, Hingham and Hull Bays are represented by OSIs that mainly fall above +6. Outer Boston Harbor and Dorchester Bay have half (n = 9) of their stations with OSIs ≤ +6 and half (n = 9) > +6. The lowest OSI values in outer Boston Harbor are located at the mouths of inner Boston Harbor and the Neponset River. Relatively high values are present on the north side of Long Island across from the Deer Island Outfall and on Deer Island Flats (with the exception of Stations T1 and 73).

Mean station OSI values in Quincy Bay tend to increase from nearshore toward Massachusetts Bay. Negative contours appear to center on Station T7, which has a high TOC content (3.2%) and a thin apparent RPD (0.98 cm). The cause for the anomaly at T7 is not known. OSI values in Hull Bay are highest around Grape Island. The lowest OSIs (<3) were recorded at Stations T7 (Quincy Bay), 33 (mouth of inner Boston Harbor), and T4 (Savin Hill Cove). Most values of the OSI fall within the range of 6.5 to 9.5 (Figure 8, inset) suggesting that organism-sediment relationships are within the normal expected range for nearshore habitats.

3.2 Benthic Infauna

3.2.1 The Summer 1992 Results

Composition of the Fauna

A composite list of infaunal species identified from Boston Harbor for the September 1991, April 1992, and August 1992 samples is shown in Table 4; the species composition at each station is listed in Appendix C. The taxonomic assessment of the August 1992 samples included identification of three species of oligochaetes that had been lumped as "Oligochaeta" in the two earlier surveys.

For the August 1992 samples, 114 species of benthic invertebrates were identified from the 24 samples. Of these polychaetes were the predominant taxa with 54 species (47%), followed by crustaceans with 30 species (26%), molluscs with 20 species (18%), and 10 species (9%) representing less abundant taxa such as flatworms, nemerteans, oligochaetes, phoronids, echinoderms, enteropneusts, and ascideans.

The identification of the oligochaetes has proven to be significant in understanding the species composition at each station; at certain stations selected oligochaete species are among the most important constituents. It is important that this group of annelids be identified in future monitoring.

Distribution and Density of Dominant Species

The total density of benthic infauna at all eight stations averaged for three replicates and expressed as number of individuals per square meter ranges from 43,742 at Station T4 to 195,525 at Station T6 (Table 5). Three stations have total densities in excess of 100,000 individuals m^{-2}. Interestingly, at each of these stations, the dominant species responsible for these high densities are entirely different. For example, at Station T1, the opportunistic polychaete *Polydora cornuta* (a.k.a *P. ligni*) contributed more than 62% of the fauna; at Station T6, the amphipod *Ampelisca* spp., *Polydora cornuta*, and the oligochaete *Tubificoides* nr. *pseudogaster* contributed nearly 75% of the individuals; and at Station T8, more than half of the fauna was represented by *Aricidea catherinae*, a small deposit-feeding polychaete.

Table 4. List of Species Identified from Eight Boston Harbor Stations Sampled in September 1991, April 1992, and August 1992.

PLATYHELMINTHES
- Turbellaria spp.

NEMERTEA
- Nemertea spp.

ANNELIDA - OLIGOCHAETA
- *Tubificoides apectinatus* Brinkhurst, 1965
- *Tubificoides benedeni* Udekem, 1855
- *Tubificoides* nr. *pseudogaster* Dahl, 1960

ANNELIDA - POLYCHAETA

Family Ampharetidae
- *Ampharete arctica* Malmgren, 1866
- *Asabellides oculata* (Webster, 1879)

Family Capitellidae
- *Capitella capitata* complex (Fabricius, 1780)
- *Heteromastus filiformis* (Claparede, 1864)
- *Mediomastus californiensis* Hartman, 1944

Family Cirratulidae
- *Chaetozone setosa* Malmgren, 1867
- *Cirriformia grandis* (Verrill, 1873)
- *Dodecaceria* sp. A
- *Monticellina baptisteae* Blake, 1991
- *Tharyx acutus* Webster & Benedict, 1887

Family Dorvilleidae
- Dorvilleidae sp. A
- *Parougia caeca* (Webster & Benedict, 1884)

Family Flabelligeridae
- *Pherusa affinis* (Leidy, 1855)

Family Glyceridae
- *Glycera dibranchiata* Ehlers, 1868

Family Hesionidae
- *Microphthalmus aberrans* (Webster & Benedict, 1887)

Family Lumbrineridae
- *Scoletoma acicularum* (Webster & Benedict, 1887)
- *Scoletoma hebes* (Verrill, 1880)
- *Ninoe nigripes* Verrill, 1873

Family Maldanidae
- *Clymenella torquata* (Leidy, 1855)

Family Nephtyidae
- *Aglaophamus circinata* (Verrill, 1874)
- *Nephtys caeca* (Fabricius, 1780)
- *Nephtys incisa* Malmgren, 1865

Family Nereididae
- *Neanthes virens* Sars, 1835

Family Opheliidae
- *Ophelina acuminata* Oersted, 1843

Family Orbiniidae
- *Leitoscoloplos robustus* (Verrill, 1873)

Family Paraonidae
- *Aricidea catherinae* Laubier, 1967
- *Levinsenia gracilis* (Tauber, 1879)

Family Pectinariidae
- *Pectinaria granulata* (Linnaeus, 1767)

Family Pholoidae
- *Pholoe minuta* (Fabricius, 1780)

Family Phyllodocidae
- *Eteone flava* (Fabricius, 1780)
- *Eteone longa* (Fabricius, 1780)
- *Eteone heteropoda* Hartman, 1951
- *Eumida sanquinea* (Oersted, 1843)
- *Paranaitis speciosa* (Webster, 1870)
- *Phyllodoce mucosa* Oersted, 1843

Family Polygordiidae
- *Polygordius* sp. A

Family Polynoidae
- *Harmothoe imbricata* (Linnaeus, 1767)
- *Lepidonotus squamatus* (Linnaeus, 1758)

Family Sabellidae
- *Euchone incolor* Hartman, 1978

Family 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* (Claparède, 1870)
- *Streblospio benedicti* Webster, 1879

Family Syllidae
- *Autolytus fasciatus* (Bosc, 1802)
- *Exogone arenosa* Perkins, 1981
- *Exogone hebes* (Webster & Benedict, 1884)
- *Exogone verugera* (Claparède, 1868)
- *Proceraea cornuta* Agassiz, 1863
- *Pionosyllis* sp. A
- *Typosyllis* sp.

Table 4 (Continued).

Family Terebellidae
Nicolea zostericola (Oersted, 1844)
Polycirrus sp. A

ARTHROPODA - CRUSTACEA - MALACOSTRACA
DECAPODA
Infraorder Caridea
Family Crangonidae
Crangon septemspinosa Say, 1818

Infraorder Anomura
Family Paguridae
Pagurus longicarpus Say, 1817

Infraorder Brachyura
Family Cancridae
Cancer irroratus Say, 1817

PERACARIDA
Order Mysidacea
Family Mysidae
Neomysis americana (S.I. Smith, 1873)

Order Cumacea
Family Diastylidae
Diastylis sculpta Sars, 1871

Order Tanaidacea
Family Nototanaidae
Tanaissus psammophilus (Wallace, 1919)

Order Isopoda
Family Anthuridae
Ptilanthura tenuis Harger, 1879

Family Idoteidae
Edotea triloba (Say, 1818)
Erichsonella sp.

Family Limnoriidae
Limnoria lignorum (Rathke, 1799)

Family Munnidae
Munna sp.

Family Paramunnidae
Pleurogonium inerme Sars, 1882

Order Amphipoda - Gammaridea
Family Ampeliscidae
Ampelisca spp. complex

Family Ampithoidae
Cymadusa compta (Smith, 1873)

Family Aoridae
Leptocheirus pinguis (Stimpson, 1853)
Unciola irrorata Say, 1818

Family Argissidae
Argissa hamatipes (Norman, 1869)

Family Corophiidae
Corophium bonelli (Milne Edwards, 1830)
Corophium crassicorne Bruzelius, 1859
Corophium insidiosum Crawford, 1937
Corophium tuberculatum Shoemaker, 1934

Family Gammaridae
Gammarus lawrencianus Bousfield, 1956

Family Isaeidae
Photis pollex Walker, 1895

Family Ischyroceridae
Ischyrocerus anguipes Kroeyer, 1838
Jassa marmorata Holmes, 1903

Family Lysianassidae
Orchomenella minuta (Kroeyer, 1842)

Family Phoxocephalidae
Phoxocephalus holbolli (Kroeyer, 1942)
Rhepoxynius hudsoni Barnard & Barnard, 1982

Family Pleustidae
Pleusymtes glaber (Boeck, 1861)

Family Podoceridae
Dyopedos monacantha (Metzger, 1875)

Family Pontogeneiidae
Pontogeneia inermis (Kroeyer, 1842

Family Stenothoidae
Metopella angusta Shoemaker, 1949
Proboloides holmesi Bousfield, 1973
Stenothoe minuta Holmes, 1905

Order Amphipoda - Caprellidea
Family Caprellidae
Aeginina longicornis (Kroeyer, 1842-43)
Caprella linearis (Linnaeus, 1767)
Paracaprella tenuis Mayer, 1903

MOLLUSCA - BIVALVIA
Family Anomiidae
Anomia simplex Orbigny, 1842

Family Arcticidae
Arctica islandica (Linnaeus, 1767)

Family Astartidae
Astarte undata Gould, 1841

Family Cardiidae
Cerastoderma pinnulatum (Conrad, 1831)

Family Hiatellidae
Hiatella arctica (Linnaeus, 1767)

Family Lyonsiidae
Lyonsia hyalina Conrad, 1831

Table 4 (Continued).

Family Mactridae
Mulinia lateralis (Say, 1822)
Spisula solidissima (Dillwyn, 1817)

Family Montacutidae
Mysella planulata (Stimpson, 1857)

Family Myidae
Mya arenaria Linnaeus, 1758

Family Mytilidae
Musculus niger (Gray, 1824)
Mytilus edulis Linné, 1758

Family Nuculanidae
Yoldia limatula (Say, 1822)

Family Nuculidae
Nucula delphinodonta Mighels and Adams, 1842

Family Pandoridae
Pandora sp.

Family Petricolidae
Petricola pholadiformis (Lamarck, 1818)

Family Solenidae
Ensis directus Conrad, 1843

Family Tellinidae
Macoma balthica (Linnaeus, 1758)
Tellina agilis Stimpson, 1857

Family Thraciidae
Asthenothaerus hemphilli Dall, 1886
Thracia sp.

Family Veneridae
Pitar morrhuana Linsley, 1848

MOLLUSCA - GASTROPODA - NUDIBRANCHIA
Dorididacea sp. A

MOLLUSCA - GASTROPODA - PROSOBRANCHIA
Family Acmaeidae
Acmaeidae sp.

Family Calyptraeidae
Crepidula fornicata (Linnaeus, 1758)
Crepidula plana Say, 1822

Family Nassariidae
Nassarius trivittatus (Say, 1822)

PHORONIDA
Phoronis architecta Andrews, 1890

ECHINODERMATA - OPHIUROIDEA
Ophiuroidea spp.

ECHINODERMATA - ECHINOIDEA
Strongylocentrotus droebachiensis (Müller, 1776)

HEMICHORDATA
Enteropneusta spp.

CHORDATA - UROCHORDATA
Ascidiacea spp.

Table 5. Benthic Community Parameters for Boston Harbor Samples Collected in August 1992.

Station	Depth (ft)	Number of Species	Number of Individuals (m^2)	Diversity (Hurlbert's Rarefaction)										Shannon-Wiener Index and Evenness	
				Spp./ 500 Ind.	Spp./ 1000 Ind.	Spp./ 2000 Ind.	Spp./ 3000 Ind.	Spp./ 4000 Ind.	Spp./ 5000 Ind.	Spp./ 6000 Ind.	Spp./ 7000 Ind.	Spp./ 8000 Ind.	Spp./ 9000 Ind.	*H'*	*J'*
T1	10	68	188,667	23.9	30.8	38.8	43.7	47.2	50.0	52.2	54.1	55.7	57.2	2.29	0.376
T2	22	54	70,942	23.1	28.9	36.2	41.0	44.7	47.6	50.0	52.0	53.8	*	2.80	0.487
T3	25	46	89,992	24.4	29.6	34.7	37.6	39.7	41.3	42.7	43.8	44.8	45.7	2.95	0.534
T4	5	9	43,742	3.6	5.0	6.7	7.7	8.4	8.9	*	*	*	*	0.08	0.025
T5	22	67	86,083	25.5	33.5	43.0	48.9	53.2	56.5	59.2	61.5	63.6	65.3	2.27	0.374
T6	21	51	195,525	18.4	23.0	28.4	31.8	34.3	36.2	37.8	39.2	40.4	41.5	2.49	0.440
T7	18	33	39,875	15.9	20.4	25.7	29.3	31.9	*	*	*	*	*	2.72	0.538
T8	38	62	104,817	27.3	33.7	40.8	45.3	48.6	51.2	53.4	55.3	56.9	58.4	2.73	0.458

* indicates that sample was too small to measure this parameter

The dominant species were ranked at each station according to their percent contribution to the entire fauna (see righthand portion of Table 6). The same procedure was performed for collections made in September 1991 and April 1992 so that temporal patterns could be compared (see discussion in Section 3.2.2). In August 1992, at Station T1 on the Deer Island Flats, the fauna was dominated by species that are typically associated with organic enrichment and sometimes considered to be opportunistic or associated with stressed or polluted environments. The most abundant species, *Polydora cornuta*, is a well-known opportunistic species (Rice and Simon, 1980) and represented more than 62% of the total fauna. Other opportunists among the 10 most abundant species included *Tubificoides* nr. *pseudogaster*, *Streblospio benedicti*, *Capitella capitata* spp. complex, and *Polydora aggregata*. It is interesting that at least one deep-burrowing deposit-feeding polychaete, *Clymenella torquata*, was also present. This species is clearly a Stage III organism, yet none were observed in the REMOTS® images from the same station (see above). *Polydora websteri*, which ranked fifth, is usually considered to be a shell borer (Blake, 1971) and may have been associated with shell hash in the samples.

Station T2 near Logan Airport also had several opportunistic species among the 10 most abundant. *Tubificoides* nr. *pseudogaster* was the most abundant species and represented about 33.3% of the total fauna. Other dominant species present that are usually associated with organically enriched environments include *Tharyx acutus*, *Streblospio benedicti*, *Polydora cornuta*, and *Tubificoides apectinatus*. *Polydora websteri* ranked ninth at this station.

Stations T3 and T5 are on the north side of Long Island, near the site of a former sludge outfall. The two stations differ considerably in their faunal components. At Station T3, the amphipod *Ampelisca* spp., the polychaete *Polydora cornuta*, and the oligochaete *Tubificoides* nr. *pseudogaster* account for more than 75% of the total fauna. Four other amphipod species occur among the 10 most abundant species at this station. In contrast, at Station T5, *Tubificoides* nr. *pseudogaster* and *Capitella* together comprise nearly 80% of the total fauna. Only a single amphipod occurs among the 10 most abundant species (*Phoxocephalus holbolli*, in rank 5).

Station T4 is located at Savin Hill Cove in a heavily stressed environment. Only nine species were identified from the site, with more than 99% of the individuals represented by the opportunistic spionid polychaete *Streblospio benedicti*.

Station T6 on the north side of Peddocks Island is similar to T3 in having the amphipod *Ampelisca* spp., the polychaete *Polydora cornuta*, and the oligochaete *Tubificoides* nr. *pseudogaster* as the three most abundant species. The fourth ranked species, *Aricidea catherinae*, was not one of the dominants at Station T3, whereas two amphipods, *Leptocheirus pinguis* and *Phoxocephalus holbolli*, that ranked fifth and sixth were also among the dominants at Station T3.

Station T7 in Quincy Bay was unusual in having dominant infauna that was a mixture of opportunistic species (e.g., *Streblospio benedicti*, *Polydora cornuta*, *Tubificoides* nr. *pseudogaster*, and *T. apectinatus*) and species not normally associated with such conditions (e.g., *Ampelisca* spp., *Aricidea catherinae*, *Asabellides oculata*, and *Spio thulini*). *Streblospio benedicti* was the most abundant species with nearly 30% of the individuals; it was followed closely by the ampeliscids with about 25%.

Station T8 in Hull Bay had probably the "healthiest" fauna of all of the stations in that, except for *Polydora cornuta* (5th rank) and *Tubificoides* nr. *pseudogaster* (rank 8), the top 10 consisted mostly

Table 6. **Ten Dominant Taxa and Their Contribution to the Total Fauna Recorded from Eight Stations in Boston Harbor as Part of the Sludge Abatement Monitoring Program.**

Station T1 (September 1991)			Station T1 (April 1992)			Station T1 (August 1992)		
Species	Percent	Density ($0.12\ m^{-2}$)	Species	Percent	Density ($0.12\ m^{-2}$)	Species	Percent	Density ($0.12\ m^{-2}$)
Oligochaeta spp.	48.8	796	Oligochaeta spp.	67.5	3,051	*Polydora cornuta*	62.7	12,806
Streblospio benedicti	19.8	323	*Microphthalmus aberrans*	9.1	410	*Tubificoides* nr. *pseudogaster*	8.0	1,628
Microphthalmus aberrans	8.2	133	*Mytilus edulis*	5.5	250	*Clymenella torquata*	7.2	1,466
Tharyx acutus	6.0	98	*Tharyx acutus*	3.0	134	*Streblospio benedicti*	5.6	1,147
Polydora cornuta	4.5	74	*Streblospio benedicti*	2.8	126	*Polydora websteri*	3.8	779
Ampelisca spp. complex	3.1	50	*Nassarius trivittatus*	2.5	112	*Microphthalmus aberrans*	3.1	628
Nassarius trivittus	2.3	37	*Polydora cornuta*	1.6	73	*Capitella capitata* spp.	2.0	402
Capitella capitata spp.	1.4	23	*Polydora socialis*	1.3	58	*Spio thulini*	1.3	263
Tellina agilis	1.2	20	*Spio setosa*	1.1	49	*Polydora aggregata*	1.0	209
Nepthys caeca	1.0	17	*Tellina agilis*	0.9	41	*Tharyx acutus*	1.0	206
Total Cumulative	96.3	1,571		95.3	4,304		95.7	19,534
Remaining Taxa	3.7	60		4.7	217		4.3	900
Total Density All Species	100.0	1,631		100.0	4,521		100.0	20,434

Table 6 (Continued).

Station T2 (September 1991)			Station T2 (April 1992)			Station T2 (August 1992)		
Species	Percent	Density (0.12 m^{-2})	Species	Percent	Density (0.12 m^{-2})	Species	Percent	Density (0.12 m^{-2})
Streblospio benedicti	49.7	72	*Streblospio benedicti*	70.0	1,456	*Tubificoides* nr. *pseudogaster*	33.3	2,708
Oligochaeta spp.	37.2	54	Oligochaeta spp.	9.5	197	*Tharyx acutus*	22.1	1,799
Crangon septemspinosa	5.5	8	*Tharyx acutus*	6.4	132	*Streblospio benedicti*	17.1	1,392
Mytilus edulis	2.0	3	*Capitella capitata* spp.	5.4	113	*Polydora cornuta*	13.4	1,090
Lyonsia hyalina	1.4	2	*Mytilus edulis*	3.7	76	*Spio thulini*	2.4	196
Turbellaria spp.	1.4	2	*Polydora socialis*	1.3	27	*Microphthalmus aberrans*	2.3	186
Nassarius trivittatus	0.7	1	*Spio limicola*	0.8	17	*Eteone longa*	1.3	104
Neomysis americana spp. complex	0.7	1	*Polydora quadrilobata*	0.6	13	*Tubificoides apectinatus*	1.2	101
Aricidea catherinae	0.7	1	*Tellina agilis*	0.5	11	*Polydora websteri*	1.1	89
Tharyx acutus	0.7	1	*Polydora cornuta*	0.5	10	*Phyllodoce mucosa*	0.9	69
Total Cumulative	100.0	145		98.7	2,052		95.1	7,734
Remaining Taxa	0.0	0		1.3	27		4.9	399
Total Density All Species	100.0	145		100.0	2,079		100.0	8,133

Table 6 (Continued).

Station T3 (September 1991)			Station T3 (April 1992)			Station T3 (August 1992)		
Species	Percent	Density (0.12 m^{-2})	Species	Percent	Density (0.12 m^{-2})	Species	Percent	Density (0.12 m^{-2})
Oligochaeta spp.	86.7	6,073	Oligochaeta spp.	61.0	1,589	*Ampelisca* spp. complex	31.1	2,923
Microphthalmus aberrans	4.1	288	*Aricidea catherinae*	6.5	170	*Polydora cornuta*	27.5	2,588
Aricidea catherinae	3.7	262	*Ampelisca* spp. complex	4.8	126	*Tubificoides* nr. *pseudogaster*	13.1	1,231
Ampelisca spp. complex	1.6	109	*Tharyx acutus*	4.5	118	*Leptocheirus pinguis*	7.8	736
Phoxocephalus holbolli	0.8	59	*Mytilus edulis*	4.3	112	*Phoxocephalus holbolli*	4.7	444
Nassarius trivittatus	0.8	58	*Nassarius trivittatus*	3.7	95	*Photis pollex*	3.0	286
Tellina agilis	0.7	52	*Microphthalmus aberrans*	3.2	84	*Aricidea catherinae*	2.8	260
Mytilus edulis	0.2	16	*Streblospio benedicti*	3.1	81	*Corophium bonelli*	1.9	179
Edotea triloba	0.2	15	*Tellina agilis*	2.9	76	*Spio thulini*	1.1	104
Streblospio benedicti	0.2	14	*Polydora cornuta*	1.0	26	*Edotea triloba*	1.1	101
Total Cumulative	99.0	6,946		95.0	2,477		94.1	8,852
Remaining Taxa	1.0	55		5.0	127		5.9	549
Total Density All Species	100.0	7,001		100.0	2,604		100.0	9,401

Table 6 (Continued).

Station T4 (September 1991)			Station T4 (April 1992)			Station T4 (August 1992)		
Species	Percent	Density (0.12 m^{-2})	Species	Percent	Density (0.12 m^{-2})	Species	Percent	Density (0.12 m^{-2})
Streblospio benedicti	80.7	343	*Capitella capitata* spp.	47.2	610	*Streblospio benedicti*	99.3	5,164
Turbellaria spp.	17.0	72	*Streblospio benedicti*	37.5	485	*Tubificoides* nr. *pseudogaster*	0.3	14
Crangon septemspinosa	1.2	5	Oligochaeta spp.	10.1	130	*Capitella capitata spp.*	0.2	9
Tharyx acutus	0.5	2	*Mytilus edulis*	2.2	29	*Mytilus edulis*	0.1	5
Paranaitis speciosa	0.2	1	*Polydora cornuta*	0.8	10	*Ampelisca* spp. complex	<0.1	3
Exogone arenosa	0.2	1	*Tharyx acutus*	0.8	10	*Microphthalmus aberrans*	<0.1	2
Oligochaeta spp.	0.2	1	*Ampelisca* spp. complex	0.5	7	*Tharyx acutus*	<0.1	2
			Eteone heteropoda	0.5	6	*Aricidea catherinae*	<0.1	2
			Microphthalmus aberrans	0.2	2	*Tubificoides benedeni*	<0.1	1
			Mya arenaria	0.1	1			
Total Cumulative	100.0	425		99.9	1,290		100.0	5,201
Remaining Taxa	0	0		0.1	2		0	0
Total Density All Species	100.0	425		100.0	1,292		100.0	5,201

Table 6 (Continued).

Station T5 (September 1991)			Station R6 (April 1992)			Station T5 (August 1992)		
Species	Percent	Density ($0.12 m^{-2}$)	Species	Percent	Density ($0.12 m^{-2}$)	Species	Percent	Density ($0.12 m^{-2}$)
Oligochaeta spp.	70.2	177	*Capitella capitata* spp.	62.0	661	*Tubificoides* nr. *pseudogaster*	54.8	5,501
Nassarius trivittatus	17.5	44	*Mytilus edulis*	9.6	102	*Capitella capitata* spp.	25.1	2,520
Capitella capitata spp.	7.1	18	*Nassarius trvittatus*	8.1	87	*Spio thulini*	3.3	332
Tellina agilis	2.0	5	Oligochaeta spp.	7.7	82	*Tubificoides benedeni*	2.6	260
Streblospio benedicti	0.8	2	*Tharyx acutus*	3.0	32	*Phoxocephalus holbolli*	2.6	259
Tharyx acutus	0.8	2	*Streblospio benedicti*	2.7	29	*Polydora cornuta*	2.6	256
Mytilus edulis	0.4	1	*Mya arenaria*	2.0	21	*Mytilus edulis*	1.5	152
Microphthalmus aberrans	0.4	1	*Spio limicola*	1.0	11	*Microphthalmus aberrans*	1.2	115
Neanthes virens	0.4	1	*Ischyrocerus anguipes*	0.8	9	*Nassarius trivittatus*	0.9	87
Nemertea spp.	0.4	1	*Tellina agilis*	0.8	9	*Polydora websteri*	0.6	64
Total Cumulative	100.0	252		97.7	1,043		95.2	9,546
Remaining Taxa	0	0		2.3	24		4.8	495
Total Density All Species	100.0	252		100.0	1,067		100.0	10,041

Table 6 (Continued).

Station T6 (September 1991)			Station T6 (April 1992)			Station T6 (August 1992)		
Species	**Percent**	**Density (0.12 m^{-2})**	**Species**	**Percent**	**Density (0.12 m^{-2})**	**Species**	**Percent**	**Density (0.12 m^{-2})**
Oligochaeta spp.	30.3	1,984	Oligochaeta spp.	55.7	3,239	*Ampelisca* spp. complex	33.2	7,456
Ampelisca spp. complex	28.0	1,838	*Ampelisca* spp. complex	15.0	874	*Polydora cornuta*	26.7	5,996
Aricidea catherinae	26.9	1,765	Aricidea catherinae	14.6	850	*Tubificoides* nr. *pseudogaster*	18.1	4,067
Polydora cornuta	7.3	480	*Mytilus edulis*	1.9	113	*Aricidea catherinae*	13.9	3,128
Phoxocephalus holbolli	2.0	133	*Phoxocephalus holbolli*	1.7	98	*Leptocheirus pinguis*	1.4	309
Mediomastus californiensis	1.0	65	*Dyopedos monacanthus*	1.7	98	*Phoxocephalus holbolli*	1.3	300
Nassarius trivittatus	1.0	63	*Spio limicola*	1.4	80	*Spio thulini*	0.9	192
Scoletoma hebes	0.7	44	*Nucula delphinodonta*	1.2	72	*Tubificoides apectinatus*	0.7	167
Tellina agilis	0.6	39	*Polydora cornuta*	1.2	68	*Mediomastus californiensis*	0.6	134
Spio thulini	0.4	29	*Polydora socialis*	1.2	68	*Phyllodoce mucosa*	0.6	133
Total Cumulative	98.2	6,440		95.6	5,560		97.4	21,882
Remaining Taxa	1.8	116		4.4	260		2.6	598
Total Density All Species	100.0	6,556		100.0	5,820		100.0	22,480

Table 6 (Continued).

Station T7 (September 1991)			Station T7 (April 1992)			Station T7 (August 1992)		
Species	**Percent**	**Density ($0.12 m^{-2}$)**	**Species**	**Percent**	**Density ($0.12 m^{-2}$)**	**Species**	**Percent**	**Density ($0.12 m^{-2}$)**
Streblospio benedicti	41.6	1,192	*Streblospio benedicti*	48.5	985	*Streblospio benedicti*	29.7	1,358
Ampelisca spp. complex	30.3	868	*Ampelisca* spp. complex	21.9	445	*Ampelisca* spp. complex	24.6	1,125
Aricidea catherinae	6.9	198	*Polydora cornuta*	7.1	144	*Aricidea catherinae*	15.1	691
Mya arenaria	6.6	189	Oligochaeta spp.	6.4	129	*Polydora cornuta*	12.0	546
Ensis directus	5.0	142	*Aricidea catherinae*	3.7	75	*Tubificoides* nr. *pseudogaster*	7.2	327
Oligochaeta spp.	3.1	89	*Mya arenaria*	2.2	44	*Leptocheirus pinguis*	4.5	207
Polydora cornuta	2.2	63	*Spio limicola*	2.1	43	*Tubificoides apectinatus*	4.0	181
Nassarius trivittatus	2.0	56	*Polydora socialis*	1.6	33	*Asabellides oculata*	0.7	30
Tharyx acutus	0.7	20	*Tharyx acutus*	1.3	27	*Tharyx acutus*	0.3	15
Crangon septemspinosa	0.6	16	*Nassarius trivittatus*	1.2	24	*Spio thulini*	0.3	13
Total Cumulative	99.0	2,833		96.0	1,949		98.4	4,493
Remaining Taxa	1.0	33		4.0	83		1.6	76
Total Density All Species	100.0	2,866		100.0	2,032		100.0	4,569

Table 6 (Continued).

Station T8 (September 1991)			Station T8 (April 1992)			Station T8 (August 1992)		
Species	Percent	Density ($0.12\ m^{-2}$)	Species	Percent	Density ($0.12\ m^{-2}$)	Species	Percent	Density ($0.12\ m^{-2}$)
Aricidea catherinae	37.4	2,445	*Aricidea catherinae*	36.9	1,225	*Aricidea catherinae*	54.7	6,494
Ampelisca spp. complex	18.1	1,182	*Polygordius* sp. A	14.9	493	*Ampelisca* spp. complex	8.5	1,014
Nucula delphinodonta	11.3	739	*Exogone hebes*	10.7	354	*Polygordius* sp. A	5.6	667
Exogone hebes	3.7	239	Oligochaeta spp.	5.4	180	*Spiophanes bombyx*	5.4	637
Polygordius sp. A	3.4	222	*Tellina agilis*	5.2	174	*Polydora cornuta*	5.3	630
Oligochaeta spp.	3.0	194	*Nucula delphinodonta*	4.9	161	*Exogone hebes*	4.9	582
Nassarius trivittatus	2.7	178	*Nassarius trivittatus*	4.3	141	*Nucula delphinodonta*	3.7	441
Clymenella torquata	2.4	157	*Tharyx acutus*	4.0	133	*Tubificoides* nr. *pseudogaster*	2.1	244
Tellina agilis	2.1	138	*Spiophanes bombyx*	3.0	101	*Pygospio elegans*	1.5	173
Lyonsia hyalina	2.0	132	*Mytilus edulis*	1.5	50	*Spio thulini*	1.3	149
Total Cumulative	86.1	5,626		90.8	3,012		93.0	11,031
Remaining Taxa	13.9	914		9.2	307		7.0	840
Total Density All Species	100.0	6,540		100.0	3,319		100.0	11,871

of species that are not normally associated with stressed or polluted environments. *Aricidea catherinae* was the most abundant species with more than 54% of the total number of individuals. This species was accompanied by ampeliscid amphipods (8.54%), seven annelid species, and one bivalve.

Species Richness and Diversity

The total number of species at the Boston Harbor stations varied from a low of 9 at Station T4 at Savin Hill Cove to a high of 68 at Station T1 on Deer Island Flats (Table 5). High numbers of species were also found at Stations T5 (Long Island) and T8 (Hull Bay).

Species diversity as measured by Shannon-Wiener (H') was extremely low at Station T4 (0.08) but ranged from 2.27 (Station T5) to 2.95 (T3) at all other stations (Table 5). When measured by Hurlbert's Rarefaction, the differences between the stations other than T4 are more apparent (Figure 9). Station T5 off Long Island has the highest diversity when measured by the rarefaction method, but T3, the station that was highest with H', was only fifth highest with rarefaction.

Community Analysis

Results of the cluster analysis on the August 1992 data (Figures 10 and 11) indicate two facts: (1) There are three well-defined clusters or station groups. (2) All replicates from one station are more similar among themselves than to any other station. These results are consistent regardless of whether Bray-Curtis or NESS is used as the clustering strategy.

The most dissimilar station in the analysis is Station T4 from off Savin Hill Cove. This should be expected because of the total dominance of *Streblospio benedicti* (99.2% of the fauna) and the very low species richness (9 species total) in this heavily polluted location. Stations T1, T2, and T5 formed a cluster (cluster 1) that was distinct from another cluster (2) that included Stations T3, T6, T7, and T8. Stations in cluster 1 are mostly dominated by opportunistic polychaetes and oligochaetes (*Polydora cornuta, Capitella capitata,* and *Tubificoides* spp.), whereas stations composing cluster 2 are characterized by ampeliscid amphipods and paraonid polychaetes (*Aricidea catherinae*).

Ordination analysis provides results that support the cluster analysis (Figure 12). In the upper diagram, the location of each of the two clusters and the outlier (Station T4) in ordination space in three axes can be seen. The locations of each of the stations within these clusters should be noted for general similarity to the temporal results (see below). Station T8 has been pulled farther along axis 2 than other stations in cluster 2, and Station T4 has been pulled the farthest from all of the stations along axes 1 and 2. The lower diagram in Figure 12 indicates those species that are responsible for the ordination patterns of the stations. Species such as *Aricidea catherinae, Pygospio elegans, Exogone hebes, Spiophanes bombyx, Nucula delphinodonta,* and *Polygordius* sp. A are responsible for pulling Station T8 away from the other cluster 2 stations. Likewise, there is little question that *Streblospio benedicti* is responsible for the placement of Station T4. The separation of clusters 1 and 2 can be visualized by the dominance of *Tubificoides benedini, Polydora websteri*, and *Clymenella torquata* for cluster 1 and the amphipods *Leptocheirus pinguis* and *Ampelisca* spp. for cluster 2. These results are supported by the dominance hierarchy results (see above).

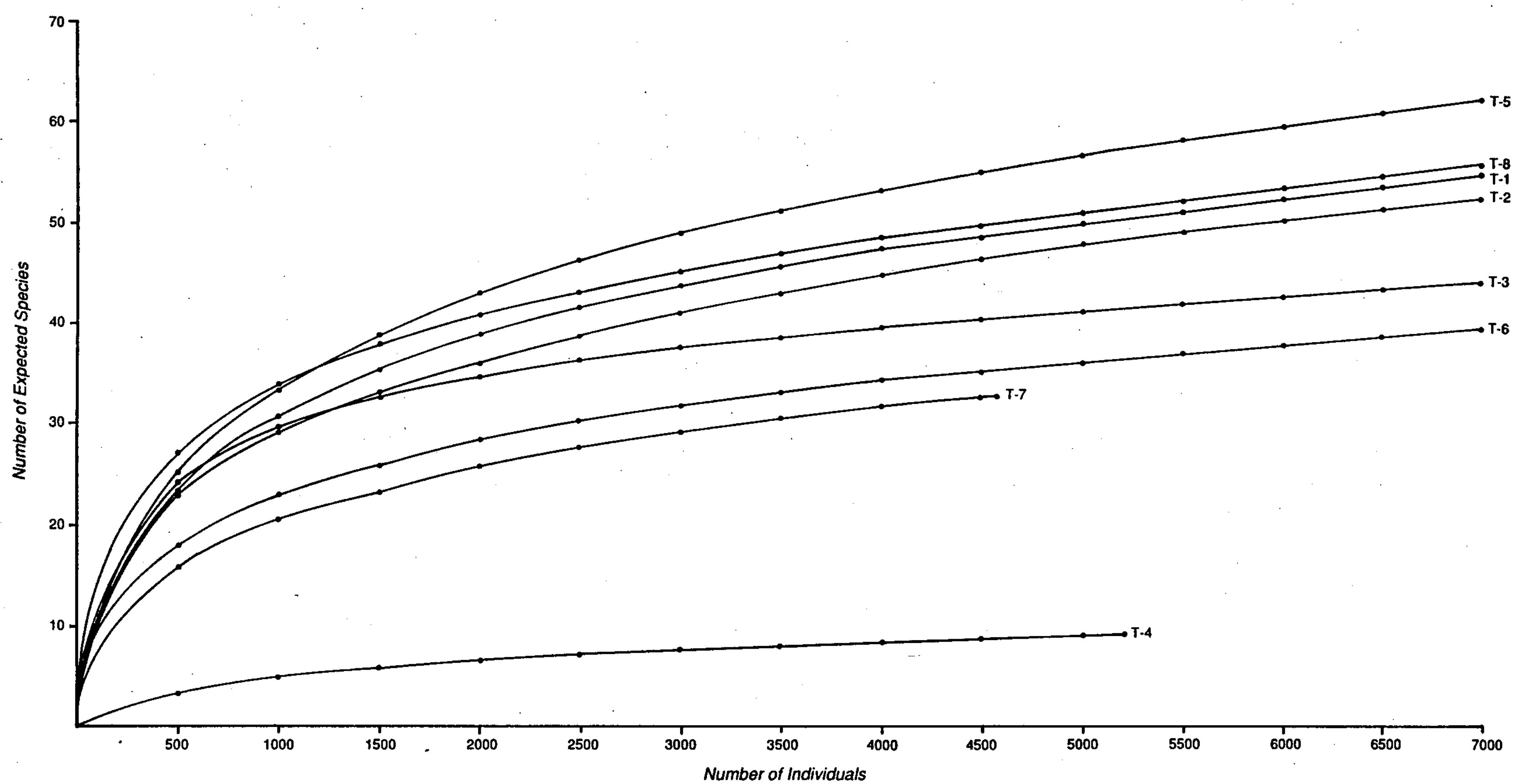

Figure 9. **Hurlbert Rarefaction Curves for Boston Harbor Stations Sampled in August 1992.**

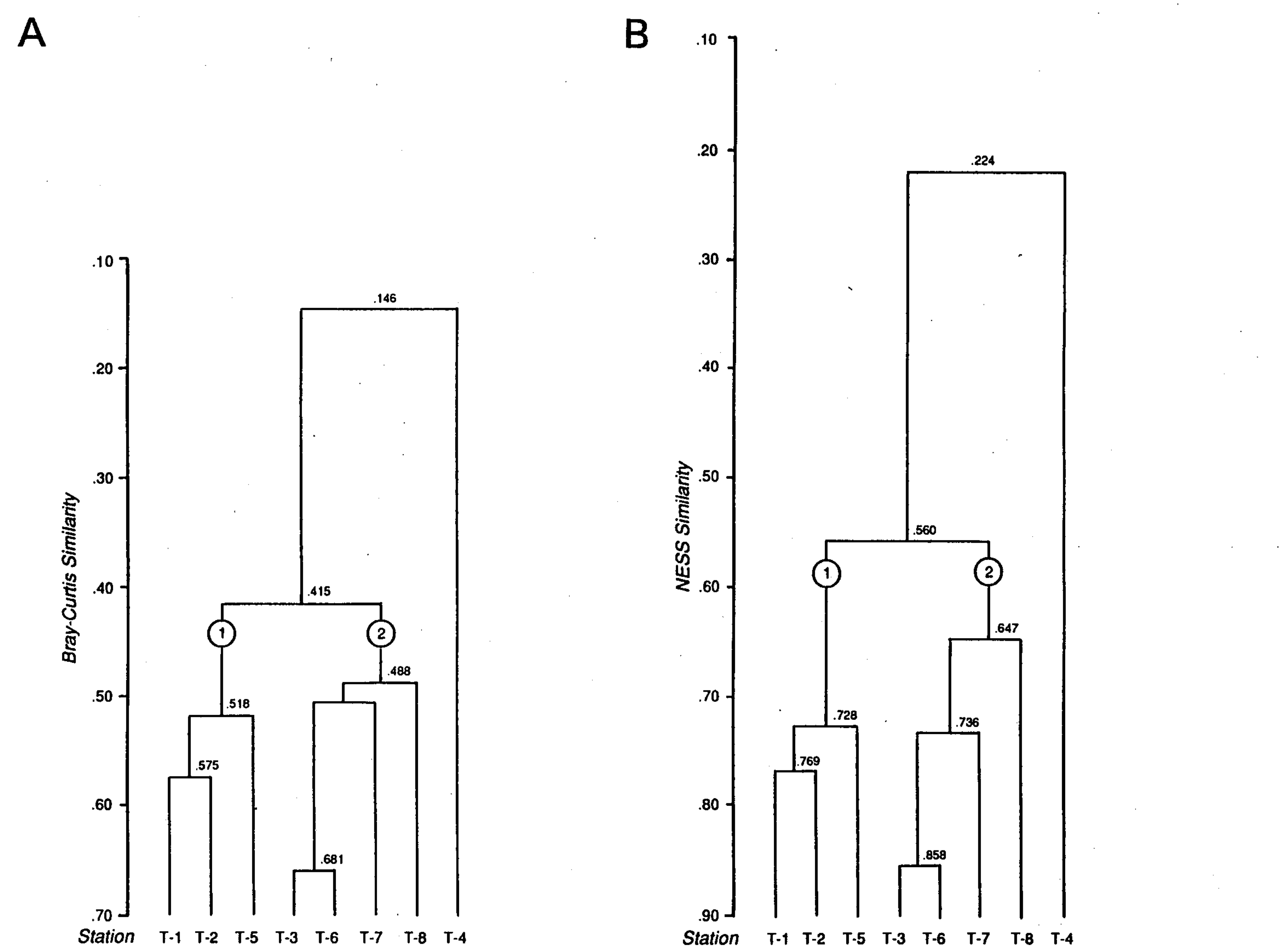

Figure 10. **Similarity Among Boston Harbor Stations Sampled in August 1992 with Three Replicates Combined. A: Bray-Curtis. B: NESS. Clustering is with group average sorting. Circled numbers mark major clusters.**

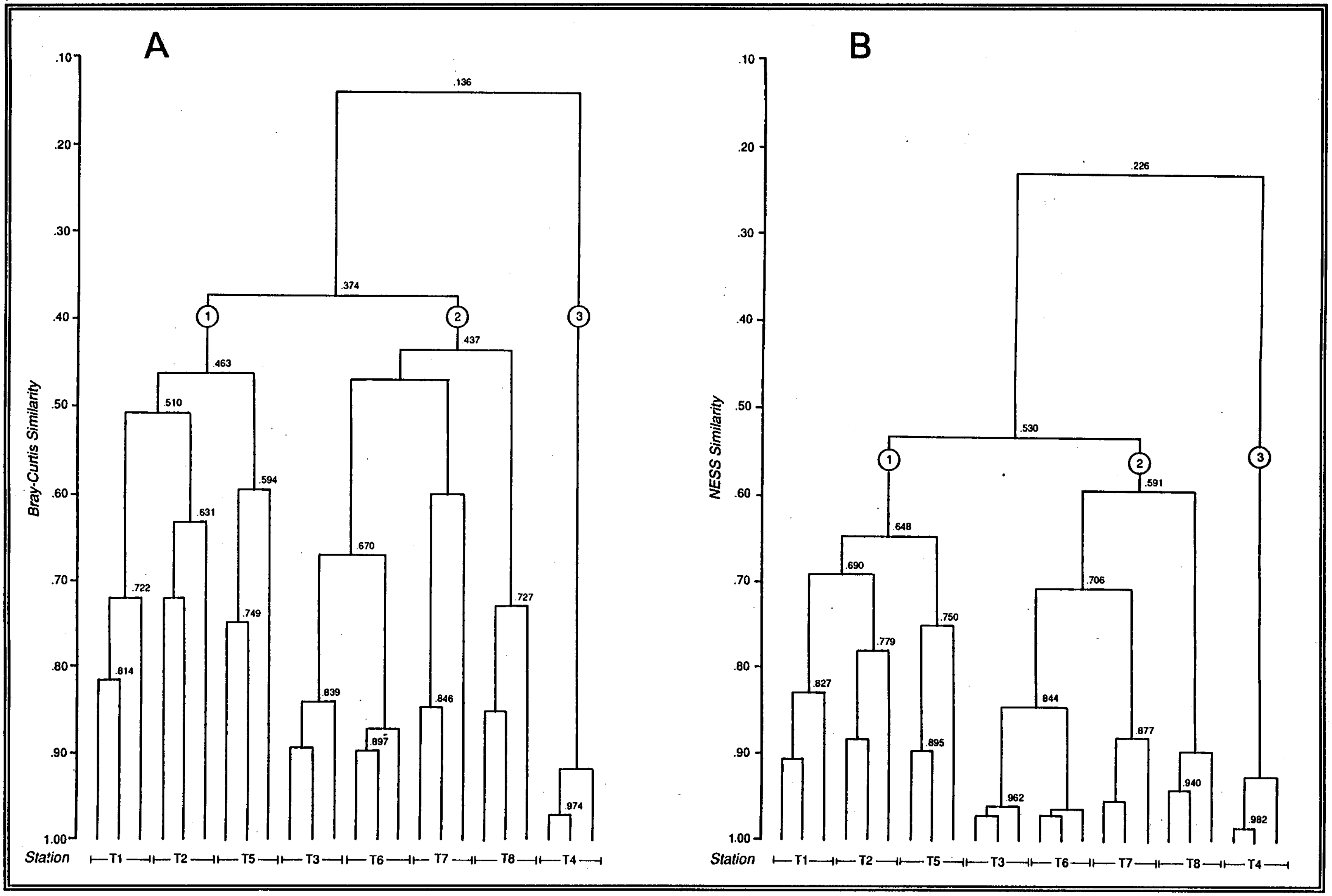

Figure 11. Similarity Among Boston Harbor Stations Sampled in August 1992 with Three Replicates Separate. A: Bray-Curtis. B: NESS. Clustering is with group average sorting. Circled numbers mark major clusters.

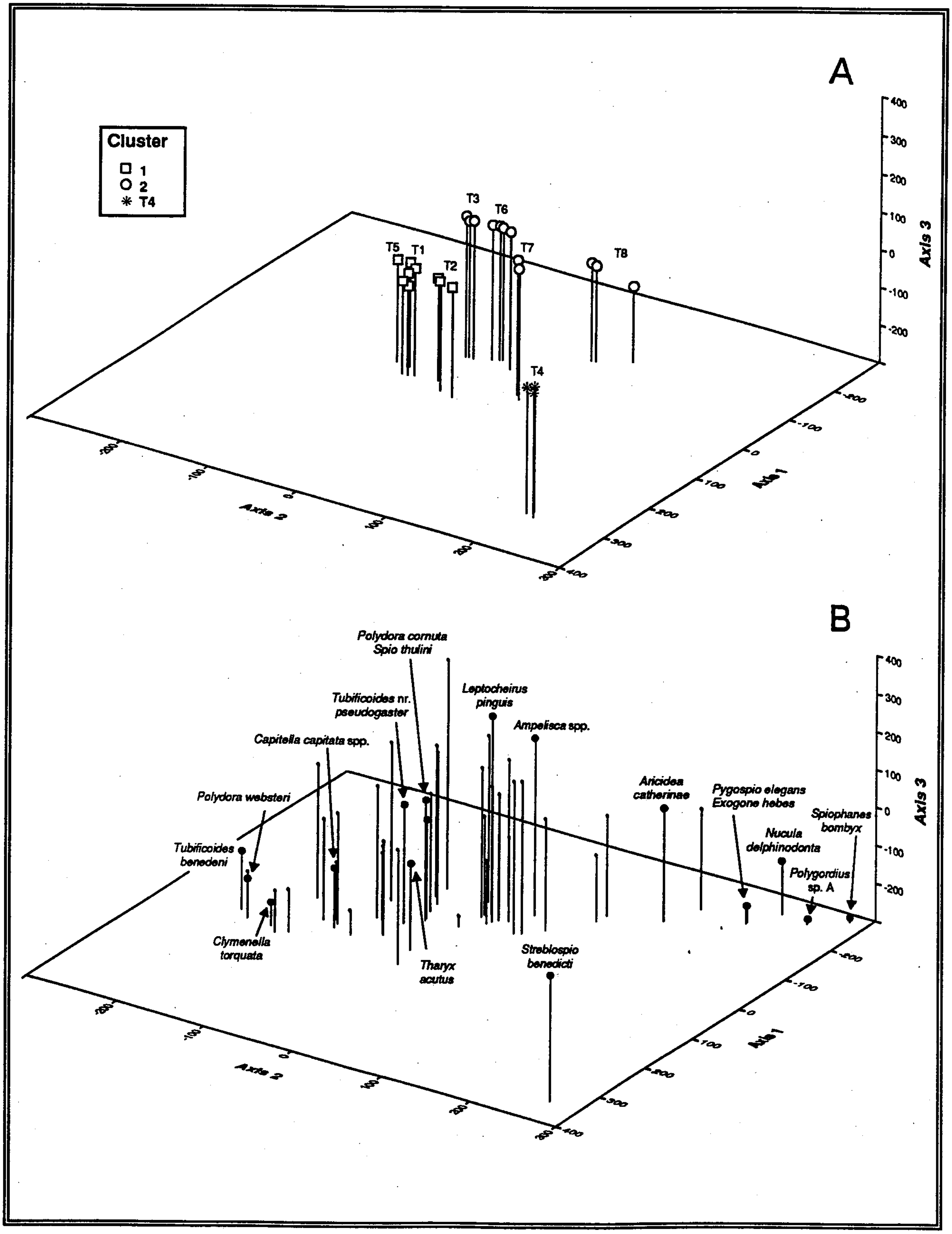

Figure 12. Results of Reciprocal Averaging Ordination, First Three Axes, Using the 50 Most Abundant Species and Square Root Transformation of Densities. A: Ordination of Stations. B: Ordination of Species. Cluster group symbols refer to the station groups identified in Figures 9 and 10.

3.2.2 Temporal Patterns: 1991 and 1992 Results

The cessation, in December 1992, of sludge disposal into Boston Harbor was a significant event during the period under consideration. In addition, the so-called No-Name, or Halloween, Storm in October 1991 may have produced local effects that could be partly responsible for apparent seasonal patterns in the data. This section presents a retrospective analysis of the infaunal data at the eight stations that were sampled in September 1991 and April 1992 as well as in August 1992. All stations except T5 were sampled on each of the three dates. Station T5 was sampled only in September and August, but a nearby location, designated as R6, was sampled in April. The three databases, when compared statistically, do not include oligochaetes because they were not identified to species until the August 1992 samples were processed. The oligochaetes are very important in controlling benthic structure and these taxa should be identified to species in all future investigations.

Composition of the Fauna

The combined fauna from three sampling periods totals 136 species, an increase of only 22 species over those collected in the single sampling period in August 1992. This results indicates that 84% of the fauna were identified in the August sampling period. The additional 22 species were mostly rare and represent a very low rate of species accumulation with repeated sampling. The percent contribution of major taxa was very similar to the August results: polychaetes (62 species, 46%), arthropods (37 species, 27%) and molluscs (22 species, 16%).

Distribution and Density of Dominant Species

The rank order, density, and percent contribution of dominant species for the September 1991, April 1992, and August 1992 samples are shown in Table 6. Benthic community parameters for all three collections are presented in Table 7. Total densities at each station in each sampling period are summarized in Figure 13. All stations show an increase in total density from September 1991 to August 1992. Stations T3, T6, and T8 decreased in density in April 1992. In order to test for the significance of these results, a one-way ANOVA *a priori* comparison was performed to test for effects due to sludge abatement and season. Multiple comparisons were tested *a posteriori* to compare all of the tests by sampling date. The results are presented in Table 8.

Faunal densities varied significantly over the three sampling periods at all stations except Station T7. For the remaining stations, comparison of the two late summer sampling periods (pre-abatement, September 1991 and post-abatement, August 1992) showed that density was higher in 1992 than in 1991 at all stations except Station T3. Seasonal effects were highly significant at all stations except Station T7. Seasonal effect was not tested for Station T5, which could not be sampled in April 1992. The very great effect that season had upon faunal density precluded the validity of testing the September 1991 (pre-abatement) samples against the mean of the April and August 1992 (post-abatement) samples. The less robust Scheffé test corroborated the ANOVA results.

Changes in densities of dominant species were associated with the increases seen in total number of individuals. Stations T1 and T2 were similar in that faunal densities did not increase significantly between September 1991 and April 1992, but did increase between the April and August 1992 sampling periods. At Station T1, there was a population explosion of the opportunistic polychaete *Polydora cornuta* from a density of 600 individuals m^{-2} in both September 1991 and April 1992 to over 100,000 individuals m^{-2} in August 1992. At Station T2, *Streblospio benedicti* was the top dominant for the first two sampling periods, but was outranked in August 1992 by large populations

Table 7. **Benthic Community Parameters for Boston Harbor Samples Collected in September 1991, April 1992, and August 1992 (Oligochaetes Excluded from Species Number and Rarefaction Analysis).**

Station	Number of Species	Number of Individuals (m^2)	Spp./ 10 Ind.	Spp./ 20 Ind.	Spp./ 40 Ind.	Spp./ 80 Ind.	Spp./ 250 Ind.	Spp./ 500 Ind.	Spp./ 1000 Ind.	Spp./ 2000 Ind.	H'	J'
T1												
9/91	28	14,433	5.3	7.6	10.3	13.5	20.3	25.0	*	*	3.01	0.626
4/92	41	39,700	6.2	9.2	12.8	17.0	25.4	31.6	37.8	*	3.58	0.668
8/92	65	188,667	3.7	5.5	7.9	10.9	17.6	23.1	29.9	37.6	2.04	0.338
T2												
9/91	9	1,417	2.8	4.1	6.0	8.5	*	*	*	*	1.27	0.399
4/92	21	21,025	2.9	4.1	5.6	7.4	11.5	14.7	18.3	*	1.41	0.320
8/92	52	70,942	4.6	6.3	8.7	12.0	19.1	24.5	31.2	39.3	2.74	0.481
T3												
9/91	25	59,000	5.1	7.0	9.4	12.1	17.9	21.9	*	*	2.88	0.620
4/92	33	23,383	6.7	9.7	12.5	15.6	22.2	27.0	32.8	*	3.69	0.731
8/92	44	89,992	4.6	6.5	8.9	12.0	18.6	23.5	28.7	33.8	2.70	0.494
T4												
9/91	6	3,642	2.1	2.4	2.8	3.4	5.0	*	*	*	0.83	0.323
4/92	11	10,900	2.5	3.0	3.8	5.0	7.4	8.9	10.6	*	1.39	0.402
8/92	7	43,742	1.0	1.1	1.2	1.3	2.0	2.7	3.9	5.3	0.05	0.017
T5/R6												
9/91	9	2,267	3.5	4.8	6.7	*	*	*	*	*	1.82	0.573
4/92	20	10,533	3.5	5.0	6.9	9.2	13.5	16.6	*	*	1.87	0.432
8/92	64	86,083	4.5	6.9	10.4	14.8	25.0	33.2	42.7	52.6	2.65	0.442
T6												
9/91	29	55,342	3.7	4.8	6.4	8.5	13.3	16.6	20.1	23.7	2.12	0.436
4/92	41	50,683	4.9	7.3	10.5	14.4	21.2	26.7	33.1	39.3	2.92	0.545
8/92	49	195,525	3.7	4.6	6.1	8.3	13.6	17.7	22.5	28.1	2.16	0.384
T7												
9/91	20	25,192	4.0	5.4	6.9	8.3	11.1	13.1	15.5	18.4	2.25	0.520
4/92	26	17,508	4.1	5.7	7.9	10.7	15.8	19.0	22.5	*	2.31	0.492
8/92	31	39,875	4.3	5.2	6.1	7.3	11.0	14.6	19.2	24.8	2.37	0.479
T8												
9/91	57	56,075	5.4	8.1	11.8	16.4	24.8	30.6	37.0	43.9	3.22	0.552
4/92	50	28,617	5.5	8.0	11.1	14.7	21.8	27.0	33.9	43.0	3.15	0.557
8/92	60	104,817	4.6	6.9	9.7	12.9	20.0	25.7	32.0	39.1	2.61	0.442

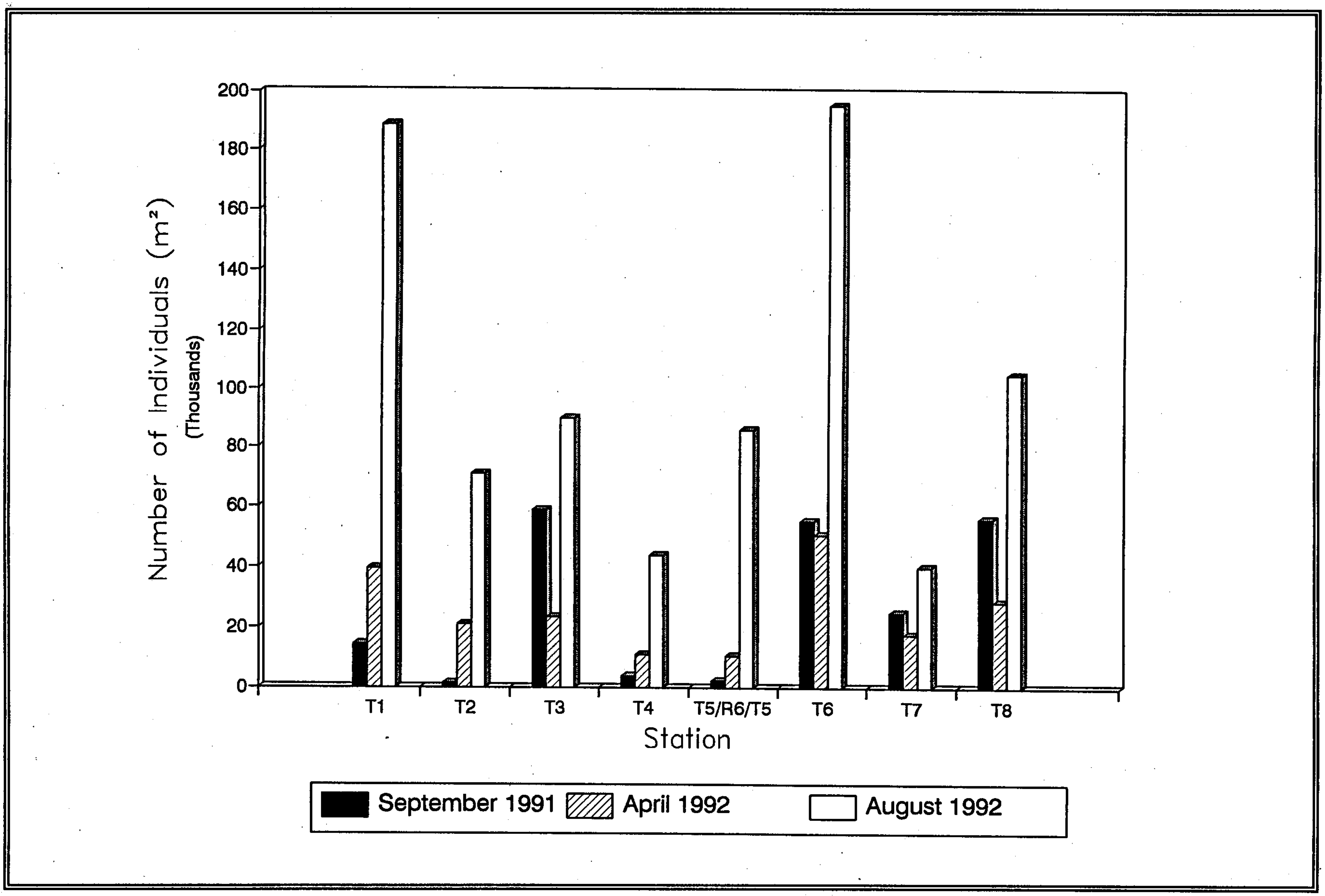

Figure 13. **Density of Benthic Infauna at Eight Boston Harbor Stations Sampled in September 1991, April 1992, and August 1992.**

Table 8. Results of Single Classification Model I ANOVA, Student Newman-Keuls Test, and Scheffé Tests Performed to Compare Number of Individuals Among Three Sampling Periods at Eight Traditional Stations Sampled in Boston Harbor.

Number of Individuals									
				A Priori Tests			A Posteriori Tests		
				ANOVA	Planned Tests Among the Means		Student Neuman-Keuls Test	Scheffé Tests	
Station	Cruise	Mean	SE	F Value	Sludge Abatement Cruise 1 vs 3	Season Cruise 2 vs 3		Sludge Abatement Cruise 1 vs 3	Season Cruise 2 vs 3
T1	1	577	246.4	42.97***	***	***	C1=C2<C3	+	+
	2	1588	239.6						
	3	7547	933.9						
T2	1	57	12.0	16.20**	**	**	C1=C2<C3	+	+
	2	841	19.6						
	3	2838	616.7						
T3	1	2360	758.4	7.62*	NS	**	C1=C2; C1=C3; C2<C3	NS	+
	2	935	241.9						
	3	3600	257.8						
T4	1	146	15.5	227.64***	***	***	C1<C2<C3	+	+
	2	436	70.6						
	3	1750	66.3						
T5	1	91	0.7	17.67*	-	-	C1<C3	-	-
	3	3443	797.7						
R6	2	421	115.8	-	-	-	-	-	-
T6	1	2214	246.4	56.21***	***	***	C2=C1<C3	+	+
	2	2027	247.8						
	3	7821	675.6						
T7	1	1008	21.5	NS	NS	NS	-	NS	NS
	2	700	85.5						
	3	1595	515.2						
T8	1	2243	522.4	24.31***	**	***	C2<C1<C3	+	+
	2	1145	135.2						
	3	4193	53.5						

Cruise dates: 1, September 1991; 2, April 1992; 3, August 1992.
Levels of significance: * = $p<0.05$; ** = $p<0.01$; *** = $p<0.001$; + = significant to at least $p<0.05$; - = tests not applicable; NS = not significant.

of another polychaete, *Tharyx acutus*, that increased in density from 8 to 1500 individuals m^{-2} between September 1991 and August 1992 and the oligochaete *Tubificoides* nr. *pseudogaster*.

At Station T3, the density of oligochaetes (the top dominant in September 1991 and April 1992) declined slightly by August 1992, while the number of amphipods, *Ampelisca* spp. complex, the top dominant in August 1992, increased twenty-five fold over that seen in September 1991. Moreover, the species composition seen in August 1992 was quite different from that seen in the earlier two surveys. Five additional crustacean species, *Leptocheirus pinguis, Phoxocephalus holbolli, Photis pollex, Corophium bonelli,* and *Edotea triloba,* were found among the top 10 dominant species in August 1992. Of these five additional crustacean species, only two were found previously (September 1991) among the top 10 dominant species. Three mollusc species, *Nassarius trivittatus, Tellina agilis,* and *Mytilus edulis,* found among the top 10 dominants in September 1991 and April 1992, were absent from the top dominance list in August 1992. Thus, at Station T3, a polychaete/mollusc assemblage present in September 1991 and April 1992 was replaced by an amphipod assemblage by August 1992.

Number of individuals increased dramatically at Station T4 over the course of the three sampling periods. *Streblospio benedicti* was the top dominant species in September 1991 and increased in density over the period of the three collections, remaining among the top two species in April and August 1992. In August 1992, the high density of *S. benedicti* (43,000 individuals m^{-2}) accounted for 99.3% of the individuals present in the samples. The opportunistic polychaete *Capitella capitata* was absent from the samples in September 1991 but appeared as the top dominant in April 1992 and was still present, although in reduced numbers, the following August.

Density at Station T5 was not examined as completely as at the other stations because the April 1992 substitute station (R6) was located 0.5 miles northwest of T5. However, it was quite clear that the infaunal density in August 1992 was much higher than it had been in September 1991. Of the top 10 species present in September 1991 (this was every species present), five were still among the top 10 species in August 1992. Oligochaetes accounted for 70.2% of the total fauna in September 1991 but had declined to 57.4% of the fauna by August 1992. *Capitella capitata* spp. complex increased in numbers from 7.1% of the fauna in September 1991 to 25.1% of the August 1992 fauna. The gastropod *Nassarius trivittatus* ranked second in abundance in September 1991 and, although this species increased in density by August 1992, it fell in rank to ninth place.

Of the top 10 dominant species present at Station T6 in September 1991, five were found in the top 10 species in April 1992 and seven were found in the top 10 species in August 1992. The top four species, oligochaetes, *Ampelisca* spp. complex, *Aricidea catherinae*, and *Polydora cornuta*, seen in September 1991, were also the top four species in August 1992. The April samples differed from both late summer samples in that a set of the mussel *Mytilus edulis* outranked the polychaete *Polydora cornuta*. Station T6 was a site rich in amphipods, and the number of amphipod species present in the top 10 dominant species increased from two species in September 1991 to three species in both April and August 1992.

Station T7 was the only station that showed no difference in number of individuals over the three sampling dates. The top two dominant species, *Streblospio benedicti* (ranking first) and *Ampelisca* spp. complex (ranking second), were the same for all three collections. In addition, *Aricidea catherinae, Polydora cornuta, Tharyx acutus,* and oligochaetes were present among the top 10 species for all three cruises. In terms of number of individuals and which species dominate, Station T7 was consistent over the time period studied.

Station T8 was the only station that had significantly fewer organisms present in April 1992 than in September 1991. The polychaete *Aricidea catherinae* was the top ranking species for all three cruises. Other species that were present among the top 10 dominant species for all three sampling periods were the bivalve *Nucula delphinodonta,* the polychaetes *Exogone hebes* and *Polygordius* sp. A, and oligochaetes. The missing element in the April 1992 collection was *Ampelisca* spp. complex, a species group that ranked second in both September 1991 and August 1992 but was not among the top 10 species in April.

Species Richness and Diversity

The total number of species at each station for each cruise is shown in Table 7 and summarized in Figure 14. It is apparent that the number of species per station increases steadily from September 1991 to August 1992 at all stations except T4 and T8. At Station T4, the number of species is lowest in the two summer collections and highest in the April 1992 collection. At Station T8, the number of species ranges from 50 to 60, with the fewest occurring in April.

Statistical tests similar to those used for density were used to test for the significance of these species data. Results of comparisons of the number of species found in the three different sampling periods (September 1991, April 1992, and August 1992) are presented in Table 9. Number of species varied significantly over all periods sampled for all stations except T4 and T7. The number of species found in August 1992 (post-abatement) was significantly greater than that found in September 1991 (pre-abatement) at Stations T1, T2, T3, T5 (mouth of inner Boston Harbor and vicinity of Governor's Island Flats), and T6 (outer Quincy Bay). Stations T4 (Savin Hill Cove), T7 (inner Qunicy Bay), and T8 (Hull Bay) showed no effect that could be attributed to the abatement of sludge dumping. The number of species collected in August 1992 was significantly greater than the number collected in April 1992 at Stations T1, T2, T3, T6, and T8. This seasonal effect was not seen at the very depauperate Station T4 nor at Station T7. Seasonal effect was not tested for Station T5, which could not be sampled in April 1992. The great effect that season had upon faunal density precluded the validity of testing the September 1991 (pre-abatement) samples against the mean of the April and August 1992 (post-abatement) samples. The Scheffé test corroborated the ANOVA results, except that the barely significant seasonal effect seen at Station T6 by the ANOVA was not distinguished.

Species diversity at each station for each cruise is shown in Table 7 and in Figures 15 and 16. Trends over time are best seen in the figures. Overall, diversities are lowest in September 1991 and higher in both of the 1992 sampling dates. Station T4 consistently has the lowest species diversity regardless of sampling season. The August T5 diversities are the highest in the program according to the rarefaction plots. When H' is used, the August T1 results are highest.

The diversity results should be reviewed in conjunction with the density and species richness results. High density and low species richness will reduce diversity. Because of this mixture of parameters, the diversity results do not produce as clear patterns as do the density and species richness data. Furthermore, rarefaction and H' results do not always correspond—that is, species having high values with one technique do not always behave similarly with the other.

Community Analysis

In attempting to analyze the combined databases for September 1991, April 1992, and August 1992, some problems were encountered because the treatment of the oligochaetes was inconsistent. The data are not fully comparable in that oligochaetes were identified to species only in the August 1992

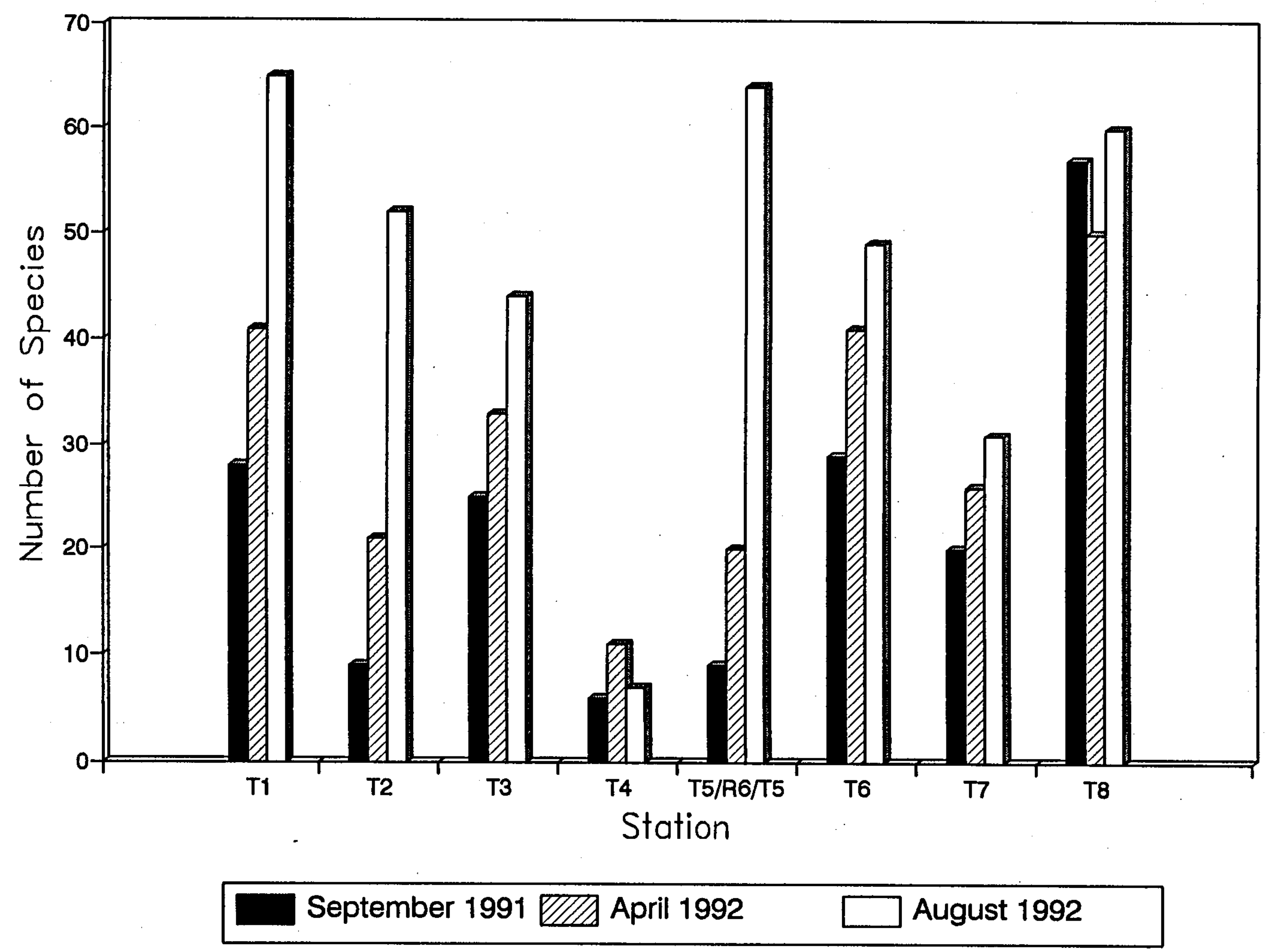

Figure 14. Number of Species Identified at Eight Boston Harbor Stations Sampled in September 1991, April 1992, and August 1992.

Table 9. **Results of Single Classification Model I ANOVA, Student Newman-Keuls Test, and Scheffé Tests Performed to Compare Number of Species Among Three Sampling Periods at Eight Traditional Stations Sampled in Boston Harbor.**

Station	Cruise	Mean	SE	Number of Species: A Priori Tests: ANOVA F Value	A Priori Tests: Planned Tests Among the Means: Sludge Abatement Cruise 1 vs 3	A Priori Tests: Planned Tests Among the Means: Season Cruise 2 vs 3	A Posteriori Tests: Student Neuman-Keuls Test	A Posteriori Tests: Scheffé Tests: Sludge Abatement Cruise 1 vs 3	A Posteriori Tests: Scheffé Tests: Season Cruise 2 vs 3
T1	1	19.0	5.00	21.69**	***	**	C1=C2<C3	+	+
	2	30.0	2.08						
	3	48.7	1.33						
T2	1	5.3	1.20	63.43***	***	***	C1<C2<C3	+	+
	2	17.3	1.76						
	3	33.3	2.19						
T3	1	19.7	1.45	31.29**	***	***	C1=C2<C3	+	+
	2	23.3	2.33						
	3	37.3	0.88						
T4	1	4.7	1.20	NS	NS	NS	-	NS	NS
	2	8.7	1.45						
	3	6.7	0.67						
T5	1	6.3	0.88	236.00***	-	-	C1<C3	-	-
	3	45.7	2.40						
R6	2	14.3	2.03	-	-	-	-	-	-
T6	1	23.7	2.33	12.11**	**	*	C1=C2<C3	+	NS
	2	31.0	1.53						
	3	39.7	2.85						
T7	1	15.3	1.20	NS	NS	NS	-	NS	NS
	2	20.3	0.33						
	3	21.3	4.18						
T8	1	43.0	2.65	6.51*	NS	*	C2<C1=C3	NS	+
	2	32.0	2.65						
	3	43.7	2.40						

Cruise dates: 1, September 1991; 2, April 1992; 3, August 1992.
Levels of significance: * = $p<0.05$; ** = $p<0.01$; *** = $p<0.001$; + = significant to at least $p<0.05$; - = tests not applicable; NS = not significant.

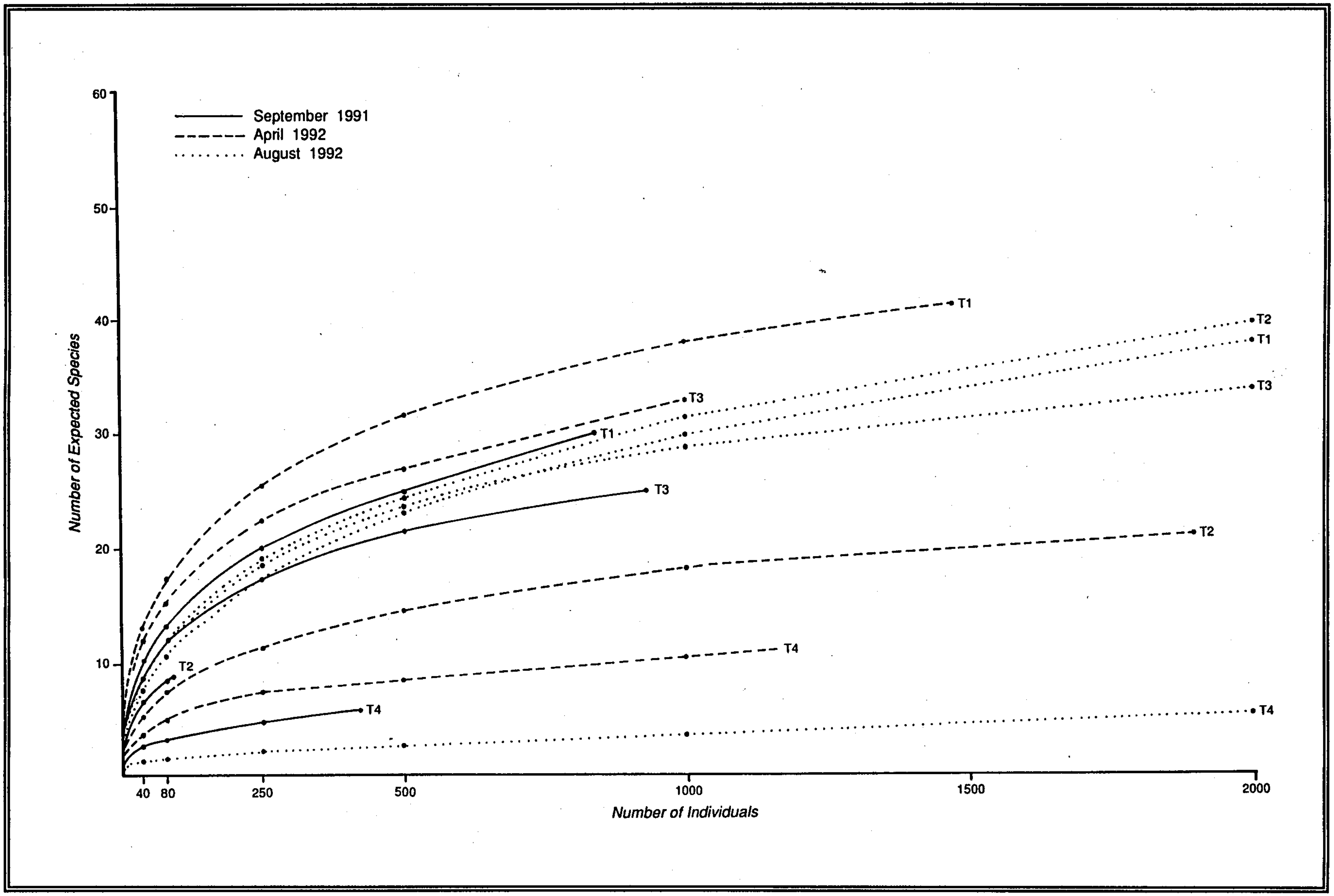

Figure 15. **Hurlbert Rarefaction Curves for Four Boston Harbor Stations (T1, T2, T3, and T4) Sampled in September 1991, April 1992, and August 1992.**

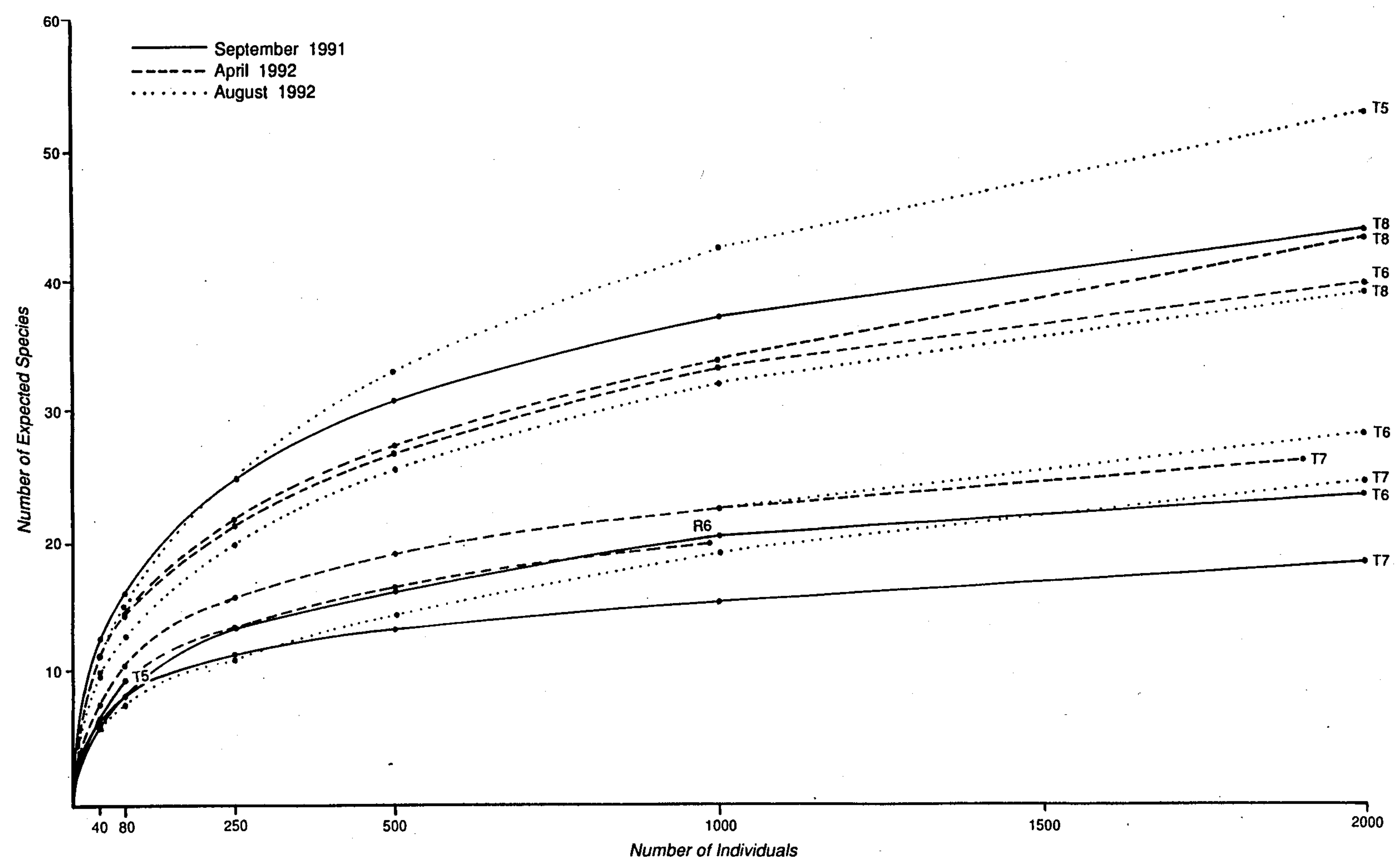

Figure 16. **Hurlbert Rarefaction Curves for Four Boston Harbor Stations (T5/R6, T6, T7, and T8) Sampled in September 1991, April 1992, and August 1992.**

project. For the combined community analysis, therefore, we deleted the oligochaetes entirely for the similarity analyses because the three species that were identified were among the dominants at different stations in the August results. Treating the oligochaetes as a single taxon would create an artificial species and obscure patterns in the data.

The results of the cluster analysis of the combined September, April, and August data are shown in Figure 17. Three distinct clusters are identified in both analyses. Cluster 3 includes the same stations in both analyses. These include the nearshore stations T2 at the mouth of inner Boston Harbor (September) and T4 at Savin Hill Cove (September and August). Cluster 2 includes all of the Station T6 and T8 surveys as well as T3 (September), located in the outer reaches of Dorchester, Quincy, and Hull Bays. The Bray-Curtis dendrogram also includes T5 (September), and NESS includes T7 (August). These latter two stations are included in cluster 1 when they are not in 2 along with all of the remaining stations. Cluster 1c in Bray-Curtis and 1a in NESS include April collections from the stations in the northern half of the Harbor.

Ordination analysis is presented in Figure 18. The upper diagram represents the arrangement of the individual stations with respect to the three axes, and the lower diagram represents the distribution of 42 species in ordination space. The groupings of stations can be partially explained by the distributions of the species.

In general, the station groups are more-or-less similar to those seen in the ordination figure for the August samples (Figure 12). The stations have been coded by season. The positions of the most obvious outlying stations or groups of stations can be readily explained by considering which species are associated with those same axis coordinates in the lower diagram.

The September and April Station T4 samples are widely separated from the August samples mostly along axis 2. Although the polychaete *Streblospio benedicti* is responsible for the outlier status of this station, it is apparent that *Turbellaria* spp. is responsible for pulling the September 1991 samples away from the August samples, and *Capitella capitata* spp. is responsible for pulling the April samples in the opposite direction. Stations T3, T6, T7, and T8 seasonal samples tend to stay closely grouped, with the most movement in ordination being in axis 3. At Stations T3, T6, and T7, the axis 3 effect in August is likely due to amphipod dominance. The grouping of Stations T3, T6, T7, and T8 is similar to that seen in the ordination diagram for the August samples alone (Figure 12).

Stations T1 and T2 exhibit a large movement along axis 2. Four species, *Polydora aggregata, P. websteri, Clymenella torquata*, and *Aeginina longicornis,* are responsible for pulling the August Station T1 samples along axis 2. Some elements of these same species are important in pulling the August T2 and T5 samples along the same axis.

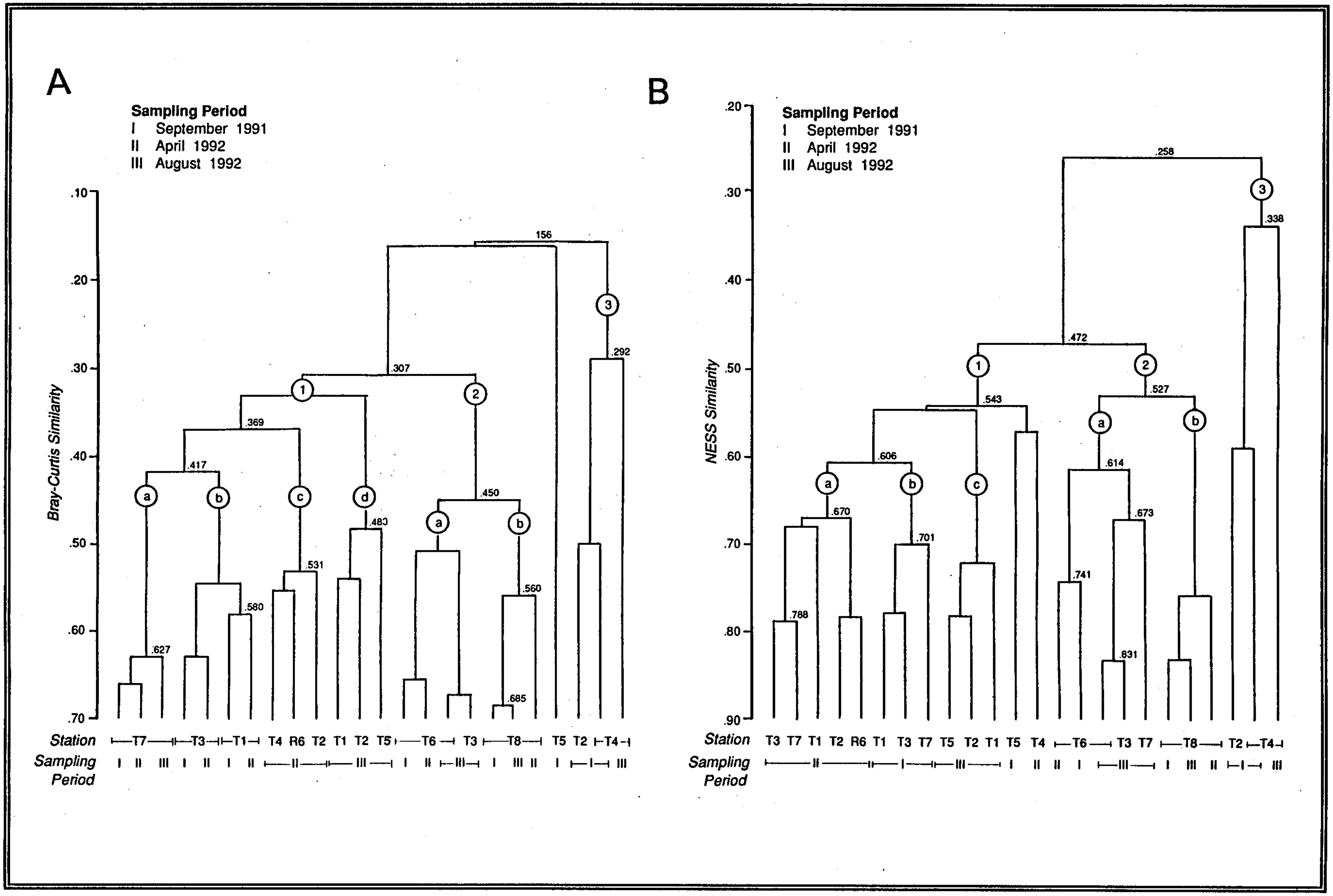

Figure 17. **Similarity Among Boston Harbor Stations Sampled in September 1992, April 1992, and August 1992 with Three Replicates Combined. A: Bray-Curtis. B: NESS. Clustering is with group average sorting. Circled numbers and lower case letters mark major clusters.**

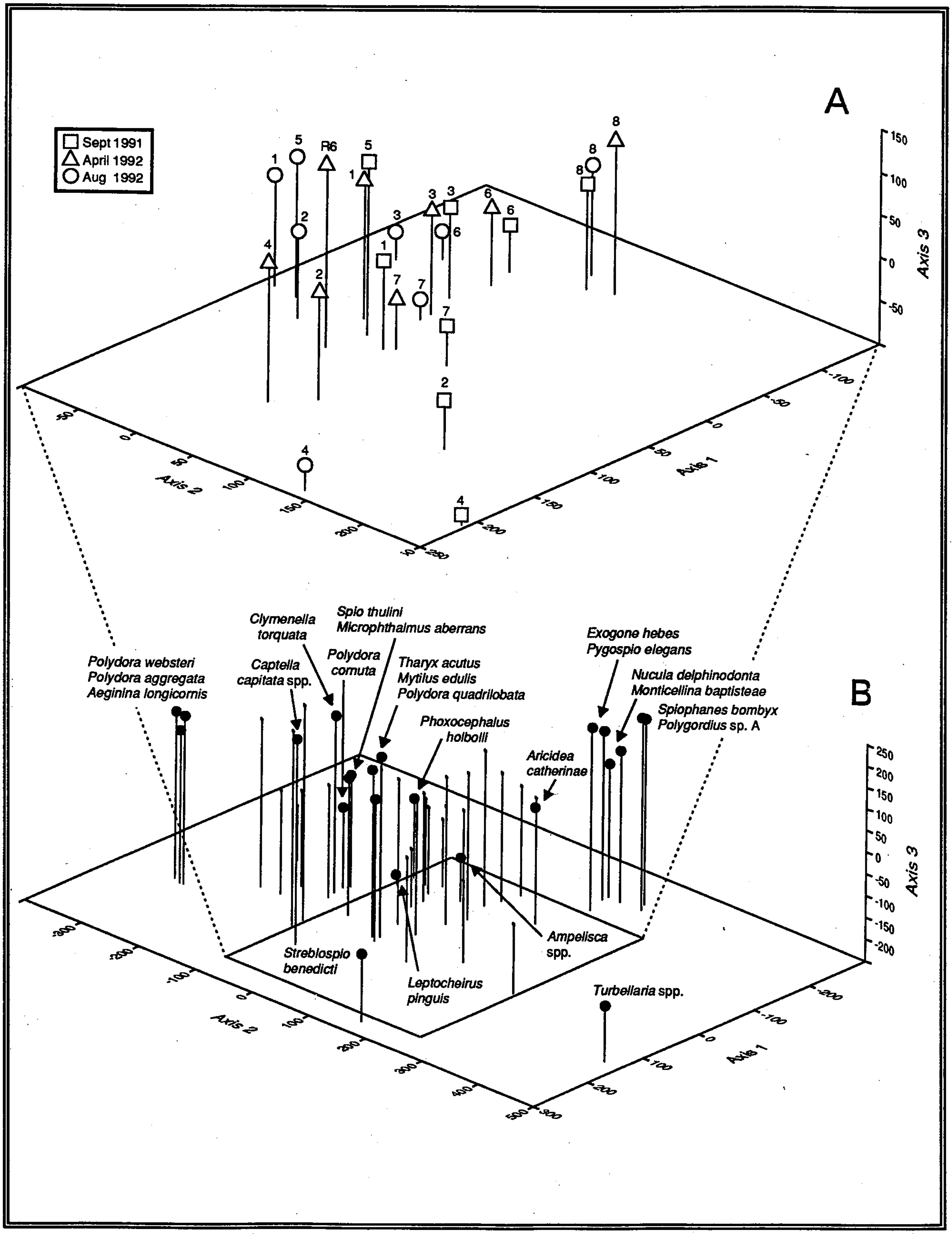

Figure 18. **Results of Reciprocal Averaging Ordination, First Three Axes, Using the 50 Most Abundant Species and Square Root Transformation of Densities. A: Ordination of Stations. B: Ordination of Species.**

4.1 Spatial/Temporal Patterns in the Sedimentary Environment

The overall distribution of sediment types as mapped in this survey (Figure 3) is consistent with textural patterns mapped in earlier surveys (SAIC, 1989, 1990, and 1992); the interpretations of benthic processes also agree with sedimentary environments of the area as mapped by the U.S. Geological Survey (USGS) (Knebel *et al.*, 1992). Figure 4 shows the distribution of depositional, erosional, and reworked sediments within the study area. All of the silt-clay sediments are located within depositional areas, whereas coarser grained sediments, especially rippled bottoms, represent either erosional or reworked environments. Only minor differences in textural trends were observed at the traditional stations (Table 10). The greatest differences between the major textural modes are the reports of gravel at Stations T1 and T5 based on sieve analysis (this report) compared to our REMOTS® visual estimates and the earlier sieve analysis reported by Kelly and Kropp (1992) that show these two stations to have a major mode within the sand-size fractions (Table 10). We interpret these differences to represent real variations in bottom type. Small differences in vessel positioning can result in sampling of different sediment types because of patchiness in bottom texture. Additionally, the No-Name nor'easter (October 1991) may have blown out much of the former large sand patch near the old sludge outfall, and the August 1992 grab samples may have been taken from a small remnant of that patch. In summary, the mapped sediment facies patterns have not changed significantly between the baseline surveys and this survey.

The TOC values for the eight traditional stations are remarkably comparable between the 1991 and 1992 surveys (Table 11). The data sets are too small for statistical comparison, but the 1992 values appear to be unchanged relative to the baseline survey.

Unlike the TOC data, spore counts of *C. perfringens* do appear to have changed since the baseline surveys (Table 12). At Station T1 on Deer Island Flats, spore counts are two orders of magnitude lower than in 1989-1990. At Station T3, counts are three orders of magnitude lower than in 1990. However, this decrease may be related to sampling of a slightly different bottom type. Stations T2, T4, T5, T6, and T7 show an order of magnitude fewer spores than in 1989-1990 or in 1991. It is unclear if the decreases are related to reduced rates of spore loading or to dilution of existing spore inventories by relatively spore-free sediment (or other factors).

4.2 Temporal/Spatial Patterns in Organism-Sediment Relationships

The post-abatement (1992) apparent RPD depth-frequency distribution appears to be much greater than those recorded in baseline surveys. This result must be interpreted with care because the pre- and post-abatement data sets are not from the same time of year; therefore, statistical comparison is not warranted. The 1991 September data from the sediment profile survey are comparable in season to the 1992 results, but the sample size is much smaller because only three of the five traditional stations produced useful data. Stations T2, T3, and T4 yielded 15 replicates with data on RPD depths (Kelly and Kropp, 1992). These data are expressed as a range of RPD depths within each image (not as a mean value as in the 1989, 1990, and 1992 data sets), and so the data are not strictly comparable. Nevertheless, the mean station RPD values for the 1992 survey fall within the observed range as reported in the September 1991 profile image analysis.

Table 10. Comparison of Major Textural Modes Between Surveys. Battelle 1991 and SAIC 1992 data (this report) are from sieve analysis. REMOTS® data are from visual estimates.

Station	Battelle 1991 (Sieve Analysis)	SAIC 1992 (Sieve Analysis)	REMOTS® 1992 (Visual Estimate)
T-1	Sand	Gravel	Sand
T-2	Sand	Sand	Sand
T-3	Sand/Silt	Sand/Silt	Sand
T-4	Silt	Silt	Silt
T-5	Sand	Gravel	Sand
T-6	Sand	Sand	Sand
T-7	Sand	Sand/Silt	Sand/Silt
T-8	Silt	Sand	Sand

Table 11. Total Organic Carbon (TOC wt %) at the Eight Traditional Stations Between the 1991 and 1992 Surveys.*

Station	Battelle 1991	SAIC 1992
T-1	2.6	1.9
T-2	1.7	1.7
T-3	3.6	3.7
T-4	3.7	4.0
T-5	1.5	1.6
T-6	1.8	2.1
T-7	2.7	3.2
T-8	0.9	0.7

*The complete 1992 data are listed in Appendix B.

Table 12. Changes in *Clostridium perfringens* Spore Counts (No. spores gm^{-1} dry wt) in the Study Area in Baseline Surveys (1989-1990 and 1991) Relative to the August 1992 Post-Abatement Survey. Because "T" stations were not established until 1991, 1989-1990 data are given from the station (in parentheses) nearest to the corresponding "T" sampling site.*

Station	1989-1990	1991	1992
T-1	1.8×10^5 (65)	1.2×10^4	2.0×10^3
T-2	3.7×10^4 (33)	2.3×10^4	7.1×10^3
T-3		2.1×10^5	3.0×10^2
T-4	4.6×10^4 (56)	3.0×10^4	1.2×10^3
T-5		3.0×10^4	3.6×10^3
T-6		2.9×10^4	2.9×10^3
T-7	2.1×10^4 (36)	1.4×10^4	2.4×10^3
T-8	3.5×10^4 (15)	7.3×10^3	2.9×10^3

*A complete listing of all *Clostridium perfringens* spore counts from the August 1992 samples can be found in Appendix B.

Seasonal comparability in RPD depth data is important because the depth of the mean apparent RPD is a function of biological mixing rates (controlled by seasonal changes in water temperature, faunal density, size and species of bioturbators) and sediment oxygen demand. Spring RPDs can be either shallower or deeper than late summer RPD depths, depending on the interplay of these variables. One possible causal factor is that sludge abatement has reduced the sediment oxygen demand (SOD), resulting in an improvement in sediment aeration (and a deepening of the RPD).

The greatest (and earliest) change in mean apparent RPD depths can be expected to take place in those sediments with the highest sediment oxygen demand (Boston Harbor and Dorchester Bay). Following sludge abatement, the stirring of these sediments by bioturbation can result in a rapid deepening of the apparent RPD. Farfield stations that have historically received lower input rates of sludge (Quincy and Hull-Hingham Bays) can, in turn, be expected to show a less dramatic change in the depth of the apparent RPD. In the May 1992 survey, the major RPD mode for all three surveys fell into frequency classes ≤ 1 cm. Figure 19 is a comparison of the RPD-depth frequency distributions between these three areas in June 1990 (pre-abatement) and August 1992 (post-abatement). The systematic shift to deeper RPD depths in 1992 is seen in all of the surveyed areas, not just in outer Boston Harbor and Dorchester Bay. This strongly suggests, but does not prove, that the deeper RPD depths observed in August 1992 may be related to seasonal effects rather than to sludge abatement.

The overall distribution of infaunal successional seres is consistent with the baseline studies that show Stage I (only) seres confined to outer Boston Harbor (T1, 73) in the area of Deer Island Flats and the mouth of Boston South Channel (T2 and 33) and Dorchester Bay (T4 and 16). Stage II seres are limited within this area to Stations T3 and T5 just north of Long Island. Two stations in Quincy Bay show only

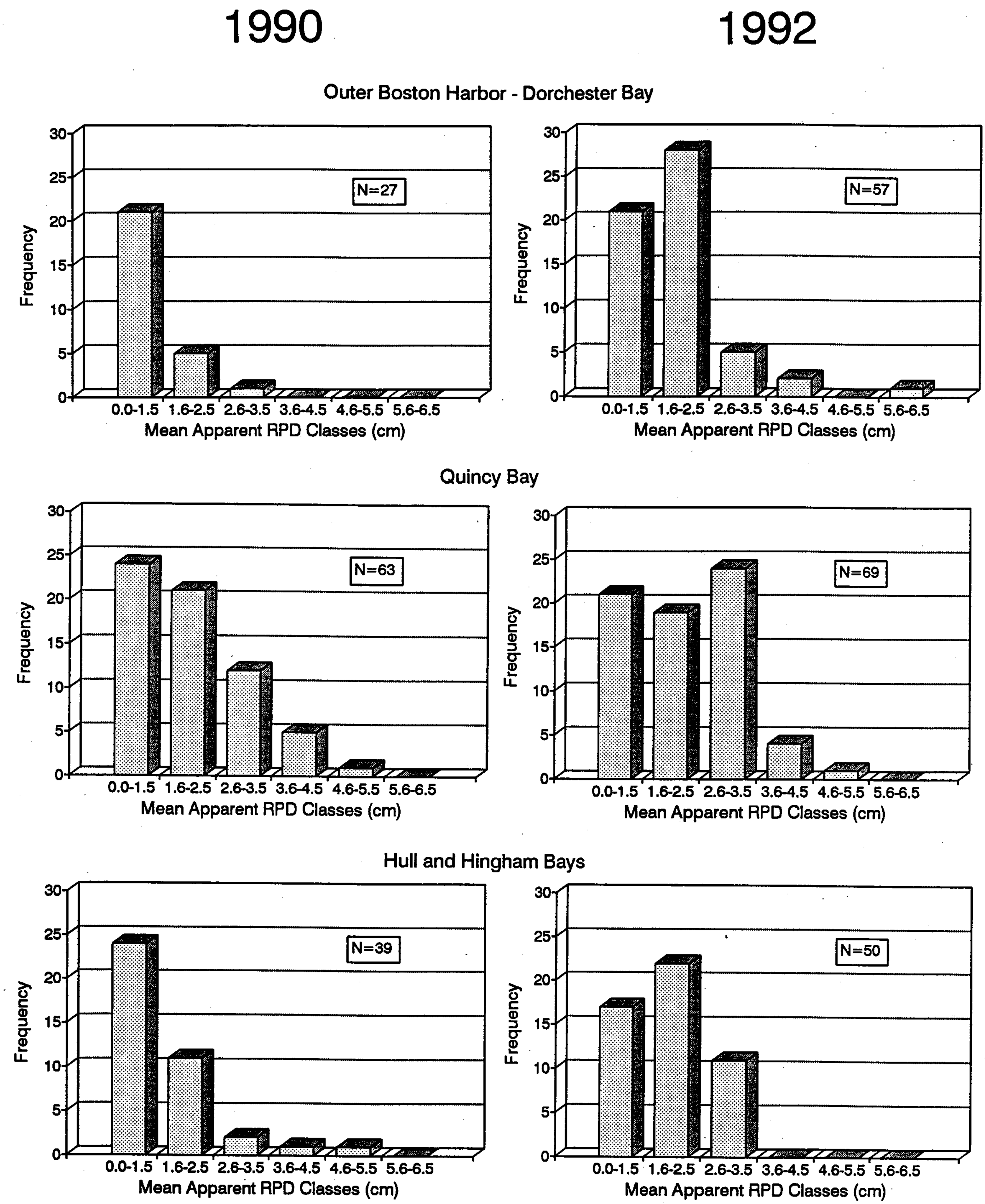

Figure 19. Comparison of Apparent RPD Depth Frequency Distribution at Stations Located in Outer Boston Harbor and Dorchester Bay, Quincy Bay, and Hull and Hingham Bays Between 1990 and 1992. Note shift in major mode to deeper apparent RPD depth in 1992.

the presence of Stage I seres (25 and 47). Station 1 in Hingham Bay is represented by a Stage I (only) sere. Stage II seres are well developed in outer Quincy and Hull Bays. These observations are consistent with the September 1991 faunal survey, which showed dense aggregations of *Ampelisca* at Stations T3, T7, T6, and T8 (Kelly and Kropp, 1992). Amphipod densities were also found to be high at Stations T3, T6, and T7 in April 1992 (Kelly and Kropp, 1992). Again the abundance of tubicolous amphipods in late summer appears to be seasonally controlled, because extensive amphipod mats were not observed in the May 1992 REMOTS® survey. The May 1992 survey did note the presence of benthic tunicates, "stick-building" podocerid amphipods, and dense algal mats in outer Quincy and Hull Bays. These associations were not observed in the August 1992 survey. Differences in early spring and autumn faunal assemblages require that temporal comparisons be limited to similar seasons.

As sludge abatement proceeds and the organic loading rate declines in outer Boston Harbor and Dorchester Bay, one expects that the Stage I seres will be replaced by Stage II amphipod mats. A convergence in successional status should be observed between the outer harbor and Quincy, Hull, and Hingham Bays.

Most of the $< +6$ OSI bottom areas are located within outer Boston Harbor and Dorchester Bay. This is the first REMOTS® survey that shows no negative OSI values. The overall OSI frequency distribution is similar to that observed in June 1989. The 1989 and 1992 OSI frequency distributions show that most values fell above OSI $= +6$, whereas the May 1990 frequency distribution had a major mode between +2 and +3, and several classes with negative values. The May 1992 REMOTS® survey showed a major OSI mode of +7 and a minor mode of +3. Only two values were negative. Subsequent surveys should see marked improvement in OSI values, particularly in the region of Deer Island Flats, as organic loading decreases. This will promote deeper apparent RPD depths and a higher successional status—two of the primary contributors to the calculated OSI.

4.3 Spatial/Temporal Trends in Benthic Infauna

The number of individuals increased at all stations from the September 1991 to the August 1992 samples. The greatest increases were at Stations T1 on Deer Island Flats where *Polydora cornuta* was dominant and at Station T6 in Hull Bay where *Ampelisca* spp. was dominant. At four stations (T1, T2, T4, and T5/R6), densities increases over all three sampling dates. At four other stations (T3, T6, T7, and T8), densities decreased in the April samples and increased again in August. All stations except T4 and T8 exhibited a steady increase in numbers of species between September 1991 and August 1992.

In terms of faunal assemblages, the shifts of stations observed in the cluster and ordination analysis over the three sampling dates largely reflect the changes in dominant species and numbers of species present at a station.

The question that arises is whether the apparent improvement in species richness and density at stations that were very degraded for these parameters is the result of the sludge abatement program or is part of natural patterns in benthic communities. Stations T1, T2, T3, and T5 have obviously changed following sludge abatement. The most dramatic changes are in species richness and density. Increases in the number and diversity of species would usually suggest that conditions have progressed beyond ones that were so highly stressed as to limit the fauna to a few opportunistic species. For all of these northern stations except for T3, densities increased continuously over the three sampling dates. At Station T3, densities declined in April before increasing in August. This same pattern was observed at Stations T6, T7, and T8 in the southern regions of the Harbor. Therefore, two patterns of density are apparent in the data. These density shifts and the corresponding improvements in species richness at stations near the outfalls cannot be confidently attributed to sludge abatement until data are available from another year of sampling. One major caveat to this interpretation is that the October Northeaster of 1991 (the so-called No-Name, or Halloween, Storm) may have so disturbed the bottom of the Harbor that areas were made suitable for recruitment.

The Boston Harbor surveys conducted in 1978, 1979, and 1982 were reviewed by Blake *et al.* (1989). Comparison with data from those surveys gives mixed results when considering the problem of outlined above concerning recovery of benthic communities following sludge abatement. For example, Station T4 on Deer Island Flats, sampled in 1978, had high densities (>54,000 individuals m^{-2}), 39 species, and a relatively high species diversity index (H' = 3.32). The dominant species at this station were oligochaetes (39.9%) and the cirratulid polychaete *Tharyx acutus* (31.4%). In contrast, Station B-5 off Logan Airport, sampled in 1982, had very low infaunal densities (1,414 individuals m^{-2}) and only 8 species, and a moderate H' value (2.95). This station was dominated by *Capitella capitata* spp., considered to the classic opportunist or pollution indicator.

In analyzing these historical databases, Blake *et al.* (1989) concluded that the benthic communities of Boston Harbor tended to shift between the Stage I and II seres described by Rhoads and Germano (1986). This conclusion was based upon examining the year-to-year faunal composition in the data from 1978, 1979, and 1982. For example, Station B-7, in Dorchester Bay, was sampled in 1979 and 1982. In 1979, the station was dominated by ampeliscid amphipods, oligochaetes, spionid polychaetes, and other amphipods. In 1982, the amphipods were not important and the site was dominated by oligochaetes and spionids. This station, therefore, had both Stage I and II dominants in 1979 and only Stage I in 1982. In contrast, Station B-6 near Logan Airport was dominated by *Capitella capitata* spp. and *Polydora cornuta* on those same dates. These trends suggest that the present results might be part of natural patterns in population dynamics, rather than improvement due to sludge abatement. Further seasonal surveys are required before these patterns can be fully understood.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

- The overall sedimentary environment of Boston Harbor is complex, consisting of a patchy mosaic of different grain-size distributions. Most stations consist of very fine sand (4-3 phi).

- Distinct sand-over-mud layering is evident at 19 REMOTS® stations, suggesting recent increases in kinetic energy, possibly from storms. These stations are located in the South Boston Channel, mouth of the Neponset River, inner Quincy Bay, mouth of Weymouth Channel, and on Crows Flats of Hull Bay. Rippled bottoms were observed in Hull Bay.

- The highest TOC values were found at the entrance to the Neponset River (Station T-4, 4.0%), off Long Island (Station T3, 3.6%), and in Quincy Bay (Station T7, 3.2%). The greatest change in TOC between collecting dates was at Station T1 on Deer Island Flats, where the values dropped from 2.6% in September 1991 to 1.9% in August 1992.

- *Clostridium perfringens* spore counts were high at all stations, but highest at Stations T2 and T5 (10^4). The lowest values were at Station T3 (10^2).

- Mean Apparent RPD depths appear to be deeper in the August post-abatement survey, but the lack of comparable data in the same time frame during pre-abatement precludes a definitive conclusion on post-abatement improvement.

- Stage II and III successional stages are widespread in Boston Harbor in the August 1992 REMOTS® data. Stations located in Deer Island Flats, South Boston Channel, and one site in Dorchester Bay contained only Stage I seres. These results are generally consistent with pre-abatement baseline results.

- The August 1992 REMOTS® survey is the first in which there were no organism sediment indices (OSIs) with negative values. All values fell within the range of 6.5 to 9.5 and are indicative of normal conditions in nearshore environments.

- The benthic infaunal taxonomy for August 1992 included identification of the oligochaetes to species for the first time. Three species were identified, each of which exhibited site-specific patterns in density and dominance. *Tubificoides* nr. *pseudogaster* Dahl proved to be one of the most important indicator species in the Harbor.

- A total of 114 species of benthic invertebrates were identified from the 24 grab samples collected in August. This total compares with a total of 136 species when the September 1991, April 1992, and August 1992 results are combined. Polychaetes were the overall dominant taxa in the combined database with 62 species (46%), followed by crustaceans with 37 species (27%) and molluscs with 22 species (16%); all remaining taxa included 15 species (11%).

- Total infaunal densities increased at all stations between September 1991 and August 1992. At five stations (T1, T2, T4, T5/R6) increases were monotonic across all three seasonal samplings. At four stations (T3, T6, T7, and T8) there was a decrease between September 1991 and April 1992 followed by a large increase in August 1992 that was higher than in the previous September. An *a priori* ANOVA designed to test for significance of post- and pre-abatement effects (September 1991 to August 1992) was significant at all stations except T3 and T8. The ANOVA designed to test for seasonal effects was significant for all stations except T7. These results were confirmed with two different multiple comparison tests.

- The total number of species at each station (species richness) increased monotoncally at all stations except T4 at Savin Hill Cove and T8 in Hull Bay. The number of species found in August 1992 (post-abatement) was significantly greater than found in September 1991 (pre-abatement) at Stations T1, T2, T3, T5, and T6. Stations T4, T7, and T8 showed no effect that could be attributed to the abatement of sludge dumping. A significant seasonal effect was seen at Stations T1, T2, T3, T6, and T8 between April and August 1992.

- Station T1 on Deer Island Flats underwent an important faunal shift from a community dominated by oligochaetes in September 1991 and April 1992 to one dominated by *Polydora cornuta* in August. This change in dominance was accompanied by an increase in species richness (28 species in September 1991 to 65 in August 1992) and total density (14,433 individuals m^{-2} to 188,667 individuals m^{-2}).

- Station T2 near Logan Airport also exhibited an important shift in species richness and density between September 1991 and August 1992. The total number of species increased from 9 to 52 and the density increased from 1,417 m^{-2} to 70,942 m^{-2} between September 1991 and August 1992.

- Between September 1991 and August 1992, the total number of species at Station T3 off Long Island increased from 25 to 44. The density decrease from 59,000 individuals m^{-2} in September 1991 to 23,383 individuals m^{-2} in April 1992, then increased to 70,942 individuals m^{-2} in August 1992.

- Station T4 at Savin Hill Cove near the mouth of Neponsett River was heavily stressed and exhibited no significant changes in benthic parameters from season to season or year to year except for increases in total density.

- Station T5 off Long Island exhibited a major change in the total number of species between September 1991 (9 species) and August 1992 (64 species). This change is dramatic and suggests that the station may be undergoing important changes that permit non-opportunistic species to survive.

- Although changes in the faunal composition of Stations T6, T7, and T8 are apparent in some parameters, these may merely be natural phenomena not related to sludge abatement because these stations are so far removed from the former sludge outfall.

- Species diversities at Stations T2 and T5 increased markedly in August 1992 over those of R6 in April 1992 and T5 in September 1991. At other stations, there was little change between seasons.

- Benthic community analysis of the combined September 1991, April 1992, and August 1992 databases provided evidence that the stations in the southern part of Boston Harbor (Quincy and Hull Bays) had retained more or less the same community structure. In contrast, stations in the northern part of the Harbor, closer to the sludge outfalls, had changed after the abatement of sludge. The August T1, T2, and T5 stations were more similar to one another than to earlier samplings of the individual stations. The August Station T3 samples tended to cluster more closely with the southern stations than to the northern stations.

- Both the REMOTS® RPD and OSI results and the benthic successional assessment and community data suggest that conditions near the former sludge outfall off Deer Island and Long Island have improved. RPD depths are greater, OSIs are all positive, species richness is up, and densities are improved in these locations and on the Deer Island Flats.

Recommendations

- We recommend that oligochaetes be identified to the species level in all future monitoring because some of the most important indicator species belong to this group.

- Despite the positive trends noted above, it will require further monitoring and careful interpretation of results before these apparent trends in improvement in the benthic environment can be uniquely attributed to the removal of sludge from the outfalls.

6.0 ACKNOWLEDGMENTS

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APPENDIX A

REMOTS® Raw Data, 1989 - 1992

Table A1. **REMOTS® Raw Data for Boston Harbor, 1989 through 1992.**

Station -Date	Rep	Latitude	Longitude	Loran-C TDs	Depth (ft)	Surface Boundary Roughness	Grain Size (phi)	Organism Sediment Index	RPD (cm)
1-90	a	42 15′ 17″N	70 56′ 53″W	14042.95, 25804.16	6	0.58	2 to 3	3	1.11
	b					1.19	2 to 3	3	1.13
	c					1.06	3 to 4	3	1.19
2-90	a	42 15′ 47″N	70 56′ 31″W	14038.38, 25804.51	8	0.71	> 4	4	1.62
	b					0	3 to 4	IND	IND
	c					0.8	2 to 3	10	3.16
3-90	a	42 15′ 42″N	70 56′ 05″W	14035.82, 25800.92	7	0.8	< -1	IND	IND
	b					1.24	2 to 3	IND	IND
	c					1.42	2 to 3	8	2.01
4-90	a	42 16′ 09″N	70 56′ 16″W	14035.07, 25804.86	10	2.3	3 to 4	9	2.76
	b					1.33	3 to 4	5	2.81
	c					3.19	3 to 4	4	2.23
5-90	a	42 16′ 08″N	70 55′ 48″W	14031.95, 25801.44	19	1.28	> 4	8	2.15
	b					0.75	> 4	8	1.92
	c					2.79	3 to 4	7	1.33
7-90	a	42 16′ 34″N	70 55′ 24″W	14027.19, 25801.02	13	1.55	3 to 4	4	1.57
	b					0	3 to 4	IND	0
	c					0.09	3 to 4	9	2.83
8-90	a	42 16′ 50″N	70 54′ 59″W	14023.46, 25799.72	12	0		IND	0
	b					1.33	3 to 4	9	2.28
	c					2.12	3 to 4	9	2.57
9-89/90	a	42 19′ 38″N	70 58′ 06″W	14030.04, 25838.46	23	1.5	3 to 4	11	4.51
	b					0.75	2 to 3	7	2.74
	c					1.9	3 to 4	9	3.87
10-90	a	42 16′ 23″N	70 54′ 29″W	14022.28, 25793.42	28	1.37	3 to 4	0	1.81
	b					2.3	3 to 4	IND	0.2
	c					3.5	3 to 4	7	0.91
11-90	a	42 16′ 28″N	70 54′ 50″W	14024.10, 25796.38	14	0.84	3 to 4	6	0.44
	b					0		IND	0

Table A1 (Continued).

Station -Date	Rep	Latitude	Longitude	Loran-C TDs	Depth (ft)	Surface Boundary Roughness	Grain Size (phi)	Organism Sediment Index	RPD (cm)
11-90	c	42 16′ 28″N	70 54′ 50″W	14024.10, 25796.38	14	0.8	3 to 4	7	1.19
13-90	a	42 16′ 30″N	70 53′ 54″W	14018.01, 25789.93	25	1.99	3 to 4	6	2.12
	b					0.8	3 to 4	9	2.63
	c					0.93	3 to 4	9	2.65
15-90	a	42 16′ 54″N	70 54′ 31″W	14020.13, 25796.68	27	2.61	3 to 4	9	3.21
	b					2.21	3 to 4	9	3.01
	c					1.28	3 to 4	9	3.1
16-89/90	a	42 18′ 24″N	71 00′ 08″W	14049.17, 25846.06	13	0.35	> 4	4	1.64
	b					1.77	3 to 4	3	1.28
	c					0.4	> 4	3	1.46
18-90	a	42 17′ 23″N	70 55′ 15″W	14022.47, 25804.78	29	0.44	3 to 4	7	2.06
	b					1.11	3 to 4	9	2.39
	c					4.29	3 to 4	6	1.81
20-90	a	42 17′ 44″N	70 55′ 39″W	14023.49, 25809.74	20	0.7	3 to 4	8	1.88
	b					0.8	3 to 4	7	1.11
	c					2.17	3 to 4	7	1.17
21-90	a	42 18′ 03″N	70 55′ 02″W	14017.83, 25807.08	32	0.71	3 to 4	4	1.46
	b					0.99	3 to 4	7	1.15
	c					1.5	3 to 4	5	1.79
22-92	a	42 17′ 46″N	70 54′ 18″W	14014.85, 25800.40	21	1.15	3 to 4	7	1.44
	b					0.58	3 to 4	3	1.13
	c					1.08	3 to 4	8	1.71
23-92	a	42 17′ 41″N	70 53′ 49″W	14012.05, 27596.31	18	0.62	3 to 4	4	1.84
	b					0.75	3 to 4	7	1.68
	c					0.97	> 4	7	1.33
24-92	a	42 17′ 13″N	70 53′ 39″W	14012.66, 25792.49	17	0.84	3 to 4	8	1.84
	b					0.22	3 to 4	8	2.08
	c					0.4	3 to 4	3	1.46
25-90	a	42 16′ 45″N	70 59′ 45″W	14054.47, 25833.74	11	1.81	3 to 4	3	1.02

Table A1 (Continued).

Station -Date	Rep	Latitude	Longitude	Loran-C TDs	Depth (ft)	Surface Boundary Roughness	Grain Size (phi)	Organism Sediment Index	RPD (cm)
25-90	b	42 16′ 45″N	70 59′ 45″W	14054.47, 25833.74		2.21	3 to 4	IND	1.62
	c				11	1.15	3 to 4	5	2.52
26-92	a	42 16′ 32″N	70 59′ 12″W	14052.16, 25828.53	9	1.11	2 to 3	IND	1.31
	b					1.11	2 to 3	IND	IND
	c					1.11	3 to 4	IND	1.06
27-90	a	42 17′ 20″N	71 00′ 25″W	14056.07, 25841.89	11	2.65	3 to 4	7	0.93
	b					1.86	3 to 4	7	1.26
	c					2.26	> 4	7	4.27
28-90	a	42 17′ 14″N	70 59′ 45″W	14052.45, 25836.54	13	0.4	3 to 4	3	1.04
	b					0.53	> 4	4	2.01
	c					2.12	> 4	7	1.35
29-90	a	42 17′ 03″N	70 59′ 17″W	14050.39, 25832.24	14	1.28	3 to 4	5	2.39
	b					1.95	3 to 4	8	1.99
	c					0.35	3 to 4	5	2.43
30-90	a	42 16′ 50″N	70 58′ 47″W	14047.96, 25827.21	13	1.99	3 to 4	8	1.95
	b					1.64	3 to 4	7	1.24
	c					0.8	3 to 4	7	0.88
31-90	a	42 16′ 41″N	70 58′ 13″W	14044.86, 25822.36	13	1.01	3 to 4	9	2.66
	b					1.01	3 to 4	8	1.56
	c					1.19	3 to 4	3	1.42
32-89/90	a	42 20′ 11″N	71 00′ 06″W	14040.67, 25856.11	41	0	3 to 4	IND	IND
	b					0	3 to 4	IND	IND
	c					1.99	> 4	4	0.75
33-89/90	a	42 20′ 31″N	71 00′ 40″W	14042.52, 25861.89	12	0.84	3 to 4	2	0.58
	b					1.37	> 4	2	0.31
	c					0.62	> 4	2	0.64
34-90	a	42 17′ 39″N	70 59′ 40″W	14049.90, 25838.43	13	0.71	> 4	8	1.81
	b					1.55	> 4	6	0.4
	c					2.3	> 4	2	0.53

Table A1 (Continued).

Station -Date	Rep	Latitude	Longitude	Loran-C TDs	Depth (ft)	Surface Boundary Roughness	Grain Size (phi)	Organism Sediment Index	RPD (cm)
35-90	a	42 17′ 26″N	70 59′ 03″W	14046.87, 25832.69	13	6.42	3 to 4	IND	IND
	b					2.35	3 to 4	9	2.9
	c					3.63	3 to 4	10	3.39
37-90	a	42 17′ 12″N	70 58′ 12″W	14042.61, 25824.99	14	2.52	> 4	9	2.68
	b					1.77	3 to 4	5	2.99
	c					3.45	3 to 4	9	2.52
38-90	a	42 17′ 05″N	70 57′ 50″W	14040.68, 25821.86	15	1.68	3 to 4	8	2.3
	b					0.93	3 to 4	9	2.94
	c					0.62	3 to 4	6	2.08
40-90	a	42 17′ 56″N	70 59′ 05″W	14044.70, 25835.93	13	0.66	> 4	7	1.06
	b					1.06	3 to 4	7	1.31
	c					1.11	3 to 4	3	1
41-90	a	42 17′ 44″N	70 58′ 13″W	14040.09, 25828.32	21	1.19	3 to 4	9	4.85
	b					0.8	3 to 4	8	3.16
	c					0.88	3 to 4	8	1.79
42-90	a	42 18′ 18″N	70 58′ 25″W	14038.33, 25832.88	31	0.84	3 to 4	8	1.95
	b					0.53	3 to 4	6	1.28
	c					1.99	3 to 4	4	0.71
43-90	a	42 18′ 13″N	70 57′ 38″W	14033.76, 25826.90	30	0.84	3 to 4	8	2.37
	b					0.09	3 to 4	8	3.08
	c					1.02	3 to 4	8	2.79
44-92	a	42 18′ 02″N	70 57′ 07″W	14031.30, 25822.04	40	0.88	2 to 3	8	3.01
	b					1.37	2 to 3	IND	IND
	c					1.02	2 to 3	7	2.37
45-90	a	42 18′ 37″N	70 58′ 04″W	14034.76, 25832.32	32	1.55	3 to 4	9	3.92
	b					1.19	3 to 4	11	4.03
	c					2.08	3 to 4	8	3.14
46-92	a	42 18′ 36″N	70 56′ 22″W	14023.77, 25819.94	37	1.7	2 to 3	9	4.01
	b					1.9	3 to 4	9	2.61
	c					4.47	3 to 4	IND	IND

Table A1 (Continued).

Station -Date	Rep	Latitude	Longitude	Loran-C TDs	Depth (ft)	Surface Boundary Roughness	Grain Size (phi)	Organism Sediment Index	RPD (cm)
47-92	a	42 18′ 42″N	70 55′ 57″W	14020.57, 25817.33	43	2.65	2 to 3	IND	IND
	b					1.06	2 to 3	IND	IND
	c					0.58	2 to 3	IND	IND
48-90	a	42 18′ 55″N	70 57′ 37″W	14030.33, 25830.79	23	2.12	3 to 4	6	2.21
	b					1.9	2 to 3	7	2.65
	c					0.53	3 to 4	8	2.17
49-90	a	42 18′ 45″N	70 56′ 46″W	14025.57, 25823.73	29	2.92	3 to 4	7	2.54
	b					2.7	3 to 4	10	3.12
	c					0.97	3 to 4	7	2.96
50-90	a	42 19′ 10″N	70 57′ 20″W	14027.23, 25830.15	22	1.19	3 to 4	8	2.81
	b					1.77	3 to 4	10	3.52
	c					1.19	3 to 4	8	2.72
51-90	a	42 19′ 04″N	70 56′ 49″W	14024.38, 25825.80	31	0.97	3 to 4	8	3.54
	b					0.62	3 to 4	8	2.65
	c					0.35	3 to 4	8	3.14
52-90	a	42 19′ 05″N	70 56′ 12″W	14020.16, 25821.48	27	1.15	3 to 4	9	3.32
	b					1.37	3 to 4	10	3.01
57-90	a	42 18′ 40″N	71 01′ 30″W	14056.63, 25857.60	18	2.88	3 to 4	8	2.15
	b					0.75	3 to 4	8	1.59
	c					0.97	3 to 4	3	1.15
58-90	a	42 19′ 11″N	71 01′ 30″W	14054.18, 25860.50	12	1.19	2 to 3	3	1.44
	b					0.44	3 to 4	4	1.88
	c					0.35	3 to 4	8	1.68
59-90	a	42 19′ 44″N	71 01′ 27″W	14051.25, 25863.20	15	0.35	3 to 4	3	0.82
	b					1.46	3 to 4	8	1.75
	c					0.8	3 to 4	7	1.33
60-90	a	42 19′ 13″N	71 00′ 47″W	14049.50, 25855.50	25	0.53	3 to 4	8	1.55
	b					0.93	3 to 4	5	2.37
	c					0.35	3 to 4	4	1.62
61-90	a	42 19′ 18″N	70 59′ 42″W	14042.23, 25848.11	18	0	> 4	IND	0

Table A1 (Continued).

Station -Date	Rep	Latitude	Longitude	Loran-C TDs	Depth (ft)	Surface Boundary Roughness	Grain Size (phi)	Organism Sediment Index	RPD (cm)
61-90	b	42 19′ 18″N	70 59′ 42″W	14042.23, 25848.11	18	1.33	3 to 4	3	1.33
	c					1.07	3 to 4	7	1.47
62-90	a	42 20′ 48″N	71 00′ 59″W	14043.19, 25866.16	37	1.11	3 to 4	8	1.9
	b					0.58	3 to 4	9	2.32
	c					4.73	> 4	4	2.04
63-90	a	42 21′ 03″N	71 01′ 28″W	14045.09, 25870.86	37	0.22	> 4	9	2.79
	b					0.4	3 to 4	8	1.62
64-90	a	42 21′ 21″N	71 02′ 02″W	14047.51, 25876.89	39	0	> 4	IND	0
	b					0	> 4	IND	0
	c					0	> 4	IND	0
65-90	a	42 21′ 42″N	71 02′ 41″W	14050.04, 25833.38	39	0	> 4	IND	0
	b					0	> 4	IND	0
	c					0	> 4	IND	0
67-92	a	42 17′ 26″N	70 54′ 15″W	14015.98, 25797.97	17	0.71	3 to 4	8	1.99
	b					0.66	3 to 4	8	1.53
	c					0.71	3 to 4	8	1.81
70-92	a	42 18′ 55″N	70 58′ 44″W	14037.36, 25838.88	11	2.21	2 to 3	10	3.21
	b					4.2	3 to 4	5	2.46
	c					3.98	> 4	IND	IND
	d					3.98	2 to 3	7	5.73
	e					1.99	3 to 4	IND	2.83
	f					0.53	3 to 4	5	2.43
71-92	a	42 20′ 34″N	70 58′ 00″W	14025.07, 25843.21	36	0.62	3 to 4	9	2.32
	b					0.84	3 to 4	4	1.9
	c					0.49	3 to 4	7	1.22
72-92	a	42 20′ 02″N	70 59′ 31″W	14037.56, 25850.92	41	1.46	2 to 3	IND	1.9
	b					2.17	2 to 3	IND	IND
	c					2.12	3 to 4	IND	IND
73-92	a	42 20′ 39″N	70 58′ 42″W	14029.04, 25848.76	12	0.75	> 4	6	2.32
	b					0.75	3 to 4	3	0.8
	c					0.44	3 to 4	5	2.74

Table A1 (Continued).

Station -Date	Rep	Latitude	Longitude	Loran-C TDs	Depth (ft)	Surface Boundary Roughness	Grain Size (phi)	Organism Sediment Index	RPD (cm)
74-92	a	42 21′ 19″N	70 58′ 35″W	14025.06, 25851.69	12	0.8	> 4	6	1.98
	b					1.02	> 4	9	2.32
	c					0.66	> 4	8	1.88
T1	a	42 20.95′N	70 57.81′W	14021.78, 25844.06	10	3.54	3 to 4	IND	IND
	b					2.21	3 to 4	3	1.15
	c					1.68	3 to 4	IND	IND
T2	a	42 20.57′N	71 00.12′W	14038.71, 25858.52	22	0.49	3 to 4	3	0.93
	b					0.62	3 to 4	3	0.88
	c					2.12	3 to 4	IND	IND
T3	a	42 19.81′N	70 57.72′W	14026.53, 25836.60	25	2.43	3 to 4	8	1.86
	b					0.88	3 to 4	9	2.54
	c					1.5	3 to 4	8	1.62
T4	a	42 18.60′N	71 02.49′W	14063.26, 25863.72	5	0	> 4	IND	IND
	b					0	> 4	IND	IND
	c					0	> 4	IND	IND
	d					0.44	3 to 4	4	1.77
	e					2.3	3 to 4	4	1.64
	f					0.4	> 4	1	1.17
	g					2.57	3 to 4	IND	IND
	h					4.56	3 to 4	2	0.51
	i					4.43	> 4	2	0.55
T5	a	42 19.91′N	70 57.21′W	14022.69, 25833.44	22	0.31	1 to 2	IND	0.09
	b					0.71	1 to 2	IND	0.8
	c					0.93	1 to 2	IND	IND
T6	a	42 17.61′N	70 56.66′W	14030.34, 25816.18	21	0.4	3 to 4	7	1.48
	b					1.73	3 to 4	8	3.14
	c					0.88	3 to 4	5	1.22
T7	a	42 17.36′N	70 58.71′W	14044.94, 25829.66	18	0.13	3 to 4	7	1.48
	b					2.17	3 to 4	-8	0
	c					0.53	3 to 4	7	1.46

Table A1 (Continued).

Station -Date	Rep	Latitude	Longitude	Loran-C TDs	Depth (ft)	Surface Boundary Roughness	Grain Size (phi)	Organism Sediment Index	RPD (cm)
T8	a	42 17.12'N	70 54.75'W	14020.51, 25799.80	38	1.02	2 to 3	6	1.77
	b					2.52	2 to 3	IND	IND
	c					0.58	2 to 3	8	3.19

APPENDIX B

Total Organic Carbon (TOC) and *Clostridium perfringens* Counts

Table B1. Total Organic Carbon (TOC) Data from August 1992.

Station	%TOC			
	Replicate 1	Replicate 2	Replicate 3	Average
BHT1	2.01	1.94	1.77	1.9
BHT2	1.54	1.88		1.7
BHT3	3.64	3.5		3.6
BHT4	3.82	4.08		4.0
BHT5	1.54	1.68		1.6
BHT6	2.05	2.41	1.89	2.1
BHT7	3.45	2.90		3.2
BHT8	0.64	0.68		0.7

Table B2. *Clostridium perfringens* Spore Analysis by Membrane Filtration from August 1992.

Station	Sediment Wet Weight (g)	Wet Weight Density (g^{-1})	Sediment Dry Weight (g)	Dry Weight Density (g^{-1})
BHT1	5	1980	2.3	4300
BHT2	5	7110	2.4	14800
BHT3	5	300	1.6	938
BHT4	5	1200	1.8	3330
BHT5	5	3600	0.6	30000
BHT6	5	2940	2.1	7000
BHT7	5	2400	1.6	7500
BHT8	5	2880	3.7	3890

APPENDIX C

Infaunal Raw Data

Boston Harbor * Aug 1992 * Good Species (no oligochaetes)

Taxa Name	CODE	T1-1	T1-2	T1-3	T2-1	T2-2	T2-3	T3-1	T3-2	T3-3	T4-1	T4-2	T4-3	T5-1	T5-2	T5-3	T6-1	T6-2	T6-3	T7-1	T7-2	T7-3	T8-1	T8-2	T8-3
				18,782			5,324			8,089			5,186			4,276			18,246			4,061			11,573
TOTAL		7,412	6,500	4,870	2,737	1,147	1,440	3,277	2,450	2,362	1,595	1,792	1,799	771	2,524	981	6,384	6,949	4,913	1,888	1,706	487	4,075	3,695	3,803
NASSARIUS TRIVITTATUS	D012	10	12	16	4	—	1	33	14	12	—	—	—	21	25	41	—	5	18	3	4	2	29	34	34
CREPIDULA FORNICATA	D032	1	—	—	6	—	—	—	—	—	—	—	—	4	—	1	—	—	—	—	—	—	—	—	—
CREPIDULA PLANA	D033	—	—	1	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
NUCULA DELPHINODONTA	D401	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	16	16	3	—	—	—	69	150	222
MYTILUS EDULIS	D402	56	15	7	22	5	33	3	1	2	4	—	1	116	8	28	9	11	9	—	1	—	1	3	6
MUSCULUS NIGER	D403	—	—	—	—	—	—	—	1	—	—	—	—	1	—	—	—	—	—	—	—	—	—	1	—
ANOMIA SIMPLEX	D411	—	—	—	—	—	—	—	—	—	—	—	—	1	—	1	—	—	—	—	—	—	—	—	—
ASTARTE UNDATA	D412	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—
ARCTICA ISLANDICA	D416	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—
CERASTODERMA PINNULATUM	D418	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
TELLINA AGILIS	D420	7	11	6	3	8	2	14	5	2	—	—	—	2	23	17	4	2	2	2	2	1	46	21	22
ENSIS DIRECTUS	D423	—	1	1	2	—	—	—	—	—	—	—	—	—	3	1	—	—	—	—	—	—	—	1	2
MYA ARENARIA	D425	2	—	1	20	2	1	—	1	—	—	—	—	—	—	—	—	—	—	3	—	—	—	—	—
LYONSIA HYALINA	D426	2	—	1	—	—	—	1	1	1	—	—	—	—	1	1	—	—	—	—	—	—	2	3	4
HIATELLA ARCTICA	D451	3	3	—	—	—	—	—	—	—	—	—	—	1	1	9	1	—	—	—	—	—	1	—	—
MYSELLA PLANULATA	D453	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
ASTHENOTHERUS HEMPHILLI	D486	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
PETRICOLA PHOLADIFORMIS	D498	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
ACMAEIDAE SP.	D499	—	—	—	—	—	—	—	—	—	—	—	—	1	1	1	—	—	—	—	—	—	—	—	—
DORIDACEA SP. A	D500	1	—	—	—	—	—	—	—	—	—	—	—	—	—	10	—	—	—	—	—	—	—	—	—
PTILANTHURA TENUIS	H002	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—
EDOTEA TRILOBA	H005	8	5	2	2	—	—	44	14	43	—	—	—	2	1	1	2	4	1	—	—	1	—	2	6
PLEUROGONIUM INERME	H019	—	—	—	—	—	—	1	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
ERICHSONELLA SP.	H035	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
UNCIOLA IRRORATA	H301	7	—	4	—	—	—	19	6	11	—	—	—	3	—	2	26	21	14	1	—	—	5	7	5
COROPHIUM BONELLI	H304	64	28	5	—	—	2	28	53	98	—	—	—	3	—	3	25	35	27	—	—	—	—	—	—
COROPHIUM CRASSICORNE	H305	—	—	—	—	—	—	—	4	5	—	—	—	—	—	—	—	—	—	—	—	—	—	11	—
ISCHYROCERUS ANGUIPES	H311	11	3	5	—	—	—	—	—	—	—	—	—	12	1	—	—	—	—	—	—	—	—	—	—
ORCHOMENELLA MINUTA	H318	—	—	—	—	—	—	11	6	23	—	—	—	—	—	—	1	1	1	—	—	—	—	—	—
LEPTOCHEIRUS PINGUIS	H325	—	—	—	—	2	64	189	237	310	—	—	—	—	—	2	156	51	102	178	16	13	—	2	30
PHOXOCEPHALUS HOLBOLLI	H335	14	—	—	—	—	8	171	141	132	—	—	—	176	45	38	127	57	116	—	—	—	4	14	31
DYOPEDOS MONACANTHUS	H340	—	—	—	—	—	—	—	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
PONTOGENEIA INERMIS	H341	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	8	4	1	—	—	—	—	—	—
METOPELLA ANGUSTA	H342	—	1	—	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	2	—
PROBOLOIDES HOLMESI	H344	—	—	—	—	—	—	—	—	—	—	—	—	11	—	1	—	—	—	—	—	—	—	1	—
CAPRELLA LINEARIS	H348	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
AEGININA LONGICORNIS	H350	19	14	42	—	2	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—
PHOTIS POLLEX	H356	5	—	43	1	—	—	92	106	88	—	—	—	—	3	—	30	37	56	—	—	—	1	22	14
AMPELISCA SPP. COMPLEX	H422	39	3	20	1	3	4	1,258	903	762	1	1	1	9	2	5	2,549	2,669	2,238	469	456	200	18	572	424
CYMADUSA COMPTA	H423	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
COROPHIUM TUBERCULATUM	H424	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—
PLEUSYMPTES GLABER	H426	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—
PARACAPRELLA TENUIS	H427	1	1	1	—	—	—	—	—	—	—	—	—	9	—	—	—	—	—	—	—	—	—	—	—
DIASTYLIS SCULPTA	H710	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—
CANCER IRRORATUS	H721	1	4	—	—	—	1	1	—	—	—	—	—	5	1	1	2	3	8	2	—	—	—	1	1
CRANGON SEPTEMSPINOSA	H732	—	1	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	3	—
TANAISSUS PSAMMOPHILUS	H736	—	—	—	—	—	1	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	4	—	2
RHEPOXYNIUS HUDSONI	H779	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
PAGURUS LONGICARPUS	H802	1	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	1
NEOMYSIS AMERICANA	H803	6	—	—	—	—	—	3	2	2	—	—	—	—	1	1	2	—	—	—	2	1	1	—	—
STRONGYLOCENTROTUS DROEBACHIENSIS	J008	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	1	—	—	—	—	—	—
OPHIUROIDEA SP.	J019	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
AGLAOPHAMUS CIRCINATA	L001	—	—	1	—	—	—	—	—	1	—	—	—	1	—	—	—	—	—	—	—	—	—	1	—
AMPHARETE ARCTICA	L003	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—
ARICIDEA CATHERINAE	L007	3	2	2	3	—	—	125	53	82	1	—	—	5	12	2	1,147	1,395	586	318	287	86	2,819	1,669	2,006
ASABELLIDES OCULATA	L009	3	2	4	2	—	—	5	5	4	—	—	—	—	—	—	2	10	2	10	20	—	—	2	9
CLYMENELLA TORQUATA	L011	769	553	144	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—
CHAETOZONE SETOSA	L012	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3	3	—
CIRRATULUS GRANDIS	L013	—	—	—	—	—	—	—	—	—	—	—	—	—	1	3	—	—	—	—	—	—	—	—	—
PECTINARIA GRANULATA	L015	1	1	—	1	—	1	—	—	—	—	—	—	1	1	3	—	1	—	—	—	—	—	—	—
ETEONE LONGA	L016	12	14	10	11	58	35	24	15	8	—	—	—	5	10	41	—	1	1	—	2	—	—	—	—
EXOGONE HEBES	L023	5	5	6	2	1	—	2	—	—	—	—	—	—	1	—	—	—	1	—	—	—	275	181	126
EXOGONE VERUGERA	L025	—	—	—	—	—	—	—	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
HARMOTHOE IMBRICATA	L036	4	—	1	—	—	5	7	9	6	—	—	—	21	—	2	—	—	—	—	—	—	—	—	—
HETEROMASTUS FILIFORMIS	L038	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

Boston Harbor * Aug 1992 * Good Species (no oligochaetes)

Taxa Name	CODE	T1-1	T1-2	T1-3	T2-1	T2-2	T2-3	T3-1	T3-2	T3-3	T4-1	T4-2	T4-3	T5-1	T5-2	T5-3	T6-1	T6-2	T6-3	T7-1	T7-2	T7-3	T8-1	T8-2	T8-3
				18,782			5,324			8,089			5,186			4,276			18,246			4,061			11,573
LEPIDONOTUS SQUAMATUS	L040	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—
MICROPHTHALMUS ABERRANS	L048	273	275	80	62	110	14	26	12	12	—	1	1	3	50	62	15	6	9	7	3	2	5	8	9
NEANTHES VIRENS	L050	4	2	5	—	12	11	7	4	5	—	—	—	2	7	22	7	9	4	2	2	—	—	—	—
NEPHTYS CAECA	L055	1	1	2	3	—	—	—	—	—	—	—	—	—	1	—	2	1	—	—	1	—	3	—	2
NEPHTYS INCISA	L056	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—
NINOE NIGRIPES	L061	—	1	—	2	2	2	—	2	1	—	—	—	—	—	—	4	6	6	—	—	—	—	1	1
NICOLEA ZOSTERICOLA	L062	—	—	—	—	—	—	—	—	—	—	—	—	4	1	—	—	—	—	—	—	—	—	—	—
PHERUSA AFFINIS	L066	3	—	—	—	—	7	4	2	2	—	—	—	—	—	1	—	1	1	—	—	—	—	—	—
PHOLOE MINUTA	L069	11	5	1	1	10	17	6	—	2	—	—	—	3	1	3	1	—	2	—	—	—	—	—	—
EUMIDA SANQUINEA	L072	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—
PHYLLODOCE MUCOSA	L074	6	5	1	38	26	5	12	9	9	—	—	—	3	—	14	44	51	38	1	1	—	6	34	25
POLYDORA AGGREGATA	L075	129	62	18	4	3	19	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
POLYDORA CAULLERYI	L077	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—
POLYDORA LIGNI	L079	4,703	4,237	3,866	701	320	69	1,114	788	686	—	—	—	117	96	43	2,054	2,445	1,497	166	209	171	37	352	241
POLYDORA SOCIALIS	L080	77	21	—	—	1	4	6	4	—	—	—	—	1	—	—	—	—	—	—	1	—	2	—	6
POLYDORA QUADRILOBATA	L081	—	21	—	—	1	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	4	—	1
POLYDORA WEBSTERI	L082	514	247	18	—	—	89	—	—	—	—	—	—	36	2	26	—	—	—	—	—	—	—	—	—
PRIONOSPIO STEENSTRUPI	L085	—	—	—	1	1	1	2	—	—	—	—	—	3	2	3	—	1	1	—	1	—	11	18	13
PROCEREA CORNUTA	L086	10	3	9	1	2	5	—	—	—	—	—	—	20	4	6	—	—	1	—	—	—	1	2	—
PYGOSPIO ELEGANS	L089	1	4	6	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	58	64	51
PARANAITIS SPECIOSA	L092	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—
PAROUGIA CAECA	L096	—	1	—	—	—	—	—	—	—	—	—	—	—	—	1	—	1	—	—	—	—	—	—	3
SPIO THULINI	L105	78	153	32	53	53	90	40	35	29	—	—	—	57	165	110	73	31	88	7	6	—	33	63	53
SPIO FILICORNIS	L106	—	1	1	1	2	—	—	—	1	—	—	—	—	5	4	—	1	—	—	—	—	4	—	5
SPIO LIMICOLA	L107	—	—	5	—	1	—	—	—	—	—	—	—	—	4	1	3	1	3	2	2	2	3	3	1
SPIO SETOSA	L108	2	24	5	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—
SPIOPHANES BOMBYX	L109	—	—	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	253	215	169
STREBLOSPIO BENEDICTI	L113	400	304	443	915	415	62	5	—	3	1,586	1,786	1,792	7	24	27	3	6	4	677	673	8	—	2	—
THARYX ACUTUS	L116	11	162	33	852	79	868	9	8	8	—	1	1	7	6	1	—	—	1	4	11	—	21	22	24
MONTICELLINA BAPTISTEAE	L117	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4	3	3	—	—	—	2	6	9
POLYGORDIUS SP. A	L119	6	2	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	339	148	180
ETEONE FLAVA	L121	—	1	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
CAPITELLA CAPITATA SPECIES COMPLEX	L152	120	276	6	6	19	—	6	2	4	3	3	3	86	2,005	429	4	1	1	1	1	—	6	11	17
LEVINSENIA GRACILIS	L166	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
OPHELINA ACUMINATA	L183	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
MEDIOMASTUS CALIFORNIENSIS	L191	—	5	9	13	8	10	7	4	3	—	—	—	4	3	3	46	43	45	10	2	—	4	12	9
SCOLETOMA HEBES	L210	7	3	—	—	—	—	—	—	—	—	—	—	—	—	—	14	12	10	—	2	—	2	21	27
GLYCERA DIBRANCHIATA	L381	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
LEITOSCOLOPLOS ROBUSTUS	L383	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	—	—	—
AUTOLYTUS FASCIATUS	L384	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	—	—	—	—	—	—	—	—
TYPOSYLLIS SP.	L389	1	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	1	—
NEMERTEA SPP.	Y004	—	—	—	—	—	—	1	1	1	—	—	—	1	3	3	3	1	1	—	—	—	—	1	2
ASCIDEACEA SPP.	Y456	—	—	—	—	—	4	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—
ENTEROPNEUSTA SPP.	Y551	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—
TURBELLARIA SPP.	Y950	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
PHORONIS ARCHITECTA	Y951	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	8	—	—	—	—	3	5

The Massachusetts Water Resources Authority
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