Boston Harbor soft-bottom benthic monitoring program: 1995 results

Massachusetts Water Resources Authority

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BOSTON HARBOR SOFT-BOTTOM BENTHIC MONITORING PROGRAM

1995 Results

submitted to

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EXECUTIVE SUMMARY

The present report treats benthic biology and sedimentology data collected in 1995 as part of a long-term monitoring program designed to document the recovery of the Boston Harbor ecosystem after sludge abatement in December of 1991. This data set constitutes the fourth year of post-abatement monitoring and includes traditional benthic biology (quantitative analysis of replicated grab samples), sediment profile image analysis, and ancillary sedimentary characteristics such as grain size, total organic carbon concentration, and *Clostridium perfringens* spore counts.

The most significant change in benthic habitat conditions since the 1991 post-sludge abatement has been the explosive population growth of the pollution sensitive tube-dwelling amphipod, *Ampelisca* sp. Although sludge abatement is only one of several factors that may contribute to this phenomenon, the fact that these amphipods have progressively populated Boston Harbor, particularly bottoms near the Deer Island and Long Island (i.e., Nut Island) outfalls is significant. Prior to sludge abatement, less than 20 percent of the stations showed the presence of amphipod tube mats. In 1995, over 60 percent of the monitoring stations show well developed tube mats. These tube mats, in turn, are effective in trapping fine-grained sediment and have had a significant impact on enhancing sedimentation rates of silt-clay and very fine sand. Seasonal breakdown of the tube mats is likely to result in resuspension and redistribution of trapped fine-grained sediment.

The strong no-name storm in November 1991 may have helped to set the stage for the establishment of *Ampelisca* mats in the harbor, as it caused a harbor-wide shift from mud to mostly fine sand, which is the substrate preferred by settling larvae. Since then, the sediments have become more fine-grained again in most of the Harbor.

Regarding inventories of total organic carbon (TOC), the ranking of Traditional stations is similar between the pre-sludge abatement and post-sludge abatement periods. Stations T3, T4, and T7 remained high in 1995 with peaks of over 3%. The lowest TOC inventories were at stations T5a and T8. It may take several years for the organically loaded stations to reflect reduced sedimentation rates of labile organic matter.

Sediment inventories of *Clostridium perfringens* showed dramatic reductions following sludge abatement. These inventories have not been consistently low as the April 1995 samples showed elevated spore counts that equaled or exceeded late summer to early fall pre-sludge abatement values. *Clostridium* spore counts may be expected to decline over time but stations with the highest spore counts (T2, T3 and T4) may continue to show high counts for several years as these resistant spores may continue to be viable for a long time and, as such, reflect historical sewage accumulations at these stations.

Although the benthic infaunal communities at the Traditional stations are quite different from station to station, they have historically fallen into two groups, the northern stations closest to the outfalls (T1, T2, T3, T4, and T5a) and the southern stations at a greater distance from the outfalls (T6, T7, and T8). The northern stations were characterized by opportunistic, seasonally or annually often highly variable assemblages that are able to tolerate high organic loading of the sediment, while the southern stations exhibited more consistent and predictable assemblages that were usually dominated by Stage II organisms that require better sediment quality. Sludge abatement, and possibly the sedimentary changes

due to the November 1991 storm, have changed the infauna at some northern stations such that they have become progressingly more similar to the southern stations.

Species richness increased harborwide since 1991, especially at the northern stations. At the same time, several species appeared among the dominants that were previously rare or absent, such as *Chaetozone vivipara* and *Corophium* spp. The success of both species is likely due to habitat modifications caused by *Ampelisca*, which in turn seems to be related to the sludge abatement even though *Ampelisca* populations were reported in the Harbor between 1978 and 1982 when sewage sludge was still discharged.

Of the two *Ampelisca* species traditionally present in the Harbor, *A. vadorum* historically had a much more restricted distribution than *A. abdita*, and this pattern has persisted. These distributional patterns, which may depend on grain size and oxygen levels in the sediments, suggest that the spread of amphipod mats throughout the Harbor observed since sludge abatement is a response of *A. abdita* to more favorable habitat conditions.

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 in order to assess the recovery of the benthos following the abatement of sludge discharges in December 1991, the planned upgrade of sewage discharges to an enhanced primary in 1996, and total cessation of sewage discharges in 1998.

Previously, sludge that had been generated at the Deer Island and Nut Island sewage treatment facilities was discharged from a point off Long Island and across President Roads into Boston Harbor on outgoing tides. The abatement of sludge disposal from the Long Island discharge point is part of the long-term effort to clean up Boston Harbor that will eventually include cessation of all sewerage discharge into the Harbor.

Pre-abatement baseline surveys using sediment profile imaging were conducted in 1989, 1990, and 1991; the infauna was sampled in September 1991. Post-abatement surveys were conducted in April-May and August 1992 to 1995. Reports on the results of these surveys have been prepared (SAIC, 1989, 1990, 1992; Kelly and Kropp, 1992; Blake *et al.* 1993; Kropp and Diaz, 1994; 1995). The current report presents results of the 1995 surveys and provides a retrospective analysis of pre- and post-abatement (sludge) 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

Prior to the initiation of MWRA's ongoing monitoring in 1991, 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. In the northern part of the Harbor, 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 including 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 the 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 the quantitative benthic infaunal data collected as part of surveys in April and August 1995 and a review of conditions in the Harbor benthos from 1991 to the present.

1.3 Overview of the Present Study

Sixty stations were sampled with the sediment profile camera in August of 1995. Eight of these stations were also sampled in April and August using traditional grabs for biology, sediment grain-size, total organic carbon (TOC), and spores of *Clostridium perfringens*; two other stations are being sampled as part of a parallel program to assess benthic nutrient flux. The station design for August 1995 has been the same since May 1992, after it had been modified from earlier surveys in 1989 and 1990, except that several sediment profile stations were relocated or added in 1995. The sediment profile 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 (Blake *et al.* 1989). 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 as well as those monitored since 1991.

2.0 METHODS

2.1 Field Operations

2.1.1 Sampling Design and Location of Stations

Benthic grab samples were collected in April and August 1995 at eight stations named Harbor Traditional stations T1- T8 (Appendix A1, Figure 1) for the analysis of macroinfauna and sedimentary characteristics. During both surveys, three replicate grabs were taken for macrofauna and one grab for sediment samples.

Sediment profile images were taken at 60 stations in August 1995 (Appendix A2, Figure 2). Fifty of those stations, including the Traditional stations, had also been sampled in 1993 and 1994; ten additional stations included the Benthic Flux stations BH02, BH03A, BH08A, and QB and six stations sampled in 1990 and 1991.

2.1.2 Navigation

Navigational positioning was accomplished with a Northstar 41X Differential GPS system with an accuracy of 5 to 15 m. If the vessel drifted more than 0.01 nmi (ca. 18 m) away from the reference coordinates, it was repositioned between replicate samples. The ship's position was logged every minute while underway and marked at the time of each touchdown of the grab or camera with the Maptech software.

2.1.3 Grab Sampling

A 0.04-m^2 Ted Young grab was used to collect biology (benthic infaunal) and chemistry samples. At each station (T1-T8, see Figure 1 and Appendix A1), three replicate grabs for benthic infauna and one grab for sediment chemistry were taken. The benthic infaunal samples were checked for depth of the apparent RPD layer, sediment color and texture, and penetration depth of the grab with a resulting rough estimate of the sample volume. The samples were then washed into a bucket, sieved through 300-μm mesh screens, and fixed in 10% buffered formalin.

The sediment chemistry grab was inspected for an undisturbed surface and acceptable penetration depth of the grab (grab at least half full). The top 2 cm of sediment were then removed with a scoop, homogenized in a stainless steel bowl, and subsampled for sediment grain size, TOC, and *C. perfringens*. The samples were kept cool on ice and blue ice packs.

2.1.4 Sediment Profile Imaging

At each of 60 Harbor sediment profiling stations (see Figure 2 and Appendix A2), the sediment profiling camera was lowered to the seafloor; when the wire went slack, the camera was allowed to stay on the bottom for 12 seconds (measured with a stop watch on board ship), during which the camera's prism penetrated into the sediment. Two photographs were taken each time, the first 2 seconds after the frame settled on the bottom and the second 10 seconds later.

This protocol helps ensure that at least one useable photograph is produced during each lowering. If the bottom is very soft, the prism will overpenetrate after 12 seconds (no sediment-water interface on the photograph), but the first exposure, taken after 2 seconds, will usually show the interface and will be suitable for a full analysis. If the sediment is compacted or mixed with rocks, the second exposure can

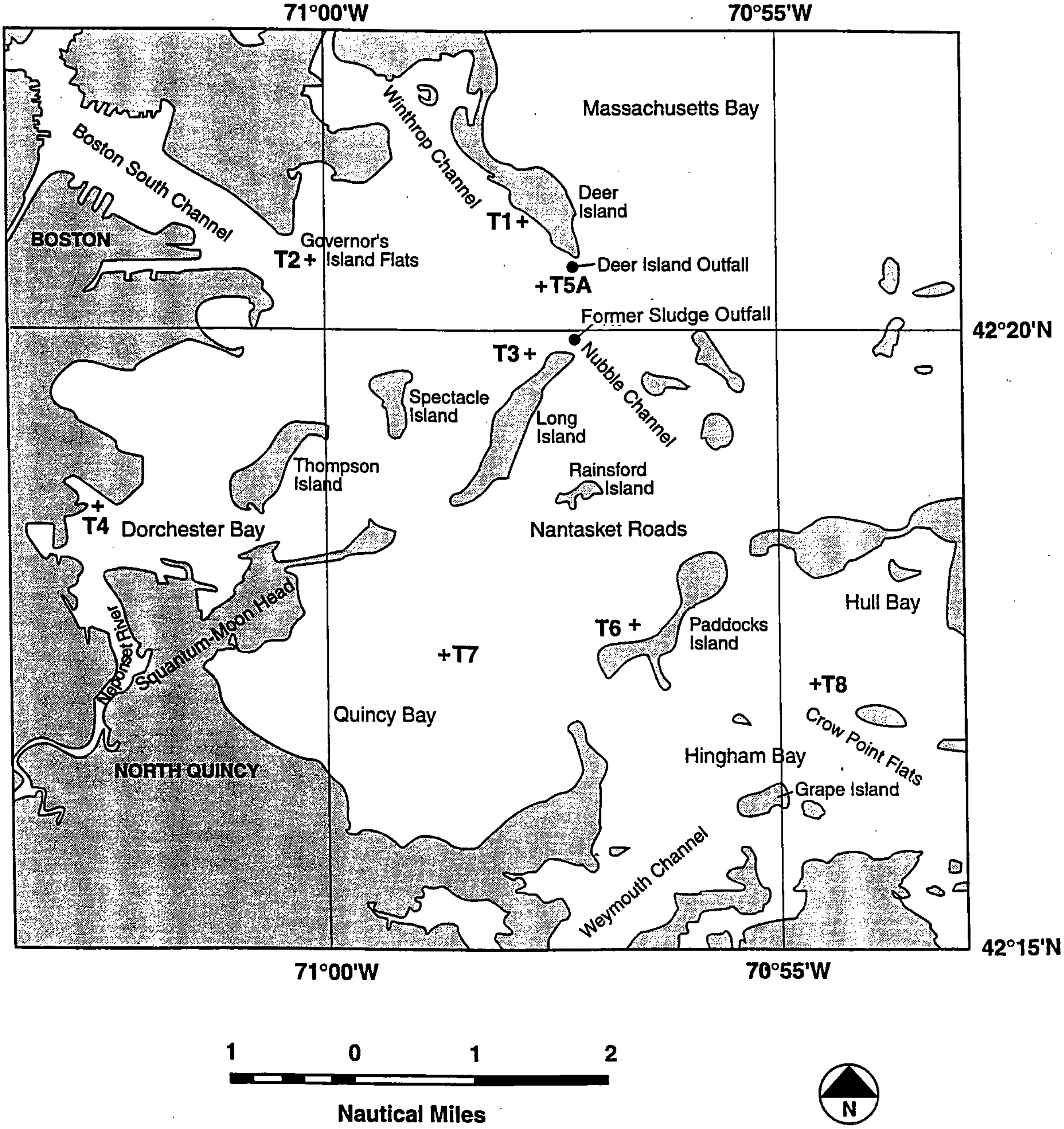


Figure 1. Boston Harbor map showing place names and locations of the eight Traditional stations.

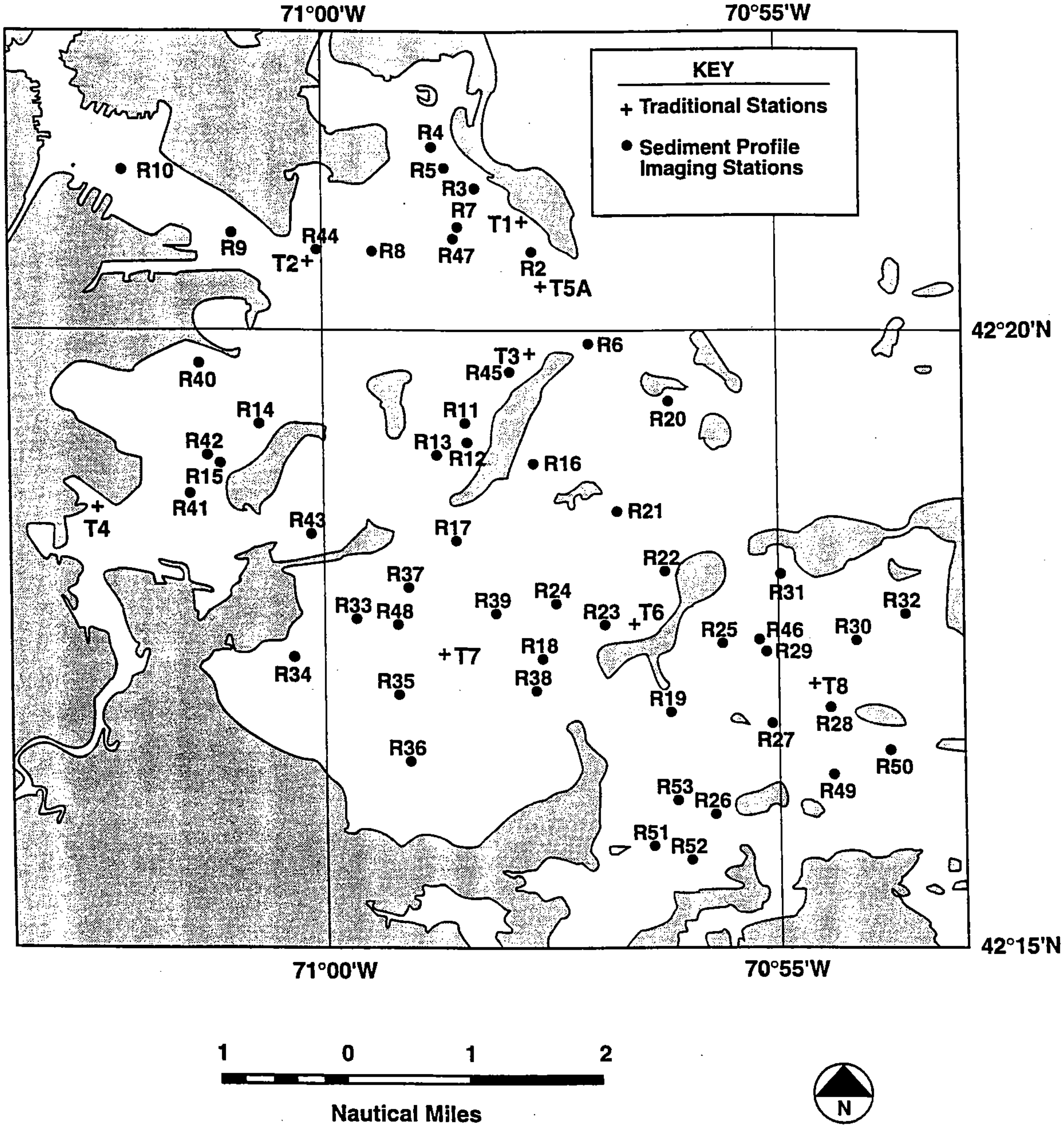


Figure 2. Station locations for 1995 Boston Harbor sediment profiling survey.

be used for analysis because the prism will usually penetrate deep enough to allow for measurement of all required parameters.

After 12 seconds, the camera was lifted off the bottom, returned to the surface for quick visual inspection while in the water, and lowered again for the next replicate set of two exposures. A total of four replicate sets (eight exposures) were taken at each station. At the end of a station, the camera was hauled back on deck for transit to the next station.

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

Standard ENSR procedures for sample tracking and custody were followed. Prior to each field survey, preprinted labels were produced that were linked to ENSR's MWRA HOM database. All sample containers were labeled on the outside, and the macrofauna containers were also labeled on the inside. Information on the labels included the survey number, date, station and replicate, sample type, and the laboratory to which the sample was to be delivered for analysis.

All pertinent information on field activities and sampling efforts was recorded into a bound, numbered logbook. The number of the logbook was entered into the MWRA HOM database. Entries were recorded in indelible ink and included, at a minimum:

- Date and time of starting work
- Names of ship's crew and scientific party
- Sampling sites and activities and references to ship's navigation system
- Deviations from survey plan, if any
- Field observations such as weather and sea state

Chain-of-custody forms were created either electronically or by hand when samples left the ship or the custody of the scientist responsible for shipping. All coolers and boxes used for shipping were sealed with numbered chain-of-custody tape; the number on the tape was recorded on the chain-of-custody form. For additional information see ENSR's Quality Assurance Project Plan (Blake and Hilbig, 1995).

2.2 Laboratory Methods: Sample Processing and Analysis

2.2.1 Benthic Infauna

About 48 h after the samples had been fixed in formalin, they were resieved on a 300-μm screen with fresh water and transferred to 70% alcohol for preservation. Before sorting, the samples were stained with a saturated alcoholic solution of Rose Bengal, a stain for proteins that enhances the visibility of organisms in the sediment. All animals, including fragments, were then removed from the sediment and sorted into major taxa, such as polychaetes, oligochaetes, mollusks, crustaceans, and echinoderms. Taxonomists then identified each taxon to the lowest practical level (usually to species) and enumerated each taxon. Sorting and identification of the benthic infauna was performed by Cove Corporation; the second replicates of each station sampled in April 1995 were sent to ENSR taxonomists for identification to ensure consistency in the identifications.

2.2.2 *Sediment Grain Size*

Grain size was determined by GeoPlan with a combination of wet and dry sieve and pipette analyses (NOAA, 1993). The sediment was sieved through a sieve series based on the Wentworth grade scale, including mesh sizes of 2 mm (-1 phi), 1 mm (0 phi), 0.5 mm (1 phi), 0.25 mm (2 phi), 0.125 mm (3 phi), and 0.063 mm (4 phi). The sediment fraction retained on each sieve was weighed and reported as percent gravel (grain size >2 mm) and percent sand (grain size 2 mm to 0.063 mm). Sediment passing through the 0.063-mm sieve was further analyzed by pipette analysis to obtain percent silt (grain size 0.063 mm to 0.004 mm) and percent clay (grain size <0.004 mm). For the sand fraction, the weight percent for each phi size were also recorded.

2.2.3 *Total Organic Carbon*

TOC analysis followed NOAA's procedures developed for the Mussel Watch program (NOAA, 1993). The sediment samples were dried to constant mass, exposed to HCl fumes to eliminate inorganic carbon, and TOC was measured with a CHN analyzer. A detailed description of the procedures can be found in the Benthic QAPP (Blake and Hilbig, 1995).

2.2.4 *Clostridium Spores*

The enumeration of *Clostridium perfringens* spores was performed using methods developed by Emerson and Cabelli (1982) and modified by Saad (personal communication). The data were recorded as units of spores per gram dry weight of sediment. Details of the laboratory procedure can be found in the Benthic QAPP (Blake and Hilbig, 1995).

2.2.5 *Sediment Profile Image Analysis*

Three out of eight replicate images (see Section 2.1.4) from each station were analyzed with the ImagePro Plus software package. Each slide was digitized and then analyzed for parameters including penetration depth, surface roughness, apparent redox potential discontinuity (RPD), grain size major mode, successional stage of the infauna, the presence of methane bubbles, and biogenic features such as burrows and tubes. Any additional observations were entered into a comment field. The data were compiled on separate data sheets for each image, and the organism-sediment index (OSI) was calculated (Rhoads and Germano, 1982). A spreadsheet (Appendix B1) was generated from the raw data files, and several parameters were mapped and contoured by hand. Due to the heterogeneity of the Harbor bottom (see Knebel and Circé, 1995), some of those contour lines may cross over small areas of very coarse sediment or hardground unsuitable for sampling.

A detailed account of the SPI parameters can be found in SAIC (1992); the following paragraph provides a brief characterization of these parameters. *Penetration depth* is measured from the bottom of the image to the sediment-water interface (maximally 20 cm) and is a measure for softness of the substratum, which depends on characteristics such as water content and grain size. *Surface roughness* is the difference between the least and greatest penetration depth across the sediment-water interface depicted on a slide (the width is 15 cm). It may be a measure for physical disturbance—natural or anthropogenic—or biological activity such as burrowing. The *apparent RPD depth* is measured from the sediment-water interface to the depth in the sediment at which there is a change in sediment color caused by the lack or absence of oxygen at depth; the color commonly changes from tan or brownish (ferric hydroxides) in the well-oxygenated surface layer to greyish (ferric hydroxides being reduced) or black (presence of sulfide, anoxic conditions) at a few mm to several cm depth. The RPD depth depends on a variety of physical and biological factors, such as currents, organic loading, and bioturbation by infaunal organisms, and is commonly used as a first-approximation measure for the health of a habitat.

Methane bubbles, discernable by their strong reflectance (silvery color) only form under severely oxygen depleted sediment conditions as a result of anaerobic bacterial metabolism. The *grain size major mode* is the dominant particle size in an image, measured visually by comparing the slide with a photograph of phi size classes. The *infaunal successional stages* are derived from a paradigm describing recolonization of disturbed habitats. Stage I organisms are those that live very close to the sediment-water interface, and they are pioneers because they do not require much oxidized sediment. By their feeding and burrowing activities these stage I organisms, often small annelids, deepen the RPD, preparing the sediment for somewhat larger animals to colonize, such as certain amphipods (stage II). Stage III organisms are large, deep-burrowing, head-down deposit feeders, such as large polychaetes and echinoderms, that aerate the sediment to several cm depth. Their presence indicates an equilibrium community and healthy environment.

2.3 Data Management and Analysis

Data from infaunal indentifications were either directly entered into a QuattroPro spreadsheet or a compatible electronic format, or they were first documented manually on data sheets and then entered into a spreadsheet. NODC codes and ENSR's alphanumeric codes were added, and the data were converted into a database format suitable for statistical analyses. Juvenile and indeterminable organisms were included in calculations of density, but were excluded from of similarity and diversity measures.

Similarity among samples was determined by the Bray-Curtis similarity coefficient (Boesch, 1977) with group average sorting. CNESS, a similarity index more sensitive to the contribution of rare species, was not used for interpretation of the 1995 data due to a programming error. Diversity was calculated as Shannon-Wiener index H' and the associated evenness J' and 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, the number of individuals was set at defined points between 100 and 8000.

3.0 RESULTS

3.1 Sedimentology

3.1.1 Sediment Grain Size and Distribution of Sediment Types

Sediment grain size, determined with combined sieve and pipette analysis from April and August samples, did not vary much between spring and summer (Figure 3, Appendix C1). Some stations, such as T1 and T6, showed an increase of fines (silt and clay) between spring and summer and a corresponding decrease in sand and gravel, which may be related to calmer weather with less scouring by storms than in the winter and spring seasons. During both sampling events, station T7 had the largest gravel fraction, and sediments at stations T3 (Long Island) and T4 (Dorchester Bay) consisted almost entirely of silt and clay, while station T8 (Hingham Bay) was characterized by a very large sand fraction of more than 90%.

Figure 4 shows the distribution of major modal grain size, sedimentary structures, and presence of sedimentary methane for SPI and Traditional stations in August 1995. The major modal grain size, as inferred from SPI images, is compared with the major modal grain size at Traditional stations as measured by traditional sieve analysis (Figure 3, Appendix B1). All SPI major modes equal traditional sieve analysis major modes; for example, SPI images taken at Station T8 indicated a major modal grain size of 3-2 phi (fine sand), and the sediment samples taken at the same station were found to consist of 72% fine sand when analyzed in the laboratory. The only exception was station T5a where the major and subordinate modes in the sediment sampple were roughly equal (3-2 and 4-3 phi), whereas the SPI analysis resulted in a major modal grain size of 4-3 phi (very fine sand).

Most surficial sediments in Boston Harbor, Dorchester, Quincy, Hingham, and Hull bays consist of silt-clay muds. Some of the muddy stations have very high inventories of labile organic matter (e.g., station T4 with 6.25% TOC) and show the presence of methane gas bubbles in SPI images (Figures 4 and 5). However, methane is not limited to organic-rich silt-clay stations. Methane was also imaged at a fine to very fine sand station T5a (0.4 to 0.7 % TOC) located near the Deer Island Outfall (Figures 4 and 6). Methane was also noted in the fluid muds of the Inner Harbor (station R9) and near the entrance to Weymouth Channel in Hingham Bay (stations R51 and R52, Figure 4). The widespread distribution of silt-clay mud is associated with the presence of dense aggregations of tube-forming amphipods (*Ampelisca* spp.) which are known to promote the sedimentation of fine particles (Rhoads and Boyer, 1982). At some stations the mapped mud facies is covered by a thin layer of sand (S/M) which may show evidence of bed load transport (ripples), or selective washing leaving a concentration of dead shell debris (shell lag) at the surface or a mixture of shell and larger clastic particles (scour lag). Other stations, including silt-clay muds, also show erosional features such as high physical boundary roughness (designated by the symbol E in Figure 4). The source of this erosion can be current scouring or foraging activities of benthic megafauna including crabs, lobsters, and demersal fish.

Most sand-dominated stations are located in, or near, high flow-rate channels (e.g., stations T2 , T8, and R17) where the bottom is washed free of fines, on shallow flats washed by waves and currents (station R8 on Governor's Island Flats), or near local sources of sand around islands within the Harbor complex (stations R16, R22, R23, and R49).

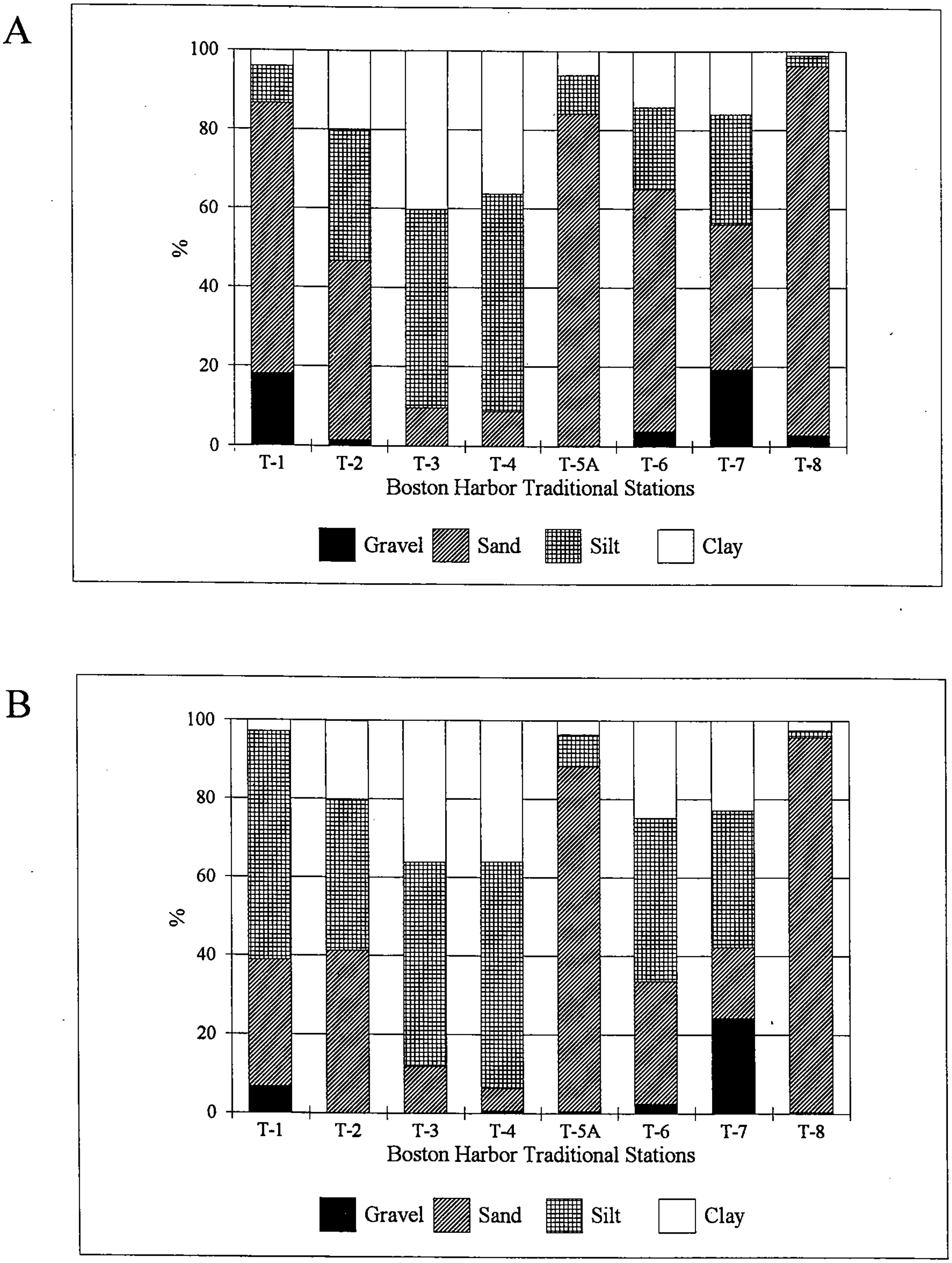


Figure 3. Percentages of gravel, sand, silt, and clay for the Boston Harbor Traditional stations determined from sieving and gravimetric analysis of sediments collected in (A) April and (B) August 1995.

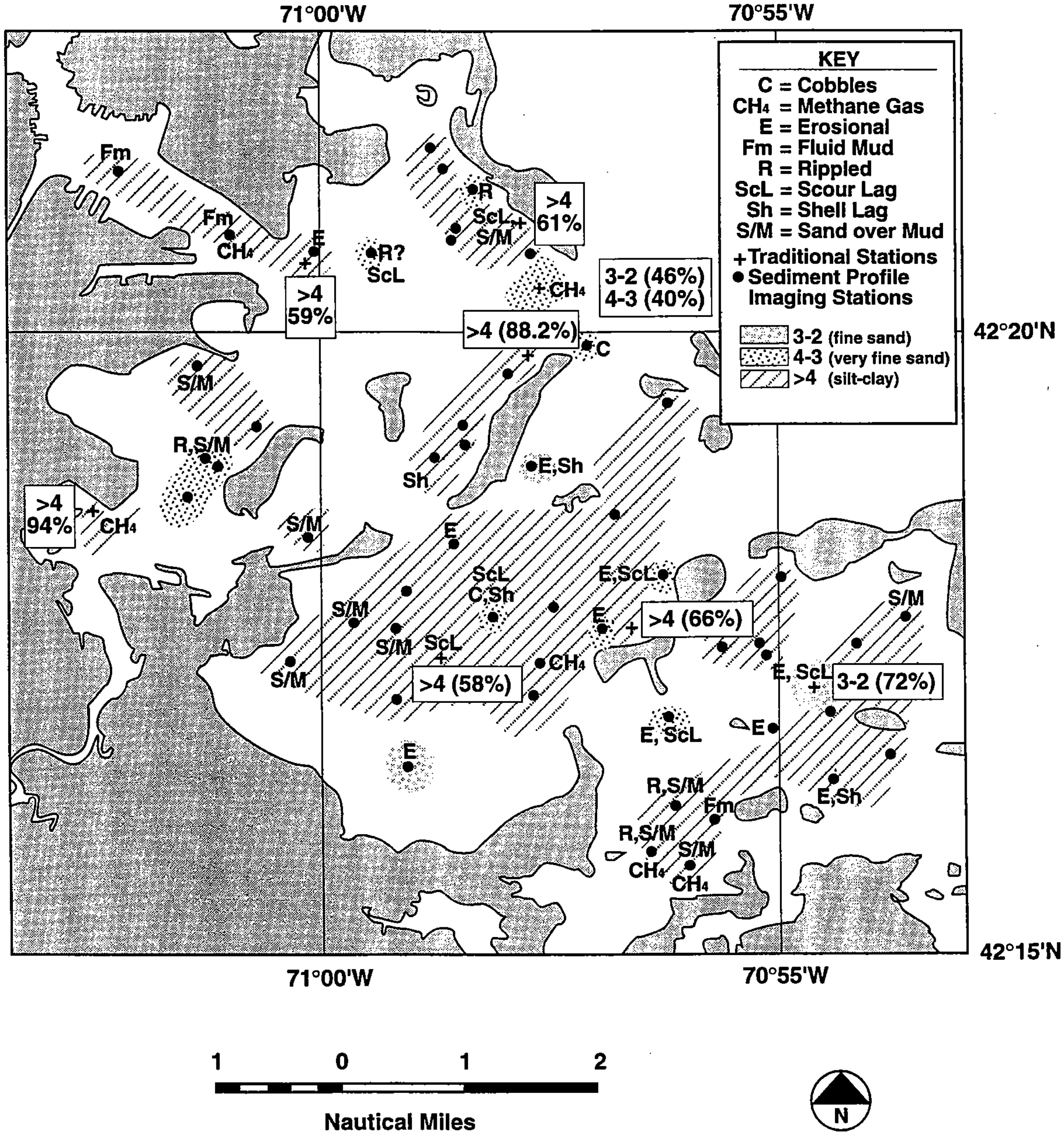
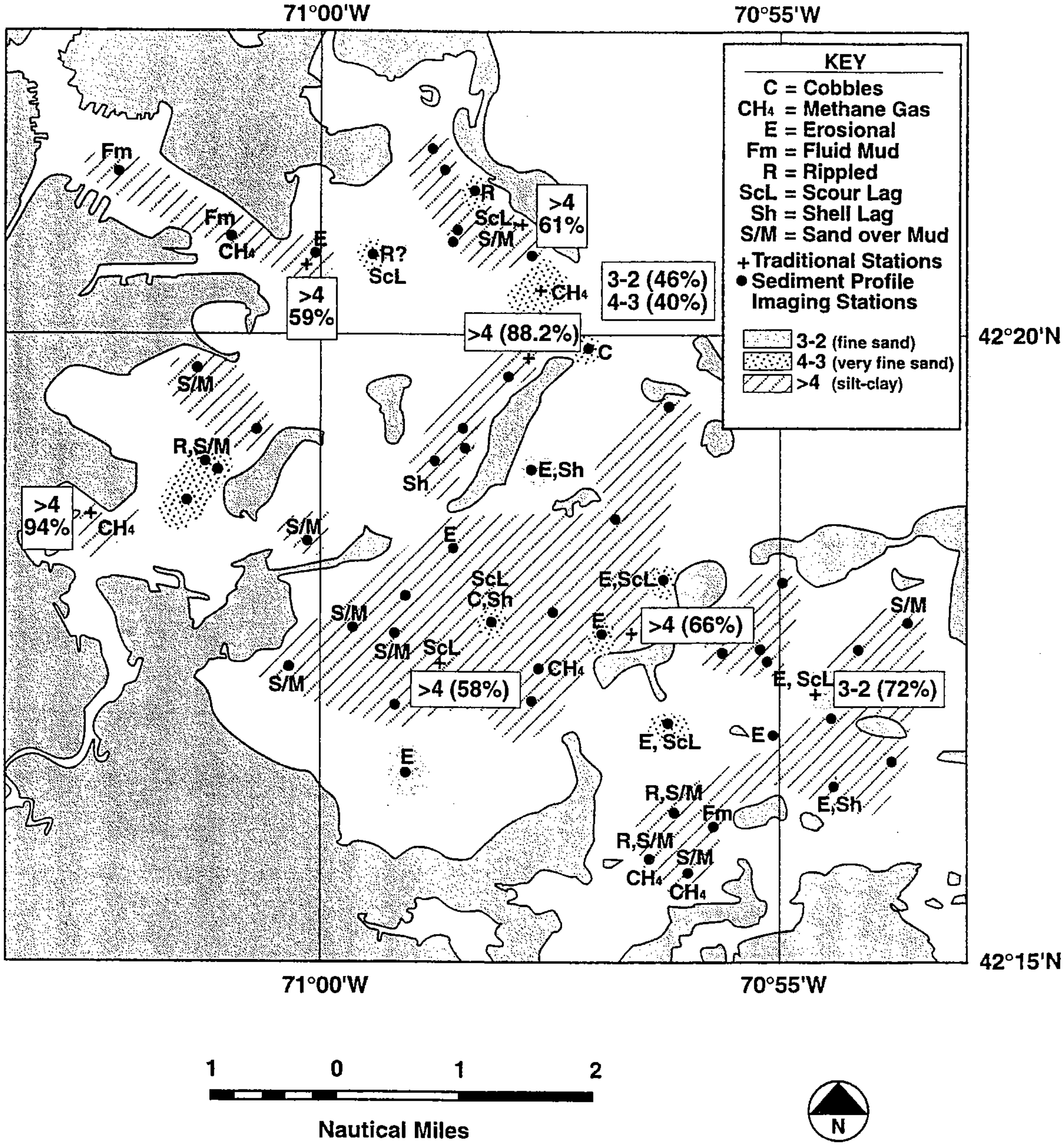


Figure 4. Distribution of major modal grain size and sedimentary features in Boston Harbor determined from sediment profile images taken in August 1995. Insets at the eight traditional stations show major modal grain size in August 1995 determined by laboratory grain-size analysis and percentage of that grain size in the sample for comparison (see also section 3.1.1).



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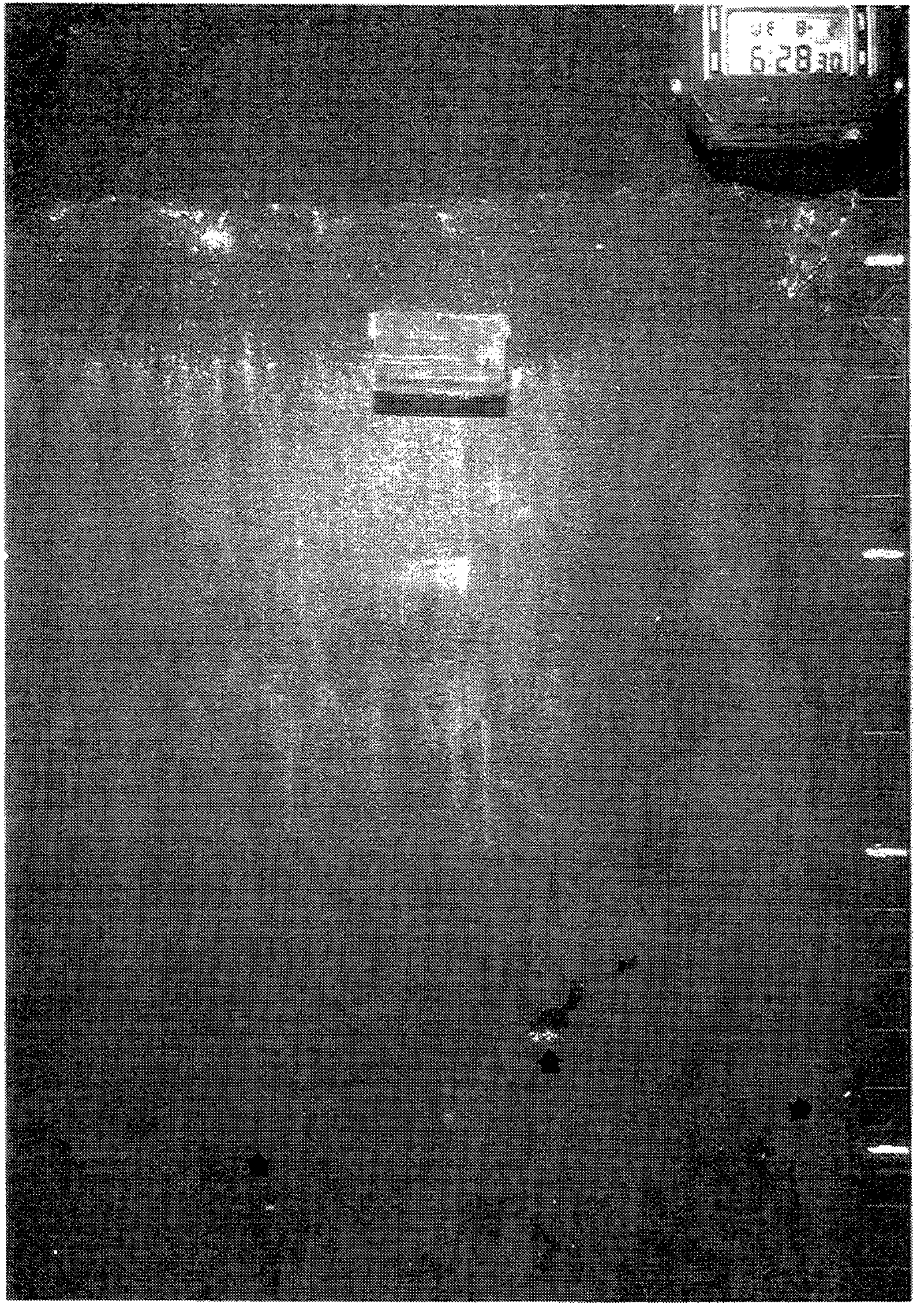


Figure 5. Station T4: organic enrichment (6% TOC), reducing sediment at the sediment-water interface (note darker sulfidic layer near the surface suggesting a recent input of higher TOC), successional sere status ranging from Stage I to Azoic (no apparent macrofaunal life), and methane gas at depth (arrows). The OSI at this station ranged from -3 to -8, representing the most degraded station as measured with this parameter within this data set. Scale: Image width is 15 cm.

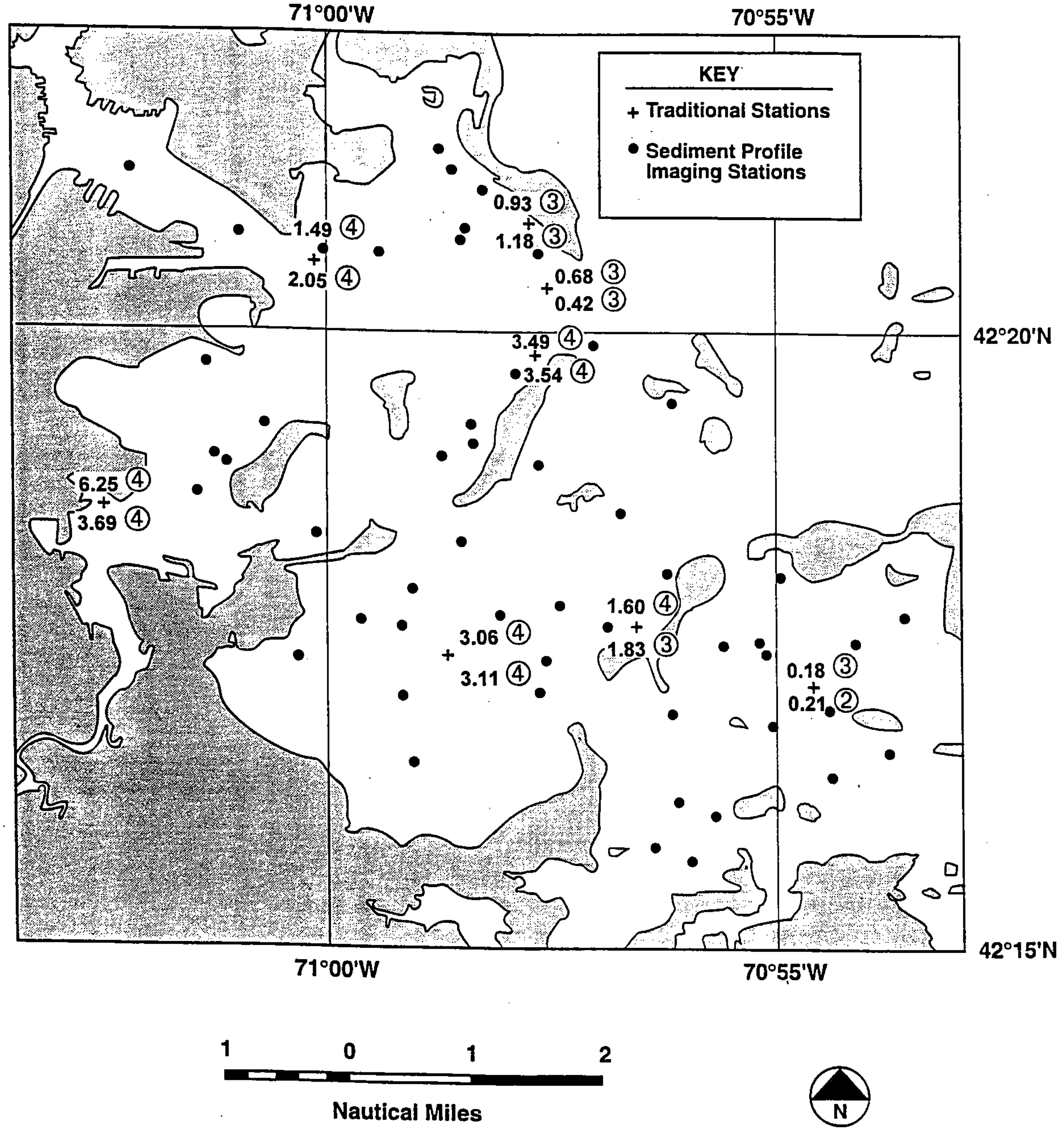


Figure 6. Total organic carbon (dry weight percent) and *Clostridium perfringens* spore counts (circled) [exponent (base 10) of colony forming units/g dry weight] at the eight Traditional stations. The upper pair of numbers at each station are April TOC and *Clostridium* values; the lower pair of numbers are August values.

3.1.2 Total Organic Carbon

Total organic carbon (TOC) content of greater Boston Harbor sediments ranged from less than 1% to over 6% with high temporal within-station variability at stations T2 and T4 (Figure 6, Appendix C2). Six stations exhibited an increase in TOC levels between April and August, although the changes at stations T7 and T8 were very small. This increase may in part be due to an increase in number of infaunal tubes and mucus-coated burrows in the summer. Two stations, however (T4 and T5a), showed a decrease in sediment TOC concentrations between April and August even though the infaunal densities, and supposedly the amount of tubes and burrows, increased dramatically during the same time. Two processes may explain this phenomenon, at least in part. Station T4 has been shown by Wallace *et al.* (1991) and Gallagher *et al.* (1992) to have a very high sedimentation rate of 4-6 cm/year, so that it seems possible that the sediments with the peak TOC concentration in April may have been overlain with sediment lower in TOC by August. It is also possible that bacterial breakdown of labile organic matter was enhanced by the increased benthic production in midsummer, resulting in lower TOC concentrations especially at station T5a.

3.1.3 Clostridium perfringens

Clostridium spore counts ranged from hundreds to tens of thousands of spores per gram dry weight (Figure 6, Appendix C3). Most muddy stations had concentrations ranging from thousands to tens of thousands of spores per gram dry weight; seasonal variability was generally low.

3.1.4 Mean Apparent RPD Depths

The spatial distribution of apparent RPD depth values shows that values of < 2.0 cm were most commonly encountered near shore, in the Inner Harbor, and near the entrance to Weymouth Channel in Hingham Bay (Figure 7). Most mean apparent RPD values fall within the 1.00 to 1.99 cm depth class (see frequency distribution inset on Figure 7). The greatest apparent RPD depths (≥ 4.0 cm) were located on the northwest side of Long Island and in outer Dorchester Bay. Most stations in central Boston Harbor, Dorchester, and Quincy Bays had apparent RPD depths ≥ 2 cm forming most of the second highest class peak in the frequency distribution. The area of relatively deep biological ventilation of sediments corresponds to the distribution of dense amphipod tube mats (see section on successional stages below). Figure 8 shows the relationship of the apparent RPD to these tube aggregations within a single SPI image. Typically, small-scale lateral variance in the RPD depth is high within the tube mat reflecting variance in tube packing and complex three-dimensional diffusional geometry (*sensu* Aller, 1982) associated with the respiratory ventilation of each amphipod tube.

3.1.5 Infaunal Successional Stages

The spatial distribution of successional stages within the Harbor complex shows Stage I or mixtures of Stage I and III taxa nearshore. The central area of the Harbor complex, dominated by Stage II seres (tubicolous amphipods), tends to be associated with silt-clay muds and with apparent RPD depths ≥ 2 cm (Figure 9). Within the tube mat area, three degrees of mat development were noted. Laterally persistent mats extended over most of the bottom and were imaged in two to three of the station image replicates. At the margin of the main amphipod facies, mats were patchy (tubes imaged at only one out of the three replicates). At stations T7 and R39, low densities of tubes indicated that the bottom was in a marginal stage of amphipod tube mat development. The dominance of Stage II amphipods within greater Boston Harbor apparently has a significant impact on trapping fine-grained sediment and determining the RPD depth distribution (i.e., via tube ventilation) as noted above.

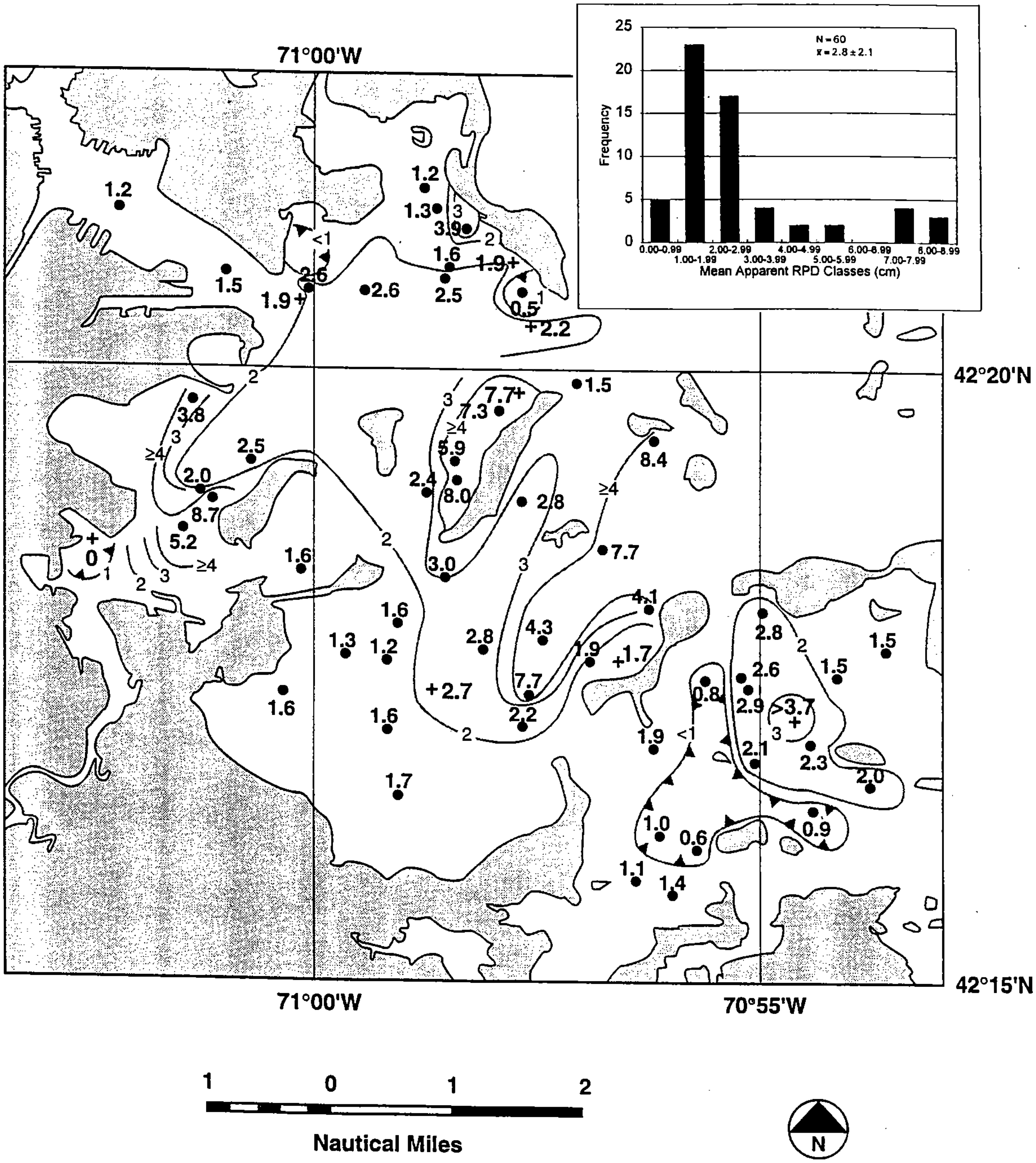


Figure 7. Mean depth of the apparent redox potential discontinuity (RPD) contoured on 1-cm intervals. Inset shows frequency distribution of apparent RPD depths for all stations.

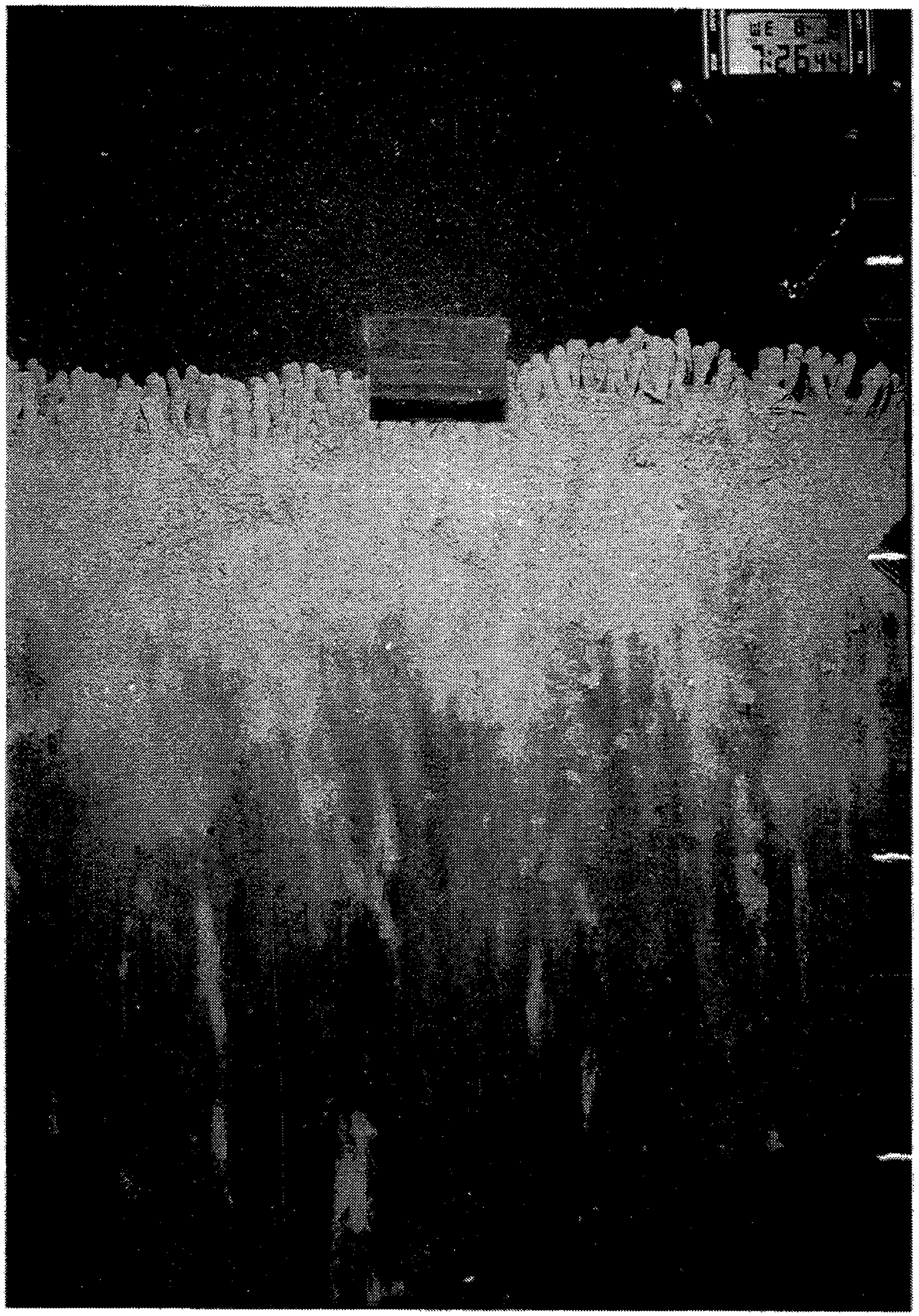


Figure 8. Station R14: small-scale variance in depth of apparent RPD associated with dense ampeliscid tubes. Irrigation of each tube by these small crustaceans is responsible for oxidation of metals and organic matter in and around tube. Scale: image width is 15 cm.

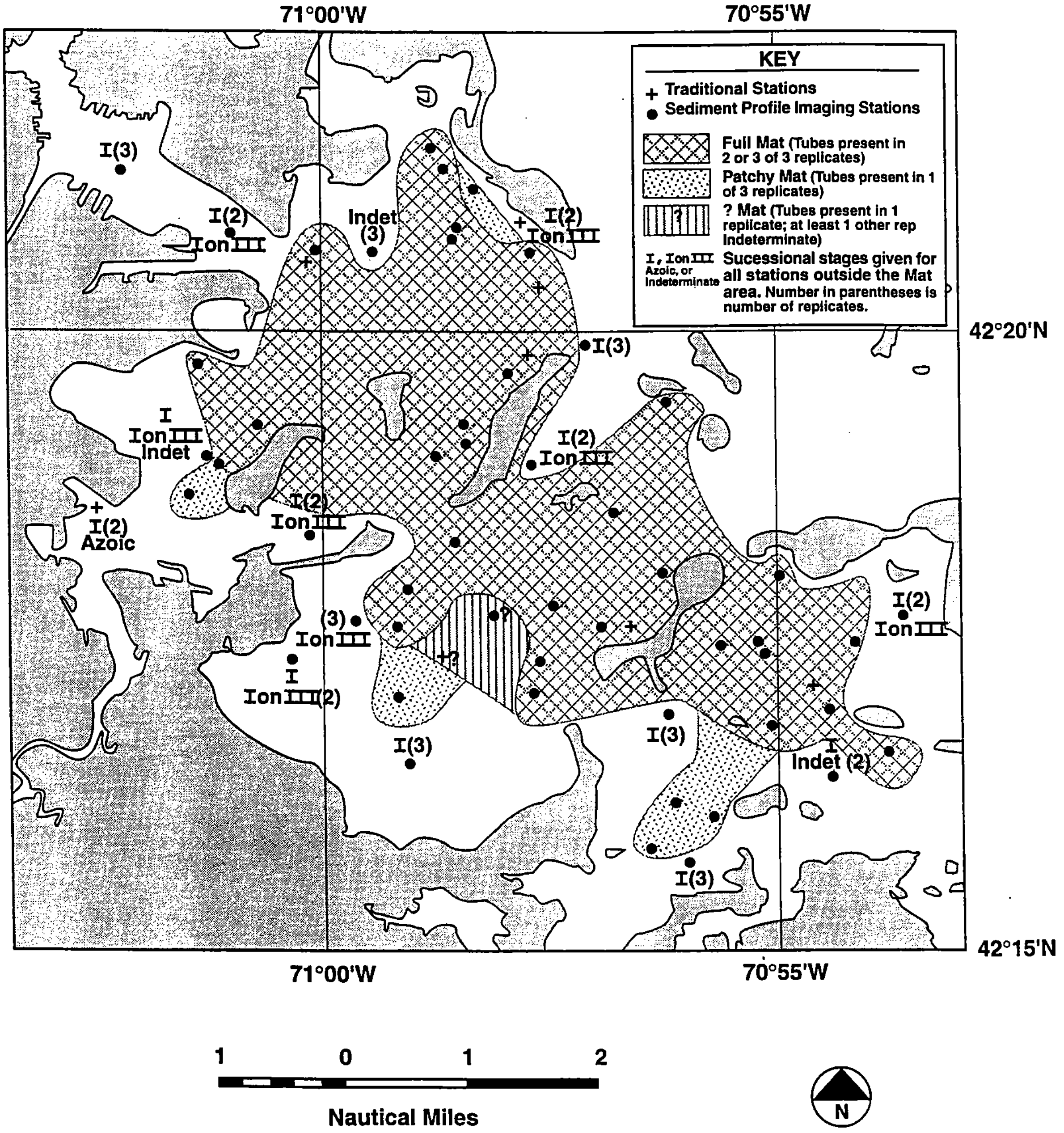


Figure 9. Distribution of amphipod tube mats in Boston Harbor determined from sediment profile images taken in August 1995.

3.1.6 Organism-Sediment Indices (OSIs)

The spatial distribution of OSI values shows that most of the values are ≥ +6 (Figure 10 and frequency distribution inset). A value of OSI +6, or greater, is chosen as an important diagnostic index (Rhoads and Germano, 1982) as this threshold value tends to separate relatively healthy benthic habitats (i.e., relatively deep apparent RPDs, high successional status, no imaged methane gas bubbles, and no sulfidic sediment at the surface of the bottom) from those bottoms showing ecological stress from organic enrichment and/or physical disturbance. The relatively low benthic habitat values (OSI < +6) are confined to nearshore areas in Dorchester Bay (note negative OSI at station T4), Quincy Bay, the mouth of Weymouth Channel in Hingham Bay, and Crow Point Flats in Hull Bay, the Inner Harbor, stations R2 and T1 near the Deer Island outfall, and station R6 near the Nut Island outfall. The frequency histogram (Figure 10, inset) shows a normal distribution with the major mode located within the 6.5-7.4 OSI class and 5 station values within the highest possible OSI class (10.5 to 11.0).

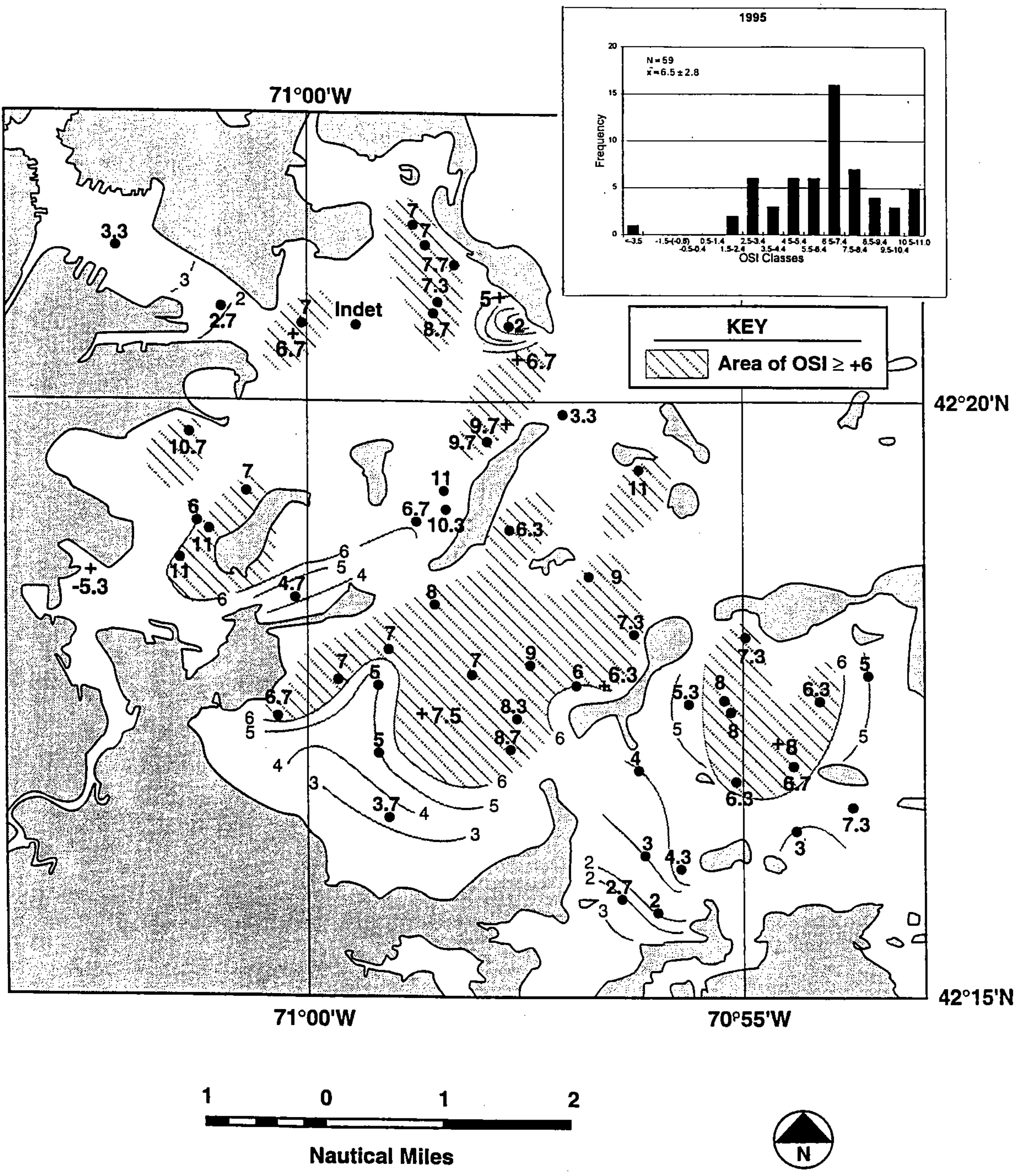


Figure 10. Mean organism-sediment index (OSI) for each Boston Harbor Station in August 1995. Contour lines are drawn on intervals of 1 (non-dimensional units). Inset shows frequency distribution of OSI values at all stations.

3.2 Benthic Infauna

3.2.1 Taxonomic Composition

The benthic infauna at the Boston Harbor Traditional stations was composed of 87 species in April and 116 species in August, with an increase in species richness of nearly 45% between spring and summer (Appendix D1). Annelids comprised the largest segment of the infauna with 42 species (54%) in the spring and 55 species (47%) in the summer; the second largest group was the arthropods with 26 species (30%) and 37 species (32%), respectively. Mollusks contributed 15 and 18 species (17 and 16%), respectively, to the benthic infauna, and the remaining fauna was composed of a small number of platyhelminths, nemerteans, sipunculans, phoronids, echinoderms, and tunicates. During both seasons, spionids were the most species-rich polychaete family, contributing roughly 25-30% to the polychaete fauna; amphipods were the predominant crustacean group in the spring with 20 of 26 crustacean species (77%) in the spring and 24 of 36 crustacean species (75%) in the summer.

3.2.2 Distribution and Density of Dominant Species

In the spring, nearly the entire sampling area in the Harbor was dominated by tubificid oligochaetes (*Tubificoides* nr. *pseudogaster* and *T. apectinatus*) that together occurred in densities of 15,000 to 26,000 individuals per square meter on Deer Island Flats (station T1), off Logan Airport (station T2), and off Peddocks Island (station T6); densities were more moderate in Quincy Bay (station T7) at about 6000 individuals m^{-2} and low (600 individuals m^{-2}) at station T5a in the deep anchorage area off Deer Island Flats where infaunal abundances as a whole were very low (Figure 11). Off Long Island (station T3), the amphipods *Ampelisca abdita* and *Leptocheirus pinguis* were the dominant species with a combined density of over 77,000 individuals m^{-2} (Figure 12). Station T4 in Dorchester Bay was dominated by the spionid polychaete *Streblospio benedicti* (about 3800 individuals m^{-2}) (Figure 13), and station T8 in Hingham Bay was dominated by the archiannelid *Polygordius* sp. A (also ca. 3800 individuals m^{-2}).

While the densities of the oligochaetes only varied roughly by a factor of ±2 between April and August, their position as dominant infaunal elements was all but eliminated in the summer when they were replaced by *Ampelisca abdita*, with the exception being station T1 on Deer Island Flats where they still ranked first with a density of about 28,000 individuals m^{-2}. Stations T2 and T5a in the northern Harbor and Stations T6 and T7 in the southern Harbor had the highest densities of *A. abdita*, ranging from nearly 42,000 to more than 92,000 individuals m^{-2}, with the most dramatic increase seen near Deer Island Flats at Station T5a from about 200 individuals m^{-2} in the spring to 92,000 individuals m^{-2} in the summer. Station T3 off Long Island remained an amphipod-dominated station, with the top ranking species being *Leptocheirus pinguis* and *A. abdita* no longer among the top ten dominants (Figures 11 and 12). By far the most abundant taxon at station T3, but excluded from statistical analyses, were juvenile *Corophium* (amphipods) that were too small to be identified to species (nearly 100,000 individuals m^{-2}). Station T4 in Dorchester Bay continued to be dominated by *Streblospio benedicti*, with the density increased more than tenfold since April to 55,000 individuals m^{-2}; a different spionid, *Spiophanes bombyx*, replaced *Polygordius* sp. A as top ranking species at station T8 in Hingham Bay (Figure 13).

Four other species, all of them polychaetes, ranked high among dominant species at several stations. Two of these polychaetes are spionids: *Streblospio benedicti*, the only species to occur in considerable densities at station T4 throughout the year, and *Polydora cornuta*. In the spring, densities of *S. benedicti* ranged from about 4000 individuals m^{-2} at stations T1, T2, and T4 in the northern Harbor to about 1000 individuals m^{-2} at station T7 in the southern Harbor, to less than 100 individuals m^{-2} at station T3 off Long Island (absent at stations T5a, T6, and T8). In the summer, densities had increased considerably at

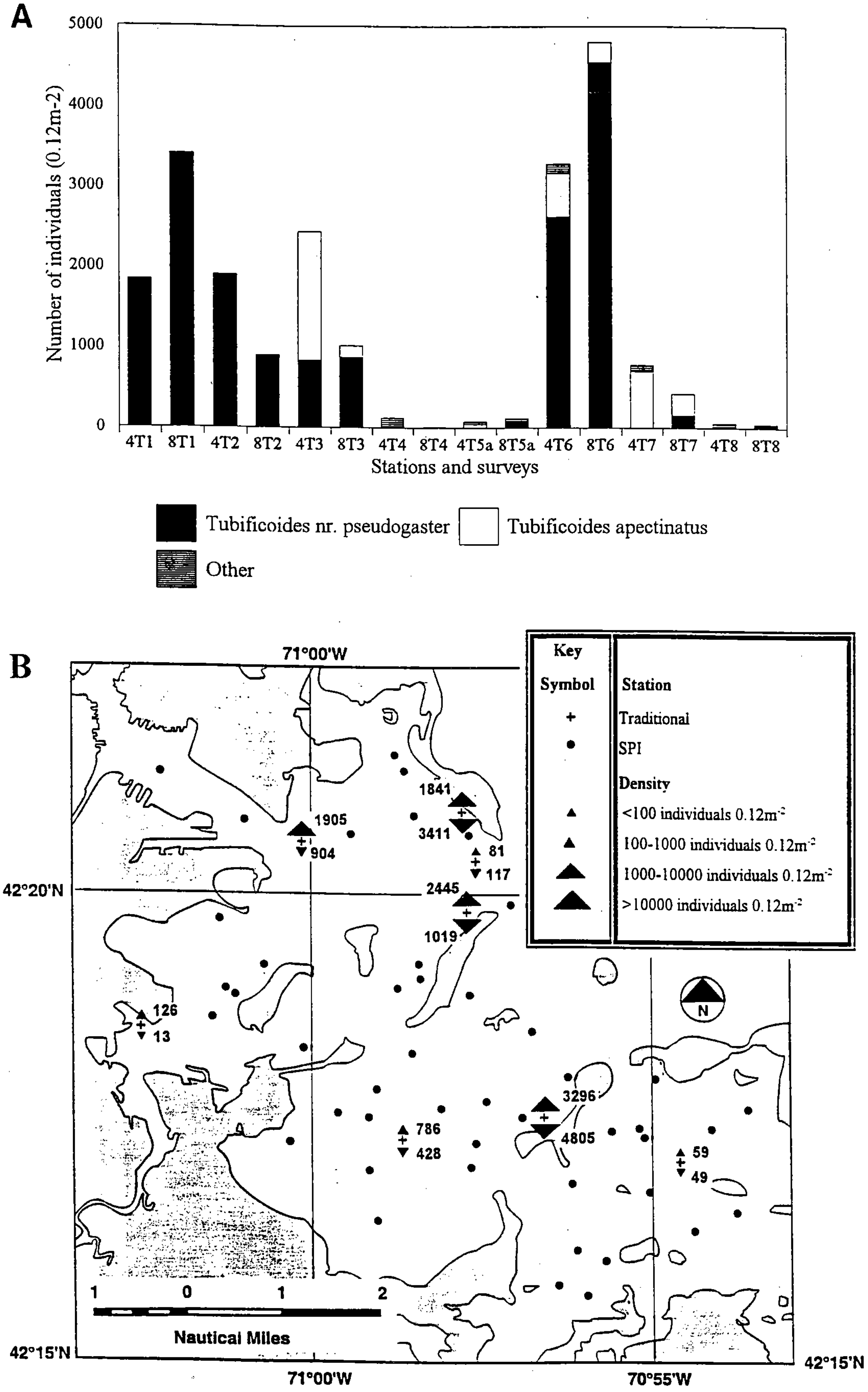


Figure 11. Oligochaete densities in Boston Harbor, April and August 1995. (A) densities by species, prefix of station names indicating month of sampling; (B) areal distribution, upper and lower triangles indicating April and August, respectively.

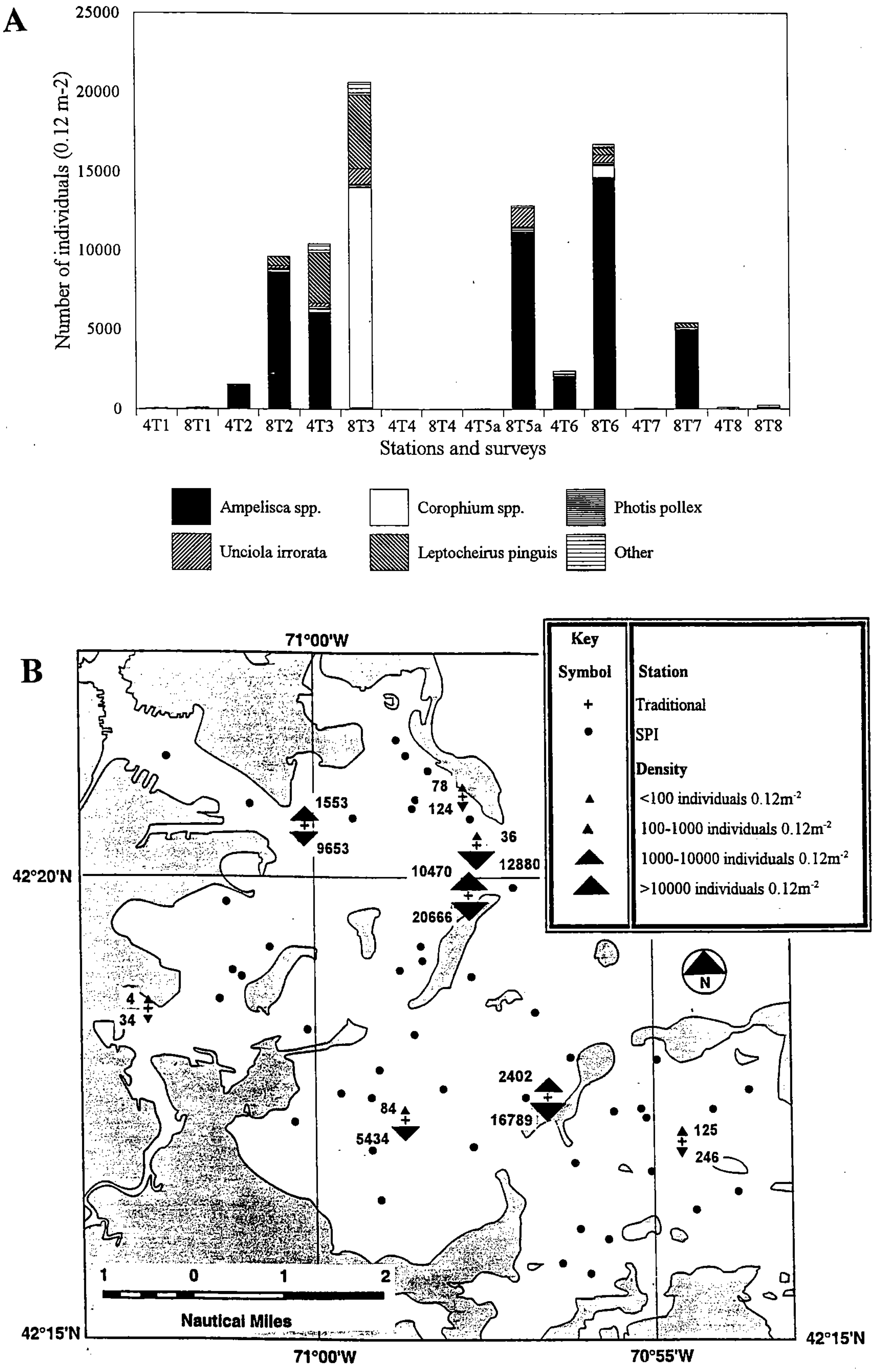


Figure 12. Amphipod densities in Boston Harbor, April and August 1995. (A) densities by species, prefix of station names indicating month of sampling; (B) areal distribution, upper and lower triangles indicating April and August, respectively.

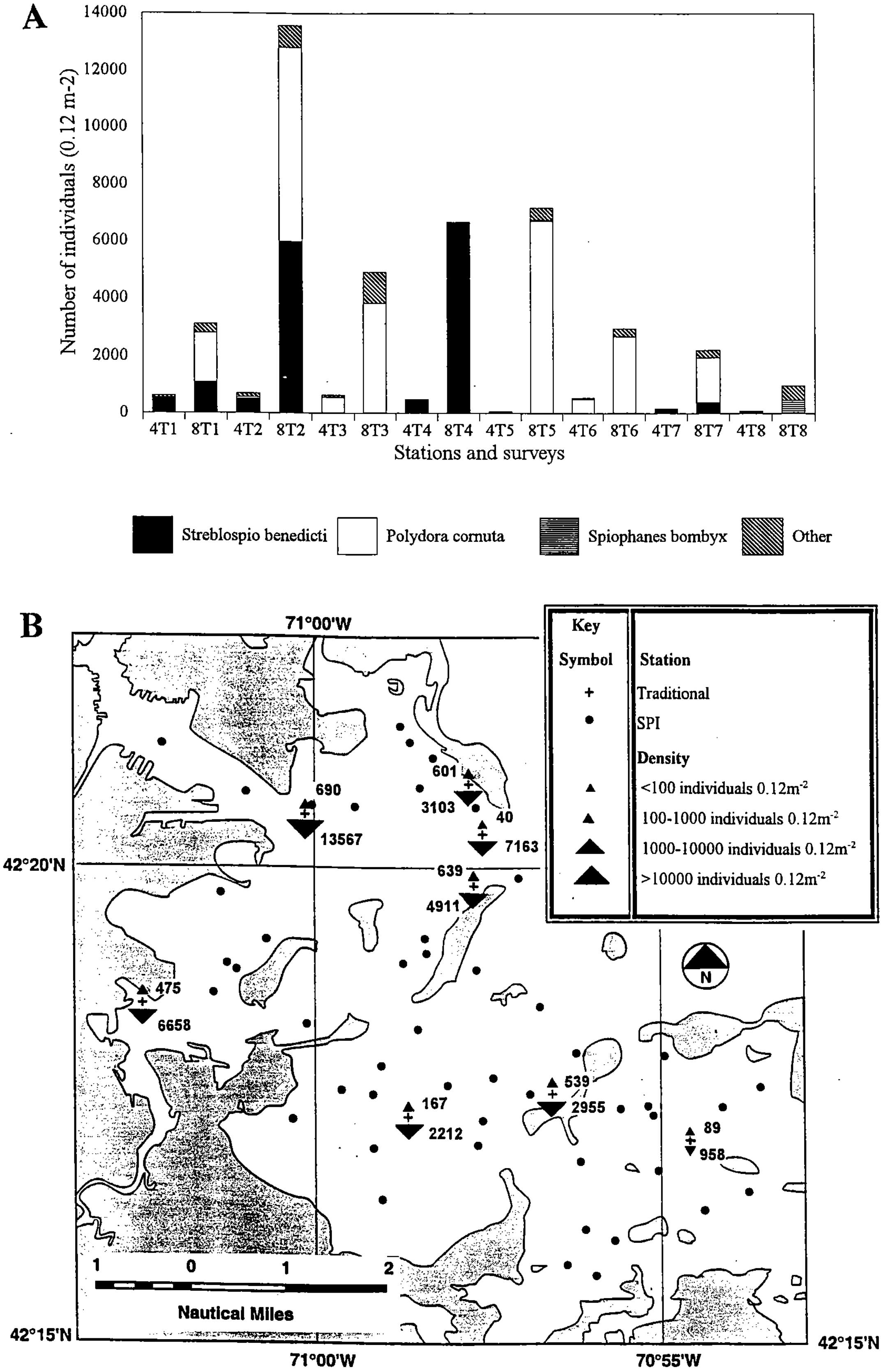


Figure 13. Spionid densities in Boston Harbor, April and August 1995. (A) densities by species, prefix of station names indicating month of sampling; (B) areal distribution, upper and lower triangles indicating April and August, respectively.

stations T2 and T4 (50,000 and 55,000 individuals m^{-2}, respectively), but only moderately at the other stations in the Harbor, with densities ranging from 17 to 9,000 individuals m^{-2} (stations T8 and T1, respectively). The populations of *P. cornuta* fluctuated much more between spring and summer, and in the summer *P. cornuta* was a widespread and common species, present at all stations and occurring in densities higher than 10,000 individuals m^{-2} at all but two stations (T4 in Dorchester Bay and T8 in Hingham Bay). The most dramatic increase was again seen at station T5a from 8 to 31,000 individuals m^{-2} between spring and summer.

Other numerically important species were the paraonid *Aricidea catherinae* and the cirratulid *Chaetozone vivipara*. *Aricidea catherinae* was found in densities between 5,000 and 11,000 individuals m^{-2} in the spring and 6,000 to 17,000 individuals m^{-2} in the summer at stations T3 in the northern Harbor and T6 and T7 in the southern Harbor. *Chaetozone vivipara* was not reported in the spring, but present in densities of 8,000 to 29,000 individuals m^{-2} at stations T1 and T2 (Deer Island Flats and Logan Airport, northern Harbor) in the summer. It is very likely that many of the juvenile cirratulids enumerated in April samples from these two stations belonged to this species which reproduces in the winter; juvenile cirratulids were the third most abundant taxon, but excluded from statistical analyses, at both stations in April. The only other station where they were as important numerically in the spring was station T5a where *C. vivipara* was found at moderate densities (400 individuals m^{-2}) in the summer.

The ten most abundant species at each station are shown in Table 1 for the spring and Table 2 for the summer (abundances of taxa not identified to species included). The most ubiquitous trend in the species composition of the benthic infauna is the decline of substantial oligochaete populations between spring and summer and the marked increase of amphipod populations, mainly of *Ampelisca abdita*. Station T1 was an exception with oligochaetes remaining the top dominant in the summer; at station T4, oligochaete populations declined, but no amphipod population was established; and at station T8, oligochaetes were a small part of the infauna during both seasons, while this was the only Harbor Traditional station where mollusks were consistently among the dominants.

Table 1. Ten most abundant species at Harbor Traditional stations, April 1995.

Rank	Species	Percent of Total Fauna	Density (Ind. 0.12m^{-2})
	Station T1 - Deer Island Flats		
1	*Tubificoides* nr. *pseudogaster* (oligochaete)	56.73	1837
2	*Streblospio benedicti* (polychaete)	16.00	518
3	*Tharyx acutus* (polychaete)	4.17	135
4	*Microphthalmus aberrans* (polychaete)	1.54	50
5	*Ampelisca abdita* (amphipod)	1.51	49
6	*Ilyanassa trivittata* (gastropod)	1.45	47
7	*Mytilus edulis* (bivalve)	1.30	42
8	*Nephtys caeca* (polychaete)	0.71	23
9	*Photis pollex* (amphipod)	0.62	20
10	*Polydora cornuta* (polychaete)	0.53	17
	Total - 10 Taxa	84.62	2740
	Remaining Fauna - 40 Taxa	15.38	498
	Total Fauna - 50 Taxa	100.00	3238
	Station T2 - Logan Airport		
1	*Tubificoides* nr. *pseudogaster* (oligochaete)	32.47	1896
2	*Ampelisca abdita* (amphipod)	24.12	1409
3	*Streblospio benedicti* (polychaete)	8.53	498
4	*Tharyx acutus* (polychaete)	6.28	367
5	*Mytilus edulis* (bivalve)	2.00	117
6	*Mediomastus californiensis* (polychaete)	1.35	79
7	*Dyopedos monacanthus* (amphipod)	1.10	64
8	*Photis pollex* (amphipod)	1.08	63
9	*Mya arenaria* (bivalve)	1.04	61
10	*Nephtys caeca* (polychaete)	0.82	48
	Total - 10 Taxa	78.75	4602
	Remaining Fauna - 35 Taxa	21.25	1238
	Total Fauna - 45 Taxa	100.00	5840

Table 1 (Continued)

Rank	Species	Percent of Total Fauna	Density (Ind. 0.12m^{-2})
Station T3 - Long Island			
1	*Ampelisca abdita* (amphipod)	36.62	6110
2	*Leptocheirus pinguis* (amphipod)	19.19	3202
3	*Tubificoides apectinatus* (oligochaete)	9.63	1607
4	*Aricidea catherinae* (polychaete)	7.72	1288
5	*Tubificoides* nr. *pseudogaster* (oligochaete)	5.02	838
6	*Mytilus edulis* (bivalve)	3.82	637
7	*Polydora cornuta* (polychaete)	3.23	539
8	*Tharyx acutus* (polychaete)	3.03	505
9	*Phoxocephalus holbolli* (amphipod)	1.98	330
10	*Unciola irrorata* (amphipod)	1.40	234
	Total - 10 Taxa	91.64	15290
	Remaining Fauna - 57 Taxa	8.36	1394
	Total Fauna - 67 Taxa	100.00	16684
Station T4 - Dorchester Bay			
1	*Streblospio benedicti* (polychaete)	55.57	459
2	Tubificidae sp. 3 (oligochaete)	15.01	124
3	*Capitella* spp. complex (polychaete)	14.65	121
4	Turbellaria (platyhelminth)	3.15	26
5	*Mytilus edulis* (bivalve)	1.33	11
6	*Polydora cornuta* (polychaete)	1.09	9
7	*Mya arenaria* (bivalve)	0.73	6
8	*Eteone longa* (polychaete)	0.37	3
9	*Nereis diversicolor* (polychaete)	0.28	2
10	*Ampelisca abdita* (amphipod)	0.28	2
	Total - 10 Taxa	92.37	763
	Remaining Fauna - 17 Taxa	7.63	63
	Total Fauna - 27 Taxa	100.00	826

Table 1 (Continued)

Rank	Species	Percent of Total Fauna	Density (Ind. 0.12m^{-2})
	Station T5a - off Deer Island Flats		
1	*Tubificoides apectinatus* (oligochaete)	8.39	48
2	*Ampelisca abdita* (amphipod)	4.90	28
3	*Tellina agilis* (bivalve)	4.90	28
4	*Tubificoides benedeni* (oligochaete)	4.20	24
5	*Nephtys caeca* (polychaete)	4.02	23
6	*Tharyx acutus* (polychaete)	3.85	22
7	*Mytilus edulis* (bivalve)	3.85	22
8	*Ilyanassa trivittata* (gastropod)	2.10	12
9	*Edotia triloba* (isopod)	2.10	12
10	*Aricidea catherinae* (polychaete)	1.57	9
	Total - 10 Taxa	39.86	228
	Remaining Fauna - 23 Taxa	60.14	344
	Total Fauna - 33 Taxa	100.00	572
	Station T6 - Peddocks Island		
1	*Tubificoides* nr. *pseudogaster* (oligochaete)	35.31	2628
2	*Ampelisca abdita* (amphipod)	27.14	2020
3	*Aricidea catherinae* (polychaete)	7.63	568
4	*Tubificoides apectinatus* (oligochaete)	7.38	549
5	*Polydora cornuta* (polychaete)	6.26	466
6	*Mytilus edulis* (bivalve)	2.26	168
7	*Dyopedos monacanthus* (amphipod)	1.72	128
8	*Photis pollex* (amphipod)	1.60	119
9	*Cirriformia grandis* (polychaete)	1.53	114
10	*Phoxocephalus holbolli* (amphipod)	0.08	58
	Total - 10 Taxa	92.96	6818
	Remaining Fauna - 50 Taxa	7.04	624
	Total Fauna - 60 Taxa	100.00	7442

Table 1 (Continued)

Rank	Species	Percent of Total Fauna	Density (Ind. 0.12m^{-2})
	Station T7 - Quincy Bay		
1	*Tubificoides apectinatus* (oligochaete)	36.94	707
2	*Aricidea catherinae* (polychaete)	31.14	596
3	*Streblospio benedicti* (polychaete)	6.39	122
4	*Ampelisca abdita* (amphipod)	3.50	67
5	*Nephtys cornuta* (polychaete)	2.51	48
6	*Scoletoma hebes* (polychaete)	2.09	40
7	*Tharyx acutus* (polychaete)	1.67	32
8	*Polydora cornuta* (polychaete)	0.94	18
9	*Microphthalmus aberrans* (polychaete)	0.73	14
10	*Mediomastus californiensis* (polychaete)	0.73	14
	Total - 10 Taxa	86.62	1658
	Remaining Fauna - 26 Taxa	13.38	256
	Total Fauna - 36 Taxa	100.00	1914
	Station T8 - Hingham Bay		
1	*Polygordius* sp. A (archiannelid)	23.50	457
2	*Ilyanassa trivittata* (gastropod)	12.03	234
3	*Nucula delphinodonta* (bivalve)	11.83	230
4	*Aricidea catherinae* (polychaete)	5.91	115
5	*Exogone hebes* (polychaete)	4.78	93
6	*Ischyrocerus anguipes* (amphipod)	4.27	83
7	*Spiophanes bombyx* (polychaete)	3.55	69
8	*Mytilus edulis* (bivalve)	2.21	43
9	*Tellina agilis* (bivalve)	1.90	37
10	*Tharyx acutus* (polychaete)	1.49	29
	Total - 10 Taxa	71.47	1390
	Remaining Fauna - 52 Taxa	28.53	555
	Total Fauna - 62 Taxa	100.00	1945

Table 2. Ten most abundant species at Harbor Traditional stations, August 1995.

Rank	Species	Percent of Total Fauna	Density (Ind. 0.12m^{-2})
	Station T1 - Deer Island Flats		
1	*Tubificoides* nr. *pseudogaster* (oligochaete)	34.73	3402
2	*Polydora cornuta* (polychaete)	17.33	1697
3	*Streblospio benedicti* (polychaete)	11.03	1080
4	*Chaetozone vivipara* (polychaete)	10.09	988
5	*Clymenella torquata* (polychaete)	4.57	448
6	*Microphthalmus aberrans* (polychaete)	2.41	236
7	*Balanus crenatus* (cirripede)	1.74	170
8	*Capitella capitata* complex (polychaete)	1.44	141
9	*Ampelisca abdita* (amphipod)	0.99	97
10	*Spio thulini* (polychaete)	0.83	81
	Total - 10 Taxa	85.16	8340
	Remaining Fauna - 68 Taxa	14.84	1455
	Total Fauna - 78 Taxa	100.00	9795
	Station T2 - Logan Airport		
1	*Ampelisca abdita* (amphipod)	29.19	8673
2	*Polydora cornuta* (polychaete)	22.98	6827
3	*Streblospio benedicti* (polychaete)	20.14	5983
4	*Chaetozone vivipara* (polychaete)	11.90	3536
5	*Tubificoides* nr. *pseudogaster* (oligochaete)	3.04	904
6	*Leptocheirus pinguis* (amphipod)	1.88	559
7	*Tharyx acutus* (polychaete)	1.30	387
8	*Phyllodoce mucosa* (polychaete)	0.75	223
9	*Unciola irrorata* (amphipod)	0.58	171
10	*Asabellides oculata* (polychaete)	0.38	114
	Total - 10 Taxa	92.14	27377
	Remaining Fauna - 61 Taxa	7.86	2337
	Total Fauna - 71 Taxa	100.00	29714

Table 2 (Continued)

	Station T3 - Long Island		
Rank	**Species**	**Percent of Total Fauna**	**Density (Ind. 0.12m^{-2})**
--	*Corophium* spp. (amphipod)*	42.29	11981
1	*Leptocheirus pinguis* (amphipod)	15.96	4523
2	*Polydora cornuta* (polychaete)	13.44	3809
3	*Corophium bonnellii* (amphipod)	6.17	1747
4	*Unciola irrorata* (amphipod)	3.48	987
5	*Tubificoides* nr. *pseudogaster* (oligochaete)	3.11	880
6	*Aricidea catherinae* (polychaete)	2.45	693
7	*Phoxocephalus holbolli* (amphipod)	1.90	538
8	*Photis pollex* (amphipod)	0.81	230
9	*Orchomenella minuta* (amphipod)	0.64	180
10	*Corophium crassicorne* (amphipod)	0.61	172
	Total - 10 Taxa	48.56	13759
	Remaining Fauna - 64 Taxa	51.44	14573
	Total Fauna - 74 Taxa	100.00	28332
	Station T4 - Dorchester Bay		
1	*Streblospio benedicti* (polychaete)	97.22	6639
2	*Ampelisca abdita* (amphipod)	0.44	30
3	*Nephtys cornuta* (polychaete)	0.29	20
4	*Tubificoides* nr. *pseudogaster* (oligochaete)	0.19	13
5	*Capitella capitata* complex (polychaete)	0.13	9
6	*Scolelepis bousfieldi* (polychaete)	0.12	8
7	*Mya arenaria* (bivalve)	0.09	6
8	*Chaetozone vivipara* (polychaete)	0.07	5
9	*Aricidea catherinae* (polychaete)	0.06	4
10	*Paranaitis speciosa* (polychaete)	0.04	3
	Total - 10 Taxa	98.65	6737
	Remaining Fauna - 18 Taxa	1.35	92
	Total Fauna - 28 Taxa	100.00	6829

*not included in statistics

Table 2 (Continued)

Rank	Species	Percent of Total Fauna	Density (Ind. 0.12m^{-2})
Station T5a - off Deer Island Flats			
1	*Ampelisca abdita* (amphipod)	58.20	11110
2	*Polydora cornuta* (polychaete)	19.34	3692
3	*Edotia triloba* (isopod)	6.80	1298
4	*Unciola irrorata* (amphipod)	6.40	1222
5	*Photis pollex* (amphipod)	1.97	377
6	*Nephtys caeca* (polychaete)	0.52	100
7	*Phyllodoce mucosa* (polychaete)	0.51	98
8	*Tubificoides* nr. *pseudogaster* (oligochaete)	0.50	95
9	*Tellina agilis* (bivalve)	0.44	84
10	*Orchomenella minuta* (amphipod)	0.30	58
	Total - 10 Taxa	94.98	18134
	Remaining Fauna - 54 Taxa	5.02	956
	Total Fauna - 64 Taxa	100.00	19090
Station T6 - Peddocks Island			
1	*Ampelisca abdita* (amphipod)	26.41	7278
--	*Ampelisca* spp. (amphipod)*	26.08	7188
2	*Tubificoides* nr. *pseudogaster* (oligochaete)	16.53	4556
3	*Polydora cornuta* (polychaete)	9.69	2671
4	*Aricidea catherinae* (polychaete)	7.05	1944
5	*Unciola irrorata* (amphipod)	1.80	496
6	*Leptocheirus pinguis* (amphipod)	1.47	405
7	*Phyllodoce mucosa* (polychaete)	1.04	286
8	*Tubificoides apectinatus* (oligochaete)	0.90	249
9	*Phoxocephalus holbolli* (amphipod)	0.84	231
10	*Photis pollex* (amphipod)	0.80	220
	Total - 10 Taxa	66.53	18336
	Remaining Fauna - 61 Taxa	33.47	9234
	Total Fauna - 71 Taxa	100.00	27561

Table 2 (Continued)

Rank	Species	Percent of Total Fauna	Density (Ind. 0.12m^{-2})
	Station T7 - Quincy Bay		
1	*Ampelisca abdita* (amphipod)	44.91	5027
2	*Aricidea catherinae* (polychaete)	18.23	2041
3	*Polydora cornuta* (polychaete)	13.94	1560
4	*Streblospio benedicti* (polychaete)	3.49	391
5	*Tharyx acutus* (polychaete)	2.92	327
6	*Tubificoides apectinatus* (oligochaete)	2.40	269
7	*Leptocheirus pinguis* (amphipod)	2.33	261
8	*Tubificoides* nr. *pseudogaster* (oligochaete)	1.42	159
9	*Nephtys cornuta* (polychaete)	0.78	87
10	*Unciola irrorata* (amphipod)	0.48	54
	Total - 10 Taxa	90.91	10176
	Remaining Fauna - 54 Taxa	9.09	1018
	Total Fauna - 64 Taxa	100.00	11194
	Station T8 - Hingham Bay		
1	*Spiophanes bombyx* (polychaete)	19.31	461
2	*Polygordius* sp. A (polychaete)	15.25	364
3	*Aricidea catherinae* (polychaete)	11.14	266
4	*Exogone hebes* (polychaete)	8.34	199
5	*Ilyanassa trivittata* (gastropod)	7.88	188
6	*Nucula delphinodonta* (bivalve)	4.73	113
7	*Unciola irrorata* (amphipod)	4.48	107
8	*Tellina agilis* (bivalve)	4.11	98
9	*Phoxocephalus holbolli* (amphipod)	2.39	57
10	*Ampelisca vadorum* (amphipod)	1.68	40
	Total - 10 Taxa	79.30	1893
	Remaining Fauna - 70 Taxa	20.70	494
	Total Fauna - 80 Taxa	100.00	2387

3.2.3 Species Richness and Diversity

The number of species identified at each station varied from 19 (T4) to 52 (T6) in April and from 22 (T4) to 63 (T1) in August (Tables 3 and 4, taxa not identified to species excluded). At stations with relatively few species in the spring, species richness increased by a factor of approximately 1.5 to 2 between spring and summer, so that generally all stations were similar in the summer, with the exception of Station T4 which was consistently low in species richness regardless of season.

The number of individuals, and consequently the diversity indices, varied much more between seasons than the species richness. The most drastic change between the two sampling events was seen at station T5a on Deer Island Flats, where abundances were 267 in the spring and over 18,000 in the summer (3 replicates pooled), mostly due to the establishment of an *Ampelisca abdita*-mat in the summer. The number of expected species per 100 individuals decreased from nearly 18 to about 9 (Figure 14, Tables 3 and 4). The Shannon-Wiener and evenness indices show a comparable dramatic decrease; while station T5a had the highest *H'* in the Harbor in the spring, it had the second lowest in the summer. Station T4 in Dorchester Bay also had a considerable increase in infaunal abundance, with the number of individuals from 3 replicate samples increasing from 778 in April to 6760 in August. As the number of species stayed nearly the same, the diversity indices fell from already low levels in the spring to very low in the summer; the number of expected species per 100 individuals was about 8 in April and little more than 2 in August, and *H'* and *J'* fell from 1.32 to 0.13 and 0.46 to 0.04, respectively.

Station T1, also on Deer Island Flats, showed an increase of both number of species and number of individuals, and the diversity was slightly higher in the summer than in the spring (species per 100 individuals: 11.5 in April, nearly 15 in August; *H'*: 1.37 in April, 2.08 in August). Stations T2, T3, T6, T7, and T8 changed little in terms of diversity because any increases in species richness were balanced by increases in abundance. The diversity indices calculated for those stations were medium high during both seasons, with the exception of station T8 that ranked highest in April and second highest (behind T5a) in August.

3.2.4 Community Analysis

The structure of the benthic communities in the Harbor in April and August was analyzed with the Bray-Curtis clustering technique. The resulting dendrograms (replicates pooled) are shown in Figure 15.

The April samples join in two clusters and three single stations (Figure 15A), and the August samples join in one cluster and four single stations (Figure 15B), probably in large part due to changing densities of the most abundant species. From the April samples, stations T1, T2, and T6 form one cluster, joining at a similarity level of 0.52, most likely because the top dominant at these stations was the oligochaete *Tubificoides* nr. *pseudogaster*. The substratum was mostly very fine sand (mean phi 3.98), and TOC levels were low (mean 1.3%). The second cluster consists of stations T5a and T8, with the similarity level being low (0.19); these two stations had different top dominants, but shared five of the ten most abundant species, including some mollusk species that were not among dominants at other stations, such as *Tellina agilis* and *Nucula delphinodonta*. The sediment at those two stations was mostly fine sand (mean phi 2.89), and the organic carbon concentration was very low (mean 0.35%). The single stations T3, T4, and T7 are separate from the two clusters probably because the top dominants at those stations were different from those at the other stations (*Ampelisca abdita* at T3, *Streblospio benedicti* at T4, and *Tubificoides apectinatus* at T7). The sediment was silt/clay at stations T3 and T4 (mean phi 6.89 and 6.80, respectively), with medium to high organic carbon inventories (3.5% at T3 and 6.3% at T4). Station T7 had mostly fine sand with moderate TOC concentrations (mean phi 3.34, 3.1% TOC).

Table 3. Community parameters, Boston Harbor, April 1995

Station	# spp (0.12m²)	# indiv. (0.12 m²)	spp./ 50 ind.	spp./100 ind.	spp./500 ind.	*H′*	*J′*
T1	35	2862	8.07	11.50	21.74	1.37	0.38
T2	34	4801	8.96	11.93	20.20	1.77	0.50
T3	57	16,136	10.86	13.69	22.55	2.06	0.52
T4	19	778	6.42	8.42	15.20	1.32	0.46
T5a	23	267	14.94	17.98	--	2.62	0.85
T6	52	7187	10.03	13.27	23.71	1.94	0.49
T7	28	1721	8.72	11.69	20.34	1.65	0.50
T8	48	1571	13.79	18.37	32.83	2.44	0.63

Table 4. Community parameters, Boston Harbor, August 1995

Station	# spp (0.12m²)	# indiv. (0.12 m²)	spp./ 50 ind.	spp./100 ind.	spp./500 ind.	*H′*	*J′*
T1	63	9019	10.97	14.91	27.06	2.08	0.50
T2	53	28,019	7.81	10.02	17.60	1.79	0.45
T3	56	14,665	10.95	14.34	25.82	2.12	0.53
T4	22	6760	1.85	2.63	7.06	0.13	0.04
T5a	52	18,544	6.70	8.82	17.95	1.35	0.34
T6	54	19,257	9.44	12.67	22.58	1.90	0.48
T7	50	10,416	8.33	10.74	18.99	1.67	0.42
T8	61	2220	15.29	20.55	38.28	2.67	0.65

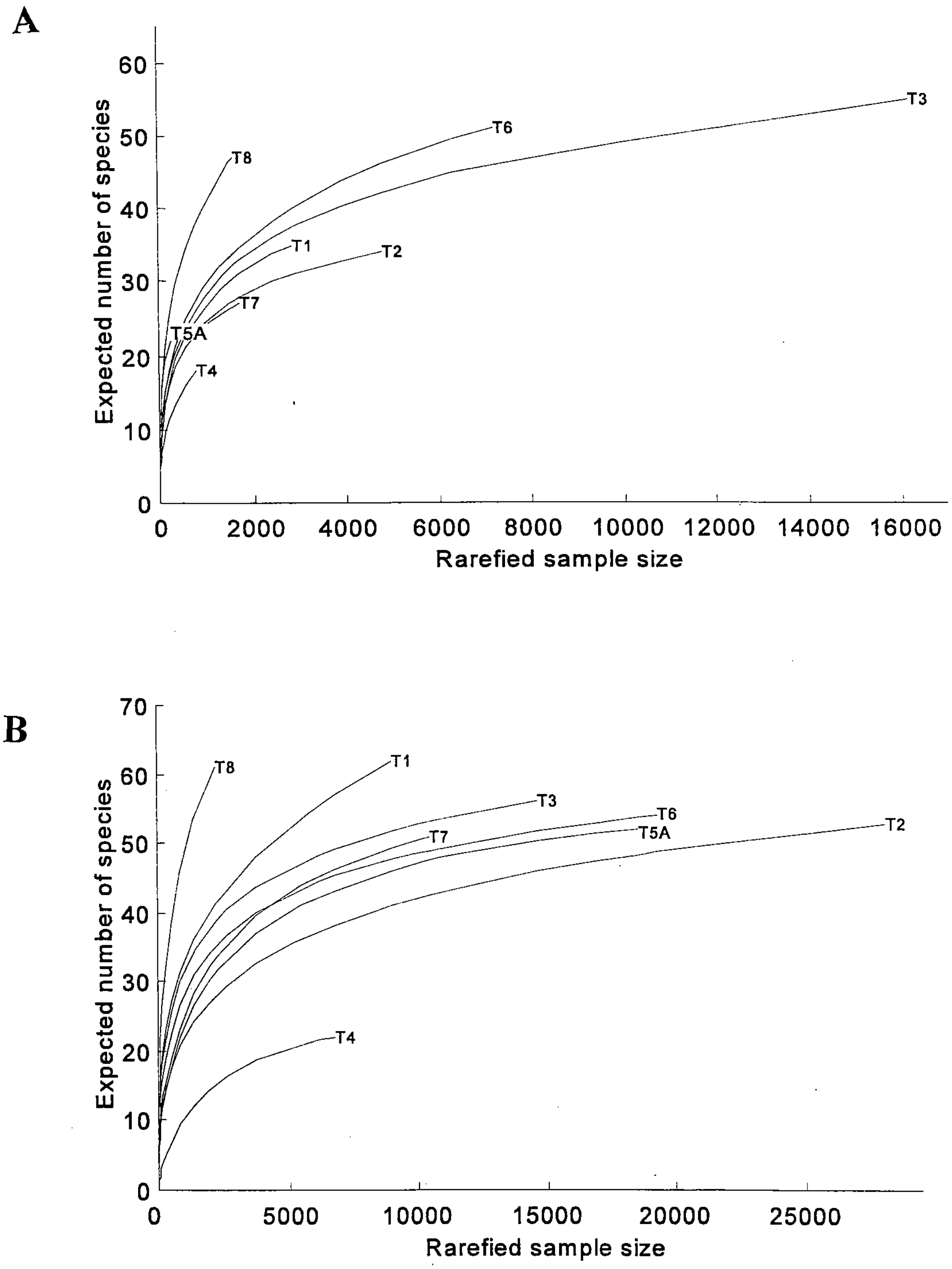


Figure 14. Rarefaction curves for samples taken in (A) April and (B) August 1995 at Harbor Traditional stations.

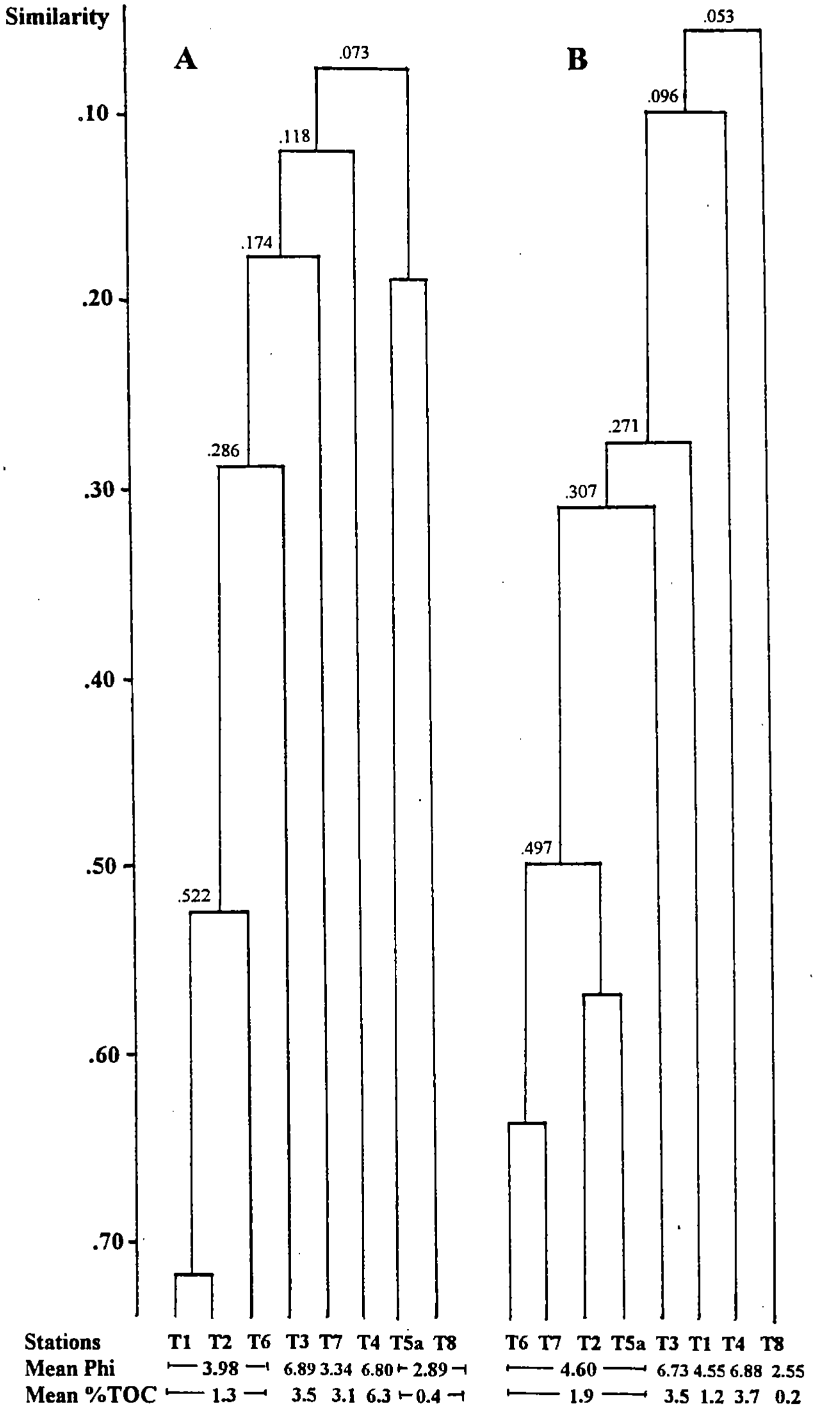


Figure 15. Similarity among Traditional stations measured with Bray-Curtis similarity measure and group average sorting. (A) April 1995, (B) August 1995.

In August, the dominant species had changed at almost all stations, and the clustering pattern changed accordingly. Station T1, which clustered with T2 in April, no longer joined with that station in August because the dominant species at T1 was still *Tubificoides* nr. *pseudogaster*, while at station T2 the oligochaetes had been replaced by *Ampelisca abdita*. Because of the very high densities of that amphipod and also the spionid polychaete *Polydora cornuta*, T2 grouped with T5a, T6, and T7 to form the only cluster in the August dendrogram. The sedimentary environment at all of these stations was mostly silt/clay (mean phi 4.60), and the organic carbon concentrations were moderately high (mean 1.87%). Stations T1, T3, T4, and T8 were all single stations in August. T3 was dominated by the amphipod *Leptocheirus pinguis* and *P. cornuta*, and T4 was still dominated by *Streblospio benedicti*, as it had been in April. The sediment at these two single stations was silt/clay (mean phi 6.73 at T3 and 6.88 at T4) with high TOC concentrations (3.45% at T3 and 3.69% at T4). Station T8 was the coarsest station (mean phi 2.55) with very low TOC (0.21%), dominated by *Spiophanes bombyx*, a spionid typical for sand, and the "archiannelid" *Polygordius* sp. A, also a typical sand-dweller.

Similarity analyses with replicates separate showed similar results, with some single replicates grouping with other stations because of within-station variability in abundances of top dominant species; in two cases, one of three replicates was outside an *Ampelisca* bed, while the other two were inside (T6 in April, T5a in August).

4.0 DISCUSSION

4.1 Spatial/Temporal Patterns in Organism/Sediment Relationships

Several changes in benthic conditions have been noted following cessation of sludge discharge in December, 1991 (Kropp and Diaz, 1995). A comparison of textural changes in bottom sediment over the period 1992-1993 and 1993-1994 shows that many stations have become finer in texture (Tables 5 and 6 of Kropp and Diaz, 1995) and that the increase in the proportion of silt-clay to fine sand is further associated with the development of dense mats of tubicolous amphipods (Tables C-2 and C-3 of Kropp and Diaz, 1995). The progressive spread of Stage II ampeliscids has continued through 1995 (Figures 16 to 19). The development of dense tube mats of ampeliscid polychaetes changes boundary layer flow leading to a phenomenon called skimming flow (*sensu* Morris, 1955 and Eckman *et al.*, 1981) where points of flow streamline detachment and reattachment are the tops of tubes rather than the sediment-water interface. One of the adaptive attributes of dense tube aggregations may be to promote the sedimentation of organic particulates (i.e., food) while also ensuring physical habitat stability. For example, immediately following the upgrading of the West Haven Connecticut sewage treatment plant adjacent to New Haven Harbor, dense populations of ampeliscids developed on the harbor bottom near the outfall and silt-clay sediments were accreted into the mat at rates of ca. 10 cm/month (Rhoads, unpublished data).

A bivariate plot of tube diameter (x-axis) versus tube packing (y-axis) shows that the phenomenon of skimming flow only operates efficiently at high densities of relatively large tubes (Figure 20). At high tube densities, suspended particles falling into the mat tend to be efficiently trapped and not experience resuspension by boundary layer turbulence.

When the ampeliscid population ages, and mortality takes place, the tubes break down and holes appear within the mat (Figure 19). As tube packing falls below the critical size/density curve for stabilization, the decaying tubes and associated fine-grained sediment may be washed out by turbulence associated with increased boundary roughness at the edges of the decaying tube mat. This phenomenon can result in massive redistributions of organic mud without a change in kinetic energy associated with the average flow field. Occasionally, decaying tube mats are recolonized by other amphipods, slowing down the release of fine-grained sediments. Station T3 was dominated by *Ampelisca* in the spring of 1995, but by the summer, the population had broken down, and instead other amphipods were present in high abundances, namely *Leptocheirus pinguis* and *Corophium* spp. Sediment profile images clearly show large specimens of *Leptocheirus* in pockets in the sediment. The tubes of *Corophium* are too small to clearly discriminate in profile images. A very similar pattern of shifting dominance at station T3 was observed by Kropp and Diaz (1994) in 1993.

As noted by Kropp and Diaz (1995), the increase in *Ampelisca* populations in the harbor is consistent with a general improvement in benthic habitat quality and their appearance would be predicted by prevailing successional paradigms (Pearson and Rosenberg, 1978; Rhoads *et al.*, 1978). Kropp and Diaz (1995) caution that explosive population growth of early successional species is common and may not necessarily be associated with sludge abatement. This assertion is supported by records of rare and anomalous dense sets of ampeliscids in pristine habitats (e.g., Barnstable Harbor, MA) (Mills, 1969) on the one hand and on the other the presence of dense amphipod populations near Deer Island Flats and Governor's Island Flats in 1979 (Blake *et al.*, 1989) when pollution in Boston Harbor was at its highest

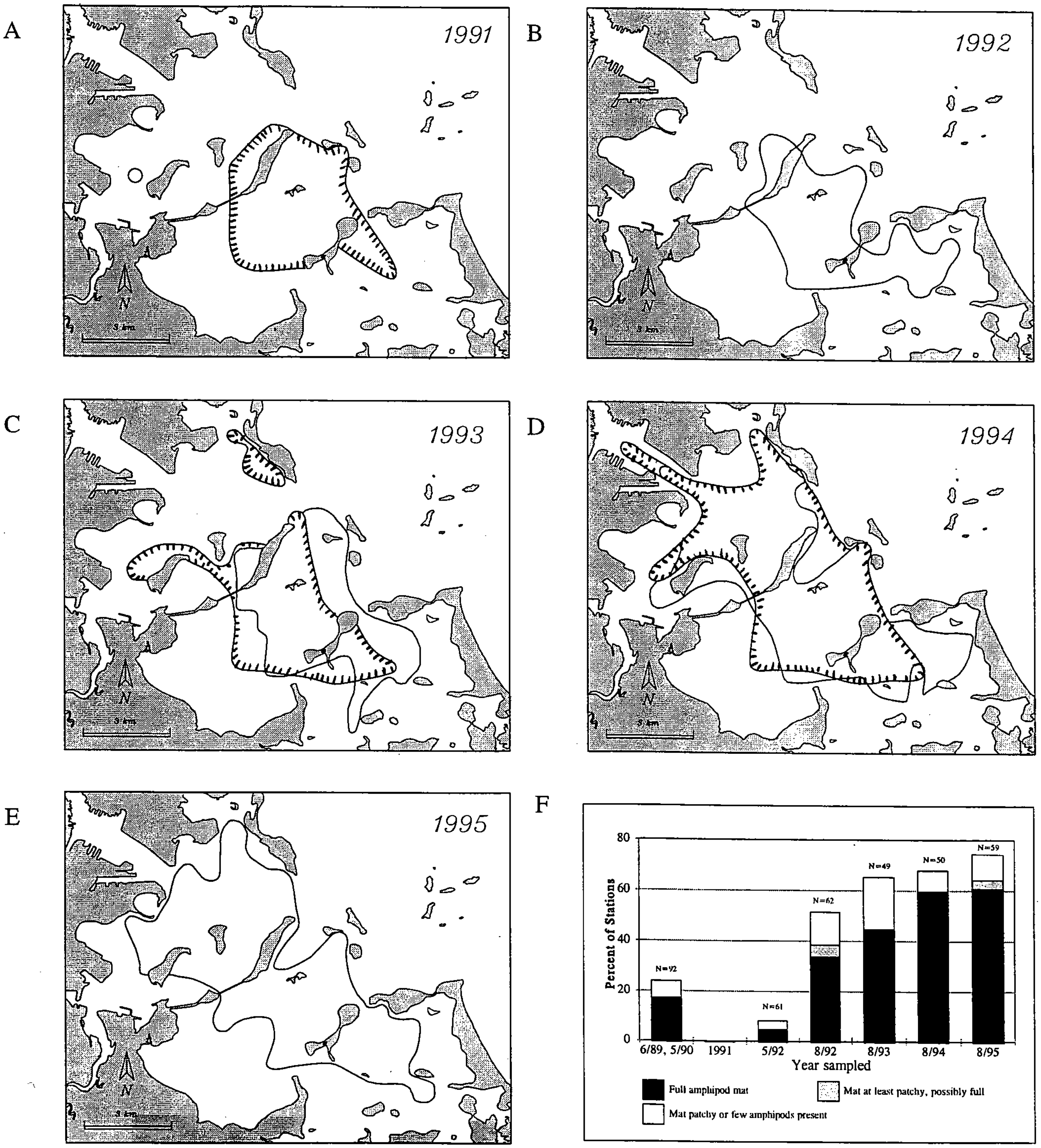


Figure 16. **(A-E) distribution of amphipod tube mats in Boston Harbor from 1991 through 1995 as determined by sediment profile image analysis (solid lines) and/or *Ampelisca* predominance in grab samples (hatched lines, after Kropp and Diaz, 1995); (F) percent of stations with full or patchy mat. Maps courtesy of Brian Howes and Tony Millham, Woods Hole Oceanographic Institution.**

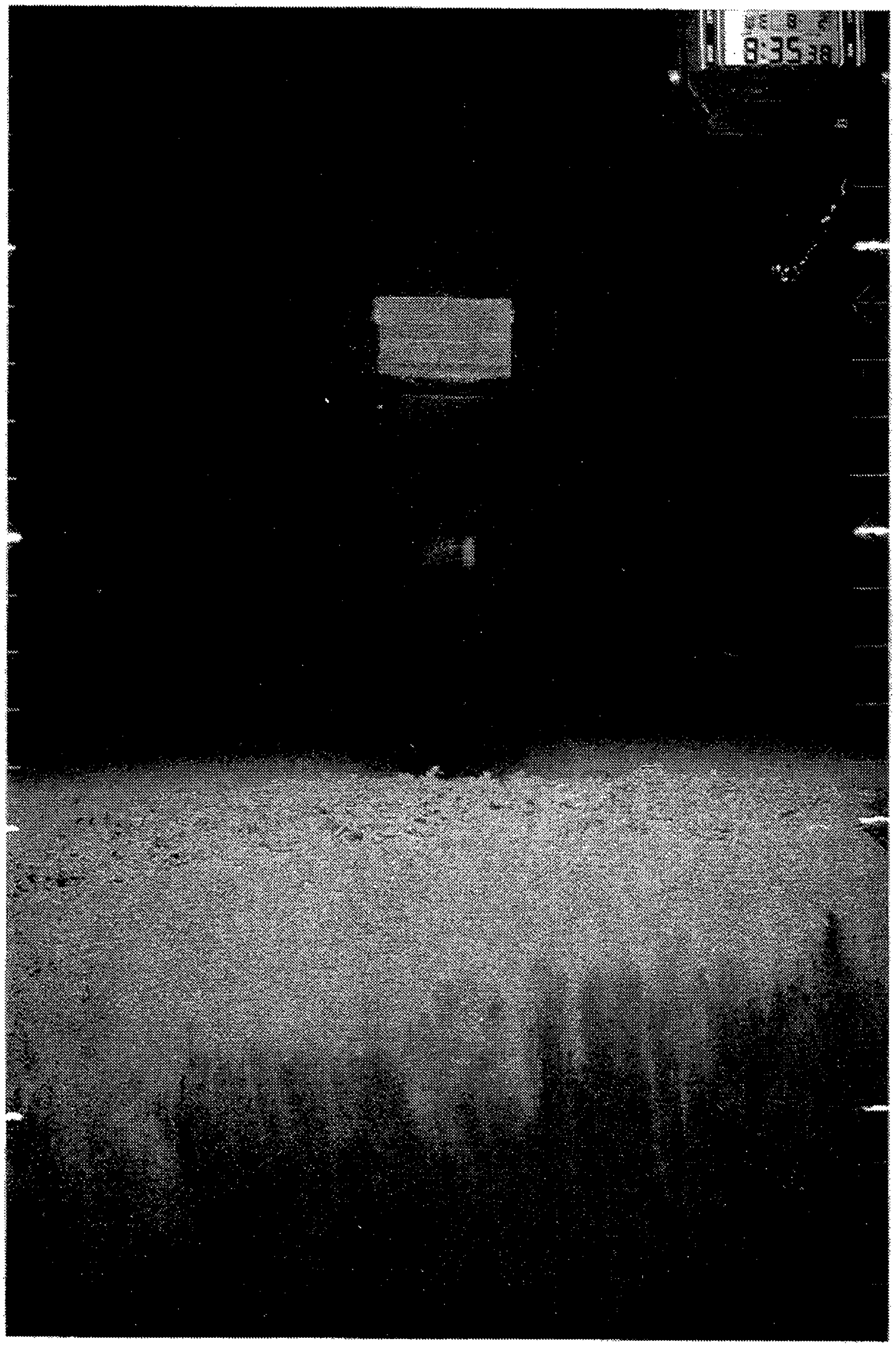


Figure 17. Various stages of development of amphipod tube mats in the Harbor I. Newly developing mat consisting of a juvenile cohort (Station T5). Scale: image width is 15 cm.

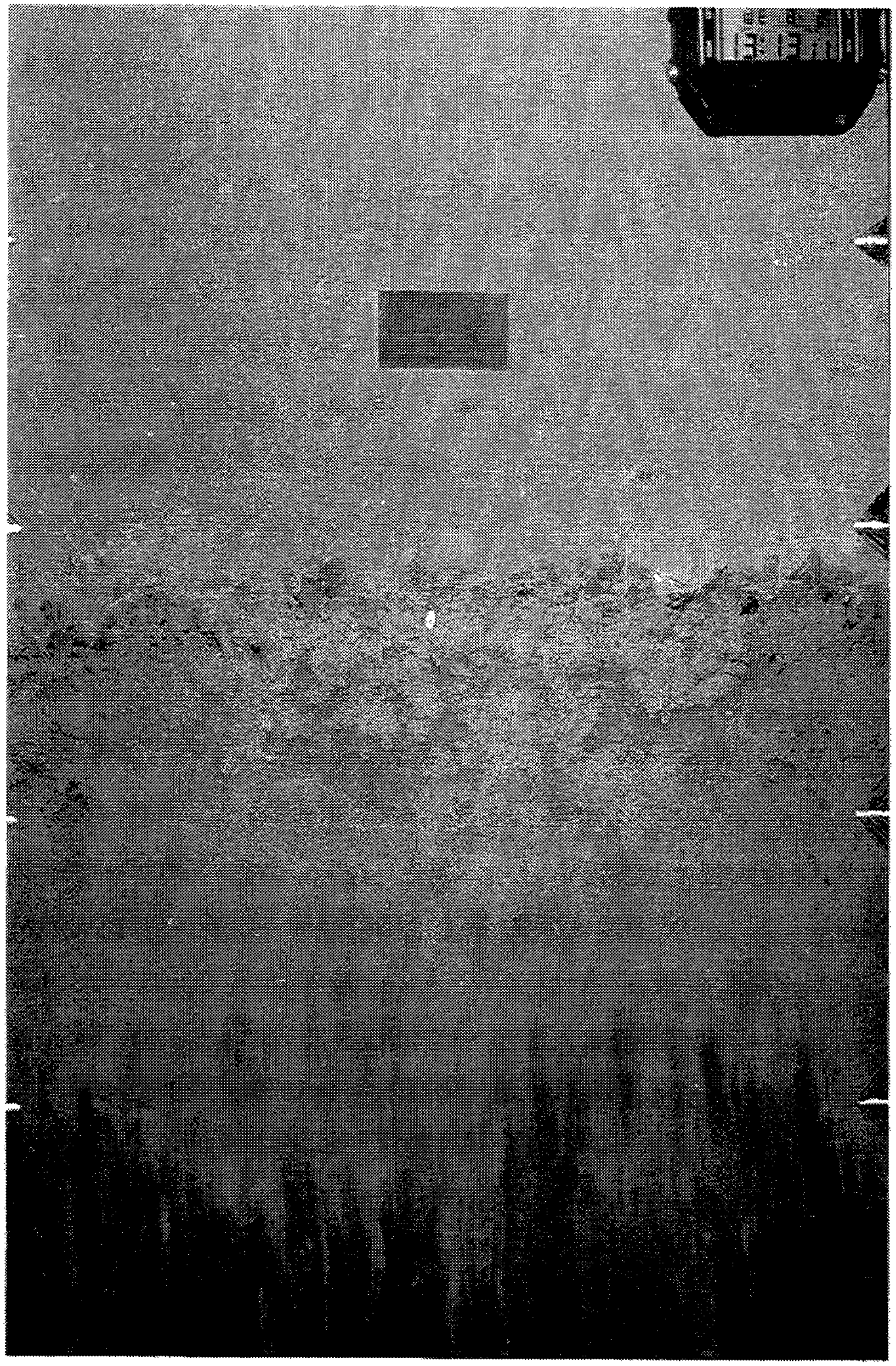


Figure 18. Various stages of development of amphipod tube mats in the Harbor II. Fully developed adult tube mat (Station R24). Scale: image width is 15 cm.

Figure 19. Various stages of development of amphipod tube mats in the Harbor III. A ripped-up decaying tube mat (Station R23). Scale: image width is 15 cm.

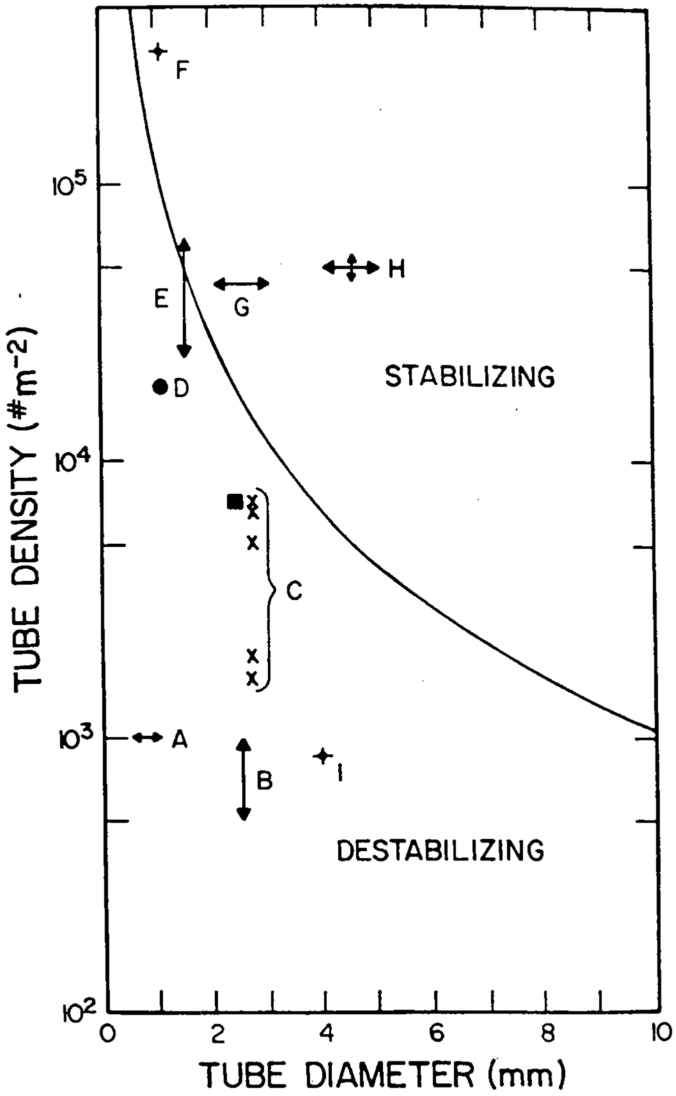


Figure 20. Relationship between tube diameter and tube spacing in affecting noncohesive bed stability. Tube values in the stabilizing field are proposed to initiate "skimming flow," which protects the bed from turbulence. Tube values in the destabilizing field cause bed scour by reattachment of wake turbulence. Modified from Eckman *et al.* (A) McCall and Fisher (1980) (oligochaetes); (B) Fager (1964) (*Owenia fusiformis*); (C) Eckman *et al.* (1981) (*O. fusiformis*); (D) McCall (1977) (*Streblospio benedicti*); (E) Bailey-Brock (1979) Chaetopterid polychaetes); (F) Myers (1979a, b) (*Corophium insidiosum*); (G) Mills (1969) (*Ampelisca abdita*); (H) Fager (1964) (*O. fusiformis*); (I) Myers (1977a,b) (*Microdeutopus gryllotalpa*).

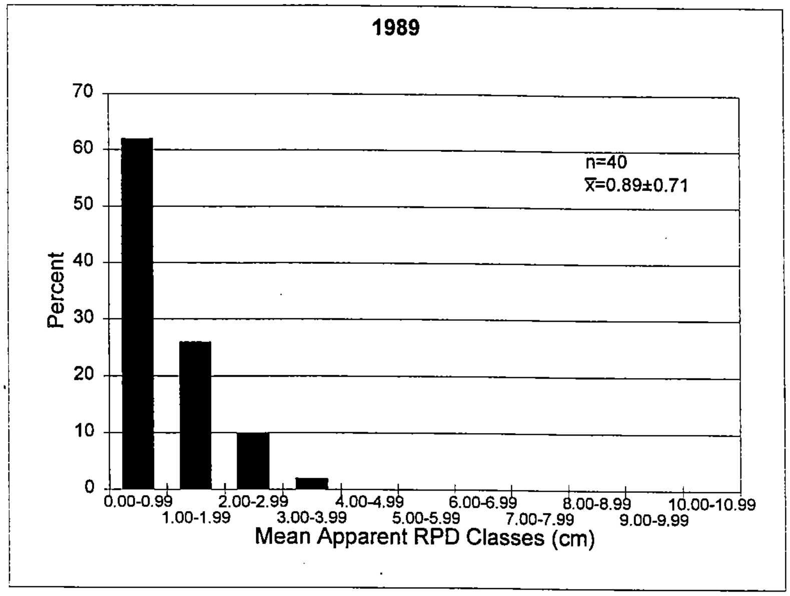
level (see section 4.2). However, the exceptional development of ampeliscid tube mats in the harbor following sewage abatement, especially in the area adjacent to the Deer Island outfalls and the Nut Island sludge outfall, is strong evidence for a direct link between this relatively pollution sensitive (although enrichment tolerant) crustacean and improving benthic habitat conditions. In 1991 and 1992, the main distribution of *Ampelisca* was limited to Hull Bay, Quincy Bay and at stations immediately north of Long Island. The 1993 distribution shows the appearance of *Ampelisca* for the first time on the Deer Island flats and an extension from Quincy Bay into Dorchester Bay (2 stations). In 1994, the populations extended into the Inner Harbor and persisted on the southwestern side of Deer Island. This distribution persisted in 1995 with the exception of the disappearance of ampeliscids in the Inner Harbor.

Prior to sludge abatement, the major modal apparent RPD class was 0-0.99 cm throughout the Harbor, with a minor mode of 1.00-1.99 cm present in the southern part of the Harbor (Figure 21) (SAIC, 1990). After December 1991, the time of sludge abatement, the major modal apparent RPD class changed to 1.00-1.99 cm and has since remained the same. Over time, the distribution has become right skewed reflecting progressive deepening of the apparent RPD by ampeliscid crustaceans (Figure 22). In 1992, no oxidized sediment particles were observed below a mixing depth of 3.99 cm. With the spread of *Ampelisca*, there has been an increase in the number of stations where the apparent RPD is ≥ 4.00 cm deep. The increase in ventilation of the sediment column by fluid and particle bioturbation is an important process for remineralization of organically loaded sediments (Aller, 1995; Boudreau and Marinelli, 1994). In this sense, bioturbation is a natural form of "tertiary sewage treatment", i.e., physical stirring and aeration to stimulate biochemical digestion. Bioturbation can be expected to be a first-order natural process for lowering TOC in surficial harbor sediments over the next few years.

Total organic carbon (TOC) values from September 1991 to August, 1995 are shown in Figure 23. Stations that were high in TOC in 1991 tended to remain high in 1995 (e.g., T3, T4, and T7), and stations with relatively low TOC in 1991 tended to remain low (e.g., T5, T5a, and T8). The observed year-to-year variance in the data reflects both spatial and temporal patchiness, i.e., differences in organic loading rates over time. For example, while inventories of TOC appear to be comparable between April and August at most of the Traditional stations, the TOC at station T4 almost doubled in April, 1995 (Figure 24). It is unclear if this apparent change relates to TOC patchiness in space or, for example, April run-off resulted in organic loading at station T4. By August 1995, the TOC concentration was down to "normal" values, possibly because the sediments with high TOC inventories sampled in April had been buried between the two sampling events (see also section 3.2.1).

The year-to-year and seasonal variance in *Clostridium perfringens* spore counts is also high although there is a consistent decrease in sediment spore counts from the pre-sludge abatement sampling (September, 1991) to immediate post-sludge abatement in 1992, 1993, and 1994 (Figure 25). In 1995, the April sampling showed high values for stations T2, T3, T4, T6, and T7 relative to earlier post-abatement sampling dates. This may be related to high run-off conditions just prior to sampling. Station T3, located near the Deer Island Outfall, remains the station with the highest spore counts. The viability of *C. perfringens* spores in sediment can extend over a long period of time (Bisson and Cabelli, 1980) and so high spore count stations may not converge with lower count stations for several years.

Organism-sediment indices (OSIs) calculated from data collected during the two pre-abatement surveys (SAIC, 1990) ranged from -10 to +11 (including the highest and lowest possible values for this parameter). The apparent shift of OSIs between 1989 and 1990, with the major modal OSI class of 2.5-3.4 in 1989 and a major modal OSI class of 5.5-6.4 in 1990 (Figure 26), is spatial in nature rather than



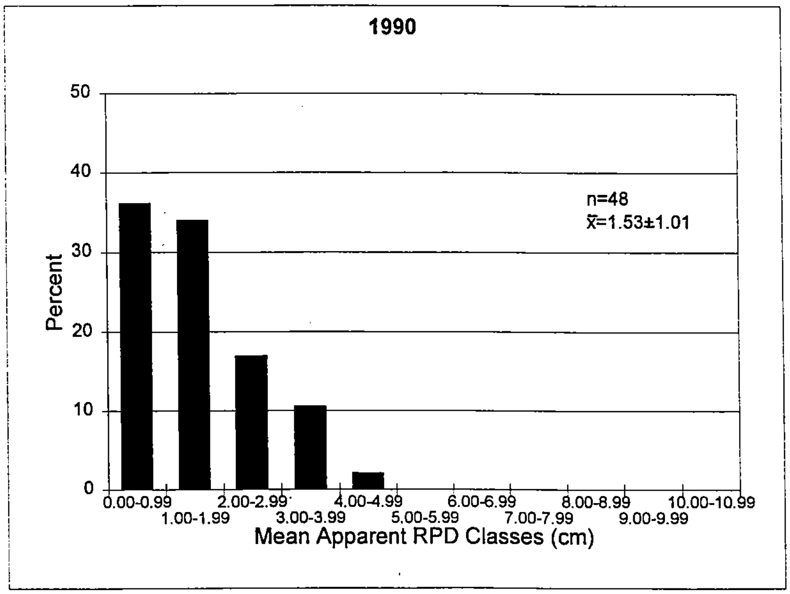


Figure 21. Percent of Boston Harbor stations in each mean apparent RPD class (cm) for the pre-abatement years 1989 and 1990.

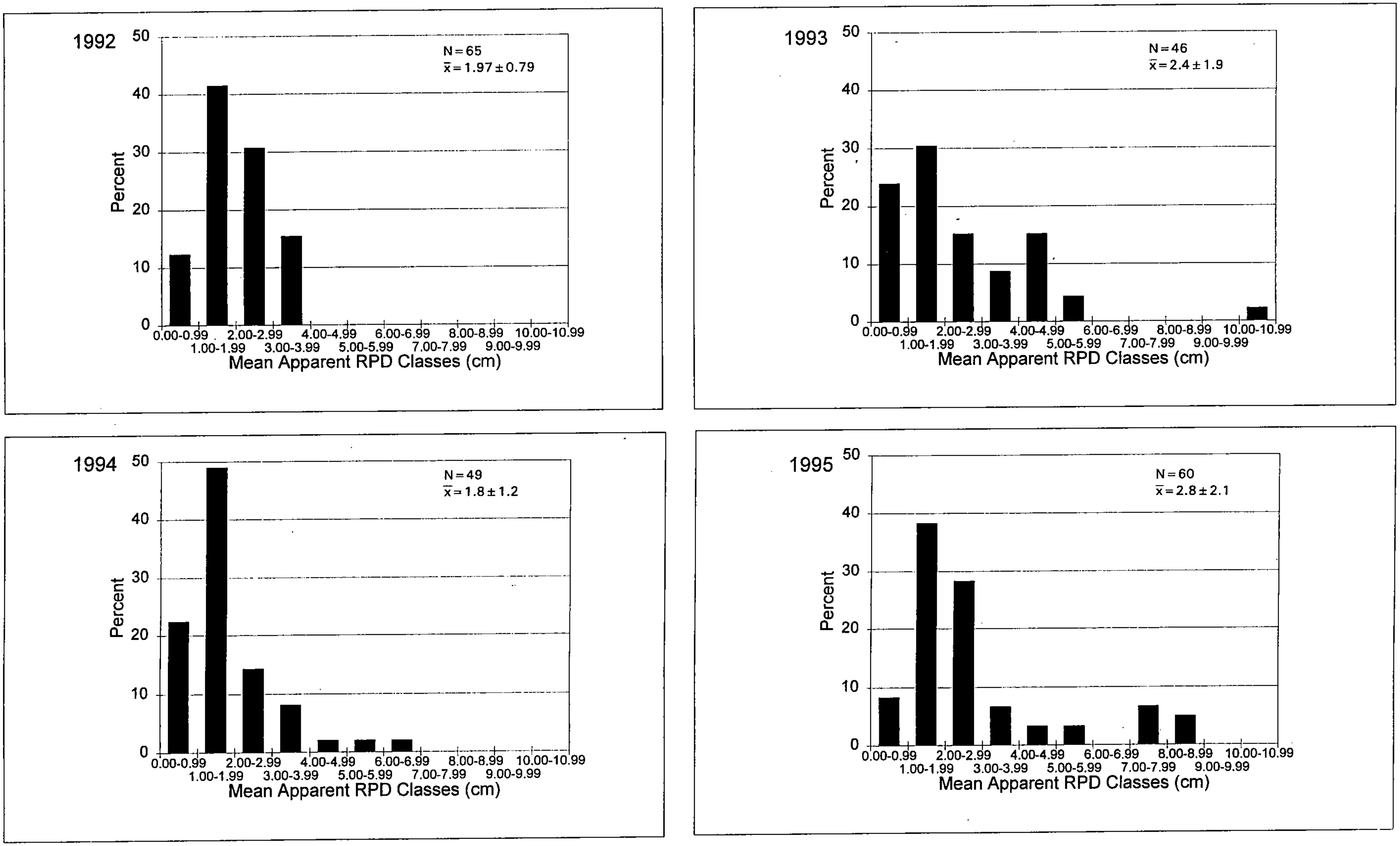


Figure 22. Percent of Boston Harbor stations in each mean apparent RPD class (cm) for the post-abatement years 1992 through 1995.

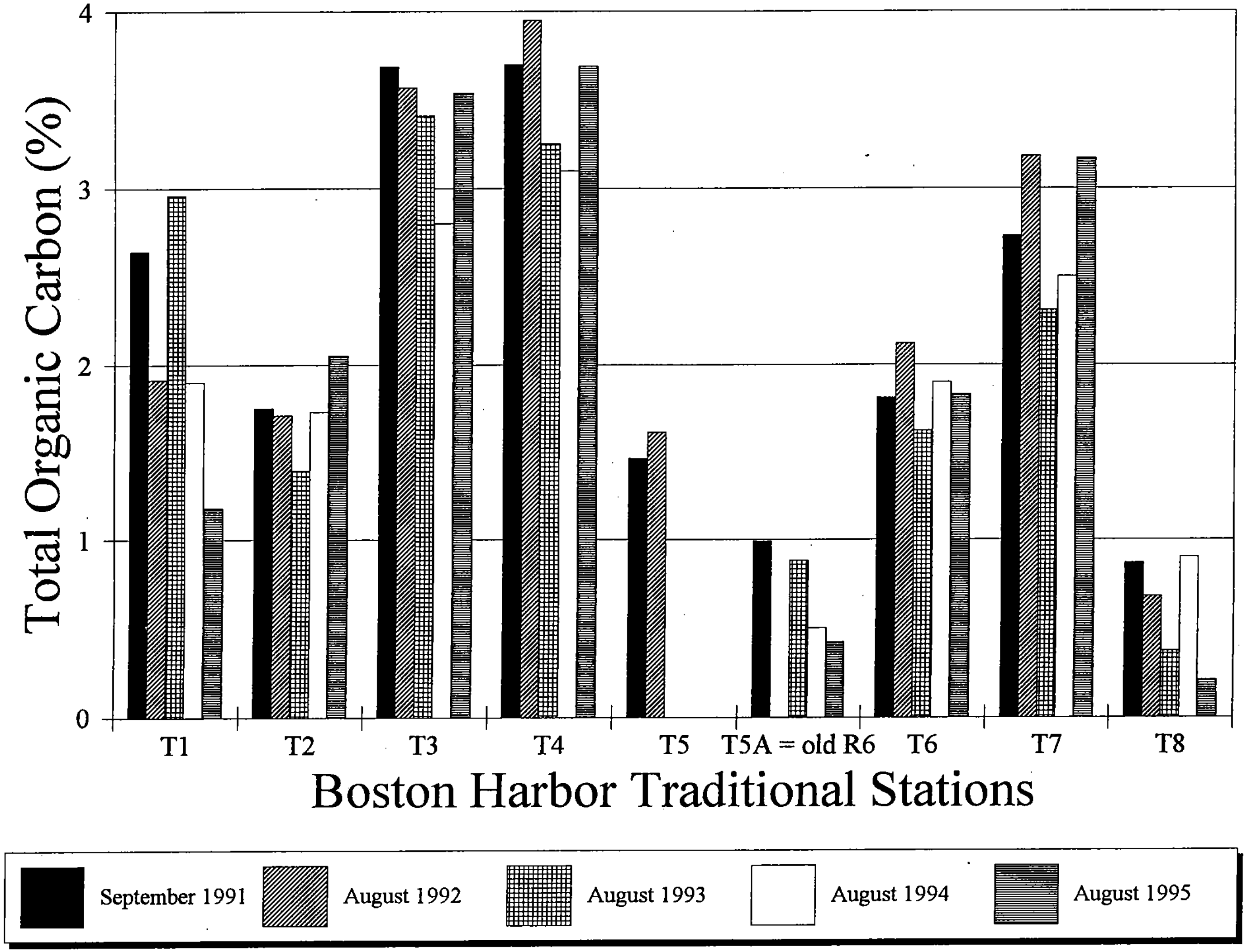


Figure 23. Total organic carbon (dry weight percent) at the eight Traditional stations, late summer of 1991 through 1995.

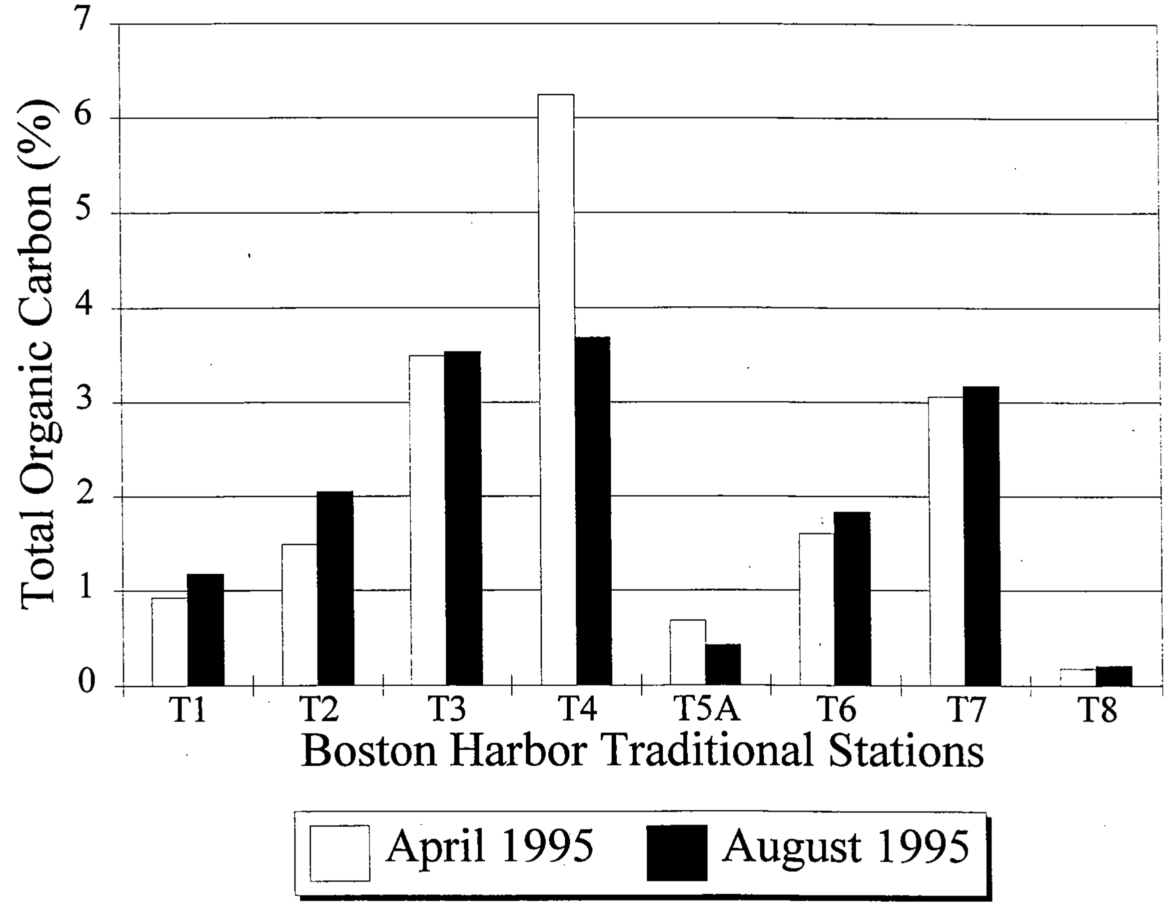


Figure 24. Total organic carbon (dry weight percent) at the eight Traditional stations in April and August 1995.

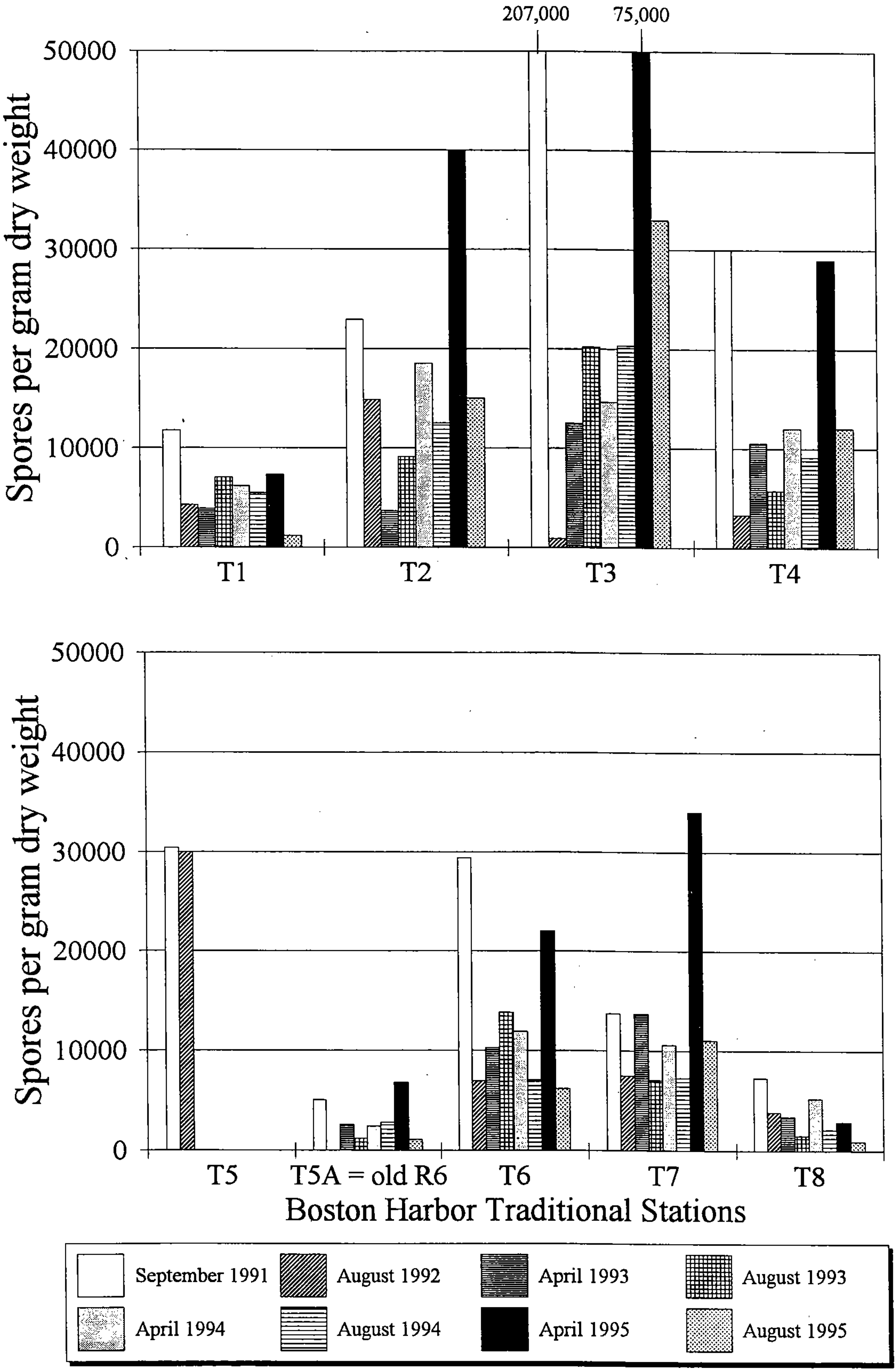


Figure 25. ***Clostridium perfringens*** **spore counts (colony forming units/g dry weight of sediment) at the eight Traditional stations, 1991 through 1995. Note that two spore counts at T3 are off scale and that the pertinent values are entered above the bars.**

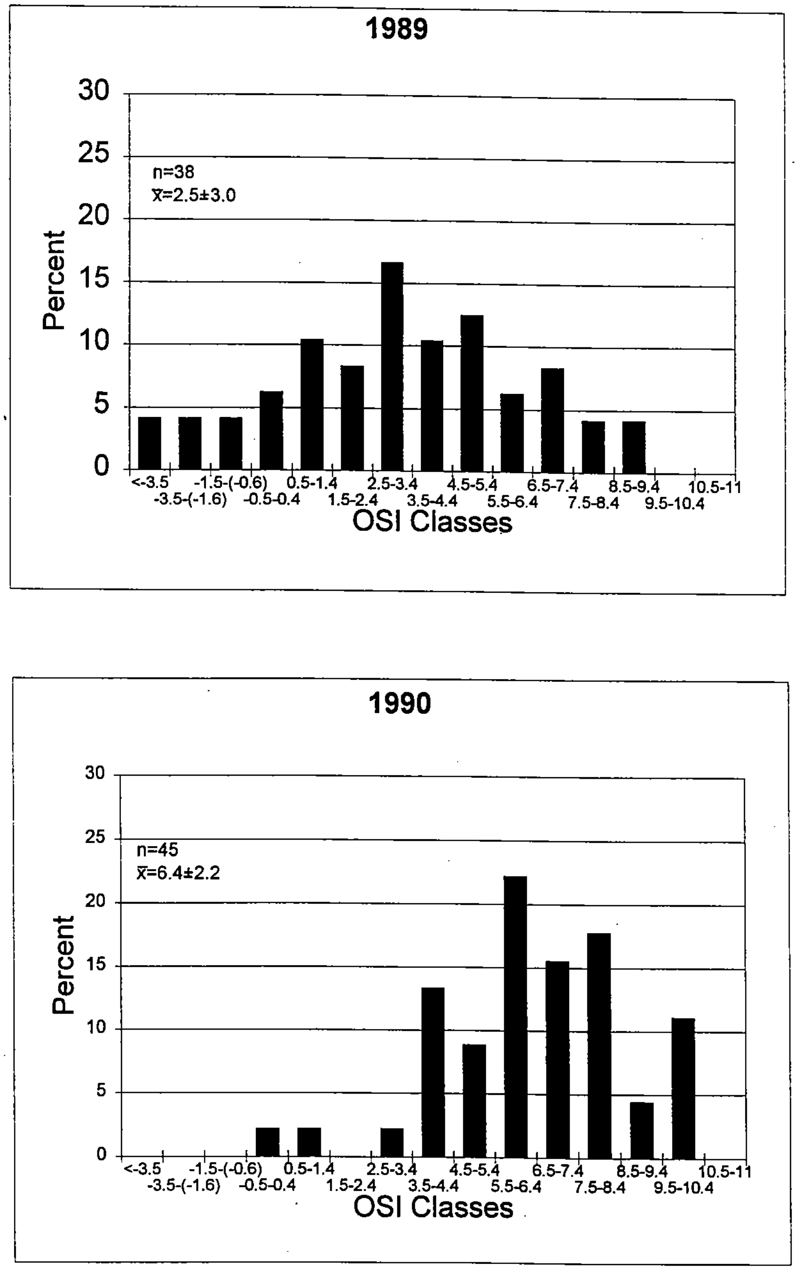


Figure 26. Percent of Boston Harbor stations in each organism-sediment index (OSI) class for the pre-abatement years 1989 and 1990.

temporal. The stations sampled in 1989 were in the northern part of the Harbor, where poor habitat quality was more common, while most of the 1990 stations were in the southern part of the Harbor where the habitat quality was higher throughout. The post-abatement frequency distribution of organism-sediment indices over the period 1992 through 1995 is shown in Figure 27. In 1992, the left-skewed unimodal distribution had a major and minor mode within the 6.5-7.4 and 7.5-8.4 OSI classes. The 1993 distribution was bimodal with the major mode falling within the 2.5 to 3.4 OSI class and a second mode within the 8.5 to 9.4 OSI class. Similar to the pre-abatement data, the 1992 and 1993 distributions reflect relatively low habitat quality in Boston Harbor and Dorchester Bay and higher quality habitat conditions in outer Quincy, Hingham and Hull Bays.

The 1994 survey was the first time that OSI values ≥ +6 were recorded near Deer Island and Long Island. The frequency distribution shows a slight improvement relative to 1993 in the modal OSI with most values falling within the 3.5 to 6.4 class range. However, the range of OSI values was great extending from <-3.5 to +11. In 1995, the normal distribution appeared similar to that observed in 1992 with a major mode of 6.5 to 7.4. Many of these mid-range OSI values reflect improving habitat conditions in Boston Harbor and Dorchester Bay. The reason for an overall decrease in benthic habitat conditions in 1993-1994 compared with 1992, as measured with the OSI parameter, is unknown. However, with continued long-term improvement in benthic habitat conditions, one may expect an overall decrease in negative OSI values and more values falling within OSI classes ≥ +6. Given the myriad natural and anthropogenic ecological stress factors that influence these harbors and embayments, it is unlikely that the OSI distribution will progress much beyond a major mode of +6 to +8 (the highest value being +11 in this parameter).

4.2 Spatial/Temporal Trends in Benthic Infauna

Prior to 1991, the only studies to address harbor-wide community structure were those conducted as part of the 301(h) waiver application, with samples collected during the summers of 1978, 1979, and 1982. These data were reviewed and summarized by Blake *et al.* (1989). With the initiation of harbor-wide benthic monitoring in the summer of 1991, and subsequent abatement of sewage sludge discharges in December of the same year, an opportunity was presented to evaluate the response of benthic communities to improvements in sediment quality. Nine sets of semiannual samples have since been collected in the Harbor from eight permanent stations located in representative areas. A composite analysis of the first seven surveys was performed by Kropp and Diaz (1995). An evaluation of their results suggests that prior to 1993, stations T1, T3, and T5/5a, located in the northern part of the Harbor, did not exhibit any consistent pattern in faunal assemblages either between seasons or between calendar years. In contrast, stations T6, T7 and T8 in the southern part of the Harbor exhibited consistency in their faunal assemblages regardless of season or calender year. Station T4 with its notoriously poor sediment quality did not show changes in faunal assemblages over time, but has always exhibited a pronounced seasonality.

Figure 28, a simplified version of Figure 12 of Kropp and Diaz (1995), shows similarity among all Traditional samples collected between 1991 and 1994. The two main parts of the dendrogram are clearly identifiable as northern and southern stations. Within the left half of the dendrogram (the northern stations), a temporal trend can be seen as clusters 1 and 2 consist of samples taken through spring of 1992, with cluster 2 also encompassing all samples from station T4 which group together in a seasonal pattern . Samples from T1 and T2 taken after the spring of 1992 group together in cluster 3, indicating changes over time. Station T3 seems to have undergone major changes in benthic communities over

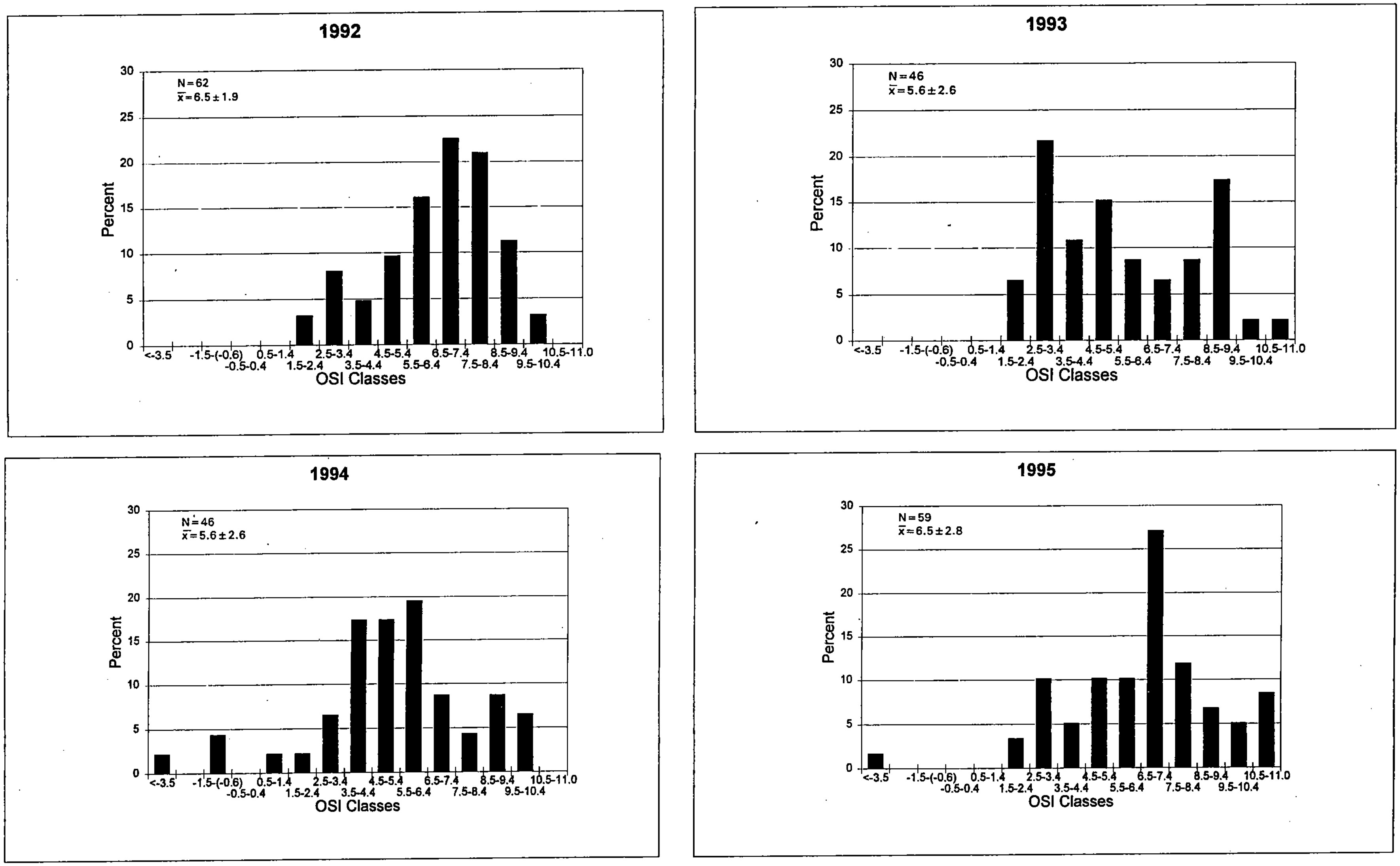


Figure 27. Percent of Boston Harbor stations in each organism-sediment index (OSI) class for the post-abatement years 1992 through 1995.

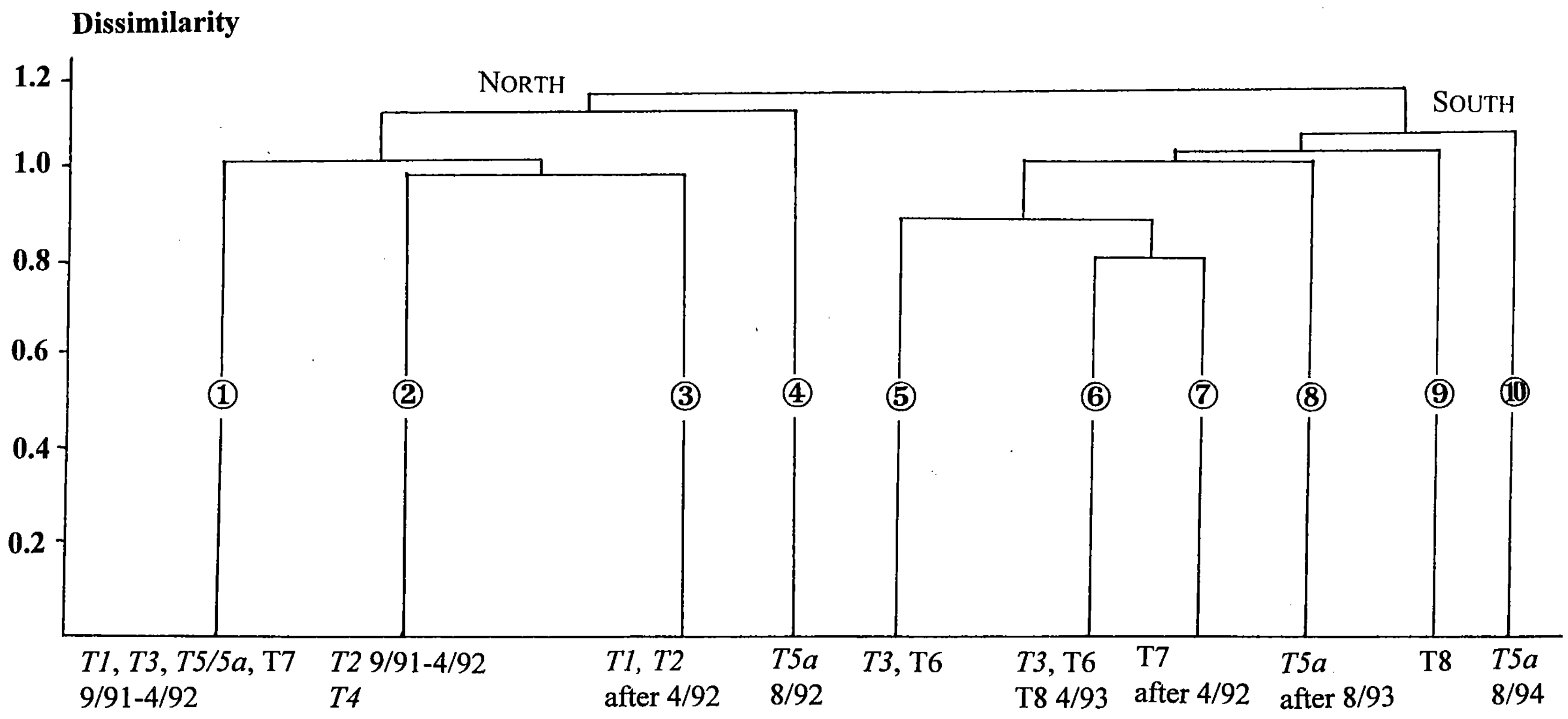


Figure 28. Clustering patterns of Traditional stations since 1991 (modified after Kropp and Diaz, 1995). Station names in italics are in the northern part of the Harbor.

time, with the samples initially grouped with the other northern stations, then later joining with the southern stations, with strongest affinities to station T6. Station T5/T5a exhibited similar changes, with the samples clustering with other northern stations through the spring of 1992, being an outlier in the northern clusters in the summer of that year, and subsequently clustering with the southern stations. All samples from station T7 taken after the spring of 1992 are grouped in cluster 7, and all samples from station T8 since 1991 are grouped together in cluster 9, suggesting a consistent faunal assemblage with more or less pronounced seasonality. The continuation of these patterns will be explored in a future analysis, but examination of the clustering patterns among the spring and summer samples of 1995 suggests that the observed trends will be true for those samples as well.

It is likely that in large part these changes have come about because of the spread of amphipod populations throughout the Harbor as described by Kropp and Diaz (1995) and supported in the present report (see also Section 4.1). While the expansion of the amphipod mats across the Harbor may be an indicator for habitat improvements connected with the sludge abatement, traditional benthic community parameters such as diversity and species richness may be considered along with the presence of new, rare, or other indicator species that might suggest improvements in sediment quality. Figures 29 through 33 show diversity and species richness over time at selected stations from the northern and southern parts of the Harbor, along with relative abundances of the top two dominant species at those stations since 1991.

Station T1 off Deer Island shows the least change among the northern stations that could be attributed to sludge abatement (Figure 29B), with considerable, mostly seasonal, variability in species richness and diversity. Its sheltered location may have protected this station from storm-related sediment transport (and subsequent establishment of amphipod populations), but also subjected it to shoreline flow of effluent from the nearby outfall (Ken Keay, personal communication). The spring samples are generally characterized by lower diversity and higher species richness than the summer samples, although this pattern is sometimes overlain by other influences. The infaunal community has been consistently dominated by opportunists such as tubificid oligochaetes and the spionid *Streblospio*, among others, that are able to tolerate high organic loading of the sediments (Figure 29A). In contrast, station T2 has undergone a faunal change over time, with opportunistic annelids being replaced by amphipods (Figure 30A). Interestingly, the cirratulid polychaete *Tharyx acutus* seems to dominate during the transitional years. The relative abundances of the top two dominant species decreased considerably after the spring of 1992, suggesting a more balanced assemblage with no one species overwhelmingly dominating. Both species richness and diversity increased between 1991 and 1995, with seasonal and annual changes being much more moderate than at T1 (Figure 30B). Station T3 off Long Island shows a progression in dominant infauna similar to station T2, although it regressed in the spring of 1994, and the abundances of the individual dominant species change somewhat more erratically over time than at T2, indicating a somewhat less stable community, at least through 1994 (Figure 31A). The species richness and diversity curves (Figure 31B) reflect this development. Both curves are noticeably smoother after the summer of 1994 than they were prior to that time, an effect most likely caused by the establishment of amphipod mats. Overall, species richness increased steadily (except for a peak in August of 1993) and quite substantially between 1991 and 1995, while diversity dropped during the same time, with seasonal and annual changes being erratic through the summer of 1994.

The benthic infaunal assemblages in the southern Harbor have not been subject to similar temporal changes since sludge abatement. For example, station T6 has been fairly constant with respect to species richness and diversity (Figure 32B), the relative abundances of the top two dominant species are

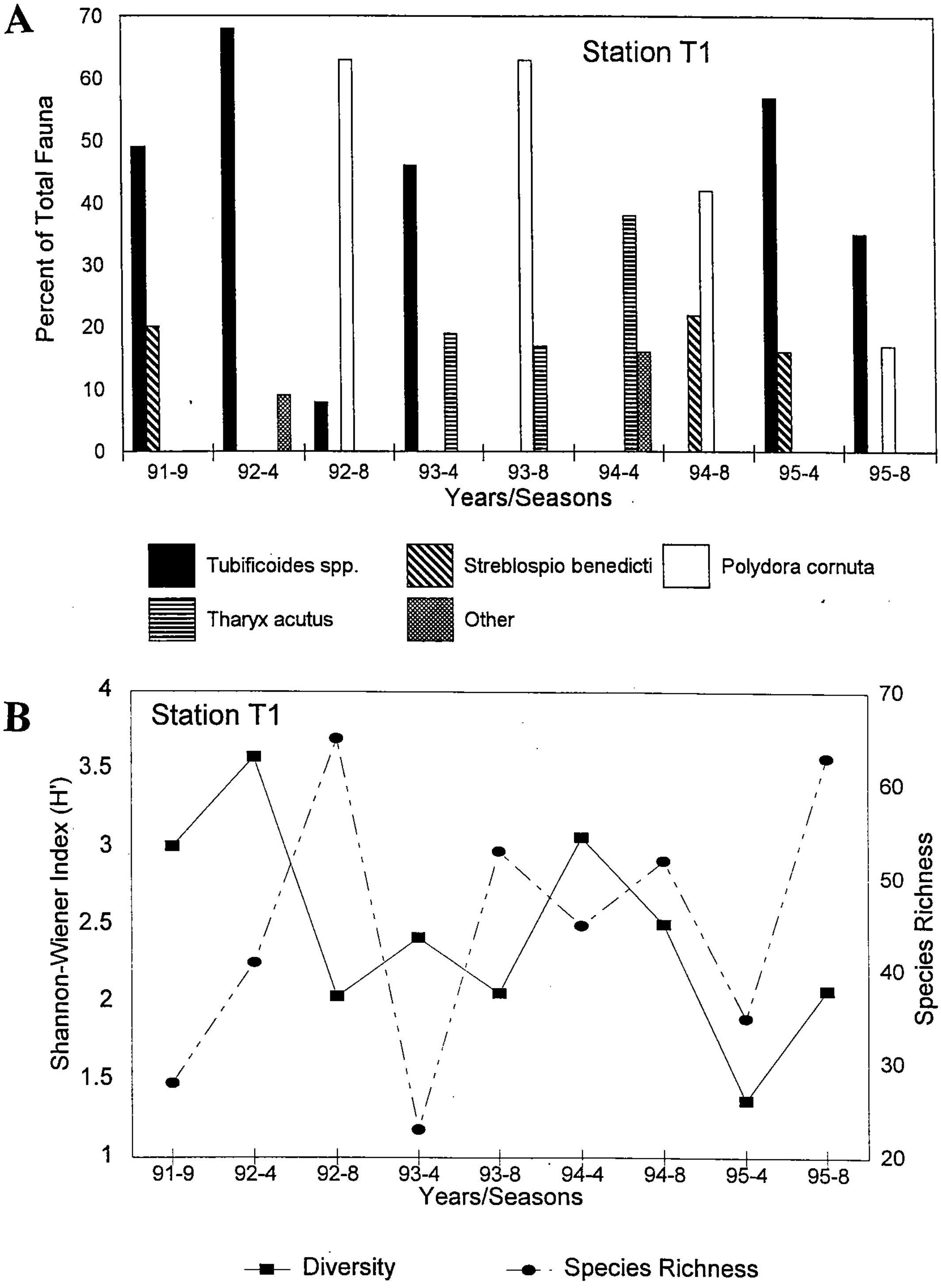


Figure 29. Temporal changes of benthic assemblages between 1991 and 1995, station T1, northern Harbor. (A) dominant species, (B) community parameters.

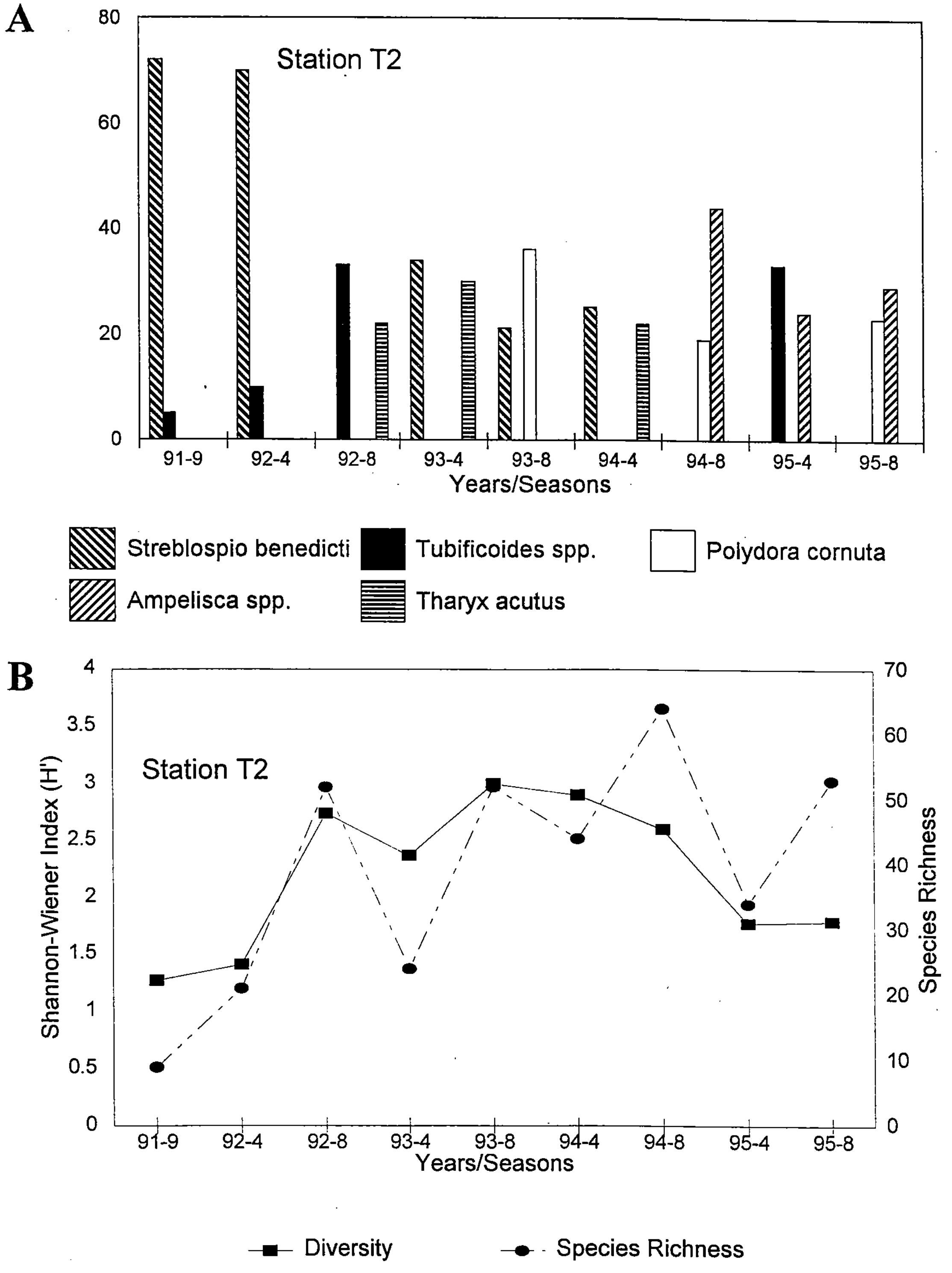


Figure 30. Temporal changes of benthic assemblages between 1991 and 1995, station T2, northern Harbor. (A) dominant species, (B) community parameters.

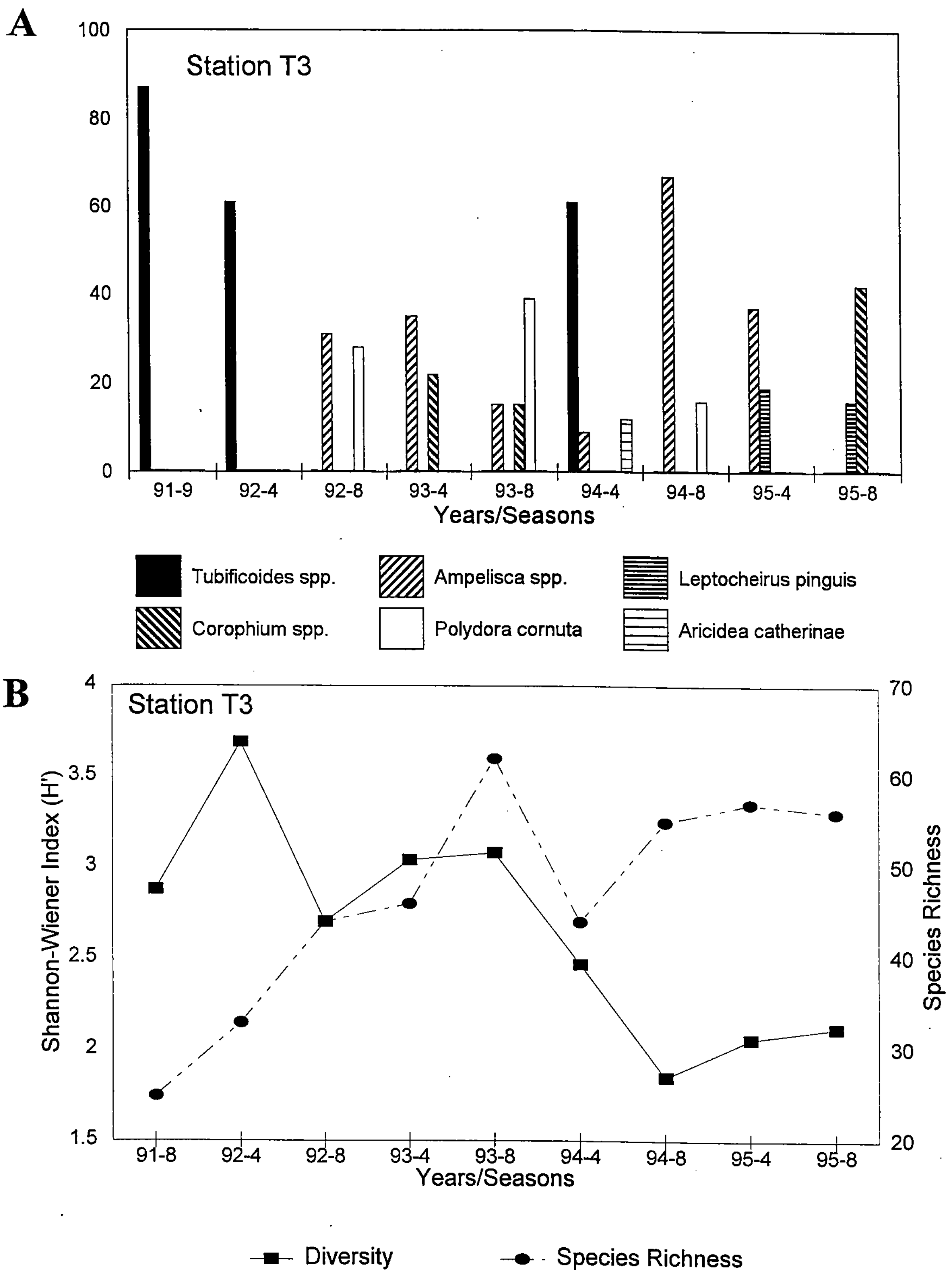


Figure 31. Temporal changes of benthic assemblages between 1991 and 1995, station T3, northern Harbor. (A) dominant species, (B) community parameters.

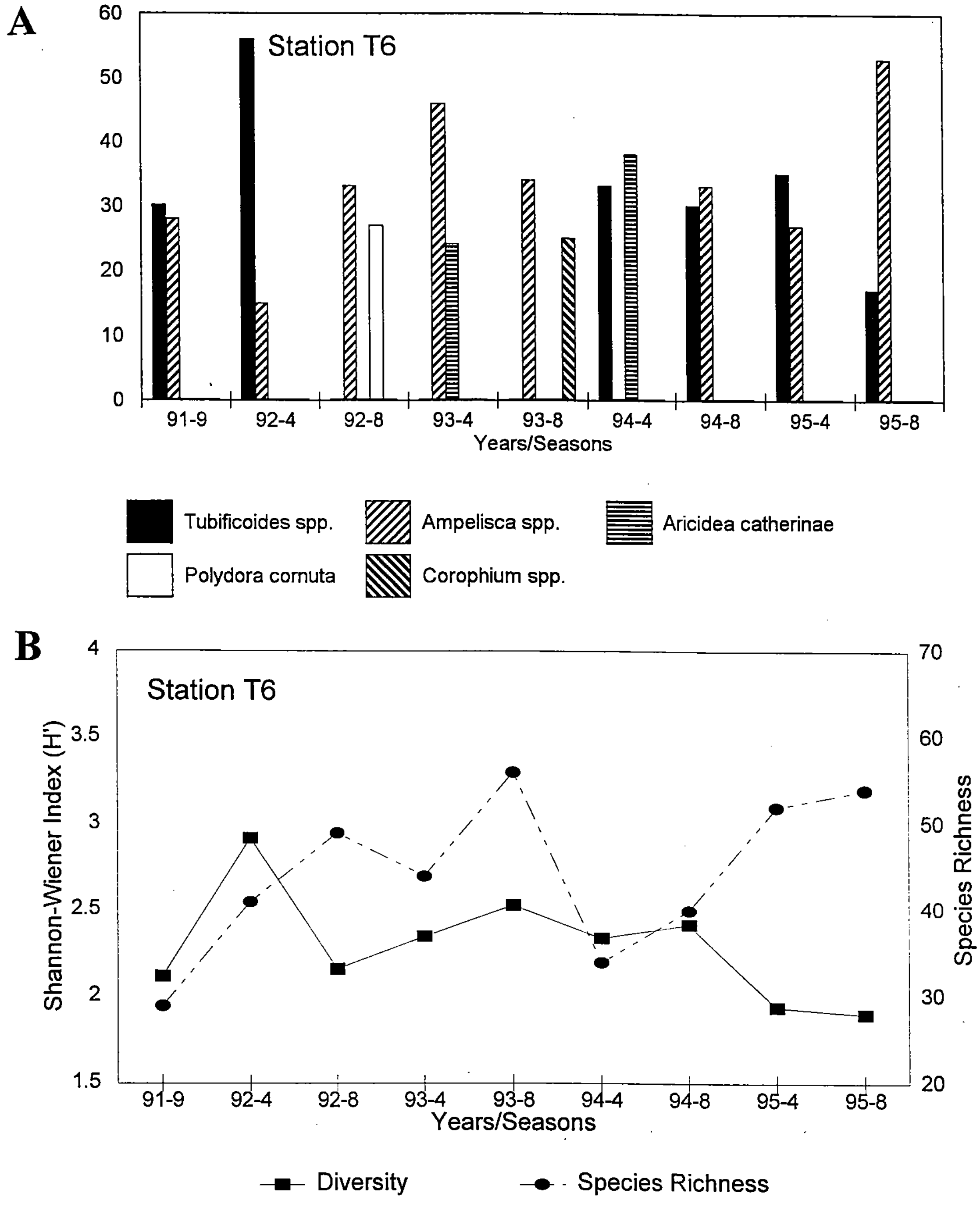


Figure 32. Temporal changes of benthic assemblages between 1991 and 1995, station T6, southern Harbor. (A) dominant species, (B) community parameters.

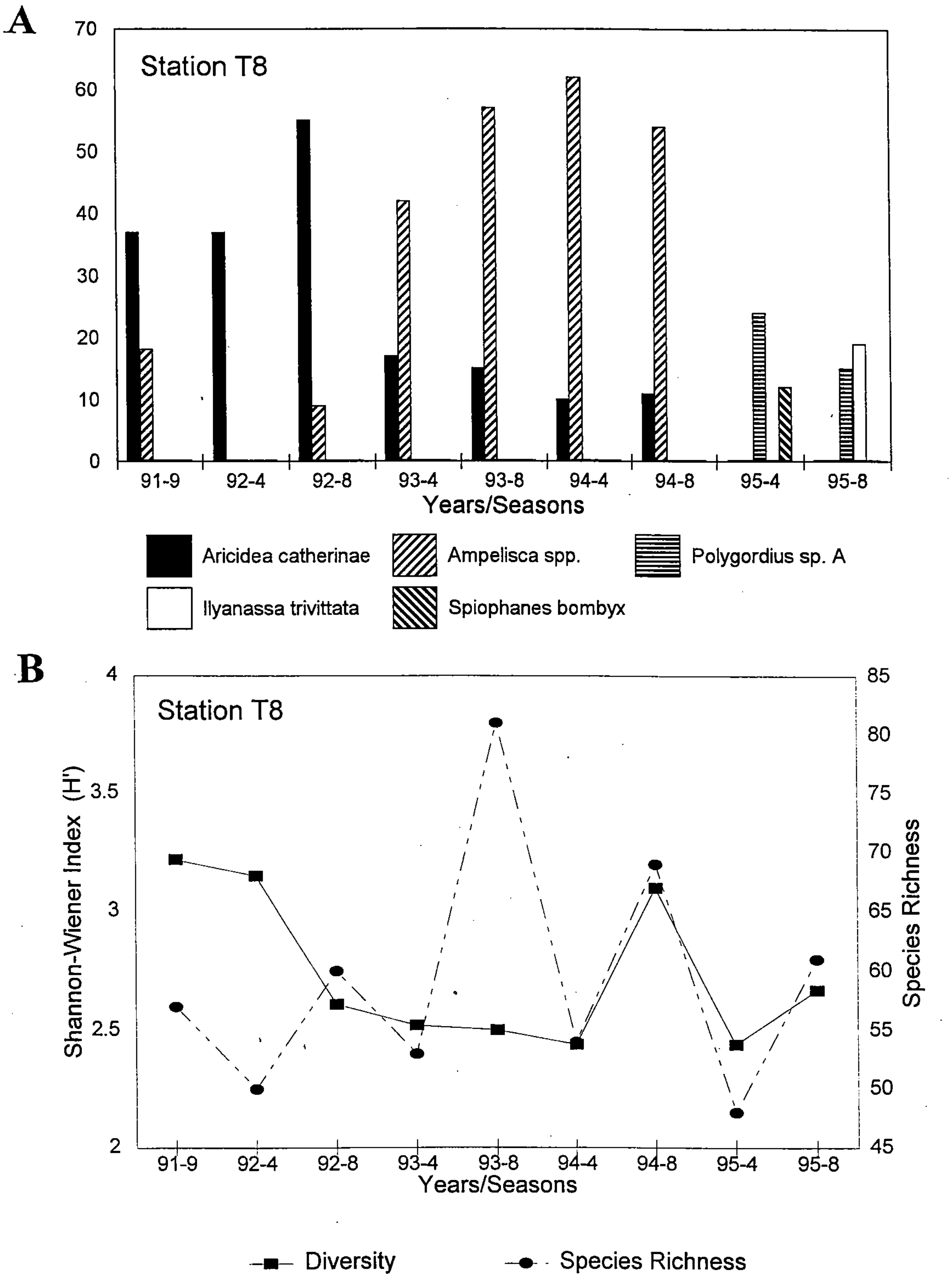


Figure 33. Temporal changes of benthic assemblages between 1991 and 1995, station T8, southern Harbor. (A) dominant species, (B) community parameters.

moderate throughout, and the assemblage is characterized by a mixture of stage I and stage II organisms (tubificids and amphipods, Figure 32A). Station T8 shows a similar consistency of the infaunal community, although there are very strong seasonal patterns in species richness and diversity (Figure 33B). The two most abundant species have been the same through the summer of 1994, with *Ampelisca* usually ranking first. In 1995, the amphipod mats were not sampled with the grab, but the SPI images taken in the summer show these mats, so that the assemblage dominated by the archiannelid *Polygordius* and the gastropod *Ilyanassa* must be regarded as a sampling artifact in an area where the amphipod mats are patchily distributed (Figure 33A).

The trends in infaunal communities at individual stations described above coalesce into several larger-scale patterns that may indicate a Harbor-wide response to sludge abatement. Commensurate with a general increase in species richness especially in the northern Harbor is the appearance of several species among the dominants that were previously rare or absent. Noteworthy examples are the cirratulid polychaete *Chaetozone vivipara* at station T2 and several amphipod species of the genus *Corophium* at station T3. *Chaetozone vivipara* was first reported in August 1993 (as *Aphelochaeta* sp. A, see Kropp and Diaz (1995: Appendix A) for records and abundances); it was not recorded during the 301(h) waiver studies (Blake, unpublished; Blake *et al.*, 1989). The success of this polychaete and the amphipod species is likely due to habitat modifications caused by *Ampelisca,* which in turn seems to be related to the sludge abatement even though *Ampelisca* populations have been reported in the Harbor between 1978 and 1982 when sewage sludge was still discharged (Figure 34). Dense populations of *Ampelisca* were then present near Deer Island Flats and Governor's Island Flats (1978), in Dorchester Bay (1979), off Nut and Peddocks Islands in Quincy Bay (all three years), and in Hingham Bay (1979 and 1982). It is noteworthy that of the two species traditionally present in the Harbor, *A. vadorum* had a much more restricted distribution than *A. abdita,* and this distribution seems to have persisted until present: in 1978-1982, *A. vadorum* was among the dominant species off Peddocks Island (near T6) and in Hingham Bay (near T8) only, while all other stations showed *A. abdita* among the dominant species. In 1995, *A. vadorum* populations were found again only at station T6 (samples from the other stations contained no or only very few specimens), suggesting that the spread of amphipod mats throughout the Harbor observed since sludge abatement is a response of *A. abdita* to more favorable habitat conditions. According to Mills (1967), *A. abdita* can tolerate lower oxygen concentrations than can *A. vadorum,* while the latter is able to settle in coarser sediments. It is therefore possible that with progressing improvement of sediment quality— less organic loading and higher oxygen levels in and above the sediments— the distribution and relative abundances of those two species may shift, although it is unlikely that *A. vadorum* will ever form dense assemblages in the Harbor comparable to the mats formed by *A. abdita.*

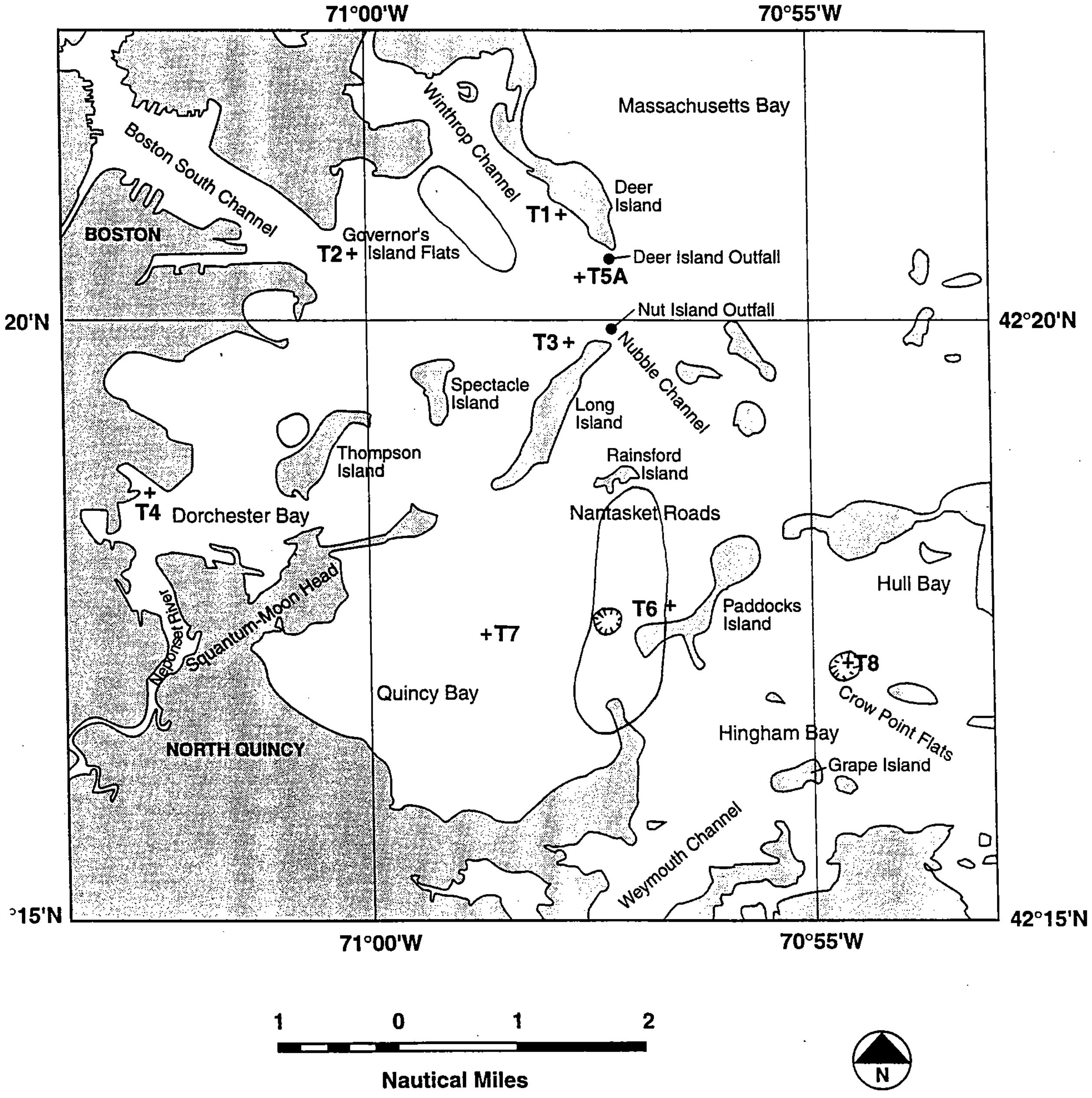


Figure 34. Distribution of ampeliscids between 1978 and 1982. Solid lines: *Ampelisca abdita*, hatched lines: *A. vadorum*.

5.0 CONCLUSIONS

- The most significant change in benthic habitat conditions since the 1991 post-sludge abatement has been the explosive population growth of the pollution sensitive tube-dwelling amphipod, *Ampelisca* sp. Although sludge abatement is only one of several factors that may contribute to this phenomenon, the fact that these amphipods have progressively populated Boston Harbor, particularly bottoms near the Deer Island and Long Island (i.e., Nut Island) outfalls is significant. Prior to sludge abatement, less than 20 percent of the stations showed the presence of amphipod tube mats. In 1995, over 60 percent of the monitoring stations show well developed tube mats. These tube mats, in turn, are effective in trapping fine-grained sediment and have had a significant impact on enhancing sedimentation rates of silt-clay and very fine sand.

- The strong no-name storm in November 1991 may have helped to set the stage for the establishment of *Ampelisca* mats in the harbor, as it caused a harbor-wide shift from mud to mostly fine sand, which is the substrate preferred by settling larvae. Since then, the sediments have become more fine-grained again in most of the Harbor.

- Successful maintenance of a dense amphipod population depends, in part, on the tubes serving to stabilize the bottom. As populations age and become senescent, the tube mats may break down. Instead of promoting skimming flow, patchy holes in the tube mat promote turbulent flow in the benthic boundary layer. This is followed by erosion, resuspension, and redistribution of trapped fine-grained sediment. This seasonal phenomenon can be expected to generate variance in both biological and sedimentological/ geochemical conditions.

- Regarding inventories of total organic carbon (TOC), the ranking of Traditional stations is similar between the pre-sludge abatement and post-sludge abatement periods. Stations T3, T4, and T7 remained high in 1995 with peaks of over 3%. The lowest TOC inventories were at stations T5a and T8. It may take several years for the organically loaded stations to reflect reduced sedimentation rates of labile organic matter.

- Sediment inventories of *Clostridium perfringens* showed dramatic reductions following sludge abatement. These inventories have not been consistently low as the April 1995 sampling (high run-off period) shows elevated spore counts that equal or exceed late summer to early fall pre-sludge abatement values. August 1995 values appear to be lower than April values reflecting low run-off inventories. *Clostridium* spore counts may be expected to decline over time but stations with the highest spore counts (T2, T3 and T4) may continue to show high counts for several years as these resistant spores may continue to be viable for a long time and, as such, reflect historical sewage accumulations at these stations.

- Although the benthic infaunal communities at the Traditional stations are quite different from station to station, they have historically fallen into two groups, the northern stations closest to the outfalls (T1, T2, T3, T4, and T5a) and the southern stations at a greater distance from the outfalls (T6, T7, and T8). The northern stations were characterized by opportunistic, seasonally or annually often highly variable assemblages that are able to tolerate high organic loading of the sediment, while the southern stations exhibited more consistent and predictable assemblages that were usually dominated by Stage II organisms that require better sediment quality. Sludge abatement, and possibly the sedimentary changes due to the November 1991 storm, has changed the infauna at some northern stations such that they have become progressively more similar to the southern stations.

- Species richness increased harborwide since 1991, especially at the northern stations. At the same time, several species appeared among the dominants that were previously rare or absent, such as *Chaetozone vivipara* and *Corophium* spp. The success of both species is likely due to habitat modifications caused by *Ampelisca*, which in turn seems to be related to the sludge abatement even though *Ampelisca* populations were reported in the Harbor between 1978 and 1982 when sewage sludge was still discharged.

- Of the two *Ampelisca* species traditionally present in the Harbor, *A. vadorum* historically had a much more restricted distribution than *A. abdita*, and this pattern has persisted. These distributional patterns, which may depend on grain size and oxygen levels in the sediments, suggest that the spread of amphipod mats throughout the Harbor observed since sludge abatement is a response of *A. abdita* to more favorable habitat conditions.

6.0 ACKNOWLEDGMENTS

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Appendices

Appendix A1. Target locations for the Harbor Traditional stations.

Station	Latitude	Longitude	Depth (m)
T1	42°20.95′N	70°57.81′W	4.0
T2	42°20.57′N	71°00.12′W	6.0
T3	42°19.81′N	70°57.72′W	9.0
T4	42°18.60′N	71°02.49′W	3.5
T5a	42°20.38′N	70°57.64′W	18.0
T6	42°17.61′N	70°56.66′W	6.0
T7	42°17.36′N	70°58.71′W	7.0
T8	42°17.12′N	70°54.75′W	11.0

Appendix A2. Target locations for the Harbor Reconnaissance stations.

Station	Latitude	Longitude	Depth (m)
T1	42°20.95′N	70°57.81′W	4.0
T2	42°20.57′N	71°00.12′W	6.0
T3	42°19.81′N	70°57.72′W	9.0
T4	42°18.60′N	71°02.49′W	3.5
T5a	42°20.38′N	70°57.64′W	18.0
T6	42°17.61′N	70°56.66′W	6.0
T7	42°17.36′N	70°58.71′W	7.0
T8	42°17.12′N	70°54.75′W	11.0
R2	42°20.66′N	70°57.69′W	12.0
R3	42°21.18′N	70°58.37′W	5.5
R4	42°21.52′N	70°58.78′W	8.5
R5	42°21.38′N	70°58.68′W	7.1
R6	42°19.91′N	70°57.12′W	6.8
R7	42°20.85′N	70°58.53′W	5.9
R8	42°20.66′N	70°59.50′W	2.8
R9	42°20.80′N	71°00.98′W	11.8
R10	42°21.32′N	71°02.20′W	13.5
R11	42°19.28′N	70°58.48′W	7.0
R12	42°19.10′N	70°58.47′W	6.3
R13	42°19.03′N	70°58.84′W	7.2
R14	42°19.25′N	71°00.77′W	7.9
R15	42°18.92′N	71°01.15′W	3.6
R16	42°18.95′N	70°57.68′W	6.9
R17	42°18.29′N	70°58.63′W	8.2
R18	42°17.33′N	70°57.67′W	7.9
R19	42°16.92′N	70°56.27′W	9.7
R20	42°19.49′N	70°56.10′W	9.7
R21	42°18.53′N	70°56.78′W	7.0
R22	42°18.02′N	70°56.37′W	8.3
R23	42°17.63′N	70°57.00′W	10.5
R24	42°17.78′N	70°57.51′W	8.3
R25	42°17.48′N	70°55.72′W	6.8
R26	42°16.13′N	70°55.80′W	5.8
R27	42°16.83′N	70°54.98′W	3.7
R28	42°16.90′N	70°54.52′W	8.2

Appendix A2 (Continued)

Station	Latitude	Longitude	Depth (m)
R29	42°17.38′N	70°55.25′W	8.8
R30	42°17.43′N	70°54.25′W	5.2
R31	42°18.05′N	70°55.03′W	9.8
R32	42°17.68′N	70°53.82′W	5.5
R33	42°17.65′N	70°59.67′W	4.0
R34	42°17.33′N	71°00.42′W	3.4
R35	42°17.05′N	70°59.28′W	4.3
R36	42°16.53′N	70°59.20′W	2.7
R37	42°17.93′N	70°59.08′W	4.0
R38	42°17.08′N	70°57.83′W	4.6
R39	42°17.73′N	70°58.22′W	6.4
R40	42°19.73′N	71°01.45′W	4.6
R41	42°18.67′N	71°01.50′W	5.5
R42	42°19.18′N	71°01.50′W	3.7
R43	42°18.40′N	71°00.13′W	4.0
R44	42°20.62′N	71°00.13′W	6.1
R45	42°19.70′N	70°58.05′W	6.7
R46	42°17.46′N	70°55.33′W	9.5
R47	42°20.67′N	70°58.72′W	8.3
R48	42°17.61′N	70°59.27′W	3.1
R49	42°16.39′N	70°54.49′W	8.4
R50	42°16.50′N	70°53.92′W	7.6
R51	42°15.80′N	70°56.53 ′W	2.4
R52	42°15.71′N	70°56.09′W	2.1
R53	42°16.15′N	70°56.27′W	3.0

Appendix B1
Sediment Profile Imaging Raw Data

HOM - 1995 BOSTON HARBOR SEDIMENT PROFILE SURVEY RESULTS

Stat_ID	Replicate	Penetration Depth (cm)			Boundary Roughness		Grain Size (phi)			Redox Potential Discontinuity (RPD) Depth (cm)			
					Thickness (cm)	Type			Major Mode	Replicates			Station Mean
		Minimum	Maximum	Mean			Minimum	Maximum		Minimum	Maximum	Mean	
BHR02	A	20.52	21.98	21.14	1.46	Biological	> 4	1 to 0	>4	0.10	0.90	0.5	
BHR02	B	21.74	22.73	22.24	0.99	Biological	> 4	3 to 2	>4	0.10	0.90	0.5	0.5
BHR02	C	21.74	23.23	22.60	1.49	Biological	> 4	1 to 0	>4	0.10	0.90	0.5	
BHR03	A	4.92	6.53	5.95	1.61	Indeterminate	> 4	1 to 0	3 to 2	1.20	4.10	2.6	
BHR03	B	9.08	11.54	9.96	2.46	Biological	> 4	3 to 2	4 to 3	0.00	9.00	4.5	3.9
BHR03	C	7.54	8.72	8.14	1.18	Physical	> 4	3 to 2	4 to 3	1.88	8.61	4.5	
BHR04	B	21.33	21.76	21.53	0.43	Biological	> 4	4 to 3	>4	0.00	2.77	1.4	
BHR04	C	22.68	23.27	22.89	0.59	Biological	> 4	4 to 3	>4	0.35	5.09	1.2	1.2
BHR04	D	17.17	18.93	18.04	1.76	Biological	> 4	4 to 3	>4	0.29	4.91	1.1	
BHR05	A	21.33	21.85	21.56	0.52	Biological	> 4	4 to 3	>4	0.40	3.12	1.5	
BHR05	B	18.90	19.51	19.24	0.61	Biological	> 4	4 to 3	>4	0.00	4.22	1.0	1.3
BHR05	C	21.19	22.51	21.81	1.32	Biological	> 4	4 to 3	>4	0.43	8.88	1.4	
BHR06	A	2.61	4.43	3.65	1.82	Physical	> 4	<-1	4 to 3	0.00	1.56	0.5	
BHR06	B	5.64	7.25	6.73	1.61	Physical	> 4	<-1	4 to 3	0.00	6.55	1.9	1.5
BHR06	C	4.98	6.69	5.77	1.71	Physical	> 4	<-1	4 to 3	0.50	3.86	2.0	
BHR07	A	19.66	20.95	20.28	1.29	Biological	> 4	4 to 3	>4	0.20	3.01	1.3	
BHR07	B	20.64	21.62	21.17	0.98	Biological	> 4	4 to 3	>4	0.00	7.52	2.1	1.6
BHR07	C	20.12	20.92	20.59	0.80	Biological	> 4	4 to 3	>4	0.10	4.57	1.4	
BHR08	A	5.54	6.67	5.99	1.13	Indeterminate	4 to 3	3 to 2	4 to 3	1.85	3.76	2.1	
BHR08	B	6.64	7.50	7.20	0.86	Indeterminate	4 to 3	<-1	4 to 3	2.54	4.91	3.5	2.6
BHR08	C	5.83	6.58	6.27	0.75	Physical	> 4	3 to 2	4 to 3	1.38	4.22	2.1	
BHR09	A'	15.90	17.16	16.40	1.26	Biological	> 4	4 to 3	>4	1.10	3.93	1.3	
BHR09	B'	15.62	16.17	16.01	0.55	Biological	> 4	4 to 3	>4	0.20	4.39	1.8	1.5
BHR09	D	23.73	24.26	24.02	0.53	Biological	> 4	4 to 3	>4	0.97	2.76	1.3	
BHR10	A'	18.41	19.30	18.90	0.89	Biological	> 4	4 to 3	>4	0.26	3.11	0.7	
BHR10	B	18.72	21.40	20.10	2.68	Biological	> 4	4 to 3	>4	0.23	2.32	0.9	1.2
BHR10	D	19.14	21.81	20.86	2.67	Biological	> 4	4 to 3	>4	0.35	3.70	2.0	
BHR11	A	18.54	19.78	19.24	1.24	Biological	> 4	3 to 2	>4	3.36	11.91	6.1	
BHR11	B	19.54	20.99	20.47	1.45	Biological	> 4	3 to 2	>4	3.54	9.70	6.0	5.9
BHR11	D	19.10	20.16	19.76	1.06	Biological	> 4	2 to 1	>4	4.45	10.76	5.5	
BHR12	A	21.78	22.85	22.39	1.07	Biological	> 4	3 to 2	>4	3.98	17.13	8.5	
BHR12	B	23.38	23.70	23.52	0.32	Biological	> 4	4 to 3	>4	5.54	15.33	8.0	8.0
BHR12	D	22.34	23.08	22.75	0.74	Biological	> 4	4 to 3	>4	3.15	11.20	7.5	
BHR13	A	12.56	15.30	14.13	2.74	Physical	> 4	3 to 2	>4	0.00	6.30	2.5	
BHR13	B	11.00	14.27	12.52	3.27	Physical	> 4	2 to 1	>4	1.24	6.81	2.0	2.4
BHR13	C	12.92	15.21	14.48	2.29	Physical	> 4	3 to 2	>4	0.33	9.76	2.6	
BHR14	A	17.22	18.16	17.77	0.94	Biological	> 4	4 to 3	>4	2.35	6.40	3.1	
BHR14	B	9.83	11.65	10.82	1.82	Biological	> 4	4 to 3	>4	1.18	8.72	3.3	2.5
BHR14	C	7.99	10.05	8.96	2.06	Physical	> 4	2 to 1	>4	0.55	3.80	1.0	
BHR15	A	18.20	19.52	18.54	1.32	Biological	> 4	3 to 2	4 to 3	6.93	13.62	8.0	
BHR15	B	18.83	20.15	19.48	1.32	Biological	> 4	3 to 2	4 to 3	5.25	14.97	9.0	8.7
BHR15	C	18.29	19.47	18.64	1.18	Biological	> 4	4 to 3	4 to 3	6.81	12.45	9.0	
BHR16	A	14.30	15.59	0.83	1.29	Physical	> 4	4 to 3	>4	0.83	9.79	2.9	
BHR16	B	16.77	17.54	17.19	0.77	Biological	> 4	3 to 2	>4	0.32	5.04	1.4	2.8
BHR16	C	10.41	12.09	11.54	1.68	Biological	> 4	3 to 2	4 to 3	2.80	6.90	4.0	

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Stat_ID	Replicate	Penetration Depth (cm)			Boundary Roughness		Grain Size (phi)			Redox Potential Discontinuity (RPD) Depth (cm)			
					Thickness (cm)	Type			Major Mode	Replicates			Station Mean
		Minimum	Maximum	Mean			Minimum	Maximum		Minimum	Maximum	Mean	
BHR17	A	18.42	19.37	18.95	0.95	Biological	> 4	4 to 3	>4	2.39	5.28	2.1	
BHR17	B	18.39	19.63	19.18	1.24	Biological	> 4	4 to 3	>4	3.68	7.16	4.0	3.0
BHR17	C	15.48	16.89	16.38	1.41	Biological	> 4	3 to 2	>4	1.39	7.40	2.9	
BHR18	A	20.34	22.34	21.55	2.00	Biological	> 4	4 to 3	>4	6.66	12.26	8.0	
BHR18	B	12.20	14.77	13.36	2.57	Biological	> 4	3 to 2	4 to 3	6.19	14.45	9.0	7.7
BHR18	C	17.98	19.51	18.99	1.53	Biological	> 4	3 to 2	>4	4.98	10.05	6.0	
BHR19	A	3.45	4.51	4.01	1.06	Physical	> 4	3 to 2	4 to 3	1.44	4.51	1.6	
BHR19	B	4.04	4.83	4.31	0.79	Physical	> 4	<-1	4 to 3	0.00	4.10	2.0	1.9
BHR19	C	1.41	4.89	3.65	3.48	Physical	> 4	<-1	4 to 3	0.00	3.66	2.2	
BHR20	A	19.66	21.19	20.74	1.53	Biological	> 4	4 to 3	>4	5.95	12.74	7.0	
BHR20	B	21.08	21.73	21.40	0.65	Biological	> 4	4 to 3	>4	6.25	12.29	8.2	8.4
BHR20	C	22.23	23.08	22.68	0.85	Biological	> 4	3 to 2	>4	6.40	16.01	10.0	
BHR21	A	12.97	14.18	13.71	1.21	Biological	> 4	3 to 2	>4	5.01	13.50	7.0	
BHR21	B	12.62	13.88	13.32	1.26	Biological	> 4	3 to 2	>4	5.19	13.24	9.0	7.7
BHR21	C	10.32	12.17	11.61	1.85	Biological	> 4	3 to 2	4 to 3	2.42	11.73	7.0	
BHR22	A	5.98	7.07	6.50	1.09	Biological	4 to 3	3 to 2	4 to 3	0.97	>7.07	2.9	
BHR22	B	9.89	10.80	10.49	0.91	Biological	> 4	3 to 2	4 to 3	1.44	>10.8	5.2	4.1
BHR22	C	2.50	4.18	3.15	1.68	Physical	4 to 3	<-1	3 to 2	0.00	>4.18	4.2	
BHR23	A	2.51	3.89	3.21	1.38	Biological	> 4	3 to 2	4 to 3	1.15	3.42	2.0	
BHR23	B	1.36	2.39	2.00	1.03	Physical	> 4	3 to 2	4 to 3	0.21	>2.39	1.2	1.9
BHR23	C	3.13	4.48	3.87	1.35	Physical	> 4	<-1	4 to 3	0.21	3.48	2.6	
BHR24	A	16.74	20.49	19.17	3.75	Biological	> 4	2 to 1	>4	4.75	9.88	5.5	
BHR24	B	14.30	15.45	14.97	1.15	Biological	> 4	2 to 1	>4	4.07	14.48	5.0	4.3
BHR24	C	6.72	7.78	7.18	1.06	Biological	> 4	2 to 1	4 to 3	1.59	6.10	2.4	
BHR25	A	14.47	15.42	14.86	0.95	Biological	> 4	4 to 3	>4	0.27	1.74	0.5	
BHR25	B	14.62	15.51	15.11	0.89	Biological	> 4	4 to 3	>4	0.00	3.42	0.8	0.8
BHR25	C	17.13	18.01	17.66	0.88	Biological	> 4	4 to 3	>4	0.15	4.22	1.1	
BHR26	A	20.37	21.37	20.85	1.00	Biological	> 4	4 to 3	>4	0.18	1.68	0.4	
BHR26	B	21.99	22.49	22.23	0.50	Biological	> 4	4 to 3	>4	0.15	3.66	0.6	0.6
BHR26	C	21.66	22.45	21.96	0.79	Biological	> 4	4 to 3	>4	0.18	5.63	0.8	
BHR27	A	18.75	19.95	19.49	1.20	Biological	> 4	3 to 2	>4	1.15	7.37	1.6	
BHR27	B	14.53	15.77	15.11	1.24	Physical	> 4	3 to 2	4 to 3	0.00	4.04	0.6	2.1
BHR27	C	22.52	24.35	23.24	1.83	Biological	> 4	3 to 2	>4	3.92	12.38	4.0	
BHR28	A	6.92	11.25	9.29	4.33	Biological	> 4	3 to 2	4 to 3	0.74	5.22	1.7	
BHR28	B	14.88	15.86	15.52	0.98	Biological	> 4	3 to 2	4 to 3	0.38	10.52	2.5	2.3
BHR28	C	15.25	16.43	15.78	1.18	Biological	> 4	3 to 2	4 to 3	1.44	8.61	2.6	
BHR29	A	17.11	18.09	17.62	0.98	Biological	> 4	4 to 3	>4	1.36	8.00	2.6	
BHR29	B	16.94	17.74	18.10	0.80	Biological	> 4	3 to 2	4 to 3	2.30	8.73	3.1	2.9
BHR29	C	15.82	17.56	16.83	1.74	Biological	> 4	3 to 2	>4	1.50	9.26	2.9	
BHR30	A	8.00	9.38	8.79	1.38	Biological	> 4	4 to 3	>4	0.38	4.54	1.8	
BHR30	B	9.49	10.08	9.90	0.59	Biological	> 4	3 to 2	>4	0.47	5.01	1.6	1.5
BHR30	D	8.96	10.35	9.79	1.39	Biological	> 4	4 to 3	>4	0.00	6.37	1.0	
BHR31	A	11.65	13.03	12.21	1.38	Biological	> 4	3 to 2	>4	0.32	7.52	2.3	
BHR31	B	13.20	13.91	13.63	0.71	Biological	> 4	4 to 3	>4	1.62	6.46	3.5	2.8
BHR31	C	12.59	14.04	13.46	1.45	Biological	> 4	4 to 3	>4	1.62	5.93	2.3	

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Stat_ID	Replicate	Penetration Depth (cm)			Boundary Roughness		Grain Size (phi)			Redox Potential Discontinuity (RPD) Depth (cm)			
					Thickness	Type			Major	Replicates			Station
		Minimum	Maximum	Mean	(cm)		Minimum	Maximum	Mode	Minimum	Maximum	Mean	Mean
BHR32	A	17.35	18.71	17.94	1.36	Biological	> 4	4 to 3	>4	0.83	5.13	1.4	
BHR32	B	13.28	13.81	13.58	0.53	Biological	> 4	4 to 3	>4	0.00	5.25	1.6	1.5
BHR32	C	12.37	13.61	13.08	1.24	Biological	> 4	4 to 3	>4	0.38	4.86	1.6	
BHR33	A	12.20	13.32	13.00	1.12	Biological	> 4	2 to 1	>4	0.00	2.60	1.3	
BHR33	B	10.70	12.00	11.46	1.30	Biological	> 4	3 to 2	>4	0.44	3.57	0.7	1.3
BHR33	C	10.35	12.76	11.71	2.41	Biological	> 4	2 to 1	>4	0.56	3.01	1.8	
BHR34	A	17.36	17.83	17.60	0.47	Biological	> 4	2 to 1	>4	0.12	3.95	1.6	
BHR34	B	16.39	17.04	16.82	0.65	Biological	> 4	2 to 1	>4	0.35	3.86	1.6	1.6
BHR34	C	15.30	15.83	15.65	0.53	Biological	> 4	3 to 2	>4	1.00	3.36	1.6	
BHR35	A	13.15	14.18	13.72	1.03	Indeterminate	> 4	4 to 3	>4	0.24	6.01	1.2	
BHR35	B	17.39	17.89	17.65	0.50	Biological	> 4	4 to 3	>4	1.12	6.34	2.0	1.6
BHR35	C	13.80	14.98	14.23	1.18	Indeterminate	> 4	4 to 3	>4	0.44	4.83	1.6	
BHR36	A	3.31	4.60	4.02	1.29	Indeterminate	> 4	2 to 1	3 to 2	0.12	4.04	2.0	
BHR36	B	4.13	6.96	5.97	2.83	Physical	> 4	3 to 2	>4	0.00	3.60	0.5	1.7
BHR36	C	1.86	2.45	2.12	0.47	Physical	> 4	<-1	3 to 2	0.00	2.45	2.5	
BHR37	A	7.40	10.29	9.70	2.89	Physical	> 4	2 to 1	>4	0.27	7.84	1.6	
BHR37	B	13.27	13.80	13.64	0.53	Biological	> 4	3 to 2	>4	1.59	4.10	1.9	1.6
BHR37	C	12.68	14.15	13.32	1.47	Biological	> 4	3 to 2	>4	0.80	4.81	1.3	
BHR38	A	17.57	19.01	18.35	1.44	Biological	> 4	4 to 3	>4	1.00	4.24	2.5	
BHR38	B	11.85	13.21	12.60	1.36	Biological	> 4	4 to 3	>4	0.74	6.66	2.5	2.2
BHR38	C	13.00	13.88	13.61	0.88	Biological	> 4	4 to 3	>4	0.94	3.95	1.7	
BHR39	B	8.76	9.43	9.16	0.67	Biological	> 4	3 to 2	4 to 3	1.47	4.75	2.4	
BHR39	C	3.98	4.75	4.28	0.77	Physical	> 4	<-1	3 to 2	1.44	4.75	4.0	2.8
BHR39	D	5.42	6.63	5.86	1.21	Physical	> 4	<-1	4 to 3	0.00	4.78	2.0	
BHR40	A	12.64	13.19	12.95	0.55	Biological	> 4	4 to 3	>4	1.82	5.25	3.1	
BHR40	B	11.78	12.31	12.06	0.53	Biological	> 4	4 to 3	>4	2.03	10.28	4.5	3.8
BHR40	C	16.68	17.21	16.28	0.53	Biological	> 4	4 to 3	>4	2.14	9.28	6.0	
BHR41	C	15.71	16.29	15.99	0.58	Biological	> 4	3 to 2	>4	1.82	10.30	5.0	
BHR41	D	13.95	14.80	14.38	0.85	Biological	> 4	3 to 2	4 to 3	3.50	11.19	5.0	5.2
BHR41	E	13.69	15.01	14.56	1.32	Biological	> 4	3 to 2	4 to 3	4.93	8.89	5.5	
BHR42	A	6.37	7.34	6.96	0.97	Physical	> 4	3 to 2	4 to 3	2.00	3.43	1.8	
BHR42	C	6.72	7.92	7.43	1.20	Physical	> 4	3 to 2	4 to 3	1.53	5.49	2.1	2.0
BHR42	D	6.21	6.88	6.54	0.67	Physical	> 4	2 to 1	4 to 3	1.43	4.67	2.1	
BHR43	A	17.45	17.78	17.63	0.33	Biological	> 4	3 to 2	>4	0.10	6.01	1.9	
BHR43	B	15.62	16.36	16.07	0.74	Biological	> 4	3 to 2	>4	0.85	6.28	1.3	1.6
BHR43	C	15.18	15.77	15.52	0.59	Biological	> 4	3 to 2	>4	0.91	4.92	1.5	
BHR44	A	5.79	6.17	5.92	0.38	Physical	> 4	<-1	4 to 3	0.91	4.29	2.0	
BHR44	B	11.74	12.71	12.28	0.97	Biological	> 4	4 to 3	>4	0.38	4.29	1.9	2.6
BHR44	C	14.06	15.68	14.80	1.62	Biological	> 4	4 to 3	>4	2.06	7.07	4.0	
BHR45	A	13.88	15.74	14.64	1.86	Biological	> 4	3 to 2	>4	4.24	14.83	6.5	
BHR45	B	14.89	15.36	15.13	0.47	Biological	> 4	3 to 2	>4	4.45	12.17	7.5	7.3
BHR45	C	14.90	16.04	15.59	1.14	Biological	> 4	3 to 2	>4	3.92	13.35	8.0	
BHR46	A	14.94	15.92	15.62	0.98	Biological	> 4	4 to 3	>4	2.45	9.73	3.5	
BHR46	B	14.68	15.44	15.02	0.76	Biological	> 4	3 to 2	>4	2.30	7.78	2.5	2.6
BHR46	C	14.85	15.68	15.44	0.83	Biological	> 4	3 to 2	>4	1.18	8.67	2.9	

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Stat_ID	Replicate	Penetration Depth (cm)			Boundary Roughness		Grain Size (phi)			Redox Potential Discontinuity (RPD) Depth (cm)			
					Thickness	Type			Major	Replicates			Station
		Minimum	Maximum	Mean	(cm)		Minimum	Maximum	Mode	Minimum	Maximum	Mean	Mean
BHR47	A	18.46	20.10	19.44	1.64	Biological	> 4	4 to 3	>4	1.00	3.00	2.5	
BHR47	B	19.47	22.71	21.95	3.24	Biological	> 4	4 to 3	>4	0.72	2.89	2.0	2.5
BHR47	C	18.92	21.78	20.22	2.86	Biological	> 4	4 to 3	>4	2.40	4.70	3.0	
BHR48	A	14.89	15.68	15.40	0.79	Biological	> 4	2 to 1	>4	0.71	3.08	1.1	
BHR48	B	14.74	15.18	14.91	0.44	Biological	> 4	3 to 2	>4	0.00	3.68	1.3	1.2
BHR48	C	14.18	14.89	14.57	0.71	Biological	> 4	3 to 2	>4	0.83	3.89	1.2	
BHR49	A	15.65	16.30	15.87	0.65	Physical	> 4	4 to 3	>4	0.00	3.45	0.6	
BHR49	B	18.27	20.19	19.35	1.92	Physical	> 4	<-1	>4	0.00	3.69	0.9	0.9
BHR49	C	12.58	14.58	13.75	2.00	Physical	> 4	3 to 2	4 to 3	0.00	11.37	1.3	
BHR50	A	13.87	15.55	14.98	1.68	Biological	> 4	3 to 2	>4	0.36	4.66	2.1	
BHR50	B	10.76	16.36	14.46	5.60	Biological	> 4	3 to 2	4 to 3	0.62	10.11	1.9	2.0
BHR50	C	14.42	15.36	14.88	0.94	Biological	> 4	3 to 2	>4	0.21	6.63	1.9	
BHR51	A	10.46	11.17	10.80	0.71	Physical	> 4	4 to 3	>4	0.00	1.35	0.4	
BHR51	B	10.91	12.23	11.57	1.32	Physical	> 4	4 to 3	>4	0.00	2.56	0.9	1.1
BHR51	C	10.79	11.82	11.39	1.03	Indeterminate	> 4	4 to 3	4 to 3	0.11	9.53	1.9	
BHR52	A	8.49	9.76	9.33	1.27	Biological	> 4	4 to 3	>4	0.91	4.01	1.9	
BHR52	B	11.61	12.71	11.97	1.10	Biological	> 4	4 to 3	>4	0.12	4.48	1.1	1.4
BHR52	C	11.61	12.50	12.10	0.89	Biological	> 4	3 to 2	>4	0.35	4.19	1.1	
BHR53	A	9.79	10.76	10.21	0.97	Physical	> 4	4 to 3	>4	0.11	2.32	1.3	
BHR53	B	11.05	11.59	11.35	0.54	Physical	> 4	3 to 2	>4	0.00	2.06	0.7	1.0
BHR53	C	7.43	7.90	7.70	0.47	Physical	> 4	<-1	>4	0.09	4.86	1.1	
BHT1	A	8.08	9.07	8.44	0.99	Biological	> 4	3 to 2	>4	0.40	4.00	1.5	
BHT1	B	7.85	10.08	9.23	2.23	Indeterminate	> 4	<-1	>4	0.00	3.96	2.0	1.9
BHT1	C	7.12	8.17	7.89	1.05	Physical	> 4	3 to 2	4 to 3	0.00	3.72	2.2	
BHT2	A	11.83	12.56	12.11	0.73	Biological	> 4	4 to 3	>4	1.70	5.67	1.3	
BHT2	B	14.91	16.67	16.03	1.76	Biological	> 4	4 to 3	>4	1.23	10.83	2.5	1.9
BHT2	C	15.73	17.44	16.70	1.71	Biological	> 4	4 to 3	>4	0.50	4.35	1.8	
BHT3	A	17.70	18.96	18.42	1.26	Biological	> 4	4 to 3	>4	6.67	15.56	8.0	
BHT3	B	17.94	19.11	18.59	1.17	Biological	> 4	4 to 3	>4	6.14	13.21	7.0	7.7
BHT3	C	14.15	16.26	15.44	2.11	Biological	> 4	4 to 3	>4	5.14	12.21	8.0	
BHT4	A	20.69	21.28	21.08	0.59	Indeterminate	> 4	4 to 3	>4	0.00	0.00	0.0	
BHT4	B	20.76	21.81	21.42	1.05	Indeterminate	> 4	4 to 3	>4	0.00	0.00	0.0	0.0
BHT4	C	20.70	21.11	20.95	0.41	Indeterminate	> 4	4 to 3	>4	0.00	0.00	0.0	
BHT5A	A	8.34	8.55	9.04	0.21	Biological	> 4	3 to 2	4 to 3	1.62	4.14	2.4	
BHT5A	B	8.37	9.45	9.16	1.08	Biological	> 4	2 to 1	>4	1.44	3.93	2.6	2.2
BHT5A	C	6.25	6.90	6.57	0.65	Biological	> 4	3 to 2	4 to 3	0.76	2.85	1.7	
BHT6	A	9.23	10.20	9.70	0.97	Biological	> 4	4 to 3	>4	0.86	10.20	2.0	
BHT6	B	3.68	9.55	5.86	5.87	Biological	> 4	4 to 3	>4	1.03	5.84	2.0	1.7
BHT6	C	11.35	12.76	11.97	1.41	Biological	> 4	4 to 3	>4	0.41	6.13	1.0	
BHT7	A	13.18	13.91	13.62	0.73	Biological	> 4	4 to 3	>4	0.91	10.79	3.0	
BHT7	B	13.52	14.89	14.05	1.37	Physical	> 4	4 to 3	>4	0.00	13.56	3.1	2.7
BHT7	C	7.87	13.44	11.15	5.57	Physical	> 4	4 to 3	>4	0.00	10.17	2.0	
BHT8	A	5.91	6.77	6.30	0.86	Physical	4 to 3	3 to 2	4 to 3	3.69	>6.77	>6.3	
BHT8	B	3.80	6.98	5.48	3.18	Physical	4 to 3	<-1	3 to 2	>3.80	>6.98	>5.5	>3.7
BHT8	C	4.25	7.11	5.66	2.86	Biological	> 4	2 to 1	3 to 2	1.28	5.60	2.5	

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Stat_ID	Replicate	Methane Bubbles		Anoxia	Successional	Organism	Comments
		Number	Depth in	Low DO	Stage	Sediment	
			sediment (cm)			Index (OSI)	
BHR02	A	2	17.5	No	Stage II	2	Thick amphipod tube mat
BHR02	B	3	17.0	No	Stage II	2	Thick amphipod tube mat
BHR02	C	30	10.0	No	Stage II	2	Thick amphipod tube mat
BHR03	A	0	-	No	Stage I	5	Well-sorted fine sand
BHR03	B	0	-	No	Stage II on III	11	Amphipod tubes
BHR03	C	0	-	No	Stage I	7	Rippled
BHR04	B	0	-	No	Stage II on III	7	Amphipod tube mat
BHR04	C	0	-	No	Stage II on III	7	Amphipod tube mat
BHR04	D	0	-	No	Stage II on III	7	Amphipod tube mat
BHR05	A	0	-	No	Stage II on III	7	Amphipod tube mat
BHR05	B	0	-	No	Stage II on III	7	Amphipod tube mat
BHR05	C	0	-	No	Stage II on III	7	Amphipod tube mat
BHR06	A	0	-	No	Stage I	2	Cobbles on surface
BHR06	B	0	-	No	Stage I	4	Cobbles on surface
BHR06	C	0	-	No	Stage I	4	Cobbles on surface
BHR07	A	0	-	No	Stage II on III	7	Amphipod tube mat
BHR07	B	0	-	No	Stage II on III	8	Amphipod tube mat
BHR07	C	0	-	No	Stage II on III	7	Amphipod tube mat
BHR08	A	0	-	No	Indeterminate	Indeterminate	Rippled (?)
BHR08	B	0	-	No	Indeterminate	Indeterminate	Rippled (?)
BHR08	C	0	-	No	Indeterminate	Indeterminate	Scour lag; rippled (?)
BHR09	A'	20	11.5	No	Stage I on III	5	High sedimentation rate
BHR09	B'	3	10.5	No	Stage I	2	High sedimentation rate
BHR09	D	3	21.0	No	Stage I	1	High sedimentation rate
BHR10	A'	0	-	No	Stage I	3	High sedimentation rate
BHR10	B	0	-	No	Stage I	3	High sedimentation rate
BHR10	D	0	-	No	Stage I	4	High sedimentation rate
BHR11	A	0	-	No	Stage II on III	11	Amphipod tube mat
BHR11	B	0	-	No	Stage II on III	11	Amphipod tube mat
BHR11	D	0	-	No	Stage II on III	11	Amphipod tube mat
BHR12	A	0	-	No	Stage II	9	Amphipod tube mat
BHR12	B	0	-	No	Stage II on III	11	Amphipod tube mat
BHR12	D	0	-	No	Stage II on III	11	Amphipod tube mat
BHR13	A	0	-	No	Stage II	7	A few amphipod tubes; chaotic fabric
BHR13	B	0	-	No	Stage I	4	Chaotic fabric
BHR13	C	0	-	No	Stage II on III	9	A few amphipod tubes; shell lag
BHR14	A	0	-	No	Stage II	8	Well-developed amphipod tube mat
BHR14	B	0	-	No	Stage II on III	10	Amphipod tube mat
BHR14	C	0	-	No	Stage I	3	Disturbed bottom
BHR15	A	0	-	No	Stage II on III	11	A few amphipod tubes in ripped-up mat
BHR15	B	0	-	No	Stage I on III	11	Ripped-up tube mat
BHR15	C	0	-	No	Stage II on III	11	A few amphipod tubes in ripped-up mat
BHR16	A	0	-	No	Stage I	5	Erosional lag (tubes and shells)
BHR16	B	0	-	No	Stage I on III	7	Ripped-up tube mat
BHR16	C	0	-	No	Stage I	7	Retrograde tube mat

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Stat_ID	Replicate	Methane Bubbles		Anoxia	Successional	Organism	Comments
		Number	Depth in	Low DO	Stage	Sediment	
			sediment (cm)			Index (OSI)	
BHR17	A	0	-	No	Stage II	6	Healthy new amphipod tube mat
BHR17	B	0	-	No	Stage II	9	Healthy new amphipod tube mat
BHR17	C	0	-	No	Stage II on III	9	Healthy new amphipod tube mat
BHR18	A	0	-	No	Stage II	9	Retrograde Stage II amphipod tube mat
BHR18	B	0	-	No	Stage II	9	Retrograde Stage II amphipod tube mat
BHR18	C	10	15.0	No	Stage II	7	Retrograde Stage II amphipod tube mat
BHR19	A	0	-	No	Stage I	4	Tube mat
BHR19	B	0	-	No	Stage I	4	Erosional; scour lag
BHR19	C	0	-	No	Stage I	4	Scour lag
BHR20	A	0	-	No	Stage II on III	11	Amphipod tube mat
BHR20	B	0	-	No	Stage II on III	11	Amphipod tube mat
BHR20	C	0	-	No	Stage II on III	11	Amphipod tube mat
BHR21	A	0	-	No	Stage II	9	Amphipod tube mat
BHR21	B	0	-	No	Stage II	9	Amphipod tube mat
BHR21	C	0	-	No	Stage II	9	Healthy amphipod tube mat
BHR22	A	0	-	No	Stage II	7	Amphipod tube mat
BHR22	B	0	-	No	Stage II	9	Retrograde Stage II amphipod tube mat
BHR22	C	0	-	No	Stage I	6	Erosional; scour lag
BHR23	A	0	-	No	Stage II	6	Healthy amphipod tube mat
BHR23	B	0	-	No	Stage II	5	Erosional; remnants of amphipod tube mat
BHR23	C	0	-	No	Stage II	7	Erosional; remnants of amphipod tube mat
BHR24	A	0	-	No	Stage II on III	11	Retrograde amphipod tube mat
BHR24	B	0	-	No	Stage II	9	Amphipod tube mat
BHR24	C	0	-	No	Stage II	7	Healthy amphipod tube mat
BHR25	A	0	-	No	Stage II	4	Healthy amphipod tube mat
BHR25	B	0	-	No	Stage II on III	7	Eroded amphipod tube mat
BHR25	C	0	-	No	Stage II	5	Amphipod tube mat
BHR26	A	0	-	No	Stage II	4	High sedimentation rate; a few amphipod tubes
BHR26	B	0	-	No	Stage I	2	High sedimentation rate
BHR26	C	0	-	No	Stage I on III	7	High sedimentation rate
BHR27	A	0	-	No	Stage II on III	8	Amphipod tube mat
BHR27	B	0	-	No	Stage I	2	Erosional; decaying Stage II amphipod tube mat
BHR27	C	0	-	No	Stage II	9	Amphipod tube mat
BHR28	A	0	-	No	Stage II	6	Healthy amphipod tube mat
BHR28	B	0	-	No	Stage II	7	Healthy amphipod tube mat
BHR28	C	0	-	No	Stage II	7	Amphipod tube mat over most of surface
BHR29	A	0	-	No	Stage II on III	9	Healthy amphipod tube mat
BHR29	B	0	-	No	Stage II	8	Healthy amphipod tube mat
BHR29	C	0	-	No	Stage II	7	Amphipod tube mat
BHR30	A	0	-	No	Stage II	6	Amphipod tube mat
BHR30	B	0	-	No	Stage II	6	Amphipod tube mat
BHR30	D	0	-	No	Stage II on III	7	Amphipod tube mat
BHR31	A	0	-	No	Stage II	7	Healthy amphipod tube mat
BHR31	B	0	-	No	Stage II	8	Amphipod tube mat
BHR31	C	0	-	No	Stage II	7	Amphipod tube mat

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Stat_ID	Replicate	Methane Bubbles		Anoxia	Successional	Organism	Comments
		Number	Depth in	Low DO	Stage	Sediment	
			sediment (cm)			Index (OSI)	
BHR32	A	0	-	No	Stage I on III	7	Pelletized v. fine sand over sulfidic mud
BHR32	B	0	-	No	Stage I	4	Pelletized v. fine sand over sulfidic mud
BHR32	C	0	-	No	Stage I	4	Pelletized v. fine sand over sulfidic mud
BHR33	A	0	-	No	Stage I on III	7	Pelletized sand over sulfidic mud
BHR33	B	0	-	No	Stage I on III	6	Pelletized sand over sulfidic mud
BHR33	C	0	-	No	Stage I on III	8	Pelletized v. fine sand over sulfidic mud
BHR34	A	0	-	No	Stage I on III	8	Pelletized v. fine sand over sulfidic mud
BHR34	B	0	-	No	Stage I on III	8	Pelletized v. fine sand over sulfidic mud
BHR34	C	0	-	No	Stage I	4	Pelletized v. fine sand over sulfidic mud
BHR35	A	0	-	No	Stage II on III	7	A few amphipod tubes
BHR35	B	0	-	No	Stage I	4	Pelletized v. fine sand over sulfidic mud
BHR35	C	0	-	No	Stage I	4	Dead amphipod tube layer
BHR36	A	0	-	No	Stage I	4	Thin layer silt over fine sand
BHR36	B	0	-	No	Stage I	2	Chaotic fabric; erosional
BHR36	C	0	-	No	Stage I	5	Erosional with lag
BHR37	A	0	-	No	Stage II	6	Erosional; low density of amphipod tubes
BHR37	B	0	-	No	Stage II on III	8	New amphipod tube mat
BHR37	C	0	-	No	Stage II on III	7	New amphipod tube mat
BHR38	A	0	-	No	Stage II on III	9	Ripped-up amphipod tube mat
BHR38	B	0	-	No	Stage II on III	9	Amphipod tube mat
BHR38	C	0	-	No	Stage II on III	8	Amphipod tube mat
BHR39	B	0	-	No	Stage II	7	Retrograde amphipod tube mat
BHR39	C	0	-	No	Indeterminate	Indeterminate	Scour lag (shells and pebbles)
BHR39	D	0	-	No	Indeterminate	Indeterminate	Scour lag (shells and pebbles)
BHR40	A	0	-	No	Stage I on III	10	V. fine sand over mud
BHR40	B	0	-	No	Stage II on III	11	V. fine sand over mud; low density amphipod tubes
BHR40	C	0	-	No	Stage II on III	11	V. fine sand over mud; low density amphipod tubes
BHR41	C	0	-	No	Stage I on III	11	Dead amphipod tube mat
BHR41	D	0	-	No	Stage I on III	11	Dead amphipod tube mat
BHR41	E	0	-	No	Stage II on III	11	Amphipod tube mat, living and dead tubes
BHR42	A	0	-	No	Stage I on III	8	Rippled; sand over mud
BHR42	C	0	-	No	Stage I	4	Rippled; sand over mud
BHR42	D	0	-	No	Indeterminate	Indeterminate	Rippled; sand over mud
BHR43	A	0	-	No	Stage I	4	Pelletized v. fine sand over sulfidic mud
BHR43	B	0	-	No	Stage I	3	Pelletized v. fine sand over sulfidic mud
BHR43	C	0	-	No	Stage I on III	7	Pelletized v. fine sand over sulfidic mud
BHR44	A	0	-	No	Stage I	4	Erosional
BHR44	B	0	-	No	Stage II	6	Amphipod tube mat
BHR44	C	0	-	No	Stage II on III	11	Amphipod tube mat
BHR45	A	0	-	No	Stage II on III	11	Amphipod tube mat
BHR45	B	0	-	No	Stage II	9	Amphipod tube mat
BHR45	C	0	-	No	Stage II	9	Amphipod tube mat
BHR46	A	0	-	No	Stage II	8	Amphipod tube mat
BHR46	B	0	-	No	Stage II on III	9	Amphipod tube mat
BHR46	C	0	-	No	Stage II	7	Amphipod tube mat

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Stat_ID	Replicate	Methane Bubbles		Anoxia	Successional	Organism	Comments
		Number	Depth in sediment (cm)	Low DO	Stage	Sediment Index (OSI)	
BHR47	A	0	-	No	Stage II on III	9	Amphipod tube mat
BHR47	B	0	-	No	Stage II on III	8	Amphipod tube mat
BHR47	C	0	-	No	Stage II on III	9	Ripped-up amphipod tube mat
BHR48	A	0	-	No	Stage I on III	7	Pelletized v. fine sand over sulfidic mud
BHR48	B	0	-	No	Stage I - II	4	Pelletized v. fine sand over sulfidic mud
BHR48	C	0	-	No	Stage I - II	4	Pelletized v. fine sand over sulfidic mud
BHR49	A	0	-	No	Indeterminate	Indeterminate	Erosional; shell lag
BHR49	B	0	-	No	Indeterminate	Indeterminate	Erosional; shell lag
BHR49	C	0	-	No	Stage I	3	Erosional; shell lag
BHR50	A	0	-	No	Stage II on III	8	Healthy amphipod tube mat
BHR50	B	0	-	No	Stage II	6	Healthy amphipod tube mat
BHR50	C	0	-	No	Stage II on III	8	Amphipod tube mat
BHR51	A	0	-	No	Stage I	2	Rippled; pelletized v. fine sand over sulfidic mud
BHR51	B	2	9.0	No	Stage I	1	Rippled; pelletized v. fine sand over sulfidic mud
BHR51	C	0	-	No	Stage I - II	5	Rippled; pelletized v. fine sand over sulfidic mud
BHR52	A	0	-	No	Stage I	4	Pelletized v. fine sand over sulfidic mud
BHR52	B	5	7.0	No	Stage I	1	Pelletized v. fine sand over sulfidic mud
BHR52	C	10	8.0	No	Stage I	1	Pelletized v. fine sand over sulfidic mud
BHR53	A	0	-	No	Stage I - II	4	Rippled; pelletized v. fine sand over sulfidic mud
BHR53	B	0	-	No	Stage I	2	Rippled; pelletized v. fine sand over sulfidic mud
BHR53	C	0	-	No	Stage I	3	Rippled; pelletized v. fine sand over sulfidic mud
BHT1	A	0	-	No	Stage I	3	Pelletized surface sand over mud
BHT1	B	0	-	No	Stage I on III	8	Scour lag; pelletized sand over mud
BHT1	C	0	-	No	Stage I	4	Scour lag; pelletized sand over mud
BHT2	A	0	-	No	Stage II on III	7	Amphipod tube mat
BHT2	B	0	-	No	Stage II	7	Amphipod tube mat
BHT2	C	0	-	No	Stage II	6	Amphipod tube mat
BHT3	A	0	-	No	Stage II	9	Ripped-up amphipod tube mat
BHT3	B	0	-	No	Stage II on III	11	Ripped-up amphipod tube mat
BHT3	C	0	-	No	Stage II	9	Ripped-up amphipod tube mat
BHT4	A	0	-	Yes	Stage I	-3	Dark sulfidic mud
BHT4	B	5	16.0	Yes	Stage I	-5	Dark sulfidic mud
BHT4	C	0	-	Yes	Azoic	-8	Dark sulfidic mud
BHT5A	A	0	-	No	Stage II	7	New amphipod tube mat
BHT5A	B	0	-	No	Stage II	7	New amphipod tube mat
BHT5A	C	0	-	No	Stage II	6	New amphipod tube mat
BHT6	A	0	-	No	Stage II on III	8	Healthy amphipod tube mat
BHT6	B	0	-	No	Stage II	6	Healthy amphipod tube mat
BHT6	C	0	-	No	Stage II	5	Amphipod tube mat
BHT7	A	0	-	No	Stage II on III	9	Retrograde amphipod tube mat
BHT7	B	0	-	No	Stage I	6	Chaotic fabric; scour lag
BHT7	C	0	-	No	Indeterminate	Indeterminate	Chaotic fabric; scour lag
BHT8	A	0	-	No	Stage II	9	Ripped-up amphipod tube mat
BHT8	B	0	-	No	Indeterminate	Indeterminate	Erosional; scour lag
BHT8	C	0	-	No	Stage II	7	Amphipod tube mat

Appendix C1. Grain-size composition of sediment from the eight Traditional Boston Harbor stations taken in April and August 1995. Data are percentages of total initial sample weight.

Station	% Gravel	% Very Coarse Sand	% Coarse Sand	% Medium Sand	% Fine Sand	% Very Fine Sand	% Total Sand	% Silt	% Clay	Mean Phi
	>2.00 mm	>1.00 to 2.00 mm	>0.50 to 1.00 mm	>0.25 to 0.50 mm	>0.125 to 0.25 mm	>0.0625 to 0.125 mm	>0.0625 to 2.00 mm	>0.0039 to 0.0625 mm	<0.0039 mm	
	Phi < -1	-1 < Phi < 0	0 < Phi < 1	1 < Phi < 2	2 < Phi < 3	3 < Phi < 4	-1 < Phi < 4	4 < Phi < 8	Phi > 8	
April										
T1	18.1	1.97	2.92	9.22	17.64	36.74	68.5	9.4	4.0	2.52
T2	1.5	0.15	0.39	1.70	8.89	34.08	45.2	33.3	20.0	5.22
T3	0.0	0.00	0.79	1.45	2.38	5.02	9.7	50.1	40.2	6.89
T4	0.0	0.20	0.40	1.59	2.19	4.38	8.8	54.9	36.3	6.80
T5a	0.2	0.07	0.57	1.17	41.38	40.78	84.0	9.7	6.1	3.61
T6	3.9	1.60	2.21	5.50	16.38	35.40	61.1	20.8	14.2	4.21
T7	19.5	9.16	6.14	6.71	7.39	7.29	36.7	27.9	16.0	3.34
T8	2.9	0.59	1.45	37.14	51.56	2.59	93.3	2.6	1.2	2.16
August										
T1	6.7	1.31	1.81	2.67	6.39	20.03	32.2	58.3	2.8	4.55
T2	0.0	0.00	0.47	3.87	7.04	29.96	41.3	38.6	20.0	5.41
T3	0.0	0.00	0.00	1.40	2.69	7.72	11.8	52.0	36.2	6.73
T4	0.6	0.09	0.00	0.28	0.95	4.35	5.7	57.7	36.0	6.88
T5a	0.5	0.00	0.05	1.83	46.25	39.65	87.8	8.1	3.6	3.37
T6	2.5	1.34	1.06	0.58	10.46	17.66	31.1	41.6	24.8	5.58
T7	24.3	7.37	2.02	1.46	0.70	6.33	17.9	34.9	22.9	4.03
T8	0.4	0.65	0.53	17.16	72.33	4.69	95.4	1.8	2.4	2.55

Appendix C2. Total organic carbon (%) in sediment samples from the eight Traditional Boston Harbor stations, April and August 1995.

Station	Total Organic Carbon %	Station Mean
April		
T1	0.93	0.93
T2	1.49	1.49
T3; T3 Dup	3.54; 3.43	3.49
T4	6.25	6.25
T5a	0.68	0.68
T6	1.60	1.60
T7	3.06	3.06
T8	0.18	0.18
August		
T1	1.18	1.18
T2	2.05	2.05
T3	3.54	3.54
T4	3.69	3.69
T5a	0.42	0.42
T6	1.83	1.83
T7	3.17	3.17
T8	0.21	0.21

Appendix C3. *Clostridium perfringens* spore analysis on sediment samples from the eight Traditional Boston Harbor stations, April and August 1995.

Station	% Water	Counts	Mean	Coefficient of Variation	*C. perfringens* Wet Weight	Spores per Gram Dry Weight Sample Mean	Spores per Gram Dry Weight Station Mean
April							
T1	41	61, 50	55.5	.14	4300	7300	7300
T2	57	113, 104	108.5	.06	17000	40000	40000
T3	68	30, 34	32.0	.09	24000	75000	75000
T4	69	64, 58	61.0	.07	9000	29000	29000
T5a	27	68, 69	68.5	.01	5000	6800	6800
T6	51	67, 73	70.0	.06	11000	22000	22000
T7	62	76, 91	73.5	.13	13000	34000	34000
T8	27	30, 24	27.0	.16	2100	2900	2900
T8 Dup.	27	27, 27	27.0	.00	2100	2900	-
August							
T1	33	5, 5	5.0	.00	780	1200	1200
T2	56	44, 54	49.0	.14	6600	15000	15000
T3	70	73, 65	69.0	.08	10000	33000	33000
T4	61	29, 32	30.5	.07	4800	12000	12000
T5a	32	6, 5	5.5	.13	730	1100	1100
T6	58	18, 14	16.0	.18	2600	6200	6200
T7	60	32, 28	30.0	.09	4200	11000	11000
T8	29	2, 3	2.5	.28	360	510	955

Appendix D1. List of species identified from the 1995 Harbor Traditional samples.

CNIDARIA
- *Ceriantheopsis americanus* (VERRILL, 1866)

PLATYHELMINTHES
- Turbellaria

NEMERTEA
- *Cerebratulus lacteus* (Leidy, 1851)
- Nemertea sp.

SIPUNCULA
- Sipuncula sp.

ANNELIDA
- Polychaeta
  - Ampharetidae
    - *Ampharete finmarchica* (Sars, 1865)
    - *Asabellides oculata* (Webster, 1879)
  - Capitellidae
    - *Capitella capitata* complex (Fabricius, 1780)
    - *Mediomastus californiensis* Hartman, 1944
  - Cirratulidae
    - *Chaetozone vivipara* (Christie, 1985)
    - *Cirriformia grandis* (Verrill, 1873)
    - *Monticellina baptisteae* Blake, 1991
    - *Tharyx acutus* Webster & Benedict, 1887
  - Dorvilleidae
    - Dorvilleidae sp. A
    - *Parougia caeca* (Webster & Benedict, 1884)
  - Flabelligeridae
    - *Pherusa affinis* (Leidy, 1855)
  - Glyceridae
    - *Glycera dibranchiata* Ehlers, 1868
  - Hesionidae
    - *Microphthalmus aberrans* (Webster & Benedict, 1887)
  - Lumbrineridae
    - *Scoletoma acicularum* (Webster & Benedict, 1887)
    - *Scoletoma hebes* (Verrill, 1880)
    - *Ninoe nigripes* Verrill, 1873
  - Maldanidae
    - *Clymenella torquata* (Leidy, 1855)
  - Nephtyidae
    - *Aglaophamus circinata* (Verrill, 1874)
    - *Nephtys caeca* (Fabricius, 1780)
    - *Nephtys cornuta* Berkeley & Berkeley, 1945
    - *Nephtys incisa* Malmgren, 1865
  - Nereididae
    - *Neanthes virens* Sars, 1835
    - *Nereis diversicolor* Müller, 1776
  - Orbiniidae
    - *Leitoscoloplos robustus* (Verrill, 1873)
  - Paraonidae
    - *Aricidea catherinae* Laubier, 1967
  - Pectinariidae
    - *Pectinaria granulata* (Linnaeus, 1767)
    - *Pectinaria hyperborea* (Malmgren, 1866)
  - Pholoidae
    - *Pholoe minuta* (Fabricius, 1780)
  - Phyllodocidae
    - *Eteone heteropoda* Hartman, 1951
    - *Eteone longa* (Fabricius, 1780)
    - *Paranaitis speciosa* (Webster, 1870)
    - *Phyllodoce groenlandica* Oersted, 1843
    - *Phyllodoce maculata* (Linnaeus, 1767)
    - *Phyllodoce mucosa* Oersted, 1843
  - Polygordiidae
    - *Polygordius* sp. A
  - Polynoidae
    - *Harmothoe imbricata* (Linnaeus, 1767)
  - Sabellidae
    - *Fabricia stellaris stellaris* (Müller, 1774)
  - Scalibregmatidae
    - *Scalibregma inflatum* Rathke, 1843
  - 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* Calparède, 1863
    - *Scolelepis bousfieldi* Pettibone, 1963
    - *Scolelepis texana* Foster, 1971
    - *Spio filicornis* (O.F.Müller, 1766)
    - *Spio limicola* Verrill, 1880
    - *Spio setosa* Verrill, 1873
    - *Spio thulini* Maciolek, 1990
    - *Spiophanes bombyx* Claparède, 1870
    - *Streblospio benedicti* Webster, 1879
  - Syllidae
    - *Exogone hebes* (Webster & Benedict, 1884)
    - *Exogone verugera* (Claparède, 1868)
    - *Proceraea cornuta* Agassiz, 1863
    - *Typosyllis alternata* (Moore, 1908)
  - Terebellidae
    - *Nicolea zostericola* (Oersted, 1844)
    - *Polycirrus medusa* Grube, 1850

- Oligochaeta
  - Tubificidae
    - Tubificidae sp. 3
    - *Tubificoides apectinatus* Brinkhurst, 1965
    - *Tubificoides benedeni* Udekem, 1855
    - *Tubificoides* nr. *pseudogaster* Dahl, 1960
    - Tubificoides sp. 2

CHELICERATA
- Pycnogonidae
  - *Achelia spuinosa*

CRUSTACEA
- Amphipoda
  - Ampeliscidae
    - *Ampelisca abdita* Mills, 1964
    - *Ampelisca vadorum* Mills, 1963
  - Aoridae
    - *Lembos websteri* Bate, 1856
    - *Leptocheirus pinguis* (Stimpson, 1853)
    - *Unciola irrorata* Say, 1818
  - Argissidae
    - *Argissa hamatipes* (Norman, 1869)
  - Corophiidae
    - *Corophium acherusicum* Costa, 1857
    - *Corophium acutum* Chevreux, 1908
    - *Corophium bonelli* (Milne Edwards, 1830)
    - *Corophium crassicorne* Bruzelius, 1859
    - *Corophium insidiosum* Crawford, 1937
    - *Corophium tuberculatum* Shoemaker, 1934
    - *Corophium* sp. A

Appendix D1 (Continued)

- Caprellidae
  - *Aeginina longicornis* (Krøyer, 1842-43)
  - *Caprella linearis* (Linnaeus, 1767)
  - *Paracaprella tenuis* Mayer, 1903
- Dexaminidae
  - *Dexamine thea* Boeck, 1861
- Gammaridae
  - *Gammarus lawrencianus* Bousfield, 1956
- Isaeidae
  - *Photis pollex* Walker, 1895
- Ischyroceridae
  - *Ischyrocerus anguipes* (Krøyer, 1842)
  - *Jassa marmorata* Holmes, 1903
- Lysianassidae
  - *Orchomenella minuta* (Krøyer, 1842)
- Phoxocephalidae
  - *Phoxocephalus holbolli* (Krøyer, 1842)
- Podoceridae
  - *Dyopedos monacanthus* (Metzger, 1875)
- Pontogeniidae
  - *Pontogenia inermis* (Krøyer, 1842)
- Stenothoidae
  - *Metopella angusta* Shoemaker, 1949
  - *Metopella carinata* (Hansen, 1887)
  - *Proboloides holmesi* Bousfield, 1973
  - *Stenothoe minuta* Holmes, 1905

- Cirripedia
  - Balanidae
    - *Balanus crenatus* Bruguiere, 1789
    - *Balanus improvisus* Darwin, 1854

- Cumacea
  - Diastylidae
    - *Diastylis polita* (S.I. Smith, 1879)
    - *Diastylis sculpta* Sars, 1871
  - Lampropidae
    - *Lamprops quadriplicata* S.I. Smith, 1879
  - Leuconidae
    - *Eudorella pusilla* Sars, 1871

- Decapoda
  - Cancridae
    - *Cancer irroratus* Say, 1817
  - Crangonidae
    - *Crangon septemspinosa* Say, 1818

- Isopoda
  - Chaetiliidae
    - *Chiridotea tuftsi* (Stimpson, 1883)
  - Idoteidae
    - *Edotia triloba* (Say, 1818)
  - Paramunnidae
    - *Pleurogonium inerme* Sars, 1882

- Mysidacea
  - Mysidae
    - *Neomysis americana* (S.I. Smith, 1873)

- Tanaidacea
  - Nototanaidae
    - *Tanaissus psammophilus* (Wallace, 1919)

- MOLLUSCA
  - Bivalvia
    - Arctidae
      - *Arctica islandica* (Linnaeus, 1767)
    - Cardiidae
      - *Cerastoderma pinnulatum* (Conrad, 1831)
    - Hiatellidae
      - *Hiatella arctica* (Linnaeus, 1767)
    - Lyonsiidae
      - *Lyonsia arenosa* Möller, 1842
      - *Lyonsia hyalina* Conrad, 1831
    - Mactridae
      - *Mulinia lateralis* (Say, 1822)
      - *Spisula solidissima* (Dillwyn, 1817)
    - Myidae
      - *Mya arenaria* Linnaeus, 1758
    - Mytilidae
      - *Musculus niger* (Gray, 1824)
      - *Mytilus edulis* Linnaeus, 1758
    - Nuculidae
      - *Nucula annulata* Hampson, 1971
      - *Nucula delphinodonta* Mighels & Adams, 1842
    - Petricolidae
      - *Petricola pholadiformis* (Lamarck, 1818)
    - Solenidae
      - *Ensis directus* Conrad, 1843
    - Tellinidae
      - *Macoma balthica* (Linnaeus, 1758)
      - *Tellina agilis* Stimpson, 1857
    - Veneridae
      - *Pitar morrhuanus* Linsley, 1848

  - Gastropoda
    - Nudibranchia
      - Nudibranchia sp.
    - Prosobranchia
      - Calyptraeidae
        - *Crepidula maculosa* Conrad, 1846
      - Lacunidae
        - *Lacuna vincta* (Montagu, 1803)
      - Nassariidae
        - *Ilyanassa trivittata* (Sars, 1822)
      - Naticidae
        - *Polinices duplicatus* (Say, 1822)
- PHORONIDA
  - *Phoronis* sp.

- ECHINODERMATA
  - Ophiuroidea
    - Ophiuroidea spp.

- CHORDATA
  - Ascidiacea
    - Ascidiacea sp.
    - Molgulidae
      - *Molgula* sp.

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