2003 Boston Harbor benthic monitoring report

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EXECUTIVE SUMMARY

The direct discharge of waste products into Boston Harbor has had a profound impact on the composition of biological communities in the harbor. Given that most pollutants are particle reactive, the sediments are the final sinks for these pollutants and where ecosystem function is most likely to be disrupted by toxic or enrichment effects. Surficial sediments are critical to many ecosystem functions with energy flows (organic carbon, living biomass, secondary production) and nutrients (nitrogen, phosphorus) regulated by processes at the sediment-water interface. Thus, characterization of the benthic environment from physical and biological points of view has been a key part of the MWRA long-term sediment monitoring within Boston Harbor.

As the MWRA improved the quality of the discharge and then diverted it to the new offshore outfall in September 2000, monitoring was conducted twice a year, in April and August, to track changes in the sediments and the biological communities. In 2003, sampling was reduced to once a year (August). Results from the 2003 harbor benthic survey are presented in this report and compared with results from 1991–2002. Recent reports have suggested that the infaunal community is responding to some degree to changes in the discharges to the harbor. The occurrence and spread of *Ampelisca abdita* tube mats, and the increase in species numbers and diversity at some of the stations are considered especially informative.

Sediment Properties

Sediment grain size and total organic carbon (TOC) as measured at the eight traditional harbor stations in 2003 generally were within the ranges observed in previous years (1991–2002). Trends in TOC suggest a slight decrease over time, although variation in the data is high and the correlation between year and TOC is not significant. Trends in TOC are confounded by the influence of a single station, T04, located in a highly depositional environment.

Abundances of *Clostridium perfringens* have decreased on a harbor-wide basis since 1998, and the system appears to be less variable. Statistical tests also show that the observed decrease in *C. perfringens* abundances over time is significant. These findings support the premise that cessation of sewage sludge disposal to the harbor in 1991 and subsequent improvements in sewage treatment have had a positive influence on harbor sediments. Moreover, the correspondence between *C. perfringens* and bulk sediment properties (percent fines and TOC) was stronger after 1998, suggesting that these two factors are more closely coupled after implementation of facility improvements and diversion of treated effluent discharge from the harbor to the offshore outfall. Finally, these findings demonstrate that *C. perfringens* continues to serve as a good indicator of the response of sediments to effluent discharge.

While a more extensive sampling program would be necessary to rigorously assess seasonal TOC patterns, data available from the Benthic Flux and Traditional Harbor studies suggest that there is a seasonal TOC peak in May. The seasonal peak likely reflects particulate carbon input to the system from a winter/spring bloom or an imbalance in production versus metabolism of organic carbon in the system over the annual cycle. Seasonal TOC decreased from July through October, likely reflecting remineralization by bacteria and infauna.

Sediment Profile Imaging

Sediment profile images (SPI) were taken at the eight traditional harbor stations and 52 additional reconnaissance stations. In 2003, the basic measure of benthic habitat quality, the Organism Sediment

Index (OSI), ranged from 2.3 to 10.0, indicating a wide range of environmental conditions in the harbor. The lowest values occurred at fine-sediment stations that had little evidence of infaunal activity, such as T04 in Dorchester Bay. The highest OSI values were also at fine-sediment stations, but those with high levels of infaunal activity, for example T03. Forty percent of the harbor stations had OSI values <6, indicating communities that were under some form of moderate stress, possibly related to organic loading or physical disturbance of the benthic habitat. Most of these lower-OSI stations were located in the inner bays and away from the harbor mouth. Higher-OSI stations occurred in a broad band that arced through the mid-harbor, running from Deer Island to Hull Bay, basically following the distribution of *Ampelisca* spp. tube mats. The source of stress to the benthos is most likely a combination of physical processes such as hydrodynamics and sediment transport at coarse-sediment stations and high rates of sediment accumulation and contaminant/organic enrichment at muddy stations (*e.g.*, T04).

Images from almost all harbor SPI stations in 2003 reflected the strong influence of biological processes in structuring surface sediments; tubes and other biogenic structures were common. Evidence that a combination of biological and physical processes was active in structuring bed roughness occurred at 43% of the stations. Physical processes dominated at 38% of the stations. Stations dominated by biological processes had mixed sediments (composed of both fines and sands) and tended to be closer to the mouth of Boston Harbor. Physically dominated stations spanned the range of sediment types from fine and sand sediments, and were scattered throughout the harbor.

Ampelisca spp. tubes were the primary biogenic structure responsible for deepening RPD layer depths at stations that were primarily silts and clays. They occurred at 38 stations (63%) in coarse to silty sediments and formed tube mats in at least one image at 18 stations (30%) across a broad band from the outer harbor to the western ends of Deer Island Flats, Long Island, Peddocks Island, and Hull Bay. Where *Ampelisca* spp. tube mats occurred, mean RPD depths were significantly deeper than at stations without *Ampelisca* spp. RPD layer depths at stations with *Ampelisca* spp. at less-than-tube-mat densities were not different from stations with mats, but were deeper than at stations without *Ampelisca* spp.

The maximum extent of oxic sediments was 13.1 cm at R45 on the President Roads side of Long Island and R46 in Hingham Bay. These deep oxic sediments were evidence that a large, deep-burrowing infaunal assemblage was present. Large infauna (*e.g*., nemerteans at R02 or R17, and polychaetes at R07 or R33) were observed in the images at seven stations.

From 1992 to 2003, the basic measure of benthic habitat quality, the Organism Sediment Index (OSI), oscillated about the long-term mean with no yearly mean deviating more than 18% from the grand mean of 5.9±2.6 SD. Overall, general benthic habitat quality in the harbor was similar from August 1992 to 2003 with minor variations from year to year. Using the OSI as a surrogate for habitat quality, none of the stations exhibited monotonic long-term trends, either improving or declining.

Infaunal Benthic Communities

The number of species and number of individuals of infaunal organisms per sample were higher, often significantly so, in August 2003 compared with August 2002 at the majority of harbor stations. The mean number of species per sample was higher at seven of the eight harbor stations (station T01 was the exception). As in previous years, species richness was lowest at T04. Stations T03, T05A, T06, and T08 had the highest means, with a range of 64 to 67 species per sample. In August 2003, 144 species of benthic infauna occurred in the samples, including 14 species that were recorded in the harbor for the first time. These 14 species, which have been recorded previously in Massachusetts Bay and other coastal New England waters, included 9 polychaetes, 1 amphipod, 1 cumacean, and 3 molluscs. For the period 1991–2003, a total of 245 species have been recorded from the summer samples.

The increased density was primarily due to large numbers of amphipods present at many stations: *Ampelisca* spp. was the top numerical dominant at six stations (all except T01 and T04), accounting for 77.5% of the identified fauna at T05A. A different amphipod species, *Leptocheirus pinguis*, was numerically dominant at T01, accounting for 25.9% of the identified fauna, followed by the polychaete *Polydora cornuta* (18.1%) and *Ampelisca* spp. (12.9%). *Leptocheirus pinguis* was also an important component of the fauna at five of the seven remaining stations (all except T04 and T06), where it accounted for 1.1 to 11.4% of the identified fauna. *Ampelisca* spp. has been considered a key organism in following the status of the infaunal community of Boston Harbor, partly because members of this genus are considered by some to be indicative of clean environments. In 2003, the areal distribution of *Ampelisca* spp. tube mats as recorded by SPI expanded to 30%, but the total number of stations with *Ampelisca* spp. tubes at any density remained at 63% as in 2002. The traditional grab samples, however, yielded the highest numbers of *Ampelisca* spp. recorded since the initiation of harbor monitoring.

Diversity as measured by Fisher's log-series *alpha* was higher in August 2003 than in 2002 at all of the stations except T01, but otherwise mirrored the pattern seen in 2002: the lowest mean value was recorded at T04 and the highest at T08. Mean Shannon diversities at stations T01, T03, and T08 were generally comparable to values at the same stations in 2002, higher at T04 and T07, slightly lower at T02 and T06, and much lower at T05A. The low Shannon index value at T05A was due to the overwhelmingly large number of *Ampelisca* spp. at that station, in addition to several other species with abundances numbering in the hundreds; however, log-series *alpha*, which is based on a different mathematical formula, was not very different between the two years at that station. Several ecologists (*e.g.*, Robert May, Stephan P. Hubble) have encouraged the use of species abundance models such as log-series *alpha* as the best way to evaluate species diversity.

Lines of evidence from the component parts of this monitoring program suggest that, when taken as a whole, the biological communities of the harbor have not changed significantly over the past decade. For example, based on the OSI calculated from the data developed as part of the SPI sampling, no station showed a monotonic trend of either improvement or decline. Multivariate analyses of the infaunal data pooled to varying levels indicate that the differences among stations are greater than differences between years. Only rarefaction analysis (a diversity measure based on species richness) indicates an increase in harbor-wide diversity over the years of the monitoring program, with a clear increase for the past three years (2001–2003). When individual stations are examined in detail, however, there is some indication that the benthic communities are responding to the elimination of pollutants. The patterns of change in species richness and log-series *alpha* were not equivalent at all stations; however, with the exception of T01 where species richness was the same in 2003 as in 2002, all stations showed large increases in these two parameters in 2003. This same increase in species richness was also observed at many of the MWRA monitoring stations in recent years in Massachusetts Bay, suggesting that the pattern of increased species richness may be regional or system-wide, rather than linked only to the recovery of the harbor. That the benthic environment in the harbor is recovering from years of pollutant input is supported by other lines of evidence, such as the decrease in levels of the sewage marker *Clostridium* and increased OSI values at several traditional stations.

1. INTRODUCTION

1.1 Background

1.1.1 History of Discharges to Boston Harbor

Boston Harbor has had a long history of anthropogenic impacts dating back at least to colonial times (Loud 1923). In addition to the damming of rivers and the filling of salt marshes and shallow embayments to create the present footprint of the city, the direct discharge of waste products has had a profound impact on the composition of the biological communities in the harbor. Prior to the 1950s, raw sewage was discharged into Boston Harbor primarily from three locations: Moon Island, Nut Island, and Deer Island. In 1952, the Nut Island treatment plant became operational and began treating sewage from the southern part of Boston's metropolitan area. The Deer Island treatment plant was completed in 1968, thus providing treatment for sewage from the northern part of the area. (The third location, Moon Island, was relegated to emergency status at that time and not used routinely thereafter.) The effluent was discharged continuously from both plants; an annual average of 120 million gallons per day (MGD) from Nut Island and 240 MGD from Deer Island. Storm events caused up to 3.8 billion gallons per year (BGY) of additional material to be occasionally discharged to the harbor through the system of combined sewer overflows (CSOs) (Rex *et al.* 2002).

Sludge, which was separated from the effluent, was digested anaerobically prior to discharge. Digested sludge from Nut Island was pumped across Quincy Bay and discharged through an outfall near Long Island on the southeastern side of President Roads. Sludge from Deer Island was discharged through that plant's effluent outfalls on the northern side of President Roads. Sludge discharges were timed to coincide with the outgoing tide, under the assumption that the tide would carry the discharges out of the harbor and away offshore. Unfortunately, studies have shown that the material from Nut Island often was trapped near the tip of Long Island and carried back into the harbor on incoming tides (McDowell *et al.* 1991).

In 1972, the Federal Clean Water Act (CWA) mandated secondary treatment for all sewage discharges to coastal waters, but an amendment allowed communities to apply for waivers from this requirement. The metropolitan Boston area's application for such a waiver was denied by the US Environmental Protection Agency (EPA), partly on the basis of the observed degradation of the benthic communities in Boston Harbor. In 1985, in response to both the EPA mandate to institute secondary treatment and a Federal Court order to improve the condition of Boston Harbor, the Massachusetts Water Resources Authority (MWRA) was created. The MWRA instituted a multifaceted approach to upgrading the sewage treatment system, including an upgrade in the treatment facility itself and construction of a new outfall pipe to carry the treated effluent to a diffuser system in Massachusetts Bay located 9.5 mi offshore in deep water.

In 1989, discharge of more than 10,000 gallons per day of floatable pollutants comprising grease, oil, and plastics from the Deer Island and Nut Island treatment plants was ended. Sludge discharge ceased in December 1991, marking the end of one of the most significant inputs of pollutants to Boston Harbor. In 1995, a new primary treatment plant at Deer Island was completed, increasing the system's overall capacity and the effectiveness of the treatment. In August 1997, the first phase of secondary treatment was completed, increasing the level of solids removal to 80%. For the first time, the MWRA's discharge met the requirements of the CWA (Rex *et al.* 2002).

In July 1998, a new screening facility at Nut Island became operational, with sand, gravel, and large objects being removed from the wastewater flow prior to transport via tunnel to Deer Island for further processing. In October 1998, the old Nut Island plant was officially decommissioned, ending more than 100 years of wastewater discharges to the shallow waters of Quincy Bay. By 2000, the average effluent solids loading to the Harbor had decreased to less than 35 tons per day (TPD), reduced from the 138 TPD discharged through the 1980s. On September 6, 2000, all wastewater discharges were diverted to the new outfall in Massachusetts Bay, and in early 2001, the final battery of secondary treatment became operational.

Ongoing MWRA pollution abatement projects for Boston Harbor involve reducing the number and discharge volumes from Combined Sewer Overflows (CSOs). In 1988, 88 CSOs discharged a total of about 3.3 billion gallons per year (BGY). By 1998, 23 CSOs had been closed, and pumping improvements reduced discharges to about 1 BGY, of which about 58% is screened and disinfected. By 2008, ongoing projects will reduce the number of CSO outfalls to fewer than 50, with an estimated discharge of 0.4 BGY, of which 95% will be treated by screening and disinfection (Rex *et al.* 2002).

1.1.2 Benthic Studies in Boston Harbor

The first extensive studies of the infaunal benthos of Boston Harbor were conducted in the summers of 1978, 1979, and 1982 in support of the secondary treatment waiver application (Maciolek 1978, 1980; McGrath *et al.* 1982). These studies documented spatial and temporal variability in infaunal communities in Boston Harbor prior to any pollution abatement projects, and informed the design of the current monitoring program.

As MWRA's long-term sediment monitoring was being developed, reconnaissance surveys were carried out using sediment profile imaging in 1989 and 1990 (SAIC 1990). This technique provides information on the depth of the apparent redox potential discontinuity (RPD), an estimation of sediment grain-size composition, the successional stage of the infauna, and the presence of any biogenic features such as burrows and tubes (Rhoads and Germano 1986). The sediment profile stations provided the means to assess benthic conditions over most of the outer Boston Harbor and Dorchester, Quincy, Hingham, and Hull Bays.

Quantitative infaunal sampling was initiated in 1991and was intended to characterize the infauna of Boston Harbor so that changes following the various phases of the Boston Harbor Project (*e.g.*, sludge abatement) could be documented. Eight stations (one was later relocated) were positioned near the major effluent and sludge discharges and in key reference locations. Benthic infaunal communities and correlated sediment parameters were first sampled in September 1991, approximately three months prior to the cessation of sludge discharge. Post-abatement surveys were conducted in April/May and August 1992 to 2002; beginning in 2003 samples were collected only in August. Reconnaissance surveys at 25–50 additional stations using sediment profile imaging and rapid partial grab analyses, or both, have been carried out annually through 2003. Reports to the MWRA on the results of these surveys have been prepared and can be requested from the MWRA through their website (http://www.mwra.state.ma.us).

Results from the 2003 harbor benthic survey are presented in this report and compared with results from previous years. Recent reports (Kropp *et al.* 2002a,b; Maciolek *et al.* 2004a) have suggested that the infaunal community is responding to some degree to changes in the discharges to the harbor. The occurrence and spread of *Ampelisca abdita* tube mats, and the increase in species numbers and diversity at some of the stations are considered especially important.

1.2 Report Overview

The Boston Harbor benthic monitoring program includes three components: sediment geochemistry, sediment profile imaging (SPI), and benthic infaunal community analysis. The sampling design and field methods are presented in Section 2. Sediment geochemistry studies, based on sediment grab samples taken at eight stations in August 2003, consist of grain-size analysis, total organic carbon (TOC) content determination, and quantification of the sewage tracer, *Clostridium perfringens*. These analytical results are presented in Chapter 3. Sediment images were collected in August 2003 at 60 stations; these images are evaluated in Chapter 4. The benthic communities were sampled at eight stations in August 2003; the results are presented in Chapter 5. The raw data generated for all of these components are available from the MWRA; summaries are included in the appendices to this report.

2. 2003 HARBOR FIELD OPERATIONS

by Isabelle P. Williams

2.1 Sampling Design

The station array provides spatial coverage of the major bays that make up Boston Harbor (Figure 2-1). The eight stations designated as "traditional" are those that are sampled for benthic infauna, followed by a full taxonomic analysis of the organisms in each sample. These station locations were selected after consideration of previous sampling programs in the harbor (*e.g.,* those conducted for the 301(h) waiver application) and consideration of water circulation patterns and other inputs to the harbor (*e.g*., combined sewer overflow). The 52 stations designated as "reconnaissance" are those at which only sediment profile images (SPI) are taken.

2.1.1 Sediment Profile Images

The Boston Harbor SPI survey was conducted in August 2003 at the eight traditional and 52 reconnaissance stations (Figure 2-1). The SPI data supplement the infaunal data to provide a large-scale picture of benthic conditions in the harbor. Sediment profile imagery, now using digital technology as in 2002, permits a faster evaluation of the benthos than can be made by traditional infaunal analyses. This qualitative evaluation can then be integrated with the quantitative results from the infaunal and sediment chemistry analyses. The target locations for Boston Harbor SPI stations are listed in Table 2-1. Specific locations of all sediment profile images collected in 2003 are listed in Appendix A, Table A1.

2.1.2 Sediment Samples

The Boston Harbor benthic infaunal survey was conducted in August 2003. Benthic infaunal and sediment chemistry samples were collected from eight traditional stations (Figure 2-1). Target locations for these stations are given in Table 2-1. The actual station coordinates for each biology and chemistry grab sample, along with a brief description of each sample, is given in Appendix A, Table A2.

2.2 Field Program Results

2.2.1 Survey Dates and Samples Collected

A summary of the samples collected during the Boston Harbor surveys conducted in 2003 is given in Table 2-2.

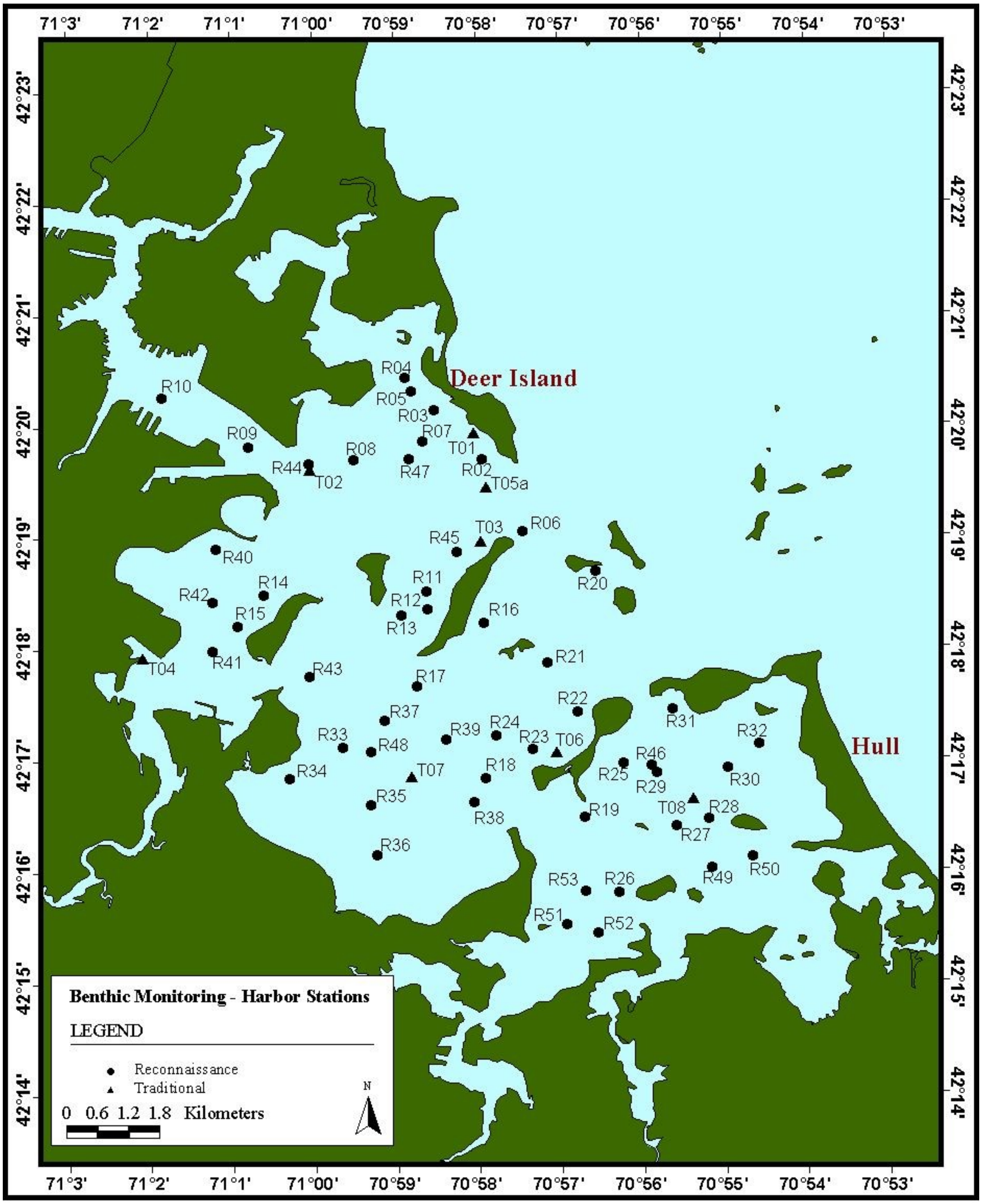

Figure 2-1. Locations of Boston Harbor grab and SPI stations sampled in 2003.
Triangles show Traditional stations sampled by grab and SPI in August.
Circles indicate Reconnaissance SPI stations sampled in August.

Table 2-1. Target locations for Boston Harbor survey grab and SPI stations.

Station	Latitude	Longitude	Depth (m)
Traditional Stations			
T01	42°20.95′N	70°57.81′W	4.9
T02	42°20.57′N	71°00.12′W	6.8
T03	42°19.81′N	70°57.72′W	8.7
T04	42°18.60′N	71°02.49′W	3.2
T05A	42°20.38′N	70°57.64′W	17.5
T06	42°17.61′N	70°56.66′W	6.6
T07	42°17.36′N	70°58.71′W	5.9
T08	42°17.12′N	70°54.75′W	11.3
Reconnaissance Stations			
R02	42°20.66′N	70°57.69′W	13.8
R03	42°21.18′N	70°58.37′W	4.5
R04	42°21.52′N	70°58.78′W	7.2
R05	42°21.38′N	70°58.68′W	5.7
R06	42°19.91′N	70°57.12′W	10.9
R07	42°20.85′N	70°58.53′W	5.6
R08	42°20.66′N	70°59.50′W	2.6
R09	42°20.80′N	71°00.98′W	11.6
R10	42°21.32′N	71°02.20′W	12.8
R11	42°19.28′N	70°58.48′W	7.3
R12	42°19.10′N	70°58.47′W	6.1
R13	42°19.03′N	70°58.84′W	6.7
R14	42°19.25′N	71°00.77′W	7.0
R15	42°18.92′N	71°01.15′W	3.2
R16	42°18.95′N	70°57.68′W	8.0
R17	42°18.29′N	70°58.63′W	8.1
R18	42°17.33′N	70°57.67′W	8.0
R19	42°16.92′N	70°56.27′W	9.2
R20	42°19.49′N	70°56.10′W	11.2
R21	42°18.53′N	70°56.78′W	8.7
R22	42°18.02′N	70°56.37′W	9.4
R23	42°17.63′N	70°57.00′W	10.8
R24	42°17.78′N	70°57.51′W	7.4
R25	42°17.48′N	70°55.72′W	7.3
R24	42°17.78′N	70°57.51′W	7.4
R25	42°17.48′N	70°55.72′W	7.3
R26	42°16.13′N	70°55.80′W	7
R27	42°16.83′N	70°54.98′W	6

Table 2.1 (continued)

Station	Latitude	Longitude	Depth (m)
R28	42°16.90′N	70°54.52′W	7
R29	42°17.38′N	70°55.25′W	11
R30	42°17.43′N	70°54.25′W	5
R31	42°18.05′N	70°55.03′W	10
R32	42°17.68′N	70°53.82′W	5
R33	42°17.65′N	70°59.67′W	5
R34	42°17.33′N	71°00.42′W	4
R35	42°17.05′N	70°59.28′W	6
R36	42°16.53′N	70°59.20′W	5
R37	42°17.93′N	70°59.08′W	6
R38	42°17.08′N	70°57.83′W	7
R39	42°17.73′N	70°58.22′W	8
R40	42°19.73′N	71°01.45′W	2
R41	42°18.67′N	71°01.50′W	4
R42	42°19.18′N	71°01.50′W	2
R43	42°18.40′N	71°00.13′W	3
R44	42°20.62′N	71°00.13′W	9.3
R45	42°19.70′N	70°58.05′W	6.8
R46	42°17.46′N	70°55.33′W	10.5
R47	42°20.67′N	70°58.72′W	6.5
R48	42°17.61′N	70°59.27′W	5.9
R49	42°16.39′N	70°54.49′W	6.1
R50	42°16.50′N	70°53.92′W	6.1
R51	42°15.80′N	70°56.53′W	5.3
R52	42°15.71′N	70°56.09′W	5.2
R53	42°16.15′N	70°56.27′W	6

Table 2-2. Survey dates and numbers of samples collected on Boston Harbor benthic surveys in 2003.

Survey Type	Survey ID	2003 Date(s)	Samples Collected				
			Inf	TOC	GS	Cp	SPI
SPI	HR031	25–26 Aug					183
Benthic	HT032	1 August	24	8	8	8	

Key: Inf: Infauna, TOC: total organic carbon, GS: grain size, Cp: *Clostridium perfringens*, SPI: individual sediment profile images.

2.2.2 Vessel and Navigation

The 2003 Boston Harbor benthic surveys were conducted from Battelle's research vessel, the R/V *Aquamonitor*. Vessel positioning was accomplished with the Battelle Oceans Sampling Systems (BOSS) Navigation system. BOSS consists of a Northstar differential global positioning system (DGPS) interfaced to an on-board computer. Data were recorded and reduced using NAVSAM© data acquisition software. The GPS receiver has six dedicated channels and is capable of locking onto six satellites at once. The system was calibrated with coordinates obtained from NOAA navigation charts at the beginning and end of each survey day.

At each sampling station, the vessel was positioned as close to target coordinates as possible. The NAVSAM© navigation and sampling software collected and stored navigation data, time, and station depth every 2 seconds throughout the sampling event, and assigned a unique designation to each sample when the sampling instrument hit the bottom. The display on the BOSS computer screen was set to show a radius of 30 m around the target station coordinates (six 5-m rings) for all MWRA benthic surveys. A station radius of up to 30 m is considered acceptable for benthic sampling in Boston Harbor.

2.2.3 Sediment Profile Imagery (SPI)

Dr. Robert Diaz was the Senior Scientist for the Boston Harbor SPI (HR031) survey conducted on 25 and 26 August 2003. Three replicate Sediment Profile Images (SPI) were successfully collected at 52 long-term reconnaissance (R) and eight traditional (T) stations. A series of 2–4 photographs was taken on each camera deployment. For this survey, a digital camera recording to an IBM 1-gigabyte microdrive was used in place of the 35-mm film camera that was described in the CWQAPP for this project (Williams *et al.* 2002). The digital camera captured a 5.2-megapixel image that produced a 14.1-megabyte RBG image; the camera was also equipped with a video-feed that was used to send images to the surface so that prism penetration could be monitored in real-time. In addition, the camera frame supported a video-plan camera mounted to view the surface of the seabed. These images were also relayed to the surface via the video cable and permitted Dr. Diaz to see the seafloor and know exactly when the camera had reached the bottom. Dr. Diaz then switched to the digital still camera and, while viewing the camera penetration, chose exactly when to record sediment profile images. Images were usually taken at about 1 and 15 sec after bottom contact.

This sampling protocol helped ensure that at least one usable photograph was produced during each lowering of the camera. The video signal showing the surface of the seafloor was recorded on 8-mm videotape for later review. Because the images were viewed in real time on the video monitor, it was rarely necessary to lower the camera to the seafloor more than three times at each station. The date, time, station, water depth, photo number, and estimated camera penetration were recorded in the field log, with each touchdown of the camera also marked as an event on the NAVSAM©.

The microdrive was capable of recording more images than could be collected during a day of sampling. For this survey, the batteries provided enough energy for each day of sampling and the camera housing had to be opened only at the end of each survey day to replace the microdrive and batteries. It was not necessary to take test shots on deck because loss of battery power to the strobe or camera would have been noticed immediately when the video cable failed to relay any images. While still in the field, images were transferred from the microdrive to a computer and then to a compact disc (CD) for long-term storage.

2.2.4 Grab Sampling

An 0.04-m^2 Young-modified Van Veen grab sampler was used to collect three replicate samples at each traditional station for infaunal analysis. Either the 0.04-m^2 or a larger 0.10-m^2 grab was used to collect one sample for analysis of the sedimentary parameters TOC, *C. perfringens*, and sediment grain size. Infaunal samples were sieved onboard with filtered seawater over a 300-μm-mesh sieve and fixed in 10% buffered formalin. For chemistry samples, the top 2 cm of the sediment in the grab was removed with a Kynar-coated scoop and homogenized in a clean glass bowl before being distributed to appropriate storage containers. The TOC samples were frozen, whereas the *C. perfringens* and grain size samples were placed on ice in coolers.

3. 2003 SEDIMENT PROPERTIES

by Deirdre T. Dahlen and Carlton D. Hunt

3.1 Introduction

From the 1990s through 2002, sediment samples were collected annually in April and August at eight stations located throughout Boston Harbor (Figure 2-1). Samples were tested for grain size, total organic carbon (TOC) content, and the sewage tracer *Clostridium perfringens*. Results from the grain-size testing showed a series of heterogeneous sediments, ranging from coarse-grained to silty sediments. Coarse-grained sediment was generally found at stations T01 and T05A, located in the northern parts of the harbor near Deer Island, and T08, located further south near Hull. Sediment found at stations T02, T03, T06, and T07 had more variable grain size over time, ranging from sandy to silty sediment. Sediment found at T04 was siltier relative to all other sampling locations within the harbor, likely because T04 is located near an area of combined sewer overflow (CSO) discharge and is in an area of sediment focus/carbon deposition for the harbor (Lefkovitz *et al.* 1999).

TOC levels in Boston Harbor did not change substantially from 1991 to 2002, although localized inputs from a major storm in June 1998 likely contributed to the highest measured TOC observed at T04 in 1998 (Maciolek *et al.* 2004a). Available seasonal TOC data suggest harbor TOC peaks in May (Maciolek *et al.* 2004a), indicative of inputs to the system from a winter/spring bloom or an imbalance in production versus metabolism of organic carbon in the system over the annual cycle. Seasonal TOC decreased from July through October, likely reflecting re-mineralization (change from organic to mineral form) by bacteria and infauna.

The abundance of *C. perfringens* decreased harbor-wide from 1998 to 2002, and the system appears to be less variable. Cessation of sewage sludge disposal in 1991 and subsequent improvements in sewage treatment likely contributed to the reduced abundances and temporal variability observed in the system. These findings demonstrate that *C. perfringens* continues to serve as a good indicator of the response in sediment from effluent discharge (Maciolek *et al.* 2003, 2004a).

Sediment TOC and grain size were strongly correlated over the 1992–2002 timeframe. Further, the correspondence between *C. perfringens* and two of the bulk sediment properties (percent fines and TOC) was stronger after 1998, suggesting that two of the factors that influenced the variability (percent fines, TOC) were more closely coupled after improvements in sewage treatment.

3.2 Methods

3.2.1 Laboratory Analyses for Ancillary Measurements

Laboratory procedures in 2003 followed those outlined in the Benthic Monitoring CWQAPP (Williams *et al.* 2002) and are consistent with the methods previously used under the MWRA HOM Program, except that April monitoring was discontinued in 2003. Revisions to the monitoring plan that were implemented in 2003 resulted in reduced frequency of monitoring (*i.e.,* April monitoring discontinued) for sediment properties. Prior to 2003, Traditional harbor stations were sampled annually for sediment properties in April and August. Summaries of the procedures are provided below.

Grain Size—Samples were analyzed for grain size by the sequence of wet and dry sieving methodologies following Folk (1974). Data were presented in weight percent by size class. In addition, the gravel:sand:silt:clay ratio and a numerical approximation of mean size and sorting (standard deviation) were calculated. Grain size determinations were made by GeoPlan Associates.

Total Organic Carbon (TOC)—Samples were analyzed for TOC using a coulometric carbon analyzer following SOP AMS-2201 (formerly AMS-TOC94).[1] Data were presented on a percent dry weight basis. TOC determinations were performed by Applied Marine Sciences, Inc.

Clostridium perfringens**—**Sediment extraction methods for determination of *C. perfringens* spores followed those developed by Emerson and Cabelli (1982), as modified by Saad (1992). Data are reported here as colony-forming units (cfu) per gram dry weight of sediment. This analysis was performed by MTH Environmental Associates.

3.2.2 Statistical Analyses and Data Treatments

Statistical Analysis—Sediment data (grain size, TOC, and *C. perfringens)* were evaluated using correlation analyses to examine the correspondence between these parameters. Probability values were taken from Rohlf and Sokal (1969).

In addition, TOC and *C. perfringens* (log transformed) data were analyzed using SAS to calculate the Pearson Product Moment correlation coefficient (r), as well as the probability of whether the correlation between concentrations (TOC and log-transformed *C. perfringens:* station mean values) and year was significant. Further, these data were tested using a simple ANOVA to determine if the concentrations (TOC and log-normalized *C. perfringens*) were significantly different across the years.

Data Treatments—Terms used to describe the sediment data are presented in Appendix B1. Appendix B1 also presents summaries of the data analyses (*e.g.*, correlations) and evaluations (*e.g.*, histogram plots) performed on the data to assess temporal and spatial trends over time.

3.3 Results and Discussion

Given that April monitoring at all Traditional harbor locations was discontinued in 2003, discussions presented in this section focus on August monitoring data. Findings from April monitoring conducted from 1993 to 2002 are presented in Maciolek *et al.* (2004a).

Bulk sediment results for all Traditional station samples collected during August surveys were evaluated to examine spatial and temporal characteristics. All sediment results discussed in this section are station mean values expressed as dry weight.

3.3.1 Grain Size 1991–2003

Patterns in grain size (*i.e.,* percentage gravel + sand, silt, and clay) in 2003 at all Traditional stations were within the ranges observed in previous years, except that T02 was comprised of slightly siltier sediment compared to earlier years (representative stations T01, T02, and T05A are shown in Figure 3-1; complete data are provided in Appendix B3). T01, T02, and T05A represent those stations where the infaunal communities have changed the most since the abatement of sludge and effluent discharges to the Harbor (Chapter 5, this report).

[1] SOPs AMS-2201 and AMS-TOC94 are comparable to EPA Method 9060, as modified by the National Institute of Standards and Technology (NIST) Benthic Surveillance Program. The change in SOP numbers from AMS-TOC94 to AMS-2201 simply represents a change in the numbering system, not a change in procedure.

Patterns in grain size were consistent over time at some stations and variable at others (Figure 3-1; Appendix B2). Stations T01, T05A and T08 were generally comprised of coarse-grained sediment. Sediment from T02, T03, T06 and T07 had more variable grain-size over time, ranging from sandy to silty sediment. Sediment from T04 was siltier (68% to 97% fines) than sediment from other Traditional harbor locations.

3.3.2 Total Organic Carbon 1991–2003

Station and overall harbor mean TOC in 2003 were within the range of values measured during previous years (Figures 3-2 through 3-4; detailed line charts for each station are included in Appendix B2). While harbor mean TOC levels are not substantially different from year to year, values measured in 1996 and 1998 were higher compared to other years (Figure 3-3). The elevated harbor mean in 1996 was associated in large part with an unusually high TOC measured at station T06, and to a lesser extent T04 (Appendix B2, Figure B2-7); for 1998, the elevated harbor mean was associated with an unusually high TOC measured at T04 (Appendix B2, Figure B2-6). Station T04 represents an area with highly localized sources (*e.g.*, CSO) compared with other Traditional stations (Lefkovitz *et al.* 1999). Had T04 been excluded from the annual harbor mean TOC, there would not have been a peak in 1998 (compare Figures 3-3 and 3-4). Further, excluding 1998, annual harbor mean TOC, based on all Traditional stations except T04, were generally 0.2% to 0.4% less (represents 8 to 18% of the harbor mean values) compared to harbor mean values with T04 (compare Figures 3-3 and 3-4). Although harbor mean TOC appears to be decreasing over time (Figure 3-5; negative slope), variation in the data is high and the correlation between TOC and year is not significant ($r = -0.13$; $p=0.23$). An ANOVA using data from all stations (excluding T04) also did not find a significant difference in TOC with time ($p=0.98$).

Stations T05A and T08 had among the lowest measured TOC over time (Figure 3-2), consistent with the coarse-grained sediment composition of these stations. Sediment from station T04 had the highest TOC across most years, followed in decreasing order by T03, T07, and T06. The highest measured TOC (8.86%) in the harbor[2] was found at station T04 in 1998 (Figure 3-2). This spike in TOC was attributed to localized inputs from a major storm event that occurred in June 1998 (Lefkovitz *et al.* 1999). Subsequent evaluation of the benthic community data from this station indicated a major *Capitella* bloom occurred at this station in August 1998, and that TOC levels had increased substantially by April 1998 (Figure 3-6). This bloom may have contributed to the spike in TOC observed in 1998. Regardless of the cause, TOC at T04 decreased in August 1999 (Figure 3-2) to previous conditions, typical of the mid 1990s. This decrease is possibly due to the rapid sedimentation rate (approximately 4 cm/year) observed at the site by Gallagher *et al.* (1992) and Wallace *et al.* (1991) or re-mineralization through biological processes.

TOC was consistent over time at some stations and more variable at others (Figure 3-2, Appendix B3). TOC in sediment from T02, T03, and T07 was more consistent over time compared to other stations (coefficient of variation (CVs) less than 13%, Appendix B3). T01, T04, and T06 were more variable, with CVs ranging from 28 to 35% among TOC levels from 1991 to 2003 (Appendix B3). TOC was generally lower and more variable in sediment from stations T05A and T08 (CVs greater than 38%, Appendix B3).

[2] The highest measured TOC in the harbor refers to data collected from the traditional stations T01 through T08. Sediment data from the Combined Sewer Overflow (CSO) study, conducted in 2002, showed that TOC was also high at station DB14, located in southern Dorchester Bay and near an area of CSO discharge (triplicate grab samples ranged from 7.91% to 9.44% TOC).

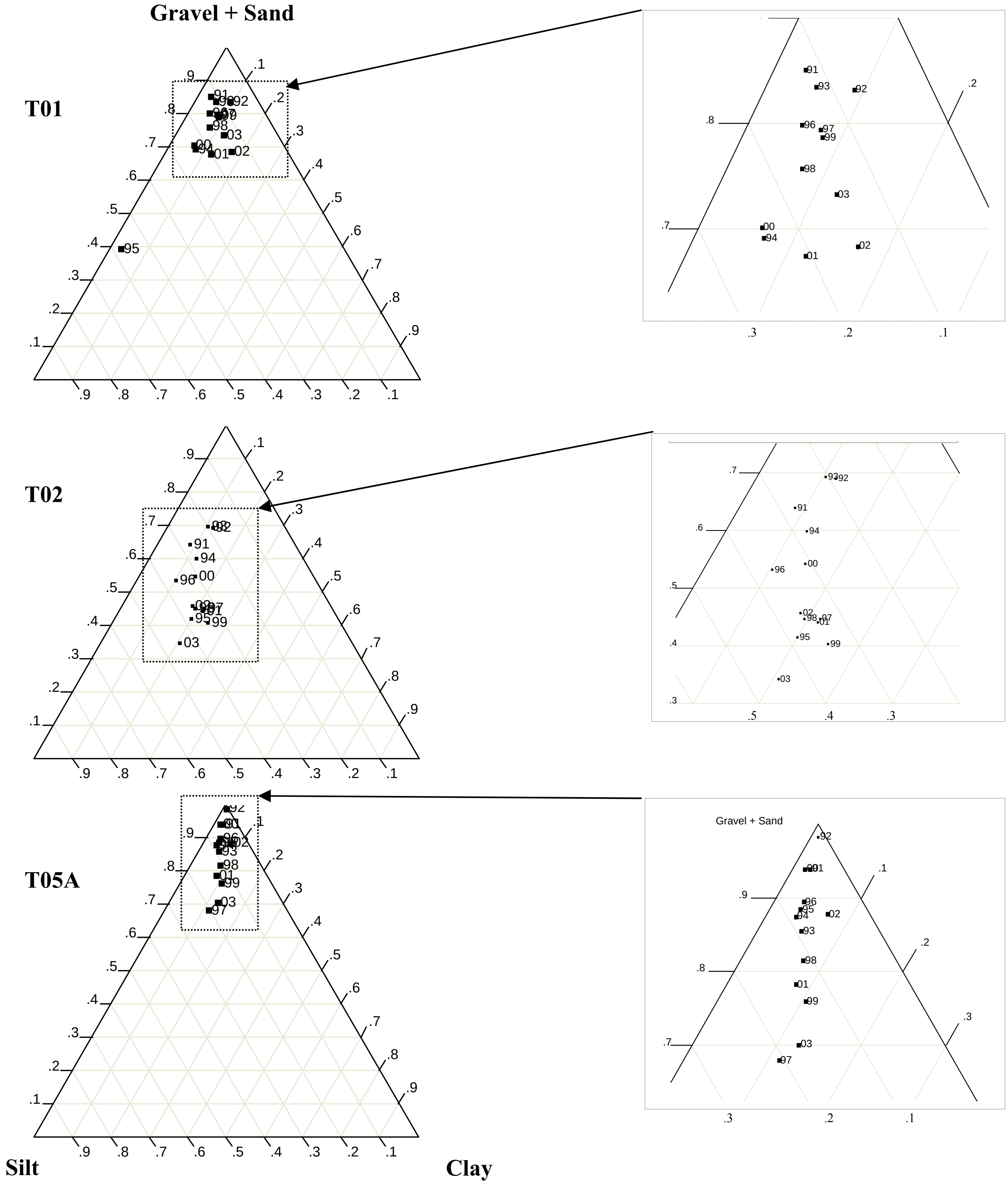

Figure 3-1. Percentage gravel + sand, silt and clay from stations T01, T02 and T05A, where infaunal communities have changed the most since the abatement of sludge and effluent discharges to the harbor. (September 1991 and August 1992-2003)

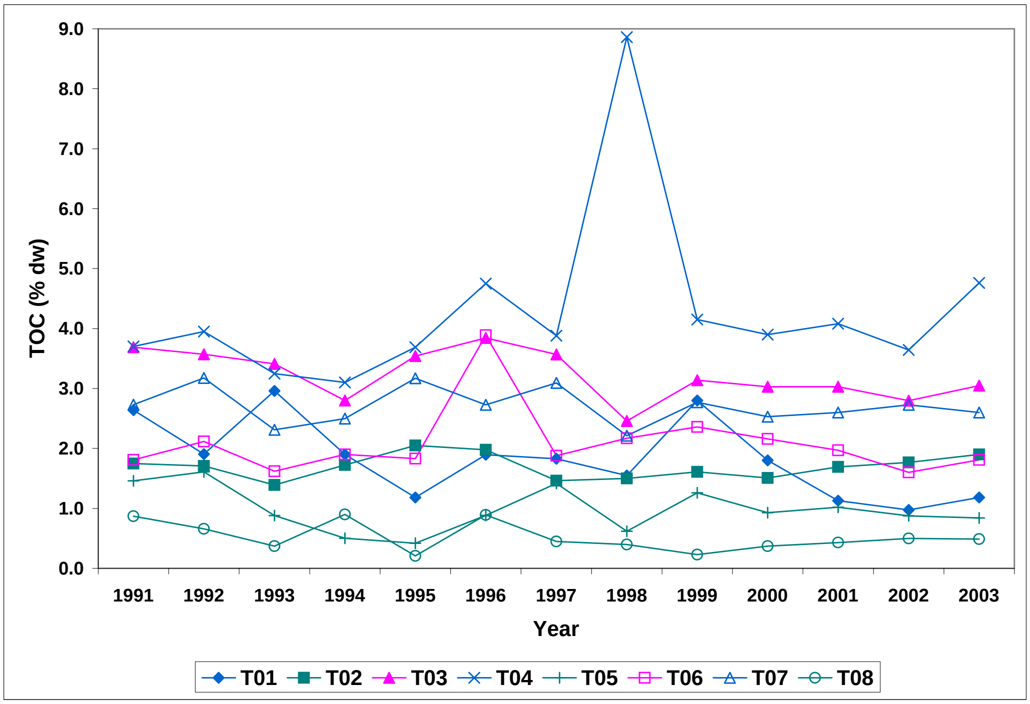

Figure 3-2. Annual station mean TOC in September 1991 and August 1992–2003.

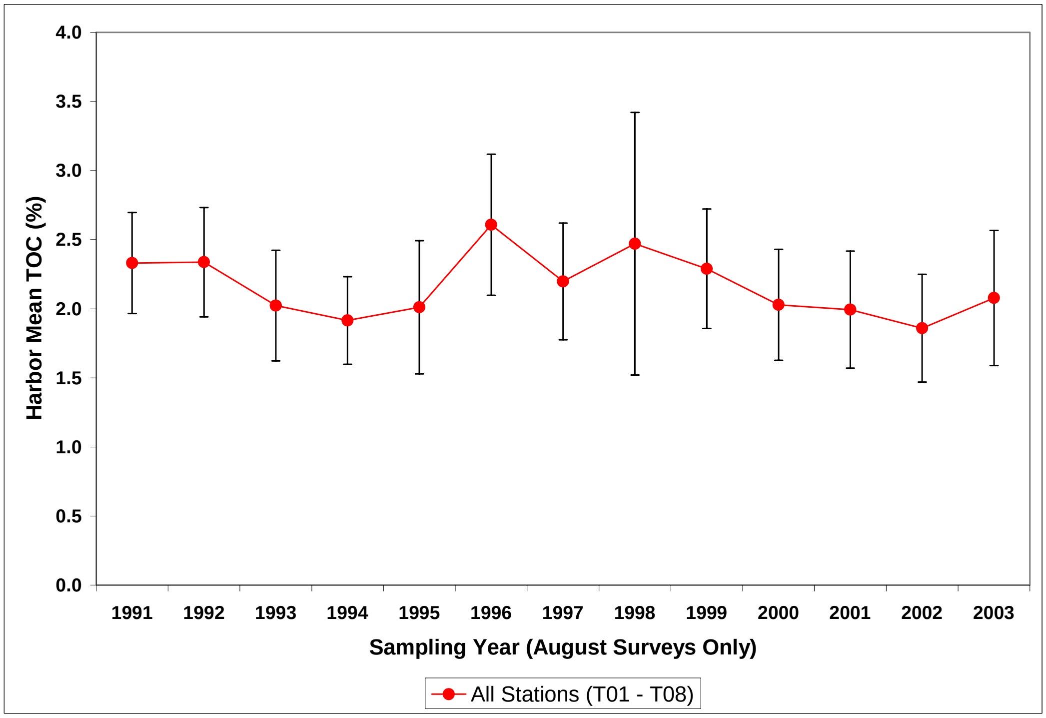

Figure 3-3. Annual harbor mean TOC from 1991 to 2003. Error bars represent one standard error.

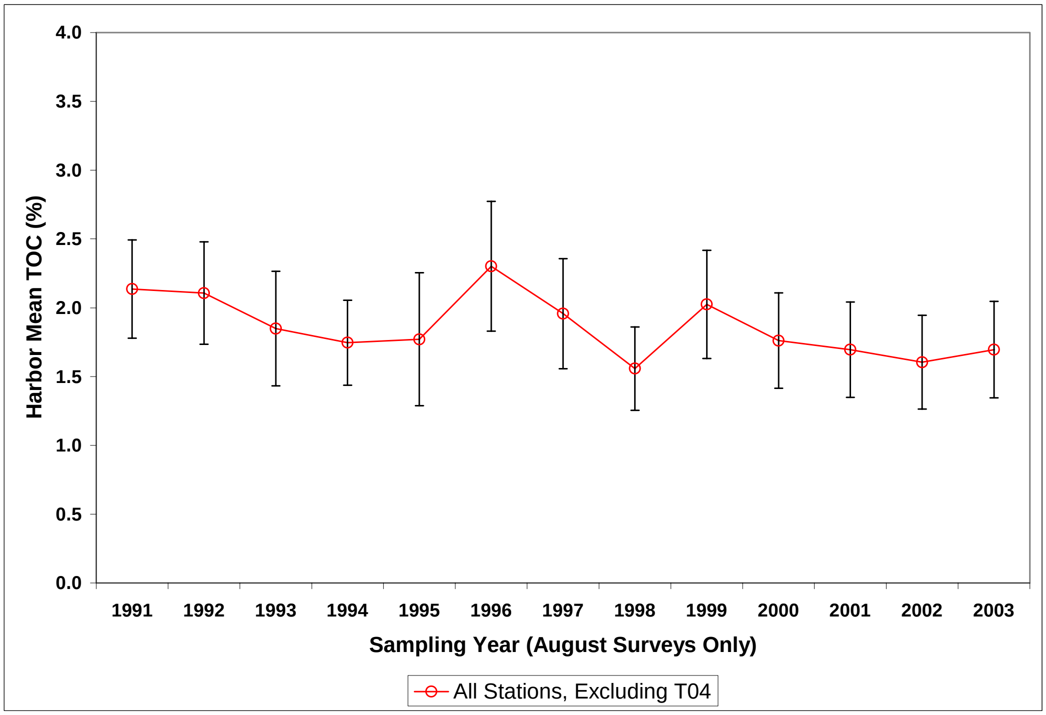

Figure 3-4. Annual harbor mean TOC, excluding Traditional Station T04, from 1991 to 2003. Error bars represent one standard error.

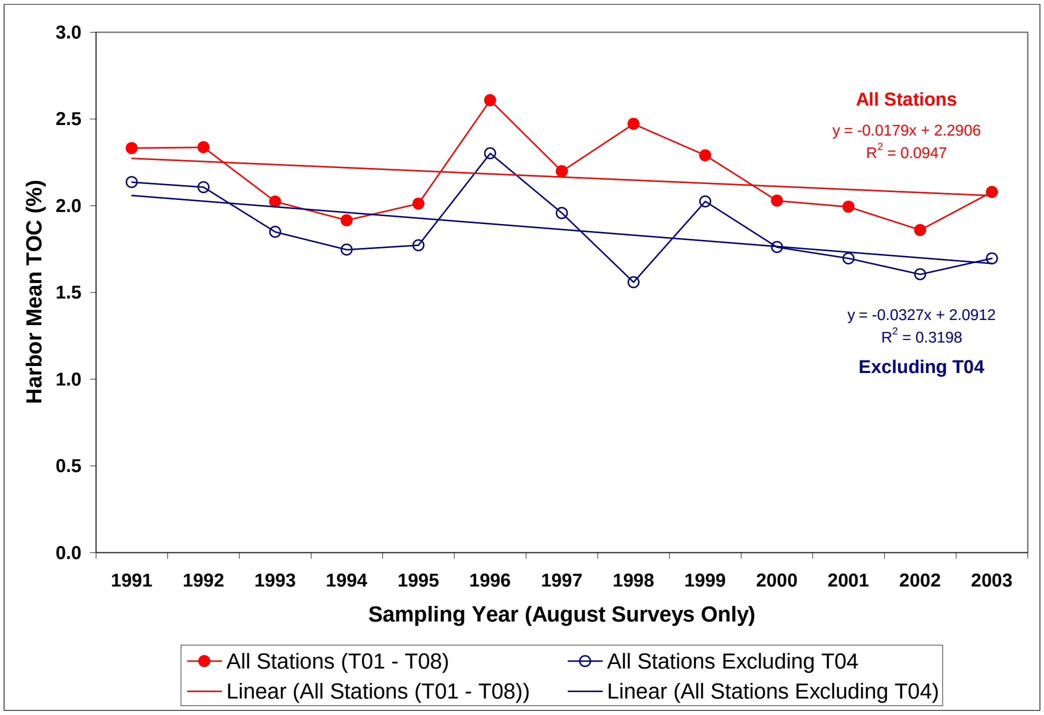

Figure 3-5. Comparison of annual harbor mean TOC, with and without station T04, from 1991 to 2003.

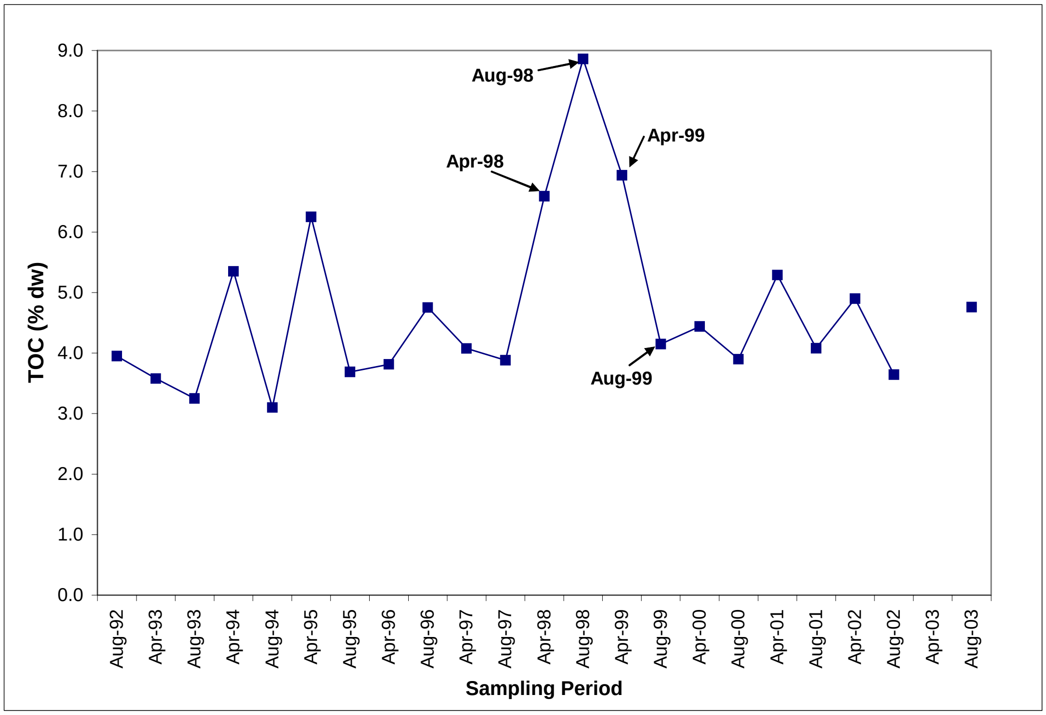

Figure 3-6. Station mean TOC at T04 from August 1992 to August 1993.

Seasonal TOC Evaluation—TOC results from the 2003 Benthic Nutrient Flux (Tucker *et al.* 2004) and Traditional Harbor programs continued to support the findings presented in Maciolek *et al.* (2004a). While a more extensive sampling program is required to rigorously assess seasonal TOC patterns, the data available do suggest an apparent seasonal peak in TOC in May, followed by decreasing carbon content from July through October (Figure 3-7).[3] Seasonal changes in TOC were small (<0.4% units, which represents 14% to 17% of the seasonal mean values), and effects in the biological community may be subtle as a result. A potential cause of the seasonal peak in the carbon content of the sediments in May is particulate carbon input to the system from winter/spring blooms, although over the baseline period the harbor did not have a distinctive nor consistent spring bloom (*i.e.,* productivity) (Libby *et al.* 2003). Alternatively, the apparent seasonal peak in May could represent an imbalance in production versus metabolism of organic carbon (slower metabolism in the winter, higher metabolism in the summer) in the system over the annual cycle. Regardless of these possible causes, the apparent reduction in carbon content of the sediments in the late summer and early fall months likely reflects TOC remineralization by bacteria and infauna.

It is also important to note that the seasonal productivity cycle at the mouth of Boston Harbor appears to be changing from a pattern of summertime blooms, as seen over the baseline period, to winter/spring peaks, which began following diversion of treated effluent discharge from the harbor to the Massachusetts Bay outfall (Libby *et al.* 2003). The switch from the summertime bloom to winter/spring peaks may influence seasonal TOC results in the future.

3.3.3 *Clostridium perfringens* 1991–2003

Abundances of *Clostridium perfringens* have decreased harbor-wide since 1998, with most values consistently below 10,000 colony forming units (cfu) even at station T04 (Figure 3-8; detailed line charts for each station are included in Appendix B2). Also, the system appears to be less variable since 1998, as evidenced by decreased variability in the data across the entire harbor (Figures 3-8 and 3-9). Statistical tests show that log-transformed *C. perfringens* is significantly correlated with year ($r = -0.47$; $p<0.0001$), indicating that the observed harbor-wide decrease in abundances of *C. perfringens* is statistically significant. The harbor-wide decrease and reduced temporal variability are likely associated with the cessation of sewage sludge disposal in 1991 and subsequent improvements in sewage treatment[4], which have resulted in documented reductions in effluent solids inputs to the system (Werme and Hunt 2001, MTH Environmental and Battelle 2003). For example, recent testing of 24-hr composite effluent samples (two primary, two secondary and two final effluent) showed that each treatment step (primary, secondary) resulted in an overall decrease in *C. perfringens* abundances measured in the samples (MTH Environmental and Battelle 2003).

With few exceptions,[5] stations T01, T05A, and T08 had among the lowest *C. perfringens* abundances (< 10,000 cfu) across all years relative to other Traditional stations (Figure 3-8; Appendix B3). Stations sampled in 1991 and 1996 had the highest *C. perfringens* abundances relative to all other sampling years (Figure 3-8). Abundances of *C. perfringens* were high at station T03 in 1991, decreased to less than 1,000 cfu in 1992, increased again in 1993, remained somewhat consistent until 1997 (20,000 to 30,000 cfu), then decreased again in 1998 and remained fairly stable and low through 2003 (Figure 3-8 and

[3] Seasonal comparison conducted using comparable harbor stations: Flux stations included BH02, BH03 and BH03A; Traditional stations included T02 and T03.
[4] Primary treatment in 1995, secondary treatment in 1997, diversion of Nut Island influent to Deer Island in 1998 and diversion of treated effluent discharged from the harbor to the new offshore outfall in 2000.
[5] Exceptions include T01 in 1991, and T05A in 1991 and 1992.

Appendix B, Figure B2-10). While abundances of *C. perfringens* at T03 in 1991 were high relative to other Traditional stations, the concentrations are not unusually high considering that sludge discharges were ongoing at that time (Ken Keay, MWRA, personal communication).

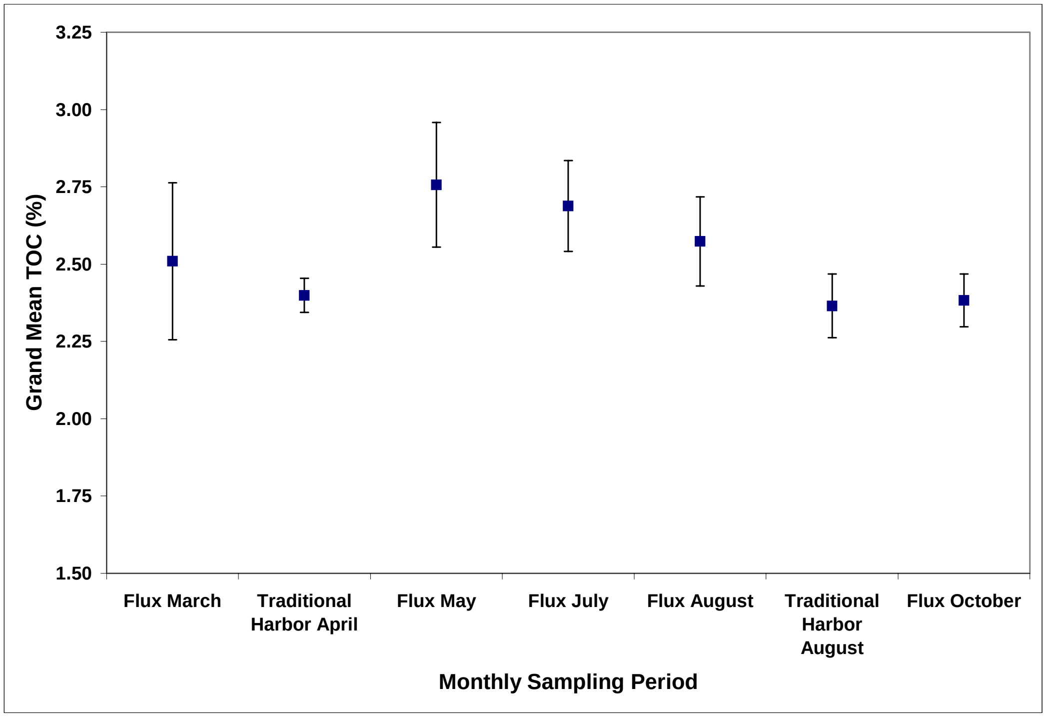

Figure 3-7. Seasonal grand mean TOC. (Flux March data from 1993-1997; Traditional Harbor April data from 1993–2002; Flux August data from 1993 and 1995–2003; All other sampling periods include data from 1993–2003. Flux stations include BH02, BH03 and BH03A; Traditional stations include T02 and T03.)

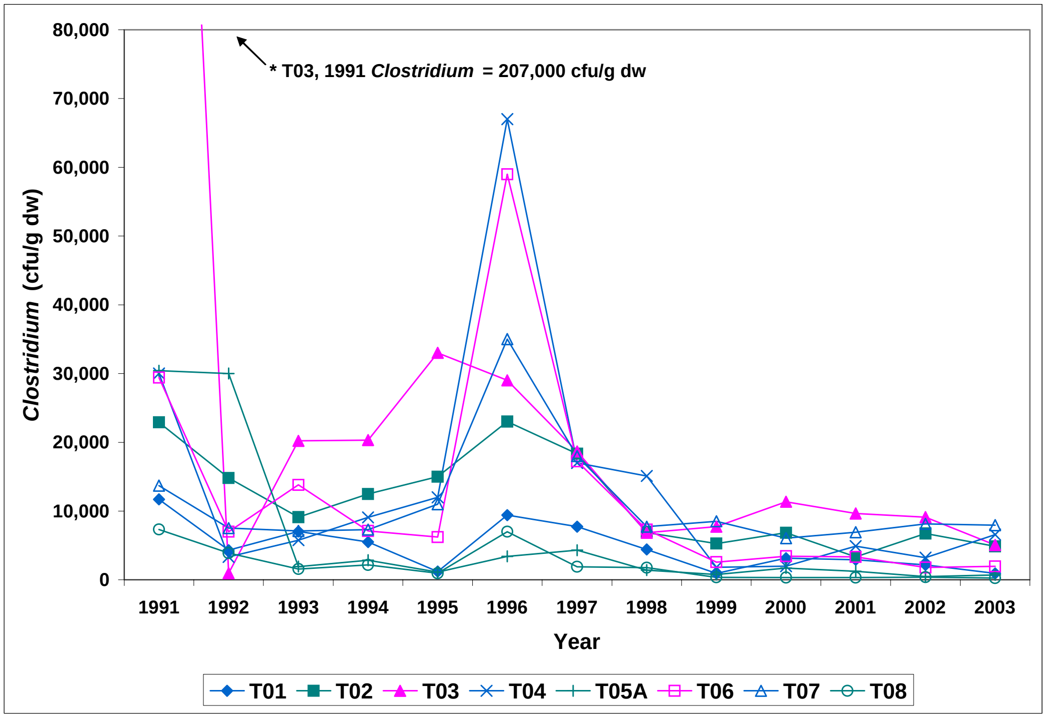

Figure 3-8. Annual station mean *Clostridium perfringens* abundances in September 1991 and August 1992–2003.

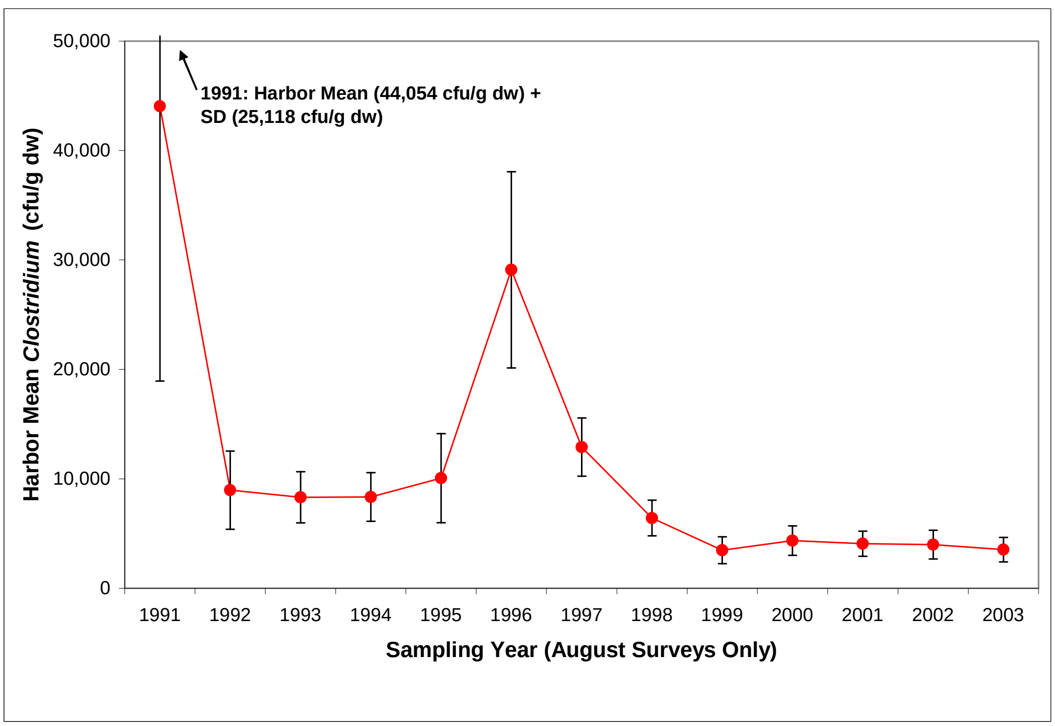

Figure 3-9. Annual harbor mean *Clostridium perfringens* abundances from 1991 to 2003. Error bars represent one standard error.

3.3.4 Correspondence within Ancillary Measurements

Station mean values from all August surveys (Appendix B3) were included in the correlation analysis to evaluate the correspondence between *C. perfringens* and two of the bulk sediment properties (percent fines and TOC) over time (1991–2003). The correlation analysis was performed using data from two sampling periods: pre-1998 and post-1998. 1998 was chosen as the cut-off because it represented the first full year after implementation of some facility improvements (*i.e.,* secondary treatment and cessation of solids discharge from Nut Island). Data from September 1991 were excluded because 1991 represented a period of sludge discharge to the harbor. T04 was also excluded from the correlation analysis because this station represents an area with highly localized source(s) (*e.g.,* CSO) compared with other Traditional stations.

Results from 2003 continued to support previous findings (Kropp *et al.* 2002a,b; Maciolek *et al.* 2004a). For example, TOC remained strongly correlated with grain size during both sampling periods (pre-1998 and 1998–2003) (Table 3-1). In contrast, the correspondence between *C. perfringens* and two of the bulk sediment properties (percent fines, TOC) was stronger after 1998 compared to earlier years (Table 3-1, Figure 3-10). This suggests that two of the factors (*i.e.,* percent fines, TOC) that influence *Clostridium* variability are more closely coupled to *C. perfringens* after implementation of facility improvements, when the inputs (solids, *C. perfringens*) to the system were reduced.

Table 3-1. Correspondence between two of the bulk sediment properties and *Clostridium* for August surveys, excluding Traditional station T04; 1992–2003.

Sampling Period	TOC by Fines		*Clostridium perfringens* by Fines		*Clostridium perfringens* by TOC		
	r	***p***	***r***	***p***	***r***	***p***	***n***
1992–2003	0.79	<0.01	0.47	<0.01	0.58	<0.01	84
1992–1997	0.79	<0.01	0.58	<0.01	0.61	<0.01	42
1998–2003	0.81	<0.01	0.79	<0.01	0.79	<0.01	42

The correlation analysis was repeated using mean station mean values from August surveys (Appendix B3), from the 1998–2000 and 2001–2003 sampling periods. Data from these two sampling periods were used to evaluate the impact, if any, on the correspondence between *C. perfringens* and two of the bulk sediment properties (percent fines, TOC) from the diversion of treated effluent discharge from the harbor to the new offshore outfall in 2000. Results showed that the correspondence was stronger after 2000, especially for *C. perfringens* against TOC (Table 3-2), suggesting that these factors are more closely coupled to *C. perfringens* after diversion of treated effluent discharge from the harbor to the offshore location.

(a)
(b)
(c)

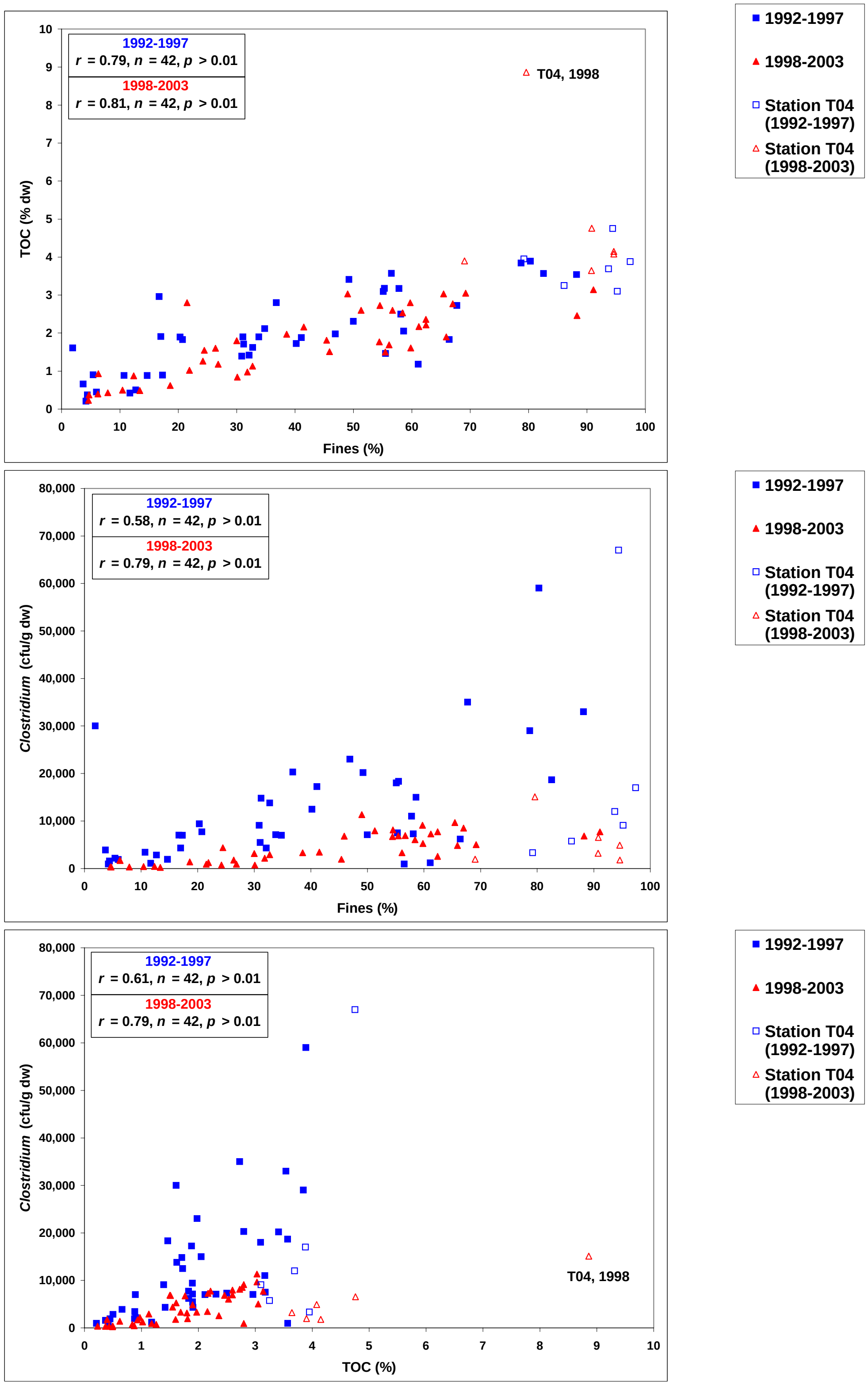

Figure 3-10. Correspondence among percent fines, TOC and *Clostridium perfringens* at Traditional Stations during August Surveys, 1992–2003. (a) TOC by percent fines; (b) *Clostridium perfringens* by percent fines; (c) *Clostridium perfringens* by TOC.

Table 3-2. Correspondence between two of the bulk sediment properties and *Clostridium* three years before and after sewage discharge diversion, excluding Traditional station T04.

Sampling Period	TOC by Fines		*Clostridium perfringens* by Fines		*Clostridium perfringens* by TOC		
	r	*p*	*r*	*p*	*r*	*p*	*n*
1998–2000	0.78	<0.01	0.77	<0.01	0.69	<0.01	21
2001–2003	0.90	<0.01	0.84	<0.01	0.90	<0.01	21

3.4 Conclusions

Sediment grain size and TOC in 2003 generally were within the ranges observed in previous years (1991–2002). Stations T01 and T05A, located in the northern parts of the harbor near Deer Island, and T08 located further south near Hull, were comprised of coarse-grained sediment and had among the lowest measured TOC and *C. perfringens* abundances. Station T04, located in a depositional area of the harbor and in the vicinity of CSO discharge, was comprised of fine-grained silty sediment and had among the highest measured TOC. Stations T02, T03, T06, and T07 had more variable grain-size over time, ranging from sandy to silty sediment.

Although TOC appears to be decreasing across the harbor over time, variation in the data is high and the correlation between TOC and year is not significant. TOC trends are confounded by the influence of a single station, T04, located in a highly depositional environment.

Abundances of *C. perfringens*, however, have decreased on a harbor-wide basis since 1998, and the system appears to be less variable. Statistical tests also show that the observed decrease in *C. perfringens* abundances over time is significant. These findings support the premise that cessation of sewage sludge disposal to the harbor in 1991 and subsequent improvements in sewage treatment have had a positive influence on harbor sediments in terms of the harbor-wide decrease in *C. perfringens* abundances. Moreover, the correspondence between *C. perfringens* and two of the bulk sediment properties (percent fines and TOC) was stronger after 1998, suggesting that these factors are more closely coupled after implementation of facility improvements and diversion of treated effluent discharge from the harbor to the offshore outfall. Finally, these findings demonstrate that *C. perfringens* continues to serve as a good indicator of the response of sediments to effluent discharge.

An evaluation of available TOC data from the Benthic Flux and Traditional Harbor studies suggests there is a seasonal peak in TOC in May, which likely reflects particulate carbon input to the system from a winter/spring bloom or an imbalance in production versus metabolism of organic carbon in the system over the annual cycle. Seasonal TOC decreased from July through October, likely reflecting re-mineralization by bacteria and infauna. A more extensive sampling program is required, however, to rigorously assess seasonal TOC patterns.

4. 2003 HARBOR SEDIMENT PROFILE IMAGING

by Robert J. Diaz

4.1 Introduction

Response of the Boston Harbor ecosystem following major reductions in inputs of pollutants, both organic and chemical, is key to our understanding of the restoration of ecosystem function within the harbor. Bothner *et al*. (1998) presented a brief history of environmental degradation within Boston Harbor and showed that sediment quality, based on lower concentrations of metals and organics, did improve after reductions in pollutant inputs, but that contaminated sediments remain a "lingering legacy of the long history of contaminant discharge." The main issues that still need to be addressed, however, relate to the response of the benthos and restoration of ecosystem function, such as the rate of bioturbation or biogenic mixing of sediments (Solan *et al.* 2004).

Given that most pollutants are particle reactive, the sediments are the final sinks where their accumulation occurs (Olsen *et al.* 1982) and where ecosystem function is most likely to be disrupted by toxic or enrichment effects. Surficial sediments are critical to many ecosystem functions with energy flows (organic carbon, living biomass, secondary production) and nutrients (nitrogen, phosphorus) regulated by processes at the sediment water interface (Rhoads 1974, Diaz and Schaffner 1990). Thus, characterization of the benthic environment from physical and biological points of view became a key part of the MWRA long-term sediment monitoring within Boston Harbor. As MWRA's long-term sediment monitoring was being developed, reconnaissance surveys were carried out using sediment profile imaging (SPI) in 1989 and 1990 (SAIC 1990). The current SPI monitoring strategy was established in 1993 and was based on data collected in 1990–1992 (SAIC 1992, Blake *et al.* 1993). This strategy includes SPI sampling at a series of 52 reconnaissance (R) stations, and SPI and grab sampling at eight traditional (T) stations (Figure 2-1).

The sediment profile camera was developed by Rhoads and Cande (1971) to investigate processes structuring the sediment-water interface and as a means of obtaining *in situ* data on benthic habitat conditions. The technology of remote ecological monitoring of the sea floor (REMOTS®) or sediment profile imaging (SPI) has allowed the development of a better understanding of the complexity of sediment dynamics, from both a biological and physical point of view (Valente *et al*. 1992, Bonsdorff *et al*. 1996, Nilsson and Rosenberg 2000, Rosenberg *et al*. 2001). This approach to evaluating the benthic environment has been combined with classical approaches to habitat and impact assessment providing scientists and managers with a more holistic ecosystem view (Diaz *et al*. 2003).

The objective of the SPI sampling is to determine the general condition of benthic habitats within the harbor and track long-term changes in condition and quality.

4.2 Materials and Methods

4.2.1 Image Analysis

Steps in the computer analysis of each image were standardized and followed the procedures in Viles and Diaz (1991). Basically, the histogram for each color channel (red, green, and blue) was equalized and trimmed to increase contrast and emphasize the reddish-brown tone associated with oxidized sediments.

Data from each image were sequentially saved to a spreadsheet file for later analysis. Details of how these data were obtained can be found in Diaz and Schaffner (1988), Rhoads and Germano (1986), and Williams *et al*. (2002).

4.2.2 Data Reduction and Statistics

Penetration at R06, R19, and R23 for all three replicates was insufficient for estimating the apparent color redox potential discontinuity (RPD) layer depth. Because of the indeterminate RPD layer depth, the organism sediment index (OSI) was also indeterminate at R19 and R23; however, at R06, the OSI was calculated for one replicate image because the RPD layer was deeper than the maximum RPD category of >3.75 cm. None of the > data was included in any comparison involving RPD or OSI. At stations R08 and R22, only one of three replicate images had sufficient penetration to allow for estimation of RPD layer depth, so for any calculation that used the mean station RPD layer depth or OSI the single replicate value was used. All other stations had three measured RPD layer depths. Analysis of variance or Student's t-test for paired data were used to test for differences between and within areas for quantitative parameters. Normality was checked with the Shapiro-Wilk test and homogeneity of variance with Bartlett's test. If variance was not homogeneous, Welch analysis of variance, which allows standard deviations to be unequal, was used in testing for mean differences (Zar 1999). Fisher Exact Test was used for comparisons involving categorical parameters (Agresti 1990). Correlation and principle components analyses were used to arrive at a relative benthic habitat quality ranking for the eight traditional stations based on sediment, infauna, and SPI images data.

4.3 Results and Discussion

Copies of 2003 Harbor SPI images and replicate data are contained in the CD-ROM in Appendix C. Table 4-1 contains a station summary of the 2003 SPI data.

4.3.1 Physical Processes and Sediments

The predominant sediment type throughout the study area appeared to be silt with a significant fine-sand component. In 2003, the three sediment categories of silty-fine-sand (SIFS, modal Phi 6 to 5), fine-sandy-silt (FSSI, modal Phi 5 to 4), and fine-sand-silt-clay (FISICL, modal Phi 5.5 to 4.5) occurred at 50% (30 of 60) of the stations (Table 4-1). The finest sediment category of silt-clay occurred at 38% of stations. The remaining 12% of the stations ranged from sands (R08, R53, and T08) to gravel and pebbles (R06, R19, R22, and R23). None of the stations appeared to have layered sediments of different grain sizes. Bedforms were observed only at sand station R53 in Hingham Bay (Table 4-1). Pure sands and coarser sediments, indicative of high-kinetic-energy bottoms tended to occur on shallow flats and in deeper channels toward the Outer Harbor.

The broad range of sedimentary habitats within the harbor was also reflected in the average station prism penetration, which ranged from 1.6 cm at fine-medium-sand-gravel-pebble station R23 in Nantasket Roads to 25.0 cm at silty-clay station R17 off the southern tip of Long Island. Prism penetration was significantly lower at stations with coarser sediments that were sand, gravel, or pebble (3.5±1.3 cm, mean ± standard error (SE), N = 7) than at either silty-sand stations (12.3±0.6 cm, N = 30) or at silty stations (17.8±0.7 cm, N = 23), (ANOVA, df = 3, F = 28.7, p = <0.001).

The bed roughness or surface relief was the same at stations that appeared to be dominated by physical or biological processes (Table 4-1). Surface relief was 1.4±0.13 cm (mean±SE) at physically dominated stations; 1.4±0.19 cm at biologically dominated stations; and 1.3±0.12 cm at stations that appeared to be intermediate. In physically dominated habitats with coarse sediments, surface relief was due to sediment grain size (gravel, pebble, or cobble) and bedforms, and in silty sediments was related to irregularities in the surface. In biologically dominated habitats, surface relief was typically biogenic structures produced by benthic organisms. *Ampelisca* spp. tube mats were the primary relief-creating biogenic features, followed by what appeared to be feeding pits or mounds.

4.3.2 Apparent Color RPD Layer Depth

The grand mean depth of the apparent color RPD layer for 2003 was 3.0±1.5 SD cm (Table 4-1). The shallowest RPD layer was 1.1 cm at station T04 in Dorchester Bay and the deepest was 6.9 cm at station R38 in Quincy Bay (Table 4-1). Stations with shallower RPD layer depths tended to be closer to shore or further from the mouth of the harbor, such as R32 in Hull Bay and R52 at the mouth of the Weymouth Fore River. Shallower RPD values (<1.5 cm) were associated with what appeared to be organically enriched dark-gray silty sediments without much indication of bioturbation—for example, stations R32 in Hull Bay and T04 in Dorchester Bay. Physical processes or a combination of physical and biological processes dominated surface sediments at these shallower RPD layer stations. Benthic community structure at station T04 consistently showed the signs of being the most stressed of the benthic stations (see Chapter 5, this report). Organic content of sediment at T04 was also highest of the eight traditional stations (see Chapter 3, this report). Organic loading and periodic low dissolved oxygen likely prevent deep bioturbating fauna, resulting in a shallow RPD layer depth at T04. Seven stations that had RPD layer depths >5 cm also had silt-clay sediments similar to T04, but tended to be close to the mouth of the harbor or away from the mainland (R02, R07, R12, R17, R38, R44, and T08). Surface sediments at these and two other silty-fine-sand (R18 and R31) deeper-RPD-layer stations were split between biologically dominated and combinations of physical and biological processes, but all were characterized by a high degree of bioturbation. For example, stations R02, R18, R31, R38, and T03 had dense *Ampelisca* spp. tube mats (defined as more than 50 tubes in one image) and other evidence of well-developed infaunal communities (Table 4-1).

Ampelisca spp. tubes were the primary biogenic structure responsible for deepening RPD layer depths at stations that were primarily silts and clays. They occurred at 38 stations (63%) in coarse to silty sediments and formed tube mats in at least one image at 18 stations (30%) across a broad band from the outer harbor to the western ends of Deer Island Flats, Long Island, Peddocks Island, and Hull Bay. Where *Ampelisca* spp. tube mats occurred, mean RPD depths were significantly deeper (3.6±0.33 cm, mean±SE) than at stations without *Ampelisca* spp. (2.1±0.30 cm). RPD layer depths at stations with *Ampelisca* spp. at less than tube mat densities were not different (3.5±0.34 cm) from stations with mats, but were deeper than at stations without *Ampelisca* spp. (ANOVA, df = 2, F = 6.7, p = 0.002). The percentage of stations with mat densities in 2003 (30%) was not significantly different from 2002 (22%). The presence of *Ampelisca* spp. at 63% of stations in 2003 is higher than the recent low of 52% in 2000, but lower than the 96% of station coverage in 1996 (Figure 4-1). Subsurface biogenic activity in the form of infaunal burrows convoluted and extended the depth of the RPD layer at most stations with *Ampelisca* spp. mats below the depth of the mean RPD layer. The maximum extent of oxic sediments was 13.1 cm at R45 on the President Roads side of Long Island and R46 in Hingham Bay. These deep oxic sediments were evidence that a large, deep-burrowing infaunal assemblage was present. At seven stations large infauna (for example, nemerteans at R02 or R17, and polychaetes at R07 or R33) were observed in the images.

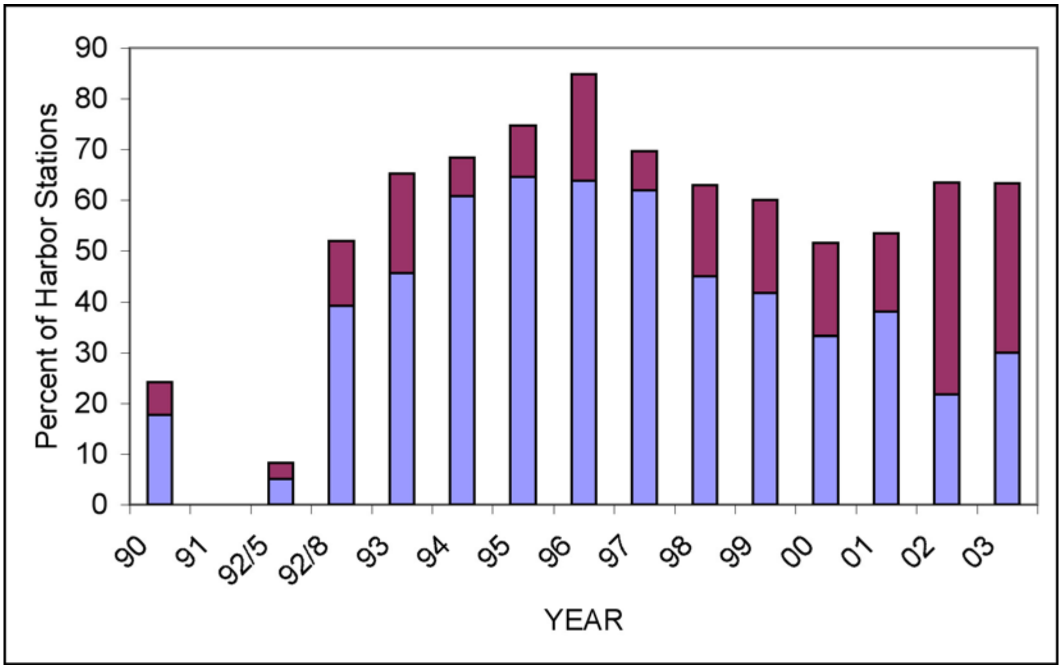

Figure 4-1. Histogram showing the percentage of stations with *Ampelisca* spp. tube mats (bottom portion of bar) and the total percentage of stations with *Ampelisca* spp. tubes from 1990 to 2003.

Table 4-1. Summary of sediment profile image data for Boston Harbor, August 2003.

STA	Pen (cm)	Max RPD (cm)	Ave. RPD (cm)	Modal Grain Size	Surface Process	*Ampelisca* Tubes	Worm Tubes	SUB. FAUNA WORMS	Burrows (#/image)	Oxic Voids (#/image)	Anaerobic Voids (#/image)	Gas Voids (#/image)	Succ. Stage	OSI
R02	19.7	12.4	6.3	SICL	BIO	MAT	FEW	3.3	5.3	5.3	3.0	0.3	II	8.3
R03	11.3	8.2	3.7	SIFS	BIO/PHY	MAT	FEW	2.3	4.7	6.7	0.3	0.0	II-III	9.0
R04	17.3	5.2	1.8	SICL	PHY	NONE	FEW	0.7	4.7	3.3	0.7	0.0	I-II	5.0
R05	17.5	8.7	2.9	SICL	BIO/PHY	FEW	FEW	2.3	10.7	4.3	2.0	0.0	II	7.3
R06	2.3	IND	>2.3	FSMSGRPB	PHY	SOME	MANY	0.0	0.0	0.0	0.0	0.0	I-II	8.0
R07	18.1	12.8	6.3	SICL	BIO/PHY	FEW	FEW	10.3	4.0	5.0	1.3	0.0	II-III	10.0
R08	3.7	5.3	3.2	FS	PHY	NONE	NONE	0.0	0.0	0.0	0.0	0.0	I	6.0
R09	15.0	8.4	2.5	SIFS	PHY	SOME	SOME	3.0	8.3	1.7	1.3	0.0	I-II	6.0
R10	17.2	3.7	1.7	SICL	PHY	NONE	FEW	0.0	0.7	0.0	4.0	0.0	I	3.7
R11	20.3	10.9	4.5	SIFS	BIO	MAT	SOME	2.3	6.0	4.3	2.3	0.0	II-III	10.0
R12	20.9	12.6	5.9	SICL	BIO/PHY	SOME	SOME	4.0	8.0	4.0	2.3	0.0	II-III	10.0
R13	12.2	3.9	1.4	FSSICL	PHY	NONE	FEW	0.0	1.7	0.0	0.3	0.7	I-II	3.7
R14	12.1	7.8	3.0	FSSI	BIO/PHY	SOME	SOME	0.3	7.0	1.7	0.0	0.0	I-II	6.7
R15	14.7	5.1	1.4	SIFS	PHY	NONE	SOME	0.3	1.3	0.0	0.0	0.0	I	3.0
R16	11.1	7.2	3.2	SIFS	BIO/PHY	MANY	SOME	0.3	3.7	3.3	2.0	0.0	I-II	7.0
R17	25.0	11.1	6.4	SICL	BIO/PHY	NONE	SOME	1.7	6.7	5.3	1.3	0.0	II-III	10.0
R18	15.7	11.8	5.0	SIFS	BIO/PHY	MAT	FEW	0.7	8.3	7.0	0.7	0.7	II-III	9.3
R19	2.2	IND	>2.3	FSMSGRPB	PHY	MANY	MANY	0.0	0.0	0.0	0.0	0.0	I-II	>5.3
R20	16.5	6.9	2.2	SIFS	BIO	MAT	NONE	0.3	5.3	1.0	1.0	0.0	II-III	7.0
R21	7.7	IND	3.3	FSSI	BIO	MAT	NONE	2.7	3.3	1.7	0.0	0.0	II-III	8.7
R22	2.2	IND	3.1	FSGR	BIO/PHY	SOME	SOME	0.0	0.0	0.0	0.0	0.0	II-III	7.0
R23	1.6	IND	>1.6	FSMSGRPB	PHY	SOME	FEW	0.0	0.0	0.0	0.0	0.0	I-II	>4.3
R24	15.3	7.2	2.2	SIFS	PHY	FEW	FEW	3.3	5.0	3.0	0.7	0.0	II-III	6.7
R25	17.8	6.6	1.4	SICL	BIO	MAT	NONE	0.7	7.7	0.3	5.3	0.7	II	4.7
R26	16.4	4.1	2.5	SICL	PHY	NONE	FEW	0.0	4.7	1.3	1.7	0.0	I-II	5.7
R27	15.6	4.1	1.6	SIFS	BIO/PHY	MAT	SOME	1.3	5.3	1.0	0.3	0.0	II	5.3

Table 4-1. Summary of sediment profile image data for Boston Harbor, August 2003.

STA	Pen (cm)	Max RPD (cm)	Ave. RPD (cm)	Modal Grain Size	Surface Process	*Ampelisca* Tubes	Worm Tubes	SUB. FAUNA WORMS	Burrows (#/image)	Oxic Voids (#/image)	Anaerobic Voids (#/image)	Gas Voids (#/image)	Succ. Stage	OSI
R28	12.1	7.1	2.9	SIFS	BIO	MAT	NONE	1.0	7.3	5.3	0.0	0.0	II-III	8.3
R29	16.7	9.8	4.1	SIFS	BIO/PHY	MAT	FEW	2.7	6.0	5.7	0.3	0.0	II-III	9.3
R30	9.2	2.3	1.4	SIFS	BIO/PHY	MAT	NONE	3.0	3.3	3.3	0.0	0.0	II	5.3
R31	13.3	IND	5.1	SIFS	BIO/PHY	MAT	SOME	4.3	5.3	2.3	0.0	0.0	II-III	10.0
R32	13.7	4.1	1.2	SICL	PHY	NONE	SOME	0.7	8.0	2.3	0.3	0.0	I-II	4.0
R33	12.1	6.8	1.6	SICL	PHY	NONE	SOME	2.0	4.0	2.0	0.0	0.0	I-II	4.7
R34	19.3	8.8	3.9	SICL	PHY	NONE	FEW	2.0	4.3	2.7	1.0	0.0	I-II	7.7
R35	9.8	4.8	1.7	SICL	PHY	NONE	SOME	0.3	3.7	0.3	0.0	0.0	I-II	4.7
R36	4.6	3.8	1.6	FSSI	PHY	NONE	FEW	0.0	0.7	0.0	0.0	0.0	I	3.3
R37	15.9	8.5	3.2	SIFS	BIO/PHY	SOME	FEW	3.0	7.3	3.3	0.7	0.0	II-III	8.0
R38	17.8	12.5	6.9	SICL	BIO	MAT	NONE	3.3	3.3	5.0	0.3	0.0	II-III	10.0
R39	13.0	8.8	2.2	SICL	BIO/PHY	NONE	SOME	1.3	1.0	0.7	0.0	0.0	I-II	5.5
R40	12.3	6.1	2.0	SIFS	BIO/PHY	NONE	SOME	2.0	5.0	5.3	0.3	0.0	II-III	7.0
R41	13.3	6.6	2.2	SIFS	BIO/PHY	FEW	SOME	1.3	6.0	2.7	0.0	0.0	II-III	7.3
R42	11.9	4.8	1.9	SIFS	PHY	NONE	FEW	0.0	6.0	0.7	0.0	0.0	I-II	5.0
R43	21.1	5.0	1.4	SICL	PHY	NONE	FEW	0.3	4.3	1.7	1.0	0.0	I-II	4.7
R44	21.4	8.5	5.0	SICL	BIO/PHY	SOME	FEW	1.3	9.7	1.7	2.7	0.0	II-III	10.0
R45	17.8	13.1	4.4	SICL	BIO/PHY	MANY	SOME	5.3	7.0	2.3	0.7	0.0	II-III	10.0
R46	18.5	13.1	4.3	SICL	BIO/PHY	MAT	SOME	1.7	3.7	3.0	0.7	0.0	II-III	10.0
R47	16.2	9.5	2.4	SICL	BIO	MAT	FEW	5.7	6.3	2.3	1.3	0.0	II-III	7.3
R48	12.9	5.6	1.9	SIFS	PHY	FEW	FEW	0.0	5.0	0.3	0.3	0.0	I-II	5.3
R49	13.5	6.0	1.4	SIFS	BIO/PHY	NONE	MANY	0.3	4.3	2.0	0.0	0.0	I-II	4.3
R50	11.2	6.1	1.9	FSSI	BIO/PHY	FEW	MANY	0.7	5.3	1.0	0.0	0.0	I-II	5.0
R51	6.6	IND	1.9	FSSI	BIO/PHY	NONE	SOME	0.0	6.3	2.7	0.0	0.0	I-II	5.0
R52	7.6	IND	1.2	FSSI	BIO/PHY	NONE	SOME	0.0	7.3	2.0	0.3	0.0	I-II	4.0
R53	6.5	2.5	1.8	FS	PHY	NONE	SOME	0.7	5.3	0.3	0.0	0.0	I	4.3

Table 4-1. Summary of sediment profile image data for Boston Harbor, August 2003.

STA	Pen (cm)	Max RPD (cm)	Ave. RPD (cm)	Modal Grain Size	Surface Process	*Ampelisca* Tubes	Worm Tubes	SUB. FAUNA WORMS	Burrows (#/image)	Oxic Voids (#/image)	Anaerobic Voids (#/image)	Gas Voids (#/image)	Succ. Stage	OSI
T01	8.3	IND	3.5	FSSI	PHY	NONE	SOME	0.3	8.0	5.7	0.0	0.0	II-III	9.3
T02	17.3	10.5	4.0	SICL	BIO/PHY	MANY	FEW	1.7	6.3	5.7	2.7	0.0	II-III	10.0
T03	17.8	10.4	5.1	SICL	BIO	MAT	FEW	0.0	7.0	2.7	1.7	0.0	II-III	10.0
T04	24.9	3.4	1.1	SICL	PHY	NONE	FEW	0.0	2.0	0.0	0.0	0.7	I	2.3
T05A	5.6	6.2	2.6	FSSI	BIO	MAT	NONE	2.0	3.7	1.3	0.0	0.0	II	7.0
T06	10.5	6.2	2.1	SIFS	BIO	MAT	NONE	0.7	7.3	1.3	0.0	0.0	II-III	7.3
T07	15.7	7.7	2.8	SIFS	PHY	SOME	SOME	0.0	3.0	1.7	1.0	0.0	I-II	6.3
T08	5.9	IND	4.9	FSMS	BIO/PHY	MANY	MANY	0.0	1.3	2.3	0.0	0.0	I-II	8.0

Partial Key: Pen = Penetration, RPD = redox potential discontinuity; OSI = Organism Sediment Index; Succ Stage = Successional Stage.

4.3.3 Biogenic Activity

Tubes and feeding structures were the predominant biogenic features at the sediment surface. The sediment surface at 18% of the stations was dominated by biological processes as evidenced by the widespread biogenic activity associated with successional Stage II and III fauna (Table 4-1). Evidence that a combination of biological and physical processes was active in structuring bed roughness occurred at 43% of the stations. Physical processes dominated at 38% of the stations. Stations dominated by biological processes had mixed sediments (composed of both fines and sands) and tended to be closer to the mouth of Boston Harbor. Physically dominated stations spanned the range of sediment types from fine and sand sediments, and were scattered throughout the harbor.

Because of subsurface activity (*e.g.*, infaunal burrows), the RPD layer at most stations with *Ampelisca* spp. mats was deeper and more convoluted than average. For example, the number of infaunal organisms per image was significantly higher at stations with *Ampelisca* spp. mats (2.1±0.41 infauna/image, mean±SE) and non-mat densities (1.8±0.39 infauna/image) than at stations without *Ampelisca* spp. (0.6±0.37 infauna/image) (Welsh ANOVA, df = 2, F = 29.3, p = 0.001). The highest number of infauna was seen at station R07 on Deer Island Flats with a mean of 10.3 infauna/image. Similar patterns of higher mean values at biologically dominated stations were observed for number of burrows, oxic voids, and anaerobic voids per image. The distribution of subsurface biogenic features (burrow structures, infaunal organisms, water- and gas-filled voids) was sediment related and tended to mirror patterns seen for surface biogenic features as shown above. Burrows were observed at 92% of all stations with a grand mean of 4.8±2.6 burrows/image (±SD). Infauna occurred at 72% of all stations (1.5±1.8 infaunal/image) and was more abundant in finer sediments than in coarser sediments. Gas-filled voids, indicative of high rates of organic loading to the sediments, occurred at five stations (R02, R13, R18, R25, and T04). Water-filled voids occurred at 87% of all stations with a distribution pattern similar to burrows and infauna (Table 4-1). Water-filled voids are biogenic structures typically created by larger infauna. When voids are active they appear to be filled with oxidized sediment. These oxic voids were 76% of all voids with the remaining 24% being anaerobic, apparently relic voids from previous infaunal activity or created by some physical processes such as sediment cracking during profiling of the sediment.

4.3.4 Successional Stage and Organism Sediment Index

The apparent modal successional stage indicated that the infaunal communities in the harbor area ranged from pioneering Stage I to equilibrium Stage III. The high degree of biogenic sediment reworking observed at many stations was consistent with both intermediate Stage II (observed at 90% of stations) and equilibrium Stage III communities (42%). Evidence of Stage I communities occurred at 48% of the stations with 10% of these stations having signs of only Stage I and the other 38% having signs of both Stage I and II communities. Station T04 in inner Dorchester Bay with a Stage I designation also had the poorest infaunal community structure of all stations (see Chapter 5, this report).

The range of the Organism Sediment Index (OSI) from 2.3 to 10.0 at harbor stations indicated a wide range of environmental conditions affecting infaunal community development. Lowest values occurred at fine sediment stations that had little evidence of infaunal activity, for example stations R15 and T04 (Table 4-1). The highest OSI values were also at fine-sediment stations, but at those with high levels of infaunal activity, for example stations R07 and T03. Forty percent of the harbor stations had OSI values <6, which indicated communities that were under some form of moderate stress, possibly related to organic loading or physical disturbance of the benthic habitat (Rhoads and Germano 1986). Most of these lower OSI stations were located in the inner bays and away from the harbor mouth. Higher OSI stations occurred in a broad band that arced through the mid harbor running from Deer Island to Hull Bay, basically following the distribution of *Ampelisca* spp. tube mats. The source of stress to the benthos at both types of harbor stations (traditional and reconnaissance) is most likely a combination of physical processes such as hydrodynamics and sediment transport at coarse-sediment stations (for example, station R53), and high rates of sediment accumulation and contaminant/organic enrichment at muddy stations (for example, station T04).

4.3.5 Comparison of 2003 and 2002 results

Images from almost all harbor SPI stations for 2003 reflected the strong influence of biological processes in structuring surface sediments with tubes and other biogenic structures common. Relative to 2002, there was an increase in the overall level of predominance in biological processes in 2003. For example, in 2002 the sediment surface at nine stations appeared to be dominated by biogenic structures such as tubes, feeding pits, and defecation mounds; in 2003 this increased to 11 stations (Table 4-2) (Fisher Exact Test, $p = 0.050$). Physical processes, as indicated by bedforms, coarse-grained sediment, or soft deep-penetration sediments, remained the same with 24 stations in 2002 and 23 in 2003. The largest changes occurred at station R24 in Nantasket Roads, which was biologically dominated in 2002 and physically dominated in 2003, and at T05A in President Roads, which was physically dominated in 2002 and biologically dominated in 2003. At R24 there appeared to be subsurface biogenic activity but none at the surface in 2003. At T05A, an *Ampelisca* spp. tube mat appeared in 2003.

Table 4-2. Summary of processes structuring surface sediments at Boston Harbor stations in 2002 and 2003. Values are percent of stations (number of stations in parentheses). For example, biological processes dominated four stations in both years.

		2002			
		Biological	**Bio/Phy**	**Physical**	**Total**
2003	**Biological**	6.7 (4)	10.0 (6)	1.7 (1)	18.3 (11)
	Bio/Phy	6.7 (4)	26.7 (16)	10.0 (6)	43.3 (26)
	Physical	1.7 (1)	8.3 (5)	28.3 (17)	38.3 (23)
	Total	15.0 (9)	45.0 (27)	40.0 (24)	

The areal distribution of *Ampelisca* spp. tube mats expanded from 22% of the stations in 2002 to 30% in 2003. However, the total number of stations with *Ampelisca* spp. tubes at any density, from a few tubes to mat densities, remained the same for both 2002 and 2003 at 63% of the stations (Table 4-3, Figure 4-1). Station R39 went from having a tube mat in 2002 to no *Ampelisca* spp. tubes in 2003. Stations R25 in Hingham Bay and T05A in President Roads both went from no tubes in 2002 to mat densities in 2003. Mats were present in both years at nine stations (Table 4-3). From the start of the monitoring program in 1990, the highest percentage of stations with mats was 65% in 1995 and the lowest was 18% in 1990 (Figure 4-1).

Table 4-3. Presence of *Ampelisca* spp. tubes at a given station in 2002 and 2003, cross-classified by density category. Values are percent of stations (number of station in parentheses). For example, 14 stations did not have *Ampelisca* spp. tubes in either 2001 or 2002.

		2002			
		None	**Few to Many**	**Mat**	**Total**
2003	**None**	23.3 (14)	11.7 (7)	1.7 (1)	36.7 (22)
	Few to Many	10.0 (6)	16.7 (10)	6.7 (4)	33.3 (20)
	Mat	3.3 (2)	11.7 (7)	15.0 (9)	30.0 (18)
	Total	36.7 (22)	40.0 (24)	23.3 (14)	

The overall level of biogenic activity appeared to be higher in 2003 relative to 2002. Infauna, while more prevalent in 2002, appeared to be smaller and likely pioneering Stage I individuals. Large infauna, likely Stage II and III individuals, were observed at seven stations in 2003 relative to three in 2002. The two principle parameters dependent on biogenic activity, RPD and OSI, were both significantly higher in 2003 relative to 2002 (Table 4-4).

Table 4-4. Comparison of biogenic activity parameters between 2002 and 2003. For each parameter, only stations with data for both years were included. Student's t-test for paired data was used to determine differences.

Parameter	Year	N	Means	Difference ± SE	Probability
Infauna (#/image)	2002 > 2003	60	2.7 > 1.5	1.2±0.26	<0.001
Burrows (#/image)	2002 = 2003	60	4.7 = 4.8	0.1±0.35	0.850
Oxic Voids (#/image)	2002 < 2003	60	1.5 < 2.4	0.8±0.23	0.001
RPD (cm)	2002 < 2003	56	1.9 < 3.0	1.1±0.16	<0.001
OSI	2002 < 2003	57	5.7 < 6.8	1.2±0.21	<0.001

Benthic habitat quality, as measured by the OSI, increased at most stations in 2003 with the mean increase being 1.2±0.21 (mean±SE). The principal reason for increased OSI values was the corresponding increase in the depth of the apparent color RPD layer (Table 4-4). Station T04 in inner Dorchester Bay continued to have the poorest habitat quality and community structure (see Chapter 5, this report) in 2003, with gas voids, an apparent color RPD layer of 1.2 cm, and OSI of 2.3 (Table 4-1).

4.3.6 Long-term trends in benthic habitats, 1990 to 2003

Over the last 12 years, averaged benthic habitat conditions at the 60 monitoring stations, as measured by sediment profile imaging, have not changed appreciably. Major disturbance events in 1991, including the severe storm that affected the entire region in October and the abatement in December of sewage sludge discharge from near Long Island (Blake *et al.* 1998), which took place prior to the current SPI sampling design may have set the stage for current patterns in benthic habitat quality. Interestingly, stations with poorest habitat quality in 1989/90 (Blake *et al.* 1993) continued to have poor quality habitat in 2002. For example, stations T04 and R43, both in Dorchester Bay, had long-term average OSI values <3 (Table 4-5). A general impression of benthic habitats at the eight traditional stations from 1991 to 2003 can be seen in Figures 4-2 and 4-3.

From 1992 to 2003, the basic measure of benthic habitat quality, the Organism Sediment Index (OSI) of Rhoads and Germano (1986), oscillated about the long-term mean with no yearly mean being more than 18% from the grand mean of 5.9±2.6 (±SD) (Figure 4-4). The largest decline in OSI from the long-term mean was 18% in 1999 and 2000, with the largest increase of 17% in 2003 (Table 4-5). Variation in the annual mean OSI was associated with changes in the apparent successional stage of the infauna, with much of the benthic habitat quality determined by the spatial distribution of Stage I and Stage II seres (Blake *et al*. 1998), and variation in the apparent color RPD layer depth. The long-term predominance of pioneering successional Stage I seres at most inner harbor stations tended to reduce yearly averages in OSI, whereas the predominance of intermediate Stage II to equilibrium Stage III seres at most outer harbor stations tended to increase the OSI and RPD. The tube-building amphipods in the genus *Ampelisca*, associated with the intermediate successional stage (Stage II) and good benthic habitat quality, were key to following temporal change in benthic habitat quality. Data from grab samples indicated that *Ampelisca* spp. tube mats were not broadly distributed in Boston Harbor prior to August 1992 (Figure 4-1). In August 1992 there was about a doubling of stations with *Ampelisca* spp. tube mats from <20% to about 40%. By 1995 the spatial distribution of tube mats increased to >60% of stations and remained at >60% until 1998, when the mats started to contract, dropping to <40% by 2000 and remaining at <40% through 2003. The lowest percentage was in 2002 at 22% of stations. In 2003 the percentage increased to 30%. An animation *(or representation thereof*) of *Ampelisca* spp. tube presence at the harbor stations is shown in Figure 4-5.

Overall, general benthic habitat quality at the R and T stations was similar from August 1992 to 2003 with minor variation from year to year (Blake *et al.* 1998, Kropp *et al.* 2000, 2001, 2002a,b; this report). Using the OSI as a surrogate for habitat quality, none of the stations exhibited monotonic long-term trends, either improving or declining (Table 4-1). However, there were six stations that consistently had OSI values ≥6 (R11, R12, R28, R29, R45, and R46), the threshold for stressed/not stressed habitat conditions (Rhoads and Germano 1986), and five stations with consistently <6 OSI values (R06, R10, R36, R43, and T04). Station T04 located in inner Dorchester Bay consistently had low OSI values with three years of negative values, indicative of a highly stressed habitat, likely from organic loading. Stations R11, R12, R45, and T03 along the western side of Long Island had consistently good habitat quality, and had the highest overall averages (Table 4-5).

Table 4-5. Summary of OSI values for harbor stations. Arranged from lowest to highest station grand mean.

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	Mean
T04	**2.6**	**2.0**	**-4.3**	**-5.3**		**2.0**	**-5.3**	**2.0**	**1.3**	**2.7**	**1.0**	**2.3**	**0.1**
R43	3.3	2.3	2.5	4.7	2.0	2.7	2.0	2.0	2.0	2.5	3.0	4.7	2.8
R36				3.7		2.3	3.0	2.0	4.3		4.0	3.3	3.2
R33	5.3	2.7	0.7	7.0	4.0	2.7	2.3	3.0	3.0	3.0	3.3	4.7	3.5
R35	7.4	2.7	-0.7	5.0	5.0	2.7	2.7	3.7	3.0		5.3	4.7	3.8
R10		2.0	3.0	3.3	4.0	5.0	5.3	4.3	3.7	3.7	3.7	3.7	3.8
R52	8.0			2.0	4.0		3.5	3.0	3.0	3.0	3.7	4.0	3.8
R49	3.5			3.0	7.7	1.0	3.0	3.3	2.3	5.3	5.7	4.3	3.9
R53	6.0			3.0	5.3		2.5	2.0	3.7	4.0	5.0	4.3	4.0
T07	2.0	2.7	3.7	7.5	4.3	3.0	2.7	4.0	3.7	5.7	3.0	6.3	4.0
R34	7.0	3.0	-1.0	6.7	5.7	3.3	2.3	2.7	2.3		5.3	7.7	4.1
R51	7.0			2.7	4.7		3.0	3.3	2.3	3.3	5.7	5.0	4.1
R42	5.0	4.7		6.0	3.0		3.7	2.3	5.0	3.0	4.0	5.0	4.2
R15	8.7	3.0	2.3	11.0	5.0		3.0	2.0	3.0	3.5	3.0	3.0	4.3
R19	7.0	5.7	4.0	4.0	6.0		3.0	2.0	3.0	4.7			4.4
R37	5.7	2.7	4.3	7.0	3.0	3.3	4.0	2.3	3.7	3.0	6.7	8.0	4.5
R06		6.0	4.0	3.3				2.3	3.3	5.0	4.3	8.0	4.5
R08					8.0	4.5	3.5	3.7	2.7	3.0	5.0	6.0	4.5
R04		2.7	4.3	7.0	5.0	3.0	4.7	2.3	2.7	10.0	3.7	5.0	4.6
R32	6.0	4.0	6.3	5.0	5.3	2.7	3.7	3.0	4.0	6.0	5.0	4.0	4.6
R48				5.0	5.7		3.0	2.3	4.0	4.7	7.0	5.3	4.6
T01	3.0	5.3	4.0	5.0	4.3	4.0	3.7	2.3	3.7	4.7	8.0	9.3	4.8
T05A				6.7	4.3	5.5	4.3	2.3	3.0	7.0	4.5	7.0	5.0
T02	3.0		5.7	6.7	5.0	4.3	3.7	3.0	3.0	5.0	6.3	10.0	5.1
R26	7.7	5.0	9.3	4.3	5.7		3.0	3.3	3.3	3.3	6.3	5.7	5.2
R13	6.8	5.3	10.0	6.7	5.0		2.7	2.0	2.3	10.0	4.3	3.7	5.3
R41	6.3	2.3	5.3	11.0	6.0	5.0	4.7	2.3	3.3	3.7	7.0	7.3	5.4
R44				7.0	3.3	2.7	5.7	3.3	3.0	7.3	6.3	10.0	5.4
R40	6.0	3.5	4.0	10.7	8.0		2.7	3.3	4.7	4.0	6.0	7.0	5.4
R09		5.3	5.0	2.7	7.3	6.3	4.7	8.0	3.7	7.7	4.0	6.0	5.5
R05	7.7	4.0	6.0	7.0	5.7		5.7	3.0	3.7	5.7	5.7	7.3	5.6
T08	7.0	7.0	4.5	8.0			3.7	2.7	4.7	6.0		8.0	5.7
R14	5.7	5.3	4.7	7.0	5.0	11.0	5.3	2.3	3.3	9.0	4.3	6.7	5.8
R02	6.7	3.0	5.7	2.0	4.7	9.3	5.7	5.7	7.0	10.0	4.7	8.3	6.1
R17	6.0	4.3	5.3	8.0	3.0	4.7	4.3	8.7	6.3	4.7	8.7	10.0	6.2
R16		8.0	2.5	6.3	9.0	8.0	4.0	5.7	5.3	8.7	3.7	7.0	6.2
R23		9.0	6.7	6.0	8.0		3.0		5.3	5.3			6.2
R50	8.0			7.3	11.0	5.7	7.7	2.7	5.0	5.3	4.7	5.0	6.2
R30	8.0	5.7	7.3	6.3	6.7	5.7	8.3	6.3	5.7	6.0	4.7	5.3	6.3
R03		3.7	6.7	7.7	8.0	8.3	6.7	3.3	4.0	9.0	8.0	9.0	6.8
R25	7.3	7.7	4.3	5.3	9.0	8.7	10.0	8.0	3.3	8.0	6.0	4.7	6.9
R27	9.0	4.3	7.0	6.3	8.0	6.0	10.3	6.3	6.7	8.7	6.3	5.3	7.0

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	Mean
T06	6.7	9.3	5.0	6.3	5.7	7.7	7.7	7.7	6.3	9.0	6.3	7.3	7.1
R22		9.0	5.7	7.3	4.3	10.3	7.7	4.5	6.0	10.0	6.3	7.0	7.1
R39	8.3	6.7	8.7	7.0	6.3	6.3	9.0	3.7	5.3	10.0	8.7	5.5	7.1
R38	7.7	5.3	4.7	8.7	6.3	9.7	6.7	9.0	4.7	9.7	9.0	10.0	7.6
R47	4.7			8.7	7.0	10.3	9.3	9.0	10.0	5.5	7.0	7.3	7.9
R20		9.3	5.5	11.0	7.3	10.3	4.0	9.0	7.7	10.0	6.3	7.0	7.9
R24	8.0	9.0	5.0	9.0	9.7		7.3	9.7	8.0	10.0	5.7	6.7	8.0
R07		2.7	6.0	7.3	8.3	10.7	6.7	9.3	9.3	10.0	9.0	10.0	8.1
R18		9.0	5.7	8.3	7.7	9.7	10.7	9.0	5.3	9.0	6.0	9.3	8.2
R29	7.3	8.0	8.7	8.0	10.3	6.7	10.0	7.0	7.3	8.7	6.7	9.3	8.2
R21		9.0	8.0	9.0	7.3	10.0	9.3	5.7	8.0	8.7	6.7	8.7	8.2
R28	9.0	6.3	10.0	6.7	9.7	7.3	9.7	8.3	7.3	10.0	6.3	8.3	8.3
R31	5.3	10.3	8.0	7.3	8.7	9.0	9.0	8.7	6.7	10.0	8.0	10.0	8.4
R46				8.0	10.3	7.7	9.0	6.3	7.7	10.0	7.0	10.0	8.4
T03	8.3	11.0	5.5	9.7	9.7	10.3	5.7	8.3	9.0	9.0	6.7	10.0	8.6
R45	9.0			9.7	9.7	9.7	7.7	7.7	8.3	10.0	8.3	10.0	9.0
R11		8.7	9.0	11.0	8.3	9.7	9.7	9.0	8.3	8.3	7.3	10.0	9.0
R12		6.7	10.0	10.3	8.0	10.0	11.0	9.0	9.3	9.0	7.0	10.0	9.1
N	40	46	46	59	56	45	59	59	60	57	57	58	
Mean	6.4	5.5	5.2	6.5	6.4	6.4	5.4	4.8	4.9	6.7	5.7	6.9	5.9
SE	0.30	0.38	0.43	0.37	0.29	0.45	0.39	0.35	0.28	0.35	0.23	0.29	2.6
CV	29	47	56	43	34	47	57	56	45	40	30	33	32
% Mean Diff.	+9	-6	-12	+10	+9	+9	-9	-18	-18	+14	-3	+17	
Median	6.9	5.3	5.3	7.0	6.0	6.3	4.7	3.3	4.0	6.0	6.0	7.0	
Min	2.0	2.0	-4.3	-5.3	2.0	1.0	-5.3	2.0	1.3	2.5	1.0	2.3	
Max	9.0	11.0	10.0	11.0	11.0	11.0	11.0	9.7	10.0	10.0	9.0	10.0	

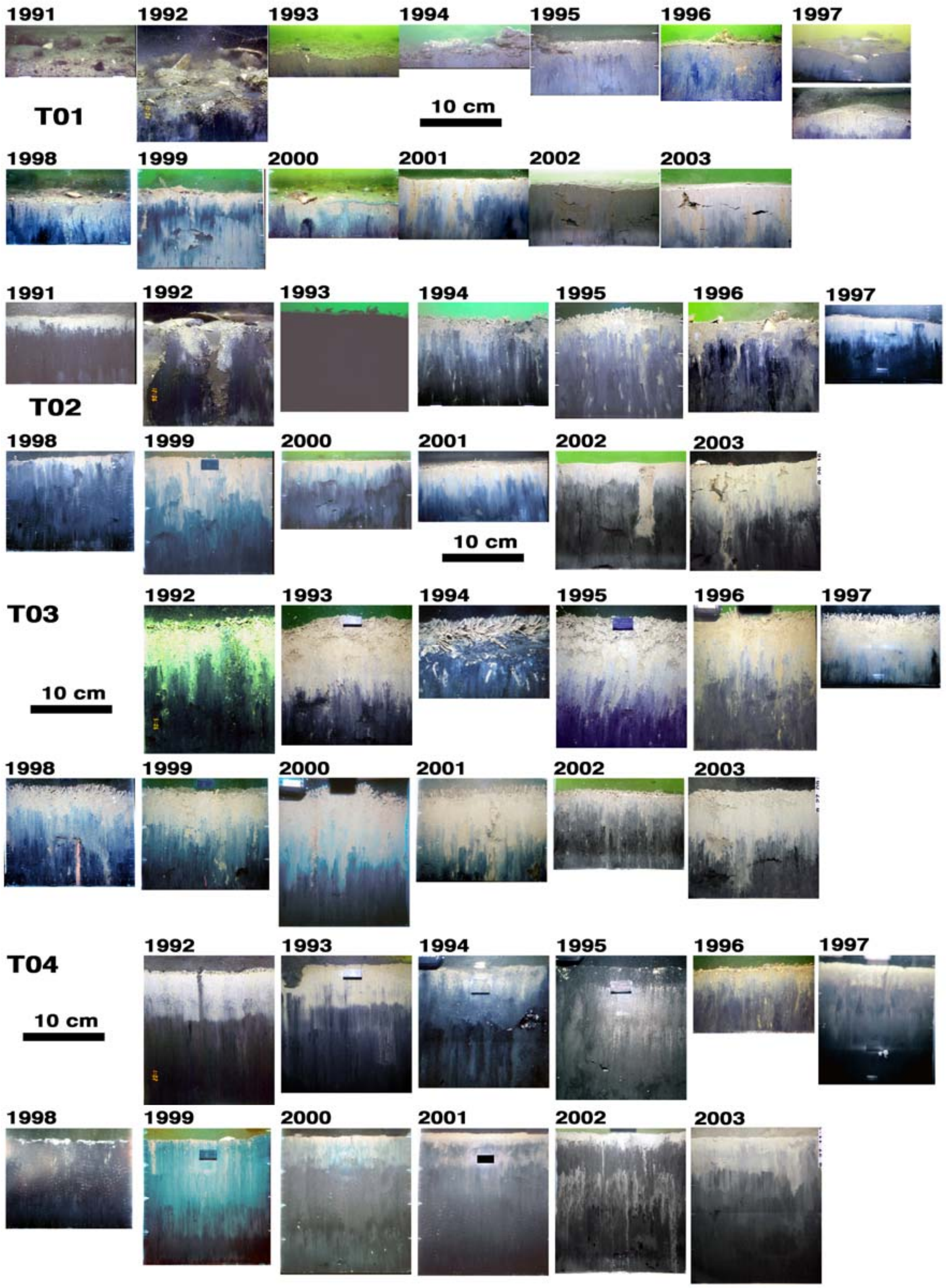

Figure 4-2. Mosaic of SPI images from T\01 to T04 for all years. Images were digitally enhanced to increase contrast.

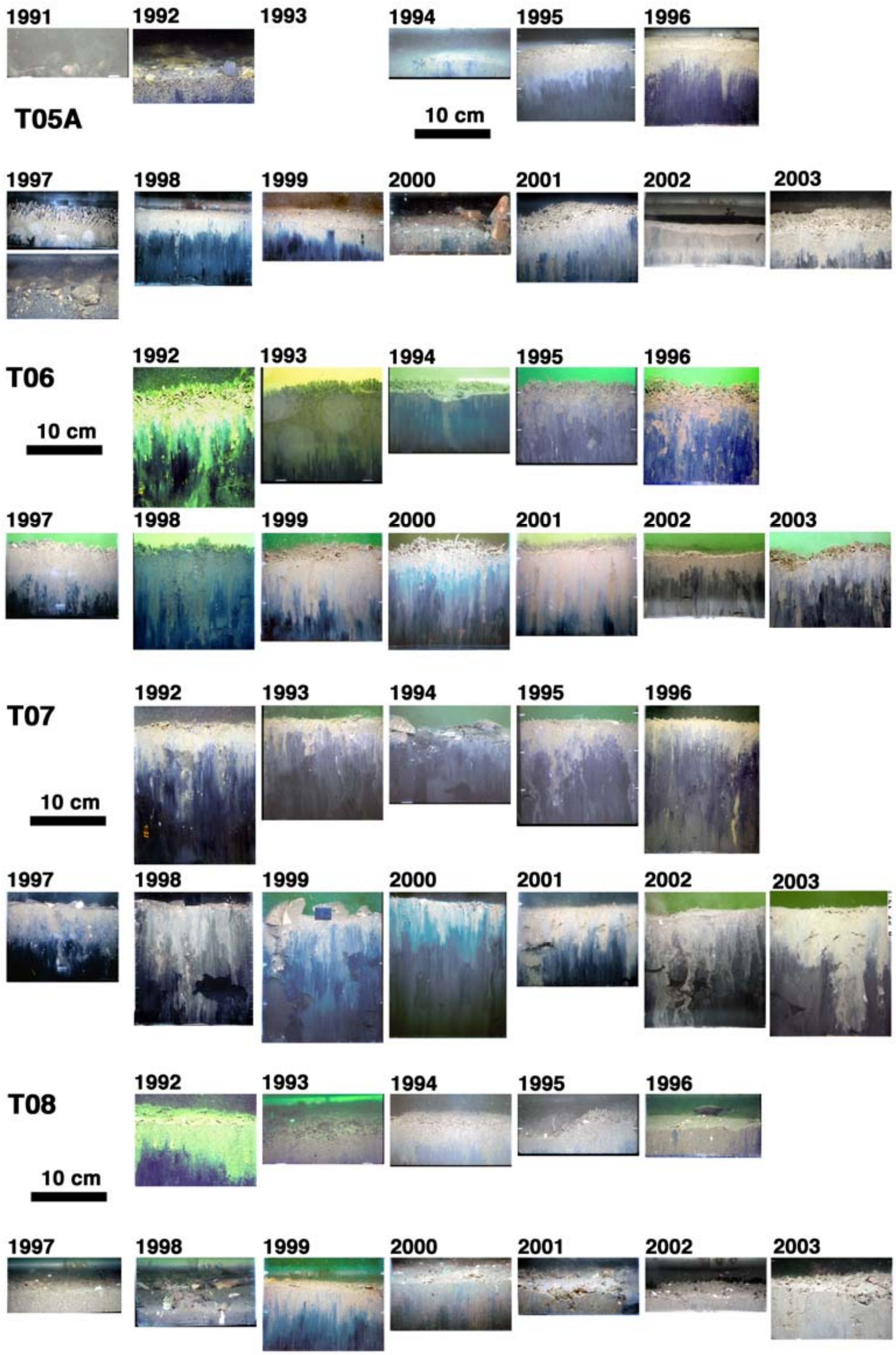

Figure 4-3. Mosaic of SPI images from T 05A to T08 for all years. Images were digitally enhanced to increase contrast.

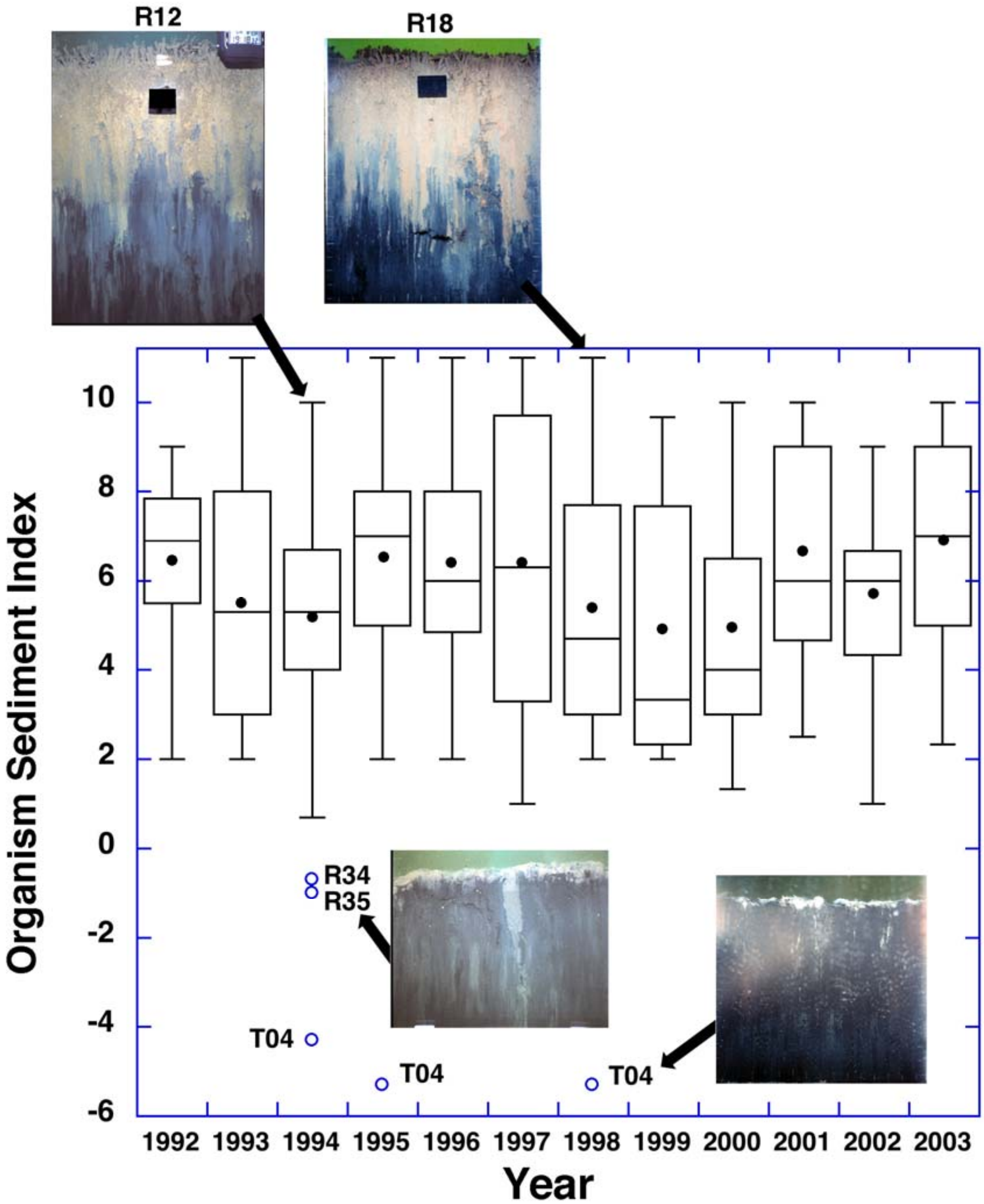

Figure 4-4. Boxplots of long-term trend in the Organism Sediment Index (OSI), an index of benthic habitat quality, for harbor stations. Box is interquartile range (IR), bar is median, dot is mean, vertical lines are 2IR. Outliers (>2IR) are identified by open circles. Images from low OSI outlier stations are shown as examples of poorer habitat quality for 1994 and 1998. These are contrasted with highest OSI stations for those same years.

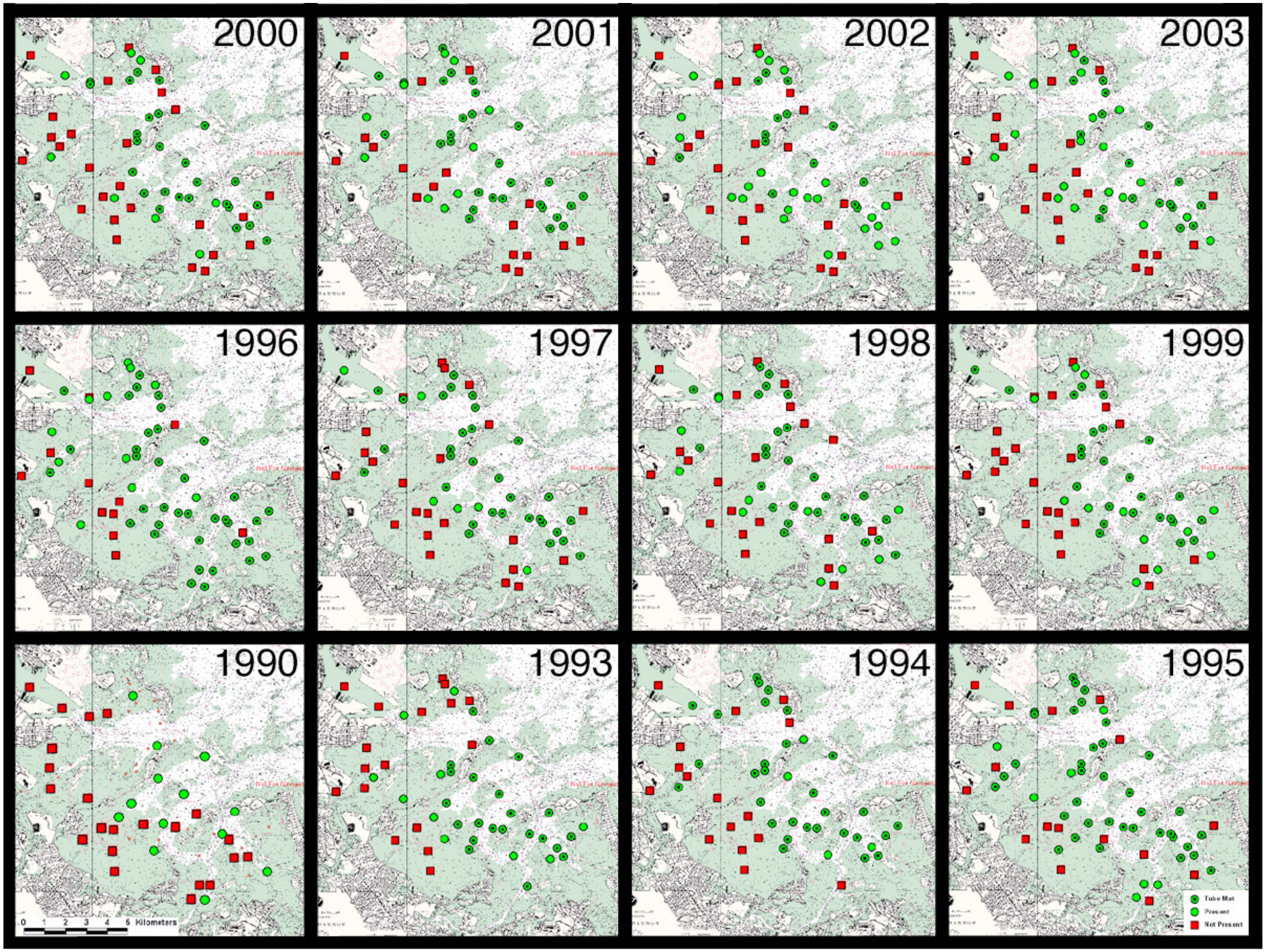

Figure 4-5. Station presence of *Ampelisca* spp. tubes from 1990 to 2003. Red squares are no tubes, green circles are few to many tubes, and circles with dots are mat densities of tubes. See Figure 2-1 for station numbering.

4.3.7 Benthic Habitat Quality at Traditional Stations

Sediment and infaunal data from grab samples were combined with the SPI image data to assess general benthic habitat conditions and quality at the Traditional (T) stations (Table 4-6). All 12 variables had significant pair-wise correlation coefficients (Table 4-7). Among the sediment variables, mean Phi, percent fines, and TOC were highly correlated (see also Chapter 3, this report). Percent gravel and mean Phi were weakly correlated and indicated that gravel tended to occur as grain-size coarsened. All four of the SPI variables were highly correlated. For the infauna variables, only total species was correlated with total abundance, *Ampelisca* spp./grab, and H′. Total abundance was also correlated with *Ampelisca*/grab as *Ampelisca* spp. were numerically dominant at the traditional stations. Significant infauna correlations were all positive, indicating that for the four variables selected they all tended to increase together. Significant correlations between sediment and SPI, and sediment and infauna variables were all negative, while correlations between infauna and SPI variables were all positive (Table 4-7).

The similar inverse relationships of species, H′, and OSI with TOC, fines, and Phi were expected as both fines and TOC are directly related to sediment grain-size, here expressed as mean Phi. Interestingly, the apparent color RPD layer depth was not correlated to any of the four sediment variables. This likely reflects the contribution of bioturbation, which was independent of the range of sediment grain-size at the eight traditional stations, to deepening the RPD. Even though station T04 consistently had the shallowest RPD, highest TOC, and limited evidence of bioturbation, the amount of biogenic activity at the other seven stations consistently deepened the RPD beyond what would be expected by diffusional processes alone (Jørgensen and Revsbech 1985). It is also well documented that higher levels of TOC tend to depress community structure and, as a consequence, the OSI index (Pearson and Rosenberg 1978, Rhoads and Germano 1986). However, the range of TOC measured at the T-stations does not appear to be sufficient to alone account for the range in habitat quality documented. Station T04 had the highest TOC annually (mean from 1992 to 2003 of 4.3%, 1.5% SD) and also the lowest habitat quality, while station T03 had higher habitat quality and consistently the second highest TOC annually (mean 3.2%, 0.4% SD). It is likely that sediment contamination, which is also strongly associated with sediment grain-size (Olsen *et al*. 1982), plays an important role in determining benthic habitat quality at muddy sites within Boston Harbor and that contaminated sediments remain a "lingering legacy of the long history of contaminant discharge" (Bothner *et al.* 1998).

The positive significant relationships between selected infaunal and SPI variables reflect the integrative nature of biological processes. The direction in the relationships between variables is seen in the biplots based on principle components analysis on station means for the 12 variables (Figure 4-6). Station T04 had the finest sediments with highest TOC and lowest values for community structure and SPI variables. Stations T05A and T08 were opposite of T04 with lower TOC and higher community structure and SPI variables. Stations T01 and T07 were separated from the other stations primarily because of low abundance, *Ampelisca* spp., RPD, and OSI. Stations T03 and T06 had highest abundance, successional stage, and OSI values. Station T02 was near the ordination centroid with variable values that were close to the grand mean of all stations from 1992 to 2003.

The functioning of a marine coastal ecosystem is dependent on a complex of processes, many of which are related to the sediment, infauna, and SPI variables listed in Table 4-6. For example, bioturbation is a primary determinant of sediment oxygen concentration, which in turn influences biomass, the rate of organic matter decomposition, and regeneration of nutrients (Giblin *et al.* 1997, Nowicki *et al*. 1997, Aller and Aller 1998). The magnitude and importance of bioturbation is primarily a function of biodiversity, species life histories, and abundance patterns (Diaz and Schaffner 1990, Solan *et al.* 2004). Sediment grain size and hydrodynamic processes are also important in determining the relative importance of biogenic to physical mixing processes. Thus benthic habitat quality can be associated with the level of bioturbation. Based on the patterns of association between the sediment, infauna, and SPI variables, a cline of relative habitat quality emerged, from lower habitat quality at station T04 to higher habitat quality at T03 and T06 (Figure 4-6).

Table 4-6. Sediment, infaunal, and SPI variables used to assess benthic habitat conditions at the eight traditional stations. All data are from August 1992–2003.

Category of Variables	Abbreviation used in Table 4-7
Sediment	
Mean Phi	Phi
Percent Gravel	Gravel %
Percent Silt and Clay	Fines %
Percent Total Organic Carbon	TOC %
SPI	
Organism Sediment Index	OSI
Apparent Color RPD	RPD
Successional Stage	Succ. Stage
Amphipod Tubes	Amphipod Tubes
Infauna	
Ampelisca spp. per grab	*Ampelisca*/grab
Total Abundance	Abundance
Total Species	Species
Diversity Index	H'

Table 4-7. Significant correlations between selected sediment, SPI, and infauna variables. (See Table 4-6 for abbreviations used.)

	Variable	Variable	N	Correlation (r)	Probability (Ho: r = 0)
Sediment					
	Gravel %	Phi	72	-0.25	0.035
	Fines %	Phi	72	0.96	<.001
	TOC %	Phi	72	0.71	<.001
	TOC %	Fines %	96	0.78	<.001
SPI					
	OSI	RPD	88	0.70	<.001
	Amphipod Tubes	RPD	88	0.43	<.001
	Amphipod Tubes	OSI	86	0.55	<.001
	Succ. Stage	RPD	88	0.52	<.001
	Succ. Stage	OSI	88	0.82	<.001
	Succ. Stage	Amphipod Tubes	89	0.63	<.001

	Variable	Variable	N	Correlation (r)	Probability (Ho: r = 0)
Infauna					
	Species	H′	96	0.58	<.001
	Species	Abundance	96	0.52	<.001
	Species	*Ampelisca*/grab	96	0.51	<.001
	Abundance	*Ampelisca*/grab	96	0.79	<.001
Sediment – SPI					
	TOC %	OSI	88	-0.28	0.007
	Gravel %	Amphipod Tubes	93	-0.24	0.019
Sediment – Infauna					
	Species	Phi	72	-0.42	<.001
	Species	Fines %	96	-0.51	<.001
	Species	TOC %	96	-0.58	<.001
	H′	Phi	72	-0.56	<.001
	H′	Fines %	96	-0.53	<.001
	H′	TOC %	96	-0.58	<.001
Infauna – SPI					
	H′	RPD	90	0.23	0.030
	H′	OSI	88	0.52	<.001
	H′	Succ. Stage	91	0.36	0.001
	Ampelisca/grab	RPD	90	0.26	0.012
	Ampelisca/grab	OSI	88	0.33	0.002
	Ampelisca/grab	Succ. Stage	91	0.43	<.001
	Ampelisca/grab	Amphipod Tubes	93	0.58	<.001
	Abundance	RPD	90	0.45	<.001
	Abundance	OSI	88	0.46	<.001
	Abundance	Succ. Stage	91	0.52	<.001
	Abundance	Amphipod Tubes	93	0.54	<.001
	Species	RPD	90	0.37	<.001
	Species	OSI	88	0.55	<.001
	Species	Succ. Stage	91	0.48	<.001
	Species	Amphipod Tubes	93	0.44	<.001

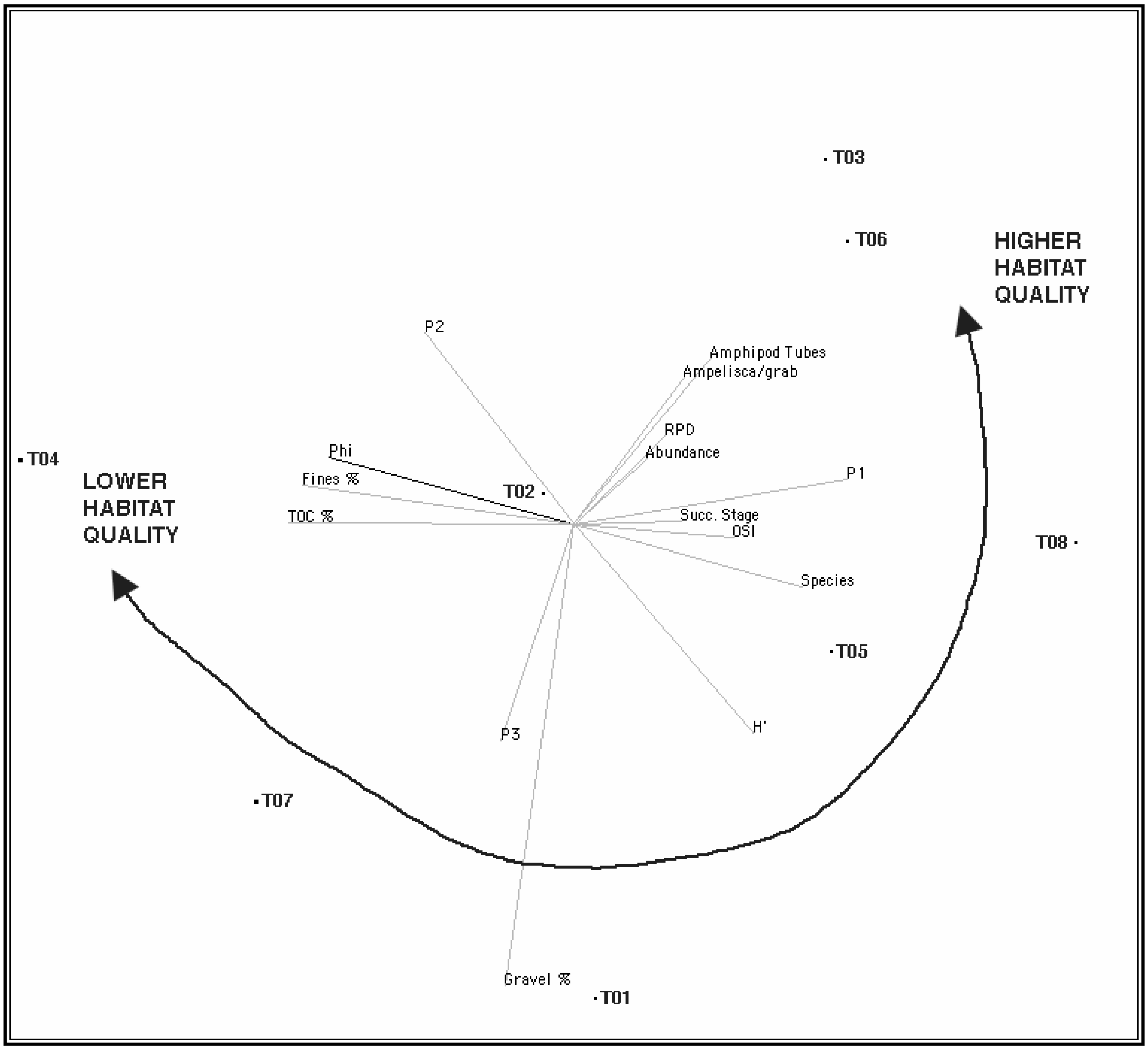

Figure 4-6. Biplot of 12 sediment, infauna, and SPI variables from principle component analysis of station-averaged data. Plot is arranged looking down on the first three principle component axes (P1, P2, and P3) at about a 45° angle. Arrow indicates general cline of habitat quality from a low at T04 to a high at T03 and T06.

5. 2003 SOFT-BOTTOM INFAUNAL COMMUNITIES

by Nancy J. Maciolek

5.1 Introduction

Eight stations in Boston Harbor were sampled in August 2003 for soft-bottom benthic infauna. These stations have been sampled consistently since September 1991, with the exception of T05A, which replaced T05 in 1993. Station locations are indicated in Figure 2-1 (Chapter 2, this report). These stations are termed "traditional" because a full taxonomic analysis of the benthic infauna is performed, rather than a cursory or rapid analysis.

In the early years of monitoring, stations in the northern part of the harbor, particularly those near Deer Island flats, were characterized as polluted, with low species richness, diversity, and evenness (Blake and Maciolek, 1990). Stations in the southern part of the harbor, *i.e*., Quincy, Hingham, and Hull Bays, were noticeably different, with a richer, more diverse fauna. As changes have been implemented in terms of the character and amount of sewage dumped into the harbor, the stations in the northern part of the harbor have exhibited more changes in terms of the number of species and diversity of the benthic fauna than have the stations in the southern part.

5.2 Methods

5.2.1 Laboratory Analyses

Samples were preserved with formalin in the field, and in the laboratory were rinsed with fresh water over 300-μm-mesh screens and transferred to 70–80% ethanol for sorting and storage. To facilitate the sorting process, all samples were stained in a saturated alcoholic solution of Rose Bengal at least overnight, but no longer than 48 h. After rinsing with clean alcohol, all organisms, including anterior fragments, were removed and sorted to major taxonomic categories such as polychaetes, arthropods, and mollusks. After samples were sorted, the organisms were identified to the lowest practical taxonomic category, usually species. Voucher specimens of any species newly identified from the harbor samples were kept as part of the MWRA reference collection.

5.2.2 Preliminary Data Treatment

Prior to performing any analyses of the 2003 and 1991–2003 MWRA datasets, several modifications were made to the database. These were generally similar to those performed in previous years as given in the standard operating procedure (SOP) for this project (Williams *et al.* 2002) and are summarized in Appendix D1. Calculations of abundance included all infaunal taxa occurring in each sample, whether identified to species level or not, but did not include epifaunal or colonial organisms. Calculations based on species (number of species, dominance, diversity, evenness, cluster and principle components analysis) included only those taxa identified to species level, or those treated as such. For report purposes, *Ampelisca abdita* and *A. vadorum* have been combined with *Ampelisca* spp. as in previous years; similarly, *Pholoe minuta* and *P. tecta* have been combined with *Pholoe* spp.

5.2.3 Statistical Analysis

Initial inspection of the benthic data included production of summaries of species densities by sample, tables of species dominance, and lists of numbers of species and numbers of individuals per sample. Data were inspected for any obvious faunal shifts or species changes between stations. Following these preliminary inspections of the data, a series of community parameters was calculated along with multivariate statistics to assess community patterns and structure.

The multivariate programs are included in COMPAH96, originally written by Dr. Donald Boesch and now available from Dr. Eugene D. Gallagher (http://www.es.umb.edu/edgwebp.htm). Patterns in benthic communities were analyzed by cluster analysis using CNESS (chord-normalized expected species shared), which was developed by Gallagher and is related to Grassle and Smith's (1976) NESS (normalized expected species shared). CNESS and NESS are families of indices that can be made more or less sensitive to rare species in the community and as such are more versatile than other similarity measures such as the Bray-Curtis algorithm, which is influenced by dominant species. Differences between CNESS and NESS are detailed in Trueblood *et al*. (1994). Both NESS and CNESS are calculated from the expected species shared (ESS) between two random draws of *m* individuals from two samples. For this project, the optimal value of *m* was determined through use of a program written by Dr. Gallagher (*findcnm*), and was set at 15 for the 2003 database. For the analysis of the 1991–2003 summer samples, replicates were pooled either to eight samples per year (*i.e*., all samples from a station were pooled, but stations were kept separate) or one sample per year (*i.e.*, all samples from all stations pooled to one annual sample) and *m* was set at 20. Results of these analyses were inspected for patterns among and between the different seasons.

Using MATLAB as an operating platform and additional programs written by Dr. Gallagher, several diversity indices were calculated, including Shannon's H′ (base 2), Pielou’s evenness value J′, Sanders-Hurlbert rarefaction, and Fisher’s log-series *alpha*. Magurran (1988) classifies diversity indices into three categories: (1) species richness indices (*e.g.*, rarefaction); (2) species abundance indices (*e*.g., log-series *alpha*), and (3) indices based on the proportional abundances of species (*e*.g., Shannon index). The Shannon index, which is based on information theory, has been popular with marine ecologists for many years, but this index assumes that individuals are randomly sampled from an infinitely large population and that all species are present in the sample (Pielou 1975, Magurran 1988): neither assumption correctly describes the environmental samples collected in most marine benthic programs. Fisher's log-series model of species abundance (Fisher *et al.* 1943) has been widely used, particularly by entomologists and botanists (Magurran 1988). Taylor's (1978) studies of the properties of this index found that it was the best index for discriminating among subtly different sites, and May (1975) demonstrated that Sanders-Hurlbert rarefaction curves are often identical to those produced under the assumption that the distribution of individuals among species follows a log-series distribution. Hubble (2001) considers *alpha* the fundamental biodiversity parameter and promoted the use of this index for studies of diversity in all environments.

Principal Components Analysis of Hypergeometric probabilities (PCA-H) was also applied to the benthic data. PCA-H is an ordination method for visualizing CNESS distances among samples (see Trueblood *et al.* 1994 for details). The PCA-H method is a multistep analysis that produces a metric scaling of the samples in multidimensional space, as well as two types of plots based on Gabriel (1971). The Gabriel Euclidean distance biplot provides a two-dimensional projection of the major sources of CNESS variation, *i.e.*, the species that contribute the most to the distances among samples. The species that contribute to the CNESS variation can be determined using matrix methods adapted from Greenacre's correspondence analysis (Greenacre 1984). These species are plotted as vectors in the Euclidean distance biplot. The Gabriel covariance biplot shows the associations among species. The metric scaling diagram, Euclidean distance biplot, and covariance plot are all based on CNESS similarities among samples, but are calculated by different algorithms.

5.3 Results and Discussion

5.3.1 Species Composition of 2003 Samples and 1991–2003 Summary

In August 2003, 144 species of benthic infauna occurred in the samples, including 14 species that were recorded in the harbor for the first time. These 14 species, which have been recorded previously in Massachusetts Bay and other coastal New England waters, included 9 polychaetes, 1 amphipod, 1 cumacean, and 3 molluscs (Appendix D2).

For the period 1991–2003, a total of 245 identified species were recorded in the summer samples (Appendix D2). As detailed in previous reports (*e.g*., Blake *et al.* 1998, Kropp *et al.* 2002a,b), annelids are usually the most abundant infaunal taxon, often accounting for 50% or more of the organisms collected, followed by amphipod crustaceans and molluscs. In August 2003, however, amphipods were especially numerous, with *Ampelisca* alone accounting for more than 55% of the 130,818 organisms in the 24 samples (Table 5-1). In contrast, in August 2002 *Ampelisca* accounted for 16.3 % of the 45,969 organisms present in the 24 harbor samples (Maciolek *et al.* 2004a). Additional amphipod species, including *Leptocheirus pinguis, Unciola irrorata, Crassicorophium bonnelli, Photis pollex, Orchomenella minuta,* and *Dyopedos monacanthus*, were also notably numerous (Table 5-1).

Table 5-1. Amphipod species present in Boston Harbor samples taken in August 2003.

Amphipod Species	Total Abundance in 2003 samples	% Total Abundance (% of 130,818)
Ampelisca spp.	73,112	55.89
Leptocheirus pinguis	4,735	3.62
Unciola irrorata	3,841	2.94
Crassicorophium bonnelli	2,148	1.64
Photis pollex	2,108	1.61
Orchomenella minuta	1,194	0.91
Dyopedos monacanthus	1,029	0.79
Phoxocephalus holbolli	96	0.07
Microdeutopus anomalus	39	0.03
Crassicorophium crassicorne	17	0.01
Ischyrocerus anguipes	9	0.01
Pontogeneia inermis	9	0.01
Jassa marmorata	2	0.00
Harpinia propinqua	1	0.00
Metopella angusta	1	0.00
Totals	88,341	67.53

5.3.2 Benthic Community Analysis for 2003

Density, Species Richness, Diversity, and Evenness—Community parameters for the grab samples collected in 2003 at the eight harbor stations are shown in Table 5-2 and Figure 5-1. For comparison with earlier dates, graphs showing five community parameters over time at each station are in Appendix D3.

Density—In August 2003, densities were higher, often significantly so, compared with August 2002 at the majority of harbor stations. Mean abundances at T01 (Deer Island Flats) and T04 (Savin Hill Cove) were similar to those recorded in 2002, but the remaining six stations had mean abundances that were double, triple, or an order of magnitude (T05A) larger than the abundances recorded in 2002. This increased density was primarily due to the large numbers of amphipods present at those stations (see section 5.3.1 above)

***Species Richness* —**The mean number of species per sample was higher at seven of the eight harbor stations (station T01 was the exception). As in previous years, species richness was lowest at T04 (Table 5-2, Figure 5-1). Stations T03, T05A, T06, and T08 had the greatest mean number of species, with a range of 64 to 67 species per sample (Figure 5-1).

***Diversity* —**As in previous years, mean Shannon diversity was lowest at T04 (H′ = 1.49) (Figure 5-1), but higher than in August 2002 when H′ at that station was 1.06. Mean Shannon diversities at stations T01, T03, and T08 were generally comparable to values at the same stations in 2002, but diversity was higher at T07, slightly lower at T02 and T06, and much lower at T05A (H′ = 4.04 in 2002 and 1.69 in 2003). This significantly lower H′ at T05A was not due to a depauperate community, but to the overwhelmingly large number (mean of 9773 per sample, Appendix D4) of *Ampelisca* spp. at that station, in addition to several other species with abundances numbering in the hundreds.

Diversity as measured by Fisher's log-series *alpha* was higher in August 2003 than in 2002 at all of the stations except T01, but otherwise mirrored the pattern seen in 2002: the lowest mean value was recorded at T04 and the highest at T08 (Table 5-2, Figure 5-1). At T05A, where abundance and species richness were so much higher in 2003 compared with 2002, log-series *alpha* was not significantly different between the two years.

***Evenness* —**Evenness values at six of the eight stations (T01, T02, T03, T05A, T06, and T08) were lower in 2003 compared with the summer values for these stations in 2002. Station T05A, which had the highest evenness value in August 2002, had significantly lower evenness (0.28) because of the thousands of *Ampelisca* present (Table 5-2, Figure 5-1). T01 had the highest evenness (0.69).

The results of the sediment image profiling (Chapter 4, this report) generally correspond well with the results from the grab samples. T04 in Dorchester Bay consistently has had the lowest OSI; T03 and T06 often have the highest. In 2003, T02 and T03 each had an OSI of 10, and T01 was only slightly lower, with an OSI of 9.3.

Table 5-2. Benthic community parameters for samples taken at Boston Harbor traditional stations in August 2003.

Station	Replicate	Total Abundance	No. Species	H′	J′	Log-Series *alpha*
T01	1	1363	43	3.67	0.68	8.54
	2	1557	42	3.47	0.64	8.04
	3	854	46	4.09	0.74	10.69
	Mean ± SD	1,258.0 ± 363.1	43.7 ± 2.1	3.74 ± 0.32	0.69 ± 0.05	9.09 ± 1.41
T02	1	5606	51	2.83	0.50	7.75
	2	4846	48	3.17	0.57	7.41
	3	4866	49	2.78	0.50	7.60
	Mean ± SD	5,106.0 ± 433.1	49.3 ± 1.5	2.93 ± 0.21	0.52 ± 0.04	7.59 ± 0.17
T03	1	5292	63	3.07	0.51	10.09
	2	9333	66	3.08	0.51	9.60
	3	11368	63	2.39	0.40	8.80
	Mean ± SD	8,664.3 ± 3092.7	64.0 ± 1.7	2.85 ± 0.40	0.47 ± 0.06	9.50 ± 0.65
T04	1	493	14	1.33	0.35	2.72
	2	177	12	1.79	0.50	2.91
	3	315	14	1.35	0.36	3.03
	Mean ± SD	328.3 ± 158.4	13.3 ± 1.2	1.49 ± 0.26	0.40 ± 0.08	2.89 ± 0.16
T05A	1	11788	68	1.68	0.28	9.56
	2	13160	67	1.59	0.26	9.23
	3	13091	62	1.80	0.30	8.45
	Mean ± SD	12,679.7 ± 773.0	65.7 ± 3.2	1.69 ± 0.11	0.28 ± 0.02	9.08 ± 0.57
T06	1	9662	66	2.28	0.38	9.62
	2	9677	67	2.14	0.35	9.77
	3	9008	59	2.18	0.37	8.53
	Mean ± SD	9,449.0 ± 382.0	64.0 ± 4.4	2.20 ± 0.07	0.37 ± 0.02	9.31 ± 0.68
T07	1	3248	47	2.93	0.53	7.87
	2	3198	47	2.97	0.53	7.93
	3	3619	40	2.94	0.55	6.39
	Mean ± SD	3,355.0 ± 230.0	44.7 ± 4.0	2.95 ± 0.02	0.54 ± 0.01	7.40 ± 0.87
T08	1	1888	56	3.37	0.58	10.94
	2	2559	67	3.26	0.54	12.64
	3	3850	77	3.24	0.52	13.72
	Mean ± SD	2,765.7 ± 997.2	66.7 ± 10.5	3.29 ± 0.07	0.55 ± 0.03	12.43 ± 1.40

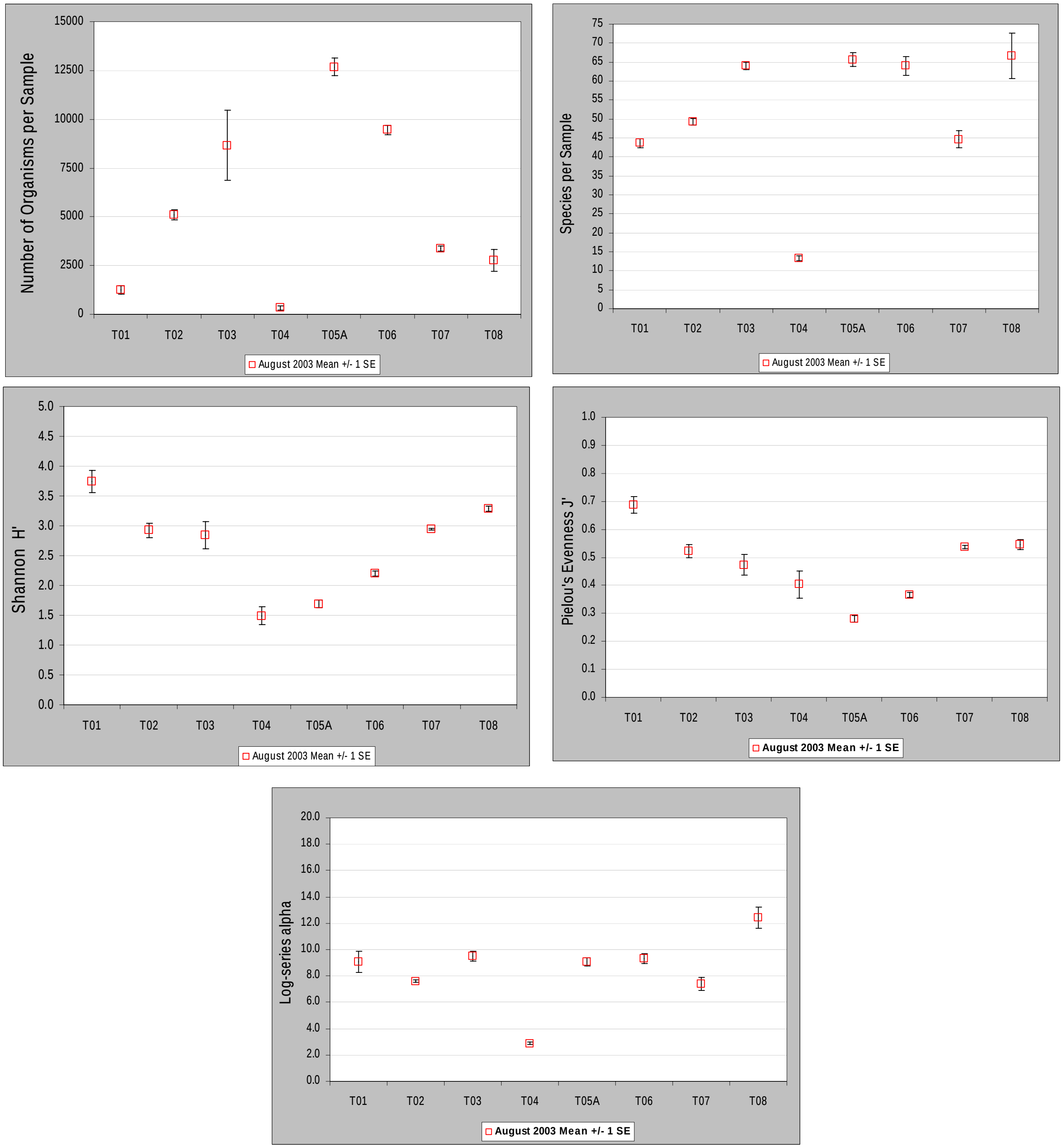

Figure 5-1. Mean ±SE of five benthic infaunal community parameters for the eight Boston Harbor traditional stations sampled by grab in August 2003.

Dominant Species **—**The numerically dominant species and their percent contribution to the fauna at each harbor station in August 2003 are given in Appendix D4. In 2002, the spionid polychaete *Prionospio steenstrupi* appeared for the first time as a numerical dominant at all eight harbor stations. In 2003, this species was still present and among the more numerous species at five stations (T01, T02, T03, T06, and T08), but was eclipsed in numbers by several species of amphipods. In 2003, *Ampelisca* spp. was the top numerical dominant at six stations (all except T01 and T04), accounting for up to 77.5% of the identified fauna at an individual station (T05A). At T01, a different amphipod species, *Leptocheirus pinguis*, was numerically dominant, accounting for 25.9% of the identified fauna, followed by *Polydora cornuta* (18.1%) and *Ampelisca* spp. (12.9%). *Leptocheirus pinguis* was also an important component of the fauna at five of the seven remaining stations (all except T04 and T06), where it accounted for 1.1 to 11.4% of the identified fauna (Appendix D4, see also Table 5-1). The community at T04 remained less species rich compared with the infauna at the other seven stations; in August 2003, as in August 2002, the overwhelming numerical dominant was *Streblospio benedicti* (76.3% of the fauna).

The amphipod species *Ampelisca abdita* has been considered a key organism in following the status of the infaunal community of Boston Harbor, partly because members of this genus are considered (by some) to be indicative of clean environments. The increase in numbers of *Ampelisca* and the spread and constriction of tube mats (*i.e.*, extremely high densities) has been followed in several reports (*e.g.*, Hilbig *et al*. 1997; Chapter 4, this report). In 2002, the results from SPI, which covers a greater number of stations throughout the harbor, suggested that areas of amphipod mats declined in 2002 compared with 2001, but the number of stations where *Ampelisca* was found in any density might have been increasing. In 2003, the areal distribution of *Ampelisca* spp. tube mats expanded from 22% of the stations to 30%, but the total number of stations with *Ampelisca* spp. tubes at any density remained at 63% (Chapter 4, this report). The traditional grab samples, however, yielded the highest numbers of *Ampelisca* spp. recorded since the initiation of monitoring (Figure 5-2).

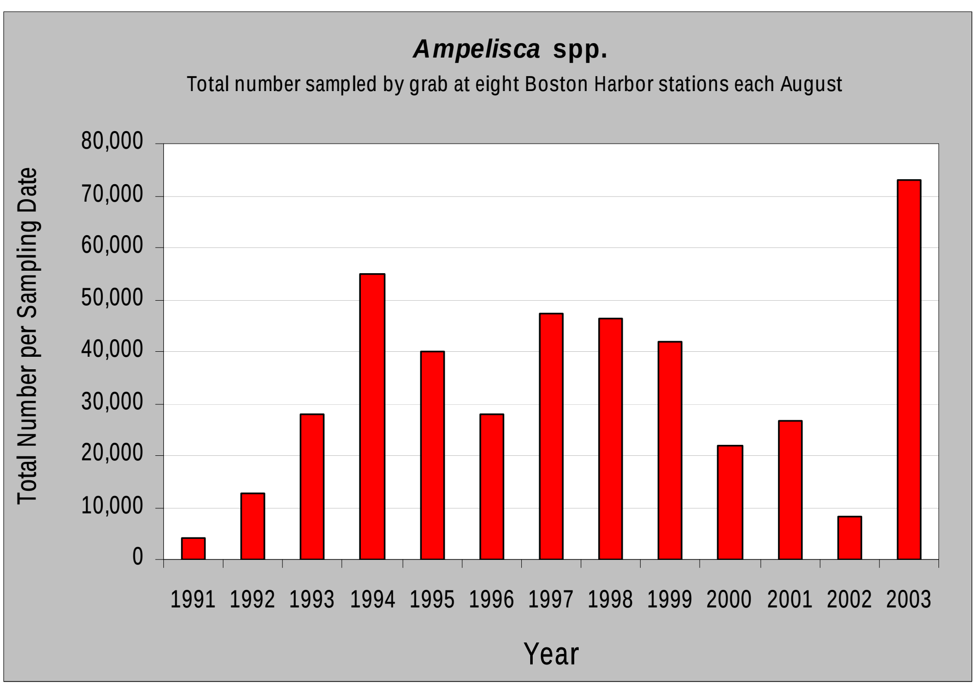

Figure 5-2. Total *Ampelisca* spp. collected at the eight traditional Boston Harbor grab stations on each August sampling date.

5.3.3 Multivariate Community Analysis of the 2003 Data

***Similarity Analysis with CNESS*—**In 2002, the CNESS analysis of spring and summer data showed four major groups of stations (Maciolek *et al.* 2004a): T01, in the northern part of the harbor near Deer Island Flats; T02/T03/T06/T07, all central harbor stations (*i.e.*, neither close to shore nor directly near the outer entrances to the harbor) in both the northern and southern sections of the harbor; T05A and T08, in Presidents' Roads and Hingham Bay; and T04 in Dorchester Bay, which has always been the most distinct station with an extremely low (or no) similarity to the other harbor stations.

The 24 samples collected in August 2003 showed a slightly different pattern, with the most notable difference being that T01, rather than being a separate group with a fairly low CNESS similarity to the remaining stations, clustered with T08 at a CNESS level of 0.83 (Figure 5-3). This is one of the few times that a station in the northern part of Boston Harbor near Deer Island Flats, once the most polluted part of the harbor, has shown any similarity to a station in the southern, traditionally more diverse, part of the harbor (see following PCA-H section for further discussion of this result). Another difference is that T03 and T06, once highly similar to each other, showed a lower level of similarity in 2003, and T05A was also loosely associated with the group comprising T02, T03, T06, and T07, rather than being in a separate grouping with T08. As in all previous years and seasons, T04 had no similarity to any of the other stations (Figure 5-3).

This pattern of station associations generally corresponds to the varying sediment types within the harbor, which have remained fairly consistent over the monitoring period (see Chapter 3, this report). The coarsest sediments, and also those with the lowest TOC content, are seen at T01, T05A, and T08. T04 has the siltiest sediments, and also the highest TOC. The remaining stations—T02, T03, T06, and T07—range from sandy to silty, and have been more variable over time.

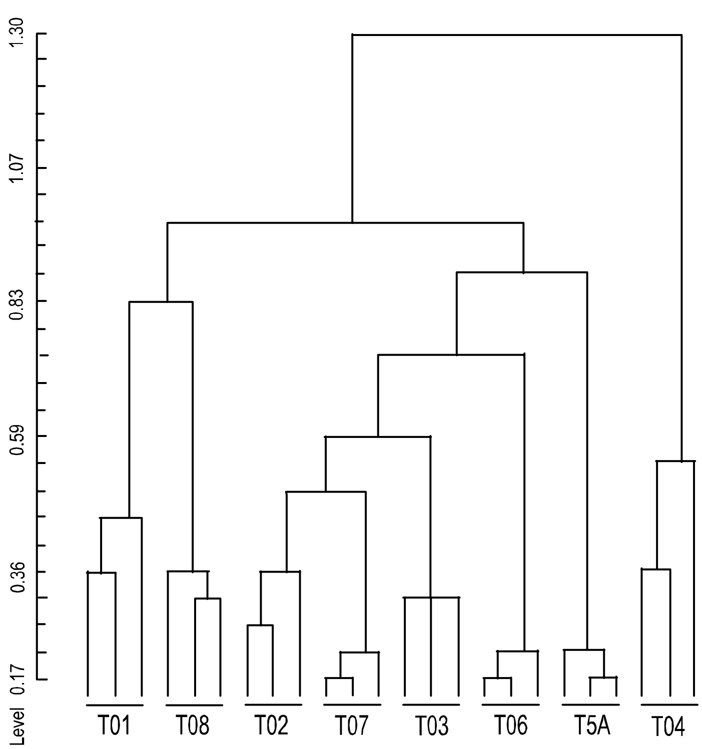

Figure 5-3. Cluster dendrogram of the 24 samples collected at the eight Boston Harbor traditional stations in 2003; based on CNESS similarity with *m* set at 15 and group average sorting.

***PCA-H Analysis*—** The metric scaling of the 2003 samples on the first two PCA-H axes, which accounted for 56% of the CNESS variation in the communities, is shown in Figure 5-4A. The separation of the T04 samples from the remaining stations, the similarity of stations T01 and T08, and the grouping of the remaining stations is reflected in this diagram.

The next step of the PCA-H analysis indicated which of the 144 species in the analysis were responsible for the metric scaling of the samples. With CNESS (*m*=15), 11 species contributed 2% or more of the total variation on PCA-H axes 1 and 2 (Table 5-3). The Gabriel Euclidean distance biplot (Figure 5-4B) shows those species superimposed over the metric scaling of the stations. The polychaete *Streblospio benedicti* and to a lesser extent the oligochaete *Tubificoides* sp. 2 and the polychaete *Tharyx* spp. distinguished T04 from the other stations. The oligochaetes *Tubificoides apectinatus* and *T*. nr. *pseudogaster* as well as the polychaete *Aricidea catherinae* are important at T02, T03, T06, and T07. The huge numbers of *Ampelisca* spp. at T05A contribute to the greater similarity of that station with the latter four stations in 2003.

In this analysis, the maldanid polychaete taxon Euclymeninae spp. was retained in the data and combined with *Clymenella torquata*. Typically a category such as this would be removed because it represents juveniles not identified to species and might include more than one species. In this case the animals were most likely all juveniles of one species, *C. torquata* (Maciolek, personal observation). They occurred only at T01 and T08 and thus accounted for much of the similarity between those two stations. The polychaetes *Spiophanes bombyx* and *Exogone hebes*, typically found in sandy environments from shallow to continental shelf depths, as well as the amphipod *Leptocheirus pinguis*, were also responsible for differentiating T01 and T08 from the remaining stations.

Table 5-3. Contribution to PCA-H axes 1 and 2 of the 11 species accounting for at least 2% of the community variation at the 2003 Boston Harbor stations. (see the Euclidean Distance Biplot, Figure 5-4B.)

PCA-H Rank	Species	Contr.[a]	Total Contr.	Axis 1	Axis 2
1	*Streblospio benedicti*	19	19	28	4
2	*Ampelisca* spp.	13	33	21	0
3	*Clymenella torquata*/ Euclymeninae spp.	11	43	0	30
4	*Tubificoides apectinatus*	10	53	7	15
5	*Aricidea catherinae*	9	63	11	6
6	*Tharyx* spp.	6	69	9	1
7	*Tubificoides* sp. 2	6	75	9	0
8	*Leptocheirus pinguis*	5	80	1	11
9	*Exogone hebes*	3	83	0	10
10	*Tubificoides* nr. *pseudogaster*	3	86	3	2
11	*Spiophanes bombyx*	3	89	0	8

[a]Percent contributions are rounded up by the computer program to the nearest whole number.

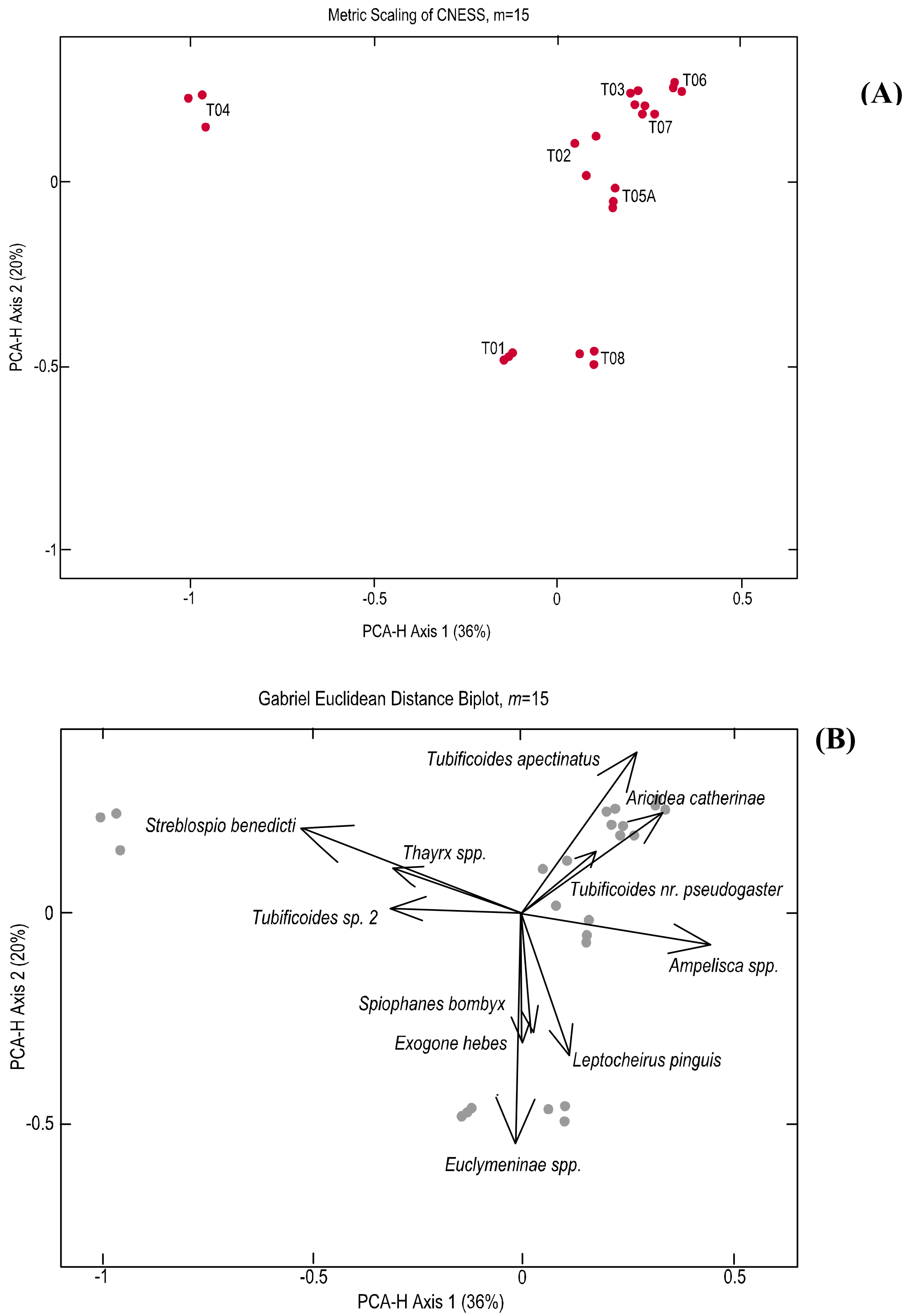

Figure 5-4. Metric scaling (A) and Gabriel Euclidean distance biplot (B) of the 2003 Boston Harbor samples. CNESS *m* was set at 15. Species that account for at least 2% of the variation are labeled.

5.3.4 Long-term Monitoring (1991–2003): Stations considered separately

T01, Deer Island Flats. Located to the west of the Deer Island Flats near the original site of effluent discharge, this general area was described in 1978 as highly polluted (J Williams, pers. com. to NJ Maciolek, Battelle, 1978; Blake and Maciolek, 1990). Two benthic samples collected in 1978 included 39 taxa and were dominated by oligochaetes and the predatory polychaetes *Pholoe minuta* and *Eteone longa*. The 72 samples taken from September 1991 through August 2003 included 146 species. Sixty species were present in the August 2003 samples, and of these, four— three polychaetes: *Ampharete acutifrons*, *Flabelligera affinis*, and *Ophelina acuminata,* and an amphipod *Harpinia propinqua*—were newly recorded from the station. With the exception of *O. acuminata*, these species were also new records for the harbor.

The early years of monitoring were marked by large fluctuations in seasonal abundances, with high densities in the August samples and low densities in the spring samples. These fluctuations were primarily due to large numbers of *Polydora cornuta* (a suspension feeding spionid polychaete) and *Clymenella torquata* (a head-down deposit feeding maldanid polychaete) that settled in August but had migrated or died off by the following spring. *Clymenella torquata* was largely absent from this station in 1999 and 2000, but was again represented by a set of juveniles in 2001 and 2003 (Figure 5-5), resulting in some similarities with T08 in the southern part of the harbor.

Two species of oligochaetes, *Tubificoides* nr. *pseudogaster* and *Tubificoides* sp. 2, along with *Polydora cornuta*, often dominated the fauna during the period 1991–2002 (Maciolek *et al.* 2004a), but in August 2003 the amphipods *Leptocheirus pinguis* and *Ampelisca* spp. (and *P. cornuta*) were the numerical dominants. *Streblospio benedicti*, an opportunistic species tolerant of stressed environmental conditions, was once common at T01 but has been present in much lower densities since 1998: only three individuals were present in the 2003 samples.

T01 has changed noticeably over the time period of the monitoring program, especially in the last two or three years. This change is reflected especially in the species composition as described above, and also in the community parameters, including diversity and species richness. Shannon diversity and log-series *alpha* both have increased, e.g., beginning in August 1998, the mean H′ has consistently been above 3.0, and reached a high of 3.8 in August 2002 (Appendix D3). Diversity as measured by log-series *alpha* has remained more variable than Shannon diversity, but has also increased over the past decade (Figure 5-6). The OSI measured by sediment profile imaging (Chapter 4, this report) has been high at 8.0 and 9.3 in 2002 and 2003, respectively.

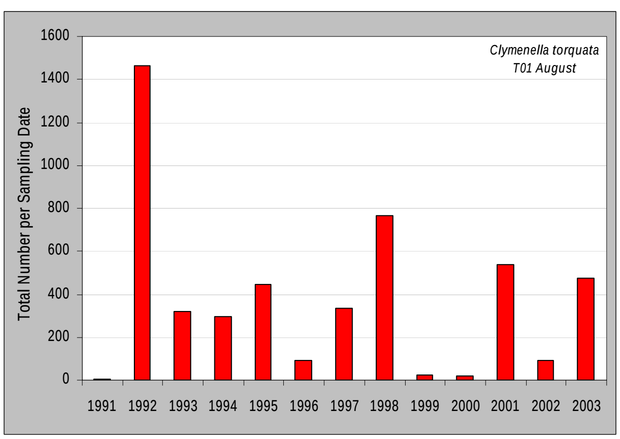

Figure 5-5. August densities of *Clymenella torquata* at T01 in Boston Harbor.

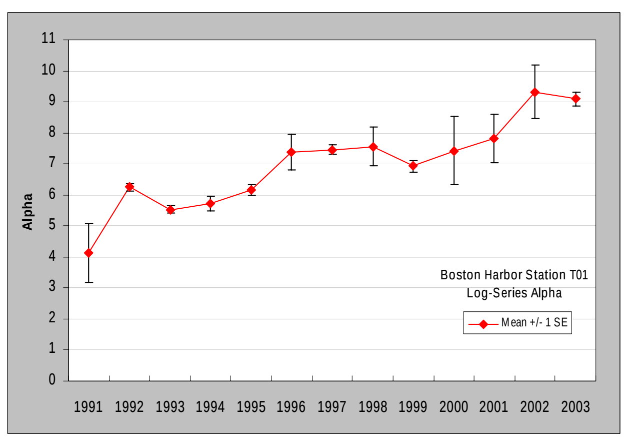

Figure 5-6. Mean log-series *alpha*, a measure of diversity, calculated for the August samples from T01 in Boston Harbor.

T02, Governor's Island Flats. This station is located in the Inner Harbor near the entrance to the Boston South Channel. It was evaluated in 1979 and 1982 (Blake and Maciolek 1990, Maciolek *et al.* 2004a) and was considered to be highly polluted with a depauperate fauna. In 1982, three replicates had only 3, 3, and 12 species, respectively, and all three samples were almost completely composed of *Capitella* spp. and *Polydora cornuta*.

The 72 samples taken from September 1991 through August 2003 at T02 included 147 species. Sixty-four species were present in the August 2003 samples, and of these, four were newly recorded from the station. These four species are all polychaetes: *Anobothrus gracilis*, *Flabelligera affinis*, *Polycirrus eximius*, and *Trochochaeta carica*; the second (*F. affinis*) and fourth (*T. carica*) were new records for the harbor.

Species that dominated the benthic infauna in the early 1990s included *Streblospio benedicti*, *Polydora cornuta*, *Tharyx* spp., and *Tubificoides* nr. *pseudogaster*. After 1998, *Tubificoides apectinatus* replaced *T.* nr. *pseudogaster* as the dominant oligochaete, and other species not previously resident in large numbers, including *Aricidea catherinae*, *Nephtys cornuta*, and *Micropthalmus pettiboneae*, became the numerical dominants. Ampeliscid amphipods have been numerous at times, most noticeably in 1994 and 1995, and again in 2003 when they comprised nearly 40% of the fauna (Figure 5-7). In addition to *Ampelisca* spp., the polychaetes *Polydora cornuta* and the amphipod *Leptocheirus pinguis* were numerical dominants in 2003. Only two specimens of the stress-tolerant polychaete *Streblospio benedicti* were present in 2003 (Figure 5-7).

In 2003, T02 appeared to be far less depauperate in terms of number of species and individuals than in most monitoring years (see Appendix D3). Mean abundances per sample have been comparable throughout the monitoring period, with the notable exceptions of the summer samples in 1994 and 1995 when amphipods were particularly numerous. Species richness and log-series *alpha* have trended toward higher values (Appendix D3, Figure 5-8), whereas Shannon diversity has followed a sine-wave-like pattern of higher and lower values (Appendix D3, Maciolek *et al.* 2004a).

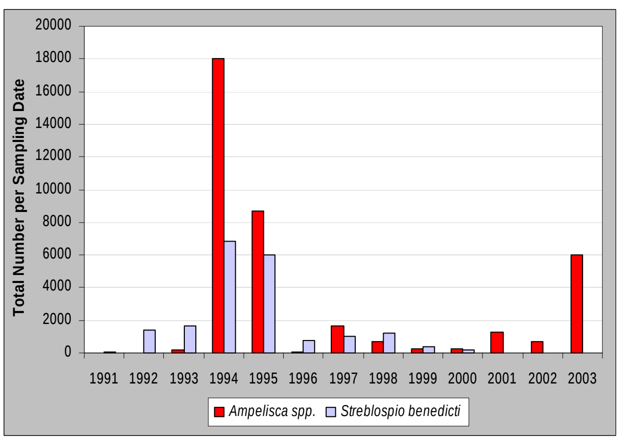

Figure 5-7. August densities of *Ampelisca* spp. and *Streblospio benedicti* at T02 in Boston Harbor.

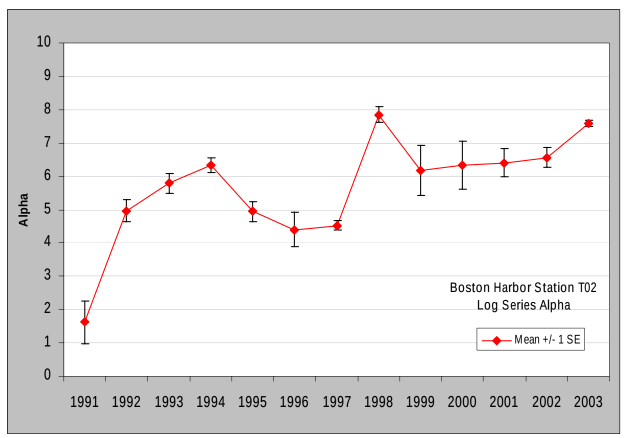

Figure 5-8. Mean log-series *alpha*, a measure of diversity, calculated for the August samples from T02 in Boston Harbor

T03, Long Island. The 71 samples taken from September 1991 through August 2003 comprised 168 species. Eighty-six species were present in the August 2003 samples, and of these, 12 were newly recorded from the station. These 12 species included nine polychaetes: *Ampharete acutifrons*, *A. lindstroemi, Flabelligera affinis*, *Leitoscoloplos acutus*, *Nereis grayi*, *Phyllodoce groenlandica, Pista cristata*, *Polycirrus eximius*, and *Terebellides atlantis;* one scaphopod mollusc *Dentalium entale*; and two nemerteans: *Amphiporus caecus* and *Micrura spp.* The polychaetes *A. acutifrons, F. affinis,* and *T. atlantis,* and the scaphopod *D. entale* were new records for Boston Harbor.

Ampelisca spp. has been important in the recent collections from T03, with peak densities in the August samples collected in 1994, 1998, and 1999 (mean densities of 6269, 8222, and 11,853 individuals per sample, respectively) (Figure 5-9). At other times, densities have ranged from 35 to 4837 in summer; in August 2003 the mean density of *Ampelisca* spp. was 4358 individuals per sample.

In addition to *Ampelisca* spp., other amphipods, including *Crassicorophium bonnelli*, *Leptocheirus pinguis* (1995–1999, 2003), *Unciola irrorata*, and *Photis pollex* have also been dominant during summer months, including 2003. As seen for station T02, *Tubificoides apectinatus* has joined or replaced *T.* nr. *pseudogaster* as a dominant in the past few years (2000–2003), and other species not previously resident in large numbers have come to dominate the fauna, including *Aricidea catherinae*, which is very common at several other harbor stations and also in the offshore samples collected in Massachusetts Bay (Maciolek *et al*. 2004b).

Diversity as measured by log-series *alpha* had been the most stable parameter at T03: except for an increase in August 1992 and a small increase in August 1998, the fluctuations in Shannon diversity or the other parameters seen at this station were not reflected in log-series *alpha* (Appendix D3). However, the 2003 samples were especially rich in numbers of species, and log-series *alpha* increased significantly (Figure 5-10). Species richness essentially doubled between 1991 and 1994, increasing from a mean of 23 to a mean of 42 species per sample, continued to remain high over several years, and in 2003 increased to a mean of 64 species per sample.

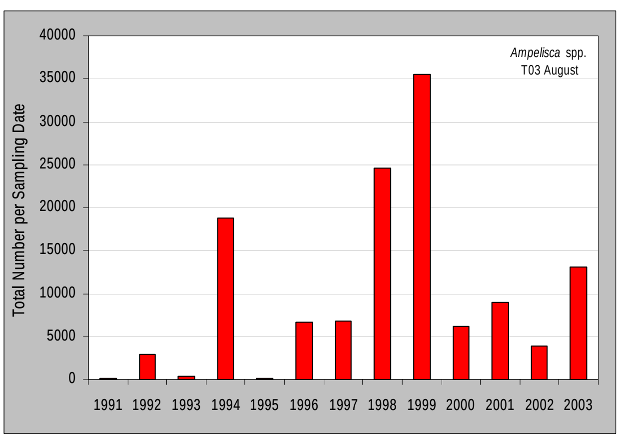

Figure 5-9. August densities of *Ampelisca* spp. at T03 in Boston Harbor.

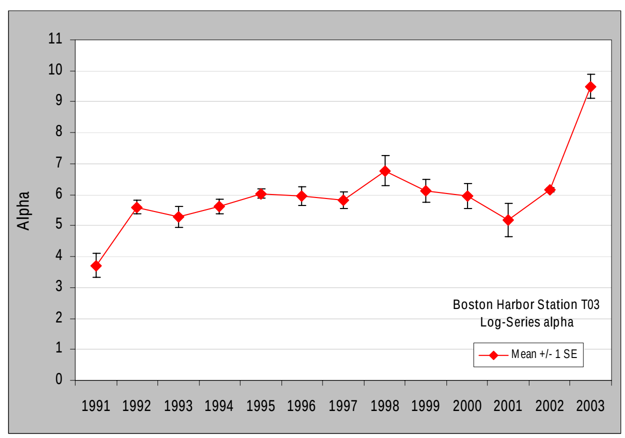

Figure 5-10. Mean log-series *alpha*, a measure of diversity, calculated for the August samples from T03 in Boston Harbor.

Station T04, Dorchester Bay. This station was included in the monitoring program as a degraded station that was unlikely to show rapid improvement after pollution abatement. Gallagher and Grassle (1989) and Gallagher *et al.* (1992) demonstrated that this site was heavily impacted by local sources and by focused deposition of effluent and sludge particulates transported from distant outfalls.

The prediction that improvement would be slow (or non-existent) has been borne out: T04 consistently has the lowest abundances, species richness, and diversity of the eight harbor stations (Appendix D3). The benthic community has appeared unstable, especially in the April collections, with no real patterns either within a sampling date (*i.e.*, large SE around parameter means) or between years (*e.g.*, numerical dominant species change from year to year) (Maciolek *et al*. 2004a). The summer samples have been somewhat more consistent in terms of dominant species: many of the collections in the early 1990s were dominated by *Streblospio benedicti*, which, with the exception of August 1998 when *Capitella* spp. was dominant, continues to be the summer numerical dominant even though its numbers are reduced (Figure 5-11). All of the 20 species present in the 2003 samples had previously been recorded from this station. August community parameters such as log-series *alpha* continue to fluctuate from year to year (Figure 5-12, Appendix D3).

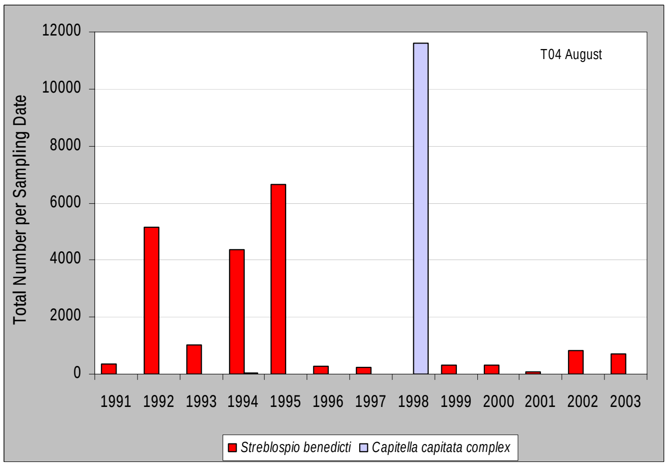

Figure 5-11. *Streblospio benedicti* and *Capitella capitata* complex in the August samples from T04 in Boston Harbor. Counts for *Capitella* were 0, except in 1992 (9), 1994 (31), 1995 (14), 1998 (11,616), 2002 (1), and 2003 (1).

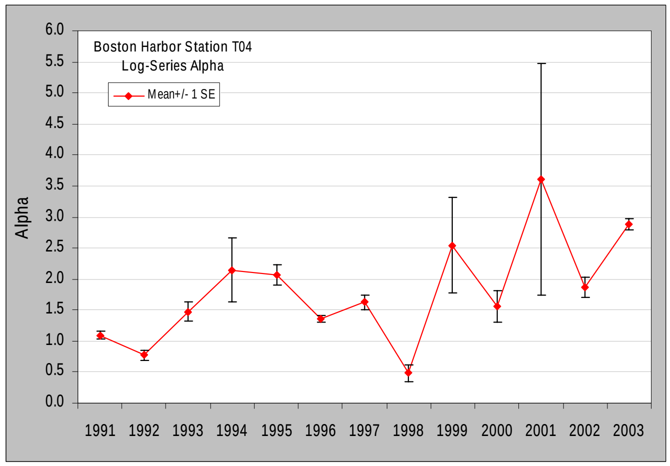

Figure 5-12. Mean log-series *alpha*, a measure of diversity, calculated for the August samples from T04 in Boston Harbor.

T05A, President Roads. Because of difficulty in sampling the coarse sediments of the original station T05 off the tip of Long Island near the old sludge discharge from Nut Island, an alternate location farther out in the channel was selected. T05A has been sampled routinely since August 1993, and the 66 samples collected there comprise 169 species. Ninety species were present in the August 2003 samples, and of these, 13 were newly recorded from the station. These 13 species included eight polychaetes: *Ampharete acutifrons, A. lindstroemi, Diplocirrus hirsutus, Euchone incolor, Laonome kroeyeri, Leitoscoloplos robustus, Nereis grayi*, and *Ophelina acuminata*; two molluscs: *Periploma papyratium* and *Yoldia sapotilla*; one cumacean *Eudorella hispida*, one amphipod *Microdeutopus anomalus*, and one echinoderm *Echinarachnius parma*. The species *A. acutifrons, D. hirsutus, L. kroeyeri*, and *E. hispida* were new to Boston Harbor as well as to the station. Some of the singleton or rare species found at T05A represent new distribution records and undescribed species that are new-to-science (Maciolek *et al*. 2004a).

Species that dominated the benthic infauna in the early- to mid-1990s included *Polydora cornuta*, *Ampelisca* spp., *Tharyx* spp., *Edotia triloba*, *Unciola irrorata*, and occasionally *Capitella capitata* complex, *Tubificoides* nr. *pseudogaster*, and *T. apectinatus*. Many of these species have continued to be important components of the benthic community along with *Ilyanassa trivittata*, *Aricidea catherinae*, and *Spiophanes bombyx*. In years when *Ampelisca* spp. or *P. cornuta* do not overwhelm the fauna, one of these taxa may be the dominant, as in 2002 when *T. apectinatus* was the numerical dominant in both spring and summer samples (Maciolek *et al*. 2004a). In 2003, amphipods were especially important at T05A, accounting for 90% of the individuals (Appendix D4): *Ampelisca* spp. accounted for 77.5% of the identified fauna, and *U. irrorata, Photis pollex, Orchomenella minuta, Dyopedos monacanthus,* and *L. pinguis* together contributed another 13%.

Benthic community parameters for samples from T05A have shown wide, primarily seasonal, fluctuations (Maciolek *et al*. 2004a), but there have also been large interannual differences (Appendix D3). Densities were especially high (mean = 21,319.3 ± 225.5 organisms per sample) in August 1997, due to high numbers of both *P. cornuta* and *Ampelisca* spp.; densities in 2003 were the second highest recorded at this station (mean = 12,679.7 ±773.0 organisms per sample) due primarily to *Ampelisca* spp. (Figure 5-13). Diversity as measured by log-series *alpha* reached lows in 1994 and 2000, but recovered in subsequent years (Figure 5-14).

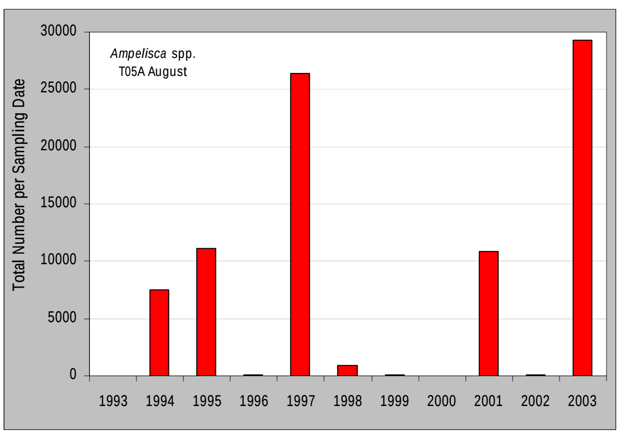

Figure 5-13. August densities of *Ampelisca* spp. at T05A in Boston Harbor.

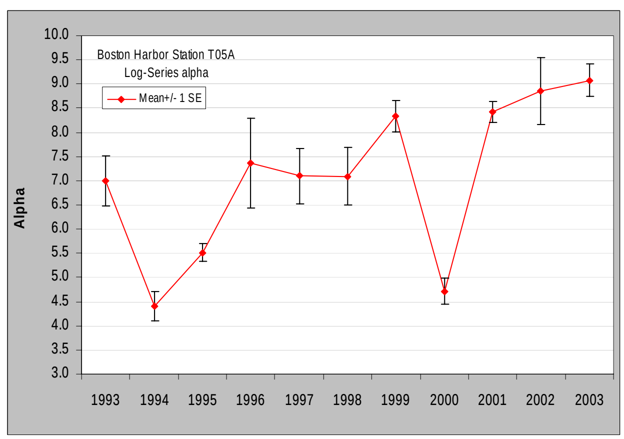

Figure 5-14. Mean log-series *alpha*, a measure of diversity, calculated for the August samples from T05A in Boston Harbor.

T06, Peddocks Island. A total of 138 species have been recorded from the 72 samples taken at T06 in the southern part of Boston Harbor. In 2003, there were 91 species present in the samples; of these, 20 were new to the station and five were new to the harbor. The species new to the station included three nemerteans: *Amphiporus bioculatus, A. caecus,* and Cephalothricidae sp.1; nine polychaetes: *Ampharete acutifrons, Eteone foliosa, Euchone incolor, F. affinis, Glycera americana, L. kroeyeri, O. acuminata, Pista cristata,* and *Polycirrus eximius*; the tanaid crustacean *Tanaissus psammophilus*; and the bivalve molluscs *Crenella decussata, Ensis directus, Nuculoma tenuis, Pitar morrhuanus, Pythinella cuneata, Spisula solidissima*, and *Yoldia sapotilla.* Five of the polychaetes and one bivalve were also new records for the harbor (*A. acutifrons, E. foliosa, F. affinis, G. americana, L. kroeyeri,* and *N. tenuis*; Appendix D2).

The species composition at T06 has remained fairly consistent throughout the years of the monitoring program. Amphipod species in particular have been diverse and numerically dominant at this station, including *Ampelisca* spp. (Figure 5-15), *Crassicorophium bonnelli*, *Phoxocephalus holbolli,* and *Leptocheirus pinguis*. In addition, the polychaetes *P. cornuta* and *Aricidea catherinae* (Figure 5-15) have occurred in large numbers. In 2003, *Ampelisca* spp. and *A. catherinae* together accounted for 74% of the identified fauna at T06 (Appendix D4).

Seasonal fluctuations or trends in species richness, evenness, and the diversity measures H′ and log-series *alpha* have not been obvious at T06 (Maciolek *et al.* 2004a). Between 1991 and 2002, the number of species per sample ranged from 26 (September 1991) to 46 (August 1999), with a mean of 35.0±0.8 SE. However, in August 2003, the mean number of species per sample was 64±4.4 (Table 5-2), resulting in a very sharp increase in log-series *alpha* (Figure 5-16), while H′ and J′ declined compared with 2002 (Appendix D3).

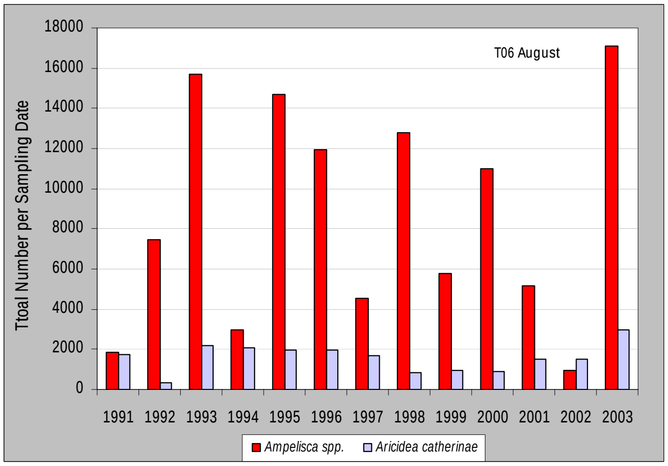

Figure 5-15. August densities of *Ampelisca* spp. and *Aricidea catherinae* at T06 in Boston Harbor.

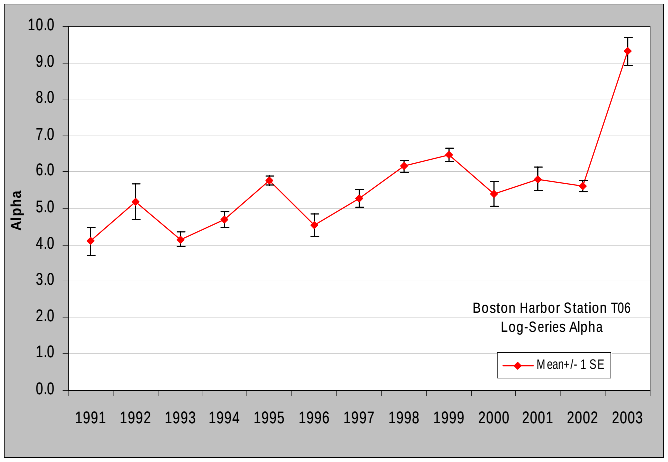

Figure 5-16. Mean log-series *alpha*, a measure of diversity, calculated for the August samples from T06 in Boston Harbor.

T07, Quincy Bay. Samples taken from September 1991 through August 2003 at T07, located in the southern central part of Boston Harbor, included 128 species. Sixty-two species were present in the 2003 samples, and seven of these were new to the station: the polychaetes *Euchone incolor, Gattyana cirrosa, Ophelina acuminata,* and *Spio filicornis;* the amphipod *Crassicorophium crassicorne;* and the molluscs *Yoldia sapotilla* and *Gemma gemma*, which was also new to the harbor (Appendix D2).

The dominant species at T07 have remained fairly consistent, with *Aricidea catherinae,* the oligochaetes *Tubificoides apectinatus* and *T.* nr. *pseudogaster*, and ampeliscid amphipods being the most numerous (Figure 5-17). The hesionid *Micropthalmus pettiboneae* and the lumbrinerid *Scoletoma hebes* are common and often among the numerical dominants, as they were in 2002 (Maciolek *et al.* 2004a). In recent years (2000–2002), the polychaete *Nephtys cornuta* and the oligochaete *Tubificoides apectinatus* have increased in abundance compared with the early 1990s, but in 2003 *Ampelisca* spp., *A. catherinae*, and *T. apectinatus* accounted for 70% of the identified fauna at this station (Appendix D4).

In 2003, all community parameters increased at T07 (Appendix D3). Total abundances were more than twice the August 2002 densities and species richness increased by about a third to a mean of 44.7 species per sample (see Table 5-2). Diversity, as measured by log-series *alpha*, has shown two periods of steep increase (1991–1995 and 2001–2003) and has generally increased from the early 1990s through 2003 (Figure 5-18). Shannon diversity also increased in 2003 compared with 2002, but the current value of 2.95 is lower than the station high value of 3.24, which was reached in August 1998 (Appendix D3, Maciolek *et al.* 2004a).

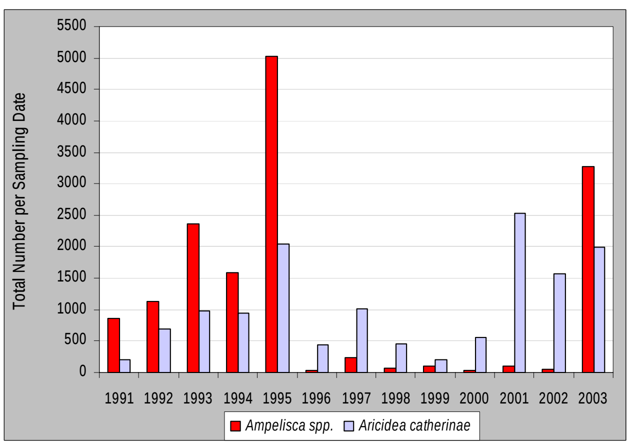

Figure 5-17. August densities of *Ampelisca* spp. and *Aricidea catherinae* at T07 in Boston Harbor.

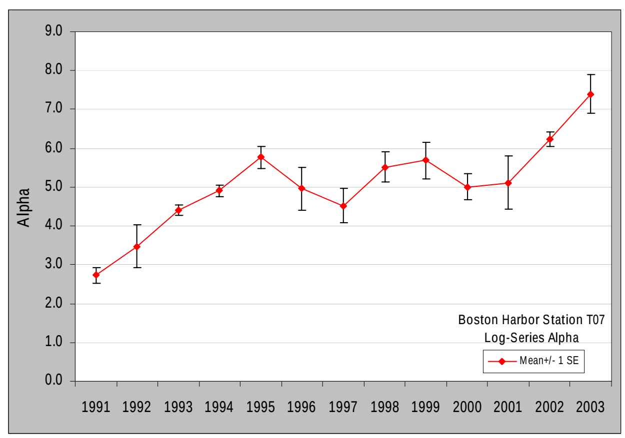

Figure 5-18. Mean log-series *alpha*, a measure of diversity, calculated for the August samples from T07 in Boston Harbor.

T08, Hingham Bay. Samples taken from September 1991 through August 2003 at T08, located in the southern part of Boston Harbor, included 188 species. Ninety-three species were present in the 2003 samples, and seven of these were new to the station: one anemone, *Edwardsia elegans*; one nemertean, *Amphiporus caecus*; one oligochaete, Enchytraeidae sp. 1; two polychaetes *Flabelligera affinis* and *Ophelina acuminata*; and two molluscs, *Nuculoma tenuis* and *Pythinella cuneata*. The polychaete *F. affinis* and the bivalve mollusc *N. tenuis* were also new to the harbor (Appendix D2).

The dominant species at T08 remained fairly constant throughout the early 1990s, with *Ampelisca* spp. and *Aricidea catherinae* as the numerical dominants. Although both remained among the most numerous species, the abundances of both taxa declined in samples taken in 1999–2002 (Figure 5-19); however, in 2003 *Ampelisca* spp. increased at this station as it did elsewhere around the harbor. *Spiophanes bombyx* was the numerical dominant in several seasons, including August 2002, and was the second most numerous taxon in 2003 (Appendix D4).

Diversity as measured by log-series *alpha* remained fairly steady during the period 1991–2000, but has increased significantly in the past three years, reaching a high mean value of 12.4 in August 2003 (Figure 5-20, Table 5-2). Species richness in samples from T08 has been variable, with no discernable pattern of seasonality (Maciolek *et al.* 2004a). The number of species per sample has varied from year to year, with a low mean value of 34.3 in 1995 and a previous high of 60.3 in 1998 (Appendix D3). In August 2003, species richness increased to a mean of 66.7 species per sample. Shannon diversity and evenness, while also showing increases and decreases throughout the monitoring period, were essentially the same in 2003 as they were in 1991, with an H′ of around 3.3 and J′ of 0.6; these values are similar to those obtained for samples taken in 1982 (Appendix D3, Maciolek *et al.* 2004a).

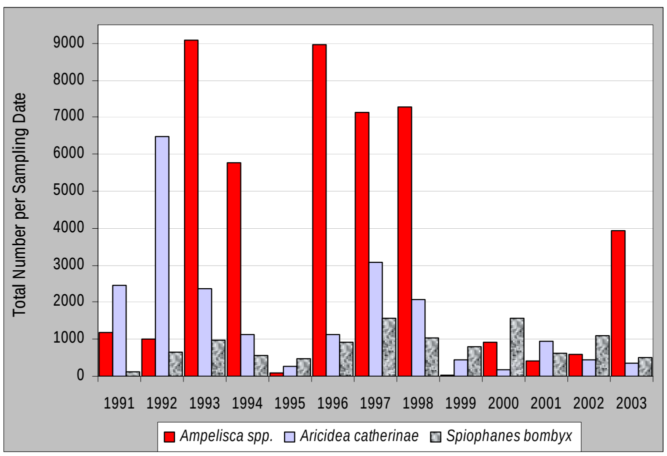

Figure 5-19. August densities of *Ampelisca* spp., *Aricidea catherinae*, and *Spiophanes bombyx* at T08 in Boston Harbor.

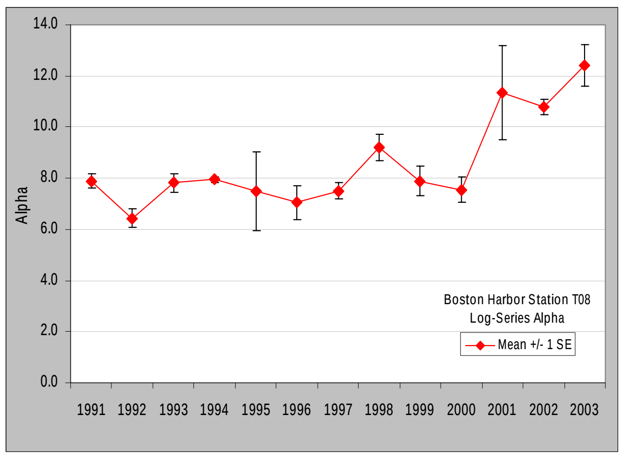

Figure 5-20. Mean log-series *alpha*, a measure of diversity, calculated for the August samples from T08 in Boston Harbor.

5.3.5 Long-term Monitoring (1991-2003): Annual Changes

Samples taken at Boston Harbor stations in August (or September, as in 1991) were pooled to eight samples per year (*i.e.*, all samples from a station were pooled, but stations were kept separate, resulting in 104 station samples). The pooled samples, which included 245 taxa, were analyzed by similarity, rarefaction, and PCA-H to investigate the relationships among successive sampling dates. Samples were also pooled to one sample per year (*i.e.*, all samples from all stations pooled to one annual harbor-wide sample, resulting in 13 harbor samples) for rarefaction analysis.

Long-term Analyses: Samples pooled to eight per year

Similarity Analysis—Figure 5-21 is a summary dendrogram for the similarity analysis with samples pooled by station for each of the 13 years, *i.e*., eight samples per year, 104 samples total (T05 is included for 1991 and 1992). Three main groups can be seen in this diagram: (1) a small group of four samples: T03 1991, T04 1998, and T05 1991 and 1992; (2) the majority of T01 and T02, particularly the early monitoring years, plus all years at T04 except 1998; and (3) a large group comprising the remaining stations, with a distinction among three subgroups: (a) T03/T06 plus recent years at T01 and T02, as well as T07, (b)T08 all years, and (c) half of T05A, (mostly years with low numbers of amphipods).

The CNESS levels indicated on the diagram are very high (maximum possible dissimilarity is 1.41; Trueblood *et al*.1994), indicating that there are large differences among these station/year clusters. An interesting point from this figure is that samples from T01 for 2001–2003 form a unique cluster group and are very dissimilar to earlier samples from this station. Similarly, samples from T02 taken in 1997 and 2000–2003 are more similar to samples from T03 and T06 than they are to T02 prior to 1997. Taken together with the increased diversity and changing species composition at this station, as well as the very high OSI seen here in 2003 (Chapter 4, this report), it would seem that conditions at T01 and T02 are improving (or at least changing) relative to their condition in the late 1970s and early 1990s.

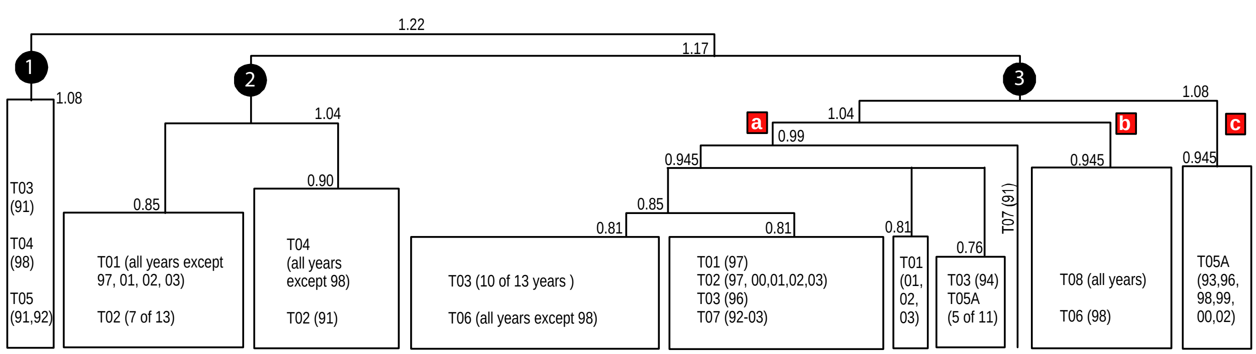

Figure 5-21. Station dendrogram for Boston Harbor 1991-2003 infauna. The similarity levels for each cluster are indicated on the diagram: the lower the number, the more similar the stations. Replicates summed at each station, CNESS *m* = 15 and group average sorting were used. 245 taxa and 104 samples from August of each year were included.

PCA-H Analysis— The metric scaling of the 104 samples on the first two PCA-H axes, which accounted for 39% of the CNESS variation in the communities, is shown in Figure 5-22, and the contribution of species to the first seven PCA-H axes is given in Table 5-6. As demonstrated by Maciolek *et al.* (2004a) for 550 individual samples taken in both April and August through 2002, CNESS distances among these pooled samples tend to distinguish stations within the multidimensional space. Samples from T08 are in the upper right corner of the diagram and those from T04 are in the left center. The portion of the diagram (lower right) where many of the samples could not be specifically determined from the computer graphic appear to be a mixture of T03 and T06. This scaling of the samples generally corresponds to the dendrogram in Figure 5-24 where similar samples are shown as major groups; because only two axes are shown in Figure 5-22, the relationships of the cluster groups to the spacing of the points is not exact.

The species responsible for the scaling of the samples are indicated in the Gabriel Euclidean distance biplot (Figure 5-23) and Table 5-7. The opportunistic species *Streblospio benedicti*, which is found primarily at T04, is the most important in structuring the scaling, followed by the amphipod *Ampelisca* spp.

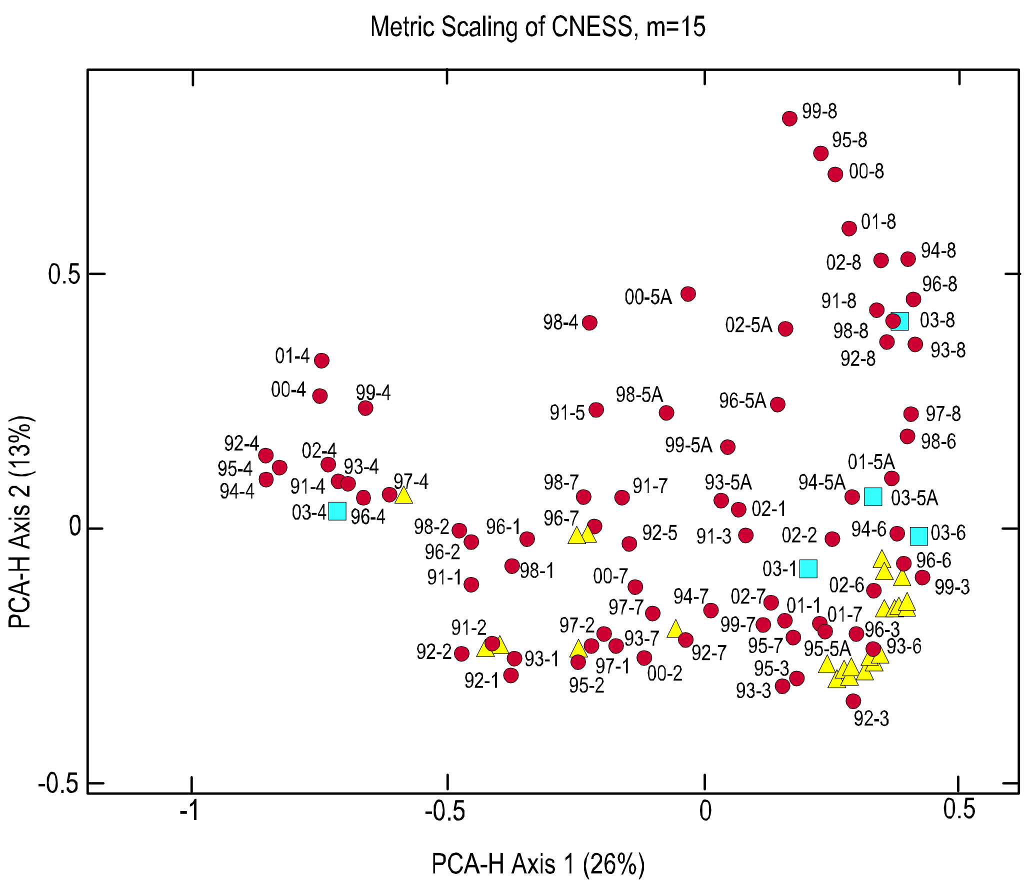

Figure 5-22. Metric scaling of 104 pooled samples taken at eight Boston Harbor stations each August (or September) 1991–2003. Labels indicate year followed by station number. Squares indicate 2003 samples, red circles indicate labeled samples; yellow triangles indicate samples that could not be specifically identified from the computer graphic.

Table 5-6. Important species, their relative and cumulative contributions to PCA-H axes 1–7 of the metric scaling of CNESS distances of pooled Boston Harbor samples (see Figure 5-22).

PCA-H Rank	Species	% Contr.	Cum. Contr.	Ax.1	Ax.2	Ax.3	Ax.4	Ax.5	Ax.6	Ax.7
1	*Streblospio benedicti*	16	16	51	0	11	1	7	3	2
2	*Ampelisca* spp.	9	25	20	2	16	5	12	0	13
3	*Polydora cornuta*	7	32	0	33	0	3	18	15	0
4	*Aricidea catherinae*	7	39	12	1	1	28	0	14	0
5	*Tubificoides* nr. *pseudogaster*	7	46	0	6	50	3	11	2	6
6	*Tubificoides apectinatus*	6	52	3	3	3	36	5	19	1
7	*Spiophanes bombyx*	4	56	1	20	0	1	3	5	2
8	*Tharyx* spp.	4	60	1	0	0	0	22	1	18
9	*Leptocheirus pinguis*	3	63	1	3	1	2	1	1	16
10	*Ilyanassa trivittata*	3	66	0	5	3	0	2	4	2
11	*Chaetozone vivipara*	2	68	0	0	1	2	3	1	19
12	*Micropthalmus pettiboneae*	2	71	1	0	2	2	2	4	0
13	*Unciola irrorata*	2	73	2	0	0	7	0	4	0
14	*Phoxocephalus holbolli*	2	75	2	1	1	0	4	1	1
15	*Polygordius* sp. A	2	77	0	10	0	0	0	2	0
16	*Tubificoides* sp. 2	2	79	1	0	0	0	1	1	4
17	*Crasicorophium bonnelli*	2	81	0	1	0	1	0	0	5
18	*Capitella capitata* complex	2	83	0	0	4	0	0	2	4
19	*Photis pollex*	1	84	1	0	0	1	2	4	0
20	*Exogone hebes*	1	86	0	6	0	0	0	5	0
21	*Nucula delphinodonta*	1	87	1	4	0	0	0	3	0
22	*Nephtys cornuta*	1	88	0	0	2	3	1	0	1
23	*Turbellaria* spp.	1	89	0	0	0	0	1	0	0
24	*Tellina agilis*	1	91	0	3	1	0	1	0	0
25	*Clymenella torquata*	1	91	0	0	0	0	1	3	0
26	*Edotia triloba*	1	92	0	0	0	1	1	2	2
27	*Tubificoides benedeni*	1	93	0	0	2	0	0	2	0
28	*Phyllodoce mucosa*	1	94	0	0	0	1	0	0	1
29	*Crangon septemspinosa*	1	94	0	0	0	0	0	0	0
30	*Prionospio steenstrupi*	1	95	0	0	0	0	0	0	0

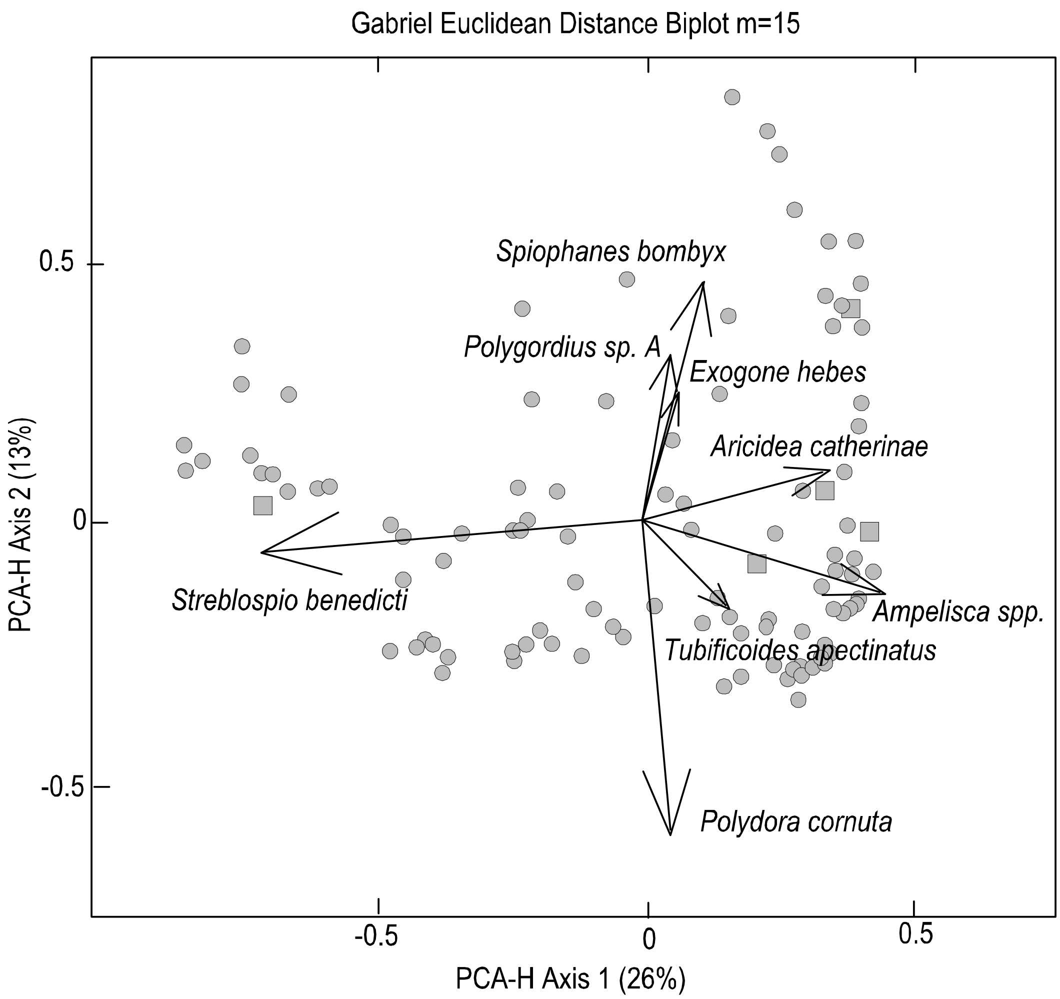

Figure 5-23. Gabriel Euclidean distance biplot of pooled Boston Harbor samples, showing the eight species that account for at least 2% of the plot variation on PCA-H axes 1 and 2.

Table 5-7. Contribution to PCA-H axes 1 and 2 of the eight species accounting for at least 2% of the annual community variation at the Boston Harbor stations (see Figure 5-23).

PCA-H Rank	Species	Contr.	Total Contr.	Axis 1	Axis 2
1	*Streblospio benedicti*	35	35	51	0
2	*Ampelisca* spp.	14	49	20	2
3	*Polydora cornuta*	11	60	0	33
4	*Aricidea catherinae*	8	68	12	1
5	*Spiophanes bombyx*	7	75	1	20
6	*Polygordius* sp. A	3	78	0	10
7	*Tubificoides apectinatus*	3	81	3	3
8	*Exogone hebes*	2	83	0	6

Long-term Analyses: Samples pooled to one per year to examine harbor-wide averages

The analyses of samples pooled to one harbor sample per year included data from T05 rather than T05A for the years 1991 and 1992; these samples were included to provide an equal number of samples in each year before pooling. Pooling across stations is probably not entirely valid because of the wide differences among stations in terms of sediment type and environmental conditions (*e.g.*, water circulation patterns, depth, etc.). Indeed, when the results of the SPI are considered as an average across all stations (Chapter 4 this report), there is no appreciable difference in benthic habitat conditions over the last 12 years. However, because some differences were seen at individual stations, both in terms of infaunal community structure, SPI, and sediment characteristics (Chapter 3, this report), averaged annual differences were investigated in order to determine if there were any apparent annual patterns as well. As discussed below, some analyses were more informative than others.

The Shannon diversity index H′ ranged from a low of 2.10 in 1992 to a high of 2.94 in 2002 (Figure 5-24). The large standard error around each mean suggests that these values are not significantly different from each other. Given the typical range of this index from 1.5 to 3.5 (Magurran 1988), it is unlikely that changes in H′ will provide great insight into trends over time for averaged harbor stations. The associated evenness index, J′ , has been stable throughout the monitoring period (Figure 5-24).

The average number of species per sample, the most direct measure of species richness, ranged from 18 in 1991 to more than 51 in 2003 (Figure 5-24). The intervening years evidenced few real changes in this measure, with a low of 29 in 1996 and a high of 41 in 1998 and an average of 34 species per sample for the period 1992–2002. Of all the parameters examined, log-series *alpha* appears to suggest a trend over time from low values in the early 1990s to higher values in recent years, with 2003 in particular different from all previous years (Figure 5-24).

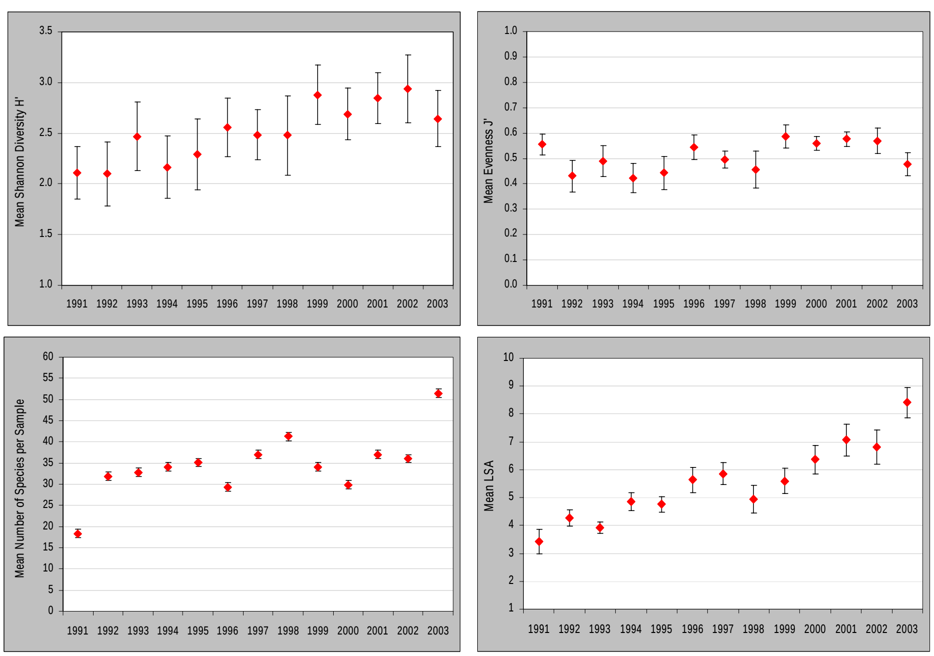

Figure 5-24. Benthic community parameters (mean ± 1 SE) in Boston Harbor, with all stations pooled for each August (or September) sampling event from 1991–2003.

Rarefaction Analysis—The curves generated by the rarefaction analysis for each sampling year indicate an increase in diversity over the years of the monitoring program, with a clear increase for the past three years (2001–2003) (Figure 5-25). Rarefaction analysis is essentially a measure of species richness, with loss of information about the relative abundances of each species (Magurran 1988). Many of these curves (*e.g.*, 1997) appear to be reaching an asymptote; however, several curves (*e*.g., 2000, 2002) appear to be continuing to rise, suggesting that the harbor remains somewhat undersampled and that more species will be found if additional area is sampled.

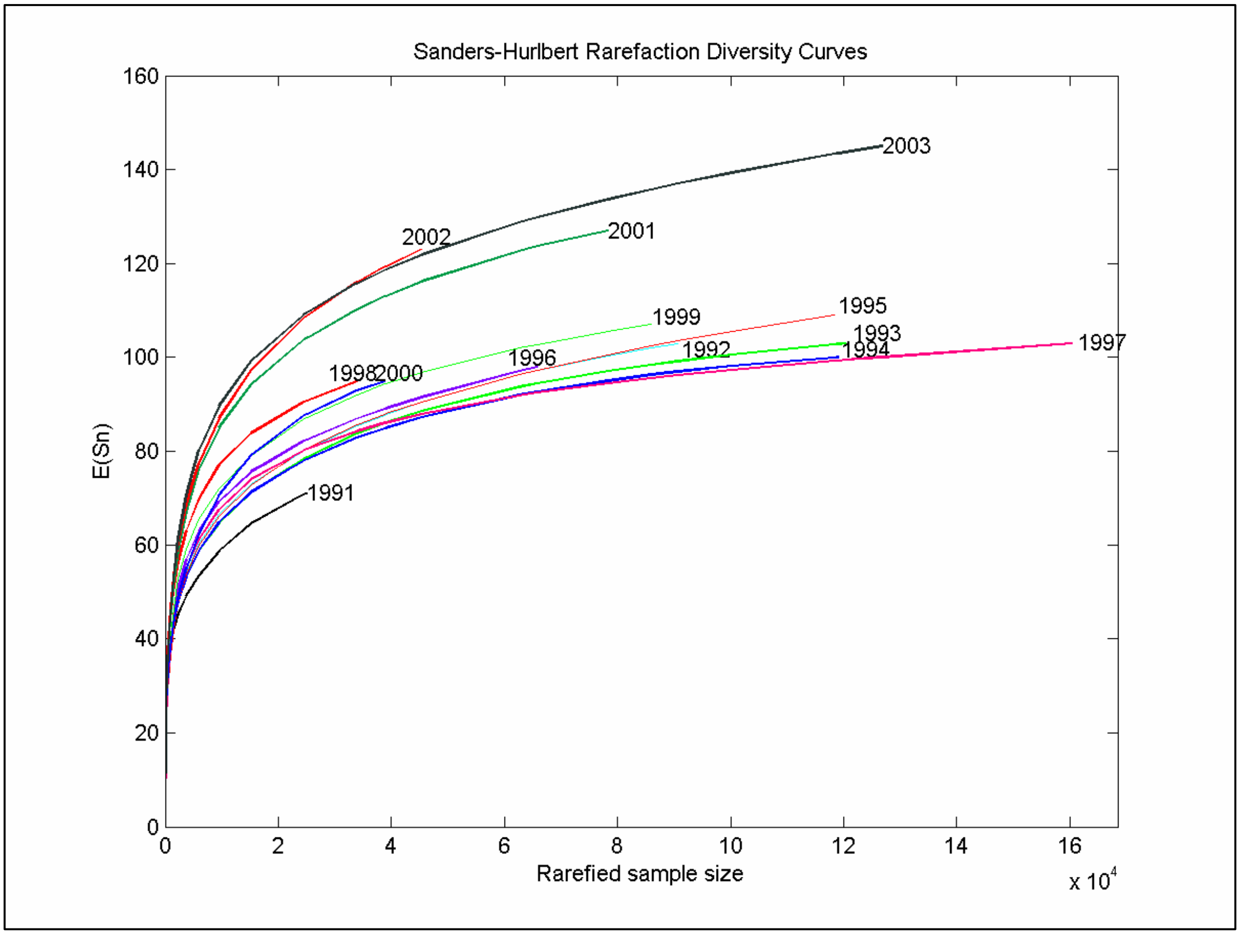

Figure 5-25. Rarefaction curves for August samples taken in Boston Harbor each year from 1991 through 2003; all samples considered together for each year.

***Similarity Analyses*—**The dendrogram based on the CNESS similarity analysis indicated three major groups or clusters of annual samples (Figure 5-26): cluster group 1 is the most dissimilar group and includes 1991, 1998, and 2002; group 2 includes 1992, 1994 and 1995; and in group 3 the later years 1999, 2000, 2001, and 2003 form a highly similar group within the larger cluster that includes 1993 and 1997 (the most similar pair of years) and 1996. The inclusion of 2002 in the cluster containing the earliest year (1991) and a "middle" year (1998) challenges the idea that there has been a trend in the infaunal communities in the harbor. Considering that the highest possible CNESS dissimilarity value is √2 (1.41) (Trueblood *et al*., 1994), all years can therefore be considered fairly similar to one another (conversely, we may conclude that comparing all samples pooled within a year is of limited usefulness). Stations considered separately within a year are often more dissimilar to each other (see Figure 5-3, this report) than the annual "samples" considered here.

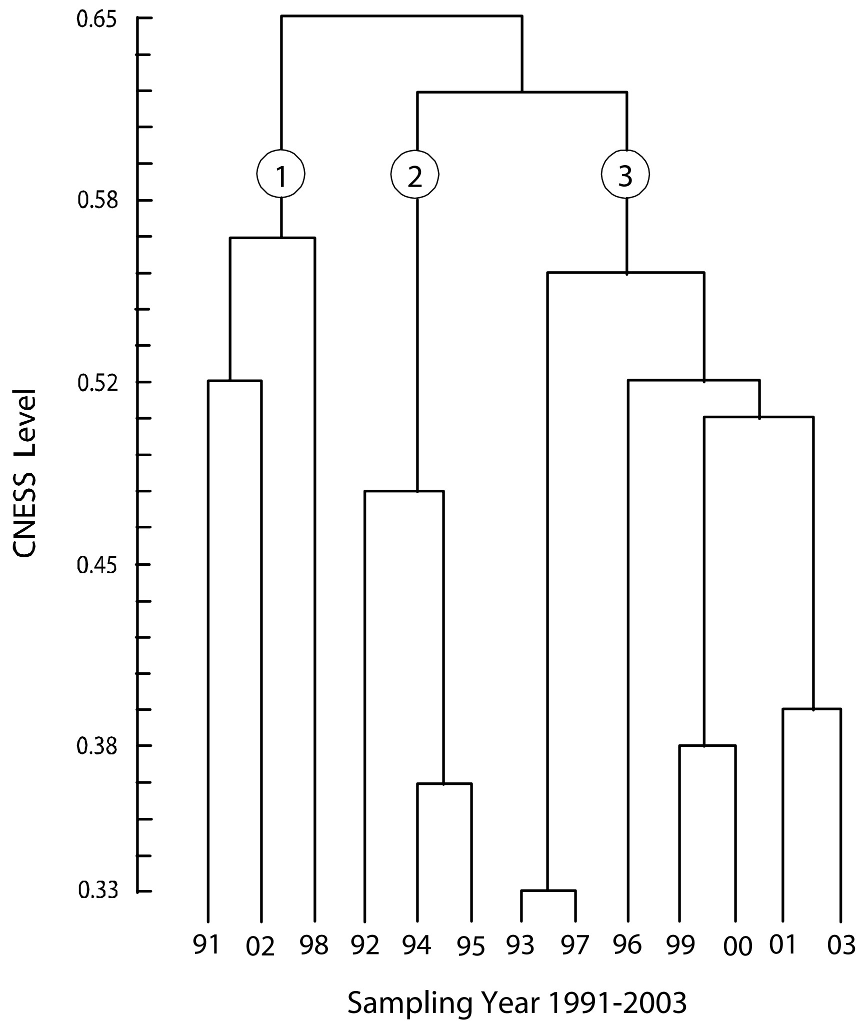

Figure 5-26. Station dendrogram for Boston Harbor 1991–2003 infauna. The lower the CNESS number, the more similar the stations. CNESS m = 20 and group average sorting were used. 245 taxa and 13 pooled annual samples were used.

PCA-H Analysis—The metric scaling of the 13 annual samples on the first two PCA-H axes, which accounted for 53% of the CNESS variation in the communities, is shown in Figure 5-27, and the contribution of species to the PCA-H axes is given in Table 5-8. There is some separation of decades along axis 2, but as seen in the dendrogram (Figure 5-26), there is no clearly directional temporal trend. Three species in particular influenced the metric scaling of the samples: the amphipod *Crassicorophium bonnelli*, the polychaete *Streblospio benedicti*, and the oligochaete *Tubificoides apectinatus*. Although *S. benedicti* continues to be found at T04, it was present in high numbers at other stations (e.g., T02) only during the early years of monitoring. As discussed earlier in the sections for each sampling station, these species are also characteristic of sediment type and perhaps levels of environmental stress.

The Gabriel Euclidean distance biplot (Figure 5-28) shows species superimposed over the metric scaling of the stations. With CNESS (m=20), 11 species contributed 2% or more of the total variation on PCA-H axes 1 and 2 (Figure 5-28, Table 5-9).

Figure 5-27. Metric scaling of 13 pooled samples taken in Boston Harbor from September 1991 through August 2003.

Table 5-8. Important species, their relative and cumulative contributions to PCA-H axes 1–7 of the metric scaling of CNESS distances of pooled Boston Harbor samples (see Figure 5-27).

PCA-H Rank	Species	% Contr.	Cum. Contr.	Ax.1	Ax.2	Ax.3	Ax.4	Ax.5	Ax.6	Ax.7
1	*Crassicorophium bonnelli*	11	11	12	16	16	2	5	28	0
2	*Streblospio benedicti*	11	22	9	33	0	0	1	0	0
3	*Tubificoides apectinatus*	10	32	23	8	6	0	0	1	5
4	*Polydora cornuta*	8	40	17	0	5	11	1	11	0
5	*Leptocheirus pinguis*	7	47	3	7	16	18	6	1	0
6	*Chaetozone vivipara*	6	53	2	3	1	6	34	4	11
7	*Phoxocephalus holbolli*	5	58	0	2	26	18	0	2	1
8	*Unciola irrorata*	5	62	5	9	0	1	1	1	3
9	*Spiophanes bombyx*	4	67	6	0	0	9	10	2	7
10	*Capitella capitata complex*	4	71	1	4	1	2	10	6	7
11	*Tubificoides* nr. *pseudogaster*	3	74	4	2	2	3	2	1	1
12	*Aricidea catherinae*	3	77	4	0	0	8	3	5	2
13	*Photis pollex*	3	79	1	3	6	0	7	2	0
14	*Prionospio steenstrupi*	2	81	2	0	5	2	0	7	8
15	*Tharyx* spp.	2	83	0	0	1	0	1	0	26
16	*Nucula delphinodonta*	2	85	1	2	2	0	1	5	4
17	*Ilyanassa trivittata*	2	87	3	0	0	0	5	1	2
18	*Phyllodoce mucosa*	1	88	0	2	2	0	1	1	0
19	*Orchomenella minuta*	1	90	0	3	0	0	0	0	2
20	*Polygordius* sp. A	1	91	1	0	2	7	0	0	2
21	*Micropthalmus pettiboneae*	1	92	1	0	1	4	3	1	1
22	*Ampelisca* spp.	1	93	0	0	0	1	0	3	0
23	*Dyopedos monacanthus*	1	93	0	0	0	3	3	0	0
24	*Tubificoides* sp. *2*	1	94	0	0	0	2	0	1	0
25	*Tubificoides benedeni*	1	95	0	1	0	0	1	3	3
26	*Tellina agilis*	1	95	1	0	0	1	1	1	2
27	*Clymenella torquata*	1	96	0	1	0	0	1	1	0
28	*Nephtys cornuta*	1	97	0	0	1	0	0	3	1

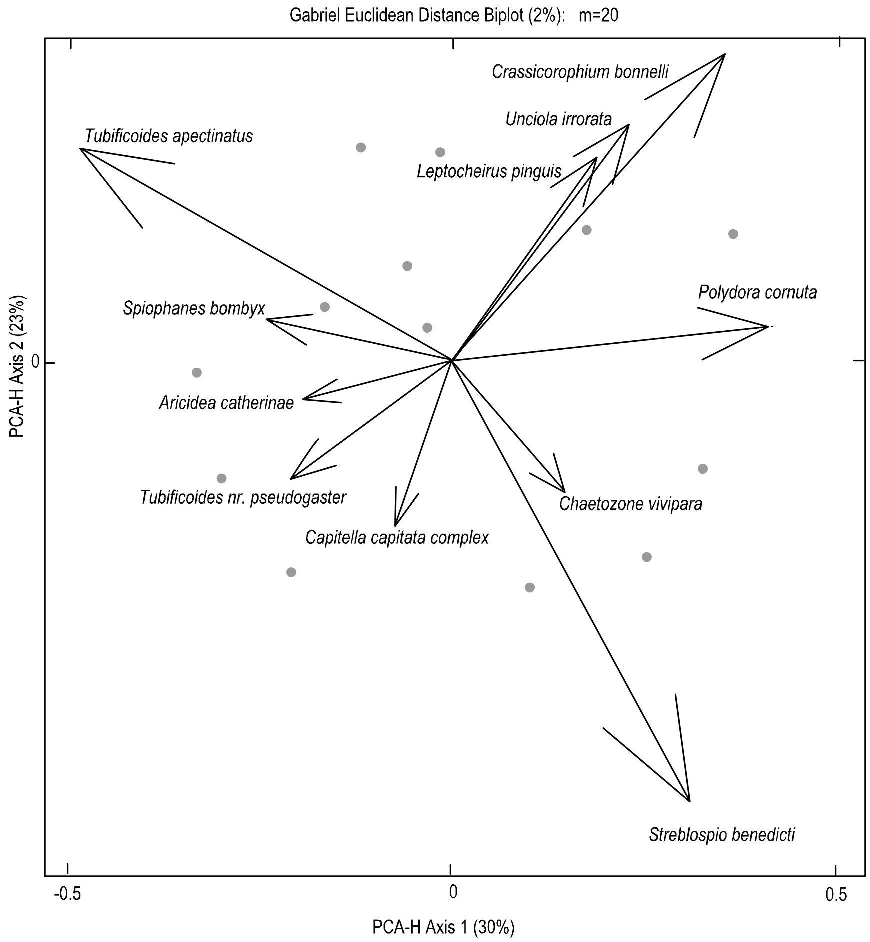

Figure 5-28. Gabriel Euclidean distance biplot of 13 pooled Boston Harbor samples, showing the 11 species that account for at least 2% of the plot variation on PCA-H axes 1 and 2.

Table 5-9. Contribution to PCA-H axes 1 and 2 of the 11 species accounting for at least 2% of the annual community variation at the Boston Harbor stations. (see Euclidean Distance Biplot, Figure 5-28.)

PCA-H Rank	Species	Contr.	Total Contr.	Axis 1	Axis 2
1	*Streblospio benedicti*	20	20	9	33
2	*Tubificoides apectinatus*	16	36	23	8
3	*Crassicorophium bonnelli*	14	50	12	16
4	*Polydora cornuta*	9	59	17	0
5	*Unciola irrorata*	7	66	5	9
6	*Leptocheirus pinguis*	5	71	3	7
7	*Tubificoides nr. pseudogaster*	3	75	4	2
8	*Spiophanes bombyx*	3	78	6	0
9	*Chaetozone vivipara*	3	81	2	3
10	*Capitella capitata* complex	2	83	1	4
11	*Aricidea catherinae*	2	85	4	0

5.3.6 Long-term Changes in the Infaunal Communities

The premonitoring studies of benthic communities in Boston Harbor (1978, 1979, 1982) indicated distinct groupings of stations that corresponded to (1) a progression from higher saline oceanic conditions in the outer harbor to estuarine conditions in the inner harbor and (2) known areas of pollution (Blake and Maciolek 1990, Maciolek *et al*. 2004a). A distinct outer harbor assemblage that included species with close affinities to faunal communities in Massachusetts Bay changed in the middle of the harbor to one that included estuarine species and elements of so-called pollution indicators or stress-tolerant taxa. All stations in the outer harbor assemblage had more species and higher species diversity values regardless of differences in sample size or analytical technique. Stations having high infaunal densities were found throughout the station array, but opportunistic species such as *Streblospio benedicti* were found only at the stations in the middle of the harbor. The early data also clearly indicated an obvious north/south pattern in the benthic communities, with stations near the northern Deer Island outfall being distinctly different from those near Nut Island in Hingham Bay in the southern part of the harbor. Tidal exchange through President Roads and Broad Sound appeared to be sufficient to maintain benthic assemblages that were only moderately stressed despite their proximity to the sewage and sludge outfalls. In contrast, shallow sites to the east and west of the outfall had low diversities and high densities of opportunistic stress-tolerant species.

Discharge of sludge into the harbor ended in 1991 and, in 1998, all effluent discharge from Nut Island was discontinued and full secondary treatment of the effluent was implemented. Since that time, and especially in the past two or three years, the benthic communities in the harbor appear to be recovering from the effects of pollutant input, although each station is responding in a slightly different way. It is also possible that changes at the harbor stations are reflective of a regional increase in species richness and diversity, as seen at Massachusetts Bay stations over the same time frame (Maciolek *et al*., 2004b)

The most dramatic changes in harbor benthic communities have been at T01, near the Deer Island Flats, and T02, near Logan Airport. Both of these stations have increased in diversity and other measures of benthic community status. Species composition has changed, especially at T01, where densities of *Streblospio benedicti*, usually considered indicative of stressed environments, have declined to nearly zero in recent years, and densities of *Aricidea catherinae*, a very common polychaete found both elsewhere in the harbor and offshore in Massachusetts Bay, have increased. The density of *S. benedicti* has also declined significantly at T02 (see Figure 5-7). The presence of particular benthic species is often related to the grain-size composition of the sediment, but any change in sediment composition at these stations (see Chapter 3, this report) does not appear to be of sufficient magnitude in and of itself to result in the changes seen in the structure of the benthic community.

Stations T03 and T05A have evidenced wide fluctuations in community parameters, often due to the seasonal presence of large numbers of amphipod species, as was the case in 2003. The largest change at T03 appears to have occurred between 1991and 1992, when sludge abatement resulted in a change in sediment composition from "black mayonnaise" to cohesive tube-bound sediments (K. Keay, MWRA, personal communication, June 2005), a decline in *Clostridium perfringens* (see Figure 3-7), and a 50% increase in species richness (as measured by log-series *alpha*, see Figure 5-10).

Although T03 does not appear to have changed significantly in recent years in terms of numerically dominant species, the dominants at T05A were very different in 2003, when huge populations of several amphipod taxa were present. It is noteworthy that rare offshore species such as *Scolelepis tridentata* and *Polydora* sp. 1 have occurred at T05A in the last year or two, although such occurrences are usually only of a single individual.

Many of the patterns in benthic community structure described for 1978–1982 (Blake and Maciolek 1990, Maciolek *et al.* 2004a) continued throughout the period 1991–2003 at stations in the southern portion of the harbor. Those stations that appeared diverse according to the several parameters measured prior to the cessation of sludge and effluent discharge have changed the least in those parameters in the years since the discharges were diverted. Stations T06, T07, and T08 have consistently had the highest species richness and diversities, and the dominant species have for the most part remained similar, although at T07 *Nephtys cornuta* and *Tubificoides apectinatus* have increased in recent years and in 2003 *Ampelisca* spp. was the numerical dominant at all three stations. Even at these stations, however, there has been an increase in species richness and diversity as measured by log-series *alpha* in the last year or two.

Recovery of areas degraded by the long-term disposal of sludge and effluents may involve a transitional stage of undetermined length before an equilibrium community is established. This intermediate stage involves the appearance of a diverse assemblage of tube-dwelling amphipods, molluscs, and polychaetes. The periodic explosion and decline of amphipod populations dominated by *Ampelisca* spp. suggests that infaunal succession patterns are being held in the Stage I and II seres as defined by Rhoads and Germano (1986). After a number of years in which *Ampelisca* populations appeared to be declining, 2003 samples once again contained large numbers of this and other amphipod species. Although numbers in 2003 were not as high as those recorded in 1998, amphipods clearly were the numerical dominants at seven of the eight infaunal sampling stations. Given the physical and oceanographic attributes of the study area (*i.e.*, near-coastal environment, relatively shallow compared with offshore areas, continuing pollutant load from CSOs or other industrial sources), it is probable that the harbor benthos will continue to evidence this episodic rise and decline of amphipod populations, and will remain in a Stage 1/Stage II pattern.

Lines of evidence from the component parts of this monitoring program suggest that, when taken as a whole, the harbor has not changed significantly over the past decade. For example, based on the OSI calculated from the data developed as part of the SPI sampling, no station showed a monotonic trend of either improvement or decline (Chapter 4, this report). The large fluctuations in numbers of, for example, amphipods at various stations resulted in little discrimination among years for most community parameters when samples were pooled across stations within each year (Figure 5-27). The exception to this trend (or lack thereof) is log-series *alpha*, which has increased steadily over the period 1991–2003 (Figure 5-24). Several authors (*e.g.*, May 1975, 1981; Southwood 1978, and most recently Hubble 2001) have encouraged the use of species abundance models such as *alpha* as the best way to evaluate species diversity.

When individual stations are examined in detail, there is some indication that the benthic communities in Boston Harbor are responding to the elimination of pollutants from the former sewage discharge(s). The patterns of change in species richness and log-series *alpha* were not equivalent at all stations (Appendix D3); however, with the exception of T01 where species richness was the same in 2003 as in 2002, all stations showed large increases in these two parameters in 2003. This same increase in species richness was also observed at many of the MWRA monitoring stations in Massachusetts Bay (Maciolek *et al.* 2004b), suggesting that the pattern of increased species richness was regional or system-wide, rather than linked only to the recovery of the harbor.

That the benthic environment in the harbor is recovering from years of pollutant input is supported by other lines of evidence, such as the decrease in levels of the sewage marker *Clostridium* (Chapter 3, this report) and increased OSI values at several traditional stations (Chapter 4, this report).

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APPENDIX A

Station Data:
Sediment Profile Images (HR031)
August Benthic Grab Samples (HT031)

Table A-1. Station data for individual sediment profile images collected in August 2003 (HR031).

SPI Station ID	SPI Sample ID	Date/Time (EDT)	Replicate analyzed*	Longitude (W)	Latitude (N)	Depth (m)
R02	HR03136A	8/25/03 14:57	1*	-70.961567	42.344367	12.5
	HR03136B	8/25/03 14:58	2*	-70.961483	42.344400	12.5
	HR03136C	8/25/03 14:59	3*	-70.961517	42.344467	12.5
R03	HR031376	8/25/03 15:25	1*	-70.972767	42.352950	3.6
	HR031377	8/25/03 15:26	2*	-70.972833	42.353033	3.6
	HR031378	8/25/03 15:27	3*	-70.972833	42.353050	3.6
R04	HR03137C	8/25/03 15:36	1*	-70.979600	42.358533	5.7
	HR03137D	8/25/03 15:38	2*	-70.979533	42.358683	5.7
	HR03137E	8/25/03 15:39	3*	-70.979617	42.358633	5.7
R05	HR031379	8/25/03 15:31	1*	-70.978233	42.356367	4.5
	HR03137A	8/25/03 15:32	2*	-70.978267	42.356367	4.5
	HR03137B	8/25/03 15:32	3*	-70.978200	42.356367	4.5
R06	HR031364	8/25/03 14:43	1*	-70.952050	42.331817	6.4
	HR031365	8/25/03 14:44	2*	-70.952117	42.331783	6.4
	HR031366	8/25/03 14:44	3*	-70.952333	42.331833	6.4
R07	HR031373	8/25/03 15:17	1*	-70.975733	42.347483	5.5
	HR031374	8/25/03 15:18	2*	-70.975700	42.347483	5.5
	HR031375	8/25/03 15:19	3*	-70.975633	42.347517	5.5
R08	HR03137F	8/25/03 15:51	1*	-70.991717	42.344367	2.0
	HR031380	8/25/03 15:52	2*	-70.991617	42.344383	2.0
	HR031381	8/25/03 15:53	3*	-70.991550	42.344400	2.0
R09	HR031388	8/25/03 16:16	1*	-71.016550	42.346700	11.2
	HR031389	8/25/03 16:17	2*	-71.016617	42.346767	11.2
	HR03138A	8/25/03 16:18	3*	-71.016467	42.346783	11.2
R10	HR03138B	8/25/03 16:28	1*	-71.036633	42.355267	12.5
	HR03138C	8/25/03 16:29	2*	-71.036600	42.355267	12.5
	HR03138D	8/25/03 16:30	3*	-71.036550	42.355300	12.5
R11	HR0313C5	8/26/03 10:14	1*	-70.974933	42.321267	8.2
	HR0313C6	8/26/03 10:16	2*	-70.974900	42.321367	8.2
	HR0313C7	8/26/03 10:17	3*	-70.974850	42.321467	8.2
R12	HR0313C8	8/26/03 10:21	1*	-70.974600	42.318533	7.0
	HR0313C9	8/26/03 10:23	2*	-70.974700	42.318433	7.0
	HR0313CA	8/26/03 10:24	3*	-70.974683	42.318367	7.0
R13	HR0313CB	8/26/03 10:30	1*	-70.980550	42.317217	7.0
	HR0313CC	8/26/03 10:31	2*	-70.980550	42.317233	7.0
	HR0313CD	8/26/03 10:32	3*	-70.980483	42.317250	7.0
R14	HR0313D1	8/26/03 10:55	1*	-71.012817	42.320900	8.5
	HR0313D2	8/26/03 10:57	2*	-71.012750	42.320933	8.5
	HR0313D3	8/26/03 10:58	3*	-71.012750	42.321000	8.5
R15	HR0313D4	8/26/03 11:03	1*	-71.019250	42.315467	5.0
	HR0313D5	8/26/03 11:05	2*	-71.019217	42.315483	5.0
	HR0313D6	8/26/03 11:06	3*	-71.019250	42.315517	5.0
R16	HR0313B8	8/26/03 9:31	1*	-70.961417	42.315983	8.2
	HR0313B9	8/26/03 9:32	2*	-70.961500	42.316000	8.2
	HR0313BA	8/26/03 9:32	3*	-70.961633	42.315900	8.2
R17	HR0313E4	8/26/03 12:24	1*	-70.977233	42.304767	8.0
	HR0313E5	8/26/03 12:25	2*	-70.977217	42.304683	8.0
	HR0313E6	8/26/03 12:26	3*	-70.977117	42.304633	8.0
R18	HR031408	8/26/03 14:00	1*	-70.961250	42.288867	8.0
	HR031409	8/26/03 14:00	2*	-70.961300	42.289000	8.0
	HR03140A	8/26/03 14:02	3*	-70.961233	42.288883	8.0

SPI Station ID	SPI Sample ID	Date/Time (EDT)	Replicate analyzed*	Longitude (W)	Latitude (N)	Depth (m)
R19	HR0313A3	8/26/03 8:28	1*	-70.937867	42.282083	9.4
	HR0313A4	8/26/03 8:29	2*	-70.937833	42.282167	9.4
	HR0313A5	8/26/03 8:30	3*	-70.938033	42.282150	9.4
R20	HR0313BB	8/26/03 9:44	1*	-70.934900	42.324833	10.8
	HR0313BC	8/26/03 9:46	2	-70.934917	42.324783	10.8
	HR0313BD	8/26/03 9:46	3*	-70.934883	42.324783	10.8
	HR0313BE	8/26/03 9:47	4*	-70.934867	42.324800	10.8
R21	HR0313B5	8/26/03 9:20	1*	-70.946167	42.308717	8.0
	HR0313B6	8/26/03 9:21	2*	-70.946083	42.308683	8.0
	HR0313B7	8/26/03 9:22	3*	-70.946167	42.308600	8.0
R22	HR0313B2	8/26/03 9:11	1*	-70.939333	42.300550	9.5
	HR0313B3	8/26/03 9:12	2*	-70.939333	42.300550	9.5
	HR0313B4	8/26/03 9:13	3*	-70.939250	42.300500	9.5
R23	HR031402	8/26/03 13:44	1*	-70.950017	42.293700	10.3
	HR031403	8/26/03 13:45	2*	-70.950033	42.293717	10.3
	HR031404	8/26/03 13:46	3*	-70.950050	42.293700	10.3
R24	HR0313FF	8/26/03 13:37	1*	-70.958717	42.296150	6.5
	HR031400	8/26/03 13:38	2*	-70.958750	42.296200	6.5
	HR031401	8/26/03 13:39	3*	-70.958700	42.296283	6.5
R25	HR0313A6	8/26/03 8:36	1*	-70.928633	42.291317	6.5
	HR0313A7	8/26/03 8:38	2*	-70.928650	42.291400	6.5
	HR0313A8	8/26/03 8:39	3*	-70.928600	42.291517	6.5
R26	HR031418	8/26/03 14:46	1*	-70.929833	42.268983	6.9
	HR031419	8/26/03 14:47	2*	-70.929833	42.268950	6.9
	HR03141A	8/26/03 14:47	3*	-70.929817	42.268933	6.9
R27	HR0313A0	8/26/03 8:17	1*	-70.916400	42.280583	5.3
	HR0313A1	8/26/03 8:18	2*	-70.916417	42.280633	5.3
	HR0313A2	8/26/03 8:19	3*	-70.916433	42.280567	5.3
R28	HR031394	8/26/03 7:37	1*	-70.908750	42.281767	8.3
	HR031395	8/26/03 7:38	2*	-70.908800	42.281783	8.3
	HR031396	8/26/03 7:39	3*	-70.908850	42.281817	8.3
R29	HR0313A9	8/26/03 8:44	1*	-70.920867	42.289633	9.4
	HR0313AA	8/26/03 8:45	2*	-70.920800	42.289667	9.4
	HR0313AB	8/26/03 8:46	3*	-70.920767	42.289700	9.4
R30	HR031397	8/26/03 7:46	1*	-70.904167	42.290600	3.3
	HR031398	8/26/03 7:47	2*	-70.904067	42.290683	3.3
	HR031399	8/26/03 7:49	3*	-70.903917	42.290583	3.3
R31	HR0313AF	8/26/03 8:59	1*	-70.917267	42.300767	9.7
	HR0313B0	8/26/03 9:00	2*	-70.917267	42.300800	9.7
	HR0313B1	8/26/03 9:01	3*	-70.917267	42.300800	9.7
R32	HR03139A	8/26/03 7:56	1*	-70.896950	42.294617	3.8
	HR03139B	8/26/03 7:57	2*	-70.896900	42.294600	3.8
	HR03139C	8/26/03 7:58	3*	-70.896900	42.294583	3.8
R33	HR0313ED	8/26/03 12:45	1*	-70.994383	42.294250	4.8
	HR0313EE	8/26/03 12:46	2*	-70.994417	42.294250	4.8
	HR0313EF	8/26/03 12:47	3*	-70.994350	42.294267	4.8
R34	HR0313F0	8/26/03 12:54	1*	-71.006950	42.288900	3.7
	HR0313F1	8/26/03 12:55	2*	-71.006967	42.288867	3.7
	HR0313F2	8/26/03 12:56	3*	-71.007067	42.288900	3.7
R35	HR0313F6	8/26/03 13:13	1*	-70.988033	42.284067	4.7
	HR0313F7	8/26/03 13:14	2*	-70.988017	42.284000	4.7
	HR0313F8	8/26/03 13:15	3*	-70.988050	42.284000	4.7

SPI Station ID	SPI Sample ID	Date/Time (EDT)	Replicate analyzed*	Longitude (W)	Latitude (N)	Depth (m)
R36	HR0313F3	8/26/03 13:05	1*	-70.986567	42.275483	3.7
	HR0313F4	8/26/03 13:06	2*	-70.986650	42.275500	3.7
	HR0313F5	8/26/03 13:07	3*	-70.986767	42.275583	3.7
R37	HR0313E7	8/26/03 12:31	1*	-70.984667	42.298733	5.8
	HR0313E8	8/26/03 12:32	2*	-70.984783	42.298717	5.8
	HR0313E9	8/26/03 12:33	3*	-70.984900	42.298717	5.8
R38	HR03140B	8/26/03 14:11	1*	-70.964050	42.284783	5.0
	HR03140C	8/26/03 14:11	2*	-70.963983	42.284850	5.0
	HR03140D	8/26/03 14:12	3*	-70.963917	42.284883	5.0
R39	HR0313FC	8/26/03 13:28	1*	-70.970333	42.295500	7.6
	HR0313FD	8/26/03 13:29	2*	-70.970467	42.295500	7.6
	HR0313FE	8/26/03 13:30	3*	-70.970483	42.295467	7.6
R40	HR0313CE	8/26/03 10:47	1*	-71.024100	42.328833	4.8
	HR0313CF	8/26/03 10:48	2*	-71.024100	42.328850	4.8
	HR0313D0	8/26/03 10:48	3*	-71.024067	42.328850	4.8
R41	HR0313DA	8/26/03 11:19	1*	-71.024850	42.311350	6.1
	HR0313DB	8/26/03 11:20	2*	-71.024950	42.311350	6.1
	HR0313DC	8/26/03 11:21	3*	-71.025017	42.311333	6.1
R42	HR0313D7	8/26/03 11:11	1*	-71.024967	42.319583	4.4
	HR0313D8	8/26/03 11:12	2*	-71.025017	42.319567	4.4
	HR0313D9	8/26/03 11:13	3*	-71.025017	42.319550	4.4
R43	HR0313E1	8/26/03 12:11	1*	-71.001967	42.306650	4.9
	HR0313E2	8/26/03 12:12	2*	-71.001850	42.306700	4.9
	HR0313E3	8/26/03 12:14	3*	-71.002167	42.306883	4.9
R44	HR031385	8/25/03 16:06	1*	-71.002150	42.343767	8.7
	HR031386	8/25/03 16:07	2*	-71.002117	42.343817	8.7
	HR031387	8/25/03 16:08	3*	-71.002100	42.343817	8.7
R45	HR0313C2	8/26/03 10:06	1*	-70.967333	42.328417	9.0
	HR0313C3	8/26/03 10:07	2*	-70.967467	42.328467	9.0
	HR0313C4	8/26/03 10:08	3*	-70.967500	42.328517	9.0
R46	HR0313AC	8/26/03 8:51	1*	-70.922233	42.291017	9.1
	HR0313AD	8/26/03 8:52	2*	-70.922167	42.291033	9.1
	HR0313AE	8/26/03 8:52	3*	-70.922133	42.291017	9.1
R47	HR031370	8/25/03 15:11	1*	-70.978783	42.344583	4.8
	HR031371	8/25/03 15:12	2*	-70.978767	42.344600	4.8
	HR031372	8/25/03 15:13	3*	-70.978817	42.344617	4.8
R48	HR0313EA	8/26/03 12:38	1*	-70.987683	42.293367	5.3
	HR0313EB	8/26/03 12:39	2*	-70.987750	42.293350	5.3
	HR0313EC	8/26/03 12:40	3*	-70.987833	42.293367	5.3
R49	HR03138E	8/26/03 7:21	1*	-70.908233	42.273267	6.0
	HR03138F	8/26/03 7:22	2*	-70.908267	42.273267	6.0
	HR031390	8/26/03 7:23	3*	-70.908283	42.273267	6.0
R50	HR031391	8/26/03 7:30	1*	-70.898750	42.274917	6.2
	HR031392	8/26/03 7:30	2*	-70.898783	42.274950	6.2
	HR031393	8/26/03 7:31	3*	-70.898783	42.274967	6.2
R51	HR031411	8/26/03 14:31	1*	-70.942150	42.263483	3.5
	HR031412	8/26/03 14:32	2*	-70.942150	42.263450	3.5
	HR031413	8/26/03 14:33	3	-70.942183	42.263433	3.5
	HR031414	8/26/03 14:33	4*	-70.942200	42.263417	3.5
R52	HR031415	8/26/03 14:38	1*	-70.934867	42.261833	3.5
	HR031416	8/26/03 14:39	2*	-70.934800	42.261817	3.5
	HR031417	8/26/03 14:40	3*	-70.934783	42.261800	3.5

SPI Station ID	SPI Sample ID	Date/Time (EDT)	Replicate analyzed*	Longitude (W)	Latitude (N)	Depth (m)
R53	HR03140E	8/26/03 14:24	1*	-70.937833	42.269150	4.2
	HR03140F	8/26/03 14:25	2*	-70.937967	42.269150	4.2
	HR031410	8/26/03 14:26	3*	-70.938050	42.269200	4.2
T01	HR03136D	8/25/03 15:03	1*	-70.963583	42.349100	4.0
	HR03136E	8/25/03 15:03	2*	-70.963600	42.349150	4.0
	HR03136F	8/25/03 15:04	3*	-70.963617	42.349183	4.0
T02	HR031382	8/25/03 16:00	1*	-71.001933	42.342733	6.3
	HR031383	8/25/03 16:01	2*	-71.001983	42.342767	6.3
	HR031384	8/25/03 16:02	3*	-71.002033	42.342800	6.3
T03	HR0313BF	8/26/03 9:58	1*	-70.961967	42.330083	9.0
	HR0313C0	8/26/03 9:59	2*	-70.961900	42.330067	9.0
	HR0313C1	8/26/03 10:00	3*	-70.961800	42.330067	9.0
T04	HR0313DD	8/26/03 11:32	1	-71.041383	42.309967	5.1
	HR0313DE	8/26/03 11:33	2*	-71.041400	42.309983	5.1
	HR0313DF	8/26/03 11:33	3*	-71.041433	42.310017	5.1
	HR0313E0	8/26/03 11:34	4*	-71.041433	42.310033	5.1
T05A	HR031367	8/25/03 14:50	1*	-70.960767	42.339850	16.6
	HR031368	8/25/03 14:51	2*	-70.960700	42.339917	16.6
	HR031369	8/25/03 14:52	3*	-70.960817	42.339917	16.6
T06	HR031405	8/26/03 13:50	1*	-70.944517	42.293550	5.8
	HR031406	8/26/03 13:51	2*	-70.944633	42.293500	5.8
	HR031407	8/26/03 13:53	3*	-70.944683	42.293400	5.8
T07	HR0313F9	8/26/03 13:21	1*	-70.978217	42.289383	6.3
	HR0313FA	8/26/03 13:22	2*	-70.978283	42.289450	6.3
	HR0313FB	8/26/03 13:23	3*	-70.978367	42.289517	6.3
T08	HR03139D	8/26/03 8:07	1*	-70.912450	42.285167	11.3
	HR03139E	8/26/03 8:10	2*	-70.912433	42.285117	11.3
	HR03139F	8/26/03 8:11	3*	-70.912433	42.285167	11.3

Table A-2. Station data and field observations for individual infauna and chemistry soft-bottom grab samples collected in August 2003(HT031).

Station ID	Sample ID	Date	Sample Type	Latitude (N)	Longitude (W)	RPD Depth (cm)	Sediment Texture	Fauna and Miscellaneous Observations
T01	HT031028	8/1/03	Biol	42.34910	-70.96339	0.5	sandy/silt	Amphipod, hermit crab, snails,
	HT03102A	8/1/03	Biol	42.34912	-70.96349	1.0	sandy/silt	Amphipod, hermit crab, snails
	HT03102B	8/1/03	Biol	42.34913	-70.96359	0.2	sandy/silt	Amphipod + worm tubes, snails
	HT031027	8/1/03	Chem	42.34917	-70.96355	0.1-1.5	sandy/silt	Amphipod, hermit crab, snails
T02	HT031031	8/1/03	Biol	42.34275	-71.00201	0.7	v. fine sandy silt	Amphipod tube mat, crabs
	HT031032	8/1/03	Biol	42.34278	-71.00207	2.0	v. fine sandy silt	Amphipod tube mat, crabs, snails
	HT031033	8/1/03	Biol	42.34286	-71.00207	1.5	fine sandy silt	Amphipod tube mat, crabs
	HT03102F	8/1/03	Chem	42.34282	-71.00204	1.5	sandy silt	Amphipod tube mat, crabs
T03	HT031017	8/1/03	Biol	42.33008	-70.96204	2.0	sandy silt	Amphipod tube mat, crab, shrimp
	HT031018	8/1/03	Biol	42.33012	-70.96198	1.5	sandy silt	Amphipod tube mat, crab
	HT031019	8/1/03	Biol	42.33013	-70.96194	2.5	sandy silt	Amphipod tube mat, crabs, snails
	HT031016	8/1/03	Chem	42.33020	-70.96204	3.0	sandy silt	Amphipod tube mat, crabs, snails
T04	HT03103B	8/1/03	Biol	42.30998	-71.04155	0.2	silt with a little sand	One amphipod tube
	HT03103A	8/1/03	Biol	42.30998	-71.04156	0.1	silt with a little sand	No animals
	HT03103C	8/1/03	Biol	42.30992	-71.04156	0.1-0.2	silt	Hermit crab, snail
	HT03103D	8/1/03	Chem	42.30998	-71.04158	0.1-0.2	silt	Hermit crab, snail
T05A	HT03101D	8/1/03	Biol	42.33963	-70.96078	1.0	sandy silt	Amphipod tube mat, crab
	HT03101E	8/1/03	Biol	42.33965	-70.96075	1.5	sandy silt	Amphipod tube mat, hermit crab
	HT03101F	8/1/03	Biol	42.33967	-70.96073	1.0	sandy silt	Amphipod tube mat, crab
	HT031021	8/1/03	Chem	42.33970	-70.96080	1.0	Not recorded	Amphipod tube mat, kelp, shell
T06	HT031043	8/1/03	Biol	42.29347	-70.94421	1.5	sandy silt	Amphipod tube mat
	HT031044	8/1/03	Biol	42.29350	-70.94428	0.3	sandy silt	Amphipod tube mat, crab
	HT031045	8/1/03	Biol	42.29355	-70.94431	1.0	sandy silt	Amphipod tube mat, crabs
	HT031046	8/1/03	Chem	42.29352	-70.94421	0.5	sandy silt	Amphipod tube mat, crab
T07	HT03104A	8/1/03	Biol	42.28940	-70.97857	1.5	sandy silt	Amphipod tube mat, hermit crab, worm tube, shrimp, shell pieces
	HT03104B	8/1/03	Biol	42.28933	-70.97861	1.5	sandy silt	Amphipod tube mat, hermit crab, snail, crab
	HT03104D	8/1/03	Biol	42.28935	-70.97858	1.3	sandy silt	Amphipod tube mat, hermit crab, shrimp
	HT03104E	8/1/03	Chem	42.28932	-70.97852	0.3	sandy silt	Amphipod tube mat, crabs, shrimp, shells
T08	HT031004	8/1/03	Biol	42.28527	-70.91255	1.5	silty sand	Amphipod tubes, crabs, shell hash
	HT031006	8/1/03	Biol	42.28540	-70.91254	2.0	silty sand	Amphipod tubes, hermit crab, snail
	HT031007	8/1/03	Biol	42.28528	-70.91261	2.0	silty sand	One amphipod tube, crab
	HT031008	8/1/03	Chem	42.28527	-70.91258	1.5	sand	Amphipod tubes, hermit crab, snail

APPENDIX B1

Terminology used in Sediment Properties Section

In the discussion of bulk sediment data, the following terms are used.

- Percent Fines—sum of percent silt and clay.

Mean parameter (*e.g.,* sand) values were determined for two categories:

- Station Mean—average of all station replicates. Laboratory replicates were first averaged to determine a single value for a given replicate prior to calculation of station means. Single grab samples were generally collected at all Traditional stations during most sampling years, but replicate grabs were also collected during some sampling years (*e.g.,* August 1994 and 1997). Station means were determined for each parameter within a given sampling year for August surveys only to assess the spatial and temporal distribution in bulk sediment properties and *C. perfringens* from 1991 to 2003.
- Harbor Mean—average of all Traditional stations, by year for August surveys only. Harbor means were determined for TOC and *C. perfringens* over all sampling yeas to assess temporal variability in the harbor from 1991 to 2003.
- Grand Station Mean—average of all years, by station for August surveys only. Grand station means were determined for each parameter over all sampling years to assess variability in the spatial and temporal distribution in bulk sediment properties and *C. perfringens* from 1991 to 2003.
- Grand Mean—average of yearly mean values, by sampling period. Grand means were determined for Flux and Traditional Harbor TOC over all sampling years (1993-2002) to assess if there was a characteristic seasonal "peak" in TOC content.

The spatial and temporal distributions of sediment grain size were evaluated by using ternary plots to visually display the distribution and variability of three-part compositional data, *i.e.,* proportion of Gravel + Sand, Silt, and Clay in sediments collected from Traditional stations from 1991 to 2003; August surveys only. Samples that cluster near the Gravel + Sand axis (top) contain more coarse-grained material. Samples that cluster near the Silt axis (bottom left) are more silty, and samples that cluster near the Clay axis (bottom right) contain higher amounts of clay material.

Results for TOC and *C. perfringens* analyses were compared from all Traditional stations by using line charts to evaluate if the spatial and temporal distributions in 2003 were substantially different from those for previous years; August surveys only.

Seasonal TOC data collected from the Benthic Flux program (BH02, BH03, and BH03A (1995-1997) only) from 1993 to 2003 were evaluated with the Harbor TOC data (stations T02 and T03 only) to explore if there was a characteristic seasonal "peak" in Harbor TOC levels that more or less corresponded to the faunal sampling events. Benthic Flux results from February were excluded from the analysis since these data were only available from a single sampling event in 1993.

Appendix B2

Supporting Ternary Plots Showing
Grain Size Composition
and
Line Charts Showing
TOC and *Clostridium perfringens* Results by Station

August Surveys Only, 1991 to 2003

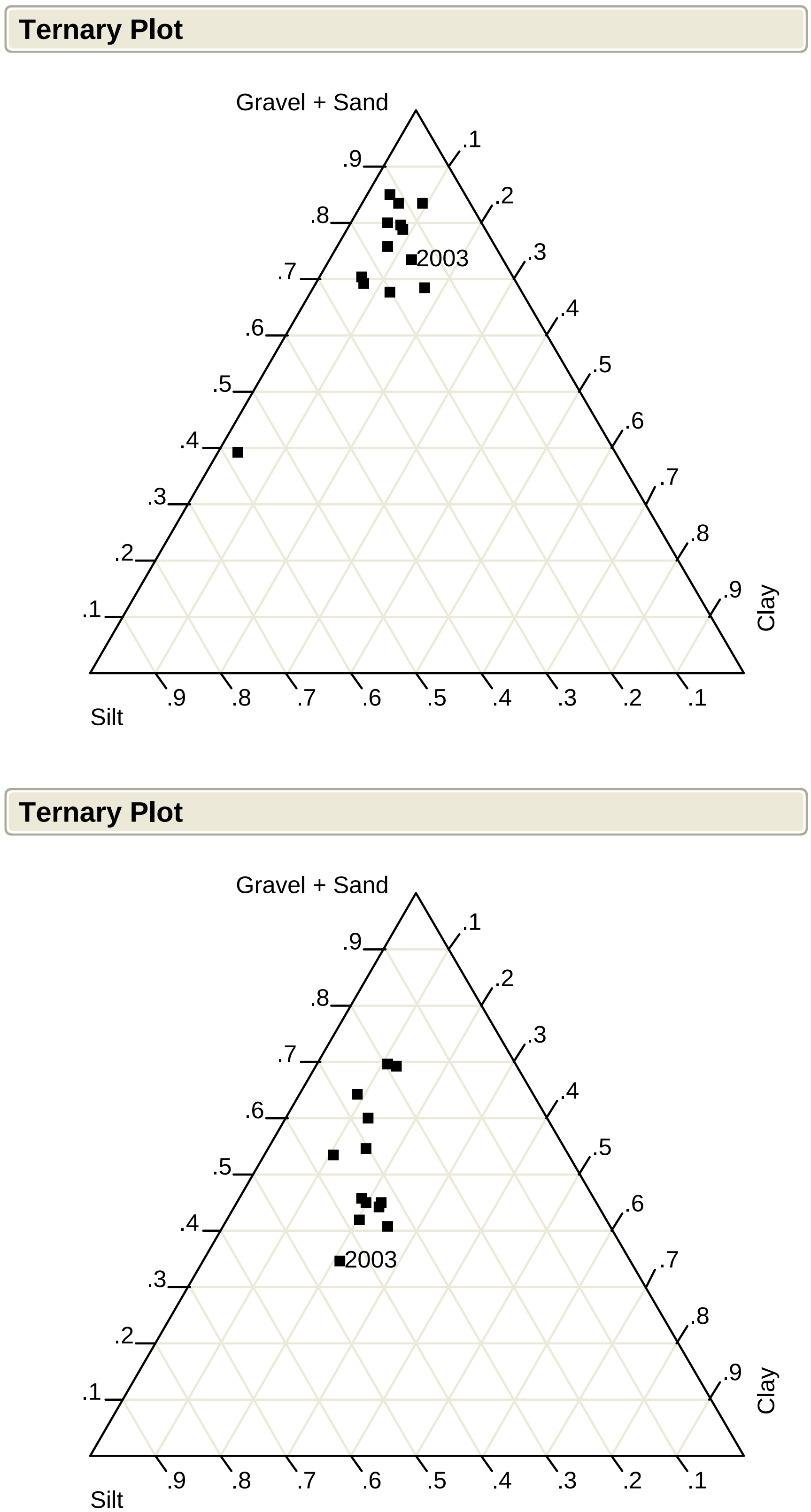
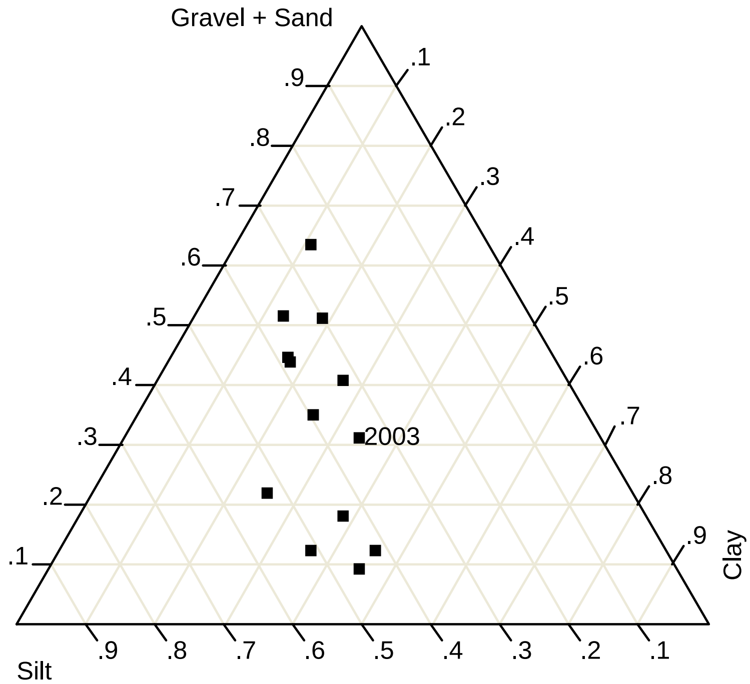


Figure B2-1. Grain size composition from sediments collected at Traditional station T01 (top) and T02 (bottom) in September 1991 and August 1992–2003.

Ternary Plot



Ternary Plot

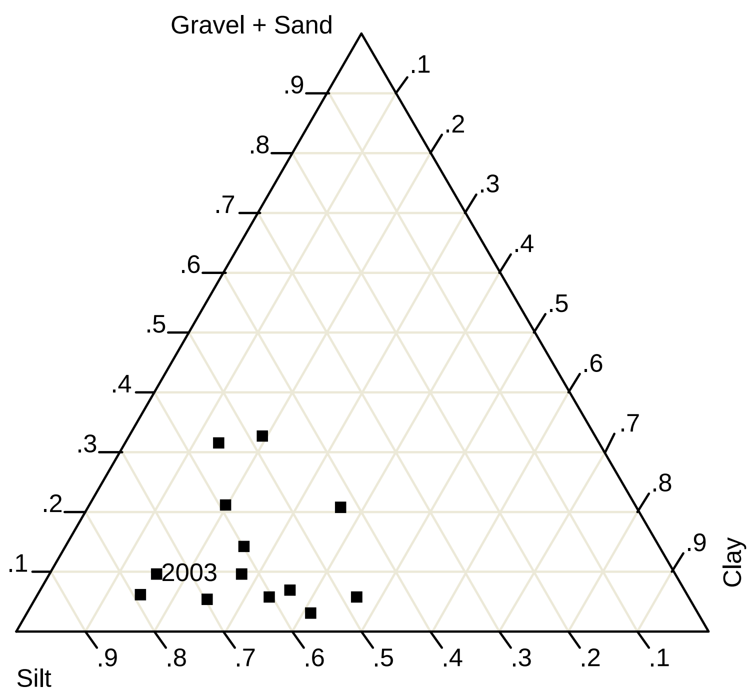
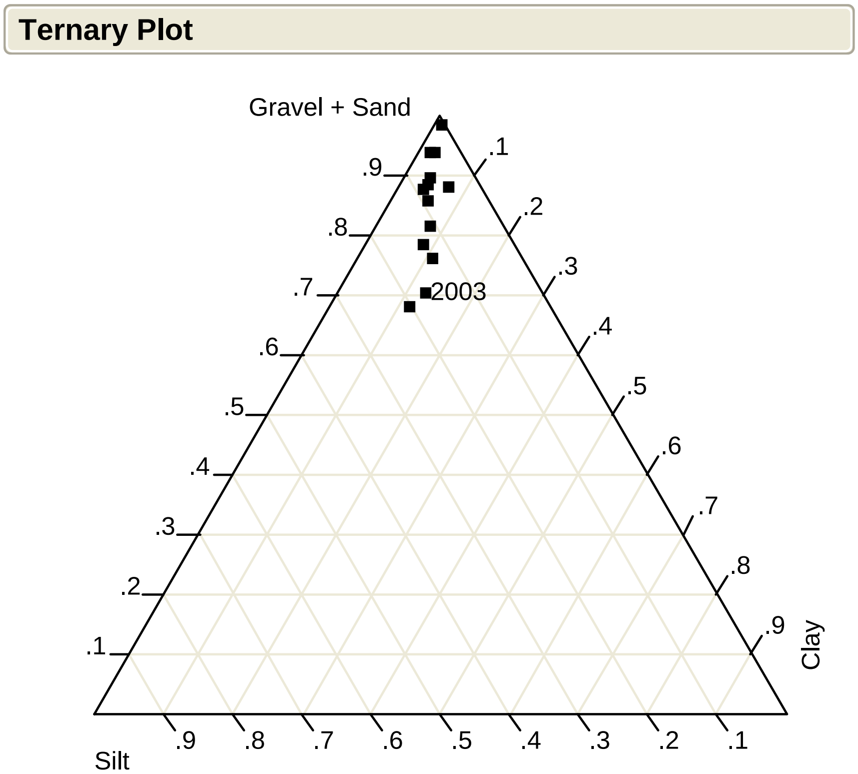


Figure B2-2. Grain size composition from sediments collected at Traditional station T03 (top) and T04 (bottom) in September 1991 and August 1992–2003.



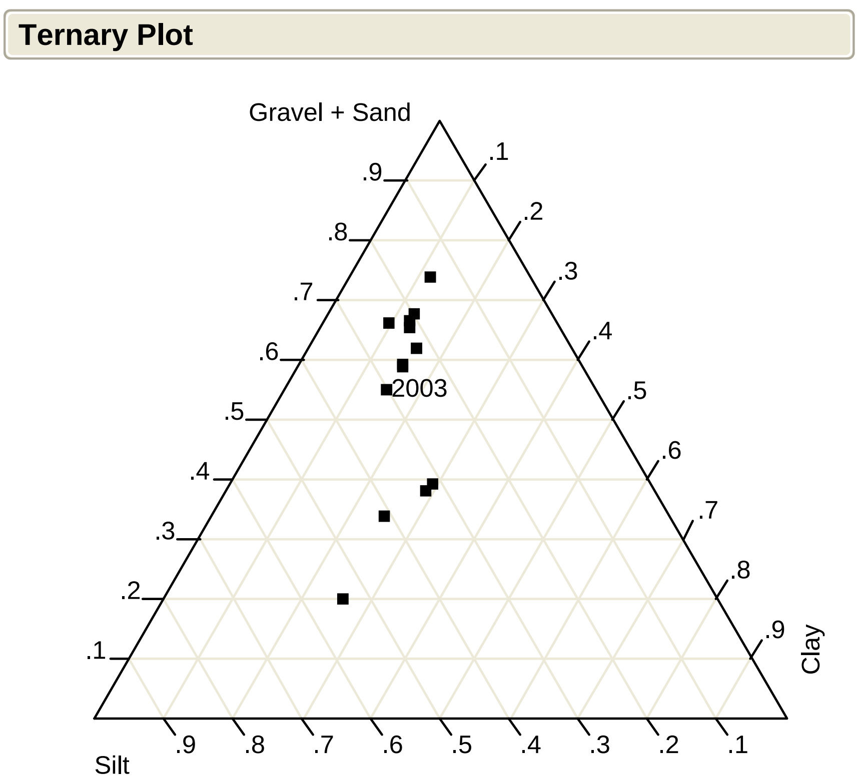
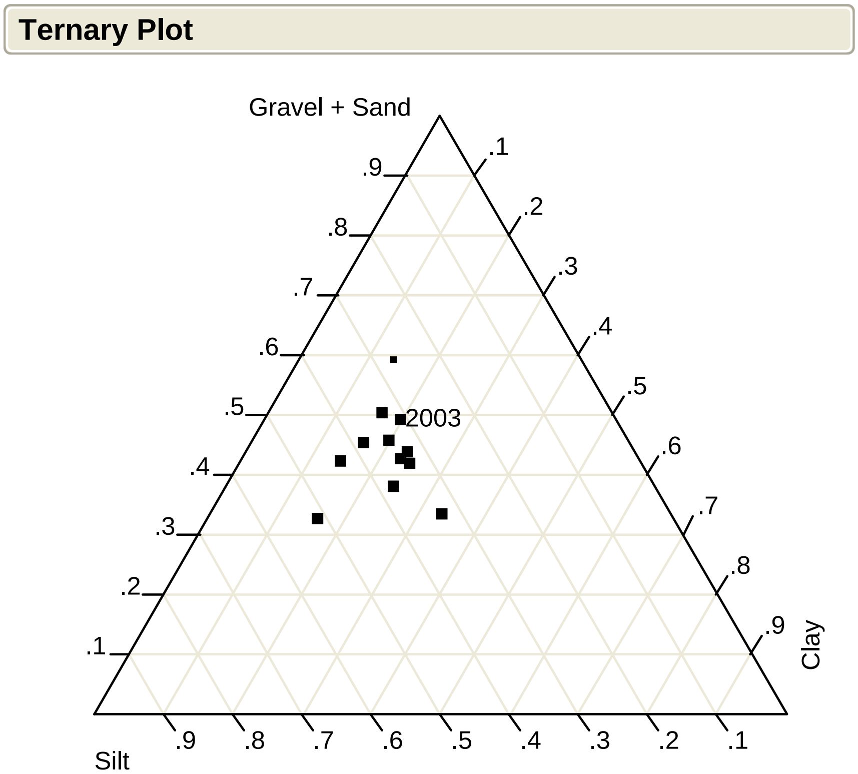


Figure B2-3. Grain size composition from sediments collected at Traditional station T05A (top) and T06 (bottom) in September 1991 and August 1992–2003.



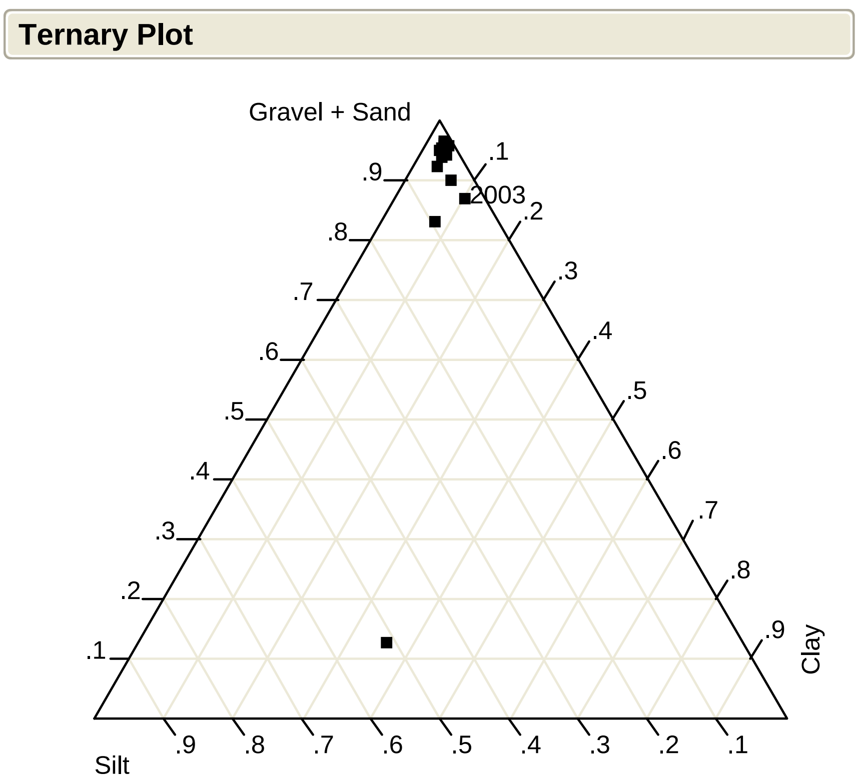
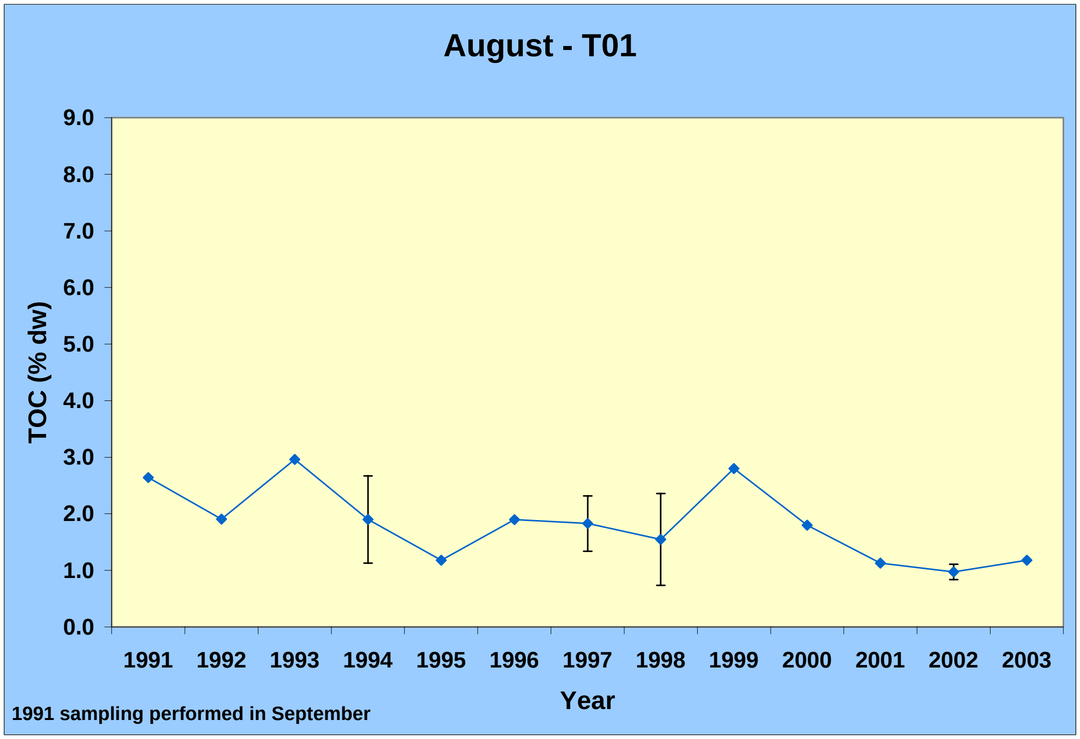


Figure B2-4. Grain size composition from sediments collected at Traditional station T07 (top) and T08 (bottom) in September 1991 and August 1992–2003.



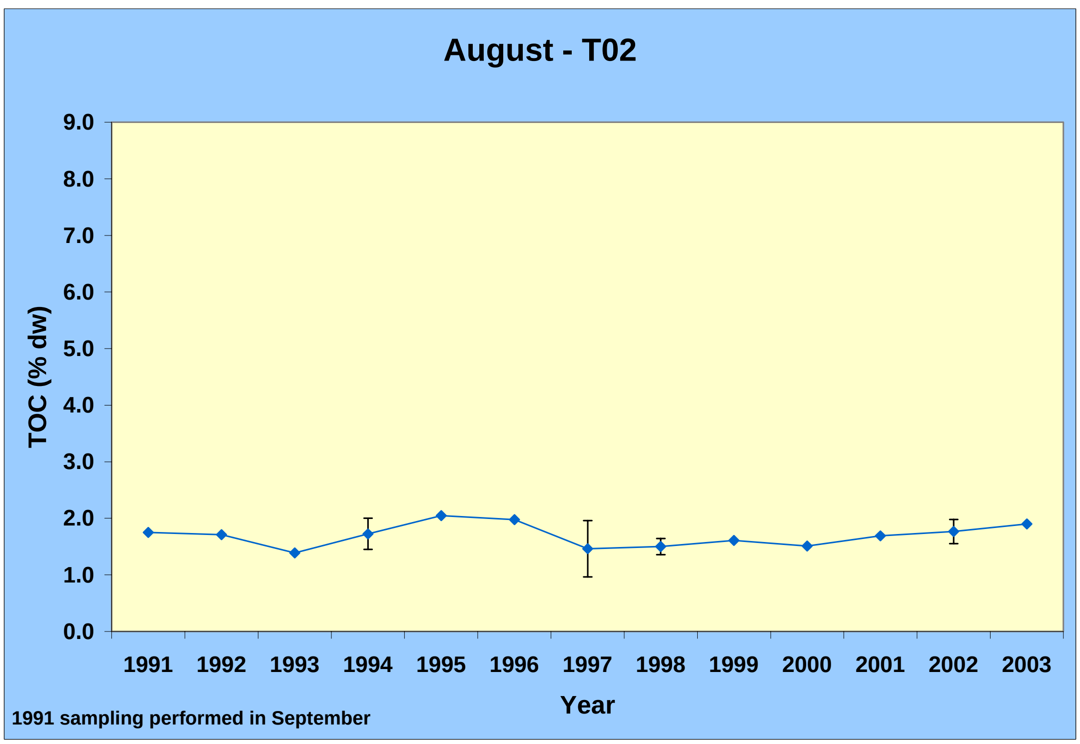
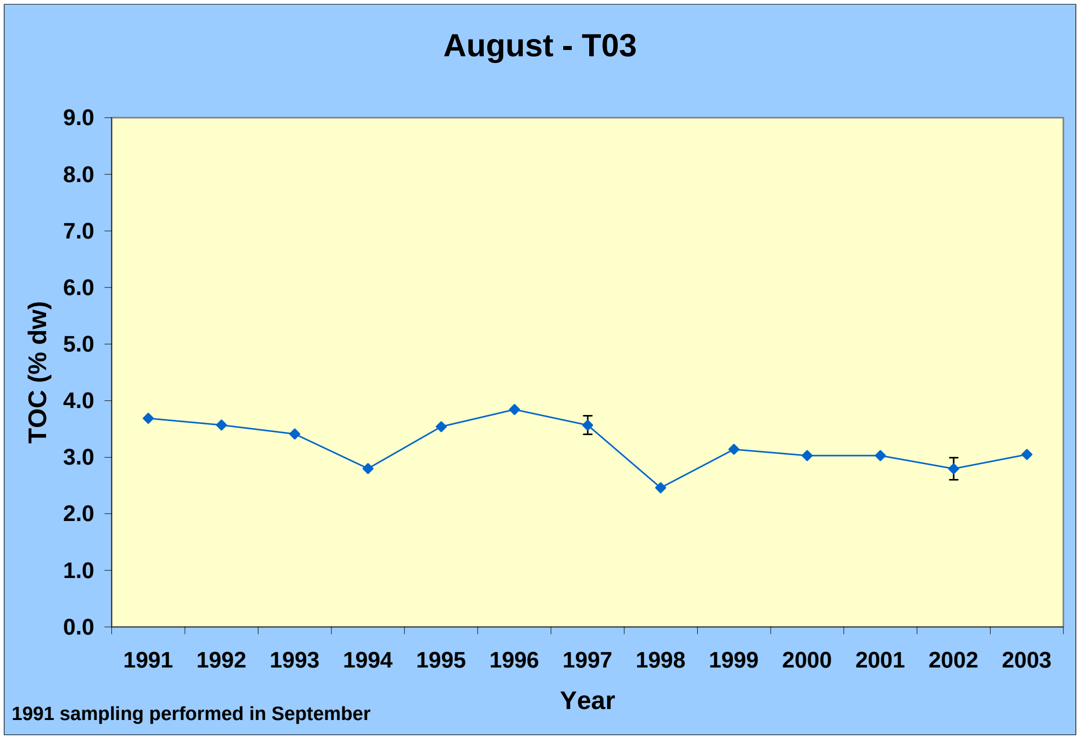


Figure B2-5. Total organic carbon content in sediments collected at Traditional stations T01 (top) and T02 (bottom) in September 1991 and August 1992–2003. Error bars represent standard deviation of replicate analyses.



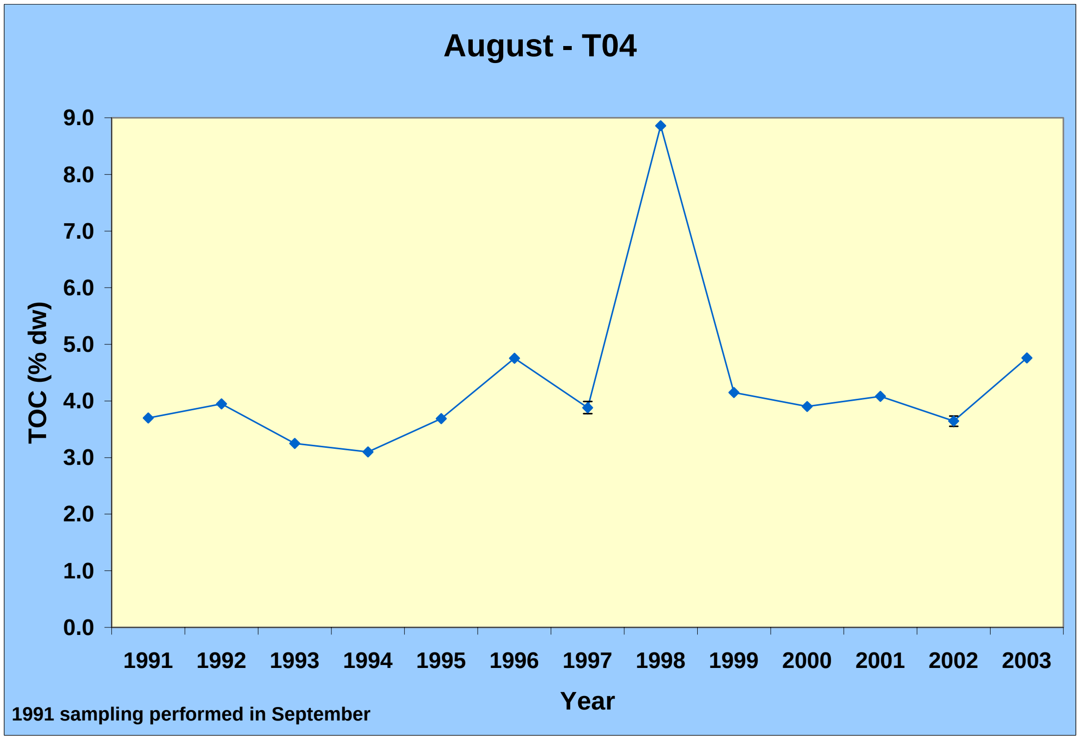
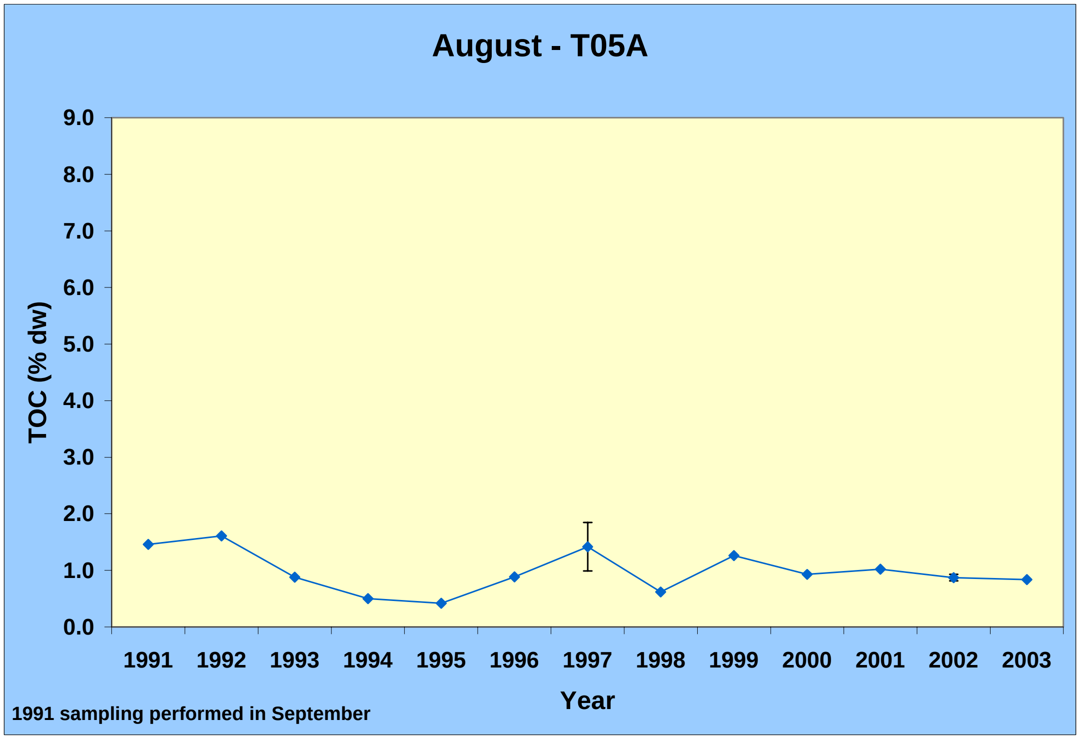


Figure B2-6. Total organic carbon content in sediments collected at Traditional stations T03 (top) and T04 (bottom) in September 1991 and August 1992–2003. Error bars represent standard deviation of replicate analyses.



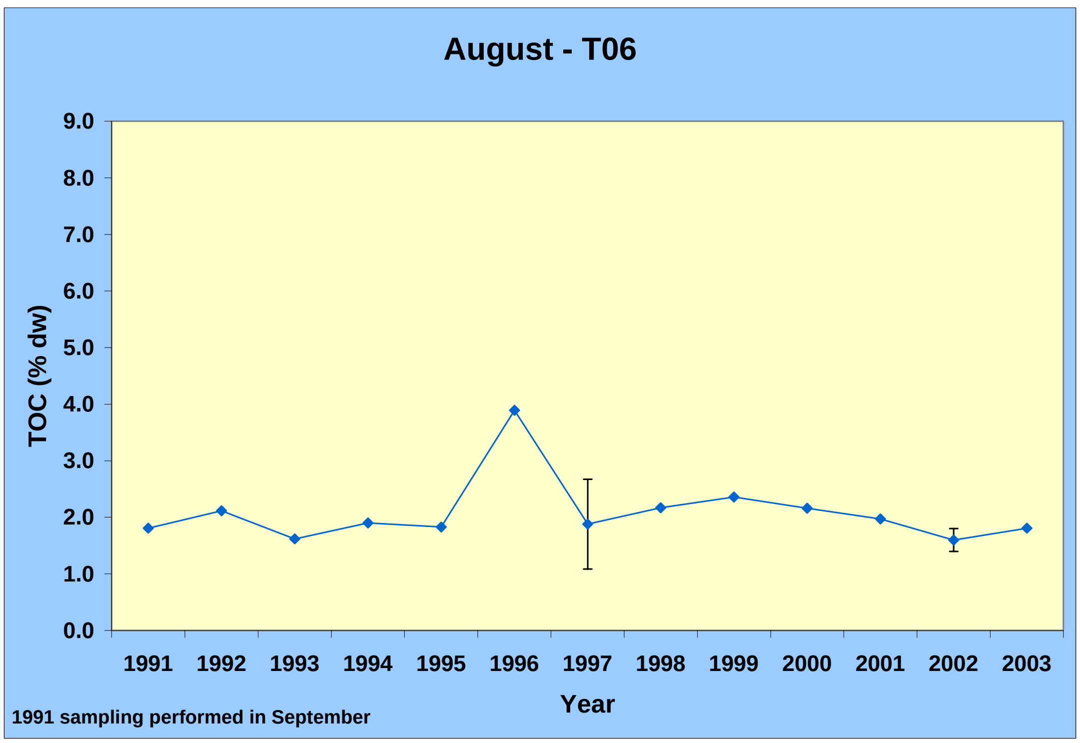
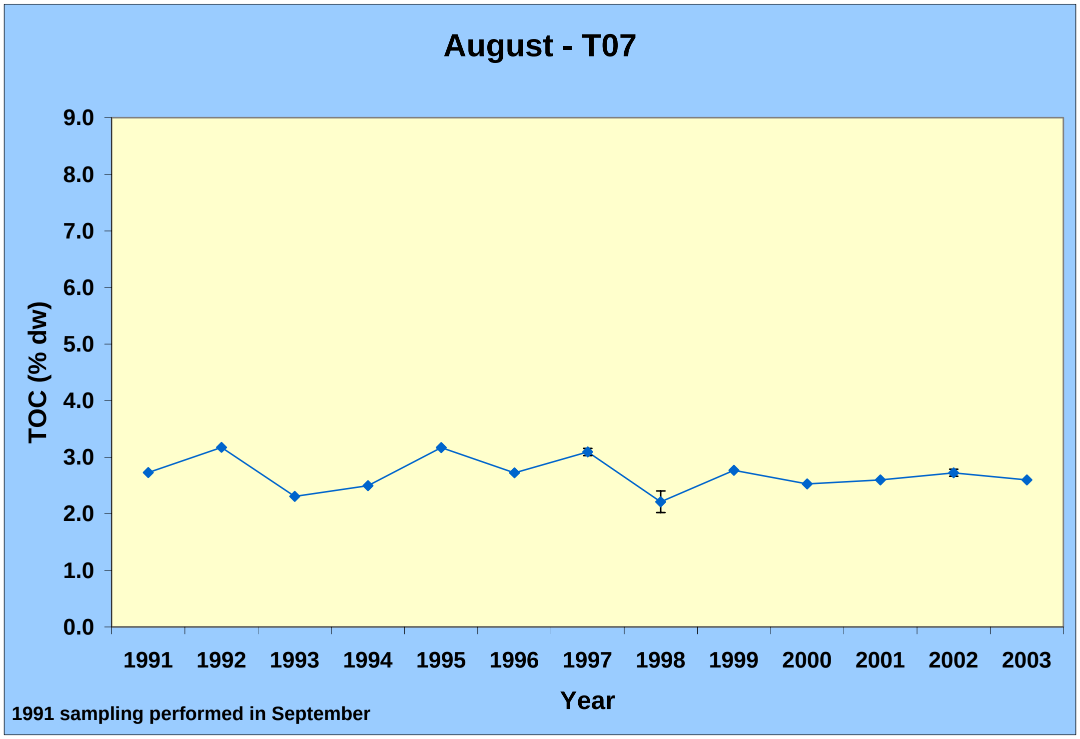


Figure B2-7. Total organic carbon content in sediments collected at Traditional stations T05A (top) and T06 (bottom) in September 1991 and August 1992–2003. Error bars represent standard deviation of replicate analyses.



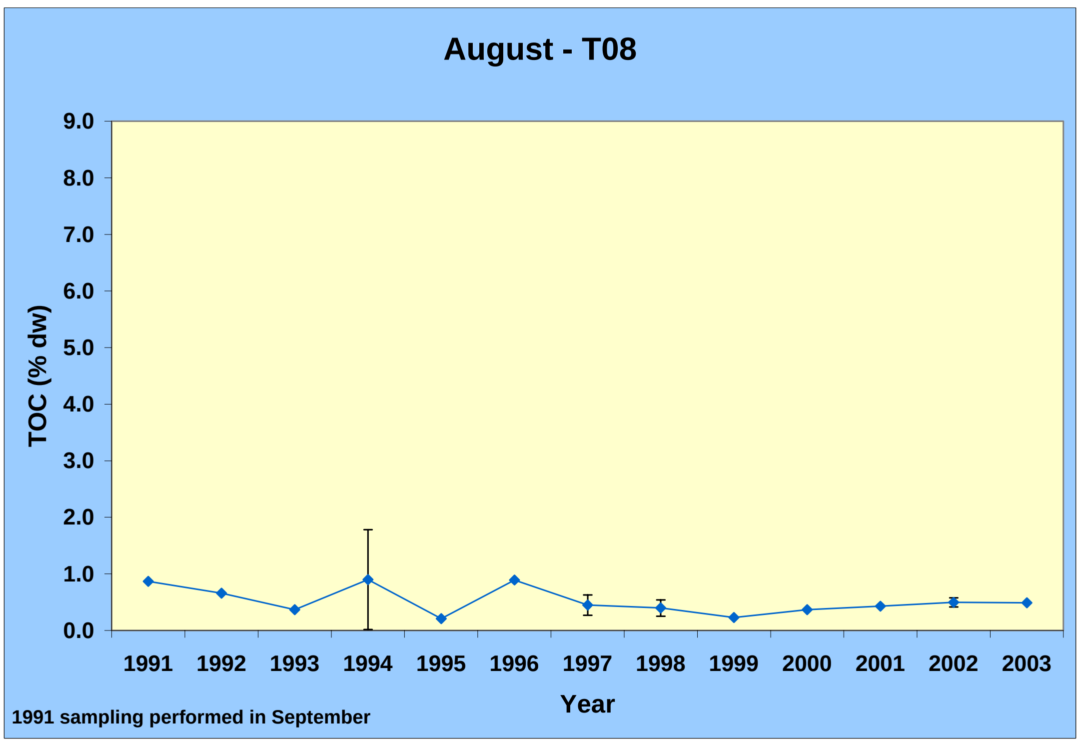


Figure B2-8. Total organic carbon content in sediments collected at Traditional stations T07 (top) and T08 (bottom) in September 1991 and August 1992–2003. Error bars represent standard deviation of replicate analyses.

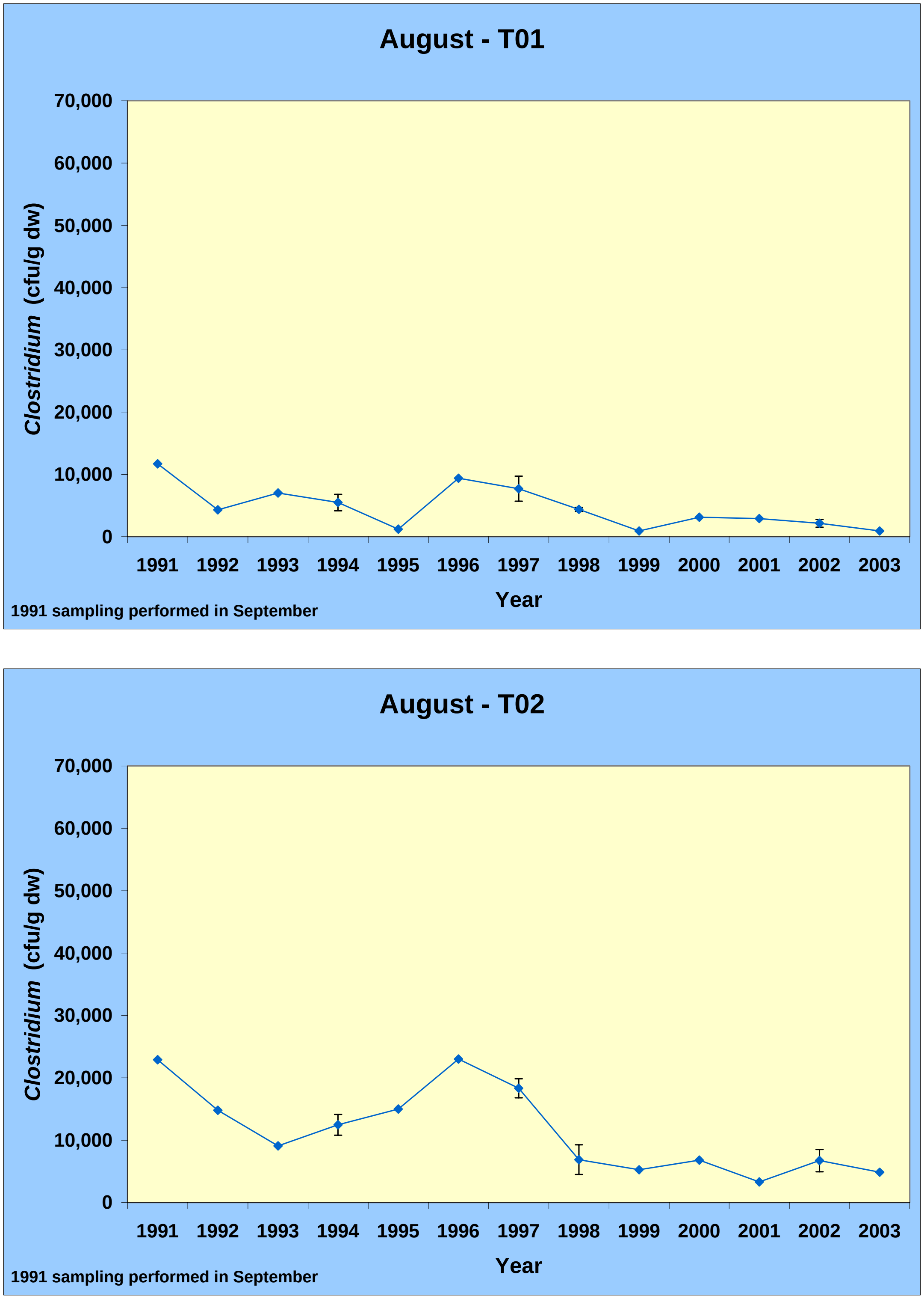
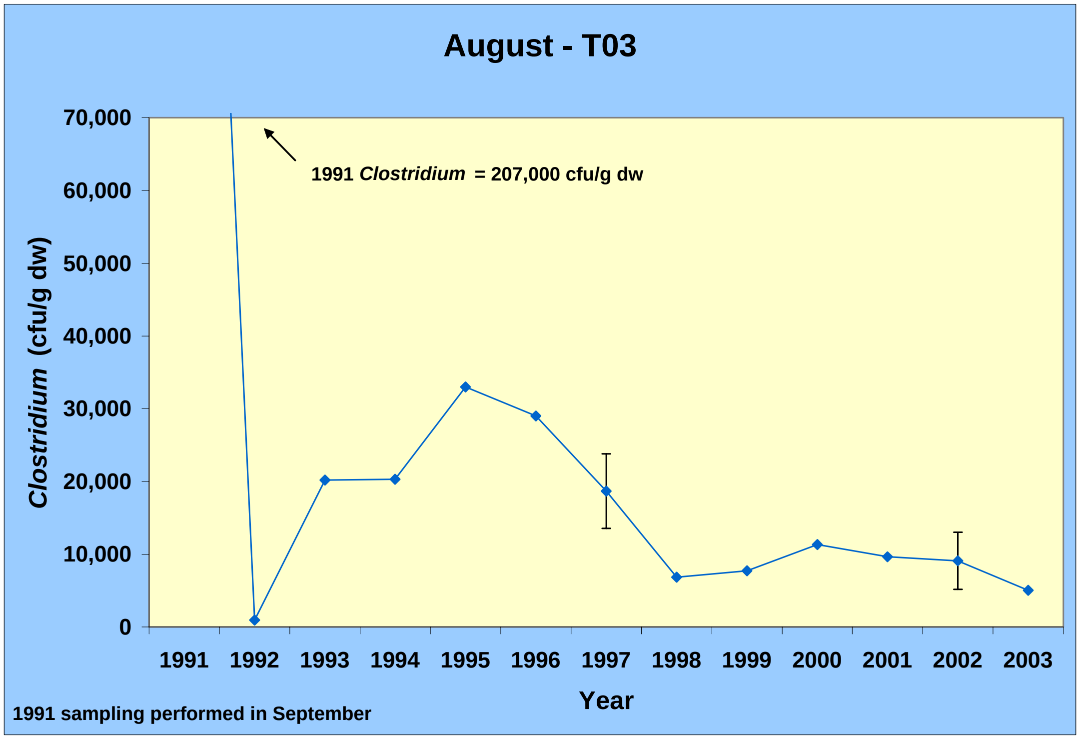


Figure B2-9. ***Clostridium perfringens*** **concentrations in sediments collected at Traditional stations T01 (top) and T02 (bottom) in September 1991 and August 1992–2002 (bottom). Error bars represent standard deviation of replicate analyses.**



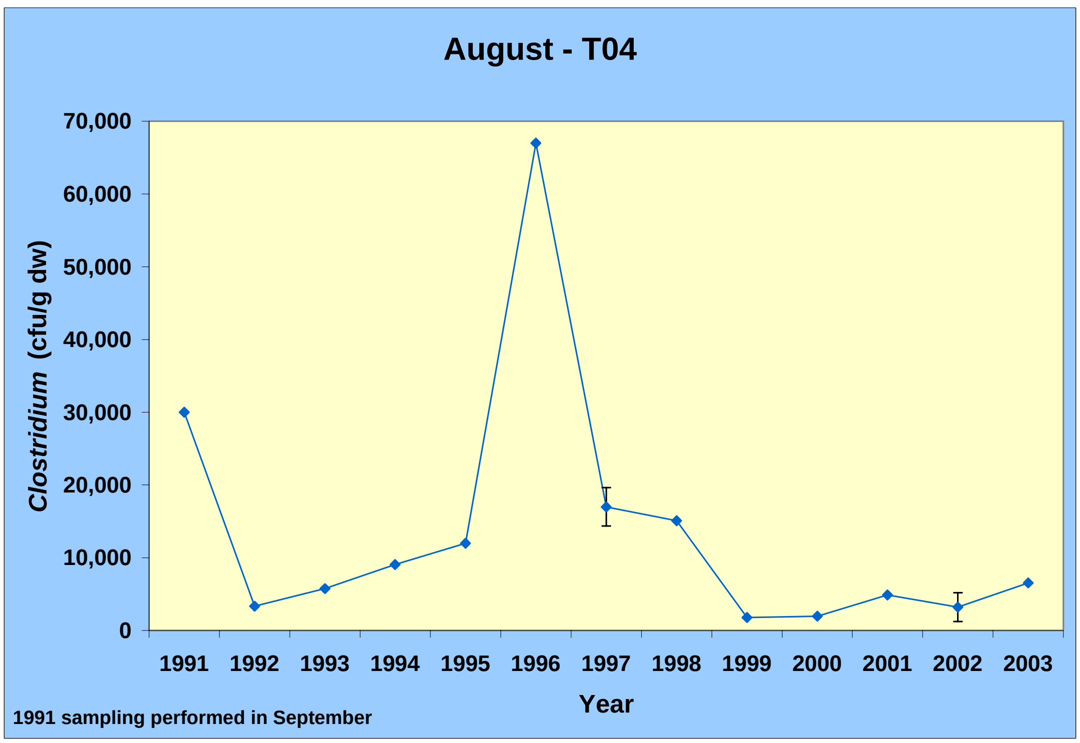
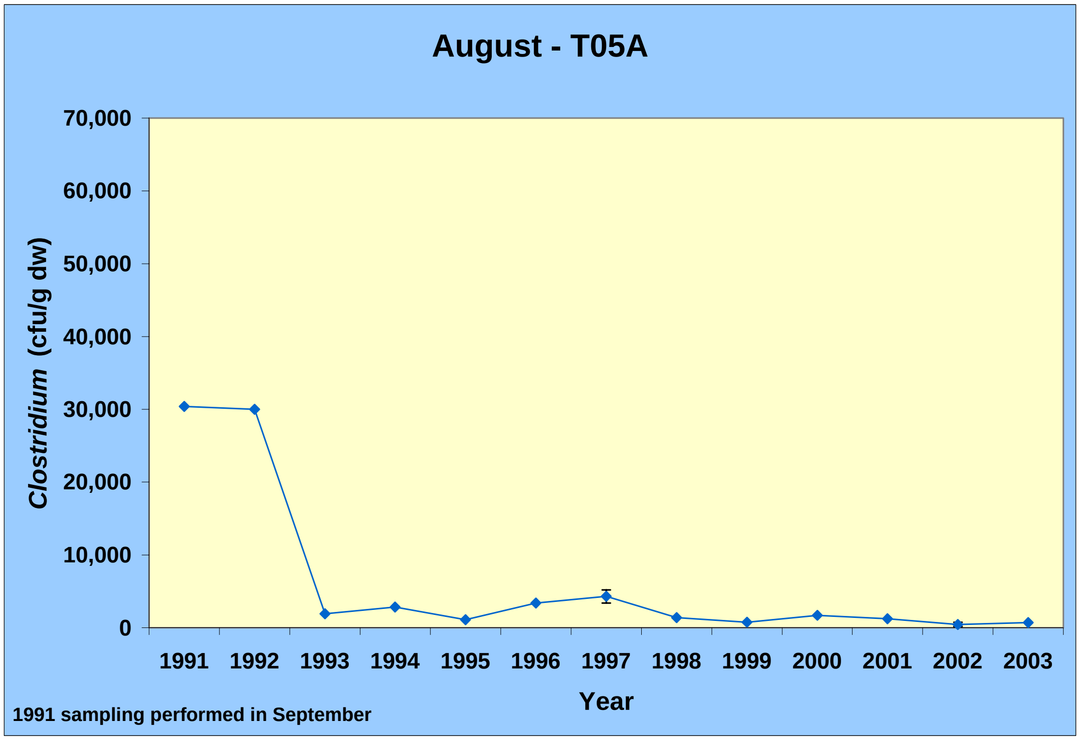


Figure B2-10. *Clostridium perfringens* concentrations in sediments collected at Traditional stations T03 (top) and T04 (bottom) in September 1991 and August 1992–2003. Error bars represent standard deviation of replicate analyses.



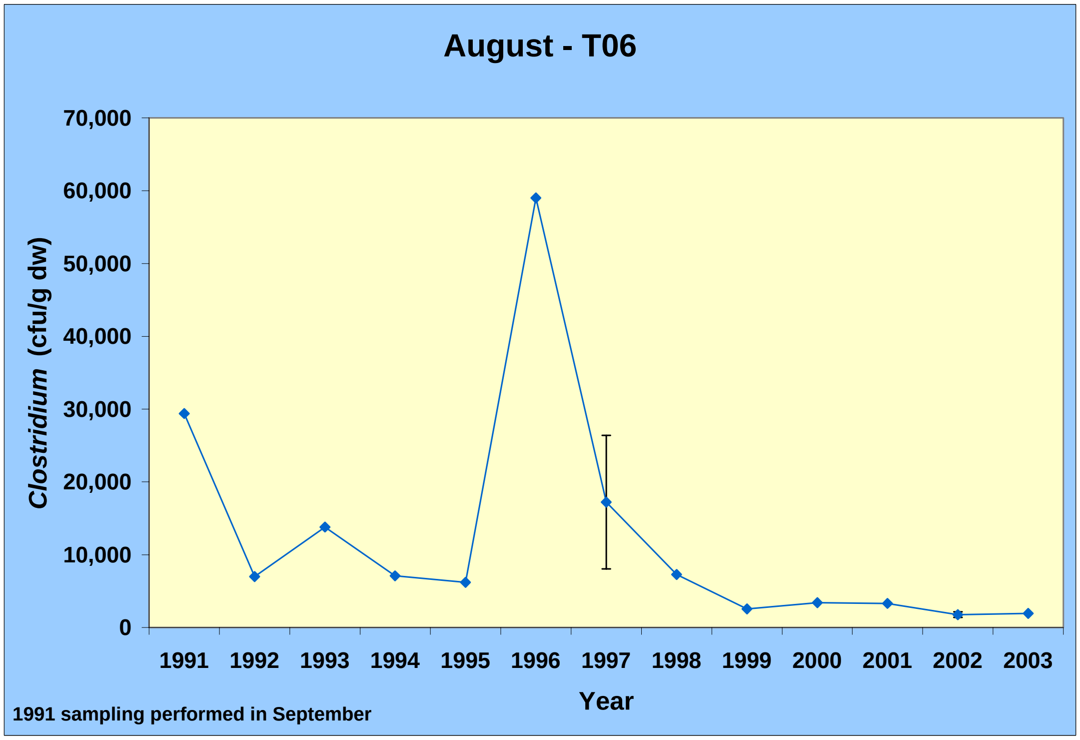


Figure B2-11. *Clostridium perfringens* concentrations in sediments collected at Traditional stations T05A (top) and T06 (bottom) in September 1991 and August 1992–2003. Error bars represent standard deviation of replicate analyses.

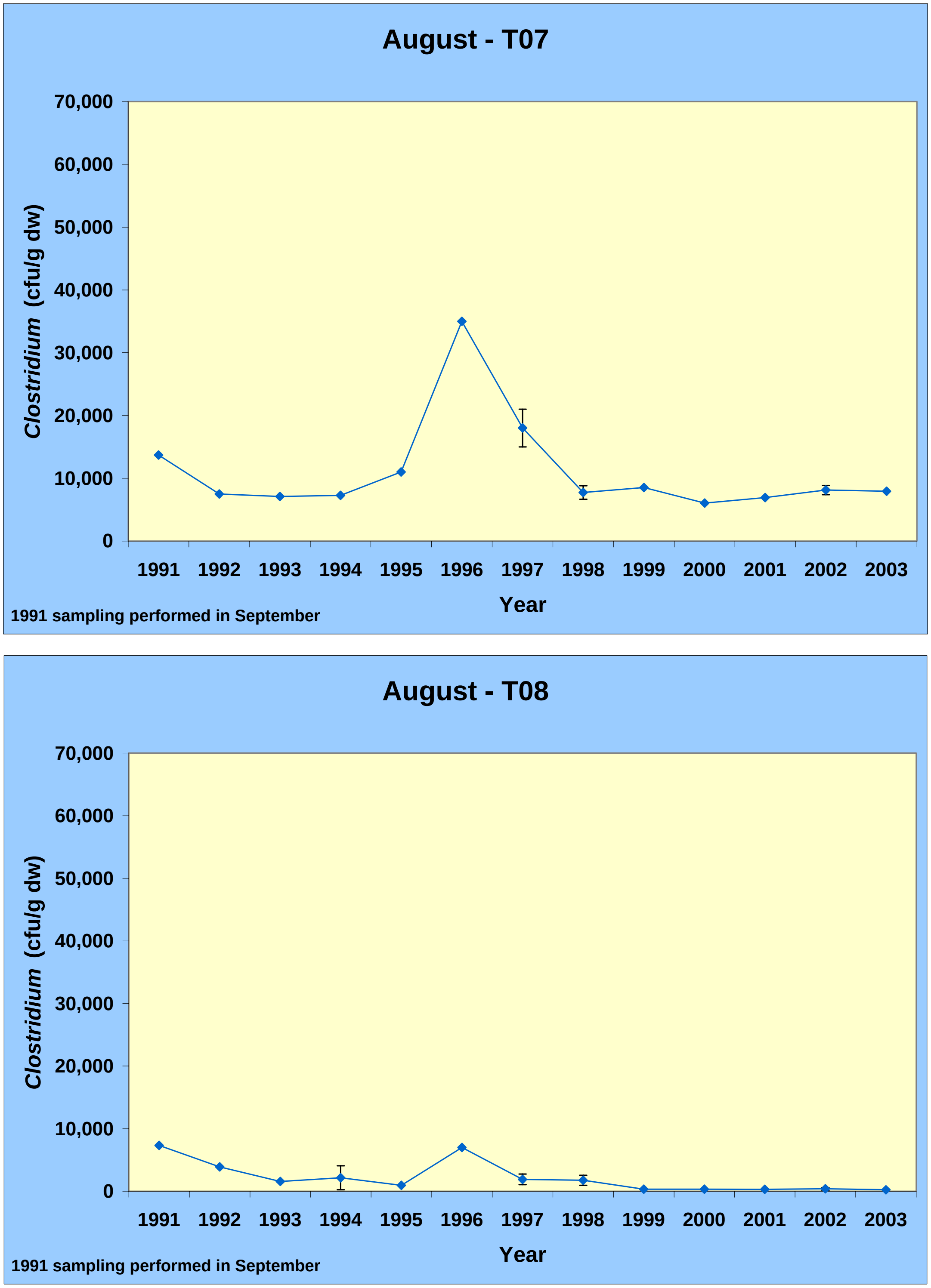


Figure B2-12. *Clostridium perfringens* concentrations in sediments collected at Traditional stations T07 (top) and T08 (bottom) in September 1991 and August 1992–2003. Error bars represent standard deviation of replicate analyses.

Appendix B3

Grain size, TOC, and *Clostridium perfringens* Data from Sediments Collected at Traditional Stations in September 1991 and August 1992–2003.

(Results reported on dry weight basis to three significant figures)

Table B3-1. Grain size, TOC, *Clostridium perfringens* data from sediments collected at Traditional stations in September 1991 and August 1992 to 2003.

Parameter	Year	T01	T02	T03	T04	T05A	T06	T07	T08
Gravel (pct)	1991	1.26	0.155	0	0	0.294	0.0841	1.75	0
	1992	65.3	21.3	0	0	92.5	0.4	4.5	2.9
	1993	8.03	3.14	0.489	0	0	0.212	10.3	1.9
	1994	8.15	2.08	6.2	0	0.3	1.4	3	3.1
	1995	6.7	0	0	0.6	0.5	2.5	24.3	0.4
	1996	12.4	0	0.9	0	0.2	0	5.1	0
	1997	15.1	0.0667	0.233	0.6	0.167	2	15.8	0.533
	1998	6.8	0.4	0.5	0	0	0.6	7.28	1.45
	1999	25.1	0.4	0	3.8	0.167	0.12	9.6	2.4
	2000	2.5	0.1	1.7	1.5	0.3	0.2	11	0.6
	2001	0.401	0.246	0.865	0	0.389	0.466	5.78	3.01
	2002	2.57	3.03	1	1.7	0.233	0.633	12.2	0.833
	2003	4.37	0.5	1.8	0	0.4	1.7	14.7	1.7
Grand Station Mean		12.2	2.42	1.05	0.631	7.34	0.794	9.64	1.45
Stdev		17.3	5.79	1.66	1.12	25.6	0.825	6.2	1.14
CV		142	239	158	178	348	104	64.3	78.9
Sand (pct)	1991	83.6	63.6	44.1	32.3	93.4	65.6	57.3	12.1
	1992	17.8	47.6	43.5	20.8	5.6	64.8	40.2	93.4
	1993	75.3	66	50.3	13.9	85.3	67.1	39.7	93.7
	1994	60.8	57.7	57	4.8	87.1	64.7	38.9	91.5
	1995	32.2	41.3	11.8	5.7	87.8	31.1	17.9	95.4
	1996	67.3	53.1	20.5	5.6	89.1	19.7	27.2	82.6
	1997	64.1	44.4	17.2	2	67.7	57	29.2	93.5
	1998	68.8	44.2	11.2	20.4	81.4	38.3	30.3	92.3
	1999	53.4	39.8	8.9	1.6	75.6	37.5	23.5	93
	2000	67.5	54	49.4	29.4	93.5	58.3	30.6	94.7
	2001	66.9	43.7	33.7	5.41	77.7	61	37.5	89.1
	2002	65.6	42.5	39.3	7.5	87.4	73	33.3	88.8
	2003	68.8	33.6	29	9.2	69.6	52.9	34	85
Grand Station Mean		60.9	48.6	32	12.2	77	53.1	33.8	85
Stdev		17.6	9.64	16.7	10.3	23	16.3	9.63	22.2
CV		29	19.9	52.1	84.6	29.9	30.6	28.5	26.1

Table B3-1. (cont.)

Parameter	Year	T01	T02	T03	T04	T05A	T06	T07	T08
Gravel + Sand (pct)	1991	84.9	63.8	44.1	32.3	93.7	65.7	59	12.1
	1992	83.1	68.9	43.5	20.8	98.1	65.2	44.7	96.3
	1993	83.3	69.1	50.8	13.9	85.3	67.3	50	95.6
	1994	69	59.8	63.2	4.8	87.4	66.1	41.9	94.6
	1995	38.9	41.3	11.8	6.3	88.3	33.6	42.2	95.8
	1996	79.7	53.1	21.4	5.6	89.3	19.7	32.3	82.6
	1997	79.2	44.5	17.4	2.6	67.9	59	44.9	94.1
	1998	75.6	44.6	11.7	20.4	81.4	38.9	37.6	93.7
	1999	78.5	40.2	8.9	5.4	75.8	37.6	33.1	95.4
	2000	70	54.1	51.1	30.9	93.8	58.5	41.6	95.3
	2001	67.3	43.9	34.6	5.41	78.1	61.4	43.3	92.1
	2002	68.2	45.5	40.3	9.2	87.6	73.6	45.5	89.6
	2003	73.1	34.1	30.8	9.2	70	54.6	48.7	86.7
Grand Station Mean		73.1	51	33	12.8	84.4	53.9	43.5	86.5
Stdev		12	11.4	17.6	10.1	9.24	16.2	7.04	22.7
CV		16.3	22.4	53.2	78.8	11	30.1	16.2	26.3
Silt (pct)	1991	11.9	27.8	39.1	48.6	4.24	25.1	27.3	52.2
	1992	8	19.1	39	59.8	1	22.2	38.8	1.7
	1993	11.7	20.4	30.7	60.4	9.43	20.6	33.7	1.9
	1994	24	28	26.2	70.4	9.1	21.8	43.8	3.08
	1995	58.3	38.6	52	57.7	8.1	41.6	34.9	1.8
	1996	14.9	36.5	53.4	79.8	7.2	54.7	52.1	9.7
	1997	13.2	33.6	44.5	56.4	20.8	26.3	39.1	2.57
	1998	17	35.9	42.7	43.3	11.2	32	38.3	3.39
	1999	13.4	34.6	46.4	48.6	13.7	33.7	33.7	1.6
	2000	23.7	31	36.3	55.5	4.9	26.7	34	2.6
	2001	20.7	34.3	40.1	61	13.7	23.1	33.5	4.72
	2002	15	36	33	63.1	5.2	14.9	35	4.1
	2003	14.7	45	35.3	75.4	17.5	30.9	31.7	3.4
Grand Station Mean		19	32.4	39.9	60	9.7	28.7	36.6	7.13
Stdev		12.7	7.14	7.94	10.5	5.61	10.3	6.15	13.7
CV		67.1	22.1	19.9	17.5	57.8	36	16.8	192

Table B3-1. (cont.)

Parameter	Year	T01	T02	T03	T04	T05A	T06	T07	T08
Clay (pct)	1991	3.2	8.46	16.8	19.1	2.07	9.21	13.6	35.7
	1992	9	12.1	17.5	19.4	0.9	12.6	16.5	2
	1993	5.05	10.4	18.6	25.6	5.24	12.1	16.2	2.51
	1994	7.03	12.3	10.6	24.8	3.6	12	14.3	2.33
	1995	2.8	20	36.2	36	3.6	24.8	22.9	2.4
	1996	5.4	10.4	25.3	14.6	3.5	25.6	15.6	7.6
	1997	7.53	21.9	38	41	11.3	14.8	16	3.4
	1998	7.48	19.6	45.6	36.3	7.4	29.2	24.2	2.83
	1999	8.1	25.2	44.7	46	10.5	28.7	33.3	3
	2000	6.3	14.9	12.7	13.5	1.4	14.8	24.4	2.1
	2001	12	21.8	25.3	33.6	8.18	15.4	23.2	3.21
	2002	16.8	18.5	26.7	27.7	7.17	11.5	19.5	6.33
	2003	12.1	20.9	33.9	15.4	12.6	14.5	19.6	10
Grand Station Mean		7.91	16.6	27.1	27.2	5.96	17.3	19.9	6.42
Stdev		3.89	5.45	11.8	10.7	3.88	7.05	5.53	9.14
CV		49.2	32.7	43.4	39.3	65.2	40.7	27.7	142
Fines (pct)	1991	15.1	36.2	55.9	67.7	6.32	34.3	41	87.9
	1992	17	31.2	56.5	79.2	1.9	34.8	55.3	3.7
	1993	16.7	30.9	49.2	86.1	14.7	32.7	50	4.42
	1994	31.1	40.2	36.8	95.2	12.7	33.8	58.1	5.4
	1995	61.1	58.6	88.2	93.7	11.7	66.4	57.8	4.2
	1996	20.3	46.9	78.7	94.4	10.7	80.3	67.7	17.3
	1997	20.7	55.5	82.6	97.4	32.1	41.1	55.1	5.97
	1998	24.5	55.5	88.3	79.6	18.6	61.2	62.4	6.23
	1999	21.5	59.8	91.1	94.6	24.2	62.4	67	4.6
	2000	30	45.9	49	69	6.3	41.5	58.4	4.7
	2001	32.7	56.1	65.4	94.6	21.9	38.6	56.7	7.93
	2002	31.8	54.4	59.7	90.8	12.4	26.4	54.5	10.4
	2003	26.8	65.9	69.2	90.8	30.1	45.4	51.3	13.4
Grand Station Mean		26.9	49	67	87.2	15.7	46.1	56.6	13.5
Stdev		11.9	11.4	17.6	10.1	9.24	16.2	7.05	22.7
CV		44.5	23.3	26.2	11.6	59	35.3	12.5	168

Table B3-1. (cont.)

Parameter	Year	T01	T02	T03	T04	T05A	T06	T07	T08	Harbor Mean
TOC (pct)	1991	2.64	1.75	3.69	3.7	1.46	1.81	2.73	0.87	2.33
	1992	1.91	1.71	3.57	3.95	1.61	2.12	3.18	0.66	2.34
	1993	2.96	1.39	3.41	3.25	0.88	1.62	2.31	0.37	2.02
	1994	1.9	1.73	2.8	3.1	0.5	1.9	2.5	0.9	1.92
	1995	1.18	2.05	3.54	3.69	0.42	1.83	3.17	0.21	2.01
	1996	1.9	1.98	3.84	4.75	0.884	3.89	2.73	0.893	2.61
	1997	1.83	1.46	3.57	3.88	1.42	1.88	3.09	0.45	2.2
	1998	1.55	1.5	2.46	8.86	0.62	2.17	2.21	0.398	2.47
	1999	2.8	1.61	3.14	4.15	1.26	2.36	2.77	0.23	2.29
	2000	1.8	1.51	3.03	3.9	0.93	2.16	2.53	0.37	2.03
	2001	1.13	1.69	3.03	4.08	1.02	1.97	2.6	0.43	1.99
	2002	0.973	1.77	2.8	3.64	0.873	1.6	2.73	0.497	1.86
	2003	1.18	1.9	3.05	4.76	0.84	1.81	2.6	0.49	2.08
Grand Station Mean		1.83	1.7	3.23	4.29	0.978	2.09	2.7	0.521	2.17 (a)
Stdev		0.648	0.201	0.412	1.46	0.368	0.585	0.301	0.238	0.227
CV		35.5	11.8	12.8	34	37.6	28	11.1	45.7	10.5
Clostridium perfringens (cfu/gdw)	1991	11700	22900	207000	30000	30400	29400	13700	7330	44100
	1992	4300	14800	938	3330	30000	7000	7500	3890	8970
	1993	7030	9090	20200	5750	1910	13800	7100	1580	8310
	1994	5490	12500	20300	9080	2840	7110	7290	2160	8340
	1995	1200	15000	33000	12000	1100	6200	11000	955	10100
	1996	9400	23000	29000	67000	3400	59000	35000	7000	29100
	1997	7720	18300	18700	17000	4300	17200	18000	1900	12900
	1998	4390	6870	6840	15100	1400	7280	7740	1750	6420
	1999	920	5260	7720	1800	750	2560	8520	350	3490
	2000	3130	6820	11300	1960	1700	3430	6040	330	4340
	2001	2910	3310	9650	4900	1240	3320	6910	320	4070
	2002	2160	6730	9110	3220	453	1770	8120	387	3990
	2003	920	4860	5040	6560	710	1950	7940	230	3530
Grand Station Mean		4710	11500	29100	13700	6170	12300	11100	2170	11400 (a)
Stdev		3410	6800	54300	17900	10700	16000	7900	2450	12000
CV		72.3	59.2	186	131	174	130	70.9	113	105

Harbor Mean = average of all Traditional stations, by year for August surveys only.
Grand Station Mean = average of all years, by station for August surveys only
(a) Grand Mean value reported. Grand mean = average of yearly mean values, by sampling period.

APPENDIX C

Sediment Profile Images (HR031)
(see enclosed CD)

APPENDIX D1

Data Manipulations on Infaunal Data Prior to Statistical Analyses

These merges are based on the entire data set, which includes April samples. There may or may not be any of these taxa in the August-samples-only data.

Merge for 1991-2003 Export for Report Only (use final name and code):

NODC Code	Taxon		Comment
6169020108	*Ampelisca abdita*		
6169020109	*Ampelisca vadorum*		
61690201SPP	*Ampelisca* spp.	use	
50010601TECT	*Pholoe tecta*		
5001060101	*Pholoe minuta*	use	
5001670216	*Ampharete baltica*		
5001670208	*Ampharete acutifrons*	use	
50014304SPP	*Polydora* spp.		
5001430448	*Polydora cornuta*	use	
8401SPP	*Ascidiacea* spp.		
84060301SPP	*Molgula* spp.		
8406030108	*Molgula manhattensis*	use	
500162SPP	*Arenicolidae* spp.		
5001620204	*Arenicola marina*	use	
55151901SPP	*Astarte* spp.		
5515190113	*Astarte undata*	use	
50017013SPP	*Fabricia* spp.		
50017013STEL	*Fabricia stellaris stellaris*	use	
61692107SPP	*Gammarus* spp.		
6169210713	*Gammarus lawrencianus*	use	
61692702SPP	*Ischyrocerus* spp.		
6169270202	*Ischyrocerus anguipes*	use	
50010211SPP	*Lepidonotus* spp.		
5001021103	*Lepidonotus squamatus*	use	
50016303SPP	*Maldane* spp.		
5001630302	*Maldane glebifex*	use	probably is *M. sarsi*

NODC Code	**Taxon**		**Comment**
61631202SPP	*Pleurogonium* spp.		
6163120204	*Pleurogonium inerme*	use	
8201SPP	Enteropneusta spp.		
8201010303	*Saccoglossus bromophenolosus*	use	JAB questions species name.
5520050206	*Lyonsia hyalina*		
55200502SPP	*Lyonsia spp.*		
5520050201	*Lyonsia arenosa*	use	
61690604SPP	*Microdeutopus* spp.		
6169060402	*Microdeutopus anomalus*	use	
50016806SPP	*Nicolea* spp.		
5001680602	*Nicolea zostericola*	use	
5001680805	*Polycirrus* cf. *haematodes*		
5001680807	*Polycirrus phosphoreus*	use	could be classified as a name change
55200201SPP	*Pandora* spp.		
5520020107	*Pandora gouldiana*	use	
50012308SPP	*Sphaerosyllis* spp.		
5001230817	*Sphaerosyllis longicauda*		
5001230801	*Sphaerosyllis erinaceus*		Name may have been changed as for MB data, I am not certain.
5001500305	*Tharyx acutus*		
50015003SP02	*Tharyx* sp. A		
50015003SP03	*Tharyx* sp. B		
50015003SPP	*Tharyx* spp.		
50014502SPP	*Trochochaeta* spp.		
5001450203	*Trochochaeta multisetosa*		
61691507SPP	*Unciola* spp.		
6169150703	*Unciola irrorata*		

Exclude from data prior to analyses:

NODC Code	Taxon
510205SPP	Acmaeidae spp.
6171010801	*Aeginina longicornis*
5509090202	*Anomia simplex*
6134020104	*Balanus crenatus*
6134020114	*Balanus improvisus*
61340201SPP	*Balanus* spp.
6171010703	*Caprella linearis*
6171010727	*Caprella penantis*
61710107SPP	*Caprella* spp.
617101SPP	*Caprellidae* spp.
5103640204	*Crepidula fornicata*
5103640207	*Crepidula plana*
51036402SPP	*Crepidula* spp.
5001430414	*Dipolydora concharum*
5001500501	*Dodecaceria concharum*
50015005SPP	*Dodecaceria* spp.
3701SPP	*Hydrozoa* spp.
6161050101	*Limnoria lignorum*
5103100108	*Littorina littorea*
5507010601	*Modiolus modiolus*
550701SPP	*Mytilidae* spp.
5507010101	*Mytilus edulis*
500201SPP	*Nerillidae* spp.
6171010901	*Paracaprella tenuis*
5001430412	*Polydora websteri*
5001650202	*Sabellaria vulgaris*

APPENDIX D2

Benthic Species identified from Boston Harbor Monitoring Program Samples from 1991–2003

Table D2-1. Species identified from Boston Harbor Monitoring Program samples from 1991–2003 and used in the 2003 community analysis. Species collected in August 2003 samples are marked with an asterisk (*). Species new to the list in 2003 are underlined.

CNIDARIA
- *Ceriantheopsis americanus* (Verrill, 1866)
- *Edwardsia elegans* Verrill, 1869
- Actiniaria sp. 2

PLATYHELMINTHES
- Turbellaria spp.

NEMERTEA
- *Amphiporus angulatus* (Fabricius, 1774)
- *Amphiporus cruentatus* Verrill, 1879
- *Amphiporus ochraceus* (Verrill, 1873)
- *Amphiporus* sp. 1
- *Carinomella lactea* Coe, 1905
- Cephalothricidae sp. 1
- *Cerebratulus lacteus* (Leidy, 1851)
- *Micrura* spp.
- Nemertea sp. 2
- Nemertea sp. D
- Nemertea sp. 5
- Nemertea sp. 12
- Nemertea sp. 13
- *Proneurotes* spp.
- *Tetrastemma vittatum* Verrill, 1874
- *Tubulanus pellucidus* (Coe, 1895)

ANNELIDA
- Polychaeta
  - Ampharetidae
    - *Ampharete acutifrons* (Grube, 1860) *
    - *Ampharete baltica* Eliason, 1955 *
    - *Ampharete finmarchica* (Sars, 1865)
    - *Ampharete lindstroemi* Malmgren, 1867 *
    - *Anobothrus gracilis* (Malmgren, 1866) *
    - *Asabellides oculata* (Webster, 1879) *
  - Amphinomidae
    - Amphinomidae spp.
  - Arenicolidae
    - *Arenicola marina* (Linnaeus, 1758)
    - *Branchiomaldane* spp.
    - Arenicolidae spp.
      (merged with *Arenicola marina* for report)
  - Capitellidae
    - *Capitella capitata* complex (Fabricius, 1780) *
    - *Heteromastus filiformis* (Claparède, 1864)
    - *Mediomastus ambiseta* (Hartman, 1947)
    - *Mediomastus californiensis* Hartman, 1944 *
  - Cirratulidae
    - *Aphelochaeta marioni* (Saint-Joseph, 1894)
    - *Aphelochaeta monilaris* (Hartman, 1960)
    - *Aphelochaeta* sp. 1
    - *Caulleriella* sp. B
    - *Chaetozone* cf. *setosa* (Boston Harbor) Malmgren, 1867 *
    - *Chaetozone vivipara* (Christie, 1985) *
    - *Cirratulus cirratus* (O.F. Müller, 1776)
    - *Cirratulus* sp. 1
    - *Cirriformia grandis* (Verrill, 1873)
    - *Monticellina baptisteae* Blake, 1991 *
    - *Monticellina dorsobranchialis* (Kirkegaard, 1959) *
    - *Tharyx acutus* Webster & Benedict, 1887 *
      (merged with *T.* spp. for report)
    - *Tharyx* sp. A *
      (merged with *T.* spp. for report)
    - *Tharyx* sp. B *
      (merged with *T.* spp. for report)
  - Cossuridae
    - *Cossura longocirrata* Webster & Benedict, 1887
  - Dorvilleidae
    - Dorvilleidae sp. A
    - *Ophryotrocha* spp.
    - *Parougia caeca* (Webster & Benedict, 1884) *
    - *Protodorvillea gaspeensis* Pettibone, 1961
  - Flabelligeridae
    - *Brada villosa* (Rathke, 1843)
    - *Diplocirrus hirsutus* (Hansen, 1879) *
    - *Flabelligera affinis* Sars, 1829 *
    - *Pherusa affinis* (Leidy, 1855) *
  - Glyceridae
    - *Glycera americana* Leidy, 1855 *
    - *Glycera dibranchiata* Ehlers, 1868
  - Hesionidae
    - *Microphthalmus pettiboneae* Riser, 2000 *
  - Lumbrineridae
    - *Ninoe nigripes* Verrill, 1873 *
    - *Scoletoma acicularum* (Webster & Benedict, 1887)
    - *Scoletoma fragilis* (O.F. Mhller, 1776)
    - *Scoletoma hebes* (Verrill, 1880) *
  - Maldanidae
    - *Clymenella torquata* (Leidy, 1855) *
    - *Maldane glebifex* Grube, 1860
    - *Sabaco elongatus* (Verrill, 1873) *
  - Nephtyidae
    - *Aglaophamus circinata* (Verrill, 1874) *
    - *Nephtys caeca* (Fabricius, 1780) *
    - *Nephtys ciliata* (O.F. Müller, 1776) *
    - *Nephtys cornuta* Berkeley & Berkeley, 1945 *
    - *Nephtys incisa* Malmgren, 1865 *
    - *Nephtys longosetosa* Oersted, 1843
    - *Nephtys picta* Ehlers, 1868
  - Nereididae
    - *Neanthes virens* Sars, 1835 *
    - *Neanthes arenaceodentata* Moore, 1903
    - *Nereis diversicolor* O.F. Müller, 1776
    - *Nereis grayi* Pettibone, 1956 *
    - *Nereis zonata* Malmgren, 1867
  - Opheliidae
    - *Ophelina acuminata* Oersted, 1843 *
  - Orbiniidae
    - *Leitoscoloplos acutus* (Verrill, 1873) *
    - *Leitoscoloplos robustus* (Verrill, 1873) *
    - *Naineris quadricuspida* (Fabricius, 1780)
    - *Scoloplos armiger* (O.F. Müller, 1776)
  - Oweniidae
    - *Galathowenia oculata* (Zachs, 1923) *
  - Paraonidae
    - *Aricidea catherinae* Laubier, 1967 *
    - *Aricidea quadrilobata* Webster & Benedict, 1887
    - *Levinsenia gracilis* (Tauber, 1879)
    - *Paradoneis armatus* GlJmarec, 1966
    - *Paraonis fulgens* (Levinsen, 1883)
    - *Paraonis pygoenigmatica* Jones, 1968

Pectinariidae
Pectinaria gouldii (Verrill, 1873)
Pectinaria granulata (Linnaeus, 1767) *
Pectinaria hyperborea (Malmgren, 1866)
Pholoidae
Pholoe minuta (Fabricius, 1780) *
Pholoe tecta Stimpson, 1854 *
Phyllodocidae
Eteone flava (Fabricius, 1780)
<u>*Eteone foliosa* Quatrefages, 1865 *</u>
Eteone heteropoda Hartman, 1951
Eteone longa (Fabricius, 1780) *
Eulalia bilineata (Johnston, 1840)
Eulalia viridis (Linnaeus, 1767)
Eumida sanguinea (Oersted, 1843) *
Paranaitis speciosa (Webster, 1870) *
Phyllodoce arenae Webster, 1879
Phyllodoce groenlandica Oersted, 1843 *
Phyllodoce maculata (Linnaeus, 1767) *
Phyllodoce mucosa Oersted, 1843 *
Polygordiidae
Polygordius sp. A *
Polynoidae
Enipo torelli (Malmgren, 1865)
Gattyana amondseni (Malmgren, 1867)
Gattyana cirrosa (Pallas, 1766)
Harmothoe extenuata (Grube, 1840)
Harmothoe imbricata (Linnaeus, 1767) *
Hartmania moorei Pettibone, 1955 *
Lepidonotus squamatus (Linnaeus, 1758)
Sabellidae
Euchone incolor Hartman, 1978 *
Fabricia stellaris stellaris (Müller, 1784) *
<u>*Laonome kroeyeri* Malmgren, 1866 *</u>
Scalibregmatidae
Scalibregma inflatum Rathke, 1843
Sigalionidae
Sthenelais limicola (Ehlers, 1864)
Sphaerodoridae
Sphaerodoridium sp. A
Spionidae
Dipolydora caulleryi Mesnil, 1897
Dipolydora quadrilobata Jacobi, 1883 *
Dipolydora socialis (Schmarda, 1861) *
Polydora aggregata Blake, 1969 *
Polydora cornuta Bosc, 1802 *
Polydora sp. 1
Prionospio steenstrupi Malmgren, 1867 *
Pygospio elegans Calparède, 1863 *
Scolelepis bousfieldi Pettibone, 1963 *
Scolelepis squamata (O.F. M**h**ller, 1806)
Scolelepis texana Foster, 1971
Scolelepis cf. *tridentata* (Southern, 1914)
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
Autolytus fasciatus (Bosc, 1802)
Brania wellfleetensis Pettibone, 1956
Exogone arenosa Perkins, 1980
Exogone hebes (Webster & Benedict, 1884) *
Exogone verugera (Claparède, 1868)
Parapionosyllis longicirrata (Webster & Benedict, 1884)
Pionosyllis spp.
Proceraea cornuta Agassiz, 1863
Sphaerosyllis erinaceus Clapar**J**de, 1863
Syllides longocirrata Oersted, 1845
Typosyllis alternata (Moore, 1908)
Typosyllis cornuta Rathke, 1843 *
Typosyllis sp. 1
Terebellidae
Lanassa spp.
Neoamphitrite figulus (Dalyell, 1853)
Nicolea zostericola (Oersted, 1844)
Nicolea spp.
(merged with *N. zostericola* for report)
Pista cristata (O.F. Müller, 1776) *
Polycirrus eximius (Leidy, 1855) *
Polycirrus medusa Grube, 1850
Polycirrus phosphoreus Verrill, 1880 *
Polycirrus sp. A
Trichobranchidae
<u>*Terebellides atlantis* Williams, 1984 *</u>
Trochochaetidae
<u>*Trochochaeta carica* (Birula, 1897) *</u>
Trochochaeta multisetosa (Oersted, 1844)

Oligochaeta
Enchytraiedae
Enchytraiedae sp. 1 *
Enchytraiedae sp. 2
Enchytraiedae sp. 3
Grania postclitellochaeta longiducta *
Naididae
Paranais litoralis (Müller, 1784)
Tubificidae
Tubificidae sp. 2
Tubificoides apectinatus Brinkhurst, 1965 *
Tubificoides benedeni Udekem, 1855 *
Tubificoides nr. *pseudogaster* Dahl, 1960 *
Tubificoides sp. 1 *
Tubificoides sp. 2 *

ARTHROPODA
Pycnogonida
Achelia spinosa (Stimpson, 1853)
Phoxichilidium femoratum (Rathke, 1799)

CRUSTACEA
Amphipoda
Ampeliscidae
Ampelisca abdita Mills, 1964 *
Ampelisca vadorum Mills, 1963 *
Ampithoidae
Cymadusa compta (Smith, 1873)
Aoridae
Lembos websteri Bate, 1856
Leptocheirus pinguis (Stimpson, 1853) *
Microdeutopous anomalus (Rathke, 1843) *
Pseudunciola obliquua (Shoemaker, 1949)
Unciola irrorata Say, 1818 *
Argissidae
Argissa hamatipes (Norman, 1869)
Corophiidae
Apocorophium acutum Chevreus, 1908
Crassicorophium crassicorne (Bruzelius, 1859) *
Crassicorophium bonnelli (Milne Edwards, 1830)*
Monocorophium acherusicum (Costa, 1857)
Monocorophium insidiosum (Crawford, 1937)
Monocorophium tuberculatum (Shoemaker,1934)
Corophiidae sp. 1
Dexaminidae
Dexamine thea Sars, 1893
Eusiridae
Pontogenia inermis (Krøyer, 1842) *

Gammaridae
Gammarus lawrencianus Bousfield, 1956
Isaeidae
Photis pollex Walker, 1895 *
Protomedeia fasciata Krryer, 1846
Ischyroceridae
Erichthonius brasiliensiss (Dana, 1853)
Ischyrocerus anguipes (Krøyer, 1842) *
Jassa marmorata Holmes, 1903 *
Liljeborgiidae
Listriella barnardi Wigley, 1966
Lysianassidae
Orchomenella minuta (Krøyer, 1842) *
Orchomene pinguis (Boeck, 1861)
Oedicerotidae
Ameroculodes sp. 1
Deflexilodes tuberculatus (Boeck, 1870)
Phoxocephalidae
Harpinia propinqua Sars, 1895 *
Phoxocephalus holbolli (Krøyer, 1842) *
Rhepoxinius hudsoni Barnard & Barnard, 1982
Pleustidae
Pleusymtes glaber (Boeck, 1861)
Podoceridae
Dyopedos monacanthus (Metzger, 1875) *
Stenothoidae
Metopella carinata Shoemaker, 1949
Metopella angusta Shoemaker, 1949 *
Proboloides holmesi Bousfield, 1973
Stenothoe gallensis Walker, 1904
Stenothoe minuta Holmes, 1905
Stenothoe sp. 1

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

Decapoda
Brachyura
Cancridae
Cancer irroratus Say, 1817 *
Portunidae
Carcinus maenas (Linnaeus, 1758)
Caridea
Crangonidae
Crangon septemspinosa Say, 1818 *
Paguridae
Pagurus acadianus Benedict, 1901 *
Pagurus annulipes (Stimpson, 1860)
Pagurus longicarpus Say, 1817 *

Isopoda
Anthuriidae
Ptilanthura tenuis Harger, 1879
Chaetiliidae
Chiridotea tuftsi (Stimpson, 1883)
Cirolanidae
Politolana polita (Stimpson, 1853)
Idoteidae
Edotia triloba (Say, 1818) *
Erichsonella spp.
Munnidae
Munna spp.
Paramunnidae
Pleurogonium inerme Sars, 1882 *

Mysidacea
Heteromysis formosa S.I. Smith, 1873
Neomysis americana (S.I. Smith, 1873) *

Tanaidacea
Nototanaidae
Tanaissus psammophilus (Wallace, 1919) *

MOLLUSCA
Bivalvia
Arcidae
Arctica islandica (Linnaeus, 1767) *
Astartidaeè
Astarte undata Gould, 1841 *
Cardiidae
Cerastoderma pinnulatum (Conrad, 1831) *
Carditidae
Cyclocardia borealis (Conrad, 1831)
Hiatellidae
Hiatella arctica (Linnaeus, 1767) *
Lasaeidae
Aligena elevata (Stimpson, 1851)
Lyonsiidae
Lyonsia arenosa Möller, 1842
Lyonsia hyalina Conrad, 1831 *
Mactridae
Mulinia lateralis (Say, 1822)
Spisula solidissima (Dillwyn, 1817) *
Montacutidae
Mysella planulata (Stimpson, 1857) *
Pythinella cuneata Dall, 1899 *
Myidae
Mya arenaria Linnaeus, 1758 *
Mytilidae
Crenella decussata (Montagu, 1808) *
Musculus niger (Gray, 1824) *
Nuculanidae
Yoldia limatula (Say, 1831)
Yoldia sapotilla (Gould, 1841) *
Nuculidae
Nucula annulata Hampson, 1971
Nucula delphinodonta Mighels & Adams, 1842 *
Nuculoma tenuis Montagu, 1808 *
Pandoridae
Pandora gouldiana Dall, 1886 *
Periplomatidae
Periploma papyratium (Say, 1822) *
Petricolidae
Petricola pholadiformis (Lamarck, 1818) *
Solenidae
Ensis directus Conrad, 1843 *
Siliqua costata Say, 1822
Tellinidae
Macoma balthica (Linnaeus, 1758)
Tellina agilis Stimpson, 1857 *
Thraciidae
Asthenothaerus hemphilli Dall, 1886
Bushia elegans (Dall, 1886)
Thracia conradi Couthouy, 1838 *
Thyasiridae
Thyasira gouldi Philippi, 1845
Turtoniidae
Turtonia minuta (Fabricius, 1780)
Veneridae
Gemma gemma (Totten, 1834) *
Pitar morrhuanus Linsley, 1848 *
Bivalvia sp. 1

Gastropoda
Nudibranchia
Doridoida sp. A

Ophisthobranchia
Diaphanidae
Diaphana minuta (Brown, 1827)
Prosobranchia
Columbellidae
Mitrella lunata (Say, 1826)
Lacunidae
Lacuna vincta (Montagu, 1803) *
Nassariidae
Ilyanassa obsoleta (Say, 1822)
Ilyanassa trivittata (Say, 1822) *
Naticidae
Euspira heros (Say, 1822)
Euspira triseriata (Say, 1826)
Polinices duplicatus (Say, 1822)
Scaphopoda
Dentaliidae
Dentalium entale (Linnaeus, 1758) *

SIPUNCULA
Nephasoma diaphanes (Gerould, 1913)
Phascolion strombi (Montagu, 1804)

ECHIURA
Echiurus echiurus (Pallas, 1767)

PHORONIDA
Phoronis architecta Andrews, 1890 *

ECHINODERMATA
Echinoidea
Echinarachnius parma (Lamarck, 1816) *
Strongylocentrotus droebachiensis (Müller, 1776)
Ophiuroidea
Axiognathus squamatus (Delle Chiaje, 1828)
Ophiura robusta (Ayres, 1851)

HEMICHORDATA
Harrimaniidae
Saccoglossus bromophenolosus King, Giray, & Kornfield, 1997

CHORDATA
Ascidiacea spp.
Molgulidae
Bostrichobranchus pilularis (Verrill, 1871)
Molgula manhattensis (DeKay, 1843) *

APPENDIX D3

Benthic Community Parameters plotted for Boston Harbor Stations, 1991–2003

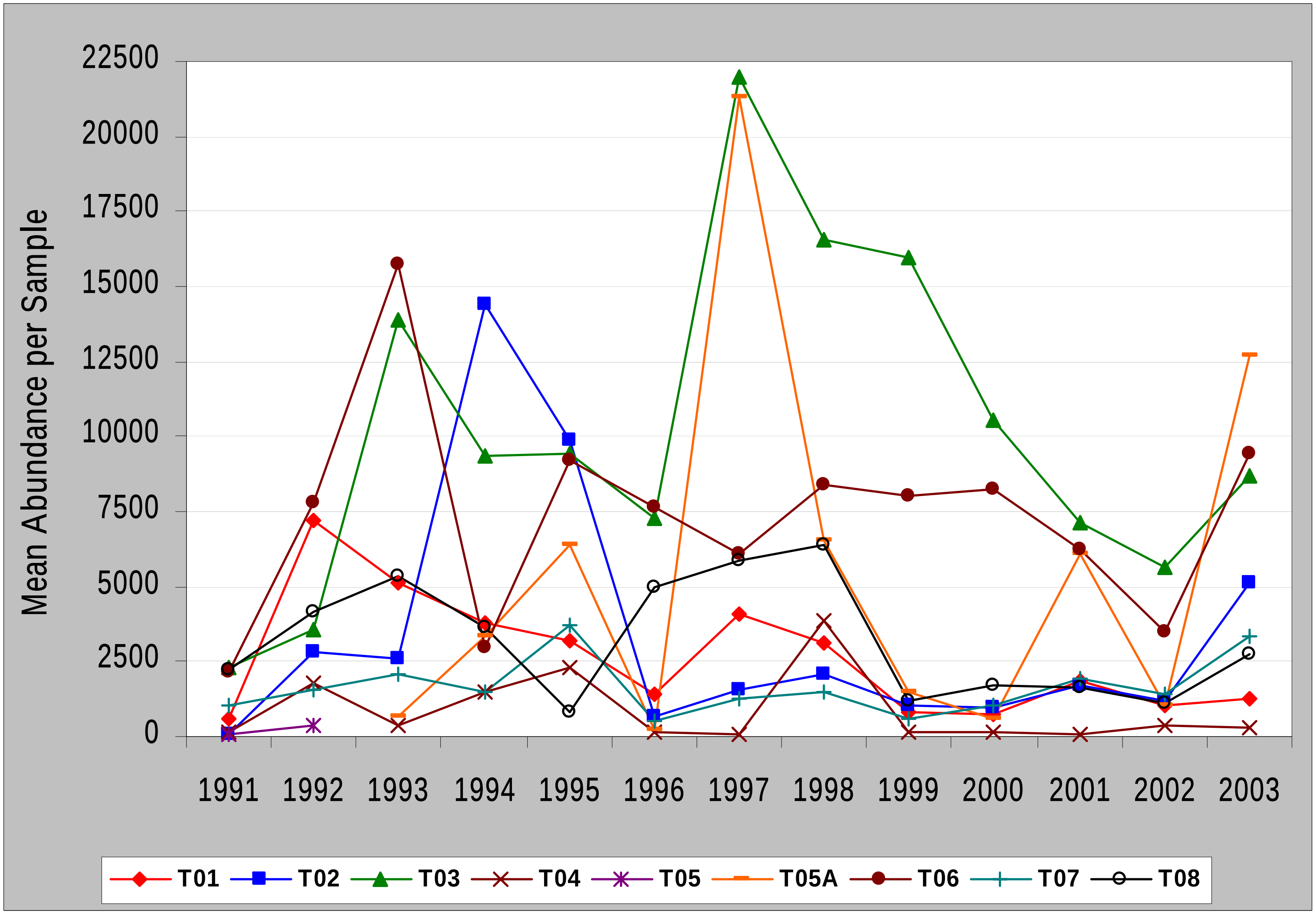


Figure D3-1. Mean abundance per sample at individual Boston Harbor stations, with samples at each station averaged for each August (or September) sampling event from 1991 through 2003.

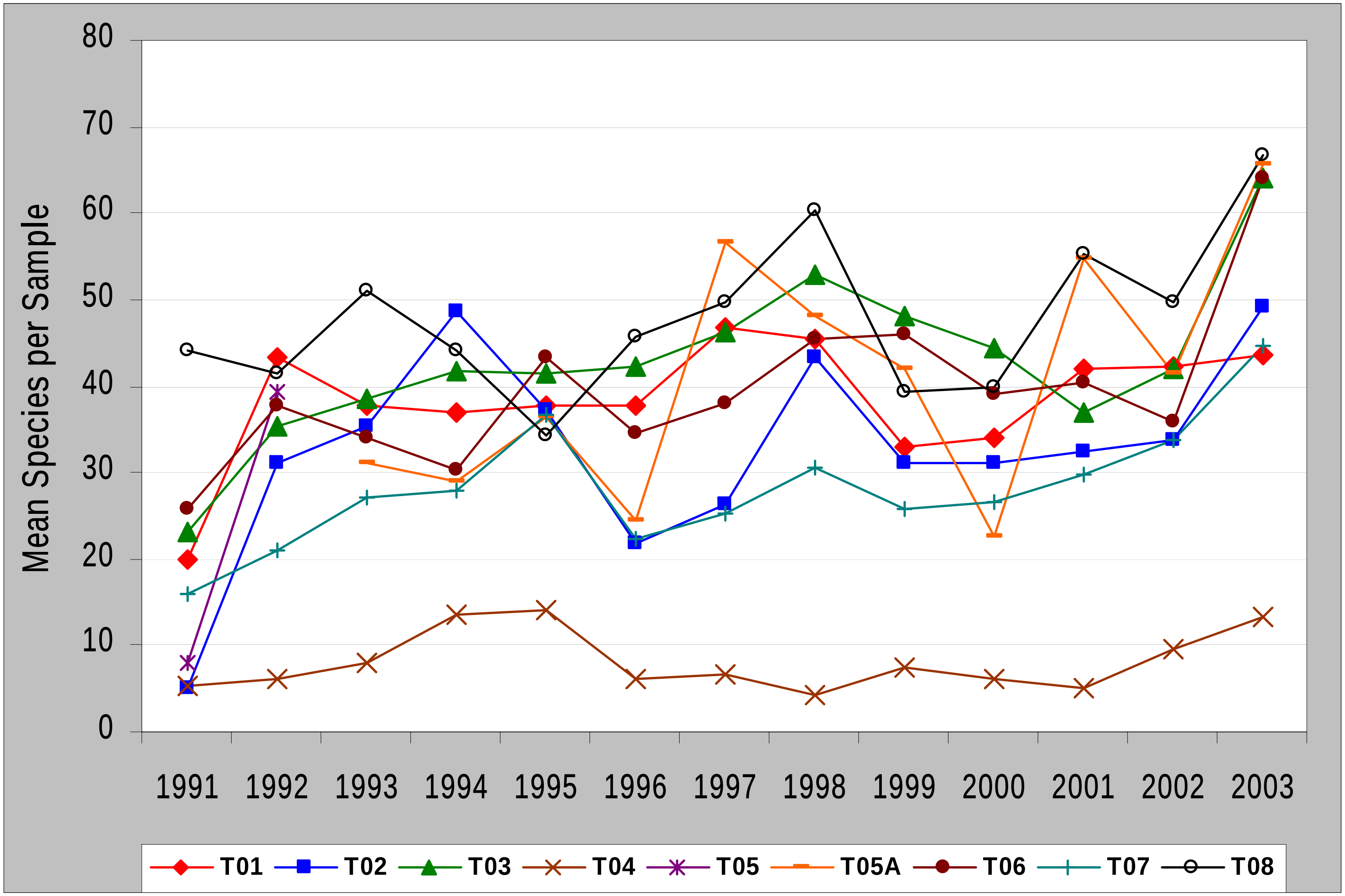


Figure D3-2. Mean species per sample at individual Boston Harbor stations, with samples at each station averaged for each August (or September) sampling event from 1991 through 2003.

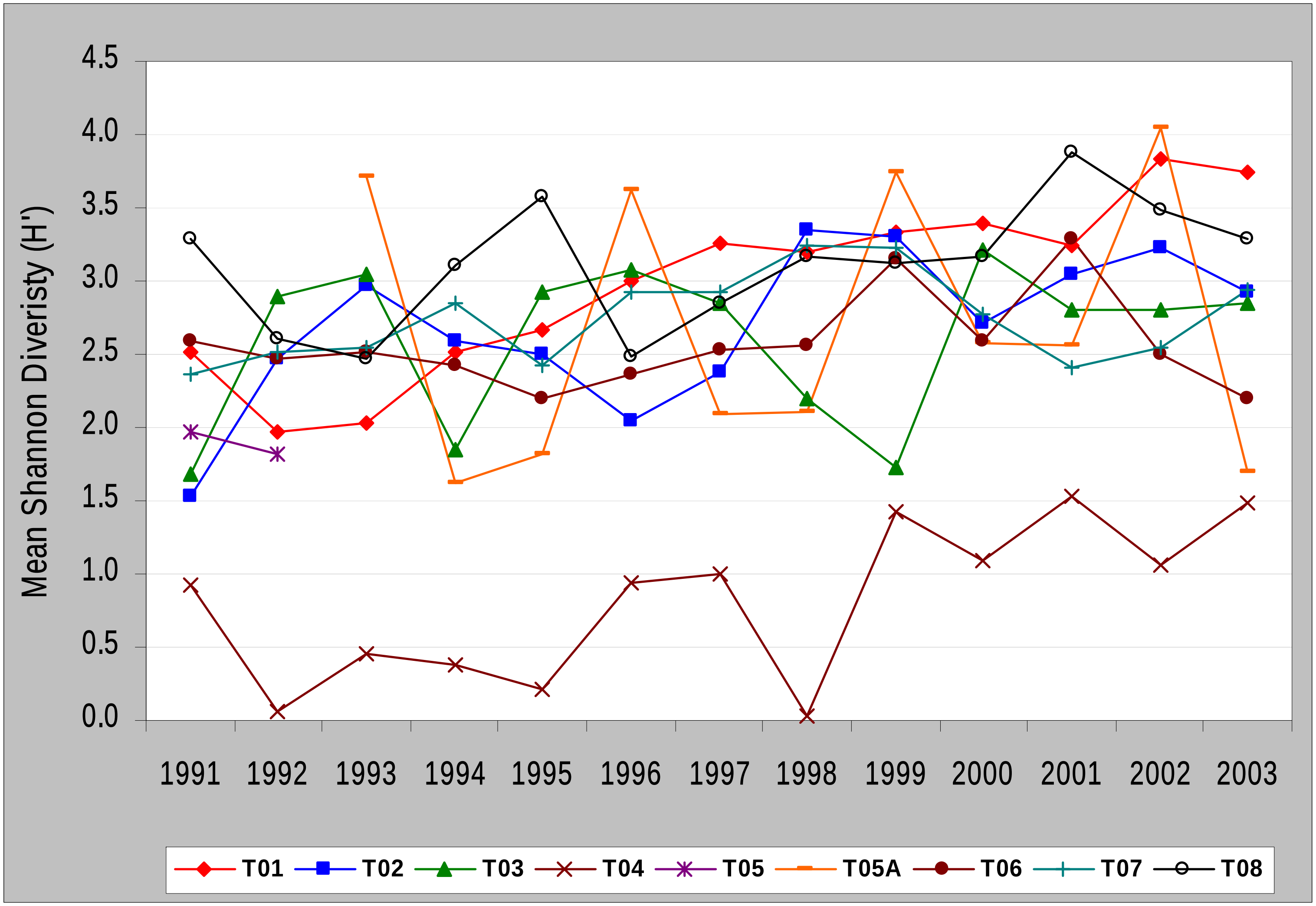


Figure D3-3. Mean Shannon diversity per sample at individual Boston Harbor stations, with samples at each station averaged for each August (or September) sampling event from 1991 through 2003.

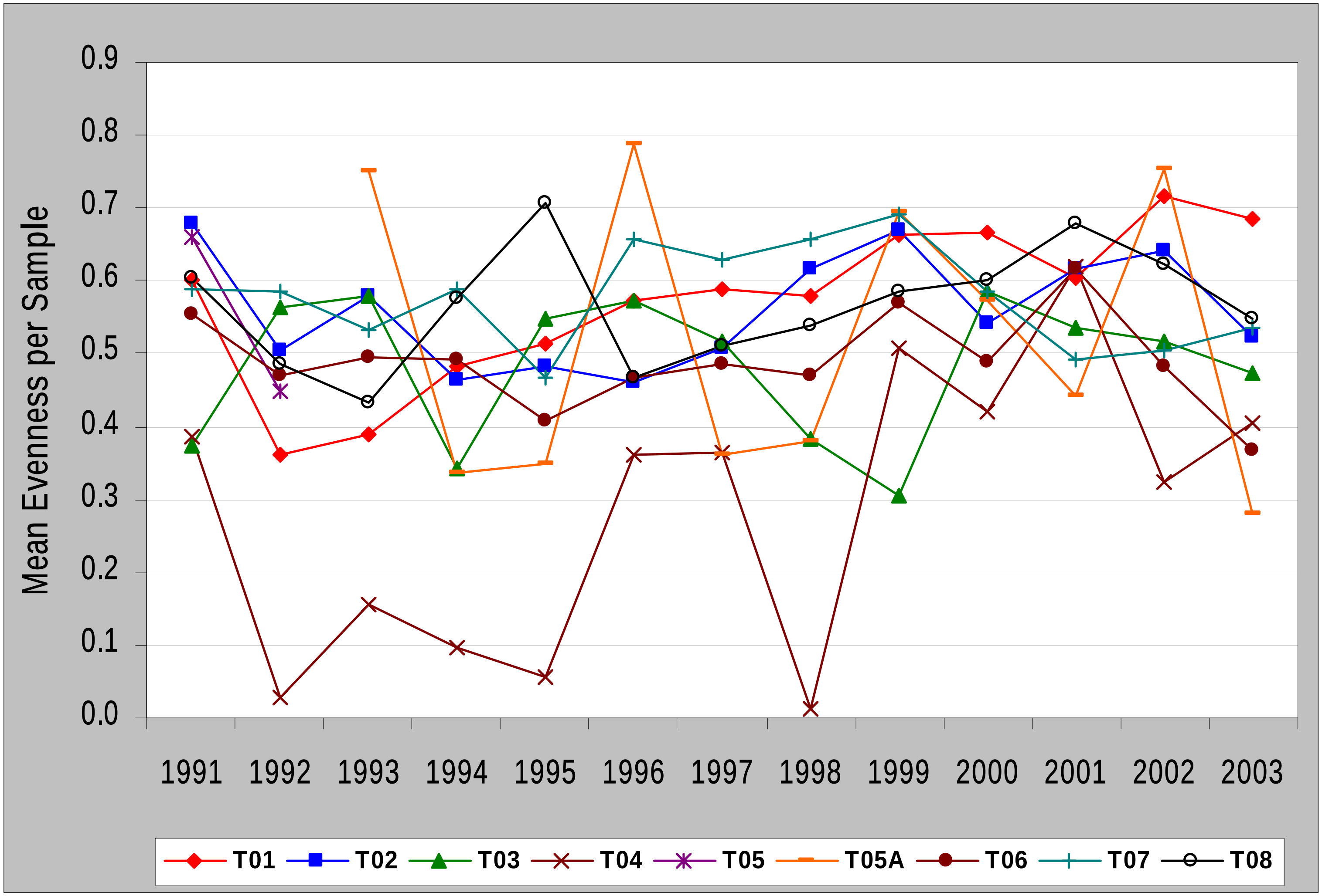


Figure D3-4. Mean evenness per sample at individual Boston Harbor stations, with samples at each station averaged for each August (or September) sampling event from 1991 through 2003.

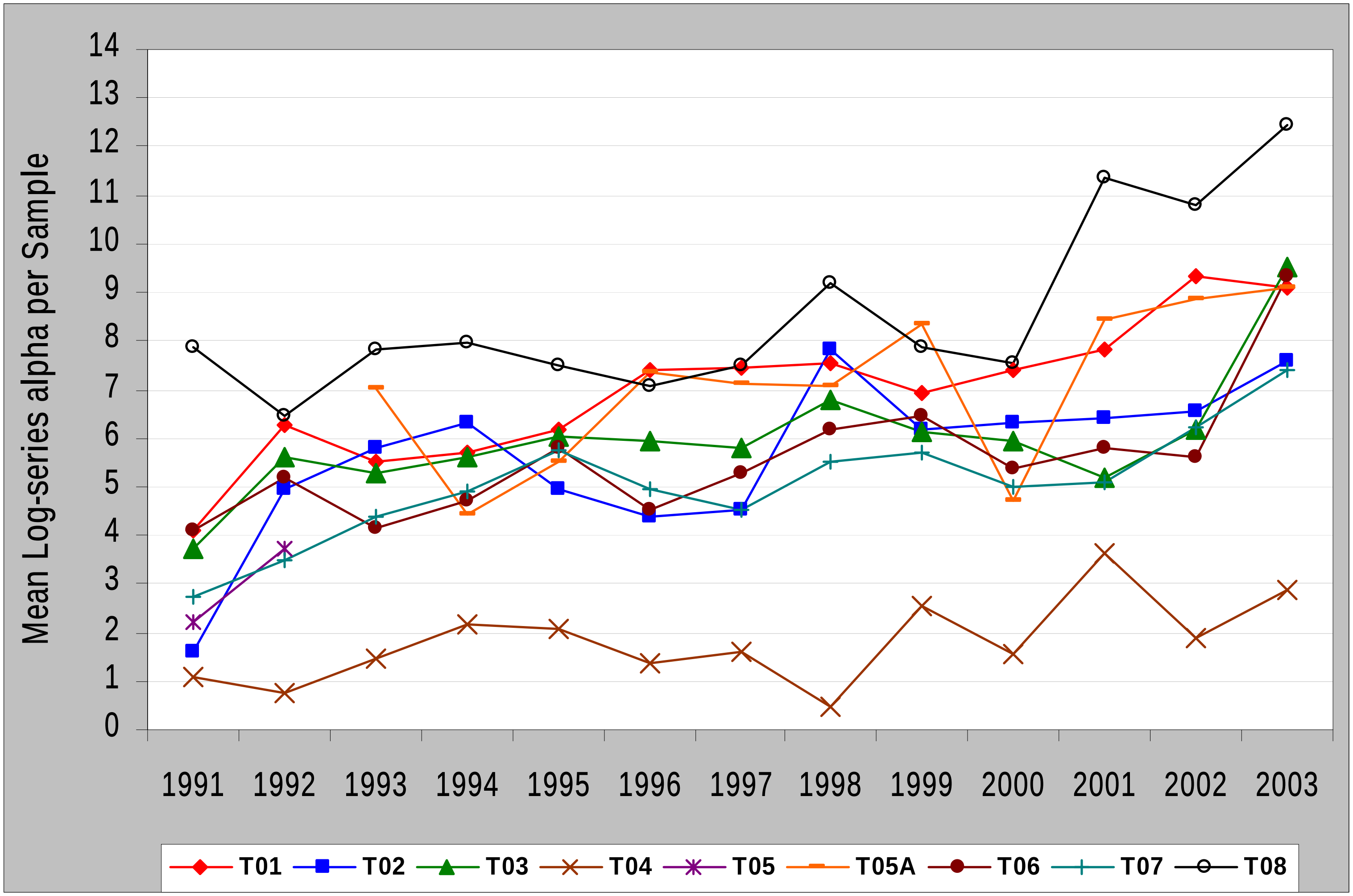


Figure D3-5. Mean log-series *alpha* per sample at individual Boston Harbor stations, with samples at each station averaged for each August (or September) sampling event from 1991 through 2003.

APPENDIX D4

Dominant Species at
Boston Harbor Stations in August 2003
(BH031)

Station	Rank	Species	Mean	Std. Dev.	%	Cum %	2002 Rank	2001 Rank	2000 Rank
T01	1	*Leptocheirus pinguis*	271.3	181.8.	25.9	25.9	8	2	17
	2	*Polydora cornuta*	189.7	76.0	18.1	44.0	2	1	2
	3	*Ampelisca* spp.	135.0	23.1	12.9	56.9	12	3	12
	4	*Nephtys ciliata*	76.3	18.7	7.3	64.2	20	NP	NP
	5	*Unciola irrorata*	49.0	34.8	4.7	68.9	25	18	18
	6	*Exogone hebes*	36.7	30.7	3.5	72.4	6	10	8
	7	*Ilyanassa trivittata*	34.3	9.0	3.3	75.7	9	12	10
	8	*Dipolydora socialis*	23.7	36.7	2.3	78.0	17	16	14
	9	*Tubificoides* sp. 2	22.3	3.8	2.1	80.1	3	7	1
	10	*Aricidea catherinae*	17.3	13.7	1.7	81.8	1	6	5
	11	*Prionospio steenstrupi*	15.7	5.9	1.5	83.3	10	27	20
	12	*Mediomastus californiensis*	14.7	3.1	1.4	84.7	11	21	12
	13	*Scoletoma hebes*	13.7	9.7	1.3	86.0	17	22	19
	14	*Nephtys cornuta*	13.0	3.6	1.2	87.2	25	29	19
	15	*Tharyx* spp.	12.0	3.0	1.1	88.3	5	9	11
		(Total Good Species)	1047.8						
		(Total Station Density)	1274.1						
T02	1	*Ampelisca* spp.	2006.7	736.5	39.6	39.6	3	2	3
	2	*Polydora cornuta*	946.7	202.3	18.7	58.3	6	1	1
	3	*Leptocheirus pinguis*	576.0	405.4	11.4	69.7	21	4	11
	4	*Tubificoides apectinatus*	379.7	76.8	7.5	77.2	2	3	2
	5	*Nephtys cornuta*	214.0	41.6	4.2	81.4	4	6	8
	6	*Aricidea catherinae*	197.3	35.6	3.9	85.3	1	5	7
	7	*Tharyx* spp.	110.7	15.0	2.2	87.5	10	8	6
	8	*Micropthalmus pettiboneae*	95.0	98.5	1.9	89.4	8	7	9
	9	*Tubificoides* nr. *pseudogaster*	75.0	49.1	1.5	90.9	9	10	17
	10	*Unciola irrorata*	70.0	41.9	1.4	92.3	18	12	18
	11	*Prionospio steenstrupi*	66.3	51.7	1.3	93.6	5	18	17
	12	*Dipolydora socialis*	50.3	81.1	1.0	94.6	23	24	20
	13	*Ilyanassa trivittata*	49.0	0.0	1.0	95.6	11	19	12
	14	*Phyllodoce mucosa*	35.3	13.8	0.7	96.3	17	18	24
	15	*Mediomastus californiensis*	28.7	3.3	0.6	96.9	8	9	10
		(Total Good Species)	5064.5						
		(Total Station Density)	5104.4						

NP = Not Present

Station	Rank	Species	Mean	Std. Dev.	%	Cum %	2002 Rank	2001 Rank	2000 Rank
T03	1	*Ampelisca* spp.	4358.0	2462.7	50.7	50.7	1	1	1
	2	*Aricidea catherinae*	944.0	161.0	11.0	61.7	2	4	5
	3	*Tubificoides apectinatus*	676.7	110.1	7.9	69.6	3	2	2
	4	*Crassicorophium bonnelli*	594.0	226.2	7.0	76.6	NP	6	13
	5	*Polydora cornuta*	412.7	211.9	4.8	81.4	7	7	3
	6	*Unciola irrorata*	259.7	11.2	3.0	84.4	22	12	9
	7	*Tharyx* spp.	224.7	12.2	2.6	87.0	6	11	7
	8	*Tubificoides* nr. *pseudogaster*	211.3	262.9	2.5	89.5	4	3	4
	9	*Leptocheirus pinguis*	199.0	53.6	2.3	91.8	28	10	10
	10	*Orchomenella minuta*	90.3	40.1	1.1	92.9	19	9	8
	11	*Photis pollex*	67.7	34.1	0.8	93.7	8	8	11
	11	*Dyopedos monacanthus*	67.7	57.1	0.8	94.5	29	22	NP
	12	*Phyllodoce mucosa*	58.3	22.9	0.7	95.2	12	11	17
	13	*Prionospio steenstrupi*	50.7	11.7	0.6	95.8	5	21	23
	14	*Ilyanassa trivittata*	35.7	22.1	0.4	96.2	11	13	12
	15	*Mediomastus californiensis*	35.0	9.5	0.4	96.6	13	16	15
		(Total Good Species)	8590.1						
		(Total Station Density)	8667.6						
T04	1	*Streblospio benedicti*	241.3	124.6	76.3	76.3	1	1	1
	2	*Tharyx spp.*	24.0	11.5	7.6	83.9	2	5	5
	3	*Tubificoides* sp. 2	14.7	4.0	4.6	88.5	3	2	2
	4	*Polydora cornuta*	11.0	10.0	3.5	92.0	4	NP	NP
	5	*Micropthalmus pettiboneae*	6.3	7.5	2.0	94.0	NP	5	NP
	6	*Ilyanassa trivittata*	6.0	5.2	1.9	95.9	5	NP	3
	7	*Crangon septemspinosa*	5.7	2.5	1.8	97.7	6	4	4
	8	*Neanthes virens*	1.0	1.0	0.3	98.0	NP	NP	NP
	8	*Ampelisca* spp.	1.0	1.0	0.3	98.3	NP	NP	6
	9	Nemertea sp. 2	0.7	0.6	0.2	98.5	NP	NP	NP
	9	*Nephtys cornuta*	0.7	0.6	0.2	98.7	NP	NP	NP
	9	*Dipolydora socialis*	0.7	1.2	0.2	98.9	NP	NP	NP
	9	*Ensis directus*	0.7	0.5	0.2	99.1	7	NP	6
	9	*Neomysis americana*	0.7	0.5	0.2	99.3	7	4	5
	10	*Eteone longa*	0.3	0.6	0.1	99.4	NP	NP	NP
	10	*Nephtys caeca*	0.3	0.6	0.1	99.5	8	NP	NP
	10	*Spio setosa*	0.3	0.6	0.1	99.6	NP	NP	NP
	10	*Capitella capitata complex*	0.3	0.6	0.1	99.7	9	NP	NP
	10	*Crassicorophium bonnelli*	0.3	0.6	0.1	99.8	NP	NP	NP
	10	*Pagurus longicarpus*	0.3	0.6	0.1	99.9	6	NP	NP
		(Total Good Species)	316.4						
		(Total Station Density)	328.4						

NP = Not Present

Station	**Rank**	**Species**	**Mean**	**Std. Dev.**	**%**	**Cum %**	**2002 Rank**	**2001 Rank**	**2000 Rank**
T05A	1	*Ampelisca* spp.	9773.3	624.9	77.5	77.5	10	1	13
	2	*Unciola irrorata*	608.3	96.3	4.8	82.3	12	2	5
	3	*Photis pollex*	360.3	86.9	2.9	85.2	17	3	11
	4	*Orchomenella minuta*	266.7	71.4	2.1	87.3	14	4	NP
	5	*Dyopedos monacanthus*	256.7	27.5	2.0	89.3	31	33	NP
	6	*Tharyx* spp.	165.0	18.0	1.3	90.6	3	8	4
	7	*Edotia triloba*	161.3	38.1	1.3	91.9	13	13	13
	8	*Phyllodoce mucosa*	161.0	118.4	1.3	93.2	18	5	14
	9	*Tubificoides apectinatus*	148.7	33.6	1.2	94.4	1	9	8
	10	*Leptocheirus pinguis*	143.3	38.9	1.1	95.5	28	10	NP
	11	*Nephtys ciliata*	57.0	20.0	0.5	96.0	5	41	19
	12	*Spiophanes bombyx*	51.0	4.4	0.4	96.4	2	15	1
	13	*Polydora cornuta*	38.3	3.2	0.3	96.7	19	16	6
	14	*Amphiporus cruentatus*	38.0	10.8	0.3	97.0	31	33	NP
	15	*Hiatella arctica*	33.3	13.3	0.3	97.3	NP	19	NP
		(Total Good Species)	12606.3						
		(Total Station Density)	12676.5						
T06	1	*Ampelisca* spp.	5694.7	194.6	63.2	63.2	4	1	1
	2	*Aricidea catherinae*	983.7	339.1	10.9	74.1	2	4	7
	3	*Tubificoides* nr. *pseudogaster*	728.0	180.4	8.1	82.2	1	2	2
	4	*Tubificoides apectinatus*	360.3	5438	4.0	86.2	3	5	5
	5	*Photis pollex*	247.7	43.7	2.7	88.9	8	3	6
	6	*Prionospio steenstrupi*	171.7	15.9	2.0	90.9	6	26	20
	7	*Unciola irrorata*	135.0	63.5	1.5	92.4	16	11	10
	8	*Phyllodoce mucosa*	100.3	13.6	1.1	93.5	9	8	18
	9	*Mediomastus californiensis*	92.3	20.5	1.0	94.5	11	23	15
	10	*Polydora cornuta*	87.3	31.8	1.0	95.5	5	12	3
	11	*Phoronis architecta*	59.7	13.4	0.7	96.2	22	34	NP
	12	*Nucula delphinodonta*	52.7	4.5	0.6	96.8	7	13	12
	13	*Crassicorophium bonnelli*	40.0	11.1	0.4	97.2	NP	9	8
	14	*Capitella capitata complex*	16.0	3.6	0.2	97.4	16	29	19
	15	*Phoxocephalus holbolli*	15.3	8.6	0.2	97.6	10	6	4
		(Total Good Species)	9013.1						
		(Total Station Density)	9450.1						

NP = Not Present

Station	Rank	Species	Mean	Std. Dev.	%	Cum %	2002 Rank	2001 Rank	2000 Rank
T07	1	*Ampelisca* spp.	1091.3	150.9	34.9	34.9	8	6	9
	2	*Aricidea catherinae*	664.7	119.5	21.2	56.1	1	1	2
	3	*Tubificoides apectinatus*	435.3	36.4	13.9	70.0	2	2	1
	4	*Leptocheirus pinguis*	223.3	63.5	7.1	77.1	9	4	NP
	5	*Polydora cornuta*	207.0	65.0	6.6	83.7	4	3	3
	6	*Unciola irrorata*	142.3	43.4	4.5	88.2	15	9	22
	7	*Nephtys cornuta*	69.7	12.4	2.2	90.4	6	7	7
	8	*Tubificoides* nr. *pseudogaster*	60.0	32.9	1.9	92.3	3	10	10
	9	*Scoletoma hebes*	55.3	9.2	1.8	94.1	5	8	8
	10	*Mediomastus californiensis*	24.0	8.9	0.8	94.9	10	13	11
	11	*Phyllodoce mucosa*	21.0	5.6	0.7	95.6	20	18	NP
	12	*Ilyanassa trivittata*	14.3	5.1	0.5	96.1	13	14	16
	13	*Tharyx* spp.	12.7	3.8	0.4	96.5	9	5	6
	14	*Crassicorophium bonnelli*	9.3	6.4	0.3	96.8	NP	NP	NP
	15	*Streblospio benedicti*	8.7	4.6	0.3	97.1	7	17	5
		(Total Good Species)	3131.1						
		(Total Station Density)	3355.7						
T08	1	*Ampelisca* spp.	1310.7	542.3	52.4	52.4	2	4	2
	2	*Spiophanes bombyx*	165.3	17.7	6.6	59.0	1	2	1
	3	*Leptocheirus pinguis*	154.0	52.4	6.2	65.2	19	14	24
	4	*Aricidea catherinae*	123.0	38.0	4.9	70.1	3	1	7
	5	*Exogone hebes*	114.7	66.2	4.6	74.7	6	6	4
	6	*Nucula delphinodonta*	52.0	31.8	2.1	76.8	4	13	8
	7	*Crassicorophium bonnelli*	49.3	7.6	2.0	78.8	30	18	26
	8	*Tubificoides* nr. *pseudogaster*	41.3	36.9	1.7	80.5	5	10	9
	9	*Molgula manhattensis*	38.3	7.1	1.5	82.0	21	8	21
	10	*Tharyx* spp.	36.0	7.0	1.4	83.4	13	7	14
	11	*Phyllodoce mucosa*	35.7	23.9	1.4	84.8	9	21	15
	12	*Polygordius* sp. A	34.0	6.1	1.4	86.2	13	3	3
	13	*Phoronis architecta*	31.7	22.7	1.3	87.5	27	28	25
	14	*Prionospio steenstrupi*	28.3	20.7	1.1	88.6	10	20	17
	15	*Ilyanassa trivittata*	26.0	14.5	1.0	89.6	7	9	6
		(Total Good Species)	2499.6						
		(Total Station Density)	2764.2						

NP = Not Present

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