2001 harbor benthic monitoring report

Massachusetts Water Resources Authority

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2001 HARBOR BENTHIC MONITORING REPORT

submitted to

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EXECUTIVE SUMMARY

MWRA began its studies of the infaunal communities and benthic habitats in Boston Harbor in 1989 and initiated the ongoing studies of infaunal communities in 1991, just prior to the cessation of sludge dumping into the Harbor. The principal aim of the Harbor studies is documentation of continuing recovery of benthic communities in areas of Boston Harbor as improvements are made to the quality of wastewater discharges. Briefly, these can be listed as the

- Repairs and upgrades to Deer Island Treatment Plant; cessation of scum discharge into the Harbor—December 1988,
- cessation of sludge discharge into the Harbor—December 1991,
- operation of a new primary treatment facility at Deer Island—January 1995,
- initiation of secondary treatment (first battery)—August, 1997,
- continuation of secondary treatment implementation (second battery)—March 1998,
- cessation of effluent discharge from Nut Island—July 1998
- transfer of effluent offshore—September 2000, and
- completion of the implementation of secondary treatment—March 2001.

Recent reports have indicated that some observed infaunal community changes are consistent with those expected with habitat improvements that have resulted from the changes in discharges into the Harbor (Kropp and Diaz 1995, Hilbig *et al.* 1996, Blake *et al.* 1998, Kropp *et al.* 2002). Among the changes reported in these studies, the increase in species numbers and diversity has been the most dramatic. The increase in the abundance and geographic distribution of the tube-dwelling amphipod *Ampelisca* that occurred soon after the cessation of sludge discharge, and the gradual decline in importance of the polychaete *Streblospio benedicti* are also notable.

Most recently, significant improvements in water quality in the Harbor were detected within the first 12 months following diversion of effluent from the Deer Island outfall to the Massachusetts Bay outfall (Taylor 2002). Taylor reported improved conditions relevant to eutrophication, water clarity, and sewerage-indicator bacteria. Among the 21 parameters measured, only total suspended solids did not show improvement after effluent diversion. As water quality conditions in the Harbor continue to improve, it will be of interest to see if and how these improvements translate to changes in the benthos.

The Boston Harbor benthic monitoring program includes three components. Sediment profile images (SPI) are collected during the late summer to monitor the general condition of the soft-bottom benthic habitats in the Harbor. Sediment geochemistry studies, conducted via the collection of sediment grab samples from Traditional stations in April and August, consist of grain-size analysis and total organic carbon (TOC) content determination. The presence of a sewage tracer, *Clostridium perfringens*, also is quantified during these studies. The 2000 studies included 16 grain-size, TOC, and *Clostridium* samples. Infaunal communities in Boston harbor are monitored via the collection of samples from eight Traditional stations. All stations were visited in 2000, although one infaunal sample (station T03, sampled in August) was lost. Summaries of the 2000 results from these studies and overall programmatic trends follow.

Sediment Profile Images

Conditions at the harbor SPI stations for 2001 reflected a continuation of the predominance of biological processes in structuring surface sediments. Bed roughness in 2001 was consistent with a continuation of biological processes dominating over physical processes. The sediment surface at 53% of the stations appeared to be dominated by biogenic structures such as tubes, feeding pits, and defecation mounds. Physical processes, as indicated by coarse-grained sediment or soft deep penetration sediments, appeared to structure the sediment surface at 26% of the stations. The remaining 21% were intermediate showing signs of both physical and biological processes.

The areal distribution of *Ampelisca* spp. tube mats at the 60 long-term stations appeared to increase for the first time since 1995. At the same time, the occurrence of epifaunal organisms was lower in 2001 relative to 2000. Although the occurrence of large infauna was more prevalent in the 2000 SPI images relative to 2001, overall biogenic activity appeared to be higher in 2001, as seen in the increased number of oxic voids, deeper RPD layer depths, and more advanced successional stage estimates. The increase in the average depth of the apparent color RPD layer from 2000 to 2001 was >1 cm at more than half of the stations sampled. The RPD declined by >1 cm at only three stations in 2001.

Benthic habitat quality, as measured by the OSI, increased a most stations in 2001. Overall, the grand mean OSI was higher in 2001 than in 2000. Sediment at station T04, which has historically shown the poorest habitat quality and community structure, appeared to be oxic with a few gas voids and had an apparent color RPD layer of 1.1 cm. The OSI at T04 was slightly higher in 2001 relative to 2000.

Overall, the harbor SPI data for 2001 continued to show the influence of biological processes in structuring surface sediments. Physical features such as bedforms were absent, while macrobenthic tubes and other biogenic structures occurred at almost all stations. Surface biogenic structures were absent at only two stations sampled in 2001. While the distribution of sediment textures in the harbor was related primarily to a combination of sources (geomorphology and hydrodynamics), surface features continued to be dominated by biogenic activity.

Sediment Chemistry

Grain size – Patterns in sediment grain size composition in 2001 were within ranges observed during previous years, suggesting that the spatial and temporal characteristics of sediment grain size in 2001 were not substantially different from previous years (1991–2000). Patterns in sediment composition between April and August surveys were similar across all common sampling years.

In general, grain size and total organic carbon (TOC) was strongly correlated across all sampling years, indicating that grain size and TOC did not change much over time.

TOC – The spatial and temporal distribution of TOC concentrations during April and August surveys in 2001 was also not substantially different from 1991-2000 because of the high variability in the historical dataset.

There were no clear year-to-year trends in TOC between April and August surveys over time. However, an evaluation of TOC results derived from the benthic Flux and Traditional Harbor surveys did show a characteristic seasonal peak in TOC in May, indicative of inputs to the system from a winter/spring bloom. TOC values also showed a trend toward decreasing concentrations between July and October, likely reflecting TOC burn-off. More importantly, the seasonal peak in carbon content to the system cannot be measured from the Traditional Harbor surveys given that the peak does not occur until May and the Traditional Harbor surveys only occur in April and August.

Clostridium – Variability in *Clostridium perfringens* concentrations appeared to decrease over time and between 1998 and 2001 the system seemed to be more stable. In addition, the overall abundance of *Clostridium perfringens* spores appeared to decrease since 1998, suggesting that *Clostridium perfringens* has shown a response to facility improvements implemented to clean-up Boston Harbor (*e.g.,* secondary treatment and the cessation of Nut Island discharges), demonstrating that *Clostridium perfringens* have served as a good tracer.

The correspondence between *Clostridium perfringens* and bulk sediment properties was stronger after 1998, suggesting that the factors controlling the variability (*i.e.,* percent fines, TOC) are more closely coupled after implementation of facility improvements. In addition, the correspondence between *Clostridium perfringens* and bulk sediment properties was generally equally strong between April and August surveys (T04 excluded from correlation).

Infaunal Communities

With only two exceptions, infaunal abundance in summer surveys increased consistently between September 1991 and August 1997. Samples from the summer of 1996 were the major exception to this pattern. The Summer 1997 value represented a seven-fold overall increase in abundance in the Harbor since 1991. Examination of the data sequentially, i.e., season-by-season, yields the interpretation that the spring 1996 values decreased compared to the summer 1995 values, as was the typical pattern for the Harbor community then. However, what was unusual was the failure, by whatever mechanism, of the typical summer community to "recruit" to the Harbor. Average abundance per sample in Summer 1996 was only slightly higher than it was in Spring 1996; species numbers were actually lower. Although this observation was significant enough that it was reflected in pooled data for the Harbor, it was restricted primarily to stations in the northern portion of the harbor (stations T01, T02, and T05A). When pooled data for those three stations are compared to pooled data for stations T03, T06, and T08 in the southern harbor, it is clear that the low summer 1996 numbers were not a Harbor-wide phenomenon. When abundance values since 1994 for the three most abundant species at stations T01, T02, and T05A (*Ampelisca* spp. *Polydora cornuta*, *Streblospio benedicti*) are plotted (Figure 5-5c), it becomes clear that their low recruitment contributed strongly to the low total abundances at these stations in 1996, 1999, and 2000.

Species numbers in Spring 2001 were the highest values for that season recorded during the monitoring program and continued the trend for increasing species numbers in Spring samples. Spring species numbers per sample have increased about 159% since 1992. Also, within the last two to three years the differences between Spring and Summer species numbers have been small. The net effect of these patterns is that from 1992 to 1995 there were considerable differences in the species numbers per sample between Spring and Summer with Summer values being higher. Since then, with the exception of 1998, these differences have been much less distinct. Log-series alpha values for each season in 2001 were the highest observed during the Harbor monitoring. Each set of seasonal values indicates that species diversity has increased noticeably during the duration of the study.

Infaunal communities patterns from 1991 to 2001, as determined by multivariate analyses, were primarily the result of strong within-station similarity, with temporal trends being of secondary importance. Two main grouping of stations emerged, one comprised of stations T01, T02, T04, and T05, and one consisting of stations T03, T05A, T06, T07, and T08. At the ten-group level, three stations formed exclusive groups; Station T04 in inner Dorchester Bay, T08 in Hingham Bay, and T05A in President Roads. There were also three exclusive seasonal groups; summer conditions at Station T04 clustered together for 9 of the 11 years, summer conditions at Station T05A were linked for 5 of the 9 years that station was sampled, spring 2000 and 2001 for stations T01 and T02 comprised the same cluster.

Over the 11-year period, Stations T01, T02, T03, T06, T07, and T08 maintained a high degree of within station similarity with most of the spring and summer collections within the same cluster group. Stations T04 and T05A were the most variable through time with collection periods spread over four and three groups, respectively. Any disturbance of infaunal communities by the major environmental events that occurred near the initiation of the T-station monitoring in 1991, the October severe storm and December sewage discharge abatement at the inner harbor outfall, was not obvious. Cluster analysis and community structure analyses indicated that infauna at the T-stations was not dominated by temporal trends.

Conclusions

The observed changes in the Harbor's infaunal communities, coupled with data from SPI studies, provide good evidence for improvement in benthic habitat conditions in the Harbor since the cessation of sludge discharge in 1991. The most substantial changes in the Harbor's benthos probably occurred within the first two to three years after sludge discharge ended. Among these were the sudden increase in abundance and geographic spread of the amphipod *Ampelisca* spp, and the general increase in infaunal abundance and species numbers that occurred after 1991. Recently, some data indicate that the harbor infaunal communities are in transition from those that appeared in the early to mid 1990s to those more likely to be found in a less-polluted Harbor. These communities are still likely to respond to occasional events, whether a physical disturbance or a biological phenomenon such as an occasional failure of some species to recruit to the Harbor.

1.0 INTRODUCTION

1.1 Program Background

MWRA began its studies of the infaunal communities and benthic habitats in Boston Harbor in 1991, just prior to the cessation of sludge dumping into the Harbor. The principal aim of the Harbor studies is documentation of continuing recovery of benthic communities in areas of Boston Harbor as improvements are made to the quality of wastewater discharges. Blake *et al.* (1998) and Werme and Hunt (2000) have summarized past and future changes in discharges into Boston Harbor. They are also listed on the MWRA web site (http://www.mwra.state.ma.us/harbor/html/soh2002_bhp.htm). Briefly, these can be listed as the

- Repairs and upgrades to Deer Island Treatment Plant; cessation of scum discharge into the Harbor—December 1988,
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Results from the 2001 harbor benthic surveys, presented in this report, represent the first data from the harbor after the diversion of effluent to the new ocean outfall on September 6, 2000.

1.2 Overview of this Report

The Boston Harbor benthic monitoring program includes three components. Sediment profile images (SPI) are collected during the late summer to monitor the general condition of the soft-bottom benthic habitats in the Harbor. In this report, the analyses of the SPI that were collected from 60 Harbor Traditional and Reconnaissance stations are presented in Section 3. Sediment geochemistry studies, conducted via the collection of sediment grab samples from Traditional stations in April and August, consist of grain-size analysis and total organic carbon (TOC) content determination. The presence of a sewage tracer, *Clostridium perfringens*, also is quantified during these studies. 2001 studies included 16 grain-size, TOC, and *Clostridium* samples from 8 stations. These analytical results are presented in Section 4. Infaunal communities in Boston harbor are monitored via the collection of samples from eight Traditional stations. All stations were visited twice in 2001. Analyses of the infaunal communities are described in Section 5. Each section also includes a programmatic evaluation.

The raw data generated for all of these studies are available from MWRA.

2.0 FIELD OPERATIONS

by Jeanine D. Boyle

2.1 Sampling Design

The Harbor Benthic Surveys provide the benthic samples and other data required to document long-term improvement of sediment quality and resulting recovery of the benthic communities in Boston Harbor following the cessation of sludge and effluent discharge into the Harbor. Data from an extensive reconnaissance survey using sediment profile images (SPI) supplements and extends traditional infaunal data to provide a large-scale picture of benthic conditions in the Harbor. This expanded coverage is particularly important because conditions are rapidly improving over a broader expanse of the Harbor as secondary treatment is implemented and effluent discharge is diverted to the offshore outfall.

2.1.1 Traditional

During the Harbor traditional surveys, conducted late April and mid August 2001, soft-sediment grab samples were collected from eight sampling locations (Figure 2-1). These "traditional" stations were selected after consideration of historic sampling sites and Harbor circulation patterns (Kelly and Kropp 1992). Samples were collected from these traditional stations for analysis of selected physical sediment parameters and sewage tracers, and for benthic infaunal community parameters. The actual locations of all Boston Harbor grab samples collected in 2001 are listed in Appendix A-1.

2.1.2 Reconnaissance

To provide for greater geographic coverage of benthic community recovery, a Harbor reconnaissance survey was conducted during August 2001. Sediment profile images (SPI) were obtained at the 52 "reconnaissance" stations, and the 8 'traditional" stations (Figure 2-1). The actual locations of all Boston Harbor sediment profile images collected in 2001 are listed in Appendix A-2.

2.2 Surveys/Samples Collected

The dates of the Boston Harbor Traditional and Reconnaissance surveys and the numbers of samples collected on them are listed in Table 2-1.

Table 2-1. Survey dates and numbers of samples collected on Boston Harbor benthic surveys in 2001.

Survey	ID	Date(s)	Samples Collected				
			Inf	TOC	gs	Cp	SPI
April Harbor Benthic	HT011	April 25, 2001	24	8	8	8	–
August Harbor Benthic	HT012	August 14 and 18, 2001	24	8	8	8	–
SPI	HR011	August 20, 21, 22, 2001	–	–	–	–	375

Key:

Inf, Infauna	Cp, *Clostridium perfringens*
TOC, total organic carbon	SPI, sediment profile images (slides)
Gs, grain size	

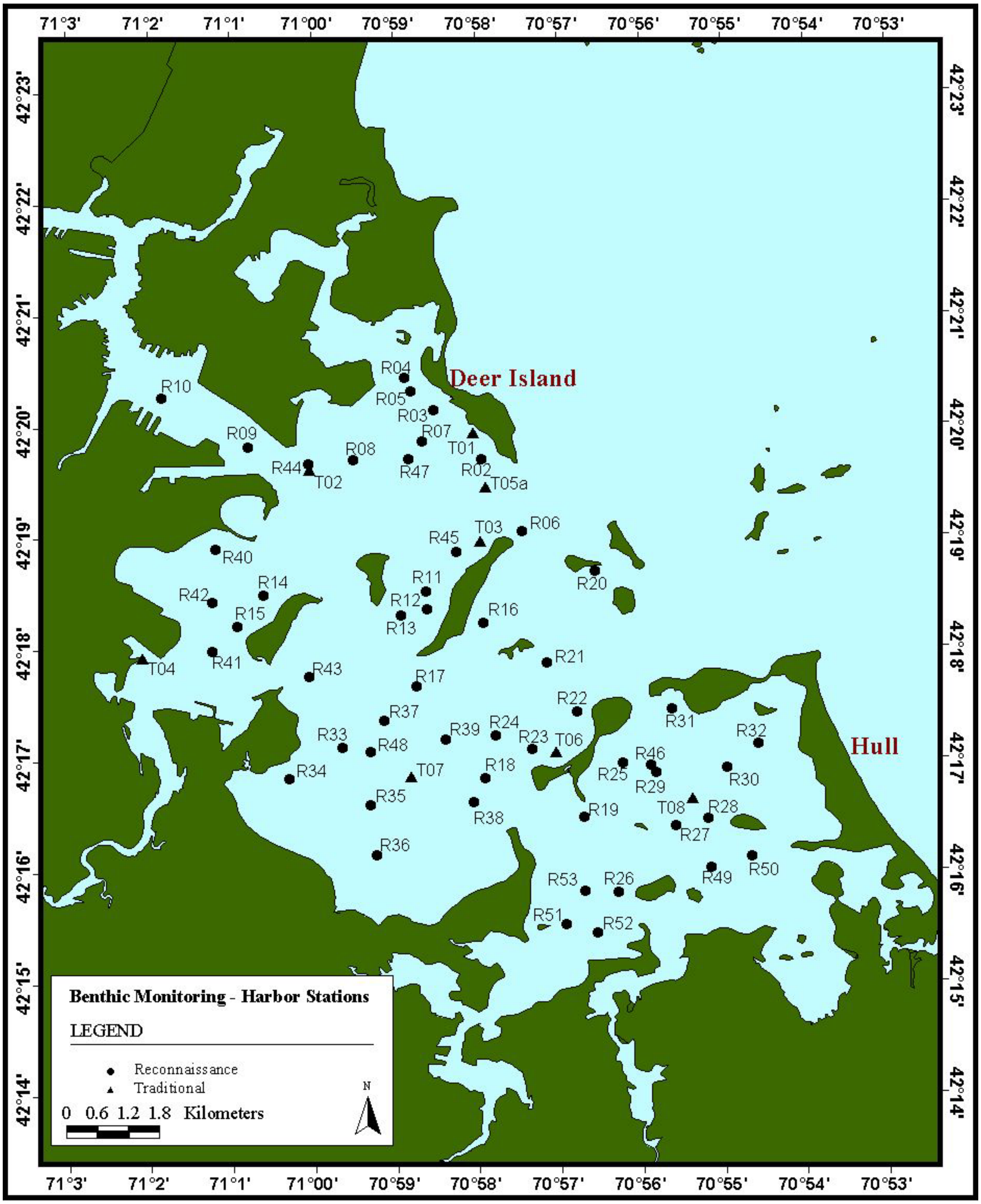


Figure 2-1. Target Locations of Boston Harbor Traditional and Reconnaissance stations.

2.3 Field Methods Overview

The following is a brief overview of the methods and protocols used on the benthic surveys. More detailed descriptions of the methods are contained in the CW/QAPP (Kropp and Boyle 2001).

2.3.1 Vessel/Navigation

Vessel positioning during benthic sample operations was accomplished with the BOSS Navigation system. This system consists of a Northstar differential global positioning system (DGPS) interfaced to the on-board BOSS computer. Data were recorded and reduced using NAVSAM data acquisition software. The GPS receiver has six dedicated channels and is capable of locking into six satellites at one time. The system was calibrated with coordinates obtained from USGS 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 ID to each sample when the sampling instrument hit bottom. The display on the BOSS computer screen was set to show a radius of 30 m around the target station coordinates (6, 5-m rings) for all Boston Harbor benthic surveys. A station radius of up to 30 m is considered acceptable for sediment sampling in Boston Harbor.

2.3.2 Grab Sampling

At all eight Traditional stations, a 0.04-m^2 Ted Young-modified van Veen grab sampler was used to collect three replicate samples for infaunal analysis. One additional sample was collected for *Clostridium perfringens*, sediment grain size, and total organic carbon (TOC) analyses. Infaunal samples were sieved onboard over a 300-μm-mesh sieve and fixed in buffered formalin. The “chemistry” grab sample was skimmed off the top 2 cm of the grab using a Kynar-coated scoop, and was 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.

2.3.3 SPI

At each Reconnaissance and Traditional station, a Hulcher Model Minnie sediment profile camera fitted with a digital video camera was deployed three times. The profile camera was set to take two pictures, using Fujichrome 100P slide film, on each deployment at 2 and 12 seconds after bottom contact. In the event that sediments were soft the two-picture sequence ensured that the sediment-water interface would be photographed before the prism window became over penetrated. The combination of video and film cameras ensured accurate and reliable collection of sediment profile images. Any replicates that appeared to be disturbed during deployment were retaken. Dr. Diaz recorded the station, time, approximate prism penetration depth and a brief description of the substrate in the survey log. In addition, Oxidation-Reduction Potential Discontinuity (apparent RPD) was estimated at each nearfield station. Each touch down of the camera was marked as an event on the NAVSAM$^{©}$.

3.0 2001 SEDIMENT PROFILE CAMERA RECONNAISSANCE OF HARBOR BENTHIC HABITATS

by Robert Diaz

3.1 Materials and Methods

3.1.1 Field Methods

On 20, 21, 22 August 2001 the sediment profile survey of Boston Harbor stations was conducted. Three replicate Sediment Profile Images (SPI) were successfully collected at 53 long-term reconnaissance (R) and traditional (T) stations. Problems with the SPI camera resulted in only two replicate images at Stations R18, R33, R47, and T08; one replicate at T02; and no images at R34 and R35. The profile camera was set to take two pictures, using Fujichrome 100P slide film, on each deployment at 2 and 12 seconds after bottom contact.

3.1.2 Image Analysis

The images were digitized using a Nikon 2000 scanner and analyzed using the Adobe PhotoShop and NTIS Image programs. 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 Kropp *et al.* (2001).

At station T02 there was only one replicate image and only one of the three replicate images at stations R08, R19, and R23 had sufficient penetration to allow for estimation of the apparent color RPD layer depth. Thus for these stations any calculation that used the mean station RPD depth the single replicate value was used. Stations that had two of three replicates in the calculation of mean RPD were R06, R15, R18, R33, R47, R52 and T08. All other stations had three measured RPD layer depths.

3.2 Results and Discussion

3.2.1 2001 Harbor Image Data

One replicate image from each station is contained in the CD-ROM Appendix. Images were selected to show the range of physical and biological processes active in the Harbor area.

3.2.2 Physical Processes and Sediments

The predominant sediment type throughout the study area continued to be silty mud (modal Phi 8 to 5) and occurred at half (29 of 58) of the stations (Table 3-1). Silty fine sands and fine sandy silts occurred at 40% of the stations and were also broadly distributed within the harbor. The remaining 10% of the stations (6 of 58) ranged from sands (R08, R23, T08) to coarser gravel and pebbles (R06, R19). None of the stations appeared to have layered sediments. Pure sands and coarser sediments, indicative of high kinetic energy bottoms tended to occur toward the Outer Harbor. However, biogenic mixing dominated surface sediments and was able to obliterate physical features such as bedforms.

Table 3-1. Summary of sediment profile image data for Boston Harbor, August 2001.

Stat	Mean Pen	Mean Surface Relief	Mean RPD	Modal Grain-Size	Modal Bed Roughness	Modal Amphipod Tubes	Modal Worm Tubes	Mean Infauna	Mean Burrows	Mean Voids Oxic	Mean Voids Anaero.	Mean Voids Gas	Modal Succ. Stage	Mean OSI
R02	12.9	1.8	5.0	SI	BIO	MAT	SOME	2.3	4.3	2.3	2.7	0.0	II-III	10.0
R03	11.4	1.1	3.3	SIFS	BIO	SOME	SOME	4.7	7.3	3.7	0.3	0.0	II-III	9.0
R04	13.9	0.7	8.0	SI	BIO	MAT	SOME	3.3	4.3	7.0	1.3	0.0	II-III	10.0
R05	12.7	0.7	2.1	SI	BIO/PHY	SOME	MANY	1.7	4.0	1.0	1.7	0.0	I-II	5.7
R06	3.3	1.4	1.9	FSMSGRPB	PHY	NONE	MANY	0.0	0.0	0.0	0.0	0.0	I-II	5.0
R07	14.8	1.4	8.4	SI	BIO	MAT	NONE	2.0	8.0	5.3	0.3	0.0	II-III	10.0
R08	0.8	1.1	1.7	VFS	PHY	NONE	NONE	0.0	0.0	0.0	0.0	0.0	I	3.0
R09	10.6	0.8	2.4	SIFS	BIO	MAT	FEW	1.0	5.0	1.7	0.7	0.0	II-III	7.7
R10	18.7	1.2	1.8	SICL	PHY	NONE	FEW	0.3	2.0	0.0	2.0	0.0	I	3.7
R11	16.6	0.8	3.6	SI	BIO	MAT	NONE	2.0	5.0	1.3	2.7	0.3	II-III	8.3
R12	13.9	1.2	5.4	SI	BIO	MAT	NONE	1.3	4.3	2.3	1.0	0.0	II-III	9.0
R13	13.4	1.2	4.8	SI	BIO	MAT	SOME	0.7	6.7	5.0	1.3	0.0	II-III	10.0
R14	10.6	1.4	3.4	SIFS	BIO	MAT	FEW	1.0	5.7	2.3	0.7	0.0	II-III	9.0
R15	6.1	3.7	1.9	FSSI	PHY	NONE	SOME	0.3	1.0	0.0	0.0	0.0	I	3.5
R16	9.3	1.3	3.9	SIFS	BIO	MANY	SOME	0.7	3.3	4.0	0.7	0.0	II	8.7
R17	10.3	1.6	3.5	SIFS	PHY	NONE	SOME	0.7	1.0	0.0	0.0	0.0	I	4.7
R18	17.3	0.7	7.5	SI	BIO	MAT	FEW	1.5	6.0	5.5	1.0	1.5	II-III	9.0
R19	2.4	0.9	3.6	MSGRPB	PHY	NONE	SOME	0.0	0.0	0.0	0.0	0.0	I	4.7
R20	12.8	2.0	5.7	SI	BIO	MAT	FEW	1.7	5.3	1.7	1.3	0.0	II-III	10.0
R21	9.2	1.6	3.0	SIFS	BIO	MAT	SOME	3.7	7.0	1.3	0.0	0.0	II-III	8.7
R22	11.0	2.2	4.3	SIFS	BIO	MAT	SOME	0.3	6.3	1.3	0.0	0.0	II-III	10.0
R23	2.6	0.9	4.1	FSMS	BIO	MAT	MANY	0.0	0.7	0.0	0.0	0.0	I-II	5.3
R24	10.6	1.7	6.2	SI	BIO	MAT	SOME	3.3	4.0	3.3	0.0	0.0	II-III	10.0
R25	19.0	0.9	7.1	SICL	BIO/PHY	NONE	SOME	0.0	6.3	4.7	1.0	0.0	I-II	8.0
R26	14.0	0.9	1.3	SI	BIO/PHY	NONE	SOME	0.0	1.3	0.3	2.0	0.0	I	3.3
R27	15.6	1.9	4.4	SI	BIO/PHY	MAT	SOME	3.7	5.0	4.0	0.3	0.0	II-III	8.7
R28	15.5	1.4	8.3	SI	BIO	MAT	NONE	3.0	5.3	0.7	0.0	0.0	II-III	10.0
R29	16.3	1.6	4.5	SI	BIO	MAT	SOME	2.7	3.0	2.0	1.0	0.0	II-III	8.7
R30	9.9	0.9	2.1	SIFS	BIO	MAT	FEW	1.7	6.0	2.0	0.0	0.0	II	6.0
R31	15.1	0.9	6.5	SI	BIO	MAT	SOME	1.7	2.7	1.3	0.0	0.0	II-III	10.0
R32	11.9	1.4	2.0	SI	BIO/PHY	MAT	SOME	1.0	8.3	3.0	0.7	0.0	II	6.0
R33	9.2	0.8	0.9	SI	PHY	NONE	SOME	0.0	3.5	0.0	0.0	0.0	I	3.0
R34	.	.	.	.	.	.	.	.	.	.	.	.	.	.
R35	.	.	.	.	.	.	.	.	.	.	.	.	.	.
R36	0.0	.	.	SAPB	PHY	.	.	.	.	.	.	.	.	.
R37	7.4	1.2	1.2	SIFSGR	BIO	NONE	MANY	0.7	3.3	0.0	0.0	0.0	I	3.0
R38	16.0	0.7	4.3	SI	BIO	MAT	NONE	1.0	4.3	3.0	0.7	0.0	II-III	9.7
R39	10.9	0.8	6.1	SI	BIO	SOME	MANY	1.7	3.3	5.3	0.0	0.0	II-III	10.0
R40	8.8	2.5	1.2	SIFS	BIO/PHY	MANY	SOME	1.7	5.0	1.3	0.3	0.0	I-II	4.0
R41	7.4	1.1	1.0	SIFS	BIO/PHY	SOME	SOME	0.3	4.3	0.0	0.3	0.0	I-II	3.7
R42	7.7	0.7	1.0	FSSI	PHY	NONE	SOME	0.0	2.3	0.0	0.0	0.0	I	3.0
R43	13.0	0.6	0.7	SI	PHY	NONE	SOME	0.0	4.0	0.0	1.7	0.0	I	2.5
R44	14.4	2.1	2.9	SI	BIO	MAT	FEW	0.7	7.3	3.3	2.0	0.0	II	7.3

Table 3-1. Summary of sediment profile image data for Boston Harbor, August 2001 (continued)

Stat	Mean Pen	Mean Surface Relief	Mean RPD	Modal Grain-Size	Modal Bed Roughness	Modal Amphipod Tubes	Modal Worm Tubes	Mean Infauna	Mean Burrows	Mean Voids Oxic	Mean Voids Anaero.	Mean Voids Gas	Modal Succ. Stage	Mean OSI
R45	18.1	1.6	5.8	SI	BIO	MAT	FEW	1.7	3.3	1.0	2.0	0.0	II-III	10.0
R46	18.5	1.4	6.0	SI	BIO	MAT	FEW	1.0	2.7	2.0	1.0	0.0	II-III	10.0
R47	11.3	1.0	1.4	SI	BIO	MAT	FEW	2.5	5.0	2.5	1.0	0.0	II	5.5
R48	8.4	2.7	2.0	SIFS	BIO/PHY	FEW	SOME	1.0	2.3	0.7	0.0	0.0	I-II	4.7
R49	11.2	1.2	2.2	SIFS	BIO/PHY	NONE	MANY	0.3	3.0	1.7	0.0	0.0	I-II	5.3
R50	10.4	0.7	2.4	SIFS	BIO/PHY	NONE	MANY	3.0	2.7	1.3	0.0	0.0	I-II	5.3
R51	11.1	0.7	1.2	SIFS	PHY	NONE	SOME	0.0	5.0	1.0	0.3	0.0	I-II	3.3
R52	7.9	2.1	1.1	SIFS	PHY	NONE	SOME	0.0	3.5	0.0	0.0	0.0	I	3.0
R53	7.2	1.3	1.7	FSSI	PHY	NONE	FEW	0.0	3.7	0.3	0.0	0.0	I-II	4.0
T01	8.6	1.2	2.1	FSSI	PHY	NONE	SOME	0.7	4.7	1.3	0.0	0.0	I-II	4.7
T02	8.0	0.7	1.7	SIFS	BIO	MANY	SOME	0.0	7.0	1.0	0.0	0.0	I-II	5.0
T03	11.6	1.7	4.0	SI	BIO	MAT	NONE	1.3	3.7	1.0	0.7	0.0	II-III	9.0
T04	19.1	0.6	1.1	SICL	PHY	NONE	FEW	0.0	0.3	0.0	1.3	1.3	I	2.7
T05A	6.2	3.6	2.8	FSMSSI	BIO	MAT	NONE	0.7	1.7	1.3	0.0	0.0	II	7.0
T06	9.7	1.4	4.4	SI	BIO	MAT	NONE	1.3	5.0	2.3	0.0	0.0	II	9.0
T07	7.8	0.6	2.6	SIFS	BIO/PHY	MANY	SOME	0.0	3.0	3.7	0.0	0.0	I-II	5.7
T08	3.3	1.8	2.9	FSMS	BIO/PHY	MAT	SOME	0.0	0.0	0.0	0.0	0.0	I-II	6.0

Grain-Size: FS = Fine-sand SA = Sand GR = Gravel
SICL = Silty-clay FSSI = Fine-sandy-silt SIFS = Silty-fine-sand
MS = Medium-sand SI = Silt PB = Pebble
VFS = Very-fine-sand

Dominant Process:
BIOLG = Biological processes dominate surface sedimentary features
BIO/PHY = Both biological and physical processes shape surface features
PHYS = Physical processes dominate surface sedimentary features

Ampelisca, Infauna:
NONE = 0 FEW = 1-6 SOME = 7-18 MANY = >18
MAT = Density high enough to completely cover the surface

Successional Stage
I = Pioneering sere II = Intermediate sere III = Equilibrium sere
OSI = Organism Sediment Index of Rhoads and Germano (1986)

The broad range of sedimentary habitats within the Harbor was also reflected in the range of average station prism penetration, which ranged from 0.0 cm at compact sand Station R36 in Quincy Bay to 19.1 cm at soft muddy T04 in inner Dorchester Bay. Overall, prism penetration was lowest (2.7±0.8 cm, mean±SE, N = 7) in coarser sediments that were sand, gravel, or pebble and highest (12.1±0.5 cm, N = 51) in sediments with a significant silt component. The bed roughness or surface relief was the same magnitude at stations that appeared to be dominated by physical or biological processes (Table 3-1).

Surface relief averaged 1.3±0.2 cm (±SE) at physically-dominated stations, 1.3±0.1 cm at biologically-dominated stations, and 1.4±0.2 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, 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.

3.2.3 Apparent Color RPD Layer Depth

The grand average depth of the apparent color redox potential discontinuity (RPD) layer for 2001 was 3.4±2.1 (±SD), with a range from 0.7 cm at station R43 to 8.4 cm at station R07 (Table 3-1). Stations with shallower RPD layer depths tended to be closest to the shore along the mainland and furthest from the mouth of the Harbor. 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 R33 in outer Quincy 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 all harbor stations (see Section 5). Organic content of sediment at T04 was also highest of all stations (see Section 4). The organic loading and periodic low dissolved oxygen that likely eliminated deep bioturbating fauna contributed to the shallow RPD layer depth at T04. Stations with deeper RPD values (>3.0 cm) also consisted of silty sediments but tended to be close to the mouth of the Harbor and away from the mainland. Surface sediments at these deeper RPD layer stations were dominated by biological processes and characterized by a high degree of bioturbation. For example, Stations R28 and R07 in Hull Bay, with dense *Ampelisca* spp. tube mats and a well-developed infaunal communities, had the deepest RPD layer depths (Table 3-1).

Ampelisca spp. were the primary bioturbating organisms responsible for the deeper RPD layer depths. They occurred at 39 stations (67%) in silty fine sand and silty sediments and formed tube mats in at least one replicate image at 29 stations (50%) 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 (4.6±0.3 cm, mean±SE) than at stations with *Ampelisca* spp. but not at mat densities (2.7±0.6 cm) and without *Ampelisca* spp. (2.0±0.4 cm) (ANOVA, $p = <0.0001$). This indicated the importance of Ampeliscid mats in the irrigation of surface sediments and advancing community succession. It appeared that the *Ampelisca* spp. population in the harbor expanded station coverage in 2001, with a half of stations having tube mats (Table 3-1). This is higher than the lows of about 33% found in 2000 and about 40% in 1998 and 1999, but short of the 60% of stations where mats were observed from 1995 to 1997 (Figure 3-1).

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 well below the depth of the average RPD layer. The maximum extent of oxic sediments exceeded 10 cm at 15 stations. The deepest penetration of apparent oxic sediments was 17.4 cm at Station R18 in inner Nantasket Road. These deep oxic sediments were evidence of a large, deep-burrowing infaunal assemblage. For example, tentacles from several large (>1 cm diameter) terrebellid-like worms were present in replicates 2 and 3 of Station R07 on Deer Island Flats.

3.2.4 Biogenic Activity

The sediment surface at 53% (31 of 58) of the stations was dominated by biological processes as evidenced by the widespread biogenic activity associated with successional Stage II and III fauna (Table 3-1). Evidence that a combination of biological and physical processes was active in structuring bed roughness occurred at 21% (12) of the stations. Physical processes dominated at 26% (15) of the stations with three stations (R06, R19 and R36) having coarse sediments and the rest finer sediments with little indication of biological activity.

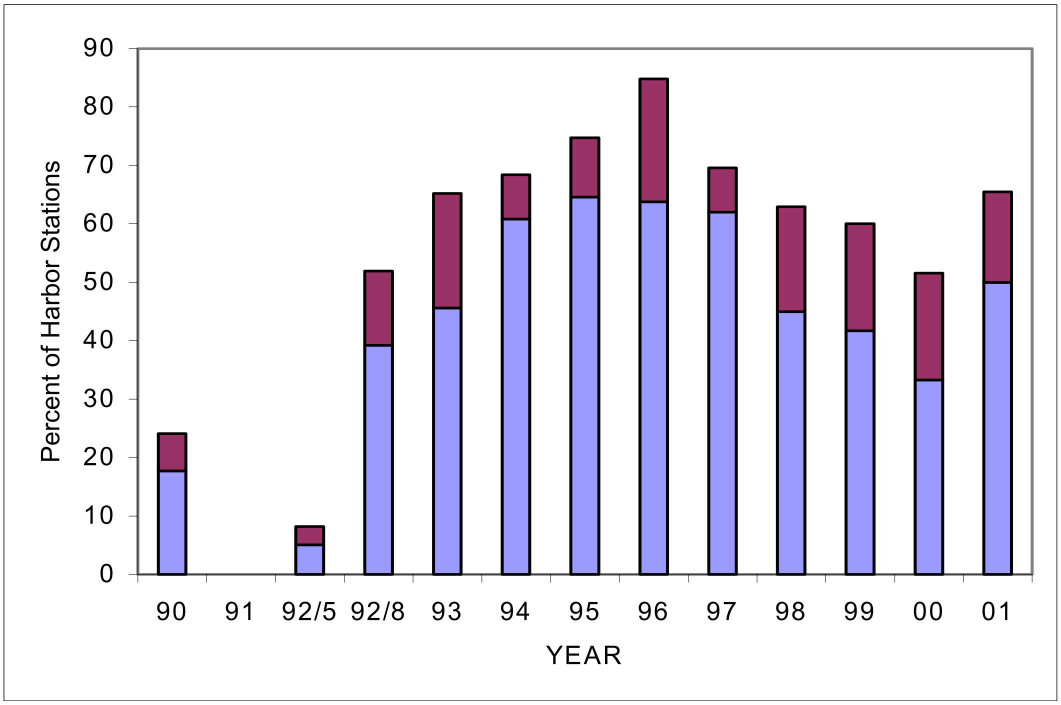


Figure 3-1. Percentage of harbor stations at which Ampelisca spp. were present. The lower portion of the bar represents the presence of tube mats.

Subsurface biogenic structures and activities were also highest at stations where biological processes dominated surface features. For example, the number of infaunal organisms per image was significantly higher at stations with *Ampelisca* spp., both tube mats (mean of 1.8±0.2 infauna/image, ±SE) and non-mat densities (1.3±0.3 infauna/image), than at stations without *Ampelisca* spp. (0.4±0.2 infaunal/image) (ANOVA, controlling for sediment type, $p = 0.0002$). The highest number of infauna was seen at Station R03 on Deer Island Flats where the average was 4.7 infauna/image. Similar patterns of higher mean and median values at biologically-dominated stations were observed for number of burrows, oxic voids and anaerobic voids per image, and also the Organism Sediment Index.

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 because of the correlation with the presence of *Ampelisca* spp. tubes. Burrows were seen at 93% of all stations with a grand average of 3.9±2.1 burrows/image (±SD). Infauna occurred at 72% of all stations (1.2±1.2 infaunal/image) and were more abundant in finer sediments than in coarser sediments. Gas-filled voids, indicative of high rates of organic loading to the sediments, occurred at three stations (T04, R11, and R18). Water-filled voids occurred at 81% of all stations with a distribution pattern similar to burrows and infauna (Table 3-1). Water-filled voids are biogenic structures typically created by larger infauna. The ratio of oxic voids (apparently filled with oxidized sediment indicating current or recent infaunal activity) to anaerobic voids (apparently relic voids from previous infaunal activity or created by some physical processes such as sediment cracking during profiling of the sediment) increased in 2001 to about 3:1. In 2000 the oxic to anaerobic void ratio was about 1:1. The increase in oxic voids points to an increase in the biogenic activity of larger subsurface deposit feeders. In 2001, oxic voids occurred at 42 stations (74%) and anaerobic voids at 30 stations (53%).

3.2.5 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 station (45 or 57) was consistent with Stage II communities, with indicators of Stage III communities observed at 23 stations. Evidence of Stage I communities occurred at 47% (27 of 57) of the stations with 12 of these stations having only signs of Stage I and the other 15 signs of both Stage I and II communities. Stations R43 southeast of Thompson Island and T04 in inner Dorchester Bay with a Stage I designation had the poorest community structure of all stations (see section 5).

The range of the Organism Sediment Index (OSI) at harbor stations indicated a wide range of environmental conditions affected infaunal community development. OSI ranged from 2.5 to 10.0, with the lowest values occurring at fine-sediment stations that had little evidence of infaunal activity, for example stations R43 and T04 (Table 3-1). The highest OSI values were also at fine-sediment stations, but at those that had high levels of infaunal activity, for example stations R04 and T06. About half of the harbor stations (46%) 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 arched 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 (T) and Reconnaissance (R), is most likely a combination of physical processes such as hydrodynamics and sediment transport at coarse sediment stations (for example station R06) and high rates of sediment accumulation and organic enrichment at muddy stations (for example station T04).

3.3 2001 Harbor Summary

Conditions at the harbor SPI stations for 2001 reflected a continuation of the predominance of biological processes in structuring surface sediments. Bed roughness in 2001 was consistent with a continuation of biological processes dominating over physical processes. The sediment surface at 53% of the stations appeared to be dominated by biogenic structures such as tubes, feeding pits, and defecation mounds. Physical processes, as indicated by coarse-grained sediment or soft deep penetration sediments, appeared to structure the sediment surface at 26% of the stations. The remaining 21% were intermediate showing signs of both physical and biological processes.

The areal distribution of *Ampelisca* spp. tube mats at the 60 long-term stations appeared to increase for the first time since 1995. From 2000 to 2001, stations R17 and R50 lost tube mats and 11 stations gained mats. At 18 stations mats were present both years. The occurrence of epifaunal organisms was lower in 2001 relative to 2000. Large infauna also appeared to be more prevalent in the 2000 SPI images relative to 2001. However, overall biogenic activity appeared to be higher in 2001, as seen in the increased number of oxic voids, deeper RPD layer depths, and more advanced successional stage estimates, relative to 2000. The increase in the average depth of the apparent color RPD layer from 2000 to 2001 was >1 cm at 53% (31 or 58) of the stations. The RPD declined by >1 cm at only three stations in 2001.

Benthic habitat quality, as measured by the OSI, increased at most stations in 2001. Overall, the grand mean OSI between 2000 and 2001 was higher in 2001, 4.9 vs. 6.7. Sediment at station T04, which consistently had the poorest habitat quality and community structure, appeared to be oxic with a few gas voids and an apparent color RPD layer of 1.1 cm. The OSI at T04 was slightly higher in 2001 relative to 2000, 2.7 vs. 1.3.

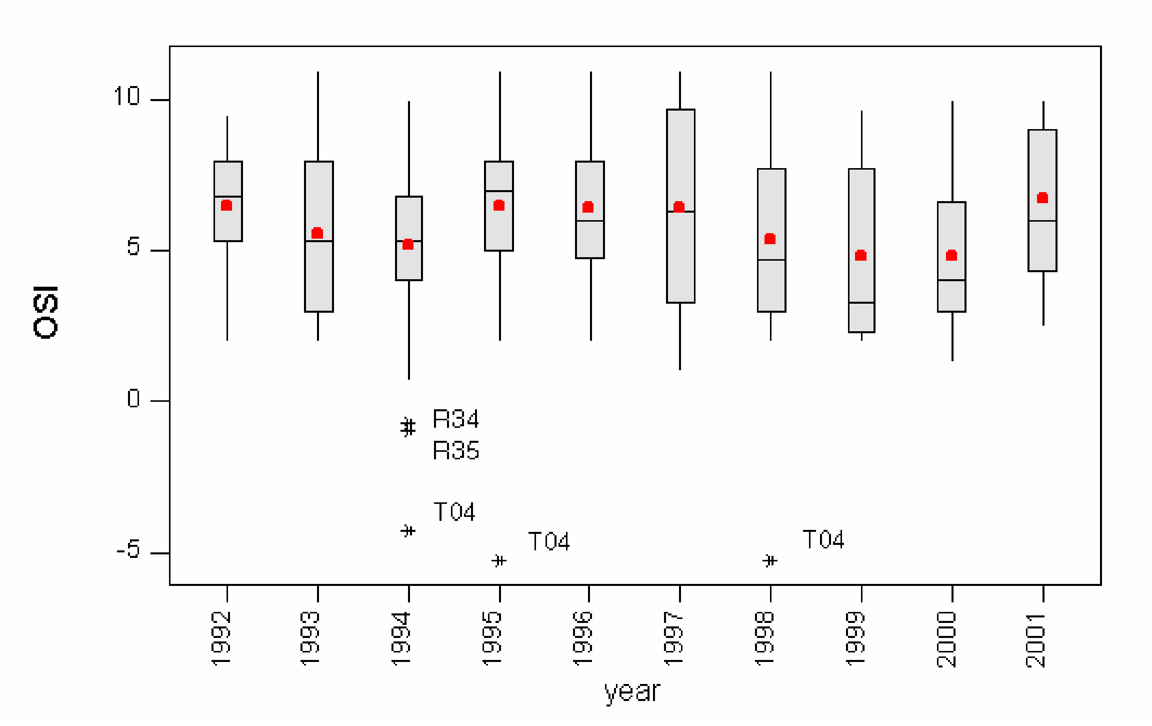
Overall, the harbor SPI data for 2001 continued the 2000 observation of the predominance of biological processes in structuring surface sediments. Physical features such as bedforms were absent, while macrobenthic tubes and other biogenic structures occurred at almost all stations. For example, the only stations lacking surface biogenic structures were R08 and R36. While the distribution of sediment textures in the harbor was related primarily to a combination of sources (geomorphology and hydrodynamics), surface features continued to be dominated by biogenic activity. *Ampelisca* spp. tube mats, feeding pits and mounds, and worm tubes were the dominant surface biogenic structures.

3.3.1 Long-term Benthic Habitat Conditions: 1992 to 2001

Some sediment profile image (SPI) data on benthic habitat conditions were collected in 1990–1992 (SAIC 1992, Blake *et al.* 1993), prior to the establishment of the current monitoring strategy in 1992, (Summer sampling at R and T stations). SPI images provide an in-situ cross-section of surface sediments that can be evaluated for the physical and biological processes that are structuring benthic habitats. From 1992 to 2001, the two basic measures of benthic habitat quality, the Organism Sediment Index (OSI) of Rhoads and Germano (1986) and the depth of the apparent color RPD layer oscillated about the long-term mean with no year being more than 17% and 45% from the grand mean, for OSI and RPD respectively (Figures 3-2 and 3-3). The OSI averaged 5.8±2.7 (mean±SD) for all years, which was slightly below the threshold of 6.0 that is indicative of some form of stress acting upon the benthos (Rhoads and Germano 1986). The largest decline in OSI from the long-term mean was 17% in 1999 and the largest increase was 16% in 2001. For the RPD, the largest decline of 25% occurred in 1994 with the largest increase of 45% in 2001. Over the last 10 years, benthic habitat quality and infaunal communities appeared to have developed in response to major disturbance events in 1991, the October severe storm and December sewage sludge discharge abatement (Blake *et al.* 1998). Interestingly, stations with poorest habitat quality in 1989/90 (Blake *et al.* 1993) continued to have poor quality habitat in 2001. Stations T04 and R43, both in Dorchester Bay, had long-term average OSI values < 3.

Variation in the yearly average OSI and RPD was associated with 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). The long-term predominance of pioneering successional Stage I seres at most inner harbor stations tended to reduce yearly averages in OSI and RPD, whereas the predominance of intermediate Stage II to equilibrium Stage III seres at most outer harbor stations tended to increase these parameters. As one successional stage or the other increases, the overall estimate of benthic habitat quality varied. In 2001, there was an overall increase in evidence for the presence of higher successional stage communities.

The tube-building amphipods in the genus *Ampelisca* were key to following temporal change in benthic habitat quality. The presence of *Ampelisca* spp. was associated with the intermediate successional stage (Stage II) and improved benthic habitat quality. Data from grab samples indicated that *Ampelisca* spp. tube mats were not broadly distributed in Boston Harbor prior to 1993. In 1992 there was about a doubling of stations with *Ampelisca* spp. tube mats from <20% to about 40%. From 1993 to 1995 the spatial distribution of tube mats increased to >60% of stations. Populations of *Ampelisca* spp. appeared stable until 1998 when the distribution of tube mats started to contract. In 2000, tube mats occurred at only 33% of stations. However, in 2001 tube mats increased and occurred at 50% of the stations. The decline in the intermediate successional stage seres, associated with the decline of the *Ampelisca* spp. populations, from 1998 to 2000 may have been a response to abatement of sewage sludge discharge at President Roads in late 1991 and other treatment improvements, which combined to reduced solids discharges to the Harbor by half between 1989 and 1995 (Werme and Hunt, 2002). The hypothesis being that as organic matter loading to the harbor declined and there would not be enough food to sustain large populations of *Ampelisca* spp. and the area covered by mat densities would eventually decline. However, patterns of total organic carbon in the sediments does not support this hypothesis since there has been little change in sedimentary carbon (see Section 4). In 2001, the number of stations with tube mats increased to 50% indicating that factors other than total organic carbon may be regulating *Ampelisca* densities.



Organism Sediment Index

	90/2	93	94	95	96	97	98	99	00	01
Median	6.8	5.3	5.3	7.0	6.0	6.3	4.7	3.7	4.0	6.0
Mean	6.4	5.6	5.2	6.5	6.4	6.4	5.3	4.9	4.9	6.7
SE	0.2	0.4	0.4	0.4	0.3	0.4	0.4	0.3	0.3	0.4
N	61	46	46	59	56	45	60	61	60	57

Figure 3-2. Boxplots of long-term trends in the Organism Sediment Index, an index of benthic habitat quality, for harbor stations. Box is interquartile range (IR), bar is median, dot is mean, vertical lines are range, asterisks are outliers (>2IR).

Outlier Stations:

R21

R12
R11
R13

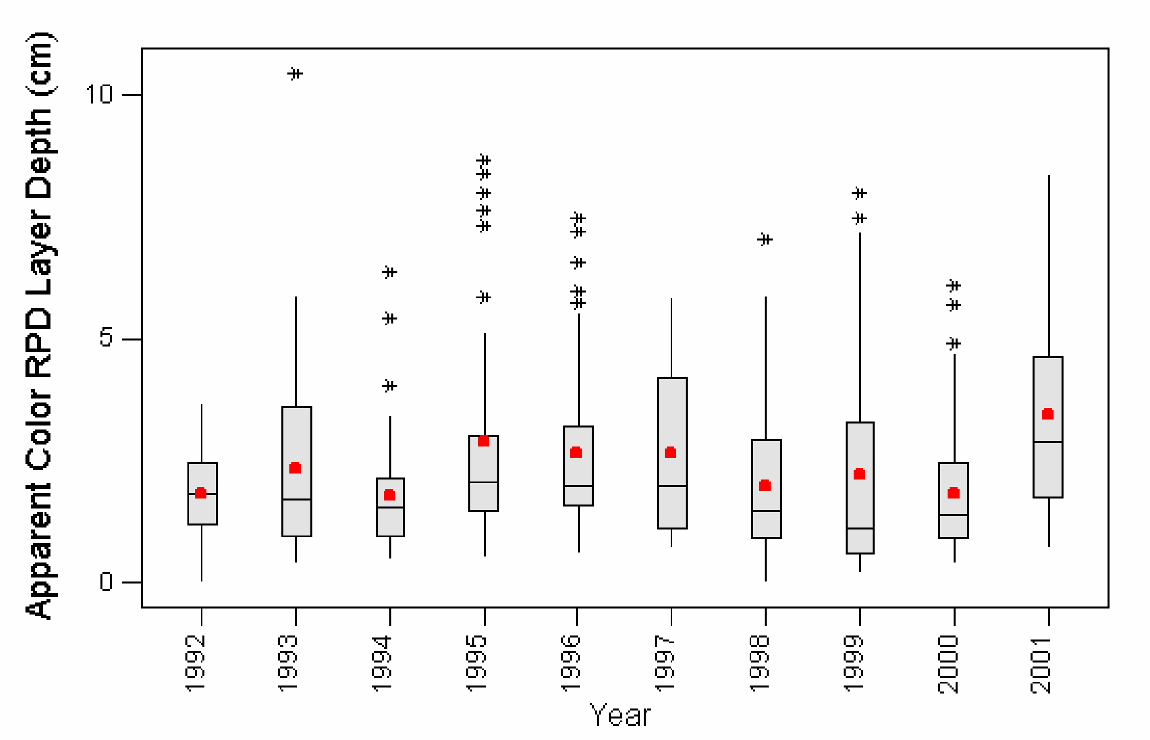
R15
R20
R18
R21
T03
R45
R11

T03
R28
R45
R50
R46
R24
R29

R11

R17
R12
R20

R12
R11
TO3



RPD Layer Depth (cm)

	90/2	93	94	95	96	97	98	99	00	01
Median	1.8	1.7	1.6	2.1	2.0	2.0	1.5	1.1	1.4	2.9
Mean	1.8	2.4	1.8	2.9	2.7	2.7	2.0	2.2	1.8	3.5
SE	0.1	0.3	0.2	0.3	0.2	0.2	0.2	0.3	0.2	0.3
N	66	46	49	59	58	45	61	61	60	57

Figure 3-3. Boxplots of long-term trends in the apparent color RPD layer depth (cm), a measure of the thickness of oxidized sediments, for harbor stations. Box is interquartile range (IR), bar is median, dot is mean, vertical lines are range, asterisks are outliers (>2IR).

Overall, general benthic habitat quality within the study area was similar from August 1992 to 2001 with minor variation from year to year (Blake *et al.* 1998, Kropp *et al.* 2000, 2001, 2002, and this report).[1] Using the OSI as a surrogate for habitat quality, none of the stations exhibited monotonic long-term trends, either improving or declining (Table 3-2). However, there were six stations that consistently had OSI values ≥6, the break point for stressed/not stressed habitat conditions (Rhoads and Germano 1986), and six stations with consistently <6 OSI values. Station T04 located in inner Dorchester Bay consistently had low OSI values with three years of negative values, indicative of a highly stressed habitat. Stations R11, R12, R45, and T03 along the western side of Long Island had consistently good habitat quality, and had the highest overall averages. Station T03 is located <1.4 km from the former Deer Island treatment plant sludge and effluent outfall and had the fourth highest long-term average OSI index of all monitoring stations (Table 3-2).

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[1] While data exist from 1990/91, it is not possible at this time to include them in direct comparisons with the other years.

Table 3-2. Long-term data for the organism sediment index from 1992 to 2001.

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Mean
T04	2.6	2.0	-4.3	-5.3		2.0	-5.3	2.0	1.3	2.7	-0.3
R43	3.3	2.3	2.5	4.7	2.0	2.7	2.0	2.0	2.0	2.5	2.6
R36				3.7		2.3	3.0	2.0	4.3		3.1
R33	5.3	2.7	0.7	7.0	4.0	2.7	2.3	3.0	3.0	3.0	3.4
R35	7.4	2.7	-0.7	5.0	5.0	2.7	2.7	3.7	3.0		3.5
R34	7.0	3.0	-1.0	6.7	5.7	3.3	2.3	2.7	2.3		3.6
R49	3.5			3.0	7.7	1.0	3.0	3.3	2.3	5.3	3.6
R51	7.0			2.7	4.7		3.0	3.3	2.3	3.3	3.8
R53	6.0			3.0	5.3		2.5	2.0	3.7	4.0	3.8
R52	8.0			2.0	4.0		3.5	3.0	3.0	3.0	3.8
R10		2.0	3.0	3.3	4.0	5.0	5.3	4.3	3.7	3.7	3.8
R37	5.7	2.7	4.3	7.0	3.0	3.3	4.0	2.3	3.7	3.0	3.9
T07	2.0	2.7	3.7	7.5	4.3	3.0	2.7	4.0	3.7	5.7	3.9
R06		6.0	4.0	3.3				2.3	3.3	5.0	4.0
T01	3.0	5.3	4.0	5.0	4.3	4.0	3.7	2.3	3.7	4.7	4.0
R42	5.0	4.7		6.0	3.0		3.7	2.3	5.0	3.0	4.1
R48				5.0	5.7		3.0	2.3	4.0	4.7	4.1
R08					8.0	4.5	3.5	3.7	2.7	3.0	4.2
R19	7.0	5.7	4.0	4.0	6.0		3.0	2.0	3.0	4.7	4.4
T02	3.0		5.7	6.7	5.0	4.3	3.7	3.0	3.0	5.0	4.4
R32	6.0	4.0	6.3	5.0	5.3	2.7	3.7	3.0	4.0	6.0	4.6
R15	8.7	3.0	2.3	11.0	5.0		3.0	2.0	3.0	3.5	4.6
R44				7.0	3.3	2.7	5.7	3.3	3.0	7.3	4.6
R04		2.7	4.3	7.0	5.0	3.0	4.7	2.3	2.7	10.0	4.6
T05A				6.7	4.3	5.5	4.3	2.3	3.0	7.0	4.7
R41	6.3	2.3	5.3	11.0	6.0	5.0	4.7	2.3	3.3	3.7	5.0
R26	7.7	5.0	9.3	4.3	5.7		3.0	3.3	3.3	3.3	5.0
R40	6.0	3.5	4.0	10.7	8.0		2.7	3.3	4.7	4.0	5.2
R05	7.7	4.0	6.0	7.0	5.7		5.7	3.0	3.7	5.7	5.4
T08	7.0	7.0	4.5	8.0			3.7	2.7	4.7	6.0	5.4
R17	6.0	4.3	5.3	8.0	3.0	4.7	4.3	8.7	6.3	4.7	5.5
R09		5.3	5.0	2.7	7.3	6.3	4.7	8.0	3.7	7.7	5.6
R13	6.8	5.3	10.0	6.7	5.0		2.7	2.0	2.3	10.0	5.6
R14	5.7	5.3	4.7	7.0	5.0	11.0	5.3	2.3	3.3	9.0	5.9
R02	6.7	3.0	5.7	2.0	4.7	9.3	5.7	5.7	7.0	10.0	6.0
R23		9.0	6.7	6.0	8.0		3.0		5.3	5.3	6.2
R03		3.7	6.7	7.7	8.0	8.3	6.7	3.3	4.0	9.0	6.4
R16		8.0	2.5	6.3	9.0	8.0	4.0	5.7	5.3	8.7	6.4
R50	8.0			7.3	11.0	5.7	7.7	2.7	5.0	5.3	6.6
R30	8.0	5.7	7.3	6.3	6.7	5.7	8.3	6.3	5.7	6.0	6.6
R39	8.3	6.7	8.7	7.0	6.3	6.3	9.0	3.7	5.3	10.0	7.1
T06	6.7	9.3	5.0	6.3	5.7	7.7	7.7	7.7	6.3	9.0	7.1
R25	7.3	7.7	4.3	5.3	9.0	8.7	10.0	8.0	3.3	8.0	7.2
R22		9.0	5.7	7.3	4.3	10.3	7.7	4.5	6.0	10.0	7.2

Table 3-2. Long-term data for the organism sediment index from 1992 to 2001 (continued)

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Mean
R38	7.7	5.3	4.7	8.7	6.3	9.7	6.7	9.0	4.7	9.7	7.2
R27	9.0	4.3	7.0	6.3	8.0	6.0	10.3	6.3	6.7	8.7	7.3
R07		2.7	6.0	7.3	8.3	10.7	6.7	9.3	9.3	10.0	7.8
R47	4.7			8.7	7.0	10.3	9.3	9.0	10.0	5.5	8.1
R29	7.3	8.0	8.7	8.0	10.3	6.7	10.0	7.0	7.3	8.7	8.2
R20		9.3	5.5	11.0	7.3	10.3	4.0	9.0	7.7	10.0	8.2
R18		9.0	5.7	8.3	7.7	9.7	10.7	9.0	5.3	9.0	8.3
R31	5.3	10.3	8.0	7.3	8.7	9.0	9.0	8.7	6.7	10.0	8.3
R21		9.0	8.0	9.0	7.3	10.0	9.3	5.7	8.0	8.7	8.3
R24	8.0	9.0	5.0	9.0	9.7		7.3	9.7	8.0	10.0	8.4
R46				8.0	10.3	7.7	9.0	6.3	7.7	10.0	8.4
R28	9.0	6.3	10.0	6.7	9.7	7.3	9.7	8.3	7.3	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	8.7
R45	9.0			9.7	9.7	9.7	7.7	7.7	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	9.1
R12		6.7	10.0	10.3	8.0	10.0	11.0	9.0	9.3	9.0	9.3

4.0 CHEMISTRY

by Deirdre T. Dahlen and Carlton D. Hunt

4.1 Methods

4.1.1 Laboratory Analyses for Ancillary Measurements

Laboratory procedures followed those outlined in the Benthic Monitoring CW/QAPP (Kropp and Boyle, 2001). Summaries of the procedures are provided below.

Grain Size — Samples were analyzed for grain size by the sequence of wet and dry sieving using Folk methodologies (1974). The sand/gravel fraction was separated from the mud fraction. This sand/gravel fraction was transferred to a 200-mL beaker, decanted, and dried overnight at 95 ºC. The dried sand/gravel fraction was mixed by hand to disaggregate the material, and then dry-sieved on stacked ! 1-, 0-, 1-, 2-, 3-, and 4-phi sieves. Each size class was weighed to the nearest 0.1 mg on a top-loading balance. Particles smaller than 4 phi were analyzed using the pipette method. 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 — A portion of the sample to be analyzed for TOC content was dried at 70 ºC for 24–36 hours and ground to a fine powder. The sample was treated with 10 % HCl to remove inorganic carbon and dried at 70 ºC for 24 hours. Between 10 and 500 mg of dry, finely ground, and homogenized sample were weighed to the nearest 0.1 mg and placed in a crucible that had been precombusted for 4 hours at 500 ºC. A Coulometric Carbon Analyzer was used to determine the TOC content of the samples. TOC determinations were performed by Applied Marine Sciences, Inc. according to SOP AMS-TOC94.

***Clostridium perfringens* —** Sediment extraction methods for determination of *Clostridium perfringens* spores followed those developed by Emerson and Cabelli (1982), as modified by Saad (1992). The filters for enumeration of *Clostridium perfringens* spores were incubated anaerobically at 44.5 ºC for 24 hours. Following incubation, the filter was exposed to ammonium hydroxide for 15–30 seconds. Yellowish colonies that turn red to dark pink upon exposure were counted as *Clostridium perfringens*. Data are reported as colony–forming units (cfu) per gram dry weight of sediment. This analysis was performed by MTH Environmental Associates.

4.1.2 Statistical Analyses and Data Treatments

Statistical Analysis — Microsoft Excel® and JMP® were used to perform correlation analysis on sediment grain size, TOC, and *Clostridium perfringens* data to examine the correlation between these parameters. Probability values were taken from Rohlf and Sokal (1969).

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

- Percent Fines—sum of percent silt and clay.
- Numerical approximate mean phi (hereafter referred to as mean phi)—calculated by weighting each class fraction measured and summing the weighted fractions as described in Kropp *et al* (2001).

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 and seasons, 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 and season (*i.e.,* April, August) to assess the spatial and temporal distribution in bulk sediment properties and *Clostridium perfringens* from 1991 to 2001.
- Grand Station Mean—average of all years, by station and season. Grand station means were determined for each parameter over all sampling years and season to assess variability in the spatial and temporal distribution in bulk sediment properties and *Clostridium perfringens* from 1991 to 2001.
- Grand Mean—average of yearly mean values, by sampling period. Grand means were determined for Flux and Traditional Harbor TOC over all sampling years (1993-2001) 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 of gravel plus sand, silt and clay in sediment collected from Traditional stations from 1991 to 2001.

Results for TOC and *Clostridium perfringens* analyses were compared from all Traditional stations by using line charts to evaluate if the spatial and temporal distributions in 2001 were substantially different from those for previous years.

Seasonal TOC data collected from the Benthic Flux program (BH02 and BH03 only) from 1993 to 2001 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.

4.2 Results and Discussion

Bulk sediment results for all Traditional samples collected in April and August surveys were evaluated separately to examine spatial and temporal characteristics. April and August 2001 results are presented in Table 4-1. Grand station means and associated standard deviation and coefficient of variation values, by station and parameter, for April (1993–2001) and August (September 1991 and August 1992–2001) surveys are presented in Table 4-2. Ternary plots showing grain size composition and line charts showing TOC and *Clostridium perfringens* results for April (1993–2001) and August (September 1991 and August 1992–2001) surveys, by station and season, are presented in Appendix C-1. Station mean and grand station mean values (with standard deviation and coefficient of variation) for grain size, TOC, and *Clostridium perfringens*, by station across all sampling years, are reported for April and August in Appendices C-2 and C-3, respectively. All sediment results are discussed in terms of dry weight using station mean values.

4.2.1 Grain Size 1991–2001

April—Patterns in sediment composition at all Traditional stations in 2001 were within the ranges observed for previous years except that T01 was comprised of slightly less coarse-grained sediments compared to other years. Patterns in sediment composition were consistent at some stations and more variable at others (Figure 4-1a; ternary plots for each individual station over time are provided in Appendix C-1).

T01 displayed very consistent grain size composition over time and was comprised of coarse-grained sediments, with gravel plus sand content generally 70% and higher across all sampling years (Appendix C-1, Figure C-1-1). T02 showed variable patterns in grain size composition over time, ranging from sandy (70% gravel plus sand in 1994) to very silty (84% fines in 1998) (Appendix C-1, Figure C-1-2). T03 also displayed variable patterns in grain size composition over time, ranging from sandy (52% gravel plus sand in 1994) to very silty (90% fines in 1995) (Appendix C-1, Figure C-1-3). T04 was comprised of very silty sediments (>80% silt plus clay) across all years except 1994 and 1999. Sediment collected in 1994 at T04 contained considerably less clay and more sand relative to other years; sediment collected in 1999 at T04 contained considerably less silt and more sand relative to other years (Appendix C-1, Figure C-1-4). T05A displayed moderately consistent grain size composition over time and was comprised primarily of coarse-grained sediments, ranging from 56 to 86% gravel plus sand (Appendix C-1, Figure C-1-5). T06 showed variable grain size composition over time, ranging from sandy (69% gravel plus sand in 1994) to silty (77 fines in 1996) (Appendix C-1, Figure C-1-6). T07 also showed variable grain size composition over time, ranging from very sandy (92% gravel plus sand in 1997) to very silty (80% fines in 1993) (Appendix C-1, Figure C-1-7). T08 was comprised of very sandy sediments (87% and higher gravel plus sand) across all years except 1997 and 1998. Sediment collected in 1997 and 1998 at T08 contained considerably more silt and clay relative to other years (Appendix C-1, Figure C-1-8).

Table 4-1. Grain size, TOC, and *Clostridium perfringens* data from sediments collected at Traditional stations in April and August 2001.

Parameter	Units	T01	T02	T03	T04	T05A	T06	T07	T08
April Survey, 2001									
Gravel	pct	0.185	0.034	0	4.51	0.109	1.4	4.55	2.55
Sand	pct	68	44.1	31.2	5.75	60.3	45.7	28.4	93
Silt	pct	19.5	32.7	34.1	48.5	22.2	24.9	35	1.38
Clay	pct	12.3	23.2	34.7	41.3	17.3	28	32	3.09
Fines	pct	31.8	55.9	68.8	89.7	39.5	52.9	67	4.48
Mean phi	pct	4.45	5.46	5.8	6.7	4.83	4.88	5.5	2.21
TOC	pct	0.85	1.54	2.99	5.29	1.01	2.5	2.9	0.35
Clostridium perfringens	cfu/g dw	1540	6510	5480	13400	1470	2510	12900	294
August Survey, 2001									
Gravel	pct	0.401	0.246	0.865	0	0.389	0.466	5.78	3.01
Sand	pct	66.9	43.7	33.7	5.41	77.7	61	37.5	89.1
Silt	pct	20.7	34.3	40.1	61	13.7	23.1	33.5	4.72
Clay	pct	12	21.8	25.3	33.6	8.18	15.4	23.2	3.21
Fines	pct	32.7	56.1	65.4	94.6	21.9	38.6	56.7	7.93
Mean phi	pct	4.37	5.31	5.43	6.84	3.82	4.34	4.88	2.51
TOC	pct	1.13	1.69	3.03	4.08	1.02	1.97	2.6	0.43
Clostridium perfringens	cfu/g dw	2910	3310	9650	4900	1240	3320	6910	320

Table 4-2. Grand station mean, standard deviation, and coefficient of variation results for sediment parameters from April and August surveys.

Stn		Gravel (pct)	Sand (pct)	Silt (pct)	Clay (pct)	Fines (pct)	TOC (pct)	*Clostridium* (cfu/g dw)
April Surveys, 1993 – 2001								
T01	**Mean**	6.05	72.4	13.9	7.59	21.5	1.14	4510
	Stdev	5.6	7.76	4.11	3.85	7.86	0.261	2270
	CV	92.6	10.7	29.7	50.8	36.7	22.9	50.4
T02	**Mean**	1.15	43.6	33.9	21.4	55.2	1.8	14000
	Stdev	1.3	14.4	9.91	7.66	14.9	0.378	11400
	CV	113	33.1	29.2	35.9	26.9	21	80.9
T03	**Mean**	1.92	29.3	39.1	29.7	68.8	3.04	22000
	Stdev	4.18	13.3	6.68	12.5	14.7	0.313	22000
	CV	217	45.3	17.1	42.2	21.3	10.3	100
T04	**Mean**	0.99	12.7	54.4	32	86.4	5.15	16500
	Stdev	1.88	10.2	9.86	10.8	9.67	1.25	8140
	CV	190	80.5	18.1	33.8	11.2	24.2	49.3
T05	**Mean**	0.235	71.2	19.2	9.29	28.5	0.808	3110
	Stdev	0.206	10.5	7.51	5.15	10.6	0.36	1840
	CV	87.6	14.8	39	55.5	37	44.6	59.2
T06	**Mean**	1.32	43.2	32	23.5	55.5	2.27	13800
	Stdev	1.98	14.4	8.31	10.7	15.9	0.61	12100
	CV	150	33.2	26	45.5	28.6	26.9	87.4
T07	**Mean**	11.2	35.7	32.6	20.6	53.2	2.76	14000
	Stdev	10	21.6	16.1	10.3	21.1	0.355	9490
	CV	89.8	60.4	49.6	50.2	39.8	12.9	67.9
T08	**Mean**	3.03	80.9	8.3	7.74	16	0.556	3520
	Stdev	3.66	21	10.9	9.92	20.7	0.356	2740
	CV	121	25.9	132	128	129	64.1	77.9
August Surveys, 1991 - 2001								
T01	**Mean**	13.3	60.5	19.5	6.77	26.3	1.89	5300
	Stdev	18.8	19.6	13.9	2.65	13	0.697	3390
	CV	141	32.3	71.1	39.1	49.6	36.8	64
T02	**Mean**	2.51	49.8	31.2	16.5	47.6	1.69	12700
	Stdev	6.32	9.74	6.76	6.13	11.7	0.2	6770
	CV	252	19.5	21.7	37.2	24.6	11.8	53.3
T03	**Mean**	0.99	31.6	40.9	26.5	67.4	3.28	33200
	Stdev	1.81	18.1	8.22	12.7	19.1	0.422	58500
	CV	183	57.2	20.1	47.9	28.3	12.9	176
T04	**Mean**	0.591	12.9	58.3	28.2	86.5	4.3	15300
	Stdev	1.16	11.1	10.2	11	10.9	1.57	19100
	CV	197	86.3	17.5	39.1	12.7	36.6	125
T05	**Mean**	8.61	76.1	10.1	5.21	15.3	0.979	6030
	Stdev	27.8	24.5	5.21	3.64	8.49	0.377	9300
	CV	323	32.2	51.4	69.8	55.3	38.6	154
T06	**Mean**	0.726	51.4	29.8	18.1	47.9	2.16	14200
	Stdev	0.852	16.6	10.4	7.4	16.6	0.612	16800
	CV	117	32.3	34.8	40.9	34.5	28.4	118
T07	**Mean**	8.33	33.1	38.2	20.4	58.6	2.73	11700
	Stdev	6.98	11.1	7.51	6.42	9.63	0.306	8530
	CV	83.8	33.6	19.7	31.5	16.4	11.2	72.9
T08	**Mean**	1.44	84.5	7.84	6.22	14.1	0.518	2470
	Stdev	1.24	24.3	14.9	9.9	24.8	0.266	2540
	CV	86.3	28.7	190	159	176	51.4	103

August—Patterns in sediment composition in 2001 at all Traditional stations were not substantially different from previous years (1991–2000). Patterns in sediment composition were consistent at some stations and variable at others (Figure 4-1b; ternary plots for each individual station are provided in Appendix C-1).

T01 displayed very consistent grain size composition across all years except 1995, and was comprised of coarse-grained sediments, with gravel plus sand content generally 67% and higher across all sampling years (Appendix C-1, Figure C-1-1). Sediment collected in 1995 at T01 contained considerably less sand and more silt relative to other years (Appendix C-1, Figure C-1-1). T02 displayed moderately consistent patterns in sediment composition over time, with sandy sediment texture in 1991–1994 ($ 60% gravel and sand), slightly more silty in 1996 and 2000 (47–46% fines), and again more silty in 1995, 1997–1999 and 2001 (55–63% fines) (Appendix C-1, Figure C-1-2). T03 also displayed variable patterns in grain size composition over time, ranging from sandy (63% gravel plus sand in 1994) to very silty (91% fines in 1999) (Appendix C-1, Figure C-1-3). T04 showed moderately consistent grain size composition over time, and was comprised of silty sediments, ranging from 68 to 97% fines (Appendix C-1, Figure C-1-4). T05A displayed the most consistent grain size composition over time and was comprised of coarse-grained sediments, ranging from 68 to 98% gravel plus sand (Appendix C-1, Figure C-1-5). T06 displayed variable patterns in sediment composition over time, with sandy sediment texture in 1991–1994, 1997 and 2000-2001 (59 to 66% gravel and sand), slightly more silty in 1995 and 1998-1999 (61–66% fines), and again more silty in 1996 (80% fines) (Appendix C-1, Figure C-1-6). T07 also showed variable sediment composition over time, ranging from sandy (59% sand and gravel) in 1991 to silty (78% fines) in 1998 (Appendix C-1, Figure C-1-7). T08 was comprised of very sandy sediments (83% and higher gravel plus sand) across all years except 1991. Sediment collected in 1991 at T08 contained considerably more silt and clay relative to other years (Appendix C-1, Figure C-1-8). Apparent temporal outliers at T08 and other sites may result from small-scale spatial heterogeneity.

Comparison of April and August Surveys —Patterns in sediment composition between April and August surveys were similar across all common sampling years (1993–2001). For example, stations that were primarily comprised of coarse-grained sediments in April (*i.e.,* T01, T05A, and T08) were also comprised of coarse-grained sediments during August surveys (Appendix C-1). However, variability in sediment composition over time was higher at some stations (*i.e.,* T02, T07, T08) in April relative to August surveys (Appendix C-1, Figures C-1-2, C-1-7 and C-1-8). In contrast, patterns in sediment composition at station T01 in April were less variable over time relative to August surveys (Appendix C-1, Figure C-1-1). Stations T03, T04, T05A, and T06 generally showed equally variable patterns in sediment composition over time during April and August surveys (Appendix C-1).

4.2.2 Total Organic Carbon 1991–2001

April—Concentrations of TOC at all Traditional stations were not substantially different in 2001 from earlier years because of the high variability in the historical dataset (Figure 4-2a, detailed line charts for each station are included in Appendix C-1). Patterns in TOC content were consistent over time at some stations, but were more variable at others (Figure 4-2a, Table 4-2). T03 and T07 showed the most consistent (<13% coefficient of variation, CV) patterns in TOC content over time (Figure 4-2a, Table 4-2). T01, T02, T04, and T06 had moderately variable (21–27% CV) concentrations of TOC over time, while stations T05A and T08 were the most variable (>44% CV) over time (Figure 4-2a, Table 4-2). Sediments from station T04 consistently had the highest levels of TOC over time, whereas the lowest levels were found at stations T05A and T08 (Figure 4-2a, Table 4-2).

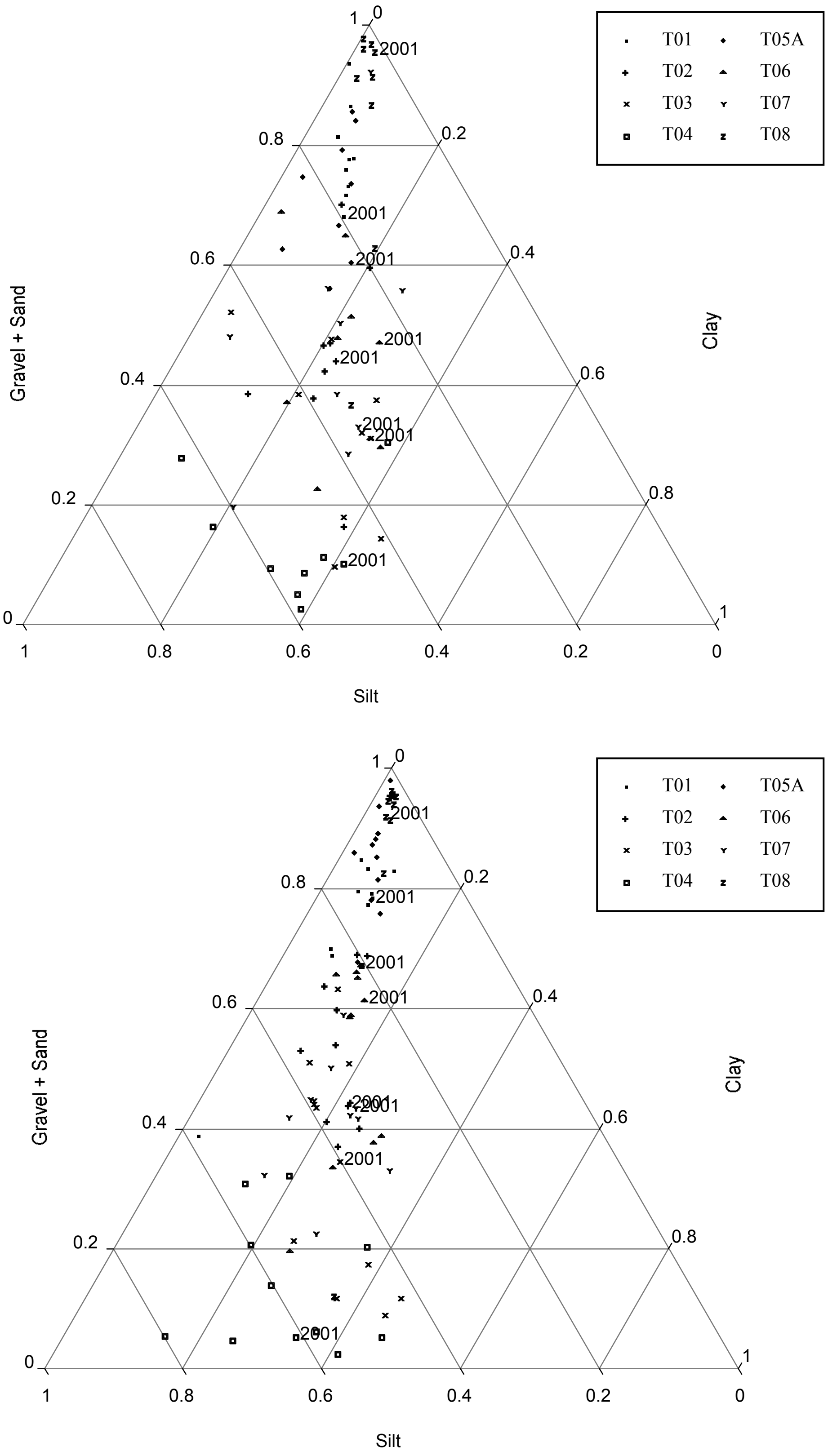

Figure 4-1. Grain size composition from sediments collected at Traditional stations in April 1993-2001 (a) and September 1991 and August 1992-2001 (b). (YR2001 data are labeled.)

August—Concentrations of TOC at all Traditional stations were not substantially different in 2001 from earlier years, again because of the high variability in the historical dataset (Figure 4-2b, detailed line charts for each station are included in Appendix C-1). Patterns in TOC content were consistent over time at some stations, but were more variable at others (Figure 4-2b, Table 4-2). Stations T02, T03, and T07 showed the most consistent (<13% CV) patterns in TOC content over time (Figure 4-2b, Table 4-2). Station T06 had moderately variable concentrations of TOC over time (28% CV), while stations T01, T04, T05A, and T08 were the most variable (>36% CV) over time (Figure 4-2b, Table 4-2). Sediments from station T04 had the highest levels of TOC over time, peaking in 1998 with the highest measured value (8.86% TOC) among all sampling years. The unusually high TOC content observed at T04 in 1998 (Figure 4-2b) is likely a result of localized inputs from a major storm event that occurred in June 1998 (Lefkovitz *et al*. 1999). Concentrations of TOC at station T04 decreased in 1999 indicating that the system has returned to previous conditions (Figure 4-2b). The return to previous conditions in 1999 may also be further explained by the rapid sedimentation rate (approximately 4 cm/year) observed at the site by Gallagher *et al* (1992) and Wallace *et al* (1991). Stations T05A and T08 consistently contained the lowest levels of TOC (generally ≤1%) over time (Figure 4-2b).

Comparison of April and August Surveys—The TOC content measured during April surveys represents the effects of several factors and processes, for example, contributions such as the spring plankton bloom, inputs resulting from spring run-off, and anthropogenic loadings (Blake *et al*. 1998). Thus, at low temperatures organic carbon is expected to build up in the sediment. Recent studies (Blake *et al*. 1998) suggested that the TOC content measured during August surveys represents the net inventory of organic matter following respiration of the spring input of carbon substrates. It also includes recent inputs from production and other run-off sources. Thus, TOC is generally expected to be higher in April than in August (Blake *et al*. 1998). Close examination of the data suggests that TOC concentrations at approximately 65% of the stations, across all sampling years, had similar (*i.e.,* R%D between April and August values within 10%) or higher concentrations of TOC in August relative to April values, suggesting that this data set does not support the mechanisms described by Blake *et al*. (1998).

To evaluate this, the individual station data by year were compared to the one-to-one correlation expected if no processes were operating to modify the TOC between April and August (Figure 4-3). TOC data from station T04 in 1998 was excluded from the correlation analysis because of the suspected localized influence from a June 1998 storm event. The correlation analysis of the data yielded a slope of less than one. Sediments with low TOC (sandy) tend to have less respiration while muddier, high TOC stations appear to have lower relative TOC due to respiration. Additionally, the data do not consistently support seasonal differences. Rather, only 35% of the April TOC values were higher than the corresponding August values and 25% of the April and August stations had similar TOC values (within 10% R%D). Further, 40% of the August TOC values were higher than the corresponding April values. For example, TOC content at stations T01 and T03 were higher in August for all sampling years except 1998 (T01 and T03) and 2000 (T03 only) relative to April values.

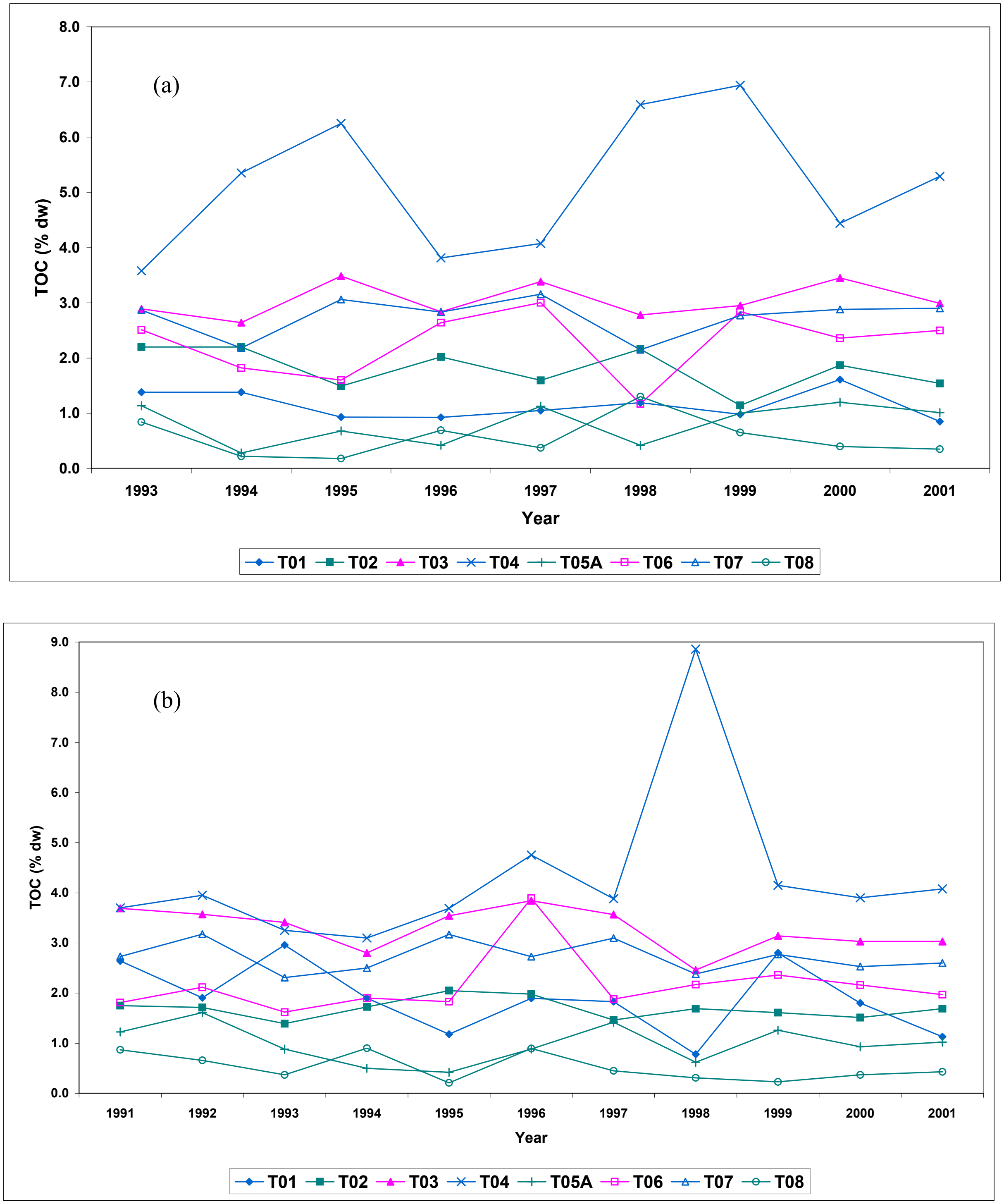

Figure 4-2. Total organic carbon content in sediments collected at Traditional stations in April 1993–2001(a) and September 1991 and August 1992-2001 (b).

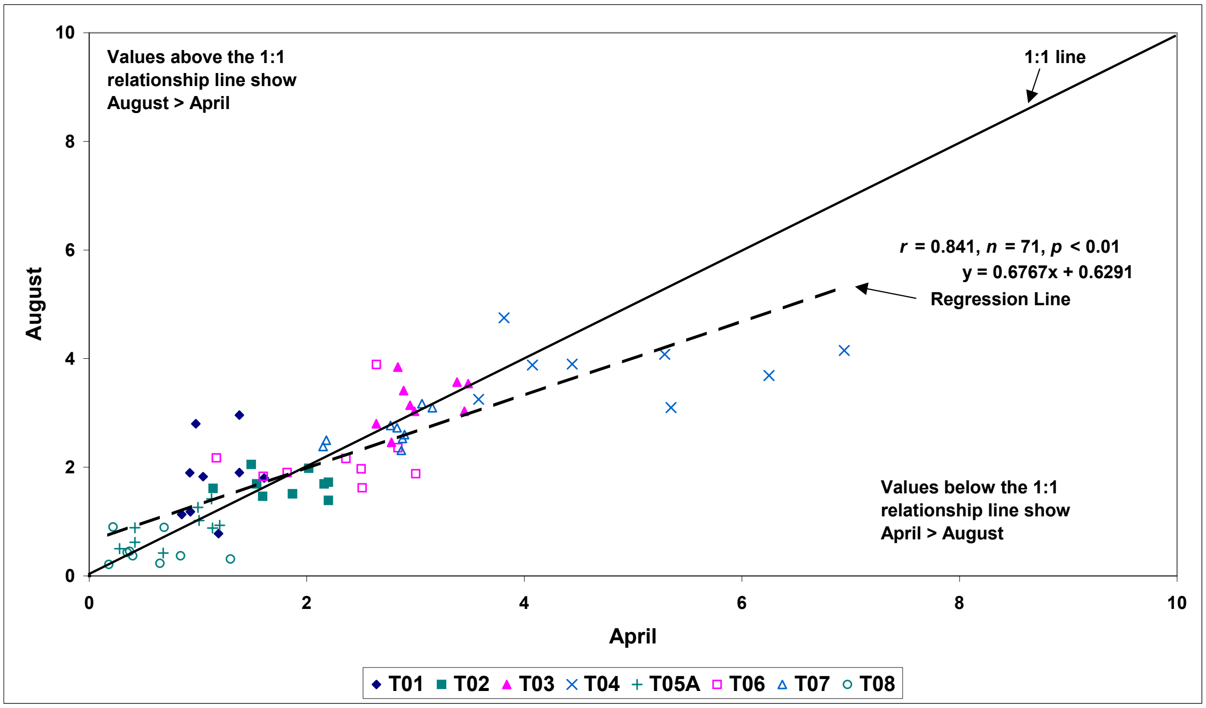

Figure 4-3. A seasonal comparison of April and August total organic carbon content in sediments collected from Traditional stations from 1993 to 2001.

Comparison of April and August Surveys to the Flux Program—Seasonal TOC data collected from the Benthic Nutrient Flux program (Tucker *et al.* 2001) from 1993 to 2001 were also evaluated with the Harbor TOC data to explore if there was a characteristic seasonal "peak" in Harbor TOC levels that corresponded to the faunal sampling events. This evaluation was limited to those stations that represented similar geographic regions of the Harbor, *i.e.,* BH02 and BH03 from the Flux Program and T02 and T03 from the Traditional Harbor program.

TOC results were evaluated at three levels. First, the distribution of Flux TOC and Traditional Harbor TOC results for all years within a given sampling month was evaluated (Appendix C-4, Figure C-4-1). Next, mean TOC results within a given sampling year and month were evaluated (Appendix C-4, Figure C-4-2). Both analyses showed that on a harbor wide basis there were no characteristic peaks in TOC values within a factor of two variability observed from 1993 to 2001. Interestingly, mean Flux TOC results from May and July were unusually high in 1996 relative to other sampling months and years (Appendix C-4, Figure C-4-2). In addition, the mean Flux TOC results determined under HOM2 (1995 to 1997) appear to be slightly higher compared to mean Flux TOC results determined under HOM1 and HOM3 (Appendix C-4, Figure C-4-2), suggesting that an evaluation of methods used across years may be warranted to determine if the difference is method related.

Last, the grand mean (average of yearly mean values) within a given sampling month was evaluated. Results showed a build up in carbon content in the system in March and April, with a seasonal peak in May, followed by decreasing carbon content from July through October (Figure 4-4). The seasonal peak in carbon content in May is not unexpected, and is likely indicative of carbon input to the system from winter/spring bloom (Figure 4-4). The reduction in carbon content in later summer and early fall months likely reflects TOC burn-off. Results also showed that carbon content at Traditional Harbor stations were fairly similar between April and August surveys (Figure 4-4), supporting the evaluation above (Section 4.2.2, Comparison of April and August Surveys). Evidently, the seasonal peak in carbon content to the system can not be measured from the Traditional Harbor surveys given that the peak does not occur until May and the Traditional Harbor surveys only occur in April and August.

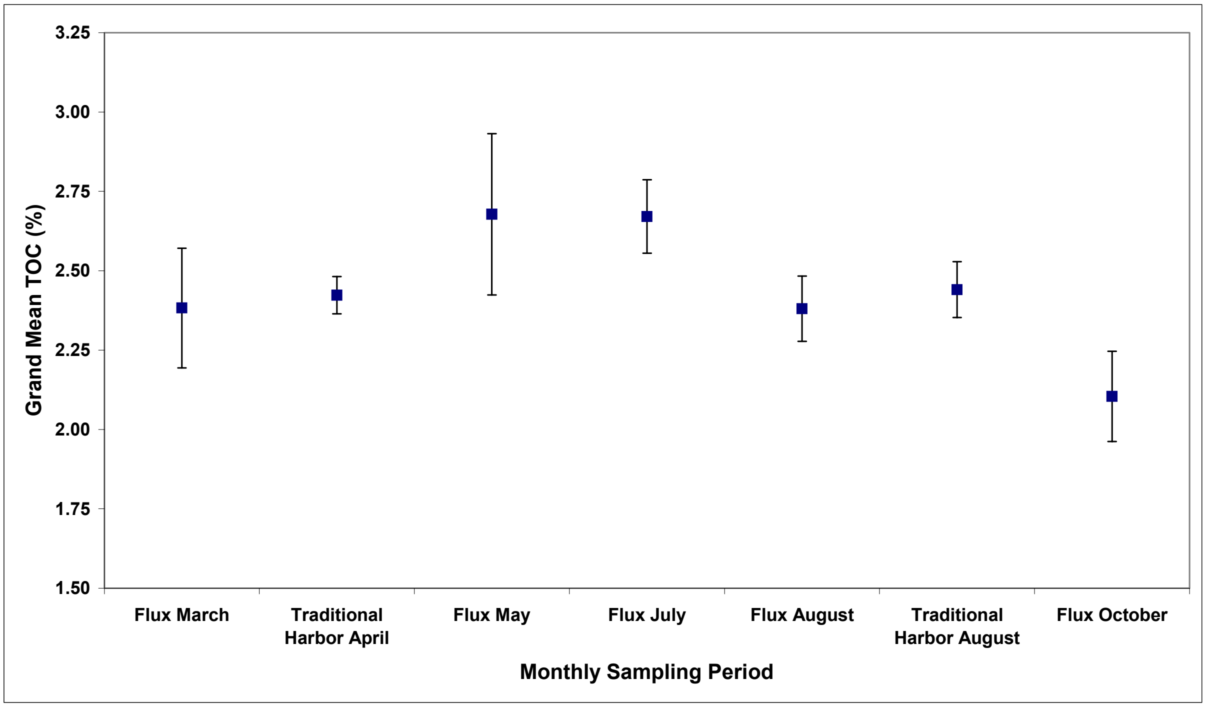

Figure 4-4. Comparison of grand mean TOC results from the flux program (BH02, BH03, only) to Traditional Harbor April and August (T02, T03 only), by sampling period (1993-2001).

4.2.3 *Clostridium perfringens* 1991–2001

April—The variability in *Clostridium perfringens* concentrations appeared to "settle down" over time and between 1998 and 2001 the system seemed to be much less variable (Figure 4-5a), possibly a result of major facility improvements implemented to clean-up Boston Harbor (*e.g.,* secondary treatment coming on-line in August 1997 and cessation of Nut Island discharges in July 1998). With the exception of stations T04 and T07, *Clostridium perfringens* concentrations decreased slightly in 2001 across all stations compared to 2000 values (Figure 4-5a, Appendix C-1).

Stations T01, T05A and T08 generally had the lowest *Clostridium perfringens* concentrations (< 8,500 cfu/g dw) relative to other Traditional stations (Figure 4-5a, Appendix C-1). In contrast, stations sampled in 1995 generally had the highest *Clostridium perfringens* concentrations relative to all other sampling years (Figure 4-5a, Appendix C-1). *Clostridium perfringens* concentrations in April 1996 generally appear unusually low at all stations except T08 (Figure 4-5a, Appendix C-1).

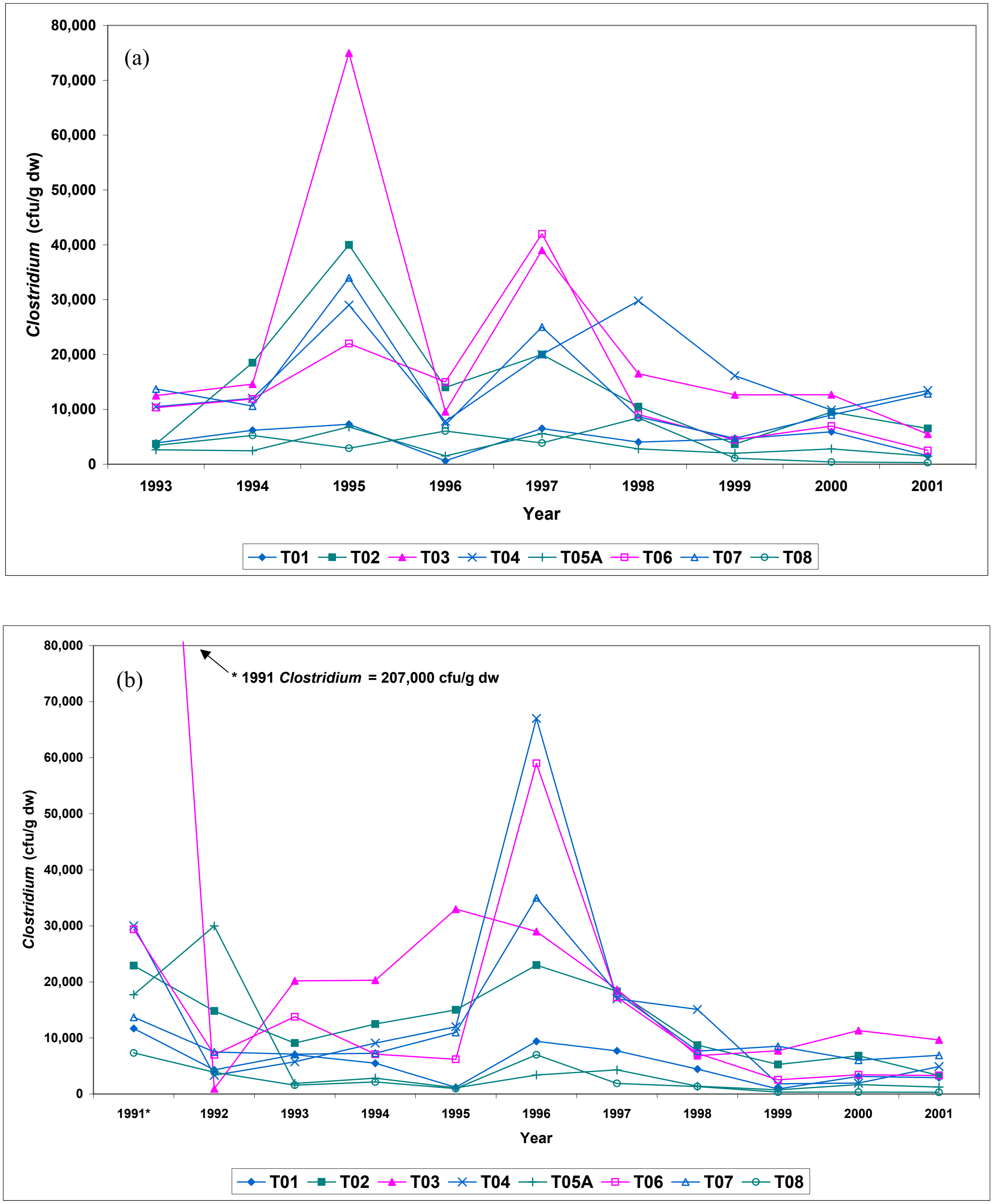

Figure 4-5. ***Clostridium perfringens*** **concentrations in sediments collected at Traditional stations in April 1993-2001(a) and September 1991 and August 1992-2001 (b).**

August—Consistent with April findings, the variability in *Clostridium perfringens* concentrations appeared to "settle down" between 1998 and 2001 and the system was more stable (Figure 4-5b), possibly a result of major facility improvements implemented to clean-up Boston Harbor. Further, *Clostridium perfringens* concentrations decreased slightly in 2001 at all stations, except T04 and T07, relative to 2000 values (Figure 4-5b, Appendix C-1). Variability in the August data was considerably higher at T04, T06 and T08 relative to April values (Table 4-2).

With few exceptions (*i.e.,* T01 in 1991; T05A in 1991 and 1992), stations T01, T05A and T08 generally had lower *Clostridium perfringens* concentrations (< 10,000 cfu) across all years relative to other Traditional stations (Figure 4-5b). In contrast, stations sampled in 1991 and 1996 generally had the highest *Clostridium perfringens* concentrations relative to all other sampling years (Figure 4-5b). *Clostridium perfringens* concentrations were high at station T03 in 1991, decreased to less than 1,000 cfu in 1992, increased again in 1993 and remained somewhat consistent until 1997 (20,000 to 30,000 cfu), decreased again in 1998 and remained fairly stable and low through 2001 (Figure 4-5b). While *Clostridium perfringens* concentrations at T03 in 1991 were high relative to other Traditional stations, the concentrations are not unusually high considering that sludge discharges were still ongoing.

Comparison of April and August Surveys—April and August station mean values (raw and normalized to percent fines and TOC) were determined for each sampling year and season. A scatter plot depicting April (x-axis) and August (y-axis) *Clostridium perfringens* concentrations was prepared to evaluate seasonal trends for common sampling years from 1993 to 2001 (Figure 4-6). With the exception of some stations in 1993 (*i.e.,* T01, T02, T03, T06) and all stations in 1996, *Clostridium perfringens* concentrations were consistently higher at most Traditional stations sampled in April relative to August values (Figure 4-6). *Clostridium perfringens* concentrations in April 1996 appear unusually low at all stations except T08.

To attempt to remove variability associated with changes in grain size and TOC, *Clostridium perfringens* concentrations were normalized to percent fines and TOC. Normalization did not improve the correspondence; in fact it degraded it, suggesting that *Clostridium perfringens* concentrations are independent of grain size and TOC factors (compare Figures 4-7 and 4-8 to 4-6).

4.2.4 Correspondence within Ancillary Measurements

Station mean values from all April and August surveys (Appendices C-2 and C-3) were included in the correlation analysis to evaluate the correspondence within bulk sediment properties and *Clostridium perfringens* over time (1991-2001). Correlation coefficients for April and August surveys were determined by sampling year across all stations and are presented in Appendix C-5. Results were consistent with findings presented in the 2000 Harbor Benthic Report (Kropp *et al,* 2002) except that the correspondence between *Clostridium perfringens* and bulk sediment properties improved (*e.g.,* higher r value) in August 2001 compared to August 1999-2000. Kropp *et al* (2002) showed that the correspondence between *Clostridium perfringens* and bulk sediment properties degraded after 1998 (August surveys), suggesting that independent processes were emerging resulting from a decrease in TOC to the system. August 2001 results did not support this evaluation in that the correspondence improved in 2001, rather then continuing to degrade.

In general, results from the correlation analysis showed that there was more variability in the system in the early 1990s, which is not unexpected given the proximity to source (harbor) (Appendix C-5). Further, T04 stood out as both a station with higher overall organic carbon content compared to other stations, and as a station influenced by storm events (*i.e.,* high TOC value in August 1998 after June storm), again

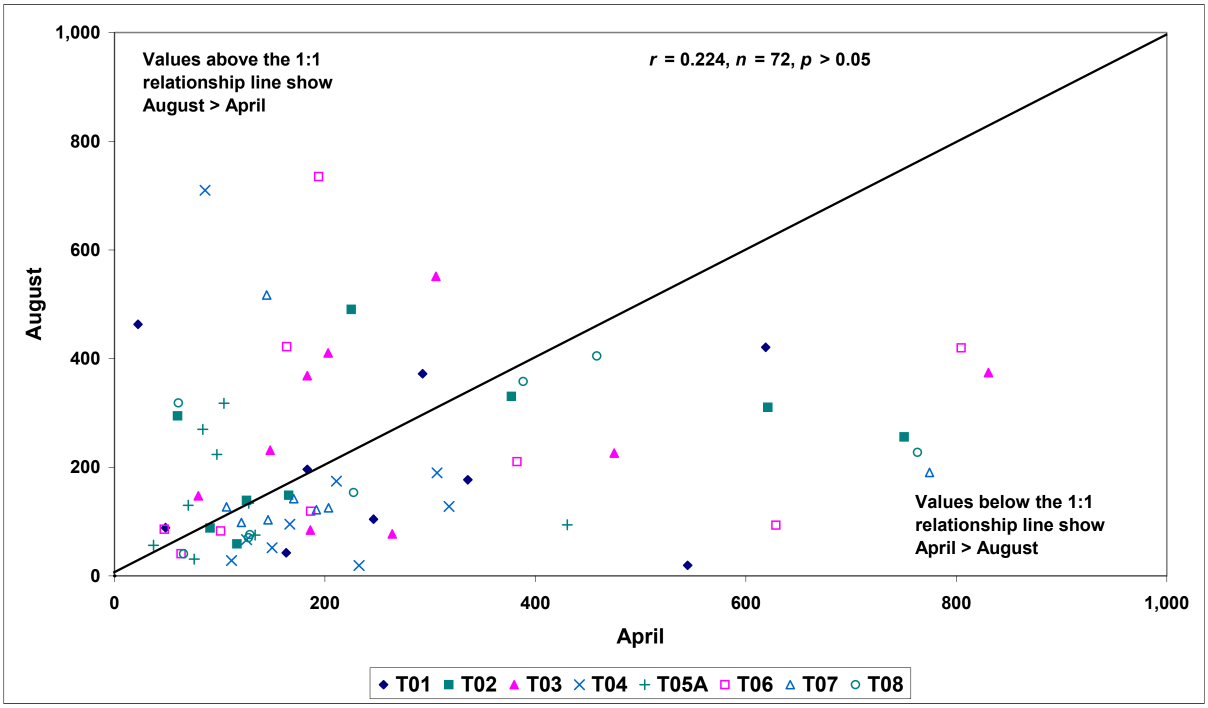

Figure 4-6. Comparison of April and August station mean values for *Clostridium perfringens* from 1993 to 2001.

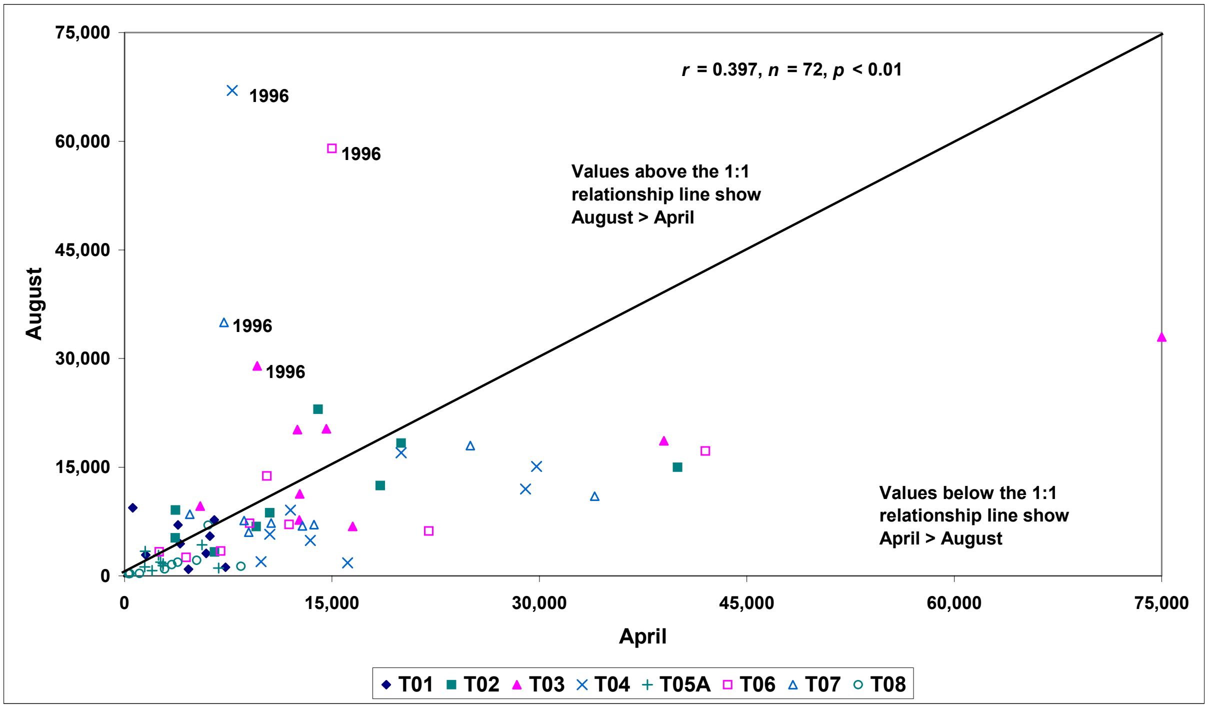

Figure 4-7. Comparison of April and August station mean values for *Clostridium perfringens* (normalized to percent fines) from 1993 to 2001.

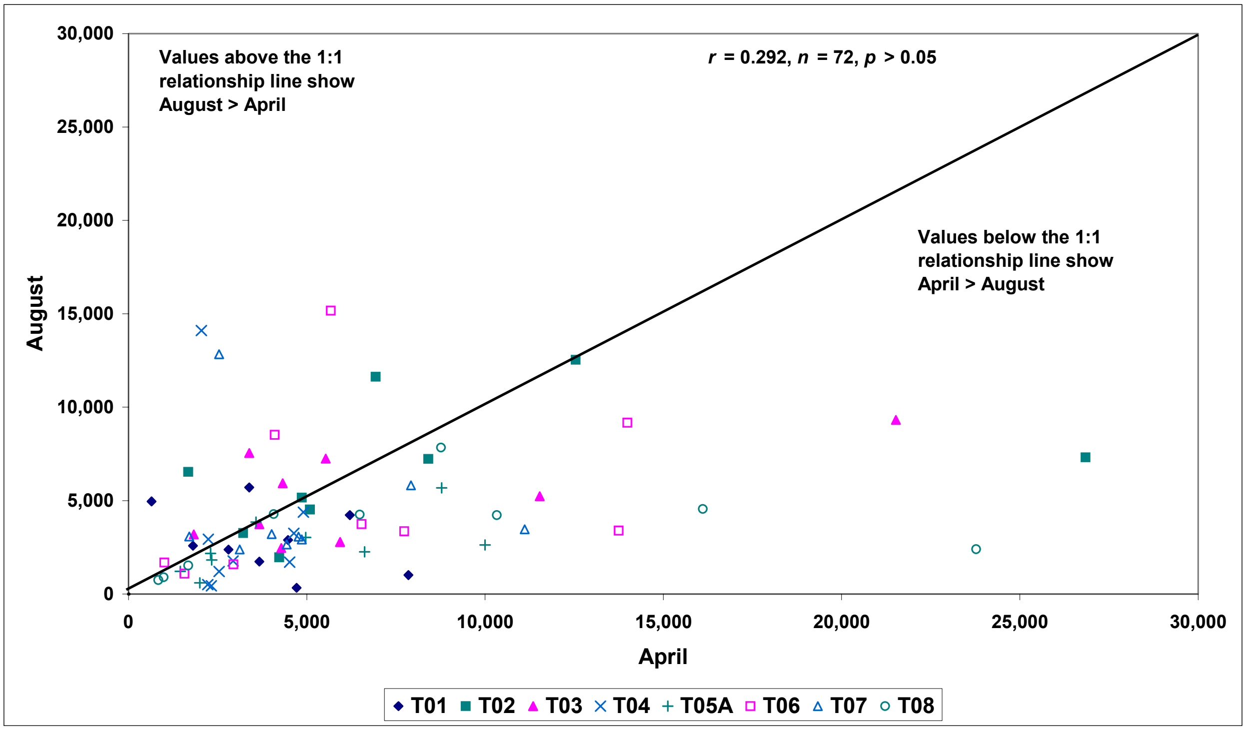

Figure 4-8. Comparison of April and August station mean values for *Clostridium perfringens* (normalized to TOC) from 1993 to 2001.

resulting in higher TOC concentrations. Higher TOC at T04 is not unexpected given that this station is 1) located near an area of combined sewer overflow (CSO) discharge and 2) is in an area of sediment focus/carbon deposition for the Harbor (Lefkovitz *et al,* 1999).

Based on these observations, the correlation analysis was repeated 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 facility improvements (*i.e.,* secondary treatment and cessation of Nut Island discharges). Data from September 1991 was also excluded because 1991 represented a period of sludge discharge to the Harbor, and inclusion of 1991 data would likely confound the correlation analysis. T04 was also excluded from the correlation analysis given that this station represents an area with highly localized source(s) (*e.g.,* CSO) compared to other Traditional stations.

Results from the correlation analysis showed that grain size remained strongly correlated to TOC during both sampling periods (pre-1998 and 1998-2001), indicating that grain size (percent fines) and TOC did not change much over time (Table 4-3). In contrast, the correspondence between *Clostridium perfringens* and bulk sediment properties (percent fines, TOC) is stronger after 1998 compared to earlier years (Table 4-3, Figure 4-9). This suggests that the factors controlling the variability (*i.e.,* percent fines, TOC) are more closely coupled to *Clostridium* after implementation of facility improvements. The correlation analysis also showed that the correspondence between *Clostridium perfringens* and bulk sediment properties was equally strong (RPD between r values <10%) between April and August surveys (Figure 4-9). This suggests that the system is more coherent in response, indicating that the processes that regulate carbon and *Clostridium perfringens* are more similar. Interestingly, these findings do not agree with the 2000 HBR (Kropp *et al,* 2002), which showed that the correspondence between *Clostridium perfringens* and bulk sediment properties was generally weaker in August relative to April. The weaker correspondence observed in August had been attributed to either 1) bioturbation and mixing of the surface

Table 4-3. Correspondence within bulk sediment properties and against *Clostridium perfringens* for April and August surveys, excluding Traditional station T04.

Sampling Period	TOC by Fines			*Clostridium perfringens* by Fines			*Clostridium perfringens* by TOC		
	r	*n*	*p*	*r*	*n*	*p*	*r*	*n*	*p*
April Surveys									
1993-2001[a]	0.847	61	<0.01	0.482	61	<0.01	0.537	61	<0.01
1993-1997[a]	0.845	33	<0.01	0.599	33	<0.01	0.621	33	<0.01
1998-2001	0.865	28	<0.01	0.743	28	<0.01	0.702	28	<0.01
August Surveys									
1992-2001	0.774	70	<0.01	0.468	70	<0.01	0.574	70	<0.01
1992-1997	0.791	42	<0.01	0.582	42	<0.01	0.612	42	<0.01
1998-2001	0.803	28	<0.01	0.794	28	<0.01	0.733	28	<0.01

[a] Grain size data for stations T07 and T08 in April 1997 are "anomalous"; results excluded from the correlation analysis.

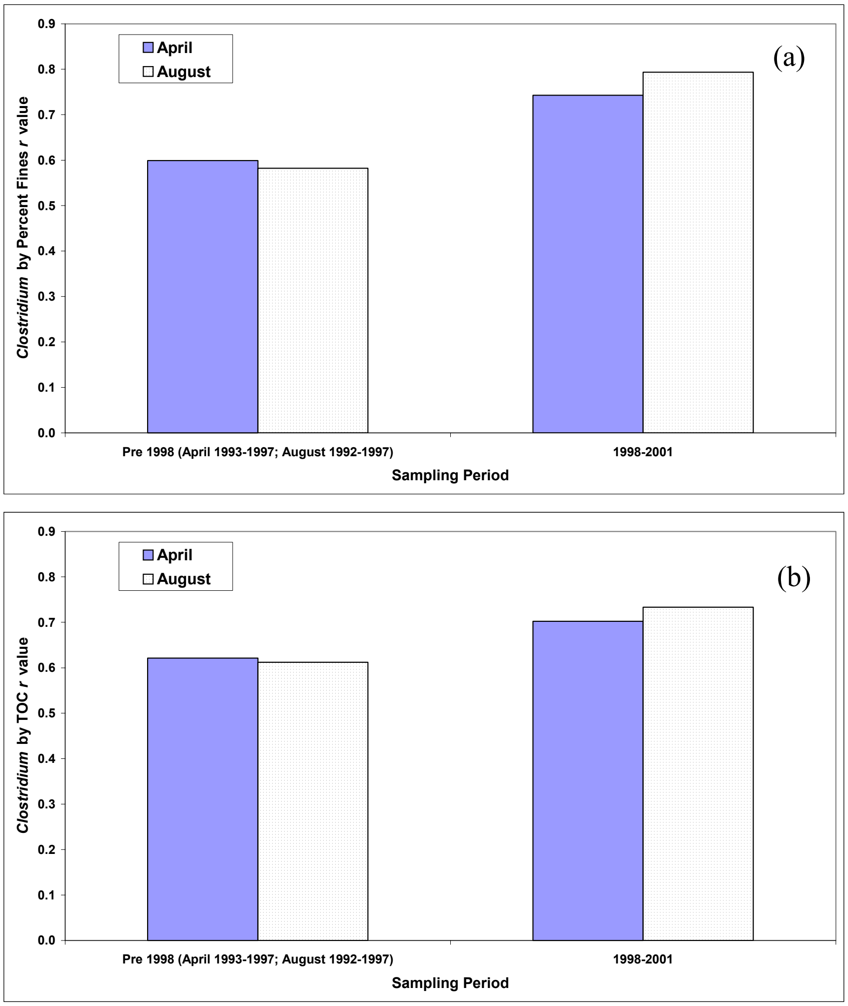

Figure 4-9. Comparison of Correlation Results (r values) between April and August surveys for *Clostridium perfringens* by Fines (a) and *Clostrium perfringens* by TOC (b).

sediment or 2) poorer response (*i.e.,* preservation) of the *Clostridium perfringens* spores in the warmer months. Had T04 been included in the correlation analysis, then the correspondence between *Clostridium perfringens* and bulk sediment properties would be weaker in August compared to April surveys (1998-2001). This suggests that inclusion of T04 confounded the correlation analysis.

4.3 Conclusions

Grain size – Patterns in sediment grain size composition in 2001 were within ranges observed during previous years, suggesting that the spatial and temporal characteristics of sediment grain size in 2001 were not substantially different from previous years (1991–2000). Patterns in sediment composition between April and August surveys were similar across all common sampling years.

In general, grain size and TOC was strongly correlated across all sampling years, indicating that grain size and TOC did not change much over time.

TOC – The spatial and temporal distribution of TOC concentrations during April and August surveys in 2001 was also not substantially different from 1991-2000 because of the high variability in the historical dataset.

There were no clear year-to-year trends in TOC between April and August surveys over time. However, an evaluation of Flux (BH02 and BH03 only) and Traditional Harbor (T02 and T03 only) TOC data did show a characteristic seasonal peak in TOC in May, indicative of inputs to the system from a winter/spring bloom. TOC values also showed a trend toward decreasing concentrations between July and October, likely reflecting TOC burn-off. More importantly, the seasonal peak in carbon content to the system cannot be measured from the Traditional Harbor surveys given that the peak does not occur until May and the Traditional Harbor surveys only occur in April and August.

Clostridium – Variability in *Clostridium perfringens* concentrations appeared to settle down over time and between 1998 and 2001 the system seemed to be more stable. In addition, the overall abundance of *Clostridium perfringens* spores appeared to decrease since 1998, suggesting that *Clostridium perfringens* has shown a response to facility improvements implemented to clean-up Boston Harbor (*e.g.,* secondary treatment and the cessation of Nut Island discharges), demonstrating that *Clostridium perfringens* have served as a good tracer.

The correspondence between *Clostridium perfringens* and bulk sediment properties was stronger after 1998, suggesting that the factors controlling the variability (*i.e.,* percent fines, TOC) are more closely coupled after implementation of facility improvements. In addition, the correspondence between *Clostridium perfringens* and bulk sediment properties was generally equally strong between April and August surveys (T04 excluded from correlation). This suggests that the system is more coherent in response, indicating that the processes that regulate carbon and *Clostridium perfringens* are more similar.

5.0 2001 SOFT-BOTTOM INFAUNAL COMMUNITIES

by Robert J. Diaz and Roy K. Kropp

5.1 Methods

5.1.1 Laboratory Analyses

Samples 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, small amounts of the sample were placed in glass dishes, and all organisms, including anterior fragments of polychaetes, were removed and sorted to major taxonomic categories such as polychaetes, arthropods, and mollusks. After samples were sorted, the organisms were sent to taxonomists for identification and enumeration. Identifications were made at the lowest practical taxonomic level, usually species by Tim Morris (Cove Corporation; polychaetes, crustaceans, miscellaneous taxa), Nancy Mountford (Cove Corporation; polychaetes and molluscs), and Russ Winchell (Ocean's Taxonomic Services; oligochaetes).

Four samples (station T02 rep 1, station T02 rep 2, station T03 rep 2, and station T05A, rep 1) collected during the Summer 2001 survey (HT012) were noted to contain animals that were in poor condition. Data quality for these four samples could be affected because the abundance of certain taxa (especially soft bodied animals such as polychaetes) may be underestimated and animals in poor condition often cannot be identified to a species level. The sample from station T05A (rep 1) contained the most animals in poor condition. Particularly affected were cirratulid polychaetes.

5.1.2 Data Analyses

Preliminary Data Treatment — Prior to performing any of the analyses of the 2001 and 1991–2001 MWRA datasets, several modifications were made. Several non-infaunal taxa were excluded (listed in Appendix D-1). Data for a few taxa were pooled. Usually this involved pooling data for a taxon identified to a level higher than species (*e.g.*, genus) with those data for a species within the higher taxon. This pooling was done only when only a single species of the higher taxon was identified. For example, *Unciola irrorata* (an amphipod) was the only species of the genus found in the Harbor, so that any amphipods identified only to the genus (*Unciola* spp.) were treated as if they were *U. irrorata*. Because the identification of some taxa has been inconsistent through the duration of the project, data for some species were pooled to a higher-level taxon. For example, the names *Pholoe minuta* and *Pholoe tecta* have not been used consistently throughout the program. Therefore, data for the two were merged (along with *Pholoe* spp.) and referred to as *Pholoe minuta* for all analyses. All such changes are listed in Appendix D-1.

Faunal data treatments in this report largely follow those used in the 1999 harbor monitoring report (Kropp *et al.* 2001). All analyses performed in this report that involve multi-year comparisons were performed on a unified dataset that was treated consistently. Therefore, all comparisons within this report are internally consistent.

Diversity Analysis — The software package BioDiversity Professional, Version 2 (© 1997 The Natural History Museum / Scottish Association for Marine Science) was used to perform calculations of total species, log-series alpha, Shannon's Diversity Index (H'), the maximum H' (Hmax), and Pielou's Evenness (J'). Shannon's H' was calculated by using $\log_2$ because that is closest to Shannon's original intent. Pielou's (1966) J', which is the observed H' divided by Hmax, is a measure of the evenness component of diversity. BioDiversity Pro is available at http://www.sams.ac.uk/dml/projects/benthic/bdpro/indep.htm. Magurran (1988) describes all of the diversity indices used here.

5.1.3 Total Species Richness Analysis

The general approach outlined by Brown *et al.* (2001) was used to examine total species richness in the Boston Harbor system (*i.e.*, all stations combined). The purpose of this analysis was to detect large-scale patterns in species richness that might offer insights not available from analyses performed at smaller scales (*i.e.*, per sample). The approach used for the 2001 analysis was the same as that used of the 2000 analysis (Kropp *et al.* 2002).

5.1.4 Cluster & Ordination

Cluster analyses were preformed with the program COMPAH96 (available on E. Gallagher's web page, http://www.es.umb.edu/edgwebp.htm), originally developed at the Virginia Institute of Marine Science in the early 1970's. The station and species cluster groups were generated using unweighted pair group mean average sorting (UPGMA) and chord normalized expected species shared (CNESS) to express similarity (Gallagher 1998). For calculation of CNESS the random sample size constant (*m*) was set to 15 for the 2001 data and to 20 for the combined analysis of 1991–2001 data (Kropp *et al.* 2002). For the species analysis, similarity was calculated from normalized hypergeometric standardization of Pearson's product moment correlation coefficient (*r*). In the combined year analysis, 1991–2001, the three replicate grabs for a station were summed. At Station T04 in spring 1995 and T03 in Summer 2000 there were only two replicates, so the two replicates were summed and multiplied by 1.5.

5.2 Results and Discussion

5.2.1 2001 Sample Handling Problem

The sorting laboratory reported that four samples (station T02 rep 1, station T02 rep 2, station T03 rep 2 and station T05A, rep 1) collected during the Summer 2001 survey (HT012) were noted to contain animals that were in poor condition. Three of the affected replicates (T02 rep 2, T03 rep 2, T05A, rep 1) had the lowest abundances at their respective stations. Two affected samples (T02 rep 2 and T05A rep 1) also had the fewest species at their respective stations. However, station T02, replicate 2 had the highest abundance and species numbers at that station. Variation, measured as the coefficient of variation (CV), among the replicates at these three stations ranged from 33% (T05A) to 96% (T02), which was similar to the variation observed at other stations (e.g., at T04, CV = 125%). Bray-Curtis similarity (with group average sorting) showed that each affected replicate retained the compositional characteristics of its respective station. That is, each was more similar to other replicates at the same station than to replicates from other stations. As was determined for the 2000 handling problem (Kropp *et al.* 2002), the potential impact of the preservation problem can't be completely discounted, but after this review the data from the affected samples were considered usable.

5.2.2 2001 Descriptive Community Measures

Abundance — Among individual Harbor samples collected in Spring 2001, infaunal abundance varied about 28-fold, ranging from 271 to 7,502 individuals/0.04 m^2 (6,775–187,550/m^2) at stations T04 (rep 1) and T03 (rep 1), respectively (Table 5-1). Mean (and standard deviation, SD) abundance per sample in Spring ranged from 374 (SD = 69.6) to 7,114 (SD = 580.2) individuals/0.04 m^2 at stations T01 and T03, respectively (Table 5-1; Figure 5-1).

Table 5-1. Descriptive ecological parameters for samples collected from Boston Harbor in Spring 2001.

	Abundance Total	Abundance Species[a]	Species	*H'*	*J'*	Log-series Alpha			Abundance Total	Abundance Species[a]	Species	*H'*	*J'*	Log-series Alpha
T01-1	345	294	38	3.51	0.67	11.6		T01	374	321	37	3.61	0.69	10.8
T01-2	453	399	36	3.43	0.66	9.6		T02	510	455	31	3.42	0.69	7.6
T01-3	323	269	36	3.88	0.75	11.2	Mean	T03	7114	7087	42	2.69	0.50	5.9
T02-1	622	568	36	3.44	0.67	8.6		T04	436	394	11	1.81	0.52	2.3
T02-2	410	363	29	3.33	0.69	7.4		T05A	1661	1498	46	3.62	0.66	9.1
T02-3	498	434	28	3.47	0.72	6.7		T06	6620	6611	40	2.86	0.54	5.6
T03-1	7,502	7479	43	2.58	0.48	6.0		T07	1666	1621	30	2.22	0.45	5.3
T03-2	6,447	6413	45	2.72	0.5	6.5		T08	1342	1292	44	3.29	0.60	8.7
T03-3	7,393	7370	38	2.76	0.53	5.3								
T04-1	271	240	10	1.64	0.49	2.1		T01	69.6	69.0	1.2	0.24	0.05	1.06
T04-2	327	259	12	2.01	0.56	2.6		T02	106.5	104.1	4.4	0.07	0.03	0.94
T04-3	711	683	12	1.78	0.5	2.1	std dev	T03	580.2	586.5	3.6	0.09	0.03	0.65
T05A-1	1,134	1041	37	3.47	0.67	7.5		T04	239.5	250.5	1.2	0.19	0.04	0.30
T05A-2	1,267	1133	53	3.66	0.64	11.5		T05A	799.8	713.4	8.1	0.13	0.02	2.13
T05A-3	2,581	2320	47	3.72	0.67	8.4		T06	768.7	764.6	2.1	0.06	0.02	0.28
T06-1	5,862	5855	39	2.83	0.54	5.6		T07	507.3	506.9	5.1	0.22	0.06	0.77
T06-2	6,599	6594	38	2.92	0.56	5.3		T08	298.0	290.6	6.1	0.44	0.08	1.09
T06-3	7,399	7384	42	2.82	0.52	5.9								
T07-1	2,251	2206	36	2.06	0.40	6.1		T01	19	22	3	7	7	10
T07-2	1,394	1344	26	2.13	0.45	4.6		T02	21	23	14	2	4	12
T07-3	1,352	1313	29	2.47	0.51	5.3	CV	T03	8	8	9	4	5	11
T08-1	1,544	1492	45	2.81	0.51	8.8		T04	55	64	10	10	7	13
T08-2	1,000	959	37	3.36	0.65	7.7		T05A	48	48	18	4	2	23
T08-3	1,483	1426	49	3.69	0.66	9.8		T06	12	12	5	2	3	5
								T07	30	31	17	10	12	15
								T08	22	22	14	13	13	12

[a] Includes only individuals identified to species

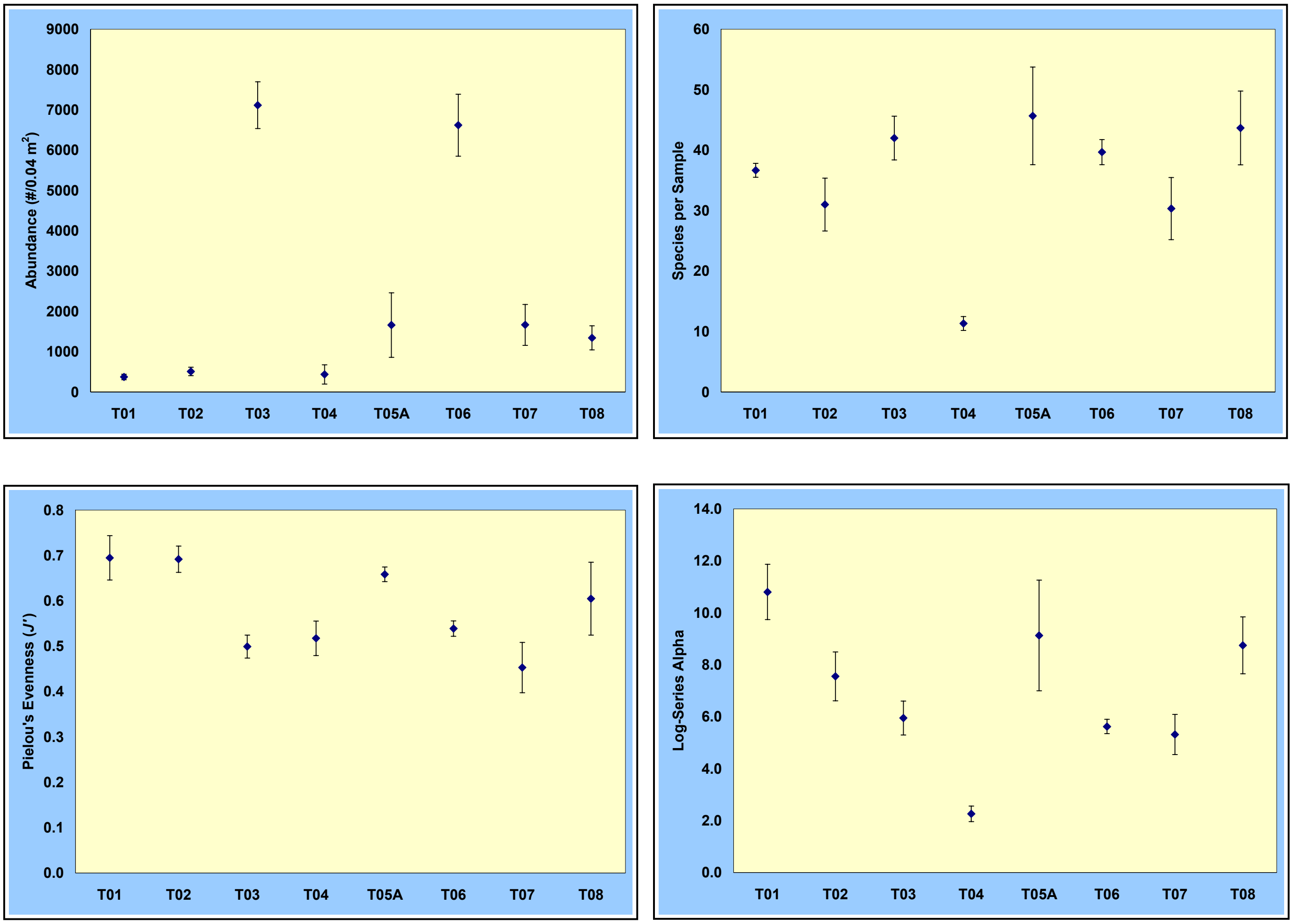

Figure 5-1. Mean (and standard deviation) for Infaunal abundance, numbers of species, evenness, and log-series alpha values for Boston Harbor samples collected in April 2001.

Among the Summer samples, infaunal abundance was very low and somewhat variable at station T04 (Table 5-2), ranging from 10 to 93 individuals per sample (mean = 38, standard deviation = 47.6). Among the remaining 7 stations, infaunal abundance varied about 43-fold, ranging from 251 to 10,796 individuals/0.04 m^2 (6,275–269,900/m^2) at stations T02 (rep 1) and T03 (rep 3), respectively (Table 5-2). Mean (SD) abundance per sample in Summer (excluding station T04) ranged from 1,626 (1,015.5) to 7,137 (3,265.0) individuals/0.04 m^2 at stations T08 and T03, respectively (Table 5-2; Figure 5-2).

Numbers of Species — The number of species found at Station T04 in Spring 2001 was low, 10–12 per replicate (mean = 11, SD = 1.2). Among the remaining stations, the total numbers of species per sample collected in Spring 2001 ranged from 26 to 53 at stations T07 (rep 2) and T05A (rep 2), respectively (Table 5-1). Mean (SD) numbers of species per sample (excluding Station T04) ranged from 30 (5.1) to 46 (8.1) species at stations T07 and T05A, respectively (Table 5-1; Figure 5-1).

The number of species found at station T04 in Summer 2001, was very low, 3–5 per replicate (mean = 4, SD = 1.2; Table 5-2). Among the remaining Harbor stations, the total numbers of species per sample collected in Summer ranged from 22 to 72 at stations T07 (rep 3) and T08 (rep 3), respectively (Table 5-2). In Summer, mean (SD) numbers of species per sample (excluding station T04) ranged from 28 (6.5) to 55 (1.5) species at stations T07 and T05A, respectively (Table 5-2; Figure 5-2).

Diversity — As measured by the traditional Shannon index (*H′*), diversity among Boston Harbor samples collected in Spring 2001 varied from about 1.6 at station T04 (rep 1) to about 3.9 at station T01 (rep 3; Table 5-1). Evenness (*J′*) among Harbor samples ranged from 0.4 to 0.8 (stations T07, rep 1 and T01, rep 3, respectively). Within-station variation was low (CV ≤13) at all stations (Table 5-1; Figure 5-1). Log-series alpha varied considerably among Harbor stations, ranging from 2.1 at station T04 (reps 1 and 3) to 11.6 at station T01 (rep 1). Mean (SD) log-series alpha per station ranged from 2.3 (0.30) at station T04 to 10.8 (1.06) at station T01, respectively (Table 5-1; Figure 5-1). Within-station variation in log-series alpha among the Harbor stations was relatively low at most stations (CV ≤15) (Table 5-1; Figure 5-1).

Diversity (*H′*) among individual Boston Harbor samples collected in Summer 2001 varied from 0.29 at station T04 (rep 1) to about 3.9 at station T08 (rep 1; Table 5-2). In Summer, evenness among Harbor samples except T04 (rep 1) ranged from 0.4 to 0.9. Within-station variation was low (CV ≤11) at most stations except T04 (CV = 61) (Table 5-2; Figure 5-2). Log-series alpha varied considerably among Summer samples, ranging from 0.6 at station T04 (rep 1) to 13.9 at station T08 (rep 3). Mean (SD) log-series alpha per station ranged from 2.0 (1.76) at station T04 to 10.8 (3.17) at station T08, respectively (Table 5-2; Figure 5-2). Within-station variation in log-series alpha among the Summer samples was highest at stations T04 (CV = 88), but was generally low (CV < 20) at most other stations (Table 5-2; Figure 5-2).

Most Abundant Species — The 12 most abundant species found at each Harbor station in Spring and Summer 2001 are listed in Appendix D-2. Perhaps the most noticeable observation in the most abundant species in Spring 2001 versus that in previous year was the relative stability of the taxa comprising the list. At all but one station (station T05A), 8 of the top 12 taxa in 2001 were also among the most abundant in 2000. Station T04 showed uncharacteristic compositional stability. In 2000, only 3 of the top 12 taxa were also among the most abundant in 1999, whereas in 2001 8 of the top 12 taxa were listed in 2000. *Tubificoides* sp. 2 remained the predominant species at station T01 and was the second most abundant at station T02. Mean abundance of *Tubificoides* sp. 2 at station T01 was 124.0 (SD = 34.2) individuals/0.04 m^2. *Tubificoides* sp. 2 also occurred at station T04.

Table 5-2. Descriptive ecological parameters for samples collected from Boston Harbor in Summer 2001.

	Abundance Total	Abundance Species[a]	Species	*H'*	*J'*	Log-series Alpha			Abundance Total	Abundance Species[a]	Species	*H'*	*J'*	Log-series Alpha
T01-1	1396	1309	39	3.3	0.63	7.6		T01	1868	1781	41	3.23	0.60	7.5
T01-2	1658	1576	44	3.48	0.64	8.4		T02	1704	1679	32	3.04	0.62	6.2
T01-3	2551	2459	39	2.90	0.55	6.6	Mean	T03	7137	7097	36	2.80	0.54	5.1
T02-1	251	237	24	3.60	0.79	6.7		T04	38	37	4	1.17	0.60	2.0
T02-2	3466	3428	40	2.64	0.50	6.4		T05A	6061	5900	55	2.56	0.44	8.4
T02-3	1394	1371	31	2.88	0.58	5.6		T06	6258	6253	39	3.28	0.62	5.7
T03-1	6096	6057	41	2.72	0.51	5.9		T07	1892	1747	28	2.40	0.50	4.8
T03-2	4520	4477	31	2.84	0.57	4.5		T08	1626	1483	53	3.82	0.68	10.8
T03-3	10796	10758	37	2.83	0.54	4.8								
T04-1	93	92	3	0.29	0.19	0.6		T01	605.5	601.9	2.9	0.30	0.05	0.91
T04-2	11	10	3	1.16	0.73	1.5		T02	1629.7	1617.6	8.0	0.50	0.15	0.53
T04-3	10	10	5	2.05	0.88	4.0	std dev	T03	3265.0	3267.2	5.0	0.07	0.03	0.75
T05A-1	3804	3603	53	2.30	0.40	8.8		T04	47.6	47.3	1.2	0.88	0.37	1.76
T05A-2	7491	7370	55	2.55	0.44	8.1		T05A	1977.9	2015.3	1.5	0.26	0.04	0.37
T05A-3	6889	6728	56	2.83	0.49	8.4		T06	1583.7	1586.2	1.2	0.06	0.02	0.42
T06-1	6288	6280	40	3.22	0.61	5.7		T07	577.0	493.5	6.5	0.34	0.04	1.25
T06-2	7827	7826	38	3.34	0.64	5.2		T08	1015.5	863.0	18.5	0.09	0.07	3.17
T06-3	4660	4654	40	3.29	0.62	6.0								
T07-1	1844	1721	35	2.78	0.54	6.2		T01	32	34	7	9	8	12
T07-2	2492	2253	28	2.26	0.47	4.5		T02	96	96	25	16	24	8
T07-3	1341	1267	22	2.15	0.48	3.8	CV	T03	46	46	14	3	6	15
T08-1	795	750	35	3.90	0.76	7.6		T04	125	127	31	75	61	88
T08-2	1325	1264	52	3.72	0.65	10.9		T05A	33	34	3	10	10	4
T08-3	2758	2434	72	3.84	0.62	13.9		T06	25	25	3	2	3	7
								T07	30	28	23	14	8	26
								T08	62	58	35	2	11	29

[a] Includes only individuals identified to species

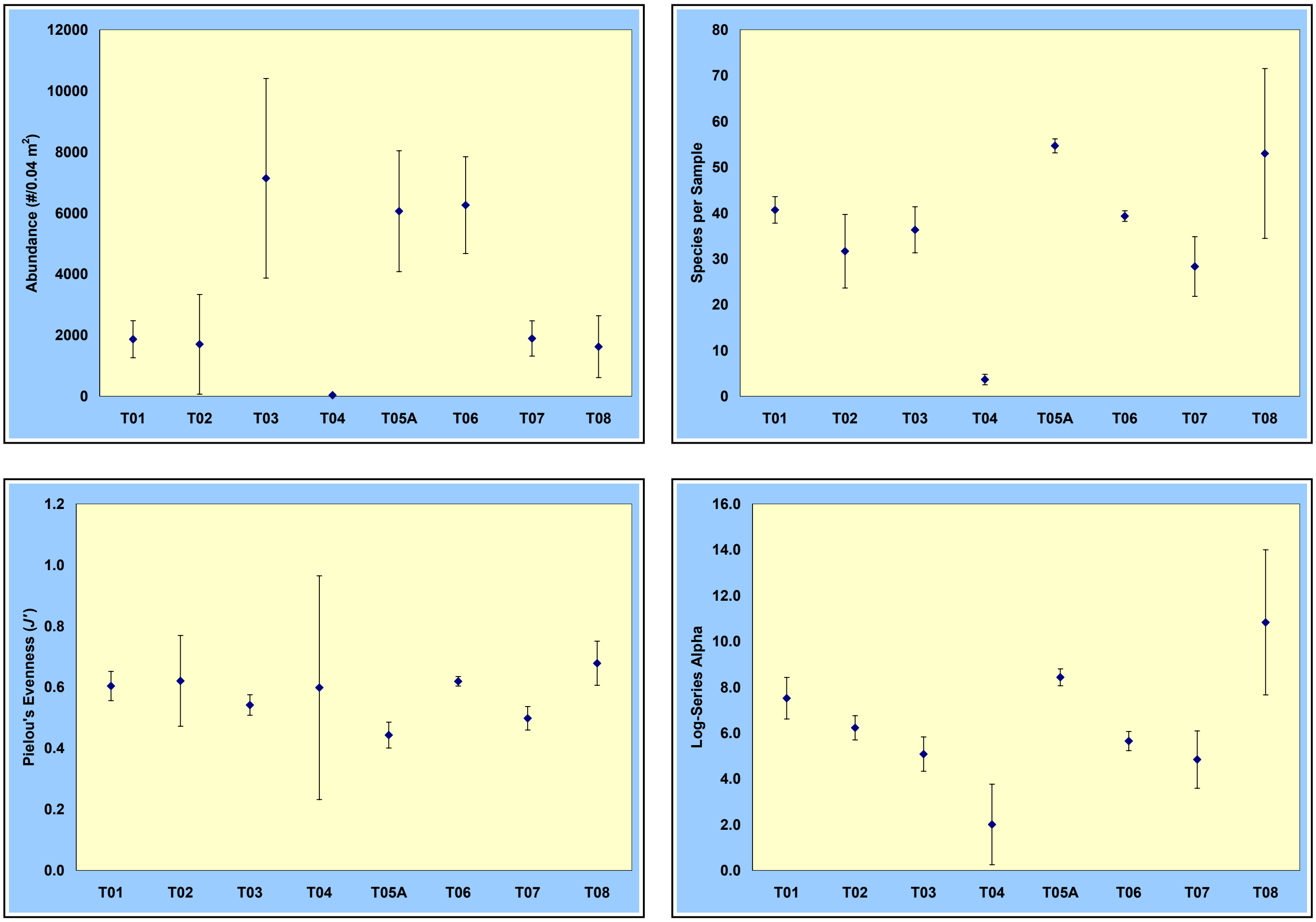

Figure 5-2. Mean (and standard deviation) for Infaunal abundance, numbers of species, evenness, and log-series alpha values for Boston Harbor samples collected in August 2001.

Two species of oligochaete worms, *Tubificoides apectinatus* and *T*. nr. *pseudogaster*, were important contributors to abundances at many of the Harbor stations. *T. apectinatus* was the top-ranked species at station T02 and occurred among the top 12 at 5 of the remaining 7 stations. *T*. nr. *pseudogaster* occurred among the 12 most abundant species at 5 of the 8 stations. The polychaete *Capitella capitata* complex (48.5%) was the most abundant species at station T04, as it was in 2000 (Appendix D-2). This opportunistic polychaete also was the most abundant species at stations T05A in the Spring 2001. The amphipod taxon *Ampelisca* spp. was the most abundant taxon at stations T03, T06, and T07. It also ranked among the top 12 at stations T02, T05A, and T08. One of the most surprising new appearances of a taxon among the most abundant species was the occurrence of the amphipod *Pontogeneia inermis* as the third most abundant species at station T01. In Spring 2001, the 12 most abundant taxa accounted for about 84–100% of the infaunal abundance at each station.

As in several of the previous years of the study, the relative numerical importance of the spionid polychaete, *Polydora cornuta*, was much greater in Summer than in Spring 2001. *P. cornuta* was the most abundant species at stations T01 and T02 and ranked among the 12 most abundant species at stations T03, T06, and T07. In Spring 2001, *P. cornuta* ranked among the top 12 only at station T03 (12th) and T04 (8th). The amphipod *Ampelisca* spp. was the most abundant taxon at stations T03, T05A, and T06 and ranked among the 12 most abundant species at all other stations except station T04. Its numerical dominance at station T05A in Summer 2001 contrasts to that in Summer 2000 when the taxon was not among the 12 most abundant taxa. The abundance of Ampelisca spp. in Summer 2001 was 3,626.3 (sd = 1,126.8) individuals/0.04 m^2, as compared to 3.0 (sd = 1.0) individuals/0.04 m^2 in Summer 2000 (Kropp *et al*. 2002). As in Summer 1999 and 2000, station T04 was numerically dominated by *Streblospio benedicti*, which comprised about 88 % of its total infaunal abundance. In Summer, the 12 most abundant taxa accounted for about 84–100% of the infaunal abundance at each station.

5.2.3 2001 Harbor Multivariate Analysis

Station Patterns — Station cluster analysis of infaunal data based on summed replicates and all 151 taxa that occurred in 2001 indicated that station patterns were similar to 2000 (see Kropp *et al*. 2002). Seasonality (spring to summer) was not a strong determinant of station clusters with no cluster group being exclusively one season, except the single station group IV that was Station T01 in the spring (Figure 5-3). In the summer, a strong recruitment by dominant species (*Ampelisca* spp., *Tubificoides* nr. *pseudogaster*, *Aricidea catherinae*, *Polydora cornuta*, and *Leptocheirus pinguis*) caused Station T01 to align with group II Stations T02 and T07. Stations T02 or T07 also experienced strong recruitment for all of these species except *Tubificoides* nr. *pseudogaster*. There was little seasonal variation at Stations T03 and T06 with both spring and summer samples from these stations joined together in group I. This was also the case for Station T08 that was in group III. Seasonal samples split between station groups for Station T05A with spring samples in group III and summer samples in group I (Figure 5-3).

While the community structure differences between spring and summer at Station T04, in inner Dorchester Bay, were most pronounced of all stations, seasonal variation in community structure was still less then between station variation. Spring and summer T04 samples joined to form group V at a dissimilarity of 1.0 and joined with the other four groups at a dissimilarity of 1.3 (Figure 5-3). This degree of separation between the stations in the cluster analysis was indicative of the varied benthic habitats found within the harbor. Station T04 with muddy high organic content sediments and at times exposed to hypoxic conditions continued to be the most dissimilar of all stations and formed the last group to join the dendrogram with the greatest difference in CNESS dissimilarity. Its removal from the analysis did not change the relationship between any of the other seven stations.

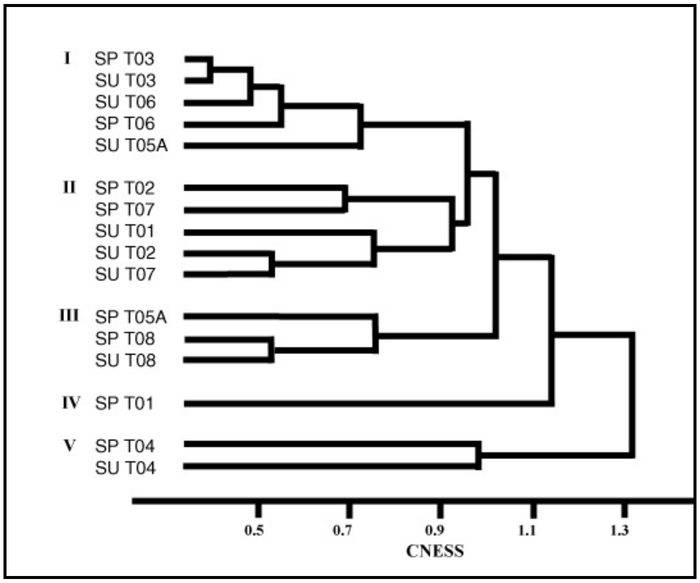

Figure 5-3. Dendrogram for Boston Harbor 2001 infauna, summed replicates with Gallagher's CNESS (*m* = 15) and group average (UPGMA) sorting.

Overall, the cluster grouping of stations primarily reflected the infaunal community response to physical parameters (primarily sediment properties and depth) and associated stressors (organic loading), and secondarily seasonality. Group III was composed of coarser sediment stations T08 in President Roads and spring T05A in Hingham Bay with amphipod tube mats but lower community structure statistics. Group I had the highest community structure values with summer T05A and Stations T03 and T06. The OSI of group I was the highest for all station groups with surface sediments dominated by biological processes with successional Stage II and III communities. Group II was intermediate in community structure with summer T01 and Stations T02 and T07. The OSI indicated that group II stations were moderately stressed with successional stage I to II fauna dominating. Group IV was only spring at Station T01, which had lower abundance relative to the other spring stations. Few of the top 20 numerical dominant species occurred at Station T01 in the spring. Group V was T04, the most stressed (shallowest water depth and RPD layer, and highest TOC) of all the stations with the lowest community structure values (Figure 5-3).

Species Patterns — For the species pattern analysis only taxa with >3 occurrences (73 of 151) were included. At this cut level there was no change in the stations group patterns compared to the analysis with all taxa included. This indicated the dominance exerted by the common taxa over community structure patterns. Five primary species groups formed at about the -0.1 CNESS dissimilarity level with groups D and E containing the top 10 numerical dominants. Groups A, B, and C contained the subdominants (from 11 to 20 in total abundance). Each of the groups contained less abundant taxa (<200 individuals for all grabs) but most of the less common taxa were in group A (Figure 5-4 and Table 5-3).

```
A    Turbellaria spp.                   -----------------------------I
A    Microphthalmus pettiboneae         --------------------I        I--I
A    Tubificoides sp. 2                 --------------------I--------I  I
A    Cerebratulus lacteus               -----I                          I-----------------I
A    Micrura spp.                       -----I--I                       I                 I
A    Mediomastus californiensis         --------I-----------------------I                 I
A    Nemertea sp. 2                     -----I                                            I
A    Pandora gouldiana                  -----I-----I                                      I
A    Ampharete finmarchica              -----------I--I                                   I
A    Proceraea cornuta                  --I           I                                   I
A    Pontogeneia inermis                --I           I                                   I
A    Monocorophium acherusicum          --I           I                                   I--------------I
A    Nephtys caeca                      --I           I--I                                I              I
A    Pygospio elegans                   --I--------I  I  I                                I              I
A    Ischyrocerus anguipes              --I        I  I  I                                I              I
A    Dipolydora socialis                -----I     I  I  I--------------I                 I              I
A    Dipolydora quadrilobata            -----I-----I--I  I              I                 I              I
A    Diastylis sculpta                  -----------I     I              I--I              I              I
A    Ninoe nigripes                     -----------------I              I  I              I              I
A    Tharyx spp.                        --------------------------------I  I--------------I              I
A    Exogone hebes                      --------------------------I        I                             I
A    Cancer irroratus                   --------------------------I--------I                             I
B    Harmothoe imbricata                -----------------------------I                                   I
B    Aglaophamus circinata              -----I                       I                                   I-----I
B    Prionospio steenstrupi             -----I-----I                 I--------------I                    I     I
B    Pherusa affinis                    -----------I-----I           I              I                    I     I
B    Lyonsia arenosa                    -----------------I-----------I              I                    I     I
B    Parougia caeca                     --I                                         I                    I     I
B    Polycirrus eximius                 --I--I                                      I--------------I     I     I
B    Nucula delphinodonta               -----I                                      I              I     I     I
B    Phoronis architecta                -----I-----I                                I              I     I     I
B    Spiophanes bombyx                  -----------I--------------I                 I              I-----I     I
B    Polygordius sp. A                  --------------------I     I-----------------I              I     I     I
B    Tellina agilis                     --------------------I-----I                                I     I     I
B    Clymenella torquata                -----------------------------------------------------------I     I     I
C    Pholoe minuta                      --------------------------I                                      I     I
C    Eteone longa                       -----------------------I  I--------------------------------I     I     I
C    Cirriformia grandis                --------------I        I--I                                I     I     I--I
C    Chaetozone cf. setosa              -----------I  I--------I                                   I     I     I  I
C    Grania postclitel. longiducta      -----I     I--I                                            I-----I     I  I
C    Tubificoides benedeni              -----I-----I                                               I           I  I
C    Streblospio benedicti              -----------------------------------------------I           I           I  I
C    Capitella capitata complex         -----------------I                             I-----------I           I  I
C    Ilyanassa trivittata               -----------------I-----------------------------I                       I  I
D    Neanthes virens                    -----------------------I                                               I  I
D    Aricidea catherinae                -----------------------I--------I                                      I  I
D    Leitoscoloplos robustus            -----I                          I-----I                                I  I
D    Mya arenaria                       -----I--------------------------I     I-----------------I              I  I
D    Scoletoma hebes                    --------------------------------------I                 I              I  I
D    Nephtys ciliata                    --------------I                                         I              I  I
D    Spio thulini                       --------------I--------------------I                    I--------------I  I
D    Polydora cornuta                   -----I                             I--------I           I                 I
D    Leptocheirus pinguis               -----I-----------------------------I        I           I                 I
D    Nephtys cornuta                    --------------------------I                 I-----------I                 I
D    Tubificoides apectinatus           --------------------------I-----------------I                             I
E    Amphiporus cruentatus              --------------I                                                           I
E    Photis pollex                      --I           I-----I                                                     I
E    Orchomenella minuta                --I-----------I     I                                                     I
E    Tubificoides nr. pseudogaster      -----------I        I--------------I                                      I
E    Phoxocephalus holbolli             -----------I--------I              I                                      I
E    Mysella planulata                  --------------I                    I-----I                                I
E    Petricola pholadiformis            -----------I  I--------------I     I     I                                I
E    Crassicorophium bonelli            -----------I--I              I-----I     I--------------I                 I
E    Dyopedos monacanthus               -----------------------------I           I              I                 I
E    Ampelisca spp.                     -----------------------------------------I              I                 I
E    Phyllodoce mucosa                  -----------------I                                      I                 I
E    Phyllodoce maculata                -----------------I--------------I                       I-----------------I
E    Chaetozone vivipara                -----I                          I                       I
E    Cerastoderma pinnulatum            --I  I-----I                    I                       I
E    Hiatella arctica                   --I--I     I                    I-----------------------I
E    Edotia triloba                     --I        I--I                 I
E    Unciola irrorata                   -----------I  I-----------------I
E    Ensis directus                     --------------I
                                        0.95        0.77           0.55           0.33           0.12           -.10
                                                                               CNESS
```

Figure 5-4. Species dendrogram for Boston Harbor 2001 infauna, summed replicates with Gallagher's CNESS (*m* = 15) and group average (UPGMA) sorting. Taxa with 3 or fewer occurrences were dropped.

Table 5-3. Abundance (#/0.12 m^2) of the 51 species that had an abundance >100 or occurred at >7 stations; arranged by cluster group for 2001 harbor infauna. Relationships between stations and taxa are shown in Figures 5-3 and 5-4. Blank spaces indicate that the species did not occur in the station group.

		I	I	I	I	I	II	II	II	II	II	III	III	III	IV	V	V		
		SP T03	SU T03	SU T06	SP T06	SU T05A	SP T02	SP T07	SU T01	SU T02	SU T07	SP T05A	SP T08	SU T08	SP T01	SP T04	SU T04		
		SP	SU	SU	SP	SU	SP	SP	SU	SU	SU	SP	SP	SU	SP	SP	SU	Total	Total
	Taxa	T03	T03	T06	T06	T05A	T02	T07	T01	T02	T07	T05A	T08	T08	T01	T04	T04	Abundance	Occurences
A	Tharyx spp.	278	140	2		440	109	126	68	63	135	374	45	147	55	1	1	1984	15
	Microphthalmus pettiboneae	116	63	1	2	28	104	59	496	68	16	33	30	38	28	5	1	1088	16
	Exogone hebes	6	1	2	1	191	1		63			154	170	229	57			875	11
	Tubificoides sp. 2					2	191		222	14		4			372	12	4	821	8
	Mediomastus californiensis	51	47	16	28	18	34	31	10	59	22	8	4	7	5			340	14
	Nemertea sp. 2	5	5			24	22	33		3	14	25	22	60	21			234	11
	Dipolydora socialis	9			17		6	9	15	2	1	8	37	21	13	1		139	12
	Pontogeneia inermis	43	1		3	6						3			58			114	6
	Dipolydora quadrilobata	4	1		4		6	4	12		1	3	41	8	27	2		113	12
	Ninoe nigripes	3		3	3	1	7	7	11	20	23		2	1	9			90	12
	Turbellaria spp.	2	1		1		17	23				5		1	8	6		64	9
	Cancer irroratus	1	2	18	1	11					3	4		6	1			47	9
	Ampharete finmarchica	1	2				1	10	2				1	5	4			26	8
	Pygospio elegans					2	1		7		1	4	1	4	5			25	8
	Pandora gouldiana	3					2	3	1	1	1		1	2	2			16	9
B	Spiophanes bombyx			2		164			13	1		225	1204	629	6			2244	8
	Polygordius sp. A		1		2	234		6				366	633	590	1		4	1837	9
	Tellina agilis	200	45	45	191	68	10	7	29	4	11	100	218	90	38	7	3	1066	16
	Lyonsia arenosa	102	102	7	11	21	26	2	29	6	42	2	22	313	13			698	14
	Clymenella torquata		2	2		4	1		538				15	99	8			669	8
	Nucula delphinodonta			147	96								333	70				646	4
	Prionospio steenstrupi	8	9	10	23	15	2		3	10	1	10	10	32				133	12
	Phoronis architecta	2	2	1	2	3	2	1			1		33	11	2			60	11
C	Capitella capitata complex	12	4	6	5	8	16	12	2	6	5	820	15	17	1	573		1502	15
	Ilyanassa trivittata	235	111	118	148	109	12		37	8	20	211	201	107	41	68		1426	14
	Streblospio benedicti	3					82	68	7	12	13				18	392	98	693	9
	Tubificoides benedeni	1				64	1					77		1				144	5
	Pholoe minuta					7	2		37	17	3	39	2	4	2			113	9
	Paranais litoralis					1			18							90		109	3

Table 5-3. Abundance (#/0.12 m^2) of the 51 species that had an abundance >100 or occurred at >7 stations; arranged by cluster group for 2001 harbor infauna. Relationships between stations and taxa are shown in Figures 5-3 and 5-4. Blank spaces indicate that the species did not occur in the station group, continued.

		I	I	I	I	I	II	II	II	II	II	III	III	III	IV	V	V		
		SP T03	SU T03	SU T06	SP T06	SU T05A	SP T02	SP T07	SU T01	SU T02	SU T07	SP T05A	SP T08	SU T08	SP T01	SP T04	SU T04		
		SP	SU	SU	SP	SU	SP	SP	SU	SU	SU	SP	SP	SU	SP	SP	SU	Total	Total
	Taxa	T03	T03	T06	T06	T05A	T02	T07	T01	T02	T07	T05A	T08	T08	T01	T04	T04	Abundance	Occurences
D	Tubificoides apectinatus	3556	3388	1392	661	410	422	1049	39	880	956	529	43	46	11			13382	14
	Aricidea catherinae	1620	1401	1507	373	471	76	320	389	155	2531	426	202	945	65			10481	14
	Polydora cornuta	196	659	359	85	130	1	19	1401	1347	638			1	5	6		4847	13
	Leptocheirus pinguis	183	192	504	531	396	9	36	941	773	458	21	2	60				4106	13
	Nephtys cornuta						25	94	14	152	49				1			335	6
	Scoletoma hebes	1	1	29	21	2		62	9		48	1	7	1	8			190	12
	Spio thulini	5	5	12	2	6			5	26		3		12				76	9
	Neanthes virens	1	3	11	1			2		1	4		1	4				28	9
E	Ampelisca spp.	8550	8251	5143	8131	10879	132	2746	598	1267	96	334	349	407	7	1		46891	15
	Tubificoides nr. pseudogaster	4311	3333	3379	2952	257	9	49	211	27	42	366	54	105	3			15098	14
	Crassicorophium bonelli	32	924	557	3368	14	2	3	2	6		12	3	44	2			4969	13
	Photis pollex	282	477	1806	933	623	2		8	15	3	19	6	7	4			4185	13
	Phoxocephalus holbolli	666	1280	1182	596	100	2	2	1	2	5	2	10	56	1			3905	14
	Orchomenella minuta	312	450	980	871	586	7	17		12	1	36	5	50	2			2044	14
	Unciola irrorata	216	135	440	308	800	6	12	13	22	43	3	14	23	9			1647	11
	Phyllodoce mucosa	28	140	815	20	583			7	10	12	1	4	27				533	5
	Chaetozone vivipara					492			26	7		7		1				349	11
	Edotia triloba	12	41	17	10	227			3	3	2	7	4	23				336	8
	Dyopedos monacanthus	93	8		178	12	2	34				3	6					197	6
	Petricola pholadiformis	16	2	27	139							4	9					162	6
	Phyllodoce maculata	5		97	16	30						12		2				136	8
	Amphiporus cruentatus	28	17	37	39	12	1							1	1			114	9
	Hiatella arctica	10	6	2	6	81		2		1			1	5				3329	13
	Taxa with <100 occurence	12	28	13	22	15	8	16	10	36	35	4	12	12	13	1	27		

Many of the species groups were strongly associated with specific stations groups (Table 1). Group A was the taxonomically most diverse and composed primarily of the less abundant taxa that were scattered across all station groups. Seven of the nine major taxa included in the analysis were part of group A (Figure 5-4). Most of the taxa in group B were polychaetes with a three bivalve species and the phoronid *Phoronis architecta*. Species group B was most abundant at sandy stations T05 and T08 and contained *Spiophanes bombyx, Polygordius* sp. A, and *Tellina agilis*, the 11th, 14th, and 19th most abundant taxa in 2001, respectively. *Prionospio steenstrupi*, the most abundant infaunal species at the nearfield stations, was part of group B and was not an important member of the harbor infauna with only a total of 133 individuals occurring at seven of the eight stations for at least one season. It did not occur at Station T04 or in the spring at T01 and T07 (Table 1).

Group B was most strongly associated with station group III and contained the species dominant at coarser sediment stations (T05 and T08) and represented the sand-dwelling component of the harbor fauna. Group C was all annelids, except for the snail *Ilyanassa trivittata*, and was also scattered across all station groups but contained the three most abundant species to occur at Station T04, which were the *Capitella capitata* complex, *Streblospio benedicti*, and *Paranais litoralis*. All three of these species have cosmopolitan distributions and opportunistic life histories, and are known to colonize high organic or disturbed habitats. The other capitellid polychaete in the collection, *Mediomastus californiensis,* occurred at all stations except T04 and was in group A. Group D species was composed primarily of annelids, eight polychaetes and one oligochaete, with a bivalve and an amphipod. Four of the top 10 abundance species, the annelids *Tubificoides apectinatus, Polydora cornuta*, and *Aricidea catherinae*, and the amphipod *Leptocheirus pinguis* were in group D. Group D species preferred mixed muddy-sand stations and were predominantly found in station groups I and II, and were rare in group V (T04). The dominant species in group D was the oligochaete *Tubificoides apectinatus*, a common North Atlantic coast marine oligochaete (Brinkhurst 1986), which was the third most abundant species in both the 2000 and 2001 data. Many of the group D species corresponded to those comprising a muddy sand-dwelling fauna consistently identified in previous years (Kropp *et al.* 2000, 2001).

Group E, composed primarily of amphipods and bivalves, contained six of the top 10 abundant species and was concentrated in station group I (T03 and T06) (Table 5-3). Relatively few individuals of group E species occurred in the other stations groups, with virtually none occurring in group V, which was Station T04, except for a single individual of *Ampelisca* spp. *Ampelisca* spp., which consists of two species (*abdita* and *vadorum*), was the top numerical dominant in 2001 and accounted for 35% of all individuals. *Ampelisca* spp., which construct a fine-sediment tube that can protrude as much as 2 cm above the bottom, was the primary biogenic structure producer among the infauna and likely provided the substrate or sedimentary conditions for high abundances of the other group E species, such as *Crassicorophium bonelli* and *Tubificoides* nr. *pseudogaster*. The infaunal predator *Amphiporus cruentatus* was also strongly associated with group I stations. Biogenic activity of *Ampelisca* spp. was very important to infaunal community structure within the Harbor. For example, *Dyopedos monacanthus*, a whip amphipod, was in group E and associated with biogenic activities of *Ampelisca* spp. as it attached its whip to the tubes of *Ampelisca* spp. *Dyopedos monacanthus* was found to be associated with *Ampelisca* spp. tube mats in previous years (Kropp *et al*. 2000, 2001).

Through time the same recognizable community groupings have occurred in the Harbor. In comparing the patterns of species groupings for the spring and summer 2001 data to the long-term dataset there are strong similarities between several of the cluster analysis species groups (Tables 5-3 and 5-5). The strongest resemblance was between species groups D in 2001 and the long-term dataset and also groups E. Group C in 2001 (Table 5-3) is similar to group F in the long-term analysis (Table 5-5). The consistent association of species through time is related primarily to life history characteristics particularly for those species that play key roles in successional dynamics. For example, *Ampelisca* spp. (group E in both analyses) can be considered habitat engineers that produce physical structure (tubes) and modify sediment geochemistry (deepening the RPD layer depth), which leads to other species being dependent on the presence of the *Ampelisca* spp.

5.2.4 Descriptive Community Measures: 1991–2001 Harbor-wide Patterns

Abundance — As has been mentioned in previous reports, summer total infaunal abundance in the Harbor was low in September 1991, increased sharply through Summer 1993, decreased between Summer 1995 and Summer 1996, then increased to its highest value in Summer 1997 (Figure 5-5a). The Summer 1997 value represented a seven-fold overall increase in abundance in the Harbor since 1991. The interpretation of the 1996 combined Harbor data (e.g., Kropp *et al*. 2002) has been that the summer 1996 community showed markedly decreased values of abundance and numbers of species than the summer 1995 community. However, this interpretation, though correct, is somewhat misleading. If the data are examined sequentially, i.e., season-by-season, then the interpretation that becomes more clear is that the spring 1996 values decreased compared to the summer 1995 values, as was the typical pattern for the Harbor community then. However, the unusual event then was the failure, by what ever mechanism, of the typical summer community to "recruit" to the Harbor. Average abundance per sample in Summer 1996 was only slightly higher than it was in Spring 1996; species numbers were actually lower. Although this observation was significant enough that it was reflected in pooled data for the Harbor, it was restricted primarily to three stations in the northern portion of the harbor (stations T01, T02, and T05A). When pooled data for those three stations are compared to pooled data for stations T03, T06, and T08, it is clear that the low summer 1996 numbers were not a Harbor-wide phenomenon (Figure 5-5b). When abundance values since 1994 for the three most abundant species at stations T01, T02, and T05A (*Ampelisca* spp. *Polydora cornuta*, *Streblospio benedicti*) are plotted (Figure 5-5c), it becomes clear that their low recruitment contributed strongly to the low total abundances at these stations in the summer of 1996, 1999, and 2000.

Species Numbers — Although the most noticeable feature of the numbers of species per sample in the Harbor during the monitoring program was the very dramatic increase between Summer 1991 and Summer 1992 (Figure 5-6a), the next most noticeable observation is that species numbers in Spring 2001 were the highest values for that season recorded during the monitoring program and continued the trend for increasing species numbers in Spring samples. Spring species numbers per sample have increased about 159% since 1992. Another observation is that within the last two to three years the differences between Spring and Summer species numbers have been small. The net effect of these patterns is that from 1992 to 1995 there were considerable differences in the species numbers per sample between Spring and Summer with Summer values being higher. Since then, with the exception of 1998, these differences have been much less distinct.

Species Diversity — The patterns shown by average species diversity (log-series alpha) per sample are somewhat similar to those shown by species numbers. Log-series alpha values for each season in 2001 were the highest observed during the Harbor monitoring (Figure 5-6b). Each set of seasonal values indicates that species diversity has increased noticeably during the duration of the study.

Total Species Richness — From survey to survey there has been considerable change in the species collected among the Harbor samples. As many as 52 species were found during one survey (Spring 2001) that were not present in the preceding survey. Twenty-two species that occurred in the Summer 2000 samples were not found in Spring 2001. When combined with the number of "new" taxa seen in Spring 2001, the net change from the Summer 2000 to Spring 2001 was 74 species, the largest survey-to-survey change thus recorded.

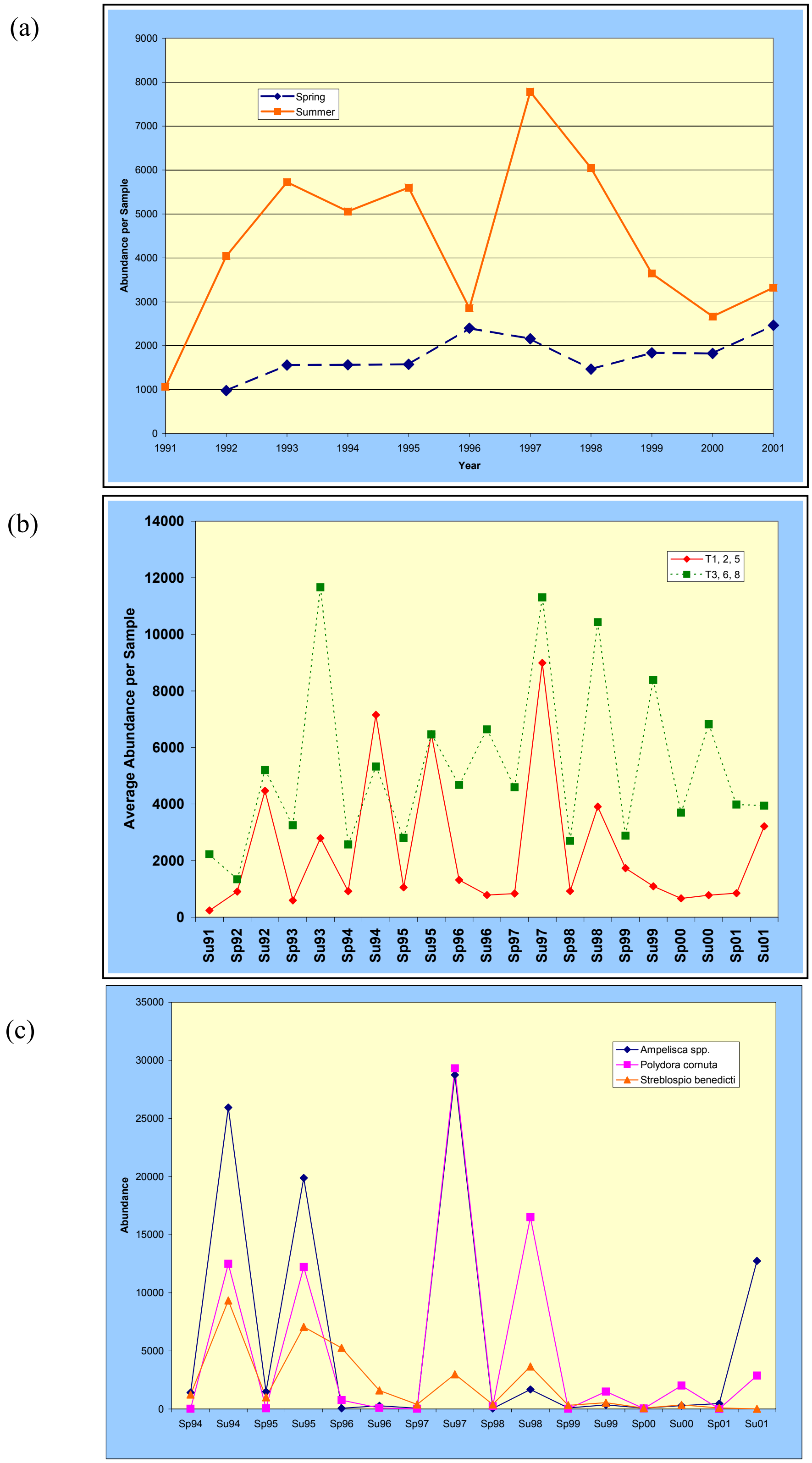

Figure 5-5. Boston Harbor total infaunal abundance (a), 1991-2001 calculated as mean values (b), and abundances of selected taxa (c) calculated as mean from stations T01, T02 and T05A.

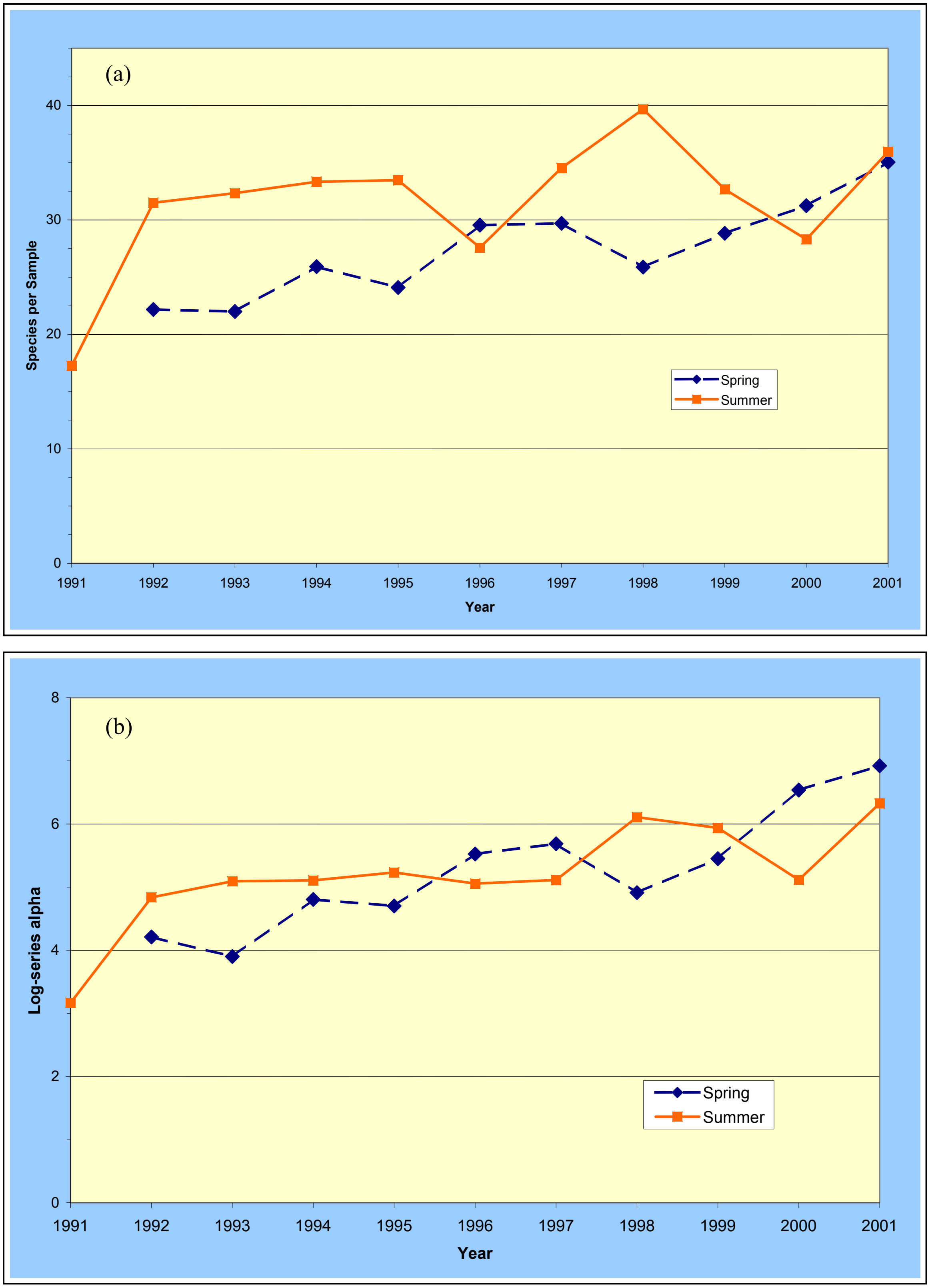

Figure 5-6. Boston Harbor numbers of species (a) and log-series alpha per sample (b) 1991-2001 calculated as mean values of all samples per survey.

The species disappearance curve (Figure 5-7, filled squares), which records the first disappearance of species found in 1991, provides an estimate of the Harbor infaunal community's "core" species, *i.e.*, those present in every survey. This core group is estimated to be about 34 species, as it was last year (Kropp *et al.* 2002).

The species number per survey curve (Figure 5-7, filled circles) shows the greatest change from the 2000 curve. In 2001, the Spring (125 species) and Summer (122 species) were two of the three highest values recorded during the monitoring and, when averaged for the year, yielded the highest yearly value yet measured (123.5 species).

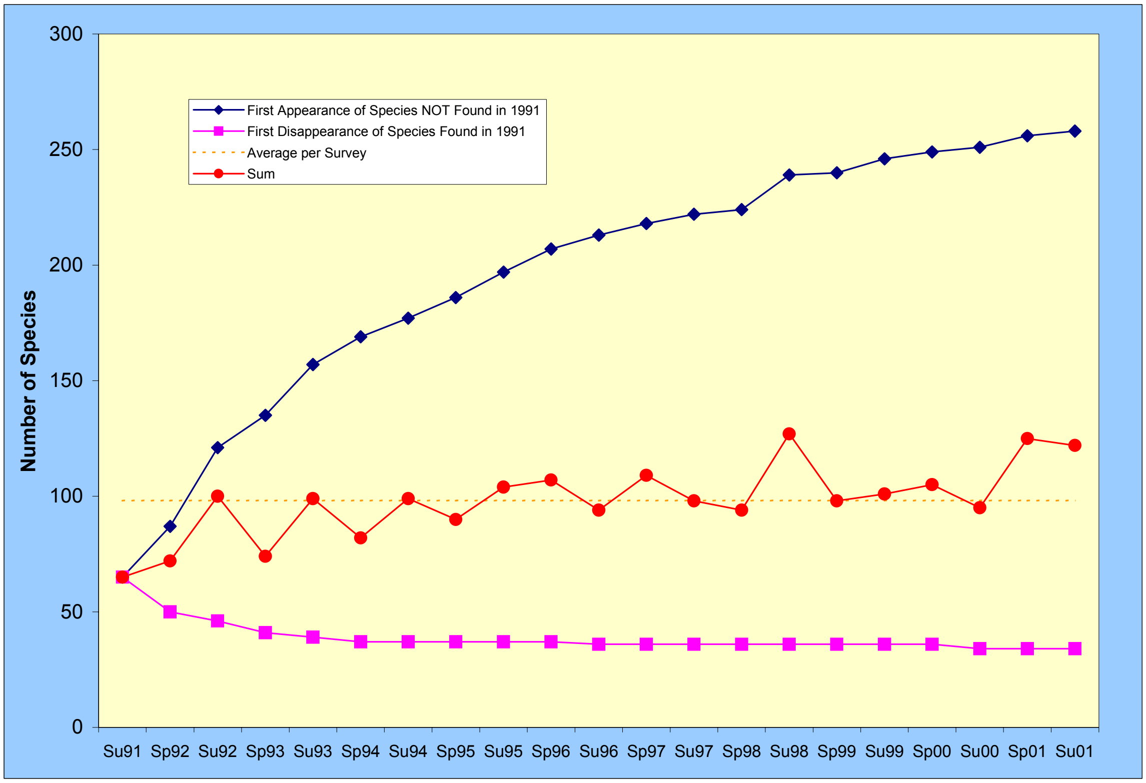

Figure 5-7. Harbor-wide total species richness patterns in Boston Harbor 1991-2001, with all species data pooled, showing year-to-year changes in species numbers.

5.2.5 Descriptive Community Measures: Station Patterns in 2001 versus 1991–2000

To compare the results of the 2001 surveys to those from previous years, plots were developed that show the 2001 data from individual stations in the context of the range of values occurring at the stations throughout the program.

Abundance — Spring 2001 abundance values were within the range encountered previously except for stations T03, T06, and T07 (Figure5-8a). The high abundance values at these stations resulted primarily from high numbers of *Ampelisca* spp, which occurred at densities of about 71,250 individuals/m^2 and 67,758 individuals/m^2 at stations T03 and T06, respectively. Conversely, abundance values at stations T01, T02, and T08 were somewhat below the average spring values.

Summer 2001 abundance values were much lower than the maximum recorded summer values for all stations (Figure 5-8b). Abundances at the stations T01, T04, and T08 were slightly below their respective 10-year averages.

Numbers of Species — During Spring 2001, the numbers of species collected at each station were generally above the 9-year spring average (Figure 5-9a). Two of three samples at stations T03, T05A, and T07 were higher than previously recorded at those stations. No samples were below the 9-year average.

During the summer of 2001, the numbers of species collected at each station were within the 10-year range of values except for one sample at station T08 (Figure 5-9b). This particular sample contained 72 species, the highest number recorded for any sample during the monitoring program. The numbers of species occurring in the Summer 2001 samples from station T05A (53–56 species) were much greater than the station's 10-year average (33 species), whereas those for the other stations were close to average.

Species Diversity — Spring 2001 log-series alpha values generally were above average for all samples collected (Figure 5-10a). One sample from station T03 was about average (log-series alpha = 5.3), whereas one sample had the highest log-series alpha recorded at the station (log-series alpha = 6.5).

The trend for somewhat above average log-series alpha values continued during the Summer 2001 (Figure 5-10b) with five stations having log-series alpha values that were above average. Two samples from station T08 (log-series alpha = 13.9 and 10.9) were the highest recorded there, with the former value being the highest recorded in the Harbor during the MWRA monitoring.

Although the data are not presented here, values for Shannon diversity (H') and Pielou's evenness (J') also were generally above average for each season.

5.2.6 Multivariate Community Analyses: 1991–2001

Station patterns—Infaunal communities patterns from 1991 to 2001 were primarily due to strong within-station similarity, with temporal trends being of secondary importance. Two main grouping of stations emerged with Stations T01, T02, T04, and T05 represented by groups I to IV, and Stations T03, T05A, T06, T07, and T08 represented by groups VI to X. Group V was positioned between these two groupings and represented spring 2000 and 2001 conditions for Stations T01 and T02 (Table 5-4 and Figure 5-11). The transitional nature of group V was related to variability of species abundance for those years that was contrary to previous years at those stations. For example, the low numbers of *Streblospio benedicti* in 2000 and 2001 at T01 and T02 aligned the stations with cluster groups VI to X. The difference between the main groupings of stations was primarily the degree of seasonal change in community composition

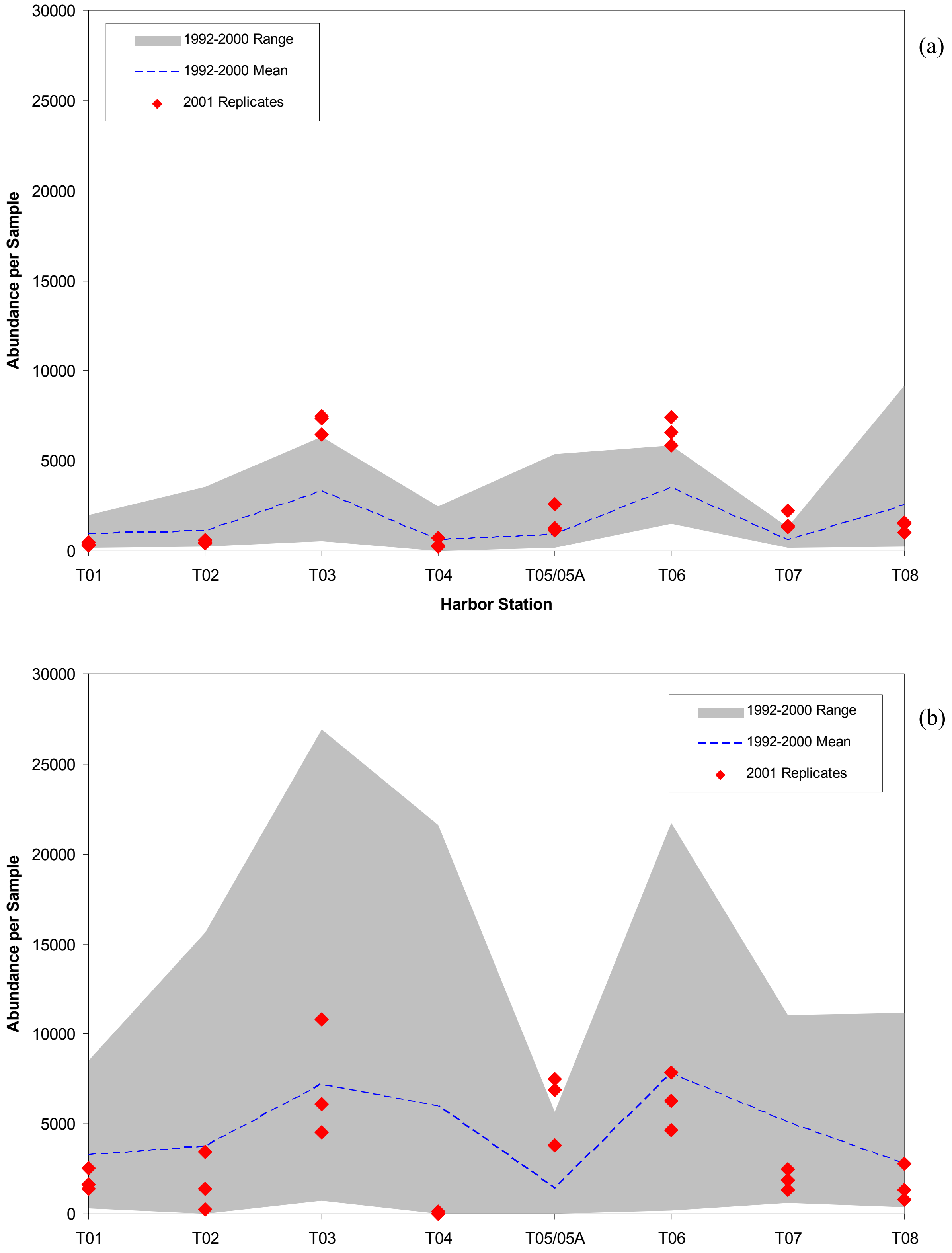

Figure 5-8. Infaunal abundance for each Boston Harbor station sampled in Spring (a) and Summer (b) 2001 (diamonds) and the range of values occurring during the harbor monitoring through 2000 (gray band). The monitoring through 2000 mean value is indicated (coarse dashed line).

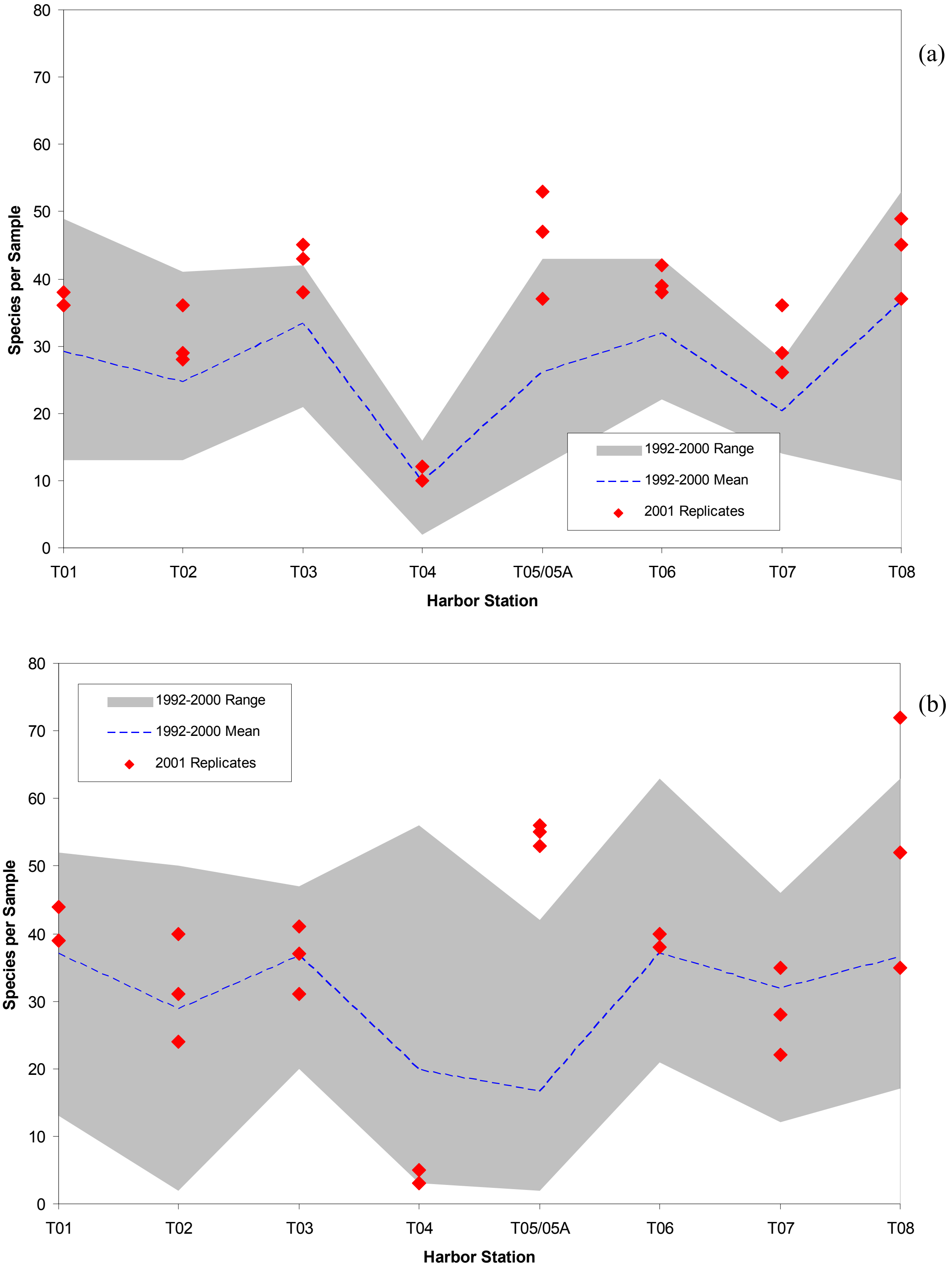

Figure 5-9. Numbers of species for each Boston Harbor station sampled in Spring (a) and Summer (b) 2001 (diamonds) and the range of values occurring during the harbor monitoring through 2000 (gray band). The monitoring through 2000 mean value is indicated (coarse dashed line).

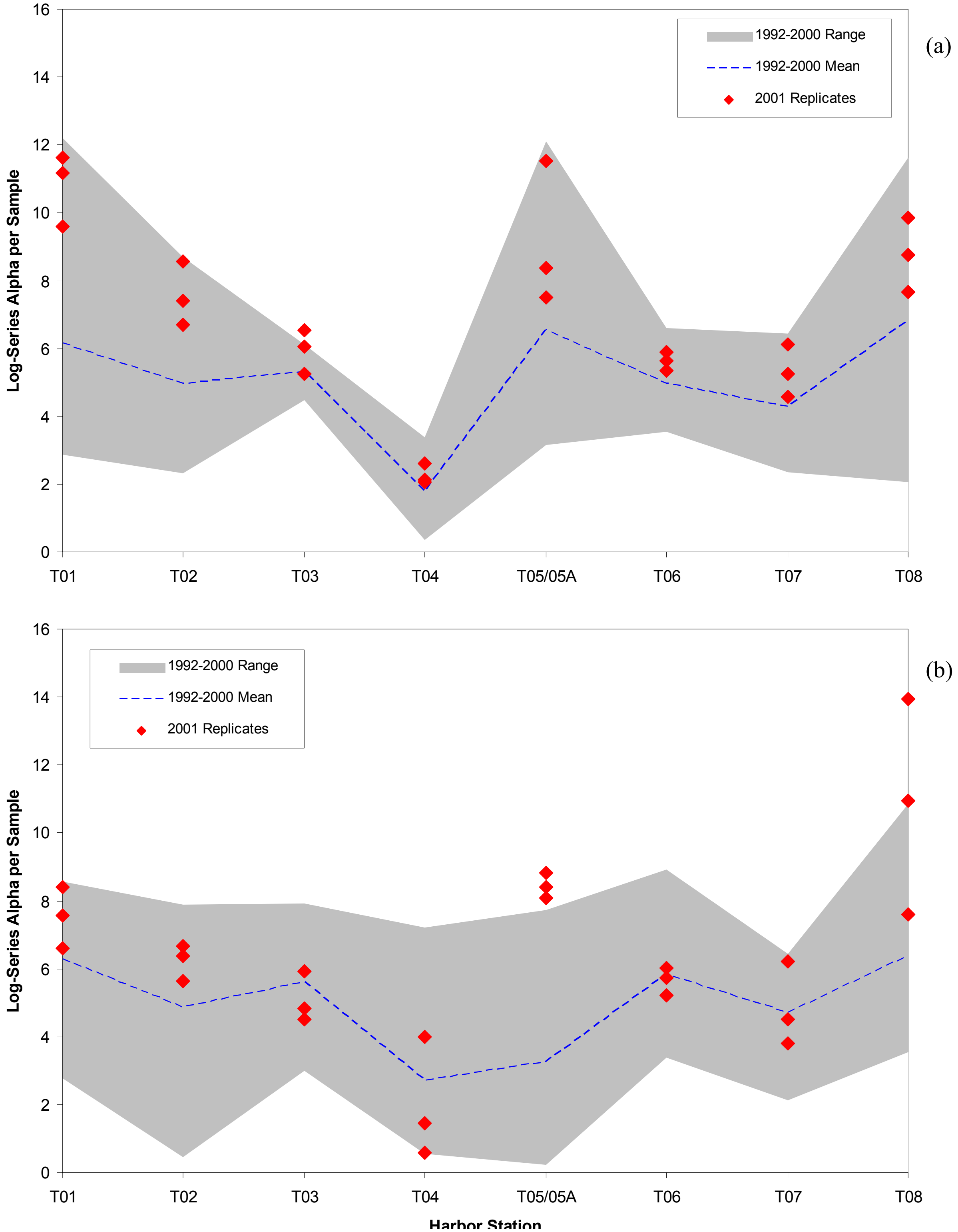

Figure 5-10. Log-series alpha for each Boston Harbor station sampled in Spring (a) and Summer (b) 2001 (diamonds) and the range of values occurring during the harbor monitoring through 2000 (gray band). The monitoring through 2000 mean value is indicated (coarse dashed line).

Table 5-4. Station group summary for 1991 to 2001 harbor infauna. Based on Gallagher's CNESS and group average sorting. SP is spring and SU is summer sampling.

		1991	1992		1993		1994		1995		1996		1997		1998		1999		2000		2001	
I'	**T01**	SU			SP		SP		SP		SP	SU	SP		SP		SP					
	T02	SU	SP		SP		SP		SP		SP	SU	SP		SP							
	T04										SP	SU										
I"	**T01**		SP	SU		SU		SU		SU						SU		SU		SU		
	T02			SU		SU		SU		SU						SU		SU				
II	**T04**	SU		SU		SU		SU		SU				SU				SU		SU		SU
III	**T04**														SP							
	T05	SU		SU																		
	T05A		SP																			
IV	**T04**		SP		SP		SP		SP				SP			SU	SP		SP		SP	
V	**T01**																		SP		SP	
	T02																		SP		SP	
VI	**T03**	SU	SP																			
	T05A				SP	SU	SP		SP		SP	SU	SP		SP		SP	SU	SP	SU	SP	
VII	**T03**			SU	SP	SU	SP	SU	SP	SU	SP	SU	SP	SU	SP	SU	SP	SU	SP	SU	SP	SU
	T06	SU	SP	SU	SP	SU	SP	SU	SP	SU	SP	SU	SP	SU	SP	SU	SP	SU	SP	SU	SP	SU
	T08				SP						SP		SP									
VIII	**T01**													SU								SU
	T02													SU			SP			SU		SU
	T07	SU	SP	SU	SP	SU	SP	SU	SP	SU	SP	SU	SP	SU	SP	SU	SP	SU	SP	SU	SP	SU
IX	**T05A**							SU		SU				SU		SU						SU
X	**T08**	SU	SP	SU		SU	SP	SU	SP	SU		SU		SU	SP	SU	SP	SU	SP	SU	SP	SU

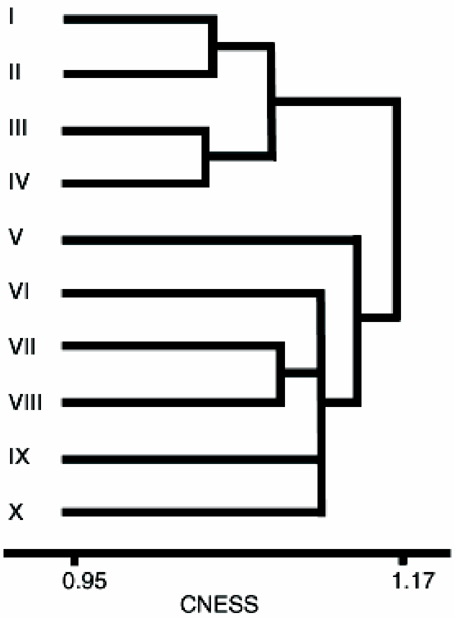

Figure 5-11. Station dendrogram for Boston Harbor 1991 to 2001 infauna, summed replicates with Gallagher's CNESS (*m* = 20) and group average (UPGMA) sorting. Taxa with >16 occurrences and >1000 total abundance at the 168 station-season-year combinations were included in the analysis.

and structure. Stations in groups I to IV expressed the largest spring to summer changes and stations in groups VI to X the least. The *Capitella capitata* complex split the main group that included groups I to IV into groups I and II with low abundances and III and IV with high abundances (85% of its total 11-year abundance). Station T04 in inner Dorchester Bay, groups II and IV, exhibited the strongest seasonal variation of all stations, followed by Stations T01 and T02 on Deer Island Flats, primarily groups I and V.

At the ten-group level, three stations formed exclusive groups; Station T04 in inner Dorchester Bay (groups II and IV), T08 in Hingham Bay (group X), and T05A in President Roads (group IX) (Table 5-4). There were also three exclusive seasonal groups; summer conditions at Station T04 were represented by group II for nine of the 11 years, group IX represented summer conditions at Station T05A for five of the nine years that station was sampled, and group V was spring 2000 and 2001 for Stations T01 and T02. Station group IV was nearly all one season and represented spring conditions at Station T04. Group I was Stations T01 and T02, with T04 for 1996, and was subdivided into predominantly spring and summer subgroups I' and I", respectively.

Differences in spring and summer infaunal composition at groups VI, VII, VIII, and X were not pronounced. The best examples are Stations T06 (group VII) and T07 (group VIII) where every collection period was in the same cluster group. Similarly, Stations T03 (primarily group VII) and T08 (primarily group X) did not have pronounced differentiation between these seasons. Group VIII was primarily composed of T07 in Quincy Bay with some occurrences of T01 and T02 in starting in 1997. Group VII was primarily T03 off Long Island and T06 off Peddocks Island with three Spring occurrences of T08 when many species associated with *Ampelisca* spp. tube mats were present. Group III contained Station T05 in its original location sampled only in summer 1991 and 1992, T04 for spring 1998, and T05A for spring 1992. Starting in spring 1993, Station T05A was in group VI most of the time with five summer collections in group IX. Analysis of the summer and spring collections separately produced station clusters that had the same station associations as the combined season analysis. The summer analysis was closest to the combined season analysis in spread of stations between cluster groups. In the spring analysis, the stations formed tighter groupings.

Over the 11-year period, Stations T01, T02, T03, T06, T07, and T08 maintained a high degree of within station similarity with most of the spring and summer collections within the same cluster group (Table 5-4). Stations T04 and T05A were the most variable through time with collection periods spread over four and three groups, respectively. Any disturbance of infaunal communities by the major events that occurred near the initiation of the T-station monitoring in 1991, the October severe storm and December sewage discharge abatement at the inner harbor outfall, was not obvious. Cluster analysis and community structure analyses indicated that infauna at the T-stations was not dominated by temporal trends.

Species Patterns — Over the eleven-year period 258 taxa occurred at the T-stations, but most of the species and taxa were neither very abundant or widespread. There were 151 taxa (59%) that occurred <10 times in the 168 station-season-year combinations. These less common taxa had a greater influence on community structure statistics than on community patterns and were not included in the species cluster analysis. Species cluster analysis of the 1991 to 2001 infaunal data was done on a reduced set of data that included only taxa with >16 occurrences and >1000 total abundance at the 168 station-season-year combinations. This cutoff level represented 33% (85) of the total taxa and 99.8% of all infaunal individuals collected. At the six-group level the dendrogram was perfectly concatenated, each group sequentially added from A to F, indicating that there were no distinct dichotomies in the species groupings.

The basic species groupings were most strongly related to general sediment preferences and life history strategies. Group A contained many of the taxa that preferred coarser sediment from fine-sand to pebbles characteristic of more physically dynamic habitats. The dominants were the polychaetes *Tharyx* spp. and

Chaetozone vivipara, and the gastropod *Ilyanassa trivittata* (Table 5-5). Group A taxa were broadly distributed at the eight T-stations with eight of 12 taxa even occurring at poor benthic habitat quality Station T04 over the sampling interval. There was a tendency for group A taxa to be more abundant in the summer particularly at Stations T01 and T02 (group I") and Station T05A (IX).

Group B was dominated by taxa that preferred finer sandy to muddy sand sediments. The polychaetes *Spiophanes bombyx Polygordius* sp. A and *Exogone hebes*, and the bivalve *Nucula delphinodonta* were the most abundant taxa in group B. Group B taxa occurred at all stations but had very limited presence at Station T04. Strongest station affinity was with T08 (group X). *Prionospio steenstrupi*, the most abundant infaunal species at the nearfield stations, was in group B but was not an important member of the harbor infauna. It had highest abundance at groups VI, IX, and X and was most affiliated with Station T08.

Group C was composed primarily of biogenic structure producing taxa. Three of the four most abundant taxa in group C produced biogenic structures: *Microphthalmus pettiboneae* a medium size filter feeding polychaete that constructs a sand-grain tube at the sediment surface, the conveyor-belt feeder *Clymenella torquata* that is a large tube-building head-down deposit feeding polychaete responsible for many of the oxic voids seen in the sediment profile images (see Section 3), and *Dipolydora socialis* that constructs a small muddy tube on the sediment surface. The nonbiogenic structure producing dominant was the oligochaete *Tubificoides* sp. 2, which is a free burrowing near surface deposit feeder. Other surface tube builders in group C were *Polydora aggregata*, *Dipolydora quadrilobata*, and *Fabricia stellaris stellaris*. A second conveyor-belt feeder in the group was *Pectinaria granulata.* Many of group C taxa occurred at all stations but had strongest affinity with Station T01 and T02 during the summer (group I"). Starting in 2000, many of group C taxa became more abundant at these two stations in the spring (group V).

Group D was a grouping of nine burrowing species dominated by the polychaete *Aricidea catherinae* and the oligochaete *Tubificoides apectinatus*, the 4th and 6th most abundant species over the 11-year period. These two species occurred at all stations but were strongly associated with station in groups V to X, as were the other species in the group.

Group E contained six of the top ten overall dominants and many of the more important bioturbating and biogenic structure creating species. The number one dominant species was the tube-building amphipod *Ampelisca* spp., a large filter feeder that constructs a fine-sediment tube that can extend several cm above the surface. The second dominant was the polychaete *Polydora cornuta*, a small surface deposit feeder that constructs a thin fine-sediment tube. These two species accounted for 30% and 14% of all individuals over the 11-year period, respectively. The third most abundant species at 11% of all individuals, the oligochaete *Tubificoides* nr. *pseudogaster,* was not a biogenic structure producer. Other tube-builders in the group were the amphipods *Unciola irrorata, Crassicorophium bonelli, C. crassicorne,* and *Leptocheirus pinguis*, along with the polychaete *Asabellides oculata*. While broadly distributed, taxa in group E dominated Stations T03 and T06 (group VII) in both summer and spring and Station T05A (IX) in the summer. Group E, to a lesser degree, was also dominant at T01 and T02 in the summer (Table 5-5).

Table 5-5. Average taxa abundance (individuals/0.12 m^2) by station cluster groups for 1991 to 2001 harbor infauna. Based on Gallagher's CNESS and group average sorting.

	Range of years:	91-99	92-00	91-01	91-98	92-01		00-01		91-01	91-01	91-01	94-01	91-01
	Primary season:	Spring	Summer	Summer	Sp/Su	Spring		Spring		Sp/Su	Sp/Su	Sp/Su	Summer	Sp/Su
	Primary stations:				T04									
		T01	T01		T05			T01			T03			
		T02	T02	T04	T05A	T04		T02		T05A	T06	T07	T05A	T08
	Minor stations:											T01		
		T04								T03	T08	T02		
	Cluster group:	I'	I"	II	III	IV		V		VI	VII	VIII	IX	X
A	Tharyx spp.	178	691	2	12	4		64		338	408	115	178	91
	Chaetozone vivipara	20	704	1				10		106	2	10	381	0
	Ilyanassa trivittata	46	46	5	139	8		33		104	86	20	253	134
	Edotia triloba	1	16		2			0		48	28	1	612	21
	Tellina agilis	11	21	1	14	3		35		78	35	10	63	138
	Tubificoides benedeni	1	1	0	75	2		0		67	1	0	24	0
	Nephtys caeca	11	25		1	0		6		12	2	2	66	12
	Diastylis sculpta	2	1		0			2		9	6	0	17	3
	Gammarus lawrencianus	0	1		7	0		1		12	1	0	11	1
	Nephtys ciliata	1	7	0				2		7	2	1	8	1
	Chaetozone cf. setosa	0	0					1		6	0	0	2	4
	Argissa hamatipes	0	0					0		0	0	0	0	0
B	Spiophanes bombyx	1	15					11		121	5	2	81	758
	Polygordius sp. A	0	2	1				1		51	10	1	163	537
	Nucula delphinodonta	0	0			0				0	118	0		372
	Exogone hebes	6	17		1	0		24		14	9	4	43	271
	Prionospio steenstrupi	2	11		2			3		5	19	5	19	68
	Lyonsia arenosa	2	7		1			11		1	22	10	8	44
	Pygospio elegans	2	5			0		6		6	0	1	7	28
	Phoronis architecta	0						1			2	0	1	12
	Parougia caeca	0	0		0			0		0	1	0	1	12
	Monticellina baptisteae	0	0							0	2	0	1	8
	Aglaophamus circinata	0	0		0					0	0	0	4	1
	Arctica islandica	0	1							0	1	0	0	3
	Metopella angusta	0	0		1					0	0		1	2
C	Microphthalmus pettiboneae	59	273	2	29	2		129		35	30	68	8	22
	Tubificoides sp. 2		32	4		2		283		0		13	0	0
	Clymenella torquata	12	242					5		1	3	33	1	36
	Dipolydora socialis	29	33		0	0		38		13	18	10	2	72
	Hiatella arctica	2	2		3			1		0	8	0	85	4
	Pholoe minuta	4	58		2			1		3	4	12	13	6
	Polydora aggregata	26	42		1			0		0	0	14		
	Nemertea sp. 2	1	12	1		10		17		11	1	5	7	8
	Dipolydora quadrilobata	15	9		2	1		19		1	5	2	0	9
	Ninoe nigripes	5	6					8		0	6	8	0	3
	Ischyrocerus anguipes	3	2		6			5		3	2		3	6
	Pontogeneia inermis	0			0			15		5	2		8	0

Table 5-5. Average taxa abundance (individuals/0.12 m^2) by station cluster groups for 1991 to 2001 harbor infauna. Based on Gallagher's CNESS and group average sorting. (continued)

	Range of years:	**91-99**	**92-00**	**91-01**	**91-98**	**92-01**		**00-01**		**91-01**	**91-01**	**91-01**	**94-01**	**91-01**
	Primary season:	**Spring**	**Summer**	**Summer**	**Sp/Su**	**Spring**		**Spring**		**Sp/Su**	**Sp/Su**	**Sp/Su**	**Summer**	**Sp/Su**
	Primary stations:				**T04**									
		T01	**T01**		**T05**			**T01**			**T03**			
		T02	**T02**	**T04**	**T05A**	**T04**		**T02**		**T05A**	**T06**	**T07**	**T05A**	**T08**
	Minor stations:											**T01**		
		T04								**T03**	**T08**	**T02**		
	Cluster group:	**I'**	**I"**	**II**	**III**	**IV**		**V**		**VI**	**VII**	**VIII**	**IX**	**X**
C	Proceraea cornuta	3	6	1	8			2		0	1	1	0	2
	Polycirrus cf. haematodes	0	11							0	0	5		1
	Ampharete finmarchica	0	1					4		0	0	1	0	2
	Spio filicornis	1	1		2			1			0		1	2
	Fabricia stellaris stellaris	3	0			1				1	0	0	1	0
	Pectinaria granulata	0	2		1					0	0	0	2	0
	Pandora gouldiana	0	0					2			0	1		1
D	Aricidea catherinae	35	73	1	5	0		59		115	1448	544	123	1512
	Tubificoides apectinatus	1	10	2	9	1		152		346	951	592	173	142
	Nephtys cornuta	3	32	6		0		22		1	1	120	3	
	Scoletoma hebes	5	9					5		0	44	28	1	64
	Mediomastus californiensis	7	34		3	1		15		10	39	13	18	12
	Spio limicola	25	12		4			1		24	6	3	7	1
	Dyopedos monacanthus	9	1			0		2		9	28	2	18	2
	Leitoscoloplos robustus	0	0			0		1			0	2		2
	Cerebratulus lacteus	0	0					1		0	1	0	1	0
E	Ampelisca spp.	144	2049	7	5	2		46		82	6632	746	11367	2762
	Polydora cornuta	68	3734	4	64	66		12		59	1956	540	8370	152
	Tubificoides nr. pseudogaster	933	1046	5	1413	6		18		502	2586	122	163	299
	Unciola irrorata	2	59		1			13		23	421	9	1520	66
	Leptocheirus pinguis	5	103		1	0		3		3	534	111	399	84
	Photis pollex	12	60	0	1	0		3		14	483	2	432	33
	Crassicorophium bonelli	0	18		2	0		1		1	943	1	31	7
	Phoxocephalus holbolli	1	5		65	0		1		5	778	3	72	40
	Phyllodoce mucosa	5	101		4			1		11	136	3	215	78
	Orchomenella minuta	4	1					3		4	153	1	212	15
	Diastylis polita							0		6	0		201	0
	Spio thulini	1	64		83	2				1	27	3	8	14
	Eteone longa	1	38	0	14	3		0		2	8	3	23	2
	Asabellides oculata	5	59	1		2				1	5	3	2	4
	Crassicorophium crassicorne	0	0					1			21		0	24
	Petricola pholadiformis	2	0		0			1		2	30	0	4	5
	Phyllodoce maculata	0	9							1	18	0	7	4
	Harmothoe imbricata	0	2	0	6					0	7	0	3	17
	Neanthes virens	1	7	0	8	0				0	5	1	1	1
	Amphiporus cruentatus		0					1		0	6	0	14	4
	Cerastoderma pinnulatum	0	1							0	4	0	14	3
	Cancer irroratus	1	3	0	2			0		0	6	1	5	2

Table 5-5. Average taxa abundance (individuals/0.12 m^2) by station cluster groups for 1991 to 2001 harbor infauna. Based on Gallagher's CNESS and group average sorting. (continued)

	Range of years:	**91-99**	**92-00**	**91-01**	**91-98**	**92-01**		**00-01**		**91-01**	**91-01**	**91-01**	**94-01**	**91-01**
	Primary season:	**Spring**	**Summer**	**Summer**	**Sp/Su**	**Spring**		**Spring**		**Sp/Su**	**Sp/Su**	**Sp/Su**	**Summer**	**Sp/Su**
	Primary stations:				**T04**									
		T01	**T01**		**T05**			**T01**			**T03**			
		T02	**T02**	**T04**	**T05A**	**T04**		**T02**		**T05A**	**T06**	**T07**	**T05A**	**T08**
	Minor stations:											**T01**		
		T04								**T03**	**T08**	**T02**		
	Cluster group:	**I'**	**I''**	**II**	**III**	**IV**		**V**		**VI**	**VII**	**VIII**	**IX**	**X**
E	Pherusa affinis	0	4		0						2	1	3	1
	Mysella planulata	1	0			0				0	3	0	1	0
F	Streblospio benedicti	723	1846	2059	23	390		44		13	6	440	13	1
	Capitella capitata complex	25	68	5	1117	2067		14		78	14	8	15	25
	Paranais litoralis	0	136		2	136		55		0		1	0	0
	Mya arenaria	16	6	2	5	2		1		6	18	11	6	1
	Turbellaria spp.	5	0	8		11		8		3	2	2	0	5
	Ensis directus	0	3	2	1	0				3	1	7	8	9
	Spio setosa	3	6		1	4		1		0	0	0		0
	Paranaitis speciosa	1	1	1				1		0	0	1		0

Group F was composed of opportunistic species that were eurytopic with regard to sediment grain-size and organic content preferences. The three dominant species were opportunistic annelids, the polychaetes *Streblospio benedicti* and *Capitella capitata* complex and the oligochaete *Paranais litoralis*. The latter two species are typically found in high abundance in organic-enriched sediments and were strongly associated with T01 and T02 during the summer (group I''), T04 in the spring (IV), and to a lesser degree in the spring at T01 and T02 (V). *Streblospio benedicti* was the most abundant species at Station T04 in the summer (group II) and also dominated Stations T01 and T02 (I'') in the summer (Table 5-5). The opportunistic bivalves *Mya arenaria* and *Ensis directus* were also in group F and occurred at all stations for most years.

Conclusions

The observed changes in the Harbor's infaunal communities, coupled with data from SPI studies, provide good evidence for improvement in benthic habitat conditions in the Harbor since the cessation of sludge discharge in 1991. The most substantial changes in the Harbor's benthos probably occurred within the first two to three years after sludge discharge ended. Among these were the sudden increase in abundance and geographic spread of the amphipod *Ampelisca* spp, and the general increase in infaunal abundance and species numbers that occurred after 1991. Recently, some data indicate that the infaunal communities are in transition from those that appeared in the early to mid 1990s to those more likely to be found in a less-polluted Harbor that is still likely to show response to periodic natural events, whether a physical disturbance or a biological phenomenon such as an occasional failure of some species to recruit to the Harbor.

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