1999 harbor benthic monitoring report

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1999 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 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

- cessation of sludge discharge into the Harbor—December 1991,
- operation of a new primary treatment facility at Deer Island—1995,
- initiation of secondary treatment (first battery)—1997,
- continuation of secondary treatment implementation (second battery)—1998,
- cessation of effluent discharge from Nut Island—July 1998, and
- cessation of effluent discharge to Harbor—September 2000.

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. Among the changes reported in these studies, the increase in abundance and geographic distribution of the tube-dwelling amphipod *Ampelisca* has been the most dramatic.

A major forthcoming change to discharges into the Harbor, the diversion of effluent to the new ocean outfall, is expected to result in further improvements in the Harbor's benthic habitats.

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. 1999 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 1999. This report also includes a programmatic evaluation of each of the components. Summaries of the 1999 results from these studies follow.

Sediment Profile Images

Typically, the distribution of sediment textures in the Harbor primarily results from a combination of sources, morphology, and hydrodynamics. The 1999 SPI data showed that surface features were dominated by biogenic activity. Feeding pits and mounds, worm tubes, epibenthic organisms, *Ampelisca* mats, and shells were the dominant surface biogenic structures. Subsurface biogenic structures and organisms were also common and widely distributed, but were most common at stations where biological processes dominated surface features. *Ampelisca* tube mats, which occurred at 25 stations, declined in predominance in 1999 and many mats appeared to be deteriorating.

The predominance of biological activity at most stations, particularly those near the mouth of the Harbor, was indicative of a well-developed fauna that was generally characterized as being intermediate in successional stage. The organism sediment index (OSI) reflected this pattern, with values > 6 occurring toward the Harbor mouth and values < 6 in the inner areas of the Harbor. *Ampelisca* tube mats, though declining from previous levels of predominance, continue to be widespread and indicative of the intermediate step (stage II) in the macrobenthic community successional transition from the pioneering-dominated (stage I) inner harbor area to the equilibrium-dominated (stage III) Nearfield area in western Massachusetts Bay.

Habitat conditions improved at station T04, inner Dorchester Bay, in 1999. A thin RPD layer was observed along with many infaunal worms and there were no gas voids in 1999, in 1998 T04 appeared to be hypoxic and had gas voids indicative of high rates of bacterial activity and organic matter in sediments.

Overall, general benthic habitat quality within the study area was similar from August 1992 to 1998, with minor variations from year-to-year. For 1999, key indicators of benthic habitat quality were slightly lower relative to previous years, however, the major changes in habitat quality appeared to have occurred in early 1992. Current benthic communities appear to have developed in response to major physical disturbance events in 1991. These included the severe storm in late October and the December sludge discharge abatement. Interestingly, stations with the poorest habitat quality measured in the 1989/90 sampling continued to have poor quality habitat in 1999. Three stations (T04, R36, and R43) each had long-term average OSI values ≤ 3, indicative of poor habitat quality.

Sediment Geochemistry

Samples collected in April and August 1999 had highly variable grain size composition, but were generally within the ranges observed for previous years, except for station T04 in April 1999. Patterns in sediment composition at station T04 were consistent from 1993 to 1998, however, sediment collected in April 1999 contained considerably higher sand (~31%) and less silt content relative to previous years.

Patterns in grain size were fairly consistent from 1991 to 1999 (April and August) at some stations, but variable at others. With few exceptions during the study years, sediments at stations T01, T05A, and T08 displayed very consistent texture, being comprised primarily of coarse-grained sediments. Sediment texture at station T04 was also fairly consistent over time, being comprised primarily of silty sediments. Patterns in sediment composition from 1991 to 1999 (April and August) were more variable at stations T02, T03, T06, and T07.

Concentrations of TOC in 1999 (April and August) at all Traditional stations were highly variable, but were generally not substantially different from earlier years because of the high variability in the historical dataset.

Patterns in TOC content from 1991 to 1999 (April and August) were consistent at some stations, but variable at others. Stations T02, T03, and T07 showed the most consistent patterns in TOC content over time, whereas stations T04, T05A, T06, and T08 were more variable. Sediments from station T04 consistently had the highest levels of TOC, peaking in August 1998 with the highest measured value (8.86% TOC) among all sampling years. The unusually high TOC content observed at T04 in August 1998 is likely a result of localized inputs from a major storm event that occurred in June 1998. Concentrations of TOC at station T04 decreased in August 1999 indicating that the system has returned to previous conditions. As in previous years, TOC content was the lowest at station T08 in 1999 (0.7% in April; 0.2% in August).

To evaluate the idea that the April TOC values in the Harbor are generally higher than the August values because the TOC content measured during August surveys represents the net inventory of organic matter following respiration of the spring input of carbon substrates, the individual station data by year were compared to the one-to-one regression expected if no processes were operating to modify the TOC between April and August. TOC data from station T04 in 1998 was excluded from the regression analysis due to the suspected localized influence from a June 1998 storm event. Linear regression of the data yields 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 because of respiration. Additionally, the data do not consistently support a seasonal difference.

With the exception of T01, *Clostridium perfringens* showed decreasing abundance at all Traditional stations in April 1999 as compared to corresponding 1997 and 1998 values. The highest counts in April 1999 were about 16,130 cfu (station T04) and 12,640 cfu (station T03). *Clostridium* counts at most stations in August 1999 were generally lower than those for August samples from earlier years and from the April 1999 samples. The highest counts were 8,520 cfu (station T07) and 7,720 cfu (station T03).

Patterns in *Clostridium* densities were highly variable from 1991 to 1999 (April and August) at all Traditional stations, although some stations (*i.e.,* T01, T04, and T08 in April; T01, T02, and T07 in August) were less variable than others. Patterns in *Clostridium* densities tended to be more consistent, with lower numbers (< 10,000 cfu), over time at stations T01, T05A, and T08. There were no clear year-to-year trends in *Clostridium* densities between the April and August surveys. *Clostridium* densities consistently correlated well with grain size and TOC in recent sampling years (1996–1998), but did not do so in 1999.

Infaunal Communities

In general, infaunal abundances in the Harbor were much lower in 1999 than they have been in recent years. Abundances in August 1999 were much lower than their 1998 counterparts at stations T01, T04, T05A, T07, and T08. Stations T01 and T05A, both off Deer Island, have shown a very similar August trend since 1995, beginning with a decrease in abundance from 1995 to 1996 followed by a large increase in 1997, then a steady decline from 1997 to 1999. The dramatic change at station T04 from August 1998 to 1999 was largely related to the very high numbers of Capitella there in 1998 followed by its disappearance by August 1999. August abundances at three stations have been relatively constant since 1996 (T02, T06) or since 1997 (T03). Changes in April infaunal abundance values were not necessarily parallel to August changes. Correlation analysis showed that there was no significant relationship between infaunal abundance in April and that of the following August for any of the Harbor stations (range from – 0.26 at station T05A to 0.52 at station T03; all $n = 8$, $p > 0.05$).

The 1999 samples showed no major differences from those collected in previous years in the numbers of species per station. Species numbers at most stations were within the general range found for the past 6–7 years. Species numbers for August samples have declined somewhat at since 1997 (T01, T05A) or 1998 (T02, T07, T08), but the 1999 values were within the range of variation observed for August samples of the earlier years of the study. However, it is also apparent that species numbers at many stations are now much higher than they were in 1991.

Species diversity, as measured by log-series alpha, in 1999 was very similar to the general range of values report previously for each station. Stations T01, T02, T03, T05A, and T06 showed an increase in diversity from 1991 to August 1992 similar to that shown for species numbers. Diversity has remained much higher, but with some fluctuation, at these stations, and at station T07, since 1992.

The major difference among the predominant species characterizing the Harbor samples in 1999 was the substantial reduction in abundance of the annelid taxon *Capitella capitata* complex, which in 1998 exerted the strongest influence on the distinction among station groups, clearly separating station T04 from the others. In sharp contrast to 1998, the taxon was not found at station T04 in August 1999. Among the most abundant species in April 1999 were the oligochaetes *Tubificoides apectinatus* and *T.* nr. *pseudogaster*, the polychaete *Aricidea catherinae*, and the amphipod *Ampelisca* spp. In August 1999, the polychaetes *Streblospio benedicti* and *Polydora cornuta* joined the former group as the most abundant taxa.

For the first time during the MWRA studies, cluster analysis of the multiyear data set included oligochaetes identified to species for each survey of the program. Including oligochaete species in the analysis revealed three main differences from analyses in which oligochaetes were summed to form a single taxon.

- There was increased consistency in the clustering of samples from station T02, and to a lesser degree, stations T01 and T03. When oligochaete species were not considered, samples from station T02 belonged to five cluster groups. When oligochaete species were identified, 15 of 17 samples from station T02 comprised a group that also included 16 of 17 samples from station T01. The three samples that "misclassified" (T02, Summer 1997 and Spring 1999; T01, Summer 1997) were characterized by relatively high abundances of *Tubificoides apectinatus*, a species not typically abundant at those two stations.
- Station T07 shifted alignment significantly. When oligochaetes were not identified to species, all station T07 samples were most similar to those from the northern part of the Harbor (*i.e.,* stations T01 and T02). However, with oligochaete species distinguished, station T07 is most similar to stations T03, T06, and T08, and is quite distinct from stations T01 and T02.
- When oligochaetes were identified to species, the Spring 1992 samples from station T03 aligned with all samples from the station collected since and comprised a cluster group that also included all samples from station T06. The Summer 1991 (*i.e*., collected before sludge discharge cessation) samples aligned with "spring" group of samples from station T05A.

Conclusions

The observed changes in the structure of Harbor's infaunal communities, coupled with data from SPI studies, provide good evidence for improvement in the condition of benthic habitats in the Harbor since the cessation of sludge discharge in 1991. Most notable was the dramatic increase in abundance and geographic spread of the amphipod *Ampelisca* spp. Also important was the general increase in infaunal abundance and species numbers that occurred after 1991. The most substantial changes in the Harbor's benthos probably occurred within the first two to three years after sludge discharge ended. Most recently there has been some indication that the infaunal communities are in transition from those that appeared soon after release from the stress caused by the sludge to those more likely to be found in a less-polluted Harbor that is still prone to periodic natural disturbance.

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. Briefly, these can be listed as the

- cessation of sludge discharge into the Harbor—December 1991,
- operation of a new primary treatment facility at Deer Island—1995,
- initiation of secondary treatment (first battery)—1997,
- continuation of secondary treatment implementation (second battery)—1998,
- cessation of effluent discharge from Nut Island—July 1998, and
- cessation of effluent discharge to Harbor—September 2000.

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.* 2000). Among the changes reported in these studies, the increase in abundance and geographic distribution of the tube-dwelling amphipod *Ampelisca* has been the most dramatic.

A major forthcoming change to discharges into the Harbor, the diversion of effluent to the new ocean outfall, is expected to result in further improvements in the Harbor's benthic habitats.

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 62 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. 1999 studies included 16 grain-size, TOC, and *Clostridium* samples. These studies 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 in 1999. 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 Roy K. Kropp and 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 expected to improve over a broader expanse of the Harbor as secondary treatment is implemented and effluent discharge is diverted to the outfall.

2.1.1 Traditional

During the Harbor traditional surveys, conducted late April and early September 1999, 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 from these traditional stations were collected 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 1999 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 1999. Sediment profile images (SPI) were obtained at the 52 "reconnaissance" stations, the 8 'traditional" stations and at an additional six stations (S01 through S06) designated by the Senior Scientist. Stations S01 and S06 were chosen to examine smaller scale spatial variation (Figure 2-2). The actual locations of all Boston Harbor sediment profile images collected in 1999 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 1999.

Survey	ID	Date(s)	Samples Collected				
			Inf	TOC	GS	Cp	SPI
April Harbor Benthic	HT991	20 April 1999	24	8	8	8	–
August Harbor Benthic	HT992	1 September 1999	24	8	8	8	–
SPI	HR991	25-26 August 1999	–	–	–	–	375

Key:

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

Figure 2-1. Target locations of the eight Boston Harbor Traditional stations.

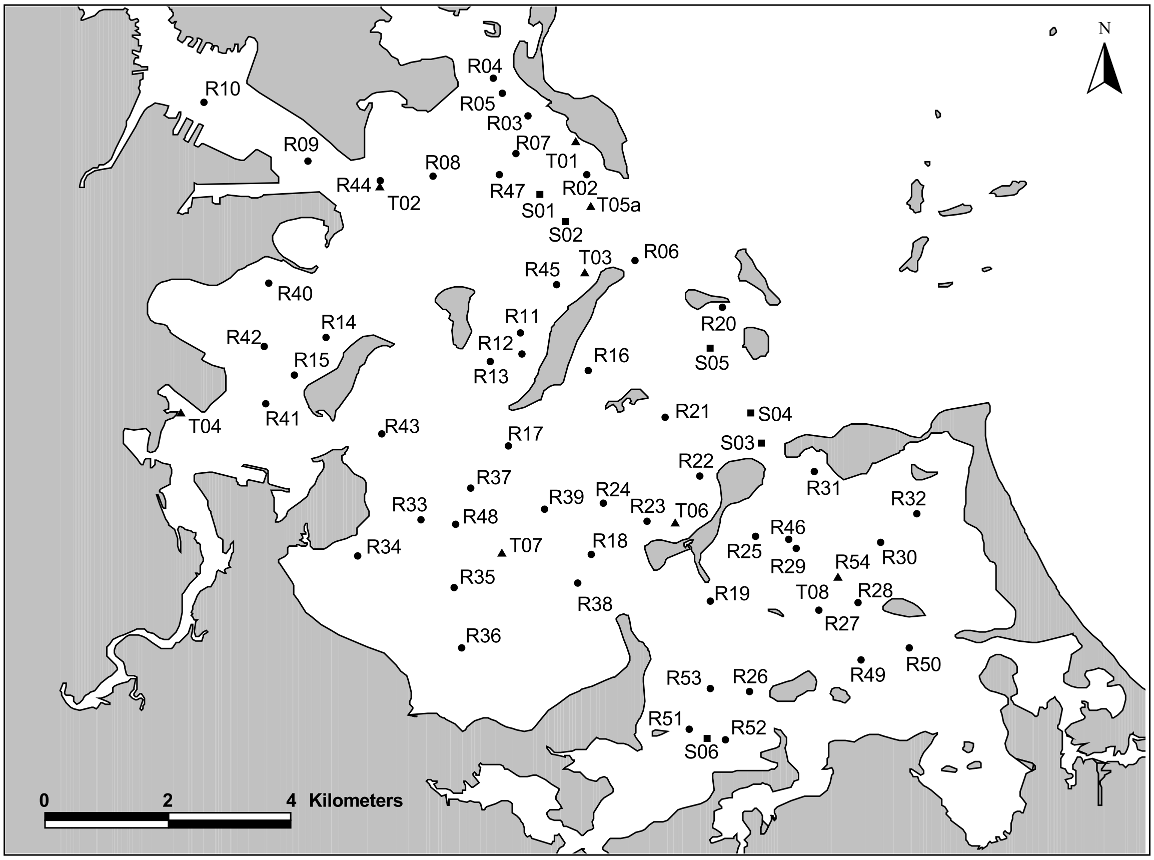


Figure 2-2. Locations of Boston Harbor Reconnaissance stations from which sediment profile images were collected in 1999.

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 1998).

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 Young-modified van Veen grab sampler was used to collect three replicate samples for infaunal analysis and one 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 by 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. At each of the additional "S" stations, the camera was deployed only once. 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. However, at station R20, three replicates were collected during each deployment. 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. The videotape was recorded during each drop and was narrated by Dr. Robert Diaz as the still photos were taken. The narration included the station, time, approximate prism penetration depth and a brief description of the substrate. In addition, Dr. Diaz estimated the Oxidation-Reduction Potential Discontinuity at each Harbor station. These measurements were hand entered in Dr. Diaz's log, and the Battelle Survey logbook. Each touch down of the camera was marked as an event on the NAVSAM©.

3.0 1999 SEDIMENT PROFILE CAMERA RECONNAISSANCE OF HARBOR BENTHIC HABITATS

by Robert J. Diaz

3.1 Materials and Methods

3.1.1 Field Methods

On 24, 25, 26 August 1999 the sediment profile survey of Boston Harbor stations was conducted. Sediment Profile Images (SPI) data were successfully collected at 60 long-term R and T stations. An additional six stations were taken to investigate spatial heterogeneity within and between long-term stations. These stations were labeled S1 through S6 (Figure 2-2). At station R20 nine replicates were collected in three sets of three replicates. These were labeled R20R1, R20R2, and R20R3.

At each station a Hulcher Model Minnie sediment profile camera fitted with a digital video camera, to allow for real-time viewing of the sediment profiles, was deployed three times. The recorded video turned out to be important in determining surface and subsurface features at several stations that were very soft. 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 would insure that the sediment-water interface would be photographed before the prism window over penetrated. Any replicates that appeared to be disturbed during deployment were retaken.

3.1.2 Image Analysis

The sediment profile images were first analyzed visually by projecting the images and recording all features seen into a preformatted standardized spreadsheet file. The images were then 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 spread sheet 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*. (2000).

3.2 Results and Discussion

3.2.1 1999 Harbor Image Data

A complete listing of SPI data can be found in Appendix B-1. Appendix B-2 provides a summary of within-station variability for quantitative measurements: prism penetration, surface relief, redox potential discontinuity (RPD) depth, organism-sediment index (OSI), and number of infauna, burrows, and voids. A station summary of SPI data is contained in Table 3-1. At least one replicate image from each target station is contained in Appendix B-3. Images were selected to show the range of physical and biological processes active in the Harbor area.

Table 3-1. Harbor area summary of SPI parameters for August 1999 stations. Data from all three replicates were averaged for quantitative parameters and summed for the qualitative parameters (for example, the presence of shell in one of the three replicates results in a + for the station). Legend key is at the end of the table.

Station	PEN	SURREL	RPD	Grain Size	Shell	Bed Forms	Rough Type	Amphipod Tubes	Worm Tubes	Stick Amphipod	Worms	Burrows
R02	18.0	1.4	2.4	SI	-	-	INTER	MAT	-	-	+	+
R03	10.7	1.2	1.1	SIFS	+	-	INTER	+	+	-	+	+
R04	21.5	0.5	0.5	SI	-	-	BIOG	-	+	-	-	+
R05	19.1	0.8	0.6	SI	-	-	BIOG	+	+	-	+	+
R06	2.7	0.9	0.7	FSMSGRPB	-	-	BIOG	-	MAT	-	-	-
R07	18.9	1.6	8.0	SI	-	-	BIOG	MAT	+	-	+	+
R08	2.7	0.7	1.6	VFS	-	-	BIOG	-	-	-	-	-
R09	14.0	0.8	3.4	SIFS	-	-	BIOG	MAT	-	+	+	+
R10	28.5	0.7	2.2	SI	-	-	BIOG	MAT	-	-	+	-
R11	23.8	1.3	6.9	SI	-	-	BIOG	MAT	-	-	+	+
R12	23.4	0.9	7.5	SI	-	-	BIOG	MAT	-	-	+	+
R13	20.2	0.6	0.4	SI	-	-	INTER	-	+	-	-	+
R14	7.1	1.6	0.7	FS/CLSI	-	-	INTER	-	+	-	+	+
R15	6.2	0.8	0.6	SIFS/CLSI	+	-	BIOG	-	+	-	+	+
R16	5.7	2.3	1.7	SI/CLSI	+	-	BIOG	MAT	-	-	+	-
R17	23.5	0.9	5.5	SI	-	-	BIOG	MAT	-	-	+	+
R18	16.9	1.3	6.8	SI	-	-	BIOG	MAT	+	+	+	+
R19	1.8	1.9	0.5	SIFSMSGRPB	-	-	INTER	+	+	-	-	-
R20R1	23.3	0.9	7.5	SI	-	-	BIOG	MAT	-	-	+	+
R20R2	19.8	2.0	7.2	SI	-	-	BIOG	MAT	+	-	+	+
R20R3	1.7	2.4	0.5	SIFSGRPBCB	-	-	INTER	+	+	-	-	-
R21	6.2	1.1	1.7	SIFS	-	-	BIOG	MAT	-	-	+	+
R22	3.8	1.6	0.8	SIFSMSGRPB	-	-	BIOG	MAT	-	-	-	-
R23	2.1	1.6	IND	FSMS	-	-	INTER	+	+	-	-	-
R24	17.7	1.6	6.8	SI	-	-	BIOG	MAT	-	-	+	+
R25	20.4	1.6	3.4	SI	-	-	BIOG	MAT	-	-	+	+
R26	18.3	0.4	0.7	SI	-	-	INTER	+	+	-	-	+
R27	18.6	1.8	1.9	SI	-	-	BIOG	MAT	-	-	+	+

Table 3-1. Harbor area summary of SPI parameters for August 1999 stations. (continued)

Station	VOIDOXIC	VOIDANOX	VOIDGAS	Range SS	Median SS	OSI	Other
R02	+	+	+	II - II/III	II	5.7	
R03	+	+	-	I - I/II	I/II	3.3	
R04	+	+	-	I - I/II	I	2.3	
R05	+	+	-	I - II	I/II	3.0	
R06	-	-	-	I	I	2.3	
R07	+	+	-	II - II/III	II	9.3	Senescent tube mat
R08	-	-	-	I	I	3.7	Macroalgae
R09	+	+	-	II	II	8.0	
R10	-	+	-	I	I	4.3	
R11	-	+	-	II	II	9.0	
R12	+	+	-	II	II	9.0	
R13	-	+	-	I	I	2.0	
R14	-	+	-	I	I	2.3	sand layer over clayeysilt
R15	-	-	-	I	I	2.0	shelly-sandy layer over clayeysilt
R16	-	-	-	II	II	5.7	Senescent mat, shelly laryer over clayeysilt
R17	+	+	+	II/III	II	8.7	
R18	+	+	-	II	II	9.0	Senescent tube mat
R19	-	-	-	I	I	2.0	
R20R1	+	+	-	II	II	9.0	
R20R2	+	+	-	II	II	9.0	
R20R3	-	-	-	I	I	5.7	
R21	+	-	-	II	II	5.7	Senescent tube mat
R22	-	-	-	I - II	II	4.5	Senescent tube mat
R23	-	-	-	I	I	IND	
R24	+	+	-	II - II/III	II/III	9.7	Senescent tube mat
R25	+	+	-	II	II	8.0	
R26	+	+	-	I - I/II	I/II	3.3	
R27	+	+	-	II	II	6.3	

Table 3-1. Harbor area summary of SPI parameters for August 1999 stations. (continued)

Station	PEN	SURREL	RPD	Grain Size	Shell	Bed Forms	Rough Type	Amphipod Tubes	Worm Tubes	Stick Amphipod	Worms	Burrows
R28	15.4	1.7	3.1	SIFS	-	-	BIOG	MAT	-	-	+	+
R29	19.1	1.9	2.8	SI	-	-	BIOG	MAT	-	-	+	+
R30	11.3	1.6	2.1	SIFS	-	-	BIOG	MAT	-	-	+	+
R31	19.2	2.0	5.1	SI	-	-	BIOG	MAT	-	-	+	+
R32	16.4	1.9	0.6	SI	-	-	INTER	+	+	-	+	+
R33	14.1	1.0	0.6	SICL	-	-	BIOG	-	MAT	-	+	+
R34	19.5	1.1	0.6	SI	-	-	INTER	-	+	-	+	-
R35	11.7	1.7	0.9	SICL	BED	-	INTER	-	MAT	-	-	+
R36	3.2	1.6	0.4	FSSI	+	-	INTER	-	+	-	-	+
R37	15.6	1.2	0.3	SI	+	-	BIOG	+	+	-	-	+
R38	18.8	1.0	5.7	SI	-	-	BIOG	MAT	-	-	+	+
R39	14.6	1.4	1.5	SI	BED	-	BIOG	+	+	-	+	+
R40	12.2	1.5	0.7	SIFS	-	-	INTER	-	+	-	+	+
R41	17.8	0.6	0.7	SI	-	-	INTER	-	+	-	+	+
R42	7.8	1.1	0.4	SIFS	-	-	INTER	-	+	-	-	+
R43	22.1	0.8	0.4	SI	-	-	INTER	-	MAT	-	+	-
R44	22.9	0.9	1.2	SI	-	-	INTER	-	+	-	-	+
R45	19.5	2.3	3.3	SI	-	-	BIOG	MAT	+	-	+	+
R46	17.0	1.9	2.1	SI	-	-	BIOG	MAT	-	-	+	+
R47	19.5	2.4	5.4	SI	-	-	BIOG	MAT	-	-	+	+
R48	13.3	1.0	0.5	SI	+	-	INTER	-	+	-	+	+
R49	16.6	2.9	1.1	SI	-	-	BIOG	-	+	-	+	+
R50	12.3	1.2	0.8	SIFS	-	-	INTER	+	-	-	+	+
R51	11.7	0.8	1.0	SIFS	-	-	INTER	+	+	-	+	+
R52	7.1	1.5	0.8	SIFS	BED	-	BIOG	-	+	-	-	+
R53	6.3	1.7	0.6	SIFS	-	-	INTER	-	+	-	-	+
S1	12.8	1.0	1.8	SI	-	-	BIOG	MAT	-	+	+	+
S2	0.0	IND	IND	PBCB	-	-	PHYS	-	+	-	IND	IND
S3	2.2	3.5	0.8	SIFS	-	-	BIOG	-	+	-	-	-
S4	1.3	1.4	0.9	MSGR	-	-	PHYS	-	+	-	-	-
S5	15.5	1.2	4.6	SI	-	-	BIOG	MAT	+	-	+	+
S6	7.4	4.6	0.8	SI	-	-	BIOG	-	+	-	+	-
T01	8.3	0.5	0.7	SIFS	-	-	INTER	-	+	-	+	+
T02	17.4	0.9	1.0	SI	-	-	BIOG	+	+	-	+	+

Table 3-1. Harbor area summary of SPI parameters for August 1999 stations. (continued)

Station	VOIDOXIC	VOIDANOX	VOIDGAS	Range SS	Median SS	OSI	Other
R28	+	-	-	II - II/III	II	8.3	
R29	+	+	-	II	II	7.0	
R30	+	-	-	II	II	6.3	
R31	+	+	-	II - II/III	II	8.7	
R32	+	+	-	I/II	I/II	3.0	
R33	+	-	-	I - I/II	I/II	3.0	
R34	+	+	-	I - I/II	I	2.7	Microalgal mat
R35	+	+	-	I - I/II	I/II	3.7	Oyster bed
R36	-	+	-	I	I	2.0	Round shell formations?
R37	-	+	-	I - I/II	I	2.3	Lobster in burrow, Silty shell layer over silt
R38	+	+	-	II	II	9.0	
R39	+	+	-	I - I/II	I	3.7	Mussel bed
R40	+	-	-	I - I/II	I/II	3.3	
R41	-	+	-	I	I	2.3	
R42	+	+	-	I - I/II	I	2.3	
R43	-	+	-	I	I	2.0	
R44	+	+	-	I - I/II	I	3.3	
R45	+	+	-	II	II	7.7	
R46	+	-	-	II - II/III	II	6.3	
R47	+	+	-	II	II	9.0	
R48	+	+	-	I - I/II	I	2.3	Silty shell layer over silt
R49	+	+	-	I - I/II	I	3.3	
R50	-	+	-	I - I/II	I	2.7	
R51	-	+	-	I - I/II	I	3.3	
R52	+	-	-	I - I/II	I	3.0	Oyster bed, microalgal mat
R53	-	-	-	I	I	2.0	
S1	+	+	-	II	II	6.0	
S2	IND	IND	IND	IND	IND	IND	
S3	-	-	-	I	I	3.0	
S4	-	-	-	I	I	3.0	
S5	-	-	-	II	II	9.0	Senescent tube mat
S6	-	-	-	I	I	3.0	
T01	+	+	-	I - I/II	I	2.3	Macroalgae
T02	-	+	-	I	I	3.0	

Table 3-1. Harbor area summary of SPI parameters for August 1999 stations. (continued)

Station	PEN	SURREL	RPD	Grain Size	Shell	Bed Forms	Rough Type	Amphipod Tubes	Worm Tubes	Stick Amphipod	Worms	Burrows
T03	14.6	2.1	3.9	SI	-	-	BIOG	MAT	-	-	+	+
T04	20.9	1.0	0.2	SI	-	-	PHYS	-	+	-	+	+
T05A	3.5	0.8	0.7	SIFS	-	-	INTER	-	+	-	-	+
T06	13.4	2.8	3.3	SIFS	-	-	BIOG	MAT	-	-	+	+
T07	15.9	2.1	1.5	SI	+	-	BIOG	-	+	-	-	+
T08	6.0	1.4	0.8	FSSI	-	-	INTER	+	+	-	-	+

Station	VOIDOXIC	VOIDANOX	VOIDGAS	Range SS	Median SS	OSI	Other
T03	+	+	-	II	II	8.3	
T04	-	-	-	I	I	2.0	
T05A	-	-	-	I	I	2.3	
T06	+	-	-	II	II	7.7	
T07	+	+	-	I/II	I/II	4.0	
T08	-	-	-	I	I	2.7	

Legend Key:

Stat. = Station
Pen. = Average prism penetration depth (cm)
SR = Average surface relief or bed roughness cross the 15 cm width of the prism face plate (cm)
RPD = Average depth of the apparent color RPD (cm)

Sediment:
CB = Cobble
CS = Coarse-sand
FS = Fine-sand
FSSI = Fine-sand-silt
GR = Gravel
MS = Medium-sand
PB = Pebble
SI = Silt
SICL = Silty-clay
SIFS = Silty Fine-sand
VFS = Very fine-sand

Shell:
– = Not present
\+ = Some SHELL present
Bed = SHELL BED

Bedforms:
– = Not present
\+ = Present

Dominant Process:
BIOLG = Biological processes dominate surface sedimentary features
INTER = Both Biological and physical processes shape surface features
PHY = Physical processes dominate surface sedimentary features

Amphipod Tubes = Amphipod tubes
Worm Tubes = Worm tubes
Stick Amphi. = Stick amphipod biogenic structures, likely the genus Dyopedos:
– = Not present
\+ = Few to many TUBES present
MAT = Tube MAT present
Burrows = Infaunal burrows
Oxic Voids = Water-filled inclusions in sediment that appear to have oxidized sediment in them
Anaero. Voids = Water-filled inclusions in sediment that appear to have anerobic sediment in them
Gas Voids = Gas filled inclusions in sediment
– = Not present
\+ = Present
Low DO = Appearance that low dissolved oxygen conditions were present when the image was taken
SS = Estimated successional stage
I = Pioneering sere
II = Intermediate sere
III = Equilibrium sere
OSSI = Organism Sediment Index of Rhoads and Germano (1986)
IND = Indeterminate

Physical Processes and Sediments—Sediment grain size ranged from cobbles and pebbles (R20R3, R06) to soft, silty sediments (T04) (Table 3-1, Appendix B-1). The predominant sediment type throughout the study area was silty mud (modal Phi 8 to 5) and occurred at 41 of the 68 stations (60%), including the additional 6 stations collected to evaluate spatial heterogeneity. Silty fine sands and fine sandy silts occurred at 18 (26%) stations throughout the study area. Fine to medium sands occurred at two stations (3%) R08 on Deer Island flats and R23 west of Peddocks Island. Coarser gravel to cobble sediments occurred at three stations (4%) R06, S2, and S4 all in the outer harbor area. Heterogeneous silty to coarse gravely-pebbly sediments occurred at three stations (4%) R22 and R19 around Peddocks Island and R20R3, the third set of three replicates collected at station R20, in the outer harbor south of Gallops Island. Three stations appeared to have layered sediments with silty and fine sand over silty-clay sediments at R14 and R15, west of Thompson Island, and silty over silty-clay at R16, east of Long Island. Shell hash was a significant component of the sediments at seven stations, most in Quincy Bay. Oyster shell beds occurred at R35 in Quincy Bay and R52 in Hingham Bay and mussel shell beds at R39 in Quincy Bay (Figure 3-1).

The stations with the most heterogeneous sediments were R19 and R22 around Peddocks Island and R20 in the outer harbor south of Gallops Island (Figure 3-1). Sediments at these stations ranged from silts to pebbles and cobbles. Stations R06 and S4 in the outer harbor also had heterogeneous sediments but little evidence of silts in the images. Station R20 appears to be located close to transition from fine to coarse sediments. The first set of three replicates (R20R1) were all silty, which was contrary to the coarse sediment found in 1998 (Kropp *et al*. 2000). Additional sampling at R20 found that the transition from silty to coarse sediments occurred within the 35-m distance between R20R2 replicate 3 and R20R3 replicate 6 (Figure 3-2). The total distance between all nine replicates at R20 was about 230 m.

Pure sands and coarser sediments, indicative of high kinetic energy bottoms tended to occur toward the Outer Harbor (Figure 3-1). However, bedforms, also an indicator of higher energy bottoms, were not seen at any of the stations. This may be a combined result of biogenic mixing of surface sediments that would tend to obliterate bedforms and quiescent hydrodynamic conditions that would not support formation of new bedforms. Most stations were homogeneous finer sediments, fine-sand-silts to silts with all three image replicates being similar (Appendix B-1, Table 3-1).

The broad range of sedimentary habitats within the Harbor is reflected in the range of average station prism penetration, which was 0.0 cm at S2 in President Roads near the Outer Harbor to 28.5 cm at R10 in the Inner Harbor. Prism penetration was related to sediment type with lowest penetration in coarser sediments with gravel and pebble and highest in silty sediments (Table 3-1, Figure 3-3). Average penetration in silty sediments was highest, 18.4 ± 0.6 cm (mean ± SE), and lowest in coarse sediments, 1.5 ± 0.6 cm (Table 3-2).

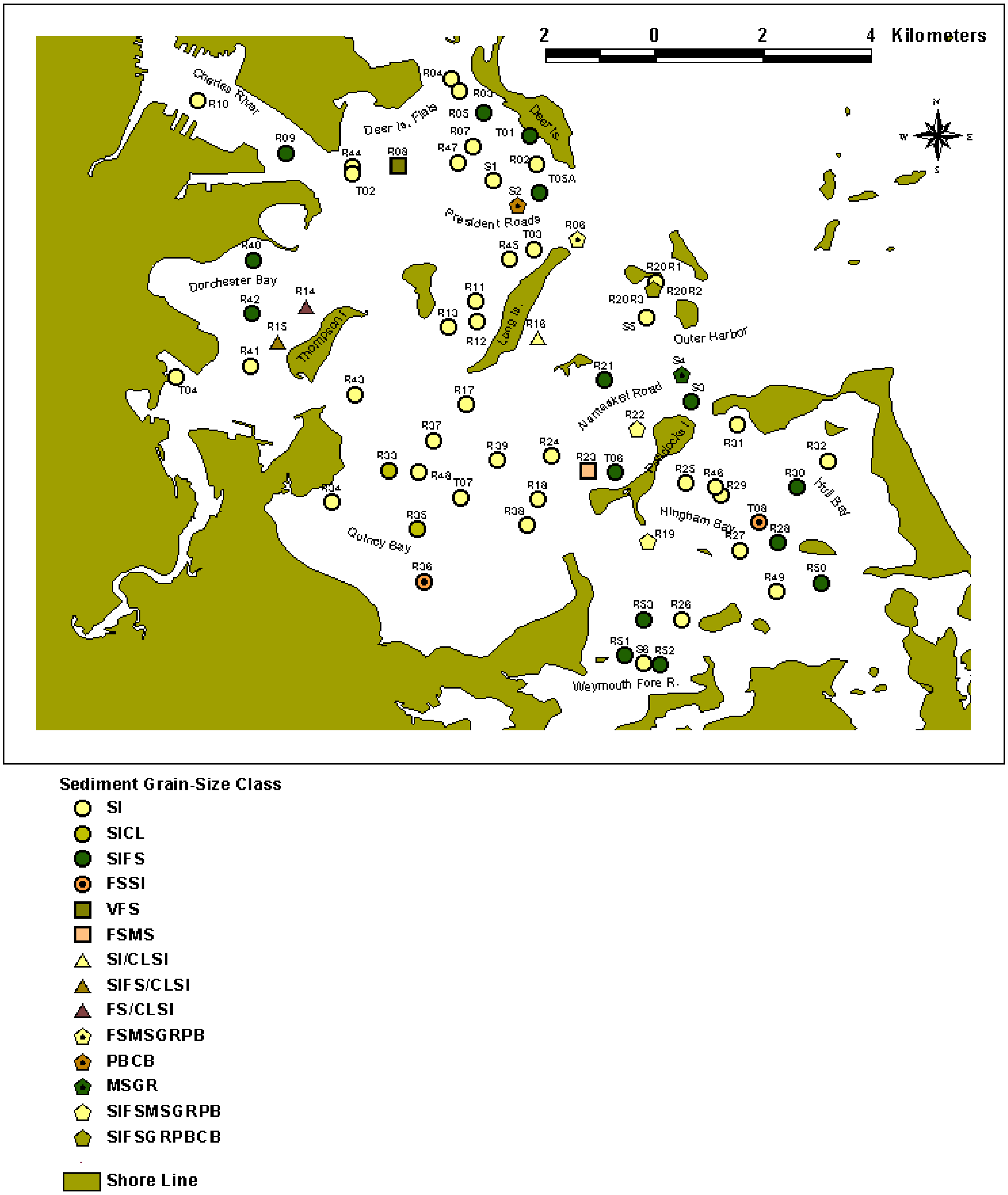


Figure 3-1. Spatial distribution of sediment types at Boston Harbor stations as determined from SPI, August 1999.

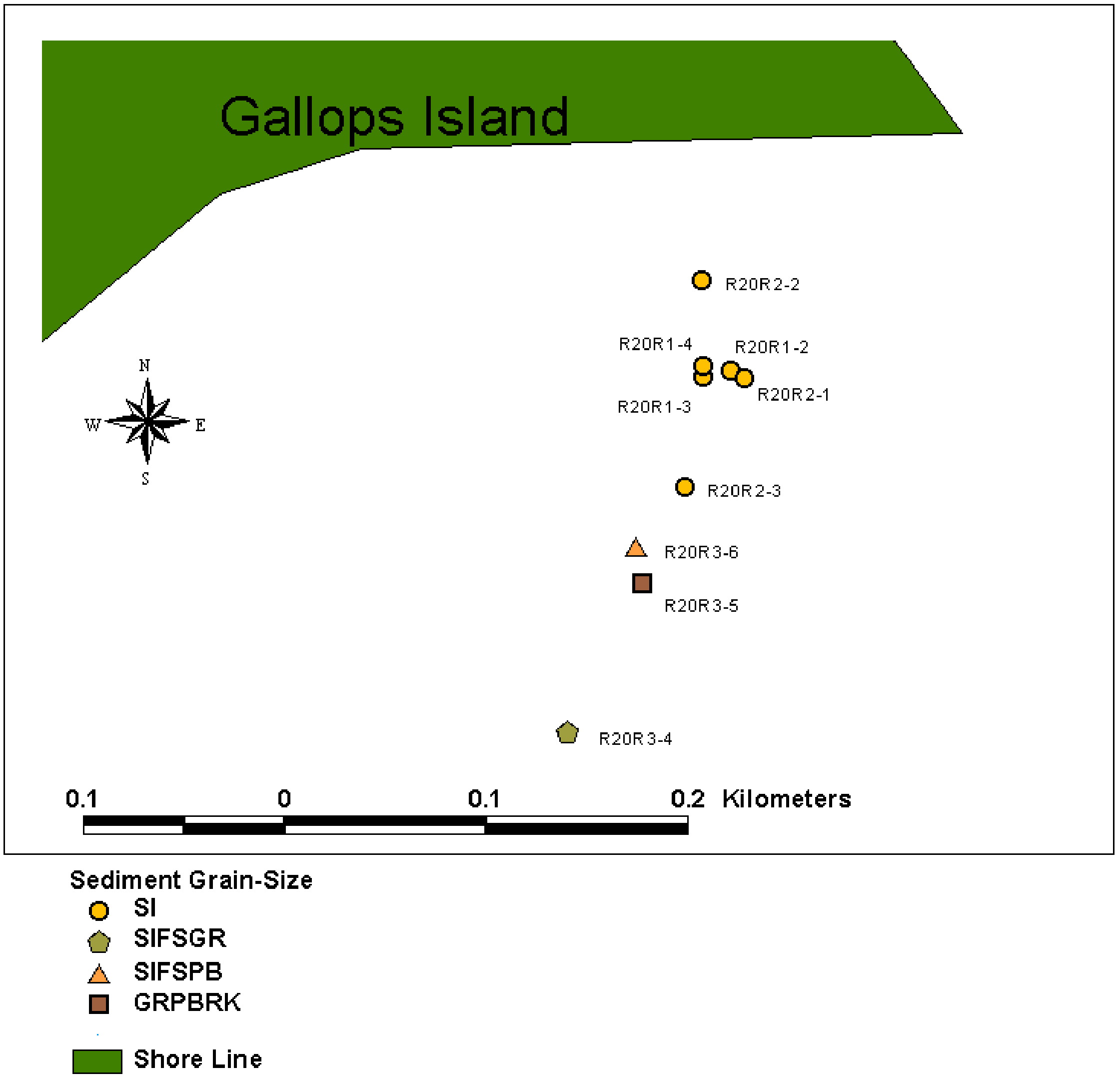


Figure 3-2. Spatial distribution of replicate images from Station R20, south of Gallops Island, August 1999. Fine to coarse sediment transition occurred between replicates R20R2-3 and R20R3-6.

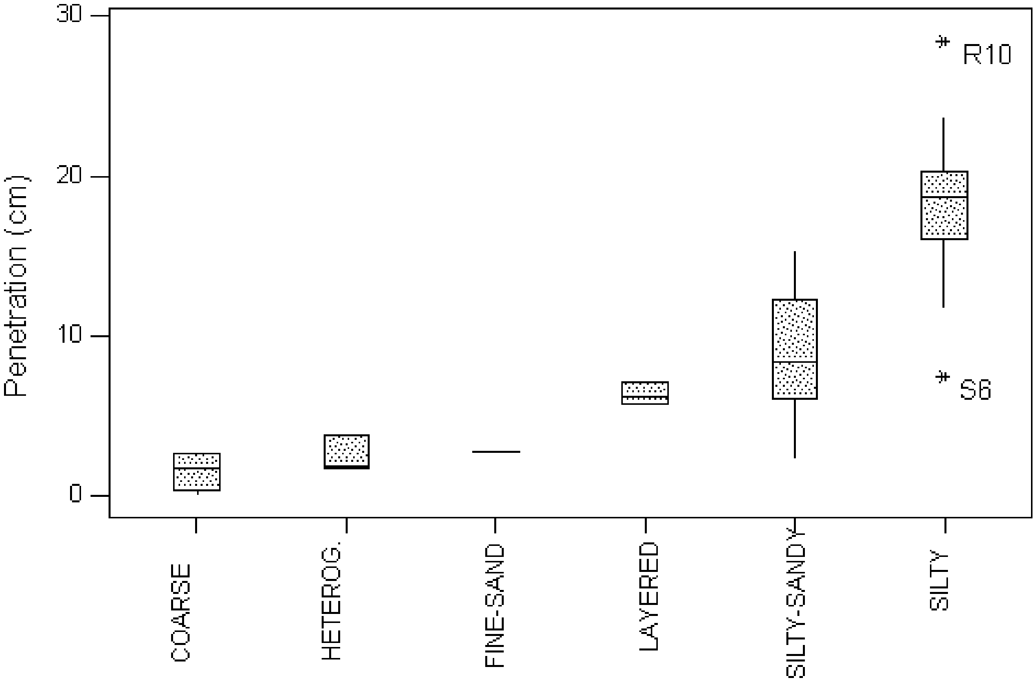


Figure 3-3. Boxplots of prism penetration (cm), a proxy for sediment compaction, by SPI sediment classes at Boston Harbor stations, August 1999. Box is interquartile range (IR), bar is median, vertical lines are range, asterisks are outliers (>2IR).

Table 3-2. Descriptive statistics summary of SPI parameters from Boston Harbor, August 1999.

Sediment Class	Penetration (cm)				
	N	Mean	Median	SD	SE
Coarse	4	1.5	1.7	1.17	0.58
Heterogeneous	3	2.4	1.8	1.18	0.68
Fine-Sand	1	2.7	2.7	–	–
Layered	3	6.3	6.2	0.71	0.41
Silty-Sandy	17	8.9	8.3	4.04	0.98
Silty-Sandy	40	18.4	18.7	3.85	0.61

Dominant Process	Bed Roughness or Surface Relief				
	N	Mean	Median	SD	SE
Biological	41	1.6	1.5	0.82	0.13
Intermediate	24	1.2	1.2	0.51	0.10
Physical	2	1.2	1.2	0.28	0.20

Sediment Class	RPD Layer Depth (cm)				
	N	Mean	Median	SD	SE
Coarse	2	0.8	0.8	0.14	0.10
Heterogeneous	3	0.6	0.5	0.17	0.10
Fine-Sand	1	1.6	1.6	–	–
Layered	3	1.0	0.7	0.61	0.35
Silty-Sandy	17	1.3	0.8	1.02	0.25
Silty	40	2.87	1.8	2.57	0.41

Dominant Process	RPD Layer Depth (cm)				
	N	Mean	Median	SD	SE
Biological	41	3.1	2.1	2.41	0.38
Intermediate	23	0.8	0.7	0.42	0.09
Physical	2	0.6	0.6	0.50	0.35

Dominant Process	RPD Layer Depth Class		
	<1 cm	1-3 cm	>3 cm
Biological	10	13	18
Intermediate	19	4	0
Physical	2	0	0

The bed roughness or surface relief in areas that appeared to be dominated by physical or biological processes were about the same magnitude (Table 3-2). Over the entire study area the range of surface relief was 0.4 – 4.6 cm (Table 3-1). Physically dominated bottoms represented about 4% of the stations, which included T04 in inner Dorchester Bay and S2 and S4 in the Outer Harbor. The latter two stations had coarser sediments while the former had silty sediments, all with surfaces that lacked evidence of biological activity. Biologically dominated bottoms, about 60% of stations, tend to have mixed to finer sediments and surface sediments modified by biogenic activity (burrowing, feeding, and irrigating). The remaining 35% of stations were intermediate and had surfaces with reflected the influence of both physical and biological processes. In physically dominated habitats with coarse sediments surface relief was due to sediment grain (gravel, pebble, or cobble) and in silty sediments 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 biogenic features, followed by what appeared to be feeding pits or mounds, creating surface relief.

Apparent Color RPD Layer Depth—The average apparent color RPD layer depth ranged from 0.2 to 8.0 cm over the study area (Table 3-1, Figure 3-4). The shallowest RPD value of 0.2 cm occurred at Station T04 in Dorchester Bay, which appeared to be organically enriched with dark-gray silty sediments. 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 all contributed to the shallow RPD layer depth at T04. Station R07 on Deer Island Flats, with silty sediments and high levels of biogenic activity, had the deepest RPD layer depths, 8.0 cm. Overall, silty sediments dominated by biogenic structures had the deepest RPD layers and the shallowest RPD depths were bottoms that were dominated by physical processes (Table 3-2).

The deepest RPD layers depths were associated with *Ampelisca* spp. tube mats in silty fine sand and silty sediments and occurred over a broad area of the mid and outer harbor (Figure 3-5). Biogenic activity in the form of infaunal burrows convoluted and extended the depth of the RPD layer at most stations with *Ampelisca* spp. mats extending well below the depth of the average RPD layer. The maximum extent of oxic sediments exceeded 10 cm in 38 station/replicate images (Appendix B-1, parameter Max RPD). The deepest penetration of apparent oxic sediments, maximum RPD layer, was 19.7 cm at Station R47 replicate 3 in President Roads near Deer Island flats. Six other stations had Max RPD depths that were ≥15 cm (R18, R24 and T06 off southwestern end of Peddocks Island, R45 off Long Island in President Roads, R49 in Hingham Bay, and R20 near Gallops Island in the Outer Harbor). These deep oxic sediments were evidence that a large, deep-burrowing infauna had developed. About 20% of the images with Max RPD depths >10 cm contained large infauna. For example, three large (>1 cm diameter) terrebellid like worms were present in replicate 3 of R24 and a terrebellid and burrowing cerianthid anemone in replicate 2.

On average, the RPD layer depth for coarse sediment stations, 0.8 cm, was low relative to other sediment types (Table 3-2, Figure 3-6). Areas with the shallowest (< 1.0 cm) RPD depths, factoring out sediments coarser then fine-sand, tended to occur toward the inner areas of the Harbor (Figure 3-4). This included all seven fine sediment stations in Dorchester Bay, half (6 of 12) of the stations in Quincy Bay, and most stations (4 of 5) at the mouth of the Weymouth Fore River. In Hingham Bay 3 of 11 stations had shallow RPD depths as did 4 of 9 fine sediment stations off Deer Island (Figure 3-4). Overall, stations with <1 cm RPD depths exhibited less biogenic activity and a greater dominance of physical processes. About 25% of stations with biological surfaces had RPD depths <1 cm verses about 85% for stations with intermediate to physical surfaces (Table 3-2).

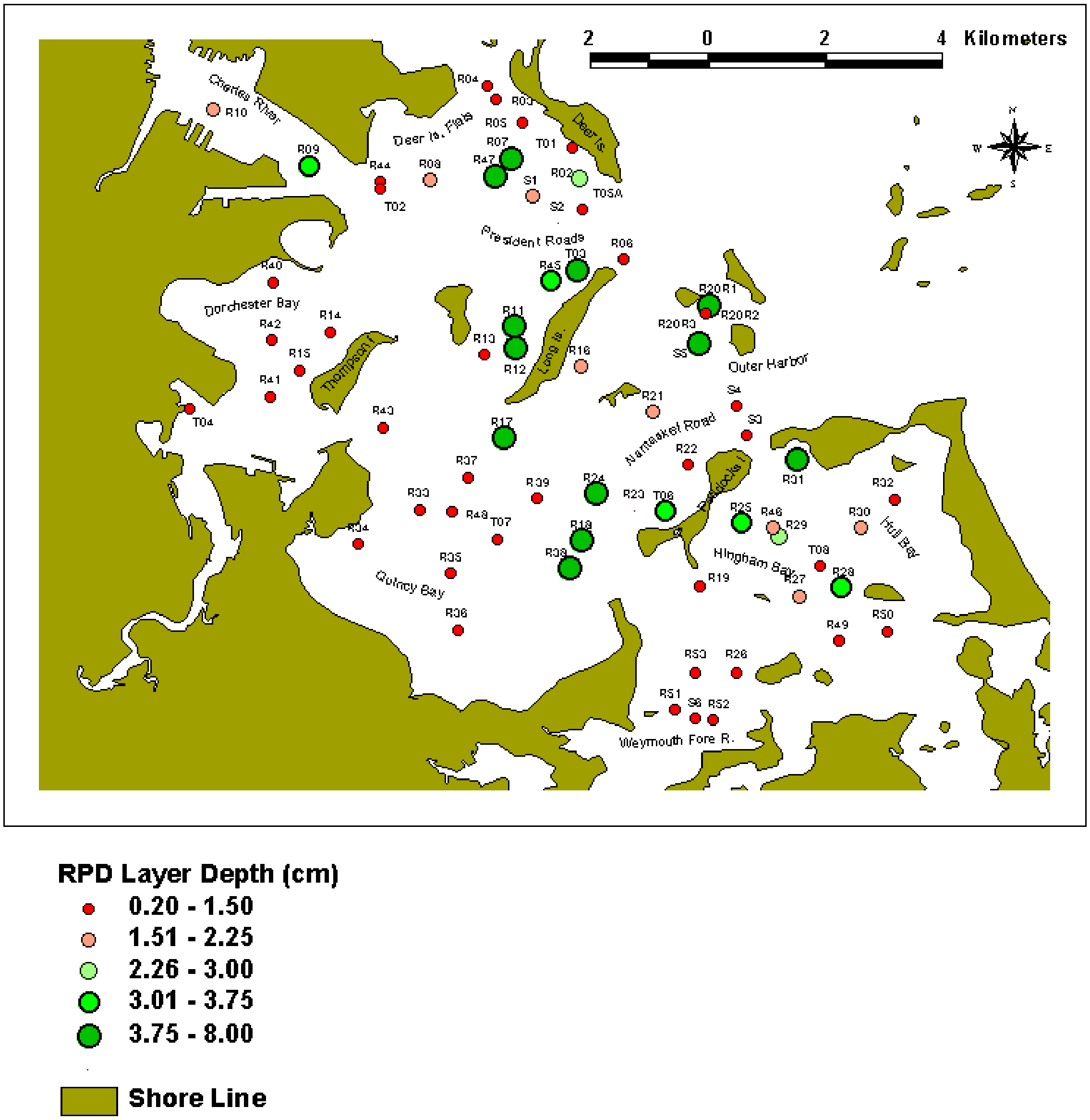


Figure 3-4. Spatial distribution of apparent color RPD layer depth (cm) at Boston Harbor stations as determined from SPI, August 1999.

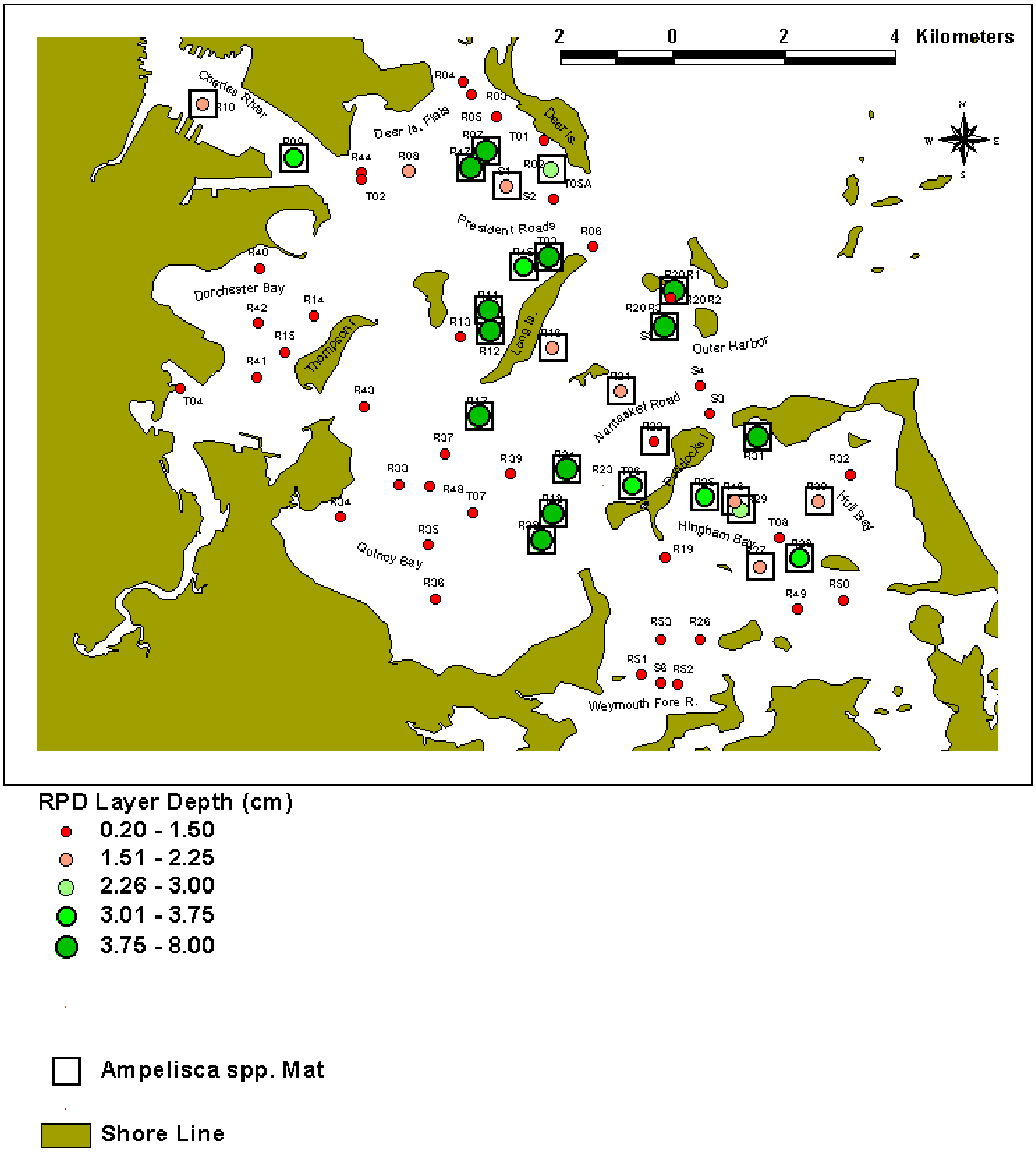


Figure 3-5. Spatial distribution of *Ampelisca* spp. tube mats overlain on apparent color RPD layer depth (cm) at Boston Harbor stations as determined from SPI, August 1999.

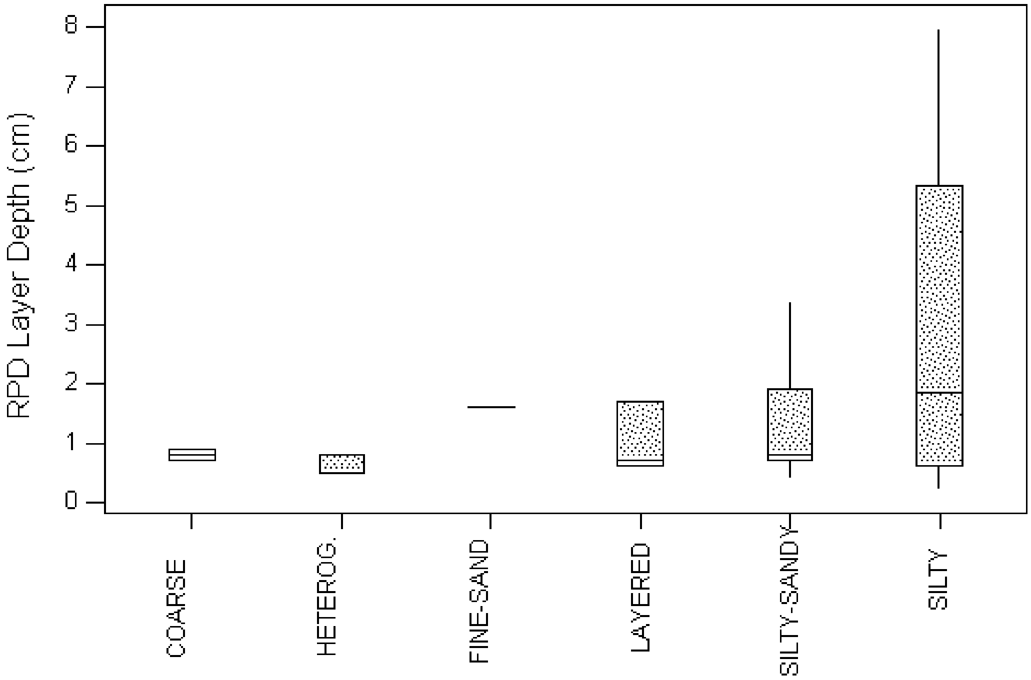


Figure 3-6. Boxplots of apparent color RPD layer depth (cm) by SPI sediment classes at Boston Harbor stations, August 1999. Box is interquartile range (IR), bar is median, vertical lines are range, asterisks are outliers (>2IR).

Biogenic Activity—The sediment surface at 60% (41 of 68) stations was dominated by biological processes as evidenced by widespread biogenic activity associated with successional Stage II fauna (Table 3-1). Evidence that a combination of biological and physical processes were active in structuring bed roughness occurred at 35% (24) of the stations. Physical processes dominated two coarse sand stations and one fine sediment station. Most of the coarse sediment stations did have biogenic surfaces that were generally associated with tubes and other encrustations. For example, the pebbles at Station R06, in the Outer Harbor off the northern tip of Long Island, were covered with mat densities of small worm tubes (Table 3-1). Worm tubes were also seen at mat densities at three other stations (R33, R35, and R43 all in Quincy Bay).

The predominant surface biogenic structures observed included feeding pits and mounds (52 stations), small and large worm tubes (42 stations), epibenthic organisms (34 stations), *Ampelisca* spp. tube mats (27 stations), and shell (10 stations). Biogenic mud whips or sticks made by amphipods likely in the genus *Dyopedos* (Mattson and Cedhagen 1989) were common in 1998 but only occurred at three stations in 1999 (Table 3-1).

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. Burrows were seen at about 81% of all stations with the average number of burrows in finer silty-fine-sand and silt sediments being about 3.5 burrows/image (Appendix B-2). Infauna occurred at about 69% of all stations and were also most abundant in finer sediments than in coarser sediment types.

Gas-filled voids, which are indicative of a higher rate of organic loading to the sediments, occurred at two stations, R02 near the south end of Deer Island and R17 near the south end of Long Island. Station T04 that was the most organic enriched of the stations had gas voids in 1998, but not in 1999 (Table 3-1). Water-filled voids, both oxic (58% of stations) and anaerobic (63%), occurred at about 75% of all stations with a pattern similar to burrows (Table 3-1). Water-filled voids and burrows are biogenic structures that are indicative of infaunal activity. The numbers of water-filled voids were about equally split between oxic 49% (apparently filled with oxidized sediment indicating current or recent infaunal activity) and anoxic 51% (apparently relic voids from previous infaunal activity or created by some physical processes such as sediment cracking during profiling of the sediment).

Subsurface biogenic structures and actives were highest at stations where biological processes dominated surface features. For example, the density of infaunal organisms present was highest at stations with *Ampelisca* spp. tube mats (3.0 ± 2.2 worms/image, mean ± SD) verses non-mat stations (Figure 3-7). Infauna were also abundant at Station T04 (3.7 worms/image) but they were smaller in size than the infauna associated with *Ampelisca* spp. tube mats. 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 OSI. The highest abundance of infauna was at Station R09 near the mouth of the Charles River (Inner Harbor) where the average was 9 worms/image and the range 4 to 13 worms/image (Appendix B-1).

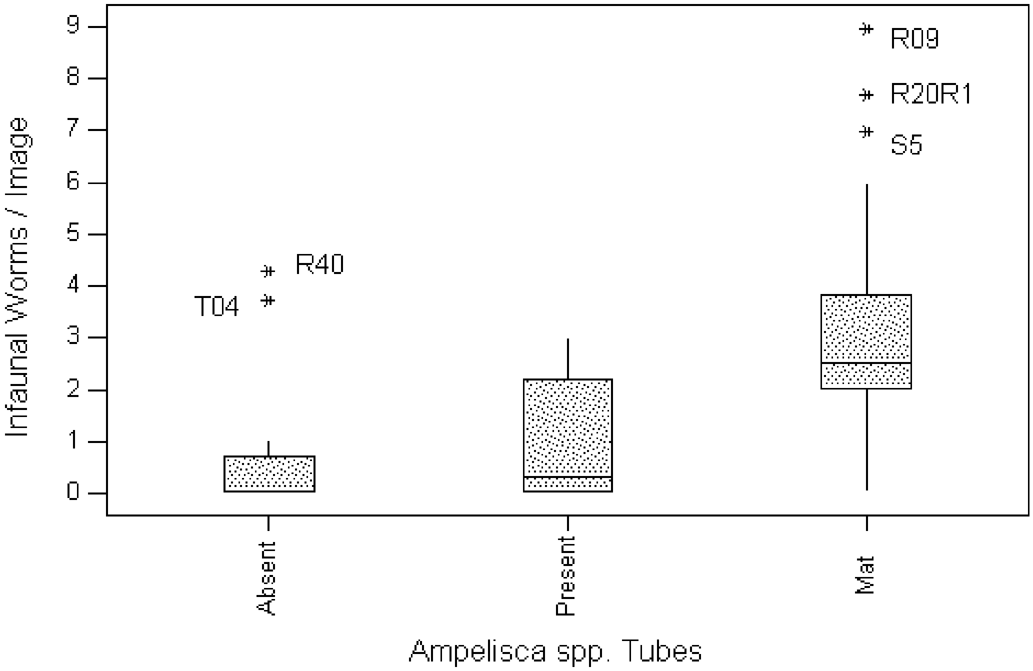


Figure 3-7. Boxplots of infaunal organisms by *Ampelisca* spp. tube density at Boston Harbor stations, August 1999. Box is interquartile range (IR), bar is median, vertical lines are range, asterisks are outliers (>2IR).

The most prominent biogenic surface feature in the sediment profile images was *Ampelisca* spp. tube mats, which occurred at 26 (42%) stations, excluding the six additional spatial stations. With these stations included the statistics change little, 28 occurrences and 41% of stations (Table 3-1, Figure 3-8). The distribution of *Ampelisca* spp. tubes appeared related to grain size with mats occurring predominantly in finer sediments (Table 3-3). *Ampelisca* spp. tube mats were present at only one heterogeneous sediment station, R22 northwest of Peddocks Island, and occurred in two of the replicates that had silty sediments. The third replicate was heterogeneous with silty to pebbly sediments and did not have any *Ampelisca* spp. tubes (Appendix B-1). It is possible that through its tube-building and feeding activities that would tend to accumulate fine sediment, *Ampelisca* spp. would contribute to an overall fining of sediments. However, it may be that the *Ampelisca* spp. population in the harbor is declining. At about 25% of the stations, the *Ampelisca* spp. mat appeared to be in senescence with the average size of the tubes on the order of 0.5 cm and much of the mat appeared to be deteriorating. *Ampelisca* spp. tube mats in 1998 were composed of long (>1 cm) tubes and appeared "fresher".

Table 3-3. Tabulation of *Ampelisca* spp. tubes by sediment class based on SPI from Boston Harbor, August 1999.

Sediment Class	***Ampelisca* spp. Tubes**				
	Absent	**Present**	**Mat**	**Totals**	
Coarse	3	1	0	4	6%
Heterogeneous	0	2	1	3	4%
Fine-Sand	1	0	0	1	2%
Layered	2	0	1	3	4%
Silty-Sandy	8	4	5	17	25%
Silty	13	6	21	40	59%
Totals	**27**	**13**	**28**	**68**	
	40%	**19%**	**41%**		

RPD Layer Depth (cm) by Sediment Class and *Ampelisca* spp. Mats

Sediment Class	***Ampelisca* spp. Mat**		
		Absent	**Present**
Silty-Sandy	N	12	5
	Mean	0.8	2.7
	SD	0.21	0.76
Silty	N	19	21
	Mean	0.7	4.8
	SD	0.36	2.14

Where *Ampelisca* spp. tube mats occurred, the mean and median RPD depth were deeper than at stations without mats, 4.2 ± 0.4 cm (mean ± SE) at stations with mats verses 0.8 ± 0.1 cm at stations without mats. Median values for RPD depth were 3.4 and 0.7 cm, respectively. This is an indication of the importance of this amphipod in irrigation of surface sediments and advancing community succession. For the same fine sediment types where mats were not present, RPD layer depths were about 4 cm less for silty sediments and 2 cm less for silty-sandy sediments (Table 3-3). The areas without *Ampelisca* spp. tube mats were Dorchester Bay, much of Quincy Bay, and Hingham Bay near the mouth of the Weymouth Fore River (Figure 3-8). Mats occurred at stations in the Inner Harbor (R09 and R10).

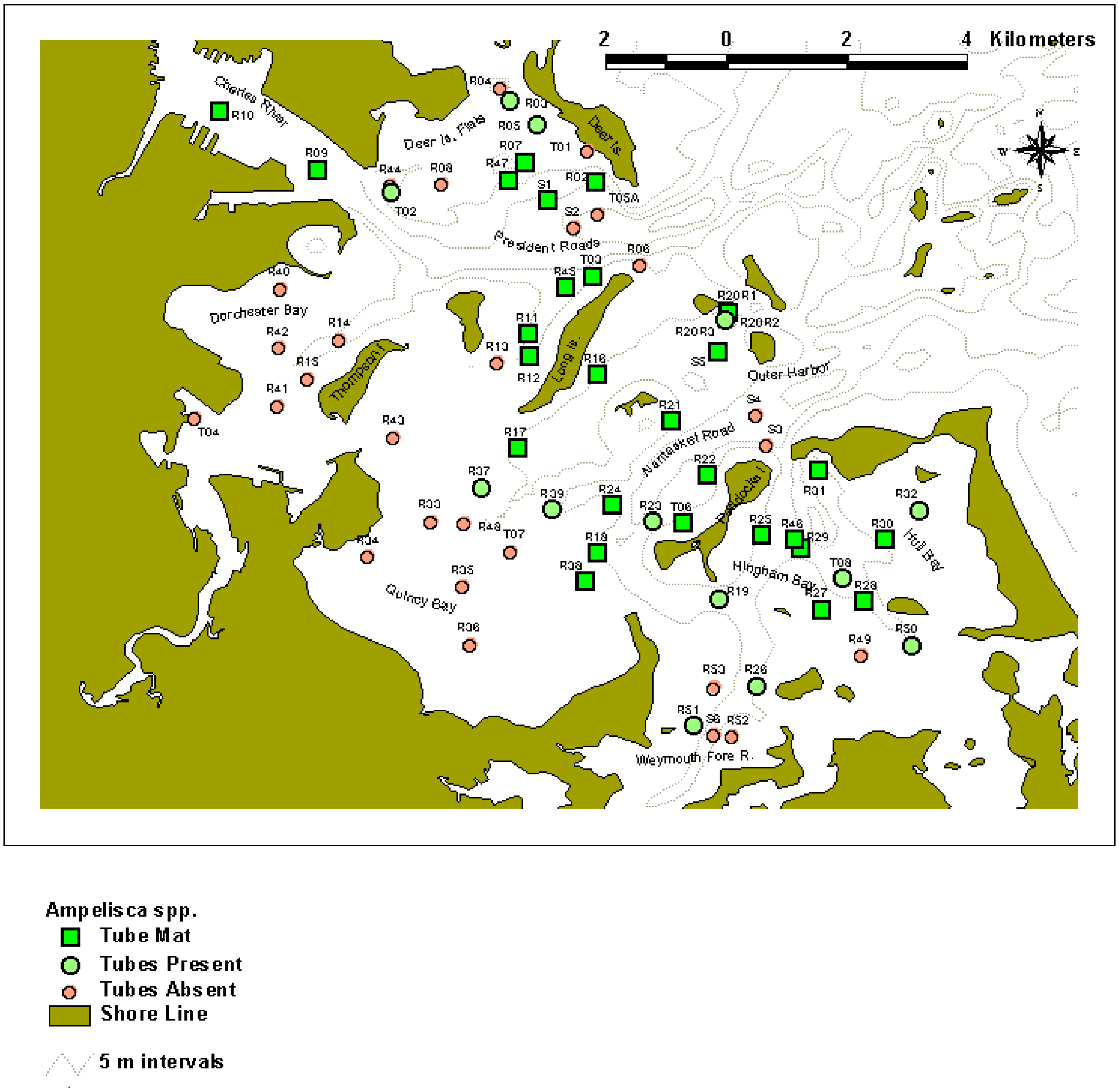


Figure 3-8. Spatial distribution of *Ampelisca* spp. tube mats at Boston Harbor stations as determined from SPI, August 1999.

Successional Stage and Organism Sediment Index—The apparent successional stage of the benthos over the study area had a bimodal distribution with modes of Stage I (32 stations) and Stage II (26 stations), indicating that macrobenthic communities in the harbor area are split between pioneering and intermediate serial stages (see Section 5). The high degree of biogenic sediment reworking observed in many images was consistent with the Stage II, and at one station Stage III, successional designation. Station T04, inner Dorchester Bay, which had the lowest successional stage designation (0 or azoic) in 1998 advanced to Stage I in 1999 with indications of a well developed pioneering community (Table 3-1) and apparently no low dissolved oxygen, at the time of sampling.

Evidence of Stage I communities occurred at about 60% of stations, an increase of about 10% over 1998, with evidence of Stage II communities at about 50% of stations, a decrease of about 15% over 1998. Silty fine sands and silts tended to have highest successional stages. *Ampelisca* spp. tube mats were present at about 77% of all stations where the median successional stage of replicate images was estimated to be >I and only at one station (R10 in the Inner Harbor) with a Stage I designation (Figure 3-9).

The average Organism Sediment Index ranged from 2.0 to 9.7 (Table 3-1). The lowest OSI values characterized coarse, heterogeneous, and fine-sand sediments, with a range of 2.0 to 4.5 and mean of 2.8 ± 0.45 (SE). Primarily because the OSI is a measure of biological activity and coarser sediment tended to have less advanced communities, OSI values for silty fine sand and silt sediment types were higher, with a range of 2.0 to 9.7 and an average OSI value of 5.0 ± 0.35. The high OSI values, >6, were in silt and silty fine sand sediments, at the mouth of the Charles River (Inner Harbor), west of Long Island, outer Quincy Bay, and Hingham and Hull Bays (Figure 3-10). Station T04 improved more than any other station from 1998 to 1999. In 1998 the OSI at T04 was –5, because of the presence of gas voids, 0.0 cm RPD layer depth, and low oxygen, whereas it was 2 in 1999.

The OSI range at harbor stations was indicative of a wide range of macrobenthic communities, from stressed to well developed. The majority of harbor stations had OSI values <6 (67%, 44 of 66 stations), which indicates communities are under some form of moderate stress (Rhoads and Germano 1986). Most of these lower-OSI stations were located in the inner bays and away from the harbor mouth. Higher-OSI stations occurred in a broad band that arced through mid harbor running from Deer Island to Hull Bay (Figure 3-10). In the case of the harbor stations, both Traditional (T) and Reconnaissance (R), the source of stress to the benthos is most likely a combination of physical processes such as hydrodynamics and sediment transport at coarse sediment stations (for example R06) and high rates of sediment accumulation and organic enrichment at muddy stations (for example T04).

3.2.2 1999 Harbor Summary

Overall, the 1999 Harbor SPI data were consistent with a continuation of biological processes dominating over physical processes. Physical process features such as bed forms were virtually absent while macrobenthic tubes and other biogenic structures occurred at almost all stations. While the distribution of sediment textures in the Harbor are due primarily to a combination of sources, morphology, and hydrodynamics, surface features seen in 1999 continued to be dominated by biogenic activity. *Ampelisca* spp. tube mats, feeding pits and mounds, and worm tubes were the dominant surface biogenic structures occurring at all stations except R08, where the sediment surface was covered with macroalgae. Subsurface biogenic structures and organisms were also common and widely distributed.

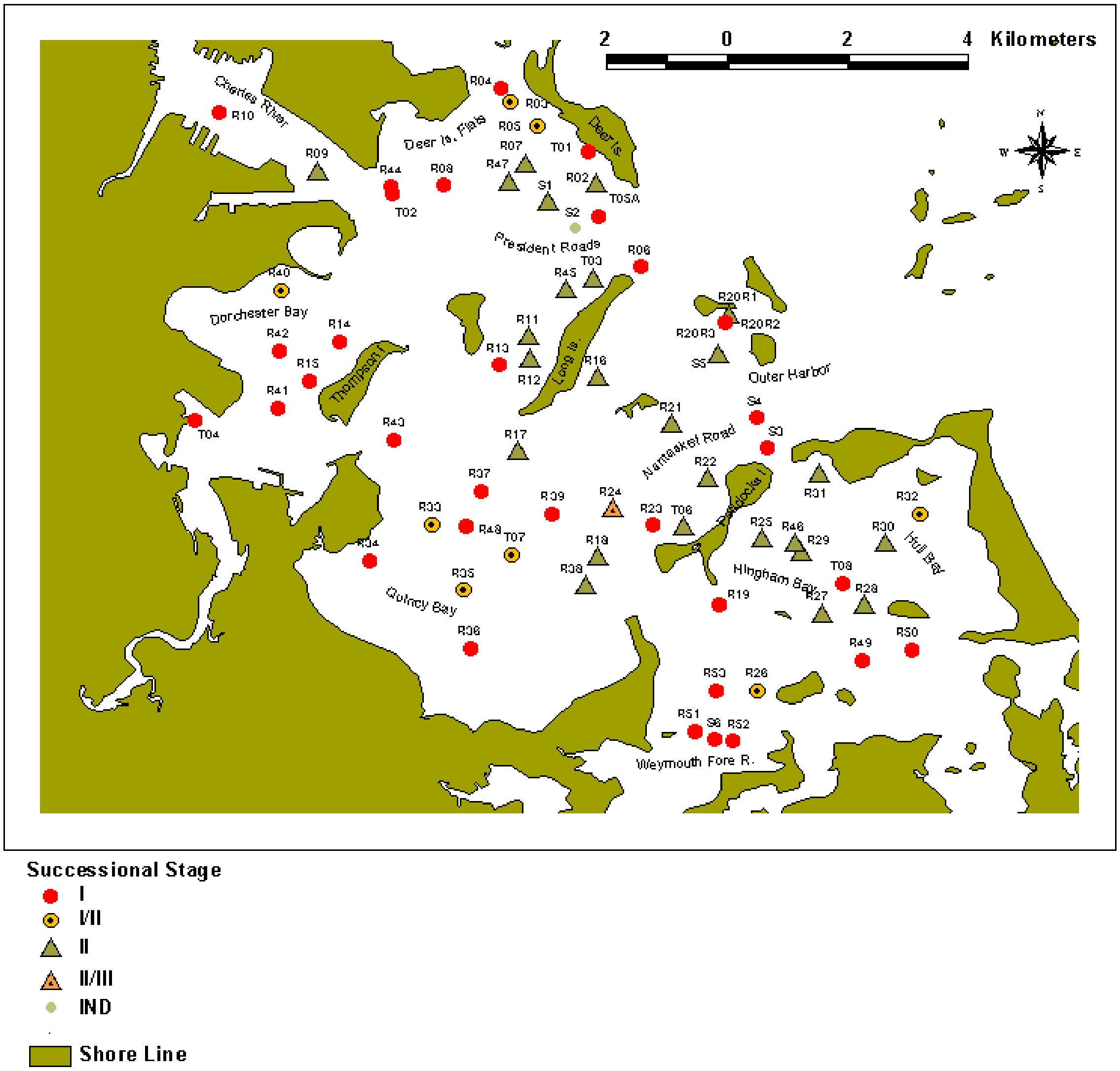


Figure 3-9. Spatial distribution of apparent successional stages at Boston Harbor stations as determined from SPI, August 1999.

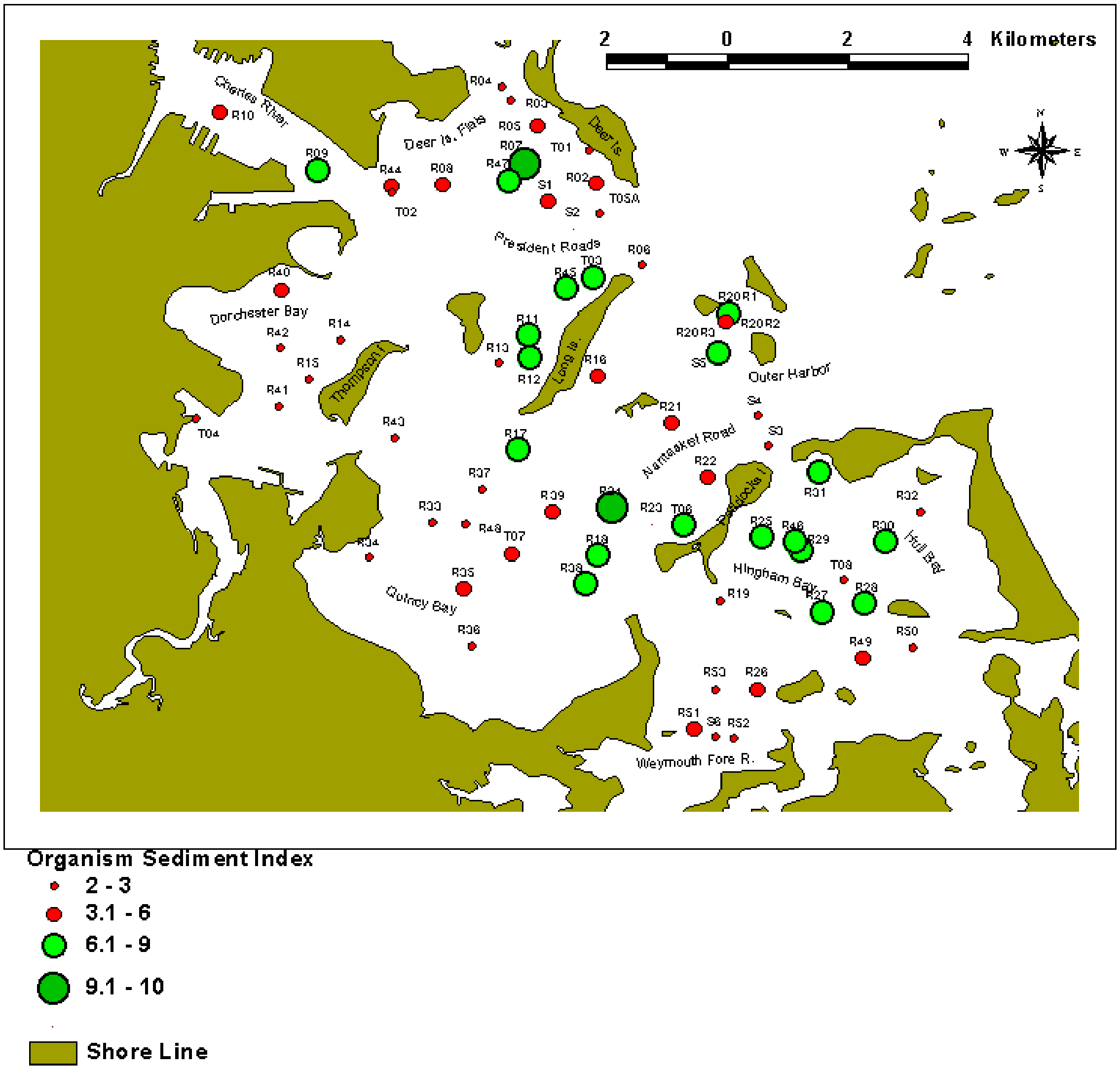


Figure 3-10. Spatial distribution of the Organism Sediment Index at Boston Harbor stations as determined from SPI, August 1999.

The predominance of biological activity at most stations, particularly those near the mouth of the Harbor and in a broad arcing band running along the mid Harbor from Deer Island to Hull Bay, was indicative of a well-developed fauna that was generally characterized as being intermediate in successional stage. The OSI reflected this pattern with values >6 occurring toward the Harbor mouth and values <6 in the inner areas of the Harbor. *Ampelisca* spp. tube mats continue to be wide spread and indicative of the macrobenthic community successional transition (Stage II) from the pioneering-dominated (Stage I) inner harbor area to the equilibrium-dominated (Stage III) nearfield area. However, the areal distribution of *Ampelisca* spp. tube mats appeared to have contracted a bit from 1998. In 1998 *Ampelisca* mats occurred at 28 long-term T and R stations in 1999 they occurred at 26. Five stations lost mats from 1998 to 1999, 2 stations picked up mats, and 23 stations had mats in both years.

The size of the *Ampelisca* tubes comprising the mats, decreased from 1998 to 1999. In 1998, many mats were composed of long (>1 cm) tubes, whereas in 1999 most tubes were about 0.5 cm long. This could be an indication of general senescence and decline in *Ampelisca* spp. populations, an event consistent with advancing succession of benthic communities (Don Rhoads, personal communication). However, the overall occurrence of Stage III fauna declined from 1998 to 1999. Populations of the stick-building amphipod *Dyopedos* spp. also declined greatly in 1999, from a high in 1998. The occurrence of mobile epifuana (crab, shrimp, fish, and lobster) appeared to be higher in 1999 relative to other years. Several large *Cancer* spp. crabs were observed, as was a lobster in its burrow at Station R37 in Quincy Bay. Preliminary results from the 1999 Massachusetts Division of Marine Fisheries stock assessment suggested that the catch per unit effort for lobsters in Boston Harbor was greater in 1999 than it was in 1998 (Bruce Estrella, Massachusetts Division of Marine Fisheries, personal communication, July 12, 2001).

Habitat conditions improved at Station T04 (inner Dorchester Bay) in 1999. In 1999, a thin RPD layer was observed along with many infaunal worms and there were no gas voids, whereas in 1998 T04 appeared to be hypoxic and had gas voids that were an indication of high rates of bacterial activity and organic matter in sediments. In 1999, gas voids were seen at Stations R02 southwest of Deer Island and R17 south of Long Island. At most stations the average depth of the apparent color RPD layer between 1998 to 1999 were similar. At five stations, however, there were large increases in the depth of the RPD layer. For example, R07 increased 6.2 cm and R17 increased 4.7 cm from 1998 to 1999. Other stations with large increases were R38, R09, and T03. Three stations (R21, R22, and R39) had a large (>2 cm) shallowing of the RPD layer depth.

In summary, the SPI Harbor data for 1999 reflect the trend toward biological dominance of sediment surfaces, similar to that seen in the Massachusetts Bay nearfield for 1999.

3.2.3 Long-term SPI Comparison, up to 1999

In 1999, sediment profile image data on benthic habitat conditions indicated a continuation of the downward trend in the Organism Sediment Index and no change in conditions for the depth of the apparent color RPD layer. Mean and median values for the OSI were lower in 1999 relative to previous years (Figure 3-11), while for the RPD layer depth 1999 was about the same as 1998 (Figure 3-12). Mean and median values for the T and R series stations by year are also summarized below.

Organism Sediment Index								
	92	**93**	**94**	**95**	**96**	**97**	**98**	**99**
Median	6.8	5.3	5.3	7.0	6.0	6.3	4.7	3.7
Mean	6.4	5.6	5.2	6.5	6.4	6.4	5.3	4.9
SE	0.2	0.4	0.4	0.4	0.3	0.4	0.4	0.3
RPD Layer Depth (cm)								
	92	**93**	**94**	**95**	**96**	**97**	**98**	**99**
Median	1.8	1.7	1.6	2.1	2.0	2.0	1.5	1.1
Mean	1.8	2.4	1.8	2.9	2.7	2.7	2.0	2.2
SE	0.1	0.3	0.2	0.3	0.2	0.2	0.2	0.3

The yearly differences in OSI were significant (Kruskal-Wallis Test, $H = 26.3$, $p < 0.001$; ANOVA was not preformed because its assumptions were not met) with current trends indicating that 1998 and 1999 had lower median OSIs relative to the other years (Figure 3-10). Similarly, there were significant year-to-year differences in apparent color RPD depth (Kruskal-Wallis Test, $H = 28.8$, $p < 0.001$, and log transformed data, ANOVA, $F = 4.55$, $p = 0.0001$), but there were no statistically distinct sets of years (Figure 3-12). For example, a multiple comparison based on the means showed yearly average RPD depths for 1992, 1993, 1994, 1998, and 1999 to be lower than 1995, 1996, and 1997, but also showed

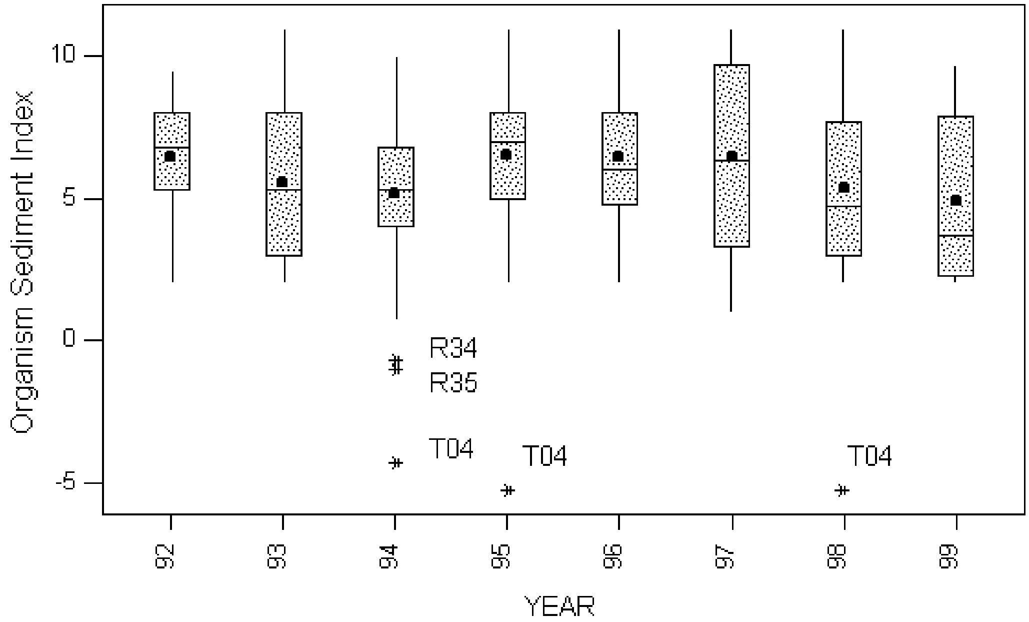


Figure 3-11. Boxplots of long-term trends in the Organism Sediment Index for Boston Harbor stations. Box is interquartile range (IR), bar is median, dot is mean, vertical lines are range, asterisks are outliers (>2IR).

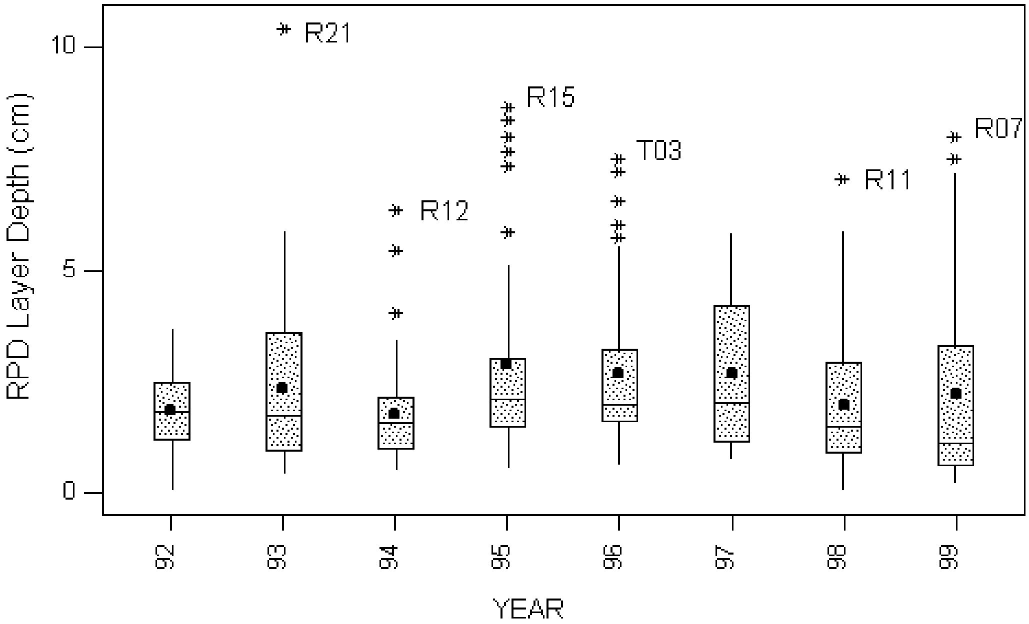


Figure 3-12. Boxplots of long-term trends in the apparent color RPD layer depth (cm) for Boston Harbor stations. Box is interquartile range (IR), bar is median, dot is mean, vertical lines are range, asterisks are outliers (>2IR).

1992 to be equal to all other years except 1999. Part of the confusion in the multiple testing lies in the large sample size (445 individual RPD measurements) that makes small mean differences significant in the ANOVA and the relatively large variability in RPD layer depth that does not clearly separate yearly means. The grand average RPD depth for all eight years was 2.3 cm with a SD of 1.74 and a SE of 0.08. The largest mean difference between years was 1.1 cm and 1.0 cm for the median.

The decline in the OSI and level RPD layer depths in 1999 appeared to be related to continued predominance of successional Stage I seres at many of the inner harbor stations (Figure 3-9). Much of the benthic habitat quality in the Boston Harbor area is determined by the distribution of Stage I and Stage II seres (Blake *et al.* 1998). As one or the other increase, a shift is seen in the OSI that is an overall measure of benthic habitat quality. In 1999, the decline in the number of stations with *Ampelisca* spp. tube mats continued, based on the 60 long-term benthic stations (Figure 3-13). This decline in the intermediate successional stage seres may represent a negative rebound of the *Ampelisca* spp. populations that had monotonically increased in areal coverage of the bottom (percentage of stations) from 1992 to 1996. In 1997, there was a slight decline in the coverage by *Ampelisca* spp. mats that continued into 1999 with about a 25% decline in stations with mats from a high of about 75% in 1995 and 1996 (Figure 3-8).

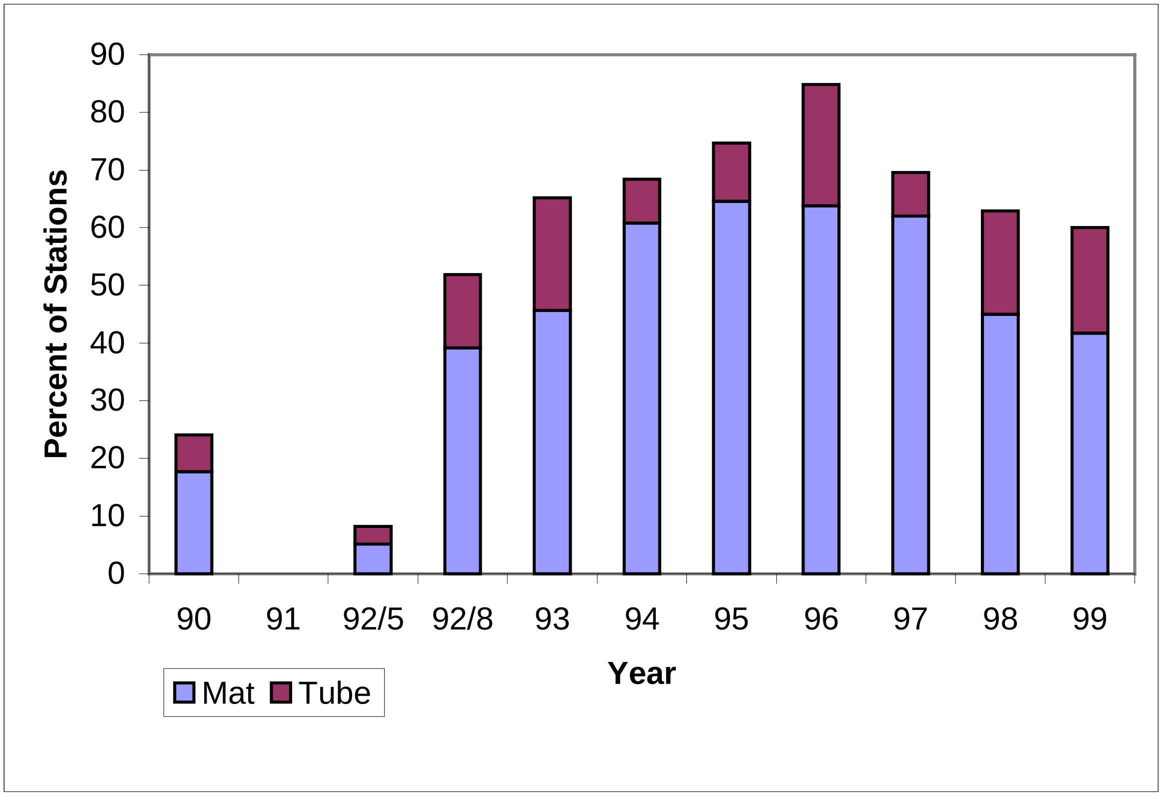


Figure 3-13. Percentage of benthic monitoring stations within Boston Harbor with *Ampelisca* spp. tubes (light bars) and mats (dark bars) from 1989 to 1999. Based in part on Blake *et al*. (1998) and Kropp *et al*. (2000).

Overall, general benthic habitat quality within the study area was similar from August 1992 to 1998 with minor variation from year to year (Blake *et al*. 1998, Kropp *et al*. 2000, this report). For 1999, key indicators of benthic habitat quality were either slightly down or level relative to previous years; however, the major changes in habitat quality appeared to have occurred in early 1992. Current benthic communities appear to have developed in response to major disturbance events in 1991, the October severe storm and December sewage discharge abatement (Blake *et al*. 1998). Interestingly, stations with poorest habitat quality in 1989/90 sampling (Blake *et al*. 1993) continued to have poor quality habitat in 1999. Three stations (T04, R36, and R43) all had long-term average OSI values ≤ 3. In 1999 habitat quality at Station T04 was improved over 1998.

4.0 ANALYTICAL 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 1998). Summaries of the procedures are provided below.

Grain Size — Samples were analyzed for grain size by a sequence of wet sieving and dry sieving. Methodologies followed Folk (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 9703.

***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® was used to perform linear regression 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 percents 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 (Table 4-1).

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

- Station Mean—average of all station replicates. 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 1999.
- 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 1999.

The spatial and temporal distributions of sediment grain size were evaluated by using ternary plots to visually display the distribution of sand, silt and clay in sediment collected from Traditional stations from 1991 to 1999.

Results from TOC and *Clostridium perfringens* analyses were compared from all Traditional stations by using histogram plots to evaluate if the spatial and temporal distributions in 1999 were substantially different from those for previous years.

Table 4-1. An example of numerical approximate mean phi determination.

phi Class	**Weight Factor**[1]	**% Fraction Measured (station T01, April 1999)**	**Weighted Fraction**[2]
phi<–1	–1.5	3.85	–0.0578
–1<phi<0	–0.5	0.62	–0.0031
0<phi<1	0.5	1.3	0.0065
1<phi<2	1.5	3.15	0.0472
2<phi<3	2.5	12.67	0.317
3<phi<4	3.5	50.05	1.75
4<phi<8	6	17.4	1.04
phi>8	9	10.9	0.981
		Sum of weighted fractions Numerical approximate mean phi[3]	4.09

[1] Weight Factor represents middle of the phi class range

[2] Weighted Fraction = (Weight Factor)*(%Fraction Measure/100)

[3] Numerical approximate mean phi = Sum of weighted fractions

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 1999 results are presented in Table 4-2. Grand station means and associated standard deviation and coefficient of variation values, by station and parameter, for April (1993–1999) and August (1991–1999) surveys are presented in Table 4-3. Ternary plots showing grain size composition for April (1993–1999) and August (1991–1999) surveys, by station, are presented in Appendix C-1. April and August mean values for grain size, TOC, and *Clostridium perfringens*, by station across all sampling years, are reported in Appendices C-2 and C-3, respectively. All sediment results are discussed in terms of dry weight using station mean values.

Table 4-2. Grain size, TOC, and *Clostridium perfringens* data from sediments collected at Traditional stations in April and August 1999.

Parameter	Units	T01	T02	T03	T04	T05A	T06	T07	T08
April Survey, 1999									
Gravel	pct	3.9	3.6	1.5	0	0.6	0.8	28.2	0.4
Sand	pct	67.8	56.1	30.6	30.6	73	28.8	27.5	91.1
Silt	pct	17.4	20.1	35	32	15.7	33.5	17.3	3.7
Clay	pct	10.9	20.3	32.9	37.4	10.7	36.9	27	4.77
Fines	pct	28.3	40.4	67.9	69.4	26.4	70.4	44.3	8.47
Mean phi	pct	4.09	4.63	5.97	6.09	4.12	6.26	3.46	2.87
TOC	pct	0.98	1.14	2.95	6.94	1	2.84	2.77	0.65
Clostridium perfringens	cfu/gdw	4,620	3,670	12,600	16,100	2,000	4,460	4,720	1,090
August Survey, 1999									
Gravel	pct	25.1	0.4	0	3.8	0.167	0.12	9.6	2.4
Sand	pct	53.4	39.8	8.9	1.6	75.6	37.5	23.5	93
Silt	pct	13.4	34.6	46.4	48.6	13.7	33.7	33.7	1.6
Clay	pct	8.1	25.2	44.7	46	10.5	28.7	33.3	3
Fines	pct	21.5	59.8	91.1	94.6	24.2	62.4	67	4.6
Mean phi	pct	2.72	5.67	7.1	7.05	4.05	5.79	5.47	2.4
TOC	pct	2.8	1.61	3.14	4.15	1.26	2.36	2.77	0.23
Clostridium perfringens	cfu/gdw	920	5,260	7,720	1,800	750	2,560	8,520	350

4.2.1 Grain Size 1991–1999

April—With the exception of station T04, patterns in sediment composition at Traditional stations in 1999 were within the ranges observed for previous years. Patterns in sediment composition were consistent at some stations and more variable at others (representative stations, T01 and T04, are shown in Figure 4-1; ternary plots for all stations are provided in Appendix C-1). Patterns in sediment composition at station T01 displayed very consistent grain size composition over time and 1999 results were consistent with previous years (Figure 4-1, Appendix C-1). Sediments collected at stations T02, T03, T06, and T07 displayed variable grain size composition over time and 1999 results were within ranges observed in previous years (Appendix C-1). Patterns in sediment composition at station T04 were consistent from 1993 to 1998; however, sediment collected in 1999 contained considerably higher sand and less silt content relative to previous years (Figure 4-1). Sediments from station T05A showed somewhat consistent patterns of sediment composition over time and 1999 results were not substantially different from previous years (Appendix C-1). Patterns in sediment composition at station T08 in 1999 were consistent with patterns observed from 1993 to 1996 (Appendix C-1), and varied from patterns observed in 1997–1998. Apparent temporal outliers at T04 (1999) and T08 (1998) may, in part, result from small-scale spatial heterogeneity.

Sediments from station T01 were comprised primarily of coarse-grained sediments and clustered in the upper apex of the ternary plot (Figure 4-1, Appendix C-1). Sediments from station T02 displayed variable sediment composition over time with sediment texture ranging from sandy (70% sand and gravel in 1994) to very silty (84% fines in 1998) (Appendix C-1). Sediments from station T03 also displayed variable sediment composition over time, ranging from sandy (52% sand and gravel in 1994) to very silty (90% fines in 1995) (Appendix C-1). Sediments from station T04 in 1993–1998 were comprised primarily of very silty sediments and clustered in the lower left of the ternary plot (Figure 4-1). In contrast, sediment from station T04 in 1999 was sandier, with less silt content, and clustered closer to the mid-region of the ternary plot (Figure 4-1). Sediments collected from stations T05A and T08 generally

Table 4-3. Grand station mean, standard deviation, and coefficient of variation results for sediment parameters from April and August surveys.

Parameter		T01	T02	T03	T04	T05A	T06	T07	T08
April Surveys, 1993–1999									
Gravel (pct)	**Mean**	6.22	1.06	2.44	0.0429	0.286	1.5	12.4	3.49
	Stdev	5.7	1.24	4.67	0.113	0.204	2.21	11.2	4.02
	CV	91.5	117	191	265	71.2	147	90	115
Sand (pct)	**Mean**	74.1	44.2	31.2	14.4	73.4	44.6	37.6	77
	Stdev	8.06	16.6	13.8	11	10.9	15.7	24.5	22.4
	CV	10.9	37.5	44.4	76.5	14.8	35.3	65.1	29.1
Silt (pct)	**Mean**	12.9	33.9	39.5	55.7	18.6	32.7	31.8	10.3
	Stdev	3.96	11.4	7.39	10.9	8.53	9.07	18.6	11.8
	CV	30.8	33.7	18.7	19.6	45.9	27.7	58.4	114
Clay (pct)	**Mean**	6.75	20.9	26.9	29.8	7.69	21.2	18.2	9.23
	Stdev	3.88	8.8	12.6	11.4	4.48	11	10.4	10.9
	CV	57.4	42	46.9	38.3	58.2	52	57.4	118
Fines (pct)	**Mean**	19.6	54.8	66.4	85.5	26.3	53.9	50	19.5
	Stdev	7.71	17.2	15.3	11	10.9	17.4	23.3	22.6
	CV	39.3	31.3	23	12.9	41.5	32.2	46.5	115
TOC (pct)	**Mean**	1.12	1.83	3	5.23	0.724	2.23	2.72	0.608
	Stdev	0.199	0.422	0.317	1.41	0.365	0.695	0.401	0.394
	CV	17.8	23.1	10.6	27	50.4	31.2	14.7	64.8
Clostridium perfringens *(cfu/gdw)*	**Mean**	4730	15800	25700	17900	3390	16400	14800	4420
	Stdev	2240	12500	23900	8790	1990	12500	10700	2380
	CV	47.4	79.2	93	49.2	58.8	76.5	72.2	53.9
August Surveys, 1991–1999									
Gravel (pct)	**Mean**	15.9	3.03	0.925	0.556	10.5	0.813	8.32	1.36
	Stdev	19.9	6.94	2	1.24	30.8	0.925	7.7	1.24
	CV	125	229	217	224	294	114	92.6	90.9
Sand (pct)	**Mean**	59	50.1	29.4	11.9	74.8	49.5	32.9	82.8
	Stdev	21.5	10.6	19	10.6	27.1	18	12.3	26.8
	CV	36.5	21.1	64.8	89.3	36.2	36.3	37.4	32.3
Silt (pct)	**Mean**	18.9	30.9	41.6	58.3	9.42	30.9	39.2	8.77
	Stdev	15.4	7.47	9.01	11.4	5.65	11.2	8.04	16.5
	CV	81.5	24.2	21.7	19.5	60	36.4	20.5	188
Clay (pct)	**Mean**	6.25	16.1	28.1	29.2	5.35	18.8	19.6	7.02
	Stdev	2.24	6.55	13.2	11	3.64	8.11	6.92	10.9
	CV	35.8	40.8	46.8	37.5	68.2	43.2	35.3	155
Fines (pct)	**Mean**	25.1	46.9	69.7	87.5	14.8	49.7	58.8	15.8
	Stdev	14.3	12.7	20.2	10.1	9.16	18	10.7	27.4
	CV	56.8	27.1	29	11.6	62	36.2	18.2	173
TOC (pct)	**Mean**	1.99	1.71	3.34	4.37	1.01	2.18	2.76	0.544
	Stdev	0.724	0.214	0.451	1.75	0.445	0.68	0.33	0.29
	CV	36.4	12.5	13.5	40.1	44.3	31.3	11.9	53.3
Clostridium perfringens (cfu/gdw)	**Mean**	5760	14400	38200	17900	8430	16600	12900	2920
	Stdev	3550	6220	64200	20300	12400	17800	9080	2600
	CV	61.6	43.2	168	113	147	107	70.6	88.9

were comprised of coarser-grained sediments (> 60% gravel and sand) and clustered in the upper quadrants of the ternary plot (Appendix C-1). One exception was observed in 1997, when sediments collected at station T08 were siltier (63% fines) in sediment texture relative to all other sampling years. Sediments collected at station T06 displayed variable patterns of sediment composition with sediment texture ranging from sandy in 1994 (69% sand and gravel) to silty in 1996 (77% fines) (Appendix C-1). Similarly, sediments from station T07 also had variable sediment composition over time, ranging from very sandy in 1997 (92% sand and gravel) to very silty in 1993 (80% fines) (Appendix C-1).

August—Patterns in sediment composition in 1999 at all Traditional stations were not substantially different from previous years (1991–1998). Patterns in sediment composition were consistent at some stations and variable at others (representative stations T01 and T04 are shown in Figure 4-2; ternary plots for all stations are provided in Appendix C-1). Sediments from station T01 displayed very consistent patterns in sediment texture during all sampling years except 1995, and were comprised primarily of coarse-grained sediments (Figure 4-2). Sediments collected at station T01 in 1995 were very silty (61% fines) by comparison. Sediments from station T02 displayed moderately consistent patterns in sediment composition over time, with sandy sediment texture in 1991–1994 (> 60% sand and gravel) and slightly more silty in 1995 and 1997–1999 (56–63% fines) (Appendix C-1). Sediments from station T03 displayed variable sediment composition from 1991 to 1999 and clustered into two groups on the ternary plot (Appendix C-1). Sediments collected from 1995 to 1999 at station T03 were silty and clustered in the lower quadrants of the ternary plot; whereas sediments collected from 1991 to 1994 were more sandy with less silt and clay content (Appendix C-1). Sediments from station T04 displayed moderately consistent sediment texture over time and were primarily comprised of silty sediments (68–97% fines), clustering in the lower, middle quadrants of the ternary plot (Figure 4-2). Sediments collected from station T05A displayed the most consistent patterns in sediment composition over time, and were comprised of very sandy sediments clustering in the upper apex of the ternary plot (Appendix C-1). Sediments collected at station T06 displayed variable patterns in sediment composition and clustered into two distinct groups on the ternary plot (Appendix C-1). Sediments collected at station T06 in 1995–1996 and 1998–1999 contained considerably higher amounts of silt and clay (61–80% fines) compared to those collected in 1991–1994 and 1997, which were sandier. Sediments collected from station T07 had variable sediment texture over time, ranging from sandy (59% sand and gravel) in 1991 to silty (78% fines) in 1998 (Appendix C-1). Sediments from station T08 had very consistent patterns in sediment composition during all sampling years except 1991, and were comprised of very sandy sediments (> 80% sand and gravel) clustering in the upper apex of the ternary plot (Appendix C-1). Sediments collected station T08 in 1991 contained high amounts of silt and clay by comparison (88% fines). Apparent temporal outliers at T08 and other sites may, in part, 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 (1993–1999). 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. However, variability in sediment composition over time was higher at some stations (*i.e.,* T01, T05A) in August relative to April surveys. In contrast, patterns in sediment composition at stations T02 and T07 in August were less variable over time relative to April surveys. Stations T03, T04, T06, and T08 generally showed equally variable patterns in sediment composition over time during April and August surveys.

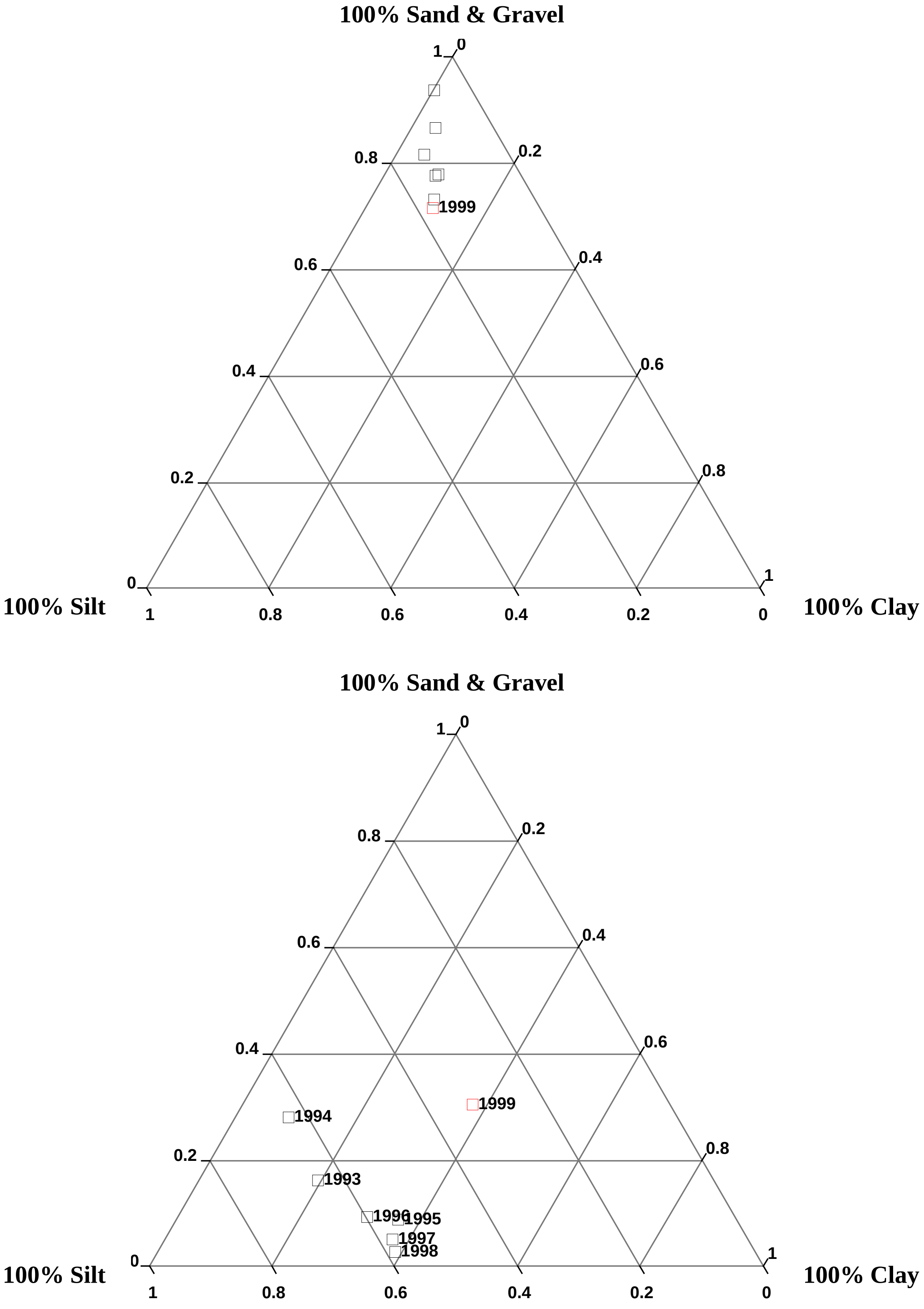
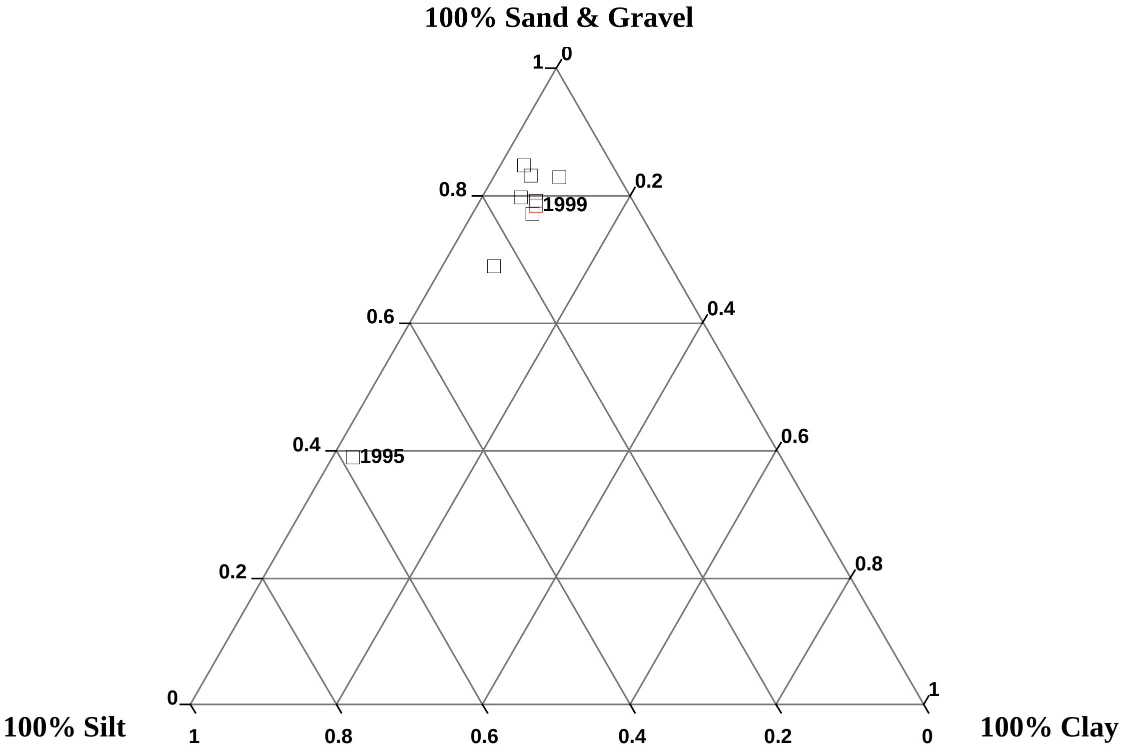


Figure 4-1. Grain size composition from sediments collected at stations T01 (top) and T04 (bottom) in April 1993–1999.



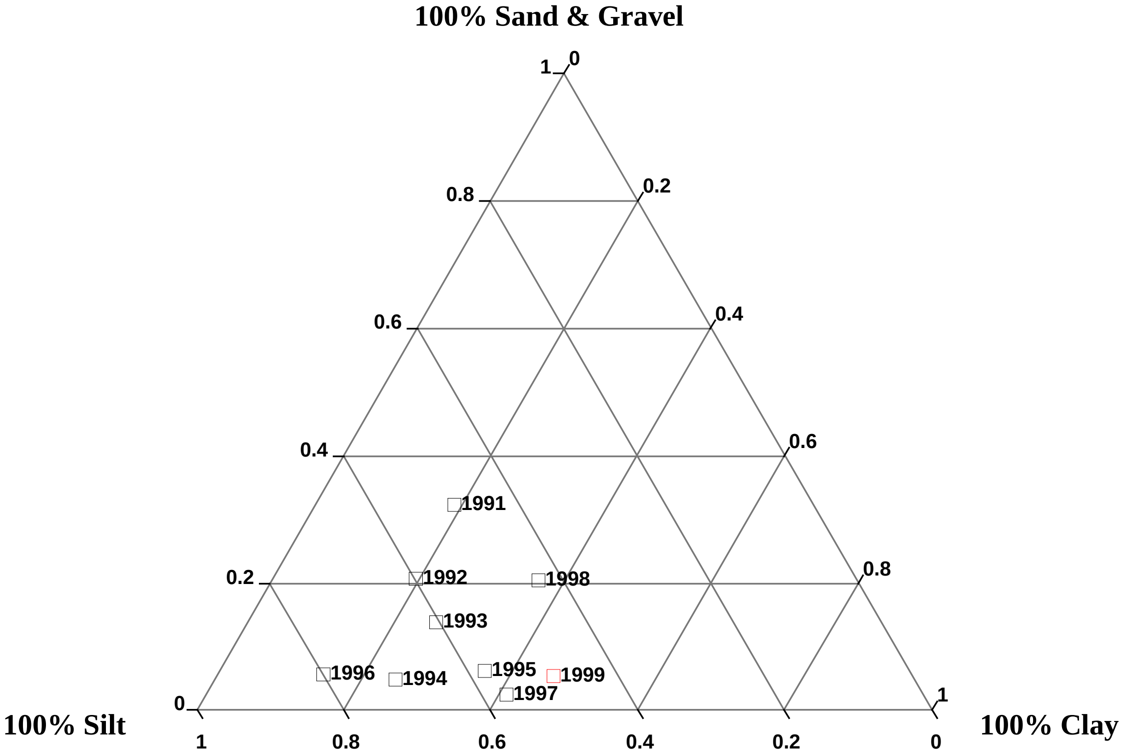


Figure 4-2. Grain size composition from sediments collected at stations T01 (top) and T04 (bottom) in September 1991 and August 1992–1999.

4.2.2 Total Organic Carbon 1991–1999

April—Concentrations of TOC at all Traditional stations were not substantially different in 1999 from earlier years because of the high variability in the historical dataset (Figure 4-3, Appendix C-2). Patterns in TOC content were consistent over time at some stations, but were more variable at others (Figure 4-3, Table 4-3). Stations T01, T03, and T07 showed the most consistent (<18% coefficient of variation, CV) patterns in TOC content over time (Figure 4-3, Table 4-3). Stations T02, T04, and T06 had moderately variable (23–31% CV) concentrations of TOC over time, while stations T05A and T08 were the most variable (>50% CV) over time (Figure 4-3, Table 4-3). 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 4-3, Table 4-3).

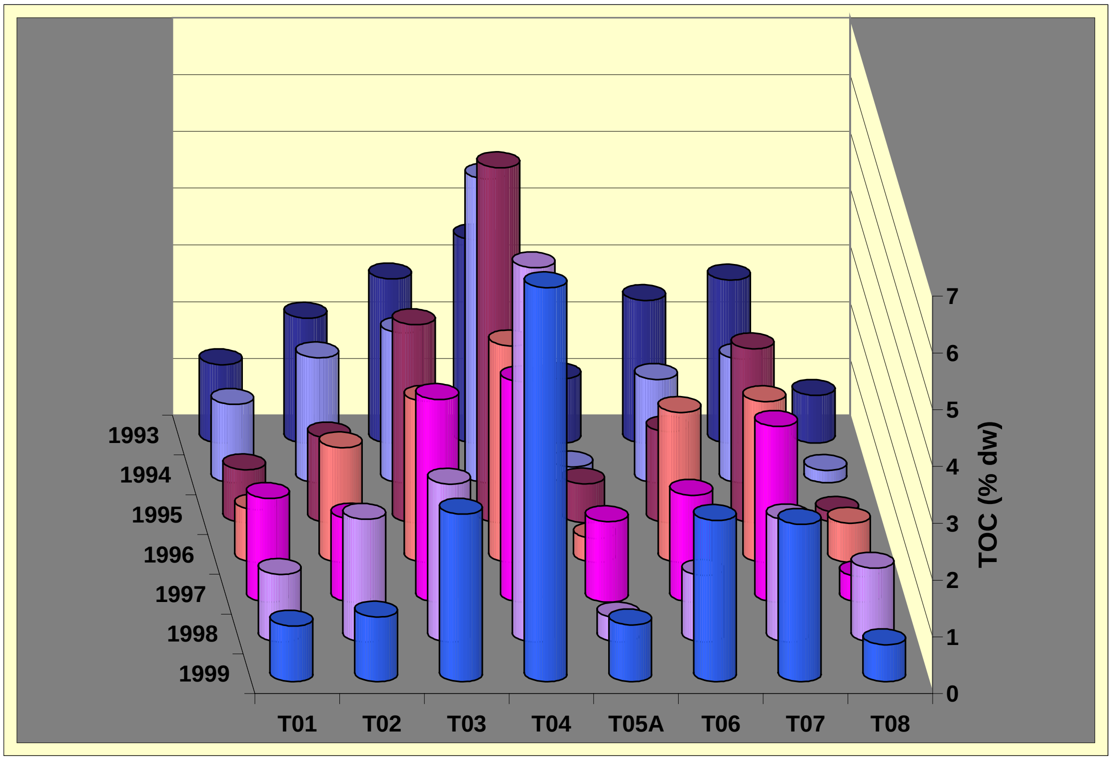


Figure 4-3. Total organic carbon content in sediments collected at Traditional stations in April 1993–1999.

August—Concentrations of TOC at all Traditional stations were not substantially different in 1999 from earlier years, again because of the high variability in the historical dataset (Figure 4-4, Appendix C-3). Patterns in TOC content were consistent over time at some stations, but were more variable at others (Figure 4-4, Table 4-3). Stations T02, T03, and T07 showed the most consistent (<14% CV) patterns in TOC content over time (Figure 4-4, Table 4-3). Stations T01 and T06 had moderately variable concentrations of TOC over time, while stations T04, T05A, and T08 were the most variable (>40% CV) over time (Figure 4-4, Table 4-3). 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 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. The return to previous conditions in

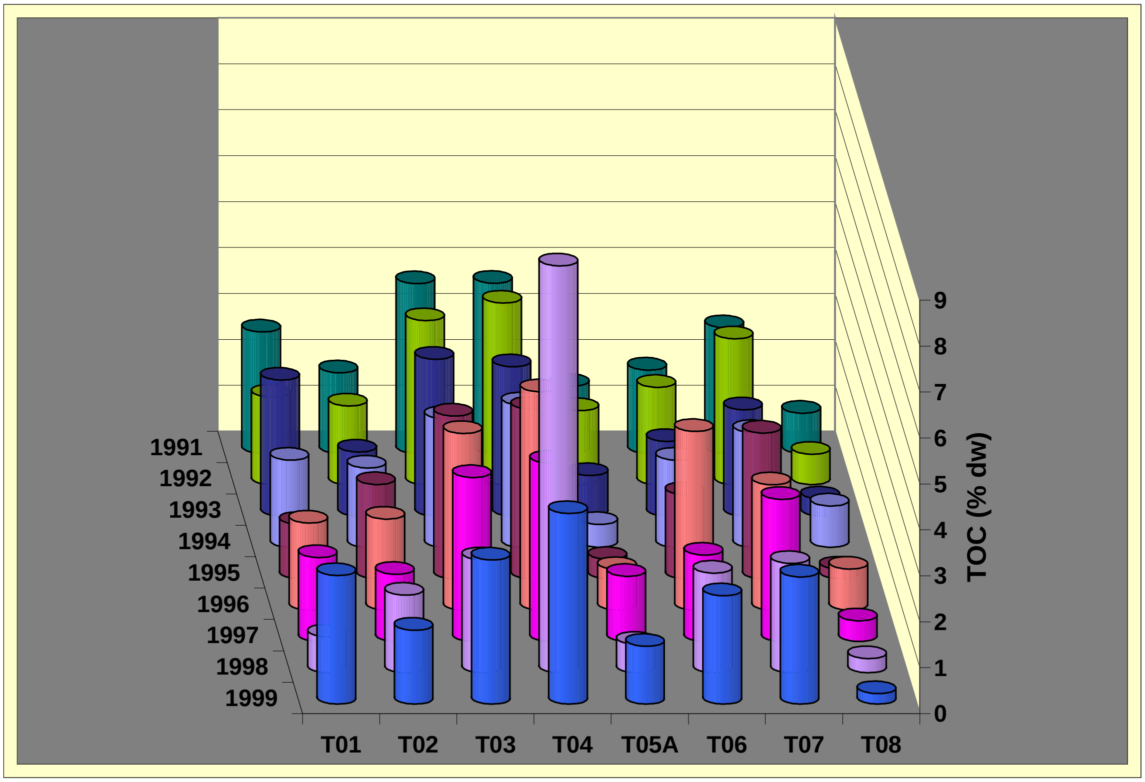


Figure 4-4. Total organic carbon content in sediments collected at Traditional stations in September 1991 and August 1992–1999.

1999 may also be further explained by the rapid sedimentation rate (approximately 4 cm/year) observed at the site by Gallagher (1992) and Wallace (1991). Stations T05A and T08 consistently contained the lowest levels of TOC (generally ≤1%) over time (Figure 4-4).

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 most stations and sampling years in August were higher relative to April (*i.e.*, T01, T05A), while the concentrations were similar at other stations (*i.e.*, T03, T07).

To evaluate this, the individual station data by year were compared to the one-to-one regression expected if no processes were operating to modify the TOC between April and August (Figure 4-5). TOC data from station T04 in 1998 was excluded from the regression analysis because of the suspected localized influence from a June 1998 storm event. Linear regression 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, April TOC values were higher than August values only 40% of the time. For example, TOC content at stations T01 and T03 was higher in August for all sampling years except 1998 relative to April values. In contrast, TOC content at station T02 was higher in April for all sampling years except 1995 and 1999 relative to August values. Similarly, TOC content at station T04 was higher in April for all sampling years except 1996 and 1998 relative to August values. In contrast, TOC content at station T05A was higher in August for all sampling years except 1993 and 1995 relative to April values. TOC content at station T06 was higher in August for all sampling years except 1993, 1997, and 1999 relative to April values. TOC content at station T07 was higher in August for all sampling years except 1993, 1996, and 1997 relative to April values. Lastly, TOC content at station T08 was higher in August for all sampling years except 1993, 1998, and 1999 relative to April values.

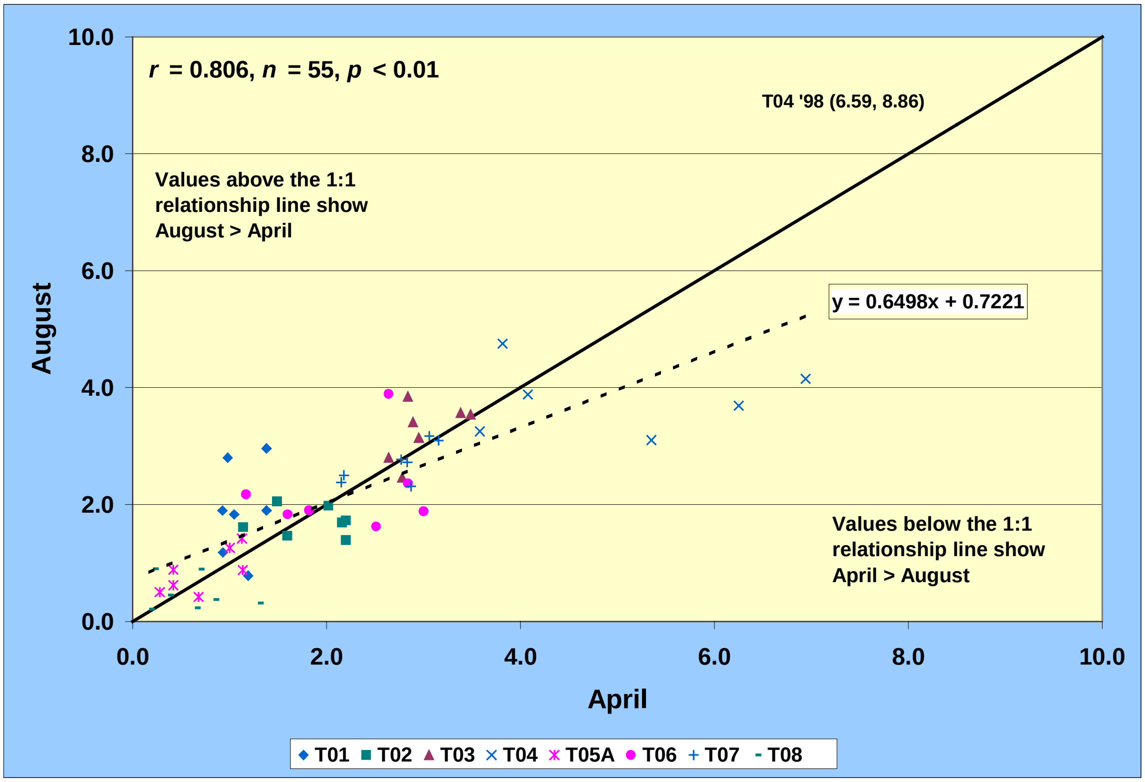


Figure 4-5. A seasonal comparison of April and August total organic carbon content in sediments collected from Traditional stations from 1993 to 1999. There are no values for April 1991–1992.

4.2.3 *Clostridium perfringens* 1991–1999

April—*Clostridium perfringens* concentrations were highly variable across all stations and sampling years from 1993 to 1999, although some stations (*i.e.,* T01, T04, T08) were less variable than others (Figure 4-6, Table 4-3). With the exception of station T01, *Clostridium perfringens* concentrations decreased in 1999 across all stations compared to 1997–1998 values (Figure 4-6, Appendix C-2). Stations T01, T05A and T08 generally had the lowest *Clostridium perfringens* concentrations (< 10,000 cfu) relative to other Traditional stations (Figure 4-6, Appendix C-2). In contrast, stations sampled in 1995 generally had the highest *Clostridium perfringens* concentrations relative to all other sampling years (Figure 4-6, Appendix C-2). *Clostridium perfringens* concentrations in April 1996 generally appear anomalously low at all stations except T08 (Figure 4-6, Appendix C-2).

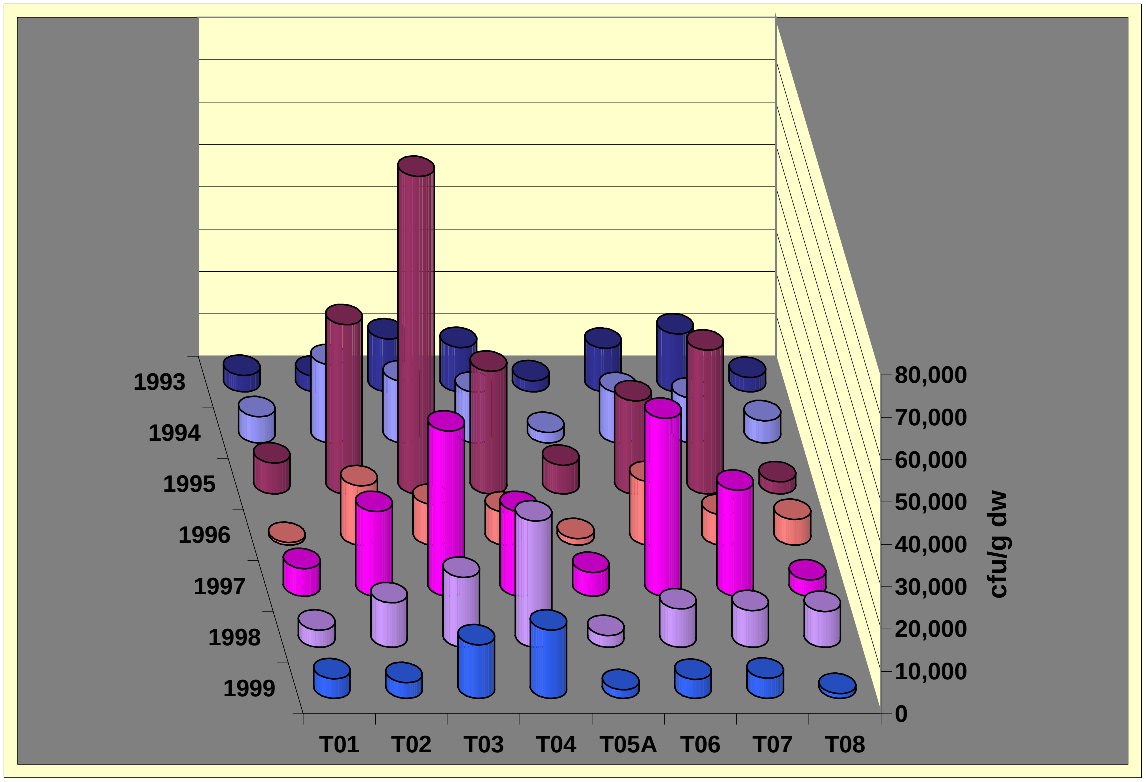


Figure 4-6. *Clostridium perfringens* concentrations in sediments collected at Traditional stations in April 1993–1999.

August—*Clostridium perfringens* concentrations were highly variable across all stations and sampling years from 1991 to 1999, although some stations (*i.e.*, T01, T02, T07) were less variable then others (Figure 4-7, Table 4-3). With the exception of T02 and T07, variability in the August data was generally higher at all stations relative to April values (Table 4-3). *Clostridium perfringens* concentrations decreased in 1999 at all stations, except T03 and T07, relative to previous years (Figure 4-7). With few exceptions (*i.e.*, T01 in 1991; T05A in 1991 and 1992), stations T01, T05A and T08 generally had the lowest *Clostridium perfringens* concentrations (< 10,000 cfu) across all years relative to other Traditional stations (Figure 4-7). In contrast, stations sampled in 1991 and 1996 generally had the highest *Clostridium perfringens* concentrations relative to all other sampling years (Figure 4-7). *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), and decreased in 1998 and 1999 from previous years values (Figure 4-7). 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 1999 (Figure 4-8). 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 4-8). *Clostridium perfringens* concentrations in April 1996 appear anomalously low.

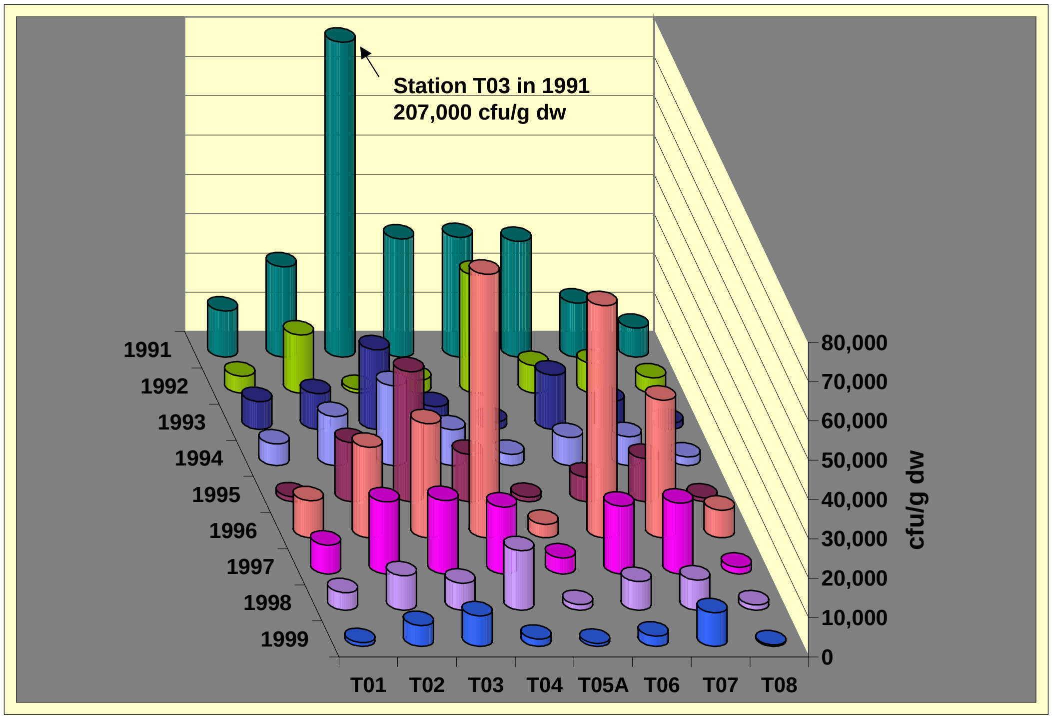


Figure 4-7. *Clostridium perfringens* concentrations in sediments collected at Traditional stations in September 1991 and August 1992–1999.

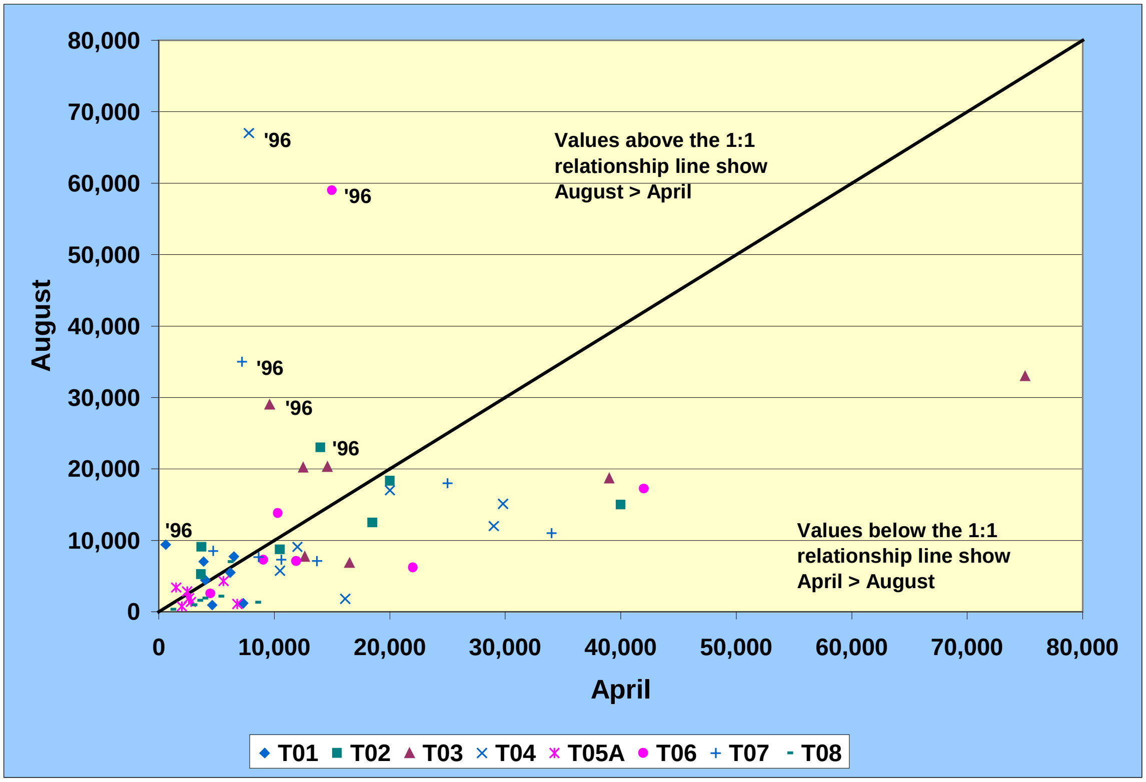


Figure 4-8. Comparison of April and August station mean values for *Clostridium perfringens* from 1993 to 1999.

To remove variability associated with changes in grain size and TOC, *Clostridium perfringens* concentrations were normalized to percent fines and TOC. Comparisons between April and August station mean values showed similar trends after normalization. That is, normalized April values were generally higher than August values for most stations during all sampling years except 1993 and 1996 (Figures 4-9 and 4-10). Station mean values for April 1996 continued to be anomalously low after normalization to percent fines and TOC.

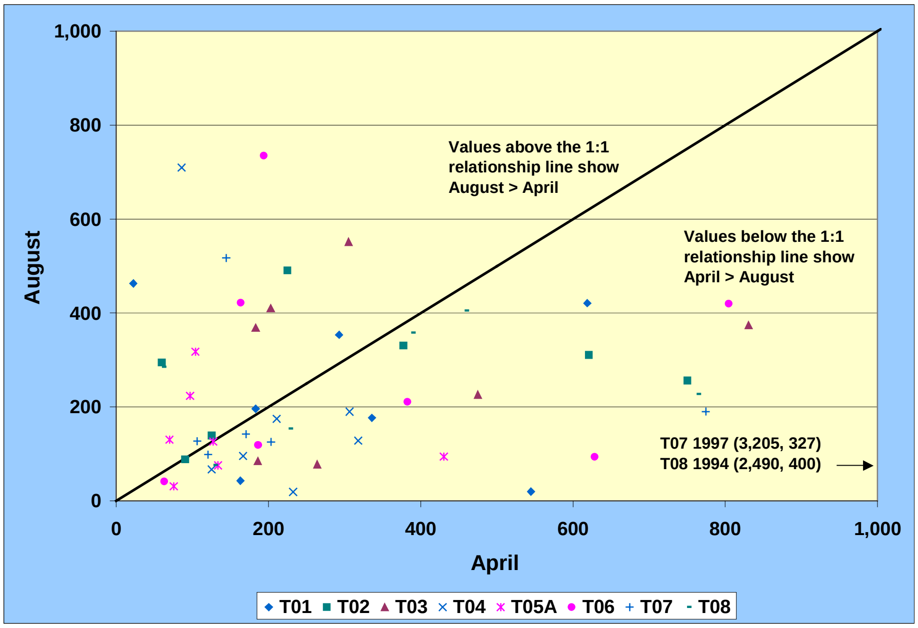


Figure 4-9. Comparison of April and August station mean values for *Clostridium perfringens* (normalized to percent fines) from 1993 to 1999.

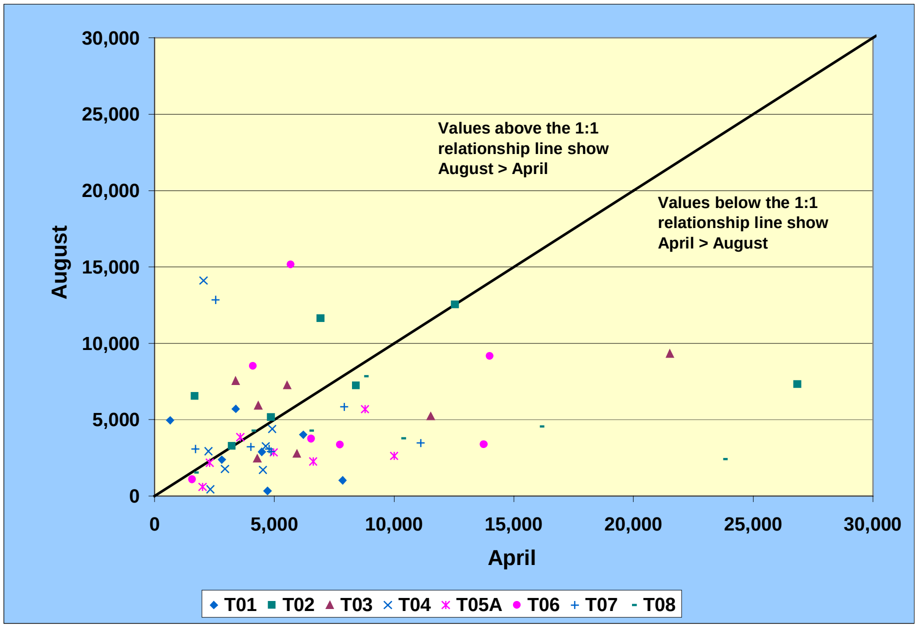


Figure 4-10. Comparison of April and August station mean values for *Clostridium perfringens* (normalized to TOC) from 1993 to 1999.

4.2.4 Chemistry Interrelationships

Station mean values from all April and August surveys (Appendices C-2 and C-3) were included in the regression analysis to evaluate the correspondence within bulk sediment properties and *Clostridium perfringens* over time. Correlation coefficients for April and August surveys were determined by sampling year across all stations and are presented in Table 4-4 and Table 4-5, respectively.

Table 4-4. Correspondence within bulk sediment properties and against *Clostridium perfringens* for April surveys from 1993 to 1999.

Year	TOC by Fines			*Clostridium perfringens* by Fines			*Clostridium perfringens* by TOC		
	r	*n*	*p*	*r*	*n*	*p*	*r*	*n*	*p*
1993	0.908	8	< 0.01	0.756	8	< 0.05	0.844	8	< 0.01
1994	0.896	8	< 0.01	0.479	8	> 0.05	0.585	8	> 0.05
1995	0.883	8	< 0.01	0.831	8	< 0.05	0.528	8	> 0.05
1996	0.914	8	< 0.01	0.707	8	0.05	0.580	8	> 0.05
1997	0.353[a]	8	> 0.05	0.233[a]	8	> 0.05	0.760	8	< 0.05
1998	0.807	8	< 0.05	0.798	8	< 0.05	0.972	8	< 0.01
1999	0.759	8	< 0.05	0.754	8	< 0.05	0.879	8	< 0.01

[a] Grain size data for stations T07 and T08 in 1997 are "anomalous". Correlation between percent fines and TOC in 1997 improved when these stations were excluded from the regression analysis ($r = 0.900$, $n = 6$, $p < 0.05$). Similarly, the correlation between percent fines and *Clostridium perfringens* in 1997 also improved when these stations (T07, T08) were excluded from the regression ($r = 0.496$, $n = 6$, $p > 0.05$).

April— With the exception of 1997, sediment grain size correlated strongly with TOC across all years, (Table 4-4, Figure 4-11). Grain size results for stations T07 and T08 in 1997 are clear outliers suggesting that these data are unusual. The correlation between bulk sediment properties and *Clostridium perfringens* in 1997 was also evaluated. Interestingly, *Clostridium perfringens* also correlated poorly against grain size in 1997, while the correlation was considerably stronger when the regression was performed against TOC (Table 4-4). This suggests that the grain size data for stations T07 and T08 in 1997 are unusual and do not fit typical patterns. The correlation between percent fines and TOC in 1997 improved considerably when stations T07 and T08 were excluded from the regression analysis ($r = 0.900$, $n = 6$, $p < 0.05$).

Clostridium perfringens correlated well with bulk sediment properties for some years, but not others (Table 4-4, Figures 4-12 and 4-13). With few exceptions (*i.e.*, 1995, 1996), the correspondence between *Clostridium perfringens* and bulk sediment properties was stronger across all years when the regression was performed against TOC (Table 4-4). The evaluation confirms that the variability in *Clostridium perfringens* concentrations is primarily controlled by bulk sediment properties.

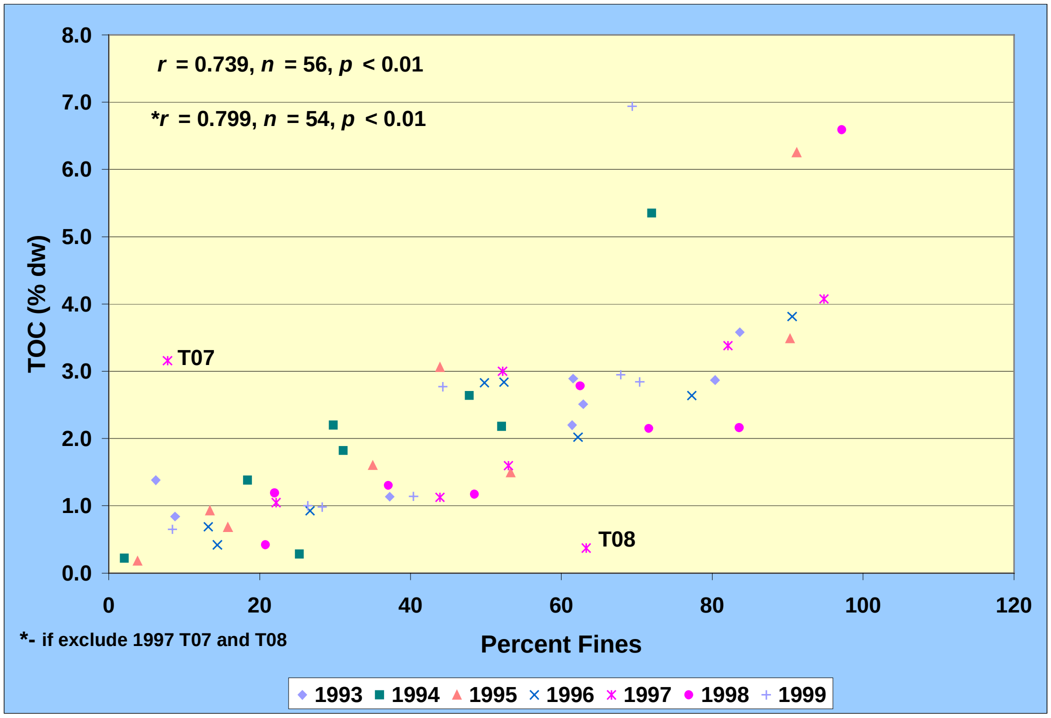


Figure 4-11. Correspondence between total organic carbon content and percent fines in sediments collected at Traditional stations in April 1993–1999.

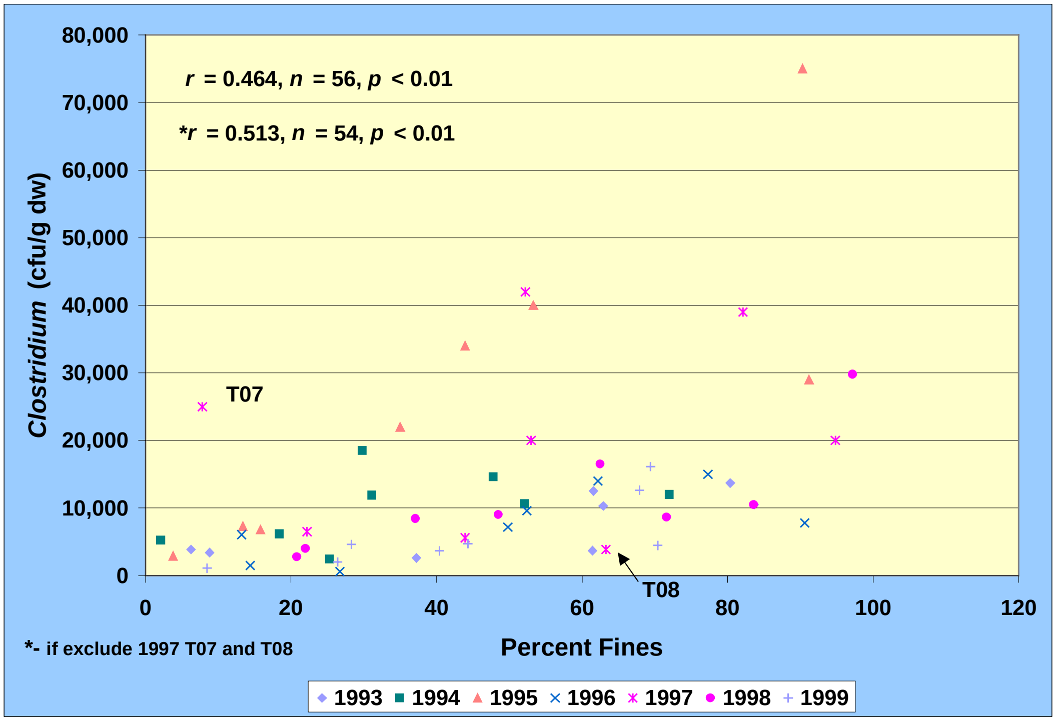


Figure 4-12. Correspondence between *Clostridium perfringens* and percent fines in sediments collected at Traditional stations in April 1993–1999.

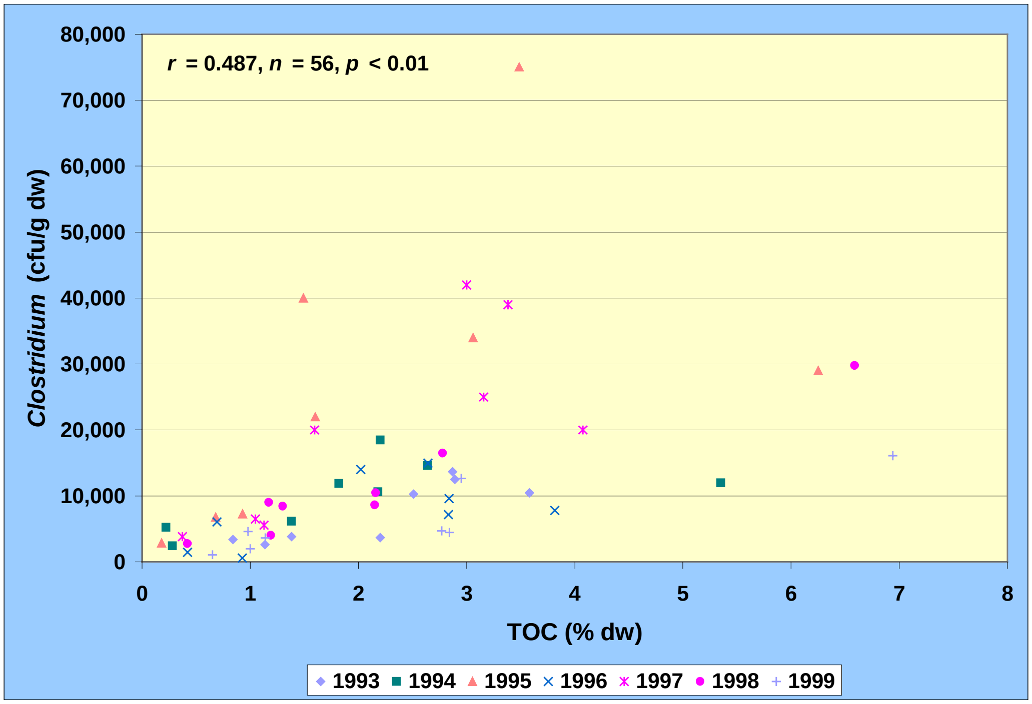


Figure 4-13. Correspondence between *Clostridium perfringens* and total organic carbon content in sediments collected at Traditional stations in April 1993–1999.

August—With the exception of 1991 and 1998, sediment grain size correlated strongly with TOC across all years, Table 4-5, Figure 4-14). Station T08 in 1991 had an unusually low TOC content and was a clear outlier on this plot (Figure 4-14). The correlation between percent fines and TOC in 1991 improved considerably by excluding this station from the regression analysis ($r = 0.780$, $n = 7$, $p < 0.05$, Table 4-5). TOC content at station T04 in 1998 was also a clear outlier and was likely influenced by a storm event in June 1998 (Lefkovitz *et al.* 1999). The correlation between percent fines and TOC in 1998 improved considerably when station T04 was excluded from the analysis ($r = 0.982$, $n = 7$, $p < 0.01$, Table 4-5). The overall correlation between percent fines and TOC across all years, excluding 1991 and station T04 in 1998, also improved considerably ($r = 0.819$, $n = 63$, $p < 0.01$, Figure 4-14).

Clostridium perfringens correlated well with grain size and TOC for some years (*i.e.,* 1996, 1997, and 1998), but not others Table 4-5). The overall correlation between *Clostridium perfringens* and percent fines across all years improved considerably when results from 1991 and station T04 in 1998 were excluded from the regression analysis ($r = 0.412$, $n = 63$, $p < 0.01$, Figure 4-15). Results from 1991 were excluded due to potential influences of sludge disposal to the harbor. Station T04 in 1998 was also excluded due to a likely influence from a storm activity in June 1998. With the exception of 1999, the correlation between *Clostridium perfringens* and bulk sediment properties was generally stronger in more recent years relative to earlier years (Table 4-5). The correlation between *Clostridium perfringens* and bulk sediment properties was stronger for some years (*i.e.,* 1991, 1993, 1994, 1995, 1998) when the regression was performed against TOC (Table 4-5, Figure 4-16). The evaluation confirms that the variability in *Clostridium perfringens* densities is primarily controlled by bulk sediment properties.

Table 4-5. Correspondence within bulk sediment properties and against *Clostridium perfringens* for September 1991 and August surveys from 1992 to 1999.

Year	TOC by Fines			*Clostridium perfringens* by Fines			*Clostridium perfringens* by TOC		
	r	*n*	*p*	*r*	*n*	*p*	*r*	*n*	*p*
1991	0.087[a]	8	> 0.05	0.148	8	> 0.05	0.552	8	> 0.05
1992	0.939	8	< 0.01	0.511	8	> 0.05	0.380	8	> 0.05
1993	0.712	8	< 0.05	0.323	8	> 0.05	0.561	8	> 0.05
1994	0.843	8	< 0.01	0.334	8	> 0.05	0.660	8	> 0.05
1995	0.888	8	< 0.01	0.664	8	> 0.05	0.762	8	< 0.05
1996	0.963	8	< 0.01	0.925	8	< 0.01	0.918	8	< 0.01
1997	0.899	8	< 0.01	0.791	8	< 0.05	0.711	8	< 0.05
1998	0.616[b]	8	> 0.05	0.791	8	< 0.05	0.906	8	< 0.01
1999	0.797	8	< 0.05	0.632	8	> 0.05	0.345	8	> 0.05

[a] TOC data for station T08 in 1991 is unusually low. Correlation between percent fines and TOC in 1991 improved when this station was excluded from the regression analysis ($r = 0.780$, $n = 7$, $p < 0.05$).

[b] TOC data for station T04 in 1998 unusually high, likely due to a storm event in June 1998. The correlation between percent fines and TOC in 1998 improved when this station (T04) was excluded from the regression ($r = 0.982$, $n = 7$, $p < 0.01$).

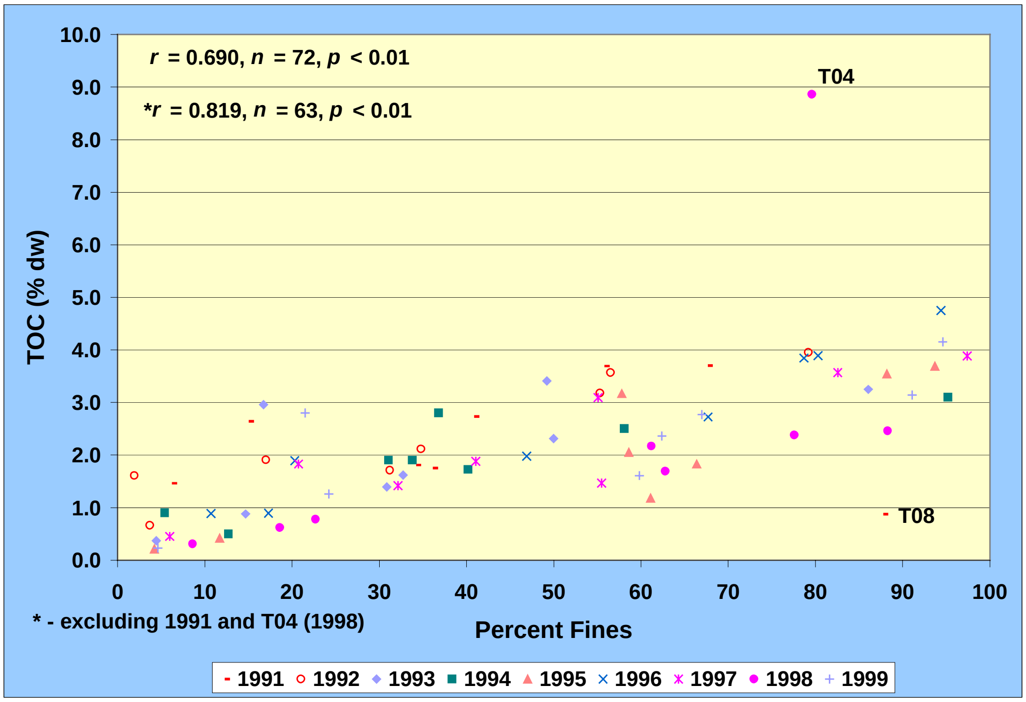


Figure 4-14. Correspondence between total organic carbon content and percent fines in sediments collected at Traditional stations in September 1991 and August 1992–1999.

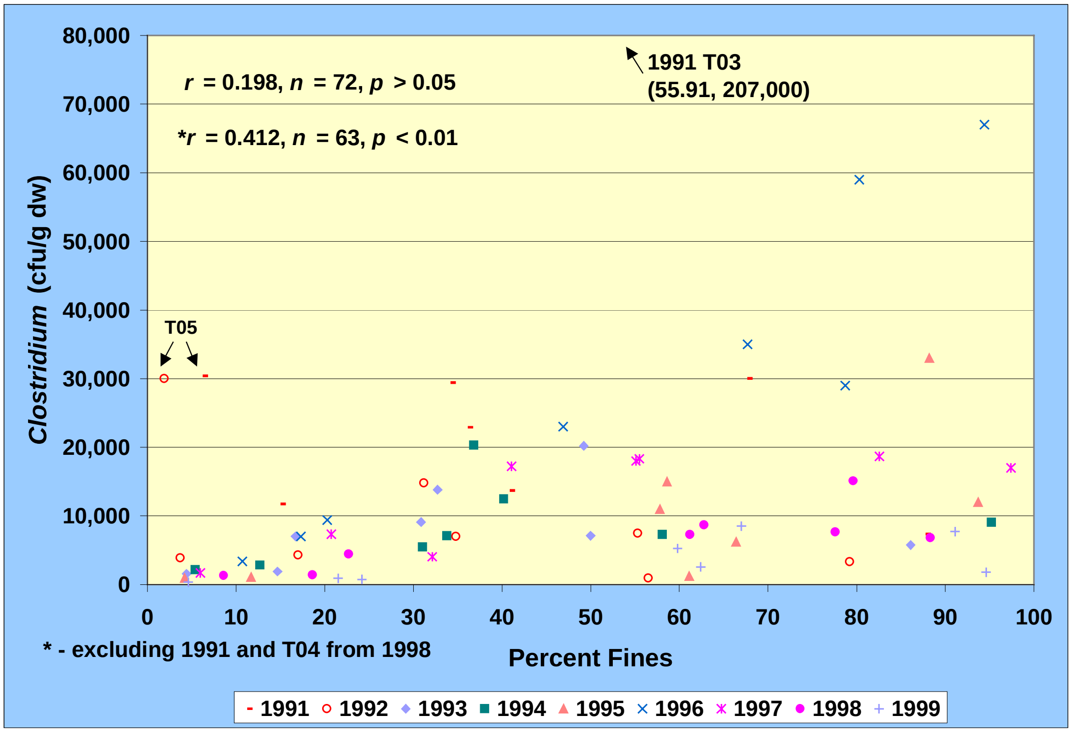


Figure 4-15. Correspondence between *Clostridium perfringens* and percent fines in sediments collected at Traditional stations in September 1991 and August 1992–1999.

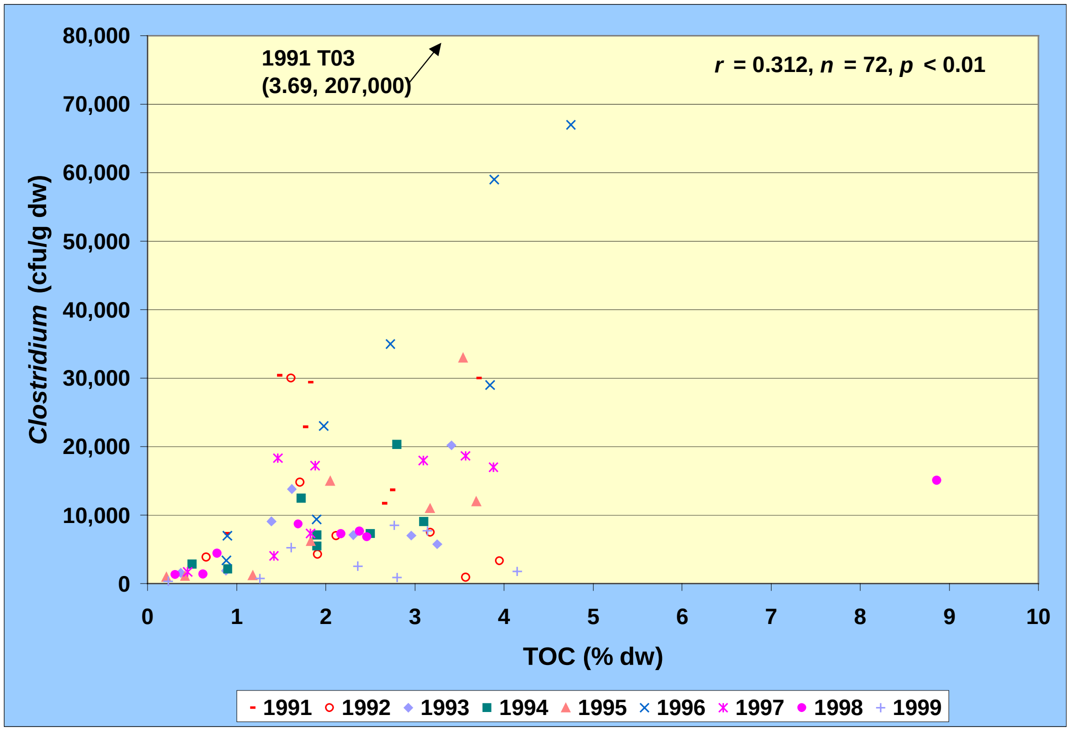


Figure 4-16. Correspondence between *Clostridium perfringens* and total organic carbon content in sediments collected at Traditional stations in September 1991 and August 1992–1999.

4.3 Conclusions

With the exception of station T04 in April 1999, patterns in sediment composition in 1999 were within ranges observed during previous years, suggesting that the spatial and temporal characteristics of sediment grain size in 1999 were not substantially different from previous years (1991–1998). The spatial and temporal distribution of TOC during April and August surveys in 1999 was also not substantially different from 1991 to 1998 because of the high variability in the historical dataset. With few exceptions, sediment grain size and TOC correlated strongly across all years.

In general, *Clostridium perfringens* concentrations were highly variable across all stations and sampling years. With few exceptions (April T01; August T03 and T07), *Clostridium perfringens* concentrations decreased in 1999 across all stations compared to 1997–1998 values. *Clostridium perfringens* generally correlated well with bulk sediment properties in recent years, indicating that grain size and TOC are likely controlling factors. With few exceptions, the correlation between *Clostridium perfringens* and bulk sediment properties was generally stronger when the regression was performed against TOC.

Patterns in sediment composition were consistent between April and August surveys of the eight Traditional Harbor stations. In contrast, there were no clear year-to-year trends in TOC between April and August surveys over time. With the exception of 1993 and 1996, station means values for *Clostridium perfringens* were consistently higher at most Traditional stations sampled in April relative to August values.

5.0 1999 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. Taxonomic responsibilities for the 1999 Boston Harbor studies are listed in Appendix D-1.

5.1.2 Data Analyses

Preliminary Data Treatment—Prior to performing any of the analyses of the 1999 and combined 1991–1999 MWRA datasets, several modifications were made. Several non-infaunal taxa were excluded (listed in Appendix D-2). Data for several 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 polychaetes *Pholoe tecta* and *Pholoe* spp. were merged with *Pholoe minuta* for these analyses. It is likely that the two taxa are the same species, but have not been consistently identified throughout the program. All such changes are listed in Appendix D-2. For calculations of total abundance, all taxa were included, whether identified to species or not. Only taxa identified to species, or those treated as if they were identified to species (*e.g.*, *Ampelisca* spp.), were included in calculations of total species, species diversity, evenness, and for cluster analyses. An additional abundance calculation that included only taxa identified to species, or treated as such, was also made for comparison to total abundance. Taxa that were treated as though they were identified to species are listed in Appendix D-2.

Several of the modifications made to the 1999 dataset prior to the analyses represented substantial departures from data treatments used in past analyses, *e.g.*, 1996 and 1997. Two of the taxa excluded in 1999 were among the numerically predominant taxa (*i.e.*, one of the 10 most abundant) at one or more stations in 1996 and/or 1997. The sevenspine bay shrimp, *Crangon septemspinosa*, was a top-10 species at station T04 in 1997 (Blake *et al.* 1998), but was excluded from the analyses in this report because it is a mobile epibenthic specie that is probably inadequately sampled by a grab sampler. Of larger importance is the exclusion of the blue mussel, *Mytilus edulis*, from the analyses in 1999. This species, which was among the predominant taxa at many stations in 1996 and 1997 (Blake *et al.* 1998), is not infaunal and the individuals obtained during the grab sample collection were typically very small, newly-settled individuals that most likely would not survive to adulthood. Also, amphipods belonging to the genus *Ampelisca* have been identified to species since 1995, but were not previously identified to species. Both species of *Ampelisca* identified from Harbor samples were treated as *Ampelisca* spp. in this report for a similar reason. *A. abdita* and *A. vadorum*, were reported in 1995–1997 (*e.g.*, Blake *et al.* 1998) and were found in 1998–1999. Blake *et al*. (1998) showed that *A. abdita* was much more abundant than *A.*

vadorum, which is consistently found only at station T08. 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.

Oligochaete annelids collected during the September 1991 and April 1992 surveys were not identified to species and were referred to as "Oligochaeta spp." Oligochaetes collected during MWRA Harbor surveys were first identified to species for the August 1992 survey and have been identified to species for all surveys since. Since late 1992, analyses of the Harbor multi-year dataset data have treated oligochaetes differently. For example, Blake *et al.* (1998) included the specific oligochaete identifications that were available for the post April 1992 data, yet had to use the "rolled up" data that were available for the first two surveys. This treatment demonstrated the relative importance of some oligochaete species as contributors to overall community structure in the Harbor since 1992, but could not track the immediate responses to changes in discharges into the Harbor that were made prior to August 1992.

Prior to the analyses performed for this report, MWRA funded a task to identify the 1991 and April 1992 oligochaetes to species. These species-level data are included in this report. Because the samples had been stored for a long period of time before the identifications were performed, some minor discrepancies between the original total oligochaete counts and the revised counts were inevitable. These differences and the solutions invoked are

1. The sum of oligochaetes as recounted in June2000 did not match the sum of oligochaetes listed in the database. Most of the samples (70 of 85) showed greater abundance in the original count than the recount. This probably resulted from loss of individuals from samples during the sorting/id/storage process. Some samples (15 of 85 cases) showed more oligochaetes in the recount than in the original. Typically (11 of 15 cases), the difference was fewer than 10 individuals. This discrepancy between the recount and original count may indicate some degree of misidentification in the original counting process. **For the analyses the recounted oligochaete values were used.**

2. For station T01 sampled in April 1992, only the 0.3-mm fraction was available for recounting. Because oligochaetes were relatively abundant at this station (based on the sum of oligochaetes in the database), the relative species composition and relative abundance in the 0.5-mm fraction was estimated. After considering several alternatives, the abundance in this fraction was estimated simply by **determining the relative proportion of each species in the 0.3-mm fraction for each replicate at station T01 (April 1992) and multiplying that proportion by the total oligochaetes recorded for the 0.5-mm fraction.**

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'). Calculations made by the software were validated by comparing values for these parameters and for total individuals calculated for the August 1998 Harbor infaunal data (Kropp *et al.* 2000) with those made by BioDiversity Pro. Calculations made by BioDiversity for all parameters except log-series alpha were the same as those reported in (Kropp *et al.* 2000). Values calculated by BioDiversity Pro for log-series alpha were 0.01–0.02 higher than those previously reported. However, when rounded to 0.1, both sets of calculations yielded the same values. The results of the validation are given in Appendix D-3. BioDiversity Pro is available at http://www.nhm.ac.uk/zoology/bdpro. Magurran (1988) describes all of the diversity indices used here.

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.

5.1.3 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 dissimilarity (Gallagher 1998). For calculation of CNESS the random sample size constant (*m*) was set to 15 for the 1999 data and to 20 for the combined analysis of 1991–1999 data (Kropp *et al.* 2000). For the species analysis, dissimilarity was calculated from normalized hypergeometric standardization of Pearson's product moment correlation coefficient (*r*). In the combined year analysis, 1991–1999, the three replicate grabs for a station were summed. At T04 in Spring 1995 there were only two replicates, so the two replicates were summed and multiplied by 1.33. To estimate the effect of station T04 on overall interpretation of the station cluster patterns, a separate analysis excluding station T04 was performed. To examine the effect of the identification of oligochaetes to species on the overall infaunal community patterns within the Harbor, two cluster analyses of the multiyear data set were run, one with all oligochaetes treated as one species (as was done for the 1998 report; Kropp *et al.* 2000) and one with oligochaetes identified to species.

Results of the station and species clusters were compared by using nodal analysis, which examines the original data matrix rearranged into a two-way table based on the cluster defined groups. Constancy, a measure of the association of species with stations (Fager 1963), was calculated from the nodal table based on the proportions of the number of occurrences of species in the station group to the total possible number of such occurrences (Boesch 1977):

$$C_{ij} = a_{ij} / (n_i \cdot n_j)$$

Where a_{ij} is the actual number of occurrences of members of species group i in station group j, n_i is the total number of species in group i, and n_j is the number of stations in group j. Constancy will range from 0.0 when none of the species in a species group occurred in a station group to 1.0 when all of the species in a species group occurred in all of the stations of a station group. Fidelity, a measure of the constancy of species in a station group compared to the constancy over all station groups (Fager 1963), was used to indicate the degree to which species prefer station groups (Boesch 1977):

$$F_{ij} = (a_{ij}\Sigma n_j) / (n_j \Sigma a_{ij})$$

where a_{ij} and n_j are the same as defined for the constancy index. Fidelity is 1.0 when the constancy of a species group in a station group is equal to its overall constancy, > 1.0 when its constancy in a station group is greater than that overall, and < 1.0 when its constancy is less than its overall constancy. Values of $F > 2.0$ suggest strong preference of species for a station group and values < 0.7 suggest avoidance of these species from the station group in question (Boesch 1977).

5.2 Results and Discussion

5.2.1 1999 Descriptive Community Measures

Abundance—Among individual Harbor samples collected in April 1999, infaunal abundance was very low at station T04, ranging from 18 to 86 individuals per sample (mean = 57, standard deviation = 35.2). Among the remaining 7 stations, infaunal abundance varied about 15-fold, ranging from 370 to 5,365 individuals/0.04 m^2 (9,250–134,125/m^2) at stations T01 (rep 2) and T05A (rep 2), respectively

Table 5-1. Descriptive ecological parameters for samples collected from Boston Harbor in April 1999.

Station-Replicate	Abundance		# Species	*H'*	*J'*	Log-series Alpha		Station	Abundance		# Species	*H'*	*J'*	Log-series Alpha
	Total	Species[a]							Total	Species[a]				
T01-1	598	463	26	2.69	0.57	6.0	**Mean**	T01	513	423	27	2.94	0.62	6.4
T01-2	370	319	21	2.91	0.66	5.0		T02	1121	718	29	2.15	0.44	6.4
T01-3	570	490	34	3.21	0.63	8.3		T03	2473	2390	31	2.80	0.57	5.0
T02-1	1066	739	24	1.58	0.34	4.8		T04	57	57	3	0.64	0.41	0.7
T02-2	1540	936	29	1.70	0.35	5.7		T05A	3566	1011	34	2.85	0.56	7.1
T02-3	757	479	35	3.16	0.62	8.7		T06	4184	4142	37	2.66	0.51	5.6
T03-1	2903	2829	32	2.61	0.52	5.1		T07	810	742	24	2.79	0.61	4.9
T03-2	2491	2418	33	2.85	0.56	5.4		T08	1983	1855	39	3.28	0.63	7.1
T03-3	2024	1923	28	2.95	0.61	4.7								
T04-1	68	68	3	1.02	0.65	0.6	**SD**	T01	124.3	91.2	6.6	0.26	0.05	1.68
T04-2	86	85	2	0.09	0.09	0.4		T02	394.4	229.2	5.5	0.88	0.16	2.06
T04-3	18	18	3	0.80	0.51	1.0		T03	439.8	453.6	2.6	0.18	0.05	0.38
T05A-1	4171	1262	32	2.44	0.49	6.0		T04	35.2	34.8	0.6	0.49	0.29	0.33
T05A-2	5365	1292	36	2.54	0.49	6.9		T05A	2165.8	461.5	2.0	0.63	0.12	1.21
T05A-3	1162	478	34	3.58	0.70	8.4		T06	1392.2	1403.5	5.6	0.58	0.10	0.81
T06-1	2632	2576	32	1.99	0.40	5.2		T07	66.0	74.0	3.1	0.17	0.01	0.86
T06-2	5323	5287	36	3.03	0.59	5.2		T08	936.1	898.7	9.5	0.17	0.06	1.41
T06-3	4597	4562	43	2.95	0.54	6.6								
T07-1	877	820	21	2.60	0.59	3.9	**CV**	T01	24	22	24	9	7	26
T07-2	808	732	25	2.85	0.62	5.0		T02	35	32	19	41	36	32
T07-3	745	673	27	2.92	0.61	5.6		T03	18	19	9	6	8	8
T08-1	2145	1982	45	3.42	0.62	8.2		T04	61	61	22	76	69	49
T08-2	976	900	28	3.33	0.69	5.5		T05A	61	46	6	22	22	17
T08-3	2827	2684	44	3.09	0.57	7.5		T06	33	34	15	22	19	14
								T07	8	10	13	6	2	18
								T08	47	48	24	5	10	20

[a] Includes only individuals identified to species

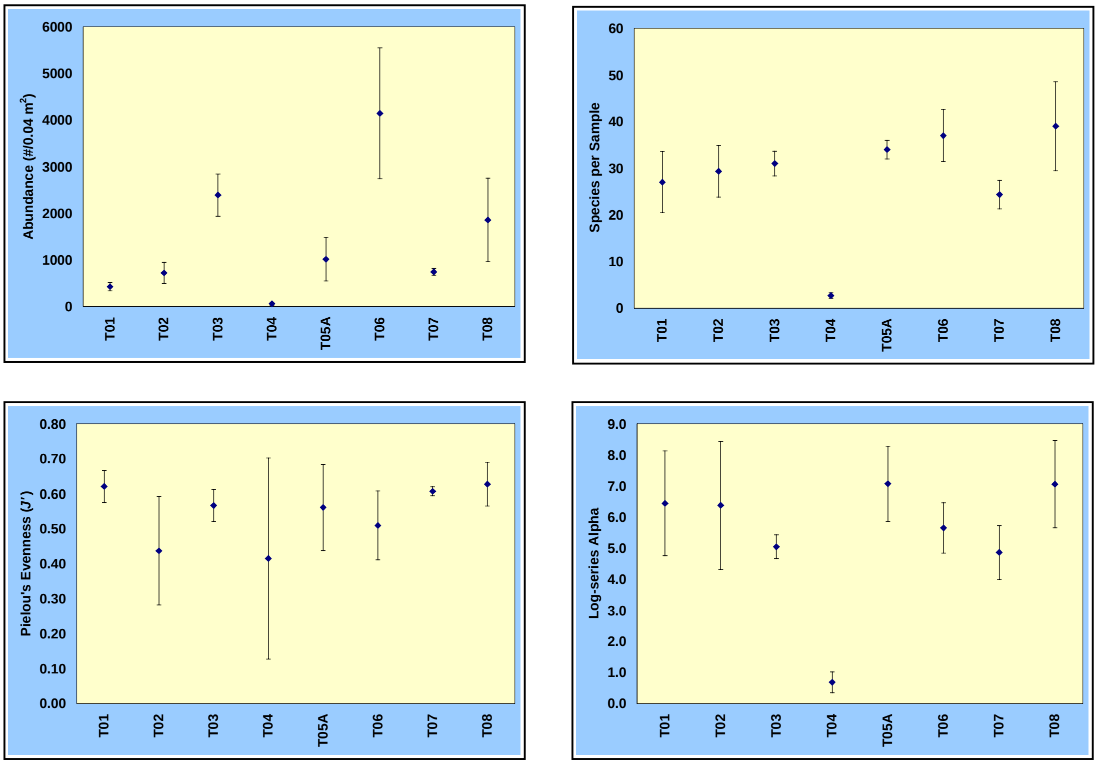


Figure 5-1. Infaunal abundance, numbers of species, evenness, and log-series alpha values for Boston Harbor samples collected in April 1999.

(Table 5-1). Mean (and standard deviation, SD) abundance per sample in April (excluding station T04) ranged from 513 (SD = 124.3) to 4,184 (SD = 1,392.2) individuals/0.04 m^2 at stations T01 and T06, respectively (Table 5-1; Figure 5-1).

Annelid worms were the most abundant higher-level infaunal taxon among the April 1999 Harbor samples (Table 5-2). Annelids accounted for more than 80% of the infauna at 6 of the Harbor stations sampled in April, with the highest percentage, 99 %, at station T04. Crustaceans were the second highest contributors to infaunal abundance at four stations. The highest proportions of crustaceans occurred at stations T06 (52 %) and T03 (29 %). Molluscs were relatively important contributors to infaunal abundance at two stations: T01 (13 %) and T08 (13 %).

Table 5-2. Relative contribution of higher-level taxa to infaunal abundance among Boston Harbor samples collected in April 1999.

Station	Mean Abundance				
	Annelida	Crustacea	Mollusca	Other	Total
T01	438.7	7.3	65.0	1.7	512.7
T02	1056.0	34.7	12.7	17.7	1121.0
T03	1704.0	705.3	59.0	4.3	2472.7
T04	57.0	0.0	0.3	0.0	57.3
T05A	3353.0	30.0	144.3	38.7	3566.0
T06	1907.7	2165.0	103.3	8.0	4184.0
T07	726.7	56.3	14.7	12.3	810.0
T08	1623.0	33.7	260.0	66.0	1982.7

Station	Standard Deviation				
	Annelida	Crustacea	Mollusca	Other	Total
T01	106.4	5.7	12.5	1.5	126.1
T02	435.3	43.8	4.5	5.1	488.8
T03	416.0	76.6	5.3	4.0	501.9
T04	34.8	0.0	0.6	0.0	35.4
T05A	2218.3	9.8	70.5	27.7	2326.3
T06	591.0	1810.2	59.0	6.6	2466.7
T07	87.6	29.5	9.0	8.1	134.2
T08	822.8	26.8	79.1	38.9	967.6

Station	Percent				
	Annelida	Crustacea	Mollusca	Other	Total
T01	85.6%	1.4%	12.7%	0.3%	100.0%
T02	94.2%	3.1%	1.1%	1.6%	100.0%
T03	68.9%	28.5%	2.4%	0.2%	100.0%
T04	99.4%	0.0%	0.6%	0.0%	100.0%
T05A	94.0%	0.8%	4.0%	1.1%	100.0%
T06	45.6%	51.7%	2.5%	0.2%	100.0%
T07	89.7%	7.0%	1.8%	1.5%	100.0%
T08	82.5%	1.7%	13.2%	2.5%	100.0%

Among the August samples, infaunal abundance again was very low at station T04 (Table 5-3), ranging from 12 to 241 individuals per sample (mean = 121, standard deviation = 114.9). Among the remaining 7 stations, infaunal abundance varied about 37-fold, ranging from 431 to 16,157 individuals/0.04 m2 (10,775–403,925/m^2) at stations T07 (rep 2) and T03 (rep 2), respectively (Table 5-3). Mean (SD) abundance per sample in August (excluding station T04) ranged from 583 (135.1) to 15,939 (224.2) individuals/0.04 m^2 at stations T07 and T03, respectively (Table 5-3; Figure 5-2).

Annelids were the most significant contributors to infaunal abundance at seven of the Harbor stations sampled in August (Table 5-4), although their overall importance was less than it was in April. Annelids accounted for 52–91 % of the infauna at the stations where they were the predominant taxon. Crustaceans were the most numerous major taxon at station T03 (83 %) in August and were almost as important as annelids at station T06 (44 % versus 52 %, respectively). Molluscs were relatively unimportant contributors to infaunal abundance in August.

Table 5-3. Descriptive ecological parameters for samples collected from Boston Harbor in August 1999.

Station-Replicate	Abundance		# Species	*H'*	*J'*	Log-series Alpha		Station	Abundance		# Species	*H'*	*J'*	Log-series Alpha
	Total	Species[a]							Total	Species[a]				
T01-1	824	775	29	3.04	0.63	6.0		T01	832	781	32	3.22	0.65	6.6
T01-2	873	819	37	3.28	0.63	8.0		T02	1001	903	28	3.16	0.66	5.6
T01-3	800	750	29	3.33	0.69	6.0	**Mean**	T03	15939	15707	46	1.67	0.30	5.8
T02-1	798	710	25	3.35	0.72	5.1		T04	121	120	6	1.23	0.48	2.1
T02-2	703	641	22	2.70	0.60	4.4		T05A	1446	1097	39	3.70	0.70	8.0
T02-3	1501	1358	38	3.42	0.65	7.3		T06	8012	7885	44	3.15	0.58	6.2
T03-1	15709	15452	46	1.67	0.30	5.9		T07	583	512	23	3.12	0.69	5.0
T03-2	16157	15984	41	1.75	0.33	5.1		T08	1198	1150	37	3.07	0.59	7.3
T03-3	15951	15686	51	1.60	0.28	6.6								
T04-1	241	240	6	0.49	0.19	1.1		T01	37.2	34.9	4.6	0.16	0.03	1.16
T04-2	109	108	8	1.42	0.47	2.0		T02	435.9	395.5	8.5	0.40	0.06	1.49
T04-3	12	12	5	1.78	0.77	3.2	**SD**	T03	224.2	266.6	5.0	0.08	0.02	0.74
T05A-1	1129	932	36	3.87	0.75	7.4		T04	114.9	114.5	1.5	0.66	0.29	1.06
T05A-2	2323	1579	46	3.61	0.65	8.9		T05A	769.2	423.9	5.8	0.14	0.05	0.74
T05A-3	886	781	36	3.63	0.70	7.8		T06	788.0	753.2	1.2	0.08	0.02	0.22
T06-1	8765	8599	45	3.07	0.56	6.2		T07	135.2	119.7	2.6	0.08	0.04	0.56
T06-2	7193	7098	45	3.16	0.58	6.4		T08	81.5	69.2	3.0	0.16	0.03	0.84
T06-3	8077	7959	43	3.22	0.59	6.0								
T07-1	628	527	21	3.09	0.70	4.4		T01	4	4	15	5	5	17
T07-2	431	386	22	3.21	0.72	5.1		T02	44	44	30	13	9	27
T07-3	690	624	26	3.07	0.65	5.5	**CV**	T03	1	2	11	5	7	13
T08-1	1281	1222	34	2.95	0.58	6.5		T04	95	95	24	54	60	50
T08-2	1195	1143	37	3.25	0.62	7.3		T05A	53	39	15	4	7	9
T08-3	1118	1084	40	3.00	0.57	8.2		T06	10	10	3	3	3	4
								T07	23	23	12	2	5	11
								T08	7	6	8	5	5	12

[a] Includes only individuals identified to species

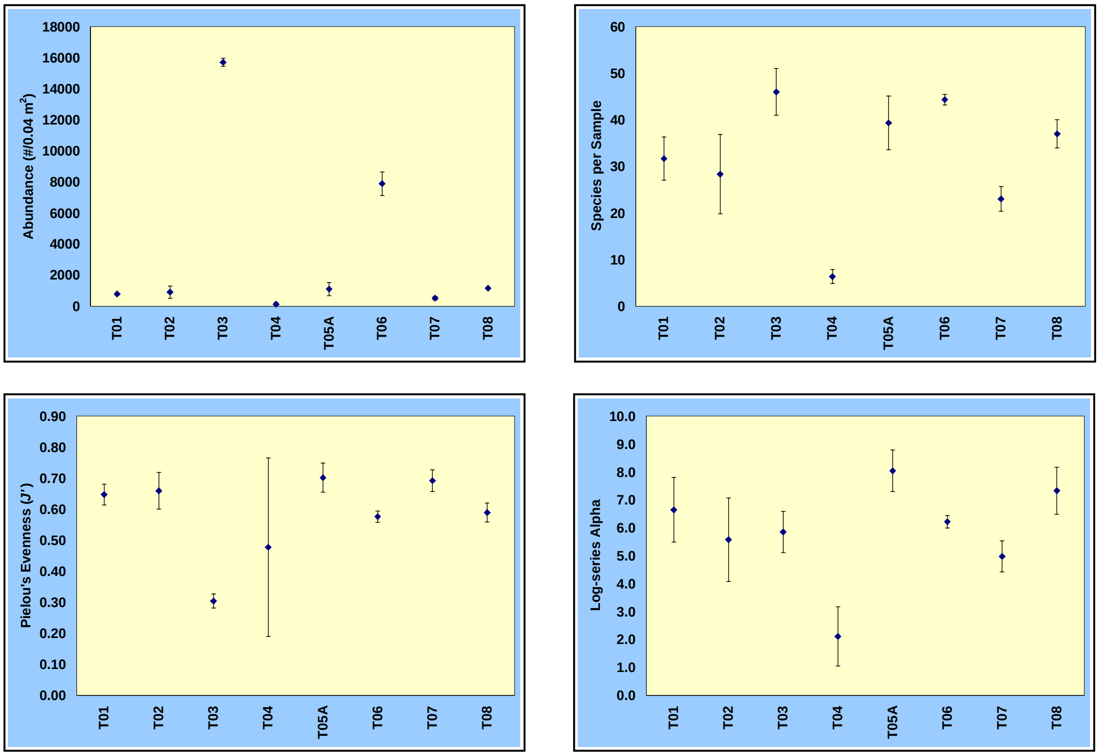


Figure 5-2. Infaunal abundance, numbers of species, evenness, and log-series alpha values for Boston Harbor samples collected in August 1999.

Table 5-4. Relative contribution of higher-level taxa to infaunal abundance among Boston Harbor samples collected in August 1999.

	Mean Abundance				
Station	**Annelida**	**Crustacea**	**Mollusca**	**Other**	**Total**
T01	758.0	14.3	54.7	5.3	832.3
T02	780.0	194.0	23.3	3.3	1000.7
T03	2468.3	13283.0	178.0	9.7	15939.0
T04	103.7	2.0	15.0	0.0	120.7
T05A	1179.0	176.7	75.7	14.7	1446.0
T06	4124.0	3502.0	375.0	10.7	8011.7
T07	512.0	45.3	25.0	0.7	583.0
T08	974.0	35.0	183.7	5.0	1197.7

	Standard Deviation				
Station	**Annelida**	**Crustacea**	**Mollusca**	**Other**	**Total**
T01	18.2	0.6	22.9	4.0	45.7
T02	170.2	261.4	5.0	3.1	439.6
T03	141.8	256.1	7.8	6.7	412.3
T04	112.4	2.0	12.5	0.0	126.9
T05A	713.8	20.4	27.5	11.2	773.0
T06	500.4	841.7	59.0	3.1	1404.1
T07	131.9	13.8	3.0	0.6	149.3
T08	111.1	16.8	35.4	1.4	164.7

	Percent				
Station	**Annelida**	**Crustacea**	**Mollusca**	**Other**	**Total**
T01	91.1%	1.7%	6.6%	0.6%	100.0%
T02	77.9%	19.4%	2.3%	0.3%	100.0%
T03	15.5%	83.3%	1.1%	0.1%	100.0%
T04	85.9%	1.7%	12.4%	0.0%	100.0%
T05A	81.5%	12.2%	5.2%	1.0%	100.0%
T06	51.5%	43.7%	4.7%	0.1%	100.0%
T07	87.8%	7.8%	4.3%	0.1%	100.0%
T08	81.3%	2.9%	15.3%	0.4%	100.0%

Numbers of Species—As for abundance, the number of species found at Station T04 in April 1999 was very low, 2–3 per replicate (mean = 3, SD = 0.6). Among the remaining stations, the total numbers of species per sample collected in April 1999 ranged from 21 to 45 at stations T01 (rep 2)/T07 (rep 1) and T08 (rep 1), respectively (Table 5-1). In April, mean (SD) numbers of species per sample (excluding Station T04) ranged from 24 (3.1) to 39 (9.5) species at stations T07 and T08, respectively (Table 5-1; Figure 5-1). In April 1999, Boston Harbor infaunal species numbers were correlated with abundance ($r = 0.636$, $n = 24$, $p < 0.01$).

Among the higher-level taxa collected in April, annelid worms contributed the highest percentage of species, accounting for about 46–100 % of the species collected at each Harbor station (Table 5-5). Crustaceans and molluscs accounted for up to 31 % and up to 17 % of the species collected at each Harbor station, respectively

Table 5-5. Relative contribution of higher-level taxa to infaunal species numbers among Boston Harbor samples collected in April 1999.

	Mean Species per Station				
Station	**Annelida**	**Crustacea**	**Mollusca**	**Other**	**Total**
T01	19.3	3.3	3.7	0.7	27.0
T02	18.0	4.3	4.3	2.7	29.3
T03	15.7	9.3	4.3	1.7	31.0
T04	2.7	0.0	0.0	0.0	2.7
T05A	23.7	4.0	3.0	3.3	34.0
T06	17.0	11.3	6.3	2.3	37.0
T07	15.3	4.7	2.3	2.0	24.3
T08	23.0	6.3	6.0	3.5	38.8

	Standard Deviation				
Station	**Annelida**	**Crustacea**	**Mollusca**	**Other**	**Total**
T01	3.5	2.1	1.5	0.6	7.7
T02	1.0	2.5	1.5	1.2	6.2
T03	1.5	2.1	0.6	1.5	5.7
T04	0.6	0.0	0.0	0.0	0.6
T05A	2.1	1.0	0.0	0.6	3.7
T06	4.0	5.0	2.5	1.5	13.1
T07	1.2	0.6	0.6	1.0	3.3
T08	5.3	2.1	2.0	0.7	10.1

	Percent				
Station	**Annelida**	**Crustacea**	**Mollusca**	**Other**	**Total**
T01	71.6%	12.3%	13.6%	2.5%	100.0%
T02	61.4%	14.8%	14.8%	9.1%	100.0%
T03	50.5%	30.1%	14.0%	5.4%	100.0%
T04	100.0%	0.0%	0.0%	0.0%	100.0%
T05A	69.6%	11.8%	8.8%	9.8%	100.0%
T06	45.9%	30.6%	17.1%	6.3%	100.0%
T07	63.0%	19.2%	9.6%	8.2%	100.0%
T08	59.2%	16.3%	15.5%	9.0%	100.0%

The number of species found at station T04 in August 1999, although higher than in April, was very low, 5–8 per replicate (mean = 6, SD = 1.5; Table 5-3). Among the remaining Harbor stations, the total numbers of species per sample collected in August ranged from 21 to 51 at stations T07 (rep 1) and T03 (rep 3), respectively (Table 5-3). In August, mean (SD) numbers of species per sample (excluding station T04) ranged from 23 (2.6) to 46 (5.0) species at stations T07 and T03, respectively (Table 5-3; Figure 5-2). In August, Boston Harbor infaunal species numbers were correlated with abundance ($r = 0.623$, $n = 24$, $p < 0.01$).

Among the samples collected in August, the proportional contributions of annelid worms was highest at all 8 stations, accounting for about 46–70 % of the species collected (Table 5-6). Crustaceans and molluscs accounted for about 11–25 % and about 15–32 % of the species collected at each Harbor station, respectively.

Table 5-6. Relative contribution of higher-level taxa to infaunal species numbers among Boston Harbor samples collected in August 1999.

Station	Mean Species per Station				
	Annelida	Crustacea	Mollusca	Other	Total
T01	22.0	3.3	5.0	1.3	31.7
T02	18.0	4.3	5.0	1.0	28.3
T03	23.3	10.7	9.3	2.7	46.0
T04	3.0	1.3	2.0	0.0	6.3
T05A	23.3	8.3	6.0	1.7	39.3
T06	20.3	11.0	9.3	3.7	44.3
T07	13.0	3.7	5.7	0.7	23.0
T08	21.0	6.7	7.7	1.5	36.8

Station	Standard Deviation				
	Annelida	Crustacea	Mollusca	Other	Total
T01	1.7	1.5	1.0	0.6	4.8
T02	2.0	3.2	2.6	1.0	8.9
T03	2.5	0.6	1.5	1.5	6.1
T04	1.7	1.2	0.0	0.0	2.9
T05A	1.5	2.5	1.0	1.2	6.2
T06	3.1	1.7	2.1	0.6	7.4
T07	1.7	0.6	1.2	0.6	4.0
T08	1.0	2.5	1.2	0.7	5.4

Station	Percent				
	Annelida	Crustacea	Mollusca	Other	Total
T01	69.5%	10.5%	15.8%	4.2%	100.0%
T02	63.5%	15.3%	17.6%	3.5%	100.0%
T03	50.7%	23.2%	20.3%	5.8%	100.0%
T04	47.4%	21.1%	31.6%	0.0%	100.0%
T05A	59.3%	21.2%	15.3%	4.2%	100.0%
T06	45.9%	24.8%	21.1%	8.3%	100.0%
T07	56.5%	15.9%	24.6%	2.9%	100.0%
T08	57.0%	18.1%	20.8%	4.1%	100.0%

Diversity—As measured by the traditional Shannon index (*H'*), diversity among Boston Harbor samples collected in April 1999 varied from about 0.1 at station T04 (rep 2) to about 3.6 at station T05A (rep 3; Table 5-1). Evenness (*J'*) among most Harbor samples ranged from 0.1 to 0.7 (stations T04, rep 2 and T05A, rep 3, respectively). Within-station variation was low (CV < 23) at all stations except T02 (CV = 36) and T04 (CV = 69) (Table 5-1; Figure 5-1). Log-series alpha varied considerably among Harbor stations, ranging from 0.4 at station T04 (rep 2) to 8.7 at station T02 (rep 3). Within-station variation in log-series alpha among the Harbor stations was relatively high at stations T01, T02, and T04 (CV = 26–49) (Table 5-1; Figure 5-1).

Diversity (*H'*) among individual Boston Harbor samples collected in August 1999 varied from 0.5 at station T04 (rep 1) to about 3.9 at station T05A (rep 1; Table 5-3). In August, evenness among most Harbor samples ranged from 0.4 to 0.7. Within-station variation was low (CV < 10) at all stations except T04 (CV = 60) (Table 5-3; Figure 5-2). Log-series alpha varied considerably among August samples, ranging from 1.1 at station T04 (rep 1) to 8.9 at station T05A (rep 2). Within-station variation in log-series alpha among the August samples was highest at stations T02 and T04 (CV = 27 and 50, respectively), but was generally low (CV < 18) elsewhere (Table 5-3; Figure 5-2).

Most Abundant Species—The 12 most abundant species found at each Harbor station in April and August 1999 are listed in Appendix D-4. In April the proportion of individuals identified to species ranged from 28 % (T05A) to 99 % (T04 and T06). Two species of oligochaete worms, *Tubificoides apectinatus* and *T.* nr. *pseudogaster*, were very important contributors to abundances at many of the Harbor stations. One of the two species was the most abundant or second most abundant species at seven of the eight stations, the only exception being station T04. *T. apectinatus* was the top-ranked species at stations T02, T05A, and T07. *T.* nr. *pseudogaster* was top-ranked at station T01 and was the second most abundant species at stations T03, T05A, T06, and T08. At station T04, the polychaete *Capitella capitata* complex (88%) was the most abundant species (Appendix D-4), although its abundance was very low (~ 50 individuals per sample). The amphipod taxon *Ampelisca* spp. was the most abundant taxon at station T06 and the paraonid polychaete *Aricidea catherinae* was the most abundant species at station T08. In April, the 12 most abundant taxa accounted for about 91–100% of the infaunal abundance at each station.

Compared to April 1999, the relative numerical importance of the two oligochaete species was reduced in August. *T. apectinatus* was much less important numerically in August. It was the most abundant species at only station T07. It was among the top 12 taxa at stations T03, T05A, T06, and T08. *T.* nr. *pseudogaster* was top-ranked at station T01 and was among the top 4 taxa at stations T02, T03, and T06. The amphipod *Ampelisca* spp. was the most abundant taxon at stations T03, and T06. It ranked no higher than 5th in abundance at the “outer”(*i.e.*, excluding station T04) Harbor stations. *Ampelisca* abundance was particularly reduced in 1999 (~ 6 individuals per sample) at station T08, at which it was the most abundant species in August 1998 (~2,424 individuals per sample). A spionid polychaete, *Polydora cornuta*, was the most abundant species at station T05A and ranked among the 12 most abundant species at all other stations except station T08. In contrast to August 1998 and April 1999, station T04 was numerically dominated by *Streblospio benedicti*, which comprised about 84 % of its total infaunal abundance. *Capitella capitata* complex, which was very abundant in August 1998, was not found at station T04 in August 1999. In August, the 12 most abundant taxa accounted for about 87–100% of the infaunal abundance at each station.

5.2.2 1999 Harbor Multivariate Analysis

Station patterns—Station cluster analysis of the 1999 Traditional (T) harbor station data including all 48 grabs (eight stations X three replicates) and 124 taxa indicated that both within and between station similarity was stronger than seasonality (Spring to Summer) in determining station patterns. Replicate 3 from Station T04 was eliminated from the analysis because with only 12 individuals it did not meet the minimum criteria set for the random sample parameter (*m* = 15) for calculation of CNESS dissimilarity. At the eight-group level (approximately 0.9 CNESS dissimilarity) all replicates for a given station were grouped together within the same cluster group, except T06 replicate 1 from Spring that grouped with Station T05A Spring replicates (Figure 5-3). Half the stations (T01, T03 T07, and T08 cluster groups I, IV, III, and VI respectively) exhibited little seasonal (Spring to Summer) difference with all replicates from Spring and Summer within the same cluster group. Largest seasonal differences occurred at Stations T05A and T04 with each season forming a separate station group based on season (Figure 5-3). Seasonal differences at Stations T02 and T06 were less pronounced. The greatest difference in CNESS dissimilarity occurred between seasonal samples from Station T04, with the community improving greatly from Spring to Summer.

The Spring infaunal community at T04, inner Dorchester Bay, formed the most dissimilar station group in the analysis. In Spring, T04 had the lowest community structure statistics with only 171 individuals/ 0.12 m^2 and 3 species, the dominant being *Capitella capitata* complex. By Summer, the community at Station T04 had changed with 360 individuals/0.12 m^2, 10 species present, no *Capitella capitata* complex, and *Streblospio benedicti* the dominant species. Small-scale spatial heterogeneity, on the order of 10’s of meters or less, may be responsible for part of this change. The sediments at Station T04 in Spring were 69% silt-clay with 6.9% TOC and in the Summer 95% silt-clay with 4.2% TOC (Section 4). For both seasons, Station T04 was so different among the stations sampled that its removal from the analysis did not change the relationship between any of the other seven stations. The station patterns described above

```
Station Rep. Season                               Cluster Group
T01     1    Spring  -----------------------I
T01     2    Spring  -----------------I     I-----------------I
T01     3    Spring  -----------------I-----I                 I
T01     1    Summer  --------------I                          I        I
T01     2    Summer  --------------I--I                       I--------------I
T01     3    Summer  -----------------I-----------------I     I              I
T02     1    Summer  -----------------I                 I     I              I
T02     3    Summer  -----------------I-----------I     I-----I              I-----I
T02     2    Summer  -----------------------------I-----I                    I     I
                                                                             I     I
T04     1    Summer  -----------------------------I               II         I     I
T04     2    Summer  -----------------------------I--------------------------I     I
                                                                                   I
T02     1    Spring  --------------I                                               I
T02     2    Spring  --------------I-----------------I                             I
T02     3    Spring  --------------------------------I--------I                    I
T07     1    Spring  -----------------I                       I        III         I
T07     3    Spring  -----------------I--------I              I-----------I        I
T07     2    Spring  --------------------------I-----I        I           I        I
T07     1    Summer  --------------I                 I--------I           I        I
T07     2    Summer  -----------I  I-----------------I                    I        I
T07     3    Summer  -----------I--I                                      I        I
                                                                          I        I
T03     1    Spring  --------I                                            I        I
T03     2    Spring  -----I  I-----------------I                          I--I     I
T03     3    Spring  -----I--I                 I                          I  I     I
T03     1    Summer  -----I                    I-----I                    I  I     I
T03     3    Summer  -----I-----I              I     I                    I  I     I
T03     2    Summer  -----------I--------------I     I              IV    I  I     I
T06     2    Spring  -----------I                    I--------------------I  I     I
T06     3    Spring  -----------I--------------I     I                       I     I
T06     1    Summer  -----I                    I     I                       I-----I
T06     2    Summer  -----I--I                 I-----I                       I     I
T06     3    Summer  --------I-----------------I                             I     I-----------I
                                                                             I     I           I
T05A    1    Spring  --------------------I                                   I     I           I
T05A    2    Spring  --------------------I--------------------I        V     I     I           I
T06     1    Spring  -----------------------------------------I-----I        I     I           I
T05A    3    Spring  -----------------------------------------------I--------I     I           I
                                                                                   I           I
T08     1    Spring  --------------I                                               I           I
T08     2    Spring  --------------I-----------I                                   I           I
T08     1    Summer  -----------I              I                                   I           I
T08     2    Summer  -----------I--I           I-----------I            VI         I           I
T08     3    Summer  --------------I-----------I           I-----------------I     I           I
T08     3    Spring  --------------------------------------I                 I     I           I
                                                                             I     I           I
T05A    1    Summer  -----------------------I                                I-----I           I
T05A    2    Summer  -----------------------I--I                        VII  I                 I
T05A    3    Summer  --------------------------I-----------------------------I                 I
                                                                                               I
T04     1    Spring  --I                                                                       I
T04     3    Spring  --I--------------------------------------I          VIII                  I
T04     2    Spring  -----------------------------------------I--------------------------------I
                    0.12        0.32           0.58           0.83           1.09           1.35
                                                Similarity
```

Figure 5-3. Station dendrogram of 1999 Harbor infauna data including all replicate grabs (Gallagher's CNESS dissimilarity and UMPGA sorting).

remained unchanged at the six-group level without T04, but the general level of CNESS dissimilarity increased to approximately 0.9.

Summing the replicates for each station by season produced a similar pattern of station associations as found in the replicate analysis (Figure 5-4). At the four-group level (approximately 1.0 CNESS dissimilarity) Stations T03, T06, T07 for Spring and Summer, plus Spring T02 formed group II. Station T05A and T08 formed group III. Group I was composed of Stations T01, Summer T02, and Summer T04. Group IV was Spring T04 and again the most dissimilar of all stations groups.

```
Station  Season                    Cluster Group
T01  Spring  -----------I
T01  Summer  -----------I--------------I   Ia
T02  Summer  --------------------------I--------------------I
T04  Summer  ------------------------------Ib---------------I-----I
                                                                  I
T02  Spring  --------------------I                                I
T07  Spring  --------I           I--------------------I IIa       I
T07  Summer  --------I-----------I                    I           I--I
T03  Spring  --I                                      I           I  I
T03  Summer  --I                                      I-----------I  I
T06  Spring  --I--------I                             I              I
T06  Summer  -----------I-----------------------------I IIb          I-----------------I
                                                                     I                 I
T05A Spring  --------------------------------------------I    IIIa   I                 I
T05A Summer  --------------------------------------------I--I        I                 I
T08  Spring  -----------I                                   I--------I                 I
T08  Summer  -----------I-----------------------------------I IIIb                     I
                                                                          IV           I
T04  Spring  --------------------------------------------------------------------------I
             0.50        0.64           0.81           0.99           1.16           1.34
```

Station Data from Sediment and SPI Analyses

Station	Season	Cluster Group	Indiv. (#/0.12 m^2)	Taxa (cm)	RPD Proc.	Interface Tube	Amp. SS	OSI	(%)	Gravel (%)	Sand (%)	Fines Class	Sedi. (%)	TOC (#/gdw)	C.per. (m)	Depth
T01	Spring	Ia	1270	41						4	68	28		1.0	4620	4.9
T01	Summer	Ia	2340	46	0.7	INTER	-	I	2.3	25	53	22	SIFS	2.8	920	4.9
T02	Summer	Ia	2710	43	1.0	BIOG	+	I	3.0	<1	40	60	SI	1.6	5260	6.8
T04	Summer	Ib	360	10	0.2	PHYS	-	I	2.0	4	2	95	SI	4.2	1800	3.2
T02	Spring	IIa	2150	41						4	56	40		1.1	3670	6.8
T07	Spring	IIa	2220	37						28	28	44		2.8	4720	5.9
T07	Summer	IIa	1540	32	1.5	BIOG	-	I/II	4.0	10	24	67	SI	2.8	8520	5.9
T03	Spring	IIa	7170	44						2	31	68		3.0	12640	8.7
T03	Summer	IIb	47120	58	3.9	BIOG	MAT	II	8.3	0	9	91	SI	3.1	7720	8.7
T06	Spring	IIb	12420	56						1	29	70		2.8	4460	6.6
T06	Summer	IIb	23660	59	3.3	BIOG	MAT	II	7.7	<1	38	62	SIFS	2.4	2560	6.6
T05A	Spring	IIIa	3030	46						1	73	26		1.0	2000	17.5
T05A	Summer	IIIa	3290	56	0.7	INTER	-	I	2.3	<1	76	24	SIFS	1.3	750	17.5
T08	Spring	IIIb	5570	53						<1	91	8		0.7	1090	11.3
T08	Summer	IIIb	3450	52	0.8	INTER	+	I	2.7	2	93	5	FSSI	0.2	350	11.3
T04	Spring	IV	170	3						0	31	69		6.9	16130	3.2

Figure 5-4. Station dendrogram of 1999 Harbor infaunal data with sediment and SPI data summarized by cluster group (all three replicates from each station summed, Gallagher's CNESS dissimilarity, and UMPGA sorting).

Cluster grouping of stations reflected the infaunal community response to physical parameters (sediment properties and depth) and associated stressors (organic loading). From the summed replicate analysis, station group I was composed of stations dominated by both biological and physical processes with what appeared to be successional Stage I communities and low OSI values (Figure 5-4). For the most part group I represented Summer conditions at Stations T01 and T02, on Deer Island Flats, and T04, inner Dorchester Bay, which all had moderately low community structure statistics. Groups Ib and IV were contained only Station T04, the most physically stressed (shallowest water depth and RPD layer, and highest TOC) of all the groups. Group III was Stations T05A in President Roads and T08 in Hingham Bay that were deeper and had sandier sediments than other T-stations. Groups Ia and III were intermediate in physical parameters and community development with Station Ia being shallow water depth (5 to 7 m) and III deepest (11 to 18 m). Group II, the largest station group, had the highest levels of biogenic activity and community succession. The group was split on the presence of *Ampelisca* spp. tube mats. Group IIa (T07 in Quincy Bay and Spring T02 on Deer Island Flats) had coarser sediments than the other subgroup and did not have *Ampelisca* spp. tube mats. Groups IIb (T03 off Long Island and T06 off Peddocks Island) had tube mats, finer sediments, deepest RPD layers, and highest OSI values. Surfaces at group II stations were all dominated by biogenic structures. Group IV was Spring T04 that had the finest sediments and lowest community structure of all stations.

Species Patterns—The inclusion of rarer species in the analysis was instructive in forming intergroup associations in the station cluster analysis but tended to complicate interpretation of species patterns by lowering nodal analysis coefficients. So rarer taxa were left out of the species cluster analysis. Comparison of a reduced 50-taxa analysis based on taxa that had >5 occurrences to the full 124-taxa analysis indicated that the relationship among the dominant species was the same in both analyses. Therefore, interpretation of species patterns was based on the 50-species analysis of the summed replicate data set.

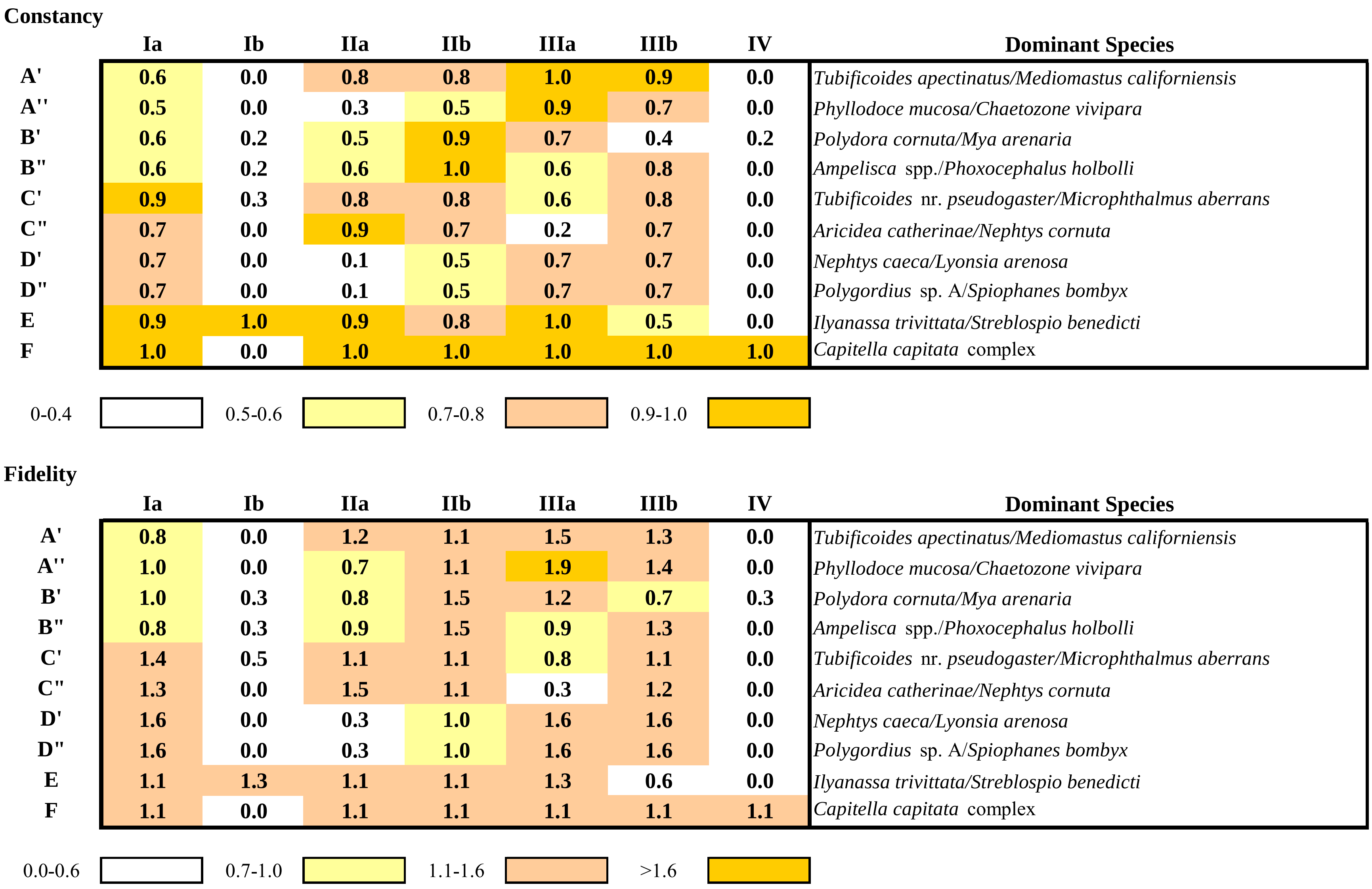
Six species groups formed at about the 0.1 CNESS dissimilarity level with groups A, B, and C containing the most of the numerical dominants and groups D, E, and F containing occurrence dominant but few numerical dominants (Figure 5-5). Many of the group A species were broadly distributed among the stations with subgroup A' abundant at all stations and subgroup A" tending to be more abundant in sandy sediments. None of the group A species occurred at Station T04. Group B species were responsible for much of the biogenic structure that dominated muddy sediments and group C species seemed to prefer mixed muddy-sand stations. Many of the group D species corresponded to those comprising a sand-dwelling fauna identified in 1998 (Kropp *et al.* 2000). Group E occurred in all sediment types but tended to be more abundant in muddy-sands including T04 in the Summer. Group F was a single species, *Capitella capitata* complex, which was broadly distributed occurring at all stations except T04 in the Summer.

Nodal constancy and fidelity indicated that many of the species groups were associated with specific stations groups (Figure 5-6). Species groups E and F, composed of polychaete and mollusc species with opportunistic life histories, had high constancy (≥ 0.8) with all station groups for both seasons. Groups E and F were the only species groups to be have strong association with Station T04. Group E being dominated by *Streblospio benedicti,* the most abundant species at T04 in Summer and group F *Capitella capitata* complex that along with the bivalve *Nucula delphinodonta* were the most abundant species at T04 in Spring (Table 5-7). Group A was most associated (high constancy and fidelity) with station group III, group B with station subgroup IIb, and group C with station subgroups Ia and IIa. Group D had moderate constancy but high fidelity with station groups Ia and III (Figure 5-6).

The dominant species in subgroup A' was the oligochaete *Tubificoides apectinatus*, the third most abundant species in the 1999 data. The polychaete *Mediomastus californiensis* that occurred at all stations, expect T04, was also in subgroup A' but not very abundant (Table 5-7). Group B contained five

```
Species                                                     Cluster Group
Turbellaria spp.                -----I
Nemertea sp. 2                  -----I-----I
Mediomastus californiensis      -----------I--------------I             A′
Tubificoides apectinatus        --------------------------I--------------------------I
                                                                                     I
Phyllodoce mucosa               -----------I                                         I
Eteone longa                    -----------I--------------I                          I--------------I
Nephtys ciliata                 -----------I              I             A″           I              I
Chaetozone vivipara             --I        I-----I        I--------------------------I              I
Edotia triloba                  --I--------I     I--------I                                         I
Pygospio elegans                -----------------I                                                  I
                                                                                                    I
Polydora cornuta                -----------------------------------------I                          I--I
Cerastoderma pinnulatum         -----------I                             I    B′                    I  I
Petricola pholadiformis         -----------I-----I                       I-----I                    I  I
Mya arenaria                    -----------I     I-----------------------I     I                    I  I
Hiatella arctica                -----------------I                             I                    I  I
                                                                                                    I  I
Ampelisca spp.                  -----------------I                             I--------------------I  I
Photis pollex                   --------I        I-----------I                 I                       I
Phoxocephalus holbolli          --------I--------I           I            B″   I                       I
Crassicorophium bonelli         --------------I              I-----------------I                       I
Orchomenella minuta             --------------I-----I        I                                         I
Unciola irrorata                --------------------I--------I                                         I
                                                                                                       I
Pholoe minuta                   --------I                                                              I
Polycirrus phosphoreus          --I     I-----------I                                                  I
Leptocheirus pinguis            --I-----I           I-----------------------I                          I
Microphthalmus aberrans         --------------------I                       I     C′                   I
Pherusa affinis                 --------------------------------------I     I-----------I              I
Tubificoides nr. pseudogaster   --------------------------------------I-----I           I              I--I
                                                                                        I              I  I
Nephtys cornuta                 --------------I                                         I              I  I
Ninoe nigripes                  --------------I-----------------------I                 I-----I        I  I
Scoletoma hebes                 -----------------------I              I           C″    I     I        I  I
Aricidea catherinae             -----------------------I--------I     I-----------------I     I        I  I
Leitoscoloplos robustus         --------------------------------I-----I                       I        I  I
                                                                                              I        I  I
Proceraea cornuta               -----I                                                        I        I  I
Nephtys caeca                   --I  I-----------------------I                                I        I  I
Clymenella torquata             --I--I                       I          D′                    I--I     I  I
Lyonsia arenosa                 --------------I              I-----------------I              I  I     I  I
Cancer irroratus                --------------I--------------I                 I              I  I     I  I
                                                                               I              I  I     I  I
Exogone hebes                   -----I                                         I              I  I     I  I
Dipolydora quadrilobata         -----I-----------------I                       I              I  I     I  I
Dipolydora socialis             --------I              I-----------I           I--------------I  I     I  I
Prionospio steenstrupi          --------I--------------I           I           I                 I     I  I
Spiophanes bombyx               --I                                I     D″    I                 I-----I  I
Polygordius sp. A               --I-----------I                    I-----------I                 I        I
Monticellina dorsobranchialis   --------------I--------I           I                             I        I
Tellina agilis                  --I                    I-----------I                             I        I
Arctica islandica               --I--------------------I                                         I        I
                                                                                                          I
Streblospio benedicti           -----------------------I                                         I        I
Ensis directus                  -----------------------I-----I            E                      I        I
Ilyanassa trivittata            -----------------------------I-----------------------------------I        I
                                                                          F                               I
Capitella capitata complex      --------------------------------------------------------------------------I
                                0.91        0.73           0.51           0.29           0.07           -.16
```

Figure 5-5. Species group dendrogram of 1999 Harbor infaunal data based on the 50 species with > 30 % occurrence at the T stations (all three replicates from each station summed, Gallagher's CNESS dissimilarity, and UMPGA sorting).



Constancy

	Ia	Ib	IIa	IIb	IIIa	IIIb	IV	Dominant Species
A'	0.6	0.0	0.8	0.8	1.0	0.9	0.0	*Tubificoides apectinatus/Mediomastus californiensis*
A''	0.5	0.0	0.3	0.5	0.9	0.7	0.0	*Phyllodoce mucosa/Chaetozone vivipara*
B'	0.6	0.2	0.5	0.9	0.7	0.4	0.2	*Polydora cornuta/Mya arenaria*
B"	0.6	0.2	0.6	1.0	0.6	0.8	0.0	*Ampelisca* spp./*Phoxocephalus holbolli*
C'	0.9	0.3	0.8	0.8	0.6	0.8	0.0	*Tubificoides* nr. *pseudogaster/Microphthalmus aberrans*
C"	0.7	0.0	0.9	0.7	0.2	0.7	0.0	*Aricidea catherinae/Nephtys cornuta*
D'	0.7	0.0	0.1	0.5	0.7	0.7	0.0	*Nephtys caeca/Lyonsia arenosa*
D"	0.7	0.0	0.1	0.5	0.7	0.7	0.0	*Polygordius* sp. A/*Spiophanes bombyx*
E	0.9	1.0	0.9	0.8	1.0	0.5	0.0	*Ilyanassa trivittata/Streblospio benedicti*
F	1.0	0.0	1.0	1.0	1.0	1.0	1.0	*Capitella capitata* complex

0-0.4 ⬜ 0.5-0.6 🟨 0.7-0.8 🟧 0.9-1.0 🟫

Fidelity

	Ia	Ib	IIa	IIb	IIIa	IIIb	IV	Dominant Species
A'	0.8	0.0	1.2	1.1	1.5	1.3	0.0	*Tubificoides apectinatus/Mediomastus californiensis*
A''	1.0	0.0	0.7	1.1	1.9	1.4	0.0	*Phyllodoce mucosa/Chaetozone vivipara*
B'	1.0	0.3	0.8	1.5	1.2	0.7	0.3	*Polydora cornuta/Mya arenaria*
B"	0.8	0.3	0.9	1.5	0.9	1.3	0.0	*Ampelisca* spp./*Phoxocephalus holbolli*
C'	1.4	0.5	1.1	1.1	0.8	1.1	0.0	*Tubificoides* nr. *pseudogaster/Microphthalmus aberrans*
C"	1.3	0.0	1.5	1.1	0.3	1.2	0.0	*Aricidea catherinae/Nephtys cornuta*
D'	1.6	0.0	0.3	1.0	1.6	1.6	0.0	*Nephtys caeca/Lyonsia arenosa*
D"	1.6	0.0	0.3	1.0	1.6	1.6	0.0	*Polygordius* sp. A/*Spiophanes bombyx*
E	1.1	1.3	1.1	1.1	1.3	0.6	0.0	*Ilyanassa trivittata/Streblospio benedicti*
F	1.1	0.0	1.1	1.1	1.1	1.1	1.1	*Capitella capitata* complex

0.0-0.6 ⬜ 0.7-1.0 🟨 1.1-1.6 🟧 >1.6 🟫

Figure 5-6. Nodal constancy and fidelity between 1999 Harbor stations and species groups derived from cluster analysis of infaunal data with all replicates summed.

Table 5-7. Abundance (individuals/0.12 m^2) for 1999 Harbor infaunal taxa with > 30 % occurrence at the T stations arranged by species cluster groupings.

		Total	Total			Station Group Mean				
Group	**Species**	**Abund.**	**Occur.**	**Ia**	**Ib**	**IIa**	**IIb**	**IIIa**	**IIIb**	**IV**
A'	Turbellaria spp.	35	6	0	0	3	2	7	2	0
	Nemertea sp. 2	278	12	9	0	25	2	68	17	0
	Mediomastus californiensis	282	14	12	0	8	32	30	17	0
	Tubificoides apectinatus	9876	12	1	0	839	1278	977	145	0
A"	*Phyllodoce mucosa*	1484	10	8	0	0	324	69	14	0
	Eteone longa	95	6	0	0	0	20	6	1	0
	Nephtys ciliata	107	7	12	0	0	2	30	1	0
	Chaetozone vivipara	363	6	22	0	0	0	148	0	0
	Edotia triloba	288	11	0	0	1	12	116	3	0
	Pygospio elegans	38	7	1	0	0	0	15	2	0
B'	*Polydora cornuta*	7758	15	271	3	117	1470	352	1	10
	Cerastoderma pinnulatum	68	6	1	0	0	16	1	0	0
	Petricola pholadiformis	185	7	0	0	0	44	1	4	0
	Mya arenaria	567	12	2	0	7	129	9	5	0
	Hiatella arctica	40	7	1	0	0	9	1	0	0
B"	*Ampelisca* spp.	46960	15	97	4	114	11550	33	30	0
	Photis pollex	3282	13	1	0	2	778	36	45	0
	Phoxocephalus holbolli	4289	10	1	0	1	1068	2	6	0
	Crassicorophium bonelli	711	6	0	0	0	177	0	1	0
	Orchomenella minuta	330	7	0	0	1	81	1	2	0
	Unciola irrorata	3305	12	11	0	7	763	88	13	0
C'	*Pholoe minuta*	69	12	8	0	2	8	1	4	0
	Polycirrus phosphoreus	125	7	35	0	4	1	2	0	0
	Leptocheirus pinguis	1100	13	102	0	8	191	2	2	0
	Microphthalmus aberrans	1334	14	305	1	42	49	25	24	0
	Pherusa affinis	18	6	1	0	0	3	0	1	0
	Tubificoides nr. *pseudogaster*	14605	15	560	2	84	2794	244	505	0
C"	*Nephtys cornuta*	993	6	32	0	296	2	0	0	0
	Ninoe nigripes	109	12	12	0	15	5	0	4	0
	Scoletoma hebes	396	8	18	0	42	22	0	64	0
	Aricidea catherinae	7779	14	108	0	168	1221	42	993	0
	Leitoscoloplos robustus	9	6	0	0	1	1	0	1	0
D'	*Proceraea cornuta*	15	6	2	0	0	1	1	1	0
	Nephtys caeca	113	7	22	0	0	0	13	11	0
	Clymenella torquata	65	9	10	0	1	1	5	11	0
	Lyonsia arenosa	110	7	7	0	1	17	2	8	0
	Cancer irroratus	21	7	1	0	0	4	1	1	0
D"	*Exogone hebes*	350	11	25	0	0	3	6	126	0
	Dipolydora quadrilobata	24	8	2	0	0	2	0	6	0
	Dipolydora socialis	412	13	15	0	17	39	15	64	0
	Prionospio steenstrupi	544	14	16	0	13	52	26	99	0
	Spiophanes bombyx	1913	9	33	0	1	0	207	699	0
	Polygordius sp. A	2089	10	3	0	5	1	150	882	0
	Monticellina dorsobranchialis	21	6	0	0	0	2	1	6	0
	Tellina agilis	433	14	17	0	5	31	35	87	0
	Arctica islandica	74	10	1	0	1	6	3	19	0
E	*Streblospio benedicti*	1269	12	212	302	98	8	4	0	0
	Ensis directus	81	11	4	7	7	3	5	10	0
	Ilyanassa trivittata	1550	15	86	36	14	150	176	132	0
F	*Capitella capitata* complex	334	15	9	0	7	9	39	11	151
*	*Nucula delphinodonta*	917	4	0	0	34	122	0	87	153
	Cirriformia grandis	231	1	0	0	77	0	0	0	0
	Tubificoides benedeni	204	4	0	0	62	0	9	0	0

* Species not included in cluster analysis because of low occurrence, but with total abundance >200

of the top ten numerical dominant species, and the species responsible for the creating most of the sediment surface biogenic structures. Subgroup B' was composed of four bivalves and the small tube-building polychaete *Polydora cornuta*, the fifth most abundant species. Subgroup B" was composed of six amphipods, four of which were among the top ten numerical dominants including the tube-building *Ampelisca* spp. Group C was mostly polychaete species that tended to be more abundant in station groups Ia and IIa, but also contained two numerical dominants, the oligochaete *Tubificoides* nr. *pseudogaster* and the polychaete *Aricidea catherinae* that were also abundant in groups IIb and III (Table 5-7). Group D was mostly low to moderate density species that preferred sandy sediments, but also contained two of the top ten dominants the polychaetes *Polygordius* sp. A (a meiofaunal species that lives in the interstial spaces between sand grains) and *Spiophanes bombyx*.

5.2.3 Comparison of 1999 Descriptive Community Measures to Previous Years

Abundance—In general, infaunal abundances in the Harbor were much lower in 1999 than they have been in recent years. Abundances in August 1999 were much lower than their 1998 counterparts at stations T01, T04, T05A, T07, and T08 (Figure 5-7). Stations T01 and T05A, both off Deer Island, have shown a very similar August trend since 1995, beginning with a decrease in abundance from 1995 to 1996 followed by a large increase in 1997, then a steady decline from 1997 to 1999. The dramatic change at station T04 from August 1998 to 1999 was largely related to the very high numbers of Capitella there in 1998 followed by its disappearance by August 1999. August abundances at three stations have been relatively constant since 1996 (T02, T06) or since 1997 (T03). Changes in April infaunal abundance values were not necessarily parallel to August changes. Correlation analysis showed that there was no significant relationship between infaunal abundance in April and that of the following August for any of the Harbor stations (range from – 0.26 at station T05A to 0.52 at station T03; all $n = 8$, $p > 0.05$).

Although somewhat “busy,” one plot showing mean infaunal abundance at all stations for all surveys allows one to observe the differences among surveys within each station and the differences among stations. This figure (Figure 5-8) points out the large, sudden increases in abundance that occurred immediately after the cessation of sludge discharge (stations T01, T02, T05A) and the lack of such a response at other stations (*e.g.*, T03, T07, T08). Also noticeable are the sudden, large increases in abundance at station T02 in August 1994 and 1995 followed by the drop to levels similar to what they were in 1992–1993. Large-scale seasonal cycling is noticeable for stations T01, T03, T05A (to a certain extent), and T06. Differences among stations in the magnitude of the cycling are readily apparent.

Numbers of Species—The 1999 samples showed no major differences from those collected in previous years in the numbers of species per station (Figure 5-9). Species numbers at most stations were within the general range found for the past 6–7 years. Species numbers for August samples have declined somewhat since 1997 (T01, T05A) or 1998 (T02, T07, T08), but the 1999 values were within the range of variation observed for August samples of the earlier years of the study. Species numbers in 1999 at the remaining three stations were similar to those in 1998.

The plot showing mean numbers of species for all stations and surveys (Figure 5-8) highlights strong, virtually straight-line, increases in species numbers from September 1991 to August 1992 at stations T01, T02, T03, T05A, and T06, followed by more typical, somewhat seasonal cycling since. Also apparent is that species numbers at many stations are now much higher than they were in 1991.

Diversity—Species diversity, as measured by log-series alpha, in 1999 was very similar to the general range of values reported previously for each station (Figure 5-10), although there were some relatively minor differences from 1998 values.

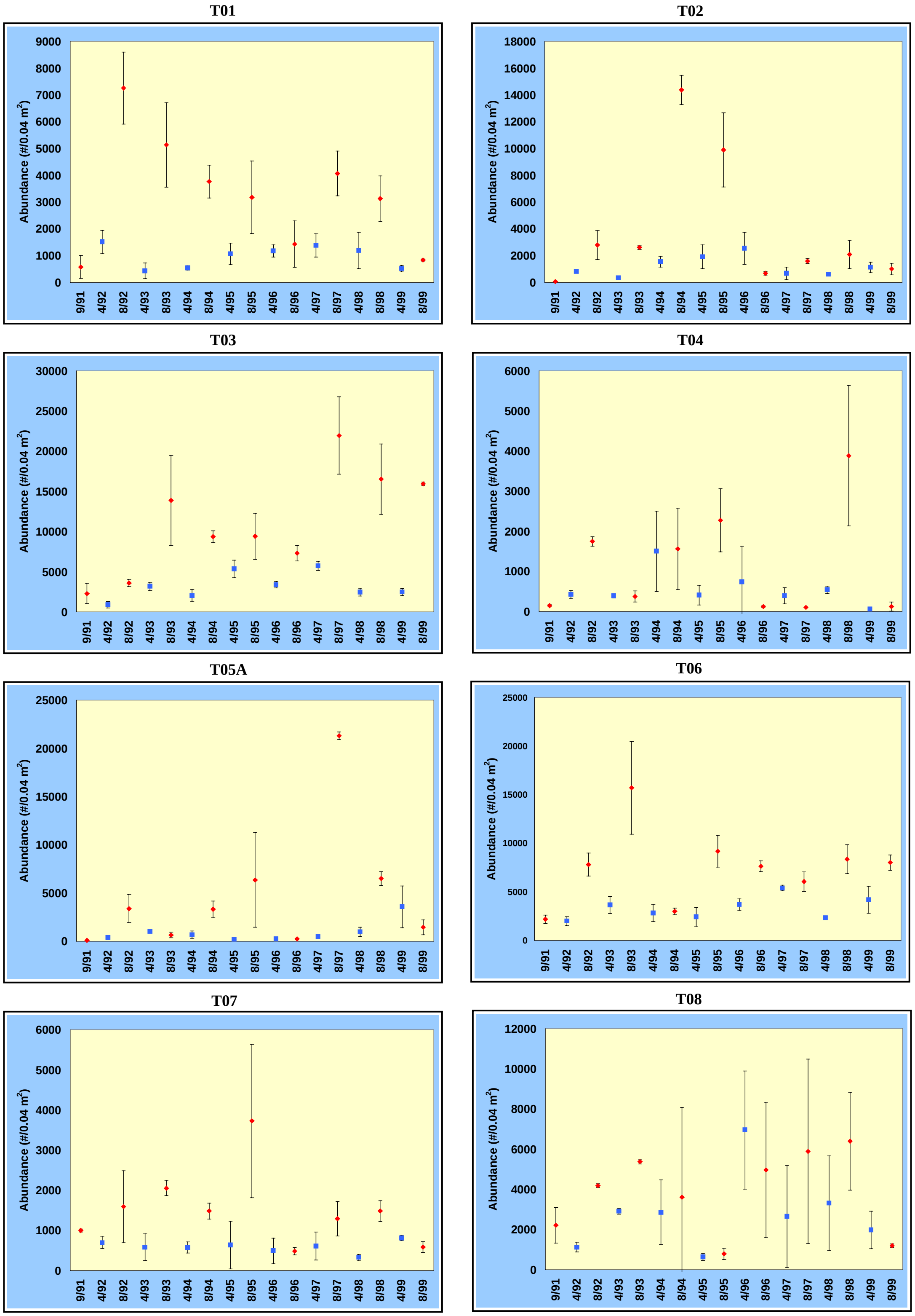


Figure 5-7. Mean (and standard deviation) infaunal abundance per sample (0.04 m^{-2}) for Boston Harbor stations sampled from 1991 to 1999.

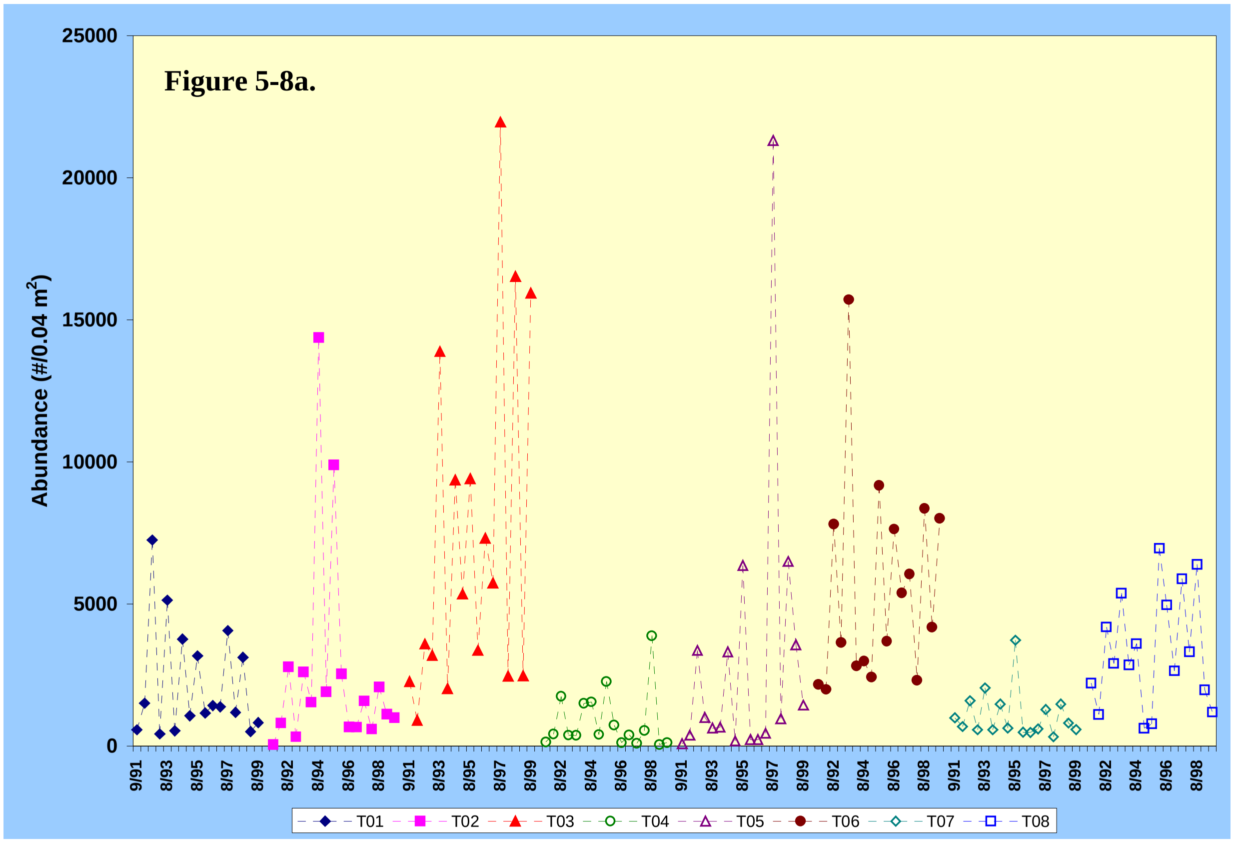


Figure 5-8a.

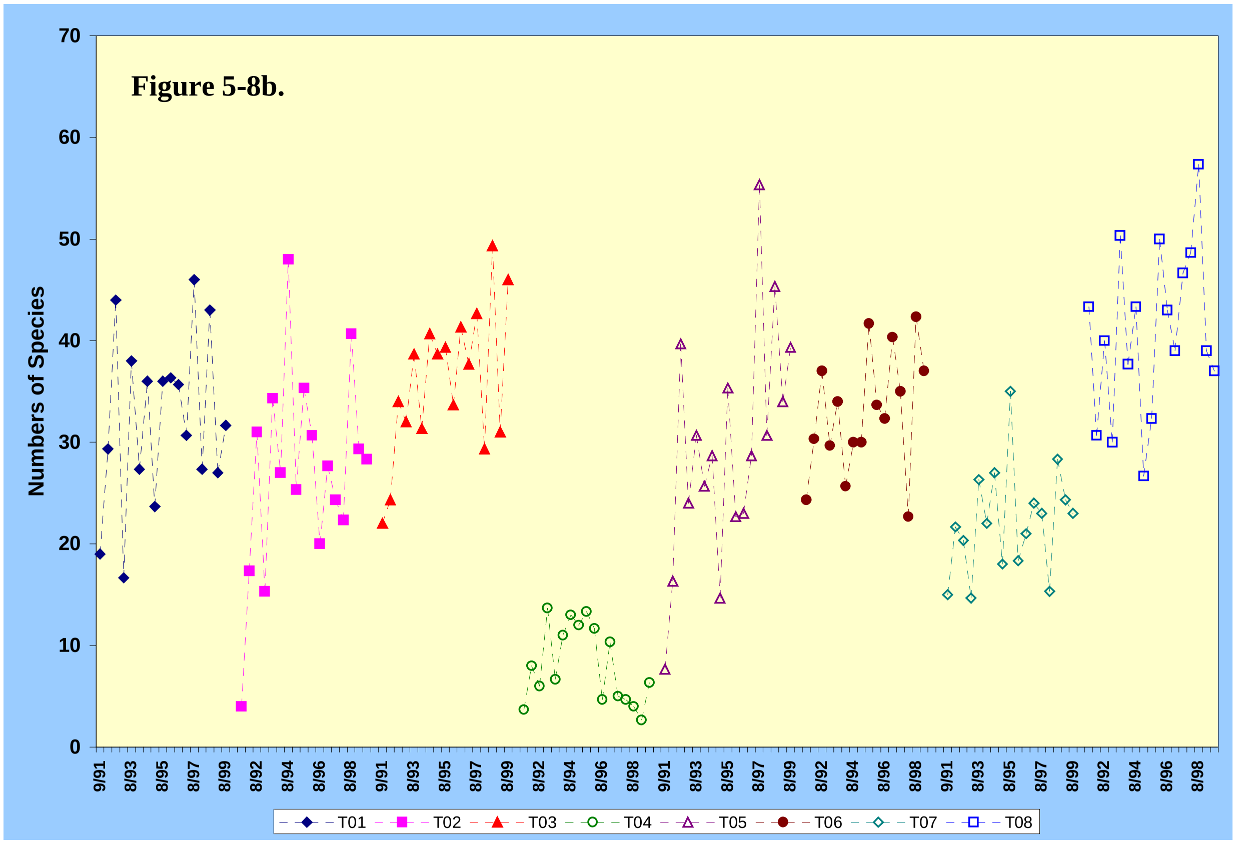


Figure 5-8b.

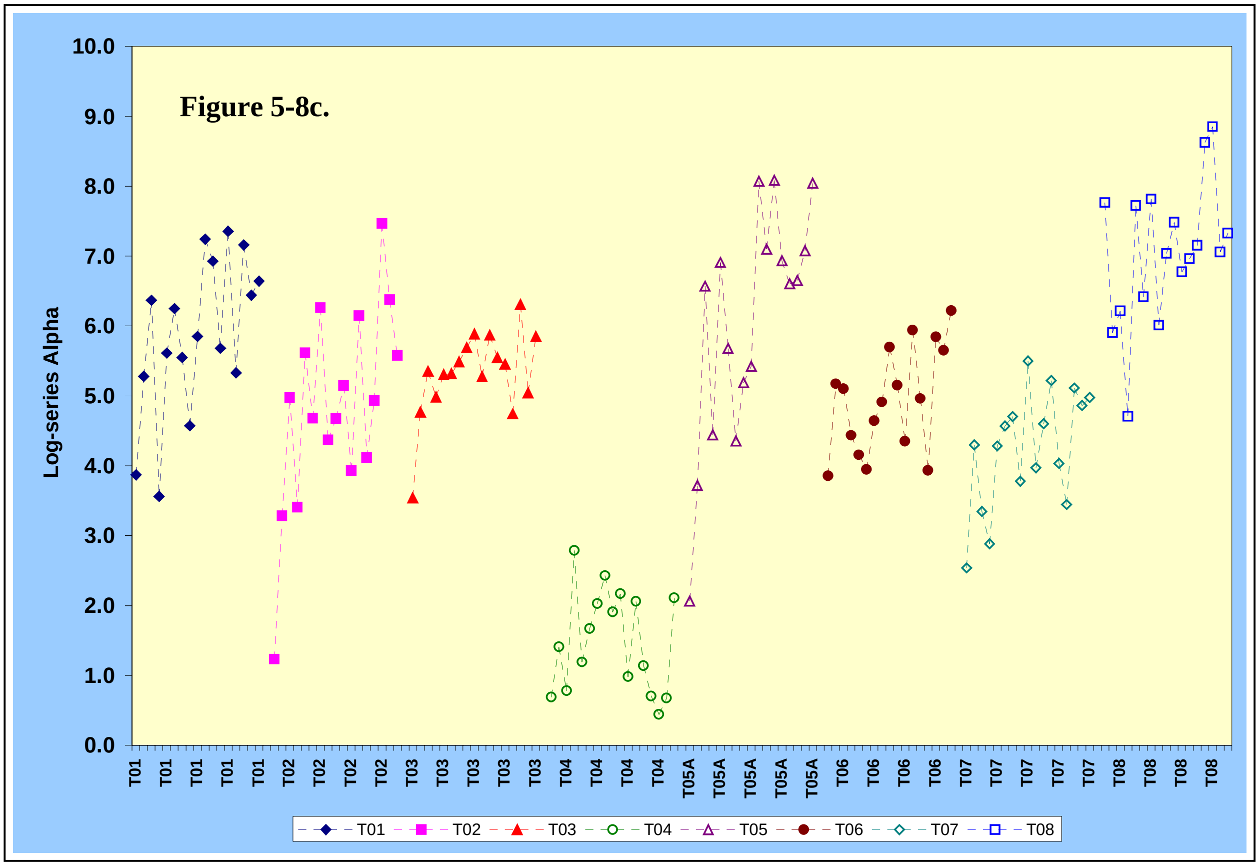


Figure 5-8. Mean abundance (a), numbers of species (b), and log-series alpha (c) for each station and survey. All surveys are not labeled on the X-axis. Survey dates are not shown, but data points are sequential from September 1991 to August 1999 for each station.

The overall plot for log-series alpha (Figure 5-8) shows trends similar to those in the species numbers plot. Stations T01, T02, T03, T05A, and T06 showed an increase in diversity from 1991 to August 1992 similar to that shown for species numbers. It is also noticeable that diversity has remained much higher, but with some fluctuation, at these stations, and at station T07, since 1992. Overall diversity has not changed much since 1991, although there has been considerable fluctuation in the interim.

5.2.4 Comparison of 1999 Multivariate Community Analysis to Previous Years

Over the years, oligochaetes have consistently occurred at all T-stations, most of the time being numerical dominants. However, oligochaetes from Summer 1991 and Spring 1992 collections were not identified to species until this year. To accommodate this difference in taxonomic treatment between collections, the long-term multivariate analysis often was done with a dataset that had all oligochaetes summed to a single "species." The primary analysis for this report included all oligochaetes identified to species, but for comparison was supplemented with an analysis for which oligochaete species were summed. First we present the overall station and species patterns based on the primary analysis, then we describe the major differences in the patterns revealed by the two analyses.

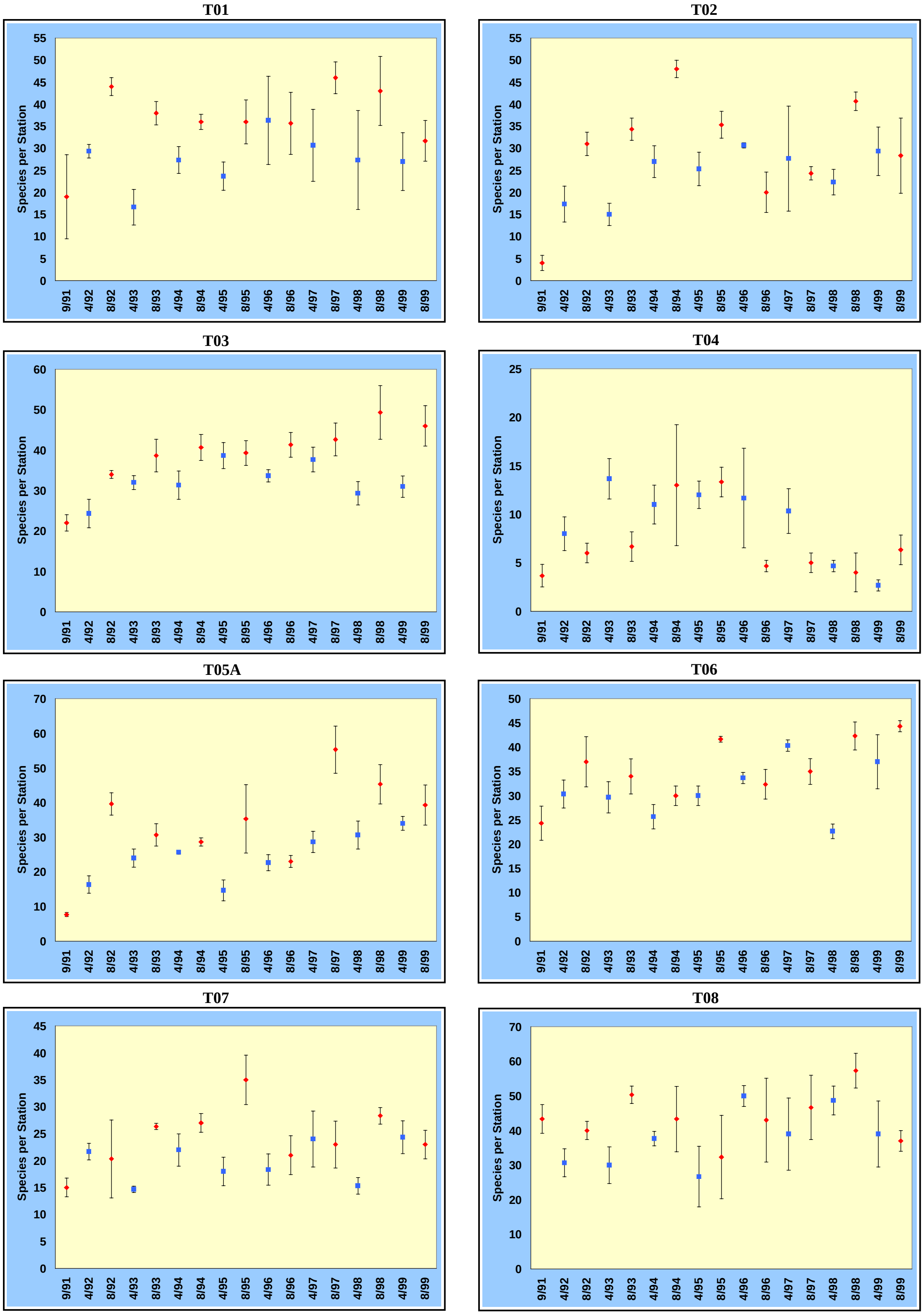


Figure 5-9. Mean (and standard deviation) infaunal species per sample (0.04 m^{-2}) for Boston Harbor stations sampled from 1991 to 1999.

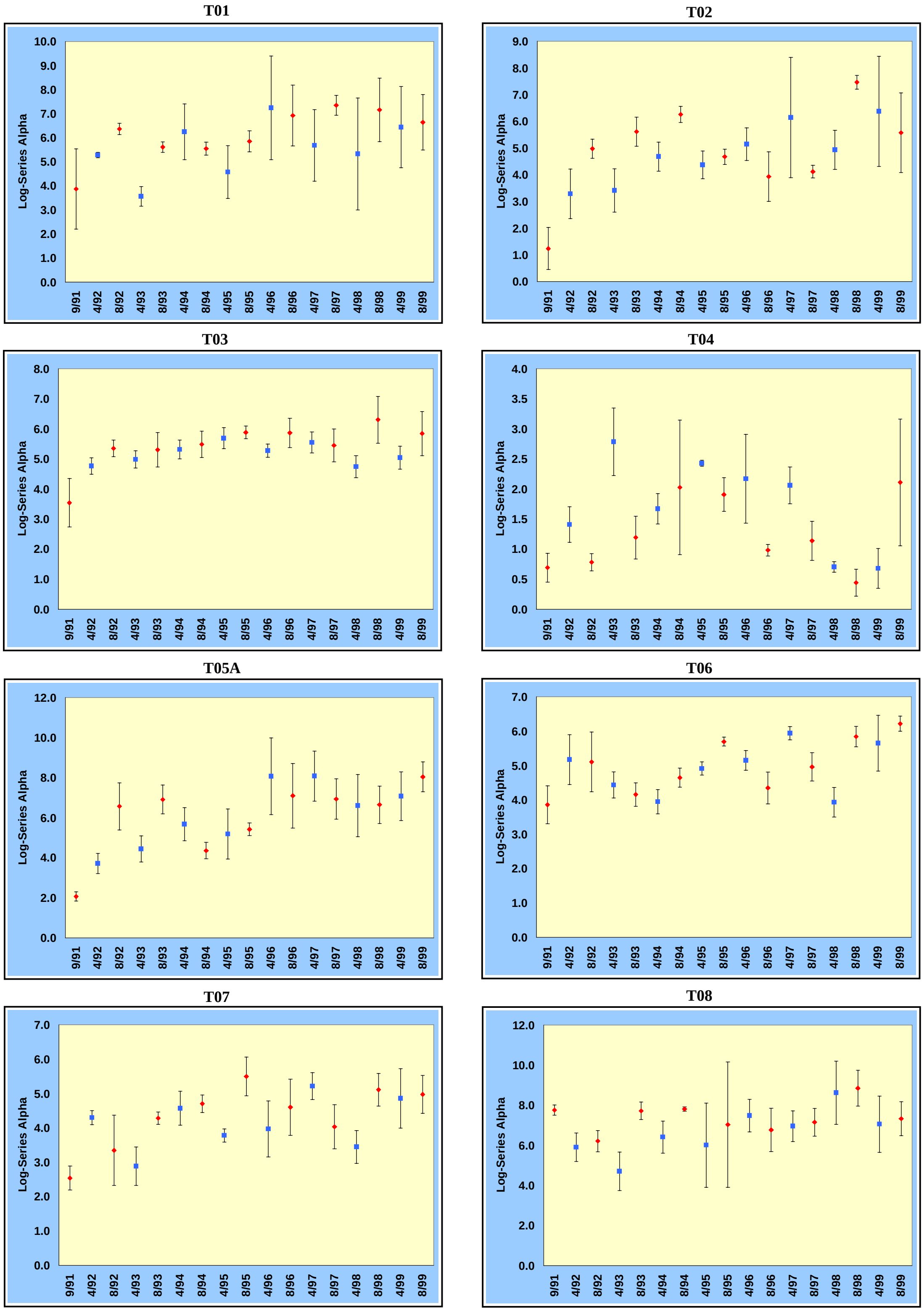


Figure 5-10. Mean (and standard deviation) infaunal log-series alpha per sample (0.04 m^{-2}) for Boston Harbor stations sampled from 1991 to 1999.

Station patterns—Patterns in infaunal communities over the Summer 1991 to 1999 study period, including all oligochaetes as species, primarily indicated strong within-station similarity and little evidence of temporal trends. At the eight group level three stations formed exclusive or near exclusive groups [T04 in inner Dorchester Bay (station group II), T08 in Hingham Bay (VII), and T05A in President Roads (IV and VIII)] that represented Spring and Summer conditions for these stations over much of the eight-year period (Figure 5-11). Station group I represented long-term conditions at T01 and T02 on Deer Island Flats. Group V was all collections at T03 (except Summer 1991) located off Long Island and T06 located off Peddocks Island. Group VI was primarily Station T07 in Quincy Bay, and three Summer 1997 stations (T01, T02, and T04) and one Spring 1999 station (T02). Over the eight-year period, Stations T03, T06, T07, and T08 maintained a high degree of within-station similarity with all 15 sampling periods (except Summer 1991, T03) within the same cluster group.

The largest seasonal signal, Spring to Summer, was identified at Station T05A where group IV primarily represented Spring conditions from 1993 to 1999 and group VIII Summer conditions from 1994 to 1999 (excluding 1996). Only Summer 1993 and 1996 for Station T05A were included with the Spring group VII (Figure 5-11). Samples collected at the original Station T05, or Station T05A in Spring 1992, were in group III along with many samples from Station T04. Station T04 was the most variable of all the T-stations through time. It was usually a member of two groups that primarily represented conditions for Summers from 1991 to 1995 and 1999 and Spring 1995 (group II), and for Spring 1992–1994, Spring 1997–1999, and Summer 1998 (group III).

Patterns in infaunal communities over the Summer 1991–1999 study period, when all oligochaete species were summed to a single taxon, showed three major differences with those just presented (Figure 5-12).

- There was increased consistency in the clustering of samples from Station T02, and to a lesser degree, Stations T01 and T03. When oligochaete species were not considered, samples from Station T02 belonged to five cluster groups. When oligochaete species were identified, 15 of 17 samples from Station T02 comprised a group that also included 16 of 17 samples from Station T01. The three samples that “misclassified” (T02, Summer 1997 and Spring 1999; T01, Summer 1997) were characterized by relatively high abundances of *Tubificoides apectinatus*, a species not typically abundant at those two stations.
- Station T07 shifted alignment significantly. When oligochaetes were not identified to species, all Station T07 samples were most similar to those from the northern part of the Harbor (*i.e.*, Stations T01 and T02). However, with oligochaete species distinguished, Station T07 was most similar to Stations T03, T06, and T08, and was quite distinct from Stations T01 and T02.
- When oligochaetes were identified to species, the Spring 1992 samples from Station T03 aligned with all samples from the station collected since and comprised a cluster group that also included all samples from Station T06. The Summer 1991 (*i.e.*, collected before sludge discharge cessation) samples aligned with “Spring” group of samples from Station T05A.

Year and Season

Cluster Group	Stat	91 Sum	92 Spr	92 Sum	93 Spr	93 Sum	94 Spr	94 Sum	95 Spr	95 Sum	96 Spr	96 Sum	97 Spr	97 Sum	98 Spr	98 Sum	99 Spr	99 Sum
I	T01	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X
I	T02	X	X	X	X	X	X	X	X	X	X	X	X		X	X		X
I	T04										X	X						
II	T04	X		X		X		X	X	X								X
III	T04		X		X		X						X		X	X	X	
III	T05	X		X														
III	T05A		X															
IV	T03	X																
IV	T05A				X	X	X		X		X	X	X		X		X	
V	T03		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
V	T06	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
VI	T01													X				
VI	T02													X			X	
VI	T04													X				
VI	T07	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	*X*
VII	T08	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
VIII	T05A							X		X				X		X		X

```
Cluster Group

I        --------------I
                       I
                       I-----I
II       --------------I     I
                             I
                             I-----I
                             I     I
III      --------------------I     I
                                   I-----I
                                   I     I
IV       -----------------------I  I     I
                                I  I     I
                                I  I     I
V        -----------------I     I  I     I
                          I     I  I     I
                          I--I  I--I     I
                          I  I  I        I
                          I  I--I        I
VI       -----------------I  I           I
                             I           I
VII      --------------------I           I
                                         I
VIII     --------------------------------I

         0.8            0.9            1.0
```

Figure 5-11. Station group dendrogram of Summer 1991–1999 Harbor data with oligochaetes identified to species, replicates summed for each station (Gallagher's CNESS dissimilarity and UMPGA sorting). All taxa included. X indicates the stations included in the cluster groups for each of the seasons and years.

Year and Season

Cluster Group	Stat	91 Sum	92 Spr	92 Sum	93 Spr	93 Sum	94 Spr	94 Sum	95 Spr	95 Sum	96 Spr	96 Sum	97 Spr	97 Sum	98 Spr	98 Sum	99 Spr	99 Sum
I	T01	X	X	X	X	X		X	X	X	X	X		X	X	X	X	X
I	T02			X		X		X		X	X	X			X	X		X
II	T01												X					
II	T02													X				
II	T03	X	X															
II	T05A				X													
II	T07	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
III	T01						X											
III	T02				X		X		X				X					
IV	T02	X															X	
IV	T04	X		X		X		X	X	X		X		X				X
V	T02		X															
V	T04		X		X		X				X		X				X	
V	T05			X														
VI	T05	X																
VI	T05A		X			X	X		X		X	X	X		X		X	
VII	T03			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
VII	T06	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
VIII	T08	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
IX	T05A							X		X				X		X		X
X	T04														X	X		

```
Cluster Group
I       ----------I
                  I
                  I
                  I--I
                  I  I
                  I  I
II      ----------I  I-----I
                     I     I
                     I     I
III     -------------I     I
                           I
                           I-----I
IV      -------------------I     I
                           I     I
                           I     I
                           I     I
V       -------------------I     I
                                 I
                                 I-------------I
VI      -------------------------I             I
                                 I             I
                                 I             I
VII     ----------I              I             I
                  I---I          I             I
VIII    ----------I   I          I             I
                      I----------I             I
IX      --------------I                        I
                                               I
X       ---------------------------------------I
                 0.8           1.05           1.3
```

Figure 5-12. Station group dendrogram of Summer 1991–1999 Harbor data with all oligochaete species summed to make one taxa, replicates summed for each station (Gallagher's CNESS dissimilarity and UMPGA sorting). All taxa included. X indicates the inclusion of the station in the cluster groups for each of the seasons and years.

Temporally the first two infaunal collections at Harbor T-stations in Summer 1991 and Spring 1992 were not distinct from subsequent years in the summed oligochaete cluster analysis. 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 sludge discharge abatement at the Long Island and Deer Island outfalls, was not obvious in the time series. Analyses with and without oligochaete species indicated that the infaunal community patterns at the T-stations were not dominated by temporal trends. Within-station community patterns remained similar over this period at the majority of the stations (T01, T02, T03, T06, T07, and T08). Station T05A located in the outer Harbor in President Roads was the only station to exhibited strong seasonal (Spring to Summer) trends in both analyses. Station T04 in inner Dorchester Bay had similar seasonal trends in the summed oligochaete analysis.

Species Patterns—Species cluster analysis of the 1991 to 1999 Harbor data was done on a reduced set of data that included only the top dominant taxa (total abundance >1500 or >30% occurrences at the station-season-year combinations). About 250 species occurred at the Harbor T-stations over the nine-year period, 53 of which were included in the summed oligochaete analysis and 55 in the analysis with oligochaetes to species.

In the summed oligochaete analysis at the eight group level species formed into three distinct clusters, about 0.0 CNESS dissimilarity (Figure 5-13). The first cluster was group A, the most distinct species group, with three taxa and dominated by the two opportunistic polychaetes, *Streblospio benedicti* and *Capitella capitata* complex (Table 5-8). Group A was broadly distributed with moderate to high constancy with and little fidelity to all the stations groups, but was the only species group to not show avoidance to station groups IV (primarily T04 in the Summer), V (primarily T04 in the Spring), and X (T04 in 1998, Figure 5-13). The second cluster was groups B and C which contained many of the more important bioturbating and biogenic structure creating taxa. Group B was all polychaetes and dominated by *Polydora cornuta*, a small sediment surface deposit feeder that constructs a thin fine-sediment tube and *Clymenella torquata*, a large tube-building head-down deposit feeder that likely created many of the oxic voids seen in the SPI images (Section 3). Group C was almost all amphipods and included many tube-building taxa, including the dominants *Ampelisca* spp. and *Crassicorophium bonelli*. Group B had highest constancy with and fidelity to station groups I, VII, and IX (primarily Stations T01, T03, and T06 both seasons, and T02 and T05A in the Summer) and tended to avoided groups IV, V, and VI (primarily T05A in the Spring and T04). Group C was similar in pattern to group B but was also closely associated with group VIII (Station T08) (Figure 5-14).

The third cluster was the largest and included the remaining species groups, D to H. Group D was dominated by oligochaetes and the polychaete *Aricidea catherinae* and while broadly distributed had its highest occurrence at station groups I, II, VII, and VIII. Group E dominated by the polychaetes *Tharyx acutus* and *Dipolydora socialis* was most strongly associated with groups III and IX. Group F represented many of the sandy species and was dominated by the polychaete *Spiophanes bombyx* and bivalve *Nucula delphinodonta* had the highest fidelity of all species groups with groups VIII, and IX. Group G dominated by the gastropod *Ilyanassa trivittata* and the isopod *Edotia triloba* was most strongly associated with group IX. Group H dominated by the polychaetes *Chaetozone vivipara* and *Mediomastus californiensis* was also most strongly associated with group IX (Figure 5-14).

Table 5-8. Percent of total and average abundance (individuals/0.12 m^2) for 1991–1999 Harbor infaunal taxa with > 30 % occurrence at the T stations arranged by species cluster groupings.

Species Group	Taxa	Percent of total											Average by group									
		I	II	III	IV	V	VI	VII	VIII	IX	X		I	II	III	IV	V	VI	VII	VIII	IX	X
A	TURBELLARIA SPP.	13	10	1	27	12	5	9	22	1	0		3	2	1	12	7	3	1	6	1	0
	STREBLOSPIO BENEDICTI	48	13	3	28	7	0	0	0	0	0		1500	437	442	1939	684	6	8	1	13	4
	CAPITELLA CAPITATA COMPLEX	4	1	1	0	32	4	2	2	0	54		44	9	38	6	960	94	13	26	14	6442
B	*PHOLOE MINUTA*	69	7	2	0	0	0	10	7	4	0		42	4	4	0	1	1	5	6	12	0
	POLYDORA CORNUTA	31	3	0	0	0	0	41	1	23	0		2365	260	14	5	87	9	2398	161	8483	3
	PHERUSA AFFINIS	39	4	0	0	1	0	40	10	7	0		3	0	0	0	0	0	2	1	2	0
	CLYMENELLA TORQUATA	85	0	1	0	0	0	1	12	0	0		162	1	9	0	0	0	1	33	2	0
	ETEONE LONGA	46	4	0	1	6	1	30	2	10	0		23	2	1	1	9	1	11	1	25	1
	SPIO THULINI	34	2	0	0	13	0	40	10	1	0		38	2	2	0	44	0	34	15	7	0
	NEANTHES VIRENS	25	6	2	1	8	1	50	5	1	0		4	1	2	0	4	0	6	1	1	0
	ASABELLIDES OCULATA	64	7	5	1	1	0	16	5	1	0		35	4	12	1	2	0	7	4	2	0
C	*PHYLLODOCE MUCOSA*	18	0	0	0	0	0	55	18	8	0		62	1	5	0	2	2	143	86	126	0
	UNCIOLA IRRORATA	3	0	0	0	0	0	63	5	28	0		36	5	2	0	1	4	487	68	1395	0
	PHYLLODOCE MACULATA	16	0	0	0	0	0	76	7	1	0		6	0	0	0	0	0	20	4	1	0
	AMPELISCA SPP.	8	4	1	0	0	0	58	16	13	0		1238	660	494	15	5	57	6667	3567	9204	0
	PHOTIS POLLEX	5	0	1	0	0	0	80	3	9	0		37	3	39	1	1	8	431	34	313	0
	PHOXOCEPHALUS HOLBOLLI	0	0	0	0	1	0	94	3	1	0		4	6	0	0	33	1	780	49	53	0
	LEPTOCHEIRUS PINGUIS	6	3	0	0	0	0	78	6	6	0		63	33	6	1	0	1	632	98	320	0
	CRASSICOROPHIUM BONELLI	1	0	0	0	0	0	98	1	0	0		10	0	1	0	1	0	1081	11	28	1
	CANCER IRRORATUS	14	4	0	1	2	0	66	9	4	0		2	1	0	0	1	0	8	2	3	0
D	*MICROPHTHALMUS ABERRANS*	62	14	4	0	2	1	13	4	1	0		190	48	61	2	16	4	30	16	9	2
	NINOE NIGRIPES	26	19	4	3	0	0	37	10	0	0		6	5	5	2	0	0	7	4	0	0
	OLIGOCHAETA SPP.	17	11	2	1	3	2	53	9	1	0		1298	953	737	156	794	423	3002	1005	319	2
	NEPHTYS CORNUTA	16	76	1	6	0	0	1	0	1	0		20	104	5	15	0	0	1	0	3	0
	SCOLETOMA HEBES	5	16	0	0	0	0	24	55	0	0		8	26	0	0	0	0	27	119	0	0
	ARICIDEA CATHERINAE	2	12	0	0	0	0	49	36	0	0		80	493	4	5	3	41	1396	1900	39	0
E	*PROCERAEA CORNUTA*	59	2	3	3	11	0	10	10	1	0		6	0	1	1	4	0	1	2	1	1
	ISCHYROCERUS ANGUIPES	19	1	9	0	4	11	19	32	5	0		3	0	6	0	2	4	2	6	3	0

Table 5–8. **Percent of total and average abundance (individuals/0.12 m^2) for 1991–1999 Harbor infaunal taxa with > 30 % occurrence at** the **T stations arranged by species cluster groupings. (continued)**

Species Group	**Taxa**	**Percent of total**										**Average by group**									
		I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**
	HIATELLA ARCTICA	5	0	2	0	1	0	37	10	44	0	2	0	3	0	1	0	9	5	69	0
	ORCHOMENELLA MINUTA	1	0	3	0	0	0	70	8	17	0	1	0	16	0	0	1	60	14	95	0
	DIPOLYDORA SOCIALIS	37	10	7	1	2	3	22	17	1	0	34	10	32	3	4	8	15	22	2	0
	DIPOLYDORA QUADRILOBATA	28	12	17	0	3	2	21	16	0	0	9	4	26	0	3	1	5	7	0	0
	SPIO LIMICOLA	12	6	34	0	2	25	18	1	3	0	7	4	96	1	3	35	8	1	8	0
	THARYX ACUTUS	30	10	7	0	1	3	45	4	1	0	392	138	461	2	22	85	452	73	70	0
F	*EXOGONE HEBES*	7	1	0	0	0	1	1	90	1	0	14	2	0	0	1	3	1	259	5	0
	POLYGORDIUS SP. A	0	0	0	0	0	2	0	87	10	0	1	0	0	1	0	14	1	414	161	0
	SPIOPHANES BOMBYX	2	0	0	0	0	1	0	91	6	0	9	0	1	0	0	12	0	575	128	0
	NUCULA DELPHINODONTA	0	0	0	0	0	0	12	88	0	0	0	0	0	0	0	1	41	546	0	0
	PYGOSPIO ELEGANS	13	6	1	0	0	4	2	67	7	0	4	2	2	0	0	3	0	29	10	0
	PRIONOSPIO STEENSTRUPI	9	3	0	1	0	1	27	52	5	0	9	3	1	2	1	3	19	68	22	0
	CERASTODERMA PINNULATUM	5	1	0	0	0	1	47	29	18	0	1	0	0	0	0	0	4	4	9	0
G	*NEPHTYS CAECA*	34	4	6	0	0	10	7	15	25	0	20	3	16	0	0	13	3	12	68	0
	EDOTIA TRILOBA	5	1	0	0	0	9	19	7	59	0	11	2	1	0	1	44	31	21	606	0
	DIASTYLIS SCULPTA	4	5	3	0	0	17	22	35	14	0	1	1	3	0	0	9	4	11	15	0
	ILYANASSA TRIVITTATA	16	6	1	0	1	11	25	21	14	4	61	27	17	4	11	97	71	113	258	170
	TELLINA AGILIS	11	9	1	0	2	10	16	41	9	0	17	15	6	1	8	38	18	86	61	1
	PETRICOLA PHOLADIFORMIS	5	0	0	0	0	2	79	11	2	0	2	0	0	0	0	2	24	6	5	1
	ENSIS DIRECTUS	13	34	0	3	1	6	4	29	8	0	3	8	0	1	1	3	1	9	9	1
	MYA ARENARIA	16	18	10	2	1	5	45	2	2	0	11	13	33	3	2	8	23	2	8	0
H	*NEPHTYS CILIATA*	31	7	1	0	0	9	21	6	24	0	5	1	1	0	0	4	3	1	18	0
	CHAETOZONE VIVIPARA	77	0	0	0	0	10	0	0	12	0	434	3	1	1	0	131	2	0	331	0
	MEDIOMASTUS CALIFORNIENSIS	22	5	4	1	0	5	49	11	4	0	22	6	18	1	1	12	37	16	17	2
	DYOPEDOS MONACANTHUS	5	4	8	0	0	9	63	6	6	0	3	2	21	0	0	12	26	4	16	0

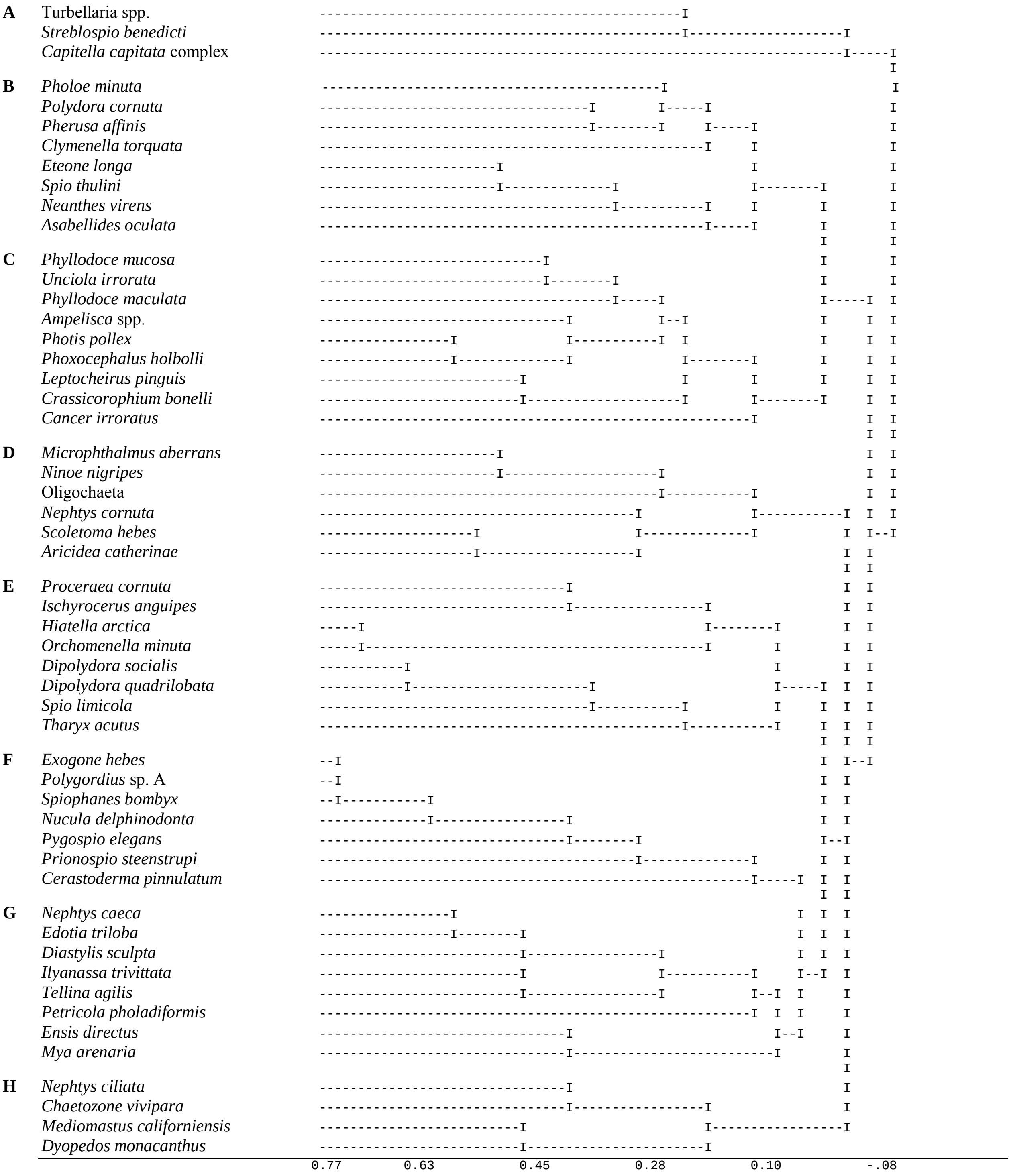


Figure 5-13. Species group dendrogram of Summer 1991–1999 Harbor infaunal data with oligochaetes summed to one taxon, based on the 53 taxa with abundance > 1500 and > 30 % occurrence (all three replicates from each station summed, Gallagher's CNESS dissimilarity, and UMPGA sorting).

Constancy

	I	II	III	IV	V	VI	VII	VIII	IX	X	Dominant Species
A	0.8	0.7	0.7	0.6	0.8	0.7	0.6	0.6	0.9	0.7	*Streblospio benedicti/Capitella capitata* complex
B	0.7	0.5	0.6	0.2	0.4	0.3	0.7	0.6	0.7	0.1	*Polydora cornuta/Clymenella torquata*
C	0.7	0.5	0.5	0.2	0.2	0.4	0.9	0.8	0.8	0.1	*Ampelisca* spp./*Crassicorophium bonelli*
D	0.8	0.9	0.7	0.4	0.3	0.5	0.8	0.8	0.6	0.3	Oligochaetes/*Aricidea catherinae*
E	0.5	0.3	0.6	0.1	0.3	0.4	0.6	0.6	0.6	0.1	*Tharyx acutus/Dipolydora socialis*
F	0.5	0.2	0.2	0.0	0.1	0.4	0.5	0.9	0.7	0.0	*Spiophanes bombyx/Nucula delphinodonta*
G	0.7	0.5	0.7	0.2	0.3	0.8	0.7	0.8	0.9	0.3	*Ilyanassa trivittata/Edotia triloba*
H	0.6	0.4	0.6	0.1	0.1	0.5	0.6	0.5	0.8	0.1	*Chaetozone vivipara/Mediomastus californiensis*

0-0.4 ☐ 0.5-0.6 🟨 0.7-0.8 🟧 0.9-1.0 🟠

Fidelity

	I	II	III	IV	V	VI	VII	VIII	IX	X	Dominant Species
A	1.1	1.1	1.0	0.9	1.1	1.0	0.9	0.8	1.2	1.0	*Streblospio benedicti/Capitella capitata* complex
B	1.3	0.9	1.0	0.3	0.6	0.5	1.3	0.9	1.3	0.2	*Polydora cornuta/Clymenella torquata*
C	1.1	0.8	0.8	0.3	0.3	0.6	1.4	1.2	1.6	0.1	*Ampelisca* spp./*Crassicorophium bonelli*
D	1.2	1.2	1.0	0.6	0.5	0.7	1.1	1.0	0.6	0.3	Oligochaetes/*Aricidea catherinae*
E	1.1	0.6	1.3	0.3	0.7	0.9	1.2	1.2	1.9	0.1	*Tharyx acutus/Dipolydora socialis*
F	1.2	0.5	0.5	0.1	0.2	1.0	1.1	1.8	2.7	0.0	*Spiophanes bombyx/Nucula delphinodonta*
G	1.2	0.8	1.0	0.3	0.5	1.2	1.1	1.1	1.7	0.4	*Ilyanassa trivittata/Edotia triloba*
H	1.2	0.9	1.2	0.2	0.3	1.0	1.2	0.8	1.9	0.2	*Chaetozone vivipara/Mediomastus californiensis*

0.0-0.6 ☐ 0.7-1.0 🟨 1.1-1.6 🟧 >1.6 🟠

Figure 5-14. Nodal constancy and fidelity between Summer 1991–1999 Harbor station and species groups derived from cluster analysis of infaunal data with oligochaetes summed to one taxa.

Analysis of the Summer 1991–1999 data with oligochaete species included produced similar patterns of stations and species, as did the combined oligochaete analysis. For the species analysis 55 taxa were included, 50 of which were included in the summed oligochaete analysis, three oligochaete species (*Tubificoides benedeni, T.* nr. *pseudogaster*, and *T. apectinatus*). Each of the oligochaete species was in a separate group (Figure 5-15). The other seven oligochaete taxa identified occurred infrequently and were not included. The addition of the three oligochaete species affected the composition of several species groups (Figures 5-13 and 5-15). In the original analysis, three major species groups were identified, group A, group B + C, and groups D–H. With the inclusion of oligochaete species in the analysis the only changes occurred within groups D–H, the composition of groups A, B, and C was not altered. In the original analysis, group D included the summed oligochaete taxon and the polychaetes *Nephtys cornuta*, *Scoletoma hebes*, and *Aricidea catherinae*. With the inclusion of oligochaete species, these three polychaetes "followed" the oligochaete *T. apectinatus* and joined with the species comprising the original group F (Figure 5-13) to form a newly-constituted group H (Figure 5-15). Group D now included the oligochaete *T.* nr. *pseudogaster*, two of the original polychaetes in the group (*Ninoe nigripes* and *Microphthalmus aberrans*), and the polychaetes *Dipolydora socialis*, *D. quadrilobata*, *Spio limicola*, and *Tharyx acutus*, that formerly were a part of group E. With the departure of the four polychaetes to group D, group E was comprised of only its four remaining original members. The original group G was modified only by the inclusion of the oligochaete *T. benedeni* within its ranks. The effect of the changes indicates the relatively close station affinity between each of the oligochaete species and several polychaete or other species (in the case of *T. benedeni*).

```
A  Turbellaria spp.               --------------------------------------------I
   Streblospio benedicti          --------------------------------------------I-----------------------I
   Capitella capitata complex     --------------------------------------------------------------------I-----I
                                                                                                            I
B  Pholoe minuta                  --------------------------------------------I                             I
   Polydora cornuta               -----------------------------------I        I--------I                    I
   Pherusa affinis                -----------------------------------I--------I        I--I                 I
   Clymenella torquata            -----------------------------------------------------I  I                 I
   Eteone longa                   --------------------------I                             I                 I
   Spio thulini                   --------------------------I-----------I                 I--------I        I
   Neanthes virens                --------------------------------------I-----------I     I        I        I
   Asabellides oculata            --------------------------------------------------I-----I        I        I
                                                                                                   I        I
C  Phyllodoce mucosa              -----------------------------I                                   I        I
   Unciola irrorata               -----------------------------I--------I                          I        I
   Ampelisca spp.                 -----------------------------------I  I-----------I              I-----I  I
   Photis pollex                  -----------------I                 I--I           I              I     I  I
   Phoxocephalus holbolli         -----------------I-----------------I              I-----I        I     I  I
   Phyllodoce maculata            -----------------------------------------I        I     I        I     I  I
   Leptocheirus pinguis           --------------------------I              I--------I     I--------I     I  I
   Crassicorophium bonelli        --------------------------I--------------I              I              I  I
   Cancer irroratus               --------------------------------------------------------I              I  I
                                                                                                         I  I
D  Microphthalmus aberrans        -----------------------I                                               I  I
   Ninoe nigripes                 -----------------------I-----------------------I                       I  I
   Tubificoides nr. pseudogaster  -----------------------------------------------I-----------I           I  I
   Dipolydora socialis            -----------I                                               I           I  I
   Dipolydora quadrilobata        -----------I-----------------------I                       I           I  I
   Spio limicola                  -----------------------------------I-----------I           I           I  I
   Tharyx acutus                  -----------------------------------------------I-----------I           I  I
                                                                                             I           I  I
E  Proceraea cornuta              --------------------------------I                          I-----I     I  I
   Ischyrocerus anguipes          --------------------------------I-----------------I        I     I     I--I
   Hiatella arctica               -----I                                            I--------I     I     I
   Orchomenella minuta            -----I--------------------------------------------I              I     I
                                                                                                   I     I
F  Nephtys ciliata                --------------------------------I                                I     I
   Chaetozone vivipara            --------------------------------I-----------------I              I     I
   Mediomastus californiensis     --------------------------I                       I--------------I--I  I
   Dyopedos monacanthus           --------------------------I-----------------------I              I  I  I
                                                                                                   I  I  I
G  Nephtys caeca                  -----------------I                                               I  I  I
   Edotia triloba                 -----------------I-----------I                                   I  I  I
   Diastylis sculpta              -----------------------------I--------------I                    I  I  I
   Tubificoides benedeni          --------------------------------------I     I--------------I     I  I  I
   Ilyanassa trivittata           --------------------------I           I-----I              I     I  I  I
   Tellina agilis                 --------------------------I-----------I                    I--I  I  I  I
   Petricola pholadiformis        -----------------------------------------------------------I  I  I  I  I
   Ensis directus                 --------------------------------I                             I--I  I  I
   Mya arenaria                   --------------------------------I-----------------------------I     I--I
                                                                                                      I
H  Exogone hebes                  --I                                                                 I
   Polygordius sp. A              --I                                                                 I
   Spiophanes bombyx              --I-----------I                                                     I
   Nucula delphinodonta           --------------I-----------------I                                   I
   Pygospio elegans               --------------------------------I--------I                          I
   Prionospio steenstrupi         -----------------------------------------I--------------I           I
   Cerastoderma pinnulatum        --------------------------------------------------------I-----I     I
   Nephtys cornuta                -----------------------------------I                          I     I
   Tubificoides apectinatus       -----------------------------------I--I                       I-----I
   Scoletoma hebes                --------------------I                 I-----------------------I
   Aricidea catherinae            --------------------I-----------------I
                                 0.78       0.64           0.46           0.28           0.10           -.08
```

Figure 5-15. Species group dendrogram of Summer 1991–1999 Harbor infaunal data with oligochaetes identified to species, based on the 55 taxa with abundance > 1500 and > 30 % occurrence (all three replicates from each station summed, Gallagher's CNESS dissimilarity, and UMPGA sorting).

6.0 CONCLUSIONS

6.1 Sediment Profile Image (SPI) Analyses

- The RPD value for 1999 ranged from 0.2 cm to 8.0 cm; the lowest value occurring at station T04 and the highest value at station R07 (off Deer Island); the highest value at a Traditional stations was 3.9 (T03).
- The average RPD value for 1999 (2.2 cm) was similar to that found in 1998.
    - Statistical comparison of RPD values showed significant differences among years, but there were no statistically distinct sets of years.
- Biogenic activity continued to be an important process in most of the Harbor sediments sampled in 1999.
    - The predominant biogenic structures were feeding pits and mound, worm tubes, epibenthic organisms, *Ampelisca* spp. tube mats, and shells.
    - *Ampelisca* mats were much reduced from 1998, occurring at only three stations in 1999.
- Successional stages in the Harbor showed a bimodal distribution with about 32 stations having Stage I communities and 26 stations having Stage II communities.
    - The number of stations having Stage I communities increased about 10% in 1999 versus 1998; the number of Stage II communities decreased about 15% in 1999.
- The average Organism-Sediment Index ranged from 2.0 to 9.7 in 1999. The lowest values were typically associated with coarse sediments, whereas the higher values were found in silty fine sand and silty sediments.
    - The majority of stations in the Harbor had OSI values < 6, which is indicative of some degree of stress, probably resulting from physical processes and high rates of sediment accumulation and organic enrichment.
    - Yearly differences in overall average OSI were statistically significant, with 1998 and 1999 having lower values than the other years.
- Overall, general habitat quality within the Harbor, as indicated by SPI, has been similar from August 1992 to 1999 with minor variation from year-to-year.

6.2 Sediment Geochemistry

- In April 1999, the patterns of sediment grain-size composition among stations in the Harbor, except station T04, were within the general patterns seen for previous years. Sediments at station T04 were much sandier (~31% sand) than in previous years.
- In August 1999, grain-size patterns were generally similar to those for previous years. Sediments at station T04 were fine (~95% silt+clay).
- Within-station patterns in total organic carbon content of the Harbor sediments in April and August 1999 were generally similar to those from previous years. Considerable variation among stations in TOC content was evident with the highest values found at station T04 and the lowest at station T08.
    - Although TOC content is generally positively associated with fine sediments, that was not the case at station T04, which in April was relatively sandy yet had a TOC content of about 7% and in August was very silty with a TOC content of about 4%.

- At all stations except T01, *Clostridium perfringens* showed decreasing abundance in April 1999 as compared to corresponding 1997 and 1998 values. The highest counts in April 1999 were about 16,130 cfu (station T04) and 12,640 cfu (station T03).
- *Clostridium* counts at most stations in August 1999 were generally lower than those for August samples from earlier years and from the April 1999 samples. The highest counts were 8,520 cfu (station T07) and 7,720 cfu (station T03).

6.3 Infaunal Communities

- Values for infaunal abundance, species numbers, diversity, and evenness in April and August 1999 generally were similar to those estimated for the previous two years.
- Among the most abundant species in April 1999 were the oligochaetes *Tubificoides apectinatus* and *T.* nr. *pseudogaster*, the polychaete *Aricidea catherinae*, and the amphipod *Ampelisca* spp. In August 1999, the polychaetes *Streblospio benedicti* and *Polydora cornuta* joined the former group as the most abundant taxa. In sharp contrast to 1998, the polychaete *Capitella capitata* complex was not found at station T04 in August 1999.
- Station grouping based on cluster analysis of the combined 1999 data set showed that within- and between-station similarity was stronger than seasonality.
- Stations T04 continued to differ substantially from the remaining seven stations. Exclusion of the station from the cluster analysis had no affect on the relationships among the other seven Harbor stations.
- For the first time during the MWRA studies, cluster analysis of the multiyear data set included oligochaetes identified to species for each survey of the program. Including oligochaete species in the analysis revealed three main differences from analyses in which oligochaetes were summed to form a single taxon.
    - There was increased consistency in the clustering of samples from station T02, and to a lesser degree, stations T01 and T03. When oligochaete species were not considered, samples from station T02 belonged to five cluster groups. When oligochaete species were identified, 15 of 17 samples from station T02 comprised a group that also included 16 of 17 samples from station T01. The three samples that "misclassified" (T02, Summer 1997 and Spring 1999; T01, Summer 1997) were characterized by relatively high abundances of *Tubificoides apectinatus*, a species not typically abundant at those two stations.
    - Station T07 shifted alignment significantly. When oligochaetes were not identified to species, all station T07 samples were most similar to those from the northern part of the Harbor (*i.e.*, stations T01 and T02). However, with oligochaete species distinguished, station T07 is most similar to stations T03, T06, and T08, and is quite distinct from stations T01 and T02.
    - When oligochaetes were identified to species, the Spring 1992 samples from station T03 aligned with all samples from the station collected since and comprised a cluster group that also included all samples from station T06. The Summer 1991 (*i.e.*, collected before sludge discharge cessation) samples aligned with "spring" group of samples from station T05A.

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