2004 Boston Harbor benthic monitoring report

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2004 Boston Harbor Benthic Monitoring Report

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EXECUTIVE SUMMARY

The direct discharge of waste products into Boston Harbor has had a profound impact on the composition of biological communities in the harbor. Most pollutants are particle reactive; therefore the sediments become the final sinks for these pollutants and represent the part of the ecosystem where disruption by toxic or enrichment effects is expected. Surficial sediments are critical to many ecosystem functions with energy flows (organic carbon, living biomass, secondary production) and nutrients (nitrogen, phosphorus) regulated by processes at the sediment-water interface. Thus, characterization of the benthic environment from physical and biological points of view has been a key part of the MWRA long-term sediment monitoring within Boston Harbor. As the MWRA improved the quality of the discharge and then diverted it to the new offshore outfall in September 2000, monitoring was conducted twice a year, in April and August, to track changes in the sediments and the biological communities. In 2003, sampling was reduced to once a year (August), and in 2004, an additional station was added in the inner harbor near a Combined Sewer Overflow (CSO).

Taylor (2005) summarized the major patterns in freshwater flows and loadings of total nitrogen (TN), total phosphorus (TP), total suspended solids (TSS), and particulate organic carbon (POC) to Boston Harbor between 1995 and 2003. He found three major periods of pollutant loadings that corresponded to milestones in the MWRA upgrade:

- Period A was from 1995 through mid-1998, corresponding to the period before the Nut Island discharge was diverted to Deer Island. During this time, the harbor received elevated freshwater flows and high loadings of TN, TP, TSS, and POC. Rivers provided most of the freshwater flows and wastewater treatment facilities contributed most of the TN, TP, TSS, and POC loadings.

- Period B was from mid-1998 to 2000, when discharges from Nut Island were transferred to and released after treatment at Deer Island. Freshwater flows remained moderately elevated above the long-term average, but loadings of TSS and POC, and to a lesser extent TN and TP, decreased.

- Period C began in 2000 with the transfer of the discharge offshore. Loadings of TSS and POC were further reduced, but the largest decrease was observed for TN and TP. Freshwater flows declined in period C.

The changes in wastewater discharge from 1995 to 2003 resulted in about a 90% decrease in loadings to Boston Harbor. For TSS and POC, most of the decreases occurred between Periods A and B, presumably in response to the transfer of the Nut Island discharge to Deer Island and treatment upgrade. For TN and TP, most of the decreases occurred between Periods B and C, in response to transfer of the discharge offshore (Taylor 2005).

Results from the 2004 harbor benthic survey are presented in this report and compared with results from 1991–2003. Recent reports have suggested that the infaunal community is responding to some degree to changes in the discharges to the harbor. The increase in species numbers and diversity at some of the stations are considered especially informative. The occurrence, spread and retreat of *Ampelisca abdita* tube mats has also been followed closely, as have levels of *Clostridium perfringens* and total organic carbon (TOC) in the sediments.

Sediment Properties

Sediment grain size and total organic carbon (TOC) content in 2004 were comparable to previous results over the course of the harbor monitoring program (1991–2003). For example, stations T01, T05A, and T08 were comprised of coarse-grained sediments; station T04 was comprised of fine-grained (silty) sediment, and stations T02, T03, T06, and T07 were comprised of sediments with roughly equal parts coarse- and fine-grained material. Fine-grained sediments (*e.g.,* T04) typically had higher TOC compared with coarse-grained sediments (*e.g.*, T05A and T08). Overall, because of the high variability in the data, there have not been consistent large-scale, harbor-wide changes in grain-size composition or TOC over time (1991–2004). There has been, however, a significant decrease in TOC with time in the northern region of the harbor at T01, near the Deer Island Treatment Plant.

Clostridium perfringens, an anaerobic bacterium found in the intestinal track of mammals, is one of the most commonly used tracers of sewage-derived sources in marine systems. Abundance of *C. perfringens* has decreased significantly in harbor sediments over time, indicating that actions taken by the Massachusetts Water Resources Authority to minimize wastewater impacts to Boston Harbor have improved the quality of sediment in the harbor.

Sediment Profile Imaging

Sediment profile images (SPI) were taken at nine harbor infaunal stations and 52 additional reconnaissance stations. In 2004, the basic measure of benthic habitat quality, the Organism Sediment Index (OSI), ranged from 2.5 to 10.3, indicating a wide range of environmental conditions in the harbor. The lowest values occurred at fine-sediment stations that had little evidence of advanced successional stage fauna, for example stations R15 and T04, which had small infauna (<1 mm diameter) and burrows (<2 mm diameter) visible. The highest OSI values were also at fine-sediment stations, but at those with high levels of advanced successional stage activity, for example stations R07 and R21, which in addition to small infauna and burrows had larger infauna and oxic feeding voids.

OSI values <6, which indicated that the communities were under some form of moderate stress, occurred at 24% of stations. Low OSI stations were located in the inner harbor and bays and near the harbor mouth. These low OSI values are likely related to either organic loading, particularly at Dorchester Bay station T04 and Quincy Bay station R35, or physical disturbance, particularly at station T01 off Deer Island and Dorchester Bay station R42. However, at many low OSI stations it appeared from the SPI images that both organic matter and physical stress contributed to these low values.

Stations with higher OSI (>8) occurred in two broad clusters centered off Deer Island and in the outer portion of Hull Bay, with three stations scattered through the mid-harbor. Three of the eight stations with *Ampelisca* spp. tube mats had OSI values <8. Stations R20 and T03, both near the mouth of the harbor, had an OSI of 7.7, but T06 in mid-harbor had an OSI of 5.7 because of a shallow RPD layer depth. Based on SPI, the sources of stress to the benthos appear to be a combination of physical processes such as hydrodynamics and sediment transport at coarse-sediment stations (for example, station R08 or T01) and high rates of sediment accumulation and organic enrichment at muddy stations (for example, station R35 or T04).

Tubes and feeding structures were the predominant biogenic features observed at the sediment surface. Evidence that a combination of biological and physical processes was active in structuring bed roughness occurred at 59% of the stations. Physical processes dominated at 31% of the stations and biological processes at 10%. The highest number of infauna was seen at station R28 in Hull Bay (mean of 8.7 infauna/image). Similar patterns of higher mean values at biologically dominated stations were observed for number of burrows and oxic voids per image. The overall level of biogenic activity in 2004 appeared to be the same as in 2003. The number of infauna increased in 2004 but burrows and voids remained the same. Of the two principle parameters dependent on biogenic activity, RPD declined in 2004 and OSI remained the same.

Ampelisca spp. tubes were the primary biogenic structures responsible for deepening RPD layers at 31 stations (52%) with sediments that ranged from coarse to silty. Where *Ampelisca* spp. tube mats occurred, mean RPD depths were significantly deeper than at stations without *Ampelisca* spp. or at stations with *Ampelisca* spp. present, but at less than tube-mat densities. Ampeliscids formed tube mats in at least one replicate image at eight stations (13%) toward the outer harbor from the western end of Deer Island Flats to Hull Bay. The percentage of stations with mat densities decreased in 2004 to 13%, the lowest level since the start of the SPI monitoring in August 1992. Previously, the high was 65% in 1995 and the low was 18% in 1990. The total number of stations with *Ampelisca* spp. tubes at any density, from a few tubes to mat densities, also declined from 38 stations in 2003 to 31 stations in 2004. All stations that had tube mats in 2004 also had tube mats in 2003. There were four stations (R02, R03, R11, and R25) that went from having tube mats in 2003 to no tubes in 2004.

Regionally within the harbor, it appears that from 1992 to 2004 benthic habitat conditions as measured by sediment profile imaging have not changed appreciably other than a small decrease in the OSI for the 1999–2000 period. Stations with poorest habitat quality in 1989–1990 (Blake *et al.* 1993) continued to have poor quality habitat in 2004. For example, stations T04 and R43, both in Dorchester Bay, had long-term average OSI values <3. Using the OSI as a surrogate for habitat quality, none of the stations exhibited monotonic long-term trends, either improving or declining, from 1992 to 2004.

Infaunal Benthic Communities

In August 2004, 148 species of benthic infauna occurred in the samples, including seven species that were recorded in the harbor for the first time. These seven species included three polychaetes, *Cossura* sp.1, *Goniada maculata*, and *Pherusa plumosa*; one amphipod *Calliopius laevisculus*; two isopods, *Idotea baltica* and *Pleurogonium rubicundum*; and one ascideacean *Molgula complanata*. Three of these seven species—*Cossura* sp.1, *C. laevisculus*, and *M. complanata*—are newly reported for the MWRA Massachusetts Bay/Boston Harbor database.

Total infaunal densities declined significantly at several stations compared with August 2003 because of the reduction of the large populations of several amphipod species that were present the previous year. At stations where amphipods have not been especially abundant over the past decade, such as T01 and T04, infaunal densities were similar in 2003 and 2004. The newly sampled station C019 had low infaunal abundances, similar to those seen at T04.

The mean number of species per sample was lower at six of the eight harbor stations in 2004 compared with 2003; stations T01 and T05A were the exceptions. As in previous years, species richness was lowest at T04, and the newly sampled station CO19 had only a few more species than T04. Diversity, whether measured by the Shannon H' index or log-series *alpha*, appeared statistically identical to diversities calculated for the 2003 samples with only a few exceptions. Shannon diversities were higher at T05A, T06, and T08, apparently because the large amphipod populations, which depressed diversity values last year, had declined in 2004 with a concomitant increase in H'. Log-series *alpha* at T05A increased in 2004 to a value of 12.2, which was the highest value recorded for the 2004 samples. CO19 had the second lowest *alpha* (3.3±0.5) of the nine stations; as reflected by other community parameters, this station is only slightly more diverse than T04.

Although the density of *Ampelisca* spp. declined significantly in 2004 compared with 2003, this taxon was the numerical dominant at three stations—T03, T05A, and T06—and was among the ten most numerous taxa at all other long-term stations in the harbor. The only exception was C019, where *Ampelisca* spp. had a mean sample density of only 2 individuals per sample.

In addition to the polychaete species such as *Prionospio steenstrupi* that have been common in the harbor in recent years, another polychaete, *Nephtys cornuta*, was an important species at several stations in 2004. It was the numerical dominant at two stations near or in the inner harbor: T02, where it accounted for about 35% of the fauna, and at C019, where it accounted for about 75% of the fauna. *Nephtys cornuta* was also among the dominants at T01 (2.8%), T04 (4.4%), and T07 (about 18%). At all of these stations, its abundance and proportion of the fauna increased compared with previous years.

The CNESS similarity analysis of the 27 samples taken at nine stations in August showed five groups of stations, with several clusters comprised of replicates from a single station

Cluster 1.	T01
Cluster 2.	T03, T06, and T05A
Cluster 3.	T02, T07, and C019
Cluster 4.	T08
Cluster 5.	T04

This pattern of station associations generally corresponds to the varying sediment types within the harbor, which have remained fairly consistent over the monitoring period, and is similar to that seen in previous years, with samples from a station almost always being more similar to samples from the same station than to those from other stations. The newly sampled station, C019, was most similar to stations T02 and T07, reflecting the species composition *(i.e.*, importance of *N. cornuta*) found at that station, rather than the low abundance and species diversity that characterize this station.

Long-term Patterns: Has the Harbor Changed?

To assess changes in benthic habitat quality, data were grouped by the time periods identified by Taylor (2005). For this analysis, period A included data from 1992 to 1998, period B from 1999 and 2000, and period C from 2001 to 2004. Based on patterns of association between the sediment, infauna, and SPI variables, there appears to be a cline of relative habitat quality from lower quality at T04 to higher quality at T03 and T06, and the stations were arranged according to the benthic habitat cline (Figure 1).

The sediment parameters grain-size and TOC remained relatively unchanged over the three time periods. The largest differences occurred in period C, when gravel and TOC declined at T01 (Figure1). The variability of TOC has declined through time at all traditional stations, suggesting that the harbor’s benthic habitats have improved.

Sediment profile image data indicated that the improvement in habitat quality was greatest in period C. Stations that were identified as having lower (T04 and T07) to average (T01, T02, T05A, and T08) habitat quality showed an increase in the OSI and a deepening of the RPD layer depth in period C relative to periods A and B (Figure 1). The stations with highest habitat quality (T03 and T06) have had consistently deep RPD layers. This general improvement in habitat conditions in period C may be related to increased bioturbation by infauna. At all stations except T04 there was an increase in the number of oxic, active feeding voids (Figure 1). Station T04 consistently had the shallowest RPD, highest TOC, and limited evidence of bioturbation of all stations. At the other seven stations, biogenic activity consistently deepened the RPD beyond what would be expected by diffusional processes alone.

Benthic community parameters, including total abundance, species richness, *Ampelisca* per sample, and diversity as measured by log-series *alpha*, are also plotted according to Taylor's periods (Figure 1). Total abundances were, with the exception of T03, highest in period A and lowest in period C. At T03, the high abundance in period B is related to the large numbers of ampeliscid amphipods. Species richness was depressed in period B compared with period A at six stations and slightly higher at two stations (T03 and T06), but was elevated at all eight stations in period C. Diversity as measured by log-series *alpha* was equal to or slightly higher at each station in period B compared with period A, and higher in period C compared with period B (Figure 4-6).

Detailed analyses of the infaunal communities at the traditional stations, as well as other lines of evidence, such as the decrease in levels of the sewage marker *Clostridium perfringens* strongly support the conclusion that the benthic environment in the harbor is indeed recovering from years of pollutant input.

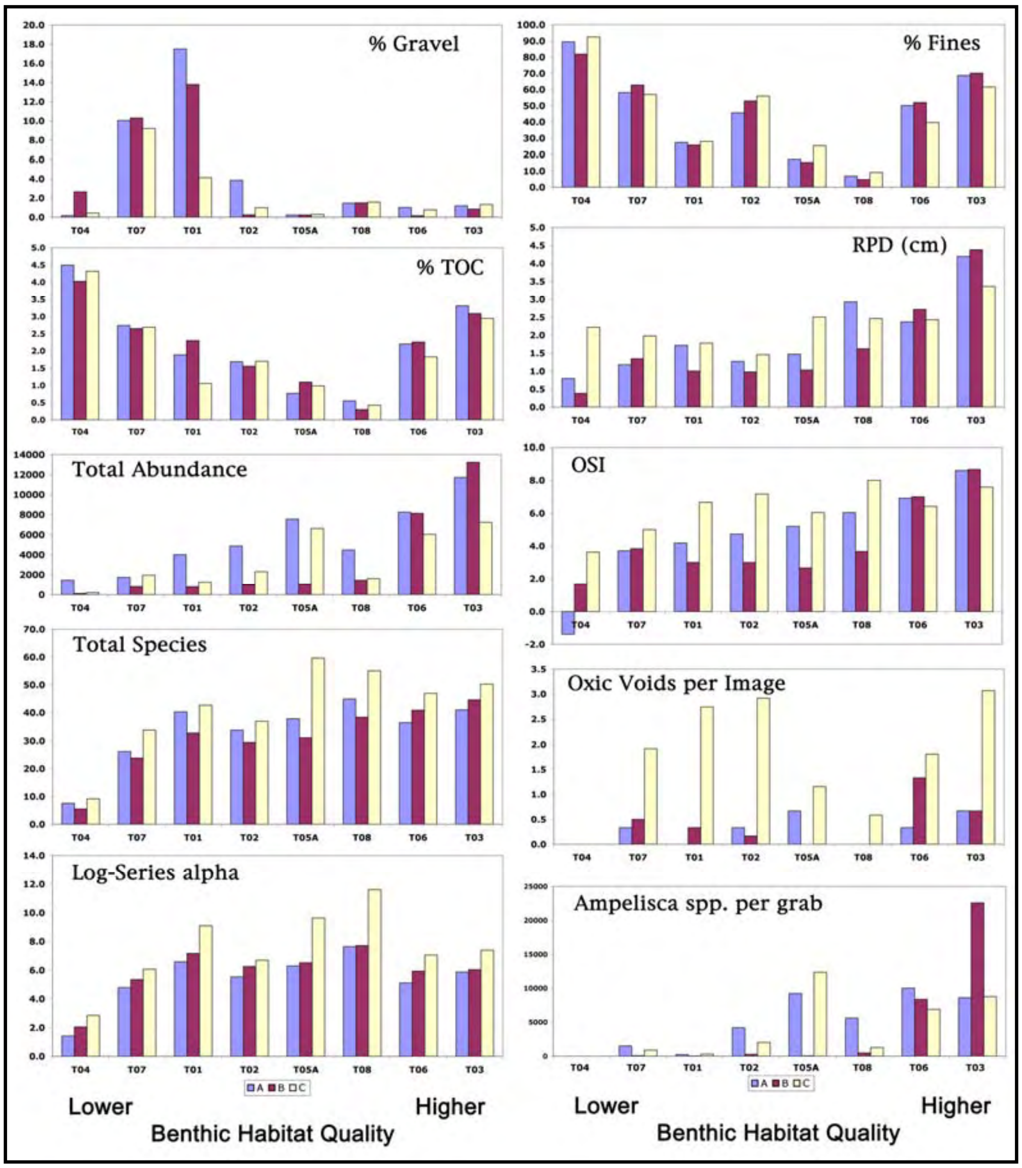


Figure 1. Benthic habitat quality at Boston Harbor traditional stations, with corresponding changes in several parameters for periods delineated by Taylor (2005).

1. INTRODUCTION

1.1 Background

1.1.1 History of Discharges to Boston Harbor

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

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

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

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

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

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

Taylor (2005) summarized the major patterns in freshwater flows and loadings of total nitrogen (TN), total phosphorus (TP), total suspended solids (TSS), and particulate organic carbon (POC) to Boston Harbor between 1995 and 2003. He found three major periods of pollutant loadings (Figure 1-1):

- Period A was from 1995 through mid-1998, when the Nut Island discharge was diverted to Deer Island; the harbor received elevated freshwater flows and high loadings of TN, TP, TSS, and POC. Rivers provided most of the freshwater flows and wastewater treatment facilities contributed most of the TN, TP, TSS, and POC loadings.

- Period B was from mid-1998 to 2000, when discharges from Nut Island were transferred and released after treatment at Deer Island. Freshwater flows remained moderately elevated above the long-term average, but loadings of TSS and POC, and to a lesser extent TN and TP, decreased.

- Period C began in 2000 with the transfer of the discharge offshore. Loadings of TSS and POC were further reduced, but the largest decrease was observed for TN and TP. Freshwater flows declined for period C.

The changes in wastewater discharge from 1995 to 2003 resulted in about a 90% decrease in loadings to Boston Harbor. For TSS and POC, most of the decreases occurred between Periods A and B, presumably in response to the transfer of the Nut Island discharge to Deer Island and treatment upgrade. For TN and TP, most of the decreases occurred between Periods B and C, in response to transfer of the discharge offshore (Taylor 2005).

1.1.2 Benthic Studies in Boston Harbor

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

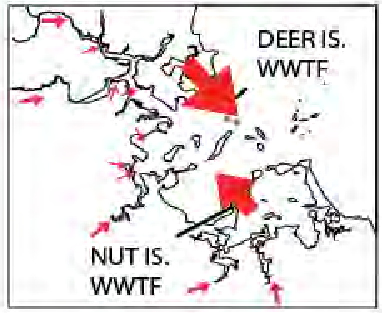
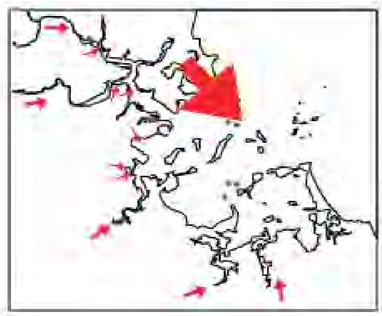
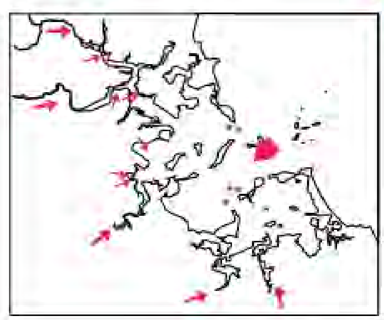
Date	Milestone	N loadings (based on (Alber and Chan 1994)	
1991 1995 1997 - 2001	Sludge dumping ended New primary treatment facility at DI Upgrade to secondary treatment at DI		PERIOD A
1998	Inter-island transfer		PERIOD B
2000	Offshore transfer		PERIOD C

Figure 1-1. Milestones of the MWRA upgrade to Boston Harbor sewerage treatment and Taylor's three periods of pollutant loadings to the harbor (from Taylor, 2005).

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

Quantitative infaunal sampling was initiated in 1991and was intended to characterize the infauna of Boston Harbor so that changes following the various phases of the Boston Harbor Project (*e.g.*, sludge abatement) could be documented. Eight stations (one was later relocated) were positioned near the major effluent and sludge discharges and in key reference locations. Benthic infaunal communities and correlated sediment parameters were first sampled in September 1991, approximately three months prior to the cessation of sludge discharge. Post-abatement surveys were conducted in April/May and August 1992 to 2002; beginning in 2003 samples were collected only in August.

In 2004, a new station in the inner harbor, C019, was added to the benthic monitoring program. Sediment contaminants have been monitored at this site periodically since 1994 as part of an MWRA study of the effect of CSOs on sediment contamination in Dorchester Bay (Durell 1995, Lefkovitz *et al.* 1999). MWRA's system upgrades will greatly reduce the amount of CSO discharge to the Fort Point Channel and the bulk of the remaining flow will be treated; therefore, C019 was added to help identify environmental improvements that may result from these upgrades.

Reconnaissance surveys at 25–50 additional stations using sediment profile imaging and rapid partial grab analyses, or both, have been carried out annually through 2004. Reports to the MWRA on the results of these surveys have been prepared and can be requested from the MWRA through their website (http://www.mwra.state.ma.us).

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

1.2 Report Overview

The Boston Harbor benthic monitoring program includes three components: determination of sedimentary parameters, imaging of sediments (SPI), and analysis of benthic infaunal communities. The sampling design and field methods are presented in Chapter 2. Sediment studies, based on grab samples taken at nine stations in August 2004, consist of grain-size analysis, total organic carbon (TOC) content determination, and quantification of the sewage tracer, *Clostridium perfringens*. These analytical results are presented in Chapter 3. Sediment images were collected in August 2004 at 61 stations; these images are evaluated in Chapter 4. The benthic communities were sampled at nine stations in August 2004; the results are presented in Chapter 5. The raw data generated for all of these components are available from the MWRA; summaries are included in the appendices to this report.

2. 2004 FIELD OPERATIONS

by Isabelle P. Williams

2.1 Sampling Design

The station array provides spatial coverage of the major bays that make up Boston Harbor (Figure 2-1). The eight stations designated as "traditional" are those that are sampled for benthic infauna, followed by a full taxonomic analysis of the organisms in each sample. These station locations were selected after consideration of previous sampling programs in the harbor (*e.g.*, those conducted for the 301(h) waiver application) and consideration of water circulation patterns and other inputs to the harbor (*e.g.*, combined sewer overflow). The 52 stations designated as "reconnaissance" are those at which only sediment profile images (SPI) are taken. In 2004, a new combined sewer overflow (CSO) station, C019, was sampled for benthic infauna, SPI images, and a full suite of sediment chemistry analyses.

2.1.1 Sediment Profile Images

The Boston Harbor SPI survey was conducted in late August 2004 at the 61 stations, including eight traditional, 52 reconnaissance, and one CSO (Figure 2-1). The SPI data supplement the infaunal data to provide a large-scale picture of benthic conditions in the harbor. Sediment profile imagery permits a faster evaluation of the benthos than can be made by traditional infaunal analyses. This qualitative evaluation can then be integrated with the quantitative results from the infaunal and sediment chemistry analyses. The target locations for Boston Harbor SPI stations are listed in Table 2-1. Field data and specific locations of all sediment profile images collected in 2004 are listed in Appendix A1 (Tables A1-1 and A1-2).

2.1.2 Sediment Samples

In 2004, the Boston Harbor benthic infaunal survey was conducted in early August. Benthic infaunal and sediment chemistry samples were collected from eight traditional stations and one CSO station (Figure 2-1). Target locations for these stations are given in Table 2-1. Field data and actual station coordinates for each biology and chemistry grab sample, along with a brief description of each sample, is given in Appendix A2 (Tables A2-1 and A2-2).

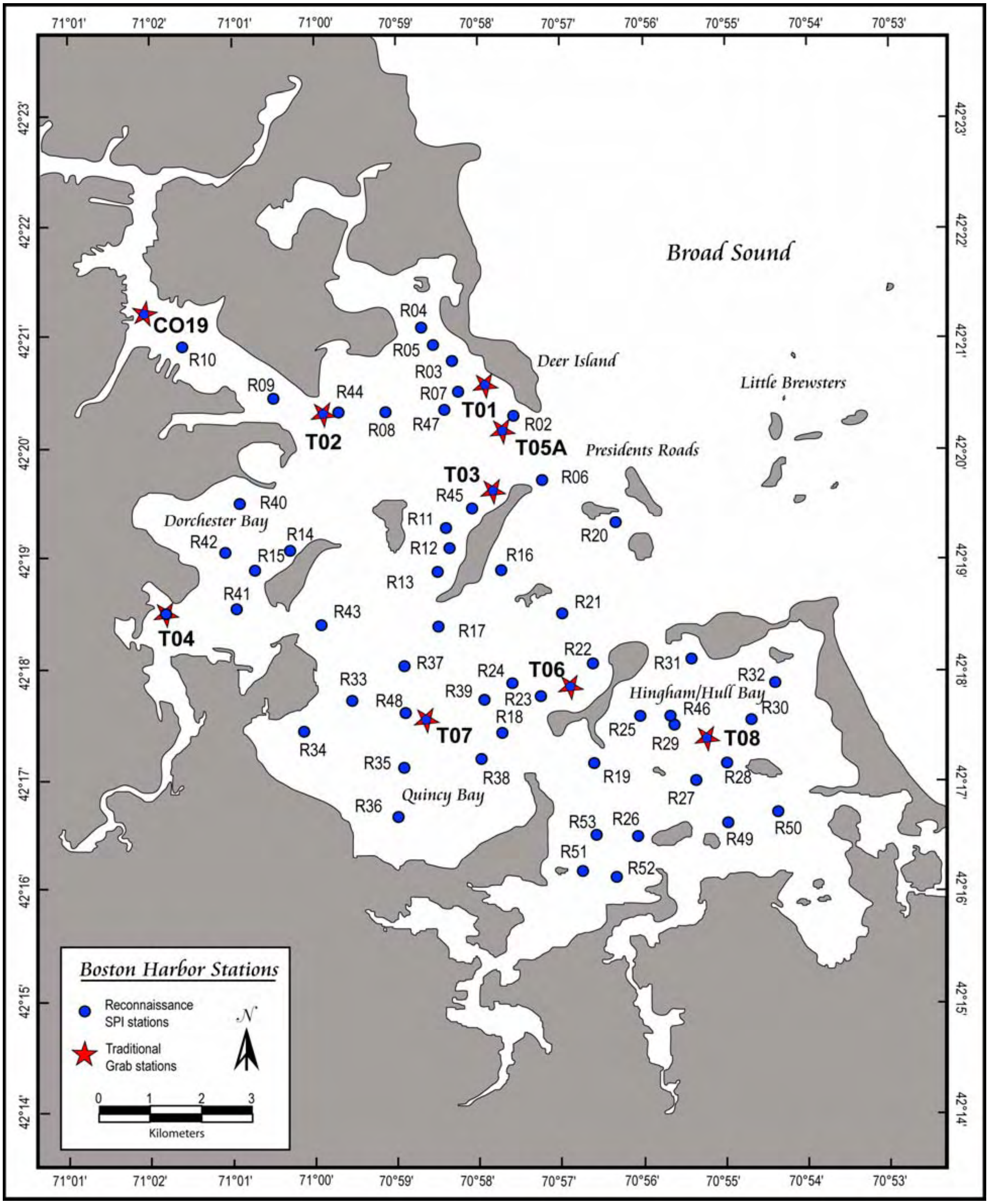


Figure 2-1. Boston Harbor grab and SPI stations sampled in 2004.

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

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

Table 2.1 (continued)

Station	Latitude	Longitude	Depth (m)
R25	42°17.48'N	70°55.72'W	7.3
R26	42°16.13'N	70°55.80'W	7
R27	42°16.83'N	70°54.98'W	6
R28	42°16.90'N	70°54.52'W	7
R29	42°17.38'N	70°55.25'W	11
R30	42°17.43'N	70°54.25'W	5
R31	42°18.05'N	70°55.03'W	10
R32	42°17.68'N	70°53.82'W	5
R33	42°17.65'N	70°59.67'W	5
R34	42°17.33'N	71°00.42'W	4
R35	42°17.05'N	70°59.28'W	6
R36	42°16.53'N	70°59.20'W	5
R37	42°17.93'N	70°59.08'W	6
R38	42°17.08'N	70°57.83'W	7
R39	42°17.73'N	70°58.22'W	8
R40	42°19.73'N	71°01.45'W	2
R41	42°18.67'N	71°01.50'W	4
R42	42°19.18'N	71°01.50'W	2
R43	42°18.40'N	71°00.13'W	3
R44	42°20.62'N	71°00.13'W	9.3
R45	42°19.70'N	70°58.05'W	6.8
R46	42°17.46'N	70°55.33'W	10.5
R47	42°20.67'N	70°58.72'W	6.5
R48	42°17.61'N	70°59.27'W	5.9
R49	42°16.39'N	70°54.49'W	6.1
R50	42°16.50'N	70°53.92'W	6.1
R51	42°15.80'N	70°56.53'W	5.3
R52	42°15.71'N	70°56.09'W	5.2
R53	42°16.15'N	70°56.27'W	6
Combined Sewer Overflow Station			
C019	42°21.55'N	71°02.71'W	7.9

2.2 Field Program Results

2.2.1 Survey Dates and Samples Collected

A summary of the samples collected during the 2004 Boston Harbor surveys is given in Table 2-2.

2.2.2 Vessel and Navigation

The 2004 Boston Harbor benthic surveys were conducted from Battelle's research vessel, the R/V *Aquamonitor*. Vessel positioning was accomplished with the Battelle Oceans Sampling Systems (BOSS) Navigation system, which consists of a Northstar differential global positioning system (DGPS) interfaced to an on-board computer. The GPS receiver has six dedicated channels and is capable of locking onto six satellites at once. Data were recorded and reduced using NAVSAM© data acquisition software. The system was calibrated at the dock using coordinates obtained from NOAA navigation charts at the beginning and end of each survey day.

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

Table 2-2. Survey dates and numbers of samples collected on Boston Harbor benthic surveys in 2004.

Survey Type	Survey ID	2004 Date(s)	Samples Collected						
			Inf	TOC	GS	Org	M	Cp	SPI
SPI	HR041	23–24 Aug							185
Benthic	HT041	3 August	27	11	11	3	3	11	

Key: Inf: Infauna, TOC: total organic carbon, GS: grain size, Cp: *Clostridium perfringens*, Org: Organic contaminants, M: Metals; SPI: individual sediment profile images.

2.2.3 Sediment Profile Imagery (SPI)

Dr. Randy Cutter (Diaz and Daughters) was the Senior Scientist for the Boston Harbor SPI survey (HR041). Three replicate SPI images were successfully collected at all 61 stations. The digital camera captured a 5.2-megapixel image that produced a 14.1-megabyte RBG image that was recorded to an IBM 1-gigabyte microdrive. The camera was also equipped with a video-feed that sent images to the surface via cable so that prism penetration could be monitored in real-time. In addition, the camera frame supported a video-plan camera mounted to view the surface of the seabed. These images were also relayed to the surface via the video cable and permitted the camera operator viewing a video monitor to see the seafloor and know exactly when the camera had reached the bottom. The camera operator then switched to the digital still camera and while viewing the camera penetration, chose exactly when to record sediment profile images. Images were usually taken at about 1 and 15 sec after bottom contact.

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

The microdrive was capable of recording more images than could be collected during a day of sampling. Consequently, the camera housing did not have to be taken apart as long as the batteries supplying the camera or the strobe did not fail. During this survey, the pressure case had to be opened four times to replace the battery and once to check camera function. Generally, images were downloaded from the microdrive to the laptop whenever the camera housing was opened. Digital capability allowed a review of the collected images within 20 min of downloading the microdrive so that it was possible to determine quickly whether or not three analyzable images had been collected at each station. Test shots on deck were not necessary, as loss of battery power to the strobe or camera would have been noticed immediately when the video cable failed to relay any images. While still in the field, images were transferred from the microdrive to a computer and then to a compact disc (CD) for long-term storage.

2.2.4 Grab Sampling

The 0.04-m^2 Young-modified Van Veen grab sampler was used to collect three replicate samples at each station for infaunal analysis and one sample for analysis of the sedimentary parameters, TOC, *C. perfringens*, and sediment grain size. At CSO station C019, triplicate samples were collected, using the 0.10-m^2 grab, for analysis of the sedimentary parameters listed above as well as for organic contaminants and metals.

Infaunal samples were sieved onboard with filtered seawater over a 300-μm-mesh sieve and fixed in 10% buffered formalin. For chemistry samples, the top 2 cm of the sediment in the grab was removed with a Kynar-coated scoop and homogenized in a clean glass bowl before being distributed to appropriate storage containers. The TOC, metals, and organics samples were frozen, whereas the *C. perfringens* and grain-size samples were stored on ice in coolers.

3. 2004 SEDIMENT PROPERTIES

by Deirdre T. Dahlen

3.1 Introduction

Surface sediment samples have been collected at eight stations throughout Boston Harbor (Figure 2-1) since 1991 to characterize the sediments and evaluate changes in sediment parameters (*e.g.,* grain-size composition, total organic carbon (TOC) and *Clostridium perfringens*) that may have resulted from improvements to wastewater treatment practices. *C. perfringens,* an anaerobic bacteria common to the intestinal track of mammals, is one of the most commonly used tracers of sewage-derived sources in marine systems. Historically, sewage effluent was one of many sources of pollution to the harbor system although industrial and household hook-ups to the sewage collection system and street runoff through combined sewer and street drainage systems were the "real" sources of the pollutants. The Boston sewer system, which has transported the contaminants of concern today from their sources to the coast since the 1800s, also carried unique tracers of the sewage and industrial process. The signature of these inputs to the system is readily captured in the sediments. Thus, understanding the response of sewage tracers in sediments to the harbor clean-up effort provides a means of evaluating how the system reacted when the intensity of sewage sources were reduced in the 1990s.

3.2 Methods

3.2.1 Laboratory Analyses for Ancillary Measurements

Sediment grab samples collected in 2004 were analyzed for grain size, TOC, and *C. perfringens* according to laboratory procedures outlined in the Benthic Monitoring CW/QAPP (Williams *et al.* 2005). Summaries of the procedures are provided below.

Grain Size—Samples were analyzed for grain size by the sequence of wet and dry sieving methodologies following Folk (1974). Data were presented in percentages of gravel, sand, silt, and clay and in weight percent by particle size. In addition, a numerical approximation of mean (and standard deviation) particle size was reported. Grain-size analyses were performed by GeoPlan Associates.

Total Organic Carbon (TOC)—Samples were analyzed for TOC by using a DC-190 analyzer following Prasse *et al.* (2004). Data were presented as percent dry weight. TOC analyses were performed by the Department of Laboratory Services (DLS), MWRA.

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

3.2.2 Data Terms and Analyses

Key terms used to describe the sediment data are summarized below; more detailed descriptions of these data terms are presented in Appendix B1.

- Percent Fines – sum of percent silt and percent clay
- Station Mean – average of all station replicates for a given year
- Grand Station Mean – average over years for a given station
- Grand Monthly Mean – average over years and stations for a given month
- Harbor-wide – refers to all traditional harbor stations, T01 through T08

Key data analyses conducted to assess spatial and temporal trends in the sediment data from 1991 to 2004[1] are summarized below.

- Line charts were used to visualize the trends in sediment data. Line charts were prepared in Microsoft® Excel 2002.
- Box plots were used to visualize the data distribution, and identify points with extreme values. The ends of the box represent the 25th and 75th quartiles, and the line across the middle represents the median value. The lines are "whiskers" that extend from the ends of the box to the outermost data point that falls within the distances computed (a distance of 1.5 times the interquartile range, difference between 25th and 75th quartiles). Data points above or below the whiskers represent possible outliers. Box plots were prepared in JMP (The Statistical Discovery Software, a product of SAS).

Seasonal TOC data collected by the benthic flux program (BH02, BH03, and BH03A (1995–1997) only) from 1993 to 2004 were evaluated with the harbor TOC data (stations T02 and T03 only) to explore if there was a characteristic seasonal "peak" in harbor TOC levels that more or less corresponded to the faunal sampling events. Benthic flux results from February 1993 and June 1996 were excluded from the analysis because benthic flux data were not typically collected in February or June (sampling periods generally included March, May, July, August and October).

Analysis of variance (ANOVA) was used to test for differences, harbor-wide (all traditional stations) and by station, in TOC and *C. perfringens* by monitoring year. Where the ANOVA showed significant differences between the two variables tested, a linear regression was performed to explain the relationship. Normality was checked with the Shapiro-Wilk test and homogeneity of variance with Bartlett's test. The distribution was normal for percent fines and TOC and log-normal for *C. perfringens*. Variances in the TOC and *C. perfringens* data with time were equal harbor-wide and at most stations. The relationship between variables (grain size, TOC, and log-transformed *C. perfringens*) was determined using correlation analyses, *i.e.*, pair-wise comparisons. The Pearson product-moment correlation coefficient (r) measures the degree to which two variables have a linear relationship if the variables have normal distributions. For Pearson correlations, values near 1 indicate that the two variables have a strong positive correlation; values near -1 indicate that the two variables have a strong negative correlation, and values near 0 indicate that the two variables are unrelated. Strong correlation coefficients do not necessarily indicate a direct dependence of the variables. Correlation analyses were performed using sediment data[2] from multiple time periods (additional time periods were also evaluated, see Appendix B1), as follows:

- 1992–1997, represents the monitoring period after cessation of sludge disposal but prior to most of the improvements to sewage treatment (*e.g.*, advanced primary and secondary treatment)

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[1] April/May data available from 1993 to 2002 and August/September data available from 1991 to 2004.
[2] Individual replicate data were used in the correlation analyses because one grab sample was typically collected at each of the eight traditional harbor stations during each survey. Replicate grab samples were collected at selected stations over time, including (1) three grabs at all stations in August 1997 and August 2002; (2) four grabs each at T01, T02 and T08 in August 1994 and August 1998; and (3) four grabs at T07 in August 1998.

- 1998–2000, represents the monitoring period after most of the improvements to sewage treatment but prior to effluent diversion
- 2001–2004, represents the monitoring period after effluent was diverted to the offshore outfall

3.3 Results and Discussion

Bulk sediment results for all Traditional station samples from 1991 to 2004 were evaluated to examine spatial and temporal characteristics. Sediment data for station CO19, located in Boston's Inner Harbor near the Fort Point Channel, were also evaluated because this station was added in 2004 to track changes after improvement to the CSO. Sediments at CO19 had been sampled in triplicate in 1994, 1998, and 2002 as part of a separate MWRA study. All sediment results discussed in this section are expressed as dry weight.

3.3.1 Grain Size 1991–2004

2004 sediment data were consistent with data collected during the monitoring program (1991–2003) in that stations T01, T05A, and T08 were comprised of coarse-grained sediments; stations T04 and CO19 were comprised of fine-grained (silty) sediment; and stations T02, T03, T06, and T07 were comprised of sediments with roughly equal parts coarse- and fine-grained material (Appendix B2).

A detailed time-series evaluation of the grain-size data by station showed no major shifts in sediment environments, although sediment at T04 showed sustained increases in silt content with coincident decreases in clay content since April 2001 (representative stations T04 and T07 are shown in Figure 3-1; all data in Appendix B2). A statistical summary of the grain-size data (percentages sand, silt, and clay) from Boston Harbor showed that grain-size composition was highly variable over time (1991–2004) (coefficient of variations (CV) ranged from 14% to 168%, and CVs >30% for many stations and grain-size fractions; Appendix B2, Table B2-1). The time-series evaluation showed sporadic marked changes in grain-size composition (Figure 3-1, Appendix B2) which are generally consistent with the possible outliers identified periodically during the program (Figure 3-2).

Possible outliers in grain-size composition (percentages silt, sand, and clay) may reflect natural variability, which can be extreme depending on the location (*e.g.*, T03, see Figure B2-2, Appendix B2). Alternatively, the possible outliers could be associated with storm activity that disturbs the sediment bottom or small changes in the sampling location. Possible outliers in grain-size composition associated with the April 1997 and May 1998 sampling events (Figure 3-2) may be storm related[3]. In contrast, possible outliers with grain-size composition observed in the early 1990s (Figure 3-2) may be associated

[3] According to the National Oceanic and Atmospheric Administration's National Climatic Data Center (NCDC) (http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwevent~storms) a strong storm passed over the Boston area in early April 1997 causing blizzard conditions with gusting winds of 30 to 50 miles per hour (mph). This storm may have contributed to the marked increase in sand content at T07 in April 1997 and increases in silt and clay content (with coincident decrease in sand content) at T08 in April 1997. Station T07 is located in the open water area of Quincy Bay and the sediment bottom at this location may have been more disturbed, exposing the coarse-grained sediment. In contrast, station T08 is located in a more protected area of the harbor (near Hull), and fine-grained sediment may have deposited at this location during the storm.

According to NCDC, a spring nor'easter passed over eastern Massachusetts in early May 1998 spreading strong northeast winds along the east coast of Massachusetts (gusts 35 to 50 mph). Further, freshwater inflows from the Charles River were well above average during the first half of 1998, and were anomalously high in May and June 1998 (Libby *et al.* 2000). The observed increase in May 1998 in silt and clay content at stations T02 and T08, which are located in relatively protected areas of the harbor, may reflect recent deposition of fine-grained material from these storm/rain events.

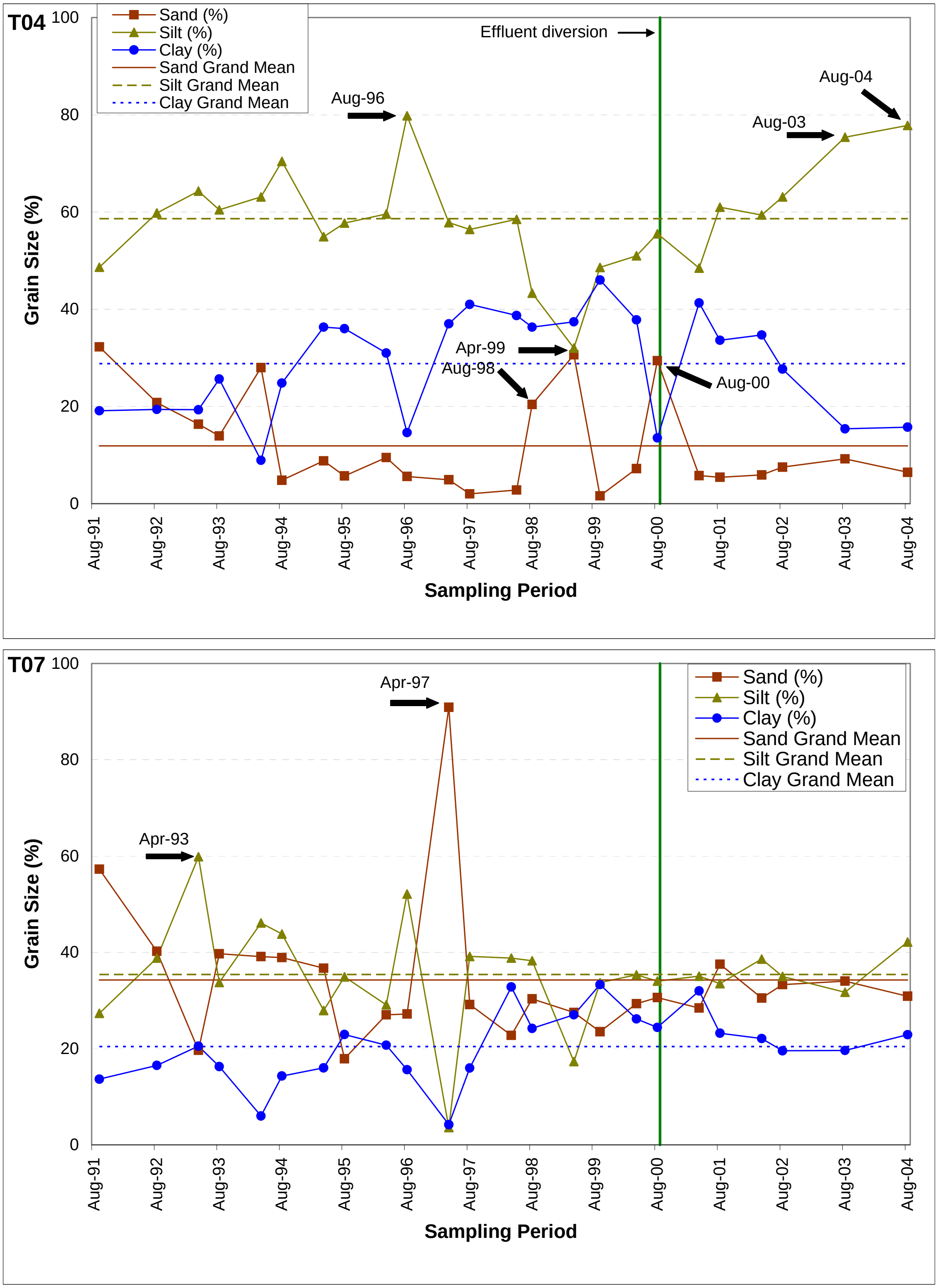

Figure 3-1. Station mean grain-size composition, presented as percentage sand, silt and clay, at stations T04 (top) and T07 (bottom), 1991–2004.

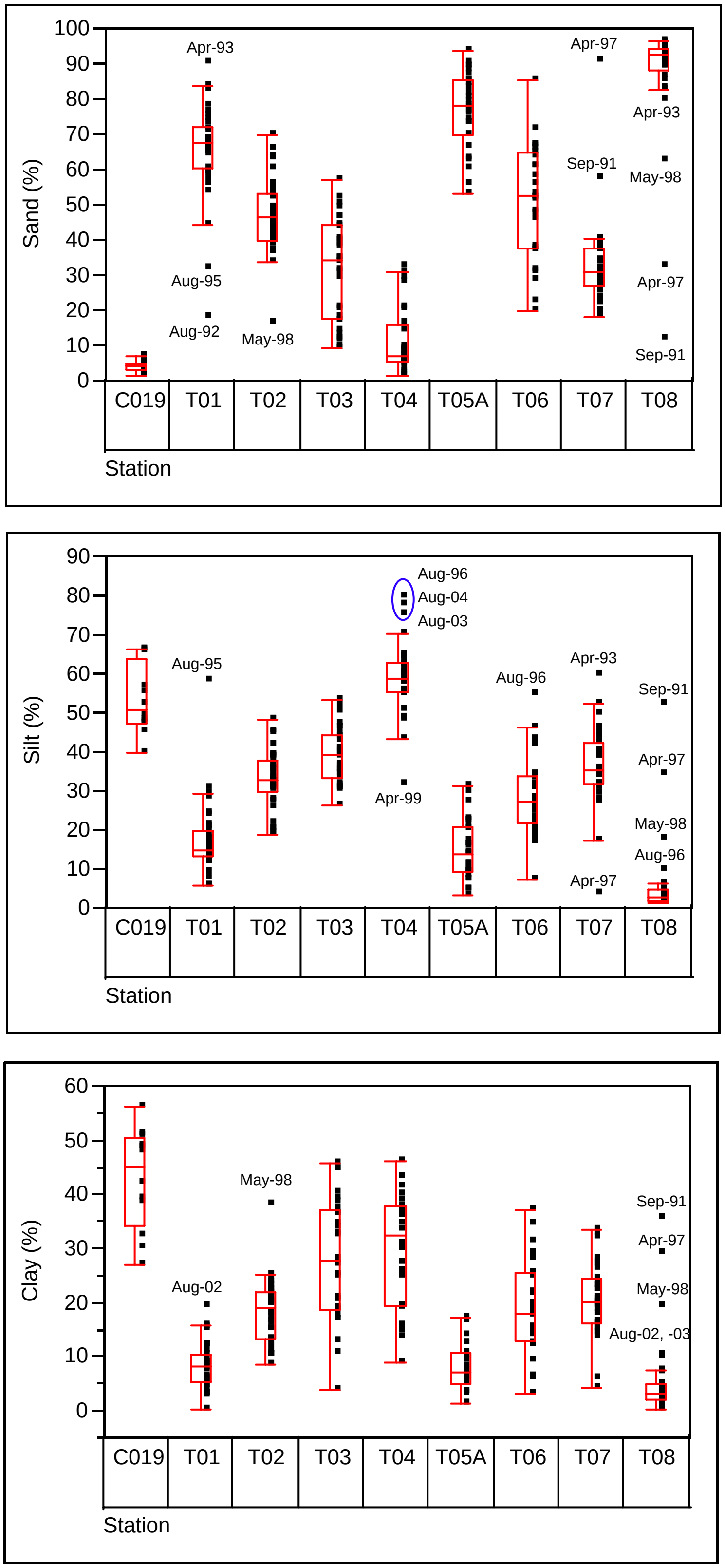

Figure 3-2. Distribution of percentages sand, silt and clay in Boston Harbor sediments, 1991–2004. For CO19, sediment data is from 1994, 1998, 2002, and 2004.

with changes in the sampling location, *i.e.*, sediment grab samples were collected more than 30-m from the target coordinates4.

The marked increase in sand content at T04 in August 1998 and April 1999, compared to mid-1990s values (Figures 3-1 and 3-2), may be associated with a *Capitella* bloom that was observed at this station in 1998. Deposit-feeding polychaete worms such as *Capitella* sp. produce sand-sized fecal pellets that are held intact in bottom sediments, thus increasing the "sandiness" of the bottom sediments (Drake *et al.* 2001). It would be surprising, however, for so much pelletized material to consistently survive the process used to analyze the grain-size, especially considering that a mechanical disaggregation is used in cases where fecal pellets are observed or where the material is particularly cohesive. Finally, an explanation is not evident for the marked increase in silt content with coincident decrease in sand content at T01 in August 1995 (Figure 3-2 and Appendix B2).

3.3.2 Total Organic Carbon 1991–2004

TOC results for 2004 are consistent with historical data (1991–2003) in that fine-grained sediments (*e.g.*, T04) typically had higher TOC compared with coarse-grained sediments (*e.g.*, T05A and T08). Station T04, located in a depositional area with highly localized sources (*e.g*., combined sewer overflow (CSO)) (Wallace *et al*. 1991; Stolzenbach and Adams 1998), consistently had the highest TOC (grand station mean = 4.5%) relative to other harbor stations. The lowest TOC was measured at stations T08 and T05A (grand station mean values <1%).

A detailed time-series evaluation of the TOC data by station showed no major shifts in TOC in harbor sediments over time (1991–2004), although TOC appears to be consistently lower at T01 (located near Deer Island Treatment Plant) following effluent diversion in September 2000 (stations T01 and T04 shown in Figure 3-3; all data in Appendix B3). Statistical analyses showed that the TOC data are highly variable throughout the harbor over time (1991–2004) (Figure 3-4), especially at T08 (71 %CV), T01 (42 % CV) and T05A (37% CV) (Appendix B3, Table B3-1). While there was not a significant harbor-wide difference in TOC with time (ANOVA, $p = 0.99$; Appendix B3), a significant decrease in TOC with time was observed in the northern region of the harbor at T01, near the Deer Island Treatment Plant (ANOVA, $F = 3.22$ and $p = 0.019$ and $r = -0.42$; Appendix B3). The Benthic Nutrient Flux program also observed pronounced decreases in TOC at selected harbor locations (BH03, followed by BH08A and QB01; Tucker *et al.* 2005). Unlike other harbor stations, a significant increase in TOC was observed with time at CO19 (ANOVA, $F = 8.71$ and $p = 0.007$, $r = 0.81$; Appendix B3). The significant increase should be viewed with caution given that TOC can vary annually, and there are 2- to 4-year data gaps between monitoring years at this station. CO19 is located in Boston's Inner Harbor area and the increase likely reflects localized inputs from an adjacent CSO and/or nearby rivers (*i.e.*, Chelsea River, Mystic River and Charles River). The absolute increase in TOC at CO19, however, is small (0.4% increase in 2002 compared with 1998) and may not be biologically important as a result.

Notable changes in TOC identified from the time-series evaluation (Figure 3-3, Appendix B3) are generally consistent with the possible outliers identified periodically during the program (Figure 3-4). TOC increased substantially at T04 in 1998 compared with 1995–1997 levels (Figure 3-3). The increases were attributed to localized inputs from two major storm events, the May 1998 nor'easter (see Section 3.3.1) and the June 1998 storm which led to widespread urban, small stream, and river flooding (Lefkovitz *et al*. 1999). TOC remained high in April 1999 (6.94%), possibly due to localized inputs from

[4] Sample maps were prepared showing actual locations sampled from 1991 to 2004 for each Harbor station (T01 through T08) (Appendix C2). Stations sampled more than 30-m from the target location were identified and cross-referenced with the grain-size data to assess if small changes in the boat position were correlated with substantial changes in grain-size composition.

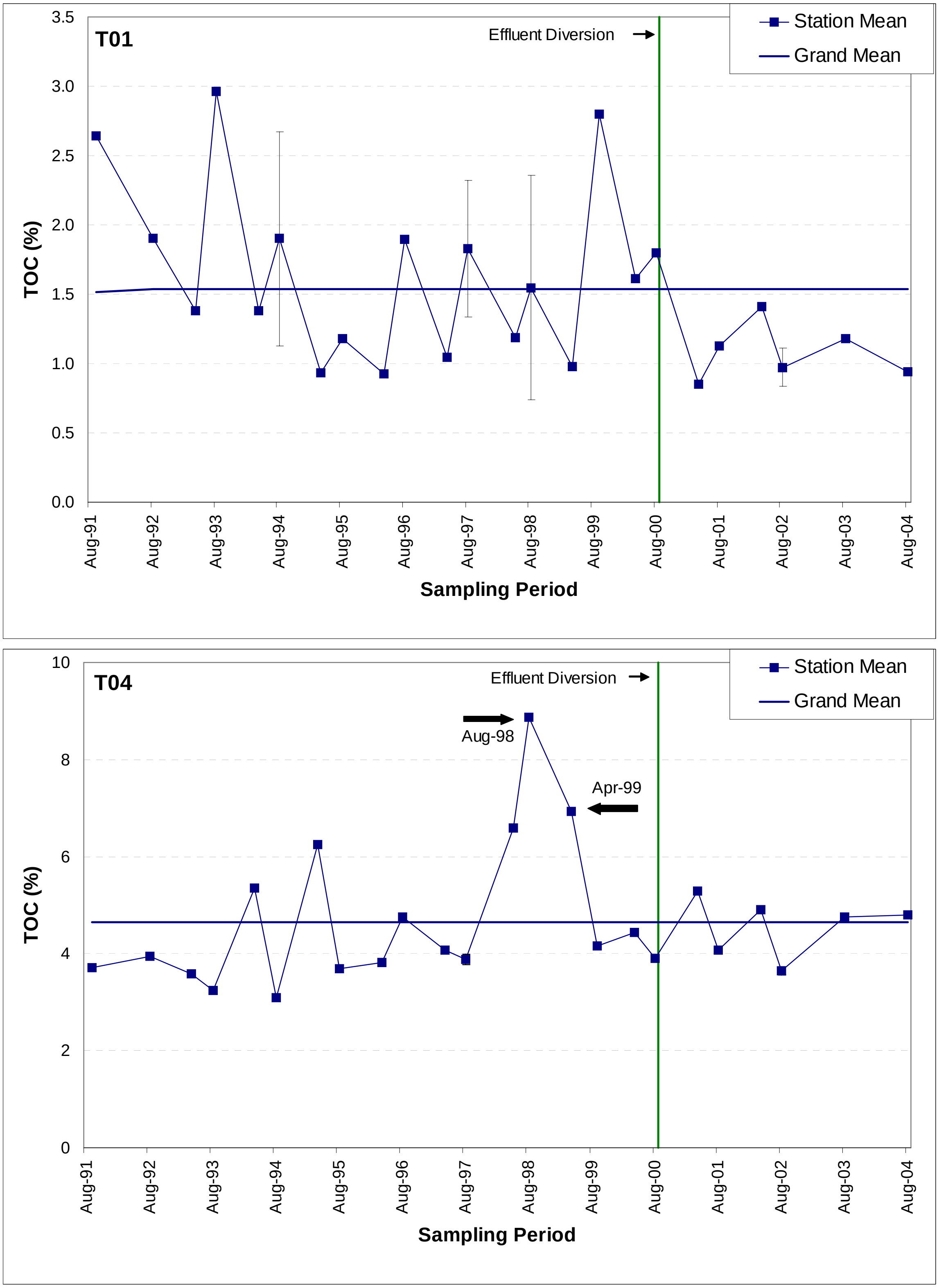

Figure 3-3. Station mean total organic carbon at T01 (top) and T04 (bottom), 1991–2004. Vertical bars represent one standard deviation.

a major *Capitella* bloom that was detected at this station in August 1998 (see Section 5.0). TOC decreased in September 1999 to previous conditions, typical of the mid-1990s (Figure 3-3). This decrease is possibly due to the rapid sedimentation rate (approximately 4 cm/year) observed at the site by Gallagher *et al.* (1992) and Wallace *et al.* (1991).

The increases in TOC at T06 in August 1996 and at T08 in May 1998 were coincident with increases in silt content (compare Figures 3-4 and 3-2), which appear to be associated with small changes in the sampling location (T06, see Appendix B1) and storm activity (T08) (see Section 3.3.1). Increases in TOC at T05A in August 1997 and at T08 in August 1994 appear to be associated with natural variability (CV between triplicate grabs = 30% at T05A and 98% at T08).

Seasonal TOC data from the Benthic Nutrient Flux (Tucker *et al.* 2005) and Traditional Harbor programs showed that grand monthly mean TOC peaks in May (northern region of the harbor evaluated only, T02 and T03). However, the data are highly variable and a one-way analysis of TOC by month showed no significant differences in TOC from March to October (Figure 3-5 and Appendix B3).

3.3.3 *Clostridium perfringens* 1991–2004

A detailed time-series evaluation of the *C. perfringens* data by station showed that abundances of the sewage tracer have decreased harbor-wide since 1998, and that the data were less variable especially at T03, T06, and T07 (station T06 shown in Figure 3-6, all data in Appendix B4). Results from 2004 are consistent with other post-1998 data, with most values consistently below 10,000 colony forming units (cfu) (Appendix C4).

A statistical summary of *C. perfringens* sediment data showed that the abundance of the sewage tracer was highly variable throughout Boston Harbor from 1991 to 2004, especially at T03 (CV = 168%), T06 (CV= 116%), and T04 (CV = 96%) (Figure 3-7; Appendix B4, Table B4-1). More importantly, there has been a significant harbor-wide decrease in the abundance (log-transformed) of *C. perfringens* with time (ANOVA, F = 6.10, $p < 0.001$ and $r = -0.41$; Appendix B4). Significant decreases in the abundance (log-transformed) of *C. perfringens* were also observed at all harbor stations, except T01, T04, T07 and CO19 (Appendix B4). The harbor-wide decrease and reduced temporal variability in the *C. perfringens* data are likely associated with the major improvements made in sewage treatment and discharge in Boston Harbor since 1991, which have resulted in documented reductions in effluent solids inputs to the system (Werme and Hunt, 2001; MTH Environmental and Battelle, 2003).

Notable increases in *C. perfringens* identified from the time-series evaluation (Appendix B4) are generally consistent with the possible outliers identified periodically during the program (Figure 3-7). All of the possible outliers (Figure 3-7) occurred prior to 1998, before most of the improvements to sewage treatment were implemented. Since 1998, there have been no anomalously high abundances of *C. perfringens* in Boston Harbor sediments.

3.3.4 Correspondence within Ancillary Measurements

Results from the correlation analyses are presented in Appendix B5 and summarized in Table 3-1. Sediment variables (percent fines, TOC, and *C. perfringens*) were positively and significantly correlated, indicating that Boston Harbor sediments with high concentrations of one variable (*e.g.*, percent fines) are associated with high concentrations of the second variable (*e.g.*, TOC or *C. perfringens*). Strong correlation coefficients do not necessarily indicate a direct dependence of the variables.

The correlations between the sediment variables were moderate to moderately strong using sediment data collected from 1992 to 2004. For example, the correlation between percent fines and TOC yielded an *r*

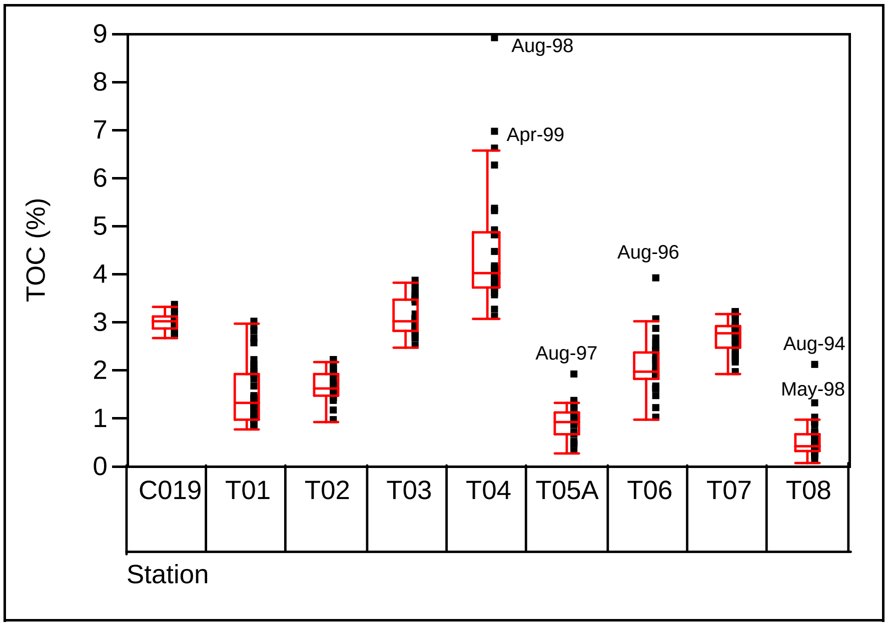

Figure 3-4. Distribution of total organic carbon in Boston Harbor sediments, 1991–2004. For CO19, sediment data from 1994, 1998, 2002 and 2004.

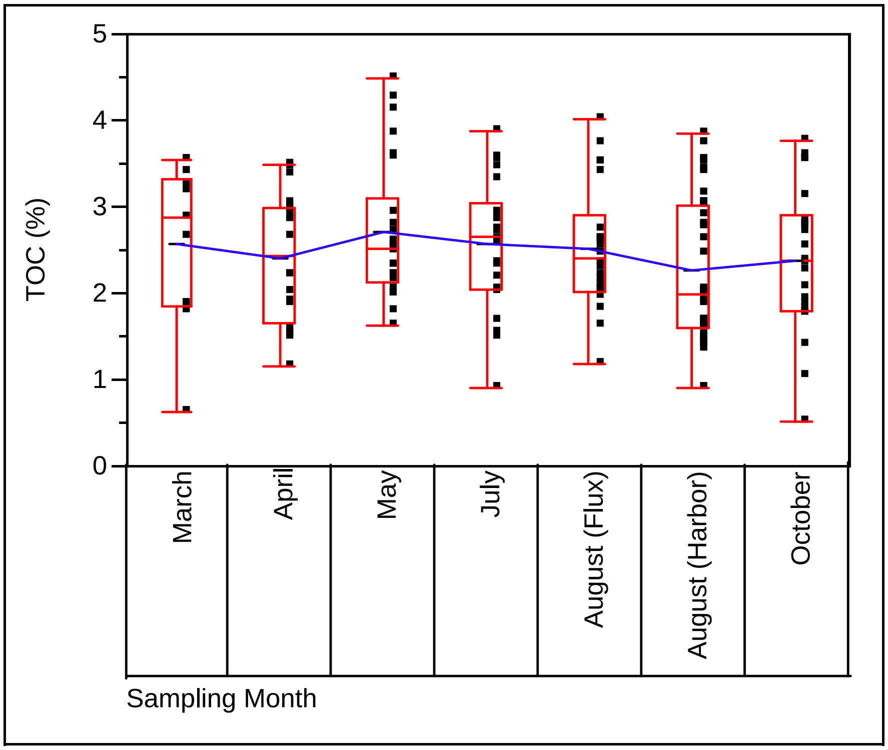

Figure 3-5. Distribution of total organic carbon in Boston Harbor sediments (T02, T03, BH02, BH03 and BH03A) from March to October, 1993–2004. The line connects the grand monthly mean values.

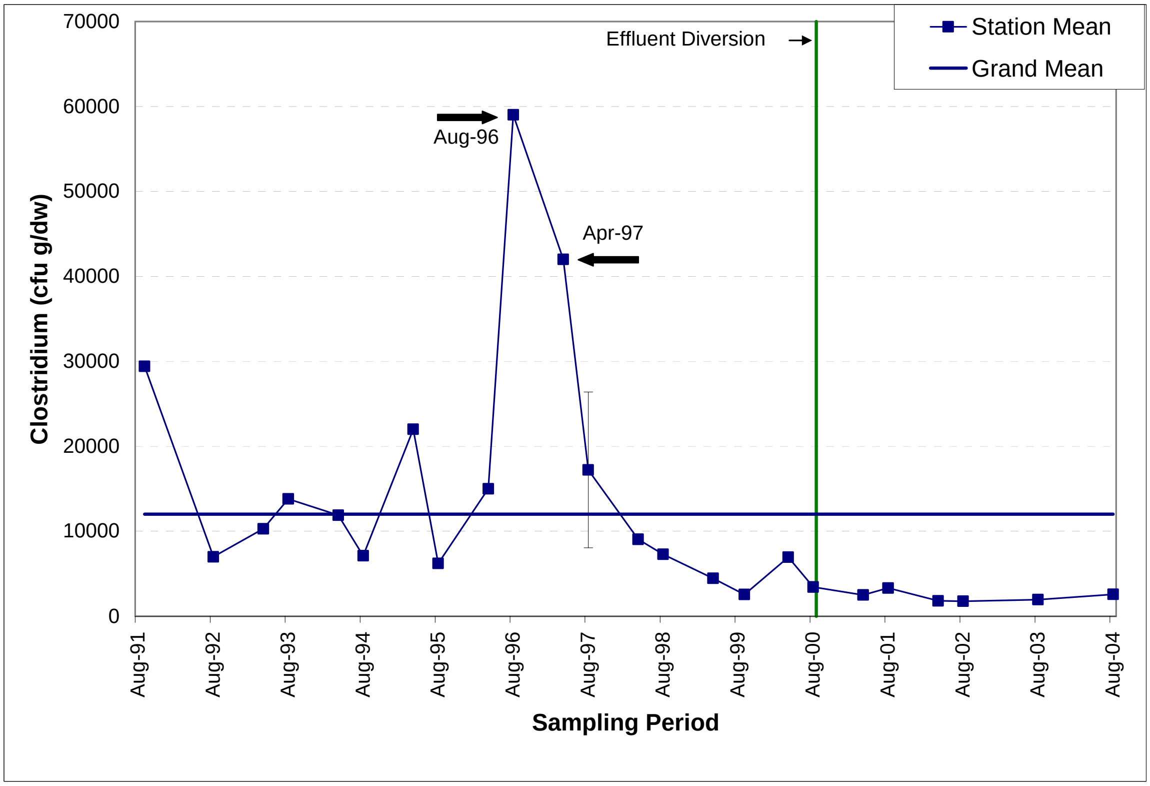

Figure 3-6. Station mean abundance of *Clostridium perfringens* at T06, 1991–2004. Vertical bars represent one standard deviation.

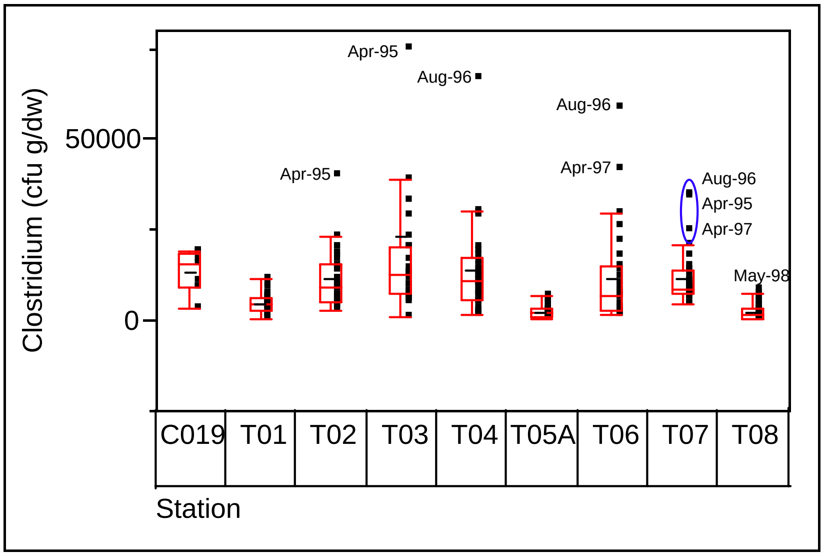

Figure 3-7. Distribution of *Clostridium perfringens* in Boston Harbor sediments, 1991–2004. For CO19, sediment data are from 1994, 1998, 2002, and 2004. Abundance of *C. perfringens* at T03 in September 1991 is not shown; value is off-scale at 207,000 cfu g/dw.

value of 0.80 (Table 3-1), which indicates that approximately 63% of the variation in the data is related[5]. The correlation between *C. perfringens* and percent fines or TOC yielded an *r* value of 0.6, which indicates that approximately 35% of the variation in the data is related.

There were no substantial changes to the strength of the correlation between sediment variables as major improvements to sewage treatment were implemented, although the correlations were typically stronger (higher *r* value) especially after diversion of effluent to the offshore outfall (Table 3-1). Notably, the correlation between *C. perfringens* and percent fines strengthened after major facility improvements were implemented (*r* increased from 0.60 to 0.73), and strengthened again with effluent diversion to the offshore outfall (*r* increased from 0.73 to 0.79; overall change from 0.60 to 0.79). These findings suggest that the sediment variables are more closely related when the inputs (solids, *C. perfringens*) to the system were reduced.

Table 3-1. Pearson product-moment correlation coefficients (r) for Boston Harbor sediment data.

Variable	by Variable	Monitoring years 1992-2004 (n = 244)	Prior to most of the facility improvements 1992–1997 (n = 112)	After most of the facility improvements 1998–2000 (n = 60)	After diversion of effluent to offshore outfall 2001–2004 (n = 64)	Signif. Prob.
		r	***r***	***r***	***r***	
Clostridium (cfu g/dw) (a)	TOC (%)	0.59	0.64	0.58	0.75	<0.001
Fines (%)	TOC (%)	0.80	0.80	0.71	0.92	<0.001
Fines (%)	*Clostridium* (cfu g/dw) (a)	0.60	0.60	0.73	0.79	<0.001

(a) log-transformed

3.4 Conclusions

Overall, because of the high variability in the data, there have not been consistent large-scale, harbor-wide changes in grain-size composition or TOC over time (1991–2004). There has been, however, a significant decrease in TOC with time in the northern region of the harbor at T01, near the Deer Island Treatment Plant. More importantly, actions taken by the MWRA to minimize wastewater impacts to Boston Harbor, beginning with the cessation of sludge disposal in 1991 and continued through 2000 with major facility improvements and effluent diversion, have improved the quality of sediment in Boston Harbor, as evidenced by the significant decrease harbor-wide in the sewage tracer *Clostridium perfringens* with time.

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[5] The square of the coefficient (or r square) is equal to the percent of the variation in one variable that is related to the variation in the other (http://www.surveysystem.com/correlation.htm). The square of 0.795 (*r* = 0.8) is 0.63.

4. 2004 SEDIMENT PROFILE IMAGING

by Robert J. Diaz

4.1 Introduction

Response of the Boston Harbor ecosystem following major reductions in inputs of pollutants, both organic and chemical, is key to our understanding of the restoration of ecosystem function within the harbor. These improvements started in the late 1980s with the formation of the Massachusetts Water Resources Authority (MWRA), which improved treatment facilities and moved sewage discharge to an offshore location. Bothner *et al*. (1998) presented a brief history of environmental degradation within Boston Harbor and showed that sediment quality did improve after reductions in pollutant inputs, but that contaminated sediments remain a "lingering legacy of the long history of contaminant discharge." The main issues that still need to be addressed, however, relate to the response of the benthos and restoration of ecosystem function following the cessation of sewage discharge within the harbor in September 2000.

Given that most pollutants are particle reactive, the sediments are the final sinks where pollutant accumulation occurs (Olsen *et al.* 1982) and where ecosystem function is most likely to be disrupted by toxic or enrichment effects. Surficial sediments are critical to many ecosystem functions with flows of energy (organic carbon, living biomass, secondary production) and nutrients (nitrogen, phosphorus) all regulated by processes at the sediment-water interface (Rhoads 1974, Diaz and Schaffner 1990). Thus, characterization of the benthic environment from physical and biological points of view became a key part of the MWRA long-term sediment monitoring within Boston Harbor. As MWRA's long-term monitoring plan was being developed, reconnaissance surveys were carried out using sediment profile imaging in 1989 and 1990 (SAIC 1990). The current sediment profile image monitoring strategy was established in 1993 and was based on data collected in 1990–1992 (SAIC 1992, Blake *et al.* 1993). This strategy includes summer sediment profile camera sampling at a series of 52 reconnaissance (R) stations, and camera and infauna sampling at eight traditional (T) stations (Figure 2-1). In 2004, station CO19, near a Combined Sewer Overflow (CSO) in the inner harbor, was added to monitor changes in the environment there after upgrades to the CSO system (Figure 2-1).

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

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

4.2 Methods

4.2.1 Image Collection and Analysis

At each station, a digital Hulcher sediment profile camera was deployed a minimum of three times. The digital profile camera captured a 5.2-megapixel image using a Minolta Dimage-7i camera. The camera was set to ISO 200, white balance to flash color temperature, contrast to normal, saturation to normal, maximum image size of 2560 X 1920 pixels, and saved using super-fine jpg compression. Images were stored in the camera on a 1-gigabyte IBM microdrive. In addition, a video feed from the digital camera to the surface vessel allowed monitoring of the Hulcher camera operation and image capture in real time. The camera was triggered from the surface about 1-sec after bottom contact and after the prism stopped penetrating the sediment. Approximately 75 pounds of lead were added to the camera frame to improve penetration at all stations.

Steps in the analysis of the sediment profile images were the same as those followed by Diaz and Schaffner (1988) and Williams *et al*. (2005). Data from each image were sequentially saved to a spreadsheet file for later analysis. Details of how these data were obtained can be found in Diaz and Schaffner (1988), Rhoads and Germano (1986), and Williams *et al*. (2005).

4.2.2 Data Reduction and Statistics

Prism penetration for all three replicates at stations R19 and T08 was insufficient for estimating the apparent color RPD layer depth. Thus, prism penetration depth was used as a minimum estimate of the RPD layer depth for these stations and designated as > in data tables. The organism sediment index (OSI) for these two stations was calculated using prism penetration depth as a minimum estimate of RPD and was also designated as > in data tables. Other stations with one or two of the three replicate images that also had shallow prism penetration leading to >RPD layer depths and >OSI were R08, R22, R23, and R36. For these four stations, only the replicate images that had sufficient penetration to allow for estimation of RPD layer depth and OSI were used. No > data were included in any comparison involving RPD or OSI. All other stations had three measured RPD layer depths, except R06 where all replicates were too disturbed to estimate the RPD and R13 and T04 where one replicate was disturbed at each.

Analysis of variance (ANOVA) or Student's t-test for paired data was used to test for differences between and within areas for quantitative parameters. Normality was checked with the Shapiro-Wilk test and homogeneity of variance with Bartlett's test. If variance was not homogeneous, Welch analysis of variance, which allows standard deviations to be unequal, was used in testing for mean differences (Zar 1999). Cochran-Mantel-Haenszel statistics and Fisher Exact Test were used for comparison involving categorical parameters (Agresti 1990). Correlation and principle components analyses were used to arrive at a relative benthic habitat quality ranking for all traditional stations based on sediment, infauna, and SPI images data. All statistical tests were conducted using SAS's JMP program for Macintosh.

4.3 Results and Discussion

Copies of 2004 harbor SPI images and replicate data are contained in the CD-ROM Appendix C. Table 4-1 contains a station summary of the 2004 SPI data. Representative images from each station are contained in Figures 4-1 and 4-2.

4.3.1 Physical Processes and Sediments

The predominant sediment type throughout the study area appeared to be silt with a significant fine-sand component. In 2004, the three sediment categories of silty-fine-sand (modal Phi 6 to 5), fine-sandy-silt (modal Phi 5 to 4), and fine-sand-silt-clay (modal Phi 5.5 to 4.5) occurred at 34% (21 of 61) of the stations (Table 4-1). The finest sediment category of silt-clay occurred at 56% of stations. The remaining 10% of the stations were sand and gravel (R08, R53, and T08). Pebbles were present at six stations but a major component of the sediment only at station R06. None of the stations appeared to have layered sediments, and bedforms were observed at five stations (Table 4-1). Relative to 2003, sediments in 2004 appeared similar in grain-size, texture, and color.

The broad range of sedimentary habitats within the harbor was also reflected in the average station prism penetration depth, which ranged from 1.8 cm at fine-medium-sand-gravel-pebble station R19 in Hull Bay to 23.4 cm at silty-clay station T04 in inner Dorchester Bay (Figures 4-1 and 4-2). Prism penetration depth was significantly lower at stations with coarser sediments that were sand, gravel, or pebble (2.5±1.3 cm, mean±SE, N = 6) than at silty-sand stations (8.6±0.7 cm, N = 21) or at silty stations (13.6±0.6 cm, N = 34), (Welch ANOVA, df = 2, p = <0.001).

The bed roughness or surface relief was the same at stations that appeared to be dominated by physical or biological processes (ANOVA, df = 2, p = 0.077). In physically dominated habitats with coarse sediments, surface relief was due to sediment grain size (gravel, pebble, or cobble) and bedforms, and in silty sediments was related to what appeared to be high sedimentation rates as indicted by soft, high-water-content sediment or to irregularities in the surface. In biologically dominated habitats, surface relief was typically biogenic structures produced by benthic organisms. *Ampelisca* spp. tube mats were the primary relief-creating biogenic features, followed by what appeared to be feeding pits or mounds.

Table 4-1. Summary of sediment profile image data for Boston Harbor, August 2004.

STA	Ave. Pen (cm)	Ave. RPD (cm)	Modal Grain Size	Surface Features	*Ampelisca* Tubes	Worm Tubes	Infauna (# per image)	Burrows (# per image)	Oxic Voids (# per image)	Anaerobic Voids (#/image)	Gas Voids (# per image)	Succ. Stage	OSI	Bedforms
R02	12.3	4.5	SIFS	BIO/PHY	NONE	SOME	8.3	6.7	4.3	0.3	0.0	II-III	10.0	No
R03	11.6	1.3	SIFS	BIO/PHY	NONE	FEW	3.0	3.3	1.7	0.3	0.0	I-III	7.3	No
R04	13.8	1.1	SICL	BIO/PHY	NONE	FEW	2.3	2.3	2.3	0.7	0.0	I-III	7.0	No
R05	13.3	1.1	SICL	BIO/PHY	SOME	FEW	3.3	4.7	4.0	0.0	0.0	I-III	6.7	No
R06	2.1	IND	FSSIPB	PHY	FEW	MANY	IND	IND	IND	IND	IND	I-II	IND	No
R07	12.3	4.3	SICL	BIO/PHY	FEW	FEW	7.7	6.0	4.3	0.3	0.0	II-III	10.3	No
R08	2.5	2.3	FS	PHY	NONE	FEW	0.0	0.7	0.0	0.0	0.0	I	5.0	Yes
R09	12.2	1.5	SIFS	PHY	FEW	SOME	3.7	4.0	1.0	0.0	0.0	I-II	6.7	No
R10	21.0	1.5	SICL	PHY	NONE	FEW	2.7	4.3	4.3	0.7	0.0	I-III	7.3	No
R11	17.3	3.2	SICL	BIO/PHY	NONE	FEW	6.0	5.7	2.7	1.0	0.0	I-III	10.0	No
R12	16.7	1.7	SICL	BIO/PHY	NONE	FEW	3.0	3.3	1.0	0.0	0.0	I-III	6.3	No
R13	9.7	1.7	FSSICL	PHY	NONE	MANY	3.0	2.7	0.3	0.0	0.0	I	3.5	No
R14	8.8	1.5	FSSI	BIO/PHY	NONE	FEW	2.3	7.7	0.3	0.0	0.0	I	4.7	No
R15	6.8	1.2	FSSI	PHY	FEW	SOME	2.3	5.3	0.0	0.0	0.0	I-II	4.0	No
R16	6.3	1.8	FSSI	PHY	NONE	SOME	1.3	3.3	0.0	0.0	0.0	I	3.7	No
R17	17.3	5.1	SICL	BIO/PHY	NONE	FEW	2.7	7.0	5.0	0.0	0.0	II-III	9.3	No
R18	16.2	1.8	SICL	BIO/PHY	SOME	SOME	3.0	4.7	2.7	1.0	0.7	II-III	6.0	No
R19	1.8	>1.8	FSMSGR	PHY	SOME	SOME	0.0	0.0	0.0	0.0	0.0	I-II	>4.3	No
R20	13.3	2.5	SICL	BIO	MAT	FEW	5.0	4.3	2.7	0.0	0.0	II-III	7.7	No
R21	8.6	5.6	SICL	BIO	MAT	FEW	6.0	7.3	6.7	0.0	0.0	II-III	10.0	No
R22	2.3	2.3	FSMSGR	PHY	NONE	SOME	0.0	0.0	0.0	0.0	0.0	I	5.0	Yes
R23	3.5	3.0	FSMSGR	PHY	SOME	SOME	0.7	0.3	0.0	0.0	0.0	I-II	6.0	Yes
R24	10.8	1.7	SICL	BIO/PHY	NONE	SOME	4.3	5.0	1.3	0.3	0.0	I-III	6.7	No
R25	15.6	1.7	SICL	BIO/PHY	NONE	SOME	2.0	4.7	3.3	0.7	0.0	I-III	7.7	No
R26	12.2	1.0	SICL	BIO/PHY	NONE	SOME	3.7	6.0	4.0	0.3	0.0	I-III	6.7	No
R27	11.2	1.5	SICL	BIO/PHY	FEW	SOME	1.7	4.3	3.0	0.0	0.0	II-III	6.7	No

Table 4-1. Summary of sediment profile image data for Boston Harbor, August 2004.

STA	Ave. Pen (cm)	Ave. RPD (cm)	Modal Grain Size	Surface Features	*Ampelisca* Tubes	Worm Tubes	Infauna (# per image)	Burrows (# per image)	Oxic Voids (# per image)	Anaerobic Voids (#/image)	Gas Voids (# per image)	Succ. Stage	OSI	Bedforms
R28	9.5	4.7	SICL	BIO/PHY	MAT	FEW	8.7	7.7	4.0	0.0	0.0	II-III	9.7	No
R29	11.3	4.3	SICL	BIO	MAT	FEW	6.7	8.0	6.0	0.0	0.0	II-III	9.7	No
R30	9.6	1.6	SICL	BIO/PHY	SOME	SOME	5.0	6.0	3.0	0.0	0.0	II-III	6.7	No
R31	11.2	3.1	SICL	BIO/PHY	SOME	FEW	7.0	9.3	1.7	0.0	0.0	II-III	8.7	No
R32	11.2	1.2	SICL	BIO/PHY	FEW	SOME	1.3	6.3	1.7	0.0	0.0	II-III	6.3	No
R33	10.1	1.4	SICL	BIO/PHY	NONE	FEW	2.3	4.7	1.0	0.0	0.0	I-III	6.0	No
R34	12.9	2.0	SICL	BIO/PHY	NONE	FEW	1.3	5.7	3.3	0.0	0.0	I-III	7.0	No
R35	10.9	1.1	SICL	BIO/PHY	NONE	FEW	0.3	6.3	1.0	0.3	0.0	I	4.3	No
R36	2.5	2.1	FS	PHY	NONE	SOME	0.0	0.0	0.0	0.0	0.0	I	4.5	Yes
R37	10.6	2.1	SICL	BIO/PHY	FEW	FEW	0.7	7.7	1.7	0.0	0.0	I-III	7.3	No
R38	16.3	1.8	SICL	BIO/PHY	SOME	FEW	1.3	6.7	2.3	0.0	0.0	II-III	7.0	No
R39	10.2	2.2	SICL	BIO/PHY	NONE	FEW	3.7	3.7	0.7	0.0	0.0	I-II	6.0	No
R40	6.8	1.0	SIFS	BIO/PHY	FEW	FEW	1.7	5.3	1.7	0.0	0.0	II-III	6.0	No
R41	10.6	1.1	SIFS	BIO/PHY	SOME	FEW	1.7	5.0	2.3	0.0	0.0	I-III	6.7	No
R42	5.1	1.4	SIFS	BIO/PHY	FEW	SOME	0.7	3.3	0.0	0.0	0.0	I-II	4.3	No
R43	16.3	1.4	SICL	PHY	NONE	FEW	4.0	3.0	1.3	0.3	0.0	I-III	7.3	No
R44	18.2	1.6	SICL	BIO/PHY	NONE	SOME	1.7	3.3	1.7	1.7	1.7	I-III	6.0	No
R45	12.2	1.9	SICL	BIO/PHY	FEW	SOME	6.3	5.3	1.0	0.0	0.0	II-III	7.0	No
R46	12.6	4.4	SICL	BIO/PHY	MAT	SOME	8.7	6.7	2.0	0.0	0.0	II-III	10.0	No
R47	12.1	4.6	SICL	BIO/PHY	SOME	FEW	5.7	6.3	3.7	0.3	0.0	II-III	9.3	No
R48	10.4	1.2	SIFS	PHY	FEW	FEW	1.7	5.7	1.3	0.0	0.0	II-III	6.7	No
R49	10.9	1.7	SIFS	BIO/PHY	SOME	FEW	1.7	6.7	1.0	0.0	0.0	I-III	6.3	No
R50	8.0	1.7	FSSI	BIO/PHY	NONE	MANY	5.3	6.0	0.0	0.0	0.0	I-II	5.0	No
R51	9.4	1.5	FSSI	BIO/PHY	NONE	FEW	1.7	4.7	1.7	0.0	0.0	I-III	6.7	No
R52	8.3	1.0	FSSI	BIO/PHY	NONE	FEW	1.3	3.3	0.3	0.0	0.0	I-II	5.0	No
R53	5.7	1.5	FSSI	PHY	NONE	FEW	0.7	6.0	0.7	0.0	0.0	I-III	6.0	No

Table 4-1. Summary of sediment profile image data for Boston Harbor, August 2004.

STA	Ave. Pen (cm)	Ave. RPD (cm)	Modal Grain Size	Surface Features	*Ampelisca* Tubes	Worm Tubes	Infauna (# per image)	Burrows (# per image)	Oxic Voids (# per image)	Anaerobic Voids (#/image)	Gas Voids (# per image)	Succ. Stage	OSI	Bedforms
T01	4.9	1.3	FSSI	PHY	NONE	MANY	0.7	3.0	0.0	0.0	0.0	I-II	4.7	No
T02	11.4	1.4	SICL	BIO/PHY	FEW	FEW	1.7	4.3	2.0	0.0	0.0	I-III	7.3	No
T03	12.1	2.6	SICL	BIO	MAT	FEW	7.0	10.3	4.3	0.3	0.0	II-III	7.7	No
T04	23.4	1.7	SICL	PHY	NONE	FEW	0.7	2.0	0.0	0.3	0.7	I	2.5	No
T05A	9.2	2.7	FSSI	BIO	MAT	NONE	2.3	8.7	2.0	0.0	0.0	II-III	8.0	No
T06	10.0	1.2	SIFS	BIO	MAT	FEW	5.0	5.0	1.3	0.0	0.0	II-III	5.7	No
T07	12.3	2.8	SIFS	PHY	NONE	SOME	4.7	2.7	2.3	0.0	0.0	I-III	7.7	No
T08	2.6	>2.6	FSMS	PHY	SOME	FEW	0.0	0.0	0.0	0.0	0.0	I-II	>5.7	Yes
C019	21.8	1.1	SICL	PHY	NONE	NONE	0.3	2.0	3.7	1.7	0.0	I-III	7.0	No

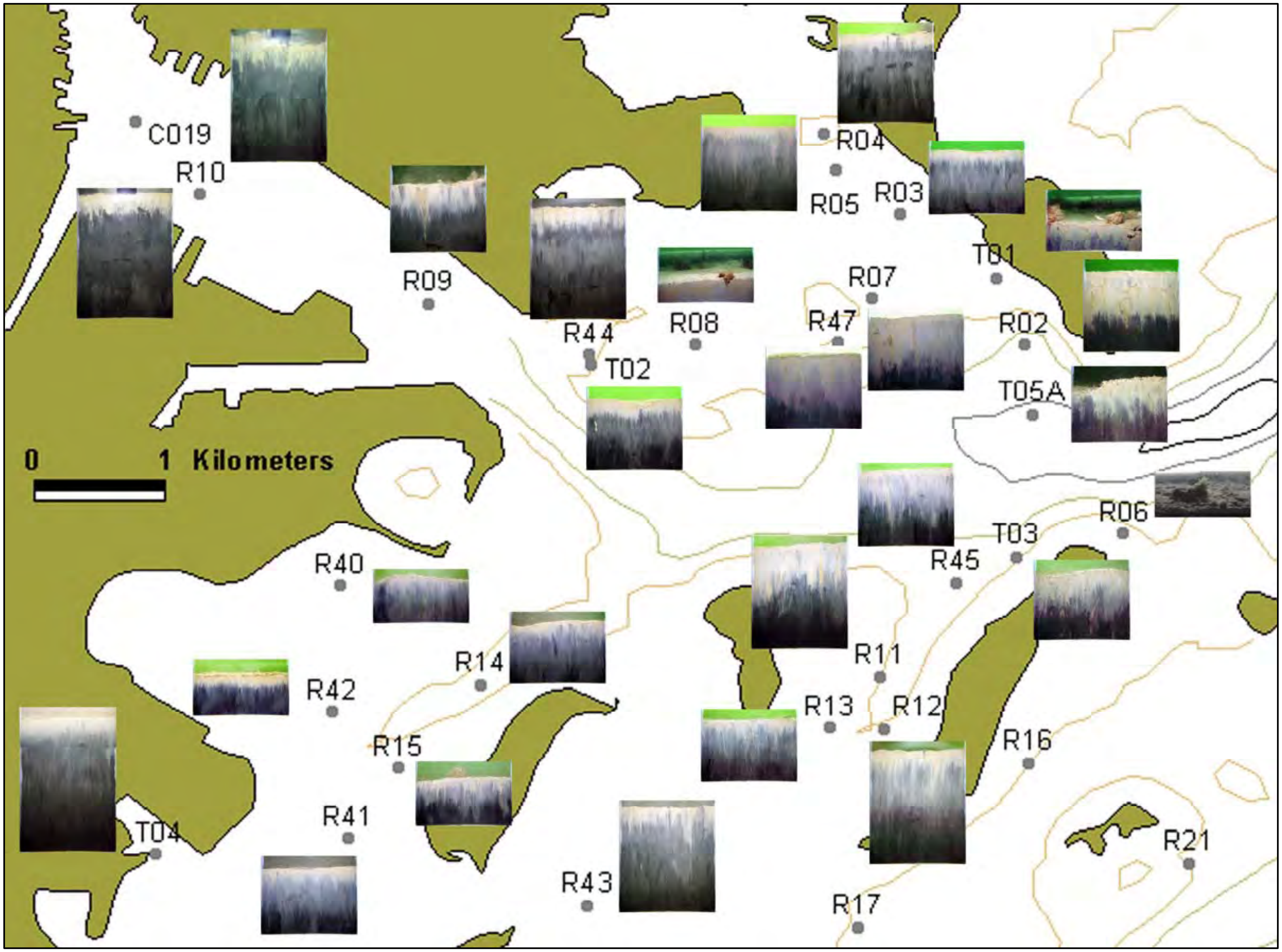


Figure 4-1. SPI images from the northern stations in Boston Harbor.

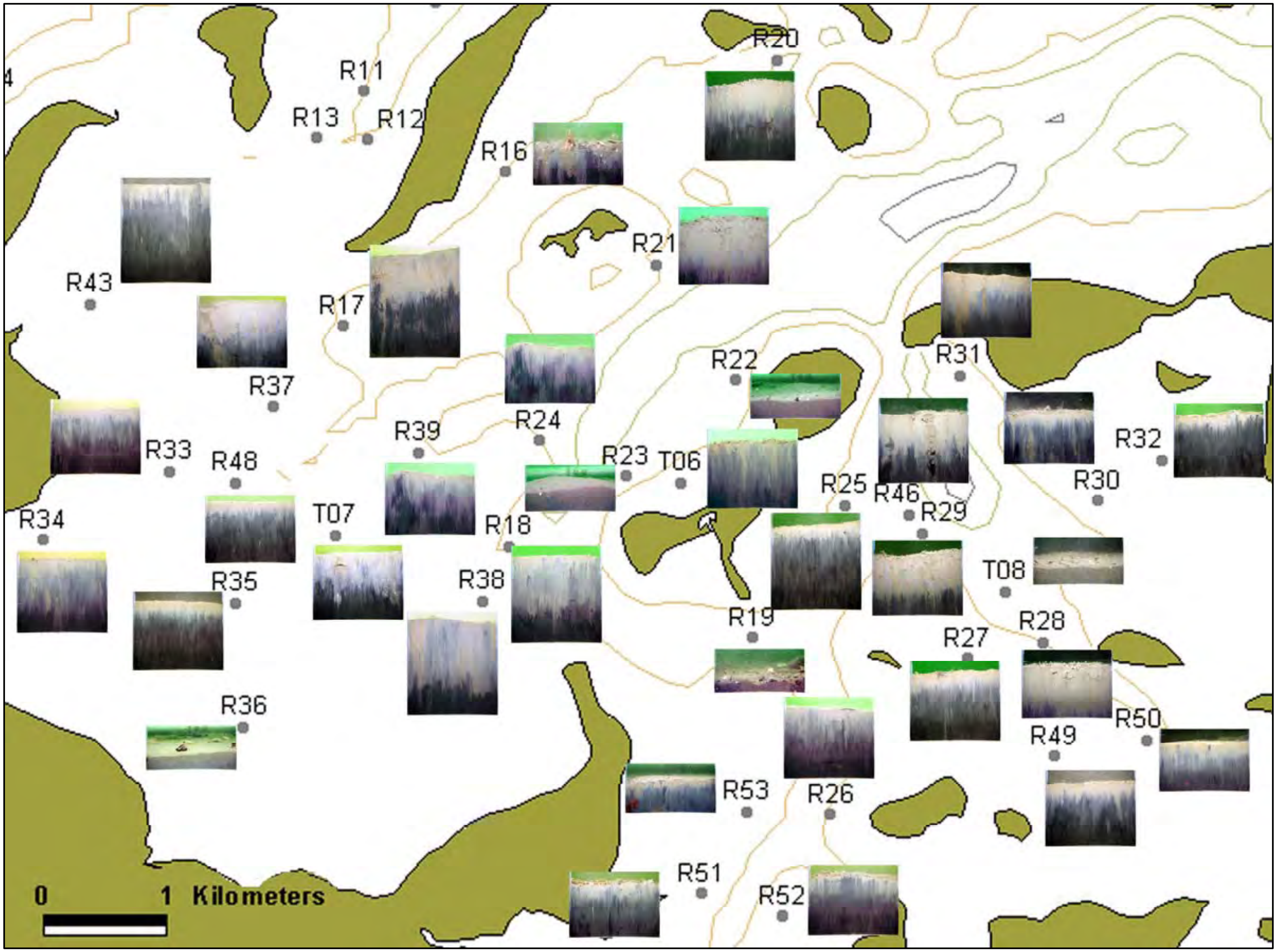


Figure 4-2. SPI images from the southern stations in Boston Harbor.

4.3.2 Apparent Color RPD Layer Depth

The grand mean depth of the apparent color redox potential discontinuity (RPD) layer for 2004 was 2.1±1.2 (±SD) cm. The shallowest RPD layer was 1.0 cm at station R26 in inner Hull Bay near the Weymouth River and deepest was 5.6 cm at station R21 in outer Quincy Bay near the harbor mouth (Table 4-1). Stations that appeared to have soft organically enriched (>3% TOC) dark-gray silty sediments also tended to have shallower RPD values. At the traditional grab stations and C019, where TOC was measured, stations T04 and C019 had the deepest penetration, darkest sediments, and highest TOC (Figure 4-3). However, there was no significant correlation between RPD layer depth and TOC ($r = 0.05$, $p = 0.771$), likely because processes dominating stations differed. The RPD layer depth at T04 was 1.7 cm and appeared to be a result of physical resuspension/deposition events with some minor bioturbation. At C019, the RPD was 1.1 cm and appeared to be structured by biogenic activity. Deep RPD layers at T03 and T07, where TOC was close to 3%, also appeared related to biogenic activity (Figure 4-3). A general impression of the T-stations is that somewhere between 1% and 2% TOC, the color and texture of the sediment lightens and becomes more complex (Figure 4-3). In a recent assessment of the effects of TOC on coastal benthic community structure, Hyland et al. (2005) found that when TOC was >3.5%, the benthos exhibited signs of stress. Station T04 has consistently had the highest TOC of the T-stations and a community structure characteristic of a stressed benthos (see Chapter 5). Organic loading, physical disturbance, and possibly periodic low dissolved oxygen prevented deep bioturbating fauna from successfully colonizing, resulting in an RPD layer that appears to be dominated by physical processes. Similar stressful conditions do not seem to be acting at station C019: even though sediment grain-size and compaction are the same, the apparent level of bioturbation at C019 is higher than at T04. In 2004, there were seven other stations that had silt-clay sediments similar to T04, but these stations tended to be close to the mouth of the harbor or away from the mainland, and had RPD layer depths >4 cm (Figures 4-1 and 4-2, Table 4-1). Surface sediments at these deeper-RPD-layer stations were either biologically dominated or reflected structuring by a combination of physical and biological processes, and all were characterized by a high degree of bioturbation. For example, stations R21, R28, R29, and R46 had dense Ampelisca spp. tube mats (defined as more than 50 tubes in one image) and other evidence of well-developed infaunal communities (Table 4-1).

Ampelisca spp. tubes were the primary biogenic structures responsible for deepening RPD layers at 31 stations (52%) with sediments that ranged from coarse to silty. Where *Ampelisca* spp. tube mats occurred, mean RPD depths were significantly deeper (3.5±0.37 cm, mean±SE) than at stations without *Ampelisca* spp. (1.9±0.20 cm) or at stations with *Ampelisca* spp. present, but at less than tube-mat densities (1.9±0.24 cm) (ANOVA, $df = 2$, $F = 7.6$, $p = 0.001$). Ampeliscids formed tube mats in at least one replicate image at eight stations (13%) toward the outer harbor from the western end of Deer Island Flats to Hull Bay (Figure 4-4). The percentage of stations with mat densities decreased in 2004 to 13%, the lowest level since the start of the SPI monitoring in August 1992 (Figure 4-5). Relative to previous years, the high was 65% in 1995 and the low was 18% in 1990. The total number of stations with *Ampelisca* spp. tubes at any density, from a few tubes to mat densities, also declined from 38 stations in 2003 to 31 stations in 2004 (Table 4-1). All stations that had tube mats in 2004 also had tube mats in 2003. The stations with mats in 2003 that declined in tube densities in 2004 were R18, R27, R30, R31, R38, and R47. There were also four stations (R02, R03, R11, and R25) that went from having tube mats in 2003 to no tubes in 2004.

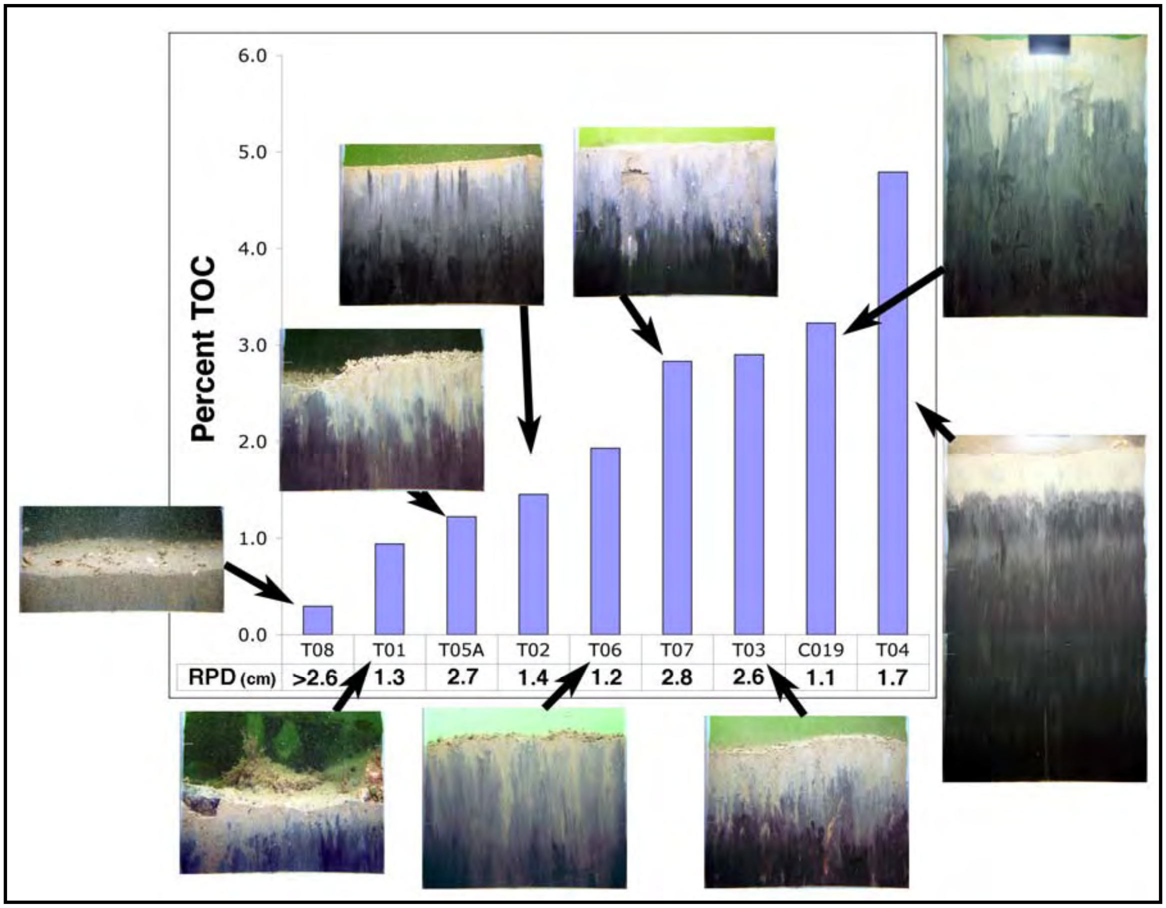


Figure 4-3. TOC (%) for traditional benthic stations, with examples of SPI images. All images are about 15 cm wide.

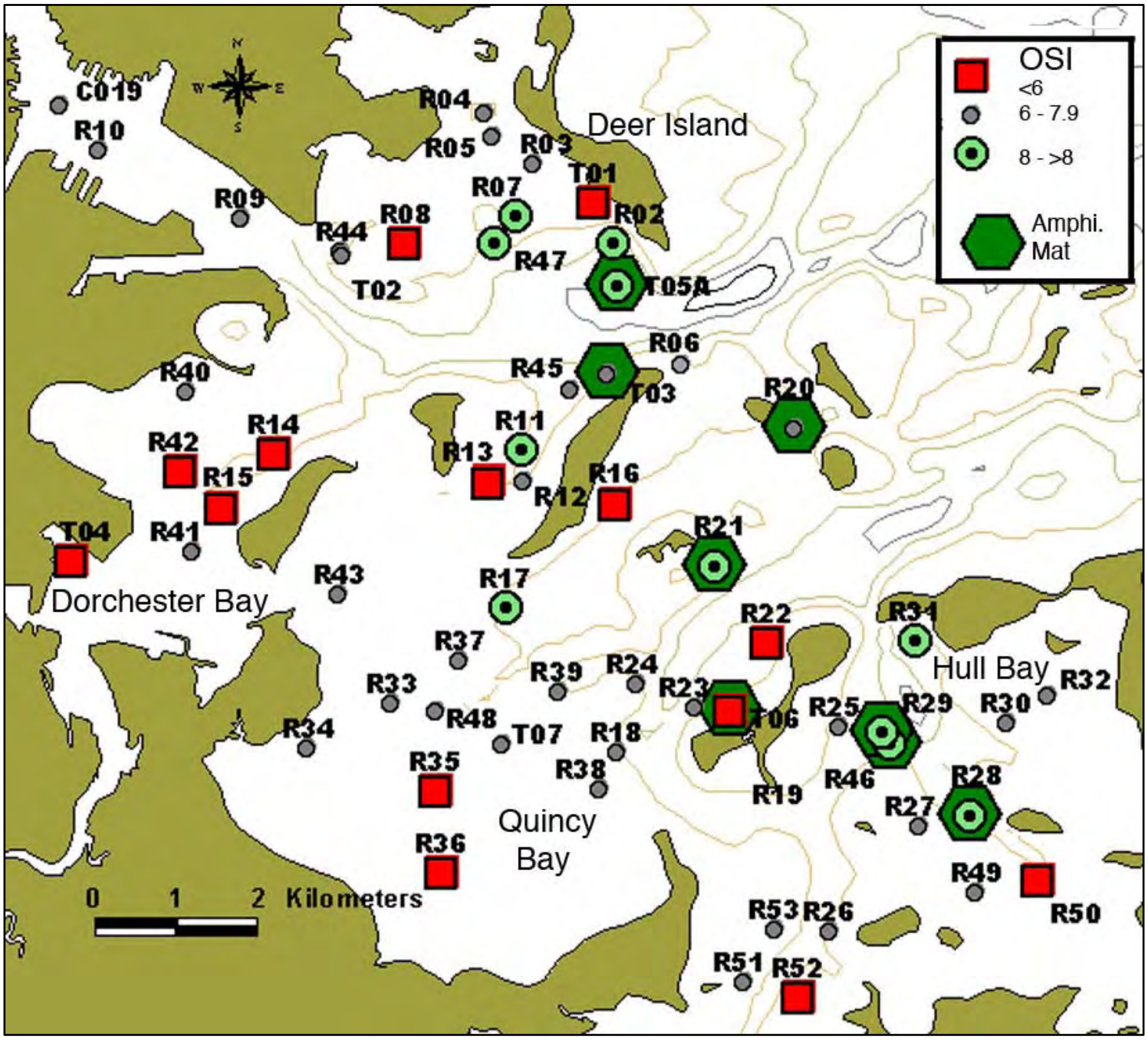


Figure 4-4. OSI and amphipod mats in Boston Harbor.

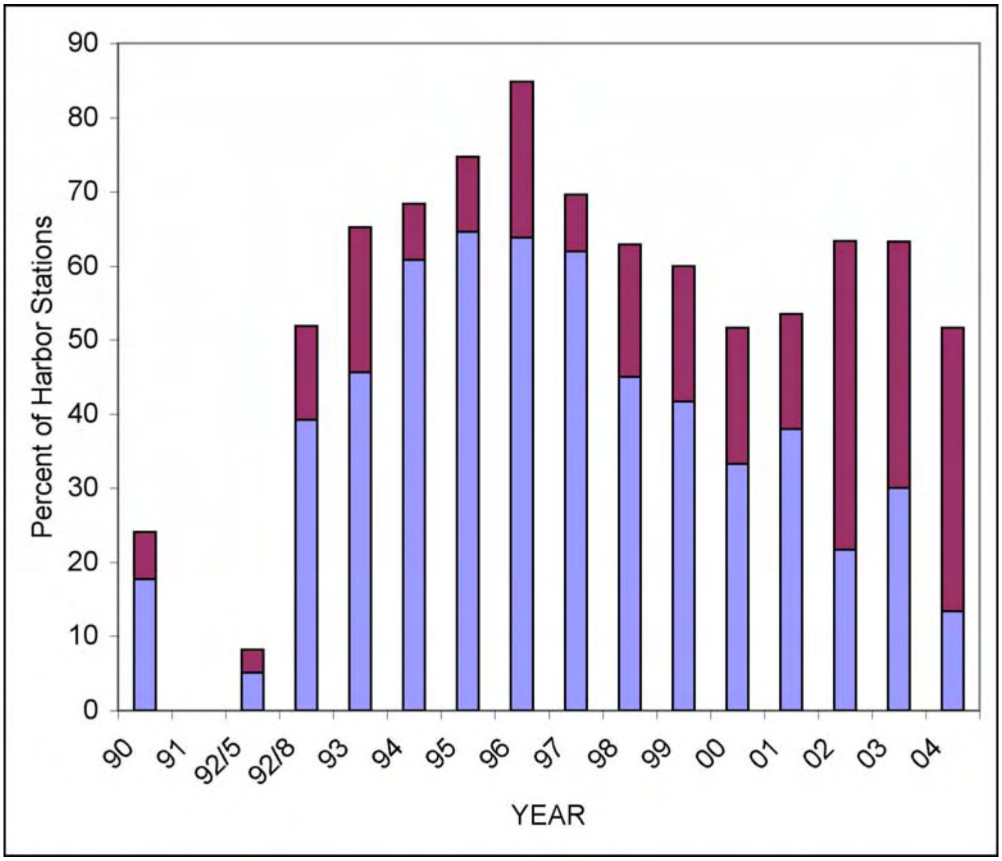


Figure 4-5. Percentage of stations with *Ampelisca* spp. tube mats (bottom portion of bar) and the total percentage of stations with *Ampelisca* spp. tubes. Based in part on Blake *et al.* (1998).

4.3.3 Biogenic Activity

Tubes and feeding structures were the predominant biogenic features observed at the sediment surface. The sediment surface at 10% of the stations was dominated by biological processes as evidenced by the widespread activity associated with successional Stage II and III fauna (Table 4-1). Evidence that a combination of biological and physical processes was active in structuring bed roughness occurred at 59% of the stations. Physical processes dominated at 31% of the stations.

The number of infaunal organisms per image was significantly higher at stations with biological or biological and physical dominated surfaces (5.3±0.88 and 3.4±0.36 infauna/image, mean±SE) relative to physically dominated surfaces (1.5±0.51 infauna/image) (ANOVA, df = 2, F = 8.8, p = 0.0005). The highest number of infauna was seen at station R28 in Hull Bay with a mean of 8.7 infauna/image. Similar patterns of higher mean values at biologically dominated stations were observed for number of burrows and oxic voids per image. Gas-filled voids, indicative of high rates of organic loading to the sediments, occurred at three stations (R18, R44, and T04). The overall level of biogenic activity in 2004 appeared to be the same as in 2003. The number of infauna increased in 2004 but burrows and voids remained the same. Of the two principle parameters dependent on biogenic activity, RPD declined in 2004 and OSI remained the same (Table 4-2).

Table 4-2. Comparison of biogenic activity parameters between 2003 and 2004. For each parameter, only stations with data for both years were included. Student's t-test for paired data was used to determine differences.

Parameter	Year	N	Means	Probability
Infauna (#/image)	2003 < 2004	58	1.5 < 3.1	<0.001
Burrows (#/image)	2003 = 2004	58	4.9 = 4.8	0.815
Oxic Voids (#/image)	2003 = 2004	58	2.4 < 1.9	0.050
RPD (cm)	2003 > 2004	55	3.0 < 2.1	<0.001
OSI	2003 = 2004	55	6.8 = 6.7	0.709

4.3.4 Successional Stage and Organism Sediment Index

The apparent modal successional stage indicated that the infaunal communities in the harbor area ranged from pioneering Stage I to equilibrium Stage III. The high degree of biogenic sediment reworking observed at many stations was consistent with both intermediate Stage II and equilibrium Stage III fauna, which were observed at 87% of stations. Large infauna, likely Stage II and III species, were observed at 14 stations. Evidence of Stage I fauna occurred at 66% of the stations, and at about half of these stations, Stage I fauna occurred in combination with Stage II and III fauna. Fourteen percent of the stations had signs of only Stage I. Station T04 in inner Dorchester Bay, with a Stage I designation, also had the poorest infaunal community structure of all stations (see Chapter 5).

The range of the Organism Sediment Index (OSI) from 2.5 to 10.3 at harbor stations indicated a wide variety of environmental conditions affecting infaunal community development. The lowest values occurred at fine-sediment stations that had little evidence of advanced successional stage fauna, for example stations R15 and T04, which had small infauna(<1 mm diameter) and burrows (<2 mm diameter) visible (Table 4- 1). The highest OSI values were also at fine-sediment stations, but at those with high levels of advanced successional stage activity, for example stations R07 and R21, which in addition to small infauna and burrows had larger infauna and oxic feeding voids. OSI values <6, which indicated communities that were under some form of moderate stress, occurred at 24% of stations. Low OSI stations were located in the inner harbor and bays and near the harbor mouth. These low OSI values are likely related to either organic loading (Hyland *et al.* 2005), particularly at Dorchester Bay station T04 and Quincy Bay station R35, or physical disturbance (Rhoads and Germano 1986), particularly at station T01 off Deer Island and Dorchester Bay station R42. However, at many low OSI stations it appeared from the SPI images that both organic matter and physical stress contributed to the low OSI values (see images from T04 and R13, Figure 4-1). Higher OSI stations (>8) occurred in two broad clusters centered off Deer Island and in the outer portion of Hull Bay, with three stations scattered through the mid-harbor (Figure 4-4). Three of the eight stations with *Ampelisca* spp. tube mats had OSI values <8. Stations R20 and T03, both near the mouth of the harbor, were close to 8 at 7.7 (Table 4-1), but T06 in mid-harbor had an OSI of 5.7 because of a shallow RPD layer depth. Based on SPI, the sources of stress to the benthos appear to be a combination of physical processes such as hydrodynamics and sediment transport at coarse-sediment stations (for example, station R08 or T01) and high rates of sediment accumulation and organic enrichment at muddy stations (for example, station R35 or T04).

4.3.5 Long-Term Benthic Habitat Conditions and Trends: 1992–2004

To look for long-term patterns in the SPI data, the data were grouped into the three periods that Taylor (2005) found when he summarized the major patterns in freshwater flows and loadings of total nitrogen (TN), total phosphorus (TP), total suspended solids (TSS), and particulate organic carbon (POC) to Boston Harbor between 1995 and 2003. Period A was from 1995 through mid-1998 when the Nut Island discharge was diverted to Deer Island; the harbor received elevated freshwater flows and high loadings of TN, TP, TSS, and POC. Rivers provided most of the freshwater flows and wastewater treatment facilities contributed most of the TN, TP, TSS, and POC loadings. Period B was from mid-1998 to 2000 when discharges from Nut Island were transferred to Deer Island for treatment prior to release. Freshwater flows remained moderately elevated above the long-term average, but loadings of TSS and POC, and to a lesser extent TN and TP, decreased. Period C was post-transfer of the discharge offshore. Loadings of TSS and POC were further reduced, but the largest decrease was observed for TN and TP. Freshwater flows declined for period C. The changes in wastewater discharge from 1995 to 2003 resulted in about a 90% decrease in loadings to Boston Harbor. For TSS and POC, most of the decreases occurred between Periods A and B, presumably in response to the transfer of the Nut Island discharge to Deer Island and treatment upgrade. For TN and TP, most of the decreases occurred between Periods B and C, in response to transfer of the discharge offshore (Taylor 2005).

SPI data from 1993 to 1998 were grouped for period A, 1999 and 2000 for period B, and 2001 to 2004 for period C. The 1993 and 1994 data were included in period A on the assumption that loadings for these years were similar to those for 1995–1998. Regional harbor trends in SPI parameters for these three periods are summarized in Table 4-3. The OSI was significantly lower for period B, likely because of the median estimated successional stage of Stage I-II, which was lower than Stage I-III in both periods A and C. This dip in OSI may be related to reduced biogenic activity during period B as organic matter stored in the sediment was exhausted. Additional TOC measurements made as part of the nutrient flux monitoring at T02 (flux station BH02) and T03 (BH03) found TOC was less variable and declined slightly in periods B and C relative to period A. For station T03, the decline in TOC for periods B and C was more pronounced (Tucker *et al.* 2004). The significant decline in the odds of a tube mat being present at a station, calculated by Taylor's periods, from A to C would also be consistent with reduction of sediment organic inventories as large amounts of organic matter are needed to sustain mat densities of *Ampelisca* spp. As infaunal succession advances in the harbor, the presence and abundance of Stage II species should decline and evidence of Stage III species should increase.

Table 4-3. Comparison of SPI parameters by Taylor's (2005) periods A, B, and C. ANOVA was used to determine differences.

	Period			
	A	B	C	
Parameter	**1992–1998**	**1999–2000**	**2001–2004**	**Probability**
RPD (cm)	2.3	2.0	2.6	0.454
OSI	6.0	> 4.8 <	6.5	0.016
Successional Stage (Median)	I-III	I-II	I-III	
Odds of Stage II or III	1.0	0.8	1.0	0.390
Odds of Amphipod Tube Mat	1.2	0.7	0.4	<0.001

Prior to 1995, the earliest year Taylor (2005) considered in assessing loadings to the harbor, it is possible that major disturbance events in 1991 prior to the start of MWRA's intensive SPI monitoring, set the stage for harbor benthic conditions. Noteworthy was the severe storm that affected the entire region in October 1991 (Blake *et al.* 1998). The most apparent change in harbor benthos was the widespread increase in *Ampelisca* spp. that took place in 1992 (Figure 4-5). The tube-building amphipods in the genus *Ampelisca*, associated with the intermediate successional stage (Stage II) and good benthic habitat quality, were key to assessing benthic conditions. Based on grab-sample data, *Ampelisca* spp. tube mats were not broadly distributed in Boston Harbor prior to mid-1992 (Hilbig *et al*. 1997). In late 1992, there was about a doubling of stations with *Ampelisca* spp. tube mats from <20% to about 40%. From 1993 to 1995, the spatial distribution of tube mats increased to >60% of stations and remained at >60% until 1998 when the distribution of tube mats started to contract and dropped to about 20% by 2000. In 2003, there was a rebound to about 30% and a decline in 2004 to the lowest percentage of stations with mats for the entire monitoring period of 13%. This progression of higher percentages of tube mat stations in the 1990s and generally declining percentages from 2000 is consistent with reduced organic loading to the harbor, as described by Taylor (2005). Based on energetics, large amounts of organic matter are required to maintain mat densities of *Ampelisca* spp. as they have a high turn-over ratio (Robertson 1979).

Had the reductions in loading associated with reduced discharges and improved treatment had effects on benthic habitat quality for infauna within the harbor, the largest effects should have been observed at stations closest to the outfalls. Based on this hypothesis of localized impacts, the stations in the area of the Nut Island (R22, R23, and T06) and Deer Island (R02 and T05A) outfalls should have shown the greatest change relative to relocation of discharges and improved treatment (Figures 4-1 and 4-2, Table 4-4). When SPI parameters were compared for these stations, there were two significant differences (Table 4-5). For the Nut Island stations, the odds of an *Ampelisca* spp. tube mat occurring declined from period A to B to C. This decline in tube mats is consistent with reduced loadings to the harbor over the three periods.

For Deer Island stations, the depth of the apparent color RPD layer increased from period A to C. This increase in RPD layer depth is also consistent with improvements water quality and reductions in loadings.

Table 4-4. SPI parameters at stations near the old Nut Island and Deer Island discharges grouped by the three loading periods defined by Taylor (2005)

Stations near Nut Island	Period A						Period B		Period C			
	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
	Modal Sediment Grain-Size											
R18	SIFS	SIFS	FSSI	SIFS	SI	SI	SI	SI	SI	SIFS	SIFS	SICL
R23	FS	FS	FSGR	FSMS	FSMSCS	FS	FSMS	FSMS	FSMS	FSMS	FSMSGRPB	FSMSGR
R38	SIFS	SIFS	SI	SI	SI	SI	SI	SI	SI	SIFS	SICL	SICL
T06	FS	SIFS	SI	SI	SIFS	SIFS	SIFS	SI	SI	SIFS	SIFS	SIFS
	Organism Sediment Index											
R18	9.0	5.7	8.3	7.7	9.7	10.7	9.0	5.3	9.0	6.0	5.0	6.0
R23	9.0	6.7	6.0	8.0		3.0		5.3	5.3		10.0	6.0
R38	5.3	4.7	8.7	6.3	9.7	6.7	9.0	4.7	9.7	9.0	7.3	7.0
T06	9.3	5.0	6.3	5.7	7.7	7.7	7.7	6.3	9.0	6.3	4.7	5.7
	Apparent Color RPD Layer Depth (cm)											
R18	3.8	1.6	7.7	2.3	5.1	4.9	6.8	1.8	7.5	2.2	2.6	1.8
R23	4.9	2.4	1.9	3.5		0.8		2.3	4.1	1.7	5.0	3.0
R38	1.3	1.0	2.2	2.0	5.3	1.8	5.7	1.7	4.3	1.2	1.4	1.8
T06	4.6	1.2	1.7	1.1	3.0	3.1	3.3	2.1	4.4	1.9	2.2	1.2
	Estimated Successional Stage											
R18	II-III	II	II	II-III	II-III	II-III	II	II	II-III	II-III	II-III	II-III
R23	II	II	II	II	I-II	I-II	I	I-II	I-II	I-II	I-II	I-II
R38	II	II	II-III	II	II-III	II-III	II	I-II	II-III	II-III	II-III	II-III
T06	II-III	I-II	II-III	II-III	II	II	II	II	II	II-III	II-III	II-III
	***Ampelisca* spp. tubes**											
R18	MAT	MAT	-	MAT	MAT	MAT	MAT	MAT	MAT	+	MAT	+
R23	MAT	MAT	MAT	MAT	MAT	+	+	MAT	MAT	+	+	+
R38	MAT	MAT	MAT	MAT	MAT	MAT	MAT	+	MAT	+	MAT	+
T06	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	+	MAT	MAT

Table 4-4. Continued.

Stations near Deer Island	Period A						Period B		Period C			
	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
	Modal Sediment Grain-Size											
R02	SI	SI	SIFSCS	SIFS	SIFS	SI	SI	SI	SI	SICL	SICL	SIFS
R06	FS	MSPB	FSGR	GR	FSGR	MSGRPB	FSMSGRPB	FSMSGRPB	FSMSGRPB	FSMSGRPB	FSMSGRPB	FSSIPB
R45			SIFS	VFS	SIFS	SI	SI	SI	SI	SI	SICL	SICL
T03	SIFS	SI	SI	SIFS	FSSI	SI	SI	SI	SI	SI	SICL	SICL
T05A		FS	FSSIMS	FSCS	GR	FS	SIFS	FSMSGRPB	FSMSSI	FSMSSI	FSSI	FSSI
	Organism Sediment Index											
R02	3.0	5.7	2.0	4.7	9.3	5.7	5.7	7.0	10.0	4.7	3.3	10.0
R06	6.0	4.0	3.3				2.3	3.3	5.0	4.3	6.7	
R45			9.7	9.7	9.7	7.7	7.7	8.3	10.0	8.3	7.3	7.0
T03	11.0	5.5	9.7	9.7	10.3	5.7	8.3	9.0	9.0	6.7	7.0	7.7
T05A			6.7	4.3	5.5	4.3	2.3	3.0	7.0	4.5	4.7	8.0
	Apparent Color RPD Layer Depth (cm)											
R02	0.6	1.6	0.5	2.0	3.9	1.0	2.4	3.0	5.0	1.3	3.9	4.5
R06	1.8	1.1	1.5			2.3	0.7	1.3	1.9	1.6	2.2	
R45			7.3	6.6	5.0	3.0	3.3	3.9	5.8	1.3	2.1	1.9
T03	5.9	1.4	7.7	7.5	3.6	1.3	3.9	4.9	4.0	1.8	5.1	2.6
T05A		1.1	2.2	1.1	1.6	1.3	0.7	1.4	2.8	1.5	3.1	2.7
	Estimated Successional Stage											
R02	0-II	II	II	II	II-III	II-III	II-III	II	II-III	II	II	II-III
R06	II	I-II	I	I	I	I	I	I	I-II	I	I-II	I-II
R45			II-III	II-III	II-III	II-III	II	II	II-III	II-III	II-III	II-III
T03	III	II	II-III	II-III	II-III	II	II	II	II-III	II-III	II-III	II-III
T05a			II	I-II	II	I-II	I	I	II	I	II	II-III
	***Ampelisca* spp. tubes**											
R02	MAT	MAT	+	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	–
R06	MAT	+	–	–	–	–	–	–	+	–	+	+
R45			MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	+	+
T03	–	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT	MAT
T05A		–	MAT	MAT	MAT	–	–	–	MAT	–	MAT	MAT

Table 4-5. Comparison of SPI parameters by Taylor (2005) periods A, B, and C for SPI stations near the Nut Island and Deer Island discharges. ANOVA and Cochran-Mantel-Haenszel tests were used to determine differences.

	PERIOD			
Nut Island	**1992–1998**	**1999–2000**	**2001–2004**	**Probability**
Parameter	**A**	**B**	**C**	
RPD (cm)	2.8	2.0	3.0	0.365
OSI	7.0	6.0	7.1	0.515
Successional Stage (Median)	II	I-II	II	
Odds of Stage II or III	2.6	1.0	1.4	0.548
Odds of Amphipod Tube Mat	8.0	5.0	0.7	0.016
	PERIOD			
Deer Island	**1992–1998**	**1999–2000**	**2001–2004**	**Probability**
Parameter	**A**	**B**	**C**	
RPD (cm)	1.5	1.9	3.1	0.020
OSI	5.1	4.5	6.5	0.289
Successional Stage (Median)	II	I-II	II	
Odds of Stage II or III	2.3	1.0	7.0	0.370
Odds of Amphipod Tube Mat	2.7	1.0	3.0	0.659

Regionally within the harbor, it appears that from 1992 to 2004 benthic habitat conditions as measured by sediment profile imaging have not changed appreciably other than a small decrease in the OSI for the 1999–2000 period. Stations with poorest habitat quality in 1989–1990 (Blake *et al.* 1993) continued to have poor quality habitat in 2004. For example, stations T04 and R43, both in Dorchester Bay, had long-term average OSI values <3 (Table 4-6). Using the OSI as a surrogate for habitat quality, none of the stations exhibited monotonic long-term trends, either improving or declining, from 1992 to 2004 (Table 4-6). However, there were six stations that consistently had OSI values ≥6 (R11, R12, R28, R29, R45, and R46), the threshold for stressed/not stressed habitat conditions (Rhoads and Germano 1986), and five stations with consistently <6 OSI values (R06, R10, R36, R43, and T04). Station T04, located in inner Dorchester Bay, consistently had low OSI values with three years of negative values, indicative of a highly stressed habitat, likely from high TOC (range of 3.1 to 8.9% for the monitoring period). This level of TOC is highly correlated with altered community structure (Hyland *et al.* 2005) and reduced benthic habitat quality for infauna (Diaz *et al.* 2003). Conversely, Stations R11, R12, R45, and T03 along the western side of Long Island had consistently good benthic habitat quality and the highest overall average OSI values from 1992 to 2004. T03 had good benthic habitat quality despite the fact that TOC ranged from 2.5% to 3.8% over this period. This is an indication that habitat quality cannot be determined solely by the quantity of organic matter. Other factors such as quality of the organic matter may be more important.

Table 4-6. Summary of OSI values for harbor stations arranged from lowest to highest station grand mean.

Station	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	Mean
T04	2.6	2.0	-4.3	-5.3		2.0	-5.3	2.0	1.3	2.7	1.0	2.3	2.5	0.1
R43	3.3	2.3	2.5	4.7	2.0	2.7	2.0	2.0	2.0	2.5	3.0	4.7	7.3	2.8
R36				3.7		2.3	3.0	2.0	4.3		4.0	3.3	4.5	3.2
R33	5.3	2.7	0.7	7.0	4.0	2.7	2.3	3.0	3.0	3.0	3.3	4.7	6.0	3.5
R35	7.4	2.7	-0.7	5.0	5.0	2.7	2.7	3.7	3.0		5.3	4.7	4.3	3.8
R10		2.0	3.0	3.3	4.0	5.0	5.3	4.3	3.7	3.7	3.7	3.7	7.3	3.8
R52	8.0			2.0	4.0		3.5	3.0	3.0	3.0	3.7	4.0	5.0	3.8
R49	3.5			3.0	7.7	1.0	3.0	3.3	2.3	5.3	5.7	4.3	6.3	3.9
R53	6.0			3.0	5.3		2.5	2.0	3.7	4.0	5.0	4.3	6.0	4.0
T07	2.0	2.7	3.7	7.5	4.3	3.0	2.7	4.0	3.7	5.7	3.0	6.3	7.7	4.0
R34	7.0	3.0	-1.0	6.7	5.7	3.3	2.3	2.7	2.3		5.3	7.7	7.0	4.1
R51	7.0			2.7	4.7		3.0	3.3	2.3	3.3	5.7	5.0	6.7	4.1
R42	5.0	4.7		6.0	3.0		3.7	2.3	5.0	3.0	4.0	5.0	4.3	4.2
R15	8.7	3.0	2.3	11.0	5.0		3.0	2.0	3.0	3.5	3.0	3.0	4.0	4.3
R19	7.0	5.7	4.0	4.0	6.0		3.0	2.0	3.0	4.7				4.4
R37	5.7	2.7	4.3	7.0	3.0	3.3	4.0	2.3	3.7	3.0	6.7	8.0	7.3	4.5
R06		6.0	4.0	3.3				2.3	3.3	5.0	4.3	8.0		4.5
R08					8.0	4.5	3.5	3.7	2.7	3.0	5.0	6.0	5.0	4.5
R04		2.7	4.3	7.0	5.0	3.0	4.7	2.3	2.7	10.0	3.7	5.0	7.0	4.6
R32	6.0	4.0	6.3	5.0	5.3	2.7	3.7	3.0	4.0	6.0	5.0	4.0	6.3	4.6
R48				5.0	5.7		3.0	2.3	4.0	4.7	7.0	5.3	6.7	4.6
T01	3.0	5.3	4.0	5.0	4.3	4.0	3.7	2.3	3.7	4.7	8.0	9.3	4.7	4.8
T05A				6.7	4.3	5.5	4.3	2.3	3.0	7.0	4.5	7.0	8.0	5.0
T02	3.0		5.7	6.7	5.0	4.3	3.7	3.0	3.0	5.0	6.3	10.0	7.3	5.1
R26	7.7	5.0	9.3	4.3	5.7		3.0	3.3	3.3	3.3	6.3	5.7	6.7	5.2
R13	6.8	5.3	10.0	6.7	5.0		2.7	2.0	2.3	10.0	4.3	3.7	3.5	5.3
R41	6.3	2.3	5.3	11.0	6.0	5.0	4.7	2.3	3.3	3.7	7.0	7.3	6.7	5.4
R44				7.0	3.3	2.7	5.7	3.3	3.0	7.3	6.3	10.0	6.0	5.4
R40	6.0	3.5	4.0	10.7	8.0		2.7	3.3	4.7	4.0	6.0	7.0	6.0	5.4
R09		5.3	5.0	2.7	7.3	6.3	4.7	8.0	3.7	7.7	4.0	6.0	6.7	5.5
R05	7.7	4.0	6.0	7.0	5.7		5.7	3.0	3.7	5.7	5.7	7.3	6.7	5.6
T08	7.0	7.0	4.5	8.0			3.7	2.7	4.7	6.0		8.0		5.7
R14	5.7	5.3	4.7	7.0	5.0	11.0	5.3	2.3	3.3	9.0	4.3	6.7	4.7	5.8
R02	6.7	3.0	5.7	2.0	4.7	9.3	5.7	5.7	7.0	10.0	4.7	8.3	10.0	6.1
R17	6.0	4.3	5.3	8.0	3.0	4.7	4.3	8.7	6.3	4.7	8.7	10.0	9.3	6.2
R16		8.0	2.5	6.3	9.0	8.0	4.0	5.7	5.3	8.7	3.7	7.0	3.7	6.2
R23		9.0	6.7	6.0	8.0		3.0		5.3	5.3			6.0	6.2
R50	8.0			7.3	11.0	5.7	7.7	2.7	5.0	5.3	4.7	5.0	5.0	6.2
R30	8.0	5.7	7.3	6.3	6.7	5.7	8.3	6.3	5.7	6.0	4.7	5.3	6.7	6.3
R03		3.7	6.7	7.7	8.0	8.3	6.7	3.3	4.0	9.0	8.0	9.0	7.3	6.8
R25	7.3	7.7	4.3	5.3	9.0	8.7	10.0	8.0	3.3	8.0	6.0	4.7	7.7	6.9

Station	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	Mean
R27	9.0	4.3	7.0	6.3	8.0	6.0	10.3	6.3	6.7	8.7	6.3	5.3	6.7	7.0
T06	6.7	9.3	5.0	6.3	5.7	7.7	7.7	7.7	6.3	9.0	6.3	7.3	5.7	7.1
R22		9.0	5.7	7.3	4.3	10.3	7.7	4.5	6.0	10.0	6.3	7.0	5.0	7.1
R39	8.3	6.7	8.7	7.0	6.3	6.3	9.0	3.7	5.3	10.0	8.7	5.5	6.0	7.1
R38	7.7	5.3	4.7	8.7	6.3	9.7	6.7	9.0	4.7	9.7	9.0	10.0	7.0	7.6
R47	4.7			8.7	7.0	10.3	9.3	9.0	10.0	5.5	7.0	7.3	9.3	7.9
R20		9.3	5.5	11.0	7.3	10.3	4.0	9.0	7.7	10.0	6.3	7.0	7.7	7.9
R24	8.0	9.0	5.0	9.0	9.7		7.3	9.7	8.0	10.0	5.7	6.7	6.7	8.0
R07		2.7	6.0	7.3	8.3	10.7	6.7	9.3	9.3	10.0	9.0	10.0	10.3	8.1
R18		9.0	5.7	8.3	7.7	9.7	10.7	9.0	5.3	9.0	6.0	9.3	6.0	8.2
R29	7.3	8.0	8.7	8.0	10.3	6.7	10.0	7.0	7.3	8.7	6.7	9.3	9.7	8.2
R21		9.0	8.0	9.0	7.3	10.0	9.3	5.7	8.0	8.7	6.7	8.7	10.0	8.2
R28	9.0	6.3	10.0	6.7	9.7	7.3	9.7	8.3	7.3	10.0	6.3	8.3	9.7	8.3
R31	5.3	10.3	8.0	7.3	8.7	9.0	9.0	8.7	6.7	10.0	8.0	10.0	8.7	8.4
R46				8.0	10.3	7.7	9.0	6.3	7.7	10.0	7.0	10.0	10.0	8.4
T03	8.3	11.0	5.5	9.7	9.7	10.3	5.7	8.3	9.0	9.0	6.7	10.0	7.7	8.6
R45	9.0			9.7	9.7	9.7	7.7	7.7	8.3	10.0	8.3	10.0	7.0	9.0
R11		8.7	9.0	11.0	8.3	9.7	9.7	9.0	8.3	8.3	7.3	10.0	10.0	9.0
R12		6.7	10.0	10.3	8.0	10.0	11.0	9.0	9.3	9.0	7.0	10.0	6.3	9.1
N	40	46	46	59	56	45	59	59	60	57	57	58	57	
Mean	6.4	5.5	5.2	6.5	6.4	6.4	5.4	4.8	4.9	6.7	5.7	6.9	6.7	6.0
SE	0.30	0.38	0.43	0.37	0.29	0.45	0.39	0.35	0.28	0.35	0.23	0.29	0.24	2.6
CV	29	47	56	43	34	47	57	56	45	40	30	33	27	32
% Mean Diff.	+9	-6	-12	+10	+9	+9	-9	-18	-18	+14	-3	+17	+17	
Median	6.9	5.3	5.3	7.0	6.0	6.3	4.7	3.3	4.0	6.0	6.0	7.0	6.7	
Min	2.0	2.0	-4.3	-5.3	2.0	1.0	-5.3	2.0	1.3	2.5	1.0	2.3	2.5	
Max	9.0	11.0	10.0	11.0	11.0	11.0	11.0	9.7	10.0	10.0	9.0	10.0	10.3	

4.3.6 Benthic Habitat Quality

Maciolek *et al.* (2005) assessed benthic habitat quality for infauna at the traditional (T) stations for August sampling dates over the period 1992–2003. Based on the patterns of association between the sediment, infauna, and SPI variables, they found a cline of relative habitat quality from lower habitat quality at station T04 to higher habitat quality at T03 and T06. The addition of August 2004 data did not change this pattern. The correlations between variables were also not affected and remained about the same. To further assess the change in benthic habitat quality for the harbor, sediment (% gravel, % fines, TOC), infaunal (total abundance, *Ampelisca* spp. abundance, species, log-series *alpha* diversity), and SPI (RPD, OSI, oxic void) data were grouped by time periods identified by Taylor (2005) as representing major patterns in freshwater flows, loadings of total nitrogen (TN), total phosphorus (TP), total suspended solids (TSS) and particulate organic carbon (POC) to Boston Harbor between 1995 and 2003. For this analysis, period A included August data from 1992 to 1998, period B from 1999 and 2000, and period C from 2001 to 2004. Stations were arranged according to the benthic habitat cline described by Maciolek *et al.* (2005) (Figure 4-6).

For the sedimentary variables, grain-size and TOC remained relatively unchanged. The largest differences occurred in period C, after operation of the offshore outfall, when gravel and TOC declined at T01 (Figure 4-6). The percent fines (silt plus clay) at each station were similar in all periods and did not vary by more than 12%. Additional TOC measurements made as part of the nutrient flux monitoring at T02 (flux station BH02) and T03 (BH03) were similar in pattern (Tucker *et al*. 2004). At T02, TOC was less variable and declined slightly in periods B and C relative to period A, whereas at T03 the decline in TOC for periods B and C was more pronounced (Tucker *et al*. 2004). Overall, T01 was the only station to show a significant decline in TOC over the monitoring period (1991–2004) (Chapter 3, this report). When grouped by periods, TOC at station T01 also declined with time (Figure 4-6). The decline in variability of TOC through time occurred at all traditional stations (Table 4-7). Tucker *et al.* (2004) suggest that this decline in variability along with decreases in benthic fluxes indicates that the harbor's benthic habitats have improved through time.

Sediment profile image data indicated that this improvement in habitat quality was greatest in period C. Stations that were identified as having lower (T04 and T07) to average (T01, T02, T05A, and T08) habitat quality experienced an increase in the OSI and a deepening of the RPD layer depth in period C relative to A and B (Figure 4-6). The stations with highest habitat quality (T03 and T06) consistently had deep RPD layer depths. Similarly, Tucker *et al.* (2004) found more positive Eh profiles and higher habitat quality at T03 and more reduced sediments with lower habitat quality at T02. This general improvement in habitat conditions for period C may be related to increased bioturbation by infauna. At all stations except T04 there was an increase in the number of oxic, active feeding voids (Figure 4-6). Station T04 consistently had the shallowest RPD, highest TOC, and limited evidence of bioturbation of all stations. At the other seven stations, biogenic activity consistently deepened the RPD beyond what would be expected by diffusional processes alone (Jørgensen and Revsbech 1985). It is also well documented that higher levels of TOC (>3%) tend to alter community structure and lower the OSI index (Pearson and Rosenberg 1978, Rhoads and Germano 1986, Hyland *et al.* 2005).

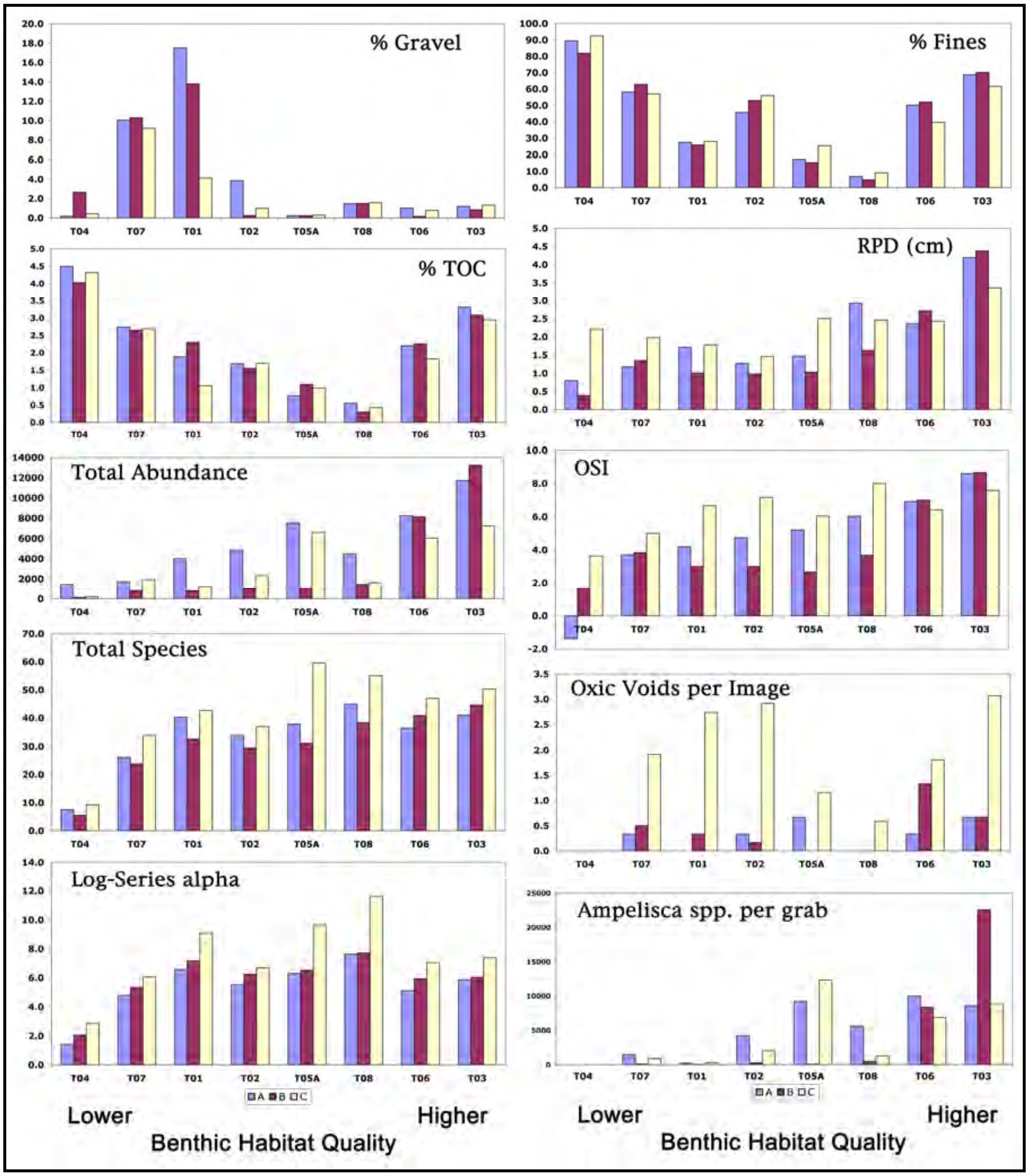


Figure 4-6. Benthic habitat quality at Boston Harbor traditional stations.

Benthic community parameters, including total abundance, species richness, *Ampelisca* spp. per sample, and diversity as measured by log-series *alpha*, are also plotted according to Taylor's periods (Figure 4-6). Total abundances were, with the exception of T03, highest in period A and lowest in period C. At T03, the high abundance in period B is related to the large numbers of ampeliscid amphipods. Species richness was depressed in period B compared with period A at six stations and slightly higher at two stations (T03 and T06), but was elevated at all eight stations in period C. Diversity as measured by log-series *alpha* was equal to or slightly higher at each station in period B compared with period A, and higher in period C compared with period B (Figure 4-6).

Table 4-7. Mean TOC (%) and coefficient of variation (%) by Taylor (2005) periods.

	T04		T07		T01		T02		T05A		T08		T06		T03	
Period	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
A	4.5	44	2.7	15	1.9	29	1.7	15	0.8	53	0.6	48	2.2	35	3.3	15
B	4.0	4	2.7	6	2.3	31	1.6	5	1.1	21	0.3	33	2.3	6	3.1	3
C	4.3	13	2.7	4	1.1	11	1.7	11	1.0	18	0.4	22	1.8	9	2.9	4

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

5. 2004 SOFT-BOTTOM INFAUNAL COMMUNITIES

by Nancy J. Maciolek

5.1 Introduction

Nine stations in Boston Harbor were sampled in August 2004 for soft-bottom benthic infauna. Seven of these stations have been sampled consistently since September 1991; the eighth, T05A, replaced T05 in 1993. A ninth station, C019, was added in 2004 to monitor changes that may occur during upgrading of the combined sewer overflow (CSO) system. Station locations are indicated in Figure 2-1 (Chapter 2, this report).

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

5.2 Methods

5.2.1 Laboratory Analyses

Samples were preserved with formalin in the field (see Chapter 2), and in the laboratory were rinsed with fresh water over 300-μm-mesh screens and transferred to 70–80% ethanol for sorting and storage. To facilitate the sorting process, all samples were stained in a saturated alcoholic solution of Rose Bengal at least overnight, but no longer than 48 h. After rinsing with clean alcohol, all organisms, including anterior fragments, were removed and sorted to major taxonomic categories such as polychaetes, arthropods, and mollusks. After the samples were sorted, the organisms were identified to the lowest practical taxonomic category, usually species. Voucher specimens of any species newly identified from the harbor samples were kept as part of the MWRA reference collection.

5.2.2 Data Analysis

Preliminary Data Treatment—Prior to performing any analyses of the 2004 and 1991–2004 MWRA datasets, several modifications were made to the database (Appendix D1). These modifications were generally similar to those performed in previous years as given in the standard operating procedure (SOP) for this project (Williams *et al.* 2005). Calculations of abundance included all infaunal taxa occurring in each sample, whether identified to species level or not, but did not include epifaunal or colonial organisms. Calculations based on species (number of species, dominance, diversity, evenness, cluster and principle components analysis) included only those taxa identified to species level, or those treated as such. For report purposes, *Ampelisca abdita* and *A. vadorum* have been combined with *Ampelisca* spp. as in previous years; similarly, *Pholoe minuta* and *P. tecta* have been combined with *Pholoe* spp.

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

The multivariate similarity and clustering programs are included in COMPAH96, originally written by Dr. Donald Boesch and now available from Dr. Eugene Gallagher at the University of Massachusetts, Boston (http://www.es.umb.edu/edgwebp.htm). Patterns in benthic communities were analyzed by similarity analysis using CNESS (chord-normalized expected species shared), which was developed by Gallagher (Trueblood *et al.* 1994) and is related to Grassle and Smith's (1976) NESS (normalized expected species shared). CNESS and NESS are families of indices that can be made more or less sensitive to rare species in the community; these algorithms were developed primarily for use with deep-sea data, in which no single species usually accounts for more than 4–10% of the individuals. CNESS is calculated from the expected species shared (ESS) between two random draws of *m* individuals from two samples. For this project, the optimal value of *m* was determined to be 15. For comparison, the Bray-Curtis similarity measure was also used, based on a fourth-root transformation of the data (performed in order to diminish the impact of numerically dominant species). Both similarity matrices were clustered using group average sorting and dendrograms were plotted. For the analysis of the 1991–2004 summer samples, replicates were pooled to one sample per year (*i.e.*, all samples from all stations pooled to one annual sample) and *m* was set at 20. Results of these analyses were inspected for patterns between and among the different seasons.

PRIMER v.5 (Clarke and Gorley 2001) was used to calculate several diversity indices, including Shannon's H′ (base 2), Pielou’s evenness value J′, Sanders-Hurlbert rarefaction, and Fisher’s log-series *alpha*. Magurran (1988) classifies diversity indices into three categories: (1) species richness indices (*e.g.*, rarefaction); (2) species abundance indices (*e.*g., log-series *alpha*), and (3) indices based on the proportional abundances of species (*e.*g., Shannon index). The Shannon index, which is based on information theory, has been popular with marine ecologists for many years, but this index assumes that individuals are randomly sampled from an infinitely large population and that all species are present in the sample (Pielou 1975, Magurran 1988): neither assumption correctly describes the environmental samples collected in most marine benthic programs. Fisher's log-series model of species abundance (Fisher *et al.* 1943) has been widely used, particularly by entomologists and botanists (Magurran 1988). Taylor's (1978) studies of the properties of this index found that it was the best index for discriminating among subtly different sites, and May (1975) demonstrated that Sanders-Hurlbert rarefaction curves are often identical to those produced under the assumption that the distribution of individuals among species follows a log-series distribution. Hubble (2001) considers *alpha* the fundamental biodiversity parameter and promoted the use of this index for studies of diversity in all environments.

Principal Components Analysis of Hypergeometric probabilities (PCA-H) was also applied to the benthic data. PCA-H is an ordination method for visualizing CNESS distances among samples (see Trueblood *et al.* 1994 for details). The PCA-H method is a multistep analysis that produces a metric scaling of the samples in multidimensional space, as well as two types of plots based on Gabriel (1971). The Gabriel Euclidean distance biplot provides a two-dimensional projection of the major sources of CNESS variation, *i.e.*, the species that contribute the most to the distances among samples. The species that contribute to the CNESS variation can be determined using matrix methods adapted from Greenacre's correspondence analysis (Greenacre 1984). These species are plotted as vectors in the Euclidean distance biplot. The Gabriel covariance biplot shows the associations among species. Species that co-occur plot with species vectors with very acute angles, whereas species that have discordant distributions plot with angles approaching 180°. The metric scaling diagram, Euclidean distance biplot, and covariance plot are all based on CNESS similarities among samples, but are calculated by different algorithms and may therefore produce slightly different results. PCA-H was performed using MATLAB as an operating platform and programs written by Dr. E.D. Gallagher.

5.3 Results and Discussion

5.3.1 Species Composition of 2004 Samples and 1991–2004 Summary

In August 2004, 148 species of benthic infauna occurred in the samples, including seven species that were recorded in the harbor for the first time (Appendix D2). These seven species included three polychaetes, *Cossura* sp.1, *Goniada maculata*, and *Pherusa plumosa*; one amphipod *Calliopius laevisculus*; two isopods, *Idotea baltica* and *Pleurogonium rubicundum*; and one ascideacean *Molgula complanata*. Three of these seven species—*Cossura* sp.1, *C. laevisculus*, and *M. complanata*—are newly reported for the MWRA Massachusetts Bay/Boston Harbor database, whereas the other four had previously been recorded in samples taken from Massachusetts Bay.

For the period 1991–2004, 251 identified species were recorded in the summer samples (Appendix D2). As detailed in previous reports (*e.g.*, Blake *et al.* 1998, Kropp *et al.* 2002a,b), annelids are usually the most abundant infaunal taxon, often accounting for 50% or more of the organisms collected, followed by amphipod crustaceans and molluscs. In August 2003, however, amphipods were especially numerous, with *Ampelisca* spp. alone accounting for more than 55% of the 130,818 organisms in the 24 samples (Table 5-1), and all amphipods accounting for 67.5% of all organisms in the samples. In 2004, the number of amphipods, including *Ampelisca* spp., *Leptocheirus pinguis*, *Unciola irrorata*, *Crassicorophium bonnelli*, and *Dyopedos monacanthus* declined sharply (Table 5-1), and amphipods accounted for 39.6% (27,309 of the 69,049) organisms collected at the eight original stations.

Table 5-1. Amphipod species present in Boston Harbor samples taken in August 2003 and August 2004.

Amphipod Species	Total Abundance in 2003 samples (8 stations)	Total Abundance in 2004 samples (8 stations)
Ampelisca spp.	73,112	21,728
Leptocheirus pinguis	4,735	1,734
Unciola irrorata	3,841	756
Crassicorophium bonnelli	2,148	9
Photis pollex	2,108	1,677
Orchomenella minuta	1,194	1,230
Dyopedos monacanthus	1,029	1
Phoxocephalus holbolli	96	153
Microdeutopus anomalus	39	3
Crassicorophium crassicorne	17	11
Ischyrocerus anguipes	9	2
Pontogeneia inermis	9	1
Jassa marmorata	2	1
Harpinia propinqua	1	0
Metopella angusta	1	3
Totals	88,341	27,309

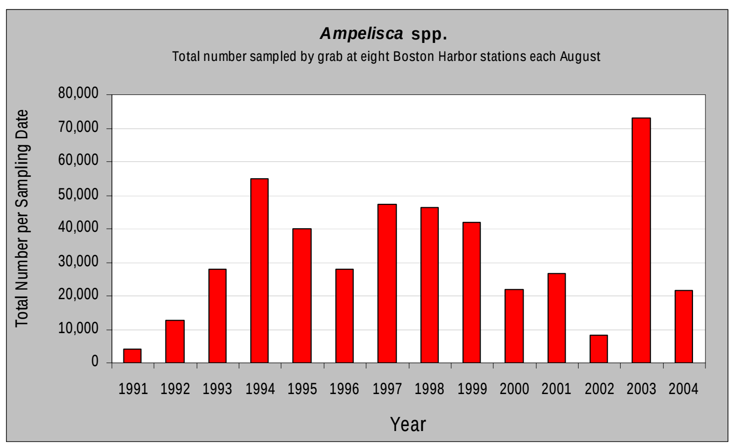


Figure 5-1. *Ampelisca* spp. at eight Boston Harbor stations.

5.3.2 Benthic Community Analysis for 2004

Density, Species Richness, Diversity, and Evenness—Community parameters for the grab samples collected in 2004 at the nine harbor stations are shown in Figure 5-2 and Table 5-2. For comparison with earlier dates, data for 2003 are included in Figure 5-2, and graphs showing five community parameters over time at each station are in section 5.3.4 of this report.

Density—In 2004, densities had declined significantly at several stations compared with those recorded in August 2003. The high densities in 2003 were due to large populations of several amphipod species (Table 5-1 and Maciolek *et al*. 2005), and the reduced densities in 2004 resulted from the decline in the populations of these same species. At stations where amphipods have not been especially abundant over the past decade, such as T01 and T04, infaunal densities were similar in 2003 and 2004. The newly sampled station C019 had low infaunal abundances, 396.0 organisms ± 71.4 SE per sample; only T04 had lower densities (74.3 organisms ± 16.0 SE per sample).

Species Richness —The mean number of species per sample was lower at six of the eight harbor stations in 2004 compared with 2003; stations T01 and T05A were the exceptions (Figure 5-2). As in previous years, species richness was lowest at T04 (Table 5-2, Figure 5-2). Station T05A showed an increase in mean number of species per sample, from 65.7±1.86 in 2003 to 76.3±5.8 in 2004. Interstation variability was greater in 2004 compared with 2003; for example, mean species richness at T01, T02, and T07 ranged from 43.7 to 49.4 species per sample in 2003 and from 28.3 to 44.0 species per sample in 2004. Similarly, mean species richness at T03, T05A, T06, and T08 ranged from 64.0 to 66.7 species per sample in 2003 and from 48.7 to 76.3 species per sample in 2004. In both years, T04 had the lowest species richness: 9.7 in 2004 species per sample compared with 13.3 in 2003. The newly sampled station CO19 was only slightly richer than T04, with 15.7 ± 2.9 species per sample.

Diversity —As in previous years, mean Shannon diversity was lowest at T04 (1.59±0.02) (Table 5-2, Figure 5-2); diversity at CO19 (1.60±0.28) was statistically identical to that at T04. Mean Shannon diversities at stations T01, T02, T03, T04, and T07 were statistically identical to those recorded in 2003, and higher at T05A, T06, and T08 (Figure 5-2). The large amphipod populations, which apparently depressed diversity values last year at the latter three stations, had declined in 2004 with a concomitant increase in H'.

The change in diversity as measured by Fisher's log-series *alpha* was variable in 2004: mean *alpha* values were higher at T01 and T05A, the same at T04, and lower at T02, T03, T06, T07, and T08 compared with 2003 values. However, with the exception of T05A, all 2004 values were statistically identical to 2003 values. The station pattern seen in 2002 and 2003 was nearly repeated in 2004: the lowest mean value was recorded at T04 (3.0±0.6) and the second-highest at T08 (11.9±2.5) (Table 5-2, Figure 5-2). At T05A, where log-series *alpha* values were similar in 2002 and 2003 in spite of increased amphipod abundances in 2003, *alpha* increased in 2004 to a value of 12.2, which was the highest value recorded for the 2004 samples. CO19 had the second lowest *alpha* (3.3±0.5) of the nine stations; as reflected by other community parameters, this station is only slightly more diverse than T04.

Evenness —Evenness values in 2004 were either nearly the same as in 2003 (T01, T02, T03, T04, T07), or, at the stations where the greatest declines in the amphipod populations were seen, considerably higher (T05A, T06, T08). The highest evenness values were 0.75 (T01) and 0.71 (T08), while the lowest values were recorded at CO19 (0.40) and at T03 (0.46).

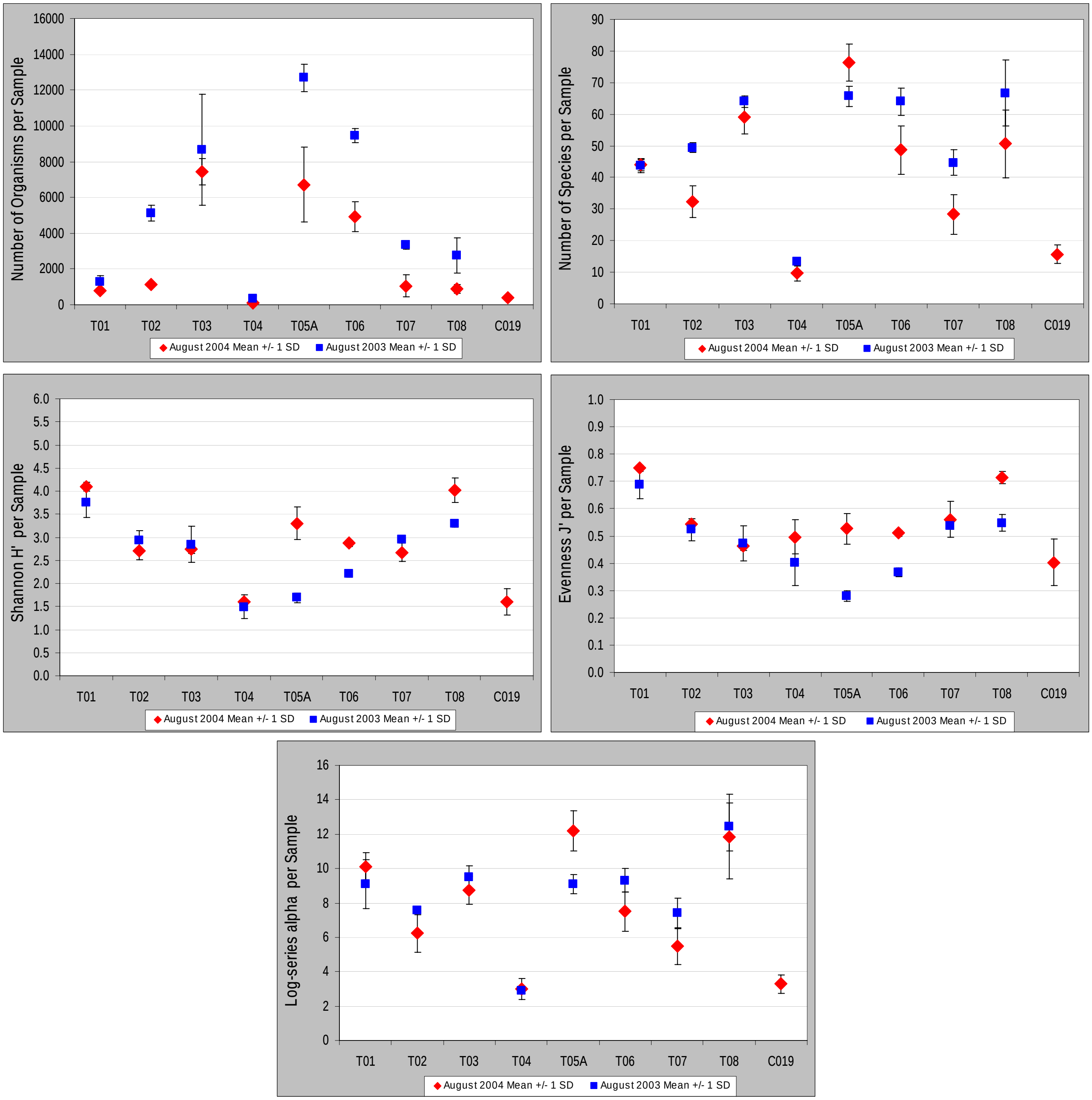


Figure 5-2. Mean ± 1SD of five benthic infaunal community parameters for the Boston Harbor stations sampled by grab in August 2004. 2003 values are included for comparison.

Table 5-2. Benthic community parameters for samples taken at Boston Harbor traditional stations in August 2004.

Station	Replicate	Total Abundance	No. Species	H′ (base 2)	J′	Log-series *alpha*
T01	1	914	46	4.18	0.76	10.2
	2	853	42	4.00	0.74	9.3
	3	623	44	4.10	0.75	10.8
	Mean ± SD	796.7±153.5	44.0±2.0	4.09±0.09	0.75±0.01	10.1±0.8
T02	1	1,214	38	2.89	0.55	7.5
	2	1,033	29	2.50	0.52	5.5
	3	1,183	30	2.73	0.56	5.7
	Mean ± SD	1143.3±96.8	32.3±4.9	2.71±0.20	0.54±0.02	6.2±1.1
T03	1	7,724	56	2.63	0.45	8.2
	2	6,579	56	2.79	0.48	8.4
	3	7,977	65	2.80	0.46	9.7
	Mean ± SD	7426.7±744.9	59.0±5.2	2.74±0.10	0.46±0.02	8.8±0.8
T04	1	100	11	1.59	0.46	3.17
	2	45	7	1.61	0.57	2.32
	3	78	11	1.58	0.46	3.53
	Mean ± SD	74.3±27.7	9.7±2.3	1.59±0.02	0.50±0.06	3.0±0.6
T05A	1	4,508	73	3.66	0.59	12.4
	2	8,690	73	2.97	0.48	10.9
	3	6,912	83	3.28	0.51	13.3
	Mean ± SD	6,703.3±2098.8	76.3±5.8	3.30±0.35	0.53±0.06	12.2±1.2
T06	1	5,659	54	2.89	0.50	8.3
	2	4,021	40	2.79	0.52	6.2
	3	5,120	52	2.93	0.51	8.1
	Mean ± SD	4,933.3±834.8	48.7±7.6	2.87±0.07	0.51±0.01	7.5±1.2
T07	1	1,730	32	2.46	0.49	5.6
	2	880	32	2.86	0.57	6.5
	3	523	21	2.70	0.62	4.4
	Mean ± SD	1,044.3±620.1	28.3±6.4	2.67±0.20	0.56±0.07	5.5±1.1
T08	1	1,149	60	4.11	0.70	13.7
	2	679	39	3.72	0.70	9.0
	3	855	53	4.23	0.74	12.8
	Mean ± SD	894.3±237.5	50.7±10.7	4.02±0.27	0.71±0.02	11.9±2.5
CO19	1	528	19	1.50	0.35	3.8
	2	377	14	1.38	0.36	2.9
	3	283	14	1.92	0.50	3.1
	Mean ± SD	396.0±123.6	15.7±2.9	1.60±0.28	0.40±0.08	3.3±0.5

***Dominant Species* —**The numerically dominant species and their percent contribution to the fauna at each harbor station in August 2004 are given in Appendix D3. The amphipod species *Ampelisca abdita* has been considered a key organism in following the status of the infaunal community of Boston Harbor, partly because members of this genus are considered (by some) to be indicative of clean environments. The increase in numbers of *Ampelisca* and the expansion and constriction of tube mats (*i.e.*, extremely high densities) has been followed in several reports (*e.g.*, Hilbig *et al*. 1997; Maciolek *et al.* 2005). In 2003, the grab samples yielded the highest numbers of *Ampelisca* spp. recorded since the initiation of monitoring (Figure 5-1). Although the density of *Ampelisca* spp. declined significantly in 2004 compared with 2003, this taxon was the numerical dominant at three stations, T03, T05A, and T06, and was among the ten most numerous taxa at all other long-term stations in the harbor. The only exception was C019, where *Ampelisca* spp. had a mean sample density of 2 individuals per sample and ranked twelfth of 24 species recorded at that station.

In 2002, the spionid polychaete *Prionospio steenstrupi* appeared for the first time as a numerical dominant at all eight harbor stations. In 2003, this species was still present and among the more numerous species at five stations (T01, T02, T03, T06, and T08), but was eclipsed in numbers by several species of amphipods. In 2004, *P. steenstrupi* was among the numerical dominants at only two stations, T05A and T06, where it accounted for only 0.8% and 0.5% of the total fauna, respectively.

At T01, *Polydora cornuta* (21.2%) was the numerical dominant, followed by the maldanid polychaete *Clymenella torquata* (9.0%) and *Nephtys ciliata* (7.4%). These two species, one a head-down deposit feeder and the other a jawed carnivore, have been numerical dominants in other years at this station, usually when sand content is higher than usual.

Another polychaete species, *Nephtys cornuta*, was a numerically important species at several stations in 2004. It was the numerical dominant at two stations in or near the inner harbor: T02, where it accounted for about 35% of the fauna, and at C019, where it accounted for about 75% of the fauna. *N. cornuta* was also among the dominants at T01 (2.8%), T04 (4.4%), and T07 (about 18%). At all of these stations, its abundance and proportion of the fauna increased compared with previous years.

The community at T04 remained less species rich compared with the infauna at all other stations; in August 2004, as in several previous years, the overwhelming numerical dominant was *Streblospio benedicti* (70.0% of the fauna).

Station CO19, although sampled in 2004 for the first time in this program, had been sampled in 1989 as part of the Sediment-Water Exchange (SWEX) study (Gallagher and Keay, 1998). At that time, 94–96 % of the fauna was comprised of *Streblospio benedicti* and a cirratulid identified as *Chaetozone setosa*; only a few individuals of four additional taxa were identified from the samples (oligochaetes, *Polydora* sp., *Mya arenaria*, and *Pectinaria gouldi*).

5.3.3 Multivariate Community Analysis of the 2004 Data

Similarity Analysis—In 2004, the CNESS analysis of the 27 samples taken at nine stations in August showed five groups of stations at the CNESS level 1.0, with several clusters comprised of replicates from a single station (Figure 5-3):

Cluster 6.	T01
Cluster 7.	T03, T06, and T05A
Cluster 8.	T02, T07, and C019
Cluster 9.	T08
Cluster 10.	T04

This pattern is similar to that seen in previous years, with samples from a station almost always being more similar to samples from the same station than to those from other stations. Within-station similarity was highest at T03 and T06. In 2003, T01 clustered with T08 when a large set of juvenile maldanids was seen at both stations; however, T01 usually has a unique station signature with low similarity to the other stations, as reflected in the results for 2004 (Figure 5-3).

The newly sampled station, C019, was most similar to stations T02 and T07, reflecting the species composition found at that station, rather than the low diversity parameters reported above (Table 5-2). The carnivorous polychaete *Nephtys cornuta* was common at all three stations in 2004 (see section 5.3.2 Dominant Species, above).

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

Figure 5-4 shows the results of a similarity analysis using the Bray-Curtis algorithm, which is more sensitive to numerically dominant species than the CNESS index. When the data are not transformed (Figure 5-4A), the results indicate a 30% level of similarity between T01 and T08. When a fourth-root transformation is applied to the data (Figure 5-4B), thus reducing the importance of numerically dominant species, the overall levels of similarity among stations is greater, but T01 is now more similar to T05A, T06, and T03 than to T08. Other relationships, such as the very low similarity of T04 to the rest of the stations, and the grouping of CO19 with T02 and T07, are similar in both analyses.

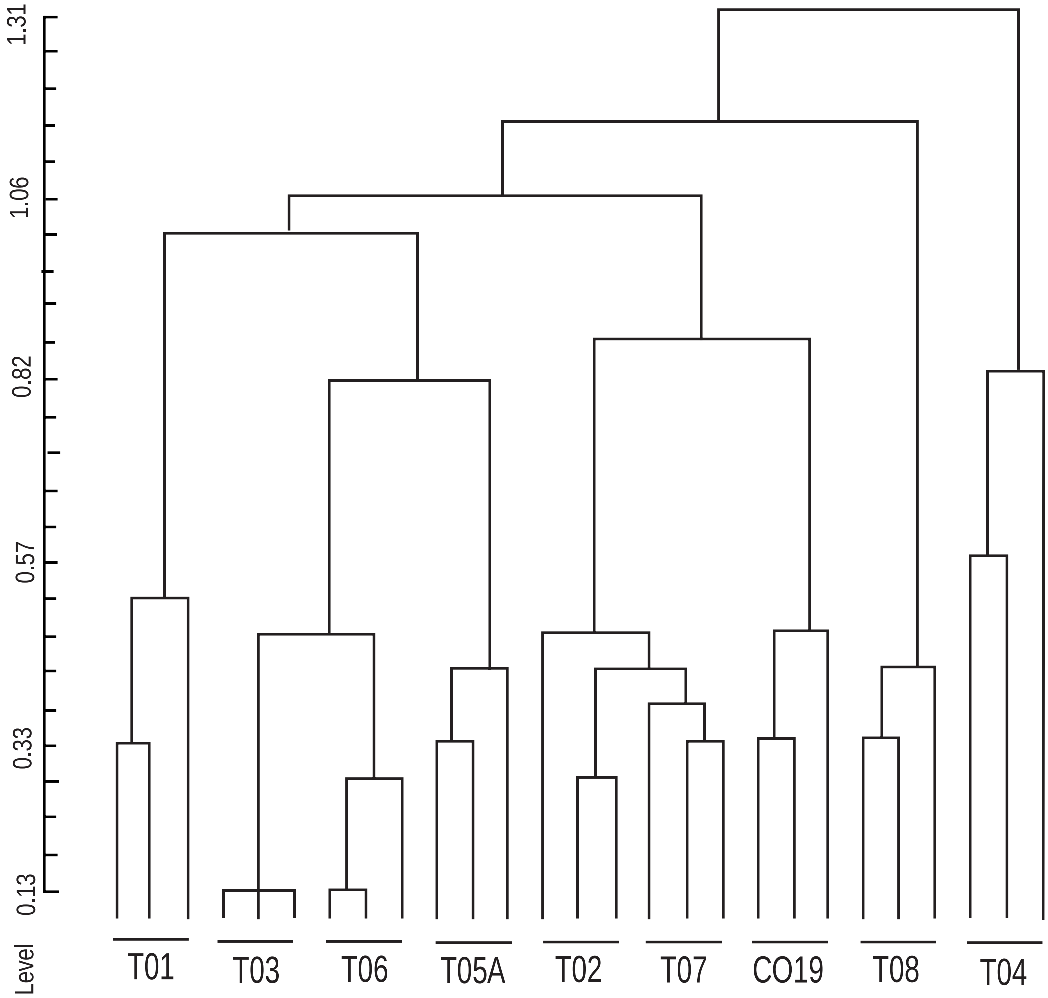


Figure 5-3. Cluster dendrogram of the 27 samples collected at the eight Boston Harbor traditional stations and C019 in 2004; based on CNESS similarity with *m* set at 15 and group average sorting.

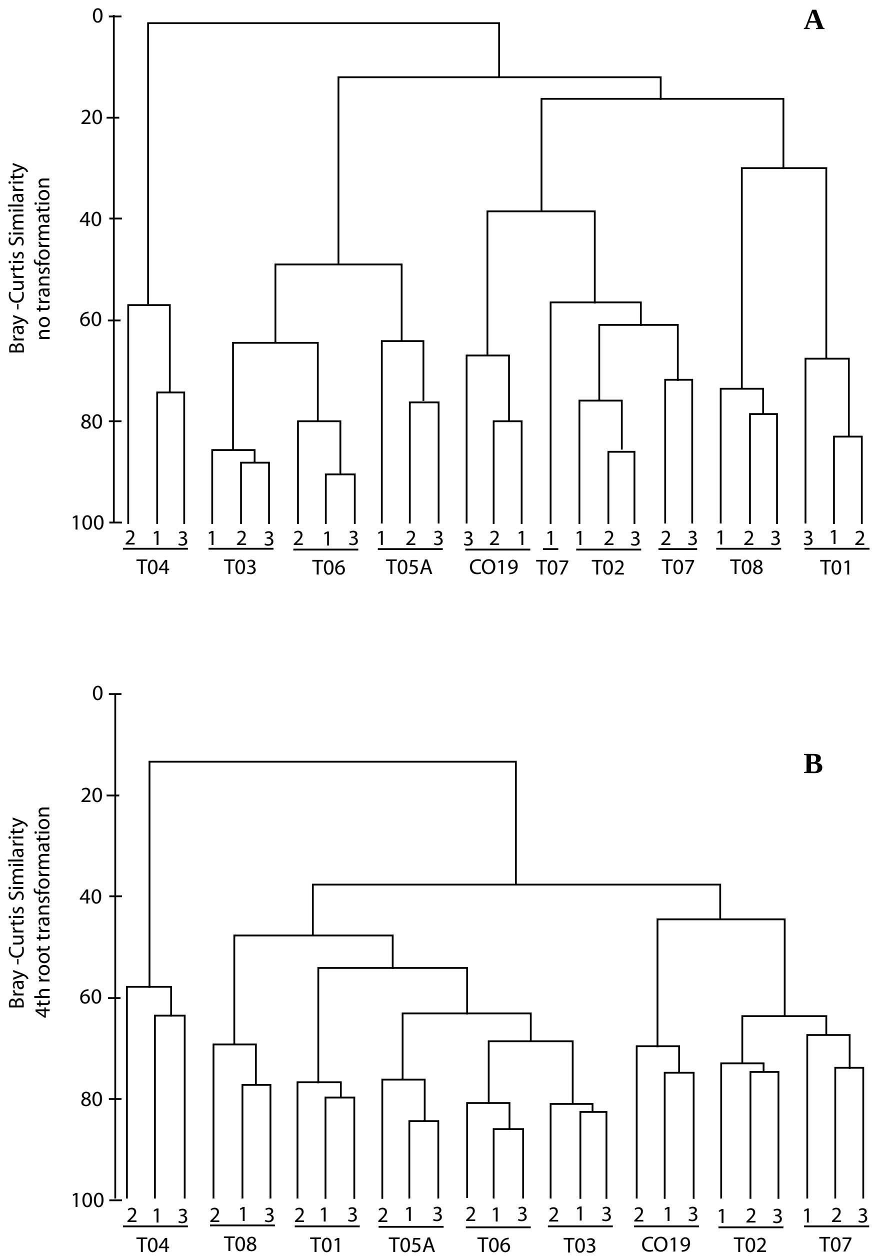


Figure 5-4. Cluster dendrogram of the 27 samples collected at the eight Boston Harbor traditional stations and C019 in 2004; based on Bray-Curtis similarity and group average sorting. A. Untransformed data. B. Fourth-root transformation of the data.

***PCA-H Analysis*—**The metric scaling of the 2004 samples on the first two PCA-H axes, which accounted for 53% of the CNESS variation in the communities, is shown in Figure 5-5. The separation of the T04 samples from the remaining stations, the similarity of station CO19 with stations T02 and T07, the close similarity of T03 and T06, and the grouping of the remaining stations are reflected in this diagram.

The next step of the PCA-H analysis indicated which of the 148 species in the samples were responsible for the relationships among samples as reflected in the metric scaling. With CNESS (*m*=15), 11 species contributed 2% or more of the total variation on PCA-H axes 1 and 2 (Table 5-3), and another two to four species also contributed to axis 3. The Gabriel Euclidean distance biplots for axes 1 v. 2, 1 v. 3, and 2 v. 3 (Figure 5-6) shows those species superimposed over the metric scaling of the stations.

The polychaete *Nephtys cornuta*, which has not been especially abundant in the harbor in previous years, was identified by the PCA-H analysis as the most important species in structuring the fauna in 2004 (Table 5-3). The polychaete *Streblospio benedicti* and the oligochaete *Tubificoides* sp. 2 distinguished T04 from the other stations. Ampelisca spp., the oligochaete *Tubificoides* nr. *pseudogaster*, and the polychaete *Aricidea catherinae* were important at T03 and T06, and another oligochaete, *T. apectinatus*, was important at T02, T03, T06, and T07. *Ampelisca* spp. at T05A contributed to the similarity of that station with T03 and T06 in 2004. The polychaetes *Spiophanes bombyx* and *Exogone hebes*, typically found in sandy environments from shallow to continental shelf depths, as well as the annelid *Polygordius* sp. A, were responsible for differentiating T01 and T08 from the remaining stations.

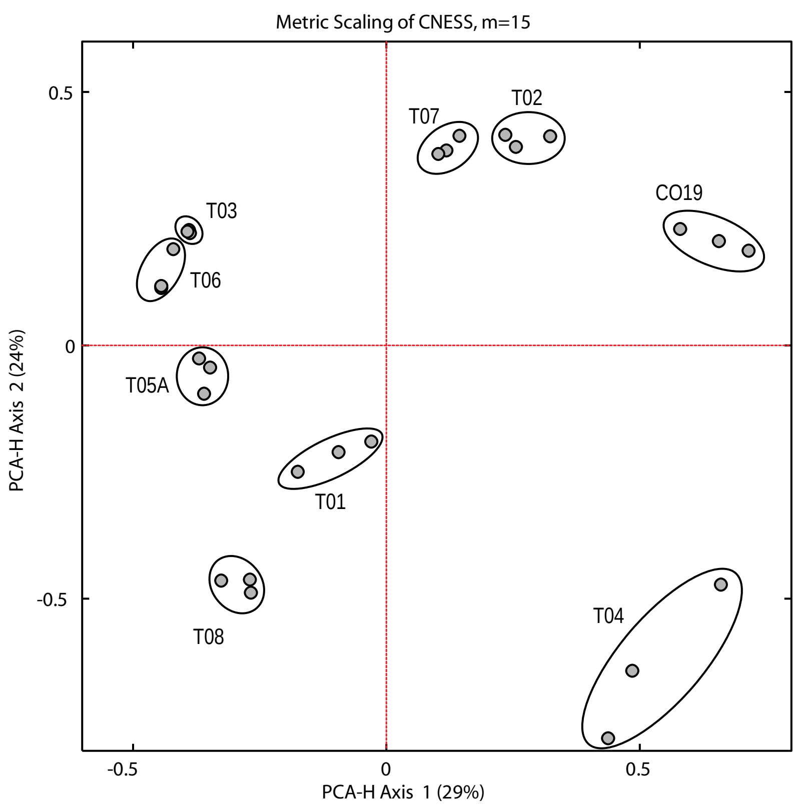


Figure 5-5. Metric scaling of the 2004 Boston Harbor samples, axis 1 v. axis 2, based on CNESS *m* set at 15.

Table 5-3. Contributions to PCA-H axes by species accounting for at least 2% of the CNESS variation among the infaunal samples collected in Boston Harbor 2004 (see Figure 5-6).

Important species: Axis 1 vs. 2					
PCA-H Rank	**Species**	**Contr.[a]**	**Total Contr.**	**Axis1**	**Axis2**
1	*Nephtys cornuta*	24	24	34	12
2	*Tubificoides apectinatus*	11	35	0	24
3	*Ampelisca* spp.	10	46	18	1
4	*Streblospio benedicti*	9	54	6	12
5	*Aricidea catherinae*	8	62	7	9
6	*Tubificoides* sp. 2	6	68	2	10
7	*Tubificoides* nr. *pseudogaster*	5	73	6	2
8	*Exogone hebes*	4	76	2	5
9	*Nephtys incisa*	3	79	3	3
10	*Spiophanes bombyx*	3	82	1	5
11	*Polygordius* sp. A	2	84	2	2
Important species: Axis 1 vs. 3					
PCA-H Rank	**Species**	**Contr.[a]**	**Total Contr.**	**Axis 1**	**Axis 3**
1	*Nephtys cornuta*	25	25	34	4
2	*Ampelisca* spp.	13	38	18	3
3	*Streblospio benedicti*	10	48	6	17
4	*Exogone hebes*	6	54	2	15
5	*Aricidea catherinae*	5	59	7	1
6	*Tubificoides* nr. *pseudogaster*	5	64	6	3
7	*Spiophanes bombyx*	5	69	1	13
8	*Tubificoides* sp. 2	4	73	2	8
9	*Polygordius* sp. A	4	77	2	7
10	*Yoldia limatula*	3	79	3	2
11	*Photis pollex*	2	81	3	2
12	*Nephtys incisa*	2	84	3	1
Important species: Axis 2 vs. 3					
PCA-H Rank	**Species**	**Contr.[a]**	**Total Contr.**	**Axis 2**	**Axis 3**
1	*Tubificoides apectinatus*	15	15	24	0
2	*Streblospio benedicti*	14	29	12	17
3	*Tubificoides* sp. 2	10	38	10	8
4	*Exogone hebes*	9	47	5	15
5	*Nephtys cornuta*	9	56	12	4
6	*Spiophanes bombyx*	8	64	5	13
7	*Aricidea catherinae*	6	70	9	1
8	*Polygordius* sp. A	4	74	2	7
9	*Tellina agilis*	3	77	2	4
10	*Tubificoides* nr. *pseudogaster*	3	80	2	3
11	*Clymenella torquata*	2	82	2	4
12	*Nephtys incisa*	2	84	3	1

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

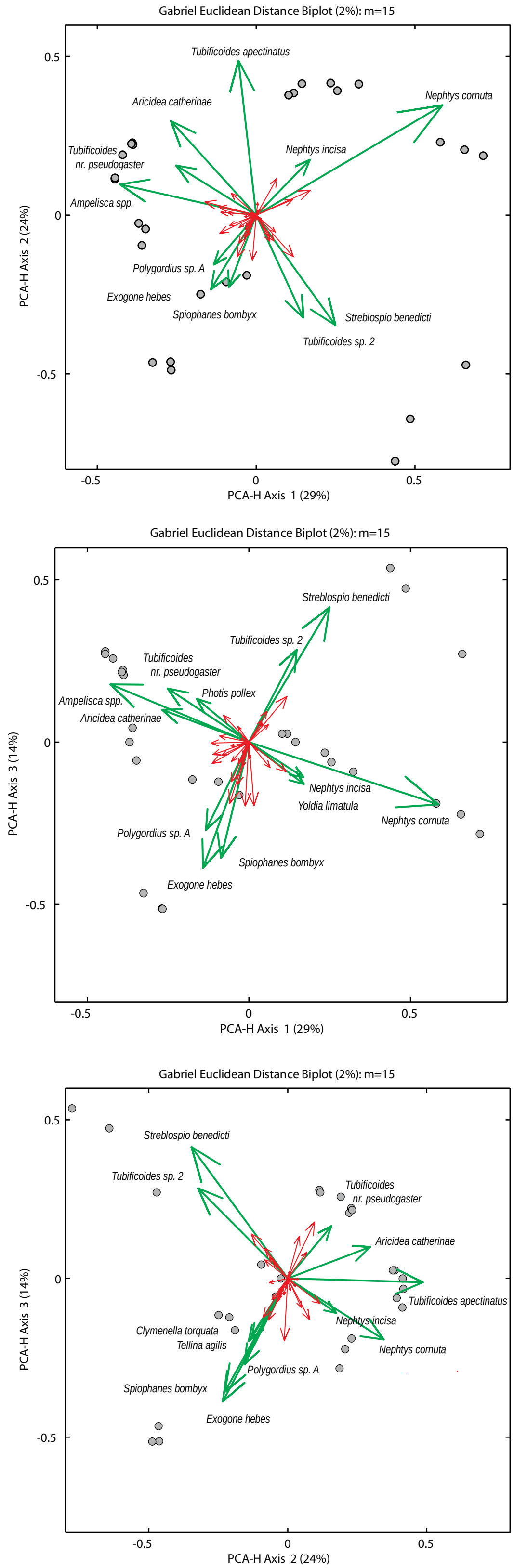


Figure 5-6. Gabriel Euclidean distance biplots of the 2004 Boston Harbor samples based on CNESS *m* set at 15. Species that account for at least 2% of the variation are labeled (see Table 5-3).

5.3.4 Long-term Monitoring (1991–2004): Stations considered separately

T01, Deer Island Flats. Located to the west of the Deer Island Flats near the original site of effluent discharge, this general area was described in 1978 as highly polluted (J Williams, pers. com. to NJ Maciolek, Battelle, 1978; Blake and Maciolek, 1990). Two benthic samples collected in 1978 included 39 taxa and were dominated by oligochaetes and the predatory polychaetes *Pholoe minuta* and *Eteone longa*. The 42 samples taken in late summer (September 1991 through August 2004) included 130 species; 58 species, with a mean of 44 ± 2.0 SD species per sample, were present in 2004 (Table 5-2).

T01 has changed noticeably over the time period of the monitoring program, especially in the last two or three years. The early years of monitoring were marked by large seasonal fluctuations in abundances, with high densities in the August samples (Figure 5-7) and low densities in the spring samples (Maciolek *et al*. 2004). These fluctuations were due primarily to large numbers of *Polydora cornuta* (a suspension feeding spionid polychaete) and *Clymenella torquata* (a head-down deposit feeding maldanid polychaete) that settled in August but had migrated or died off by the following spring. *Clymenella torquata* was largely absent from this station in 1999 and 2000, but was again represented by a set of juveniles in 2001 and 2003 (Maciolek *et al*. 2005), resulting in some similarities with T08 in the southern part of the harbor. Fewer *C. torquata* were present in 2004, resulting in a weaker similarity with T08 than in 2003. In general, the last few years of monitoring (*i.e.*, 1999–2004) have been marked by lower abundances compared with the period prior to 1999.

Community parameters, especially diversity, also reflect the changes at T01 (Figure 5-7). Although the number of taxa recorded at this station in 2004 did not exceed the highs recorded in 1997 and 1998, Shannon diversity (H′) and log-series *alpha* have both increased over time. For example, beginning in August 1997, the mean H′ has been greater than 3.0, and reached a high of 4.1 in August 2004 (Table 5-2). Diversity as measured by log-series *alpha* has been more variable than Shannon H′, but has also increased over the past decade (Figure 5-7) to a high of 10.1 in 2004. Rarefaction curves (Figure 5-8) based on samples pooled for each August sampling date demonstrates higher diversities in 2001–2004 compared with earlier years.

Changes in species composition at T01 are reflected in the multivariate analyses (Figures 5-9 and 5-10). CNESS similarity analysis of samples pooled within each sampling date indicate three clusters of years: (1) 1991, 1996, 1999, and 2000; (2) 1992–1995, 1997, 1998; and the most dissimilar group (3) 2001–2004. *Streblospio benedicti*, an opportunistic species tolerant of stressed environmental conditions, was once common at T01 but has been present in much lower densities since 1998: only three individuals were present in the 2003 samples and two in 2004. Similarly, *Polydora cornuta*, which numbered 2000–12,000 in years prior to 1998, is now found in much lower numbers, typically 500 or fewer each year. The very high similarity between 1993 and 1994 is due to unusually high numbers of *Tharyx* spp. in those two years. One species of oligochaete, *Tubificoides* nr. *pseudogaster*, was common in the early years of monitoring, but a second species, *Tubificoides* sp. 2, has also been present in recent years. Other species that were not found at T01 in the early monitoring years, but are now common, include *Nephtys ciliata*, *Leptocheirus pinguis*, and *Exogone hebes*. Axes 1 and 2 in the PCA-H analysis accounted for 56% of the CNESS variation among samples (Figure 5-10A). Species that contributed 2% or more to the CNESS variation are indicated in the Gabriel Euclidean biplot (Figure 5-10B) and in Table 5-4.

The OSI measured by sediment profile imaging (Chapter 4, this report) increased from low values of 3.0-5.3 from 1992–2001 to highs of 8.0 and 9.3 in 2002 and 2003, respectively, but declined again in 2004 to 4.8 (Table 4-6). Sediments at T01 have been consistently high in sand content, with the exception of 1992 and 1995 (Chapter 3, this report; Appendix B, Figure B2-1, top).

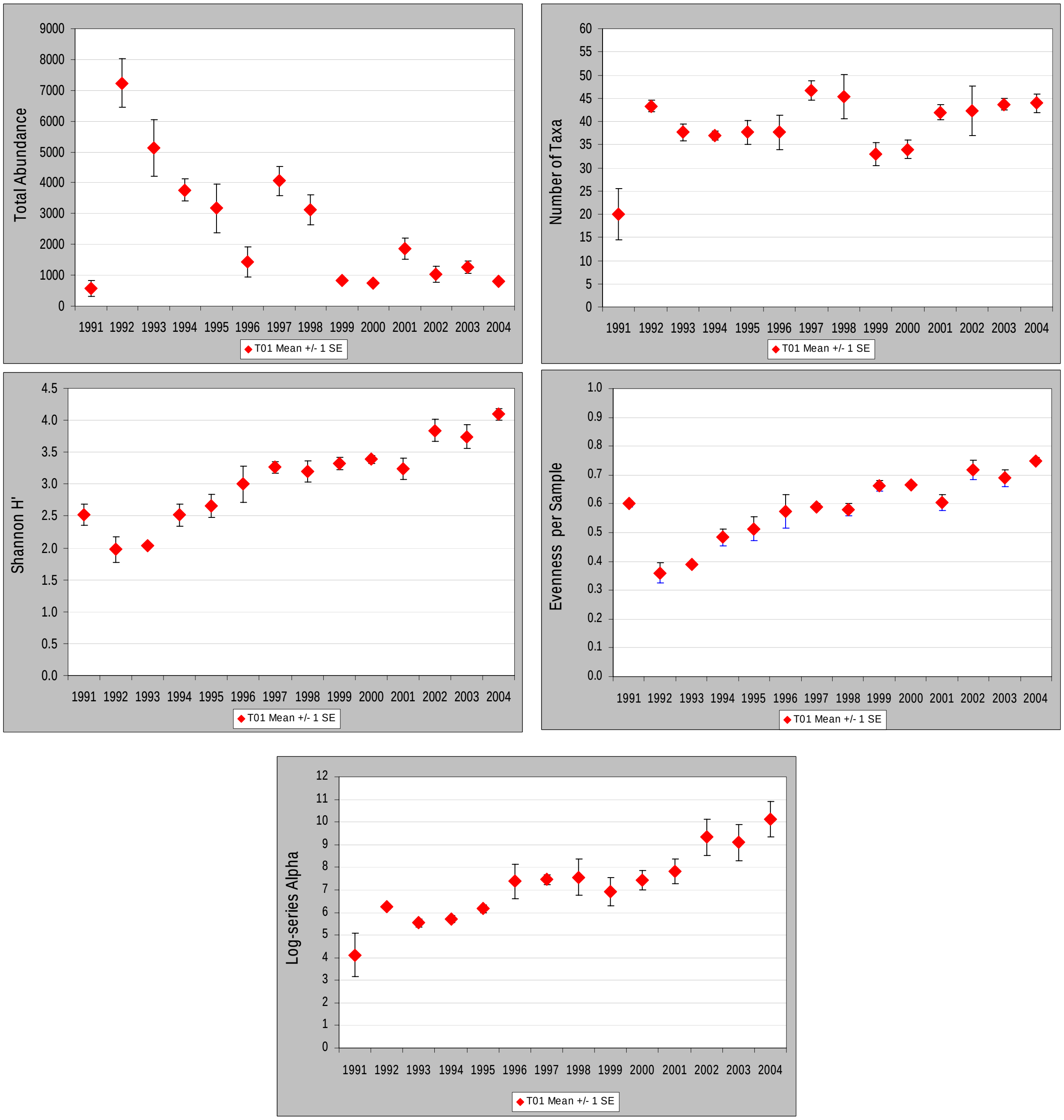


Figure 5-7. Benthic community parameters measured in August 1991 through 2004 at Boston Harbor station T01.

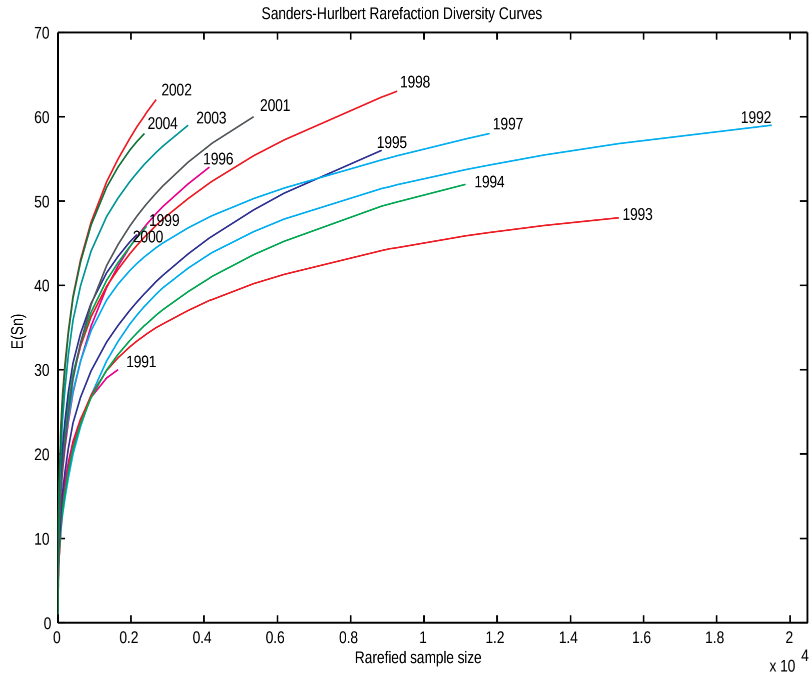


Figure 5-8. Rarefaction curves for T01, based on samples pooled for each August sampling date.

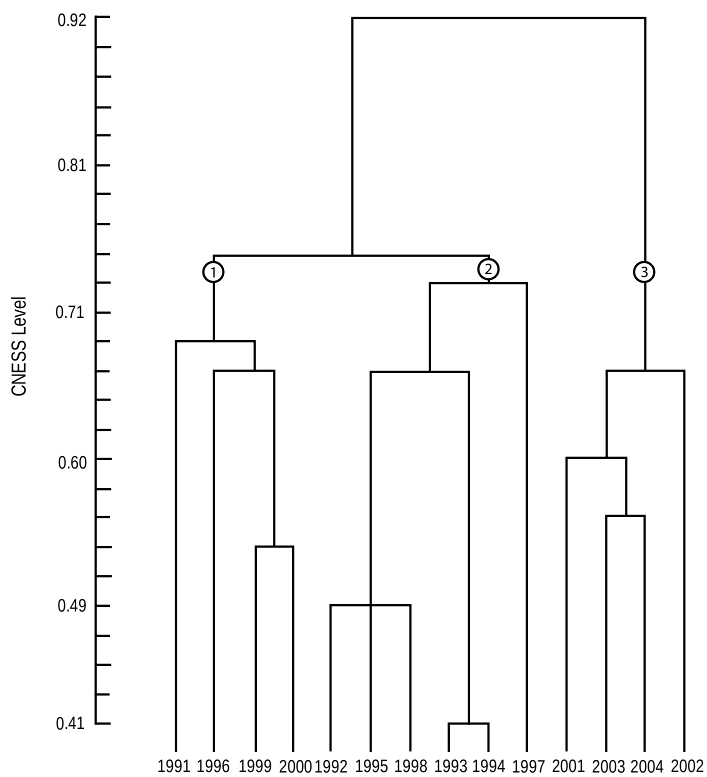


Figure 5-9. Dendrogram based on CNESS, *m* = 20, for T01 samples pooled within each August sampling date.

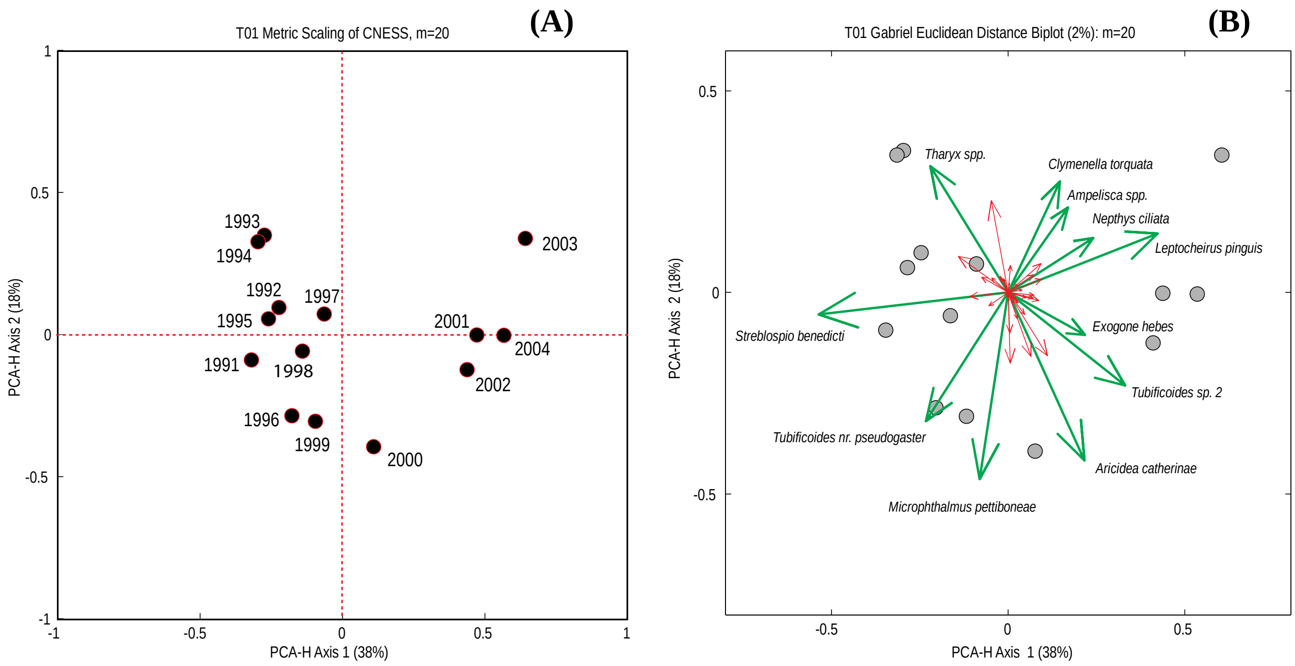


Figure 5-10. PCA-H analysis of T01, based on samples pooled for each year. (A) Metric scaling of station-years; (B) Species vectors accounting for >2% of plot variation in green; other species vectors plotted in red and unlabeled.

Table 5-4. Contribution to PCA-H axes 1 and 2 of the 11 species accounting for at least 2% of the community variation at Boston Harbor station T01 (see Figure 5-10B).

PCA-H Rank	Species	Contr.[a]	Total Contr.	Axis 1	Axis 2
1	*Streblospio benedicti*	20	20	29	0
2	*Leptocheirus pinguis*	13	33	18	2
3	*Tubificoides* sp. 2	9	42	11	5
4	*Aricidea catherinae*	9	50	5	17
5	*Microphthalmus pettiboneae*	7	58	1	21
6	*Tubificoides* nr. *pseudogaster*	7	65	5	10
7	*Thayrx* spp.	6	71	5	10
8	*Nepthys ciliata*	5	76	6	2
9	*Clymenella torquata*	4	79	2	8
10	*Exogone hebes*	4	83	5	1
11	*Ampelisca* spp.	3	86	3	4

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

T02, Governor's Island Flats. This station is located adjacent to the Inner Harbor near the entrance to the Boston South Channel. Sediments at T02 have been variable (Chapter 3, this report), with total sand content fluctuating from highs of nearly 70% in 1993 and 1994 to a low of 35% in 2003 (Appendix B, B2-1, bottom). This station was sampled in 1979 and 1982 (Blake and Maciolek 1990) and was considered to be highly polluted with a depauperate fauna. In 1991, only nine species were recorded in the three samples taken, but by 1992, the number of species had increased to 49, which was typical of the station in the following decade. The 42 samples taken in late summer through August 2004 included 131 species; 48 species (mean of 32.3 ± 4.9 SD species per sample), were present in 2004 (Table 5-2).

Mean abundances per sample have been comparable throughout the monitoring period, with the notable exceptions of the summer samples in 1994 and 1995 when amphipods were particularly numerous (Figure 5-11). In 2003, T02 appeared to be far less depauperate than in most monitoring years, but in 2004, densities and species richness were again low and comparable to values recorded in 1999–2002 (Figure 5-11). Mean values of Shannon diversity and log-series *alpha* have followed a sine-wave-like pattern of higher and lower values over the 14 years of sampling, with lower values in 2004 compared with those in 2003. Evenness in 2004 was comparable to that recorded in 2003 (Figure 5-11). Rarefaction curves (Figure 5-12) based on samples pooled for each August suggest that diversities in 1998–2004 were higher than in any year prior to 1998.

CNESS similarity analysis of samples pooled within each sampling date (Figure 5-13) indicated three major clusters of years: (1) 1991 and 1996; (2) 1992–1995, 1998, 1999 and (3) 1997 and 2000–2004. The level of similarity between groups 1 and 2 is a bit lower than the often-used 50% level of 0.71 to distinguish major clusters: if that level is used as a criterion, 1991, 1996, and 1992 would each represent separate clusters of a single stations each. The year 1991 was unusual in that only nine taxa and 137 organisms were present in the three combined replicates. The years 1994 and 1995 show a very high level of similarity, due to similar species composition and numbers of numerically dominant species, including *Ampelisca* spp., *Asabellides oculata, Chaetozone vivipara, Photis pollex, Polydora cornuta, Streblospio benedicti, and Tubificoides* nr. *pseudogaster.* These species, in particular, *Ampelisca* spp., *C. vivipara, P. cornuta,* and *S. benedicti* were either missing from the community in other years, or were present in much lower numbers. Only two specimens of the stress-tolerant polychaete *S. benedicti* were present in 2003, and one in 2004, a significantly lower population level compared with the hundreds or thousands of individuals present in 1992–1998. After 1998, *T. apectinatus* replaced *T.* nr. *pseudogaster* as the dominant oligochaete, and other species not previously resident in large numbers, including *Aricidea catherinae* and *Nephtys cornuta* became the numerical dominants.

Axes 1 and 2 in the PCA-H analysis accounted for 64% of the CNESS variation among samples (Figure 5-14A). Years 2001–2004 were clearly separated along axis 1 from the majority of earlier years; 1997 and 2000 were intermediate between the two groups. Species that contributed 2% or more to the CNESS variation are indicated in the Gabriel Euclidean biplot (Figure 5-14B) and in Table 5-5. *Streblospio benedicti* and *T. apectinatus,* which were nearly mutually exclusive in terms of the years in which they were present in the samples, were the most important in separating the years along axis 1.

The OSI determined from sediment profile imaging (Chapter 4, this report) has been variable over time, ranging from a low of 3.0 in 1992, to 5.7 and 6.7 in 1994 and 1995 when the community was dominated by amphipods, and declining again to 3.0 in 1999 and 2000. The highest OSI, 10.0, was reached in 2003, but declined again in 2004 to 7.3 (Table 4-6).

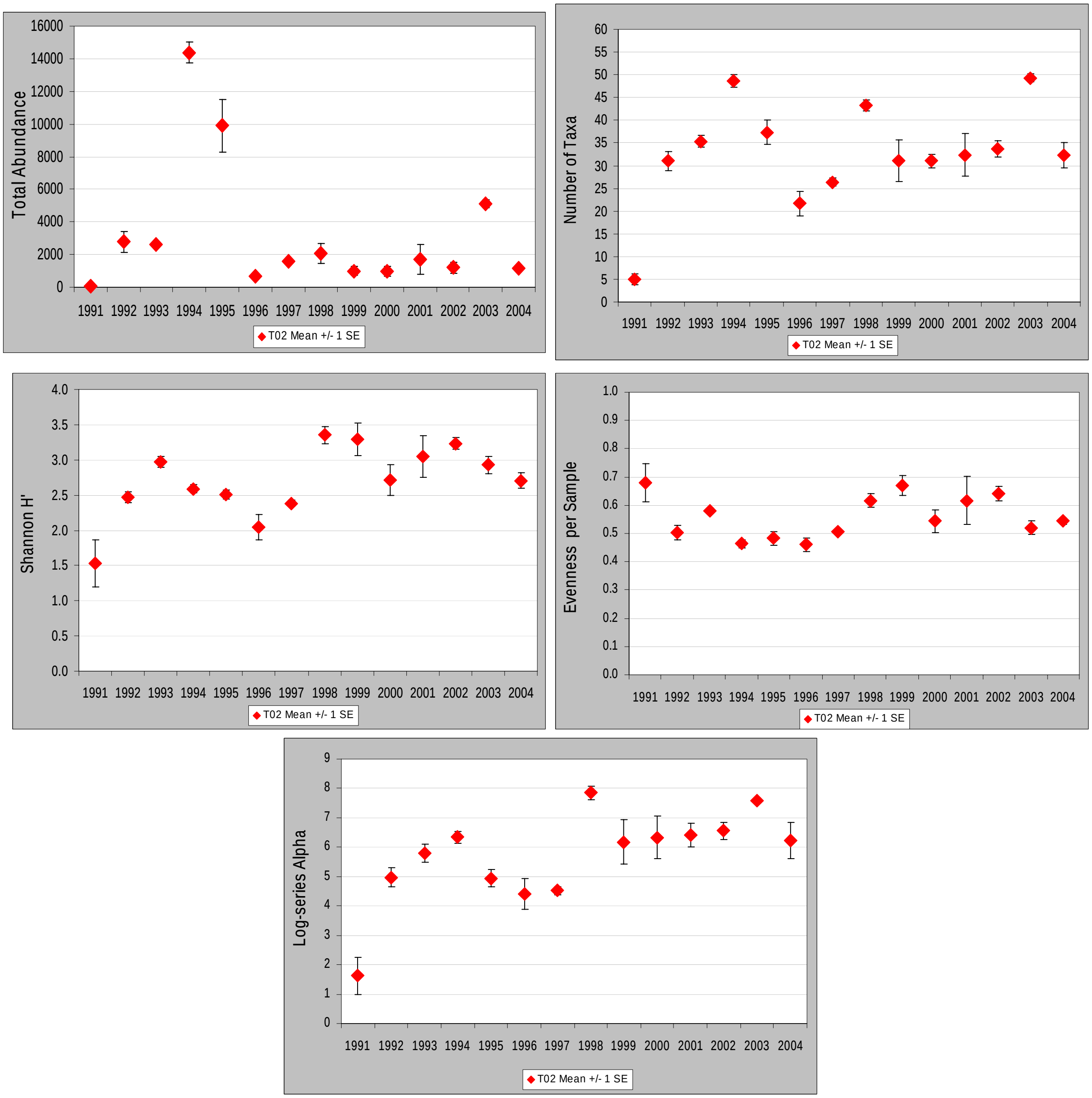


Figure 5-11. Benthic community parameters measured in August 1991 through 2004 at Boston Harbor station T02.

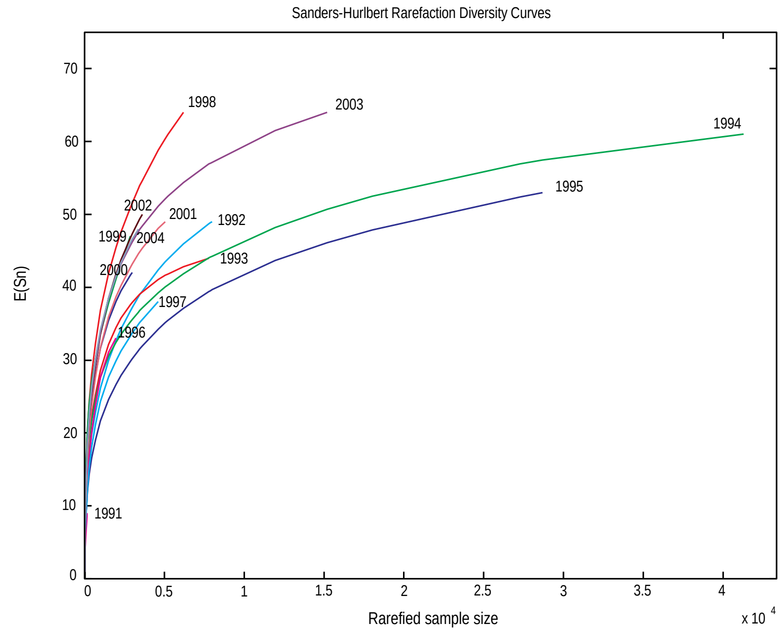


Figure 5-12. Rarefaction curves for T02, based on samples pooled for each August sampling date.

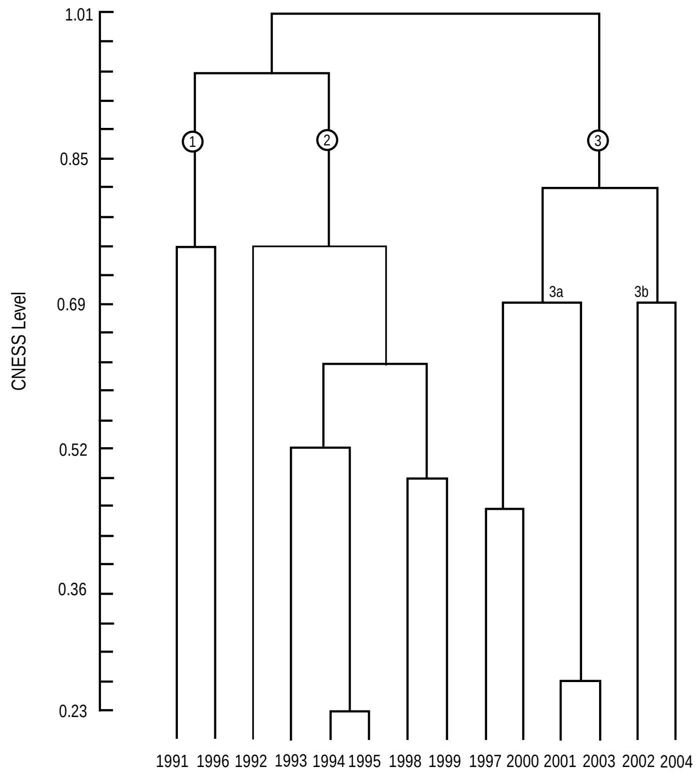


Figure 5-13. Dendrogram based on CNESS, *m* = 20, for T02 samples pooled within each August sampling date.

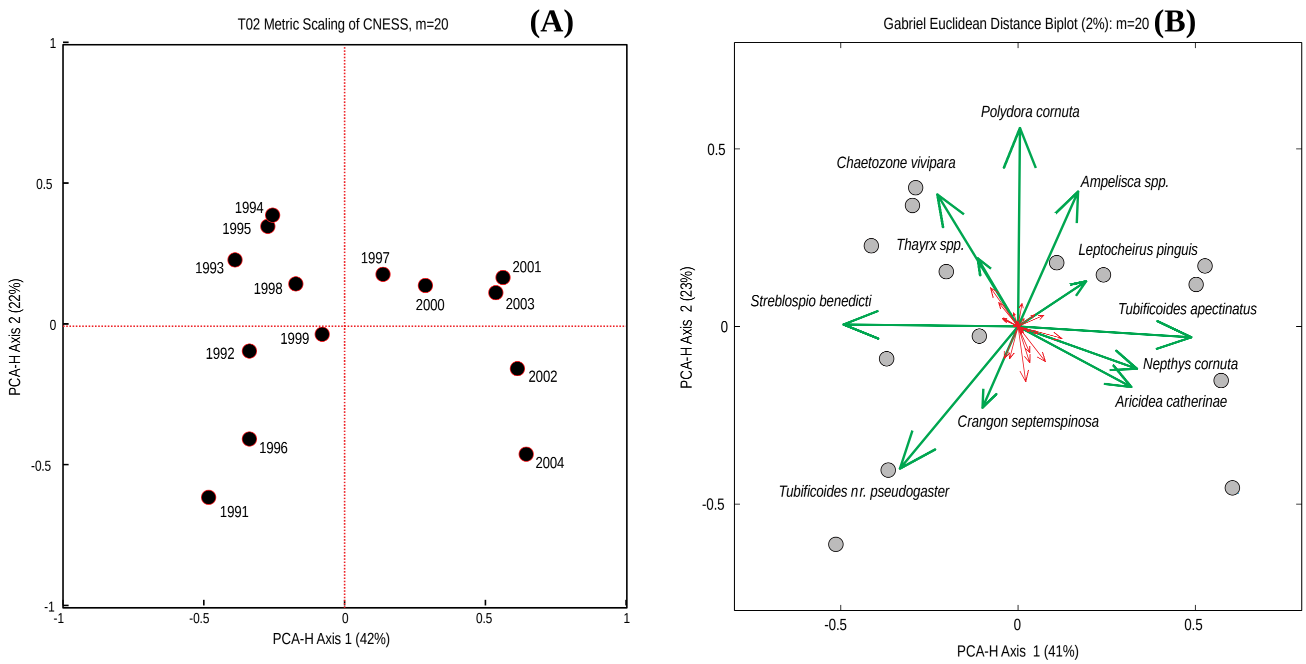


Figure 5-14. PCA-H analysis of T02, based on samples pooled for each year. (A) Metric scaling of station-years; (B) Species vectors accounting for >2% of plot variation in green; other species vectors plotted in red and unlabeled.

Table 5-5. Contribution to PCA-H axes 1 and 2 of the 11 species accounting for at least 2% of the community variation at Boston Harbor station T02 (see Figure 5-14B).

PCA-H Rank	Species	Contr.[a]	Total Contr.	Axis 1	Axis 2
1	*Streblospio benedicti*	16	16	24	0
2	*Tubificoides apectinatus*	15	31	24	0
3	*Tubificoides* nr. *pseudogaster*	13	44	11	16
4	*Polydora cornuta*	11	55	0	31
5	*Chaetozone vivipara*	8	63	5	14
6	*Nephtys cornuta*	8	71	11	1
7	*Aricidea catherinae*	8	79	10	3
8	*Ampelisca* spp.	7	85	3	14
9	*Leptocheirus pinguis*	3	88	4	2
10	*Crangon septemspinosa*	2	91	1	5
11	*Tharyx* spp.	2	93	1	4

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

T03, Long Island. This station is located seaward of T02, and sediments there have been highly variable (Chapter 3, this report), probably due to the sediment-trapping influence of the tube-building amphipods that often characterize the area. Amphipod crustaceans have been particularly important constituents of the community at T03, especially *Ampelisca* spp., which occurred in peak densities in August 1994, 1998, and 1999 (mean densities of 6269, 8222, and 11,853 individuals per sample, respectively). At other times, August densities have ranged from 35 to 4837 per sample; in 2004 the mean density of *Ampelisca* spp. was 2624 organisms per sample, which represented a 40% reduction from the mean number present in the year before (4358 individuals per sample). In addition to *Ampelisca* spp., other amphipod species, including *Crassicorophium bonnelli*, *Leptocheirus pinguis* (1995–1999, 2003), *Unciola irrorata,* and *Photis pollex* have also been dominant in some August collections, especially 2003 (Maciolek *et al.* 2005). However, the mean density of *C. bonnelli* dropped from 594 organisms per sample in 2003 to absent (only one individual was recorded) in 2004. The mean density of *L. pinguis* in 2004 was 77% of the 2003 densities, having declined from 199 organisms per sample in 2003 to 154 organisms per sample in 2004, while *U. irrorata* was present at only 14% of 2003 densities (260 organisms per sample in 2003 and 38 organisms per sample in 2004). *Photis pollex* increased by 65%, but the numbers were very low (68 organisms per sample in 2003 and 112 organisms per sample in 2004).

As seen for station T02, *Tubificoides apectinatus* has joined or replaced *T.* nr. *pseudogaster* as a dominant in the past few years (since 2000), and the mean density of this species increased by 250% from 677 organisms per sample in 2003 to 1750 organisms per sample in 2004. Other species not previously resident in large numbers have come to dominate the fauna, including *Aricidea catherinae,* which is very common at several other harbor stations and also in the offshore samples collected in Massachusetts Bay (Maciolek *et al*. 2005). The 42 samples taken in late summer (September 1991 through August 2004) included 153 species; 81 species, with a mean of 59.0 ± 5.2 SD species per sample, were present at this station in 2004 (Table 5-2).

Diversity as measured by log-series *alpha* was the most stable parameter at T03 through 2002: except for an increase in August 1992 and a small increase in August 1998, the large fluctuations in Shannon diversity (as well as evenness and total abundance) seen at this station were not reflected in log-series *alpha* (Figure 5-15). However, the 2003 samples were especially rich in numbers of species, and log-series *alpha* increased significantly; in 2004, *alpha* was only slightly lower than in 2003. Species richness essentially doubled between 1991 and 1994, increasing from a mean of 23 to a mean of 42 species per sample, and continued to remain high for several years. In 2003, the mean increased to 64 species per sample, and was only slightly lower in 2004 (59 species ±5.2 SE, Table 5-2). Rarefaction curves (Figure 5-16) based on samples pooled for each August sampling date demonstrate much higher diversities in 2003 and 2004 compared with earlier years.

CNESS similarity analysis of samples pooled within each sampling date (Figures 5-17) indicate three clusters of years: (1) 1991, (2) 1993 and 1995; and (3) all remaining years. 1991 was an outlier with low similarity to any other year; these samples had very few species and high densities of only the oligochaete *T*. nr. *pseudogaster*. The years 1993 and 1995 were distinguished by high densities of both *C. bonnelli* and *L. pinguis*. Axes 1 and 2 in the PCA-H analysis accounted for 59% of the CNESS variation among samples (Figure 5-18A). The years 1991 and 1993/1995 were clearly separated along axis 1, with all remaining years separated from these two station groups along axis 2, and among themselves along axis 1. Species that contributed 2% or more to the CNESS variation are indicated in the Gabriel Euclidean biplot (Figure 5-18B) and in Table 5-6. *Tubificoides apectinatus* and *Ampelisca* spp. were the most important species contributing to axes 1 and 2, respectively.

The OSI at T03, based on sediment profile imaging (Chapter 4, this report), has ranged from 5.5 to 11.0; the years with the lowest OSI were 1994 (5.5) and 1998 (5.7), when *Ampelisca* spp. were especially numerous.

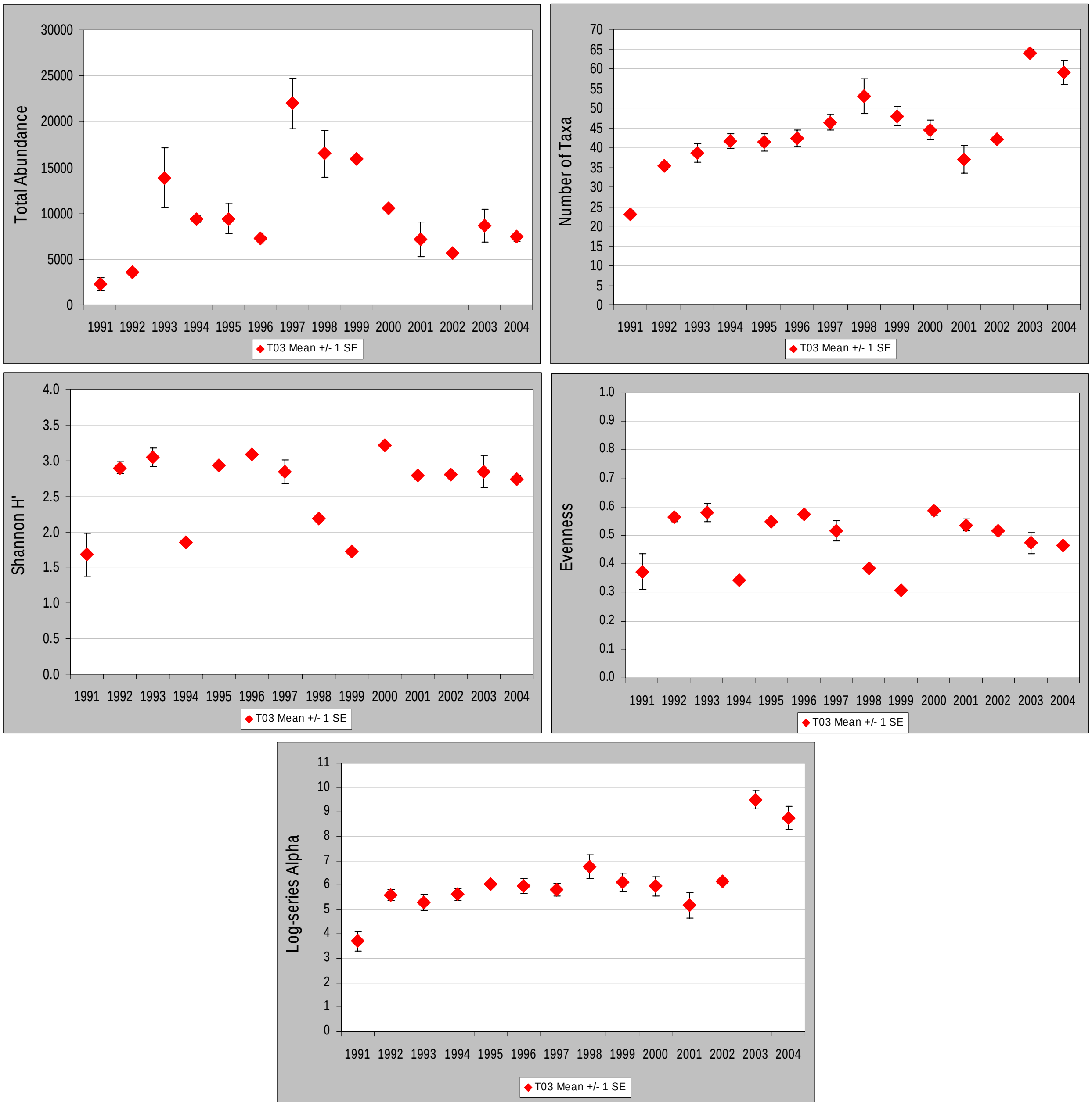


Figure 5-15. Benthic community parameters measured in August 1991 through 2004 at Boston Harbor station T03.

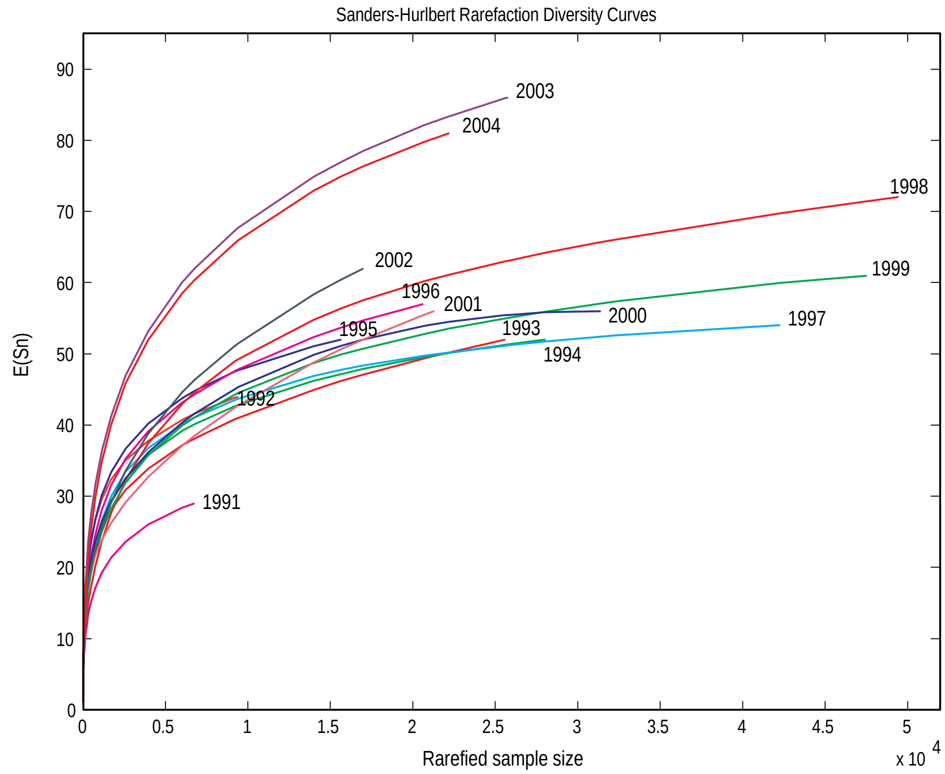


Figure 5-16. Rarefaction curves for T03, based on samples pooled for each August sampling date.

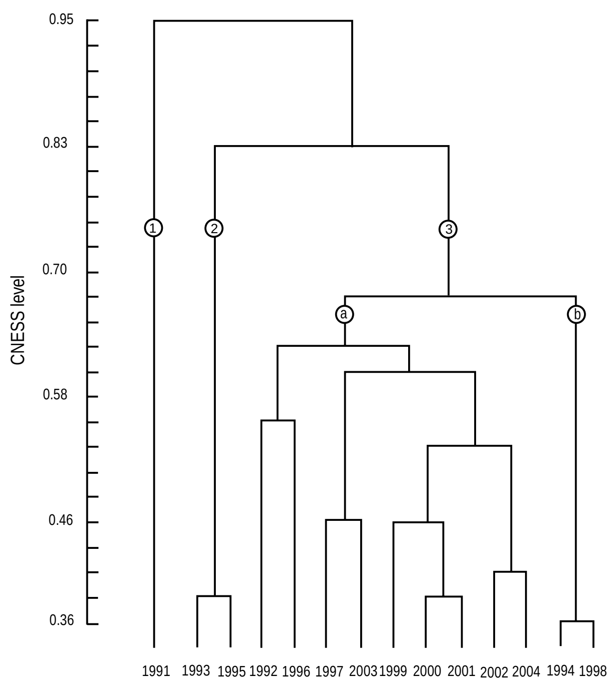


Figure 5-17. Dendrogram based on CNESS, *m* = 20, for T03 samples pooled within each August sampling date.

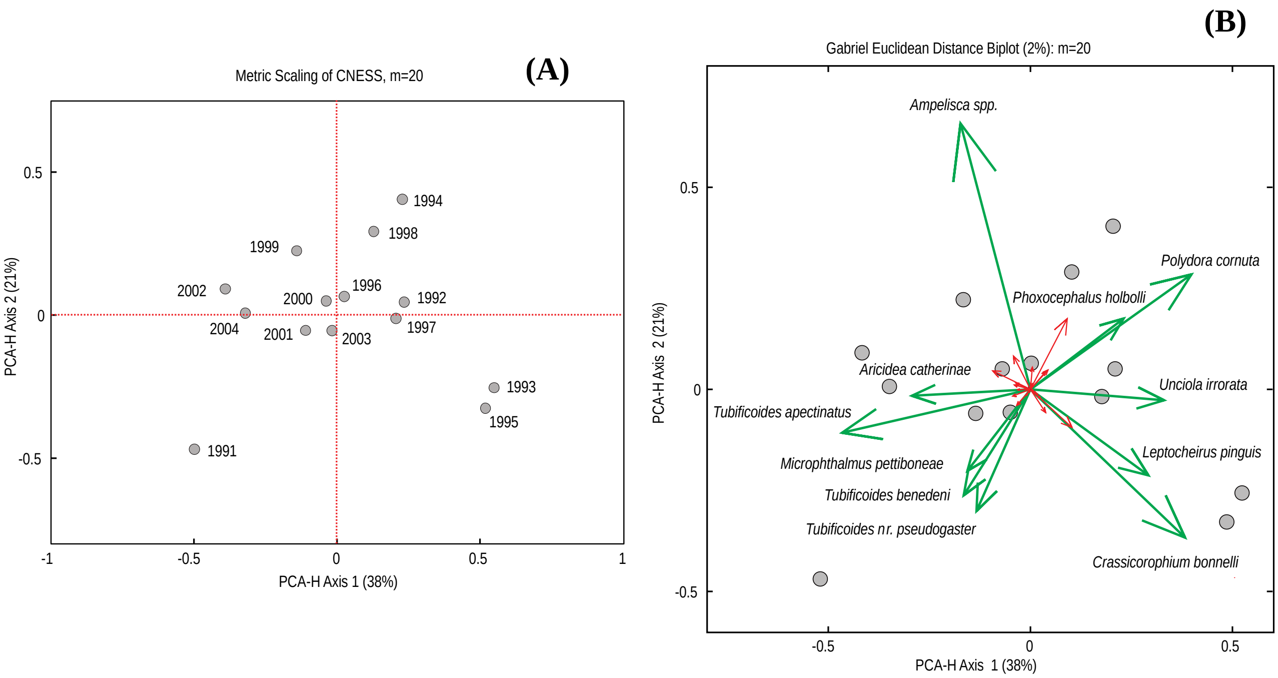


Figure 5-18. PCA-H analysis of T03, based on samples pooled for each year. (A) Metric scaling of station-years; (B) Species vectors accounting for >2% of plot variation in green; other species vectors plotted in red and unlabeled.

Table 5-6. Contribution to PCA-H axes 1 and 2 of the 11 species accounting for at least 2% of the community variation at Boston Harbor station T03 (see Figure 5-18B).

PCA-H Rank	Species	Contr.[a]	Total Contr.	Axis 1	Axis 2
1	*Ampelisca* spp.	18	18	3	43
2	*Tubificoides apectinatus*	14	32	22	1
3	*Crassicorophium bonnelli*	14	46	15	13
4	*Polydora cornuta*	13	59	16	8
5	*Leptocheirus pinguis*	7	66	9	5
6	*Unciola irrorata*	7	73	11	0
7	*Aricidea catherinae*	5	79	9	0
8	*Phoxocephalus holbolli*	5	83	5	3
9	*Tubificoides* nr. *pseudogaster*	4	88	2	9
10	*Tubificoides benedeni*	4	92	3	7
11	*Microphthalmus pettiboneae*	3	95	2	4

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

T04, Dorchester Bay. This station was included in the monitoring program as a degraded station that was unlikely to show rapid improvement after pollution abatement. Gallagher and Grassle (1989) and Gallagher *et al.* (1992) demonstrated that this site was heavily impacted by local sources and by focused deposition of effluent and sludge particulates transported from distant outfalls. Sediments at T04 have been consistently comprised of high percentages of silt+clay (fines), with correspondingly high TOC content (Chapter 3, this report). In 1998, when the *Capitella* population bloomed, TOC was measured at 8.9%, even though fines were only at 79.6%, the fourth lowest percentage recorded from the August samples. In all other years, the percent TOC in August samples ranged from 3.1 to 4.8.

T04 consistently has the lowest abundances, species richness, and diversity of the eight traditional harbor stations (Table 5-2; Maciolek *et al.* 2005: Appendix D3). Only 55 species have been recorded from the August samples collected at T04; in 2004, 17 species were present, and of these, *Spiophanes bombyx* and *Yoldia* spp., each represented by a single individual, were newly recorded from the station (but not the harbor).

The benthic community has appeared unstable, especially in the April collections, with no real patterns either within a sampling date (*e.g.*, large SE around parameter means) or between years (*e.g.*, numerical dominant species change from year to year) (Maciolek *et al*. 2005). Many of the August collections in the early 1990s were dominated by *Streblospio benedicti*, which often occurred in high densities of up to 2213 individuals per sample (Maciolek *et al*. 2005). A major exception to dominance by *Streblospio* was the population explosion of *Capitella capitata* complex in 1998, when an average of 3872 ± 1742 SD individuals per sample were found to the exclusion of almost all other species.

August community parameters such as diversity and evenness also fluctuate from year to year (Figure 5-19), always around very low values: the mean for all years of monitoring is 0.9 for Shannon diversity, 0.3 for evenness, and 1.89 for log-series *alpha*. Rarefaction curves (Figure 5-20) based on samples pooled for each August sampling date would appear to indicate higher diversities in 2003 and 2004 compared with earlier years, but the samples are so depauperate that most of the curves are simply short lines with steep slopes.

CNESS similarity analysis of samples pooled within each sampling date (Figures 5-21) indicates three clusters plus the outlier year 1998 (labeled cluster 4 in Figure 5-21) when high densities of *Capitella capitata* complex were found to the exclusion of almost all other species. Group 1 includes 1991 and 1996, which were characterized by *Streblospio* in moderate numbers and only as many as four additional species. Group 2 includes 1992–1995, 1997, and 1999; these years were characterized by even higher numbers of *Streblospio*, plus other species such as *P. cornuta*, *Ampelisca* spp., and a predatory polychaete, *Nephtys cornuta*. Group 3 includes 2000–2004, during which time oligochaetes (species of *Tubificoides*) and cirratulids (species of *Tharyx*) have become more common.

Axes 1 and 2 in the PCA-H analysis accounted for 49% of the CNESS variation among samples (Figure 5-22A). With the exception of 1998, there is little or no spread along axis 1. The samples from 2000–2004 have positive loadings on axis 2, whereas the majority of the earlier samples have negative loadings. Species that contributed 2% or more to the CNESS variation are indicated in the Gabriel Euclidean biplot (Figure 5-22B) and in Table 5-6. *Capitella capitata* complex and S. benedicti were the most important species contributing to axis 1, while *Tubificoides* sp. 2 and *Turbellaria* spp. separated the samples along axis 2. These four species together accounted for 86% of the total CNESS variation within the community.

The OSI at T04, based on sediment profile imaging (Chapter 4, this report), has ranged from a low of -5.3 in 1998 to a high of 2.7 in 2001 (Table 4-6). There has been no trend at this station, however, because the second-highest value (2.6) was in 1992, and the high in 2001 was followed by an OSI of 1.0 in 2002.

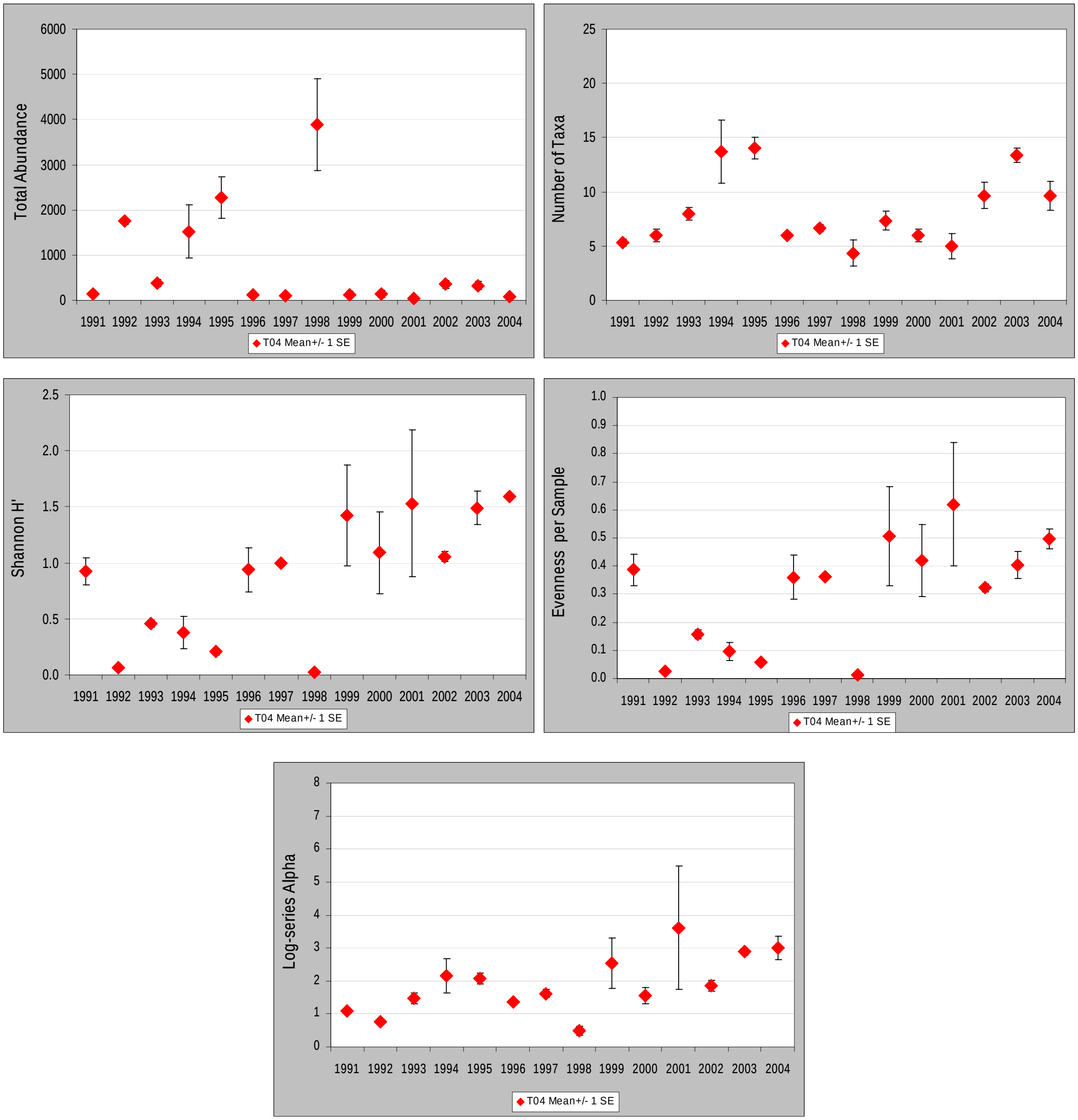


Figure 5-19. Benthic community parameters measured in August 1991 through 2004 at Boston Harbor station T04.

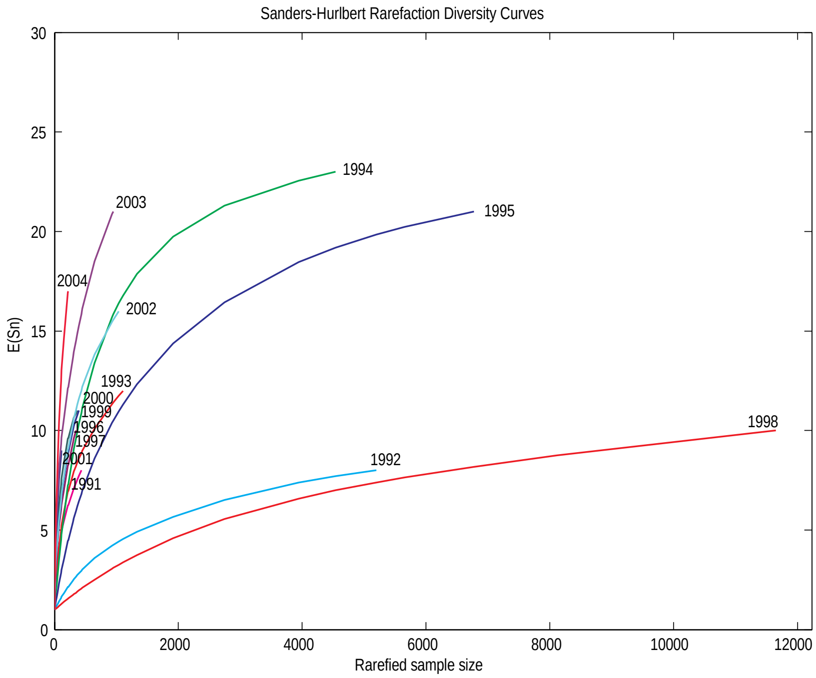


Figure 5-20. Rarefaction curves for T04, based on samples pooled for each August sampling date.

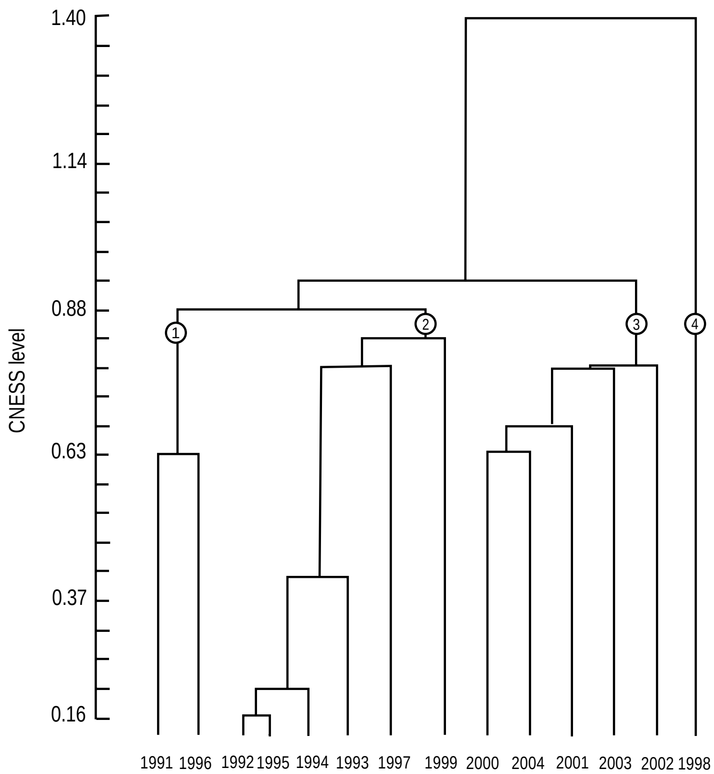
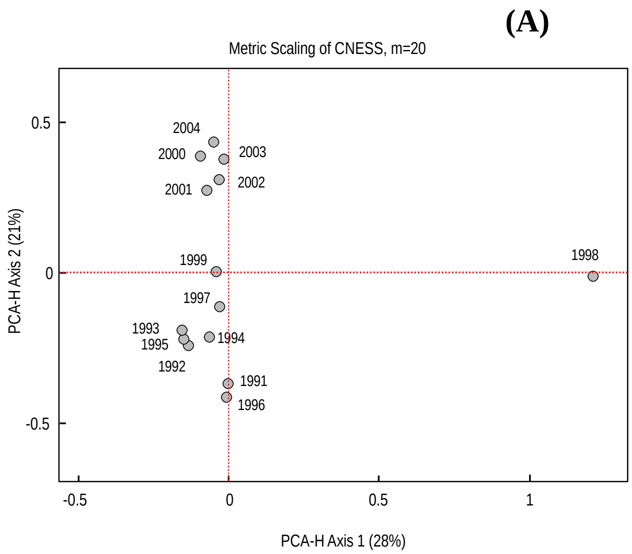


Figure 5-21. Dendrogram based on CNESS, *m* = 20, for T04 samples pooled within each August sampling date.



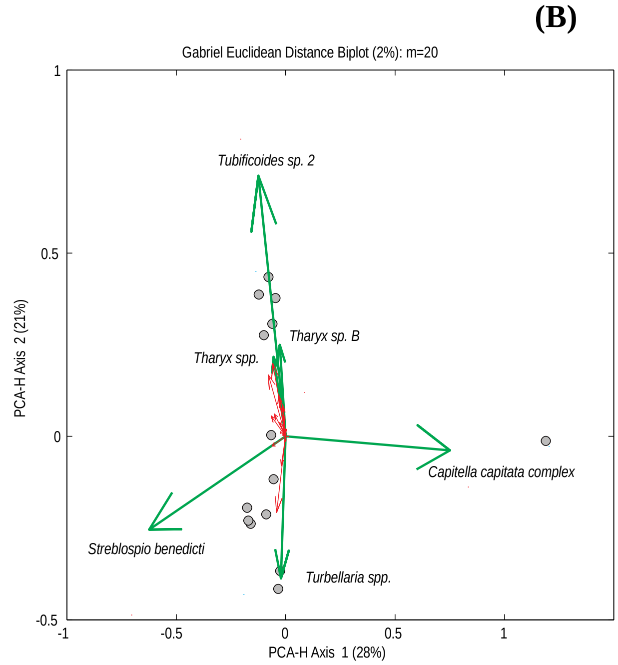


Figure 5-22. PCA-H analysis of T04, based on samples pooled for each year. (A) Metric scaling of station-years; (B) Species vectors accounting for >2% of plot variation in green; other species vectors plotted in red and unlabeled.

Table 5-7. Contribution to PCA-H axes 1 and 2 of the six species accounting for at least 2% of the community variation at Boston Harbor station T04 (see Figure 5-22B).

PCA-H Rank	Species	Contr.[a]	Total Contr.	Axis 1	Axis 2
1	*Capitella capitata* complex	32	32	56	0
2	*Streblospio benedicti*	25	57	39	6
3	*Tubificoides* sp. 2	23	80	2	50
4	*Turbellaria* spp.	6	86	0	15
5	*Tharyx* sp. B	3	89	0	6
6	*Tharyx* spp.	2	91	0	5

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

T05A, President Roads. Because of difficulty in sampling the coarse sediments of the original station T05 off the tip of Long Island near the old sludge discharge from Nut Island, an alternate location farther out in the channel was selected. Sediments here are sandy, varying around a mean of nearly 80% sand (Chapter 3, this report). T05A has been sampled routinely since August 1993, and the 36 summer samples collected there comprise 155 species. In 2004, 102 taxa were recorded from this station, with an average of 76.3±5.8 SD per sample (Table 5-2). *Caulleriella* sp. B, *Paradoneis armatus, Paranaitis speciosa, Pleurogonium rubicundum, Tetrastemma elegans,* and *Molgula complanata* were all newly recorded at T05A in 2004; of these, the isopod *P. rubicundum* and the ascidian *M. complanata* were also new records for the harbor. Some of the singleton or rare species found at T05A represent new distribution records and undescribed species that are new to science (Maciolek *et al*. 2004).

Species that dominated the benthic infauna in the early- to mid-1990s included *Polydora cornuta*, *Ampelisca* spp., *Tharyx* spp., *Edotia triloba*, *Unciola irrorata*, and occasionally *Capitella capitata* complex, *Tubificoides* nr. *pseudogaster*, and *T. apectinatus*. Many of these species have continued to be important components of the benthic community along with *Ilyanassa trivittata*, *Aricidea catherinae*, and *Spiophanes bombyx*. In years when *Ampelisca* spp. or *P. cornuta* do not overwhelm the fauna, one of these taxa may be the dominant, as in 2002 when *T. apectinatus* was the numerical dominant in both spring and summer samples (Maciolek *et al*. 2004). In 2003, amphipods were especially important, accounting for 90% of the individuals; in 2004, *Ampelisca* spp. accounted for 45%, and all amphipods accounted for just over 60%, of the fauna (Appendix D3).

Benthic community parameters for samples from T05A have shown wide, primarily seasonal, fluctuations (Maciolek *et al*. 2004), but there have also been large interannual differences (Figure 5-23). Densities were especially high (mean = 21,319.3 ± 225.5 organisms per sample) in August 1997, due to high numbers of both *P. cornuta* and *Ampelisca* spp.; densities in 2003 were the second highest recorded at this station (mean = 12,679.7 ±773.0 organisms per sample) due primarily to *Ampelisca* spp. but decreased in 2004 by half (Figure 5-23). The lower densities and increased number of species in 2004 resulted in significantly higher diversity (Shannon H', Pielou's evenness, and log-series *alpha*) values (Figure 5-23). Community diversity as measured by rarefaction (Figure 5-24) suggests that while diversity has increased over time at this station, especially after 1998, the community sampled in 2004 was the most diverse seen at T05A.

CNESS similarity analysis of samples pooled within each sampling date (Figures 5-25) indicates two major, highly dissimilar clusters, each of which may be further divided into two or three subgroups (alternatively, five groups may be identified, these are labeled a–e in Figure 5-25.). Groups a (1993), b (2002), and c (1996, 1999, 2000, 2002) comprise major cluster 1. Groups d (1995, 1997, 1998) and e (1994, 2001, 2003, and 2004) comprise cluster 2. These groups are reflected in the PCA-H and Euclidean distance diagrams (Figure 5-26). Major cluster 1 (groups a, b, c) are defined by abundances of several polychaete species, as well as the oligochaete *T. apectinatus*, the bivalve *Tellina agilis*, and the gastropod *I. trivittata*. The years in group d were characterized by high abundances of *P. cornuta* (mean densities of 1370, 8407, and 4249 individuals per sample, respectively); whereas group e (1994, 2001, 2003, 2004) was characterized chiefly by amphipod species. Axes 1 and 2 of the PCA-H analysis account for 58% of the CNESS variation, with *Ampelisca* spp. the most important on axis 1 and *P. cornuta* the most important on axis 2 (Table 5-8).

The OSI at T05A, based on sediment profile imaging (Chapter 4, this report), has ranged from a low of 2.3 in 1999 to a high of 8.0 in 2004; there has been no apparent long-term trend in OSI at this station.

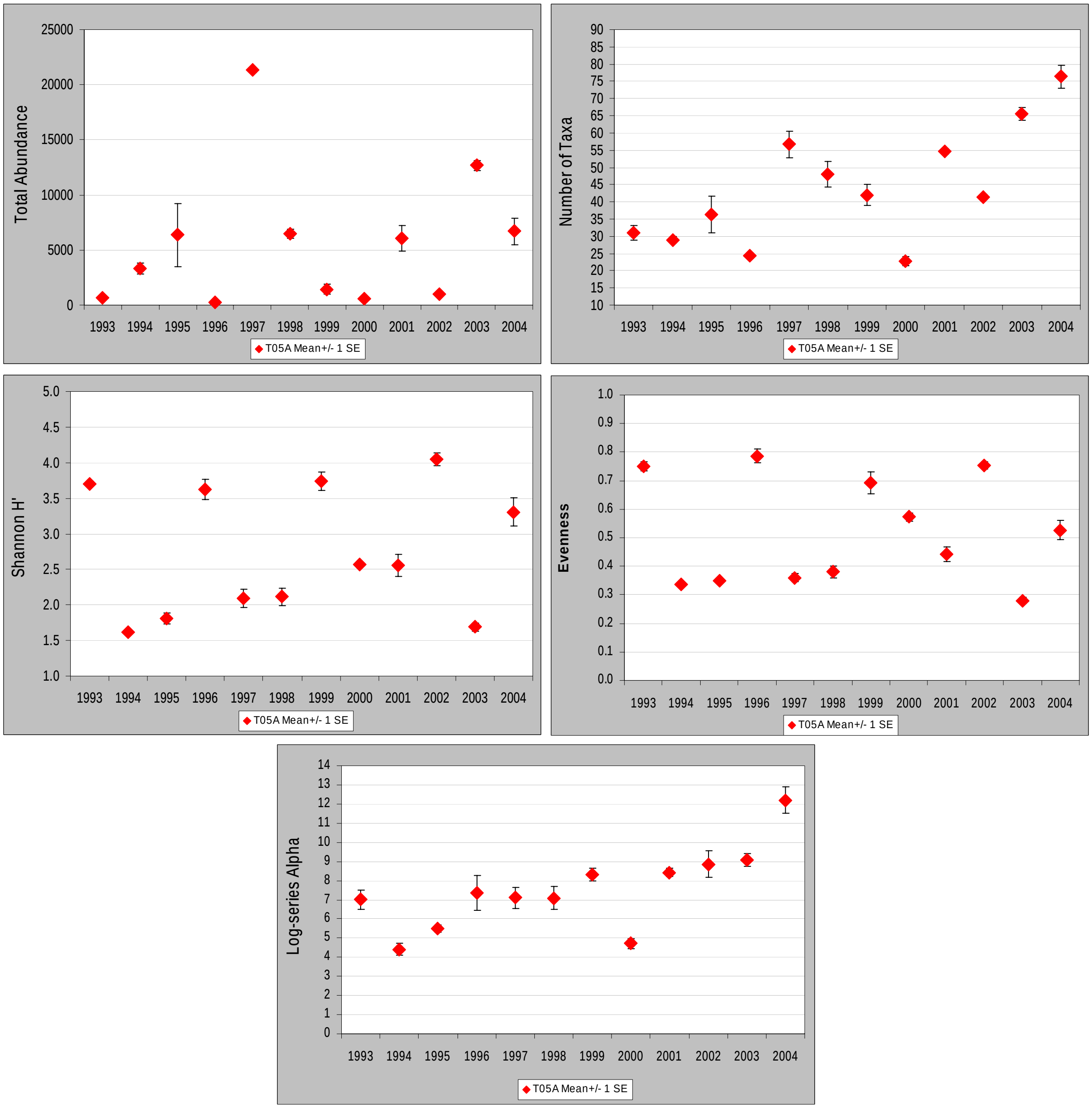


Figure 5-23. Benthic community parameters measured in August 1993 through 2004 at Boston Harbor station T05A.

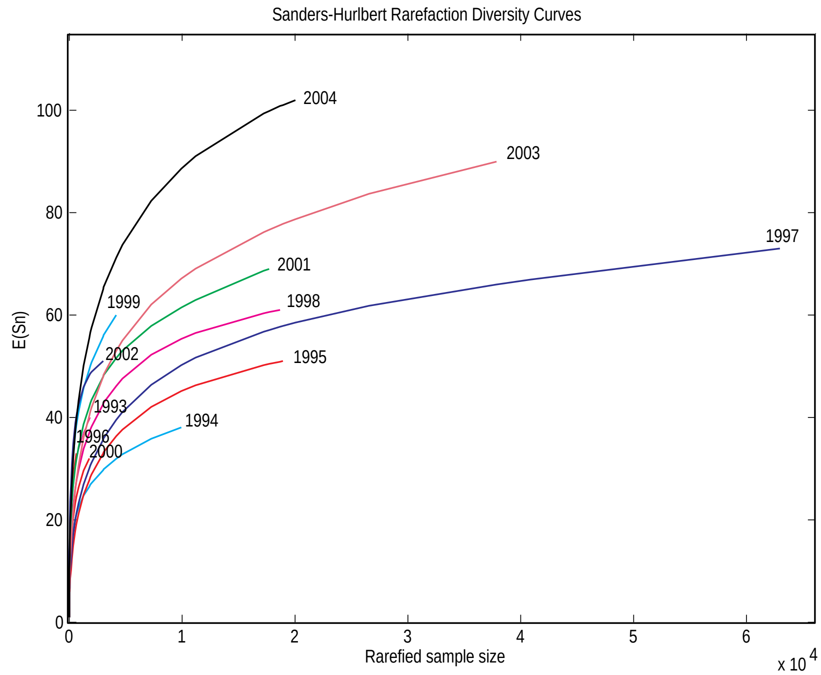


Figure 5-24. Rarefaction curves for T05A, based on samples pooled for each August sampling date.

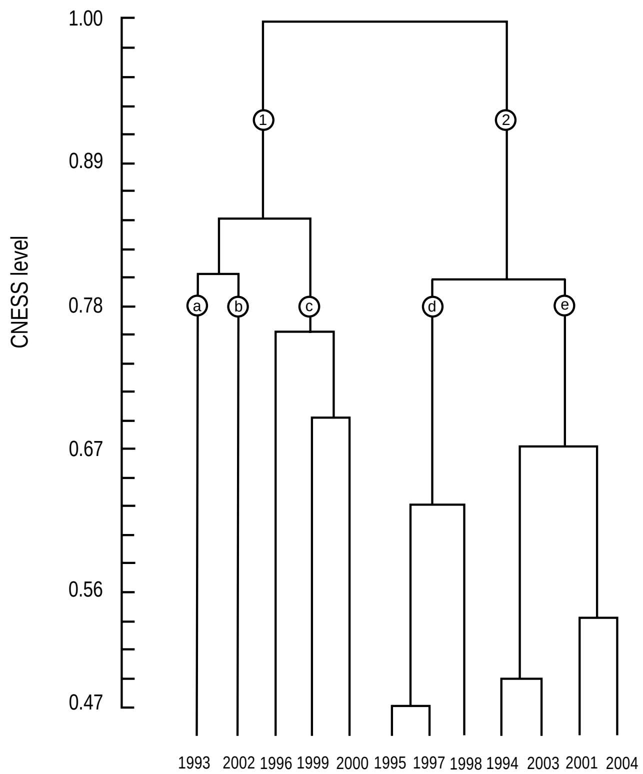


Figure 5-25. Dendrogram based on CNESS, *m* = 20, for T05A samples pooled within each August sampling date.

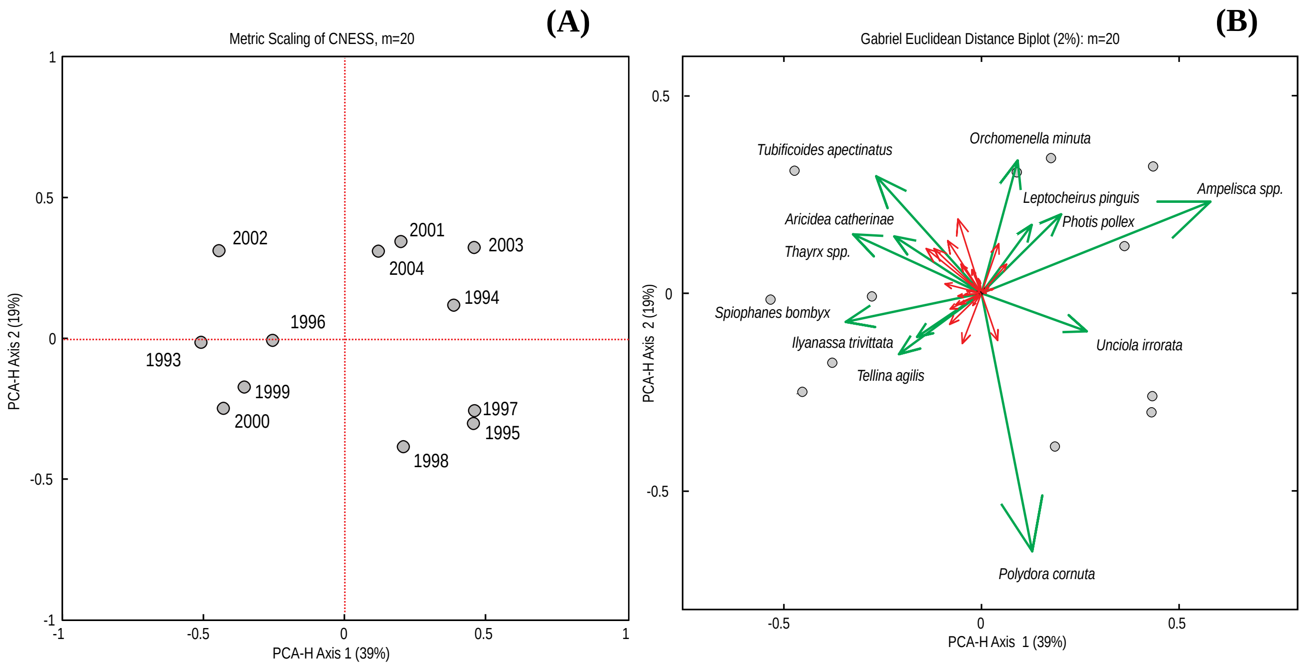


Figure 5-26. PCA-H analysis of T05A, based on samples pooled for each year. (A) Metric scaling of station-years; (B) Species vectors accounting for >2% of plot variation in green; other species vectors plotted in red and unlabeled.

Table 5-8. Contribution to PCA-H axes 1 and 2 of the 12 species accounting for at least 2% of the community variation at Boston Harbor station T05A (see Figure 5-26B).

PCA-H Rank	Species	Contr.[a]	Total Contr.	Axis 1	Axis 2
1	*Ampelisca* spp.	24	24	34	5
2	*Polydora cornuta*	15	39	2	43
3	*Spiophanes bombyx*	8	48	12	1
4	*Tharyx* spp.	8	55	11	2
5	*Tubificoides apectinatus*	8	63	7	9
6	*Unciola irrorata*	5	68	7	1
7	*Orchomenella minuta*	4	72	1	11
8	*Photis pollex*	4	76	4	4
9	*Aricidea catherinae*	4	80	5	2
10	*Tellina agilis*	4	84	4	2
11	*Ilyanassa trivittata*	2	86	3	1
12	*Leptocheirus pinguis*	2	88	2	3

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

T06, Peddocks Island. T06 in the southern part of Boston Harbor is a sandy station often dominated by many species of amphipods. Sediment composition has been variable over time, with percent sand varying widely around a mean of nearly 50%, lower than found at T05A or T08 (Chapter 3, this report). A total of 141 species have been recorded from the 42 summer samples taken at T06; in 2004, there were 64 species present in the samples (48.7 ± 7.6 SD per sample) (Table 5-2), fewer than were recorded in 2003, but more than recorded in any other previous year.

Despite variability in sediments, the species composition at T06 has remained fairly consistent throughout the years of monitoring. Amphipod species including *Ampelisca* spp., *Crassicorophium bonnelli*, *Phoxocephalus holbolli,* and *Leptocheirus pinguis* in particular have been diverse and numerically dominant at this station. In addition, the polychaetes *Polydora cornuta* and *Aricidea catherinae* (Figure 5-15) have occurred in large numbers. In 2004, the same five species were the numerical dominants as in 2003: *Ampelisca* spp., *Aricidea catherinae*, *Tubificoides* nr. *pseudogaster, T. apectinatus,* and *Photis pollex* together accounted for 84% of the identified fauna (Appendix D3).

Seasonal fluctuations or trends in species richness, evenness, and the diversity measures H′ and log-series *alpha* were not obvious (Maciolek *et al.* 2004). On an annual basis, the number of species per sample between 1991 and 2002 ranged from 26 (September 1991) to 46 (August 1999), with a slight trend towards increased species richness in the late 1990s (Figure 5-27). Mean values of 40 or more species per sample were recorded in 1995, 1998, 1999, and 2001. In August 2003, however, the mean number of species per sample increased to 64±4.4, resulting in a very sharp increase in log-series *alpha*, while H′ and J′ declined compared with 2002 (Maciolek *et al.* 2005). This increase was reversed to some extent in 2004, when abundance, number of taxa, and log-series *alpha* declined, and H' and evenness rose relative to 2003 (Figure 5-27). Rarefaction curves for T06 (Figure 5-28) also indicate that diversity was much higher in 2004 than in any previous year, and all years after 1998 were more diverse than the previous years.

Multivariate analysis of the August data indicates two outlier years plus two larger groups (Figure 5-29). The most dissimilar year is 1993 (group 1), which was characterized by especially high densities of *C. bonnelli*, *L. pinguis*, and *P. cornuta* (mean densities were 3933, 504, and 3376 individuals per sample, respectively). Samples from 2001 (group 2) were characterized by high (but not exceptionally high) densities of *L. pinguis*, *P. pollex*, and *Orchomenella minuta* (mean densities were 168, 602, and 327 individuals per sample, respectively) and were also somewhat dissimilar to the remaining years. The larger groups were comprised of samples from 1992, 1994–2000 (group 3) and 1991 plus 2002–2004 (group 4). The reason for the similarity of 1991 with the three most recent years is not immediately obvious from inspection of the raw data.

Axes 1 and 2 of the PCA-H analysis accounted for 56% of the CNESS variation, with *C. bonnelli* and *T.* nr. *pseudogaster* the most important species contributing to axis 1and *P. cornuta*, *P. holbolli* and *P .pollex* the most important on axis 2 (Figure 5-30, Table 5-9).

The OSI at T06, based on sediment profile imaging (Chapter 4, this report), has not varied as much as at other stations. Values have ranged from a low of 5.0 in 1994 to a high of 9.3 in 1993, but for many years (*e.g*., 1997–1999), the OSI was 7.7, resulting in a mean value of 7.1 (Table 4-6).

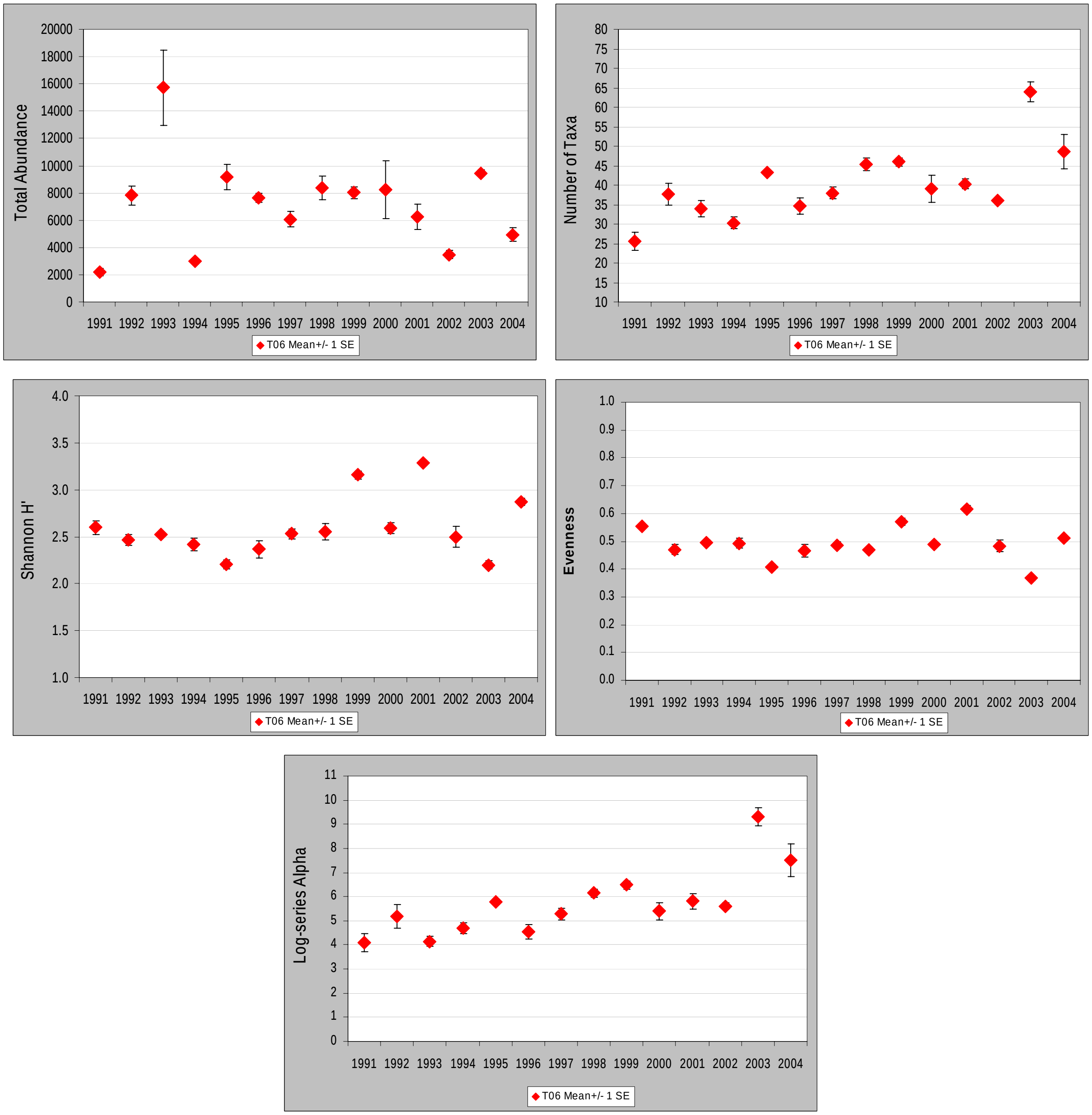


Figure 5-27. Benthic community parameters measured in August 1991 through 2004 at Boston Harbor station T06.

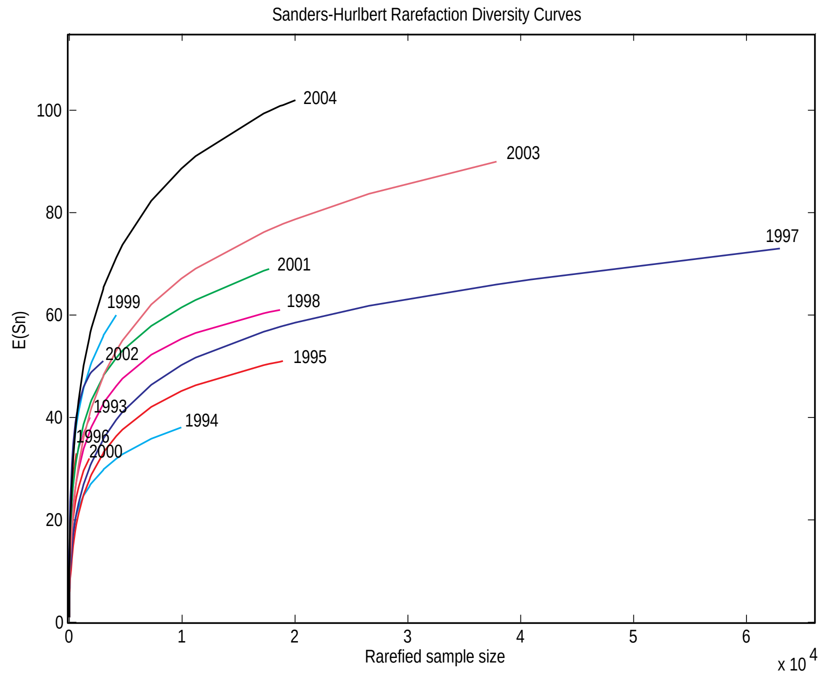


Figure 5-28. Rarefaction curves for T06, based on samples pooled for each August sampling date.

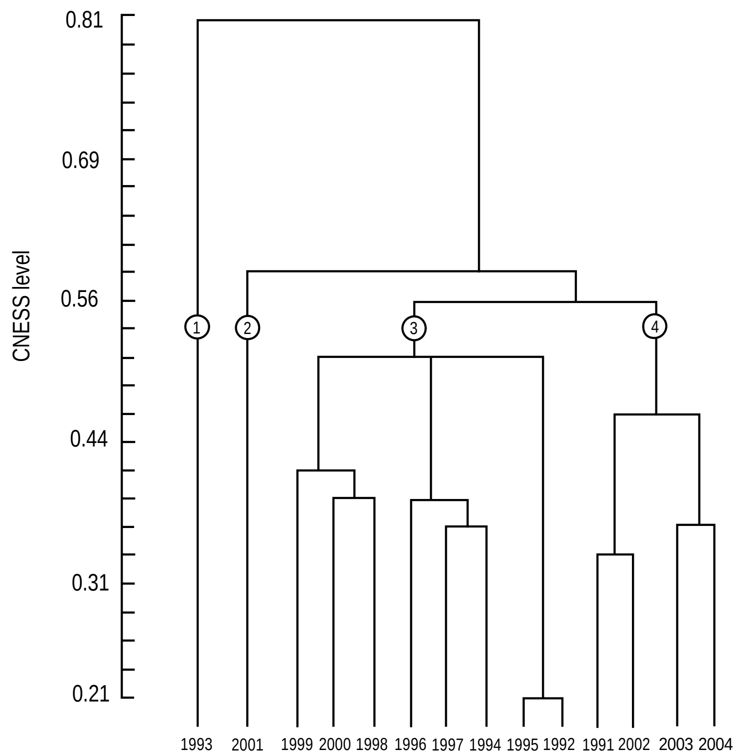


Figure 5-29. Dendrogram based on CNESS, *m* = 20, for T06 samples pooled within each August sampling date.

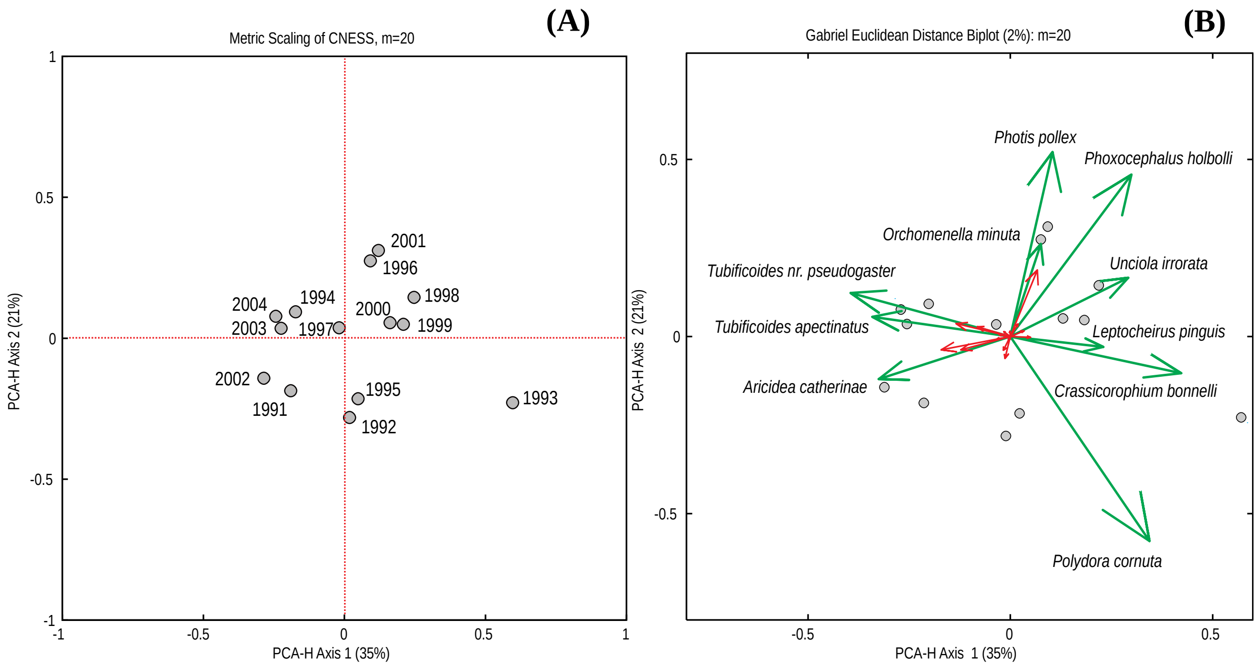


Figure 5-30. PCA-H analysis of T06, based on samples pooled for each year. (A) Metric scaling of station-years; (B) Species vectors accounting for >2% of plot variation in green; other species vectors plotted in red and unlabeled.

Table 5-9. Contribution to PCA-H axes 1 and 2 of the ten species accounting for at least 2% of the community variation at Boston Harbor station T06 (see Figure 5-30B).

PCA-H Rank	Species	Contr.[a]	Total Contr.	Axis 1	Axis 2
1	*Polydora cornuta*	20	20	12	33
2	*Phoxocephalus holbolli*	13	33	9	21
3	*Crassicorophium bonnelli*	12	45	18	1
4	*Photis pollex*	11	56	1	27
5	*Tubificoides* nr. *pseudogaster*	10	66	16	2
6	*Tubificoides apectinatus*	7	73	12	0
7	*Aricidea catherinae*	7	80	11	1
8	*Unciola irrorata*	6	87	8	3
9	*Leptocheirus pinguis*	3	90	5	0
10	*Orchomenella minuta*	3	93	1	7

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

T07, Quincy Bay. Summer samples taken from September 1991 through August 2004 at T07, located in the southern central part of Boston Harbor, included 106 species. Forty-four species were present in the 2004 samples, with a mean of 28.3±6.4 species per sample (Table 5-2). The gastropod *Mitrella lunata* was newly reported for this station (but not for the harbor). Sediments sampled in August at T07 have been about 30–35% sand (Chapter 3, this report), and with the exception of April 1997 when sand constituted about 90% of the sample, have been consistent during the past decade.

The dominant species at T07 have remained fairly consistent, with *Aricidea catherinae*, the oligochaetes *Tubificoides apectinatus* and *T.* nr. *pseudogaster*, and ampeliscid amphipods generally being the most numerous. The hesionid *Microphthalmus pettiboneae* and the lumbrinerid *Scoletoma hebes* are common and often among the numerical dominants, as they were in 2002, 2003, and 2004 (Maciolek *et al.* 2004, 2005, Appendix D3). In recent years (2000–2004), the polychaete *Nephtys cornuta* and the oligochaete *Tubificoides apectinatus* have increased in abundance compared with the early 1990s; in 2004 *T. apectinatus*, *A. catherinae*, and *N. cornuta* together accounted for 80% of the identified fauna at this station (Appendix D3).

Community parameters at T07 have fluctuated in a sine-wave-like pattern over the past 14 years, with an overall increase in the number of species and log-series *alpha* over this period. In 2003 abundance, number of species, and log-series *alpha* were significantly higher than in previous years (Figure 5-31). With the exception of evenness, all parameters declined in 2004 to values near or lower than the 2002 levels (Figure 5-31). For example, species richness had increased in 2003 to a mean of 44.7 species per sample, but in 2004 was only 28.3± 6.4 SD (Table 5-2). Diversity, as measured by log-series *alpha*, has shown two periods of steep increase (1991–1995 and 2001–2003) and has generally increased from the early 1990s through 2004, even with the decline in the 2004 value (Figure 5-31). The station high value for Shannon diversity (3.24) was reached in August 1998 (Maciolek *et al.* 2004), the 2004 value was 2.67±020 (Table 5-2). The most diverse year as measured by rarefaction (Figure 5-32) is 2003, with 2004 only slightly less diverse, and nearly identical to the curves for 1999 and 2002.

CNESS multivariate analysis indicated one outlier and two clusters (Figure 5-33): 1991, which was characterized by low species richness and high numbers of *Streblospio*, was an outlier to all other years. Group 2 can be further subdivided into two clusters consisting of 1992–1995 and 1997 (cluster 2a) and 1996 plus 1998–2000, 2002, and 2004 (cluster 2b); generally reflecting a separation of years before and after 1998. Group 3 was a unit of two years, 2001 and 2003, that formed a sister group to group 2; *Leptocheirus pinguis* occurred in higher abundances in these two years than in the other sampling years. Axes 1 and 2 of the PCA-H analysis accounted for 56% of the CNESS variation (Figure 5-34). *Ampelisca* spp. and *S. benedicti* accounted for the majority of the variation on Axis 1, and *L. pinguis* and *S. benedicti* accounted for much of the variation on axis 2 (Table 5-10).

With the exception of 1995 and 2004, benthic habitat quality as evaluated by the OSI (Chapter 4, this report) is generally poor at T07. In those years the OSI was 7.5 and 7.7, respectively, but in the remaining years ranged from 2.0 to 6.3, with a grand mean of 4.0 (Table 4-2).

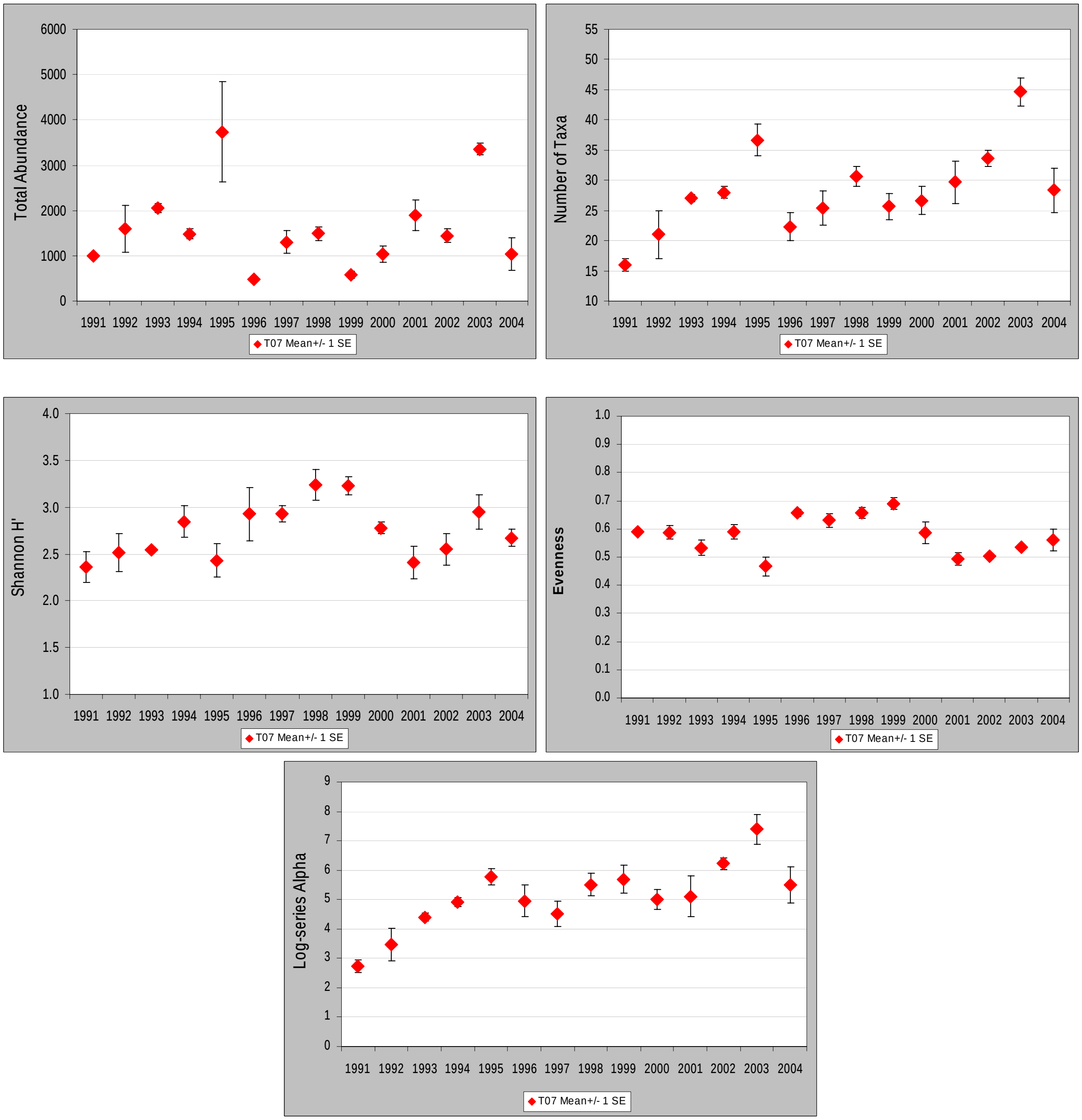


Figure 5-31. Benthic community parameters measured in August 1991 through 2004 at Boston Harbor station T07.

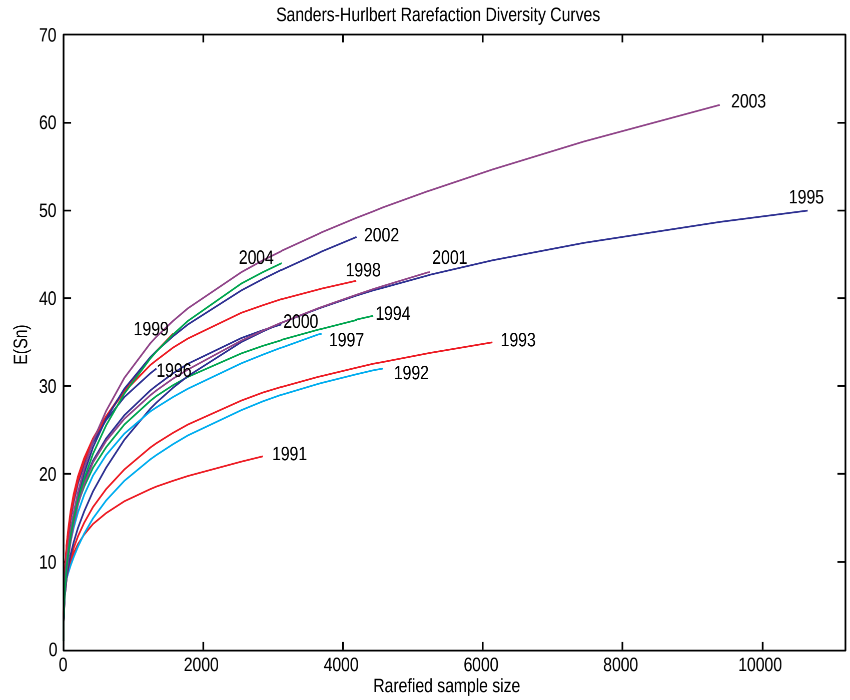


Figure 5-32. Rarefaction curves for T07, based on samples pooled for each August sampling date.

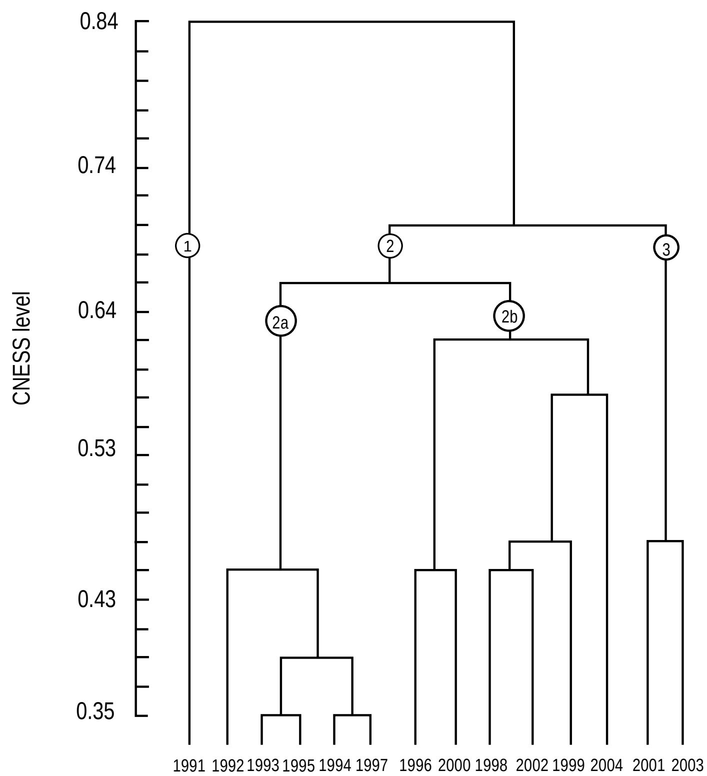


Figure 5-33. Dendrogram based on CNESS, *m* = 20, for T07 samples pooled within each August sampling date.

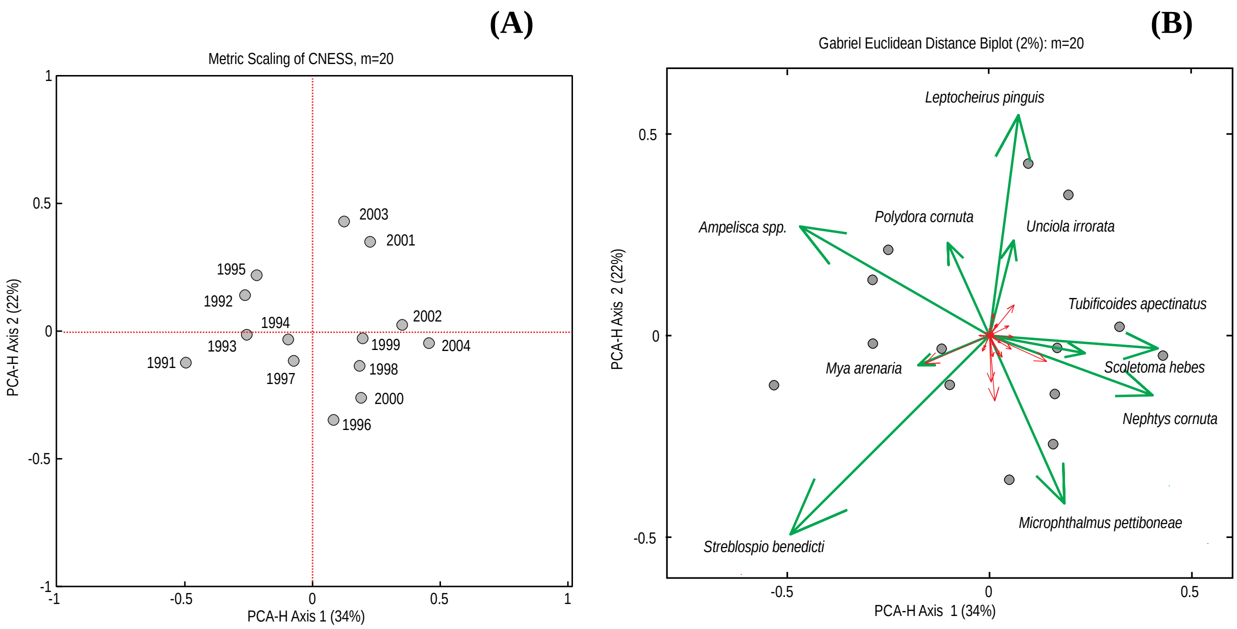


Figure 5-34. PCA-H analysis of T07, based on samples pooled for each year. (A) Metric scaling of station-years; (B) Species vectors accounting for >2% of plot variation in green; other species vectors plotted in red and unlabeled.

Table 5-10. Contribution to PCA-H axes 1 and 2 of the ten species accounting for at least 2% of the community variation at Boston Harbor station T07 (see Figure 5-34B).

PCA-H Rank	Species	Contr.[a]	Total Contr.	Axis 1	Axis 2
1	*Streblospio benedicti*	24	24	24	24
2	*Ampelisca* spp.	16	40	22	7
3	*Leptocheirus pinguis*	12	52	1	30
4	*Nephtys cornuta*	11	63	16	2
5	*Tubificoides apectinatus*	10	74	17	0
6	*Microphthalmus pettiboneae*	9	83	3	17
7	*Scoletoma hebes*	3	86	6	0
8	*Polydora cornuta*	3	89	1	5
9	*Unciola irrorata*	2	91	0	6
10	*Mya arenaria*	2	93	3	1

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

T08, Hingham Bay. With the exception of September 1991, T08, located in the southern part of Boston Harbor, has consistently had high sand content in each late summer sampling (April 1997 was also low in sand) (Chapter 3, this report). Summer samples taken from September 1991 through August 2004 at T08, included 167 species; 75 species were recorded in 2004, with a mean of 50.7±10.7 per sample (Table 5-2.) Species richness in samples from T08 has had no discernable pattern of seasonality (Maciolek *et al.* 2004) or significant increase over time. The number of species per sample ranged from a low mean value of 34.3±6.17 in 1995 to a high of 66.7±6.06 in 2003 (Figure 5-35).

Dominant species at T08 remained fairly constant throughout the early 1990s, with *Ampelisca* spp. and *Aricidea catherinae* as the numerical dominants. Although both remain among the most numerous species, the abundances of both taxa declined in samples taken in 1999–2004, with the exception of 2003, when *Ampelisca* spp. increased at this station as it did elsewhere around the harbor. *Spiophanes bombyx* was the numerical dominant in several seasons, including August 2002 and 2003, and was the most numerous taxon in 2004, when it accounted for about 25% of all organisms collected (Appendix D3).

Shannon diversity and evenness, while also showing increases and decreases throughout the monitoring period, were essentially the same in 2003 as they were in 1991, with an H′ of around 3.3 and J′ of 0.6; these values are similar to those obtained for samples taken in 1982 (Maciolek *et al*. 2004). H′ was higher in 2004 (4.02±0.27 SD), but this value was similar to that obtained in 2001(3.88; Figure 5-35). Diversity as measured by log-series *alpha* remained fairly steady during the period 1991–2000, but has been significantly higher in the past four years, reaching a high mean value of 12.4 in August 2003 and a similar value of 11.9±2.5 SD in 2004. (Figure 5-35, Table 5-2). The rarefaction curves for this station also reflect the higher diversity seen in 2001–2004 (Figure 5-36).

Multivariate analysis based on CNESS resulted in three major groups of years (Figure 5-37). The three groups were similar to each other at the 0.67 CNSS level, indicating that there were no significant dichotomies among the years. Group 1 included 1991, 1992–1994, 1997–1998, and 2002, which were influenced by *Aricidea catherinae*, *Polydora cornuta*, and *Nucula delphinodonta*. Group 2 included only 1996 and 2003, when *Leptocheirus pinguis* was slightly more numerous. Group 3 included 1995, 1999, 2000, 2001, and 2004, which were influenced more by *Polygordius* sp. A, *Tellina agilis*, *Ilyanassa trivittata*, and *Spiophanes bombyx*. Axes 1 and 2 of the PCA-H analysis accounted for 48% of the total CNESS variation (Figure 5-38). Species that contributed most to axis 1 included *Ampelisca* spp., *Polygordius* sp. A, and *T. agilis*, while *N. delphinodonta* and *P. cornuta* contributed the most to axis 2 (Table 5-11).

The OSI index for T08 was lowest in 1998 and 1999 (3.7 and 2.7, respectively) but otherwise has varied from 4.5 to 8.0 (Table 4-6).

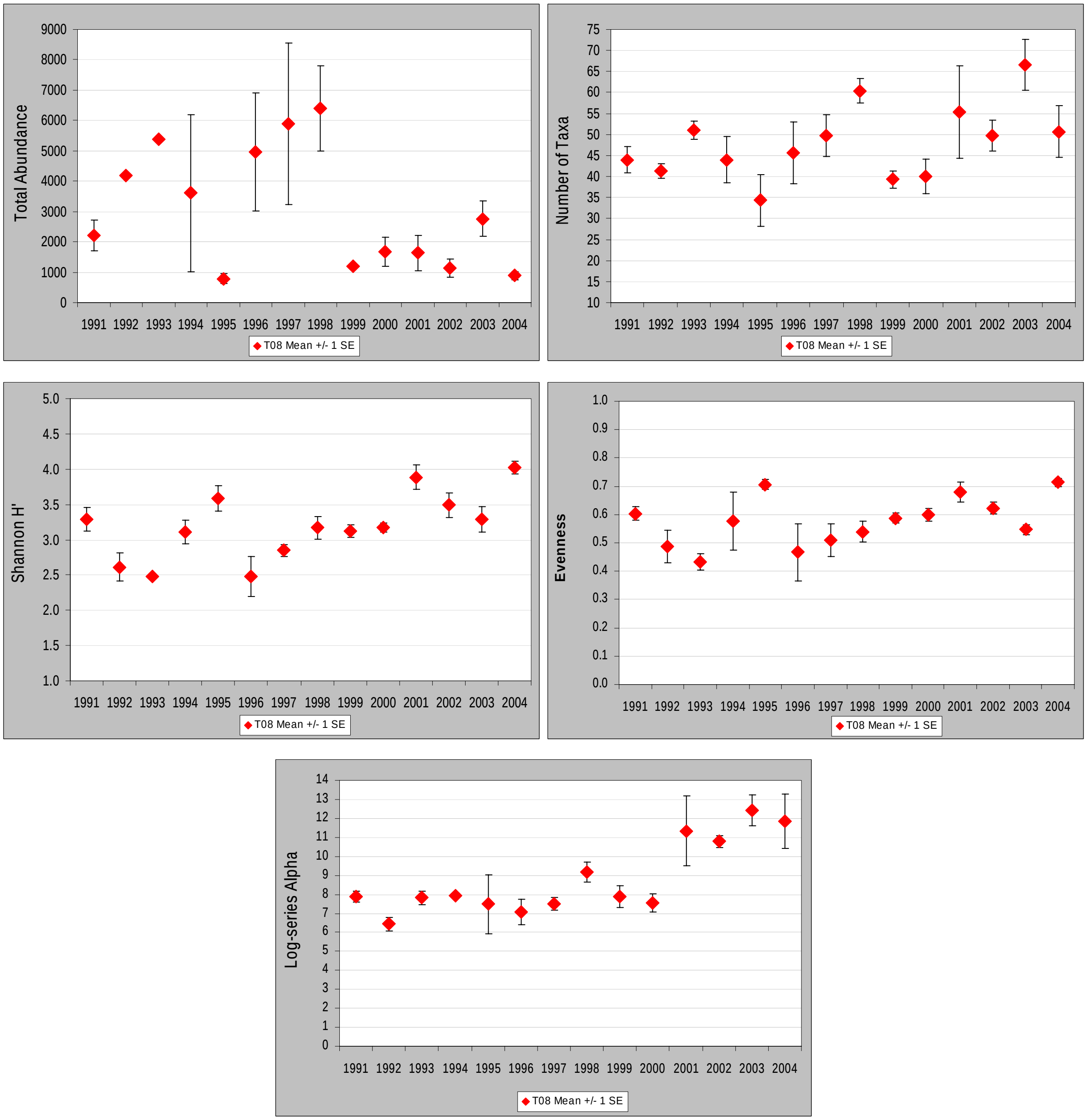


Figure 5-35. Benthic community parameters measured in August 1991 through 2004 at Boston Harbor station T08.

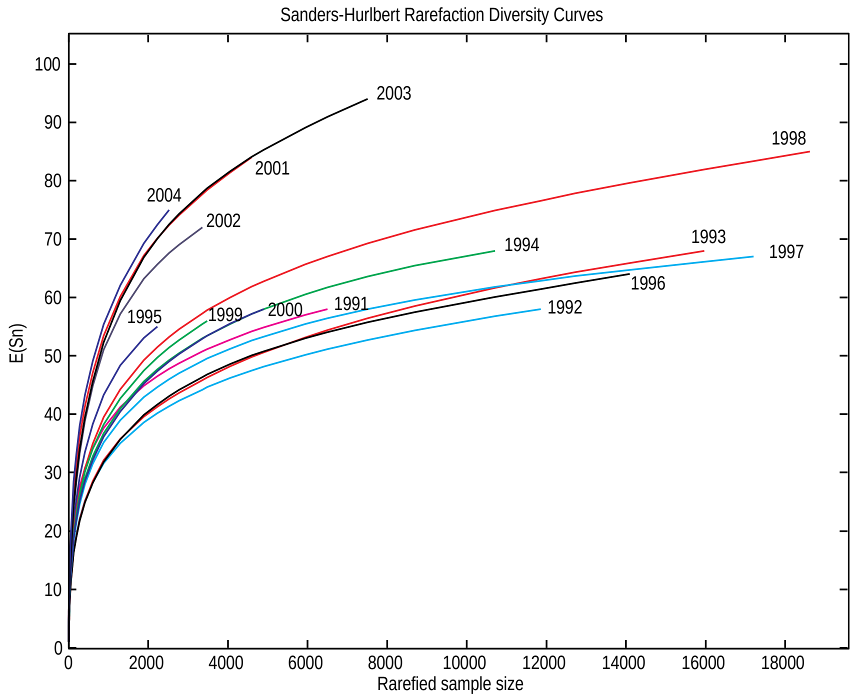


Figure 5-36. Rarefaction curves for T08, based on samples pooled for each August sampling date.

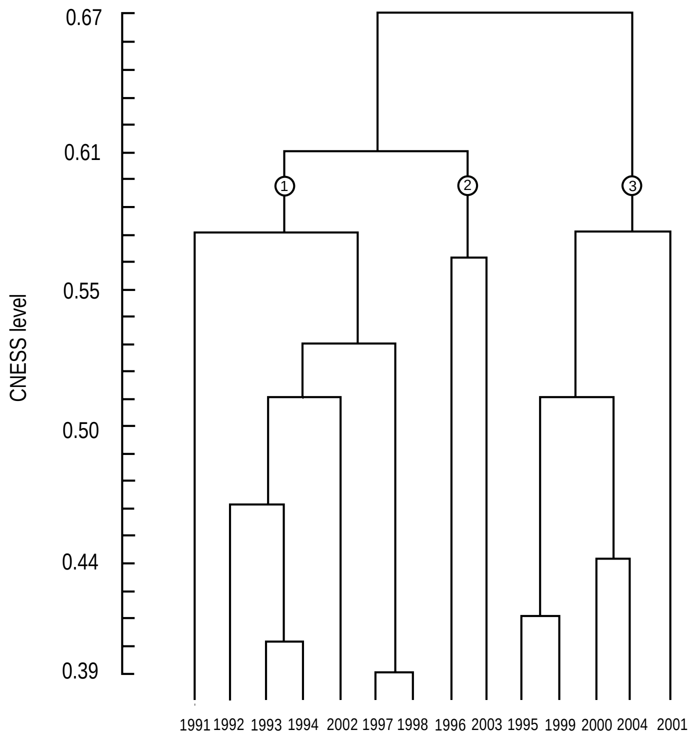


Figure 5-37. Dendrogram based on CNESS, *m* = 20, for T08 samples pooled within each August sampling date.

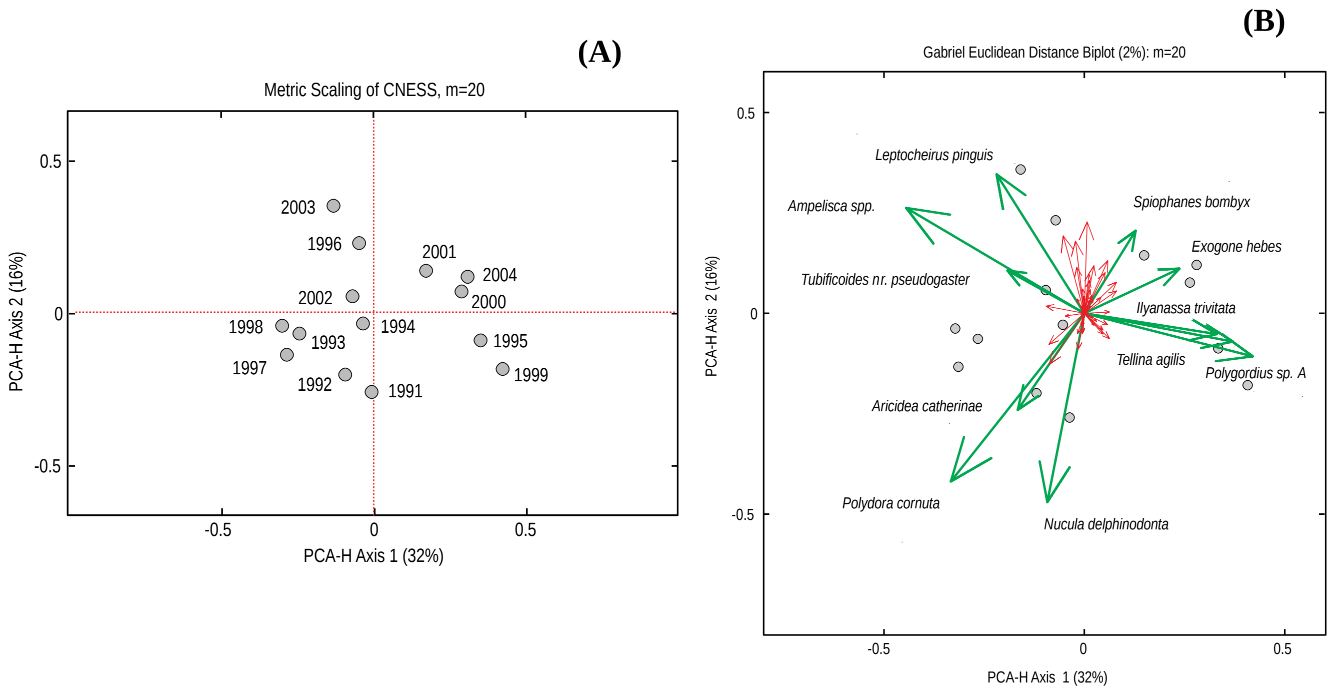


Figure 5-38. PCA-H analysis of T08, based on samples pooled for each year. (A) Metric scaling of station-years; (B) Species vectors accounting for >2% of plot variation in green; other species vectors plotted in red and unlabeled.

Table 5-11. Contribution to PCA-H axes 1 and 2 of the 11 species accounting for at least 2% of the community variation at Boston Harbor station T08 (see Figure 5-38B).

PCA-H Rank	Species	Contr.[a]	Total Contr.	Axis 1	Axis 2
1	*Ampelisca* spp.	15	15	20	7
2	*Polydora cornuta*	13	29	11	17
3	*Polygordius* sp. A	12	41	18	1
4	*Tellina agilis*	9	50	14	1
5	*Nucula delphinodonta*	8	58	1	22
6	*Ilyanassa trivittata*	7	65	11	0
7	*Leptocheirus pinguis*	7	73	5	12
8	*Exogone hebes*	4	77	6	1
9	*Aricidea catherinae*	4	81	3	6
10	*Tubificoides* nr. *pseudogaster*	3	83	4	1
11	*Spiophanes bombyx*	3	86	2	4

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

5.3.5 Long-term Monitoring (1991-2004): Annual Harborwide Changes

Samples taken at Boston Harbor stations in August (or September, as in 1991) were pooled to one sample per year (*i.e.*, all samples from all stations were pooled to one annual harbor-wide sample, resulting in 14 harbor samples) to examine harbor-wide averages.

The analyses of samples pooled to one harbor sample per year included data from T05 rather than T05A for the years 1991 and 1992; these samples were included to provide an equal number of samples in each year before pooling. Pooling across stations is probably not entirely valid because of the wide differences among stations in terms of sediment type and environmental conditions (*e.g*., water circulation patterns, depth, etc.). Indeed, when the results of the SPI are considered as an average across all stations (Chapter 4 this report); there is no appreciable difference in benthic habitat conditions over the last 13 years. However, because differences were seen at individual stations, both in terms of infaunal community structure, SPI, and sediment characteristics (Chapter 3, this report), averaged annual differences were investigated in order to determine if there were any apparent annual patterns as well. As discussed below, some analyses were more informative than others.

The Shannon diversity index H′ ranged from a low of 2.11 in 1992 to a high of 3.00 in 2004 (Figure 5-39). The large standard error around each mean suggests that these values are not significantly different from each other. Given the typical range of this index from 1.5 to 3.5 (Magurran 1988), it is unlikely that changes in H′ will provide great insight into trends over time for averaged harbor stations. The associated evenness index, J′, has been stable throughout the monitoring period (Figure 5-39).

The average number of species per sample, the most direct measure of species richness, ranged from 18.4 in 1991 to 50.9 in 2003, with a subsequent drop to 43.6 in 2004 (Figure 5-39). The intervening years (1992–2002) evidenced few real changes in this measure, with a low of 29.0 in 1996 and a high of 40.8 in 1998 and an average of 34.3 species per sample for the period.

Log-series *alpha* appears to suggest an upwards trend over time, from low values in the early 1990s to higher values in recent years, with 2003 and 2004 in particular having higher mean values than in all previous years (Figure 5-39). Similarly, a plot of the estimated number of species per 500 individuals (Figure 5-39) shows the same upward trend. May (1975) pointed out that Sanders' rarefaction curves for marine benthic communities are similar to log-series curves, so the similarity between the two plots is not surprising.

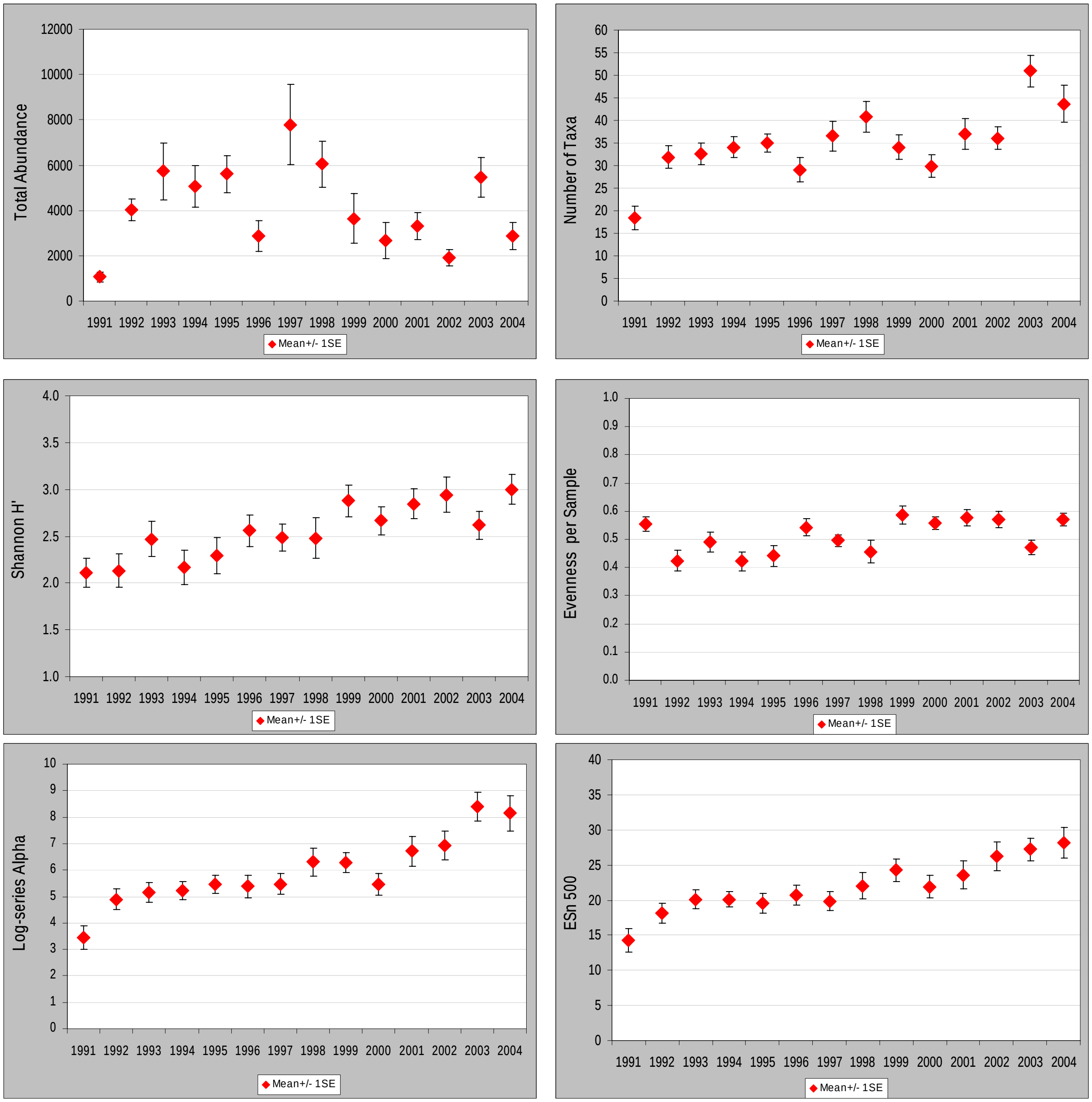


Figure 5-39. Benthic community parameters (mean ± 1 SE) for Boston Harbor stations for each August (or September) sampling event from 1991–2004.

Rarefaction Analysis— Rarefaction analysis is essentially a measure of species richness, with loss of information about the relative abundances of each species (Magurran 1988). However, it is useful as a way to compare the overall diversity in the harbor for each year of the sampling program. The results indicate an increase in diversity since the early 1990s, with a clear increase after 2000, when the discharge was routed offshore. The curve for 2004 (Figure 5-40) is even higher than that reported for 2003 (Maciolek *et al.* 2005). Many of these curves (*e.g.*, 1997) appear to be reaching an asymptote; however, several curves (*e*.g., 2002, 2004) appear to be continuing to rise, suggesting that the harbor remains somewhat undersampled and that more species will be found when additional area is sampled.

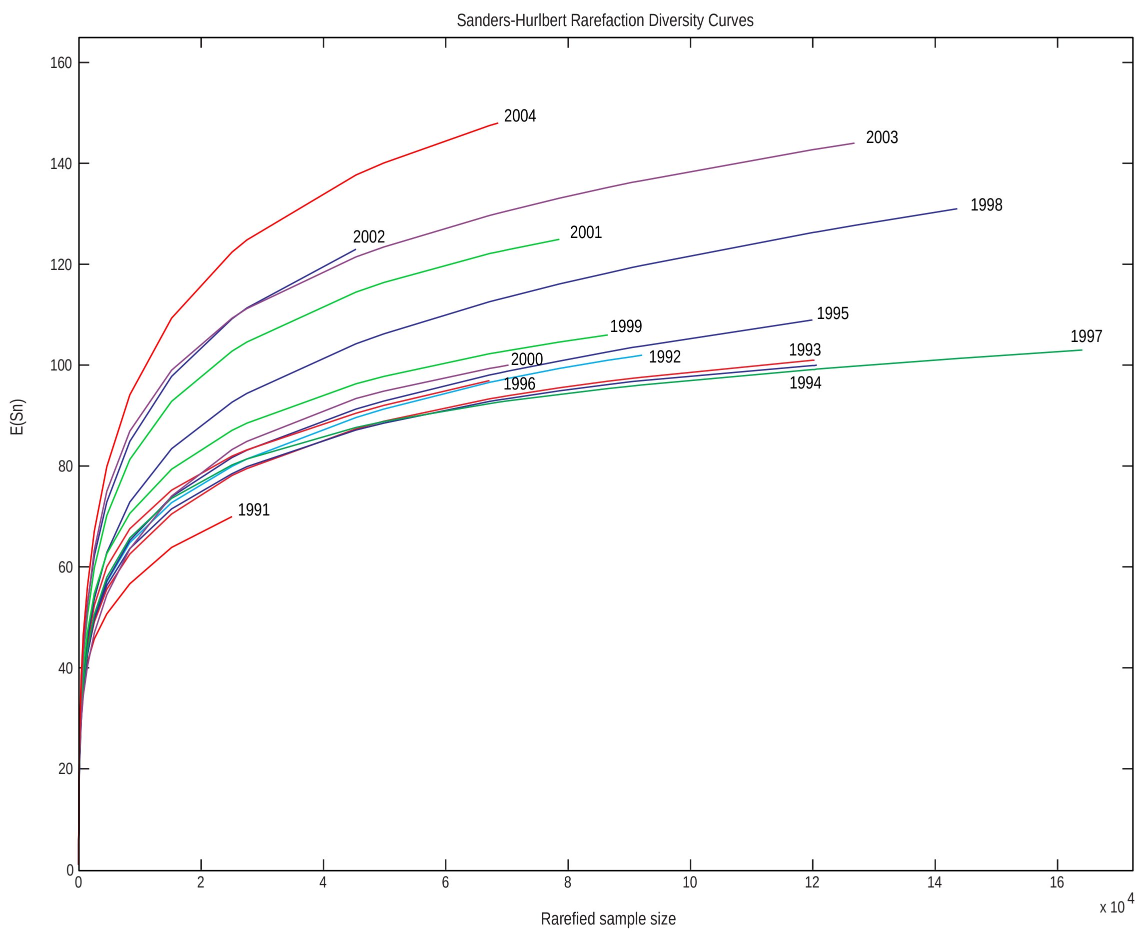


Figure 5-40. Rarefaction curves for August samples taken in Boston Harbor each year from 1991 through 2004; all samples considered together for each year.

Similarity Analyses—The dendrogram based on the CNESS similarity analysis indicated three major groups or clusters of annual samples (Figure 5-41). The highest possible CNESS dissimilarity value is √2 (1.41) (Trueblood *et al*., 1994), therefore all years can be considered fairly similar to one another. However, using a criterion of 0.60, three groups can be distinguished (Figure 5-41); these groups differed somewhat from those described in Maciolek *et al*. (2005). Cluster group 1 is the most dissimilar group and includes years 1992–1998 (except 1996). Group 2 comprises only 1991, and Group 3 includes 1996 plus 1999–2004.

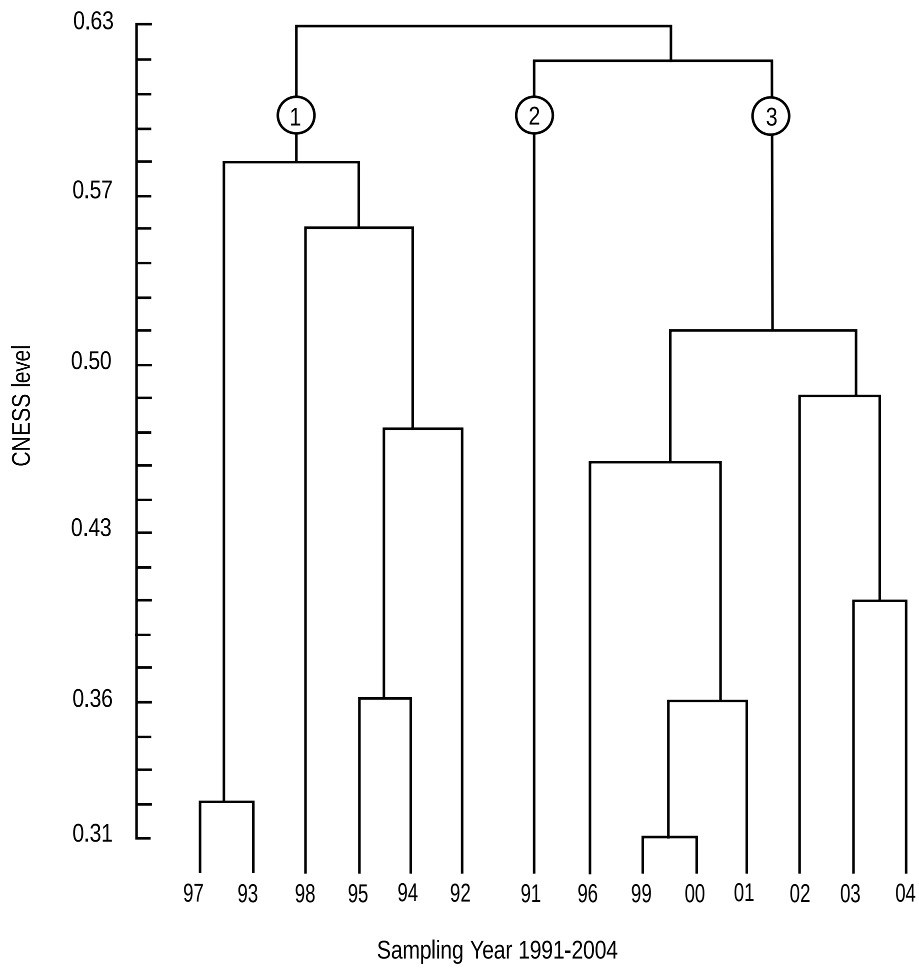


Figure 5-41. Station dendrogram for Boston Harbor 1991–2004 infauna. The lower the CNESS number, the more similar the stations. CNESS m = 20 and group average sorting were used. 259 taxa and 14 pooled annual samples were used.

PCA-H Analysis—The metric scaling of the 14 annual samples on the first two PCA-H axes, which accounted for 54% of the CNESS variation in the communities, is shown in Figure 5-42, and the contribution of species to the PCA-H axes is given in Table 5-12. All years after 1998 (*i.e.*, 1999–2004) and 1991 have negative loadings on axis 1, whereas 1992–1998 have positive loadings.

As reported for samples taken in 2003 (Maciolek *et al*. 2005), three species in particular influenced the metric scaling of the samples: the polychaete *Streblospio benedicti*, the oligochaete *Tubificoides apectinatus*, and the amphipod *Crassicorophium bonnelli*. Although *S. benedicti* continues to be found at T04, it was present in high numbers at other stations (*e.g.*, T02) only during the early years of monitoring. As discussed earlier in the sections for each sampling station, these species are also characteristic of sediment type and perhaps levels of environmental stress.

The Gabriel Euclidean distance biplot (Figure 5-43) shows species superimposed over the metric scaling of the stations. With CNESS (*m*=20), 10 species contributed 2% or more of the total variation on PCA-H axes 1 and 2 (Figure 5-42, Table 5-13).

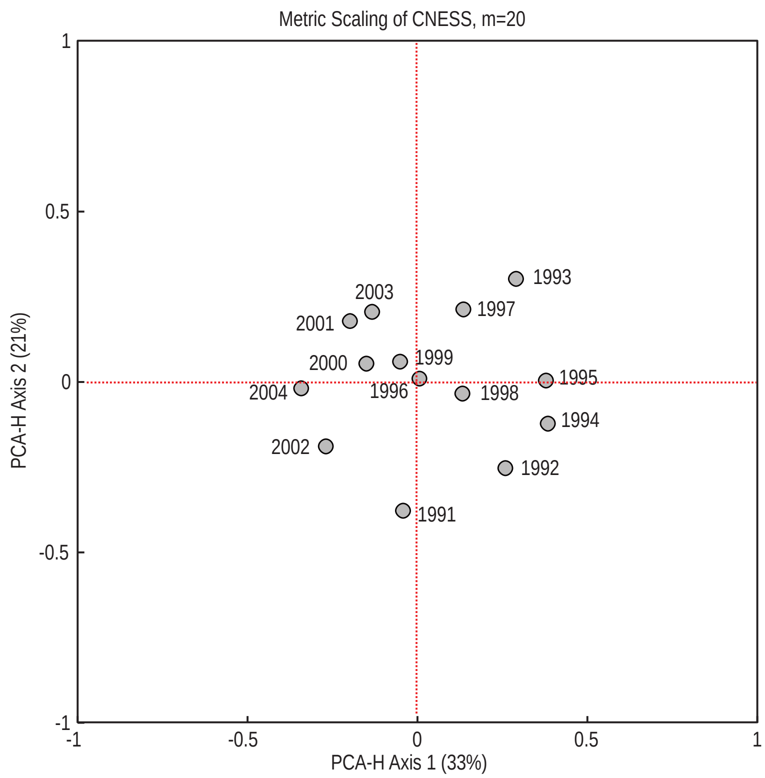


Figure 5-42. Metric scaling of 14 pooled samples taken in Boston Harbor from September 1991 through August 2004.

Table 5-12. Important species, their relative and cumulative contributions to PCA-H axes 1–7 of the metric scaling of CNESS distances of pooled Boston Harbor samples (see Figure 5-42).

PCA-H Rank	Species	% Contr.	Cum. Contr.	Ax.1	Ax.2	Ax.3	Ax.4	Ax.5	Ax.6	Ax.7
1	*Streblospio benedicti*	13	13	26	16	2	2	0	1	0
2	*Tubificoides apectinatus*	12	24	33	0	1	3	3	1	4
3	*Crassicorophium bonnelli*	11	36	3	30	17	0	16	12	0
4	*Capitella capitata complex*	7	42	2	2	21	24	0	21	3
5	*Leptocheirus pinguis*	6	49	0	9	0	8	38	5	0
6	*Phoxocephalus holbolli*	6	55	0	2	27	23	7	0	1
7	*Polydora cornuta*	6	61	10	2	2	11	5	2	1
8	*Unciola irrorata*	4	65	1	15	1	1	0	1	2
9	*Chaetozone vivipara*	4	69	6	0	0	0	3	20	8
10	*Tubificoides nr. pseudogaster*	3	73	1	6	1	7	1	0	1
11	*Aricidea catherinae*	3	76	4	2	6	1	2	6	2
12	*Photis pollex*	3	78	1	3	9	1	3	1	0
13	*Spiophanes bombyx*	2	81	2	0	1	0	6	6	9
14	*Prionospio steenstrupi*	2	83	1	0	2	4	0	4	12
15	*Orchomenella minuta*	2	85	3	2	0	0	1	0	3
16	*Tharyx* spp.	2	87	0	0	0	3	0	2	26
17	*Nephtys cornuta*	2	88	2	0	0	4	2	1	0
18	*Nucula delphinodonta*	1	90	0	2	1	0	2	1	4
19	*Phyllodoce mucosa*	1	91	0	1	1	0	3	0	0
20	*Polygordius* sp. A	1	92	0	0	4	0	0	0	3
21	*Microphthalmus pettiboneae*	1	93	0	1	1	2	1	2	2
22	*Tubificoides benedeni*	1	93	0	1	1	0	0	2	3
23	*Ampelisca* spp.	1	94	0	0	0	1	1	1	0
24	*Ilyanassa trivittata*	1	94	1	0	0	0	1	0	2
25	*Clymenella torquata*	1	95	0	1	0	0	0	4	0

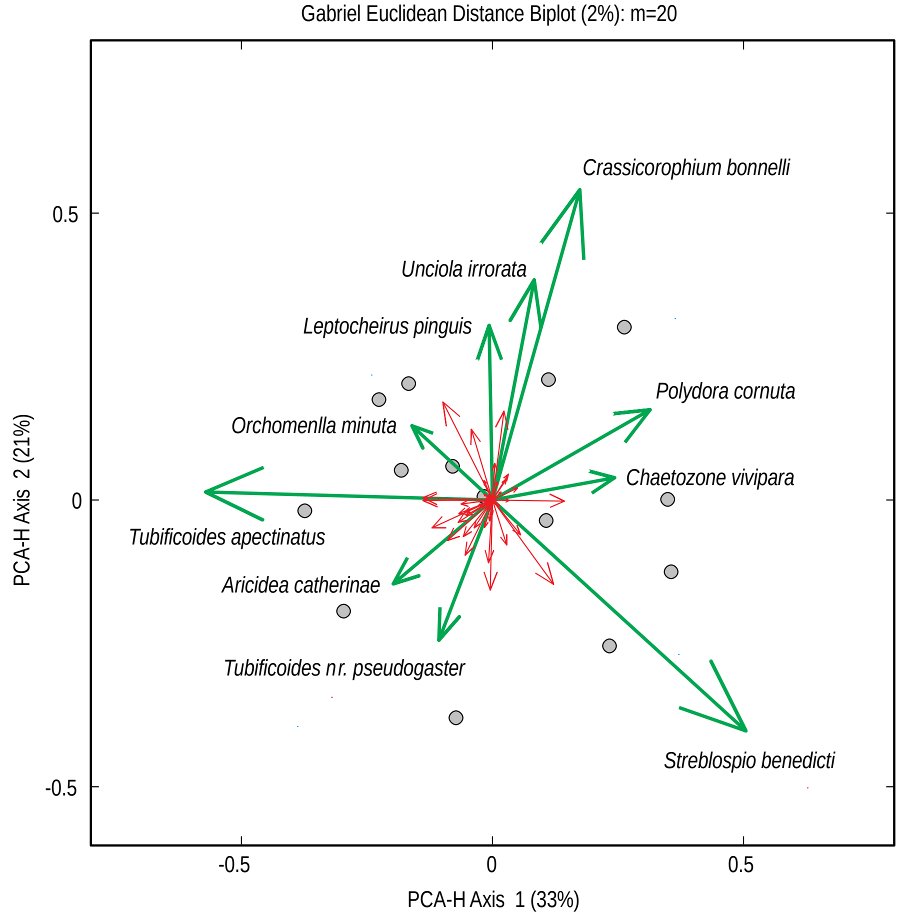


Figure 5-43. Gabriel Euclidean biplot of 14 annual pooled samples. Species vectors accounting for >2% of plot variation in green; other species vectors plotted in red and unlabeled.

Table 5-13. Contribution to PCA-H axes 1 and 2 of the 10 species accounting for at least 2% of the annual community variation at the Boston Harbor stations. (see Euclidean Distance Biplot, Figure 5-43.) %Contribution is rounded by the computer program to nearest whole number.

PCA-H Rank	Species	% Contr.	Cum. Contr.	Axis 1	Axis 2
1	*Streblospio benedicti*	22	22	26	16
2	*Tubificoides apectinatus*	20	42	33	0
3	*Crassicorophium bonnelli*	14	56	3	30
4	*Polydora cornuta*	7	63	10	2
5	*Unciola irrorata*	6	69	1	15
6	*Chaetozone vivipara*	4	73	6	0
7	*Leptocheirus pinguis*	4	77	0	9
8	*Aricidea catherinae*	3	80	4	2
9	*Tubificoides* nr. *pseudogaster*	3	83	1	6
10	*Orchomenella minuta*	2	85	3	2

5.3.6 Long-term Changes in the Infaunal Communities

Benthic communities in Boston Harbor were clearly impacted by decades of pollutant discharge. The early studies of benthic communities in Boston Harbor (1978, 1979, and 1982) indicated distinct groupings of stations that corresponded to (1) a progression from higher saline oceanic conditions in the outer harbor to estuarine conditions in the inner harbor and (2) known areas of pollution (Blake and Maciolek 1990, Maciolek *et al*. 2004). A distinct outer harbor assemblage that included species with close affinities to faunal communities in Massachusetts Bay changed in the middle of the harbor to one that included estuarine species and elements of so-called pollution indicators or stress-tolerant taxa.

All stations in the outer harbor assemblage had more species and higher species diversity values regardless of differences in sample size or analytical technique. Stations having high infaunal densities were found throughout the station array, but opportunistic species such as *Streblospio benedicti* were found only at the stations in the middle of the harbor. The early data also clearly indicated an obvious north/south pattern in the benthic communities, with stations near the northern Deer Island outfall being distinctly different from those near Nut Island in Hingham Bay in the southern part of the harbor. Tidal exchange through President Roads and Broad Sound appeared to be sufficient to maintain benthic assemblages that were only moderately stressed despite their proximity to the sewage and sludge outfalls. In contrast, shallow sites to the east and west of the outfall had low diversities and high densities of opportunistic stress-tolerant species.

Discharge of sludge into the harbor ended in 1991 and in 1998 all effluent discharge from Nut Island was discontinued and full secondary treatment of the effluent was implemented. On September 6, 2000, all wastewater discharges were diverted to the new outfall in Massachusetts Bay, and in early 2001, the final battery of secondary treatment became operational. Taylor (2005) summarized the major patterns in freshwater flows and loadings of total nitrogen (TN), total phosphorus (TP), total suspended solids (TSS), and particulate organic carbon (POC) to Boston Harbor between 1995 and 2003. He found three periods:

- Period A was from 1995 through mid-1998 (Nut Island and Deer Island discharges received some improved treatment)
- Period B was from mid-1998 to 2000 (the Nut Island discharge was diverted to Deer Island)
- Period C began in 2000 with the transfer of the discharge offshore

The changes in wastewater discharge from 1995 to 2003 resulted in about a 90% decrease in loadings to Boston Harbor. For TSS and POC, most of the decreases occurred between Periods A and B, presumably in response to the transfer of the Nut Island discharge to Deer Island and treatment upgrade. For TN and TP, most of the decreases occurred between Periods B and C, in response to transfer of the discharge offshore (Taylor 2005).

Recovery of areas degraded by the long-term disposal of sludge and effluents may involve a transitional stage of undetermined length before an equilibrium community is established. This intermediate stage involves the appearance of a diverse assemblage of tube-dwelling amphipods, molluscs, and polychaetes. The periodic explosion and decline of amphipod populations dominated by *Ampelisca* spp. suggests that infaunal succession patterns are being held in the Stage I and II seres as defined by Rhoads and Germano (1986). After a number of years in which *Ampelisca* spp. appeared to be declining, in 2003 the populations of this and other species of amphipods accounted for 75 % of the sampled fauna, and occurred in numbers second only to those obtained in 1998. However, in 2004 the population levels had declined once again. Given the physical and oceanographic attributes of the study area (*i.e.*, near-coastal environment, relatively shallow compared with offshore areas, continuing pollutant load from CSOs or other industrial sources), it is probable that the harbor benthos will continue to evidence this episodic rise and decline of amphipod populations, and will remain in a Stage I/Stage II pattern. The addition of station CO19 in the inner harbor will allow tracking of changes that take place after a planned upgrade of the nearby CSO as part of the MWRA's continuing program to upgrade and/or close CSOs.

Mean parameters for the harbor overall were not significantly different between Taylor's three time periods (Table 5-14). Lines of evidence from other components of this monitoring program suggest that, when taken as a whole, the harbor has not changed significantly over the past decade. For example, based on the OSI calculated from the data developed as part of the SPI sampling, no station showed a monotonic trend of either improvement or decline (Chapter 4, this report).

Table 5-14. Characteristics for Boston Harbor traditional stations summarized by time periods defined by Taylor (2005).

Parameter	Period		
	A	B	C
	1991–1998	1999–2000	2001–2004
	n = 192	*n*= 47	*n* = 96
Number of Species	32.3 ± 14.3	32.0±12.5	41.9 ± 17.4
H′	2.3 ± 0.9	2.8 ± 0.8	2.8 ± 0.8
log-series *alpha*	5.2 ± 2.1	5.9 ± 1.9	7.6 ± 2.2
Rarefaction curve (Figure 5-40)	low	high	highest
Fauna	higher abundances of opportunistic species such as *Streblospio benedicti* and *Polydora cornuta*		fewer opportunists, more oligochaetes

However, detailed analyses of the infaunal communities at the traditional stations, as well as other lines of evidence, such as the decrease in levels of the sewage marker *Clostridium perfringens* (Chapter 3, this report) strongly support a different conclusion: that the benthic environment in the harbor is indeed recovering from years of pollutant input. The graphic presented in Chapter 4 (Figure 4-6) summarizes several parameters determined through SPI and infaunal community structure analysis. When each station is evaluated individually according to the three periods elucidated by Taylor (2005), it is clear that species richness and diversity (as measured by log-series *alpha*) have increased at each of the eight traditional harbor stations. Additionally, the apparent RPD depth is lower and oxic voids per image have increased at all stations except T03 and T06.

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APPENDIX A1

Station Data:
Sediment Profile Images (HR041)

Table A1-1. Listing of field data for sediment profile image survey HR041.

(Times are reported in Eastern Standard Time)

STUDY_ID	EVENT_ID	STAT_ID	LOC_DESC	STAT_ARRIV (EST)	BEG_LATITUDE	BEG_LONGITUDE	DEPTH_TO_BOTTOM	DEPTH_UNIT_CODE	NAVIGATION_CODE	NAV_QUAL
BHSOFT	HR041	C019	FORT POINT CHANNEL	8/24/04 14:46	42.3591499	-71.0451202	9.3	m	DGPS	+/- 10m
BHSOFT	HR041	R02	DEER ISLAND FLATS	8/24/04 12:41	42.3444176	-70.9615326	12.4	m	DGPS	+/- 10m
BHSOFT	HR041	R03	DEER ISLAND FLATS	8/24/04 13:10	42.3532181	-70.9727478	4.6	m	DGPS	+/- 10m
BHSOFT	HR041	R04	DEER ISLAND FLATS	8/24/04 13:52	42.3585663	-70.9796677	7.3	m	DGPS	+/- 10m
BHSOFT	HR041	R05	DEER ISLAND FLATS	8/24/04 13:47	42.3562508	-70.9778976	5.3	m	DGPS	+/- 10m
BHSOFT	HR041	R06	OUTER HARBOR	8/23/04 13:50	42.3318329	-70.9521484	7.3	m	DGPS	+/- 10m
BHSOFT	HR041	R07	DEER ISLAND FLATS	8/24/04 13:02	42.3474655	-70.975502	5.6	m	DGPS	+/- 10m
BHSOFT	HR041	R08	OFF LOGAN AIRPORT	8/24/04 14:04	42.3443985	-70.9916	3	m	DGPS	+/- 10m
BHSOFT	HR041	R09	CHARLES RIVER	8/24/04 14:24	42.346817	-71.0161133	12.5	m	DGPS	+/- 10m
BHSOFT	HR041	R10	CHARLES RIVER	8/24/04 14:34	42.3552818	-71.0365982	13.6	m	DGPS	+/- 10m
BHSOFT	HR041	R11	OFF LONG ISLAND	8/24/04 12:08	42.3212509	-70.9747162	5.8	m	DGPS	+/- 10m
BHSOFT	HR041	R12	OFF LONG ISLAND	8/24/04 12:03	42.318367	-70.9745026	4.5	m	DGPS	+/- 10m
BHSOFT	HR041	R13	OFF LONG ISLAND	8/24/04 11:54	42.3172493	-70.9807129	5.4	m	DGPS	+/- 10m
BHSOFT	HR041	R14	DORCHESTER BAY	8/24/04 15:27	42.320816	-71.0127335	8.4	m	DGPS	+/- 10m
BHSOFT	HR041	R15	DORCHESTER BAY	8/24/04 15:33	42.3152504	-71.0189819	4.4	m	DGPS	+/- 10m
BHSOFT	HR041	R16	OFF LONG ISLAND	8/23/04 14:34	42.315815	-70.9613495	8.8	m	DGPS	+/- 10m
BHSOFT	HR041	R17	OFF LONG ISLAND	8/24/04 11:42	42.3047981	-70.9770966	5.9	m	DGPS	+/- 10m
BHSOFT	HR041	R18	QUINCY BAY	8/24/04 10:02	42.2890167	-70.9610977	7.4	m	DGPS	+/- 10m
BHSOFT	HR041	R19	HINGHAM BAY	8/24/04 9:46	42.2820816	-70.9378204	8.5	m	DGPS	+/- 10m
BHSOFT	HR041	R20	OUTER HARBOR	8/23/04 14:20	42.3246994	-70.9349136	11.2	m	DGPS	+/- 10m
BHSOFT	HR041	R21	NANTASKET ROADS	8/23/04 14:43	42.3087349	-70.9461136	8	m	DGPS	+/- 10m
BHSOFT	HR041	R22	NANTASKET ROADS	8/23/04 14:51	42.3003502	-70.9397507	10.2	m	DGPS	+/- 10m
BHSOFT	HR041	R23	NANTASKET ROADS	8/24/04 10:16	42.2937851	-70.9500504	9	m	DGPS	+/- 10m
BHSOFT	HR041	R24	NANTASKET ROADS	8/24/04 10:23	42.2962341	-70.9585342	5.6	m	DGPS	+/- 10m
BHSOFT	HR041	R25	HINGHAM BAY	8/24/04 16:29	42.2914505	-70.9285202	7.7	m	DGPS	+/- 10m
BHSOFT	HR041	R26	HINGHAM BAY	8/24/04 9:37	42.2688675	-70.9299698	6	m	DGPS	+/- 10m
BHSOFT	HR041	R27	HINGHAM BAY	8/24/04 17:17	42.2807007	-70.9160843	6.3	m	DGPS	+/- 10m
BHSOFT	HR041	R28	HINGHAM BAY	8/24/04 17:12	42.2817497	-70.9085159	10.6	m	DGPS	+/- 10m
BHSOFT	HR041	R29	HINGHAM BAY	8/24/04 16:34	42.2897491	-70.9206161	10.7	m	DGPS	+/- 10m
BHSOFT	HR041	R30	HINGHAM BAY	8/24/04 16:59	42.2904167	-70.9040298	5.5	m	DGPS	+/- 10m
BHSOFT	HR041	R31	HINGHAM BAY	8/24/04 16:45	42.3009338	-70.9169998	11.8	m	DGPS	+/- 10m
BHSOFT	HR041	R32	HINGHAM BAY	8/24/04 16:54	42.2946815	-70.8968201	5.6	m	DGPS	+/- 10m
BHSOFT	HR041	R33	QUINCY BAY	8/24/04 11:23	42.2942352	-70.9945526	2.5	m	DGPS	+/- 10m
BHSOFT	HR041	R34	QUINCY BAY	8/24/04 11:13	42.2890015	-71.0067673	1.7	m	DGPS	+/- 10m
BHSOFT	HR041	R35	QUINCY BAY	8/24/04 10:48	42.2842331	-70.9880142	2.8	m	DGPS	+/- 10m
BHSOFT	HR041	R36	QUINCY BAY	8/24/04 11:00	42.2757339	-70.9867325	2.7	m	DGPS	+/- 10m
BHSOFT	HR041	R37	QUINCY BAY	8/24/04 11:36	42.2989159	-70.9846497	3.5	m	DGPS	+/- 10m
BHSOFT	HR041	R38	QUINCY BAY	8/24/04 9:56	42.2846336	-70.9638367	4.6	m	DGPS	+/- 10m
BHSOFT	HR041	R39	QUINCY BAY	8/24/04 10:31	42.2953835	-70.9702301	5.9	m	DGPS	+/- 10m
BHSOFT	HR041	R40	DORCHESTER BAY	8/24/04 15:12	42.3287506	-71.0237808	4.4	m	DGPS	+/- 10m

STUDY_ID	EVENT_ID	STAT_ID	LOC_DESC	STAT_ARRIV (EST)	BEG_LATITUDE	BEG_LONGITUDE	DEPTH_TO_BOTTOM	DEPTH_UNIT_CODE	NAVIGATION_CODE	NAV_QUAL
BHSOFT	HR041	R41	DORCHESTER BAY	8/24/04 15:39	42.3110161	-71.0251694	6	m	DGPS	+/- 10m
BHSOFT	HR041	R42	DORCHESTER BAY	8/24/04 15:22	42.3196487	-71.0251312	4	m	DGPS	+/- 10m
BHSOFT	HR041	R43	DORCHESTER BAY	8/24/04 16:05	42.3067017	-71.0020981	5	m	DGPS	+/- 10m
BHSOFT	HR041	R44	OFF LOGAN AIRPORT	8/24/04 14:16	42.3436852	-71.0021515	9.9	m	DGPS	+/- 10m
BHSOFT	HR041	R45	OFF LONG ISLAND	8/24/04 12:16	42.3283501	-70.9675369	6.6	m	DGPS	+/- 10m
BHSOFT	HR041	R46	HINGHAM BAY	8/24/04 16:38	42.2911148	-70.9222641	10.3	m	DGPS	+/- 10m
BHSOFT	HR041	R47	DEER ISLAND FLATS	8/24/04 12:56	42.3445168	-70.9786835	4.7	m	DGPS	+/- 10m
BHSOFT	HR041	R48	QUINCY BAY	8/24/04 11:29	42.2935829	-70.9878311	3	m	DGPS	+/- 10m
BHSOFT	HR041	R49	HINGHAM BAY	8/24/04 17:32	42.2731323	-70.9082031	7.8	m	DGPS	+/- 10m
BHSOFT	HR041	R50	HINGHAM BAY	8/24/04 17:27	42.2749481	-70.8983536	8.7	m	DGPS	+/- 10m
BHSOFT	HR041	R51	HINGHAM BAY	8/24/04 9:26	42.2632179	-70.9420853	3.1	m	DGPS	+/- 10m
BHSOFT	HR041	R52	HINGHAM BAY	8/24/04 8:56	42.2618675	-70.9346695	3.1	m	DGPS	+/- 10m
BHSOFT	HR041	R53	HINGHAM BAY	8/24/04 9:32	42.269165	-70.9380798	3.4	m	DGPS	+/- 10m
BHSOFT	HR041	T01	OFF DEER ISLAND WEST SIDE	8/24/04 12:47	42.3490677	-70.9636154	4	m	DGPS	+/- 10m
BHSOFT	HR041	T02	PRESIDENT ROADS	8/24/04 14:12	42.3429184	-71.0020828	7.2	m	DGPS	+/- 10m
BHSOFT	HR041	T03	OFF NORTH EAST TIP OF LONG ISLAND	8/24/04 12:23	42.3300018	-70.9621658	7.4	m	DGPS	+/- 10m
BHSOFT	HR041	T04	DORCHESTER BAY	8/24/04 15:51	42.3098831	-71.0416183	4.2	m	DGPS	+/- 10m
BHSOFT	HR041	T05A	PRESIDENT ROADS	8/24/04 12:33	42.3396683	-70.9606323	15.7	m	DGPS	+/- 10m
BHSOFT	HR041	T06	NANTASKET ROADS	8/23/04 14:58	42.2934837	-70.9441833	6.3	m	DGPS	+/- 10m
BHSOFT	HR041	T07	QUINCY BAY	8/24/04 10:39	42.2894325	-70.978653	4.2	m	DGPS	+/- 10m
BHSOFT	HR041	T08	HINGHAM BAY	8/24/04 17:06	42.2853165	-70.9123154	13.3	m	DGPS	+/- 10m

Table A1-2. Station data from SPI survey conducted in August 2004 (HR041).

SurveyID	SampleID	Sample Date	Sample Time	StationID	Replicate *analyzed	Longitude	Latitude
HR041	HR041139	08/23/04	3:00:57 PM	R06	1*	-70.9521	42.3318
HR041	HR04113A	08/23/04	3:01:20 PM	R06	2*	-70.9521	42.3318
HR041	HR04113B	08/23/04	3:01:52 PM	R06	3*	-70.9521	42.3319
HR041	HR041144	08/23/04	3:30:31 PM	R20	1*	-70.9349	42.3247
HR041	HR041146	08/23/04	3:31:13 PM	R20	2*	-70.9350	42.3247
HR041	HR041147	08/23/04	3:31:49 PM	R20	3*	-70.9349	42.3247
HR041	HR04114D	08/23/04	3:44:20 PM	R16	1*	-70.9613	42.3158
HR041	HR04114F	08/23/04	3:45:10 PM	R16	2*	-70.9614	42.3159
HR041	HR041150	08/23/04	3:45:39 PM	R16	3*	-70.9614	42.3159
HR041	HR041158	08/23/04	3:53:59 PM	R21	1*	-70.9461	42.3087
HR041	HR04115A	08/23/04	3:54:36 PM	R21	2*	-70.9461	42.3087
HR041	HR04115B	08/23/04	3:55:59 PM	R21	3*	-70.9463	42.3087
HR041	HR041161	08/23/04	4:01:23 PM	R22	1*	-70.9398	42.3004
HR041	HR041163	08/23/04	4:01:57 PM	R22	2*	-70.9398	42.3004
HR041	HR041164	08/23/04	4:02:26 PM	R22	3*	-70.9398	42.3004
HR041	HR04116B	08/23/04	4:07:00 PM	T06	1*	-70.9442	42.2935
HR041	HR04116A	08/23/04	4:08:06 PM	T06	2*	-70.9442	42.2935
HR041	HR04116C	08/23/04	4:09:07 PM	T06	3*	-70.9441	42.2934
HR041	HR04117A	08/24/04	10:06:55 AM	R52	1*	-70.9347	42.2619
HR041	HR04117B	08/24/04	10:07:32 AM	R52	2*	-70.9347	42.2619
HR041	HR04117C	08/24/04	10:08:16 AM	R52	3*	-70.9347	42.2619
HR041	HR041182	08/24/04	10:36:19 AM	R51	1*	-70.9421	42.2632
HR041	HR041183	08/24/04	10:36:52 AM	R51	2*	-70.9421	42.2632
HR041	HR041184	08/24/04	10:37:21 AM	R51	3*	-70.9422	42.2633
HR041	HR04118A	08/24/04	10:42:26 AM	R53	1*	-70.9381	42.2692
HR041	HR04118B	08/24/04	10:42:55 AM	R53	2*	-70.9380	42.2692
HR041	HR04118C	08/24/04	10:43:24 AM	R53	3*	-70.9380	42.2692
HR041	HR041192	08/24/04	10:47:57 AM	R26	1*	-70.9300	42.2689
HR041	HR041193	08/24/04	10:49:09 AM	R26	2*	-70.9300	42.2690
HR041	HR041194	08/24/04	10:49:49 AM	R26	3*	-70.9301	42.2690
HR041	HR04119D	08/24/04	10:56:47 AM	R19	1*	-70.9378	42.2821
HR041	HR04119E	08/24/04	10:57:32 AM	R19	2*	-70.9379	42.2821
HR041	HR04119F	08/24/04	10:57:46 AM	R19	3*	-70.9379	42.2820
HR041	HR0411A5	08/24/04	11:06:53 AM	R38	1*	-70.9638	42.2846
HR041	HR0411A6	08/24/04	11:07:49 AM	R38	2*	-70.9639	42.2847
HR041	HR0411A7	08/24/04	11:07:57 AM	R38	3*	-70.9639	42.2847
HR041	HR0411AD	08/24/04	11:12:58 AM	R18	1*	-70.9611	42.2890
HR041	HR0411AE	08/24/04	11:14:16 AM	R18	2*	-70.9611	42.2889
HR041	HR0411AF	08/24/04	11:15:01 AM	R18	3*	-70.9612	42.2888
HR041	HR0411B7	08/24/04	11:26:10 AM	R23	1*	-70.9501	42.2938
HR041	HR0411B8	08/24/04	11:26:52 AM	R23	2*	-70.9501	42.2938
HR041	HR0411B9	08/24/04	11:27:51 AM	R23	3*	-70.9501	42.2939

SurveyID	SampleID	Sample Date	Sample Time	StationID	Replicate *analyzed	Longitude	Latitude
HR041	HR0411BF	08/24/04	11:33:00 AM	R24	1*	-70.9585	42.2962
HR041	HR0411C0	08/24/04	11:33:50 AM	R24	2*	-70.9584	42.2962
HR041	HR0411C1	08/24/04	11:35:24 AM	R24	3*	-70.9583	42.2963
HR041	HR0411C7	08/24/04	11:41:41 AM	R39	1*	-70.9702	42.2954
HR041	HR0411C8	08/24/04	11:42:32 AM	R39	2*	-70.9703	42.2955
HR041	HR0411C9	08/24/04	11:43:31 AM	R39	3*	-70.9703	42.2955
HR041	HR0411CF	08/24/04	11:49:56 AM	T07	1*	-70.9787	42.2894
HR041	HR0411D0	08/24/04	11:50:24 AM	T07	2*	-70.9786	42.2895
HR041	HR0411D1	08/24/04	11:51:06 AM	T07	3*	-70.9786	42.2895
HR041	HR0411DA	08/24/04	11:58:20 AM	R35	1*	-70.9880	42.2842
HR041	HR0411DB	08/24/04	11:58:58 AM	R35	2*	-70.9881	42.2842
HR041	HR0411DC	08/24/04	11:59:44 AM	R35	3*	-70.9882	42.2842
HR041	HR0411E3	08/24/04	12:10:04 PM	R36	1*	-70.9867	42.2757
HR041	HR0411E4	08/24/04	12:10:53 PM	R36	2*	-70.9867	42.2757
HR041	HR0411E5	08/24/04	12:11:50 PM	R36	3*	-70.9866	42.2756
HR041	HR0411EB	08/24/04	12:23:55 PM	R34	1*	-71.0068	42.2890
HR041	HR0411EC	08/24/04	12:24:46 PM	R34	2*	-71.0069	42.2890
HR041	HR0411ED	08/24/04	12:25:28 PM	R34	3*	-71.0070	42.2890
HR041	HR0411F3	08/24/04	12:33:49 PM	R33	1*	-70.9946	42.2942
HR041	HR0411F4	08/24/04	12:34:46 PM	R33	2*	-70.9945	42.2943
HR041	HR0411F5	08/24/04	12:35:30 PM	R33	3*	-70.9945	42.2943
HR041	HR0411FB	08/24/04	12:39:53 PM	R48	1*	-70.9878	42.2936
HR041	HR0411FC	08/24/04	12:40:38 PM	R48	2*	-70.9878	42.2936
HR041	HR0411FD	08/24/04	12:41:12 PM	R48	3*	-70.9878	42.2937
HR041	HR041203	08/24/04	12:46:36 PM	R37	1*	-70.9846	42.2989
HR041	HR041204	08/24/04	12:46:43 PM	R37	2*	-70.9847	42.2989
HR041	HR041205	08/24/04	12:47:28 PM	R37	3*	-70.9848	42.2989
HR041	HR04120B	08/24/04	12:52:35 PM	R17	1*	-70.9771	42.3048
HR041	HR04120C	08/24/04	12:53:32 PM	R17	2*	-70.9771	42.3048
HR041	HR04120D	08/24/04	12:54:21 PM	R17	3*	-70.9772	42.3048
HR041	HR041216	08/24/04	1:04:09 PM	R13	1*	-70.9807	42.3172
HR041	HR041217	08/24/04	1:05:17 PM	R13	2*	-70.9809	42.3172
HR041	HR041218	08/24/04	1:05:49 PM	R13	3*	-70.9809	42.3172
HR041	HR04121E	08/24/04	1:13:21 PM	R12	1*	-70.9745	42.3184
HR041	HR04121F	08/24/04	1:14:11 PM	R12	2*	-70.9745	42.3184
HR041	HR041220	08/24/04	1:14:53 PM	R12	3*	-70.9746	42.3184
HR041	HR041226	08/24/04	1:18:33 PM	R11	1*	-70.9747	42.3213
HR041	HR041227	08/24/04	1:19:39 PM	R11	2*	-70.9748	42.3214
HR041	HR041229	08/24/04	1:20:21 PM	R11	3*	-70.9748	42.3214
HR041	HR04122F	08/24/04	1:26:06 PM	R45	1*	-70.9675	42.3284
HR041	HR041230	08/24/04	1:27:04 PM	R45	2*	-70.9677	42.3283
HR041	HR041231	08/24/04	1:27:38 PM	R45	3*	-70.9675	42.3284
HR041	HR041237	08/24/04	1:33:16 PM	T03	1*	-70.9622	42.3300

SurveyID	SampleID	Sample Date	Sample Time	StationID	Replicate *analyzed	Longitude	Latitude
HR041	HR041238	08/24/04	1:35:47 PM	T03	2*	-70.9618	42.3303
HR041	HR041239	08/24/04	1:36:43 PM	T03	3*	-70.9618	42.3303
HR041	HR04123F	08/24/04	1:43:15 PM	T05A	1*	-70.9606	42.3397
HR041	HR041240	08/24/04	1:44:43 PM	T05A	2*	-70.9606	42.3397
HR041	HR041241	08/24/04	1:44:59 PM	T05A	3*	-70.9605	42.3398
HR041	HR041247	08/24/04	1:51:01 PM	R02	1*	-70.9615	42.3444
HR041	HR041248	08/24/04	1:51:14 PM	R02	2*	-70.9615	42.3444
HR041	HR041249	08/24/04	1:51:49 PM	R02	3*	-70.9615	42.3443
HR041	HR041254	08/24/04	1:57:15 PM	T01	1*	-70.9636	42.3491
HR041	HR041255	08/24/04	1:58:10 PM	T01	2*	-70.9635	42.3492
HR041	HR041256	08/24/04	1:58:44 PM	T01	3*	-70.9636	42.3493
HR041	HR04125C	08/24/04	2:06:33 PM	R47	1*	-70.9787	42.3445
HR041	HR04125D	08/24/04	2:07:34 PM	R47	2*	-70.9787	42.3447
HR041	HR04125E	08/24/04	2:07:58 PM	R47	3*	-70.9786	42.3446
HR041	HR041264	08/24/04	2:12:19 PM	R07	1*	-70.9755	42.3475
HR041	HR041265	08/24/04	2:13:03 PM	R07	2*	-70.9754	42.3475
HR041	HR041266	08/24/04	2:13:54 PM	R07	3*	-70.9755	42.3476
HR041	HR04126F	08/24/04	2:20:16 PM	R03	1*	-70.9727	42.3532
HR041	HR041270	08/24/04	2:22:21 PM	R03	2*	-70.9730	42.3530
HR041	HR041271	08/24/04	2:22:59 PM	R03	3*	-70.9728	42.3531
HR041	HR041280	08/24/04	2:57:18 PM	R05	1*	-70.9779	42.3563
HR041	HR041281	08/24/04	2:57:56 PM	R05	2*	-70.9779	42.3563
HR041	HR041282	08/24/04	2:58:35 PM	R05	3*	-70.9779	42.3564
HR041	HR041288	08/24/04	3:02:35 PM	R04	1*	-70.9797	42.3586
HR041	HR041289	08/24/04	3:03:10 PM	R04	2*	-70.9796	42.3586
HR041	HR04128A	08/24/04	3:03:46 PM	R04	3*	-70.9796	42.3586
HR041	HR041290	08/24/04	3:14:38 PM	R08	1*	-70.9916	42.3444
HR041	HR041291	08/24/04	3:15:15 PM	R08	2*	-70.9915	42.3445
HR041	HR041292	08/24/04	3:15:48 PM	R08	3*	-70.9915	42.3445
HR041	HR041296	08/24/04	3:22:44 PM	T02	1*	-71.0021	42.3429
HR041	HR041297	08/24/04	3:22:57 PM	T02	2*	-71.0021	42.3429
HR041	HR041298	08/24/04	3:23:32 PM	T02	3*	-71.0020	42.3429
HR041	HR04129E	08/24/04	3:26:51 PM	R44	1*	-71.0022	42.3437
HR041	HR04129F	08/24/04	3:27:23 PM	R44	2*	-71.0022	42.3437
HR041	HR0412A0	08/24/04	3:28:01 PM	R44	3*	-71.0023	42.3438
HR041	HR0412A6	08/24/04	3:34:28 PM	R09	1*	-71.0161	42.3468
HR041	HR0412A7	08/24/04	3:35:12 PM	R09	2*	-71.0162	42.3469
HR041	HR0412A8	08/24/04	3:35:41 PM	R09	3*	-71.0163	42.3469
HR041	HR0412AC	08/24/04	3:44:41 PM	R10	1*	-71.0366	42.3553
HR041	HR0412AD	08/24/04	3:45:15 PM	R10	2*	-71.0366	42.3553
HR041	HR0412AE	08/24/04	3:45:41 PM	R10	3*	-71.0366	42.3553
HR041	HR0412B6	08/24/04	3:56:16 PM	C019	1*	-71.0451	42.3591
HR041	HR0412B7	08/24/04	3:56:53 PM	C019	2*	-71.0451	42.3592

SurveyID	SampleID	Sample Date	Sample Time	StationID	Replicate *analyzed	Longitude	Latitude
HR041	HR0412B8	08/24/04	3:57:10 PM	C019	3*	-71.0451	42.3592
HR041	HR0412BE	08/24/04	4:22:04 PM	R40	1*	-71.0238	42.3288
HR041	HR0412BF	08/24/04	4:22:53 PM	R40	2	-71.0239	42.3288
HR041	HR0412C0	08/24/04	4:23:30 PM	R40	3*	-71.0240	42.3288
HR041	HR0412C1	08/24/04	4:23:41 PM	R40	4*	-71.0240	42.3287
HR041	HR0412C7	08/24/04	4:32:04 PM	R42	1*	-71.0251	42.3196
HR041	HR0412C8	08/24/04	4:32:33 PM	R42	2*	-71.0250	42.3196
HR041	HR0412C9	08/24/04	4:32:53 PM	R42	3*	-71.0250	42.3196
HR041	HR0412CF	08/24/04	4:37:59 PM	R14	1*	-71.0127	42.3208
HR041	HR0412D0	08/24/04	4:38:37 PM	R14	2*	-71.0127	42.3208
HR041	HR0412D1	08/24/04	4:39:08 PM	R14	3*	-71.0127	42.3208
HR041	HR0412D7	08/24/04	4:43:57 PM	R15	1*	-71.0190	42.3153
HR041	HR0412D8	08/24/04	4:44:25 PM	R15	2*	-71.0191	42.3153
HR041	HR0412D9	08/24/04	4:44:50 PM	R15	3*	-71.0191	42.3153
HR041	HR0412DF	08/24/04	4:49:28 PM	R41	1*	-71.0252	42.3110
HR041	HR0412E0	08/24/04	4:49:40 PM	R41	2*	-71.0251	42.3111
HR041	HR0412E1	08/24/04	4:50:13 PM	R41	3*	-71.0250	42.3111
HR041	HR0412E7	08/24/04	5:01:07 PM	T04	1*	-71.0416	42.3099
HR041	HR0412E8	08/24/04	5:01:38 PM	T04	2*	-71.0416	42.3099
HR041	HR0412E9	08/24/04	5:02:04 PM	T04	3*	-71.0415	42.3099
HR041	HR0412EF	08/24/04	5:15:31 PM	R43	1*	-71.0021	42.3067
HR041	HR0412F0	08/24/04	5:16:10 PM	R43	2*	-71.0022	42.3067
HR041	HR0412F1	08/24/04	5:16:40 PM	R43	3*	-71.0022	42.3068
HR041	HR0412F7	08/24/04	5:39:37 PM	R25	1*	-70.9285	42.2915
HR041	HR0412F8	08/24/04	5:40:04 PM	R25	2*	-70.9285	42.2914
HR041	HR0412F9	08/24/04	5:40:48 PM	R25	3*	-70.9286	42.2915
HR041	HR041301	08/24/04	5:44:51 PM	R29	1*	-70.9206	42.2897
HR041	HR041302	08/24/04	5:45:12 PM	R29	2*	-70.9206	42.2898
HR041	HR041303	08/24/04	5:45:37 PM	R29	3*	-70.9207	42.2898
HR041	HR041309	08/24/04	5:48:47 PM	R46	1*	-70.9223	42.2911
HR041	HR04130A	08/24/04	5:49:23 PM	R46	2*	-70.9222	42.2910
HR041	HR04130B	08/24/04	5:49:48 PM	R46	3*	-70.9222	42.2910
HR041	HR041311	08/24/04	5:55:24 PM	R31	1*	-70.9170	42.3009
HR041	HR041312	08/24/04	5:55:54 PM	R31	2*	-70.9171	42.3010
HR041	HR041313	08/24/04	5:56:20 PM	R31	3*	-70.9171	42.3010
HR041	HR041319	08/24/04	6:04:18 PM	R32	1*	-70.8968	42.2947
HR041	HR04131A	08/24/04	6:04:45 PM	R32	2*	-70.8968	42.2947
HR041	HR04131B	08/24/04	6:05:10 PM	R32	3*	-70.8968	42.2948
HR041	HR04131E	08/24/04	6:05:22 PM	R32	4	-70.8968	42.2948
HR041	HR041320	08/24/04	6:09:27 PM	R30	1*	-70.9040	42.2904
HR041	HR041321	08/24/04	6:09:55 PM	R30	2*	-70.9039	42.2905
HR041	HR041322	08/24/04	6:10:21 PM	R30	3*	-70.9039	42.2904
HR041	HR04132C	08/24/04	6:16:50 PM	T08	1*	-70.9123	42.2853

SurveyID	SampleID	Sample Date	Sample Time	StationID	Replicate *analyzed	Longitude	Latitude
HR041	HR04132D	08/24/04	6:17:29 PM	T08	2*	-70.9123	42.2853
HR041	HR04132E	08/24/04	6:18:05 PM	T08	3*	-70.9123	42.2854
HR041	HR041332	08/24/04	6:22:05 PM	R28	1*	-70.9085	42.2817
HR041	HR041333	08/24/04	6:22:33 PM	R28	2*	-70.9085	42.2817
HR041	HR041334	08/24/04	6:23:00 PM	R28	3*	-70.9086	42.2817
HR041	HR04133A	08/24/04	6:27:55 PM	R27	1*	-70.9161	42.2807
HR041	HR04133C	08/24/04	6:30:20 PM	R27	2*	-70.9162	42.2806
HR041	HR04133D	08/24/04	6:31:20 PM	R27	3*	-70.9161	42.2806
HR041	HR041343	08/24/04	6:37:28 PM	R50	1*	-70.8984	42.2749
HR041	HR041344	08/24/04	6:37:50 PM	R50	2*	-70.8984	42.2750
HR041	HR041345	08/24/04	6:38:15 PM	R50	3*	-70.8984	42.2750
HR041	HR04134B	08/24/04	6:42:35 PM	R49	1*	-70.9082	42.2731
HR041	HR04134C	08/24/04	6:43:05 PM	R49	2*	-70.9083	42.2731
HR041	HR04134D	08/24/04	6:43:45 PM	R49	3*	-70.9083	42.2731

APPENDIX A2

Station Data:
Benthic Grab Samples (HT041)

Table A2-1. Listing of field data from harbor traditional benthic survey HT041.

(Times are reported as Eastern Standard Time)

STUDY_ID	EVENT_ID	STAT_ID	STAT_ARRIV (EST)	BEG_LATITUDE	BEG_LONGITUDE	DEPTH_TO_BOTTOM	DEPTH_UNIT_CODE	NAVIGATION_CODE	NAV_QUAL	MATRIX_CODE	GEAR_CODE	DEPTH	DEPTH_TOP	DEPTH_UNIT_CODE	SAMPLE_ID	SAMP_VOL	SAMP_VOL_UNIT_CODE	DEPTH_CLASS_CODE
BHSOFT	HT041	C019	08/03/2004 10:11:26	42.3592148	-71.0450668	8.8	m	DGPS	+/- 10m	SED	VV01	14	0	cm	HT04105A	11	L	E
BHSOFT	HT041	C019	08/03/2004 10:11:26	42.3592148	-71.0450668	8.8	m	DGPS	+/- 10m	SED	VV01	14	0	cm	HT041059	11	L	E
BHSOFT	HT041	C019	08/03/2004 10:11:26	42.3592148	-71.0450668	8.8	m	DGPS	+/- 10m	SED	VV01	14	0	cm	HT041058	11	L	E
BHSOFT	HT041	C019	08/03/2004 10:11:26	42.3592148	-71.0450668	8.8	m	DGPS	+/- 10m	SED	VV04	10	0	cm	HT041055	3.25	L	E
BHSOFT	HT041	C019	08/03/2004 10:11:26	42.3592148	-71.0450668	8.8	m	DGPS	+/- 10m	SED	VV04	10	0	cm	HT041054	3.25	L	E
BHSOFT	HT041	C019	08/03/2004 10:11:26	42.3592148	-71.0450668	8.8	m	DGPS	+/- 10m	SED	VV04	10	0	cm	HT041057	3.25	L	E
BHSOFT	HT041	T01	08/03/2004 08:42:23	42.3492012	-70.9634323	3.8	m	DGPS	+/- 10m	SED	VV04	9	0	cm	HT04103C	3	L	E
BHSOFT	HT041	T01	08/03/2004 08:42:23	42.3492012	-70.9634323	3.8	m	DGPS	+/- 10m	SED	VV04	9.5	0	cm	HT04103B	3.25	L	E
BHSOFT	HT041	T01	08/03/2004 08:42:23	42.3492012	-70.9634323	3.8	m	DGPS	+/- 10m	SED	VV04	9.5	0	cm	HT041039	3.25	L	E
BHSOFT	HT041	T01	08/03/2004 08:42:23	42.3492012	-70.9634323	3.8	m	DGPS	+/- 10m	SED	VV04	8.5	0	cm	HT041038	3	L	E
BHSOFT	HT041	T02	08/03/2004 09:26:23	42.3429337	-71.0020523	6.6	m	DGPS	+/- 10m	SED	VV04	9.5	0	cm	HT04104C	3.25	L	E
BHSOFT	HT041	T02	08/03/2004 09:26:23	42.3429337	-71.0020523	6.6	m	DGPS	+/- 10m	SED	VV04	9	0	cm	HT04104B	3	L	E
BHSOFT	HT041	T02	08/03/2004 09:26:23	42.3429337	-71.0020523	6.6	m	DGPS	+/- 10m	SED	VV04	9.5	0	cm	HT041046	3.25	L	E
BHSOFT	HT041	T02	08/03/2004 09:26:23	42.3429337	-71.0020523	6.6	m	DGPS	+/- 10m	SED	VV04	9.5	0	cm	HT041044	3.25	L	E
BHSOFT	HT041	T03	08/03/2004 07:22:02	42.330101	-70.9619522	6.4	m	DGPS	+/- 10m	SED	VV04	9	0	cm	HT041025	3	L	E
BHSOFT	HT041	T03	08/03/2004 07:22:02	42.330101	-70.9619522	6.4	m	DGPS	+/- 10m	SED	VV04	9	0	cm	HT04101F	3	L	E
BHSOFT	HT041	T03	08/03/2004 07:22:02	42.330101	-70.9619522	6.4	m	DGPS	+/- 10m	SED	VV04	10	0	cm	HT04101D	3.25	L	E
BHSOFT	HT041	T03	08/03/2004 07:22:02	42.330101	-70.9619522	6.4	m	DGPS	+/- 10m	SED	VV04	10	0	cm	HT041021	3.25	L	E
BHSOFT	HT041	T04	08/03/2004 11:28:15	42.309967	-71.0415802	4.4	m	DGPS	+/- 10m	SED	VV04	9.5	0	cm	HT041070	3.25	L	E
BHSOFT	HT041	T04	08/03/2004 11:28:15	42.309967	-71.0415802	4.4	m	DGPS	+/- 10m	SED	VV04	9.5	0	cm	HT04106E	3.25	L	E
BHSOFT	HT041	T04	08/03/2004 11:28:15	42.309967	-71.0415802	4.4	m	DGPS	+/- 10m	SED	VV04	9.5	0	cm	HT04106F	3.25	L	E
BHSOFT	HT041	T04	08/03/2004 11:28:15	42.309967	-71.0415802	4.4	m	DGPS	+/- 10m	SED	VV04	10	0	cm	HT041062	3.25	L	E
BHSOFT	HT041	T05A	08/03/2004 07:52:32	42.3396339	-70.9607162	15.1	m	DGPS	+/- 10m	SED	VV04	10	0	cm	HT04102E	3.25	L	E
BHSOFT	HT041	T05A	08/03/2004 07:52:32	42.3396339	-70.9607162	15.1	m	DGPS	+/- 10m	SED	VV04	9.5	0	cm	HT04102B	3.25	L	E
BHSOFT	HT041	T05A	08/03/2004 07:52:32	42.3396339	-70.9607162	15.1	m	DGPS	+/- 10m	SED	VV04	9	0	cm	HT04102A	3	L	E
BHSOFT	HT041	T05A	08/03/2004 07:52:32	42.3396339	-70.9607162	15.1	m	DGPS	+/- 10m	SED	VV04	10	0	cm	HT04102C	3.25	L	E
BHSOFT	HT041	T06	08/03/2004 13:07:09	42.2936325	-70.9441147	6.6	m	DGPS	+/- 10m	SED	VV04	9	0	cm	HT04108C	3	L	E
BHSOFT	HT041	T06	08/03/2004 13:07:09	42.2936325	-70.9441147	6.6	m	DGPS	+/- 10m	SED	VV04	9.5	0	cm	HT04108A	3.25	L	E
BHSOFT	HT041	T06	08/03/2004 13:07:09	42.2936325	-70.9441147	6.6	m	DGPS	+/- 10m	SED	VV04	8	0	cm	HT041089	2.75	L	E
BHSOFT	HT041	T06	08/03/2004 13:07:09	42.2936325	-70.9441147	6.6	m	DGPS	+/- 10m	SED	VV04	7	0	cm	HT04108B	2.25	L	E
BHSOFT	HT041	T07	08/03/2004 12:35:23	42.2893677	-70.9785538	7.1	m	DGPS	+/- 10m	SED	VV04	9	0	cm	HT04107D	3	L	E
BHSOFT	HT041	T07	08/03/2004 12:35:23	42.2893677	-70.9785538	7.1	m	DGPS	+/- 10m	SED	VV04	9.5	0	cm	HT041079	3.25	L	E
BHSOFT	HT041	T07	08/03/2004 12:35:23	42.2893677	-70.9785538	7.1	m	DGPS	+/- 10m	SED	VV04	9.5	0	cm	HT041077	3.25	L	E
BHSOFT	HT041	T07	08/03/2004 12:35:23	42.2893677	-70.9785538	7.1	m	DGPS	+/- 10m	SED	VV04	9	0	cm	HT04107C	3	L	E
BHSOFT	HT041	T08	08/03/2004 06:37:16	42.28528	-70.91253	9.5	m	DGPS	+/- 10m	SED	VV04	8	0	cm	HT041017	2.75	L	E
BHSOFT	HT041	T08	08/03/2004 06:37:16	42.28528	-70.91253	9.5	m	DGPS	+/- 10m	SED	VV04	7.5	0	cm	HT041016	2.5	L	E
BHSOFT	HT041	T08	08/03/2004 06:37:16	42.28528	-70.91253	9.5	m	DGPS	+/- 10m	SED	VV04	9	0	cm	HT041014	3	L	E
BHSOFT	HT041	T08	08/03/2004 06:37:16	42.28528	-70.91253	9.5	m	DGPS	+/- 10m	SED	VV04	9	0	cm	HT041013	3	L	E

Table A2-2. Station data and field observations for individual infauna and chemistry soft-bottom grab samples collected in August 2004(HT041).

Station ID	Sample ID	Date/Time (EDT)	Sample Type	Latitude (N)	Longitude (W)	RPD Depth (cm)	Sediment Texture	Fauna and Miscellaneous Observations
T01	HT041038	8/3/04 09:49	Chem	42.34920	-70.96343	0.2	Very fine sandy silt	Bacterial mat, hermit crabs, snails
T01	HT041039	8/3/04 09:55	Biol	42.34918	-70.96345	0.4	Very fine sandy silt	Bacterial mat, snails
T01	HT04103B	8/3/04 10:02	Biol	42.34912	-70.96347	0.4	Very fine sandy silt	Bacterial mat, sand shrimp (*Crangon*), snails
T01	HT04103C	8/3/04 10:08	Biol	42.34922	-70.96343	0.4	Very fine sandy silt	Snails
T02	HT041044	8/3/04 10:27	Biol	42.34293	-71.00205	0.1	silt	Bacterial mat, crab, snail, sm. sand dollar
T02	HT041046	8/3/04 10:33	Biol	42.34285	-71.00195	0.3	silt	Bacterial mat, amphipod, crab. snail, worm
T02	HT04104B	8/3/04 10:39	Chem	42.34293	-71.00200	0.2	silt	Small bacterial mat, snail
T02	HT04104C	8/3/04 10:45	Biol	42.34288	-71.00200	0.2	silt	Amphipod tubes, snail
T03	HT04101D	8/3/04 08:26	Biol	42.33010	-70.96195	0.5	sandy silt	Amphipod tube mat
T03	HT04101F	8/3/04 08:29	Biol	42.33013	-70.96201	1.5	sandy silt	Amphipod tube mat
T03	HT041021	8/3/04 08:34	Biol	42.33018	-70.96197	1.3	v. fine sandy silt	Amphipod tube mat, *Ilyanassa*
T03	HT041025	8/3/04 08:40	Chem	42.33015	-70.96201	1.0	v. fine sandy silt	Amphipod tube mat, worm
T04	HT041062	8/3/04 12:34	Biol	42.30997	-71.04158	0.1-0.2	silt	No fauna seen
T04	HT04106E	8/3/04 12:52	Chem	42.31005	-71.04145	0.3	silt	One sand shrimp (*Crangon*)
T04	HT04106F	8/3/04 12:59	Biol	42.31000	-71.04140	0.2	silt	No fauna seen
T04	HT041070	8/3/04 13:03	Biol	42.30998	-71.04150	0.1-0.2	silt	No fauna seen
T05A	HT04102A	8/3/04 08:58	Chem	42.33963	-70.96072	0.3	v. fine sandy silt	Amphipod tube mat, crab
T05A	HT04102B	8/3/04 09:06	Biol	42.33977	-70.96065	0.3	v. fine sandy silt	Amphipod tube mat, snail, crab
T05A	HT04102C	8/3/04 09:11	Biol	42.33970	-70.96065	0.4	v. fine sandy silt	Amphipod tube mat, isopod, snail
T05A	HT04102E	8/3/04 09:17	Biol	42.33972	-70.96067	0.2	v. fine sandy silt	Amphipod tube mat, snails
T06	HT041089	8/3/04 14:09	Chem	42.29363	-70.94411	0.5	v. fine sandy silt	Tube mat, crabs
T06	HT04108A	8/3/04 14:15	Biol	42.29327	-70.94420	0.4	v. fine sandy silt	Bacterial mat, tube mat, crabs
T06	HT04108B	8/3/04 14:19	Biol	42.29330	-70.94448	0.5	v. fine sandy silt	Bacterial mat, amphipod tube mat, crabs
T06	HT04108C	8/3/04 14:24	Biol	42.29332	-70.94420	0.4	v. fine sandy silt	Amphipod tube mat, crabs
T07	HT041077	8/3/04 13:37	Biol	42.28937	-70.97855	0.2	v. fine sandy silt	A few amphipod tubes, snail
T07	HT041079	8/3/04 13:42	Biol	42.28928	-70.97852	0.3	v. fine sandy silt	A few amphipod tubes
T07	HT04107C	8/3/04 13:49	Chem	42.28937	-70.97858	0.3	v. fine sandy silt	Hermit crabs, shell hash
T07	HT04107D	8/3/04 13:55	Biol	42.28923	-70.97845	0.2	v. fine sandy silt	Amphipod tubes, snail
T08	HT041013	8/3/04 07:41	Chem	42.28528	-70.91523	1.2	sandy	Snails, tubes
T08	HT041014	8/3/04 07:47	Biol	42.28532	-70.91248	1.0	sandy	Hermit crabs, snails, tubes
T08	HT041016	8/3/04 07:53	Biol	42.28532	-70.91248	1.5	sandy	Hermit crabs, snails, tubes
T08	HT041017	8/3/04 07:59	Biol	42.28530	-70.91247	1.5	sandy	Snails (*Ilyanassa*), tubes
C019	HT041054	8/3/04 11:13	Biol	42.35921	-71.04507	0.3	silt	Snail
C019	HT041055	8/3/04 11:19	Biol	42.35915	-71.04505	0.5	silt	Isopod
C019	HT041057	8/3/04 11:24	Biol	42.35921	-71.04508	0.3	silt	Isopod, snail, tubes
C019	HT041058	8/3/04 11:36	Chem	42.35918	-71.04497	0.2	silt	Isopod, tubes
C019	HT041059	8/3/04 11:44	Chem	42.35909	-71.04520	0.2	silt	Tubes
C019	HT04105A	8/3/04 11:52	Chem	42.35917	-71.04507	0.4	silt	Sand shrimp (*Crangon*)

Appendix B1

Terminology

Key terms used to describe the sediment data include:

- Percent Fines – sum of percent silt and clay
- Station Mean – average of all station replicates for a given year. Single grab samples were generally collected at all Traditional stations during most sampling years, but replicate grabs were also collected during some sampling years (*e.g.,* August 1994 and 1997). Station means were determined for each parameter within a given sampling year (April and August surveys) to assess the spatial and temporal distribution in bulk sediment properties and *C. perfringens* from 1991 to 2004
- Grand Station Mean – average over years for a given station. Grand station means were determined for each parameter over all sampling years to assess variability in the spatial and temporal distribution in bulk sediment properties and *C. perfringens* from 1991 to 2004.
- Grand Monthly Mean – average over years and stations for a given sampling month. Grand monthly means were determined for Flux (BH02, BH03 and BH03) and Traditional Harbor (T02 and T03) TOC from 1993 to 2004 to assess if there was a characteristic seasonal "peak" in TOC content
- Harbor-wide – refers to all Traditional Harbor stations, including T01 through T08. All data from stations T01 through T08 were used in statistical analyses to assess if there was a significant 'harbor-wide' change in TOC and *C. perfringens* with time (1991–2004). CO19 was not included in the 'harbor-wide' evaluations.

Key data analyses conducted to assess spatial and temporal trends in the sediment data from 1991 to 2004 included:

- Line charts were used to visualize the trends in sediment data. Line charts were prepared by using Microsoft® Excel 2002.
- Box plots were used to visualize the data distribution, and identify points with extreme values. The ends of the box represent the 25^{th} and 75^{th} quartiles, and the line across the middle represents the median value. The lines are "whiskers" that extend from the ends of the box to the outermost data point that falls within the distances computed (a distance of 1.5 times the interquartile range, difference between 25^{th} and 75^{th} quartiles). Data points above or below the whiskers represent possible outliers. Box plots were prepared by using JMP (The Statistical Discovery Software, a product of SAS).

Seasonal TOC data collected by the Benthic Flux program (BH02, BH03, and BH03A (1995-1997) only) from 1993 to 2004 were evaluated with the Harbor TOC data (stations T02 and T03 only) to explore if there was a characteristic seasonal "peak" in Harbor TOC levels that more or less corresponded to the faunal sampling events. Benthic Flux results from February 1993 and June 1996 were excluded from the analysis because benthic flux data were not typically collected in February or June (sampling periods generally included March, May, July, August and October).

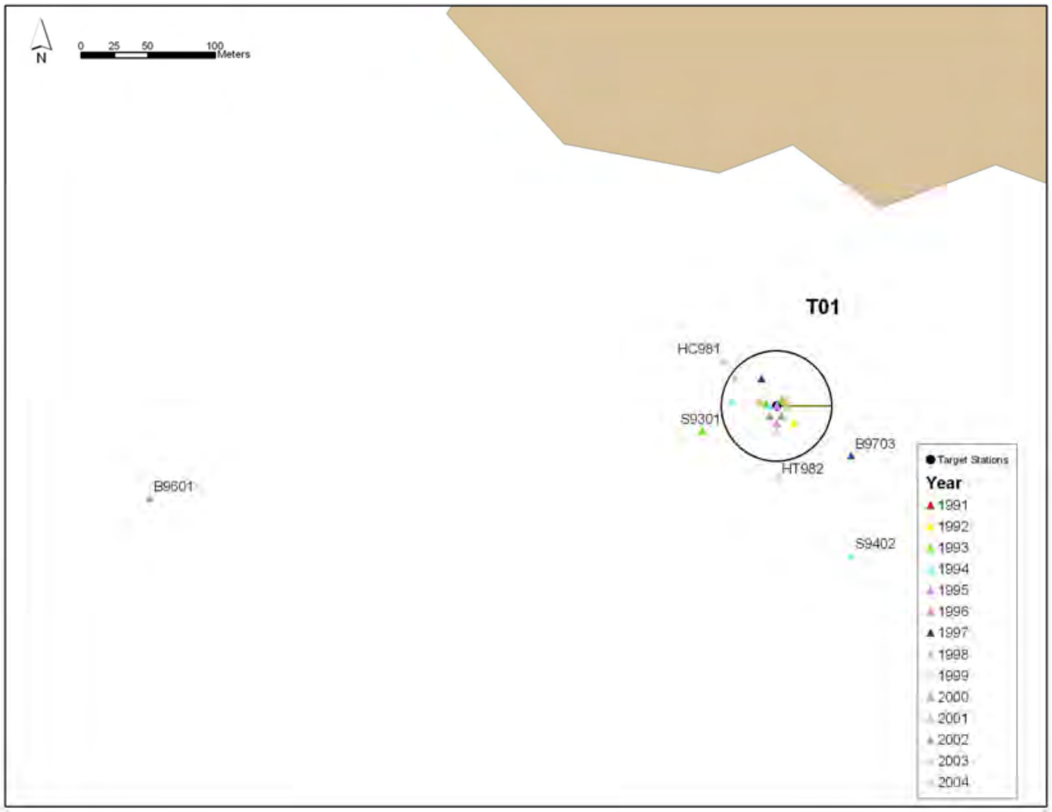
Analysis of variance (ANOVA was used to test for differences, harbor-wide (all traditional stations) and by station, in TOC and *C. perfringens* by monitoring year. Where the ANOVA showed significant differences between the two variables tested, a linear regression was performed to explain the relationship. Normality was checked with the Shapiro-Wilk test and homogeneity of variance with Bartlett's test. For normality, the raw sediment data and logarithms of the sediment data were used, and the *p*-value for each test was calculated. Given the large sample sizes ($n > 50$), the distribution corresponding to the larger of the two *p*-values was selected as the appropriate distribution.

The distribution was normal for percent fines and TOC and log-normal for *C. perfringens*. Variances in the TOC and *C. perfringens* data with time were equal harbor-wide and by station, except for variances in TOC and year at T07 and T08 and variances in log-transformed *C. perfringens* and year at T01 and CO19.

The relationship between variables (percentages gravel, sand, silt, clay, fines, TOC, and log-transformed *C. perfringens*) was determined using correlation analyses, *i.e.,* pair-wise comparisons yielding the Pearson product-moment correlation coefficient (*r*). The Pearson correlation coefficient measures the degree to which two variables have a linear relationship if the variables have normal distributions. For Pearson correlations, values near 1 indicate that the two variables have a strong positive correlation, values near -1 indicate that the two variables have a strong negative correlation, and values near 0 indicate that the two variables are unrelated. ***Strong correlation coefficients do not necessarily indicate a direct dependence of the variables.*** Correlation analyses were performed using sediment data from multiple time periods (below). Individual replicate data were used in the correlation analyses, as opposed to station mean values, because typically only one grab sample was collected at each of the eight traditional harbor stations during harbor monitoring. Replicate grab samples were collected less frequently (three grabs at all stations in August 1997 and August 2002; four grabs each at T01, T02 and T08 in August 1994 and August 1998; and four grabs at T07 in August 1998.).

- 1991–2004, represents the complete period of harbor monitoring
- 1992–2004, represents the complete period of harbor monitoring excluding 1991 when sludge was actively disposed to the harbor
- 1992–1997, represents the monitoring period after cessation of sludge disposal but prior to the bulk of improvements to sewage treatment (e.g., advanced primary and secondary treatment)
- 1998–2000, represents the monitoring period after the bulk of improvements to sewage treatment and before effluent diversion
- 2001–2004, represents the monitoring period after effluent was diverted to the offshore outfall

Finally, sample maps were prepared showing actual locations sampled from 1991 to 2004 for each Harbor station (T01 through T08). Stations sampled more than 30-m from the target location were identified and cross-referenced with the sediment data to assess if small changes in the boat position were associated with substantial changes in grain-size composition. Sample maps follow.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0 25 50 100 Meters
T01
HC981
S9301
B9703
HT982
B9601
S9402
Target Stations
Year
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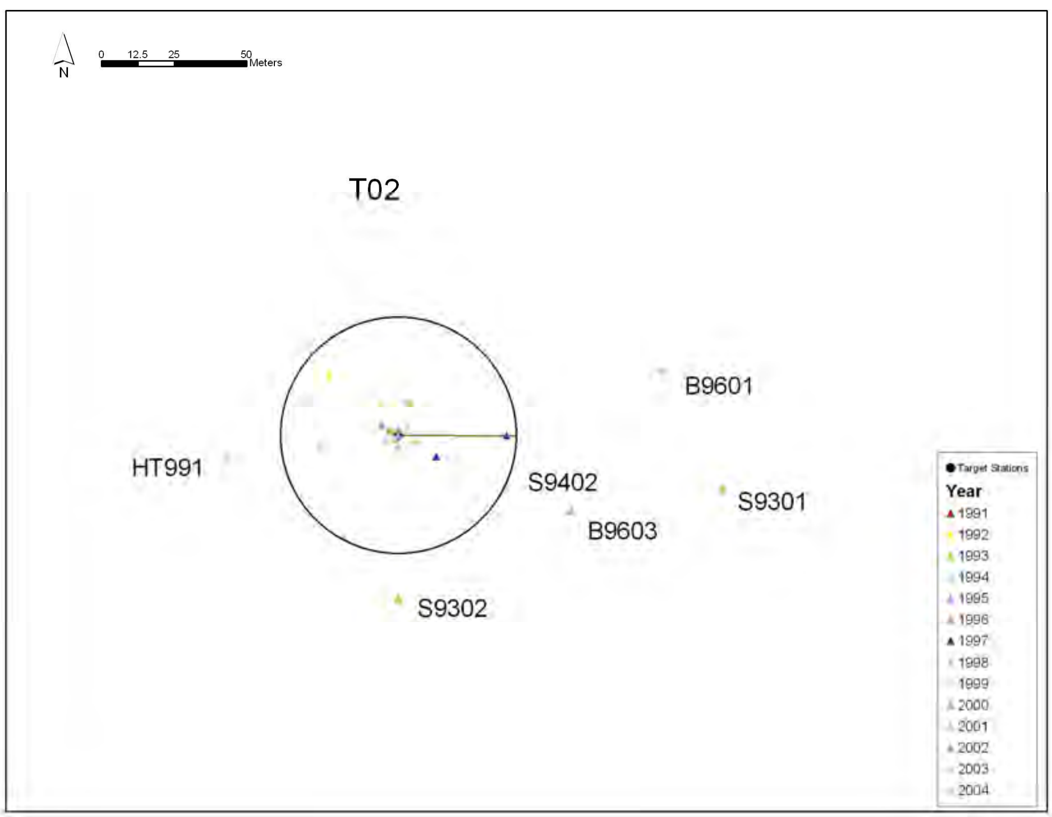
2000
2001
2002
2003
2004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T02
B9601
HT991
S9402
S9301
B9603
S9302
Target Stations
Year
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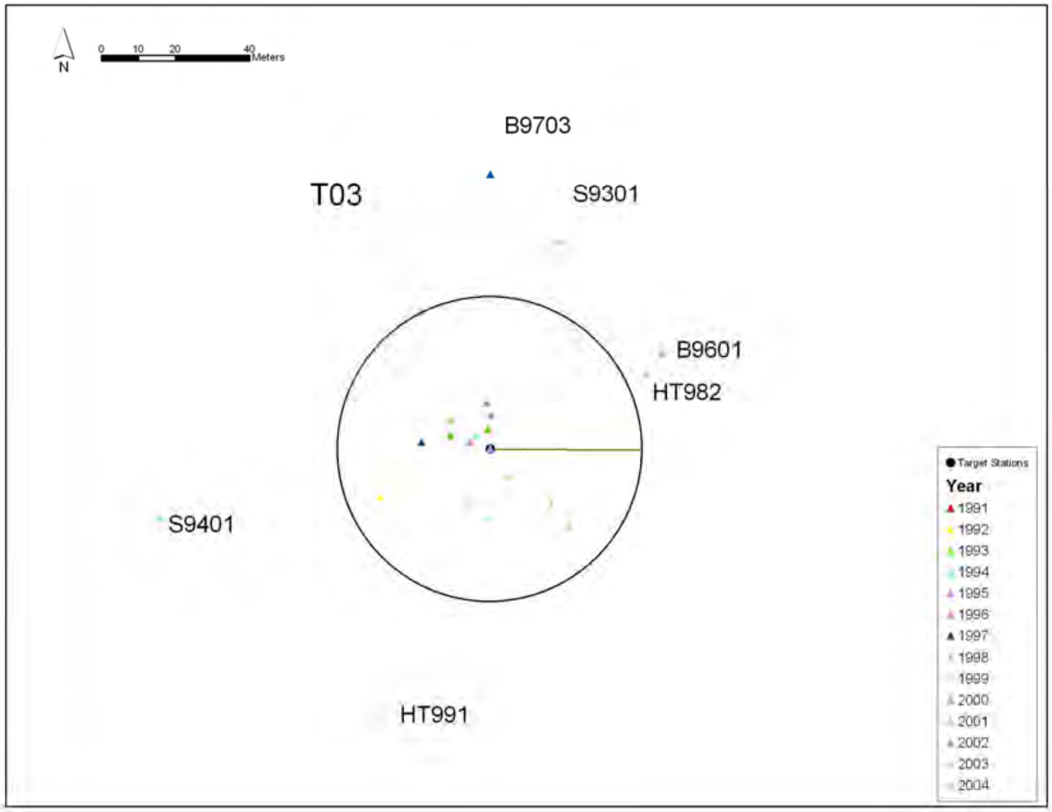
2000
2001
2002
2003
2004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B9703
T03
S9301
B9601
HT982
S9401
HT991
Target Stations
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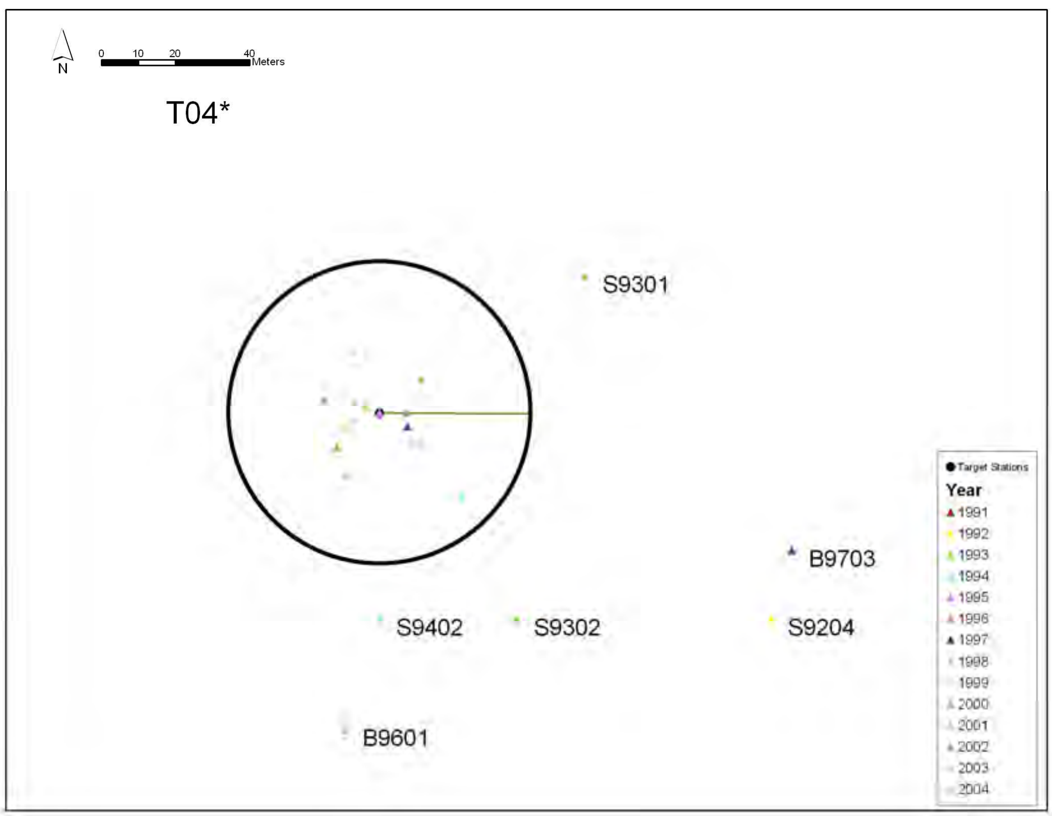
2000
2001
2002
2003
2004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T04*
S9301
B9703
S9402
S9302
S9204
B9601
Target Stations
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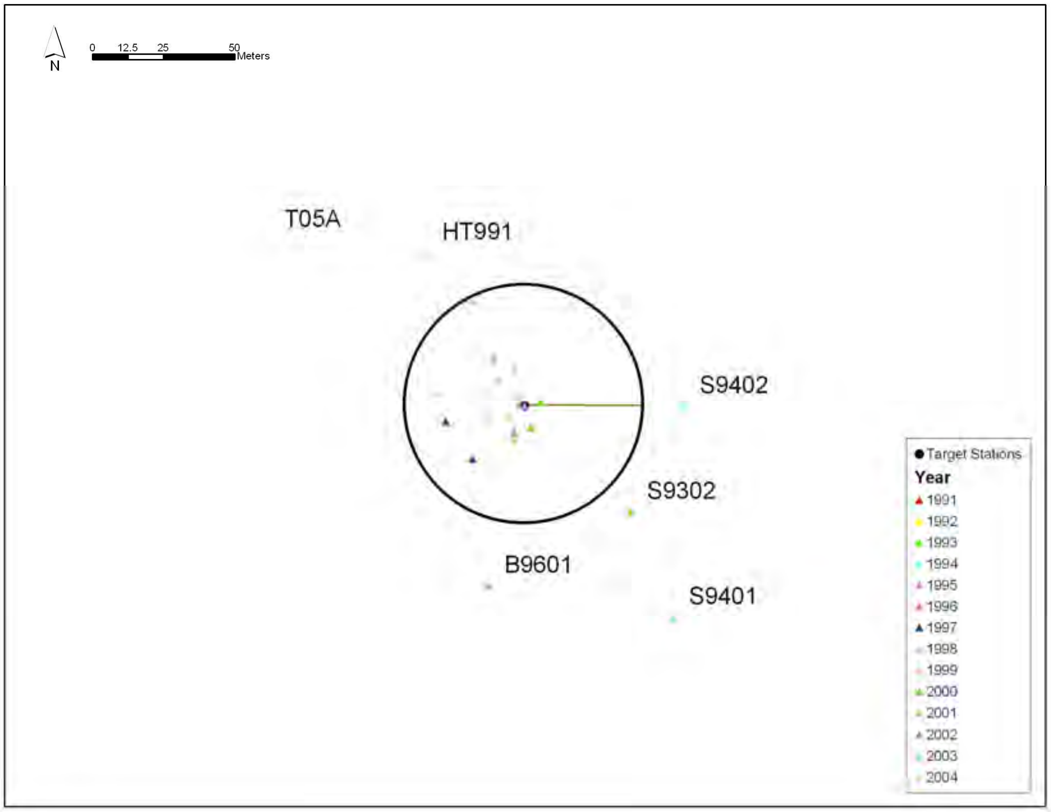
2000
2001
2002
2003
2004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T05A
HT991
S9402
S9302
B9601
S9401
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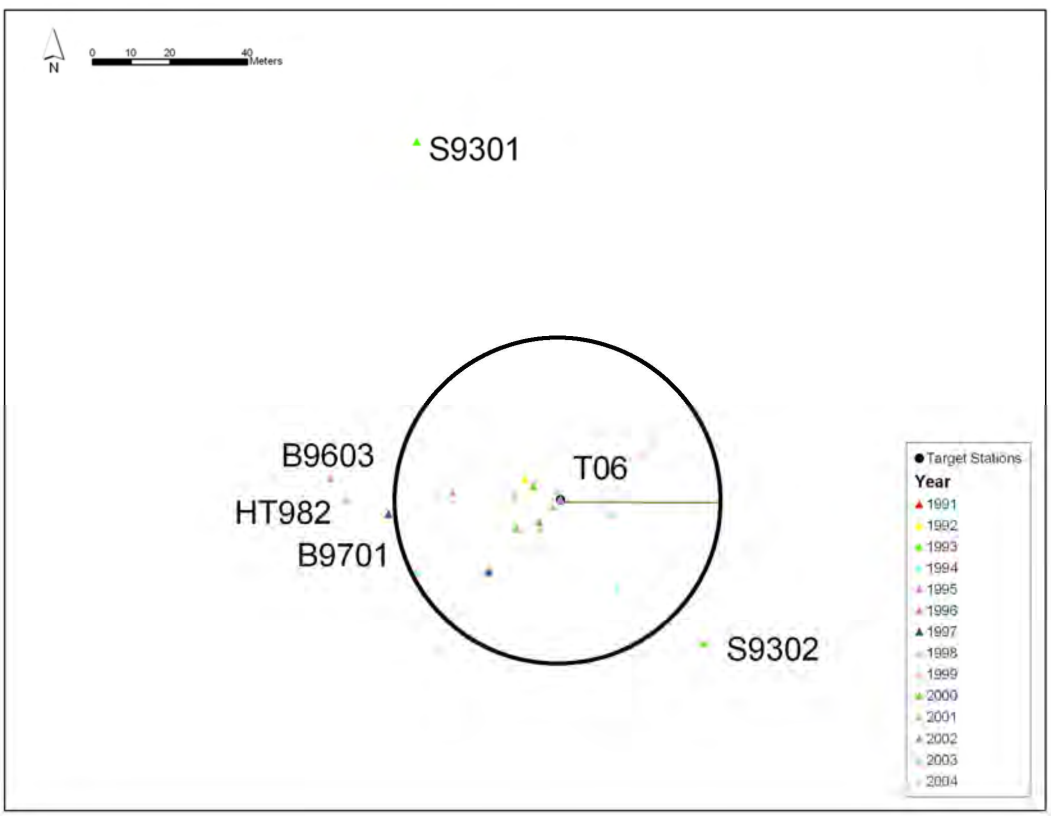
2000
2001
2002
2003
2004


N
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S9301
B9603
T06
HT982
B9701
S9302
Target Stations
Year
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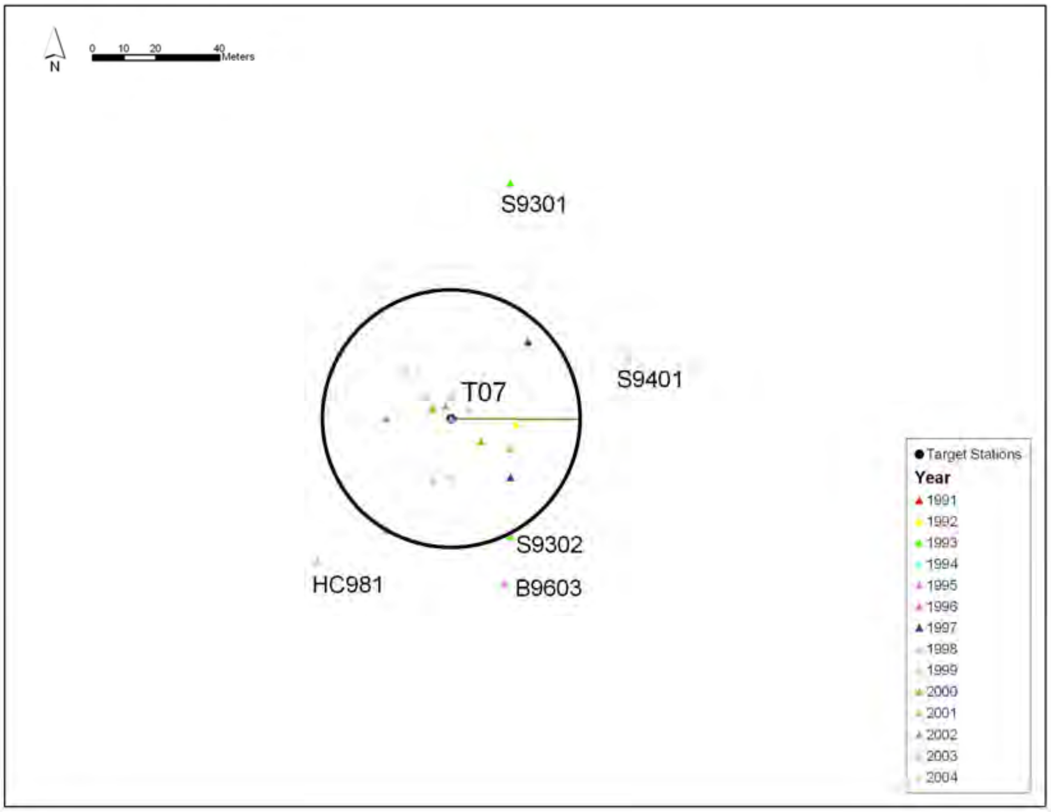
2000
2001
2002
2003
2004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S9301
T07
S9401
S9302
HC981
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Target Stations
Year
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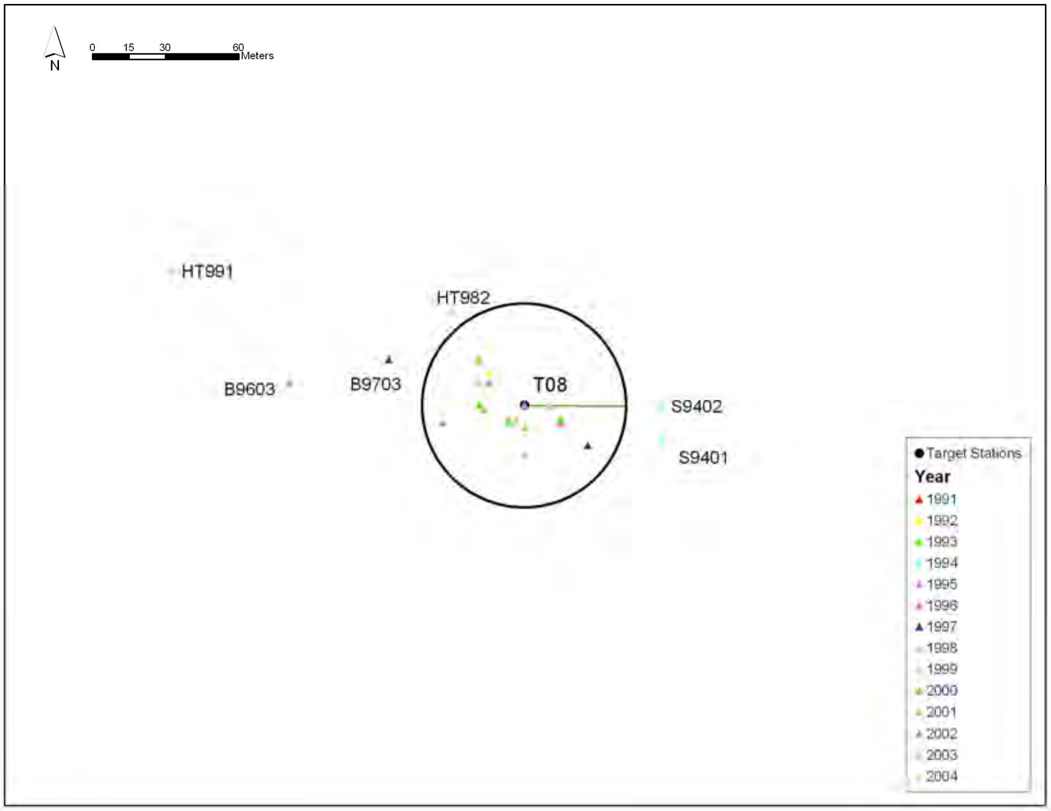
2001
2002
2003
2004


N
0 15 30 60 Meters
HT991
HT982
B9603
B9703
T08
S9402
S9401
Target Stations
Year
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1999
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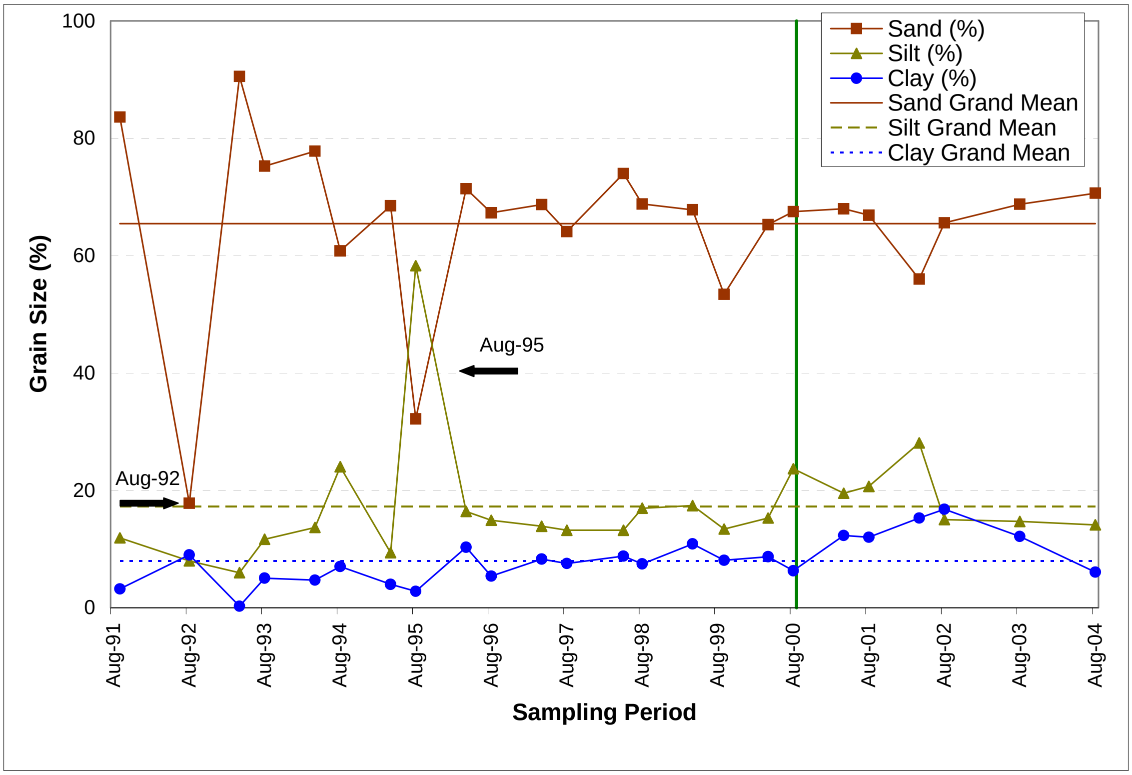
2004

Appendix B2

Grain Size, 1991–2004



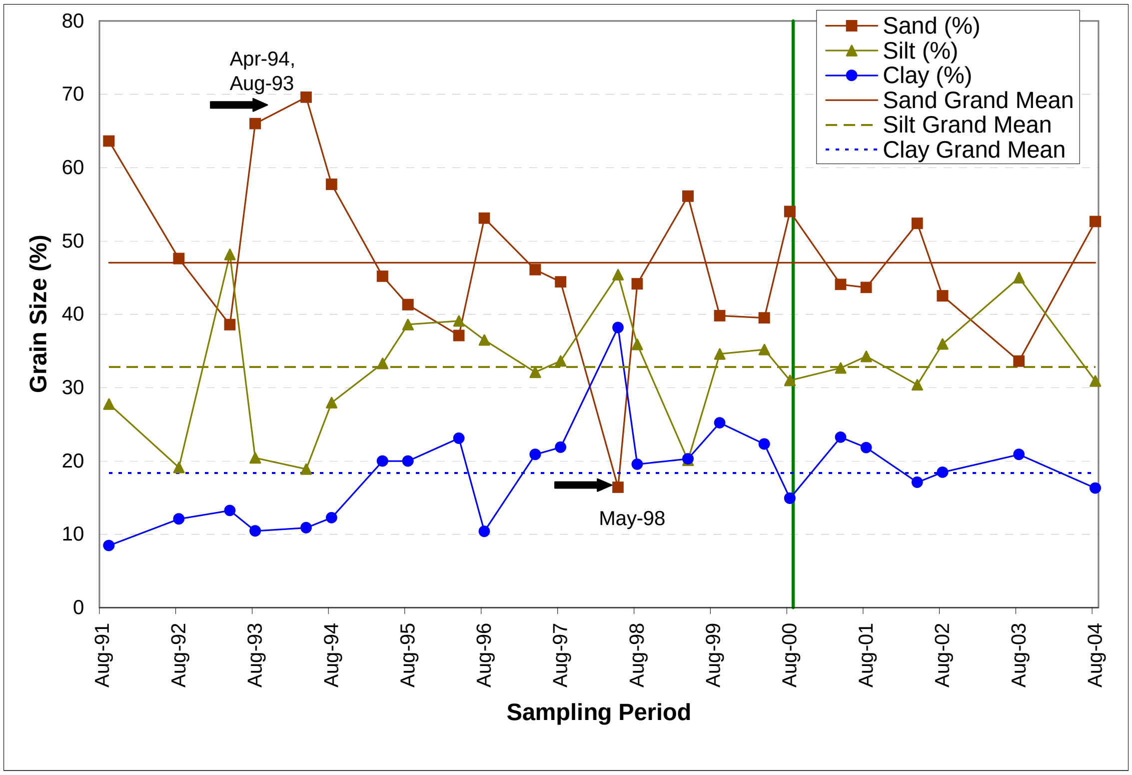
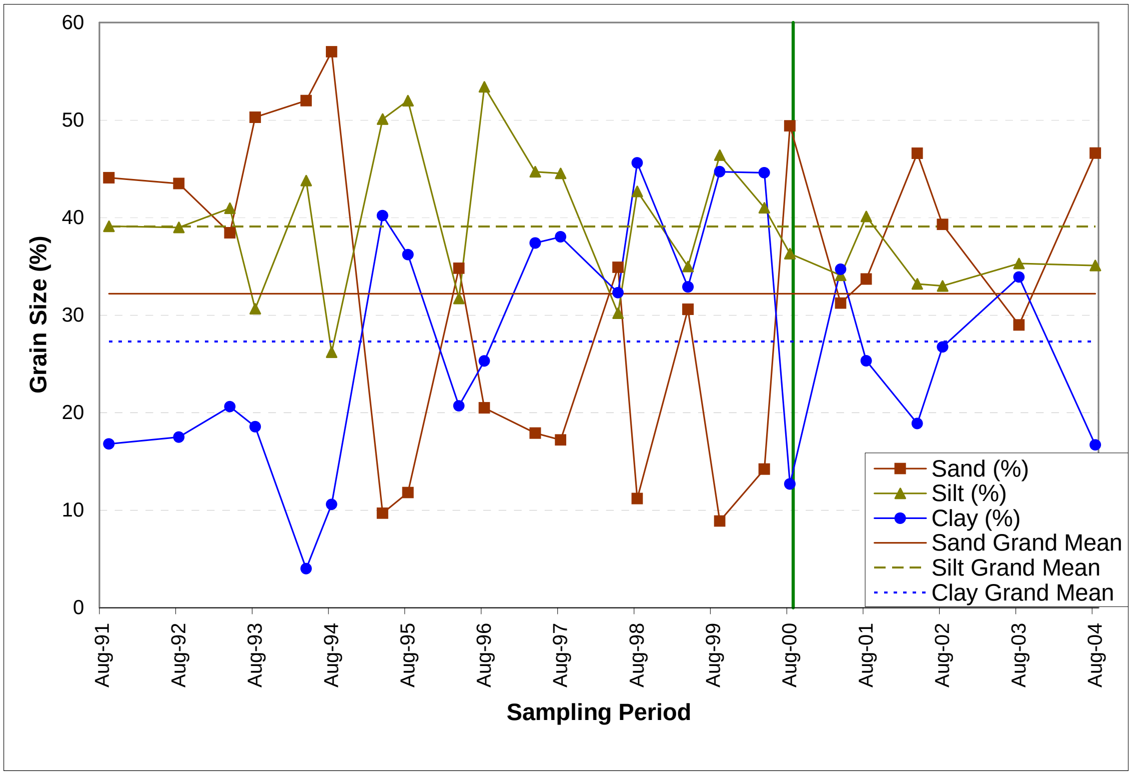


Figure B2-1. Station mean grain-size composition, presented as percentage sand, silt and clay, at stations T01 (top) and T02 (bottom), 1991–2004.



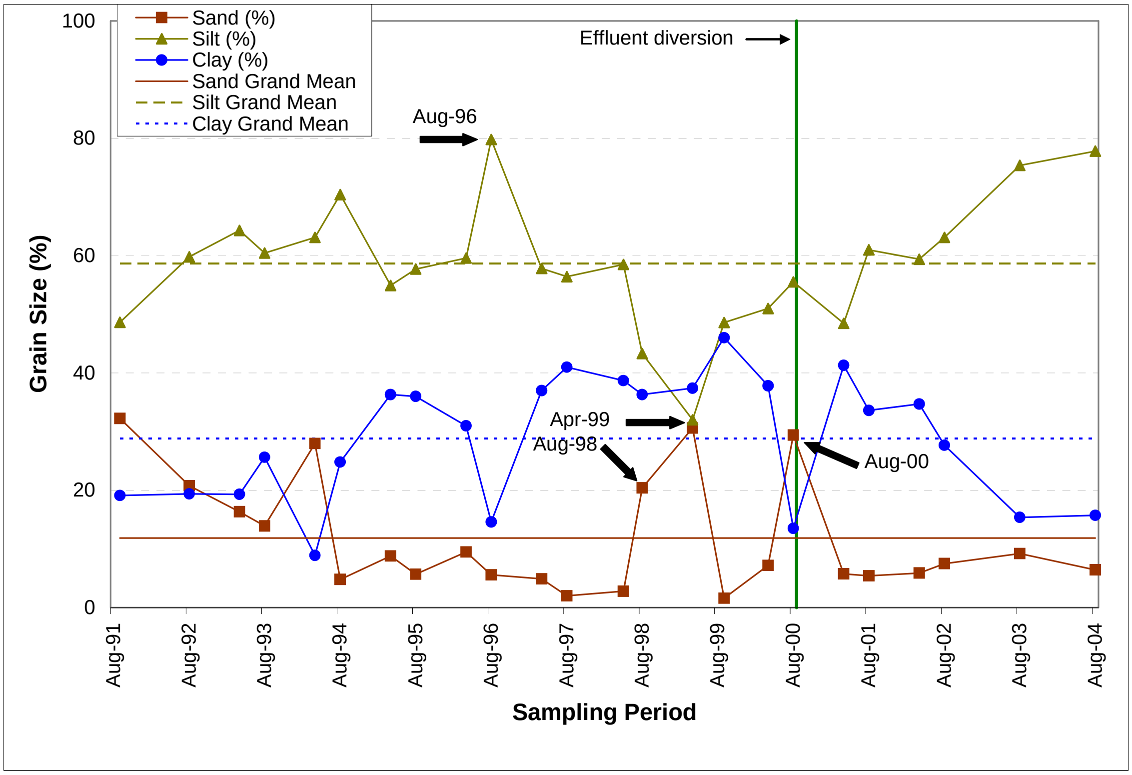
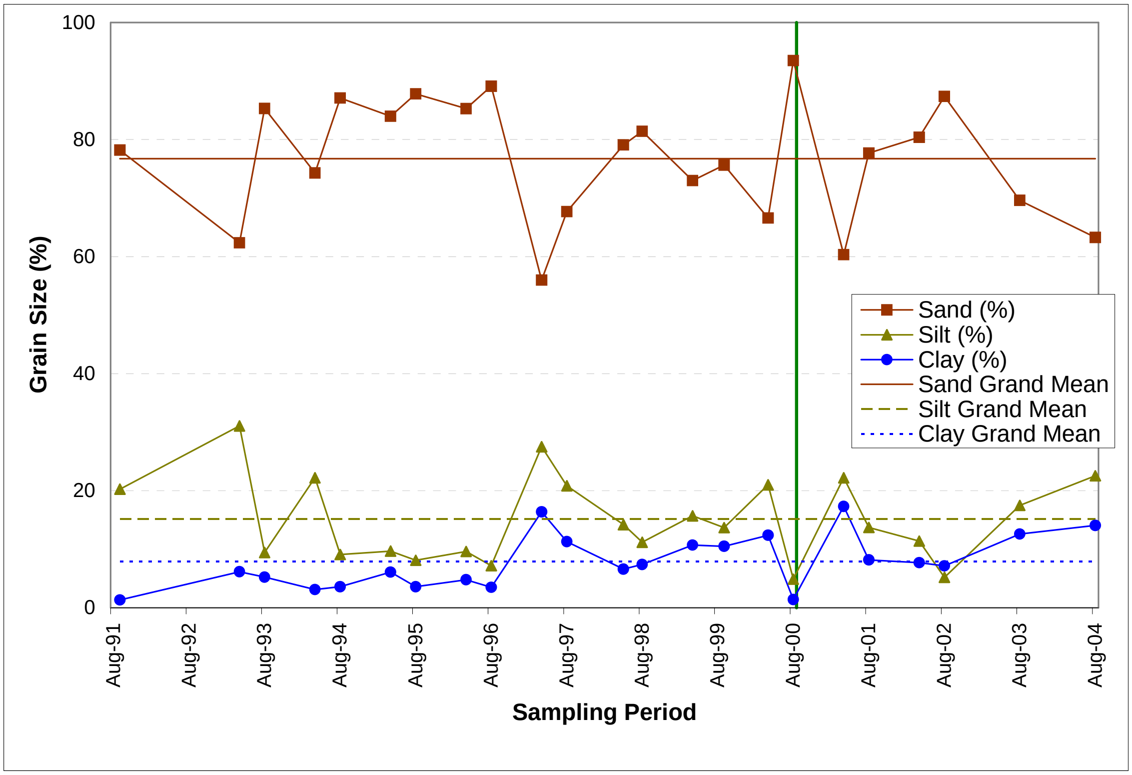


Figure B2-2. Station mean grain-size composition, presented as percentage sand, silt and clay, at stations T03 (top) and T04 (bottom), 1991–2004.



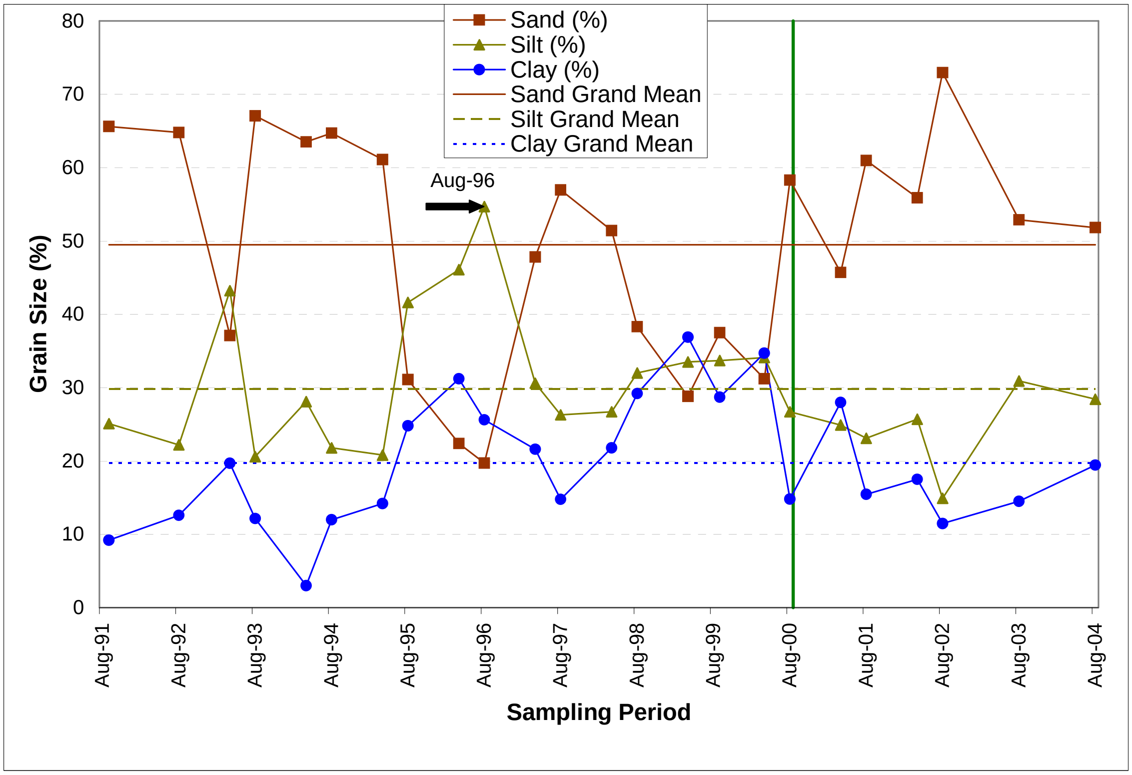
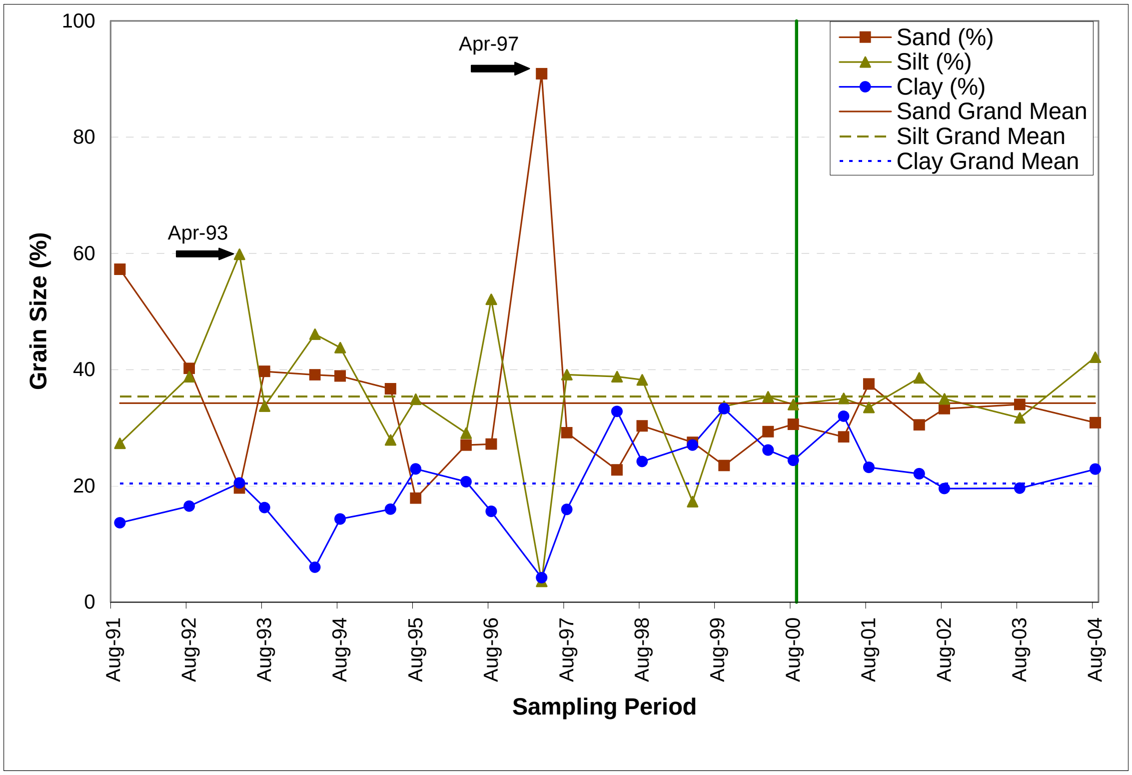


Figure B2-3. Station mean grain-size composition, presented as percentage sand, silt and clay, at stations T05A (top) and T06 (bottom), 1991–2004.



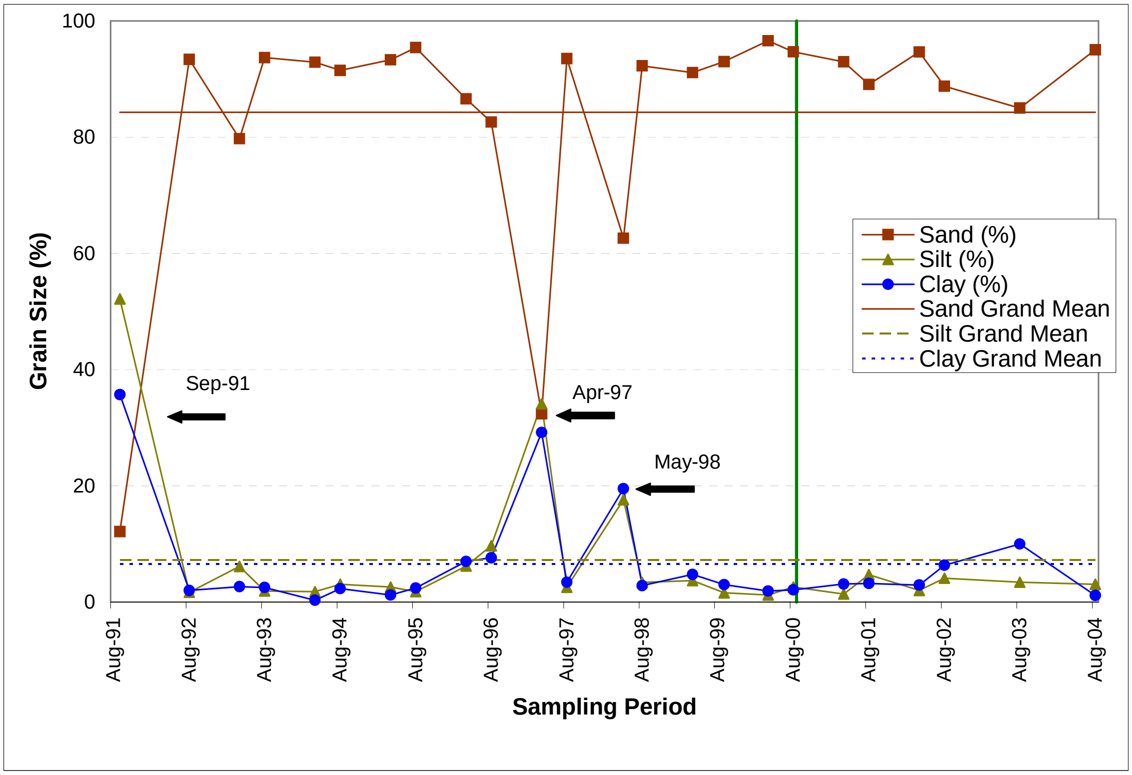


Figure B2-4. Station mean grain-size composition, presented as percentage sand, silt and clay, at stations T07 (top) and T08 (bottom), 1991–2004.

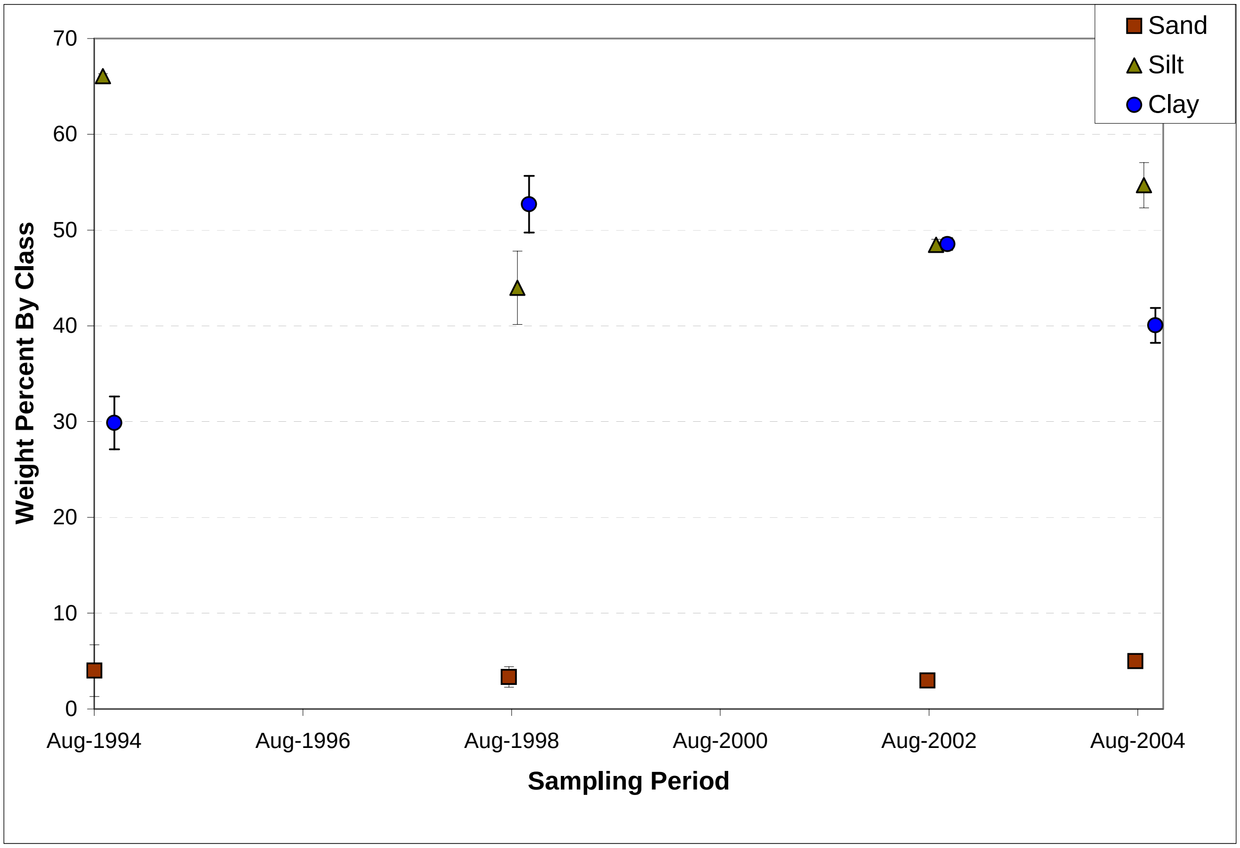
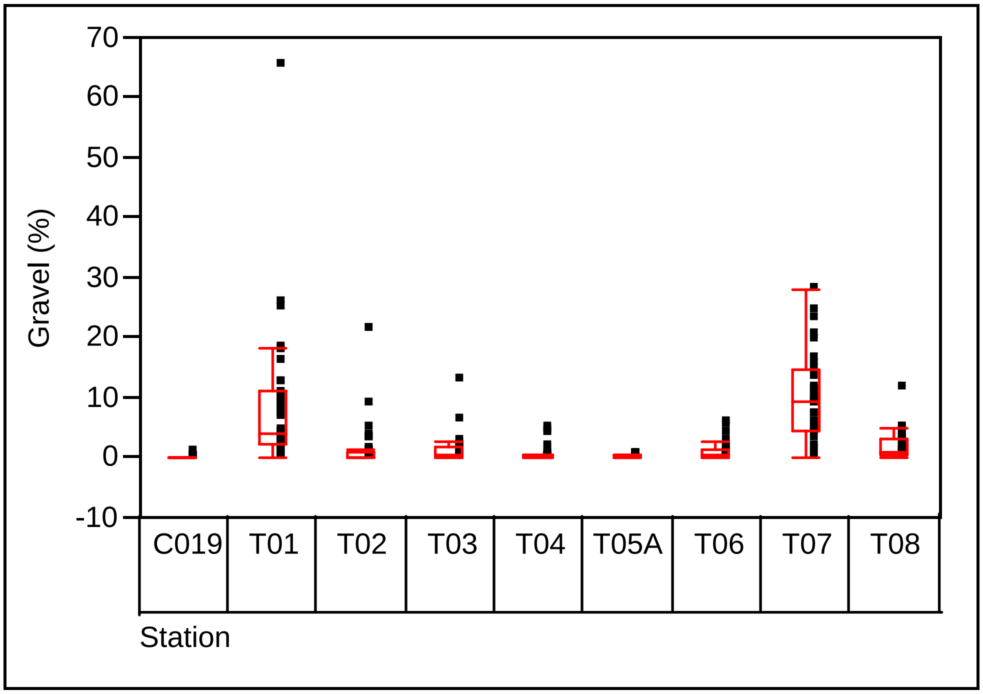


Figure B2-5. Station mean grain-size composition, presented as percentage sand, silt and clay, at station CO19, 1994–2004. Vertical bars represent one standard deviation.



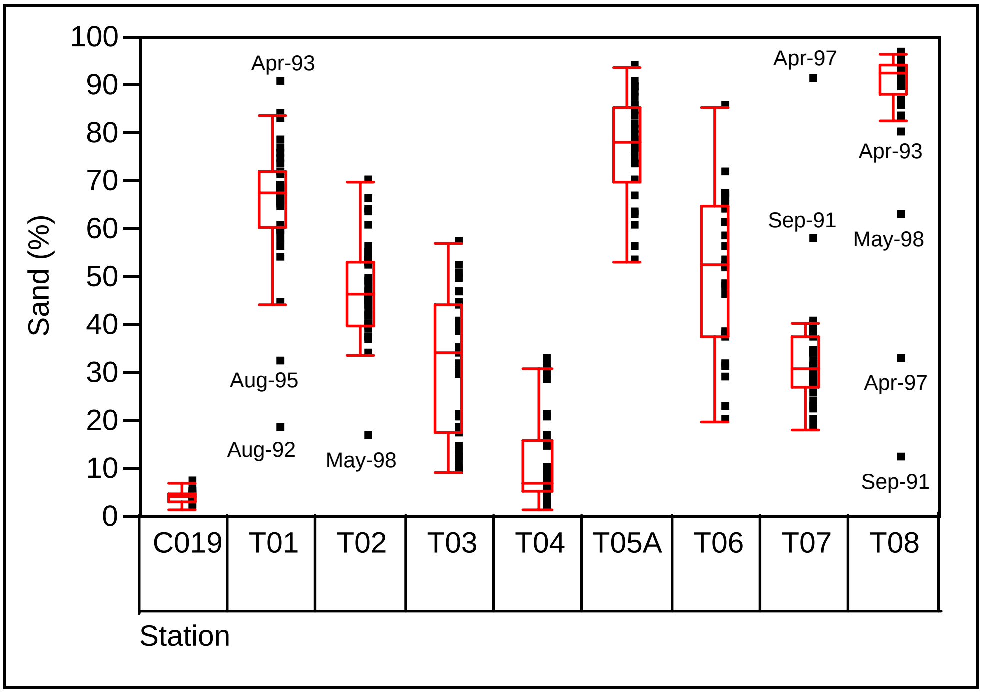


Figure B2-6. Distribution of percentages gravel (top) and sand (bottom) in Boston Harbor sediments, 1991–2004. For CO19, sediment data from 1994, 1998, 2002 and 2004.

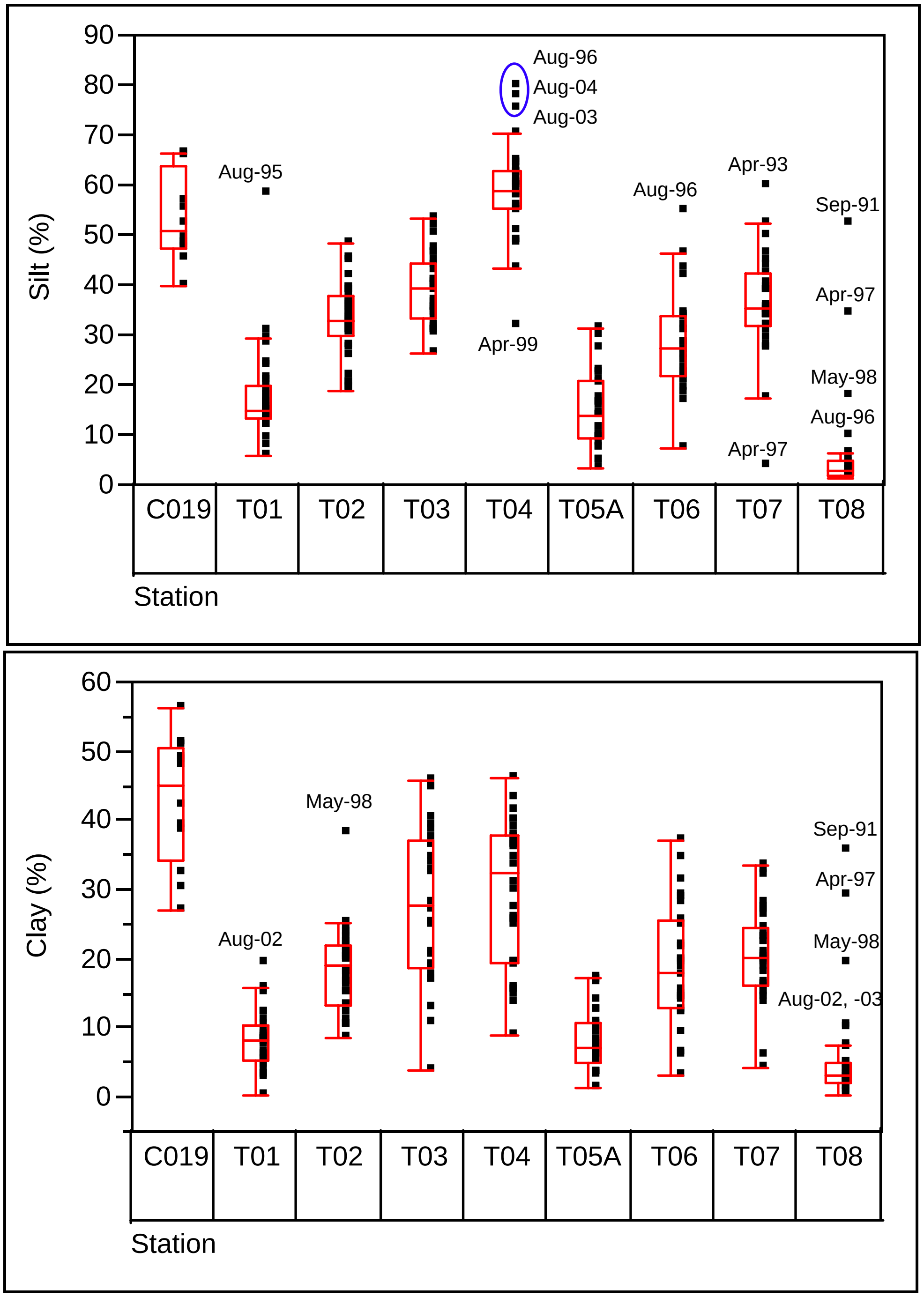


Figure B2-7. Distribution of percentages silt (top) and clay (bottom) in Boston Harbor sediments, 1991–2004. For CO19, sediment data from 1994, 1998, 2002 and 2004.

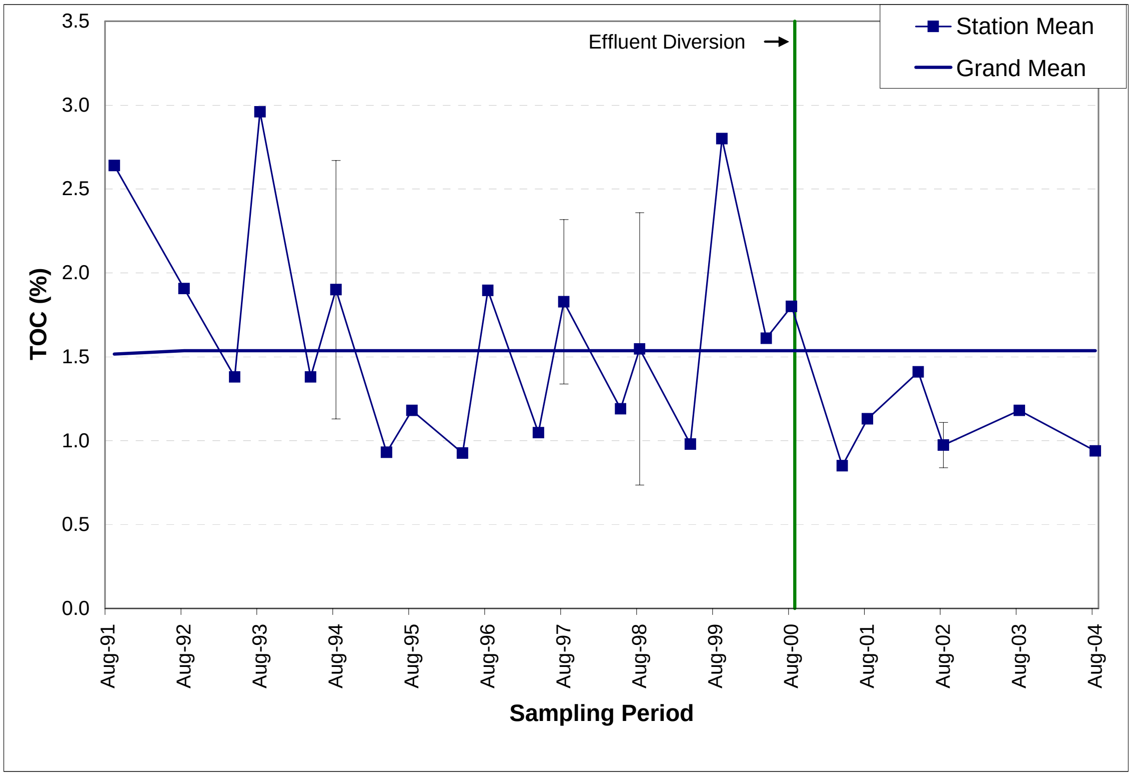
Table B2-1. Coefficient of variation (CV) in percentages gravel, sand, silt and clay data collected during three sampling periods of harbor monitoring. Sampling periods encompass more than a decade of major facility improvements to sewage treatment to Boston Harbor.

Station	Sampling Period	No. Obs.	CVs (a)				
			Gravel	Sand	Silt	Clay	Fines
T01	1991-1997	17	125	29	72	47	55
T01	1998-2000	9	97	10	22	18	15
T01	2001-2004	8	106	7	28	29	21
T02	1991-1997	17	237	20	26	34	25
T02	1998-2000	9	141	28	20	31	22
T02	2001-2004	8	244	16	17	16	15
T03	1991-1997	14	239	54	19	46	27
T03	1998-2000	6	94	65	15	36	23
T03	2001-2004	8	73	17	9	24	11
T04	1991-1997	14	256	88	12	38	11
T04	1998-2000	6	124	86	20	32	15
T04	2001-2004	8	186	19	14	32	2
T05A	1991-1997	13	75	16	52	72	52
T05A	1998-2000	6	117	12	39	49	42
T05A	2001-2004	8	64	15	58	40	49
T06	1991-1997	14	146	34	37	48	39
T06	1998-2000	6	106	28	11	30	20
T06	2001-2004	8	59	20	33	38	32
T07	1991-1997	14	80	49	37	33	31
T07	1998-2000	9	73	19	26	17	16
T07	2001-2004	8	52	9	11	19	10
T08	1991-1997	17	115	28	169	155	162
T08	1998-2000	9	105	12	112	119	115
T08	2001-2004	8	76	5	47	70	55
T01	1991-2004	34	135	21	53	49	40
T02		34	242	22	22	33	23
T03		28	200	46	18	40	23
T04		28	203	87	17	35	10
T05A		27	77	14	52	56	48
T06		28	152	31	34	46	35
T07		31	71	39	28	33	23
T08		34	121	20	168	137	151

(a) Coefficient of variation (CV) is a measure of the variability among the data:
(standard deviation ÷ average value) × 100

Appendix B3

Total Organic Carbon, 1991–2004



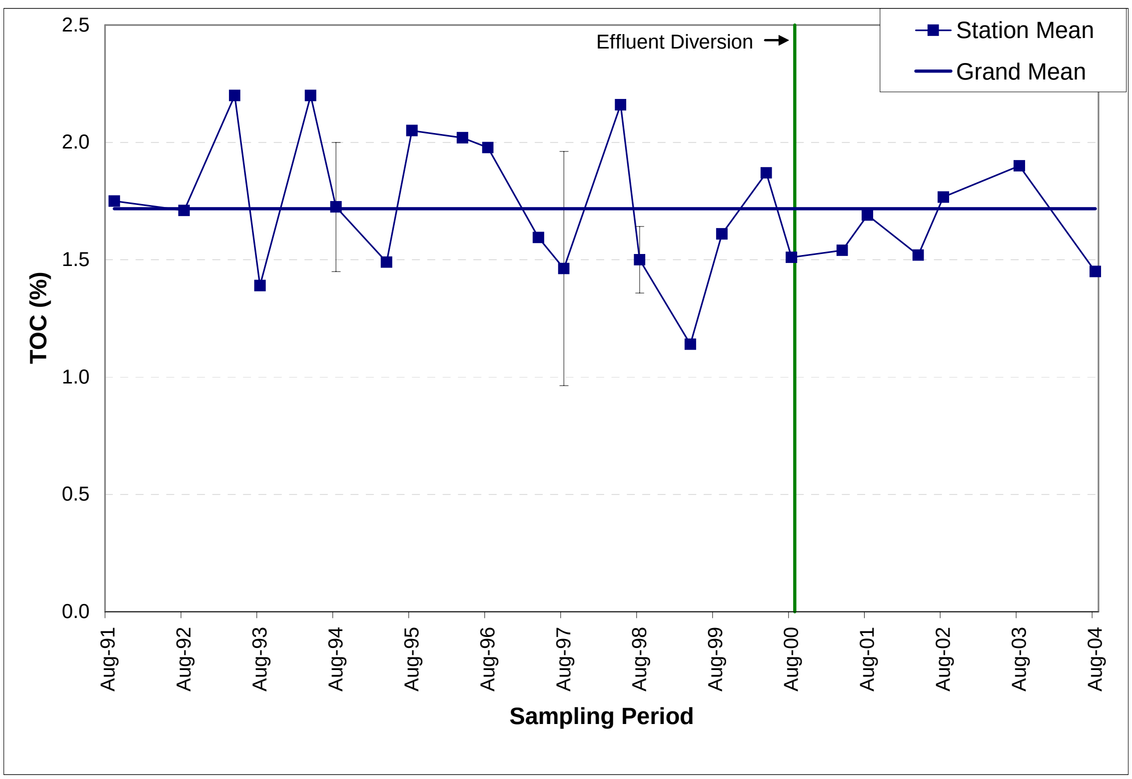
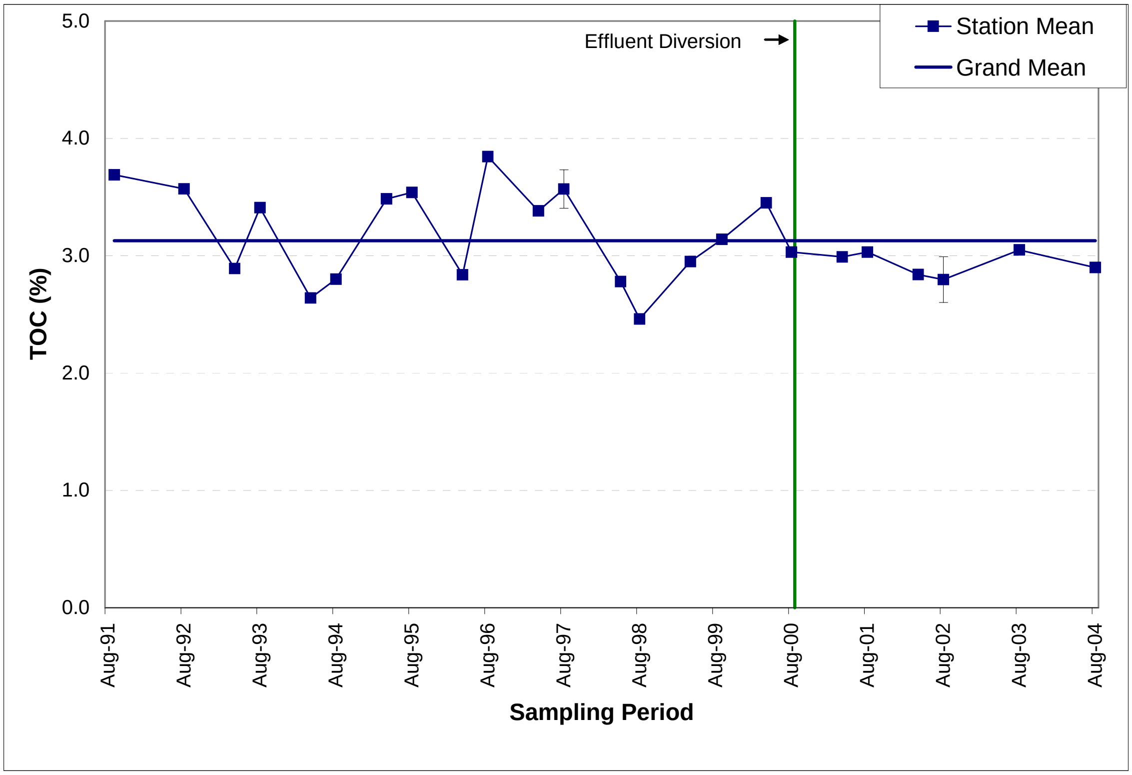


Figure B3-1. Station mean TOC at stations T01 (top) and T02 (bottom), 1991–2004. Vertical bars represent one standard deviation.



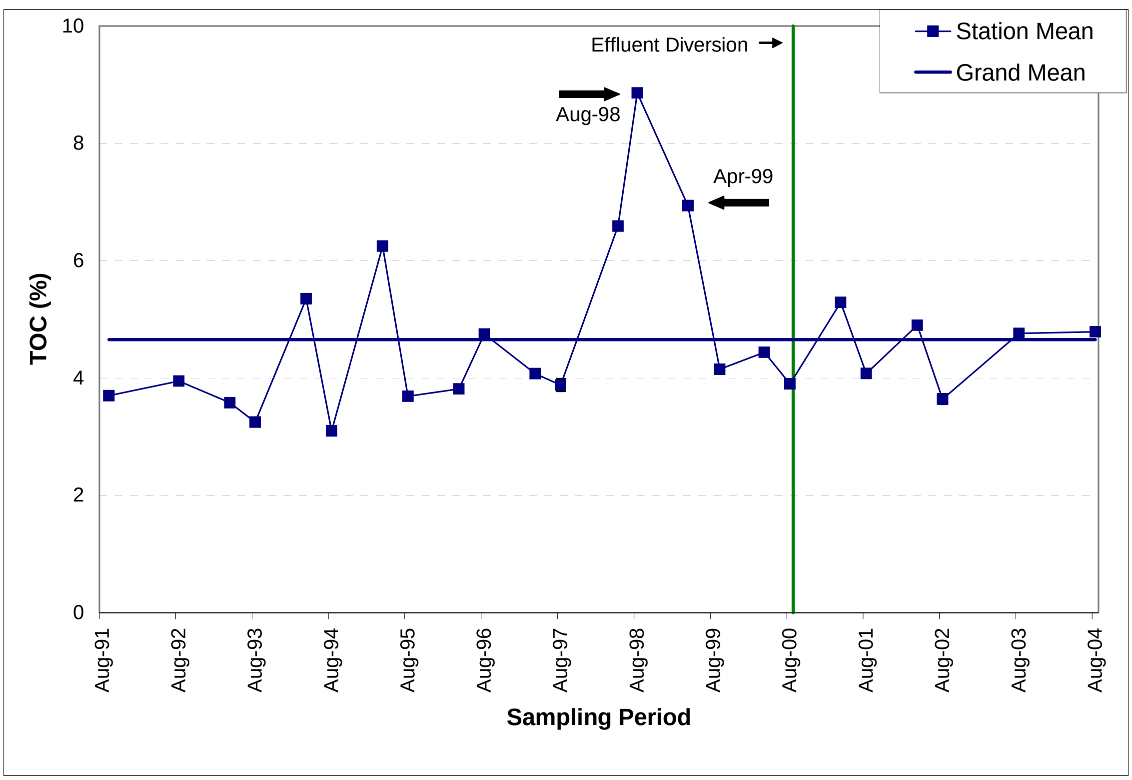
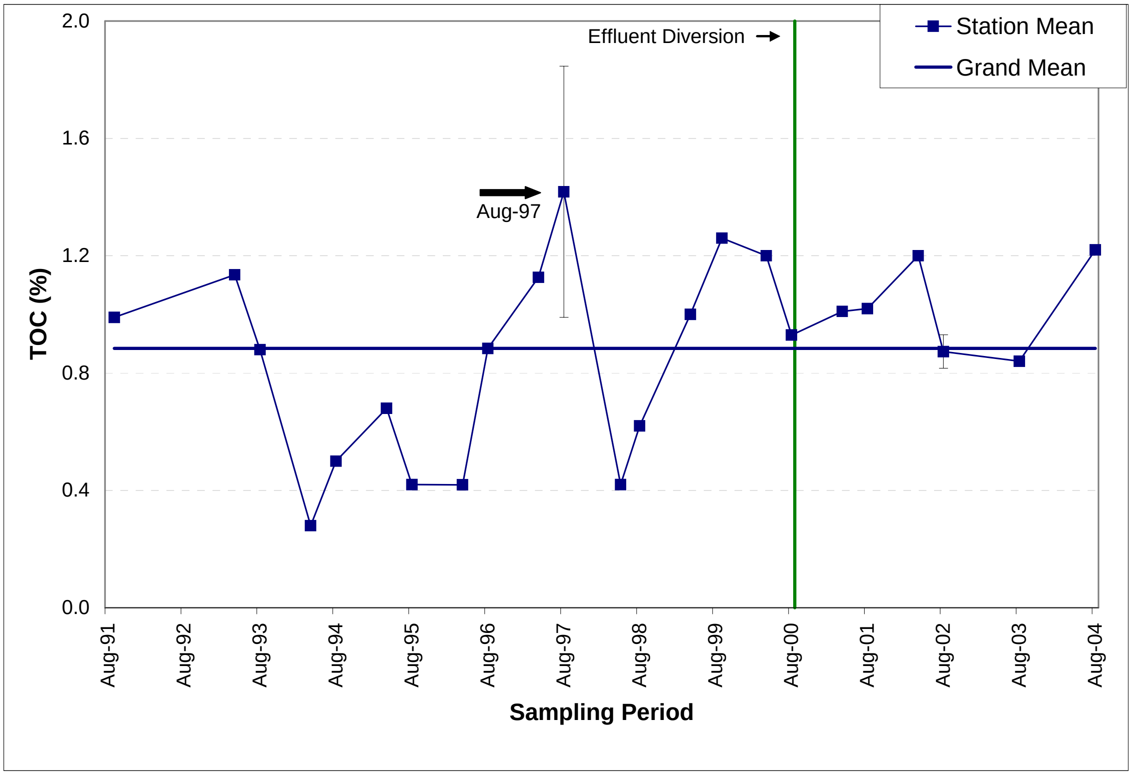


Figure B3-2. Station mean TOC at stations T03 (top) and T04 (bottom), 1991–2004. Vertical bars represent one standard deviation.



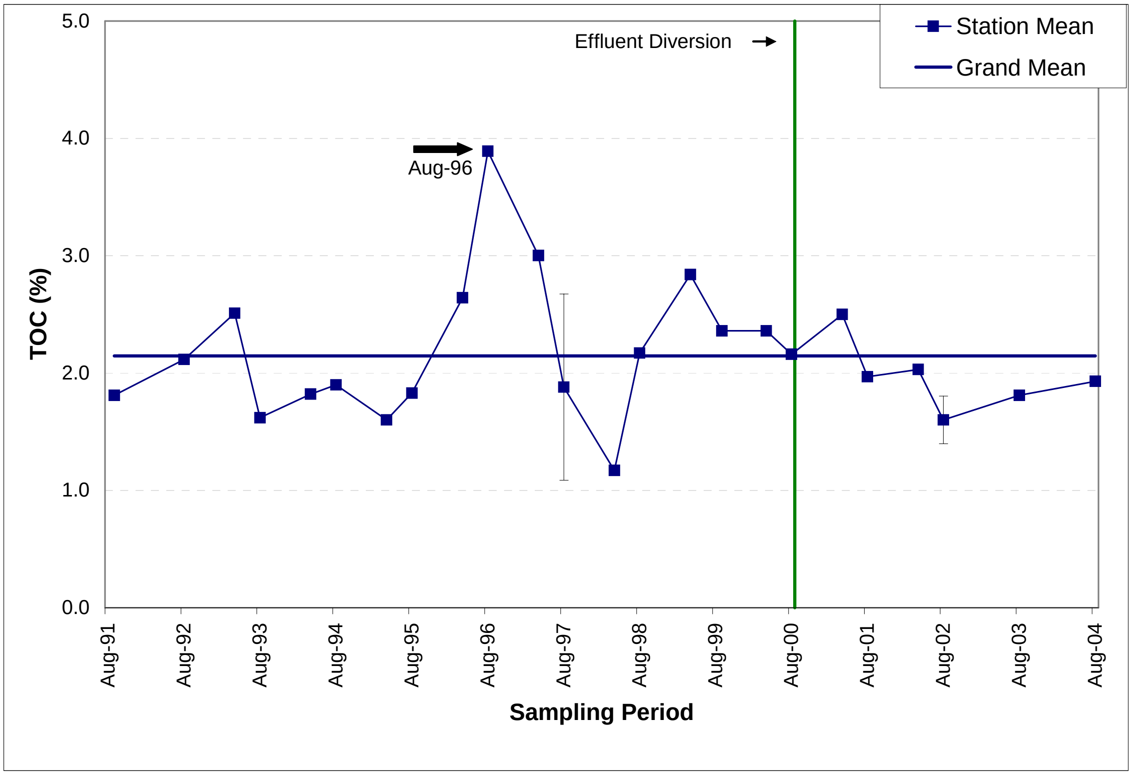


Figure B3-3. Station mean TOC at stations T05A (top) and T06 (bottom), 1991–2004. Vertical bars represent one standard deviation.

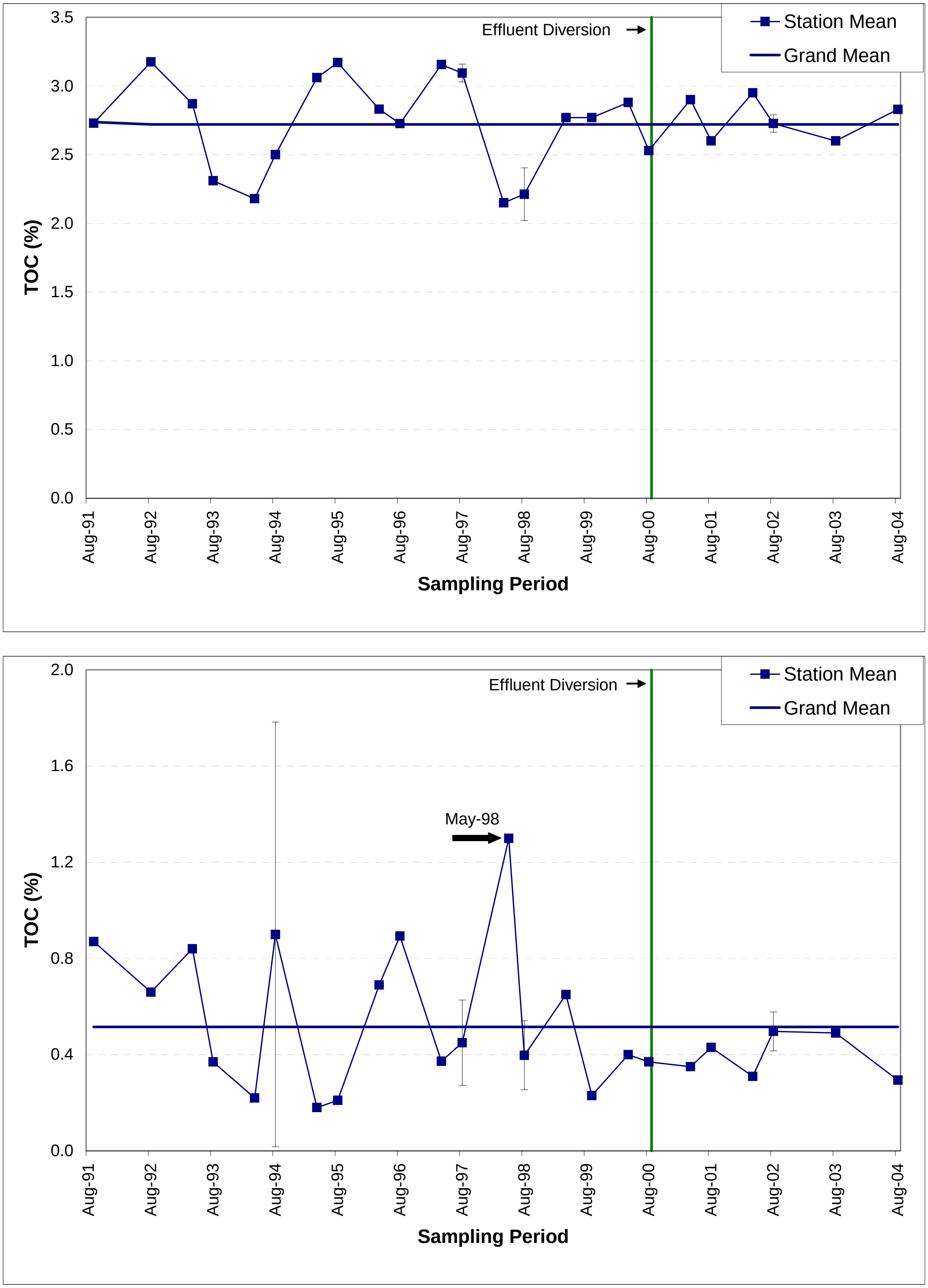


Figure B3-4. Station mean TOC at stations T07 (top) and T08 (bottom), 1991–2004. Vertical bars represent one standard deviation.

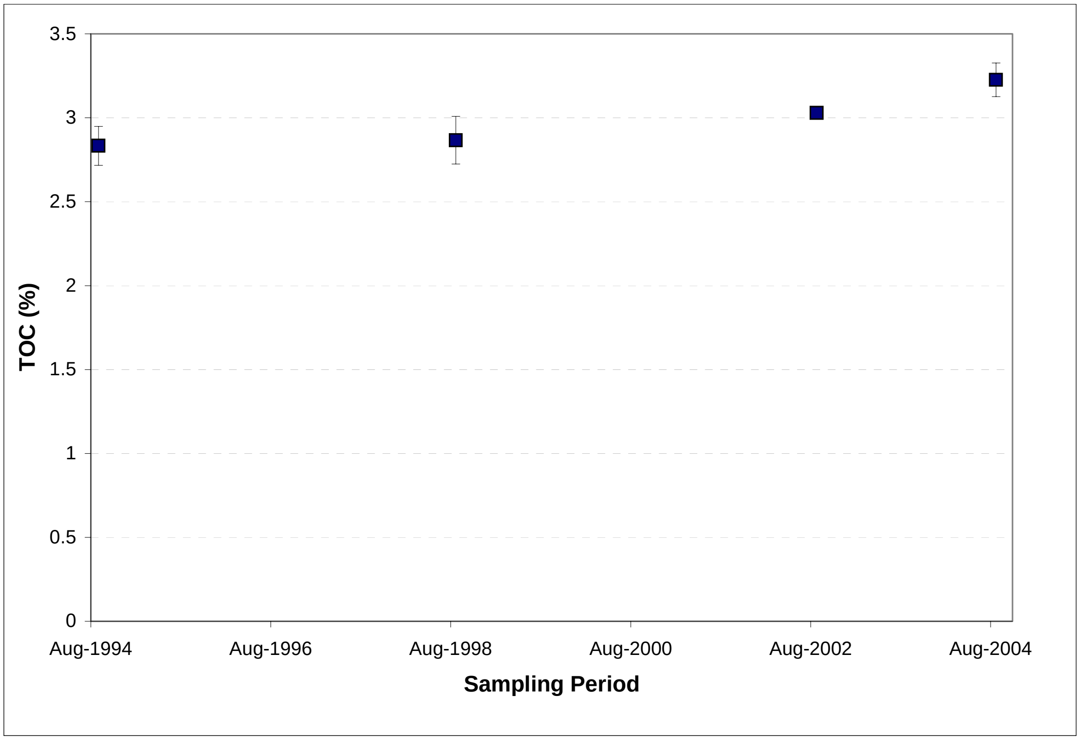


Figure B3-5. Station mean TOC at station CO19, 1994–2004. Vertical bars represent one standard deviation.

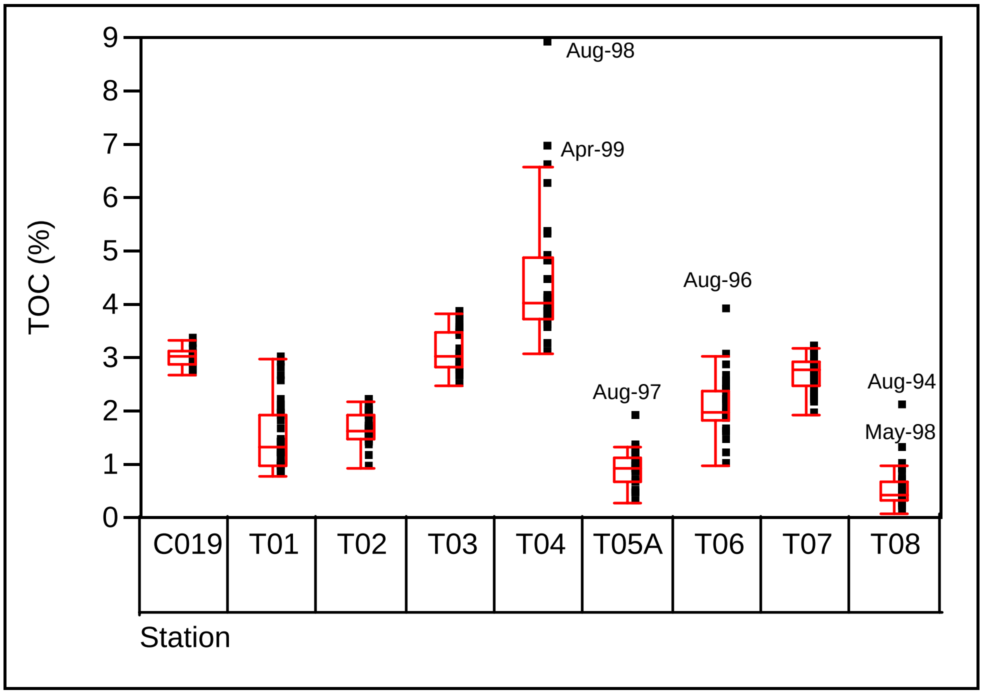
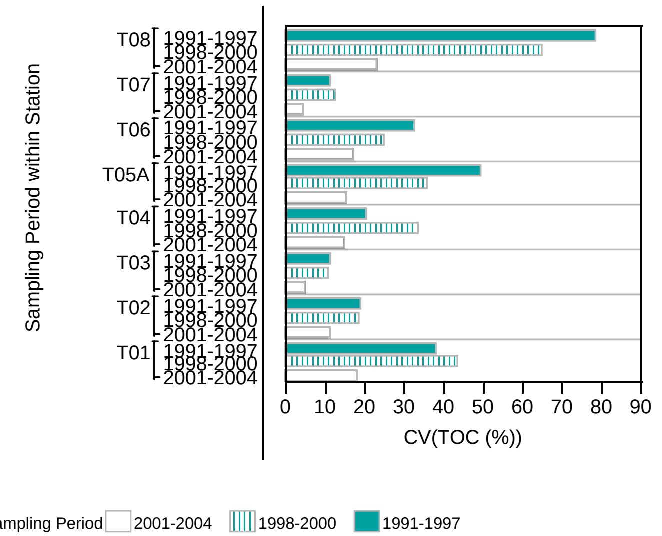


Figure B3-6. Distribution of total organic carbon in Boston Harbor sediments, 1991–2004. For CO19, sediment data from 1994, 1998, 2002 and 2004.

Table B3-1. Coefficient of variation (CV) in total organic carbon (TOC) content data collected during three sampling periods of harbor monitoring. Sampling periods encompass more than a decade of major facility improvements to sewage treatment to Boston Harbor.

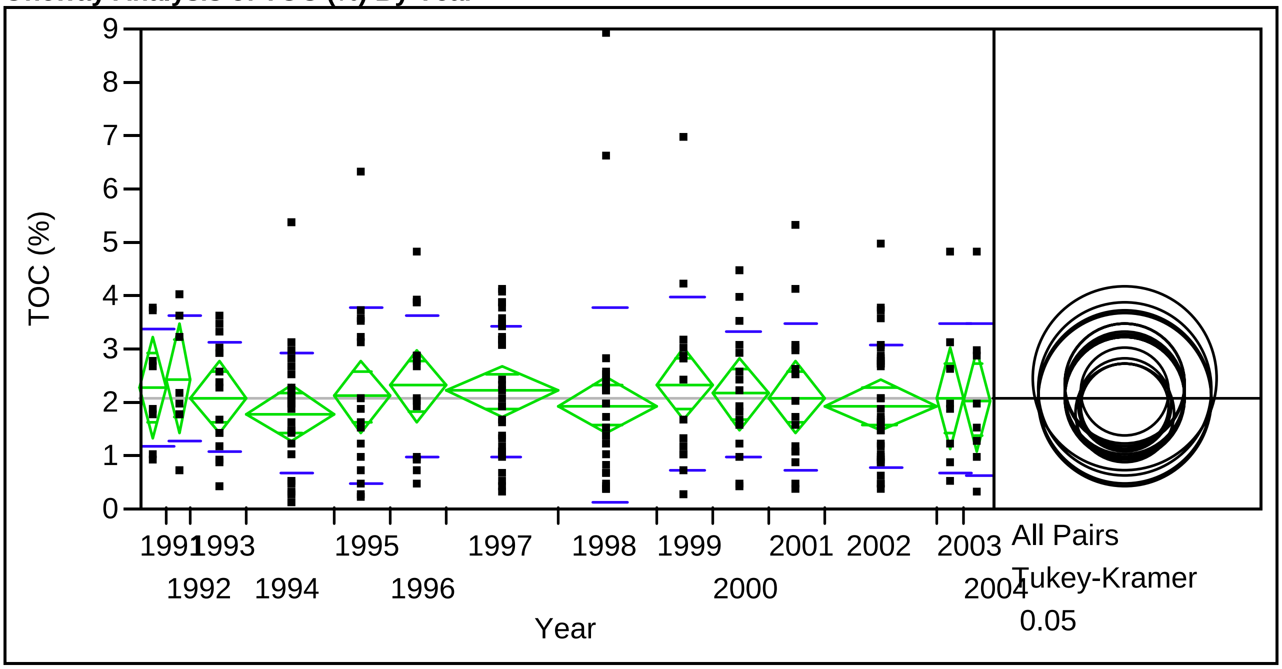
Station	Sampling Period	No. Obs.	CV (a) TOC
T01	1991-1997	17	39
T01	1998-2000	9	44
T01	2001-2004	8	18
T02	1991-1997	17	19
T02	1998-2000	9	19
T02	2001-2004	8	12
T03	1991-1997	14	12
T03	1998-2000	6	11
T03	2001-2004	8	5
T04	1991-1997	14	21
T04	1998-2000	6	34
T04	2001-2004	8	15
T05A	1991-1997	13	50
T05A	1998-2000	6	36
T05A	2001-2004	8	16
T06	1991-1997	14	33
T06	1998-2000	6	25
T06	2001-2004	8	17
T07	1991-1997	14	12
T07	1998-2000	9	13
T07	2001-2004	8	5
T08	1991-1997	17	79
T08	1998-2000	9	65
T08	2001-2004	8	24
T01	1991-2004	34	42
T02		34	18
T03		28	12
T04		28	28
T05A		27	37
T06		28	28
T07		31	12
T08		34	71

(a) Coefficient of variation (CV) is a measure of the variability among the data:
(standard deviation ÷ average value) × 100



ANOVA and Correlation Output (correlation output provided where ANOVA test significant)
Harbor-wide evaluation of TOC with Time (Year)
Data Source: 1991–2004 Individual Replicate Sediment TOC Data, using data from all Traditional Harbor stations (T01–T08)

Oneway Analysis of TOC (%) By Year



Oneway Anova
Summary of Fit

Rsquare	0.016334
Adj Rsquare	-0.03926
Root Mean Square Error	1.355987
Mean of Response	2.089449
Observations (or Sum Wgts)	244

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Year	13	7.02234	0.54018	0.2938	0.9924
Error	230	422.90095	1.83870		
C. Total	243	429.92329			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1991	8	2.27250	0.47941	1.3279	3.2171
1992	7	2.44119	0.51251	1.4314	3.4510
1993	16	2.09969	0.33900	1.4318	2.7676
1994	25	1.79880	0.27120	1.2645	2.3331
1995	16	2.11031	0.33900	1.4424	2.7782
1996	16	2.31509	0.33900	1.6472	2.9830
1997	32	2.20321	0.23971	1.7309	2.6755
1998	28	1.94643	0.25626	1.4415	2.4513
1999	16	2.34938	0.33900	1.6814	3.0173
2000	16	2.15250	0.33900	1.4846	2.8204
2001	16	2.08625	0.33900	1.4183	2.7542
2002	32	1.93094	0.23971	1.4586	2.4032
2003	8	2.07875	0.47941	1.1341	3.0234
2004	8	2.04413	0.47941	1.0995	2.9887

Std Error uses a pooled estimate of error variance

ANOVA Output (cont)

Harbor-wide evaluation of TOC with Time (Year)

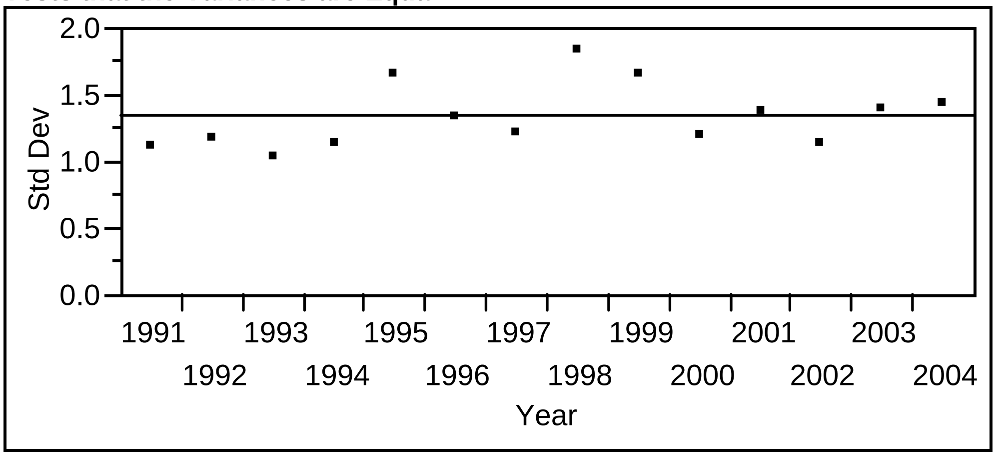
Means Comparisons
Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
3.39007	0.05

Level		Mean
1992	A	2.4411905
1999	A	2.3493750
1996	A	2.3150919
1991	A	2.2725000
1997	A	2.2032140
2000	A	2.1525000
1995	A	2.1103125
1993	A	2.0996875
2001	A	2.0862500
2003	A	2.0787500
2004	A	2.0441250
1998	A	1.9464286
2002	A	1.9309375
1994	A	1.7988000

Levels not connected by same letter are significantly different

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
1991	8	1.101308	0.917500	0.917500
1992	7	1.168154	0.963265	0.946905
1993	16	1.021790	0.885352	0.872812
1994	25	1.138824	0.824544	0.818800
1995	16	1.649592	1.316641	1.274062
1996	16	1.327391	1.101894	1.101894
1997	32	1.208639	1.054626	1.053289
1998	28	1.822294	1.084235	1.063571
1999	16	1.640555	1.196953	1.195625
2000	16	1.183675	0.941250	0.941250
2001	16	1.366464	1.098281	1.083750
2002	32	1.139526	0.949805	0.927188
2003	8	1.382270	1.043438	0.998750
2004	8	1.425251	1.096906	1.068375

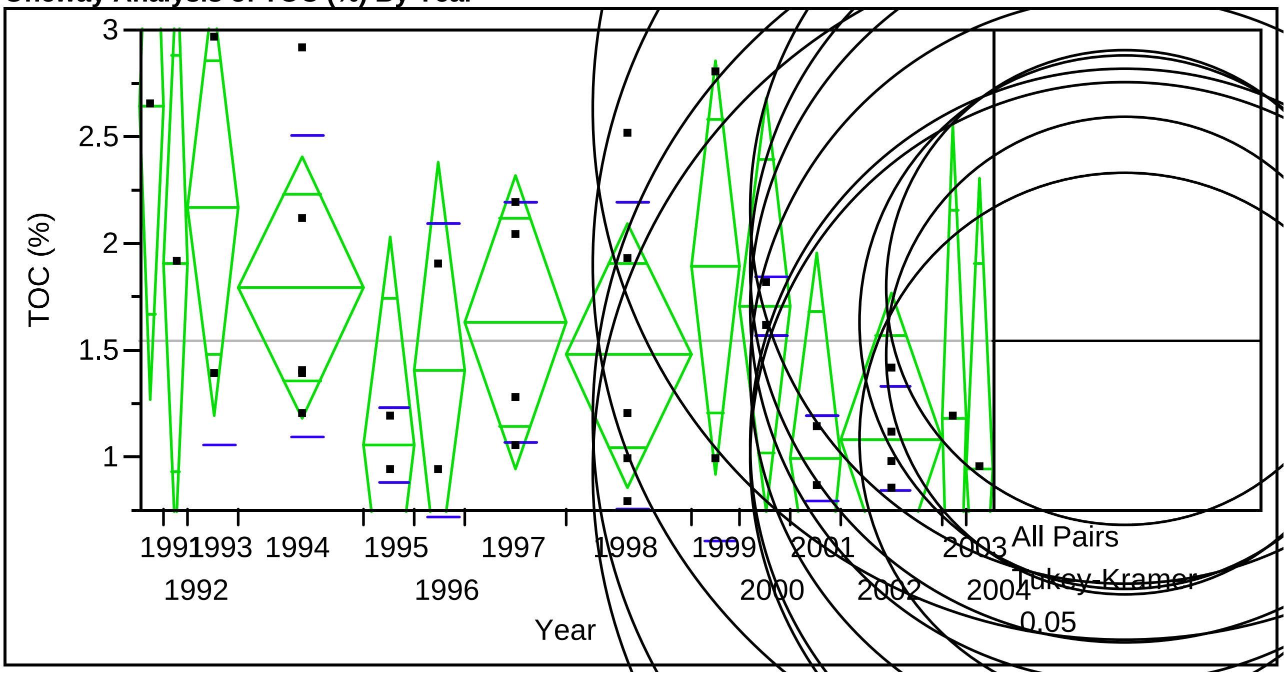
Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.5197	13	230	0.9114
Brown-Forsythe	0.3562	13	230	0.9813
Levene	0.4301	13	230	0.9578
Bartlett	1.1547	13	.	0.3067

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
0.3060	13	63.776	0.9891

ANOVA and Correlation Output (correlation output provided where ANOVA test significant)
A Station Evaluation of TOC with Time (Year)
Data Source: 1991–2004 Individual Replicate Sediment TOC Data for Traditional Harbor stations and 1994–2004 for station CO19

Station=T01
Oneway Analysis of TOC (%) By Year



Oneway Anova
Summary of Fit

Rsquare	0.377892
Adj Rsquare	-0.02648
Root Mean Square Error	0.657816
Mean of Response	1.539067
Observations (or Sum Wgts)	34

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Year	13	5.257030	0.404387	0.9345	0.5383
Error	20	8.654429	0.432721		
C. Total	33	13.911459			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1991	1	2.64000	0.65782	1.268	4.0122
1992	1	1.90667	0.65782	0.534	3.2788
1993	2	2.17000	0.46515	1.200	3.1403
1994	5	1.79600	0.29418	1.182	2.4097
1995	2	1.05500	0.46515	0.085	2.0253
1996	2	1.41087	0.46515	0.441	2.3812
1997	4	1.63271	0.32891	0.947	2.3188
1998	5	1.47600	0.29418	0.862	2.0897
1999	2	1.89000	0.46515	0.920	2.8603
2000	2	1.70500	0.46515	0.735	2.6753
2001	2	0.99000	0.46515	0.020	1.9603
2002	4	1.08250	0.32891	0.396	1.7686
2003	1	1.18000	0.65782	-0.192	2.5522
2004	1	0.93900	0.65782	-0.433	2.3112

Std Error uses a pooled estimate of error variance

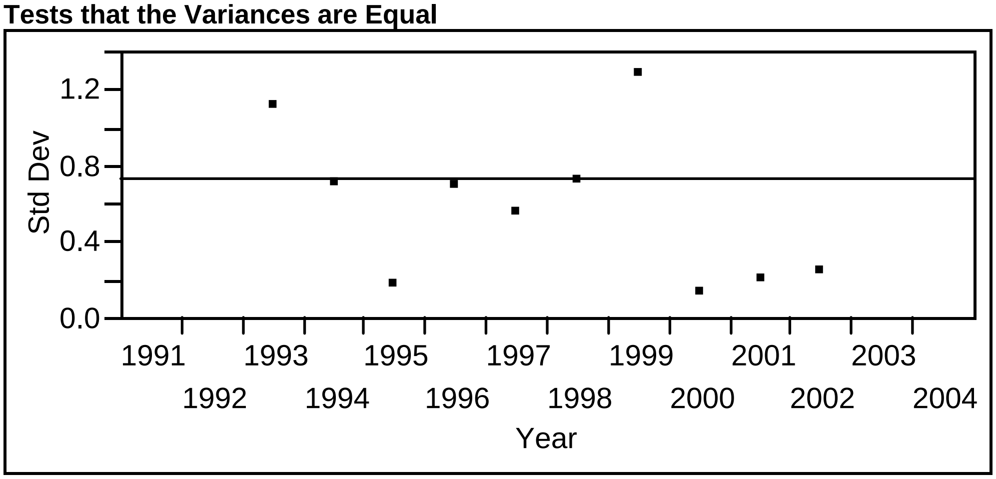
Means Comparisons
Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
3.78816	0.05

Level		Mean
1991	A	2.6400000
1993	A	2.1700000
1992	A	1.9066667
1999	A	1.8900000
1994	A	1.7960000
2000	A	1.7050000
1997	A	1.6327134
1998	A	1.4760000
1996	A	1.4108750
2003	A	1.1800000
2002	A	1.0825000
1995	A	1.0550000
2001	A	0.9900000
2004	A	0.9390000

Levels not connected by same letter are significantly different

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
1991	1	.	0.0000000	0.0000000
1992	1	.	0.0000000	0.0000000
1993	2	1.117229	0.7900000	0.7900000
1994	5	0.706456	0.5632000	0.4880000
1995	2	0.176777	0.1250000	0.1250000
1996	2	0.686240	0.4852450	0.4852450
1997	4	0.558656	0.4744881	0.4744881
1998	5	0.720854	0.5912000	0.5760000
1999	2	1.286934	0.9100000	0.9100000
2000	2	0.134350	0.0950000	0.0950000
2001	2	0.197990	0.1400000	0.1400000
2002	4	0.244591	0.1775000	0.1775000
2003	1	.	0.0000000	0.0000000
2004	1	.	0.0000000	0.0000000

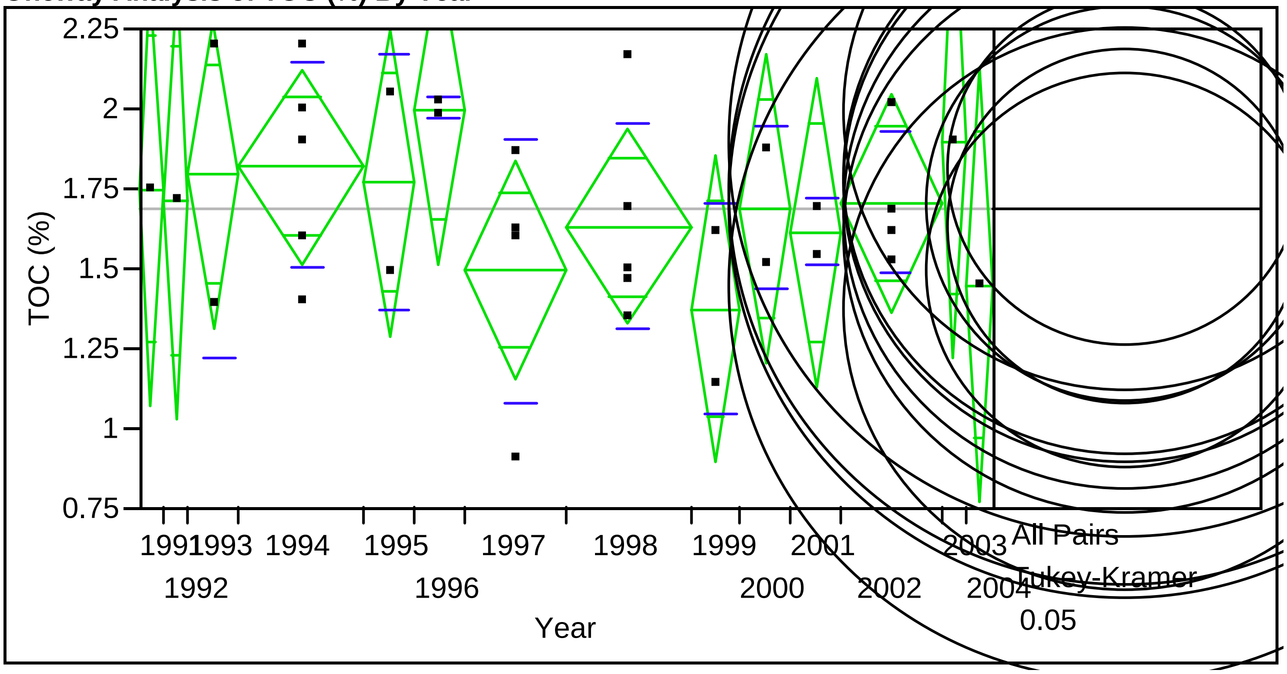
Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.8404	3	14	0.4941
Brown-Forsythe	1.4673	9	20	0.2266
Levene	4.7511	9	20	0.0018
Bartlett	0.9966	9	.	0.4401

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
2.0420	9	5.7274	0.2048

Station=T02
Oneway Analysis of TOC (%) By Year



Oneway Anova
Summary of Fit

Rsquare	0.270891
Adj Rsquare	-0.20303
Root Mean Square Error	0.326854
Mean of Response	1.687047
Observations (or Sum Wgts)	34

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Year	13	0.7938517	0.061066	0.5716	0.8485
Error	20	2.1366701	0.106834		
C. Total	33	2.9305217			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1991	1	1.75000	0.32685	1.0682	2.4318
1992	1	1.71000	0.32685	1.0282	2.3918
1993	2	1.79500	0.23112	1.3129	2.2771
1994	5	1.82000	0.14617	1.5151	2.1249
1995	2	1.77000	0.23112	1.2879	2.2521
1996	2	1.99862	0.23112	1.5165	2.4807
1997	4	1.49559	0.16343	1.1547	1.8365
1998	5	1.63200	0.14617	1.3271	1.9369
1999	2	1.37500	0.23112	0.8929	1.8571
2000	2	1.69000	0.23112	1.2079	2.1721
2001	2	1.61500	0.23112	1.1329	2.0971
2002	4	1.70500	0.16343	1.3641	2.0459
2003	1	1.90000	0.32685	1.2182	2.5818
2004	1	1.45000	0.32685	0.7682	2.1318

Std Error uses a pooled estimate of error variance

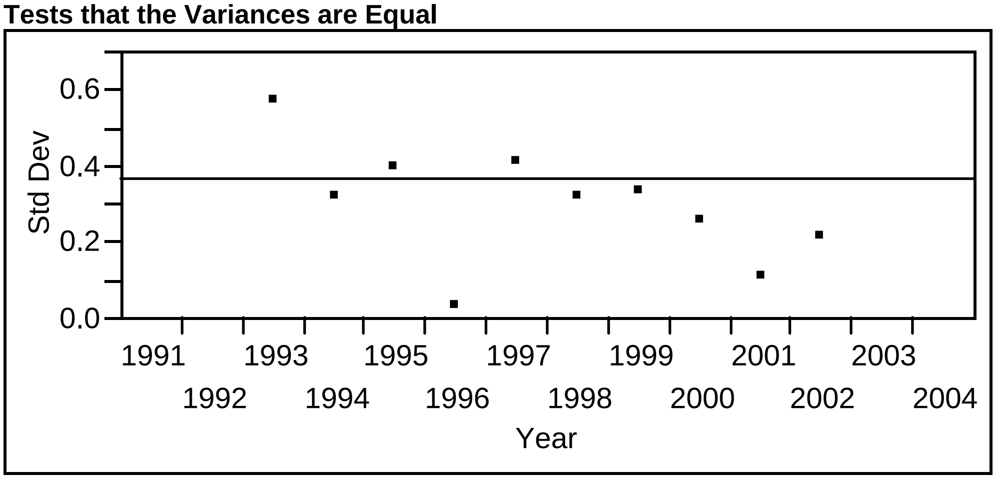
Means Comparisons
Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
3.78816	0.05

Level		Mean
1996	A	1.9986250
2003	A	1.9000000
1994	A	1.8200000
1993	A	1.7950000
1995	A	1.7700000
1991	A	1.7500000
1992	A	1.7100000
2002	A	1.7050000
2000	A	1.6900000
1998	A	1.6320000
2001	A	1.6150000
1997	A	1.4955911
2004	A	1.4500000
1999	A	1.3750000

Levels not connected by same letter are significantly different

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
1991	1	.	0.0000000	0.0000000
1992	1	.	0.0000000	0.0000000
1993	2	0.5727565	0.4050000	0.4050000
1994	5	0.3193744	0.2560000	0.2600000
1995	2	0.3959798	0.2800000	0.2800000
1996	2	0.0296348	0.0209550	0.0209550
1997	4	0.4126588	0.2955549	0.2461254
1998	5	0.3196404	0.2344000	0.2160000
1999	2	0.3323402	0.2350000	0.2350000
2000	2	0.2545584	0.1800000	0.1800000
2001	2	0.1060660	0.0750000	0.0750000
2002	4	0.2136196	0.1525000	0.1400000
2003	1	.	0.0000000	0.0000000
2004	1	.	0.0000000	0.0000000

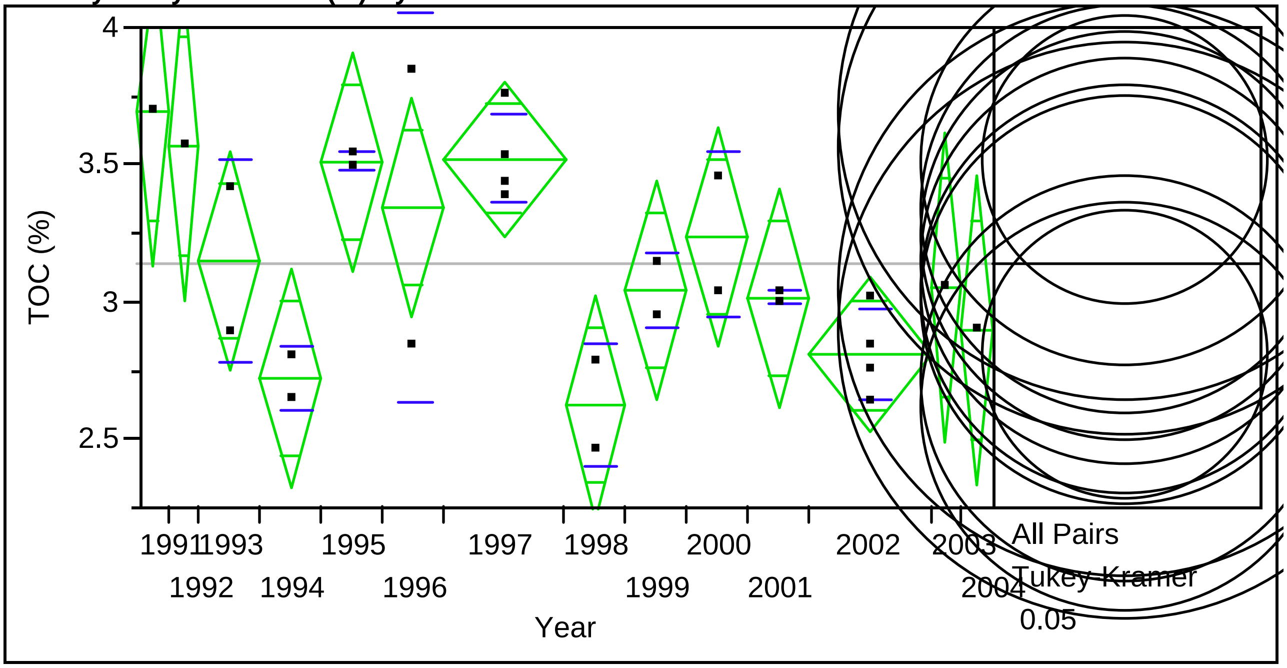
Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.3811	3	14	0.7682
Brown-Forsythe	0.6792	9	20	0.7187
Levene	1.3193	9	20	0.2879
Bartlett	0.6621	9	.	0.7440

Warning: Small sample sizes. Use Caution.
Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
2.8059	9	5.5235	0.1212

Station=T03

Oneway Analysis of TOC (%) By Year



Oneway Anova

Summary of Fit

Rsquare	0.74917
Adj Rsquare	0.516256
Root Mean Square Error	0.263357
Mean of Response	3.13577
Observations (or Sum Wgts)	28

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Year	13	2.9001247	0.223087	3.2165	0.0192
Error	14	0.9709947	0.069357		
C. Total	27	3.8711193			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1991	1	3.69000	0.26336	3.1252	4.2548
1992	1	3.57000	0.26336	3.0052	4.1348
1993	2	3.15000	0.18622	2.7506	3.5494
1994	2	2.72000	0.18622	2.3206	3.1194
1995	2	3.51250	0.18622	3.1131	3.9119
1996	2	3.34063	0.18622	2.9412	3.7400
1997	4	3.52132	0.13168	3.2389	3.8037
1998	2	2.62000	0.18622	2.2206	3.0194
1999	2	3.04500	0.18622	2.6456	3.4444
2000	2	3.24000	0.18622	2.8406	3.6394
2001	2	3.01000	0.18622	2.6106	3.4094
2002	4	2.80750	0.13168	2.5251	3.0899
2003	1	3.05000	0.26336	2.4852	3.6148
2004	1	2.90000	0.26336	2.3352	3.4648

Std Error uses a pooled estimate of error variance

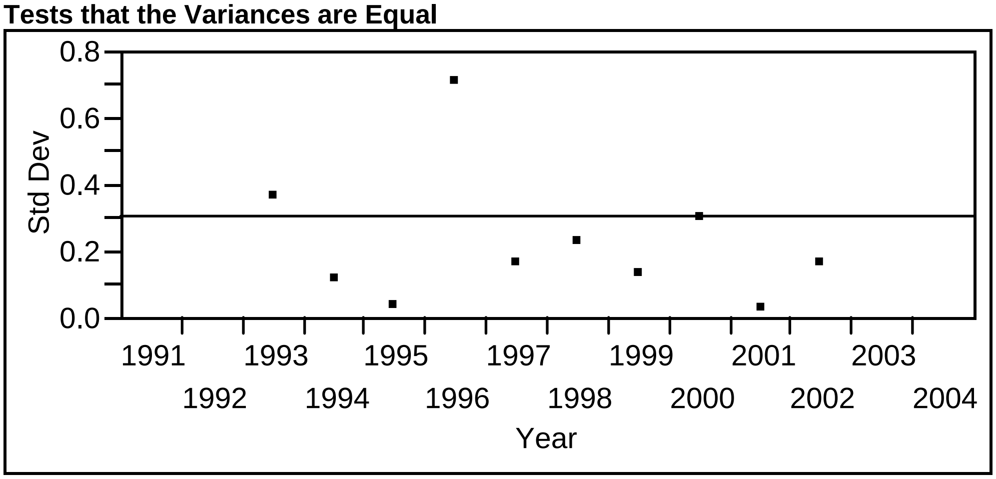
Means Comparisons
Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
3.98541	0.05

Level		Mean
1991	A	3.6900000
1992	A	3.5700000
1997	A	3.5213231
1995	A	3.5125000
1996	A	3.3406350
2000	A	3.2400000
1993	A	3.1500000
2003	A	3.0500000
1999	A	3.0450000
2001	A	3.0100000
2004	A	2.9000000
2002	A	2.8075000
1994	A	2.7200000
1998	A	2.6200000

Levels not connected by same letter are significantly different

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
1991	1	.	0.0000000	0.0000000
1992	1	.	0.0000000	0.0000000
1993	2	0.3676955	0.2600000	0.2600000
1994	2	0.1131371	0.0800000	0.0800000
1995	2	0.0388909	0.0275000	0.0275000
1996	2	0.7117383	0.5032750	0.5032750
1997	4	0.1630805	0.1162514	0.1162514
1998	2	0.2262742	0.1600000	0.1600000
1999	2	0.1343503	0.0950000	0.0950000
2000	2	0.2969848	0.2100000	0.2100000
2001	2	0.0282843	0.0200000	0.0200000
2002	4	0.1600781	0.1175000	0.1175000
2003	1	.	0.0000000	0.0000000
2004	1	.	0.0000000	0.0000000

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.0015	1	6	0.9705
Brown-Forsythe	10.3184	9	14	<.0001
Levene	12.1337	9	14	<.0001
Bartlett	1.2300	9	.	0.2710

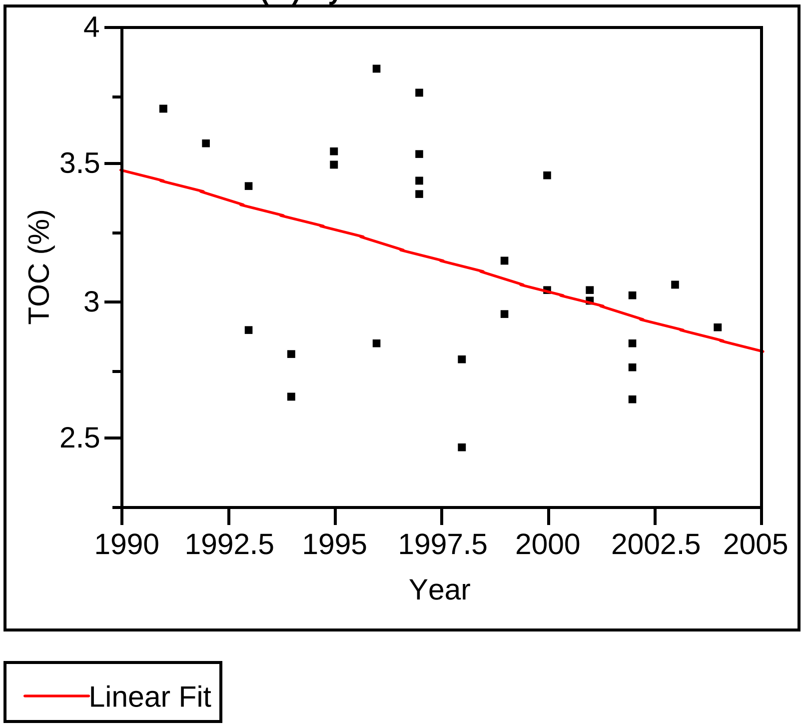
Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
15.6043	9	4.609	0.0052

Station=T03

Bivariate Fit of TOC (%) By Year



Linear Fit

TOC (%) = 92.154257 - 0.0445586 Year

Summary of Fit

RSquare	0.178853
RSquare Adj	0.14727
Root Mean Square Error	0.349657
Mean of Response	3.13577
Observations (or Sum Wgts)	28

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	12	2.2077641	0.183980	2.6527
Pure Error	14	0.9709947	0.069357	Prob > F
Total Error	26	3.1787587		0.0424
				Max RSq
				0.7492

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.6923606	0.692361	5.6630
Error	26	3.1787587	0.122260	Prob > F
C. Total	27	3.8711193		0.0249

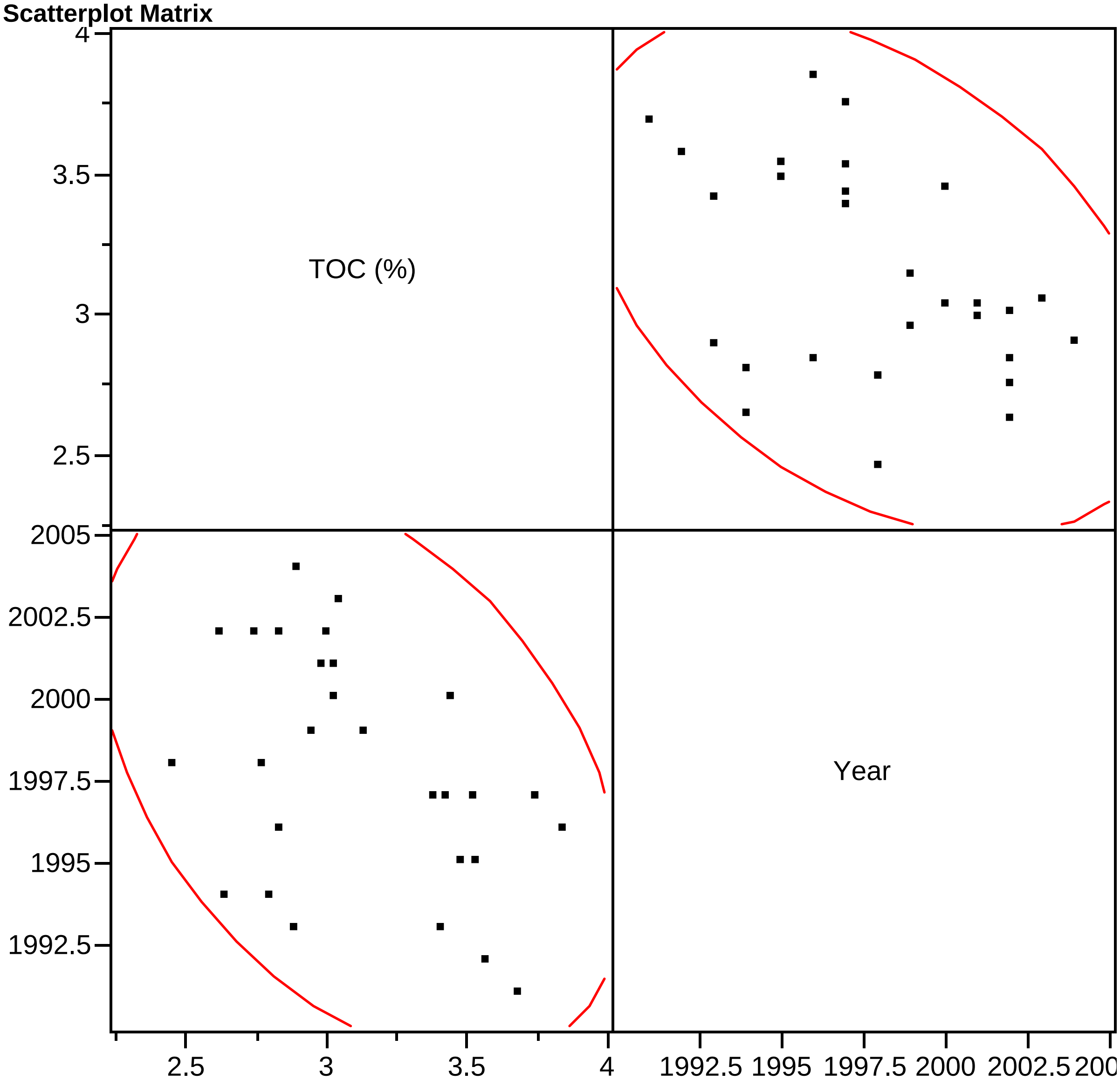
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	92.154257	37.40734	2.46	0.0207
Year	-0.044559	0.018724	-2.38	0.0249

Station=T03
Multivariate
Correlations

	TOC (%)	Year
TOC (%)	1.0000	-0.4229
Year	-0.4229	1.0000

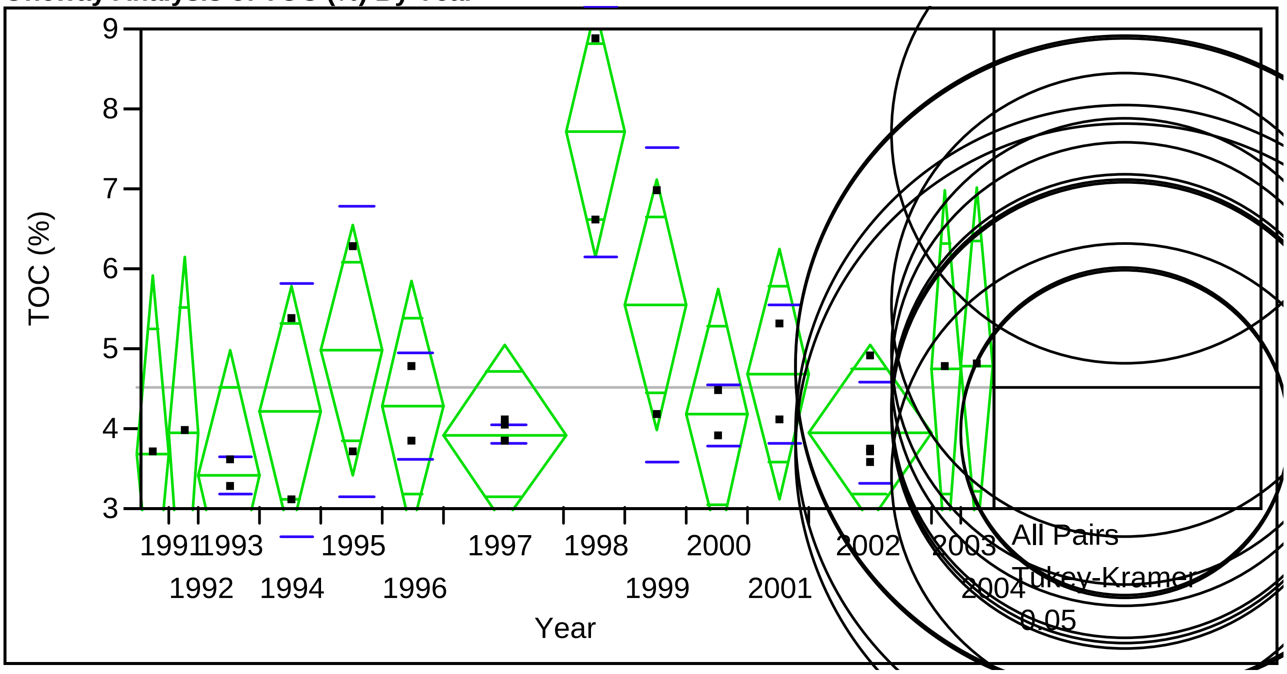
Scatterplot Matrix



Pairwise Correlations

Variable	by Variable	Correlation	Count	Signif Prob	Plot Corr
Year	TOC (%)	-0.4229	28	0.0249	

Station=T04
Oneway Analysis of TOC (%) By Year



Oneway Anova
Summary of Fit

Rsquare	0.667123
Adj Rsquare	0.358022
Root Mean Square Error	1.031648
Mean of Response	4.528092
Observations (or Sum Wgts)	28

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Year	13	29.861563	2.29704	2.1583	0.0833
Error	14	14.900159	1.06430		
C. Total	27	44.761721			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1991	1	3.70000	1.0316	1.4873	5.9127
1992	1	3.95000	1.0316	1.7373	6.1627
1993	2	3.41500	0.7295	1.8504	4.9796
1994	2	4.22500	0.7295	2.6604	5.7896
1995	2	4.97000	0.7295	3.4054	6.5346
1996	2	4.28305	0.7295	2.7185	5.8476
1997	4	3.93012	0.5158	2.8238	5.0365
1998	2	7.72500	0.7295	6.1604	9.2896
1999	2	5.54500	0.7295	3.9804	7.1096
2000	2	4.17000	0.7295	2.6054	5.7346
2001	2	4.68500	0.7295	3.1204	6.2496
2002	4	3.95750	0.5158	2.8512	5.0638
2003	1	4.76000	1.0316	2.5473	6.9727
2004	1	4.79000	1.0316	2.5773	7.0027

Std Error uses a pooled estimate of error variance

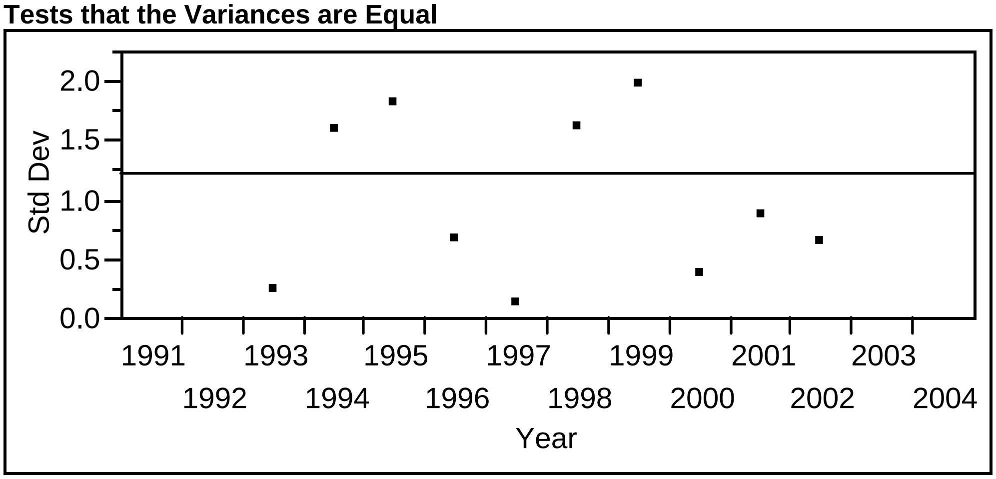
Means Comparisons
Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
3.98541	0.05

Level			Mean
1998	A		7.7250000
1999	A	B	5.5450000
1995	A	B	4.9700000
2004	A	B	4.7900000
2003	A	B	4.7600000
2001	A	B	4.6850000
1996	A	B	4.2830550
1994	A	B	4.2250000
2000	A	B	4.1700000
2002		B	3.9575000
1992	A	B	3.9500000
1997		B	3.9301196
1991	A	B	3.7000000
1993		B	3.4150000

Levels not connected by same letter are significantly different

Tests that the Variances are Equal



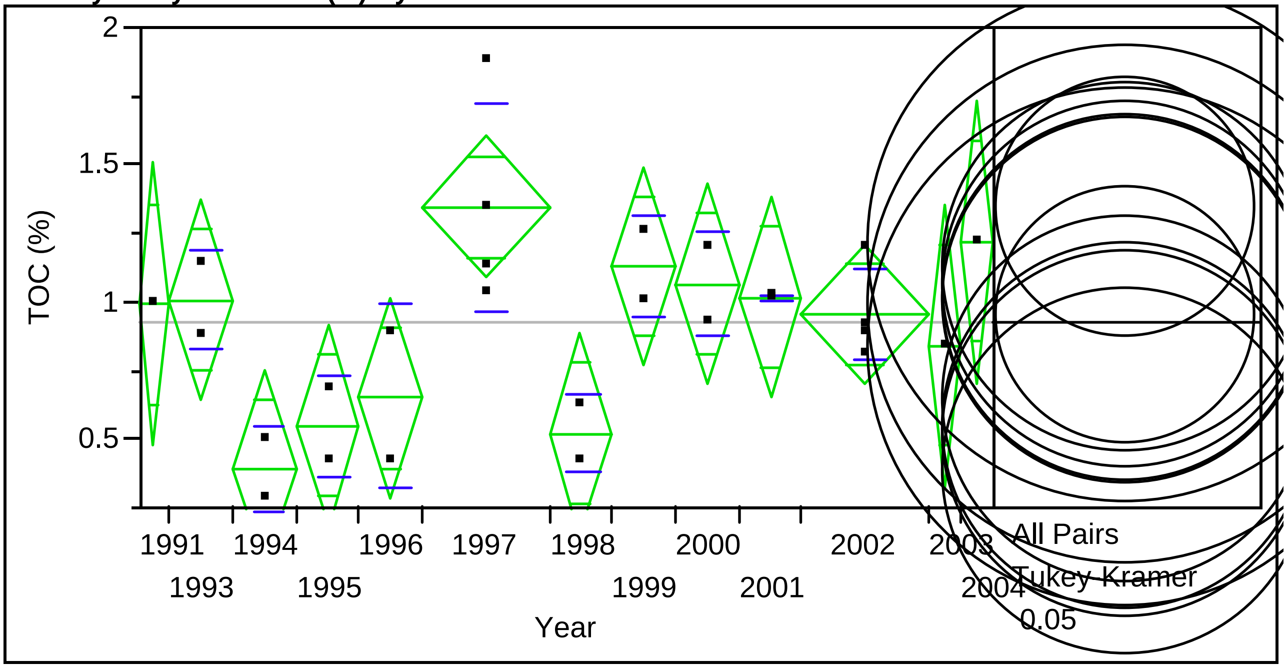
Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
1991	1	.	0.000000	0.000000
1992	1	.	0.000000	0.000000
1993	2	0.233345	0.165000	0.165000
1994	2	1.590990	1.125000	1.125000
1995	2	1.810193	1.280000	1.280000
1996	2	0.663132	0.468905	0.468905
1997	4	0.129987	0.109463	0.109463
1998	2	1.605132	1.135000	1.135000
1999	2	1.972828	1.395000	1.395000
2000	2	0.381838	0.270000	0.270000
2001	2	0.855599	0.605000	0.605000
2002	4	0.632686	0.471250	0.347500
2003	1	.	0.000000	0.000000
2004	1	.	0.000000	0.000000

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	1.3546	1	6	0.2887
Brown-Forsythe	8.0473	9	14	0.0003
Levene	24.3925	9	14	<.0001
Bartlett	1.4673	9	.	0.1535

Warning: Small sample sizes. Use Caution.
Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
1.2521	9	4.1495	0.4409

Station=T05A
Oneway Analysis of TOC (%) By Year



Oneway Anova
Summary of Fit

Rsquare	0.739741
Adj Rsquare	0.516662
Root Mean Square Error	0.239983
Mean of Response	0.922536
Observations (or Sum Wgts)	27

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Year	12	2.2917335	0.190978	3.3160	0.0179
Error	14	0.8062876	0.057592		
C. Total	26	3.0980211			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1991	1	0.99000	0.23998	0.4753	1.5047
1993	2	1.00750	0.16969	0.6435	1.3715
1994	2	0.39000	0.16969	0.0260	0.7540
1995	2	0.55000	0.16969	0.1860	0.9140
1996	2	0.65172	0.16969	0.2878	1.0157
1997	4	1.34501	0.11999	1.0877	1.6024
1998	2	0.52000	0.16969	0.1560	0.8840
1999	2	1.13000	0.16969	0.7660	1.4940
2000	2	1.06500	0.16969	0.7010	1.4290
2001	2	1.01500	0.16969	0.6510	1.3790
2002	4	0.95500	0.11999	0.6976	1.2124
2003	1	0.84000	0.23998	0.3253	1.3547
2004	1	1.22000	0.23998	0.7053	1.7347

Std Error uses a pooled estimate of error variance

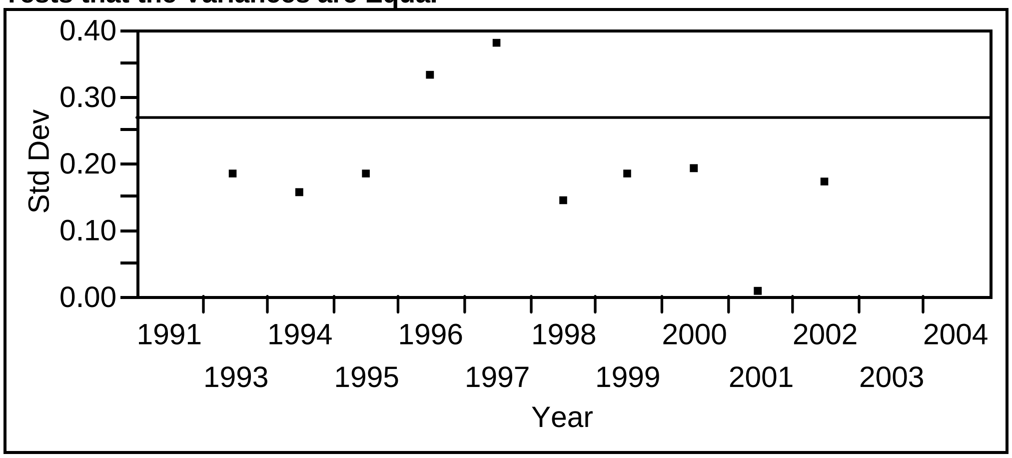
Means Comparisons
Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
3.92663	0.05

Level			Mean
1997	A		1.3450121
2004	A	B	1.2200000
1999	A	B	1.1300000
2000	A	B	1.0650000
2001	A	B	1.0150000
1993	A	B	1.0075000
1991	A	B	0.9900000
2002	A	B	0.9550000
2003	A	B	0.8400000
1996	A	B	0.6517150
1995	A	B	0.5500000
1998		B	0.5200000
1994		B	0.3900000

Levels not connected by same letter are significantly different

Tests that the Variances are Equal



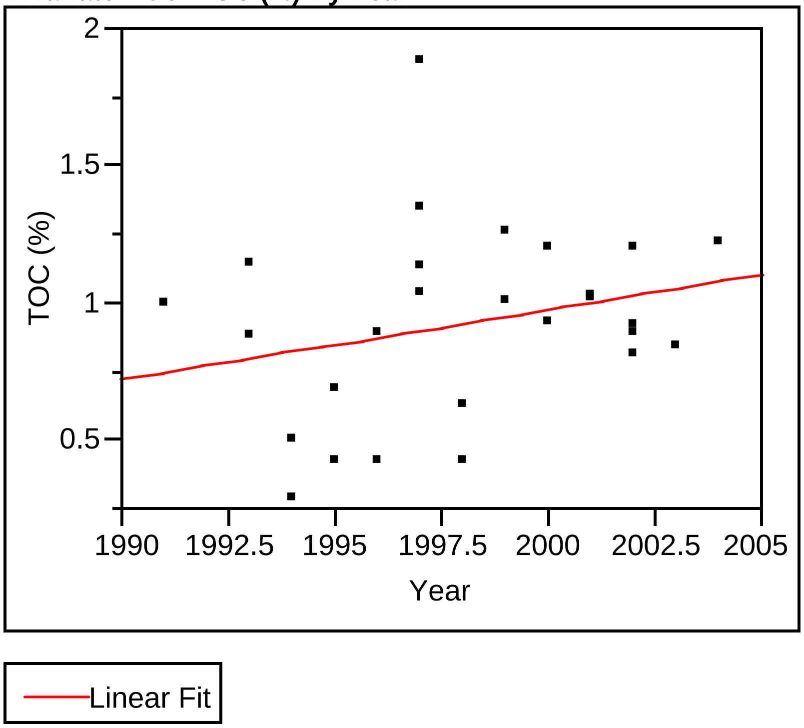
Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
1991	1	.	0.0000000	0.0000000
1993	2	0.1803122	0.1275000	0.1275000
1994	2	0.1555635	0.1100000	0.1100000
1995	2	0.1838478	0.1300000	0.1300000
1996	2	0.3287410	0.2324550	0.2324550
1997	4	0.3789918	0.2673145	0.2652995
1998	2	0.1414214	0.1000000	0.1000000
1999	2	0.1838478	0.1300000	0.1300000
2000	2	0.1909188	0.1350000	0.1350000
2001	2	0.0070711	0.0050000	0.0050000
2002	4	0.1698038	0.1225000	0.1050000
2003	1	.	0.0000000	0.0000000
2004	1	.	0.0000000	0.0000000

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	1.1572	1	6	0.3234
Brown-Forsythe	0.7846	9	14	0.6348
Levene	1.1295	9	14	0.4043
Bartlett	0.8237	9	.	0.5942

Warning: Small sample sizes. Use Caution.
Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
3.7825	9	4.3178	0.0962

Station=T05A
Bivariate Fit of TOC (%) By Year



Linear Fit
TOC (%) = -49.96978 + 0.0254716 Year

Summary of Fit

RSquare	0.06576
RSquare Adj	0.02839
Root Mean Square Error	0.340253
Mean of Response	0.922536
Observations (or Sum Wgts)	27

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	11	2.0880091	0.189819	3.2959
Pure Error	14	0.8062876	0.057592	Prob > F
Total Error	25	2.8942966		0.0195
				Max RSq
				0.7397

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.2037244	0.203724	1.7597
Error	25	2.8942966	0.115772	Prob > F
C. Total	26	3.0980211		0.1967

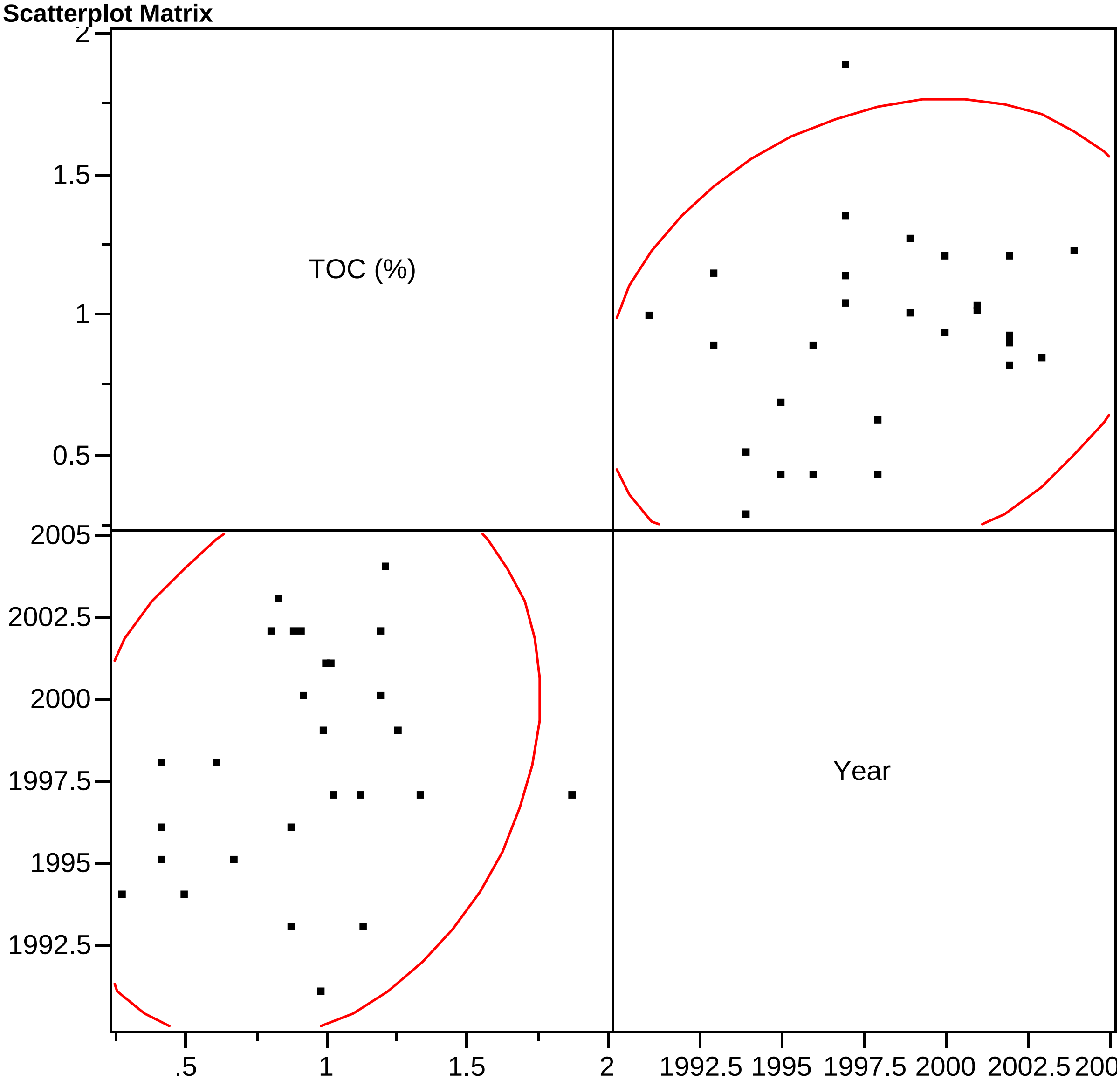
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-49.96978	38.36479	-1.30	0.2046
Year	0.0254716	0.019202	1.33	0.1967

Station=T05A
Multivariate
Correlations

	TOC (%)	Year
TOC (%)	1.0000	0.2564
Year	0.2564	1.0000

Scatterplot Matrix

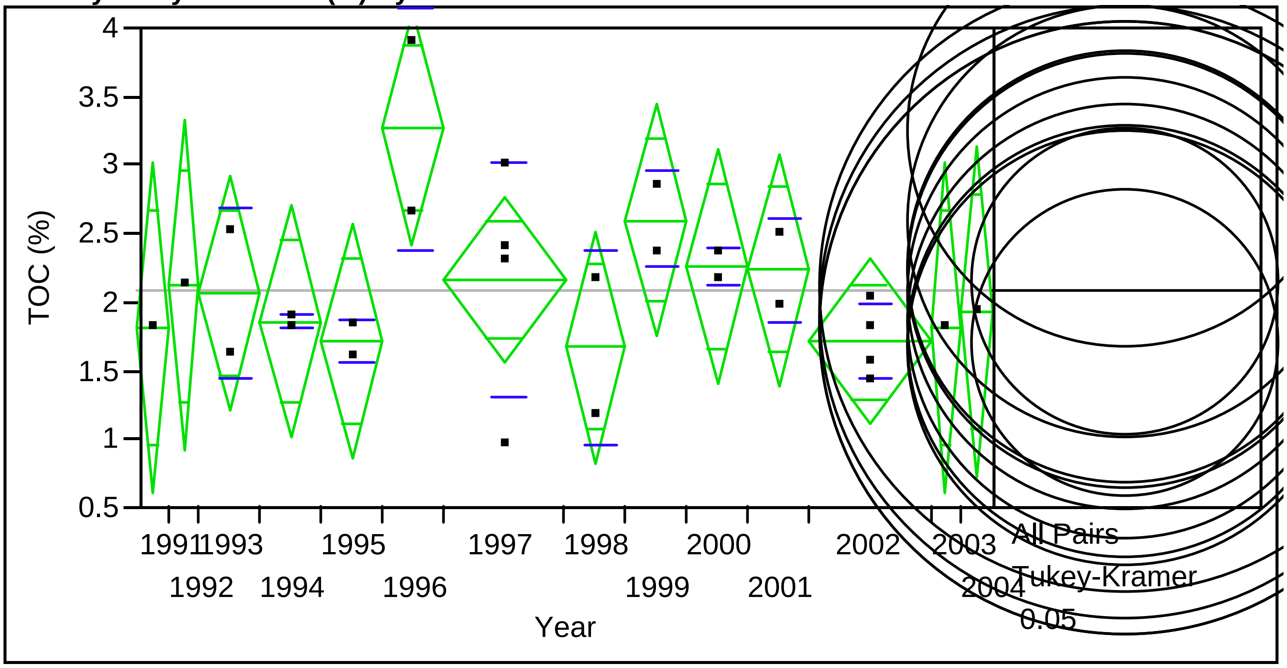


Pairwise Correlations

Variable	by Variable	Correlation	Count	Signif Prob	Plot Corr
Year	TOC (%)	0.2564	27	0.1967	

Station=T06

Oneway Analysis of TOC (%) By Year



Oneway Anova

Summary of Fit

Rsquare	0.527248
Adj Rsquare	0.088264
Root Mean Square Error	0.56098
Mean of Response	2.088617
Observations (or Sum Wgts)	28

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Year	13	4.9136513	0.377973	1.2011	0.3680
Error	14	4.4057781	0.314698		
C. Total	27	9.3194294			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1991	1	1.81000	0.56098	0.6068	3.0132
1992	1	2.11667	0.56098	0.9135	3.3198
1993	2	2.06500	0.39667	1.2142	2.9158
1994	2	1.86000	0.39667	1.0092	2.7108
1995	2	1.71500	0.39667	0.8642	2.5658
1996	2	3.26561	0.39667	2.4148	4.1164
1997	4	2.16085	0.28049	1.5593	2.7624
1998	2	1.67000	0.39667	0.8192	2.5208
1999	2	2.60000	0.39667	1.7492	3.4508
2000	2	2.26000	0.39667	1.4092	3.1108
2001	2	2.23500	0.39667	1.3842	3.0858
2002	4	1.70750	0.28049	1.1059	2.3091
2003	1	1.81000	0.56098	0.6068	3.0132
2004	1	1.93000	0.56098	0.7268	3.1332

Std Error uses a pooled estimate of error variance

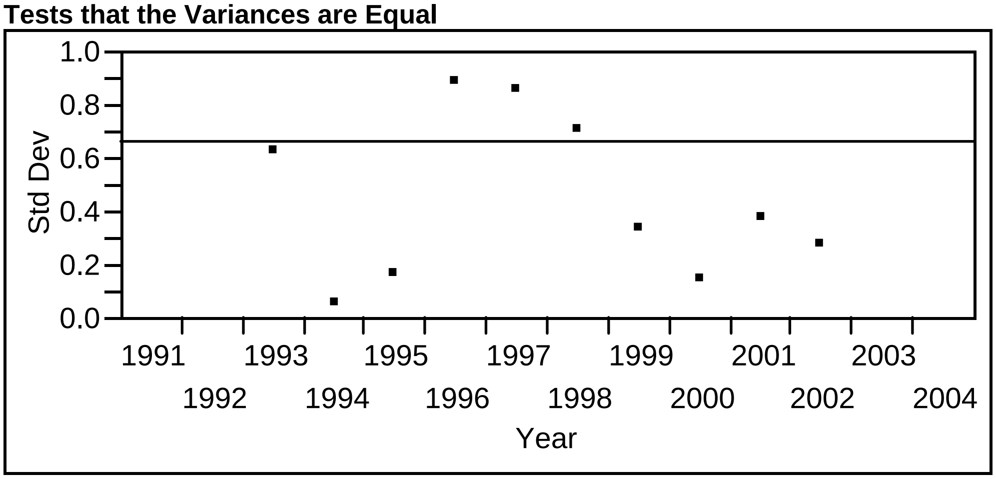
Means Comparisons
Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
3.98541	0.05

Level		Mean
1996	A	3.2656150
1999	A	2.6000000
2000	A	2.2600000
2001	A	2.2350000
1997	A	2.1608474
1992	A	2.1166667
1993	A	2.0650000
2004	A	1.9300000
1994	A	1.8600000
1991	A	1.8100000
2003	A	1.8100000
1995	A	1.7150000
2002	A	1.7075000
1998	A	1.6700000

Levels not connected by same letter are significantly different

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
1991	1	.	0.0000000	0.0000000
1992	1	.	0.0000000	0.0000000
1993	2	0.6293250	0.4450000	0.4450000
1994	2	0.0565685	0.0400000	0.0400000
1995	2	0.1626346	0.1150000	0.1150000
1996	2	0.8830279	0.6243950	0.6243950
1997	4	0.8570521	0.5976050	0.5335493
1998	2	0.7071068	0.5000000	0.5000000
1999	2	0.3394113	0.2400000	0.2400000
2000	2	0.1414214	0.1000000	0.1000000
2001	2	0.3747666	0.2650000	0.2650000
2002	4	0.2714621	0.2175000	0.2175000
2003	1	.	0.0000000	0.0000000
2004	1	.	0.0000000	0.0000000

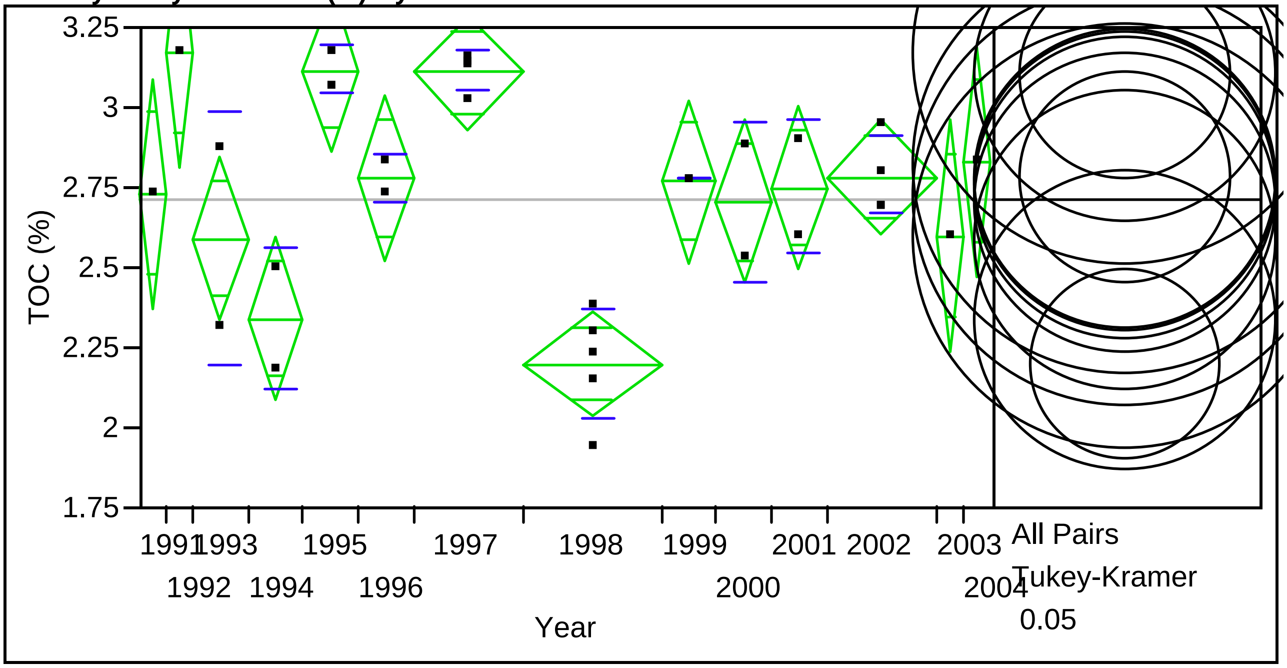
Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	1.4117	1	6	0.2797
Brown-Forsythe	1.0965	9	14	0.4231
Levene	1.9003	9	14	0.1358
Bartlett	0.9983	9	.	0.4387

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
1.7436	9	4.549	0.2930

Station=T07
Oneway Analysis of TOC (%) By Year



Oneway Anova
Summary of Fit

Rsquare	0.85196
Adj Rsquare	0.738753
Root Mean Square Error	0.170802
Mean of Response	2.709709
Observations (or Sum Wgts)	31

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Year	13	2.8541266	0.219548	7.5257	0.0001
Error	17	0.4959454	0.029173		
C. Total	30	3.3500720			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1991	1	2.73000	0.17080	2.3696	3.0904
1992	1	3.17500	0.17080	2.8146	3.5354
1993	2	2.59000	0.12078	2.3352	2.8448
1994	2	2.34000	0.12078	2.0852	2.5948
1995	2	3.11500	0.12078	2.8602	3.3698
1996	2	2.77864	0.12078	2.5238	3.0335
1997	4	3.10967	0.08540	2.9295	3.2899
1998	5	2.20000	0.07638	2.0388	2.3612
1999	2	2.77000	0.12078	2.5152	3.0248
2000	2	2.70500	0.12078	2.4502	2.9598
2001	2	2.75000	0.12078	2.4952	3.0048
2002	4	2.78250	0.08540	2.6023	2.9627
2003	1	2.60000	0.17080	2.2396	2.9604
2004	1	2.83000	0.17080	2.4696	3.1904

Std Error uses a pooled estimate of error variance

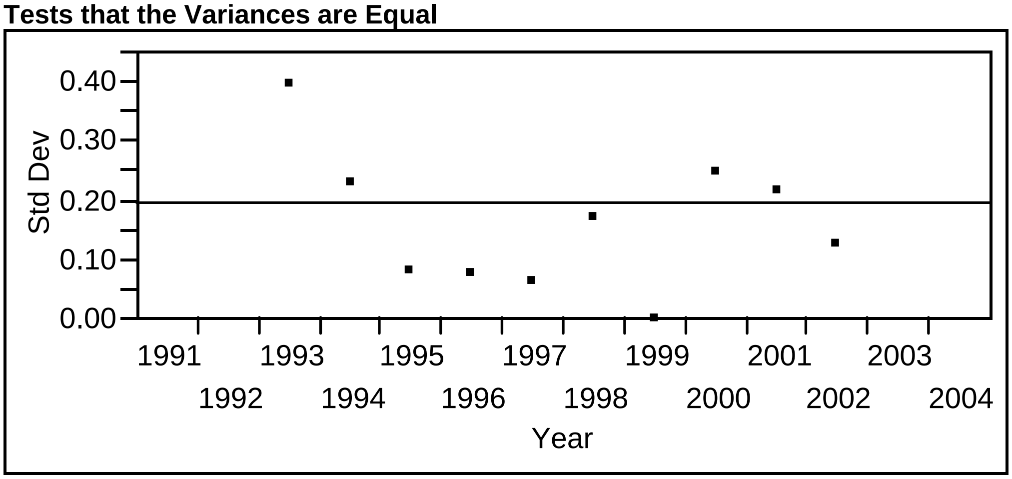
Means Comparisons
Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
3.86859	0.05

Level				Mean
1992	A			3.1750000
1995	A			3.1150000
1997	A			3.1096737
2004	A	B	C	2.8300000
2002	A	B		2.7825000
1996	A	B		2.7786400
1999	A	B		2.7700000
2001	A	B	C	2.7500000
1991	A	B	C	2.7300000
2000	A	B	C	2.7050000
2003	A	B	C	2.6000000
1993	A	B	C	2.5900000
1994		B	C	2.3400000
1998			C	2.2000000

Levels not connected by same letter are significantly different

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
1991	1	.	0.0000000	0.0000000
1992	1	.	0.0000000	0.0000000
1993	2	0.3959798	0.2800000	0.2800000
1994	2	0.2262742	0.1600000	0.1600000
1995	2	0.0777817	0.0550000	0.0550000
1996	2	0.0745291	0.0527000	0.0527000
1997	4	0.0611443	0.0449955	0.0359462
1998	5	0.1683746	0.1240000	0.1320000
1999	2	0.0000000	0.0000000	0.0000000
2000	2	0.2474874	0.1750000	0.1750000
2001	2	0.2121320	0.1500000	0.1500000
2002	4	0.1231192	0.0925000	0.0925000
2003	1	.	0.0000000	0.0000000
2004	1	.	0.0000000	0.0000000

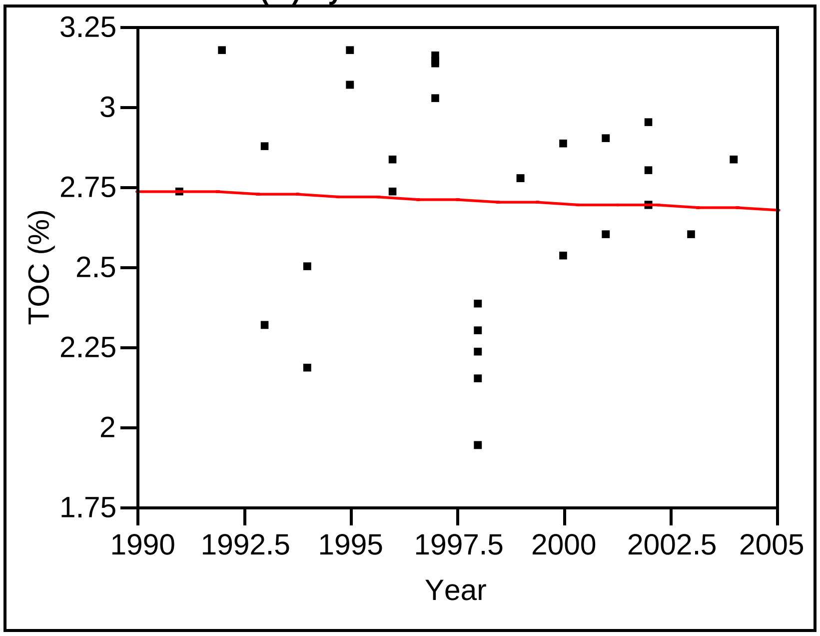
Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.8527	2	10	0.4551
Brown-Forsythe	4.2675	9	17	0.0049
Levene	4.8352	9	17	0.0026
Bartlett	.	9	.	0.0000

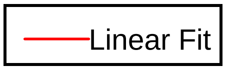
Warning: Small sample sizes. Use Caution.
Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
.	9	.	.

Station=T07

Bivariate Fit of TOC (%) By Year





Linear Fit

TOC (%) = 10.756182 - 0.0040277 Year

Summary of Fit

RSquare	0.001689
RSquare Adj	-0.03274
Root Mean Square Error	0.339595
Mean of Response	2.709709
Observations (or Sum Wgts)	31

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	12	2.8484677	0.237372	8.1366
Pure Error	17	0.4959454	0.029173	Prob > F
Total Error	29	3.3444132		<.0001
				Max RSq
				0.8520

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.0056589	0.005659	0.0491
Error	29	3.3444132	0.115325	Prob > F
C. Total	30	3.3500720		0.8262

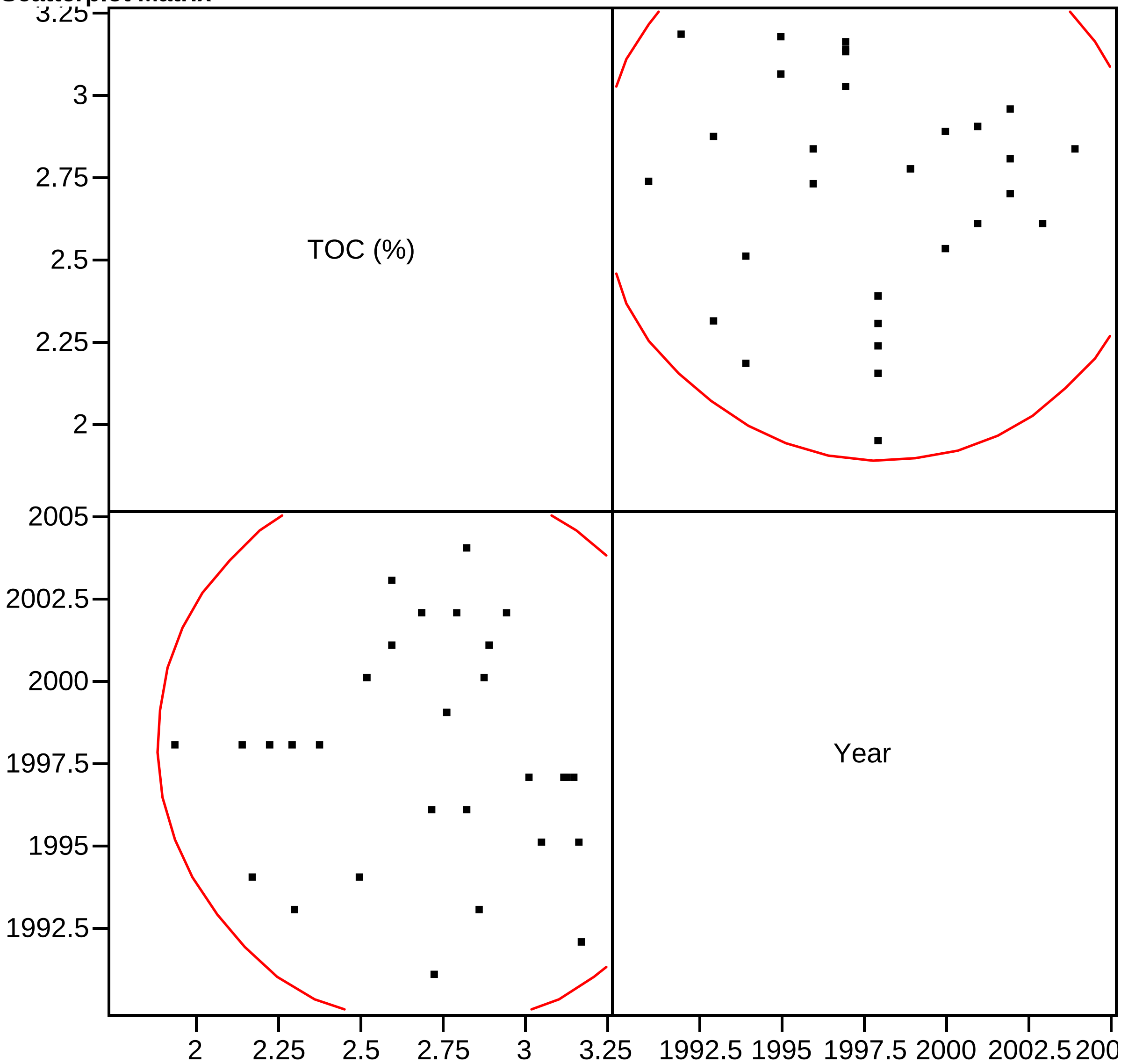
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	10.756182	36.32475	0.30	0.7693
Year	-0.004028	0.018182	-0.22	0.8262

Station=T07
Multivariate
Correlations

	TOC (%)	Year
TOC (%)	1.0000	-0.0411
Year	-0.0411	1.0000

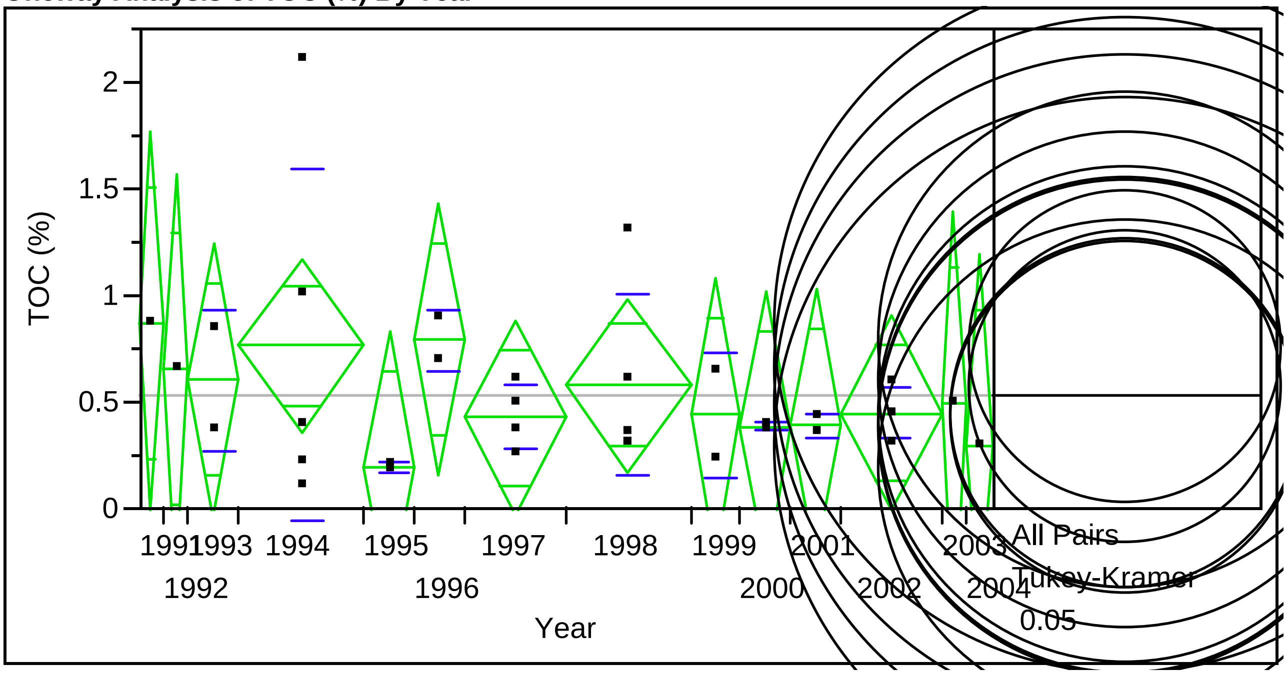
Scatterplot Matrix



Pairwise Correlations

Variable	by Variable	Correlation	Count	Signif Prob	Plot Corr
Year	TOC (%)	-0.0411	31	0.8262	

Station=T08
Oneway Analysis of TOC (%) By Year



Oneway Anova
Summary of Fit

Rsquare	0.211992
Adj Rsquare	-0.30021
Root Mean Square Error	0.433215
Mean of Response	0.534085
Observations (or Sum Wgts)	34

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Year	13	1.0097771	0.077675	0.4139	0.9467
Error	20	3.7534967	0.187675		
C. Total	33	4.7632738			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1991	1	0.870000	0.43321	-0.0337	1.7737
1992	1	0.660000	0.43321	-0.2437	1.5637
1993	2	0.605000	0.30633	-0.0340	1.2440
1994	5	0.764000	0.19374	0.3599	1.1681
1995	2	0.195000	0.30633	-0.4440	0.8340
1996	2	0.791575	0.30633	0.1526	1.4306
1997	4	0.430432	0.21661	-0.0214	0.8823
1998	5	0.578000	0.19374	0.1739	0.9821
1999	2	0.440000	0.30633	-0.1990	1.0790
2000	2	0.385000	0.30633	-0.2540	1.0240
2001	2	0.390000	0.30633	-0.2490	1.0290
2002	4	0.450000	0.21661	-0.0018	0.9018
2003	1	0.490000	0.43321	-0.4137	1.3937
2004	1	0.294000	0.43321	-0.6097	1.1977

Std Error uses a pooled estimate of error variance

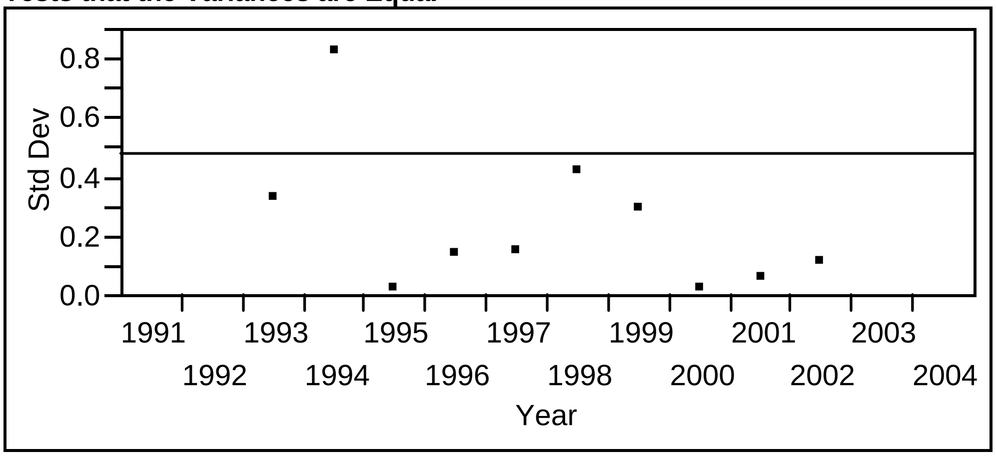
Means Comparisons
Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
3.78816	0.05

Level		Mean
1991	A	0.87000000
1996	A	0.79157500
1994	A	0.76400000
1992	A	0.66000000
1993	A	0.60500000
1998	A	0.57800000
2003	A	0.49000000
2002	A	0.45000000
1999	A	0.44000000
1997	A	0.43043163
2001	A	0.39000000
2000	A	0.38500000
2004	A	0.29400000
1995	A	0.19500000

Levels not connected by same letter are significantly different

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
1991	1	.	0.0000000	0.0000000
1992	1	.	0.0000000	0.0000000
1993	2	0.3323402	0.2350000	0.2350000
1994	5	0.8230917	0.6288000	0.5920000
1995	2	0.0212132	0.0150000	0.0150000
1996	2	0.1437477	0.1016450	0.1016450
1997	4	0.1499814	0.1169994	0.1169994
1998	5	0.4223387	0.3016000	0.2680000
1999	2	0.2969848	0.2100000	0.2100000
2000	2	0.0212132	0.0150000	0.0150000
2001	2	0.0565685	0.0400000	0.0400000
2002	4	0.1143095	0.0700000	0.0700000
2003	1	.	0.0000000	0.0000000
2004	1	.	0.0000000	0.0000000

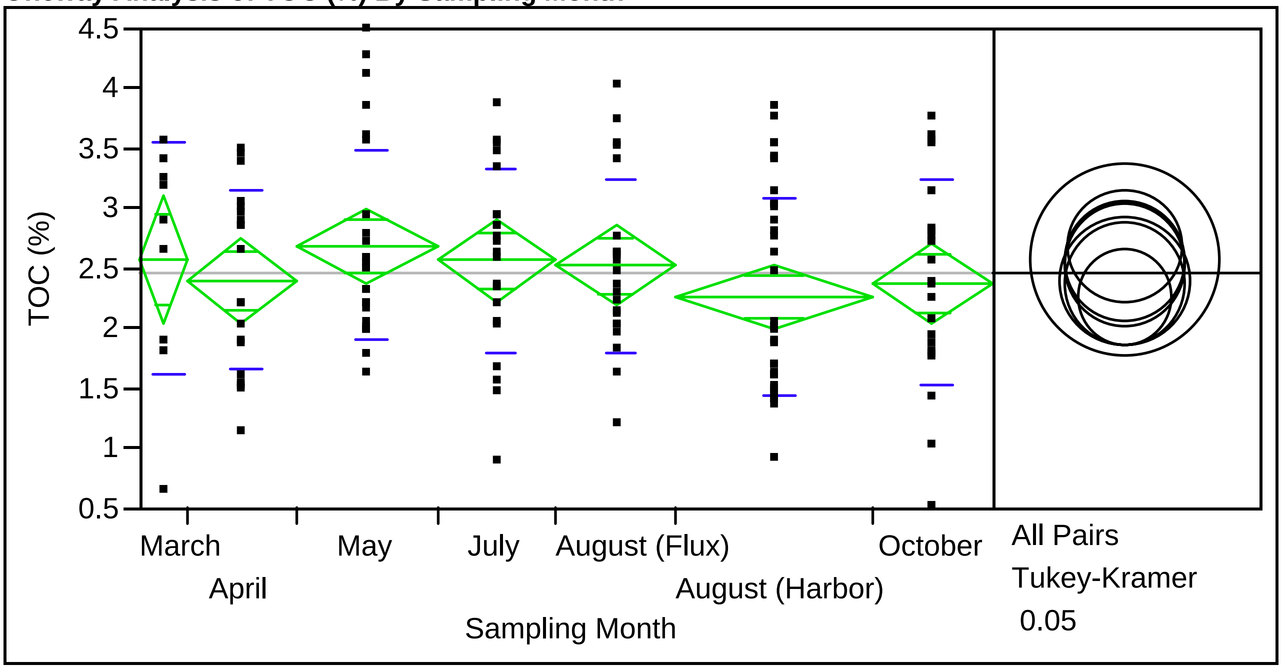
Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	1.3648	3	14	0.2941
Brown-Forsythe	1.0666	9	20	0.4268
Levene	2.7406	9	20	0.0290
Bartlett	2.5550	9	.	0.0062

Warning: Small sample sizes. Use Caution.
Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
7.2363	9	5.8703	0.0136

JMP ANOVA Output
Seasonal TOC Evaluation with Month
Data Source: 1993–2004 Individual Replicate Sediment TOC Data for Boston Harbor Stations T02 and T03 and Flux Program Stations BH02, BH03 and BH03A

Oneway Analysis of TOC (%) By Sampling Month



Excluded Rows
5 **Oneway Anova**

Summary of Fit

Rsquare	0.035273
Adj Rsquare	-0.00332
Root Mean Square Error	0.800049
Mean of Response	2.466938
Observations (or Sum Wgts)	157

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sampling Month	6	3.510445	0.585074	0.9141	0.4866
Error	150	96.011844	0.640079		
C. Total	156	99.522289			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
March	9	2.57957	0.26668	2.0526	3.1065
April	20	2.39941	0.17890	2.0459	2.7529
May	26	2.69645	0.15690	2.3864	3.0065
July	22	2.56768	0.17057	2.2306	2.9047
August (Flux)	22	2.52618	0.17057	2.1891	2.8632
August (Harbor)	36	2.26425	0.13334	2.0008	2.5277
October	22	2.38271	0.17057	2.0457	2.7197

Std Error uses a pooled estimate of error variance

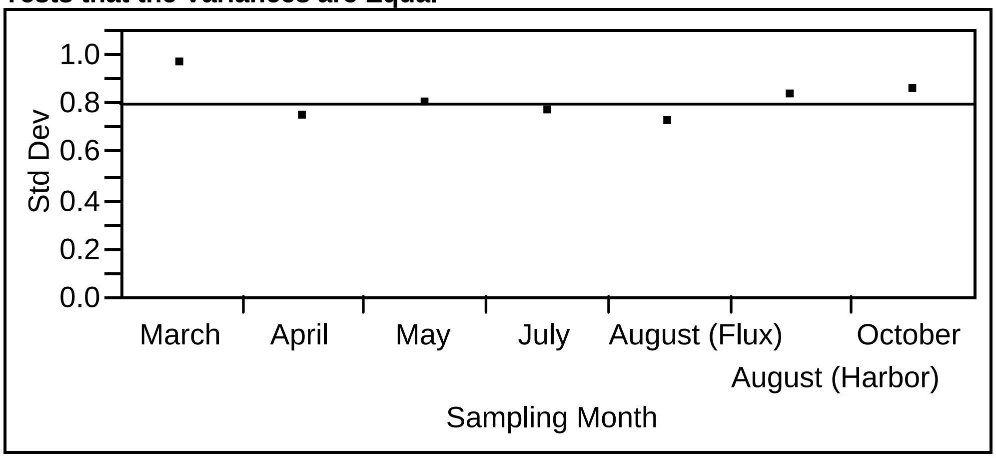
Means Comparisons
Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.98876	0.05

Level		Mean
May	A	2.6964493
March	A	2.5795656
July	A	2.5676755
August (Flux)	A	2.5261760
April	A	2.3994125
October	A	2.3827118
August (Harbor)	A	2.2642480

Levels not connected by same letter are significantly different

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
March	9	0.9618733	0.7612086	0.7385638
April	20	0.7374808	0.6520095	0.6520095
May	26	0.7944961	0.6178758	0.5746434
July	22	0.7606920	0.5986996	0.5942424
August (Flux)	22	0.7238424	0.5550773	0.5497592
August (Harbor)	36	0.8299945	0.7379791	0.6972711
October	22	0.8516140	0.6745463	0.6740446

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.4110	6	150	0.8709
Brown-Forsythe	0.3820	6	150	0.8896
Levene	0.6081	6	150	0.7236
Bartlett	0.2648	6	.	0.9534

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
0.8386	6	52.703	0.5458

Appendix B4

Clostridium perfringens, 1991–2004

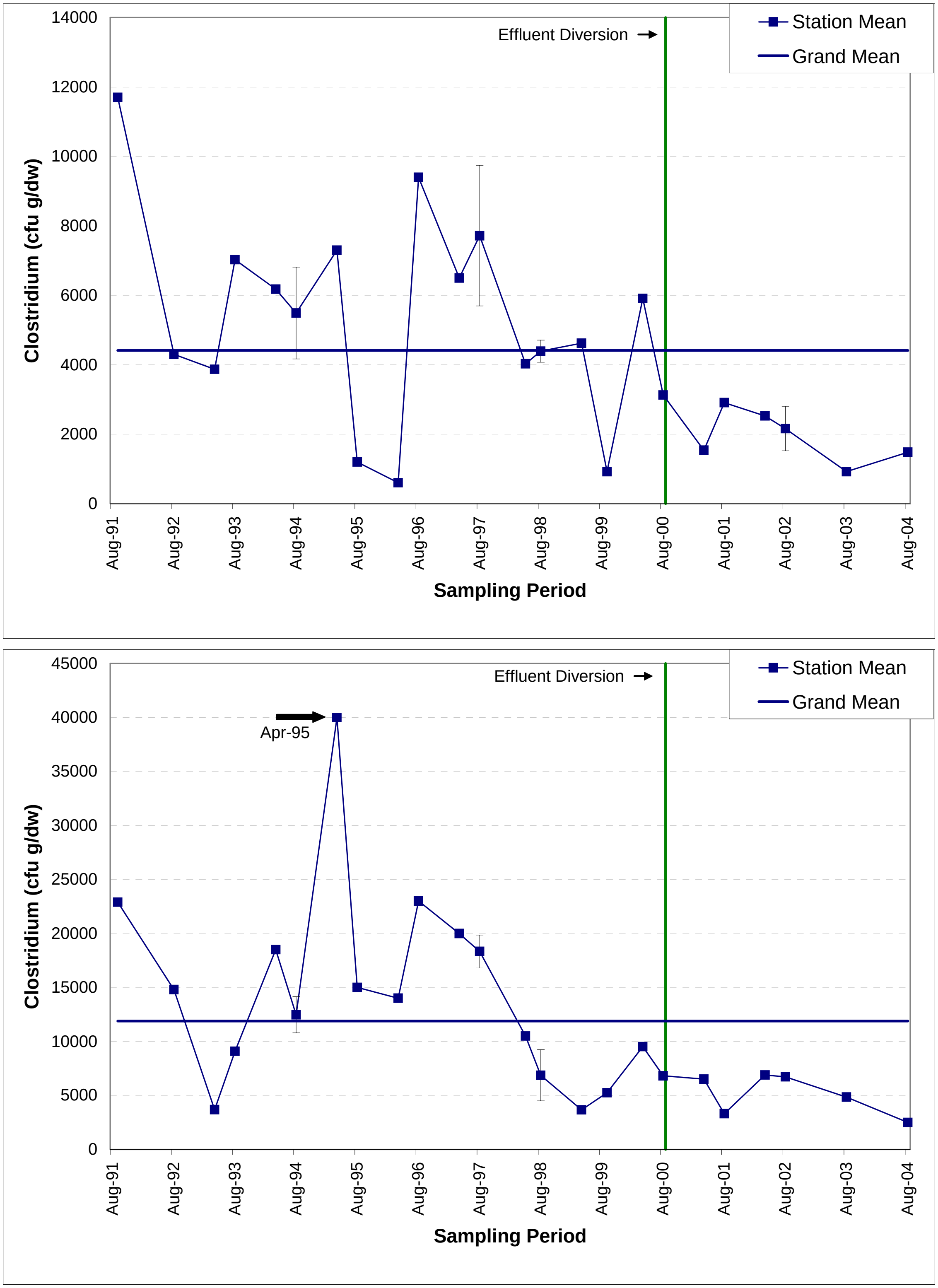
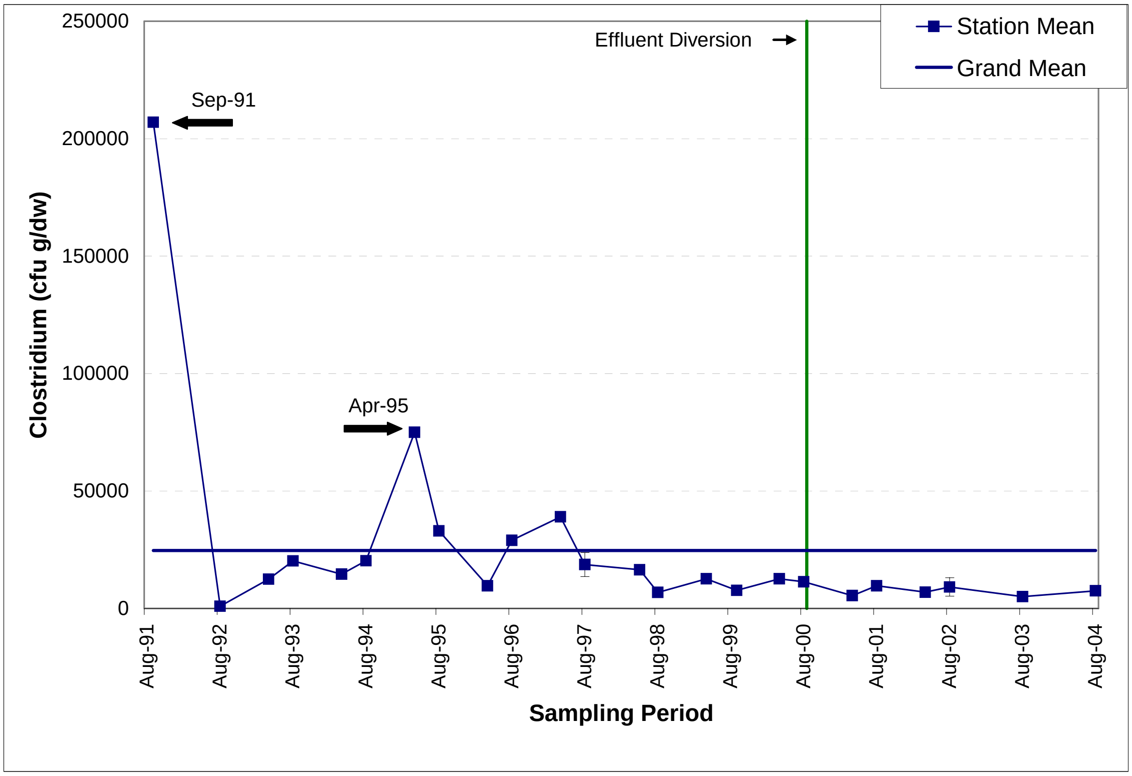


Figure B4-1. Station mean abundance of *Clostridium perfringens* at T01 (top) and T02 (bottom), 1991–2004. Vertical bars represent one standard deviation.



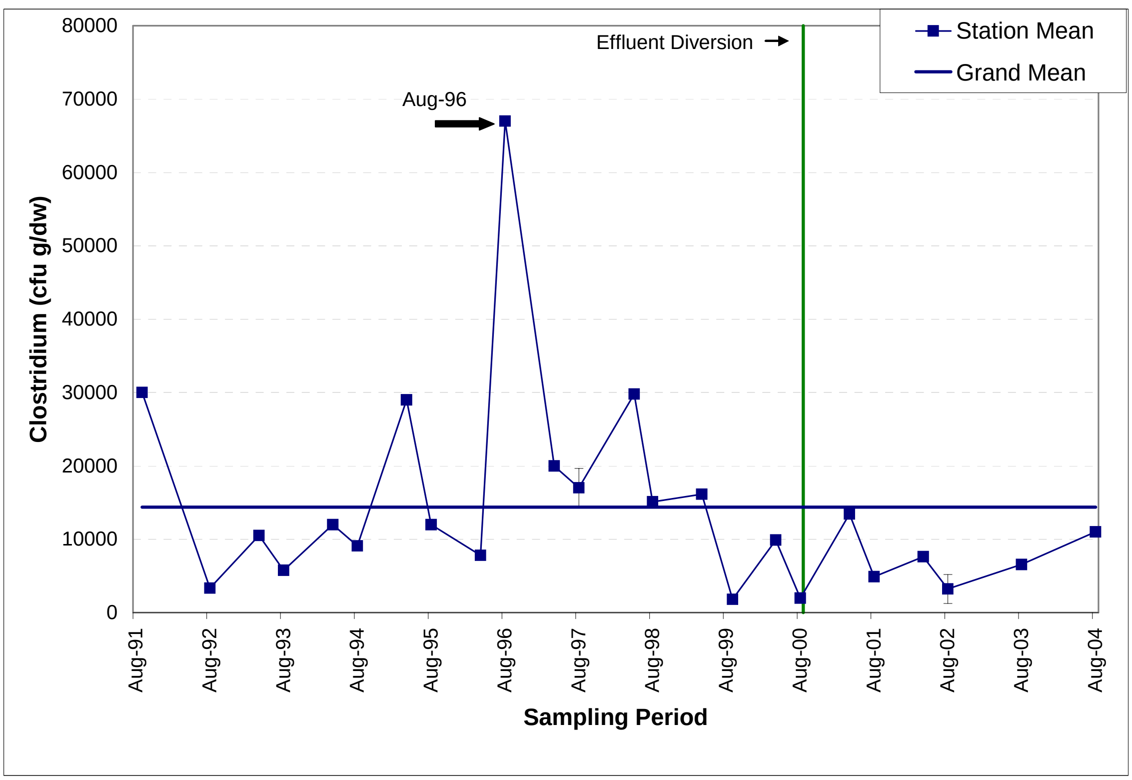
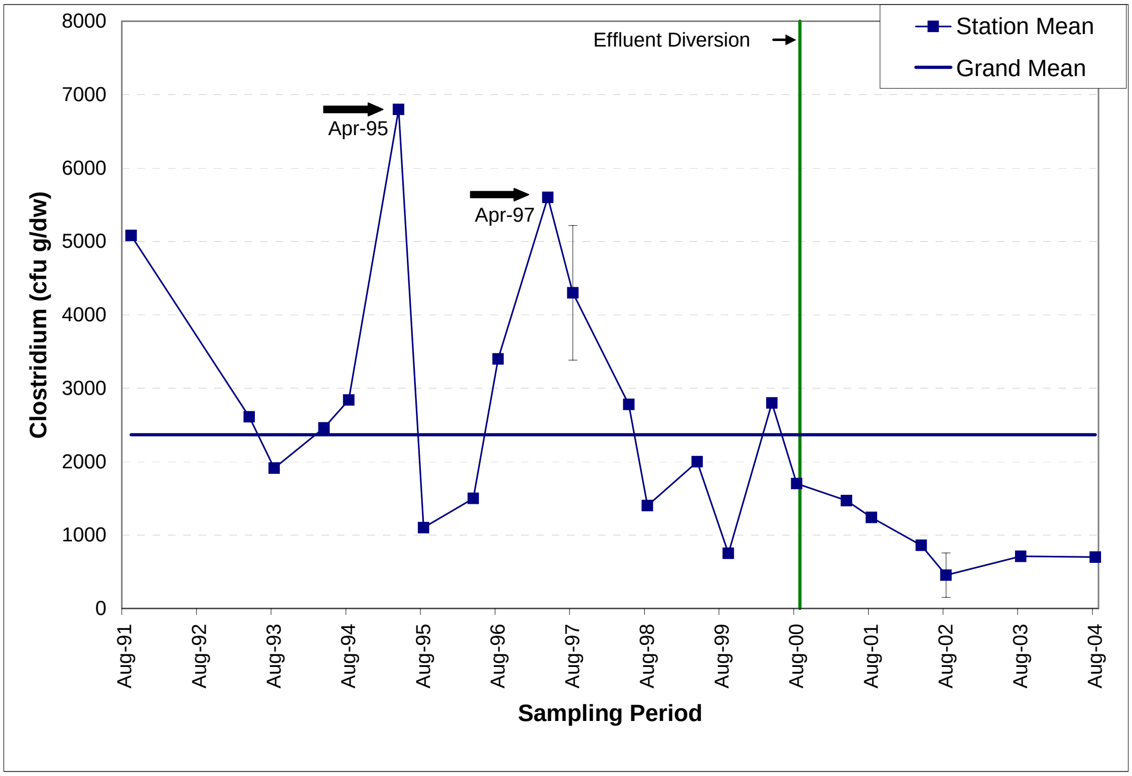


Figure B4-2. Station mean abundance of *Clostridium perfringens* at stations T03 (top) and T04 (bottom), 1991–2004. Vertical bars represent one standard deviation.



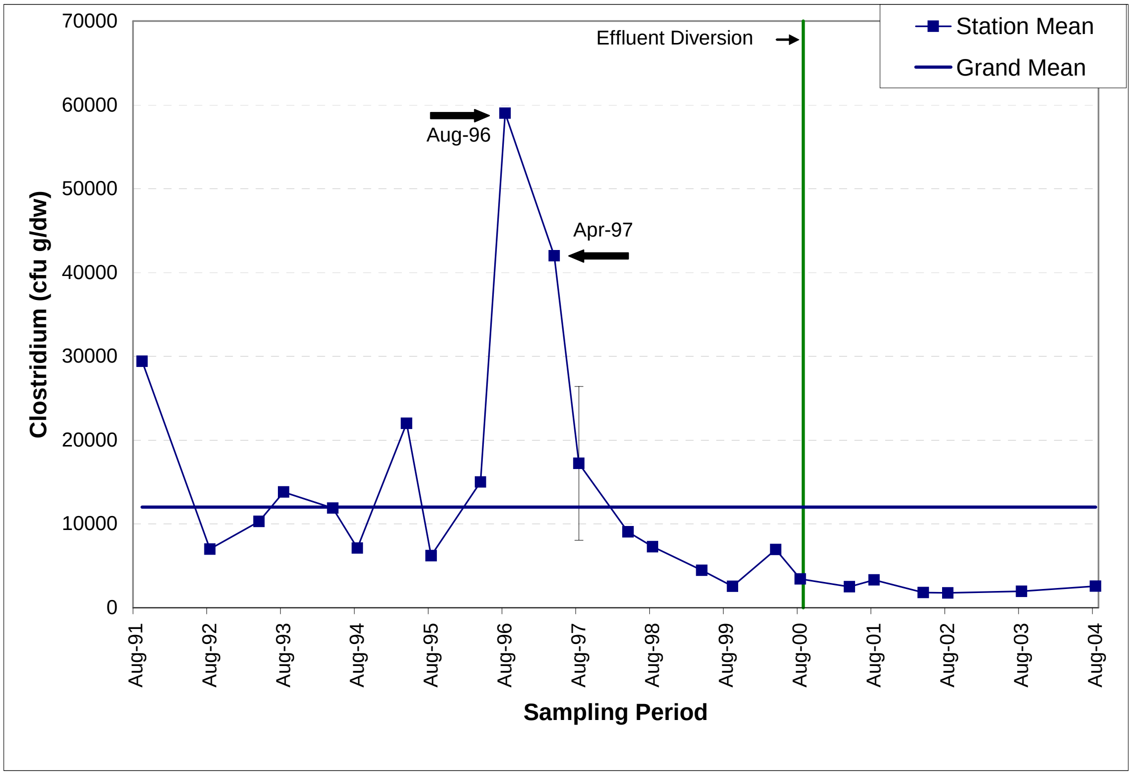


Figure B4-3. Station mean abundance of *Clostridium perfringens* at stations T05A (top) and T06 (bottom), 1991–2004. Vertical bars represent one standard deviation.

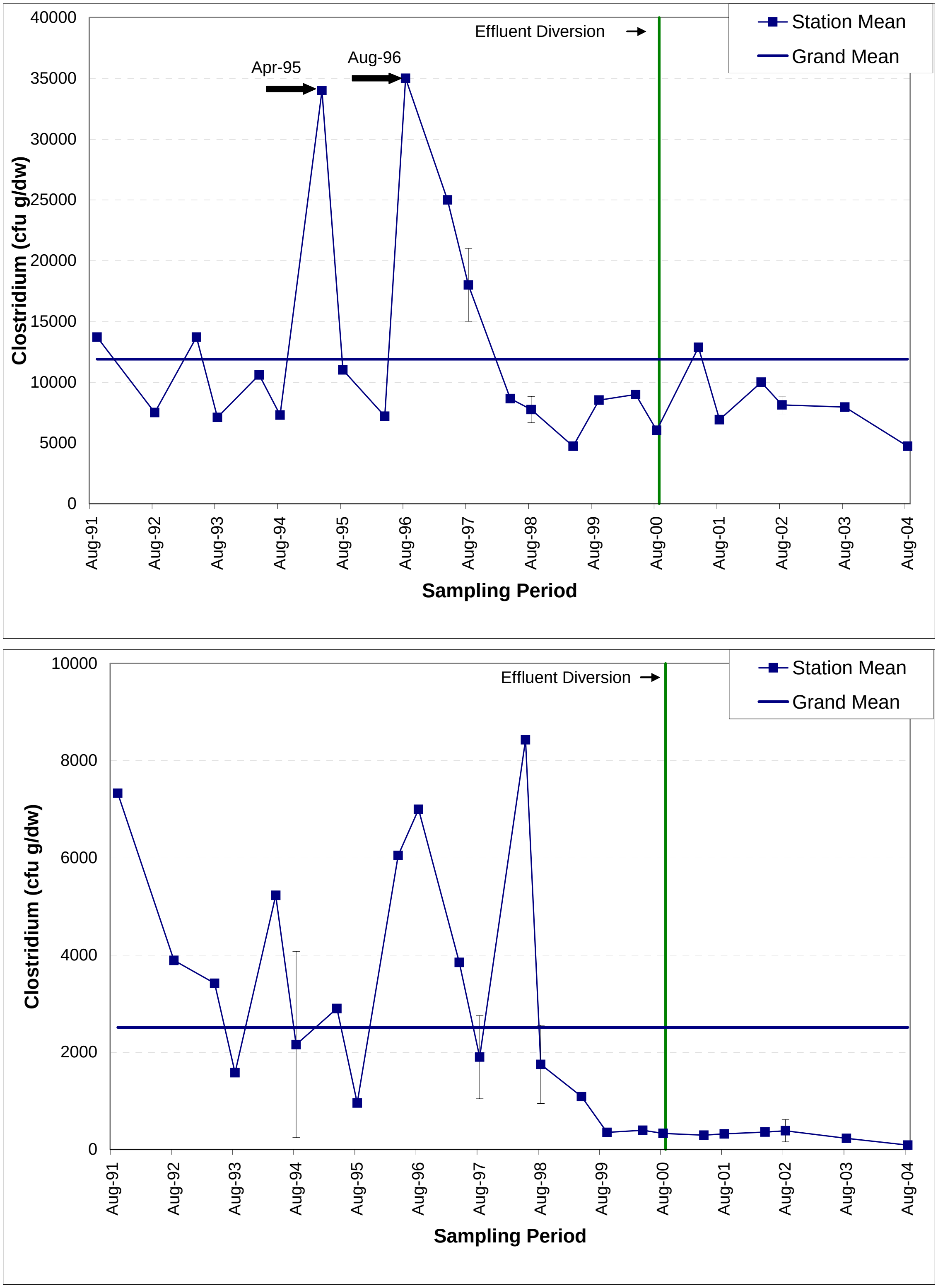


Figure B4-4. Station mean abundance of *Clostridium perfringens* at stations T07 (top) and T08 (bottom), 1991–2004. Vertical bars represent one standard deviation.

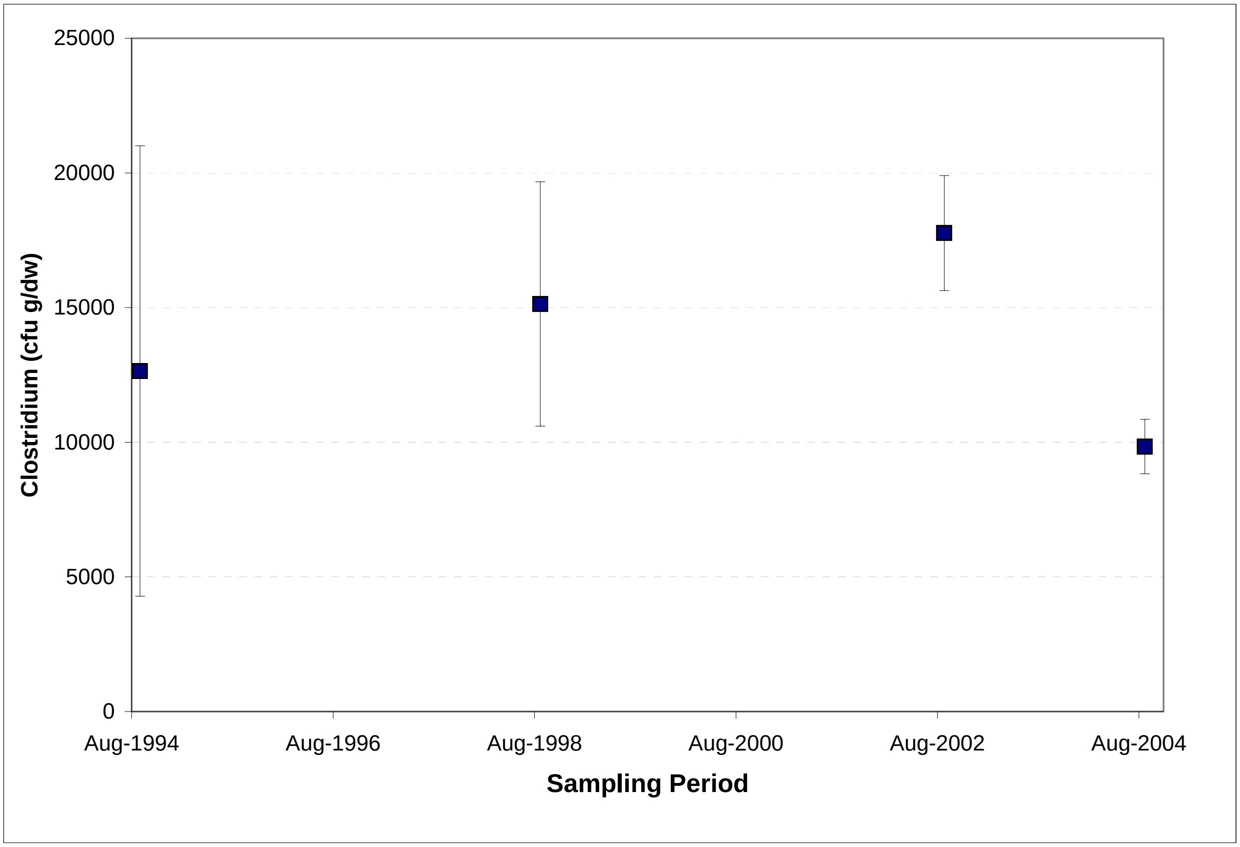
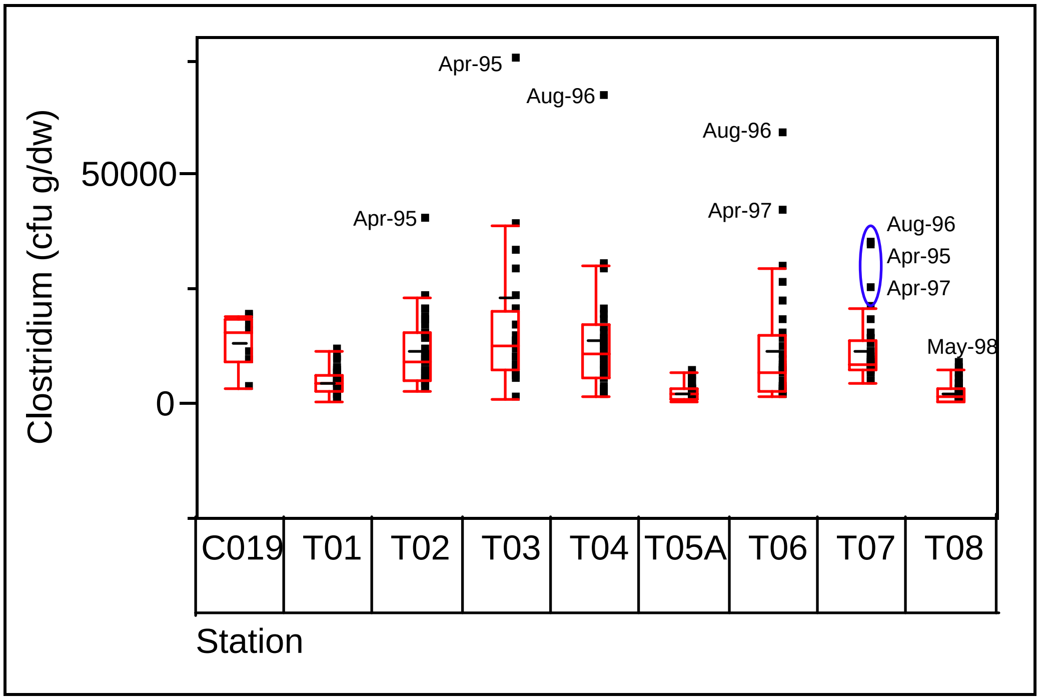


Figure B4-5. Station mean abundance of *Clostridium perfringens* at station CO19, 1994–2004. Vertical bars represent one standard deviation.



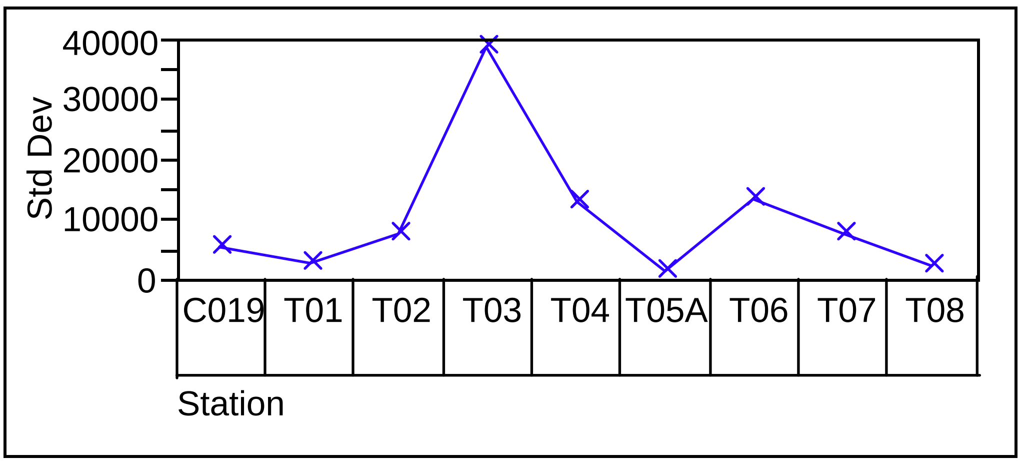
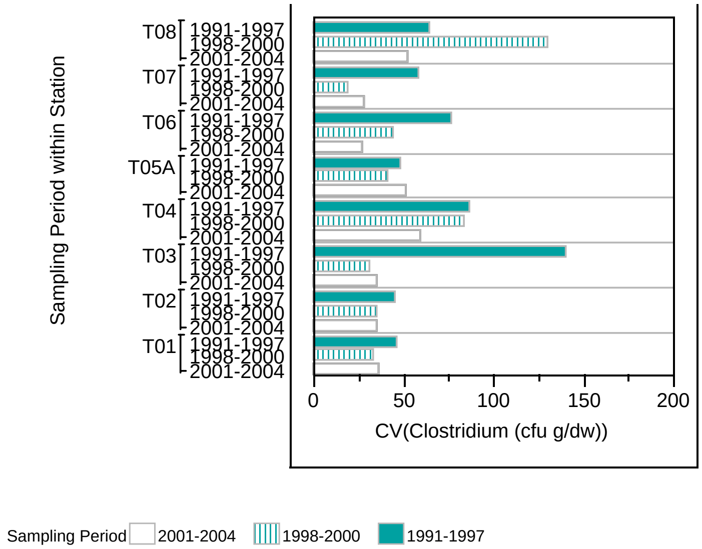


Figure B4-6. Distribution of *Clostridium perfringens* in Boston Harbor sediments, 1991–2004. For CO19, sediment data are from 1994, 1998, 2002, and 2004. Abundance of *C. perfringens* at T03 in September 1991 is not shown; value is off-scale at 207,000 cfu g/dw.

Table B4-1. Coefficient of variation (CV) in the abundance of *Clostridium perfringens* collected during three sampling periods of harbor monitoring. Sampling periods encompass more than a decade of major facility improvements to sewage treatment to Boston Harbor.

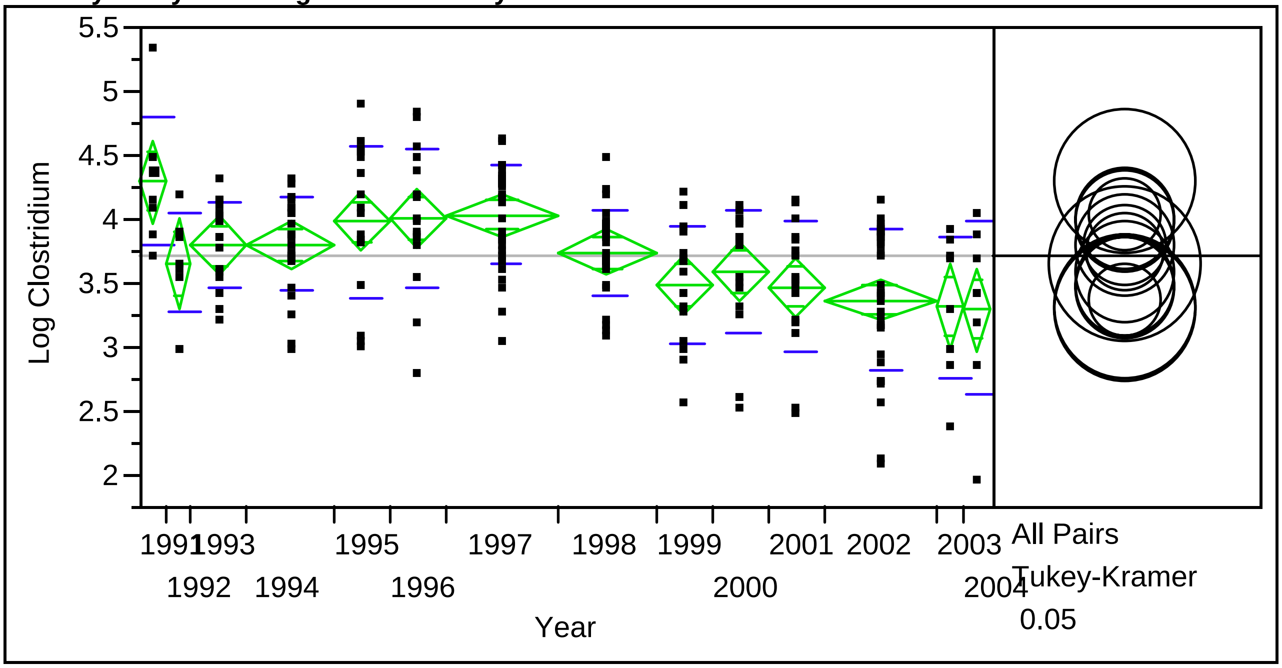
Station	Sampling Period	No. Obs.	CV (a) Clostridium
T01	1991-1997	17	47
T01	1998-2000	9	34
T01	2001-2004	8	36
T02	1991-1997	17	46
T02	1998-2000	9	35
T02	2001-2004	8	36
T03	1991-1997	14	141
T03	1998-2000	6	32
T03	2001-2004	8	36
T04	1991-1997	14	87
T04	1998-2000	6	84
T04	2001-2004	8	60
T05A	1991-1997	13	49
T05A	1998-2000	6	42
T05A	2001-2004	8	52
T06	1991-1997	14	78
T06	1998-2000	6	45
T06	2001-2004	8	28
T07	1991-1997	14	59
T07	1998-2000	9	20
T07	2001-2004	8	29
T08	1991-1997	17	65
T08	1998-2000	9	131
T08	2001-2004	8	53
T01	1991-2004	34	59
T02		34	67
T03		28	168
T04		28	96
T05A		27	74
T06		28	116
T07		31	66
T08		34	103

(a) Coefficient of variation (CV) is a measure of the variability among the data:
(standard deviation ÷ average value) × 100



ANOVA and Correlation Output (correlation output provided where ANOVA test significant)
Harbor-wide evaluation of *Clostridium perfringens* (log-transformed) with Time (Year)
Data Source: 1991–2004 Individual Replicate Sediment *Clostridium perfringens* (log-transformed) Data
Boston Harbor Stations, T01 through T08

Oneway Analysis of Log Clostridium By Year



Oneway Anova
Summary of Fit

Rsquare	0.256523
Adj Rsquare	0.2145
Root Mean Square Error	0.466704
Mean of Response	3.718605
Observations (or Sum Wgts)	244

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Year	13	17.284953	1.32961	6.1044	<.0001
Error	230	50.096823	0.21781		
C. Total	243	67.381776			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1991	8	4.29964	0.16500	3.9745	4.6248
1992	7	3.65836	0.17640	3.3108	4.0059
1993	16	3.79465	0.11668	3.5648	4.0245
1994	25	3.80587	0.09334	3.6220	3.9898
1995	16	3.97999	0.11668	3.7501	4.2099
1996	16	4.00655	0.11668	3.7767	4.2364
1997	32	4.03662	0.08250	3.8741	4.1992
1998	28	3.74403	0.08820	3.5703	3.9178
1999	16	3.48662	0.11668	3.2567	3.7165
2000	16	3.58927	0.11668	3.3594	3.8192
2001	16	3.47691	0.11668	3.2470	3.7068
2002	32	3.37182	0.08250	3.2093	3.5344
2003	8	3.32157	0.16500	2.9965	3.6467
2004	8	3.29598	0.16500	2.9709	3.6211

Std Error uses a pooled estimate of error variance

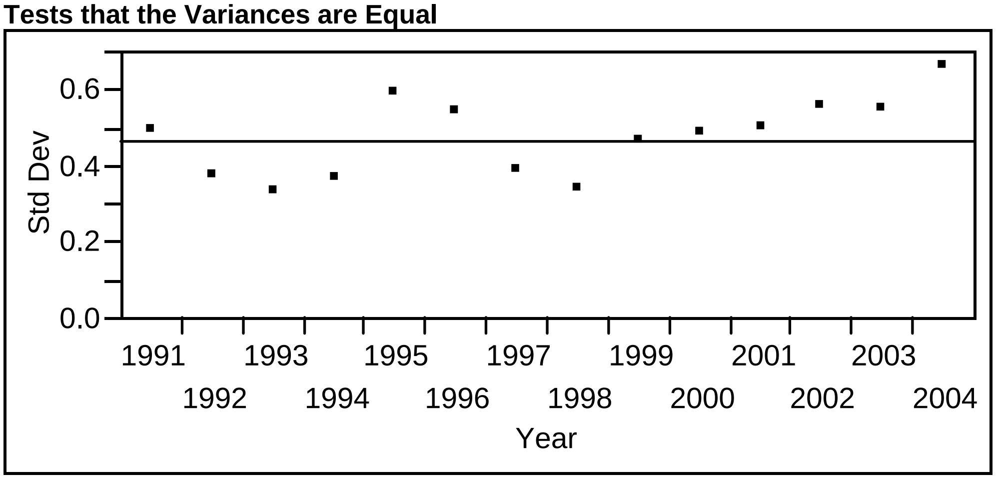
Means Comparisons
Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
3.39007	0.05

Level						Mean
1991	A					4.2996436
1997	A	B				4.0366217
1996	A	B	C			4.0065463
1995	A	B	C	D		3.9799874
1994	A	B	C	D		3.8058680
1993	A	B	C	D	E	3.7946517
1998	A	B	C	D	E	3.7440336
1992	A	B	C	D	E	3.6583552
2000		B	C	D	E	3.5892666
1999			C	D	E	3.4866184
2001			C	D	E	3.4769058
2002					E	3.3718218
2003			C	D	E	3.3215750
2004				D	E	3.2959772

Levels not connected by same letter are significantly different

Tests that the Variances are Equal



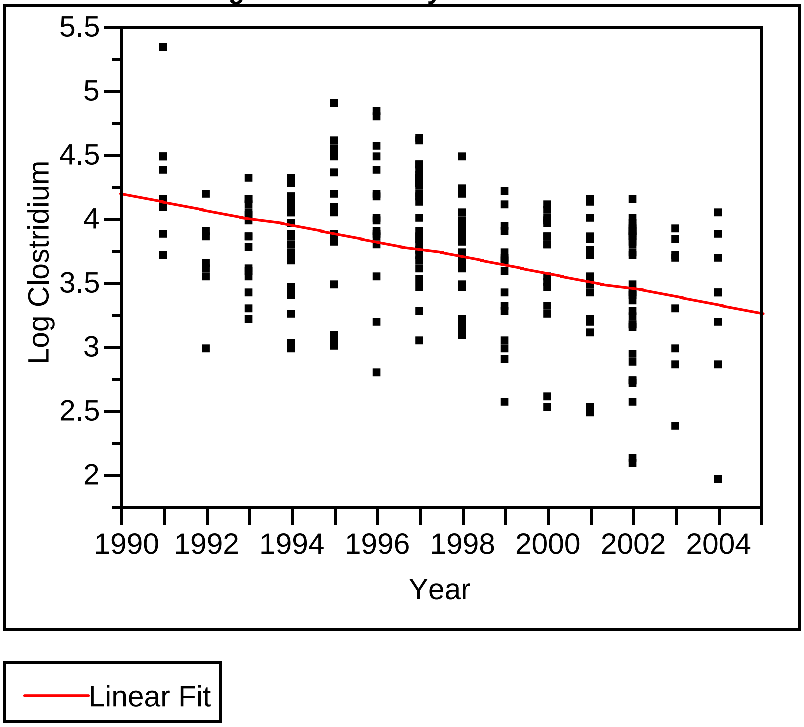
Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
1991	8	0.4954101	0.3556750	0.3556750
1992	7	0.3738222	0.2615302	0.2641919
1993	16	0.3312393	0.2772250	0.2706870
1994	25	0.3647423	0.2843566	0.2788026
1995	16	0.5904384	0.4760891	0.4684135
1996	16	0.5455803	0.4051895	0.4021551
1997	32	0.3872105	0.3241210	0.3037275
1998	28	0.3374174	0.2634174	0.2592217
1999	16	0.4648970	0.3776804	0.3679244
2000	16	0.4832672	0.3761317	0.3533416
2001	16	0.4992616	0.3816271	0.3762618
2002	32	0.5564028	0.4534888	0.4504486
2003	8	0.5515627	0.4548728	0.4548728
2004	8	0.6627804	0.4795823	0.4540916

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	1.3931	13	230	0.1635
Brown-Forsythe	1.1537	13	230	0.3153
Levene	1.4216	13	230	0.1502
Bartlett	1.5097	13	.	0.1049

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
4.7569	13	63.216	<.0001

Bivariate Fit of Log Clostridium By Year



Linear Fit

Log Clostridium = 126.19761 - 0.0613106 Year

Summary of Fit

RSquare	0.160836
RSquare Adj	0.157368
Root Mean Square Error	0.483378
Mean of Response	3.718605
Observations (or Sum Wgts)	244

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	12	6.447535	0.537295	2.4668
Pure Error	230	50.096823	0.217812	Prob > F
Total Error	242	56.544358		0.0048
				Max RSq
				0.2565

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	10.837418	10.8374	46.3823
Error	242	56.544358	0.2337	Prob > F
C. Total	243	67.381776		<.0001

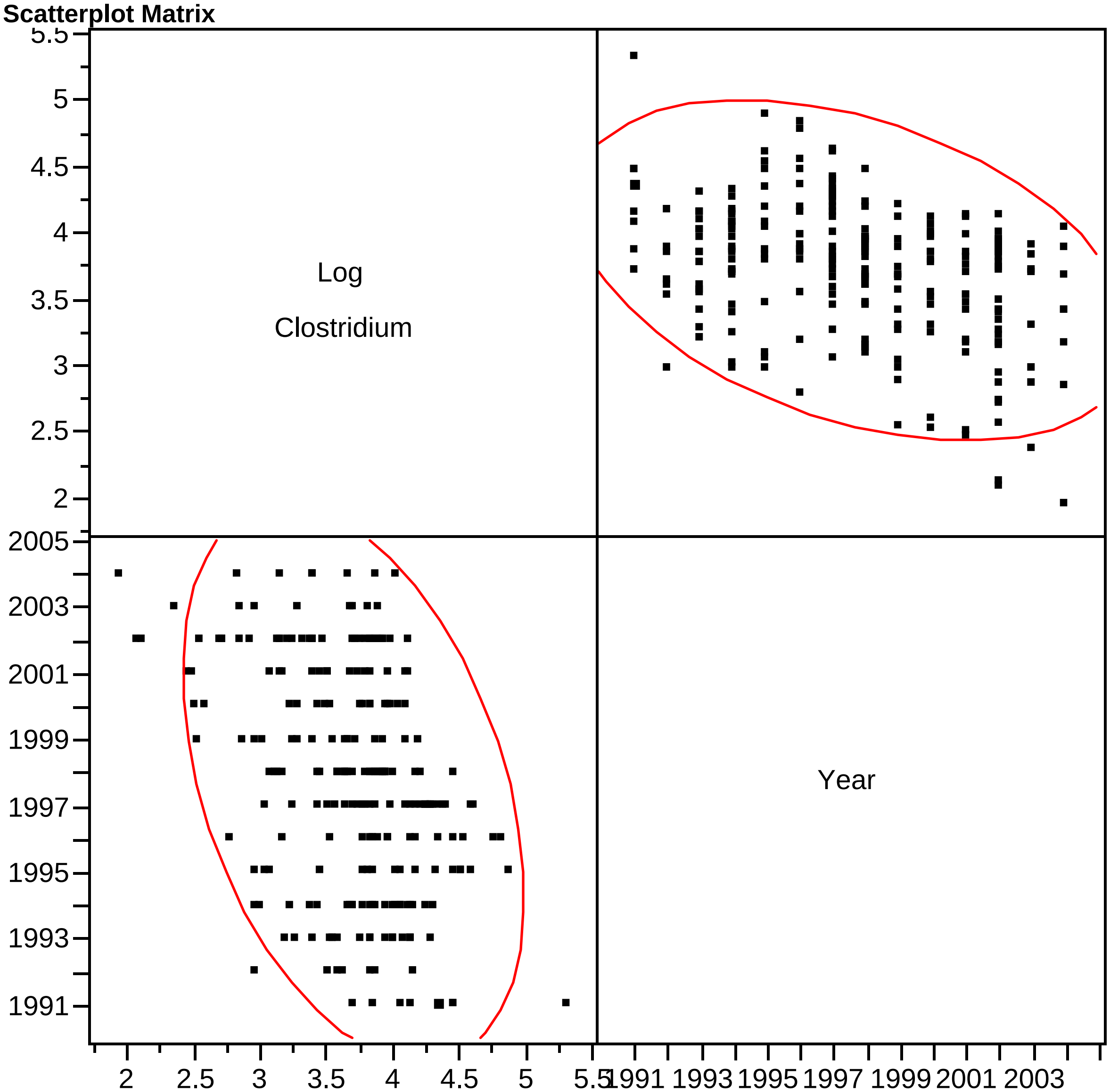
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	126.19761	17.984	7.02	<.0001
Year	-0.061311	0.009002	-6.81	<.0001

Multivariate
Correlations

	Log Clostridium	Year
Log Clostridium	1.0000	-0.4010
Year	-0.4010	1.0000

Scatterplot Matrix

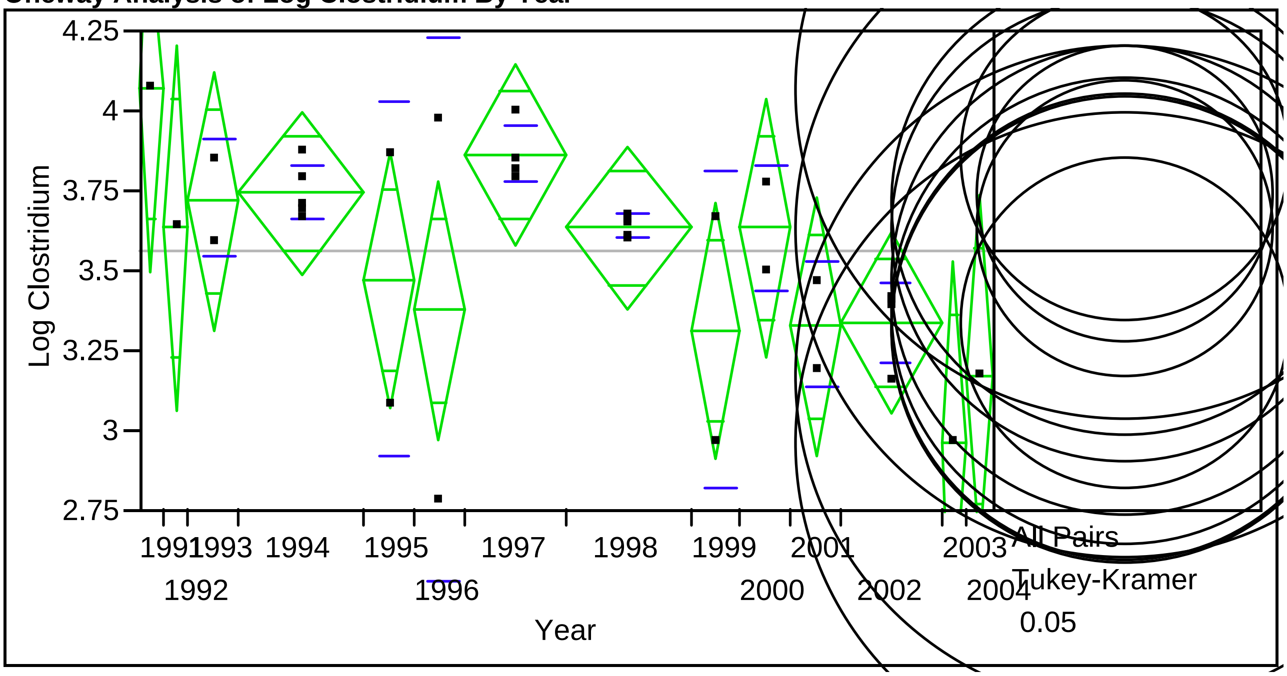


Pairwise Correlations

Variable	by Variable	Correlation	Count	Signif Prob	Plot Corr
Year	Log Clostridium	-0.4010	244	0.0000	

ANOVA and Correlation Output (correlation output provided where ANOVA test significant)
A Station evaluation of *Clostridium perfringens* (log-transformed) with Time (Year)
Data Source: 1991–2004 Individual Replicate Sediment *Clostridium perfringens* (log-transformed) Data for Boston Harbor Stations, T01 through T08. CSO station CO19, 1994–2004.

Station=T01
Oneway Analysis of Log Clostridium By Year



Oneway Anova
Summary of Fit

Rsquare	0.560954
Adj Rsquare	0.275575
Root Mean Square Error	0.272457
Mean of Response	3.564966
Observations (or Sum Wgts)	34

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Year	13	1.8968931	0.145915	1.9656	0.0844
Error	20	1.4846525	0.074233		
C. Total	33	3.3815456			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1991	1	4.06819	0.27246	3.4999	4.6365
1992	1	3.63347	0.27246	3.0651	4.2018
1993	2	3.71733	0.19266	3.3155	4.1192
1994	5	3.74313	0.12185	3.4890	3.9973
1995	2	3.47125	0.19266	3.0694	3.8731
1996	2	3.37564	0.19266	2.9738	3.7775
1997	4	3.86172	0.13623	3.5776	4.1459
1998	5	3.63452	0.12185	3.3803	3.8887
1999	2	3.31421	0.19266	2.9123	3.7161
2000	2	3.63357	0.19266	3.2317	4.0354
2001	2	3.32571	0.19266	2.9238	3.7276
2002	4	3.34065	0.13623	3.0565	3.6248
2003	1	2.96379	0.27246	2.3955	3.5321
2004	1	3.17026	0.27246	2.6019	3.7386

Std Error uses a pooled estimate of error variance

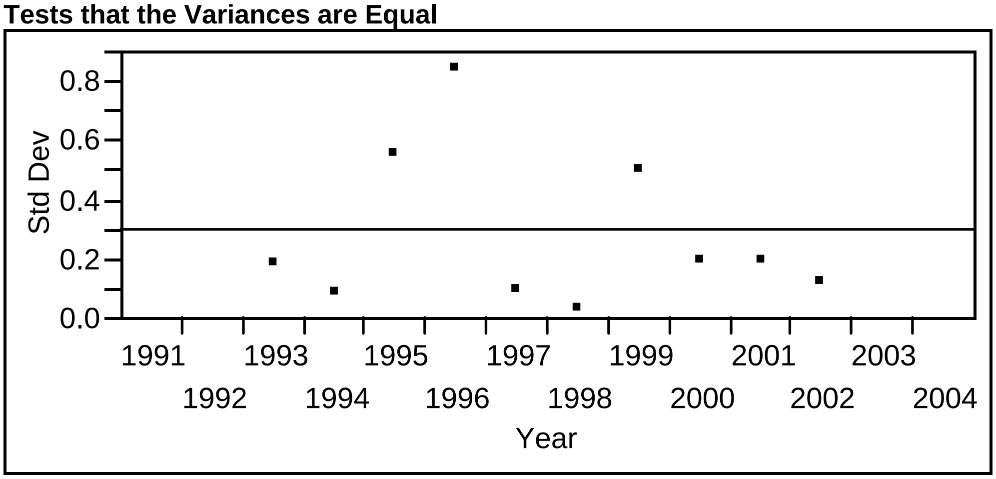
Means Comparisons
Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
3.78816	0.05

Level		Mean
1991	A	4.0681859
1997	A	3.8617216
1994	A	3.7431290
1993	A	3.7173331
1998	A	3.6345161
2000	A	3.6335659
1992	A	3.6334685
1995	A	3.4712521
1996	A	3.3756396
2002	A	3.3406490
2001	A	3.3257069
1999	A	3.3142149
2004	A	3.1702617
2003	A	2.9637878

Levels not connected by same letter are significantly different

Tests that the Variances are Equal



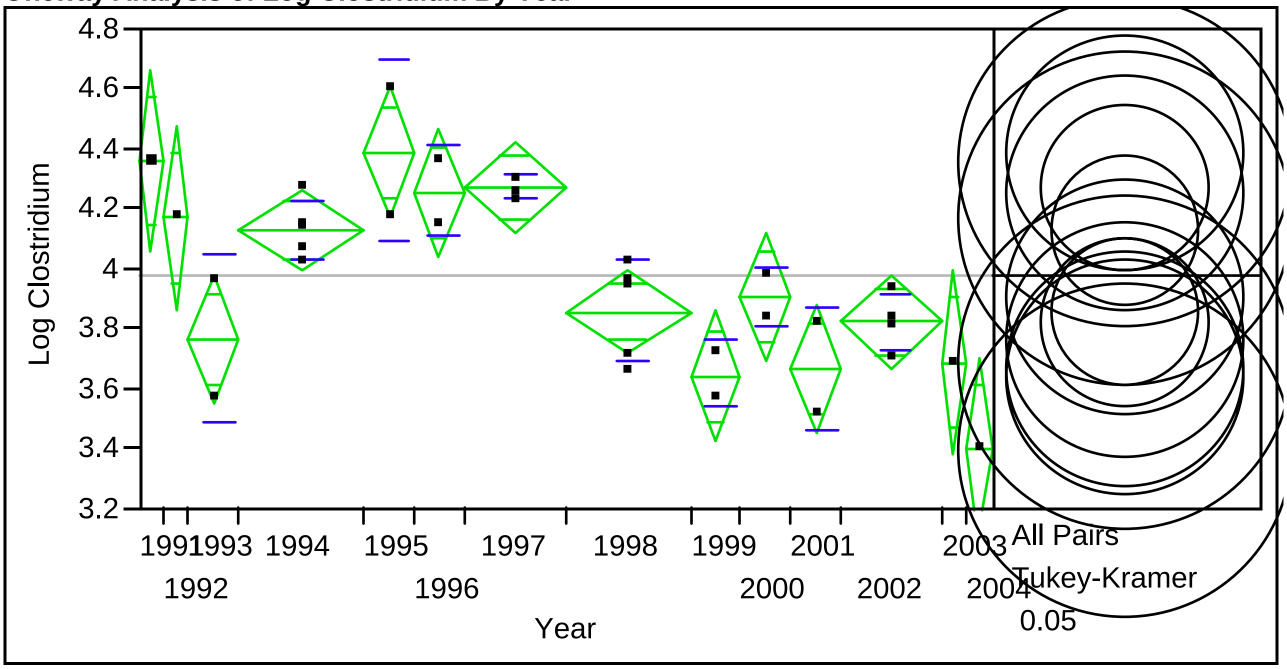
Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
1991	1	.	0.0000000	0.0000000
1992	1	.	0.0000000	0.0000000
1993	2	0.1833134	0.1296222	0.1296222
1994	5	0.0870385	0.0709877	0.0663650
1995	2	0.5544719	0.3920708	0.3920708
1996	2	0.8449761	0.5974883	0.5974883
1997	4	0.0950195	0.0691392	0.0608274
1998	5	0.0325022	0.0272924	0.0253008
1999	2	0.4955787	0.3504271	0.3504271
2000	2	0.1951920	0.1380216	0.1380216
2001	2	0.1954247	0.1381861	0.1381861
2002	4	0.1239914	0.0926565	0.0683979
2003	1	.	0.0000000	0.0000000
2004	1	.	0.0000000	0.0000000

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.7514	3	14	0.5395
Brown-Forsythe	22.7812	9	20	<.0001
Levene	65.2695	9	20	<.0001
Bartlett	3.0271	9	.	0.0013

Warning: Small sample sizes. Use Caution.
Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
3.1188	9	4.8875	0.1146

Station=T02
Oneway Analysis of Log Clostridium By Year



Oneway Anova
Summary of Fit

Rsquare	0.839619
Adj Rsquare	0.735372
Root Mean Square Error	0.146333
Mean of Response	3.97543
Observations (or Sum Wgts)	34

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Year	13	2.2420558	0.172466	8.0541	<.0001
Error	20	0.4282679	0.021413		
C. Total	33	2.6703237			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1991	1	4.35984	0.14633	4.0546	4.6651
1992	1	4.17026	0.14633	3.8650	4.4755
1993	2	3.76280	0.10347	3.5470	3.9786
1994	5	4.12786	0.06544	3.9914	4.2644
1995	2	4.38908	0.10347	4.1732	4.6049
1996	2	4.25393	0.10347	4.0381	4.4698
1997	4	4.27195	0.07317	4.1193	4.4246
1998	5	3.85739	0.06544	3.7209	3.9939
1999	2	3.64283	0.10347	3.4270	3.8587
2000	2	3.90621	0.10347	3.6904	4.1221
2001	2	3.66670	0.10347	3.4509	3.8825
2002	4	3.82320	0.07317	3.6706	3.9758
2003	1	3.68664	0.14633	3.3814	3.9919
2004	1	3.39794	0.14633	3.0927	3.7032

Std Error uses a pooled estimate of error variance

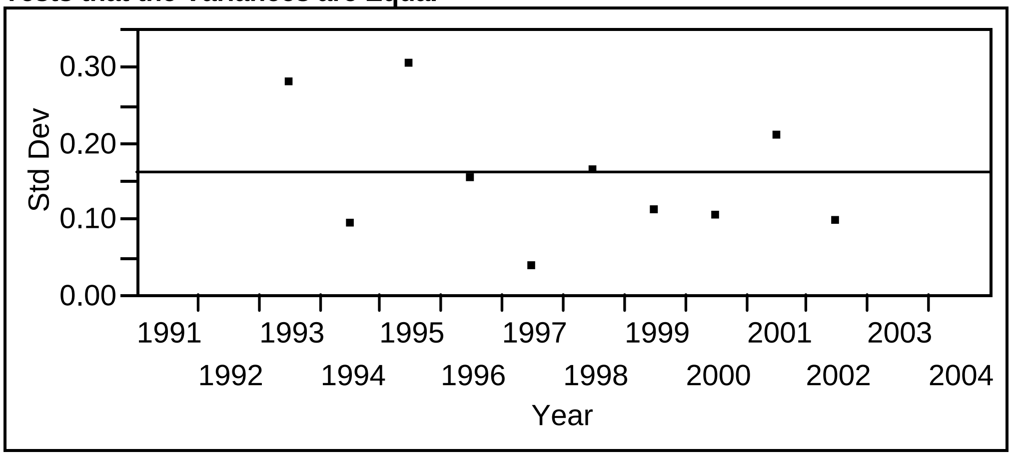
Means Comparisons
Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
3.78816	0.05

Level						Mean
1995	A					4.3890756
1991	A	B	C			4.3598355
1997	A		C			4.2719454
1996	A	B	C			4.2539279
1992	A	B	C	D	E	4.1702617
1994	A	B	C	D		4.1278610
2000	A	B	C	D	E	3.9062107
1998		B		D	E	3.8573925
2002		B		D	E	3.8232004
1993		B		D	E	3.7627951
2003		B	C	D	E	3.6866363
2001				D	E	3.6667045
1999					E	3.6428259
2004					E	3.3979400

Levels not connected by same letter are significantly different

Tests that the Variances are Equal



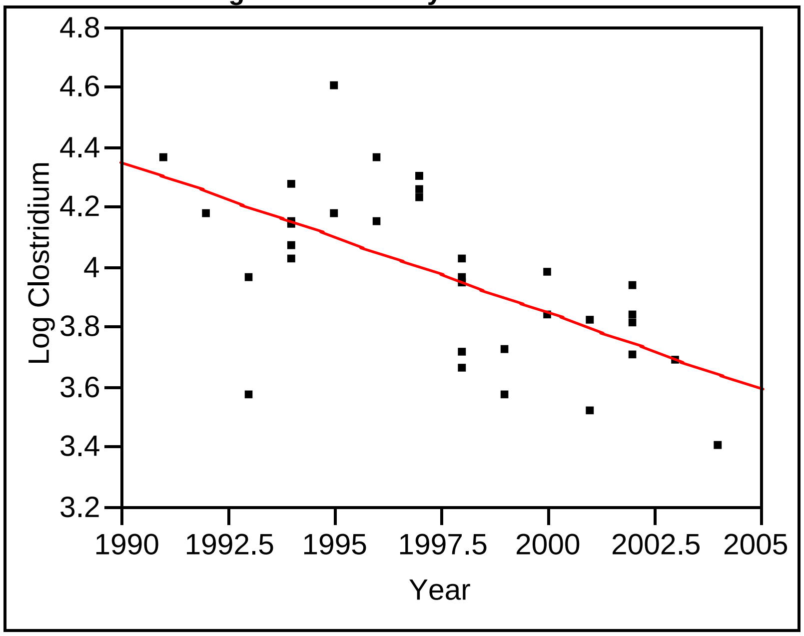
Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
1991	1	.	0.0000000	0.0000000
1992	1	.	0.0000000	0.0000000
1993	2	0.2768588	0.1957688	0.1957688
1994	5	0.0933218	0.0665387	0.0685392
1995	2	0.3012054	0.2129844	0.2129844
1996	2	0.1524521	0.1077999	0.1077999
1997	4	0.0350798	0.0290846	0.0290846
1998	5	0.1630037	0.1394278	0.1265080
1999	2	0.1105347	0.0781598	0.0781598
2000	2	0.1024262	0.0724263	0.0724263
2001	2	0.2077147	0.1468765	0.1468765
2002	4	0.0948470	0.0644810	0.0644810
2003	1	.	0.0000000	0.0000000
2004	1	.	0.0000000	0.0000000

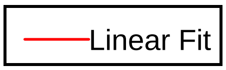
Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	2.8812	3	14	0.0733
Brown-Forsythe	2.2417	9	20	0.0637
Levene	6.1210	9	20	0.0004
Bartlett	1.0271	9	.	0.4151

Warning: Small sample sizes. Use Caution.
Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
9.8542	9	5.0511	0.0104

Station=T02
Bivariate Fit of Log Clostridium By Year





Linear Fit
Log Clostridium = 105.28625 - 0.0507196 Year

Summary of Fit

RSquare	0.374236
RSquare Adj	0.35468
Root Mean Square Error	0.228514
Mean of Response	3.97543
Observations (or Sum Wgts)	34

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	12	1.2427255	0.103560	4.8362
Pure Error	20	0.4282679	0.021413	Prob > F
Total Error	32	1.6709934		0.0010
				Max RSq
				0.8396

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.9993303	0.999330	19.1375
Error	32	1.6709934	0.052219	Prob > F
C. Total	33	2.6703237		0.0001

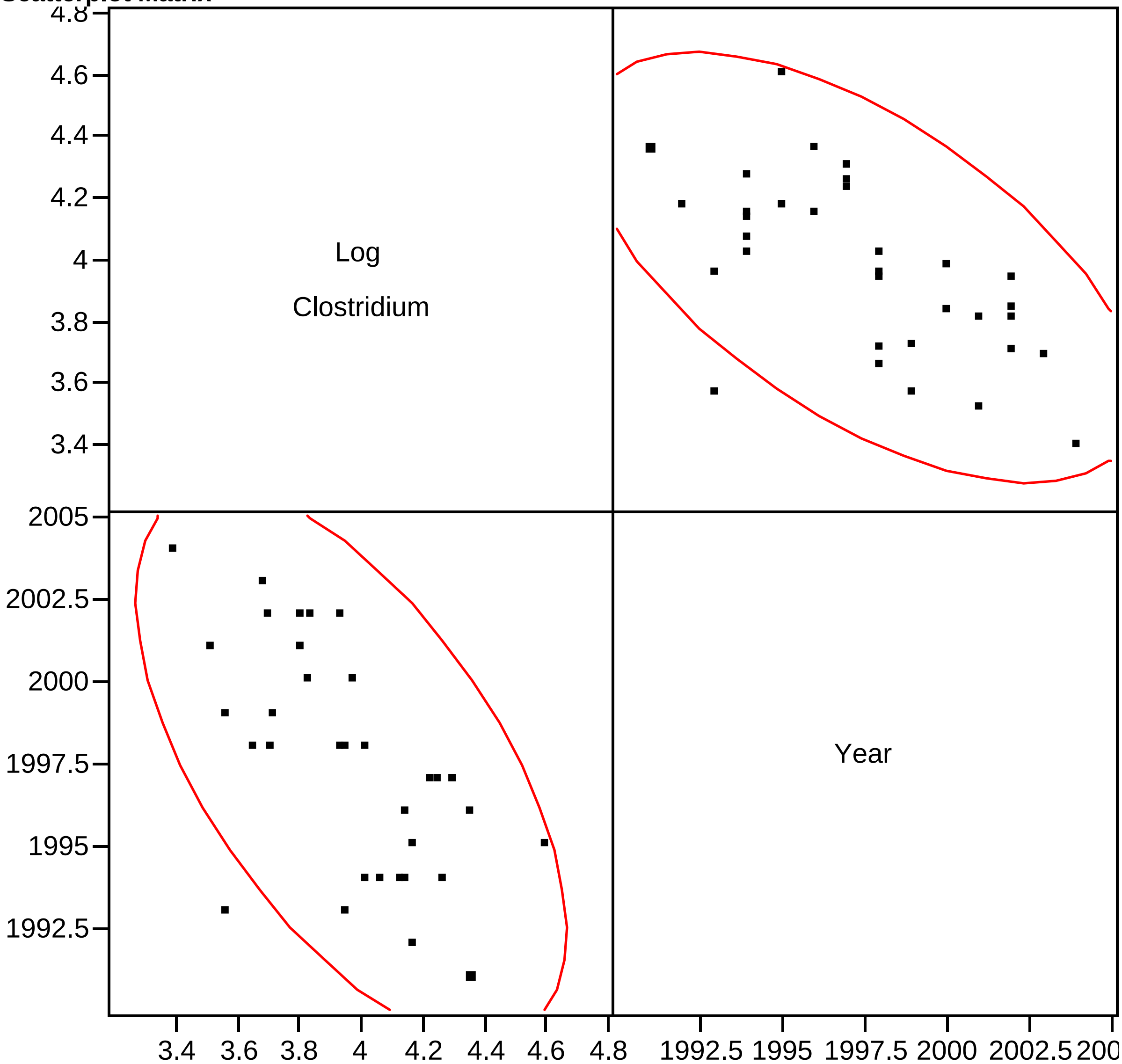
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	105.28625	23.15871	4.55	<.0001
Year	-0.05072	0.011594	-4.37	0.0001

Station=T02
Multivariate
Correlations

	Log Clostridium	Year
Log Clostridium	1.0000	-0.6117
Year	-0.6117	1.0000

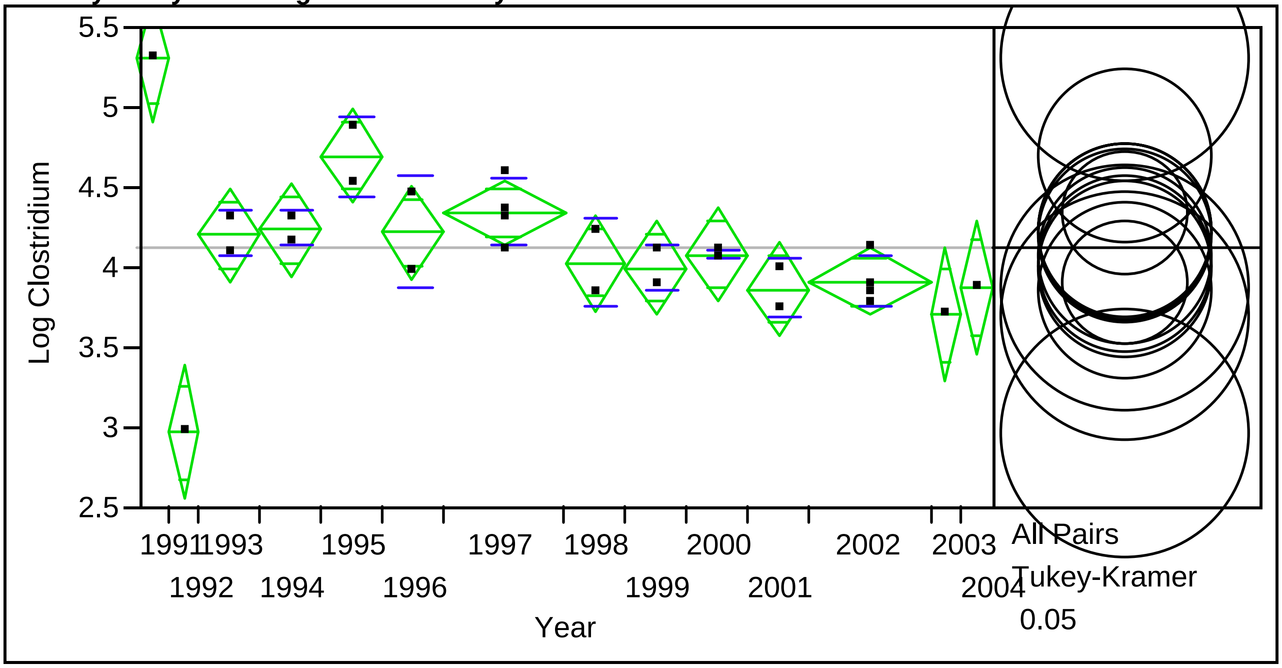
Scatterplot Matrix



Pairwise Correlations

Variable	by Variable	Correlation	Count	Signif Prob	Plot Corr
Year	Log Clostridium	-0.6117	34	0.0001	

Station=T03
Oneway Analysis of Log Clostridium By Year



Oneway Anova
Summary of Fit

Rsquare	0.890266
Adj Rsquare	0.788371
Root Mean Square Error	0.193838
Mean of Response	4.125261
Observations (or Sum Wgts)	28

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Year	13	4.2676114	0.328278	8.7371	0.0001
Error	14	0.5260224	0.037573		
C. Total	27	4.7936338			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1991	1	5.31597	0.19384	4.9002	5.7317
1992	1	2.97220	0.19384	2.5565	3.3879
1993	2	4.20113	0.13706	3.9072	4.4951
1994	2	4.23592	0.13706	3.9420	4.5299
1995	2	4.69679	0.13706	4.4028	4.9908
1996	2	4.22233	0.13706	3.9284	4.5163
1997	4	4.34194	0.09692	4.1341	4.5498
1998	2	4.02627	0.13706	3.7323	4.3202
1999	2	3.99468	0.13706	3.7007	4.2887
2000	2	4.07869	0.13706	3.7847	4.3727
2001	2	3.86165	0.13706	3.5677	4.1556
2002	4	3.91016	0.09692	3.7023	4.1180
2003	1	3.70243	0.19384	3.2867	4.1182
2004	1	3.87332	0.19384	3.4576	4.2891

Std Error uses a pooled estimate of error variance

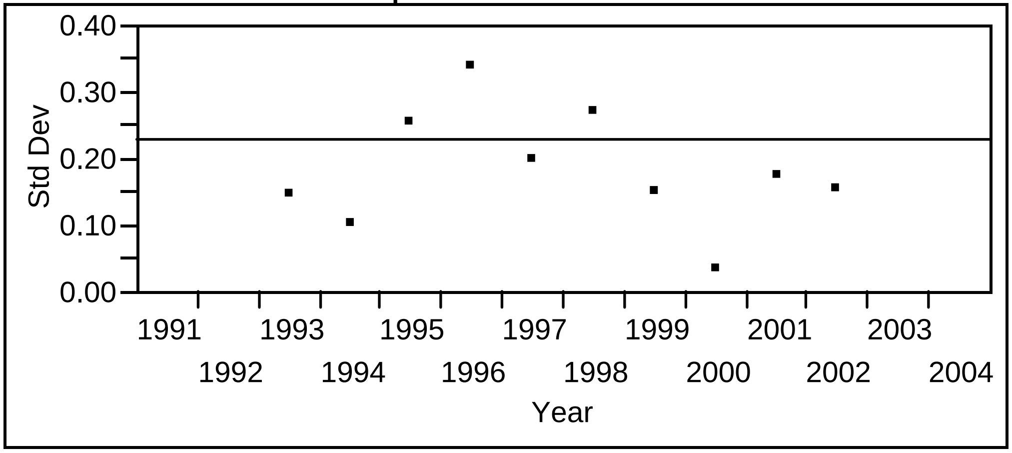
Means Comparisons
Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
3.98541	0.05

Level					Mean
1991	A				5.3159703
1995	A	B			4.6967876
1997		B	C		4.3419414
1994		B	C		4.2359244
1996		B	C		4.2223346
1993		B	C		4.2011307
2000		B	C		4.0786948
1998		B	C		4.0262700
1999		B	C		3.9946822
2002			C		3.9101640
2004		B	C	D	3.8733206
2001			C	D	3.8616539
2003			C	D	3.7024305
1992				D	2.9722028

Levels not connected by same letter are significantly different

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
1991	1	.	0.0000000	0.0000000
1992	1	.	0.0000000	0.0000000
1993	2	0.1473903	0.1042207	0.1042207
1994	2	0.1012175	0.0715716	0.0715716
1995	2	0.2521170	0.1782737	0.1782737
1996	2	0.3395009	0.2400634	0.2400634
1997	4	0.1967322	0.1344548	0.1344548
1998	2	0.2704173	0.1912139	0.1912139
1999	2	0.1514126	0.1070649	0.1070649
2000	2	0.0340568	0.0240818	0.0240818
2001	2	0.1737692	0.1228734	0.1228734
2002	4	0.1546092	0.1100849	0.1024378
2003	1	.	0.0000000	0.0000000
2004	1	.	0.0000000	0.0000000

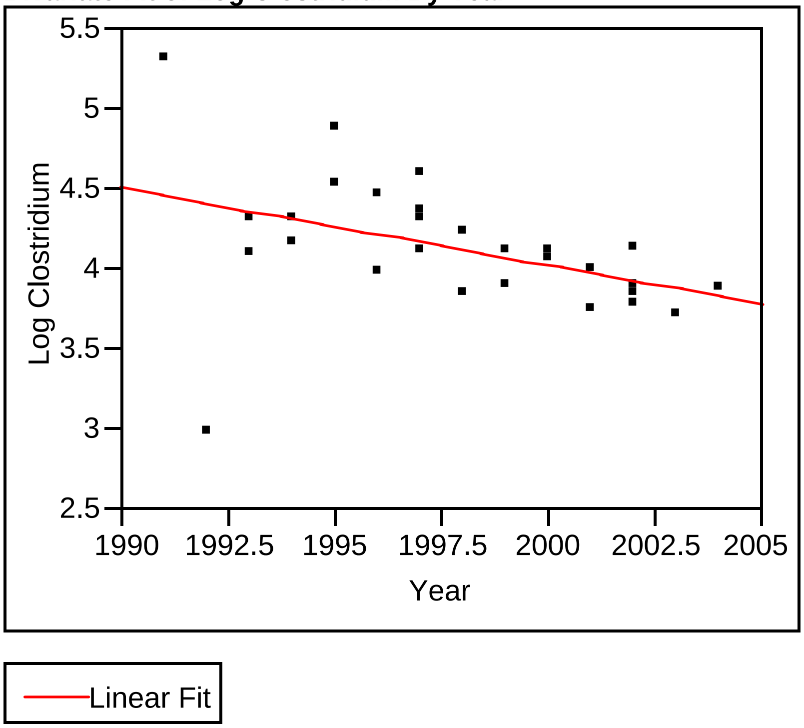
Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.2057	1	6	0.6661
Brown-Forsythe	1.3550	9	14	0.2944
Levene	1.6158	9	14	0.2030
Bartlett	0.4208	9	.	0.9248

Warning: Small sample sizes. Use Caution.
Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
1.7177	9	4.5248	0.2994

Station=T03

Bivariate Fit of Log Clostridium By Year



Linear Fit

Log Clostridium = 100.60863 - 0.0482952 Year

Summary of Fit

RSquare	0.169673
RSquare Adj	0.137737
Root Mean Square Error	0.391264
Mean of Response	4.125261
Observations (or Sum Wgts)	28

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	12	3.4542626	0.287855	7.6612
Pure Error	14	0.5260224	0.037573	Prob > F
Total Error	26	3.9802850		0.0003
				Max RSq
				0.8903

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.8133488	0.813349	5.3130
Error	26	3.9802850	0.153088	Prob > F
C. Total	27	4.7936338		0.0294

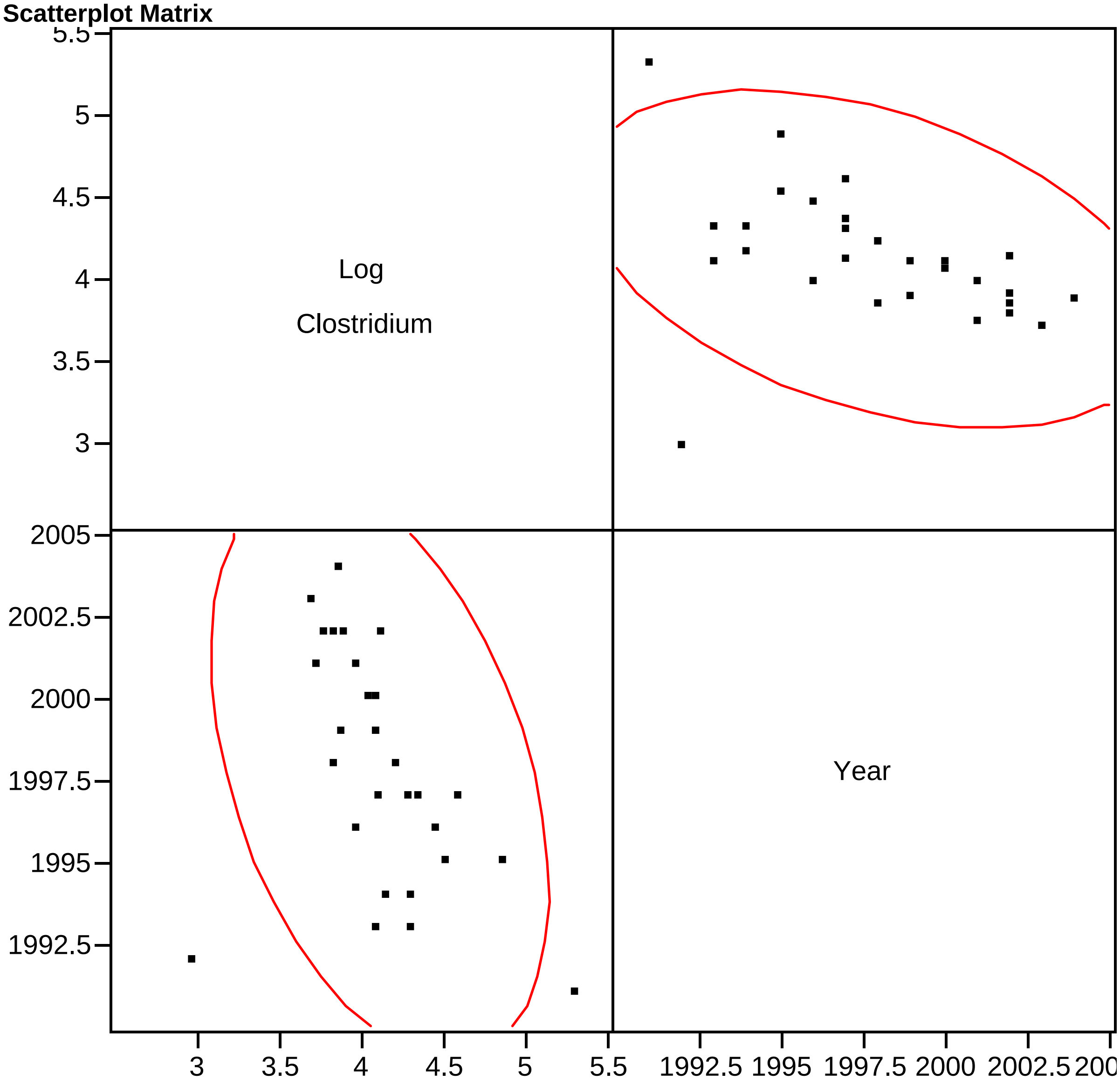
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	100.60863	41.85864	2.40	0.0237
Year	-0.048295	0.020952	-2.30	0.0294

Station=T03
Multivariate
Correlations

	Log Clostridium	Year
Log Clostridium	1.0000	-0.4119
Year	-0.4119	1.0000

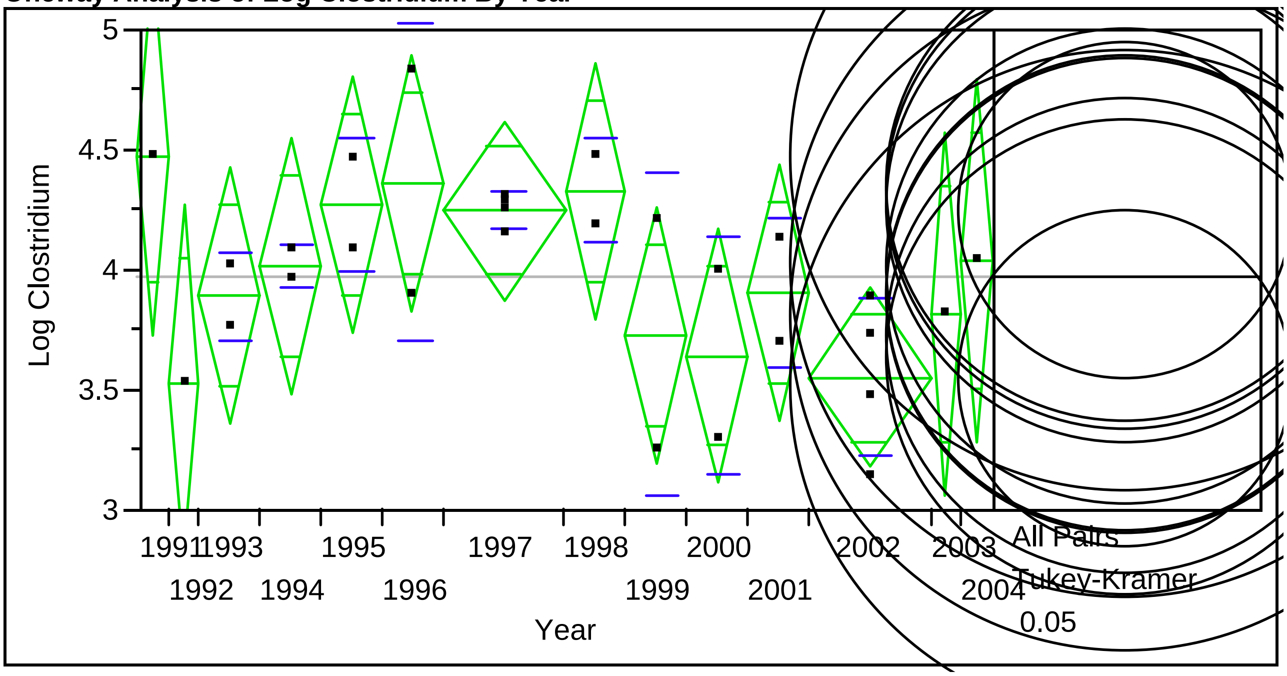
Scatterplot Matrix



Pairwise Correlations

Variable	by Variable	Correlation	Count	Signif Prob	Plot Corr
Year	Log Clostridium	-0.4119	28	0.0294	

Station=T04
Oneway Analysis of Log Clostridium By Year



Oneway Anova
Summary of Fit

Rsquare	0.598374
Adj Rsquare	0.225436
Root Mean Square Error	0.350954
Mean of Response	3.976983
Observations (or Sum Wgts)	28

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Year	13	2.5690957	0.197623	1.6045	0.1956
Error	14	1.7243658	0.123169		
C. Total	27	4.2934615			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1991	1	4.47712	0.35095	3.7244	5.2298
1992	1	3.52244	0.35095	2.7697	4.2752
1993	2	3.89043	0.24816	3.3582	4.4227
1994	2	4.01863	0.24816	3.4864	4.5509
1995	2	4.27079	0.24816	3.7385	4.8030
1996	2	4.35908	0.24816	3.8268	4.8913
1997	4	4.24530	0.17548	3.8689	4.6217
1998	2	4.32660	0.24816	3.7943	4.8589
1999	2	3.73145	0.24816	3.1992	4.2637
2000	2	3.64351	0.24816	3.1113	4.1758
2001	2	3.90930	0.24816	3.3770	4.4416
2002	4	3.55422	0.17548	3.1779	3.9306
2003	1	3.81690	0.35095	3.0642	4.5696
2004	1	4.04139	0.35095	3.2887	4.7941

Std Error uses a pooled estimate of error variance

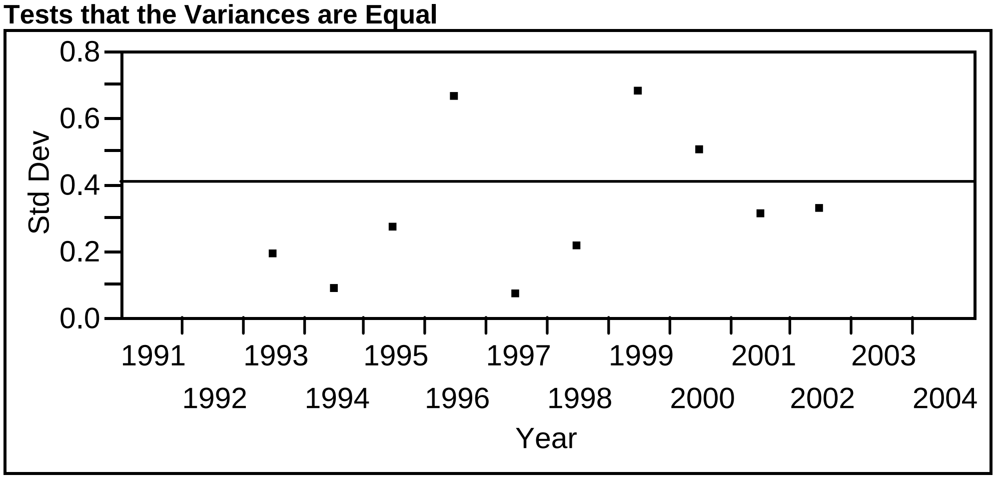
Means Comparisons
Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
3.98541	0.05

Level		Mean
1991	A	4.4771213
1996	A	4.3590847
1998	A	4.3265966
1995	A	4.2707896
1997	A	4.2452960
2004	A	4.0413927
1994	A	4.0186335
2001	A	3.9092977
1993	A	3.8904286
2003	A	3.8169038
1999	A	3.7314534
2000	A	3.6435065
2002	A	3.5542228
1992	A	3.5224442

Levels not connected by same letter are significantly different

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
1991	1	.	0.0000000	0.0000000
1992	1	.	0.0000000	0.0000000
1993	2	0.1849236	0.1307607	0.1307607
1994	2	0.0856274	0.0605477	0.0605477
1995	2	0.2709752	0.1916084	0.1916084
1996	2	0.6604237	0.4669901	0.4669901
1997	4	0.0687011	0.0495840	0.0445958
1998	2	0.2087657	0.1476197	0.1476197
1999	2	0.6734215	0.4761809	0.4761809
2000	2	0.4967431	0.3512504	0.3512504
2001	2	0.3098564	0.2191016	0.2191016
2002	4	0.3262136	0.2488927	0.2488927
2003	1	.	0.0000000	0.0000000
2004	1	.	0.0000000	0.0000000

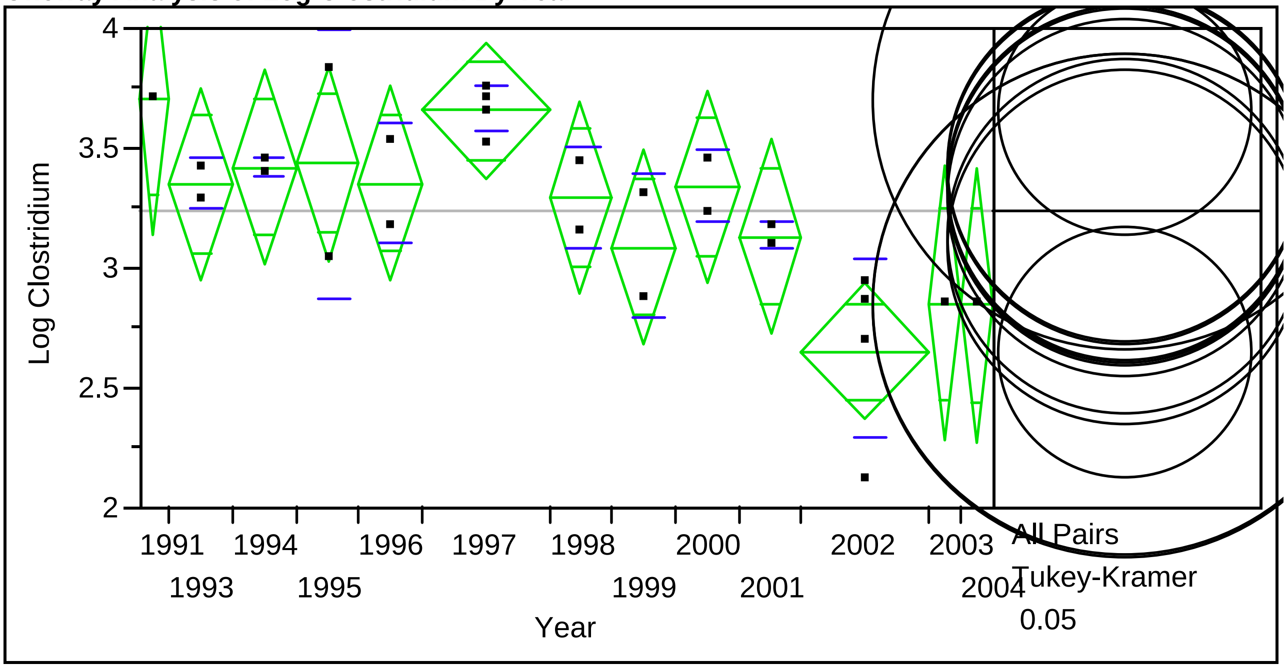
Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	2.4405	1	6	0.1693
Brown-Forsythe	8.6959	9	14	0.0002
Levene	9.9780	9	14	0.0001
Bartlett	1.0846	9	.	0.3701

Warning: Small sample sizes. Use Caution.

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
1.7633	9	4.2647	0.2978

Station=T05A
Oneway Analysis of Log Clostridium By Year



Oneway Anova
Summary of Fit

Rsquare	0.743818
Adj Rsquare	0.524233
Root Mean Square Error	0.266562
Mean of Response	3.239572
Observations (or Sum Wgts)	27

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Year	12	2.8882957	0.240691	3.3874	0.0163
Error	14	0.9947740	0.071055		
C. Total	26	3.8830696			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1991	1	3.70586	0.26656	3.1341	4.2776
1993	2	3.34884	0.18849	2.9446	3.7531
1994	2	3.42213	0.18849	3.0179	3.8264
1995	2	3.43695	0.18849	3.0327	3.8412
1996	2	3.35379	0.18849	2.9495	3.7581
1997	4	3.65687	0.13328	3.3710	3.9427
1998	2	3.29509	0.18849	2.8908	3.6994
1999	2	3.08805	0.18849	2.6838	3.4923
2000	2	3.33880	0.18849	2.9345	3.7431
2001	2	3.13037	0.18849	2.7261	3.5346
2002	4	2.65268	0.13328	2.3668	2.9385
2003	1	2.85126	0.26656	2.2795	3.4230
2004	1	2.84510	0.26656	2.2734	3.4168

Std Error uses a pooled estimate of error variance

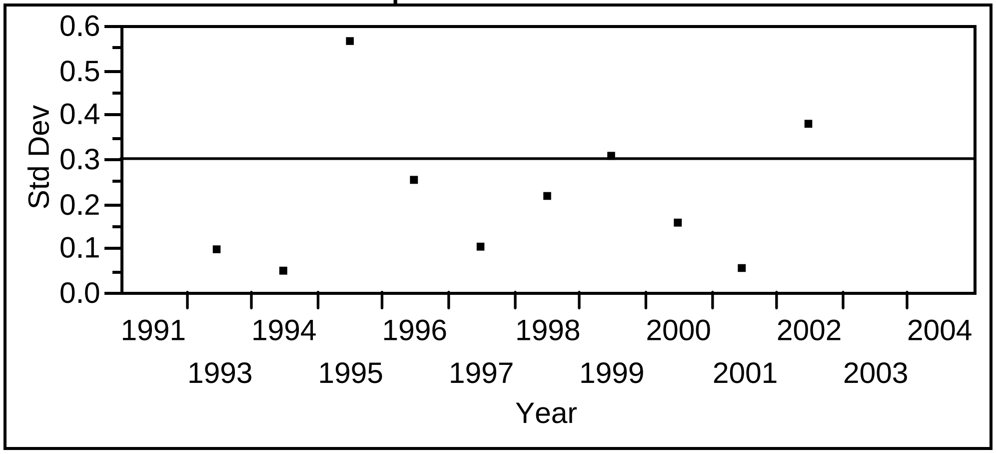
Means Comparisons
Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
3.92663	0.05

Level			Mean
1991	A	B	3.7058637
1997	A		3.6568712
1995	A	B	3.4369508
1994	A	B	3.4221267
1996	A	B	3.3537851
1993	A	B	3.3488369
2000	A	B	3.3388035
1998	A	B	3.2950864
2001	A	B	3.1303695
1999	A	B	3.0880456
2003	A	B	2.8512583
2004	A	B	2.8450980
2002		B	2.6526837

Levels not connected by same letter are significantly different

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
1991	1	.	0.0000000	0.0000000
1993	2	0.0958887	0.0678036	0.0678036
1994	2	0.0441116	0.0311916	0.0311916
1995	2	0.5594036	0.3955581	0.3955581
1996	2	0.2512970	0.1776938	0.1776938
1997	4	0.1001087	0.0710079	0.0710079
1998	2	0.2106590	0.1489584	0.1489584
1999	2	0.3012054	0.2129844	0.2129844
2000	2	0.1532365	0.1083546	0.1083546
2001	2	0.0522521	0.0369478	0.0369478
2002	4	0.3724567	0.2693702	0.2462270
2003	1	.	0.0000000	0.0000000
2004	1	.	0.0000000	0.0000000

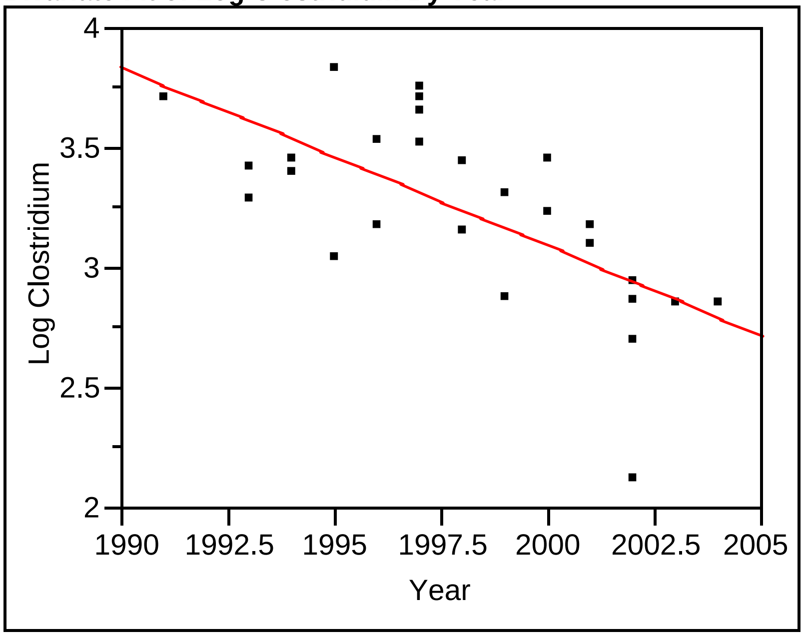
Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	1.4474	1	6	0.2743
Brown-Forsythe	1.6237	9	14	0.2007
Levene	3.2318	9	14	0.0243
Bartlett	1.0737	9	.	0.3784

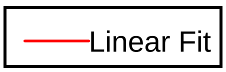
Warning: Small sample sizes. Use Caution.
Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
4.8482	9	4.6223	0.0559

Station=T05A

Bivariate Fit of Log Clostridium By Year





Linear Fit

Log Clostridium = 152.05505 - 0.0744822 Year

Summary of Fit

RSquare	0.4486
RSquare Adj	0.426544
Root Mean Square Error	0.292652
Mean of Response	3.239572
Observations (or Sum Wgts)	27

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	11	1.1463488	0.104214	1.4667
Pure Error	14	0.9947740	0.071055	Prob > F
Total Error	25	2.1411227		0.2467
				Max RSq
				0.7438

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	1.7419469	1.74195	20.3392
Error	25	2.1411227	0.08564	Prob > F
C. Total	26	3.8830696		0.0001

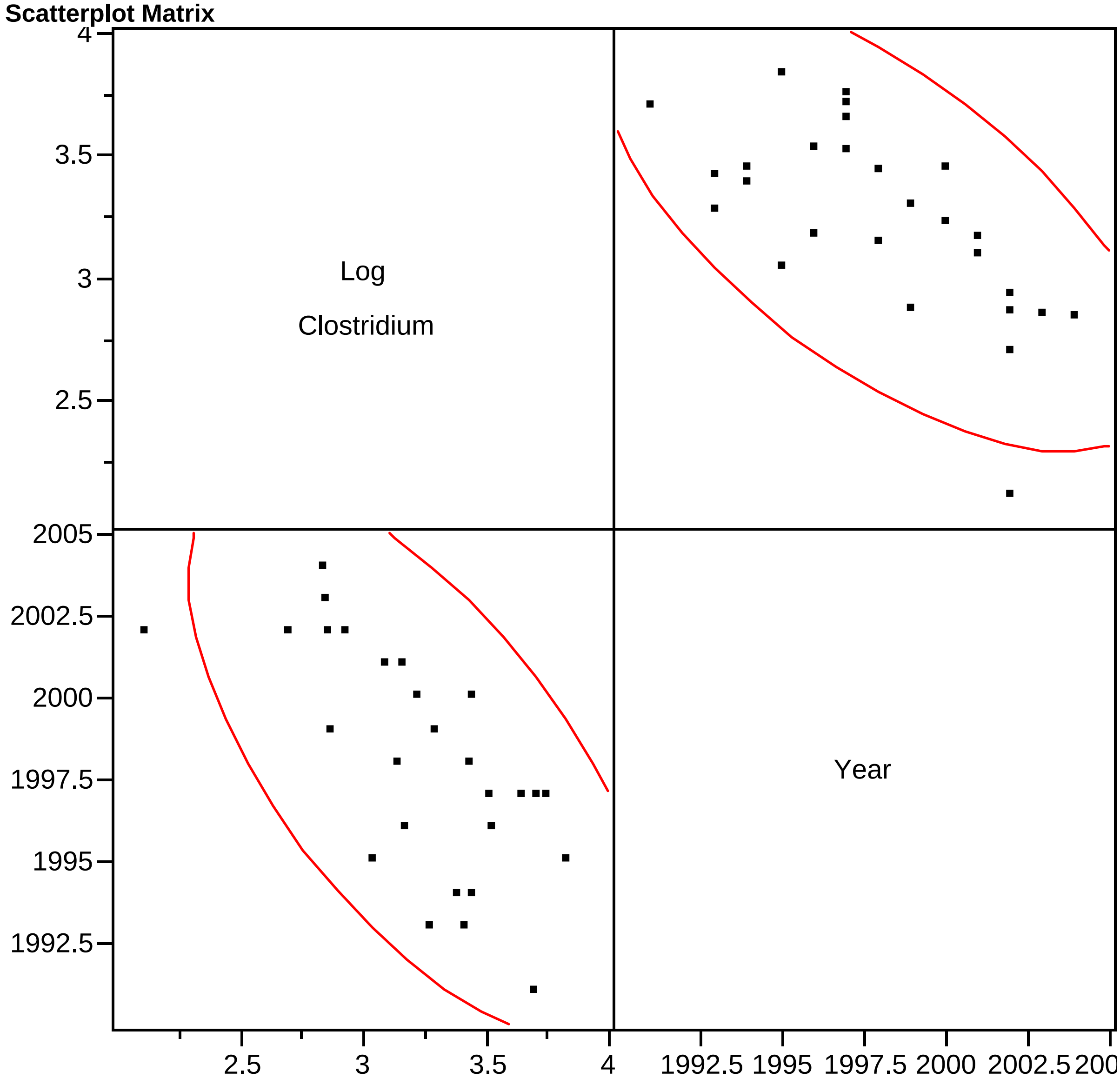
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	152.05505	32.99758	4.61	0.0001
Year	-0.074482	0.016515	-4.51	0.0001

Station=T05A
Multivariate
Correlations

	Log Clostridium	Year
Log Clostridium	1.0000	-0.6698
Year	-0.6698	1.0000

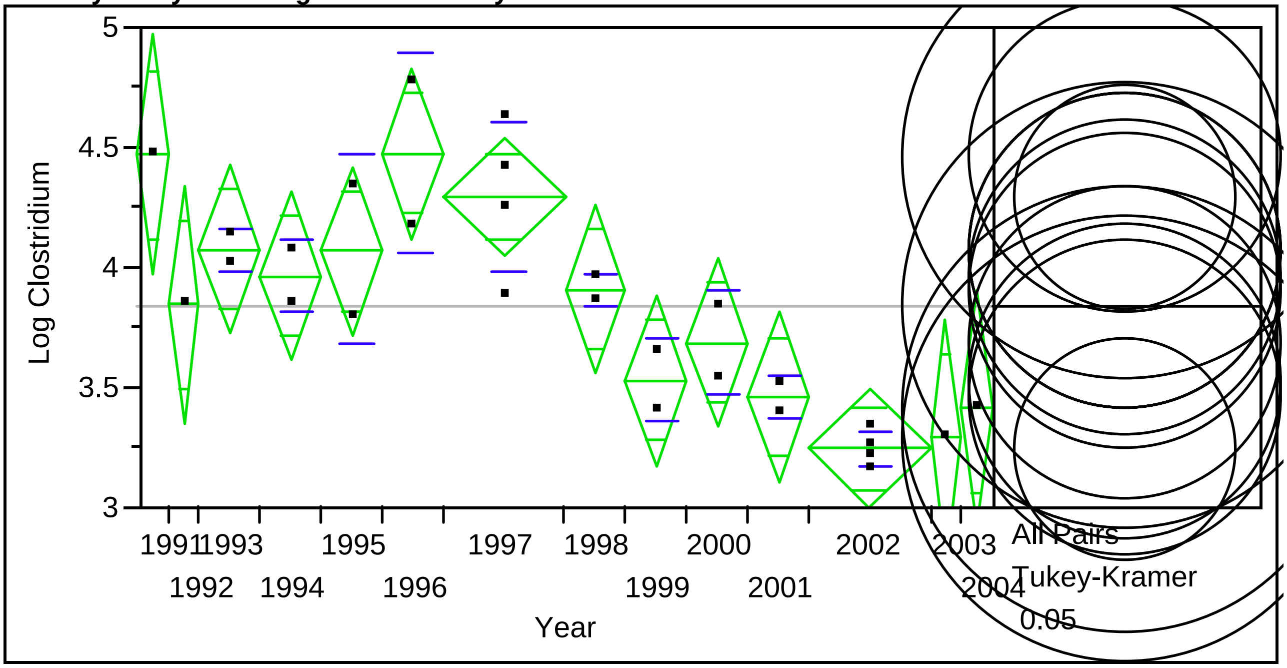
Scatterplot Matrix



Pairwise Correlations

Variable	by Variable	Correlation	Count	Signif Prob	Plot Corr
Year	Log Clostridium	-0.6698	27	0.0001	

Station=T06
Oneway Analysis of Log Clostridium By Year



Oneway Anova
Summary of Fit

Rsquare	0.861606
Adj Rsquare	0.733098
Root Mean Square Error	0.232402
Mean of Response	3.839786
Observations (or Sum Wgts)	28

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Year	13	4.7076093	0.362124	6.7047	0.0006
Error	14	0.7561509	0.054011		
C. Total	27	5.4637602			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1991	1	4.46835	0.23240	3.9699	4.9668
1992	1	3.84510	0.23240	3.3466	4.3436
1993	2	4.07636	0.16433	3.7239	4.4288
1994	2	3.96371	0.16433	3.6112	4.3162
1995	2	4.06741	0.16433	3.7149	4.4199
1996	2	4.47347	0.16433	4.1210	4.8259
1997	4	4.29500	0.11620	4.0458	4.5442
1998	2	3.90939	0.16433	3.5569	4.2618
1999	2	3.52879	0.16433	3.1763	3.8812
2000	2	3.68864	0.16433	3.3362	4.0411
2001	2	3.46041	0.16433	3.1079	3.8129
2002	4	3.24565	0.11620	2.9964	3.4949
2003	1	3.29003	0.23240	2.7916	3.7885
2004	1	3.41162	0.23240	2.9132	3.9101

Std Error uses a pooled estimate of error variance

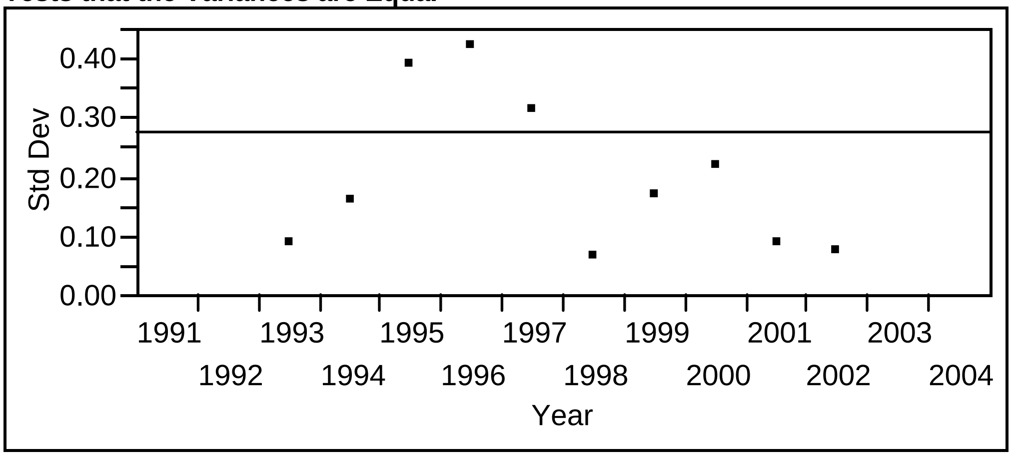
Means Comparisons
Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
3.98541	0.05

Level					Mean
1996	A				4.4734716
1991	A	B	C		4.4683473
1997	A	B			4.2949965
1993	A	B	C		4.0763582
1995	A	B	C		4.0674072
1994	A	B	C	D	3.9637083
1998	A	B	C	D	3.9093900
1992	A	B	C	D	3.8450980
2000	A	B	C	D	3.6886395
1999		B	C	D	3.5287874
2001			C	D	3.4604059
2004	A	B	C	D	3.4116197
2003		B	C	D	3.2900346
2002				D	3.2456459

Levels not connected by same letter are significantly different

Tests that the Variances are Equal



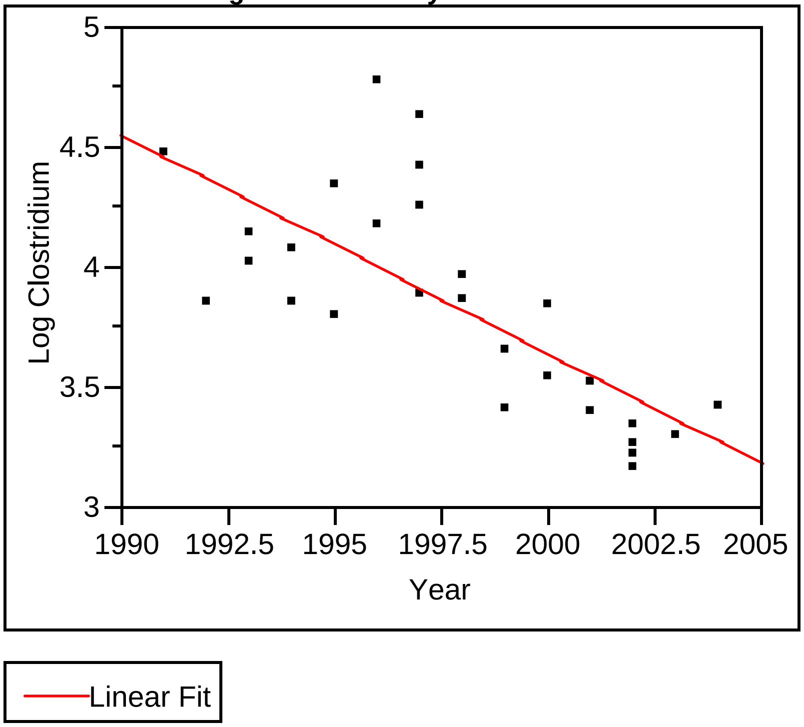
Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
1991	1	.	0.0000000	0.0000000
1992	1	.	0.0000000	0.0000000
1993	2	0.0898322	0.0635209	0.0635209
1994	2	0.1581638	0.1118387	0.1118387
1995	2	0.3889306	0.2750155	0.2750155
1996	2	0.4205594	0.2973804	0.2973804
1997	4	0.3112337	0.2241149	0.2241149
1998	2	0.0668338	0.0472586	0.0472586
1999	2	0.1704798	0.1205474	0.1205474
2000	2	0.2168631	0.1533453	0.1533453
2001	2	0.0858883	0.0607322	0.0607322
2002	4	0.0739194	0.0534154	0.0534154
2003	1	.	0.0000000	0.0000000
2004	1	.	0.0000000	0.0000000

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	1.9390	1	6	0.2132
Brown-Forsythe	2.8940	9	14	0.0366
Levene	3.0965	9	14	0.0286
Bartlett	0.9116	9	.	0.5137

Warning: Small sample sizes. Use Caution.
Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
12.1284	9	4.5009	0.0097

Station=T06
Bivariate Fit of Log Clostridium By Year



Linear Fit
Log Clostridium = 186.23452 - 0.0912984 Year

Summary of Fit

RSquare	0.531992
RSquare Adj	0.513991
Root Mean Square Error	0.313607
Mean of Response	3.839786
Observations (or Sum Wgts)	28

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	12	1.8009339	0.150078	2.7787
Pure Error	14	0.7561509	0.054011	Prob > F
Total Error	26	2.5570848		0.0358
				Max RSq
				0.8616

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	2.9066754	2.90668	29.5546
Error	26	2.5570848	0.09835	Prob > F
C. Total	27	5.4637602		<.0001

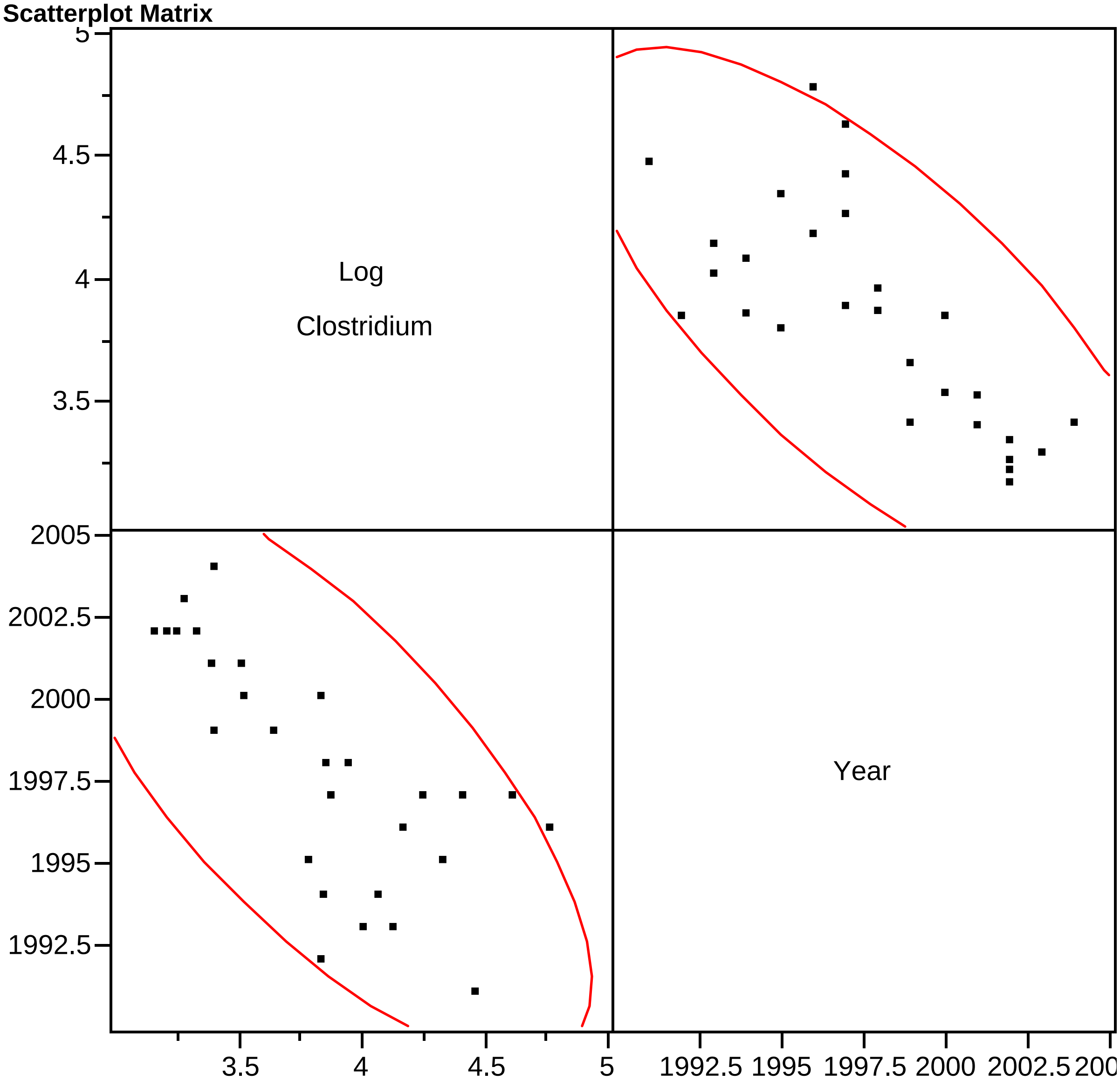
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	186.23452	33.55062	5.55	<.0001
Year	-0.091298	0.016794	-5.44	<.0001

Station=T06
Multivariate
Correlations

	Log Clostridium	Year
Log Clostridium	1.0000	-0.7294
Year	-0.7294	1.0000

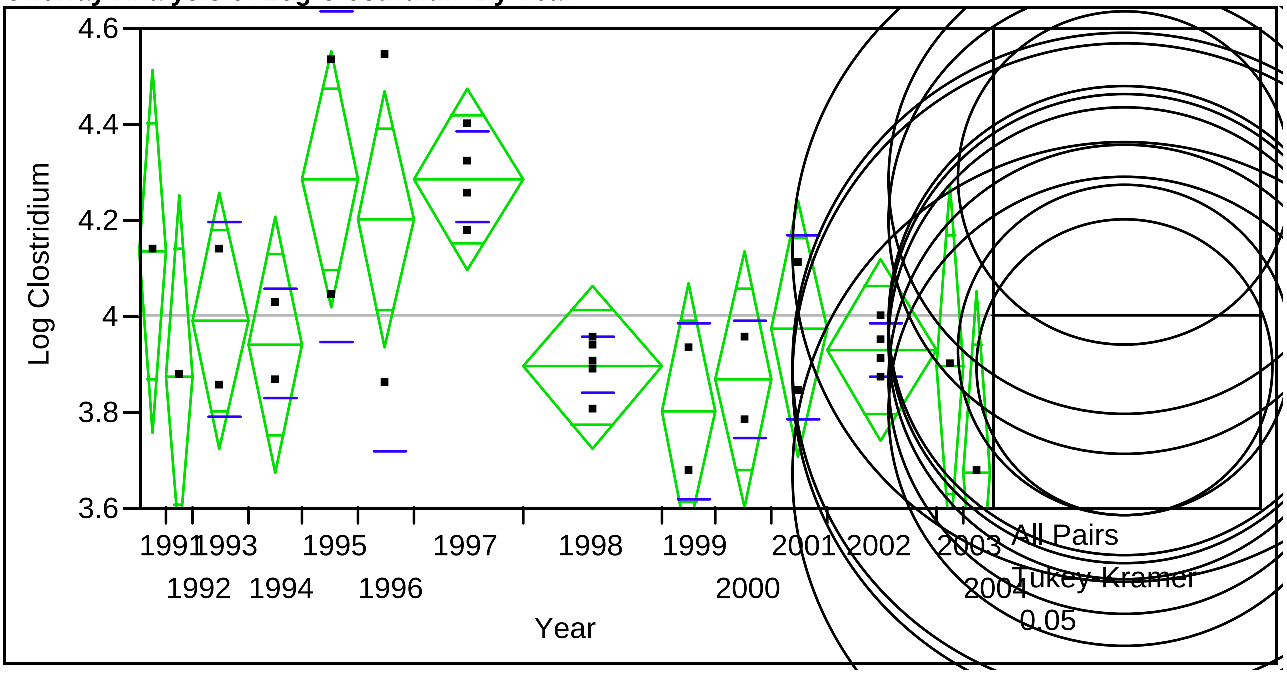
Scatterplot Matrix



Pairwise Correlations

Variable	by Variable	Correlation	Count	Signif Prob	Plot Corr
Year	Log Clostridium	-0.7294	28	0.0000	

Station=T07
Oneway Analysis of Log Clostridium By Year



Oneway Anova
Summary of Fit

Rsquare	0.628797
Adj Rsquare	0.344936
Root Mean Square Error	0.178879
Mean of Response	4.00247
Observations (or Sum Wgts)	31

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Year	13	0.9214438	0.070880	2.2152	0.0628
Error	17	0.5439635	0.031998		
C. Total	30	1.4654073			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1991	1	4.13672	0.17888	3.7593	4.5141
1992	1	3.87506	0.17888	3.4977	4.2525
1993	2	3.99399	0.12649	3.7271	4.2609
1994	2	3.94402	0.12649	3.6772	4.2109
1995	2	4.28644	0.12649	4.0196	4.5533
1996	2	4.20070	0.12649	3.9338	4.4676
1997	4	4.28788	0.08944	4.0992	4.4766
1998	5	3.89545	0.08000	3.7267	4.0642
1999	2	3.80219	0.12649	3.5353	4.0691
2000	2	3.86716	0.12649	3.6003	4.1340
2001	2	3.97436	0.12649	3.7075	4.2412
2002	4	3.93114	0.08944	3.7424	4.1198
2003	1	3.89982	0.17888	3.5224	4.2772
2004	1	3.67394	0.17888	3.2965	4.0513

Std Error uses a pooled estimate of error variance

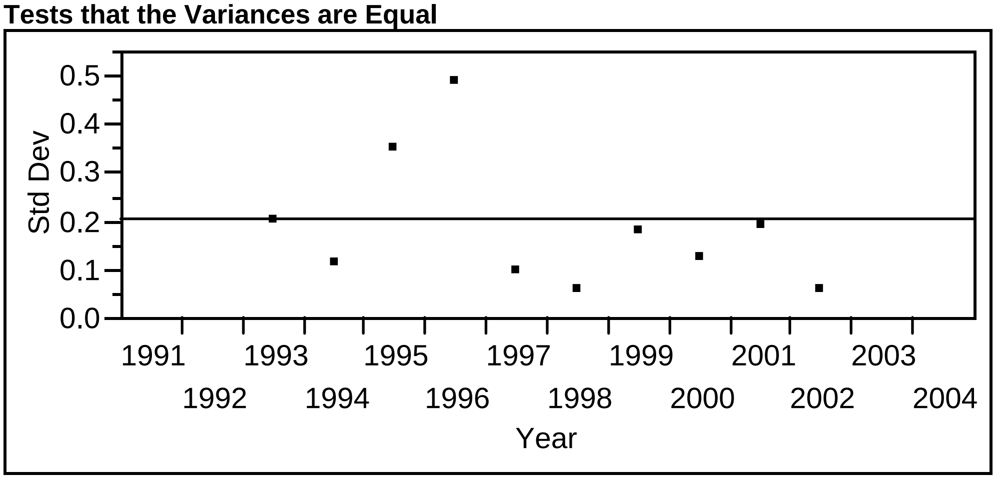
Means Comparisons
Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
3.86859	0.05

Level		Mean
1997	A	4.2878808
1995	A	4.2864358
1996	A	4.2007003
1991	A	4.1367206
1993	A	3.9939895
2001	A	3.9743595
1994	A	3.9440167
2002	A	3.9311360
2003	A	3.8998205
1998	A	3.8954520
1992	A	3.8750613
2000	A	3.8671566
1999	A	3.8021908
2004	A	3.6739420

Levels not connected by same letter are significantly different

Tests that the Variances are Equal



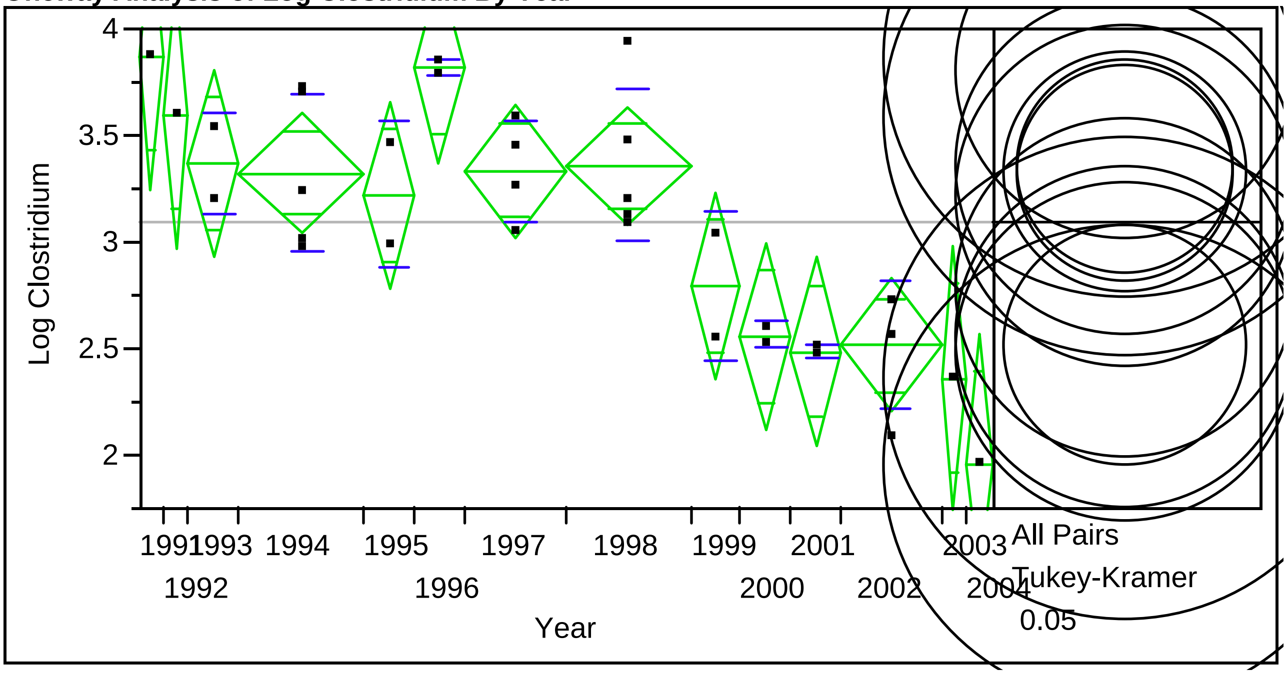
Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
1991	1	.	0.0000000	0.0000000
1992	1	.	0.0000000	0.0000000
1993	2	0.2018523	0.1427311	0.1427311
1994	2	0.1149602	0.0812892	0.0812892
1995	2	0.3465433	0.2450431	0.2450431
1996	2	0.4855954	0.3433678	0.3433678
1997	4	0.0946086	0.0721989	0.0721989
1998	5	0.0585019	0.0417875	0.0441456
1999	2	0.1813712	0.1282488	0.1282488
2000	2	0.1217916	0.0861197	0.0861197
2001	2	0.1907512	0.1348815	0.1348815
2002	4	0.0561286	0.0420901	0.0420901
2003	1	.	0.0000000	0.0000000
2004	1	.	0.0000000	0.0000000

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.8856	2	10	0.4425
Brown-Forsythe	29.0134	9	17	<.0001
Levene	28.2995	9	17	<.0001
Bartlett	1.5193	9	.	0.1344

Warning: Small sample sizes. Use Caution.
Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
3.0860	9	4.5631	0.1260

Station=T08
Oneway Analysis of Log Clostridium By Year



Oneway Anova
Summary of Fit

Rsquare	0.810333
Adj Rsquare	0.687049
Root Mean Square Error	0.297394
Mean of Response	3.089536
Observations (or Sum Wgts)	34

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Year	13	7.5573090	0.581331	6.5729	0.0001
Error	20	1.7688694	0.088443		
C. Total	33	9.3261785			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1991	1	3.86510	0.29739	3.2447	4.4855
1992	1	3.58995	0.29739	2.9696	4.2103
1993	2	3.36634	0.21029	2.9277	3.8050
1994	5	3.32459	0.13300	3.0472	3.6020
1995	2	3.22120	0.21029	2.7825	3.6599
1996	2	3.81343	0.21029	3.3748	4.2521
1997	4	3.33232	0.14870	3.0221	3.6425
1998	5	3.35629	0.13300	3.0789	3.6337
1999	2	2.79075	0.21029	2.3521	3.2294
2000	2	2.55756	0.21029	2.1189	2.9962
2001	2	2.48675	0.21029	2.0481	2.9254
2002	4	2.51687	0.14870	2.2067	2.8270
2003	1	2.36173	0.29739	1.7414	2.9821
2004	1	1.95424	0.29739	1.3339	2.5746

Std Error uses a pooled estimate of error variance

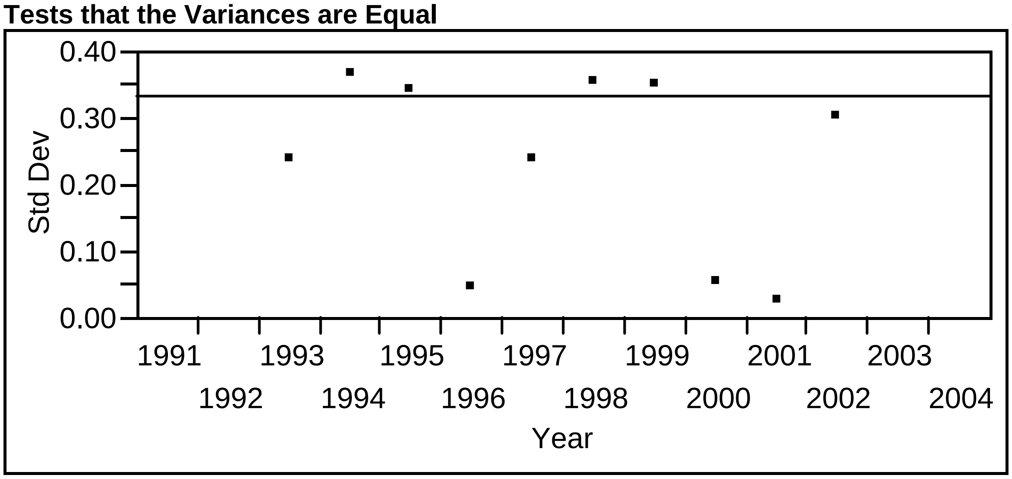
Means Comparisons
Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
3.78816	0.05

Level					Mean
1991	A	B			3.8651040
1996	A				3.8134267
1992	A	B	C		3.5899496
1993	A	B	C		3.3663416
1998	A	B			3.3562902
1997	A	B			3.3323210
1994	A	B			3.3245860
1995	A	B	C	D	3.2212007
1999	A	B	C	D	2.7907473
2000		B	C	D	2.5575555
2002			C	D	2.5168726
2001		B	C	D	2.4867487
2003		B	C	D	2.3617278
2004				D	1.9542425

Levels not connected by same letter are significantly different

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
1991	1	.	0.0000000	0.0000000
1992	1	.	0.0000000	0.0000000
1993	2	0.2371417	0.1676845	0.1676845
1994	5	0.3642822	0.3066236	0.3340406
1995	2	0.3411045	0.2411973	0.2411973
1996	2	0.0447900	0.0316713	0.0316713
1997	4	0.2365326	0.1839884	0.1839884
1998	5	0.3527621	0.2726378	0.2522733
1999	2	0.3488571	0.2466792	0.2466792
2000	2	0.0552131	0.0390416	0.0390416
2001	2	0.0260234	0.0184013	0.0184013
2002	4	0.3013495	0.2188457	0.1991307
2003	1	.	0.0000000	0.0000000
2004	1	.	0.0000000	0.0000000

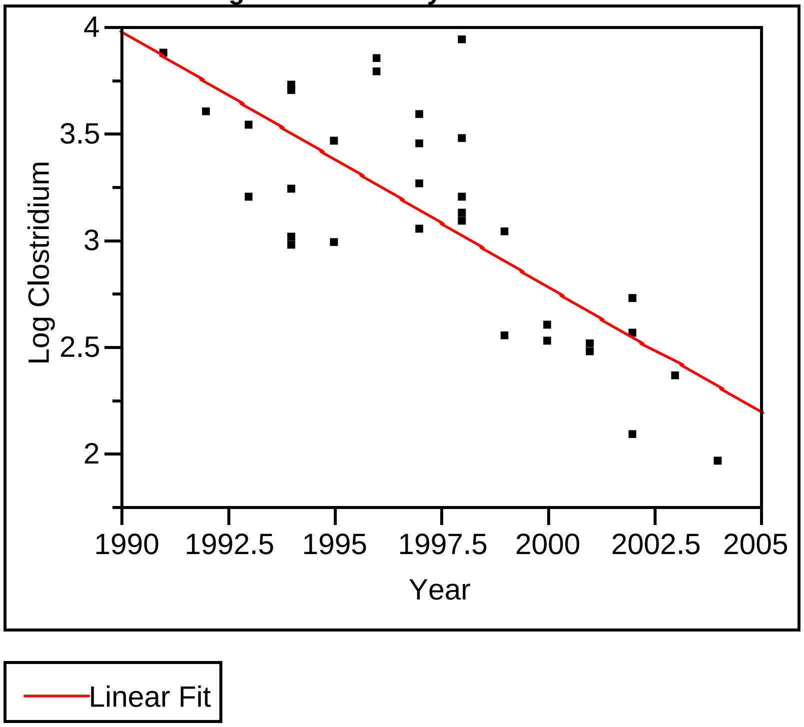
Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	0.3144	3	14	0.8147
Brown-Forsythe	1.0726	9	20	0.4230
Levene	1.9988	9	20	0.0946
Bartlett	0.8961	9	.	0.5276

Warning: Small sample sizes. Use Caution.
Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
82.0727	9	5.8402	<.0001

Station=T08

Bivariate Fit of Log Clostridium By Year



Linear Fit

Log Clostridium = 242.25318 - 0.1197333 Year

Summary of Fit

RSquare	0.597151
RSquare Adj	0.584562
Root Mean Square Error	0.342648
Mean of Response	3.089536
Observations (or Sum Wgts)	34

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	12	1.9881747	0.165681	1.8733
Pure Error	20	1.7688694	0.088443	Prob > F
Total Error	32	3.7570441		0.1035
				Max RSq
				0.8103

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	5.5691343	5.56913	47.4342
Error	32	3.7570441	0.11741	Prob > F
C. Total	33	9.3261785		<.0001

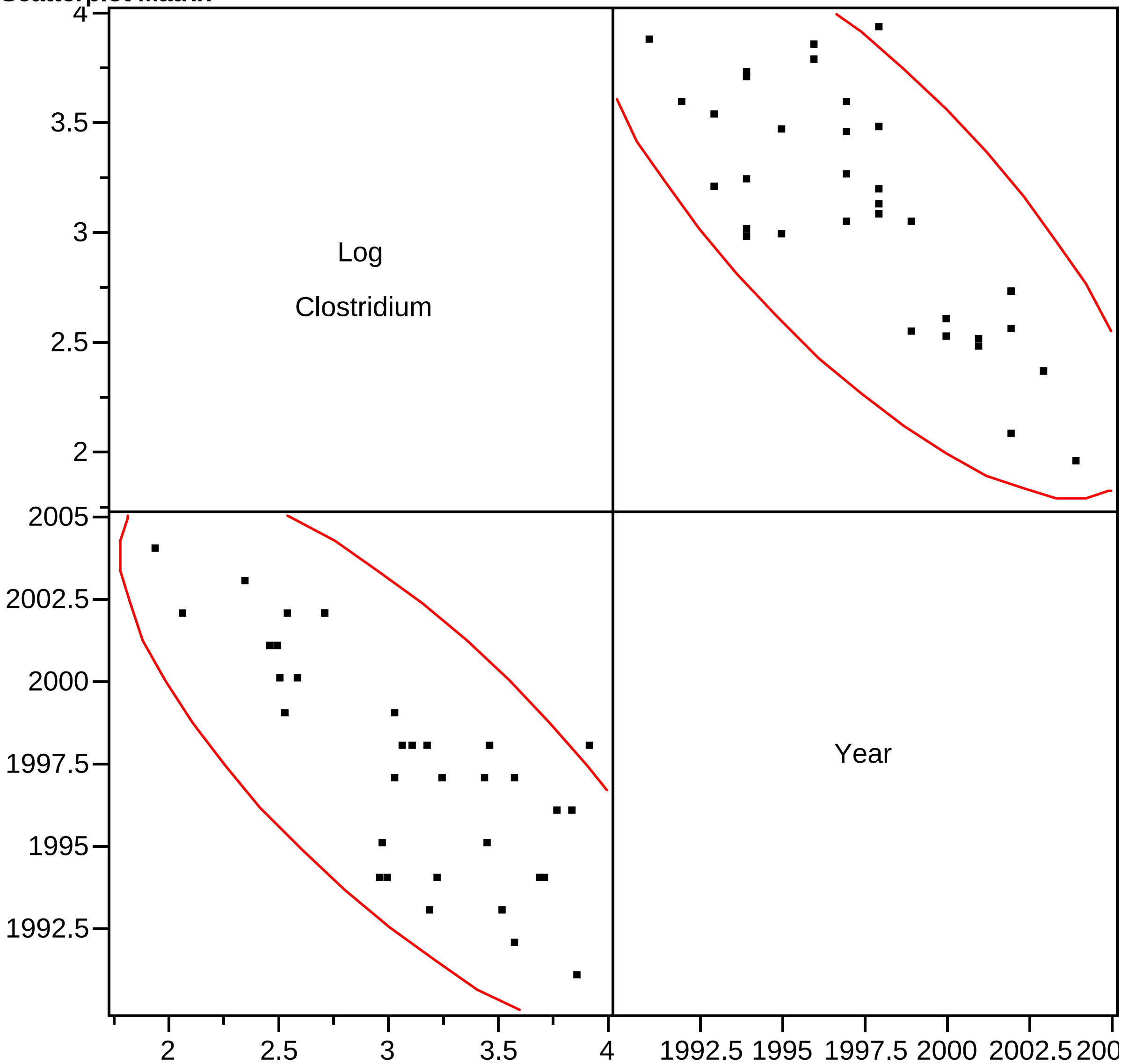
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	242.25318	34.72563	6.98	<.0001

Station=T08
Multivariate
Correlations

	Log Clostridium	Year
Log Clostridium	1.0000	-0.7728
Year	-0.7728	1.0000

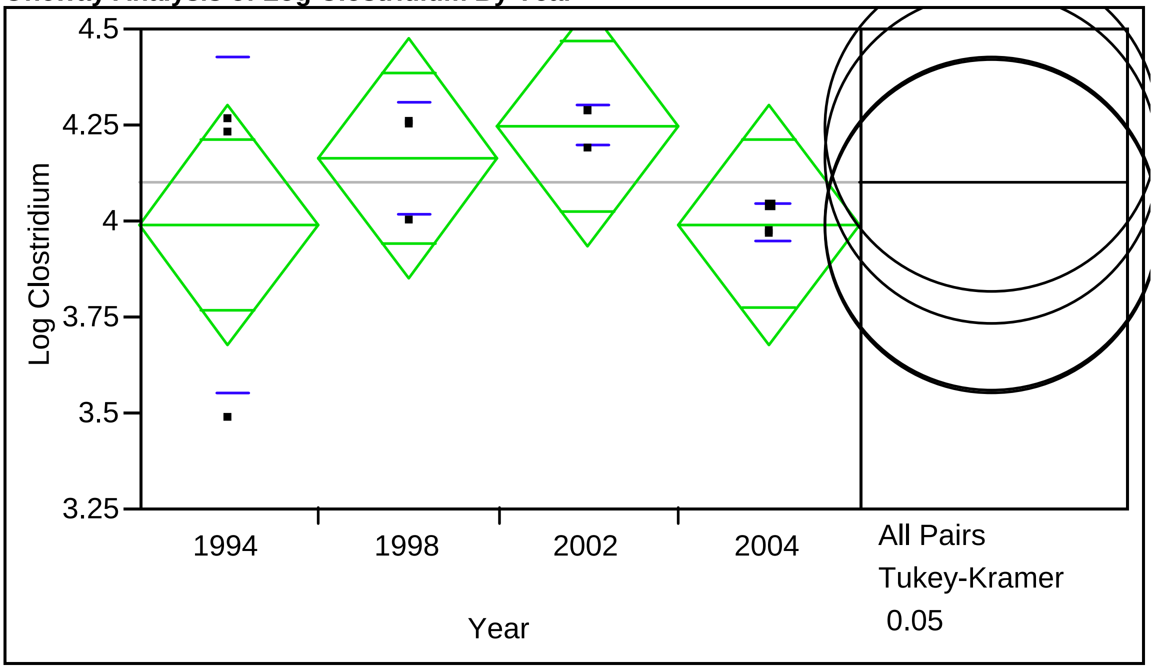
Scatterplot Matrix



Pairwise Correlations

Variable	by Variable	Correlation	Count	Signif Prob	Plot Corr
Year	Log Clostridium	-0.7728	34	0.0000	

Station CO19
Oneway Analysis of Log Clostridium By Year



Oneway Anova
Summary of Fit

Rsquare	0.255805
Adj Rsquare	-0.02327
Root Mean Square Error	0.234065
Mean of Response	4.097877
Observations (or Sum Wgts)	12

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Year	3	0.15065531	0.050218	0.9166	0.4752
Error	8	0.43829169	0.054786		
C. Total	11	0.58894700			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1994	3	3.98808	0.13514	3.6764	4.2997
1998	3	4.16467	0.13514	3.8530	4.4763
2002	3	4.24740	0.13514	3.9358	4.5590
2004	3	3.99137	0.13514	3.6797	4.3030

Std Error uses a pooled estimate of error variance

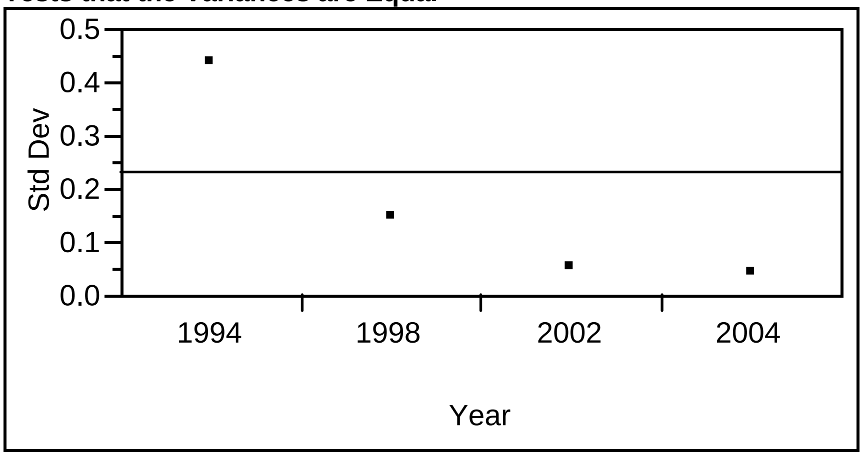
Means Comparisons
Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
3.20238	0.05

Level		Mean
2002	A	4.2473995
1998	A	4.1646670
2004	A	3.9913666
1994	A	3.9880768

Levels not connected by same letter are significantly different

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
1994	3	0.4391554	0.3377561	0.2719946
1998	3	0.1464318	0.1126878	0.0881861
2002	3	0.0543068	0.0418054	0.0313541
2004	3	0.0435526	0.0333507	0.0294711

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	1.6148	3	8	0.2611
Brown-Forsythe	0.8317	3	8	0.5129
Levene	9.8138	3	8	0.0047
Bartlett	3.2909	3	.	0.0197

Warning: Small sample sizes. Use Caution.
Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
10.3995	3	4.0506	0.0226

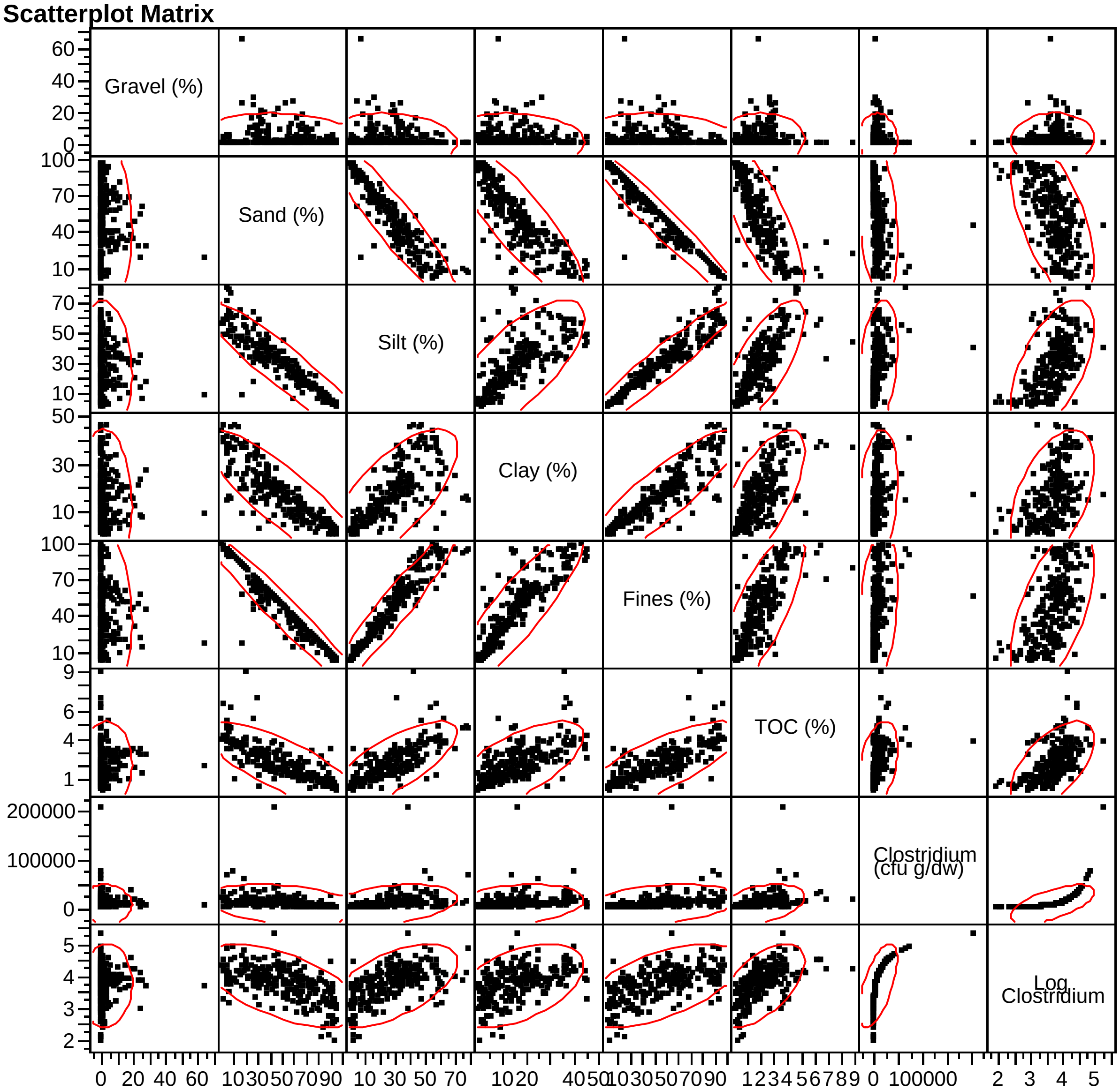
Appendix B5

Correlation Analyses
Sediment Data, 1991–2004

JMP Multivariate Correlation Output
Data Source: 1991–2004 Individual Replicate Sediment Data
Boston Harbor Stations, T01 through T08

Multivariate Correlations

Scatterplot Matrix

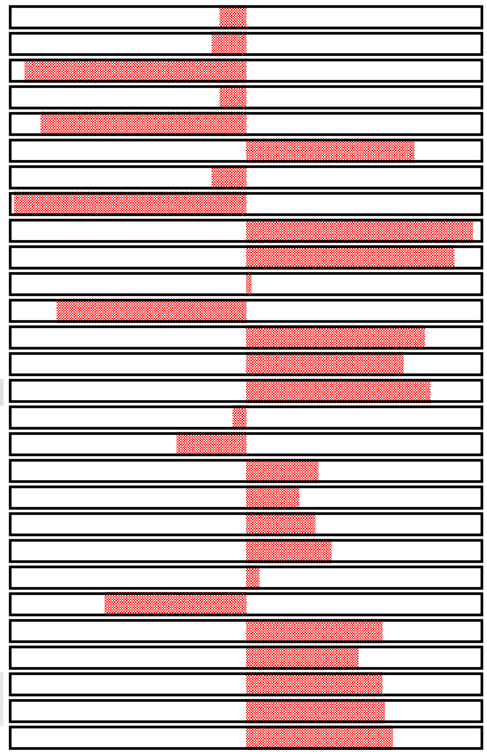


Multivariate Correlations (cont)

Data Source: 1991–2004 Individual Replicate Sediment Data
Boston Harbor Stations, T01 through T08

Pairwise Correlations

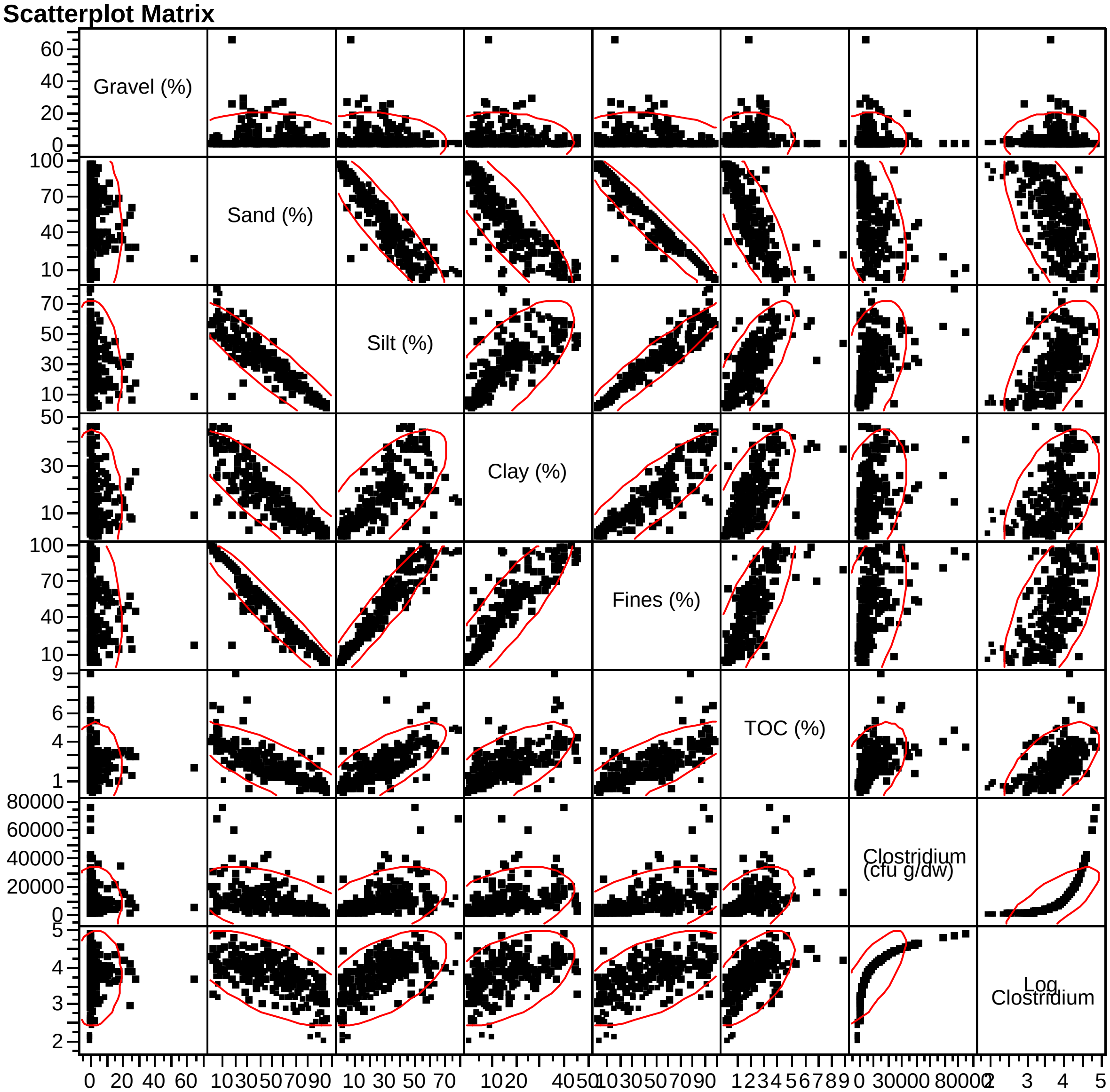
Variable	by Variable	Correlation	Count	Signif Prob	Plot Corr
Sand (%)	Gravel (%)	-0.1106	244	0.0846	
Silt (%)	Gravel (%)	-0.1366	244	0.0329	
Silt (%)	Sand (%)	-0.9247	244	0.0000	
Clay (%)	Gravel (%)	-0.1083	244	0.0915	
Clay (%)	Sand (%)	-0.8628	244	0.0000	
Clay (%)	Silt (%)	0.7108	244	0.0000	
Fines (%)	Gravel (%)	-0.1352	244	0.0347	
Fines (%)	Sand (%)	-0.9698	244	0.0000	
Fines (%)	Silt (%)	0.9554	244	0.0000	
Fines (%)	Clay (%)	0.8867	244	0.0000	
TOC (%)	Gravel (%)	0.0261	244	0.6851	
TOC (%)	Sand (%)	-0.7885	244	0.0000	
TOC (%)	Silt (%)	0.7576	244	0.0000	
TOC (%)	Clay (%)	0.6717	244	0.0000	
TOC (%)	Fines (%)	0.7797	244	0.0000	
Clostridium (cfu g/dw)	Gravel (%)	-0.0512	244	0.4256	
Clostridium (cfu g/dw)	Sand (%)	-0.2898	244	0.0000	
Clostridium (cfu g/dw)	Silt (%)	0.3135	244	0.0000	
Clostridium (cfu g/dw)	Clay (%)	0.2276	244	0.0003	
Clostridium (cfu g/dw)	Fines (%)	0.3015	244	0.0000	
Clostridium (cfu g/dw)	TOC (%)	0.3609	244	0.0000	
Log Clostridium	Gravel (%)	0.0617	244	0.3376	
Log Clostridium	Sand (%)	-0.5940	244	0.0000	
Log Clostridium	Silt (%)	0.5744	244	0.0000	
Log Clostridium	Clay (%)	0.4758	244	0.0000	
Log Clostridium	Fines (%)	0.5771	244	0.0000	
Log Clostridium	TOC (%)	0.5859	244	0.0000	
Log Clostridium	Clostridium (cfu g/dw)	0.6231	244	0.0000	



JMP Multivariate Correlation Output
Data Source: 1992–2004 Individual Replicate Sediment Data (1991 excluded – active sludge disposal to harbor)
Boston Harbor Stations, T01 through T08

Multivariate Correlations

Scatterplot Matrix



Multivariate Correlations (cont)

Data Source: 1992–2004 Individual Replicate Sediment Data (1991 excluded – active sludge disposal to harbor)

Boston Harbor Stations, T01 through T08

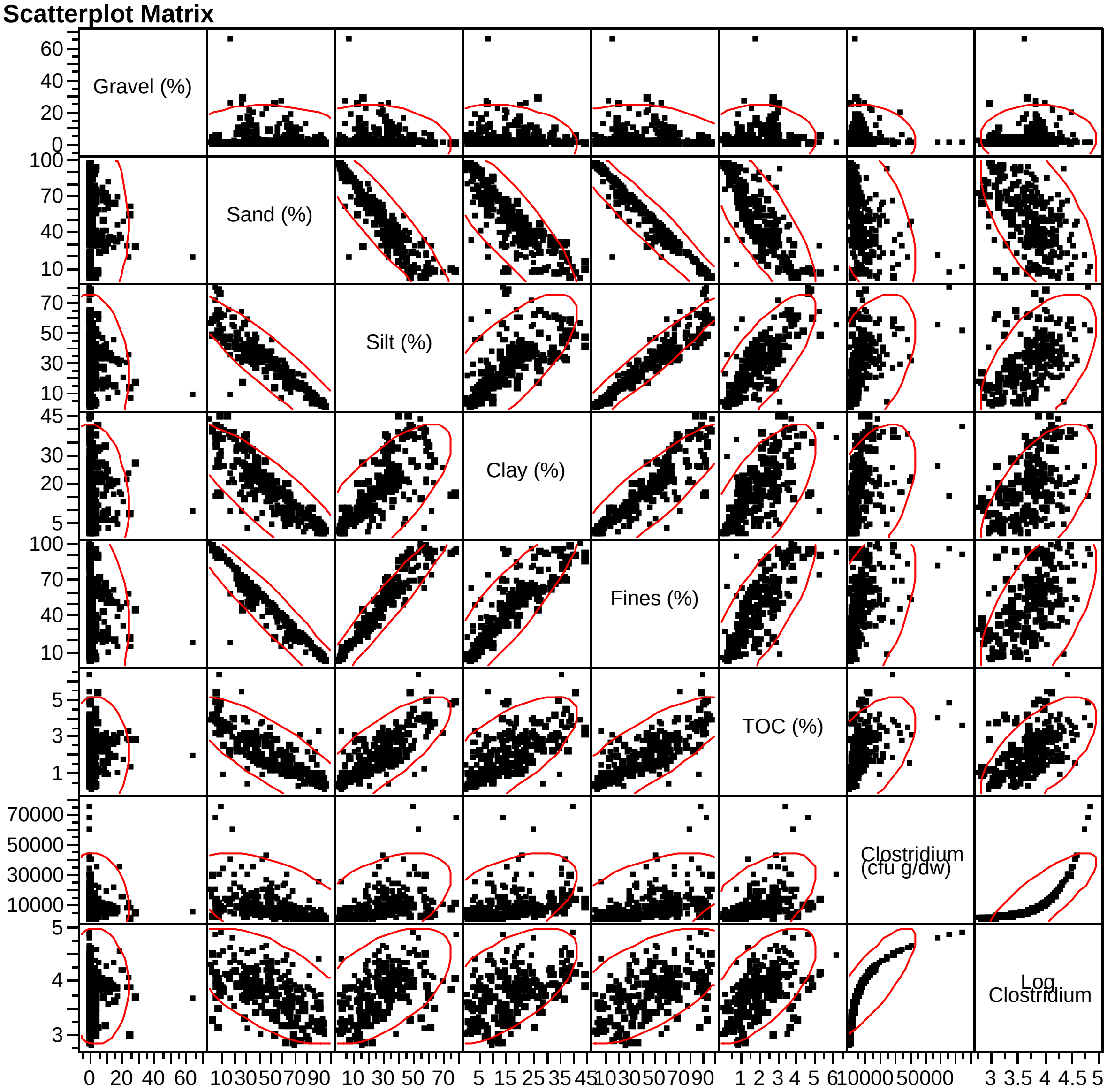
Pairwise Correlations

Variable	by Variable	Correlation	Count	Signif Prob	Plot Corr
Sand (%)	Gravel (%)	-0.1116	236	0.0873	
Silt (%)	Gravel (%)	-0.1346	236	0.0388	
Silt (%)	Sand (%)	-0.9252	236	0.0000	
Clay (%)	Gravel (%)	-0.1140	236	0.0806	
Clay (%)	Sand (%)	-0.8603	236	0.0000	
Clay (%)	Silt (%)	0.7099	236	0.0000	
Fines (%)	Gravel (%)	-0.1363	236	0.0364	
Fines (%)	Sand (%)	-0.9693	236	0.0000	
Fines (%)	Silt (%)	0.9556	236	0.0000	
Fines (%)	Clay (%)	0.8859	236	0.0000	
TOC (%)	Gravel (%)	0.0281	236	0.6670	
TOC (%)	Sand (%)	-0.8049	236	0.0000	
TOC (%)	Silt (%)	0.7689	236	0.0000	
TOC (%)	Clay (%)	0.6908	236	0.0000	
TOC (%)	Fines (%)	0.7954	236	0.0000	
Clostridium (cfu g/dw)	Gravel (%)	-0.0304	236	0.6426	
Clostridium (cfu g/dw)	Sand (%)	-0.4562	236	0.0000	
Clostridium (cfu g/dw)	Silt (%)	0.4584	236	0.0000	
Clostridium (cfu g/dw)	Clay (%)	0.3837	236	0.0000	
Clostridium (cfu g/dw)	Fines (%)	0.4624	236	0.0000	
Clostridium (cfu g/dw)	TOC (%)	0.4826	236	0.0000	
Log Clostridium	Gravel (%)	0.0823	236	0.2075	
Log Clostridium	Sand (%)	-0.6225	236	0.0000	
Log Clostridium	Silt (%)	0.5880	236	0.0000	
Log Clostridium	Clay (%)	0.5092	236	0.0000	
Log Clostridium	Fines (%)	0.6003	236	0.0000	
Log Clostridium	TOC (%)	0.5902	236	0.0000	
Log Clostridium	Clostridium (cfu g/dw)	0.7573	236	0.0000	

JMP Multivariate Correlation Output
Data Source: 1992–1997 Individual Replicate Sediment Data (period prior to bulk of sewage treatment upgrades)
Boston Harbor Stations, T01 through T08

Multivariate Correlations

Scatterplot Matrix



Multivariate Correlations (cont)

Data Source: 1992–1997 Individual Replicate Sediment Data (period prior to bulk of sewage treatment upgrades)

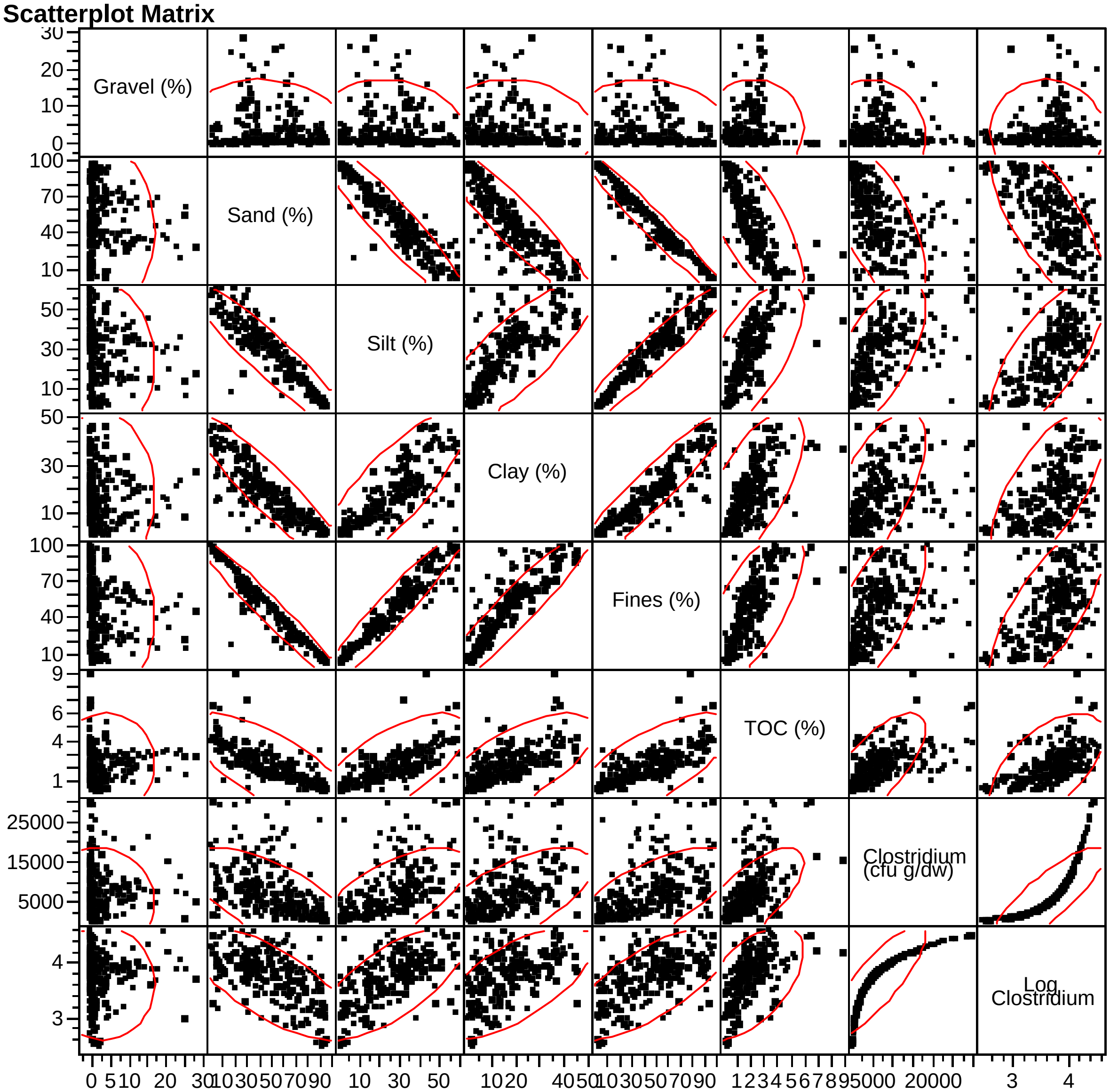
Boston Harbor Stations, T01 through T08

Pairwise Correlations

Variable	by Variable	Correlation	Count	Signif Prob	Plot Corr
Sand (%)	Gravel (%)	-0.0946	112	0.3210	
Silt (%)	Gravel (%)	-0.2035	112	0.0314	
Silt (%)	Sand (%)	-0.9185	112	0.0000	
Clay (%)	Gravel (%)	-0.1654	112	0.0814	
Clay (%)	Sand (%)	-0.8545	112	0.0000	
Clay (%)	Silt (%)	0.7351	112	0.0000	
Fines (%)	Gravel (%)	-0.2023	112	0.0324	
Fines (%)	Sand (%)	-0.9558	112	0.0000	
Fines (%)	Silt (%)	0.9637	112	0.0000	
Fines (%)	Clay (%)	0.8894	112	0.0000	
TOC (%)	Gravel (%)	-0.0240	112	0.8018	
TOC (%)	Sand (%)	-0.8101	112	0.0000	
TOC (%)	Silt (%)	0.7873	112	0.0000	
TOC (%)	Clay (%)	0.6939	112	0.0000	
TOC (%)	Fines (%)	0.8041	112	0.0000	
Clostridium (cfu g/dw)	Gravel (%)	-0.1120	112	0.2395	
Clostridium (cfu g/dw)	Sand (%)	-0.5041	112	0.0000	
Clostridium (cfu g/dw)	Silt (%)	0.4860	112	0.0000	
Clostridium (cfu g/dw)	Clay (%)	0.5114	112	0.0000	
Clostridium (cfu g/dw)	Fines (%)	0.5291	112	0.0000	
Clostridium (cfu g/dw)	TOC (%)	0.5449	112	0.0000	
Log Clostridium	Gravel (%)	-0.0275	112	0.7734	
Log Clostridium	Sand (%)	-0.6023	112	0.0000	
Log Clostridium	Silt (%)	0.5455	112	0.0000	
Log Clostridium	Clay (%)	0.5915	112	0.0000	
Log Clostridium	Fines (%)	0.6008	112	0.0000	
Log Clostridium	TOC (%)	0.6386	112	0.0000	
Log Clostridium	Clostridium (cfu g/dw)	0.8274	112	0.0000	

JMP Multivariate Correlation Output
Data Source: 1998–2000 Individual Replicate Sediment Data (period after bulk of sewage treatment upgrades and before effluent diversion)
Boston Harbor Stations, T01 through T08

Multivariate Correlations
Scatterplot Matrix



Multivariate Correlations (cont)

Data Source: 1998–2000 Individual Replicate Sediment Data (period after bulk of sewage treatment upgrades and before effluent diversion)

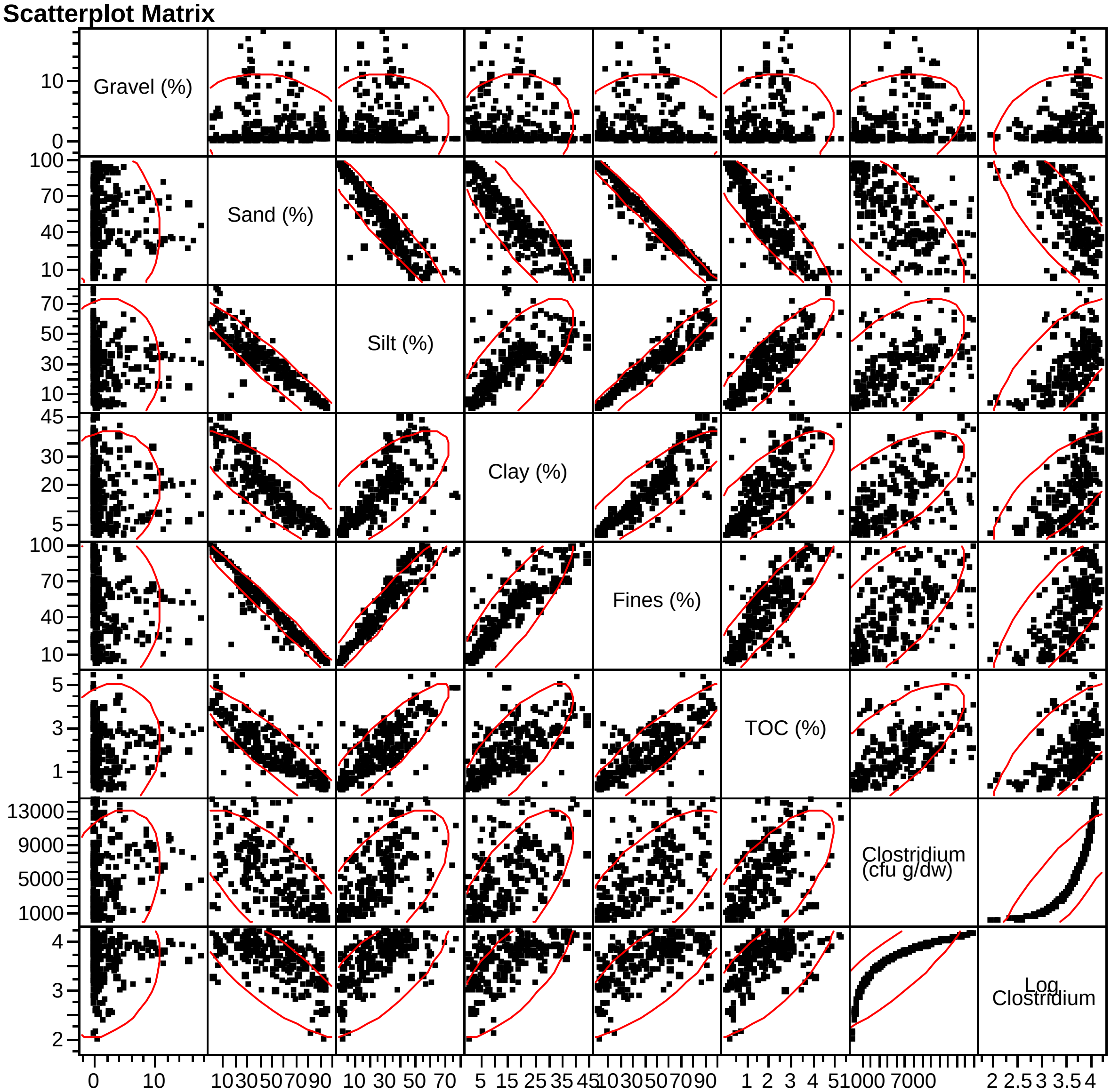
Boston Harbor Stations, T01 through T08

Pairwise Correlations

Variable	by Variable	Correlation	Count	Signif Prob	Plot Corr
Sand (%)	Gravel (%)	-0.1292	60	0.3251	
Silt (%)	Gravel (%)	-0.0992	60	0.4510	
Silt (%)	Sand (%)	-0.9335	60	0.0000	
Clay (%)	Gravel (%)	-0.0511	60	0.6983	
Clay (%)	Sand (%)	-0.9318	60	0.0000	
Clay (%)	Silt (%)	0.8183	60	0.0000	
Fines (%)	Gravel (%)	-0.0803	60	0.5418	
Fines (%)	Sand (%)	-0.9780	60	0.0000	
Fines (%)	Silt (%)	0.9592	60	0.0000	
Fines (%)	Clay (%)	0.9474	60	0.0000	
TOC (%)	Gravel (%)	0.0716	60	0.5869	
TOC (%)	Sand (%)	-0.7225	60	0.0000	
TOC (%)	Silt (%)	0.6787	60	0.0000	
TOC (%)	Clay (%)	0.6779	60	0.0000	
TOC (%)	Fines (%)	0.7113	60	0.0000	
Clostridium (cfu g/dw)	Gravel (%)	-0.0952	60	0.4693	
Clostridium (cfu g/dw)	Sand (%)	-0.6465	60	0.0000	
Clostridium (cfu g/dw)	Silt (%)	0.6411	60	0.0000	
Clostridium (cfu g/dw)	Clay (%)	0.6363	60	0.0000	
Clostridium (cfu g/dw)	Fines (%)	0.6699	60	0.0000	
Clostridium (cfu g/dw)	TOC (%)	0.6997	60	0.0000	
Log Clostridium	Gravel (%)	-0.0048	60	0.9707	
Log Clostridium	Sand (%)	-0.7272	60	0.0000	
Log Clostridium	Silt (%)	0.7154	60	0.0000	
Log Clostridium	Clay (%)	0.6786	60	0.0000	
Log Clostridium	Fines (%)	0.7320	60	0.0000	
Log Clostridium	TOC (%)	0.5754	60	0.0000	
Log Clostridium	Clostridium (cfu g/dw)	0.8388	60	0.0000	

JMP Multivariate Correlation Output
Data Source: 2001–2004 Individual Replicate Sediment Data (post-diversion period)
Boston Harbor Stations, T01 through T08

Multivariate Correlations
Scatterplot Matrix



Multivariate Correlations (cont)

Data Source: 2001–2004 Individual Replicate Sediment Data (post-diversion period)
Boston Harbor Stations, T01 through T08

Pairwise Correlations

Variable	by Variable	Correlation	Count	Signif Prob	Plot Corr
Sand (%)	Gravel (%)	-0.1893	64	0.1342	
Silt (%)	Gravel (%)	0.0383	64	0.7641	
Silt (%)	Sand (%)	-0.9590	64	0.0000	
Clay (%)	Gravel (%)	0.0696	64	0.5850	
Clay (%)	Sand (%)	-0.8635	64	0.0000	
Clay (%)	Silt (%)	0.7217	64	0.0000	
Fines (%)	Gravel (%)	0.0519	64	0.6840	
Fines (%)	Sand (%)	-0.9904	64	0.0000	
Fines (%)	Silt (%)	0.9699	64	0.0000	
Fines (%)	Clay (%)	0.8685	64	0.0000	
TOC (%)	Gravel (%)	0.1409	64	0.2669	
TOC (%)	Sand (%)	-0.9256	64	0.0000	
TOC (%)	Silt (%)	0.8992	64	0.0000	
TOC (%)	Clay (%)	0.7894	64	0.0000	
TOC (%)	Fines (%)	0.9215	64	0.0000	
Clostridium (cfu g/dw)	Gravel (%)	0.3356	64	0.0067	
Clostridium (cfu g/dw)	Sand (%)	-0.7253	64	0.0000	
Clostridium (cfu g/dw)	Silt (%)	0.6374	64	0.0000	
Clostridium (cfu g/dw)	Clay (%)	0.6658	64	0.0000	
Clostridium (cfu g/dw)	Fines (%)	0.6906	64	0.0000	
Clostridium (cfu g/dw)	TOC (%)	0.7343	64	0.0000	
Log Clostridium	Gravel (%)	0.2811	64	0.0244	
Log Clostridium	Sand (%)	-0.8110	64	0.0000	
Log Clostridium	Silt (%)	0.7318	64	0.0000	
Log Clostridium	Clay (%)	0.7431	64	0.0000	
Log Clostridium	Fines (%)	0.7853	64	0.0000	
Log Clostridium	TOC (%)	0.7451	64	0.0000	
Log Clostridium	Clostridium (cfu g/dw)	0.8659	64	0.0000	

APPENDIX C

Sediment Profile Images (HR041)
(see enclosed CD)

APPENDIX D1

Data Manipulations on Infaunal Data Prior to Statistical Analyses

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

Merge for 1991-2004 Export for Report Only (use final name and code):

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

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

Exclude from data prior to analyses:

NODC Code	Taxon
510205SPP	Acmaeidae spp.
6171010801	*Aeginina longicornis*
5509090202	*Anomia simplex*
6134020104	*Balanus crenatus*
6134020114	*Balanus improvisus*
61340201SPP	*Balanus* spp.
6171010703	*Caprella linearis*
6171010727	*Caprella penantis*
61710107SPP	*Caprella* spp.
617101SPP	*Caprellidae* spp.
5103640204	*Crepidula fornicata*
5103640207	*Crepidula plana*
51036402SPP	*Crepidula* spp.
5001430414	*Dipolydora concharum*
5001430410	*Dipolydora commensalis*
5001500501	*Dodecaceria concharum*
50015005SPP	*Dodecaceria* spp.
3701SPP	*Hydrozoa* spp.
6161050101	*Limnoria lignorum*
5103100108	*Littorina littorea*
5507010601	*Modiolus modiolus*
550701SPP	*Mytilidae* spp.
5507010101	*Mytilus edulis*
500201SPP	*Nerillidae* spp.
6171010901	*Paracaprella tenuis*
5001430412	*Polydora websteri*
5001650202	*Sabellaria vulgaris*

APPENDIX D2

Benthic Species identified from Boston Harbor Monitoring Program Samples 1991–2004

Table D2-1. Species identified from Boston Harbor Monitoring Program samples from 1991-2004 and used in the 2004 community analysis. Species collected in August 2004 samples are marked with an asterisk (*). Species new to the MWRA database in 2004 are bolded and underlined; species new to the Boston Harbor list are underlined.

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

PLATYHELMINTHES
- Turbellaria spp. *

NEMERTEA
- *Amphiporus caecus* Verrill, 1892 *
  [formerly *A. angulatus* (Fabricius, 1774)]
- *Amphiporus bioculatus* McIntosh, 1873 *
- *Amphiporus cruentatus* Verrill, 1879 *
- *Amphiporus ochraceus* (Verrill, 1873)
- *Amphiporus* sp. 1
- *Carinomella lactea* Coe, 1905*
- Cephalothricidae sp. 1 *
- *Cerebratulus lacteus* (Leidy, 1851) *
- *Micrura* spp. *
- Nemertea sp. 2 *
- Nemertea sp. D
- Nemertea sp. 5
- Nemertea sp. 12 *
- Nemertea sp. 13
- *Proneurotes* spp.
- *Tetrastemma elegans* (Girard, 1852) *
- *Cyanophthalmus cordiceps* (Friedrich, 1933)
  (formerly *Tetrastemma vittatum* Verrill, 1874)
- *Tubulanus pellucidus* (Coe, 1895)

ANNELIDA

Polychaeta

Ampharetidae
- *Ampharete acutifrons* (Grube, 1860)
- *Ampharete baltica* Eliason, 1955
- *Ampharete finmarchica* (Sars, 1865)
- *Ampharete lindstroemi* Malmgren, 1867 *
- *Anobothrus gracilis* (Malmgren, 1866)
- *Asabellides oculata* (Webster, 1879) *

Amphinomidae
- Amphinomidae spp.

Arenicolidae
- *Arenicola marina* (Linnaeus, 1758)
- *Branchiomaldane* spp.
- Arenicolidae spp.
  (merged with *Arenicola marina* for report)

Capitellidae
- *Capitella capitata* complex (Fabricius, 1780) *
- *Heteromastus filiformis* (Claparède, 1864)
- *Mediomastus ambiseta* (Hartman, 1947) *
- *Mediomastus californiensis* Hartman, 1944 *

Cirratulidae
- *Aphelochaeta marioni* (Saint-Joseph, 1894) *
- *Aphelochaeta monilaris* (Hartman, 1960)
- *Aphelochaeta* sp. 1 *
- *Caulleriella* sp. B *
- *Chaetozone* cf. *setosa* (Boston Harbor) Malmgren, 1867 *
- *Chaetozone vivipara* (Christie, 1985) *
- *Cirratulus cirratus* (O.F. Müller, 1776)
- *Cirratulus* sp. 1
- *Cirriformia grandis* (Verrill, 1873) *
- *Monticellina baptisteae* Blake, 1991 *
- *Monticellina dorsobranchialis* (Kirkegaard, 1959) *
- *Tharyx acutus* Webster & Benedict, 1887 *
  (merged with *T.* spp. for report)
- *Tharyx* sp. A *
  (merged with *T.* spp. for report)
- *Tharyx* sp. B *
  (merged with *T.* spp. for report)

Cossuridae
- *Cossura longocirrata* Webster & Benedict, 1887
- <u>***Cossura*** **sp. 1 ***</u>

Dorvilleidae
- Dorvilleidae sp. A
- *Ophryotrocha* spp.
- *Parougia caeca* (Webster & Benedict, 1884) *
- *Protodorvillea gaspeensis* Pettibone, 1961

Flabelligeridae
- *Brada villosa* (Rathke, 1843) *
- *Diplocirrus hirsutus* (Hansen, 1879)
- *Flabelligera affinis* Sars, 1829
- *Pherusa affinis* (Leidy, 1855) *
- <u>*Pherusa plumosa* (O.F. Müller, 1776) *</u>

Glyceridae
- *Glycera americana* Leidy, 1855 *
- *Glycera dibranchiata* Ehlers, 1868

Goniadidae
- <u>*Goniada maculata* Oersted, 1843 *</u>

Hesionidae
- *Microphthalmus pettiboneae* Riser, 2000 *

Lumbrineridae
- *Ninoe nigripes* Verrill, 1873 *
- *Scoletoma acicularum* (Webster & Benedict, 1887)
- *Scoletoma fragilis* (O.F. Mηller, 1776)
- *Scoletoma hebes* (Verrill, 1880) *

Maldanidae
- *Clymenella torquata* (Leidy, 1855) *
- *Maldane glebifex* Grube, 1860
- *Sabaco elongatus* (Verrill, 1873) *

Nephtyidae
- *Aglaophamus circinata* (Verrill, 1874) *
- *Nephtys caeca* (Fabricius, 1780) *
- *Nephtys ciliata* (O.F. Müller, 1776) *
- *Nephtys cornuta* Berkeley & Berkeley, 1945 *
- *Nephtys incisa* Malmgren, 1865 *
- *Nephtys longosetosa* Oersted, 1843
- *Nephtys picta* Ehlers, 1868

Nereididae
- *Neanthes virens* Sars, 1835 *
- *Neanthes arenaceodentata* Moore, 1903
- *Nereis diversicolor* O.F. Müller, 1776
- *Nereis grayi* Pettibone, 1956 *
- *Nereis zonata* Malmgren, 1867 *

Opheliidae
- *Ophelina acuminata* Oersted, 1843 *

Orbiniidae
- *Leitoscoloplos acutus* (Verrill, 1873)
- *Leitoscoloplos robustus* (Verrill, 1873) *
- *Naineris quadricuspida* (Fabricius, 1780)
- *Scoloplos armiger* (O.F. Müller, 1776) *

- Oweniidae
  - *Galathowenia oculata* (Zachs, 1923)
- Paraonidae
  - *Aricidea catherinae* Laubier, 1967 *
  - *Aricidea quadrilobata* Webster & Benedict, 1887
  - *Levinsenia gracilis* (Tauber, 1879)
  - *Paradoneis armatus* Glϑmarec, 1966 *
  - *Paraonis fulgens* (Levinsen, 1883)
  - *Paraonis pygoenigmatica* Jones, 1968
- Pectinariidae
  - *Pectinaria gouldii* (Verrill, 1873)
  - *Pectinaria granulata* (Linnaeus, 1767) *
  - *Pectinaria hyperborea* (Malmgren, 1866)
- Pholoidae
  - *Pholoe minuta* (Fabricius, 1780) *
  - *Pholoe tecta* Stimpson, 1854 *
    (merged with *P. minuta*. for report)
- Phyllodocidae
  - *Eteone flava* (Fabricius, 1780)
  - *Eteone foliosa* Quatrefages, 1865 *
  - *Eteone heteropoda* Hartman, 1951
  - *Eteone longa* (Fabricius, 1780) *
  - *Eulalia bilineata* (Johnston, 1840)
  - *Eulalia viridis* (Linnaeus, 1767)
  - *Eumida sanguinea* (Oersted, 1843) *
  - *Paranaitis speciosa* (Webster, 1870) *
  - *Phyllodoce arenae* Webster, 1879
  - *Phyllodoce groenlandica* Oersted, 1843
  - *Phyllodoce maculata* (Linnaeus, 1767) *
  - *Phyllodoce mucosa* Oersted, 1843 *
- Polygordiidae
  - *Polygordius* sp. A *
- Polynoidae
  - *Enipo torelli* (Malmgren, 1865)
  - *Gattyana amondseni* (Malmgren, 1867)
  - *Gattyana cirrosa* (Pallas, 1766) *
  - *Harmothoe extenuata* (Grube, 1840)
  - *Harmothoe imbricata* (Linnaeus, 1767) *
  - *Hartmania moorei* Pettibone, 1955 *
  - *Lepidonotus squamatus* (Linnaeus, 1758)
- Sabellidae
  - *Euchone incolor* Hartman, 1978 *
  - *Fabricia stellaris stellaris* (Müller, 1784)
  - *Laonome kroeyeri* Malmgren, 1866
- Scalibregmatidae
  - *Scalibregma inflatum* Rathke, 1843
- Sigalionidae
  - *Sthenelais limicola* (Ehlers, 1864) *
- Sphaerodoridae
  - *Sphaerodoridium* sp. A
- Spionidae
  - *Dipolydora caulleryi* Mesnil, 1897
  - *Dipolydora quadrilobata* Jacobi, 1883 *
  - *Dipolydora socialis* (Schmarda, 1861) *
  - *Polydora aggregata* Blake, 1969 *
  - *Polydora cornuta* Bosc, 1802 *
  - *Polydora* sp. 1
  - *Prionospio steenstrupi* Malmgren, 1867 *
  - *Pygospio elegans* Calparède, 1863 *
  - *Scolelepis bousfieldi* Pettibone, 1963 *
  - *Scolelepis squamata* (O.F. Mηller, 1806)
  - *Scolelepis texana* Foster, 1971
  - *Scolelepis* cf. *tridentata* (Southern, 1914)
  - *Spio filicornis* (O.F.Müller, 1766) *
  - *Spio limicola* Verrill, 1880 *
  - *Spio setosa* Verrill, 1873
  - *Spio thulini* Maciolek, 1990 *
  - *Spiophanes bombyx* Claparède, 1870 *
  - *Streblospio benedicti* Webster, 1879 *
- Syllidae
  - *Autolytus fasciatus* (Bosc, 1802)
  - *Brania wellfleetensis* Pettibone, 1956
  - *Exogone arenosa* Perkins, 1980
  - *Exogone hebes* (Webster & Benedict, 1884) *
  - *Exogone verugera* (Claparède, 1868)
  - *Parapionosyllis longicirrata* (Webster & Benedict, 1884)
  - *Pionosyllis* spp.
  - *Proceraea cornuta* Agassiz, 1863 *
  - *Sphaerosyllis erinaceus* Claparϑde, 1863 *
  - *Syllides longocirrata* Oersted, 1845
  - *Typosyllis alternata* (Moore, 1908)
  - *Typosyllis cornuta* Rathke, 1843 *
  - *Typosyllis* sp. 1
- Terebellidae
  - *Lanassa* spp.
  - *Neoamphitrite figulus* (Dalyell, 1853)
  - *Nicolea zostericola* (Oersted, 1844)
  - *Nicolea* spp.
    (merged with *N. zostericola* for report)
  - *Pista cristata* (O.F. Müller, 1776) *
  - *Polycirrus eximius* (Leidy, 1855) *
  - *Polycirrus medusa* Grube, 1850
  - *Polycirrus phosphoreus* Verrill, 1880 *
  - *Polycirrus* sp. A
- Trichobranchidae
  - *Terebellides atlantis* Williams, 1984
- Trochochaetidae
  - *Trochochaeta carica* (Birula, 1897)
  - *Trochochaeta multisetosa* (Oersted, 1844) *

Oligochaeta

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

ARTHROPODA

Pycnogonida

- *Achelia spinosa* (Stimpson, 1853)
- *Phoxichilidium femoratum* (Rathke, 1799)

CRUSTACEA

Amphipoda

- Ampeliscidae
  - *Ampelisca abdita* Mills, 1964 *
    (merged with *Ampelisca* spp. for report)
  - *Ampelisca vadorum* Mills, 1963 *
    (merged with *Ampelisca* spp. for report)
- Ampithoidae
  - *Cymadusa compta* (Smith, 1873)
- Aoridae
  - *Lembos websteri* Bate, 1856
  - *Leptocheirus pinguis* (Stimpson, 1853) *
  - *Microdeutopous anomalus* (Rathke, 1843) *
  - *Pseudunciola obliquua* (Shoemaker, 1949)
  - *Unciola irrorata* Say, 1818 *
- Argissidae
  - *Argissa hamatipes* (Norman, 1869)

Calliopiidae
- ***Calliopius laeviusculus* (Krøyer, 1838) ***

Corophiidae
- *Apocorophium acutum* Chevreus, 1908 *
- *Crassicorophium crassicorne* (Bruzelius, 1859) *
- *Crassicorophium bonnelli* (Milne Edwards, 1830)*
- *Monocorophium acherusicum* (Costa, 1857)
- *Monocorophium insidiosum* (Crawford, 1937)
- *Monocorophium tuberculatum* (Shoemaker, 1934)
- Corophiidae sp. 1

Dexaminidae
- *Dexamine thea* Sars, 1893 *

Eusiridae
- *Pontogenia inermis* (Krøyer, 1842) *

Gammaridae
- *Gammarus lawrencianus* Bousfield, 1956 *

Isaeidae
- *Photis pollex* Walker, 1895 *
- *Protomedeia fasciata* Krρyer, 1846

Ischyroceridae
- *Erichthonius brasiliensis* (Dana, 1853)
- *Ischyrocerus anguipes* (Krøyer, 1842) *
- *Jassa marmorata* Holmes, 1903 *

Liljeborgiidae
- *Listriella barnardi* Wigley, 1966

Lysianassidae
- *Orchomenella minuta* (Krøyer, 1842) *
- *Orchomene pinguis* (Boeck, 1861)

Oedicerotidae
- *Ameroculodes* sp. 1
- *Deflexilodes tuberculatus* (Boeck, 1870)

Phoxocephalidae
- *Harpinia propinqua* Sars, 1895
- *Phoxocephalus holbolli* (Krøyer, 1842) *
- *Rhepoxinius hudsoni* Barnard & Barnard, 1982

Pleustidae
- *Pleusymtes glaber* (Boeck, 1861)

Podoceridae
- *Dyopedos monacanthus* (Metzger, 1875) *

Stenothoidae
- *Metopella carinata* Shoemaker, 1949
- *Metopella angusta* Shoemaker, 1949 *
- *Proboloides holmesi* Bousfield, 1973
- *Stenothoe gallensis* Walker, 1904
- *Stenothoe minuta* Holmes, 1905
- Stenothoe sp. 1

Cumacea

Diastylidae
- *Diastylis polita* (S.I. Smith, 1879) *
- *Diastylis sculpta* Sars, 1871 *

Lampropidae
- *Lamprops quadriplicata* S.I. Smith, 1879

Leuconidae
- *Eudorella hispida* Sars, 1871
- *Eudorella pusilla* Sars, 1871

Decapoda

Brachyura

Cancridae
- *Cancer irroratus* Say, 1817 *

Portunidae
- *Carcinus maenas* (Linnaeus, 1758)

Caridea

Crangonidae
- *Crangon septemspinosa* Say, 1818 *

Paguridae
- *Pagurus acadianus* Benedict, 1901
- *Pagurus annulipes* (Stimpson, 1860)
- *Pagurus longicarpus* Say, 1817 *

Isopoda

Anthuriidae
- *Ptilanthura tenuis* Harger, 1879

Chaetiliidae
- *Chiridotea tuftsi* (Stimpson, 1883) *

Cirolanidae
- *Politolana polita* (Stimpson, 1853)

Idoteidae
- *Edotia triloba* (Say, 1818) *
- *Erichsonella* spp.
- *Idotea balthica* (Pallas, 1772) *

Munnidae
- *Munna* spp.

Paramunnidae
- *Pleurogonium inerme* Sars, 1882 *
- *Pleurogonium rubicundum* (Sars, 1863) *

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

Tanaidacea

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

MOLLUSCA

Bivalvia

Arcidae
- *Arctica islandica* (Linnaeus, 1767) *

Astartidaeè
- *Astarte undata* Gould, 1841 *

Cardiidae
- *Cerastoderma pinnulatum* (Conrad, 1831) *

Carditidae
- *Cyclocardia borealis* (Conrad, 1831)

Hiatellidae
- *Hiatella arctica* (Linnaeus, 1767) *

Lasaeidae
- *Aligena elevata* (Stimpson, 1851)

Lyonsiidae
- *Lyonsia arenosa* Möller, 1842 *
- *Lyonsia hyalina* Conrad, 1831 * (merged with *L. arenosa* for report)

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

Montacutidae
- *Mysella planulata* (Stimpson, 1857) *
- *Pythinella cuneata* Dall, 1899

Myidae
- *Mya arenaria* Linnaeus, 1758 *

Mytilidae
- *Crenella decussata* (Montagu, 1808)
- *Musculus niger* (Gray, 1824)

Nuculanidae
- *Yoldia limatula* (Say, 1831) *
- *Yoldia sapotilla* (Gould, 1841)

Nuculidae
- *Nucula annulata* Hampson, 1971
- *Nucula delphinodonta* Mighels & Adams, 1842 *
- *Nuculoma tenuis* Montagu, 1808

Pandoridae
- *Pandora gouldiana* Dall, 1886 *

Periplomatidae
- *Periploma papyratium* (Say, 1822) *

Petricolidae
- *Petricola pholadiformis* (Lamarck, 1818) *

Solenidae
- *Ensis directus* Conrad, 1843 *
- *Siliqua costata* Say, 1822

Tellinidae
Macoma balthica (Linnaeus, 1758)
Tellina agilis Stimpson, 1857 *
Thraciidae
Asthenothaerus hemphilli Dall, 1886
Bushia elegans (Dall, 1886)
Thracia conradi Couthouy, 1838 *
Thyasiridae
Thyasira gouldi Philippi, 1845
Turtoniidae
Turtonia minuta (Fabricius, 1780)
Veneridae
Gemma gemma (Totten, 1834)
Pitar morrhuanus Linsley, 1848 *
Bivalvia sp. 1

Gastropoda
Nudibranchia
Doridoida sp. A

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

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

ECHIURA
Echiurus echiurus (Pallas, 1767)

PHORONIDA
Phoronis architecta Andrews, 1890 *

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

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

CHORDATA
Ascidiacea spp.
Molgulidae
Bostrichobranchus pilularis (Verrill, 1871)
Molgula manhattensis (DeKay, 1843) *
Molgula complanata (Alder & Hancock, 1870) *

Appendix D3
Dominant Species at Boston Harbor Stations

Station	Rank	Species	Mean	Std. Dev.	% Total	% Ident.	Cum % (Total)	Cum % (Ident.)	2003 Rank	2002 Rank	2001 Rank
T01	1	*Polydora cornuta*	169.0	30.8	21.2	21.4	21.2	21.4	2	2	1
	2	*Clymenella torquata*	71.7	27.4	9.0	9.1	30.2	30.5	28	7	4
	3	*Nephtys ciliata*	59.3	10.6	7.4	7.5	37.6	38.0	4	20	NP
	3	*Tubificoides* nr. *pseudogaster*	59.3	30.1	7.4	7.5	45.0	45.5	19	4	8
	4	*Leptocheirus pinguis*	59.0	43.3	7.4	7.5	52.4	53.0	1	8	2
	5	*Aricidea catherinae*	45.7	35.0	5.7	5.8	58.1	58.8	11	1	6
	6	*Exogone hebes*	42.0	17.6	5.3	5.3	63.4	64.1	6	6	10
	7	*Tubificoides* sp. 2	39.7	6.0	5.0	5.0	68.4	69.1	9	3	7
	8	*Ilyanassa trivittata*	33.3	4.7	4.2	4.2	72.6	73.3	7	9	12
	9	*Tubificoides apectinatus*	28.0	18.2	3.5	3.5	76.1	76.8	27	24	11
	10	*Ampelisca* spp.	25.7	13.7	3.2	3.2	79.3	80.0	3	12	3
	11	*Nephtys cornuta*	22.0	13.2	2.8	2.8	82.1	82.8	15	25	17
	12	*Microphthalmus pettiboneae*	21.3	19.1	2.7	2.7	84.8	85.5	17	16	5
	13	*Lyonsia arenosa*	10.3	2.1	1.3	1.3	86.1	86.8	31	17	13
	14	*Scoletoma hebes*	7.7	4.6	1.0	1.0	87.1	87.8	14	17	22
	14	*Tharyx* spp.	7.7	2.1	1.0	1.0	88.1	88.8	16	5	9
	15	*Nephtys caeca*	7.0	2.6	0.9	0.9	89.0	89.7	26	17	18
(No. Species)	(59)	Station Mean Abundance	796.7 (all) 789.7 (ident.)						(60)	(63)	(60)
T02	1	*Nephtys cornuta*	396.3	63.0	34.7	35.3	34.7	35.3	5	4	6
	2	*Tubificoides apectinatus*	361.3	99.3	31.6	32.2	66.3	67.5	4	2	3
	3	*Aricidea catherinae*	95.7	48.6	8.4	8.5	74.7	76.0	6	1	5
	4	*Microphthalmus pettiboneae*	46.7	25.9	4.1	4.1	78.8	80.1	8	8	7
	5	*Nephtys incisa*	41.3	3.2	3.6	3.7	82.4	83.8	27	23	24
	6	*Tubificoides* nr. *pseudogaster*	28.7	15.9	2.5	2.6	84.9	86.4	9	9	10
	7	*Ampelisca* spp.	23.3	4.0	2.0	2.1	86.9	88.5	1	3	2
	7	*Leptocheirus pinguis*	23.3	39.6	2.0	2.1	88.9	90.6	3	21	4
	8	*Ilyanassa trivittata*	19.0	8.2	1.7	1.7	90.6	92.3	13	11	19
	9	*Ninoe nigripes*	13.0	2.6	1.1	1.1	91.7	93.4	25	13	13
	10	*Arctica islandica*	5.7	0.6	0.5	0.5	92.2	93.9	38	22	NP
	10	*Mya arenaria*	5.7	3.2	0.5	0.5	92.7	94.4	34	23	NP
	10	*Pholoe minuta*	5.7	8.1	0.5	0.5	93.2	94.9	35	15	14
	11	*Polydora cornuta*	5.3	1.2	0.5	0.5	93.7	95.4	2	6	1
	11	*Scoletoma hebes*	5.3	4.0	0.5	0.5	94.2	95.9	35	23	NP
	12	*Orchomenella minuta*	5.0	8.7	0.5	0.4	94.7	96.3	19	14	17
	13	*Yoldia limatula*	4.3	3.2	0.4	0.4	95.1	96.7	NP	21	NP
	14	*Mediomastus californiensis*	4.0	5.2	0.3	0.4	95.4	97.1	15	8	9
	14	*Pandora gouldiana*	4.0	1.0	0.3	0.4	95.7	97.5	NP	NP	25
	15	*Lyonsia arenosa*	3.7	2.1	0.3	0.3	96.0	97.8	30	22	21
(No. Species)	(48)	Station Mean Abundance	1143.3 (all) 1121.7 (ident.)						(64)	(50)	(49)

NP = Not present in sample

Station	Rank	Species	Mean	Std. Dev.	% Total	% Ident.	Cum % (Total)	Cum % (Ident.)	2003 Rank	2002 Rank	2001 Rank
T03	1	*Ampelisca* spp.	2624.3	597.5	35.3	35.5	35.3	35.5	1	1	1
	2	*Tubificoides apectinatus*	1750.0	302.4	23.6	23.6	58.9	59.1	3	3	2
	3	*Aricidea catherinae*	1411.3	134.6	19.0	19.1	77.9	78.2	2	2	4
	4	*Tubificoides* nr. *pseudogaster*	534.3	159.8	7.2	7.2	85.1	85.4	8	4	3
	5	*Polydora cornuta*	265.7	33.1	3.6	3.6	88.7	89.0	5	7	7
	6	*Leptocheirus pinguis*	154.3	8.0	2.1	2.1	90.8	91.1	9	28	10
	7	*Photis pollex*	111.7	19.0	1.5	1.5	92.3	92.6	11	8	8
	8	*Tharyx* spp.	69.0	27.7	0.9	0.9	93.2	93.5	7	6	11
	9	*Orchomenella minuta*	51.7	22.9	0.7	0.7	93.9	94.2	10	19	9
	10	*Mediomastus californiensis*	46.7	14.6	0.6	0.6	94.5	94.8	15	13	16
	11	*Unciola irrorata*	38.0	18.2	0.5	0.5	95.0	95.3	6	22	12
	12	*Microphthalmus pettiboneae*	33.3	14.4	0.5	0.5	95.5	95.8	17	15	15
	13	*Scoletoma hebes*	32.7	18.1	0.4	0.4	95.9	96.2	38	26	28
	14	*Phyllodoce mucosa*	30.0	12.1	0.4	0.4	96.3	96.6	12	12	11
	15	*Ilyanassa trivittata*	27.0	15.7	0.4	0.4	96.7	97.0	14	11	13
(No. Species)	(81)	Station Mean Abundance	7426.7 (all) 7400.0 (ident.)						(86)	(62)	(56)
T04	1	*Streblospio benedicti*	52.0	22.3	70.0	70.9	70.0	70.9	1	1	1
	2	*Tubificoides* sp. 2	8.0	5.2	10.8	10.9	80.8	81.8	3	3	2
	3	*Nephtys cornuta*	3.3	3.5	4.4	4.5	85.2	86.3	10	NP	NP
	4	*Crangon septemspinosa*	2.0	1.0	2.7	2.7	87.9	89.0	7	7	4
	5	*Nephtys caeca*	1.3	1.5	1.8	1.8	89.7	90.8	NP	9	NP
	5	*Tharyx* sp. B	1.3	2.3	1.8	1.8	91.5	92.6	2	5	NP
	6	*Neomysis americana*	1.0	0.0	1.4	1.4	92.9	94.0	10	8	4
	7	*Ampelisca* spp.	0.7	1.2	0.9	1.0	93.8	95.0	9	NP	NP
	7	*Pagurus longicarpus*	0.7	0.6	0.9	1.0	94.7	96.0	11	7	NP
	7	*Tellina agilis*	0.7	0.6	0.9	1.0	95.6	97.0	NP	NP	3
	7	*Tharyx* spp.	0.7	0.6	0.9	1.0	96.5	98.0	8	2	5
	8	*Aricidea catherinae*	0.3	0.6	0.4	0.4	96.9	98.4	NP	NP	NP
	8	*Ilyanassa trivittata*	0.3	0.6	0.4	0.4	97.3	98.8	6	6	NP
	8	*Mediomastus californiensis*	0.3	0.6	0.4	0.4	97.7	99.2	NP	NP	NP
	8	*Spiophanes bombyx*	0.3	0.6	0.4	0.4	98.1	99.6	NP	NP	NP
	8	*Tubificoides* nr. *pseudogaster*	0.3	0.6	0.4	0.4	98.5	100.0	NP	NP	NP
(No. Species)	(16)	Station Mean Abundance	74.3 (all) 73.3 (ident.)						(21)	(16)	(9)

NP = Not present in sample

Station	Rank	Species	Mean	Std. Dev.	% Total	% Ident.	Cum % (Total)	Cum % (Ident.)	2003 Rank	2002 Rank	2001 Rank
T05A	1	*Ampelisca* spp.	3031.0	1581.6	45.2	45.4	45.2	45.4	1	10	1
	2	*Tubificoides apectinatus*	770.0	275.4	11.5	11.5	56.7	56.9	9	1	9
	3	*Orchomenella minuta*	344.3	135.7	5.1	5.2	61.8	62.1	4	14	4
	4	*Leptocheirus pinguis*	307.0	180.1	4.6	4.6	66.4	66.7	10	28	10
	5	*Tharyx* spp.	281.7	64.7	4.2	4.2	70.6	70.9	6	3	8
	6	*Polydora cornuta*	272.7	127.9	4.1	4.1	74.7	75.0	13	19	16
	7	*Polygordius* sp. A	229.0	36.1	3.4	3.4	78.1	78.4	32	15	12
	8	*Photis pollex*	213.0	158.2	3.2	3.2	81.3	81.6	3	17	3
	9	*Unciola irrorata*	166.3	155.7	2.5	2.5	83.8	84.1	2	12	2
	10	*Phyllodoce mucosa*	125.7	46.5	1.9	1.9	85.7	86.0	8	18	5
	11	*Aricidea catherinae*	110.7	28.0	1.7	1.7	87.4	87.7	23	7	7
	12	*Exogone hebes*	101.0	53.4	1.5	1.5	88.9	89.2	23	6	14
	13	*Ilyanassa trivittata*	95.3	54.5	1.4	1.4	90.3	90.6	17	9	17
	14	*Edotia triloba*	74.7	96.5	1.1	1.1	91.4	91.7	7	13	13
	15	*Prionospio steenstrupi*	56.7	17.7	0.8	0.8	92.2	92.5	16	11	31
(No. Species)	(102)	Station Mean Abundance	6703.3 (all) 6678.7 (ident.)						(90)	(51)	(69)
T06	1	*Ampelisca* spp.	1459.3	333.4	29.6	29.7	29.6	29.7	1	4	1
	2	*Aricidea catherinae*	1305.7	158.0	26.5	26.6	56.1	56.3	2	2	4
	3	*Tubificoides* nr. *pseudogaster*	934.3	268.9	18.9	19.0	75.0	75.3	3	1	2
	4	*Tubificoides apectinatus*	227.3	63.8	4.6	4.6	79.6	79.9	4	3	5
	5	*Photis pollex*	226.0	73.1	4.6	4.6	84.2	84.5	5	8	3
	6	*Scoletoma hebes*	209.3	112.5	4.2	4.3	88.4	88.8	26	13	19
	7	*Polydora cornuta*	85.0	37.5	1.7	1.7	90.1	90.5	11	5	12
	8	*Phyllodoce mucosa*	84.0	43.1	1.7	1.7	91.8	92.2	9	9	8
	9	*Nucula delphinodonta*	65.7	6.7	1.4	1.4	93.2	93.6	13	7	13
	10	*Mediomastus californiensis*	48.7	13.6	1.0	1.0	94.2	94.6	10	11	23
	11	*Unciola irrorata*	30.7	24.8	0.6	0.6	94.8	95.2	7	16	11
	12	*Phoxocephalus holbolli*	30.0	16.5	0.6	0.6	95.4	95.8	16	10	6
	13	*Prionospio steenstrupi*	22.3	6.1	0.5	0.5	95.9	96.3	6	6	26
	14	*Leptocheirus pinguis*	21.3	9.1	0.4	0.4	96.3	96.7	18	20	10
	15	*Tellina agilis*	20.7	4.0	0.4	0.4	96.7	97.1	31	16	17
(No. Species)	(64)	Station Mean Abundance	4933.3 (all) 4911.0 (ident.)						(91)	(50)	(49)

NP = Not present in sample

Station	Rank	Species	Mean	Std. Dev.	% Total	% Ident.	Cum % (Total)	Cum % (Ident.)	2003 Rank	2002 Rank	2001 Rank
T07	1	*Tubificoides apectinatus*	362.3	289.1	34.7	34.8	34.7	34.8	3	2	2
	2	*Aricidea catherinae*	284.0	209.8	27.2	27.3	61.9	62.1	2	1	1
	3	*Nephtys cornuta*	187.0	97.9	17.9	18.0	79.8	80.1	8	6	7
	4	*Tubificoides* nr. *pseudogaster*	49.3	5.5	4.7	4.7	84.5	84.8	9	3	10
	5	*Ampelisca* spp.	29.3	16.1	2.8	2.8	87.3	87.6	1	8	6
	6	*Microphthalmus pettiboneae*	21.7	25.7	2.1	2.1	89.4	89.7	22	11	15
	7	*Ilyanassa trivittata*	18.0	4.0	1.7	1.7	91.1	91.4	13	13	14
	8	*Scoletoma hebes*	16.0	5.0	1.5	1.5	92.6	92.9	10	5	8
	9	*Nephtys incisa*	15.3	7.6	1.5	1.5	94.1	94.4	25	16	NP
	10	*Leptocheirus pinguis*	11.7	14.2	1.1	1.1	95.2	95.5	4	9	4
	11	*Tharyx* spp.	8.7	14.2	0.8	0.8	96.0	96.3	14	9	5
	12	*Polydora cornuta*	4.7	3.8	0.5	0.4	96.5	96.7	5	4	3
	13	*Ninoe nigripes*	3.7	1.5	0.4	0.4	96.9	97.1	23	12	12
	14	*Tellina agilis*	3.3	3.2	0.3	0.3	97.2	97.4	32	17	19
	15	*Tubificoides benedeni*	2.7	4.6	0.3	0.3	97.5	97.7	NP	NP	NP
(No. Species)	(44)	Station Mean Abundance	1044.3 (all) 1041.3 (ident.)						(62)	(47)	(43)
T08	1	*Spiophanes bombyx*	210.7	46.1	23.6	25.0	23.6	25.0	2	1	2
	2	*Exogone hebes*	126.3	45.5	14.1	15.0	37.7	40.0	5	6	6
	3	*Polygordius* sp. A	67.0	9.2	7.5	8.0	45.2	48.0	12	13	3
	4	*Ampelisca* spp.	49.0	41.6	5.5	5.8	50.7	53.8	1	2	4
	5	*Aricidea catherinae*	48.3	11.1	5.4	5.7	56.1	59.5	4	3	1
	6	*Tellina agilis*	47.0	6.0	5.2	5.6	61.3	65.1	19	11	12
	7	*Ilyanassa trivittata*	25.0	8.7	2.8	3.0	64.1	68.1	15	7	9
	8	*Dipolydora quadrilobata*	23.7	6.1	2.6	2.8	66.7	70.9	16	30	24
	9	*Clymenella torquata*	22.3	12.2	2.5	2.6	69.2	73.5	24	12	11
	9	*Phyllodoce mucosa*	22.3	13.7	2.5	2.6	71.7	76.1	11	9	21
	10	*Tubificoides* nr. *pseudogaster*	19.0	3.5	2.1	2.3	73.8	78.4	8	5	10
	11	*Nucula delphinodonta*	16.7	4.0	1.9	2.0	75.7	80.4	6	4	13
	12	*Tubificoides apectinatus*	13.3	1.5	1.5	1.6	77.2	82.0	23	15	17
	13	*Tharyx* spp.	13.0	10.6	1.5	1.5	78.7	83.5	10	13	7
	14	*Carinomella lactea*	12.7	8.1	1.4	1.5	80.1	85.0	38	NP	31
	15	*Unciola irrorata*	11.7	3.2	1.3	1.4	81.4	86.4	19	18	23
(No. Species)	(75)	Station Mean Abundance	894.3 (all) 842.7 (ident.)						(93)	(72)	(84)

NP = Not present in sample.

Station	Rank	Species	Mean	Std. Dev.	% Total	% Ident.	Cum % (Total)	Cum % (Ident.)
C019	1	*Nephtys cornuta*	296.3	112.5	74.8	75.8	74.8	75.8
	2	*Tubificoides apectinatus*	19.7	9.3	5.0	5.0	79.8	80.8
	3	*Yoldia limatula*	17.3	7.8	4.4	4.4	84.2	85.2
	4	*Chaetozone vivipara*	13.3	10.2	3.3	3.4	87.5	88.6
	5	*Nephtys incisa*	11.7	3.8	2.9	3.0	90.4	91.6
	6	*Polydora cornuta*	6.7	3.5	1.7	1.7	92.1	93.3
	7	*Ilyanassa trivittata*	5.0	2.6	1.2	1.3	93.3	94.6
	8	*Tharyx* spp.	4.0	3.6	1.0	1.0	94.3	95.6
	9	*Crangon septemspinosa*	3.0	1.0	0.8	0.8	95.1	96.4
	10	*Microphthalmus pettiboneae*	2.7	1.2	0.7	0.7	95.8	97.1
	11	*Tellina agilis*	2.3	2.1	0.6	0.6	96.4	97.7
	12	*Ampelisca* spp.	2.0	1.7	0.5	0.5	96.9	98.2
	13	*Mya arenaria*	1.7	1.5	0.4	0.4	97.3	98.6
	14	*Lyonsia arenosa*	1.0	1.0	0.3	0.3	97.6	98.9
	15	*Cossura* sp. 1	0.7	1.2	0.2	0.2	97.8	99.1
	15	*Streblospio benedicti*	0.7	1.2	0.2	0.2	98.0	99.3
(No. Species)	(24)	Station Mean Abundance	396.0 (all) 390.7 (ident.)					

NP = Not present in sample.

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