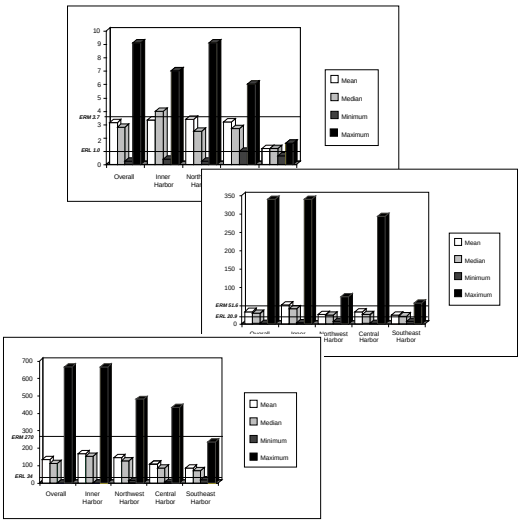
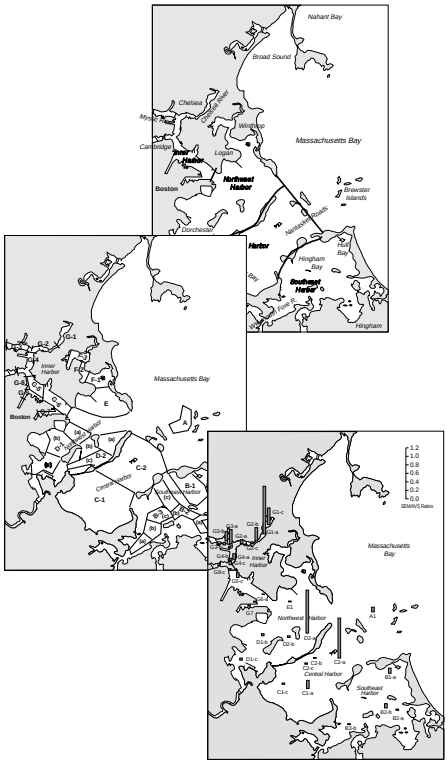
NOAA Technical Memorandum NOS ORCA 96

National Status and Trends Program
for Marine Environmental Quality

Sediment Toxicity in Boston Harbor: Magnitude, Extent, and Relationships with Chemical Toxicants





Silver Spring, Maryland
June 1996

noaa National Oceanic and Atmospheric Administration

National Ocean Service
Office of Ocean Resources Conservation and Assessment
Coastal Monitoring and Bioeffects Assessment Division

NOAA Coastal Ocean Office

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National Oceanic and Atmospheric Administration
U.S. Department of Commerce
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Notice

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June, 1996

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Sediment Toxicity in Boston Harbor: Magnitude, Extent, and Relationships with Chemical Toxicants

Edward R. Long (NOAA), Gail M. Sloane (NOAA), R. Scott Carr (NBS), K. John Scott (SAIC), Glen B. Thursby (SAIC), and Terry L. Wade (GERG)

ABSTRACT

A survey of the toxicity of sediments throughout Boston Harbor and vicinity was conducted by NOAA's National Status and Trends (NS&T) Program. The objectives of the survey were to determine the magnitude and spatial extent of toxicity and the relationship between measures of toxicity and the concentrations of chemical toxicants in the sediments. This survey was conducted as a part of a nationwide program supported by the Coastal Ocean Program and the NS&T Program of NOAA in which the biological effects of toxicants are determined in selected estuaries and bays. Major funding for this survey was provided by the Coastal Ocean Program of NOAA.

The survey was conducted in 1993. Surficial sediments were collected from 55 locations (stations) throughout the Harbor. The survey area covered approximately 57 kilometers^2. Station locations were chosen randomly within specified strata.

Multiple toxicity tests were performed including: an amphipod survival test performed with whole sediments, a microbial bioluminescence test performed with organic solvent extracts of the sediments, and sea urchin fertilization and embryological development tests performed with the pore waters extracted from the sediments. These tests were chosen because: they were consistent with the tests used in similar surveys performed elsewhere in the U.S.: they usually provide complementary, but not duplicative, information on toxicity; the results of these tests often are highly correlated with gradients in toxicant concentrations; and they are known to be dose-responsive to the kinds of toxicants commonly found in urban bays, such as Boston Harbor. Chemical analyses were performed on selected samples for trace metals, polynuclear aromatic hydrocarbons, chlorinated pesticides, PCBs and butyltins.

In the amphipod and microbial bioluminescence tests, 21.8% and 56.4% of the samples, respectively, were significantly different from controls. In the sea urchin tests performed with 100% pore water, 3.6% and 100% of the samples were significantly toxic in fertilization success and normal embryological development tests, respectively. The results of the different toxicity tests generally showed poor concordance with each other, probably as a result of differences in sensitivity and differential responses to the kinds of chemicals in the sediments.

The results of the toxicity tests were weighted to the spatial dimensions of each stratum to estimate the spatial extent of toxicity. Based upon these estimates, 100% of the area was toxic in the sea urchin tests of embryo development in 100% pore water. In contrast, only 6.6% of the area was toxic in the sea urchin fertilization tests performed in 100% pore water. In the microbial bioluminescence and amphipod survival tests, approximately 45% and 10% of the area was estimated to be toxic, respectively.

Toxicity was apparent throughout all regions of the study area. Overall, the incidence of toxicity was highest in portions of the inner harbor where chemical concentrations were the highest. Toxicity diminished beyond the entrance to the inner harbor. However, some of the inner harbor samples were not toxic and one sample each from central harbor and northwest harbor were the most toxic of the 55 samples tested. Toxicity was lowest in portions of northwest harbor, central harbor, southeast harbor, and in an area beyond the entrance to Boston Harbor.

A determination of the causes of toxicity were not an objective of this survey. Rather, the data were analyzed to determine which substances, if any, may have contributed to toxicity. Correlations between toxicity and chemical concentrations were relatively poor. No single substance or chemical group was highly correlated with toxicity. None of the chemical concentrations were extremely high relative to estimated toxicity thresholds. Furthermore, the bioavailability of many of these substances may have been inhibited by high organic carbon content in the sediments. However, the concentrations of 18 individual substances, including ammonia, were sufficiently high to have contributed to toxicity. The data suggest that complex mixtures of potentially toxic substances, including PAHs, PCBs, pesticides, trace metals, and ammonia probably contributed to the observed toxicity.

Purpose

Introduction

As a part of its bioeffects assessment program, NOAA has begun a series of surveys of the toxicity and other biological effects of toxicants in selected bays and estuaries of the U.S. (Wolfe et al., 1993). In these surveys, adverse biological effects (bioeffects) are measured in sediments with laboratory toxicity tests and in bivalve molluscs and demersal fishes with selected biomarkers. The data are used to identify the significance of chemical contamination, spatial patterns in measures of effects, the severity or magnitude of effects, and the relationships between measures of effects and the concentrations of toxicants. In the surveys of sediment quality, toxicity tests are performed as measures of biological effects. The objectives of the sediment quality surveys are to determine: (1) the spatial patterns and extent of toxicity, (2) the severity or degree of toxicity, and (3) the relationships between toxicity and potentially toxic substances in the sediments.

In this survey the study area included the four major regions of Boston Harbor: (1) the inner harbor (including the lower Chelsea and Mystic rivers), (2) northwest harbor (including the Winthrop basin and Dorchester Bay), (3) central harbor (including Quincy Bay and Nantasket Roads), and (4) southeast harbor (including Hingham Bay) (Figure 1). In addition, the survey included a fifth area located beyond the entrance to Boston Harbor near the Brewster Islands. Samples were collected at randomly-chosen locations to represent conditions within each of these areas.

Background

Contamination in Boston Harbor has been documented in numerous studies of water, sediment, and resident biota (see MacDonald, 1991 and Leo et al., 1994 for reviews). Contamina-

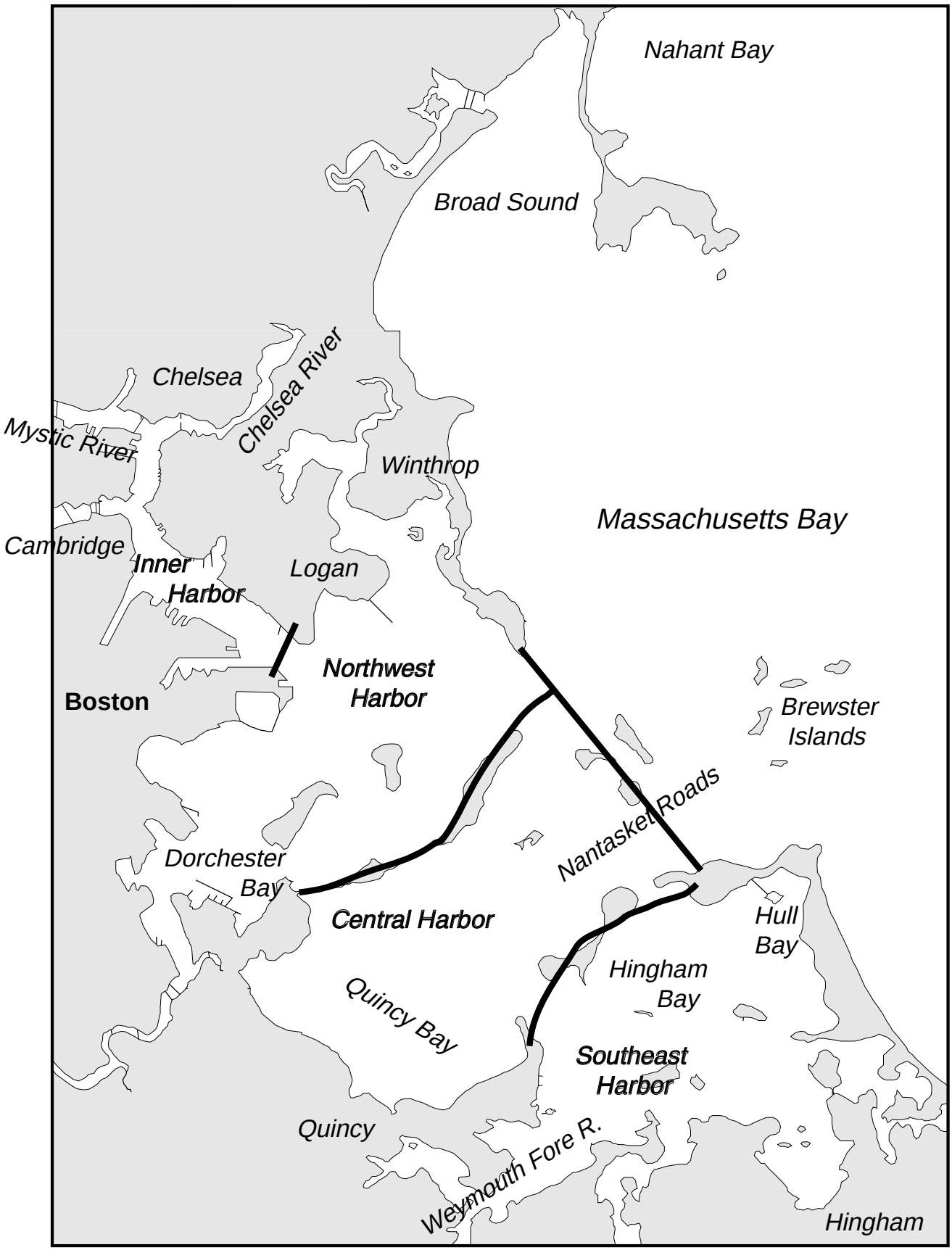

Figure 1. Boston Harbor survey area.

tion with pathogens and toxic chemicals has been documented for many years (MWRA, 1993). Among the many studies of Boston Harbor pollution problems, there have been several surveys and reviews of the contamination of sediments (Gilbert et al., 1976; Cahill and Imbalzano, 1991; Manheim and Hathaway, 1991; MacDonald, 1991; Leo et al., 1994). Contaminant levels in many sediment samples from Boston Harbor have exceeded estimated toxicity thresholds or other guidelines (Manheim and Hathaway, 1991; Long and Morgan, 1990).

The bathymetry and geochemistry of the sediments have been documented and the patterns in the deposition of fine-grained materials have been shown to influence the distribution of toxicants (Knebel et al., 1991). For most substances, the concentrations were highest in the inner harbor and gradually diminished southward into the northwest harbor, central harbor, and southeast harbor (Leo et al., 1994).

Summary of Historical Chemical Concentrations

Figures 2-9 provide a summary of the concentrations of selected trace metals and organic compounds measured in Boston Harbor sediments based on historical data summarized by MacDonald (1991). These data were compiled by MacDonald (1991) from numerous surveys performed throughout Boston Harbor. They do not include the 1993 data gathered during the survey reported herein. The data compiled by MacDonald (1991) differed in quantity and quality and by merging data from multiple studies some apparent patterns in concentrations may be attributable, at least in part, to these differences. The histograms in Figures 2-9 reflect the ranges in chemical concentrations observed in the area and in the four major regions of the area. Also included in Figures 2-9 are comparisons of between the chemical concentrations and the effects-range values determined by Long et al. (1995). The Effects Range-Low (ERL) values are those below which toxicity and other biological effects rarely occur and the Effects Range-Median (ERM) values are those above which biological effects frequently occur (Long et al., 1995a).

Silver (Ag). The overall mean silver concentration in Boston Harbor (3.12 ppm) was slightly below the ERM value (3.7 ppm) and exceeded the ERL value (1.0 ppm) of Long et al. (1995) (Figure 2). The maximum silver concentration (9.12 ppm) in Boston Harbor exceeded the ERM value by a factor of approximately three-fold. Mean and median concentrations in the inner harbor, northwest harbor, and central harbor were similar, whereas the mean and median concentrations in southeast harbor were considerably lower than in the other areas.

Copper (Cu). The overall mean and median concentrations of copper in Boston Harbor (105 ppm and 83 ppm, respectively) were considerably lower than the ERM value (270 ppm) of Long et al. (1995a) (Figure 3). The maximum concentration observed in the area (785 ppm) exceeded the ERM value by a factor of approximately three-fold. The mean and median concentrations indicated a decreasing trend in copper concentrations from the inner harbor to the southeast harbor. In all of the four regions, the mean and median concentrations of copper exceeded the ERL value, but not the ERM value. The maximum concentrations in both the inner and northwest harbors exceeded the ERM value by considerable amounts.

Mercury (Hg). The mean concentrations of mercury in all regions and throughout all of Boston Harbor exceeded or equalled the ERM value (0.71 ppm) of Long et al. (1995a) (Figure 4). There was a decreasing trend in concentrations from the inner harbor to the southeast

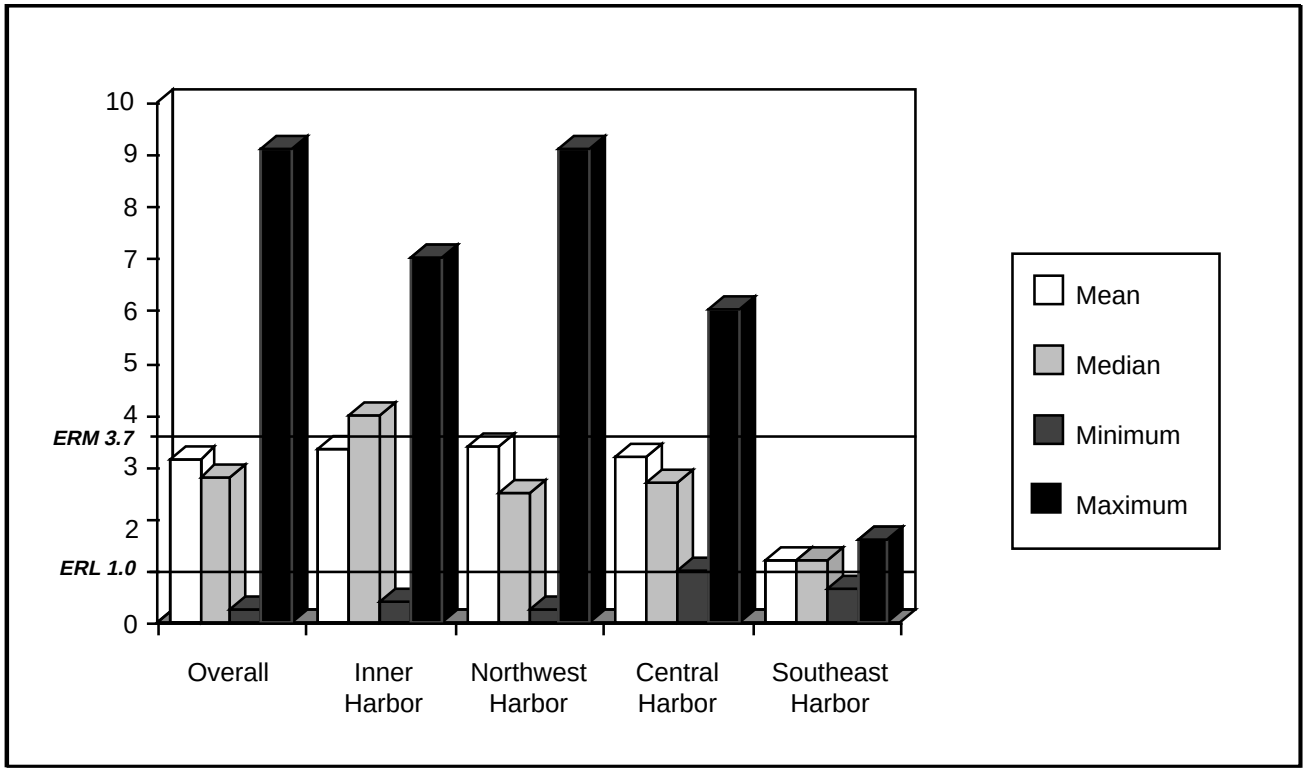

Fig. 2. A comparison of the mean, median, minimum and maximum concentrations of silver (ppm) in Boston Harbor (from MacDonald, 1991), with the ERL and ERM values for silver (from Long et. al, 1995).

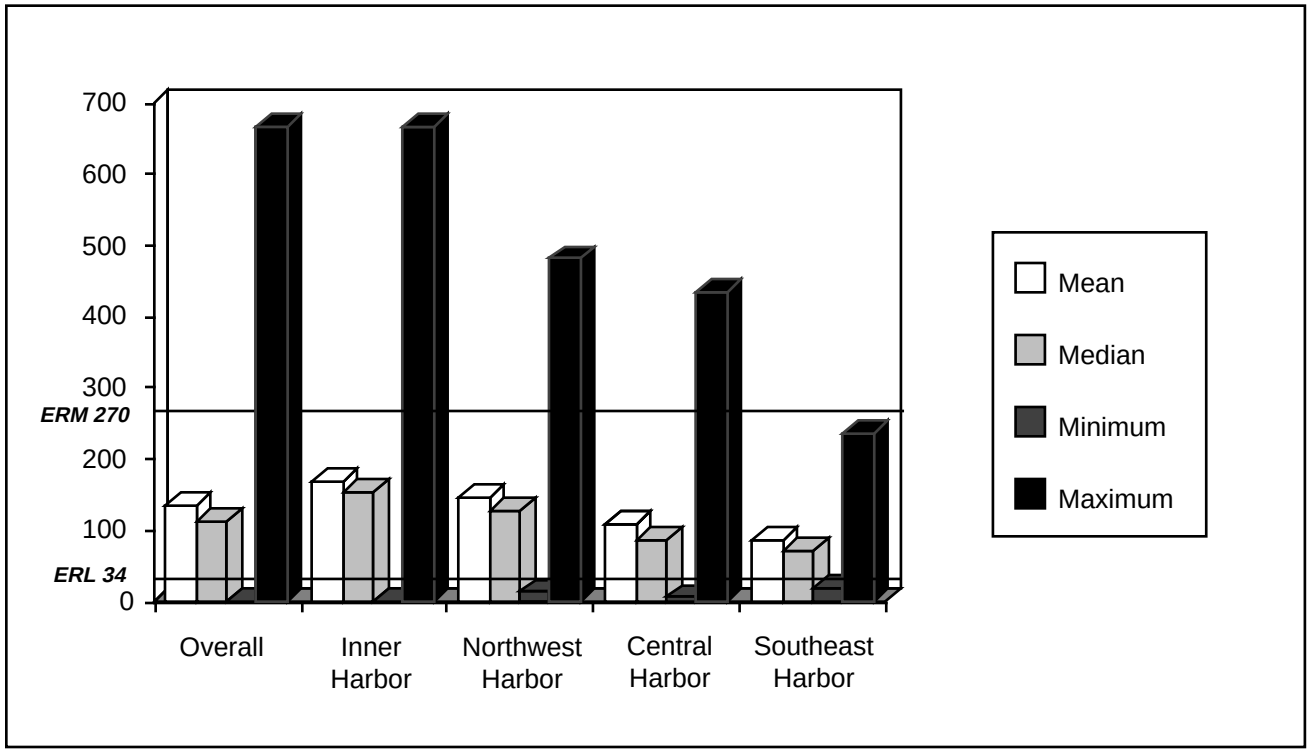

Fig. 3. A comparison of the mean, median, minimum and maximum concentrations of copper (ppm) in Boston Harbor (from MacDonald, 1991), with the ERL and ERM values for copper (from Long et. al., 1995).

harbor. The median concentrations indicated in northwest and inner harbor areas exceeded the ERM value. The highest median was in the northwest harbor, while the lowest median was in the central harbor. The maximum concentrations were highest in the inner harbor and northwest harbor areas.

Lead (Pb). The overall mean lead concentration in Boston Harbor (131 ppm) exceeded the ERL value (46.7 ppm), but not the ERM value (218 ppm) of Long et al. (1995a) (Figure 5). The highest lead concentrations were found in the inner harbor, and the lowest concentrations were observed in the central harbor. Maximum concentrations in each region exceeded the ERM value. Throughout Boston Harbor, the maximum concentration of 1180 ppm reported from a sample in northwest harbor exceeded the ERM value by a factor of approximately five-fold.

Nickel (Ni). The overall mean concentration of nickel (34 ppm) exceeded the ERL, but not the ERM value reported by Long et al. (1995a) (Figure 6). Mean concentrations of nickel were above the ERM value in the inner harbor and were lower than the ERM in all other regions. The maximum concentrations (340 and 293 ppm) were reported in samples from the inner harbor and the central harbor, respectively.

Zinc (Zn). Mean and median zinc concentrations in all regions exceeded the ERL value (150 ppm) of Long et al. (1995a) (Figure 7). Zinc concentrations were highest in the inner harbor compared to all other regions. The maximum concentration reported (1750 ppm) was observed in a sample from the inner harbor.

Total PAHs. Among the various studies that have been conducted in Boston Harbor in which PAH concentrations were quantified, only six compounds (phenanthrene, fluoranthene, pyrene, chrysene, benz(a)anthracene, and benzo(a)pyrene) were reported in all studies. MacDonald (1991) reported the overall mean for each data set based on the total number of PAHs in the data set and the six common PAHs. Based upon the mean concentrations of the six common PAHs, samples from the inner harbor were the most contaminated (Figure 8). The mean and median concentrations of PAHs in the inner harbor exceeded the ERL value, but not the ERM value of Long et al. (1995a). The ERL and ERM values were calculated for the sum of 15 compounds or total extracted PAHs, whereas the data shown in Figure 8 were based upon the sums of only six compounds. Therefore, the sums of only six PAHs probably under-represents the actual concentrations in Boston Harbor sediments. PAH concentrations in the other regions were lower than those in the inner harbor and approximated the ERL value. However, maximum concentrations of 93,000 ppb and 59,000 ppb exceeded the ERM value (44792 ppb) in samples from both the inner harbor and northwest harbor, respectively.

Three sediment cores taken in the Fort Point Channel of the Inner Harbor, near Spectacle Island in northwest harbor, and near Peddocks Island in southeast harbor were analyzed recently for PAH concentrations (McGroddy and Farrington, 1995). Sediments in the upper 2 cm. of the Fort Point Channel core had PAH concentrations that exceeded the respective ERM values. Surficial PAH concentrations were lower at the northwest harbor site (generally, below the ERM values) and lower, again, at the southeast harbor site (approximately equal to the ERL values).

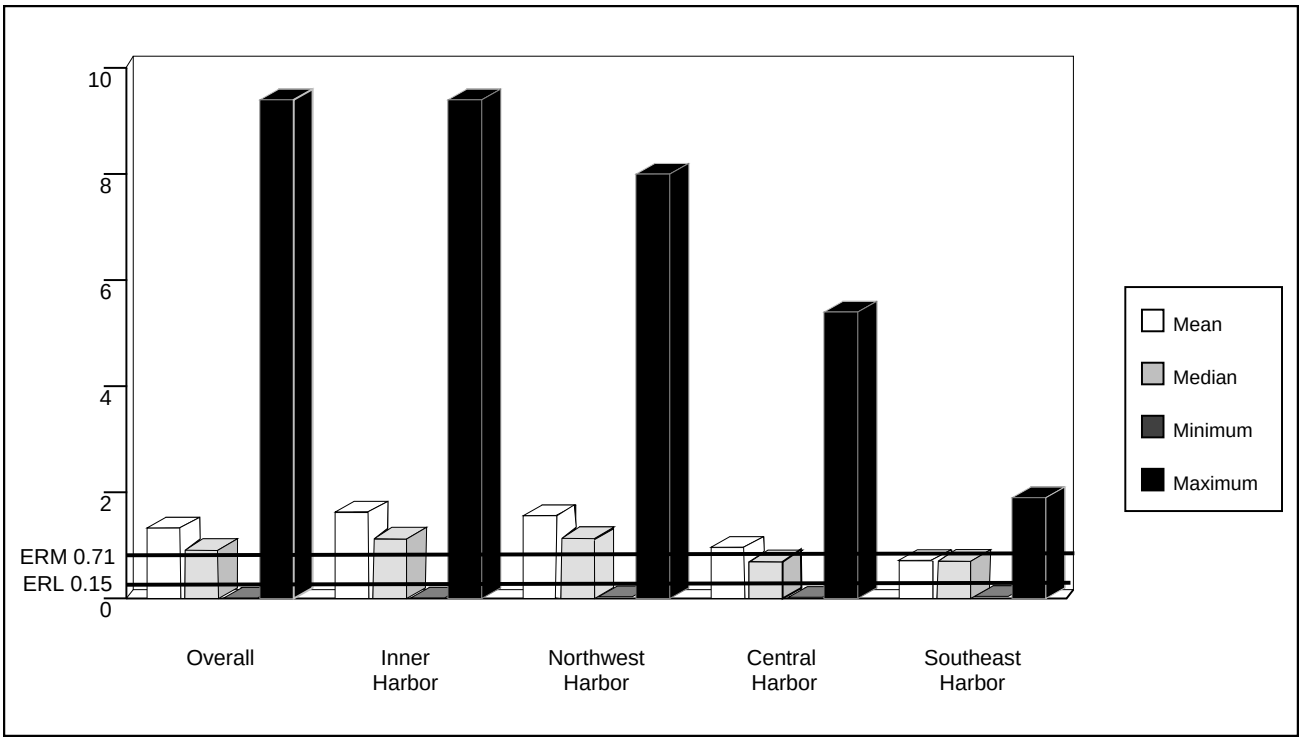

Fig. 4. A comparison of the mean, median, minimum and maximum concentrations of mercury (ppm) in Boston Harbor (from MacDonald, 1991) with the ERL and ERM values for mercury (from Long et al. 1995).

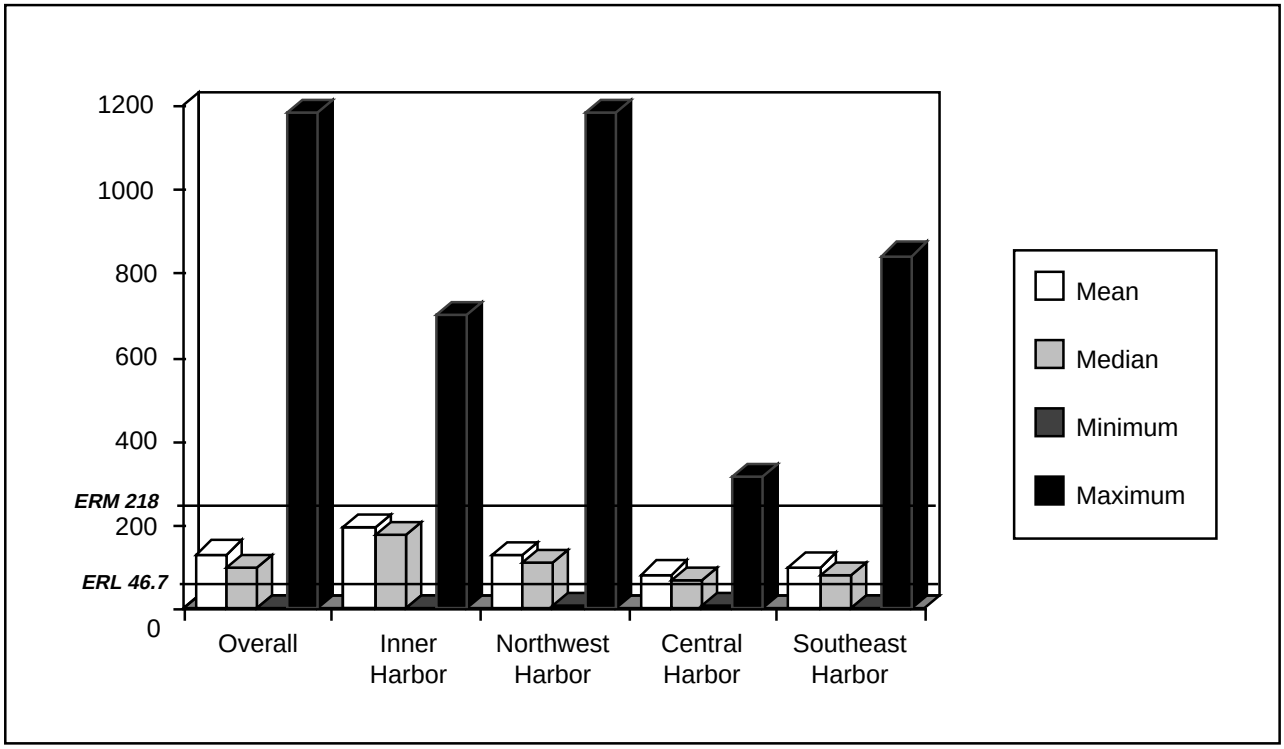

Fig. 5. A comparison of the mean, median, minimum and maximum concentrations of lead (ppm) in Boston Harbor (from MacDonald, 1991), with the ERL and ERM values for lead (from Long et. al., 1995).

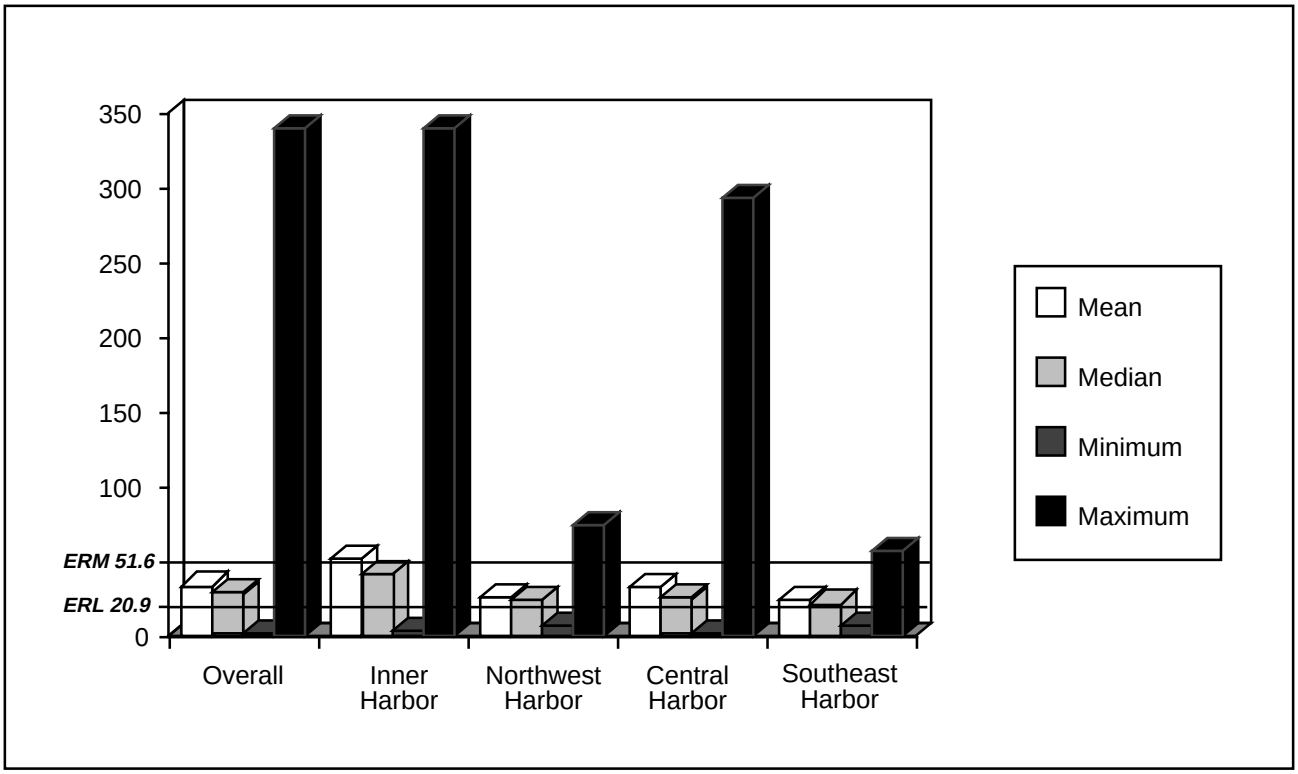

Fig. 6. A comparison of the mean, median, minimum and maximum concentrations of nickel (ppm) in Boston Harbor (from MacDonald, 1991), with the ERL and ERM values for nickel (from Long et. al, 1995).

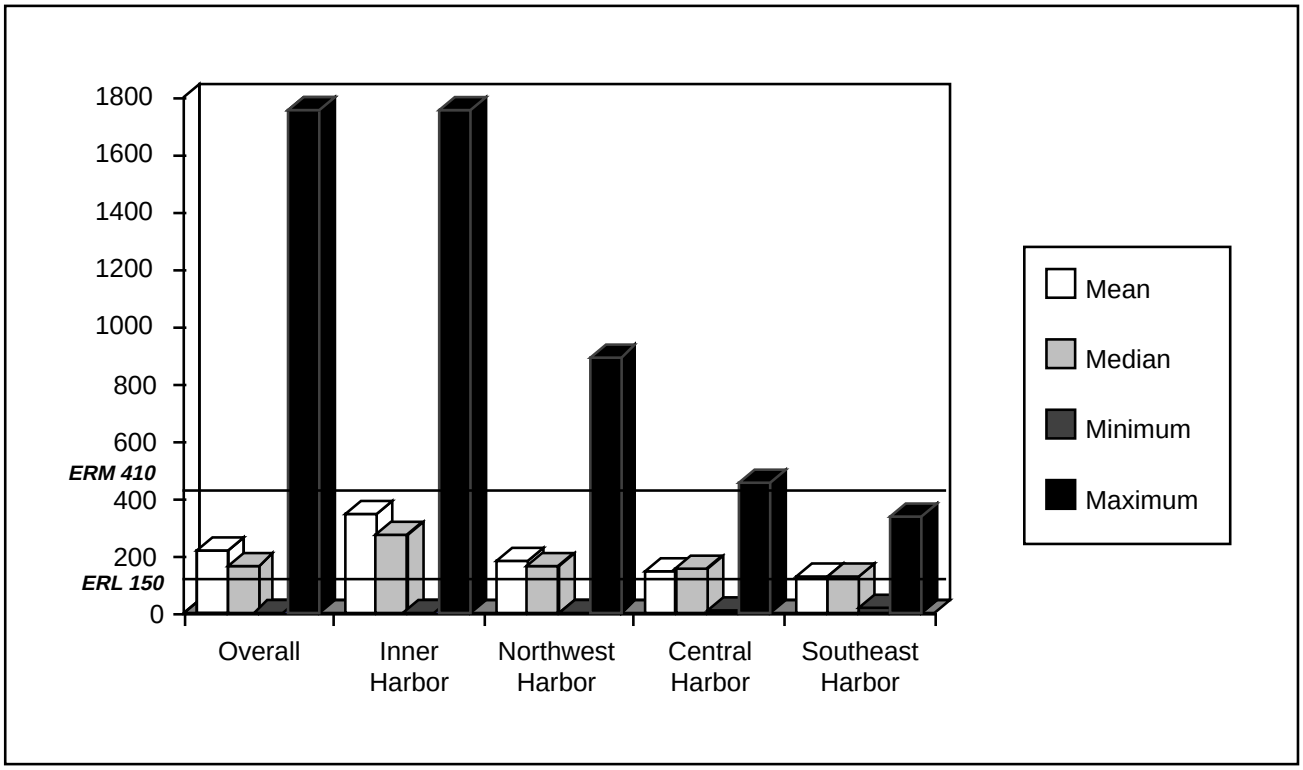

Fig. 7. A comparison of the mean, median, minimum and maximum concentrations of zinc (ppm) in Boston Harbor (from MacDonald, 1991), with ERL and ERM values for zinc (from Long et. al., 1995).

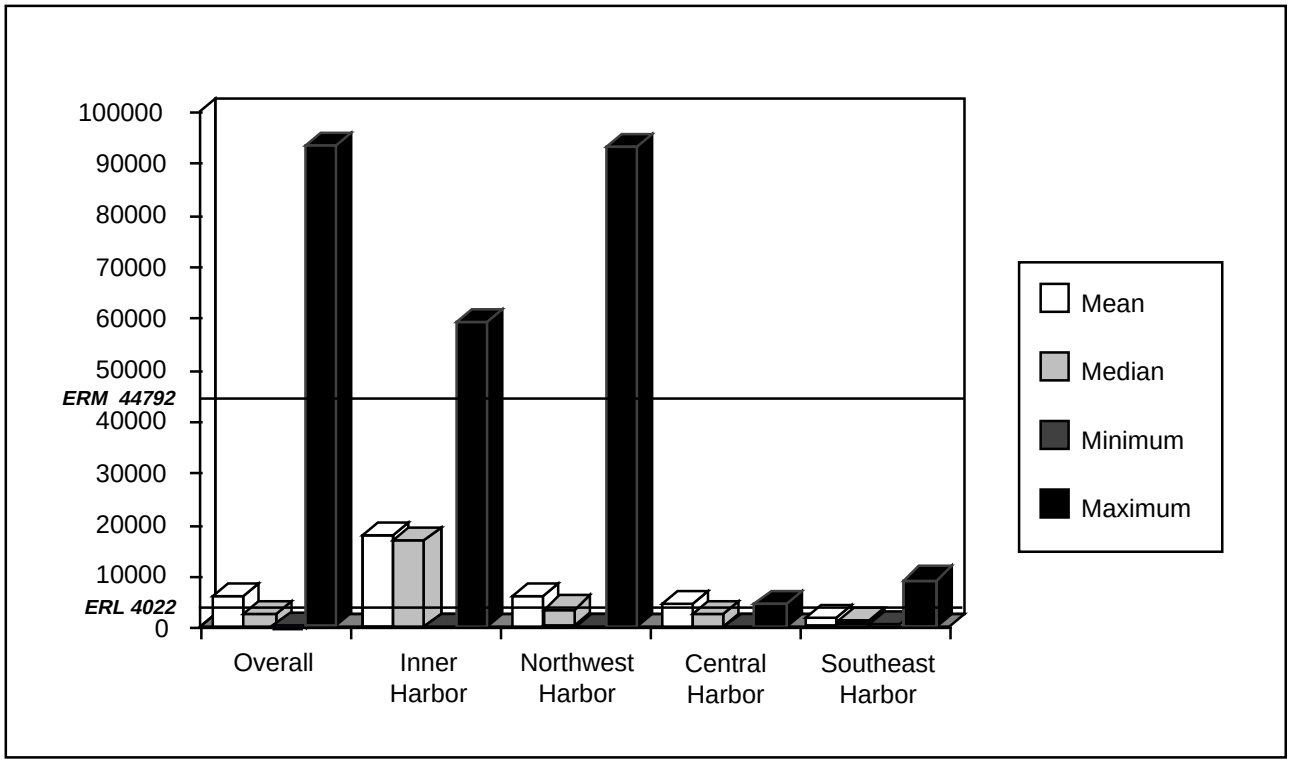

Fig. 8. A comparison of the mean, median, minimum and maximum concentrations of six selected PAHs (tPAH ppb) in Boston Harbor from MacDonald (1991), with the ERL and ERM values for tPAH (from Long et. al., 1995). These data exclude three samples over 200,000 ppb (see text).

Total PCBs. The NS&T Program currently determines the concentrations of 18 PCB congeners and reports the sums of these congeners. Individual PCB congeners have varying degrees of toxicity. Therefore, toxicity is not solely dependent on tPCB concentrations, but also depends on the individual congeners and their concentrations which make up the mixture. In 1984, one surficial sediment sample from the southwest Deer Island site was reported to have a tPCB concentration of 51,000 ppb. This value was approximately 50 times higher than the second highest concentration reported for any of the other NS&T Program sites. Also, it exceeded the ERM value for tPCB (180 ppb) by a factor of 283. Therefore, this sample was eliminated by MacDonald (1991) from the regional summaries. Mean and median tPCB concentrations exceeded the ERM value in all regions except the southeast harbor (Figure 9). Total PCB concentrations were highest in the inner harbor and northwest harbor and were lowest in the southeast harbor. Also, maximum concentrations were observed in the inner and northwest harbors.

Summary of Chemical Contamination.

Overall, the concentrations of most potentially toxic contaminants were highest in the inner harbor, followed by the northwest harbor. For most chemicals, the concentrations were lowest in the southeast harbor and near the mouth of the harbor. Maximum and mean concentrations usually paralleled each other and many of the maxima exceeded the respective ERM values by a considerable amount. MacDonald (1991) concluded that the contaminants of most toxicological concern included silver, chromium, mercury, and PCBs, followed by copper, lead, zinc, DDT and PAHs. Cadmium, arsenic, and nickel appear to be of less concern, since they rarely exceeded concentrations frequently associated with toxicity.

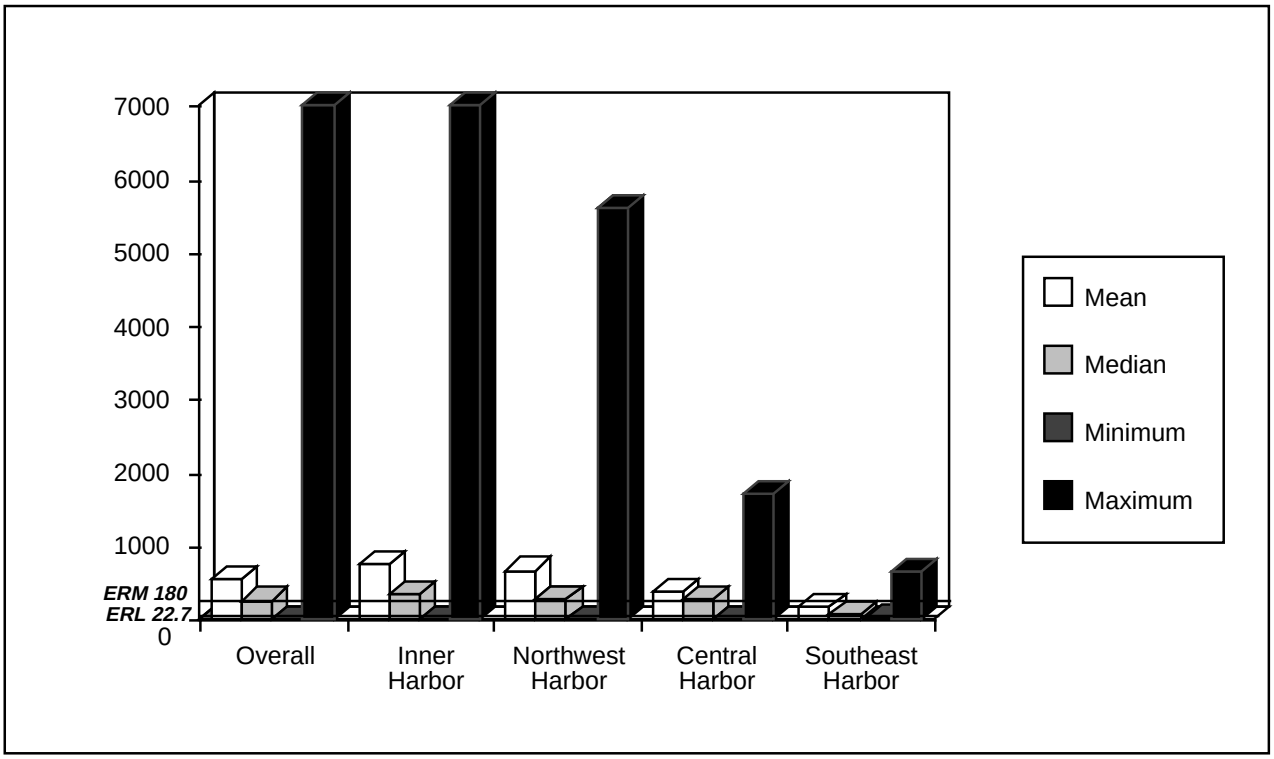

Fig. 9. A comparison of the mean, median, minimum and maximum concentrations of tPCBs (ppb) in Boston Harbor from MacDonald (1991), with the ERL and ERMvalues for tPCBs (from Long et. al., 1995). These data exclude one samplewith 51,000 ppb tPCB (see text).

Contamination problems in Boston Harbor may have improved in recent years due to additional treatment and controls of sources and reduced input rates (Boston Globe, 1992; MWRA, 1993). The incidence of fin rot, other diseases, beach closures due to sewage, and the presence of debris have decreased. The volumes of trace elements discharged to the Harbor have decreased steadily over the past five to ten years. The disposal of municipal sewage sludge into the harbor was terminated in 1991. The volumes of toxic chemicals and other priority pollutants diminished between 1990 and 1992. Concentrations of many of these substances in ambient water near the Deer Island sewage outfall were below Federal standards. Average concentrations of zinc and copper in water samples from the inner harbor and northwest harbor fell during 1972 to 1989. The concentrations of PCBs and some pesticides decreased from 1987 to 1992 in transplanted mussels, however, the concentrations of PAHs remained similar. Blake et al. (1993) concluded that a number of measures of the quality of sediments, including the density and structure of benthic communities, showed apparent improvement between 1991 and 1992. Overall, data from several studies in Boston Harbor point to a trend of improving water and sediment quality, probably attributable to improved waste water management and treatment (MWRA, 1993).

Summary of Historical Sediment Toxicity Investigations

Sediment toxicity tests have been performed in several surveys and pre-dredging studies in Boston Harbor. In five of these previous studies (SEA Plantations, Inc., 1992; Camp, Dresser and McKee, Inc., 1991; U. S. Army Corps of Engineers, 1990; 1994; Hyland and Costa, 1994), tests were performed with the marine amphipod, *Ampelisca abdita*. Amphipod survival was

significantly lower in all six samples from the Mystic River, Chelsea River, and Reserved Channel, however, the numerical data from this study were not provided (U. S. Army Corps of Engineers, 1990). The statistical significance of the amphipod survival data was not determined in one of the other studies (U. S. Army Corps of Engineers, 1994). Therefore, only the data from the remaining four studies are compared qualitatively among stations as percent amphipod survival relative to reference materials (Figure 10).

In nine of the 21 samples plotted in Figure 10, amphipod survival was 80.0% or greater relative to controls. In the remaining 12 samples, amphipod survival ranged from 4.0% in a sample from the lower Mystic River to 76.5% in a sample from the outer Reserved Channel. Samples that caused relatively low amphipod survival were collected in the Mystic River, Fort Point Channel, lower Chelsea River, Reserved Channel, and along the inner harbor channel. Amphipod survival in four samples collected by A. D. Little, Inc. in the northwest harbor, central harbor, and southeast harbor ranged from 81.0% to 92.6% relative to controls (Hyland and Costa, 1994). Amphipod survival was significantly different from controls in three of the four samples tested by A. D. Little (Hyland and Costa, 1994). Collectively, the data from these different studies demonstrated that amphipod survival was relatively low in more than one-half of the samples, most of which were collected in various portions of the inner harbor.

In the study conducted by A.D. Little, toxicity tests also were performed by the National Biological Service with sediment pore water (Hyland and Costa, 1994). Fertilization success and embryological development of sea urchin (*Arbacia punctulata*) were determined for each sample, using the same protocols used in the present survey. Percent fertilization success was significantly reduced (and <80% of controls) in one of the four pore water samples from Boston Harbor (station 8 in Hull Bay). Three of the four samples were highly toxic in the tests of embryological development, including two samples (station 5 in northwest harbor and station 8) that caused 0.0% normal development in 100% pore water.

Hyland and Costa (1994) reported that, in addition to the observations of toxicity in Boston Harbor samples, the benthic community structures at two stations were altered relative to reference areas and the concentrations of many toxicants were elevated in the sediments. In particular, the concentrations of PCBs, dieldrin, total DDT, silver, copper, and zinc were relatively high in the Boston Harbor stations. The concentrations of silver, chlordane and DDT exceeded threshold levels, such as the numerical guidance values of Long and Morgan (1990), and, therefore, may have contributed to the observed toxicity.

As a part of the Boston Harbor Improvement Dredging Project, chemical and biological testing of sediment were conducted and the correlations between the survival of amphipods and the concentrations of numerous chemicals were determined (Michael J. Wade, Wade Research, Inc., personal communication). A mixture of toxicants, particularly cadmium, mercury, benzo(a)pyrene, and phenanthrene, were significantly correlated with toxicity to the amphipods.

Samples from 16 locations within Boston Harbor were tested in 1988 for toxicity to bioluminescent bacteria (Demuth et al., 1993). Some of the samples from the inner harbor and northwest harbor were highly toxic relative to controls and relative to the other samples. Thirteen samples collected within the Boston Harbor study area were significantly more toxic than

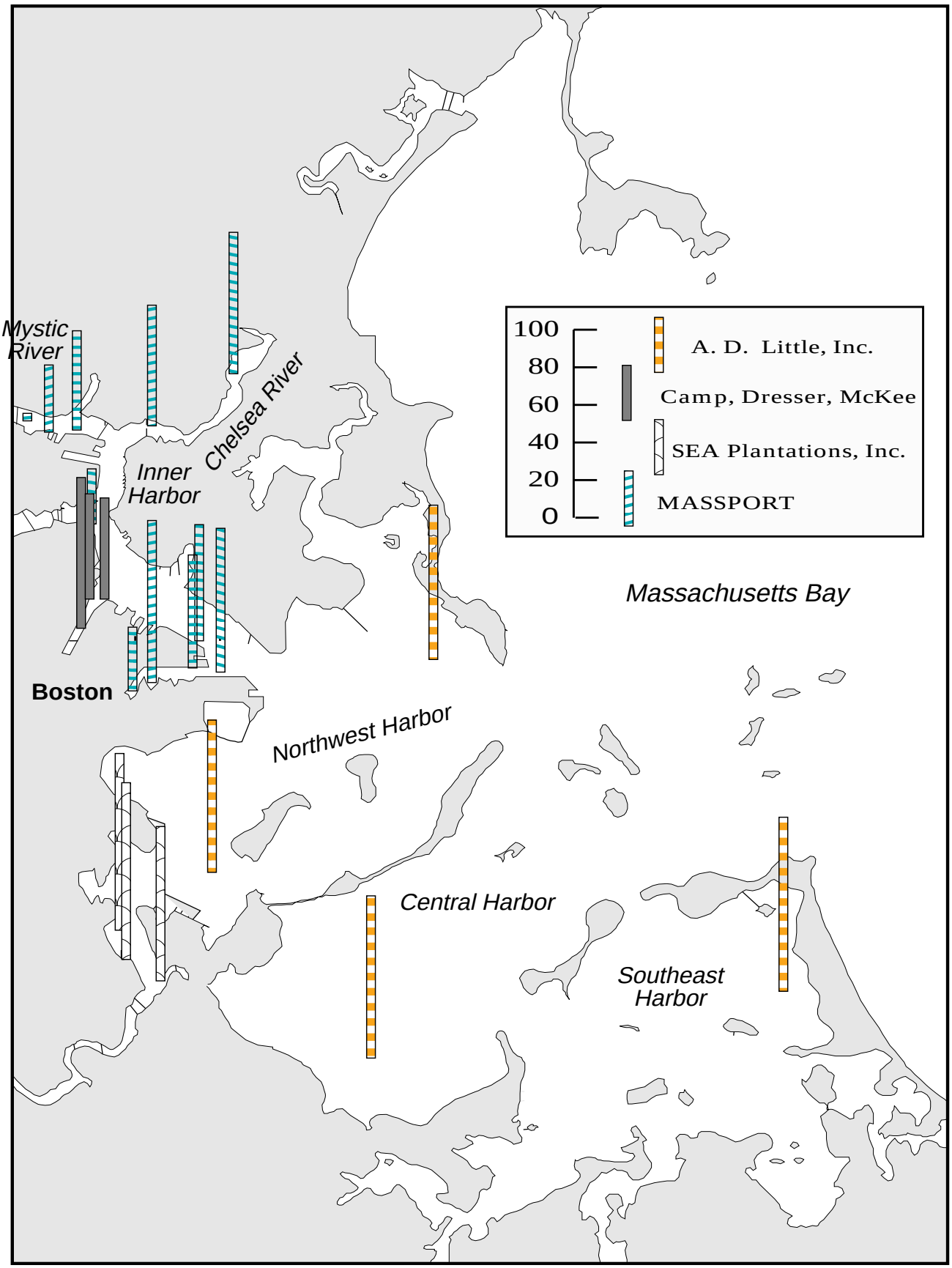

Fig. 10. Percent survival of amphipods (*Ampelisca abdita*) in previous surveys of sediment toxicity in Boston Harbor.

three samples collected outside Boston Harbor in tests performed with the organic solvent extracts.

Summary

Contaminant levels quantified in many studies of Boston Harbor sediments have often equalled or exceeded concentrations previously associated with toxicity. In addition, the toxicity of sediments has been observed in laboratory tests performed in a few small surveys. However, there is evidence from recent studies that sediment quality in Boston Harbor has improved noticeably. Therefore, although there was considerable evidence to suggest that Boston Harbor sediments would be toxic in relatively sensitive tests, there was also evidence that recently-deposited sediments may not be highly toxic in all areas. Furthermore, if toxicity were observed, it would be expected to be most severe in the inner harbor and least severe in the southeast harbor.

METHODS

Survey Design

A survey of the toxicity of sediments was conducted by NOAA's National Status and Trends Program throughout Boston Harbor and vicinity. The survey was conducted in June and July of 1993. Surficial sediments (upper 2-3 cm.) were collected from 55 locations throughout the harbor. The total survey area covered approximately 57 kilometers^2.

The upper 2-3 cm. of the sediment were sampled to ensure the collection of recently-arrived materials. The age and depositional rates of the sediments were not determined in this survey. However, Knebel et al. (1991) estimated that recent sediment accumulation rates in Boston Harbor ranged from 0.01 to 0.11 g/cm^2 or 0.13 to 0.32 cm/yr (average of 0.23 cm/yr). Therefore, based upon an average depositional rate of 0.23 cm/yr, the upper 2-3 cm. sampled in this survey may have represented materials deposited over the previous 8-12 years.

Previous studies in Boston Harbor, as summarized by MacDonald (1991), indicated that the areas of greatest concern for potential biological effects were the inner harbor and adjacent areas in Northwest Harbor. Therefore, the greatest number of samples in the present study were located in this area. Station locations were chosen randomly within the boundaries of each sampling stratum, using a probabilistic sampling design fashioned after EPA Environmental Monitoring and Assessment Program (EMAP) protocols (Schimmel et al., 1994). This approach combines the strengths of a stratified design with the random-probabalistic selection of sampling locations. Data generated within each stratum can be attributed to the dimensions of the stratum. Therefore, these data can be used to estimate the spatial extent of toxicity with a quantifiable degree of confidence.

Each of the four major subdivisions of Boston Harbor, plus the harbor entrance, were sampled (Figure 1). Within each subdivision, geographic strata were identified of roughly equal dimensions (Figure 11). Each stratum represented a topographic feature such as a basin, waterway, or channel in which depth, substrate type and proximity to known or suspected toxicant sources were expected to be relatively similar. A total of 21 strata were identified.

Within most strata, three independent samples were collected to provide a measure of field replication of the stratum. Because the locations of each sampling station were determined independently and all latitude/longitude coordinates of each stratum had equal probabilities of being selected as a sampling station, these stations were considered as true replicates of each stratum. Replicate samples were not collected in the field at each sampling station, since a measure of variance at each location was of minimal interest. However, by collecting the material from several or more deployments of the grab at each station and compositing their contents, toxicity and chemistry results were an average of the conditions at the chosen location.

Only one sample each was collected in strata F-1, F-2, F-3, and G-7. These strata were relatively small and relatively little heterogeneity was expected.

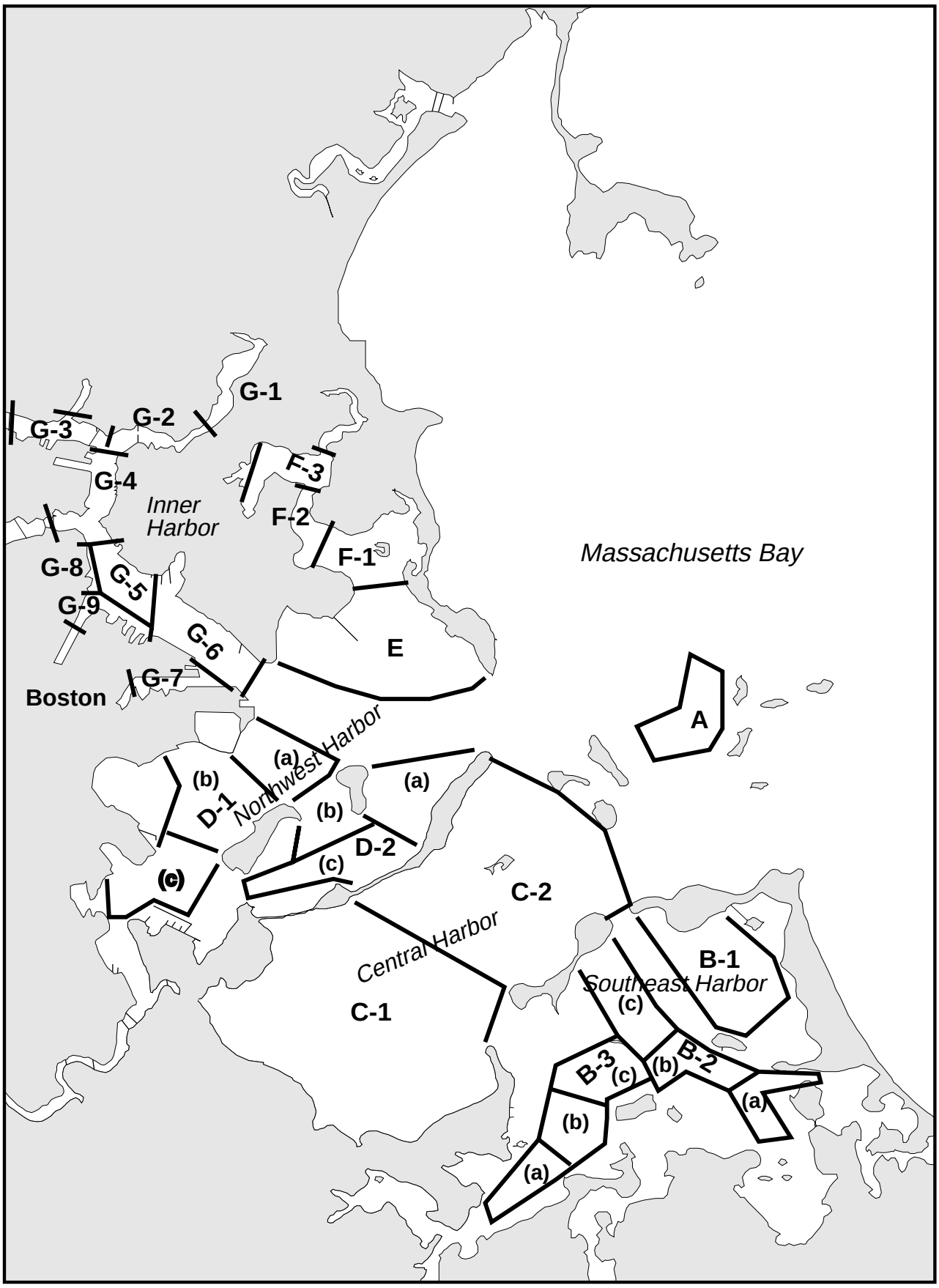

Figure 11. Locations and boundaries of sampling strata in Boston Harbor.

The locations (latitudes, longitudes) of each station were selected randomly, using a computer program of the U. S. EPA EMAP office in Gulf Breeze, Florida. For each prospective sampling station, four alternate locations were provided by the program. In the field, the vessel was positioned at the latitude and longitude with the aid of Loran and a sample was collected at the first alternate, if feasible. If the first alternate location could not be sampled because of obstructions, presence of only rock, gravel or coarse sand, etc., it was abandoned and the vessel was moved to the second alternate. In almost all cases the first alternate locations were sampled successfully in each stratum. Exceptions included two of the three stations in stratum A in Massachusetts Bay, in which a sample was collected at the first alternate (A1), but the alternates 2-5 proved to be rock, kelp, or lobster traps and the collection of mud was infeasible. Therefore, samples were taken at locations A7 and A8. Also, the collection of samples at several locations were infeasible in strata G1 and G2. A sample from station D1-a was retained despite the capture of an irate, live lobster in the sampler.

Sample Collection

Sample collection and shipping were coordinated by Science Applications International Corporation (SAIC). All sediments were collected using a modified 0.1m^2 Van Veen (Young) grab. The grab sampler and sampling utensils were thoroughly cleaned with site water and acetone before each sample collection.

Locations of the individual sampling stations are illustrated in Figure 12 and coordinates for each are listed in Table 1. Field log notes containing information on depth and sediment characteristics at each station are listed in Appendix A.

Table 1. Locations of sediment sampling stations in Boston Harbor.

Strata No.	Station Location	Station No.	Date	Latitude	Longitude	Depth ft.
A	Massachusetts Bay	1	6/29/93	42° 20.45' N	70° 54.45' W	46
		2	6/29/93	42° 20.27' N	70° 54.31' W	50
		3	6/29/93	42° 20.59' N	70° 54.11' W	53
B-1	Hull Bay	a	7/14/93	42° 17.92' N	70° 54.21' W	13
		b	7/14/93	42° 17.36' N	70° 54.16' W	18
		c	7/14/93	42° 17.82' N	70° 53.55' W	11
B-2	Hingham Bay	a	6/29/93	42° 16.38' N	70° 53.62' W	21
		b	6/29/93	42° 16.78' N	70° 54.32' W	32
		c	6/29/93	42° 17.76' N	70° 55.50' W	25
B-3	Weymouth Fore River	a	7/14/93	42° 15.11' N	70° 57.13' W	41
		b	7/14/93	42° 15.88' N	70° 56.45' W	16
		c	7/14/93	42° 16.54' N	70° 55.58' W	17

Table 1 contd.

Strata No.	Station Location	Station No.	Date	Latitude	Longitude	Depth ft.
C-1	Quincy Bay	a	7/12/93	42° 17.94' N	70° 58.46' W	18
		b	7/12/93	42° 16.61' N	70° 58.10' W	11
		c	7/12/93	42° 17.60' N	70° 59.50' W	13
C-2	Nantasket Roads	a	6/29/93	42° 18.54' N	70° 56.80' W	23
		b	6/29/93	42° 18.51' N	70° 58.46' W	13.5
		c	6/29/93	42° 18.34' N	70° 58.69' W	14
D-1	Dorchester Bay	a	6/30/93	42° 19.77' N	70° 00.60' W	19
		b	6/30/93	42° 19.31' N	71° 00.81' W	22
		c	6/30/93	42° 18.40' N	71° 02.12' W	25
D-2	Sculpin Ledge	a	7/12/93	42° 19.55' N	70° 58.58' W	17
		b	7/12/93	42° 19.33' N	70° 59.55' W	19
		c	7/12/93	42° 18.64' N	70° 59.30' W	17
E	Northwest Harbor	1	7/14/93	42° 20.56' N	71° 00.32' W	19
		2	7/14/93	42° 20.63' N	70° 59.45' W	10
		3	7/14/93	42° 20.91' N	70° 58.23' W	16
F-1	Snake Island	1	6/30/93	42° 21.74' N	70° 59.23' W	14
F-2	Chelsea Point	2	6/30/93	42° 22.13' N	70° 59.84' W	18
F-3	Orient Heights	3	6/30/93	42° 22.73' N	70° 59.90' W	31
G-1	Upper Chelsea River	a	6/28/93	42° 23.52' N	71° 00.99' W	35
		b	6/28/93	42° 23.26' N	71° 01.21' W	33
		c	6/28/93	42° 23.76' N	71° 00.78' W	33
G-2	Lower Chelsea River	a	7/13/93	42° 23.14' N	71° 02.41' W	41
		b	7/13/93	42° 23.14' N	71° 02.11' W	43
		c	7/13/93	42° 23.13' N	71° 01.48' W	36
G-3	Mystic River	a	7/13/93	42° 23.05' N	71° 03.02' W	35
		b	7/13/93	42° 23.20' N	71° 03.30' W	38
		c	7/13/93	42° 23.10' N	71° 03.21' W	42
G-4	Charleston Channel	a	7/15/93	42° 22.42' N	71° 02.72' W	45
		b	7/15/93	42° 22.36' N	71° 02.91' W	45
		c	7/15/93	42° 22.35' N	71° 03.08' W	29
G-5	Boston Channel	a	6/28/93	42° 21.41' N	71° 02.16' W	41
		b	6/28/93	42° 21.62' N	71° 02.17' W	36
		c	6/28/93	42° 21.79' N	71° 02.59' W	50

Table 1 contd.

Strata No.	Station Location	Station No.	Date	Latitude	Longitude	Depth ft.
G-6	Channel Mouth	a	7/15/93	42° 21.01' N	71° 00.94' W	38
		b	7/15/93	42° 21.36' N	71° 01.72' W	37
		c	7/15/93	42° 20.82' N	71° 01.19' W	46
G-7	Reserved Channel	1	6/28/93	42° 20.55' N	71° 01.80' W	36
G-8	Boston Wharves	a	6/30/93	42° 21.74' N	71° 02.79' W	24
		b	6/30/93	42° 21.94' N	71° 02.90' W	24
		c	6/30/93	42° 21.99 N	71° 02.94 W	24
G-9	Fort Point	a	7/13/93	42° 21.48' N	71° 02.76' W	30
		b	7/13/93	42° 21.28' N	71° 02.44' W	39
		c	7/13/93	42° 21.11' N	71° 02.48' W	48

Multiple toxicity tests were performed on all 55 sediment samples. Chemical analyses were performed on 30 of the 55 samples for trace metals, butyl tins, polynuclear aromatic hydrocarbons, chlorinated pesticides and PCBs.

Special care was taken for samples collected for acid volatile sulfide (AVS) analyses. Sampling methods were designed to reduce the possibility of loss of AVS during field sampling, storage, and shipment without resorting to extremely expensive and cumbersome equipment and protocols. Samples for simultaneously-extracted metals (SEM) and AVS analyses were collected by taking 2 to 3 plugs from the top 2 cm. of a grab with a 10 ml plastic syringe and depositing the plugs in a 30 ml glass vial. To minimize exposure to air and subsequent oxidation of AVS, the vial was covered between addition of sediment plugs, and was kept on ice between grabs. Once the vial was full to the shoulder, it was sealed and frozen on dry ice. Samples were transferred to a freezer at SAIC's Environmental Testing Center for storage prior to analysis.

After collecting the sediment needed for SEM and AVS analyses, sediment from the top 2 to 3 cm were removed from the grab for other analyses. At all times, contact with the side of the grab was avoided. The top 2 to 3 cm of sediment was collected with a disposable, sterile, polystyrene sampling scoop and placed in a Kynar-coated stainless steel bowl. Between grabs, the bowl was placed on a layer of ice in a covered container to protect the sediment from airborne contaminants. Successive grabs were taken until approximately 8 to 10 liters of sediment were collected. The sample was thoroughly mixed by hand and only contacted Kynar and Teflon during homogenization activities.

Separate sub-samples for organics, metals and grain size analyses were placed into a 500 ml, pre-cleaned glass jar with a Teflon-lined lid for trace organics, butyltins, and TOC; a 30 ml glass vial for trace metals and ziplock bags for grain size. Samples for organics and metals were placed in a freezer or in a cooler with dry ice and kept frozen until analysis. Grain size

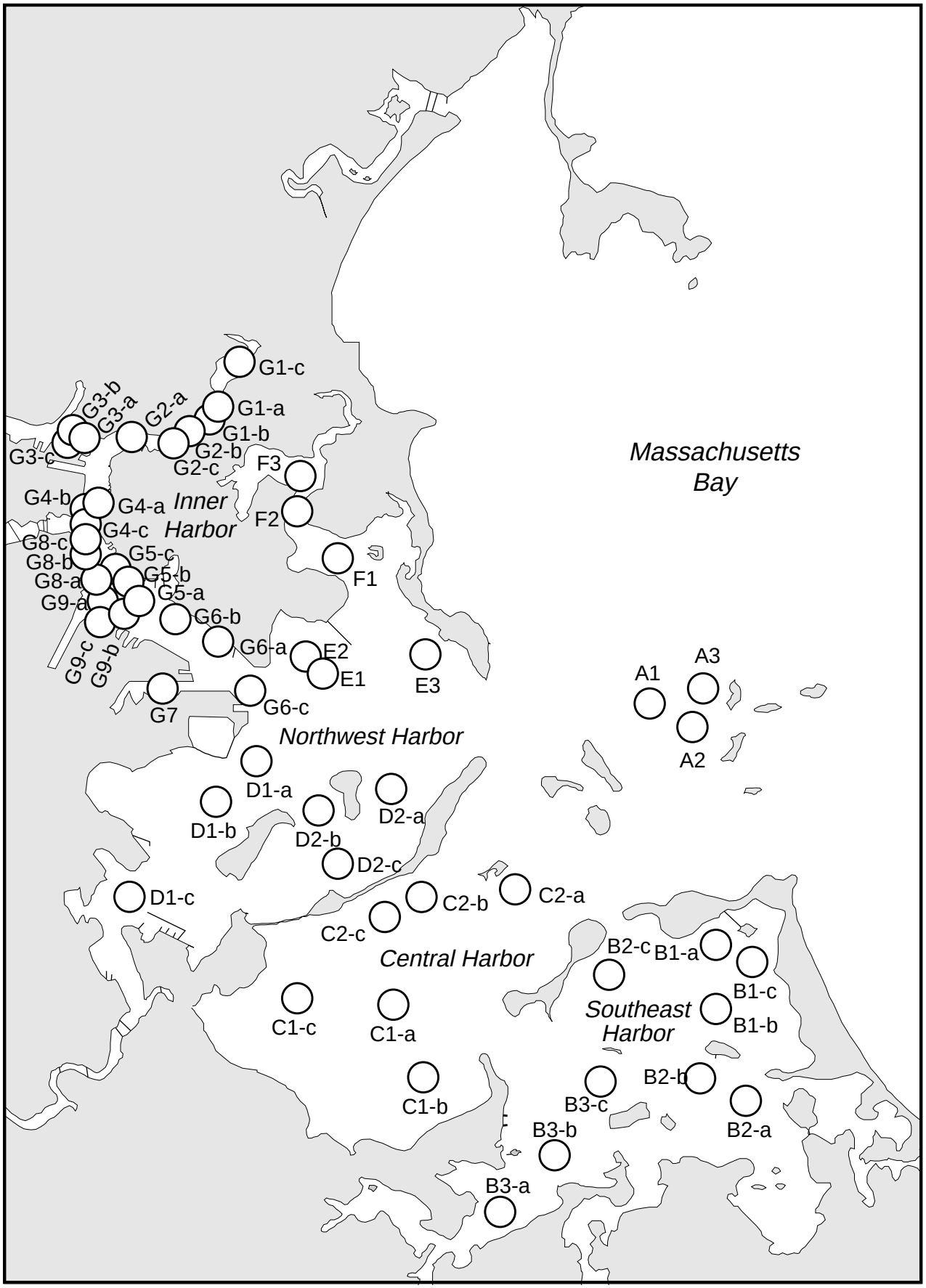

Figure 12. Locations of sediment sampling stations in Boston Harbor.

samples were stored refrigerated. Frozen samples were shipped on dry ice to the Texas A&M University/GERG laboratory where they were held frozen until toxicity testing had been completed and chemical analyses were subsequently initiated.

Toxicity samples were stored in pre-washed, 3.8 liter plastic (HDPE - polyethylene) containers; separate sample containers were prepared for each station for the U.S. National Biological Service (NBS) in Corpus Christi, Texas, and for SAIC's Environmental Testing Center in Narragansett, Rhode Island. Toxicity samples were refrigerated (not frozen) until testing was initiated. Subsamples for Microtox testing were collected after sediment toxicity samples had been press sieved. These were shipped refrigerated (unfrozen) in a double cooler by overnight delivery to ToxScan, Inc. in California.

Amphipod Test

The amphipod tests are the most widely and frequently used assays in sediment evaluations performed in North America. They are performed with adult crustaceans exposed to relatively unaltered, bulk sediments. *Ampelisca abdita* has shown relatively little sensitivity to nuisance factors such as grain size and organic carbon. In previous surveys, the NS&T Program has observed wide ranges in responses among samples, strong statistical associations with toxicants, and small within-sample variability (Long et al., 1994; Wolfe et al., 1994; Long et al., 1995).

The species chosen for the solid-phase toxicity test was *Ampelisca abdita*, a euryhaline benthic amphipod that ranges from Newfoundland to south-central Florida, and the eastern Gulf of Mexico. The amphipod test with *A. abdita* has been routinely used for sediment toxicity tests in support of numerous EPA programs, including EMAP in the Virginian, Louisianian, and Carolinian provinces (Schimmel et al., 1994). Amphipod toxicity tests followed ASTM protocols (ASTM, 1990) and were conducted by SAIC.

Test animals were collected from tidal flats in the Pettaquamscutt (Narrow) River, a small estuary flowing into Narragansett Bay, Rhode Island. Animals were held in the laboratory in pre-sieved uncontaminated ("home") sediments under static conditions. Fifty percent of the water in the holding containers was replaced every second day when the amphipods were fed. During holding, *A. abdita* were fed laboratory cultured diatoms (*Phaeodactylum tricornutum*). Ninety-six hour water-only tests with sodium dodecyl sulfate (SDS) were performed as reference toxicant tests (positive controls).

Control sediments were collected from the Central Long Island Sound (CLIS) reference station of the U.S Army Corps of Engineers, New England Division. These sediments have been tested repeatedly with the amphipod survival test and other assays and found to be non-toxic (amphipod survival has exceeded 90% in 85% of the tests) and un-contaminated (Wolfe et al., 1994; Long et al., 1995b). Sub-samples of the CLIS sediments were tested along with each series of samples from Boston Harbor.

Each test sediment was press-sieved through a 2.0-mm-mesh stainless-steel screen and thoroughly homogenized before addition to exposure chambers. Sediments were added to exposure chambers, and containers filled with overlying filtered sea water from Narragansett

Bay, R.I. Tests were conducted “blind” so investigators did not know the identity of the sample in individual replicate jars. Exposure chambers were numbered and individual replicates randomly assigned to a particular jar.

Amphipods were exposed to test sediments for 10 days with 5 replicates under static conditions, using filtered sea water. The exposure chambers were quart size canning jars with an inverted glass dish as a cover. Two hundred milliliters of control or test sediment was placed in the bottom of the jar and covered with approximately 600 ml of seawater. Exposure containers were incubated in a 20° C water bath. Air was delivered by air pumps into the water column through a glass 2-ml pipette inserted through the cover opening, providing dissolved oxygen concentrations greater than 60% saturation. Lighting was continuous during the 10-day test to inhibit swimming behavior of the organisms.

Twenty subadult amphipods were distributed randomly to each of the test chambers. Exposure chambers were checked daily, and the number of individuals that were dead, moribund, on the sediment surface and on the water surface were recorded. Dead individuals were removed daily. At the completion of 10 days, animals were counted in each of the chambers, and results recorded.

Sea Urchin Fertilization and Embryological Development Tests

Tests of sea urchin fertilization and embryo development have been used in assessments of ambient water and effluents and in previous NS&T Program surveys of sediment toxicity (Long et al., 1994). Test results have shown very wide ranges in responses among test samples, excellent within-sample homogeneity, and strong associations with the concentrations of toxicants in the sediments. The tests, performed with the early life stages of the sea urchins, have demonstrated high sensitivity.

In previous surveys, the tests of embryological development have shown higher sensitivity than tests of fertilization success and have had relatively poor correlations with each other (Long, et al., 1990; Carr, 1993; NBS, 1994; Carr et al., in press). It appears that these two end-points respond to different toxic substances in complex mixtures.

Toxicity of sediment pore waters was determined using fertilization and embryological development tests with the sea urchin *Arbacia punctulata.* Sea urchin toxicity tests were performed by the National Biological Service, National Fisheries Contaminant Research Center in Corpus Christi, Texas at their laboratory in Port Aransas. Sea urchins used in this study were obtained from Gulf Specimen Company, Inc. (Panacea, Florida), and were acclimated to Port Aransas seawater for a minimum of 17 days before gametes were collected for testing.

Pore water was extracted from sediments for toxicity testing with sea urchins using a pneumatic extraction device (Carr and Chapman, 1992; Carr et al., in press). Sediment samples were held refrigerated (at 4° C) until pore water was extracted. Pore water was extracted as soon as possible after receipt of the samples, but in no event were sediments held longer than 7 days from the time of collection before they were processed. After extraction, pore water samples were centrifuged in polycarbonate bottles at 4200 g for 15 minutes to remove any particulate matter, and were then frozen. Two days before the start of a toxicity test,

samples were moved from a freezer to a refrigerator at 4° C, and one day prior to testing, thawed in a tepid water bath. Temperature of samples was maintained at 20±1° C. Sample salinity was measured and adjusted to 30±1 ppt, if necessary, using ultrapure sterile water or concentrated brine. Other water quality measurements, including: dissolved oxygen, pH, sulfide and total ammonia, were made. Temperature and dissolved oxygen were measured with YSI meters; salinity was measured with Reichert or American Optical refractometers; pH, sulfide and total ammonia (expressed as nitrogen, TAN) were measured with Orion meters and their respective probes. The concentrations of un-ionized ammonia (UAN) were calculated using respective TAN, salinity, temperature, and pH values.

Each of the 55 pore water samples was tested in a dilution series of 100%, 50%, and 25% of the water quality adjusted sample with 5 replicates per treatment. Dilutions were made with clean, filtered (0.45 *u*m), Port Aransas laboratory seawater. Pore water samples were both stored and handled under ambient atmospheric conditions.

The tests were conducted with the gametes and embryos of the sea urchin *Arbacia punctulata*, following the methods of Carr and Chapman (1992). Pore water from a reference area in Redfish Bay, Texas, an area located near the testing facility and in which sediment pore waters have been determined to be non-toxic in this test (e. g., Long et al., 1994), was included with each toxicity test as a negative (non-toxic) control. Adult male and female urchins were stimulated to spawn with a mild electric shock, and gametes collected separately.

For the sea urchin fertilization test, 50 *u*L of appropriately diluted sperm were added to each vial, and incubated at 20±2°C for 30 minutes. One ml of a well mixed dilute egg suspension was added to each vial, and incubated an additional 30 minutes at 20± 2°C. Two mls of a 10% solution of buffered formalin solution was added to stop the test. Fertilization membranes were counted, and fertilization percentages calculated for each replicate test.

For the sea urchin embryological development test, a well mixed dilute egg solution was added to each vial. Then, 50 *u*L of appropriately diluted sperm were added to each vial, and vials were incubated at 20±1°C for 48 hours. At the end of 48 hours, 2 mls of 10% buffered formalin were added to each vial to stop the test. One hundred embryos were counted, and recorded as normal, unfertilized, embryological development arrested or otherwise abnormal. The percent of the embryos that were normal was reported for each replicate test.

Microbial bioluminescence tests

Microtox™ tests were performed with organic extracts of the sediments using the organic extract protocol described by Long and Markel (1990). Solvent extractions and analyses were performed by ToxScan, Inc. This is a test of the relative toxicity of extracts of the sediments, and, therefore, it is relatively immune to the effects of nuisance environmental factors, such as grain size and organic carbon. Organic toxicants and, to a lesser degree, trace metals that may or may not be readily bioavailable are virtually made bioavailable with the solvent extraction. Therefore, this test can be considered as a test of potential toxicity. In previous NS&T Program surveys, the results of Microtox tests have shown extremely high correlations with the concentrations of mixtures of organic compounds (Long et al., 1994; Long et al., 1995b; Wolfe et al., 1994).

Excess water from the top of the samples was decanted and discarded. Sediments were homogenized and a 3.3 g wet weight sample was weighed into a 50 ml Pyrex centrifuge with a Teflon lined screw cap. The 3.3 g extraction samples were centrifuged for 5 minutes and the aqueous layer discarded. Any remaining water was removed by the addition of 15 grams anhydrous sodium sulfate. Then, 30 ml of dichloromethane (DCM) were added to each sample, the samples were thoroughly mixed and placed on a shaker for 16 hours. Samples were then centrifuged for 5 min. and the DCM poured into a 100 ml bottle with a Teflon lined screw cap. A second 30 ml aliquot was added and the extraction repeated for 16 hours. The extraction was again repeated with a final 30 ml of DCM for 16 hours. The 3.3 g wet weight that was extracted was converted to dry weight using percentage moisture values determined using a portion of each sample.

Solvent exchanges and concentrations were carried out using a Kuderna-Danish flask attached to a Snyder column. The DCM was reduced to <10 ml at 75°C, followed by the addition of 25 to 30 ml of undenatured ethanol. The mixture was concentrated to a volume of 10 ml or less at 100°C, thus providing an ethanol solution containing no DCM. Upon completion, the sample was brought up to exactly 10 ml with undenatured ethanol and transferred to a clean vial. Method blanks were prepared using methods outlined above for extraction, solvent exchange and concentration of test samples without the addition of sediment.

Sediment extracts were tested in duplicate using the Microtox assay procedure (Microbics Corporation, 1992). Freeze dried bacteria were rehydrated with toxicant-free distilled water, covered and stored in a 4°C well on the Microtox analyzer. The sediment extract was diluted 1:100 with Microtox diluent, resulting in a stock solution for testing containing 1% ethanol. Concentration of the stock test solution was 3.3 mg wet sediment per ml of solution. Serial dilutions of 50, 25, 6.25, 3.13, 1.56 and 0 percent of the stock solution were made using Microtox diluent (2% NaCl) containing 1% undenatured ethanol. In each of seven test cuvettes, 20 *u*L of the rehydrated bacterial suspension was added to 500 *u*L of diluent and incubated at 15°C for 15 minutes. At 15 minutes, the initial luminescence was measured in each of the seven test cuvettes. At regular intervals, 500 *u*L aliquots of each extract dilution was added to one of the cuvettes. Exactly 5 minutes after addition of the sediment extracts, luminescence was measured at the same intervals and in the same sequence used for adding supernatant.

Percent decrease in luminescence of each cuvette relative to the reagent blank was calculated. Based upon these data, the sediment concentrations that caused 50% decreases in light production (EC50's) were reported.

Chemical Analyses

Concentrations of trace inorganic elements and organic compounds, butyltins, grain size, acid volatile sulfide and simultaneously extracted metals (AVS-SEM), and total organic carbon (TOC) were measured on 30 sediment samples by the GERG/TAMU laboratory in College Station, Texas. All analytical techniques and quality assurance/quality control procedures followed those of the NS&T Program (see Lauenstein and Cantillo, 1993 for a review). These were not "standard" equipment-based protocols, but, rather, were performance-based methods adopted by both the NS&T Program and U.S. EPA's Environmental Monitoring and

Assessment Program -Estuaries. The 30 samples selected for chemical analyses were chosen based upon a review of the results of the toxicity tests. First, those samples showing the most toxic responses in assays were chosen for analysis. Additional samples showing intermediate and no response to toxicity were also selected for analysis to provide a gradient.

Inorganic and physical measurements. Grain size was determined by the standard pipette method following sieving for the sand and gravel fractions. TOC was determined using a Leco Carbon analyzer. Sediment samples were digested for final analysis by procedures specific to the instrument method used. Various concentrating and trapping techniques were used for selected analytes. The analysis for mercury was performed by cold vapor atomic absorption. Analyses for tin, arsenic, selenium, silver, and cadmium were performed by graphite furnace atomic absorption spectroscopy. All other metals were determined by flame atomic absorption spectroscopy. All sediment metals concentrations were reported on a dry weight basis. Detection limits attained in the analyses are listed in Table 2.

Table 2. Trace metals measured in Boston Harbor sediments and method detection limits (MDLs).

Parameter	Method Detection Limit (ppm, based on dry weight)	Analytical Method *
Aluminum	440	FAA
Iron	40	FAA
Manganese	5.0	FAA
Arsenic	0.3	GFAAS
Cadmium	0.008	GFAAS
Chromium	0.1	GFAAS
Copper	0.44	GFAAS
Lead	0.35	GFAAS
Mercury	0.007	CVAA
Nickel	0.7	GFAAS
Selenium	0.2	GFAAS
Silver	0.03	GFAAS
Tin	0.1	GFAAS
Zinc	2.2	FAA
SEM-Copper	0.50	FAA
SEM-Cadmium	0.01	GFAAS
SEM-Nickel	0.7	GFAAS
SEM-Lead	0.4	GFAAS
SEM-Zinc	2.2	FAA
SEM-Mercury.	0.001	CVAA

* FAA = Flame atomic absorption spectroscopy;
GFAAS = Graphite furnace atomic absorption spectroscopy
CVAA = Cold vapor atomic absorption.

The analytical method used for AVS analysis employed selective generation of hydrogen sulfide and determination by gravimetric, colorometric or titrametric methods, depending on the expected concentration of sulfide. Following the AVS analysis, and digestate filtration, SEM analysis was performed on the HCl sediment digestate. The concentrations of cadmium, copper, lead, mercury, nickel and zinc were quantified in the AVS.

Organic Compounds. The analytes determined in the organic analyses are listed in Table 3, along with some of their representative MDLs. Sediment samples for organic analysis were prepared by methylene chloride extraction, purified by silicon gel/alumina chromatography and concentration. Quantification was performed using the internal standards method. Polycyclic aromatic hydrocarbons (PAHs) were analyzed by gas chromatography with a mass selective detector in the selective ion mode. Sediment samples analyzed for butyltins were extracted with methylene chloride containing 2% tropolone, hexylated, purified by silica gel chromatography, and concentrated. Butyltins were analyzed by gas chromatography with a tin selective flame photometric detector. Polychlorinated biphenyls and chlorinated pesticides were determined by gas chromatography/electron capture detection. Concentrations of sediment organic compounds are reported on a dry weight basis.

Table 3. Organic compounds measured in Boston Harbor sediments and method detection limits (MDLs).

Compound	(ng/g dry)	Parameter	(ng/g dry)
2,4'Dichloro Diphenyl Ethylene (O,P'DDE)	0.28	Naphthalene	0.5
4,4'Dichloro Diphenyl Ethylene (P,P'DDE)	0.85	C1-Naphthalenes	
2,4'Dichloro Diphenyl Dichloroethylene (O,P'DDD)	0.13	C2-Naphthalenes	
4,4'Dichloro Diphenyl Dichloroethylene (P,P'DDD)	0.51	C3-Naphthalenes	
2,4'Dichloro Diphenyl Trichloroethylene (O,P'DDT)	0.25	C4-Naphthalenes	
4,4'Dichloro Diphenyl Trichloroethylene (P,P'DDT)	0.24	1- Methylnaphthalene	0.8
Aldrin	0.25	2- Methylnaphthalene	0.8
Cis-Chlordane	0.66	2,6-Dimethylnaphthalene	2.4
Oxychlordane		2,3,5- Trimethynaphthalene	2.4
Alpha-Chlordane	0.23	Acenaphthalene	3.7
Trans-Nonachlor	0.1	Acenaphthylene	4.5
Cis-Nonachlor		Fluorene	2.5
Dieldrin	0.16	C1-Fluorenes	
Heptachlor	0.2	C2-Fluorenes	
Heptachloro-Epoxide	0.16	C3-Fluorenes	
Hexachlorobenzene	0.37	Phenanthrenes	0.5
Alpha-Benzene Hexachloride		C1-Phenanthrenes	
Beta-Benzene Hexachloride		C2-Phenanthrenes	
Lindane (Gamma-Benzene Hexachloride)	0.22	C3-Phenanthrenes	
Delta-Benzene Hexachloride	0.17	C4-Phenanthrenes	
Endrin		1- Methylphenanthrene	0.6
Mirex	0.08	Anthracene	4.1
Polychlorinated Biphenyls		Fluoranthene	0.4
PCB#8 (CL2)	0.08	Pyrene	3.1

Table 3 contd.

Compound	(ng/g dry)	Parameter	(ng/g dry)
PCB#18 (CL3)	0.25	Indeno-1,2,3-c,d-Pyrene	1.6
PCB#28 (CL3)	0.09	Dibenzothiophene	
PCB#44 (CL4)	0.09	C1-Dibenzothiophenes	
PCB#52 (CL4)	0.09	C2-Dibenzothiophenes	
PCB#66 (CL4)	0.14	C3-Dibenzothiophenes	
PCB#101 (CL5)	0.13	C1- Fluoranthene Pyrene	
PCB#105 (CL5)	0.1	Benzo-a-Anthracene	1.4
PCB#110/77 (CL5/4)	*	Chrysene	0.5
PCB#118/108/149 (CL5/5/6)	0.12	C1-Chrysenes	
PCB#128 (CL6)	0.13	C2-Chrysenes	
PCB#138 (CL6)	0.18	C3-Chrysenes	
PCB#126 (CL6)	*	C4-Chrysenes	
PCB#153 (CL6)	0.12	Benzo-b-Fluoranthene	1.8
PCB#170 (CL7)	0.81	Benzo-k-Fluoranthene	1.9
PCB#180 (CL7)	0.16	Benzo-a-Pyrene	1.2
PCB#187/182/159 (CL7/7/6)	0.14	Benzo-e-Pyrene	2.4
PCB#195 (CL8)	0.25	Perylene	3.3
PCB#206 (CL9)	0.09	Benzo-g,h,i-Perylene	0.3
PCB#209 (CL10)	0.78	Dibenzo-a,h-Anthracene	2.6
Biphenyl	2.4		

Chemistry QA/QC. Quality assurance procedures included analyses of duplicates, standard reference materials, and spiked internal standards. In the organic analyses, internal standards were added at the start of the procedure and carried through the extraction, cleanup, and instrumental analysis steps. The organic recovery rate data was used to correct analytical data before reporting. The following specific quality assurance steps were used to insure measurement accuracy and precision:

1. Trace and major metals, including SEM: Two method blanks and three standard reference materials were run with each set of no more than 30 samples.

2. Physical/chemical measurements: Grain size duplicates were run every 20 samples. For TOC, one method blank, one duplicate, and one standard reference material were run every 20 samples.

3. AVS: One sample duplicate and one procedural blank were run with each set of ten samples.

4. Pesticides, PCBs and PAHs: One procedural blank, one matrix spike, one duplicate spike and one standard reference material were run with each batch of no more than 20 samples. Surrogate recoveries were tracked.

Statistical methods

Amphipod percentage survival data from each station that had a mean survival less than that of the control was compared to the control using a one-way, unpaired t-test (alpha = 0.05) assuming unequal variance. A standard t-test requires that variances be homogeneous. When sample sizes are small (5 replicates), procedures used to test for equality of variance are not

powerful. The statistical error associated with assuming unequal variance when the variances are in reality equal is less than the error associated with assuming equal variance when they are in reality unequal (Moser and Stevens, 1992). Data were not transformed since an examination of data from previous tests have shown that *A. abdita* percentage survival data met the requirement for normality. A one-sample t-test was used to compare data from each sampling block within Boston Harbor with the mean performance control for each block.

Significant toxicity in tests performed with *A. abdita* is defined here as percent survival statistically less than that in the performance control sediments. Samples in which survival was significantly less than controls and less than 80% of control values were regarded as either "highly toxic" or "numerically significant". The 80% criterion has been used by U.S. EPA in tests performed with *A. abdita* in EMAP-Estuaries studies (Holland, 1990; Schimmel et al., 1994). Similarly, proposed recommendations in the dredged material guidance manual (the "green book") also consider sediments toxic if survival relative to a reference sediment is less than 80% (U.S. EPA/U.S. ACOE, 1990). In addition, a cumulative frequency distribution (power curve) of the results of 566 tests performed by SAIC with *A. abdita* indicated that a difference of 20% survival was detectable in approximately 90% of the samples (beta = 0.10).

Microtox data were analyzed using the computer software package developed by Microbics Corporation to determine concentrations of the extract that inhibited luminescence by 50%. (EC50). This value was then converted to mg dry wt. using the calculated dry weight of sediment present in the original extract. To determine significant differences of samples from each station, pair-wise comparisons were made between contaminated samples and results from Long Island sound control sediment using analysis of covariance (ANCOVA). Concentrations tested were expressed as mg dry weight based on the percentage extract in the 1 ml exposure volume and the calculated dry weight of the extracted sediment. Both the concentration and response data were log-transformed before the analysis. ANCOVA was used first to determine if two lines had equal slopes (alpha = 0.05). If the slopes were equal, ANCOVA then determined the quality of the Y-intercepts (alpha = 0.05). A one-sample t-test was used to compare data from each sampling block within Boston Harbor with the mean of the duplicate performance control data from Long Island Sound.

Significant toxicity in the Microtox tests is defined here as an EC50 statistically less than that in the performance control. Samples were considered highly toxic or numerically significant when the EC50s were significantly different from controls and less than 80% of the controls. The statistical significance of the 80% criterion has not been determined for this test, however, the 80% criterion was used to ensure consistency with the other toxicity tests.

For both the sea urchin fertilization and morphological development tests, statistical comparisons among treatments were made using ANOVA and Dunnett's one-tailed *t*-test (which controls the experiment-wide error rate) on the arcsine square root transformed data with the aid of SAS (SAS, 1989). The trimmed Spearman-Karber method (Hamilton et al., 1977) with Abbott's correction (Morgan, 1992) was used to calculate EC_{50} (50% effective concentration) values for dilution series tests. Prior to statistical analyses, the transformed data sets were screened for outliers (SAS, 1992). Outliers were detected by comparing the studentized residuals to a critical value from a t-distribution chosen using a Bonferroni-type adjustment. The adjustment is based on the number of observations (n) so that the overall probability of a type

1 error is at most 5%. The critical value (CV) is given by the following equation: $cv = t(df_{Error}, .05/(2 \times n))$. After omitting outliers but prior to further analyses, the transformed data sets were tested for normality and for homogeneity of variance using SAS/LAB Software (SAS, 1992).

Spatial patterns in chemical concentrations and toxicity were estimated by plotting data on base maps of the area. Estimates of the spatial extent of toxicity were determined with cumulative distribution functions in which the toxicity results from each station were weighted to the dimensions (km^2) of the sampling stratum in which the samples were collected (Heimbuch et al., 1995; Schimmel et al., 1994). The size of each stratum (Km2) was determined with a planimeter on navigation charts, upon which the boundaries of each stratum were outlined. A critical value of 80% of control response or less was used in the calculations of the spatial extent of toxicity.

Chemistry/toxicity relationships were determined in a five-step sequence (Long et al., 1995b). First, simple Spearman-rank correlations were determined for each toxicity test and each chemical or physical variable. Next, for those chemicals in which a significant correlation was observed, the data were examined in scatterplots to determine if there was a reasonable pattern of increasing toxicity with increasing chemical concentration, and then, if any chemical in the toxic samples equalled or exceeded previously published numerical guidelines. Third, the numbers of samples out of the 30 that were analysed that exceeded the respective guidelines were determined. Fourth, the average concentrations of chemicals in non-toxic samples were compared with the average concentrations in significantly toxic samples, and ratios between the two averages were calculated and compared. Finally, the average concentrations of chemicals in the toxic samples were compared with the respective numerical guidelines. The combined results of these steps were examined to determine which chemical(s), if any, may have contributed to the observed toxicity.

RESULTS

Distribution and Concentrations of Chemical Contaminants

Physical and chemical analyses were performed on 30 of the 55 samples following review of the data from the toxicity tests. These 30 samples were not chosen randomly. Rather, they were chosen to represent gradients in high-to-low toxicity among contiguous or nearby stations.

Potentially toxic chemicals readily sorb to and accumulate with finer-grained materials in low-energy depositional areas. Therefore, toxicity can frequently be tracked by the concentrations of fine- grained materials. Concentrations of fine-grained materials are expressed as percentages of silt plus clay. The majority of the sampling stations were dominated by silts and clays (Figure 13). Many of stations in the inner harbor, central harbor, and the western portion of northwest harbor had high concentrations of silts and clays. Stations with relatively low percentages of fine-grained materials included B2(b) in southeast harbor, D1(b) in northwest harbor, and all three stations in the G2 stratum in the lower Chelsea River. Some stations in the lower Chelsea River appeared to be erosional and scoured. Sediments from station A1 beyond the entrance to the Harbor had a relatively high percent of fines.

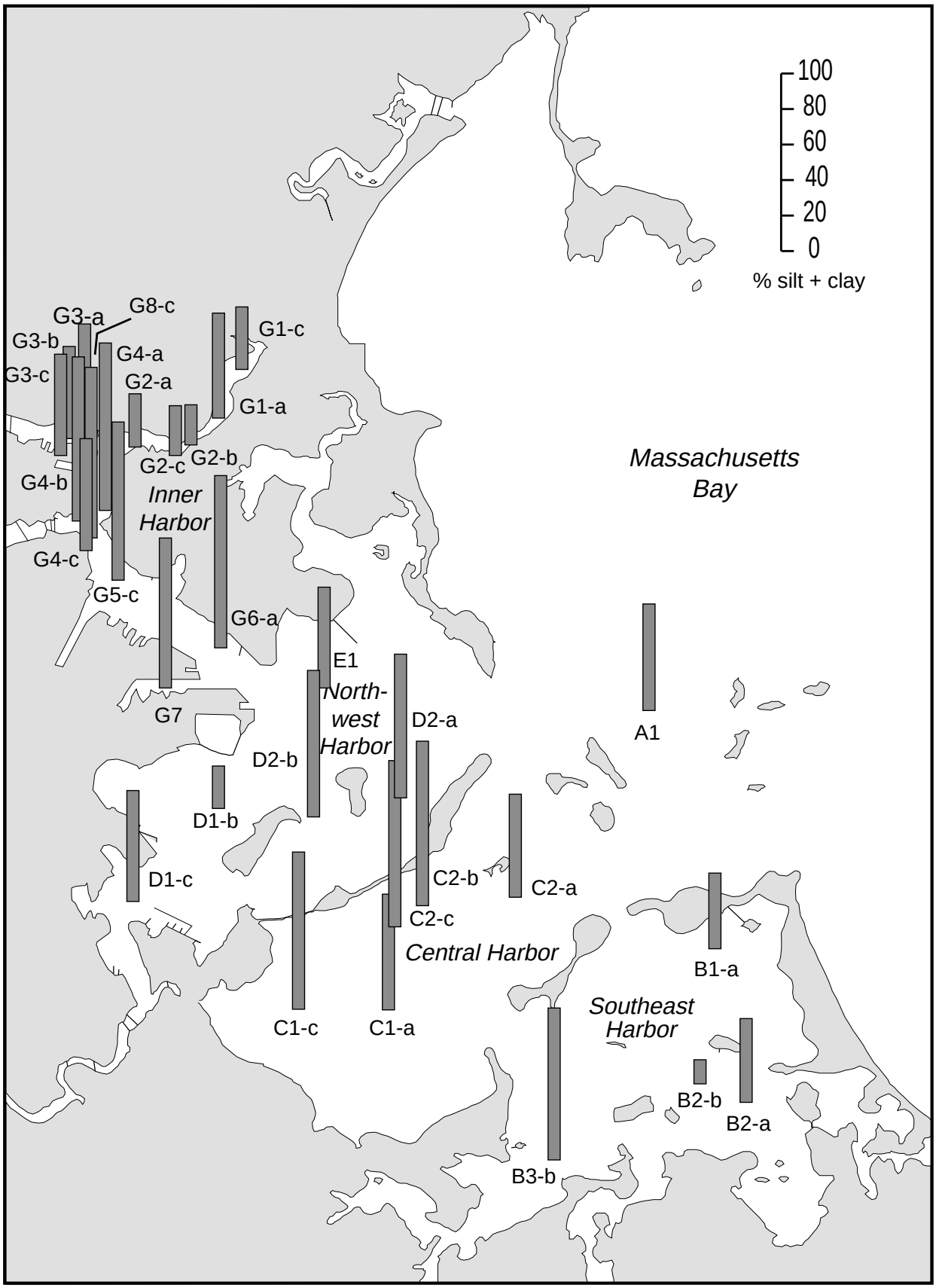

Figure 13. Distribution of fine-grained sediment particles (percent fines) in selected stations in Boston Harbor.

All the substances that were measured in the chemical analyses varied in concentrations among the sampling stations (Appendices C-F). Distributions of both metals and organic contaminants were examined, and those showing the greatest variation in concentrations throughout the Harbor were identified for further analysis and discussion.

Spearman-rank correlations among most trace metals were significant (Rho <0.05) and often highly significant (Rho <0.0001), indicating that these substances co-varied with each other to a large degree. Correlations between the concentrations of fine-grained sediments and all trace metals were significant (Rho <0.05 to <0.0001), suggesting that trace metal concentrations paralleled the distribution of fines.

The ranges in concentrations of lead and zinc were among the highest for the trace metals that were measured and were representative of the distribution patterns for most other metals. The concentrations of lead in the 30 samples ranged from 29.6 ug/g at station B2(b) in southeast harbor to 468.0 ug/g at station G2(a) in the lower Chelsea River (Figure 14). Generally, lead concentrations were highest in the samples from the inner harbor and lowest in the samples from the southeast harbor. Lead concentrations were intermediate in samples from northwest and central harbor stations. The concentrations of lead closely paralleled the distribution of the fine-grained materials (Figure 13). Furthermore, the Spearman-rank correlation between lead concentrations and percent fines was significant (Rho = 0.515, $p < 0.05$, $n = 30$).

The pattern in zinc concentrations among the 30 stations was similar to that of lead (Figure 15). Zinc ranged in concentration from 54.5 ug/g at station B2(b) to 698.5 ug/g at station G4(c). Generally, concentrations were highest in the G strata (inner harbor), intermediate in the northwest harbor and central harbor stations (strata C-E), and lowest in the southeast harbor stations (B strata).

Based upon equilibrium-partitioning theory, the bioavailability, and therefore, the potential toxicity of trace metals should be a function of the excess concentration of simultaneously-extracted metals (SEM) relative to the acid-volatile sulfides (AVS) in sediments (U. S. EPA, 1994a). Sediments in which molar AVS concentrations exceed molar SEM concentrations (i.e., SEM/AVS ratios <1.0 or SEM minus AVS concentrations <1.0) are not expected to be toxic as a consequence of metals contamination. In theory, under those conditions, potentially toxic metals should be sufficiently bound to the AVS, rendering them non-toxic. SEM/AVS ratios or differences are intended for use as a non-toxicity tool, as opposed to a toxicity tool (U.S. EPA, 1994a). Therefore, SEM/AVS ratios of <1.0 should predict non-toxic conditions in sediments due to metals contamination. However, SEM/AVS ratios >1.0 may or may not accurately predict toxicity.

In the 30 samples from Boston Harbor, SEM/AVS ratios ranged from 0.01 to 1.12. Only three samples (those from stations C2(a), D2(a), and G1(a)) had SEM/AVS ratios that approached or exceeded 1.0 (Figure 16). There were no obvious spatial patterns in the SEM/AVS ratios among the 30 stations; however, the ratios in the inner harbor stations were slightly higher than those from other regions. Based upon these data and the application of the equilibrium-partitioning theory, trace metals would not be expected to represent a toxicological threat in at least 27 of the 30 samples.

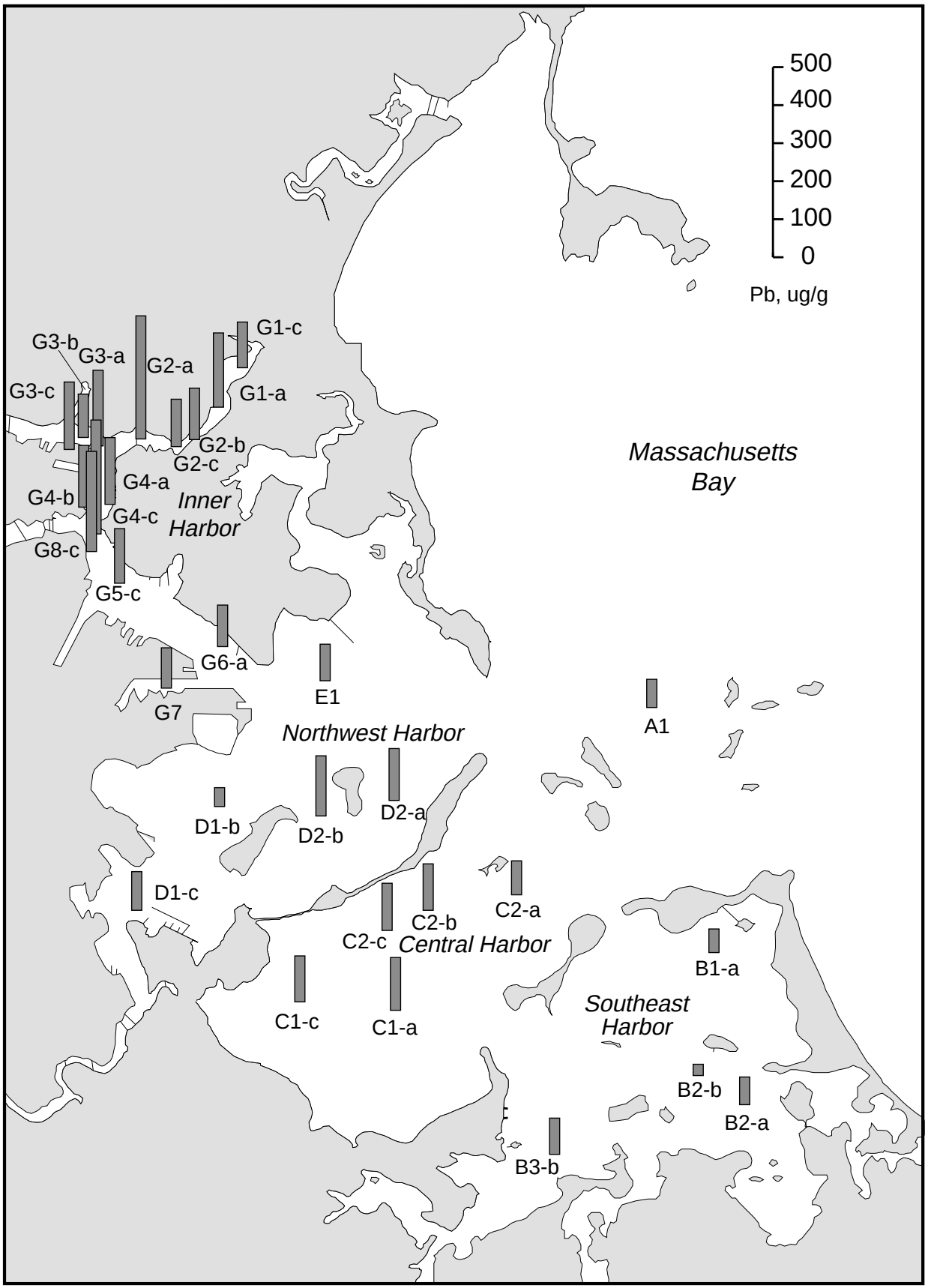

Figure 14. Distribution of lead concentrations (ug/g) in sediments from selected sampling stations in Boston Harbor.

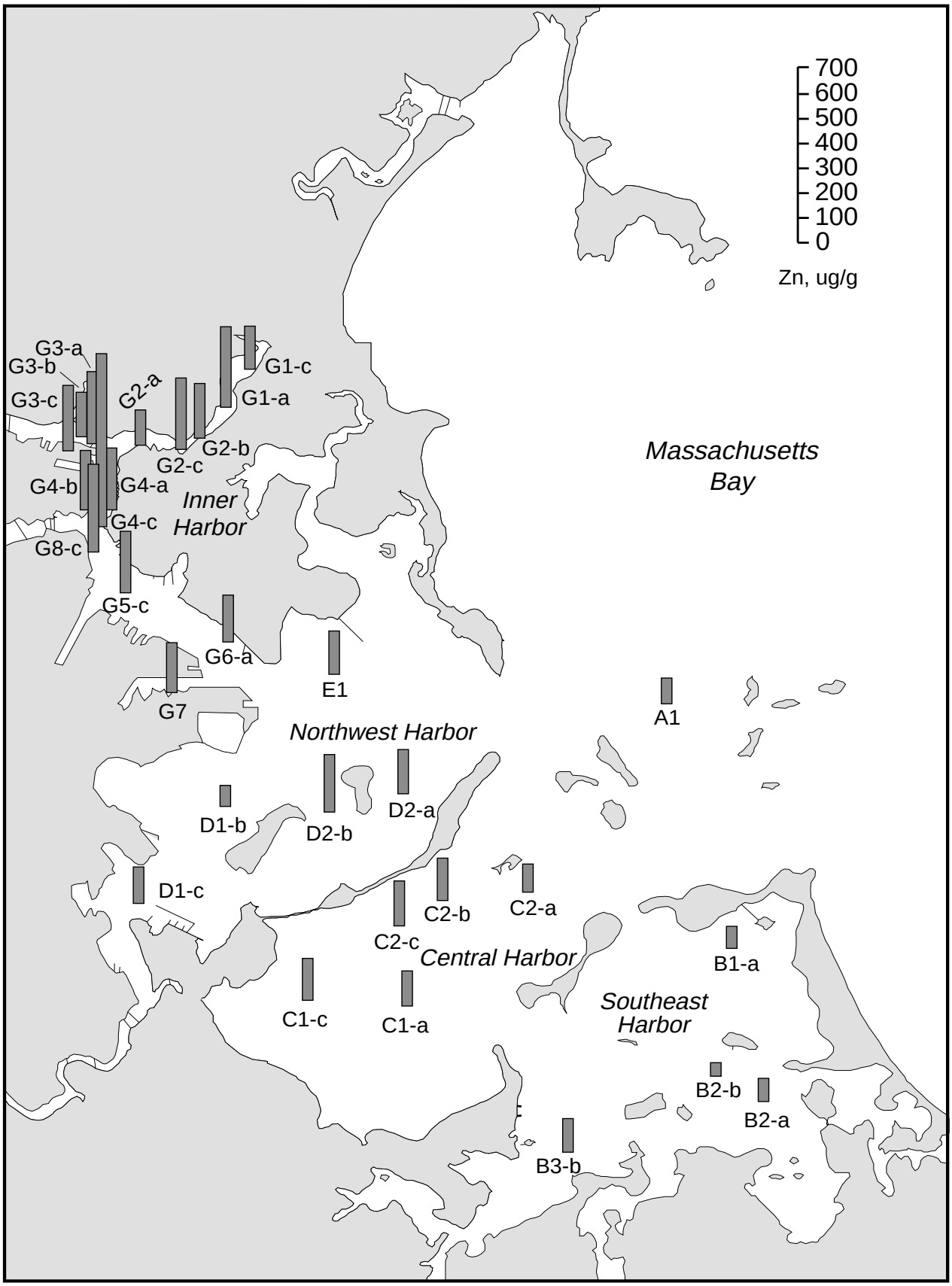

Figure 15. Distribution of zinc concentrations (ug/g) in sediments from selected stations in Boston Harbor.

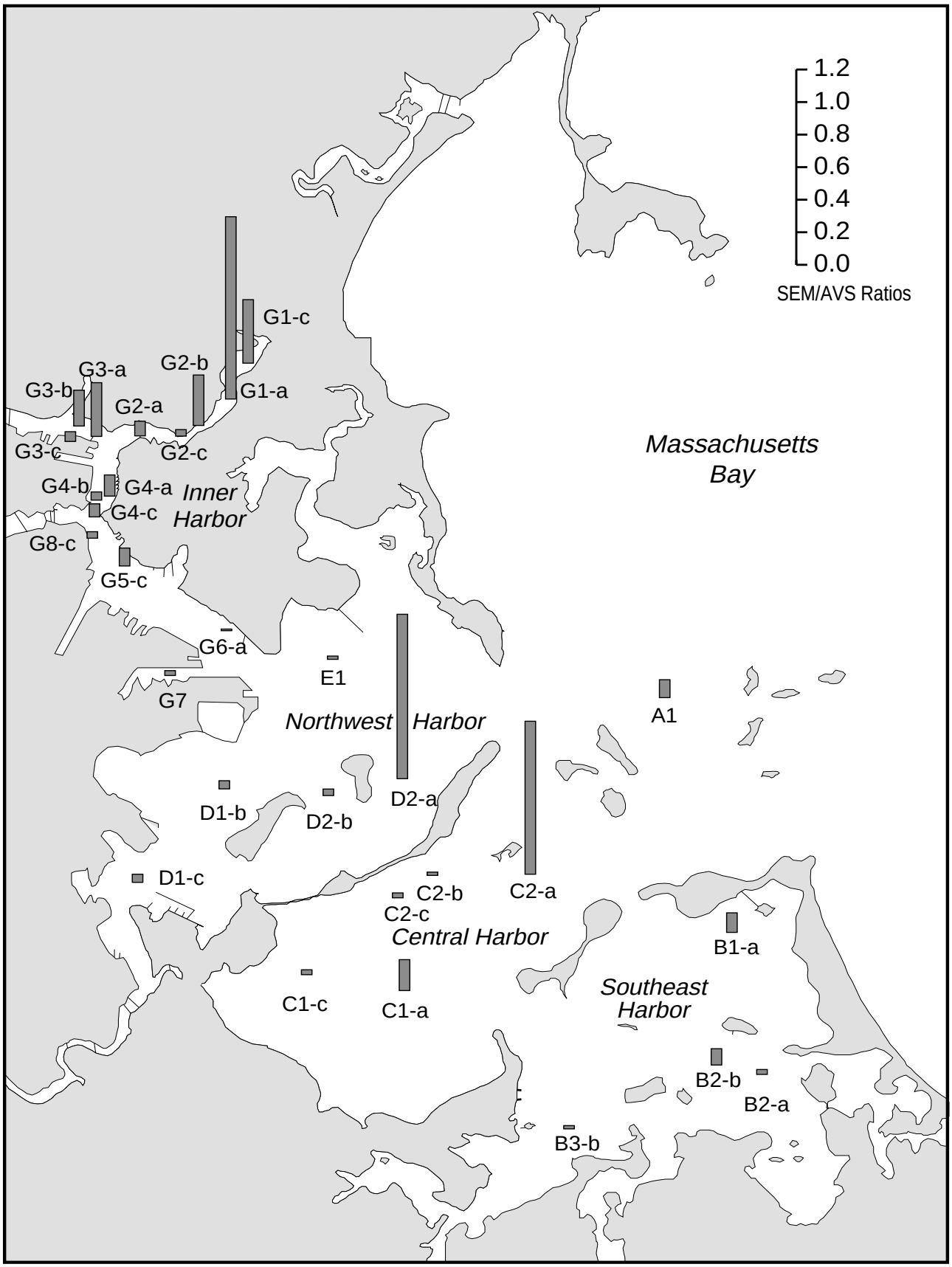

Figure 16. Total SEM/AVS ratios in sediments from selected sampling stations in Boston Harbor.

Tributyltin (TBT) and other butyltins can enter sediments from anti-fouling paints, and can be highly toxic. Concentrations of tributyltin (TBT) followed the same general pattern as lead and zinc (Figure 17) with relatively high concentrations in the inner harbor samples, diminishing down the harbor to the stations in southeast harbor. TBT concentrations ranged from 5.5 ng Sn/g at station B1(a) to 243.6 ng Sn/g at station G2(c).

Concentrations of 18 polynuclear aromatic hydrocarbons (PAHs) and many of their substituted homologs were quantified in each sample (Appendix D). The sums of the concentrations of these individual compounds were plotted and compared among stations (Figure 18). Total PAH concentrations ranged from 1718 ng/g at station B1(a) to 40,004 ng/g at station G4(c) and 46,445 ng/g at station G2(c). The concentrations of these compounds were considerably higher in the samples from the inner harbor than in those from the other regions of the harbor. As with lead and zinc, the concentrations of the PAHs generally were lowest in samples from southeast harbor.

The concentrations of 20 individual PCB congeners were quantified in each sample and summed to determine total PCB concentrations (Appendix E). The pattern in PCB concentrations followed that of the PAHs (Figure 19). Total PCB concentrations ranged from 39.8 ng/g at station B2(b) to 786.7 ng/g at station G4(c) and 832.6 ng/g at station G8(c). The latter two stations were located near each other in the inner harbor channel.

In summary the data from the 30 samples subjected to chemical analyses indicated a relatively clear pattern: high chemical concentrations in the inner harbor samples, intermediate levels in the samples from northwest and central harbor areas, and lowest concentrations in southeast harbor samples. This pattern generally followed that reported by MacDonald (1991) based upon a thorough review of historical data compiled from numerous studies. These data suggest that if toxicity were to follow the spatial pattern in chemical concentrations in bulk sediments, then toxicity would be most severe in the inner harbor, intermediate in northwest and central harbor, and lowest in southeast harbor samples.

Amphipod Survival

Amphipod tests were performed with *Ampelisca abdita* in five different series, corresponding to the five periods of sampling effort. In four of the series, test samples were held for periods of less than 10 days before the tests were initiated. In the fifth series a few samples from previous series were re-tested after a total holding time of 24 days. Mean survival of amphipods exposed to controls ranged from 86% to 96%. Ninety-six hour LC50 concentrations of sodium dodecyl sulfate (SDS) in water-only exposures performed with *A. abdita* ranged from 5.91 to 7.94 mg/L in the five test series.

Results of the amphipod survival tests are listed in Table 4; mean percent survival (± standard deviation), statistical significance, and percent of control survival are compared among stations. Data are listed for each sampling stratum and each station. Means are based upon laboratory replicates (n=5). Stations in which mean survival was significantly lower than controls ($p<0.05$) are shown with a single asterisk, and those in which mean survival was lower than controls and less than 80% of the control are shown with two asterisks

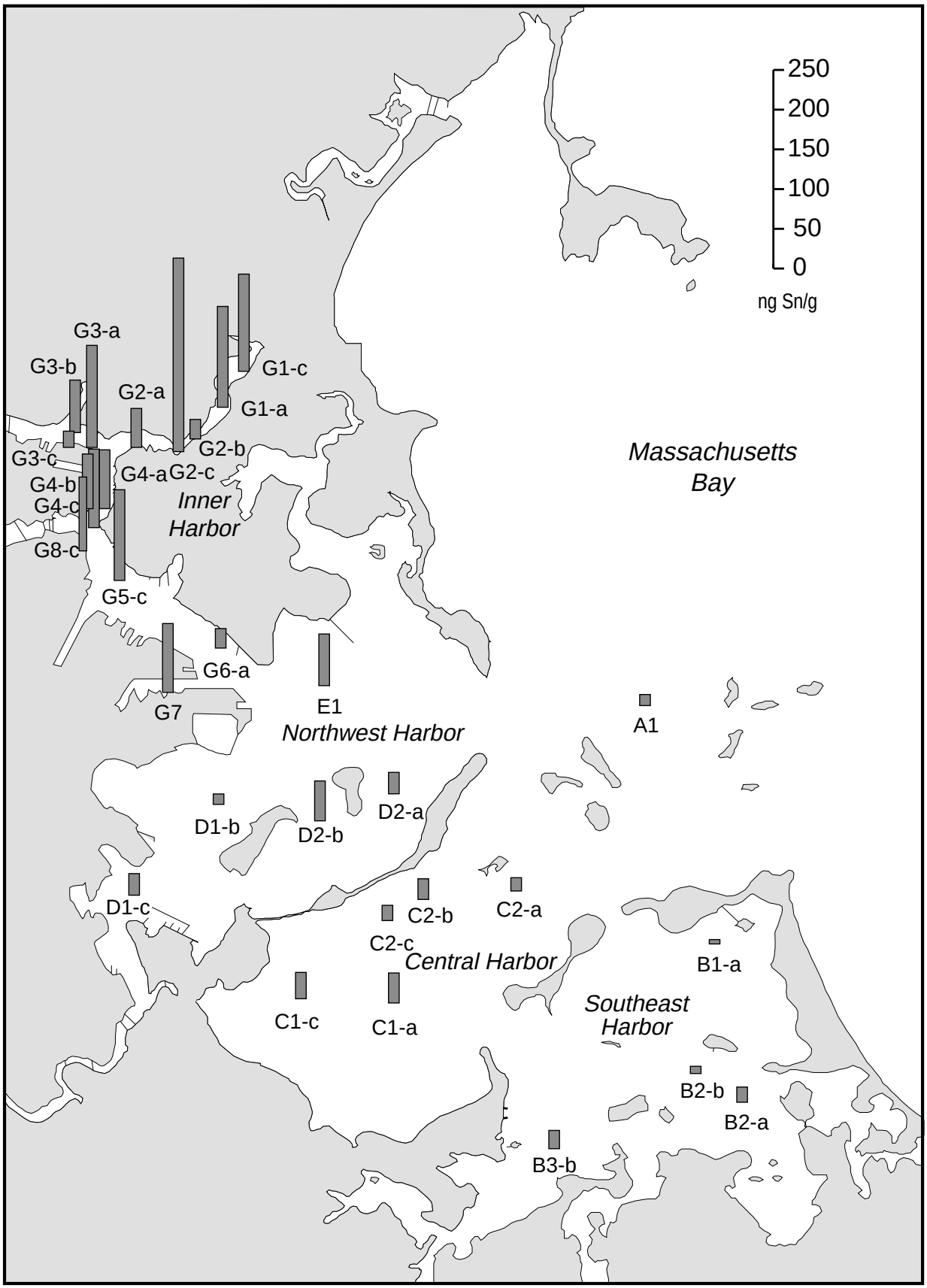

Figure 17. Distribution of tributyltin (ng Sn/g) in sediments from selected sampling stations in Boston Harbor.

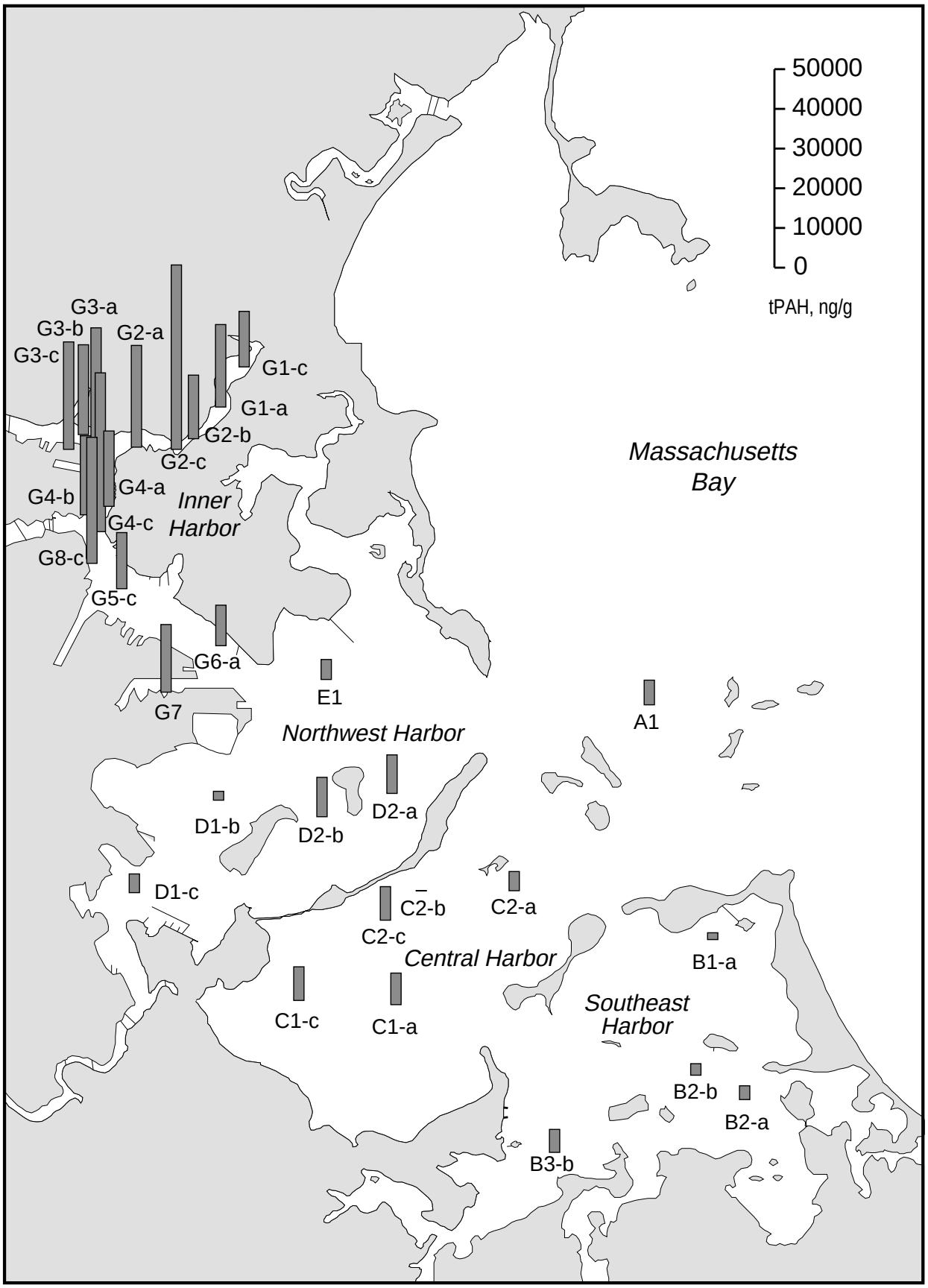

Figure 18. Distribution of total PAHs (ng/g) in sediments from selected sampling stations in Boston Harbor.

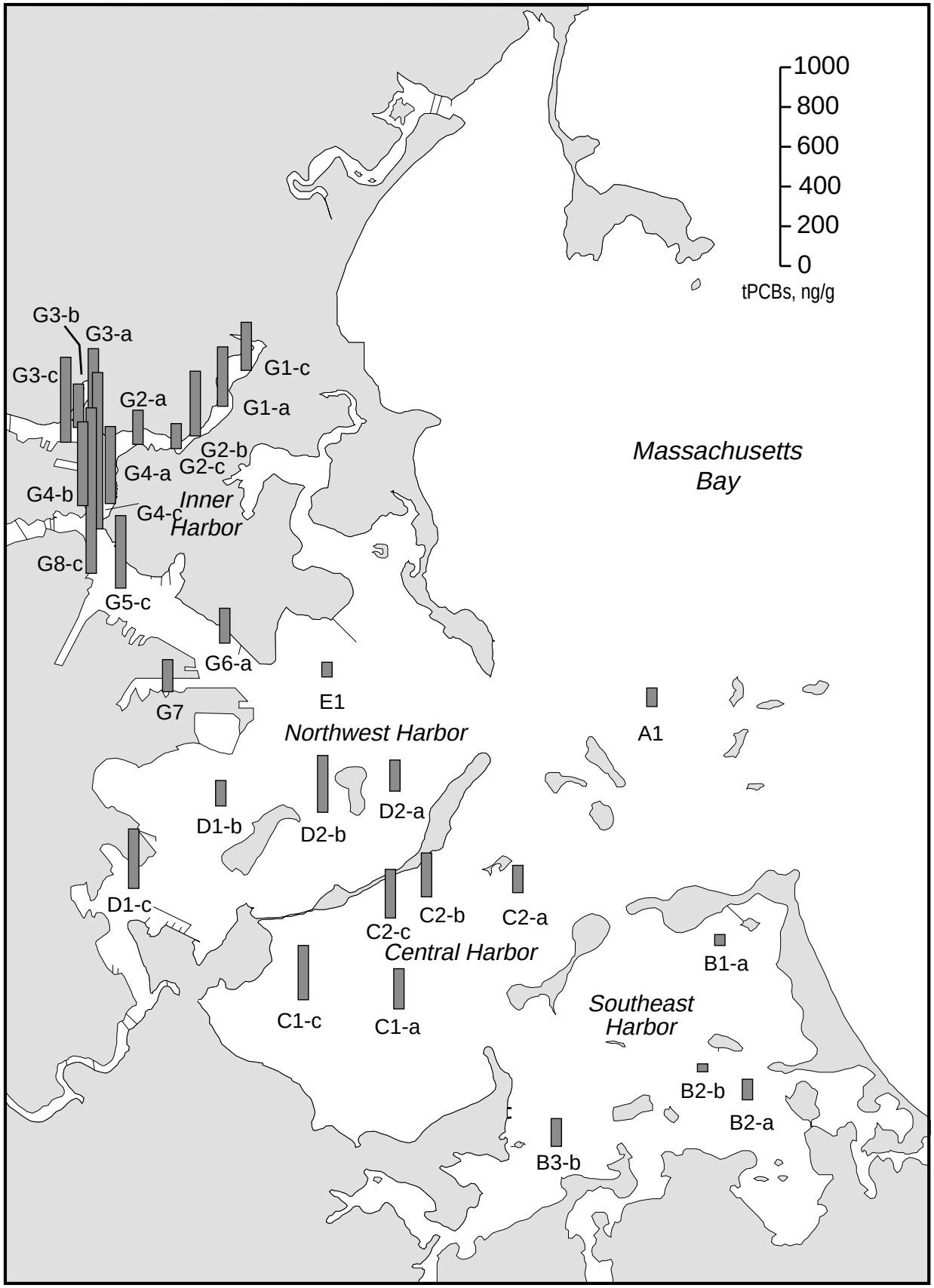

Figure 19. Distribution of total PCBs (ng/g) in sediments from selected sampling stations in Boston Harbor.

Of the 55 samples that were tested, amphipod survival was significantly reduced in sediments from 12 stations (Table 4). Based upon these data, the incidence of toxicity was 21.8%. In 6 samples, amphipod survival was less than 80% of the controls; and was significantly different from controls in all 6 of those samples. In the initial test of the sample from station D-2 (b), survival in the controls was relatively low (86%) and survival in the test samples was variable, so the sample was re-tested. In the re-test, the mean survival increased, but the variability decreased, resulting in a significant difference from controls. Because the mean survival relative to controls in both the initial and repeated tests exceeded 80%, this station was considered non-toxic.

Mean amphipod survival relative to controls ranged from 8.1% in a sample from station D-2(a) in northwest harbor and 14.0% in station C2(a) to 100% or more in many samples collected throughout the study area. Only three strata (D-1, G-1, and G-2) had two samples that were significantly different from controls in amphipod survival. Amphipod survival was less than 80% of controls in two of the samples from stratum G-2. There were no strata in which toxicity to the amphipods was observed in all three samples.

Of the 25 stations sampled in the inner harbor (region G), 6 (24%) were significantly toxic and 4 were highly toxic (i. e., survival was less than 80% of controls). In northwest harbor (regions D, E, and F), 3 of 12 (25%) samples were significantly toxic and one was highly toxic. In central harbor (region C), 1 of 6 (17%) samples was significantly toxic as well as highly toxic. In southeast harbor (region B), 1 of 9 (11%) samples was significantly toxic, but none were highly toxic. Finally, one of the three samples collected in Massachusetts Bay (region A) was significantly toxic, but none were highly toxic.

Table 4. Mean (± standard deviation) percent survival of amphipods (*Ampelisca abdita*) for each sampling station.

Strata. Control	Station No.	Test No.	Mean % Surv. Series	Statistical (± std dev)	Percent of Significance
CLIS		1	91 ± .84	~	
Control		2	96 ± .08	~	
		3	86 ± 1.9	~	
		4	91 ± 1.1	~	
		5	93 ± .55	~	
A	1	1	83 ± 12.0	ns	91.2
	2	1	76 ± 8.2	*	83.5
	3	1	81 ± 19.2	ns	89.0
B-1	a	4	94 ± 4.2	ns	103.3
	b	4	84 ± 5.5	*	92.3
	c	4	86 ± 9.6	ns	94.5
B-2	a	1	82.5 ± 12.6	ns	90.7
	b	1	90 ± 13.2	ns	98.9
	c	1	88 ± 11.5	ns	96.7
B-3	a	4	92 ± 4.5	ns	101.1
	b	4	87 ± 5.7	ns	95.6
	c	4	85 ± 7.1	ns	93.4
C-1	a	3	83 ± 8.4	ns	96.5
	b	3	89 ± 9.6	ns	103.5

Table 4 contd.

Strata. No.	Station No.	Test Series	Mean % Surv. (± std dev)	Statistical Significance	Percent of Control
	c	3	83 ± 13.5	ns	96.5
C-2	a	1	14 ± 23.3	**	15.4
	b	1	93 ± 4.5	ns	102.2
	c	1	83.8 ± 16.5	ns	92.1
D-1	a	2	81 ± 4.2	*	84.4
	b	2	83 ± 11.5	*	86.5
	c	2	95 ± 3.5	ns	99.0
D-2	a	3	7 ± 9.8	**	8.1
	b	3	75 ± 16.7	ns	87.2
DUPLICATE	b	5	83 ± 9.1	* a	89.2
	c	3	83 ± 25.2	ns	96.5
E	1	4	82 ± 13.5	ns	90.1
	2	4	87 ± 7.6	ns	95.6
	3	4	91 ± 2.2	ns	100.0
F-1	1	2	94 ± 4.2	ns	97.9
F-2	1	2	94 ± 6.5	ns	97.9
F-3	1	2	96 ± 4.2	ns	100.0
G-1	a	1	78 ± 7.6	*	85.7
	b	1	87 ± 16.0	ns	95.6
	c	1	47 ± 12.6	**	51.6
G-2	a	3	79 ± 11.9	ns	91.9
DUPLICATE	a	5	87 ± 12.0	ns	93.5
	b	3	31 ± 12.4	**	36.0
	c	3	25 ± 12.8	**	29.1
G-3	a	3	79 ± 4.2	ns	91.9
DUPLICATE	a	5	83.8 ± 9.4	ns	90.1
	b	3	81 ± 8.2	ns	94.2
	c	3	22 ± 11.5	**	25.6
G-4	a	4	90 ± 7.1	ns	98.9
	b	4	88 ± 9.1	ns	96.7
	c	4	91 ± 6.5	ns	100.0
G-5	a	1	82 ± 10.4	ns	90.1
	b	1	97 ± 4.5	ns	106.6
	c	1	78.8 ± 17.5	ns	86.6
G-6	a	4	90 ± 6.1	ns	98.9
	b	4	92 ± 2.7	ns	101.1
	c	4	90 ± 7.9	ns	98.9
G-7	1	1	86 ± 9.6	ns	94.5
G-8	a	2	93 ± 5.7	ns	96.9
	b	2	93 ± 2.7	ns	96.9
	c	2	80 ± 6.1	*	83.3
G-9	a	3	81 ± 8.9	ns	94.2
	b	3	88 ± 11.5	ns	102.3
	c	3	88 ± 9.8	ns	102.3

* Survival significantly reduced relative to controls, one-way, unpaired t-tests ($p<0.05$, $n=5$).
** Survival significantly less than controls and less than 80% of control survival.
[a] Listed as non-toxic (see text).

Samples in which amphipod survival was significantly reduced ($p<0.05$) relative to controls were scattered throughout the survey area (Figure 20). At least one sample in each of the major subdivisions of Boston Harbor was toxic ($p<0.05$) to the amphipods. In the inner harbor, four samples collected in the Chelsea River were toxic, including three that were highly toxic (i. e., survival was less than 80% of controls). Also, one sample from the Mystic River and one collected off downtown Boston were toxic. Two samples taken from northwest harbor, one from central harbor, and one from southeast harbor were toxic. In addition, one of the three samples collected beyond the mouth of Boston Harbor was significantly toxic.

None of the samples from Winthrop Bay and vicinity (regions E and F), the lower reaches of the inner harbor (strata G4, G5, G6, G9), the western portion of central harbor (stratum C1), and the western portion of southeast harbor (stratum B3) were toxic in the amphipod tests. Amphipod survival was lowest (8.1% relative to controls) in the sample from station D2(a) located within Sculpin Ledge.

Microbial Bioluminescence

The mean EC50 in Microtox tests of the Long Island Sound control was 0.126 mg dry weight/ml (Table 5). Results from tests of all the 55 samples were compared to those from the controls. Samples in which microbial bioluminescence was significantly different from controls ($p<0.05$) are listed with a single asterisk and those in which test results also were less than 80% of the control are listed with two asterisks. A total of 31 (56.4%) of the 55 samples was significantly different from controls in this test. In 30 (96.8%) of the 31 samples that were different from controls, the mean value was less than 80% of the control value. EC50 values ranged from 22% of controls to over 1000% of controls. In the inner harbor (region G), 18 (72%) of 25 samples were significantly more toxic than controls in this test. In contrast, none of the three samples from Massachusetts Bay (region A) and only one of the 6 samples from northwest harbor (regions E and F) were toxic. Several of the samples were considerably less toxic than the controls.

Table 5. Mean EC50 values for microbial bioluminescence tests of samples from each station.

Strata No.	Station No.	Mean EC50 (mg dw/ml)	Statistical Significance
LIS Control		0.126	-
A	1	0.200	ns
	2	0.115	ns
	3	0.286	ns
B-1	a	0.250	ns
	b	0.088	**
	c	0.092	ns
B-2	a	0.068	**
	b	0.390	ns
	c	0.129	ns
B-3	a	0.081	**
	b	0.056	**
	c	0.070	**

Table 5 contd.

Strata No.	Station No.	Mean EC50 (mg dw/ml)	Statistical Significance
C-1	a	0.141	ns
	b	0.126	ns
	c	0.067	**
C-2	a	1.872	ns
	b	0.071	**
	c	0.033	**
D-1	a	0.113	*
	b	0.227	ns
	c	0.067	**
D-2	a	0.718	ns
	b	0.080	**
	c	0.041	**
E	1	0.124	ns
	2	0.865	ns
	3	0.196	ns
F-1	1	0.298	ns
F-2	1	0.544	ns
F-3	1	0.041	**
G-1	a	0.258	ns
	b	0.074	ns
	c	0.247	ns
G-2	a	0.084	**
	b	0.147	ns
	c	0.083	**
G-3	a	0.117	ns
	b	0.279	ns
	c	0.056	**
G-4	a	0.045	**
	b	0.056	**
	c	0.027	**
G-5	a	0.089	ns
	b	0.058	**
	c	0.035	**
G-6	a	0.032	**
	b	0.081	**
	c	0.065	**
G-7	1	0.044	**
G-8	a	0.063	**
	b	0.047	**
	c	0.083	**
G-9	a	0.056	**
	b	0.075	**
	c	0.048	**

Means based upon two laboratory replicates.
* significantly different from controls ($p<0.05$)
** significantly different from controls and less than 80% of control value.

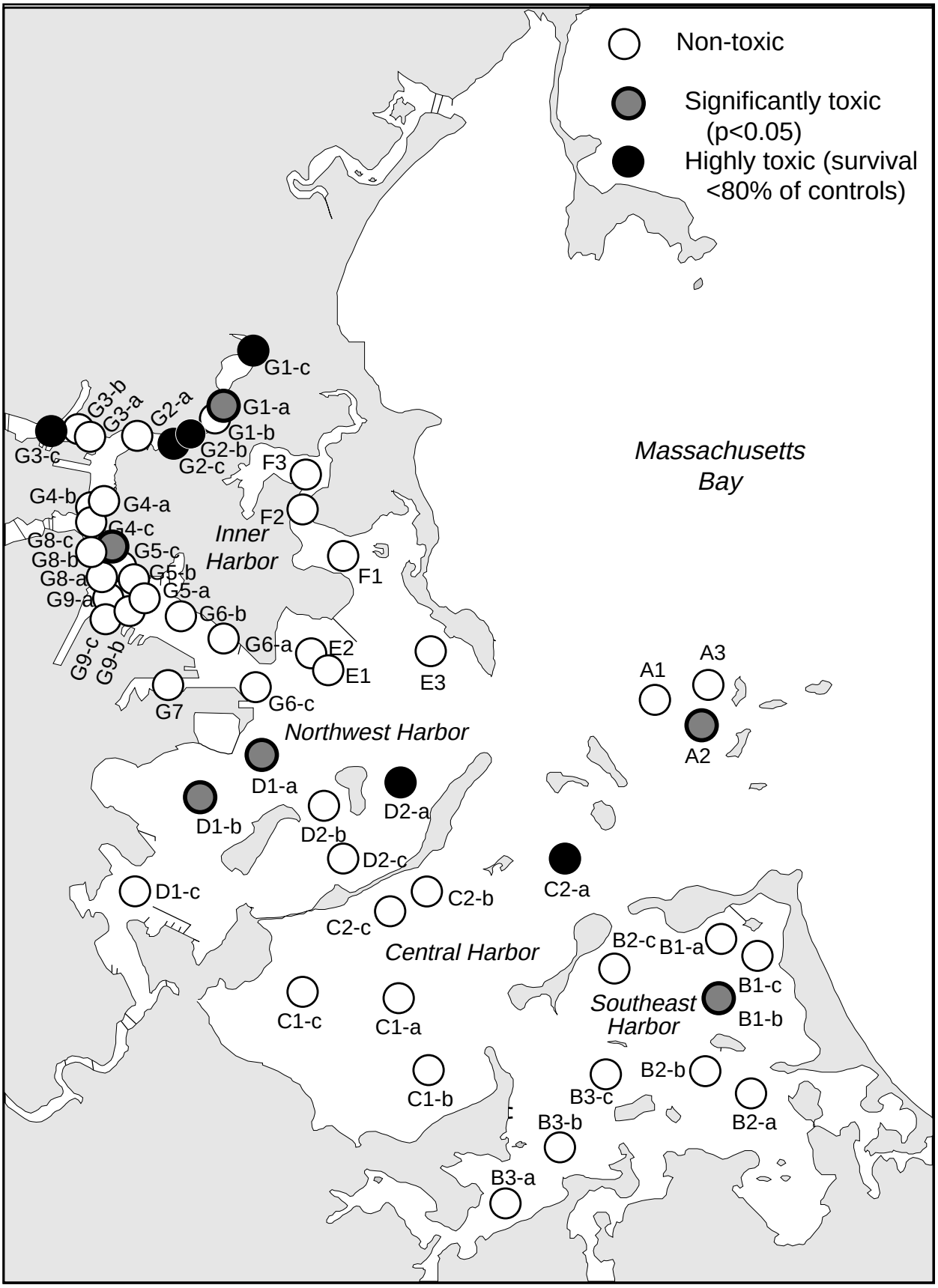

Figure 20. Stations in which sediments were non-toxic, significantly toxic, or highly toxic to amphipod survival.

Spatial patterns in toxicity are illustrated in Figure 21 in which mean Microtox EC50 values are plotted for each station. Based upon these data, many of the samples from the lower reaches of the inner harbor were significantly toxic, especially in strata G4-G9. The sample from station G4-c was the most toxic in this test. Also, a few of the samples from the Mystic and Chelsea rivers were toxic. However, toxicity was not restricted to only the inner harbor. Three samples from northwest harbor, three samples from central harbor, and five samples from southeast harbor were toxic. In contrast, only one of the samples from strata E and F in and near Winthrop Bay were toxic and none of the samples collected outside Boston Harbor were toxic.

Sea Urchin Fertilization and Embryological Development Tests

The pore waters extracted from each sample were tested with two independent tests performed with sea urchins: percent fertilization of eggs and percent normal development of embryos. In the fertilization tests, sperm cells were exposed to the pore water samples followed by the addition of eggs. After a brief incubation period, the percent of the eggs that were successfully fertilized was quantified. In the embryological development tests, the eggs and sperm were exposed together to the pore water and the percent that developed with normal morphological characteristics was quantified. Both tests were performed with 100%, 50%, and 25% water quality - adjusted seawater. The results of both tests were reported for each sample for each of the three pore water concentrations (Tables 6 and 7).

In the tests of the reference sediments from Redfish Bay, Texas, egg fertilization success was 97.2%, 97.8%, and 97.6% in the three pore water concentrations (Table 6). In 53 of the 55 samples, fertilization success was 93% or greater. In the samples from stations C2(a) and G6(a), fertilization success was 0.0% and 92.4%, respectively. Only these two samples were significantly different from controls (Figure 22). Also, in sample C2-a fertilization was significantly reduced in both the 100% and 50% pore water concentrations.

Table 6. Percent fertilization success (means ± std. dev.) of sea urchins exposed to three concentrations of pore water extracted from Boston Harbor sediments. (*indicates means were significantly different from controls, alpha<0.05. ** indicates means were less than 80% of controls.)

Strata	Station	100% WQAP[a]	50% WQAP[a]	25% WQAP[a]
Reference	n/a	97.2±0.8	97.8±0.8	97.6±0.5
A	1	98.0±0.7	99.0±0.7	97.2±1.6
A	2	97.8±0.8	98.0±1.2	97.8±1.1
A	3	97.0±1.4	98.4±1.1	98.6±0.5
Stratum A mean		97.6	98.5	97.9
B1	a	97.4±0.9	97.8±1.5	98.4±1.1
B1	b	97.4±1.1	99.9±0.7	99.0±1.0
B1	c	98.4±0.9	99.0±0.7	98.6±1.1
Stratum B1 mean		97.7	98.6	98.7

Table 6 contd.

Strata	Station	100% WQAP[a]	50% WQAP[a]	25% WQAP[a]
B2	a	97.8±1.9	98.8±1.1	96.4±1.3
B2	b	98.2±0.8	98.0±1.0	98.0±0.7
B2	c	96.0±1.2	98.8±0.8	97.6±1.1
Stratum B2 mean		97.3	98.5	97.3
B3	a	98.2±1.3	99.2±1.1	98.0±0.7
B3	b	97.8±1.1	98.0±1.2	98.8±0.8
B3	c	97.2±2.4	97.8±1.1	98.6±0.9
Stratum B3 mean		97.7	98.3	98.5
C1	a	98.0±0.7	97.4±1.1	97.0±1.4
C1	b	99.0±1.0	98.8±0.8	97.8±1.3
C1	c	97.8±1.9	98.6±1.1	97.4±1.5
Stratum C1 mean		98.3	98.3	97.4
C2	a	0.0±0.0**	86.6±5.5*	96.4±1.1
C2	b	97.2±1.9	98.0±1.4	97.2±1.5
C2	c	98.0±1.0	97.6±1.1	98.4±0.9
Stratum C2 mean		65.1**	94.1	97.3
D1	a	98.4±2.1	98.6±0.9	97.2±1.3
D1	b	94.2±2.4	98.0±0.7	96.8±0.8
D1	c	98.2±0.8	97.6±0.5	98.6±0.5
Stratum D1 mean		96.9	98.1	97.5
D2	a	93.0±2.6	97.6±1.3	98.4±1.1
D2	b	98.8±0.8	99.0±0.7	98.0±1.2
D2	c	97.0±1.9	98.6±1.1	98.4±1.3
Stratum D2 mean		96.3	98.4	98.3
E	1	97.8±0.8	98.4±1.3	98.8±1.3
E	2	98.2±1.3	97.8±1.6	97.6±1.5
E	3	97.8±0.8	96.8±1.6	97.6±0.5
Stratum E mean		97.9	97.7	98.0
F	1	98.6±0.5	97.8±1.3	98.4±0.9
F	2	98.0±1.0	98.6±1.1	98.2±1.5
F	3	97.0±1.6	97.6±1.1	99.2±0.8
Stratum F mean		97.9	98.0	98.6
G1	a	98.0±1.6	97.2±1.6	98.0±1.6
G1	b	96.6±0.9	97.6±1.1	98.4±2.1
G1	c	97.4±1.1	98.2±0.8	97.2±1.8
Stratum G1 mean		97.3	97.7	97.9

Table 6 contd.

Strata	Station	100% WQAP[a]	50% WQAP[a]	25% WQAP[a]
G2	a	97.2±0.8	98.0±1.2	97.2±0.8
G2	b	93.6±2.4	98.4±1.1	99.0±1.2
G2	c	98.0±1.4	98.8±1.1	98.0±1.0
Stratum G2 mean		96.3	98.4	98.1
G3	a	98.4±1.5	98.0±1.9	98.8±0.8
G3	b	98.0±0.7	98.6±1.1	98.4±1.5
G3	c	97.4±1.8	98.0±0.7	97.6±1.1
Stratum G3 mean		97.9	98.2	98.3
G4	a	96.8±1.3	98.0±2.0	98.2±1.5
G4	b	98.2±0.8	98.8±0.8	98.0±1.9
G4	c	98.2±1.1	98.6±0.5	97.8±0.8
Stratum G4 mean		97.7	98.5	98.0
G5	a	97.8±1.6	97.8±1.1	98.0±0.7
G5	b	97.0±1.4	98.0±1.4	98.4±1.1
G5	c	98.2±2.0	97.8±1.8	98.4±1.1
Stratum G5 mean		97.7	97.9	98.3
G6	a	92.4±2.6*	98.8±0.8	98.4±1.5
G6	b	97.6±2.6	98.2±0.8	98.4±1.5
G6	c	96.8±1.6	98.2±1.1	98.0±0.7
Stratum G6 mean		95.6	98.4	98.3
G7	a	99.0±1.2	98.4±1.5	97.8±1.9
G8	a	98.6±0.5	98.2±1.8	98.0±1.6
G8	b	97.6±1.7	98.0±2.5	96.6±2.1
G8	c	97.2±0.8	97.4±2.1	98.8±1.1
Stratum G8 mean		97.8	97.9	97.8
G9	a	98.0±1.2	98.0±0.7	98.6±1.1
G9	b	97.4±2.3	98.8±1.1	97.6±1.8
G9	c	96.6±2.8	98.4±0.9	98.0±1.6
Stratum G9 mean		97.3	98.4	98.1

[a]Water Quality Adjusted Pore water

In sharp contrast to the results from the fertilization tests, the tests of embryo morphological development were highly sensitive, indicating significant toxicity in all 55 samples @100% pore water concentrations (Table 7). In the tests of reference sediment pore water, percent normal embryo development was 93.0%, 93.4%, and 92.8% in the three pore water concentrations. Normal embryo development was significantly reduced in 53 of the tests of 100%

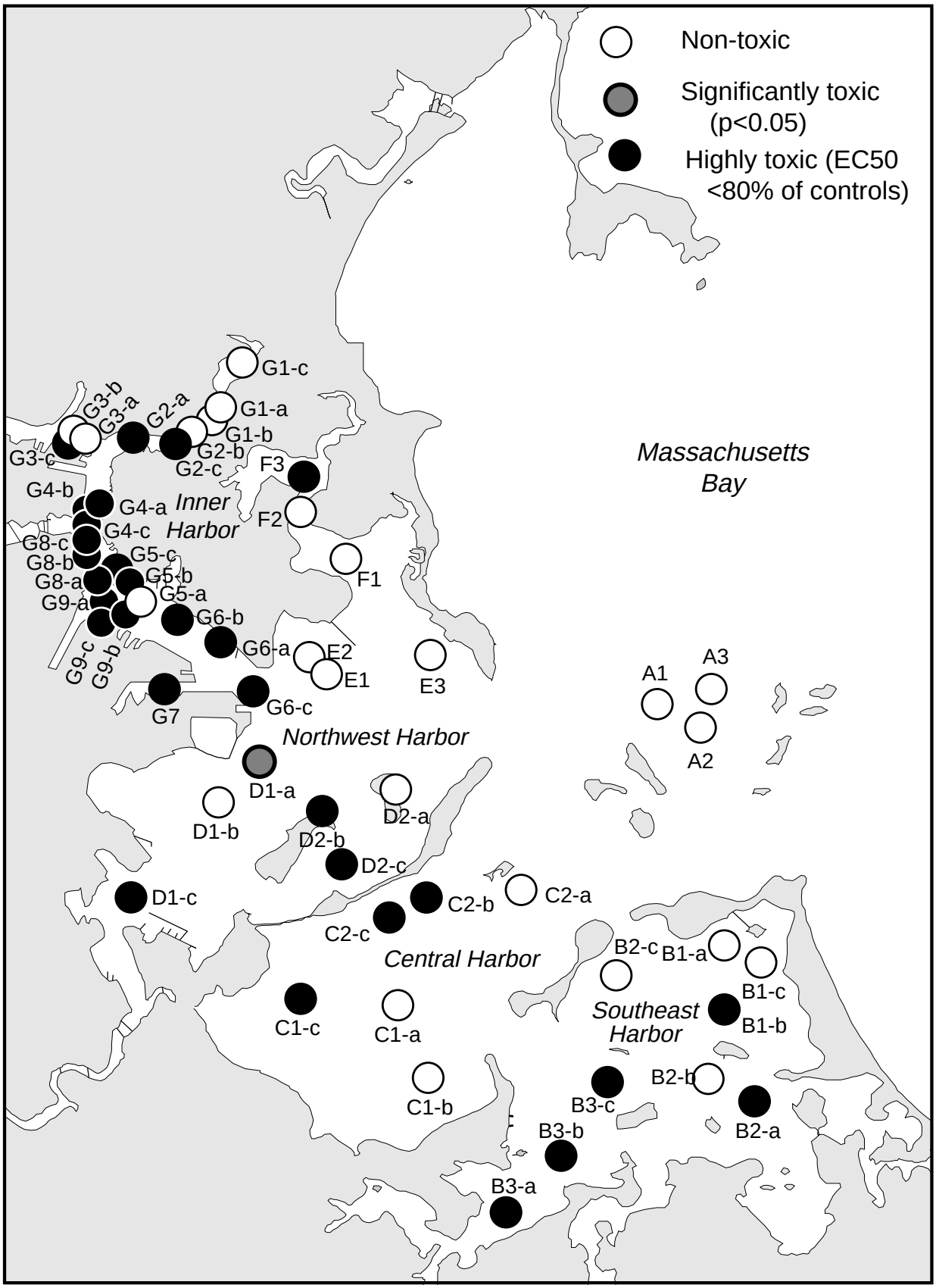

Figure 21. Sampling stations in which sediments were non-toxic or significantly toxic in microbial bioluminescence (Microtox) tests.

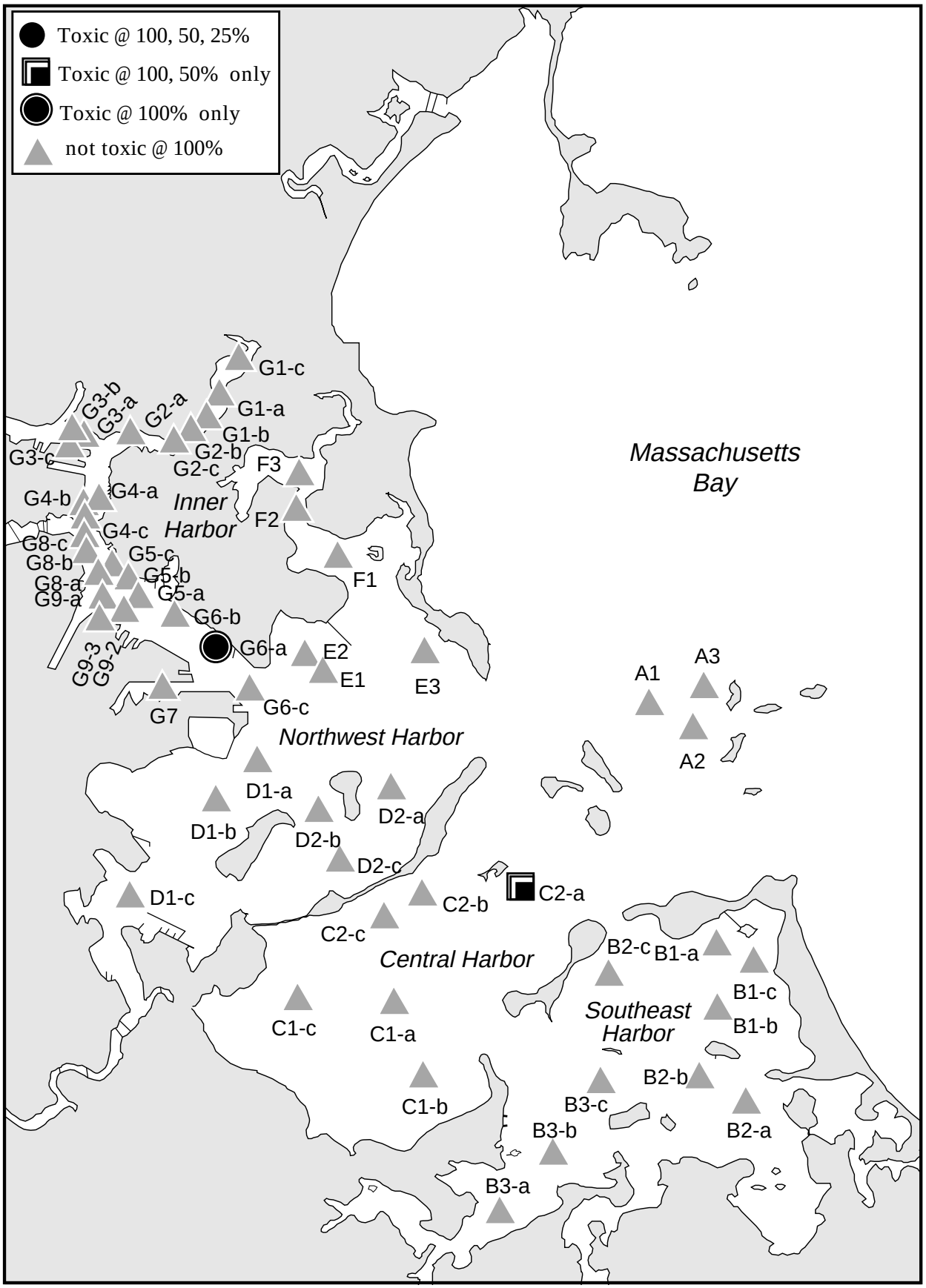

Figure 22. Sampling stations in which sediment pore water was non-toxic or was significantly toxic in sea urchin fertilization tests ($p<0.05$).

pore water. In 52 of the samples, percent normal development was 0.0% in tests of 100% pore water. In the tests of 50% pore water, 38 of the samples caused 0.0% normal development and 50 were significantly different from controls. Even in the tests of 25% pore water, percent normal development was 0.0% in 17 of the samples and 28 were significantly different from controls.

In the majority of the sampling strata, the results were consistent among the three samples, however, in a few strata (e.g., C1 @50% pore water) heterogeneous results were obtained among the three samples (Table 7). In all 19 sampling strata, mean results were significantly different from controls in tests of both 100% and 50% pore water. Mean results in 9 sampling strata were different from controls in the tests of 25% pore water.

In the embryological development test, there was a general pattern of relatively high toxicity in the samples from the inner harbor, diminishing toward and into southeast harbor (Figure 23). Many of the samples from the inner harbor were toxic in all pore water dilutions, or, at least, in both the 100% and 50% pore water concentrations. However, this pattern was not consistent, since many of the samples collected elsewhere throughout the survey area also were significantly toxic. For example, the three samples from region A outside the harbor entrance were highly toxic in this test.

Table 7. Percent normal development (means ± std. dev.) of sea urchins exposed to three concentrations of pore water extracted from Boston Harbor sediments. (*indicates results were significantly different from controls, alpha<0.05. ** indicates results were less than 80% of controls.)

Strata	Station	100% WQAP[a]	50% WQAP[a]	25% WQAP[a]
Reference	n/a	93.0±1.2	93.4±3.6	92.8±2.0
A	1	0.0±0.0**	0.0±0.0**	62.8±29.7**
A	2	0.0±0.0**	0.0±0.0**	80.0±5.4
A	3	0.0±0.0**	0.0±0.0**	94.8±3.5
Stratum A mean		0.0**	0.0**	79.1
B1	a	0.0±0.0**	3.2±6.6**	95.8±2.8
B1	b	0.0±0.0**	0.0±0.0**	91.3±5.6
B1	c	0.2±0.4**	85.0±22.7	94.8±2.7
Stratum B1 mean	0.1**	29.4**	94.1	
B2	a	0.0±0.0**	0.2±0.4**	93.4±3.5
B2	b	0.0±0.0**	0.0±0.0**	20.6±21.5**
B2	c	0.0±0.0**	0.0±0.0**	0.0±0.0**
Stratum B2 mean	0.0**	0.1**	38.0**	
B3	a	0.0±0.0**	0.0±0.0**	54.0±15.3**
B3	b	0.0±0.0**	0.6±1.3**	94.2±2.2
B3	c	0.0±0.0**	0.0±0.0**	94.2±2.6
Stratum B3 mean	0.0**	0.2**	80.8	

Table 7 contd.

Strata	Station	100% WQAP[a]	50% WQAP[a]	25% WQAP[a]
C1	a	0.0±0.0**	1.0±1.7**	93.8±0.8
C1	b	0.0±0.0**	93.0±4.5	93.0±1.6
C1	c	0.0±0.0**	26.8±18.3**	96.0±0.7
Stratum C1 mean	0.0**	40.3**	94.3	
C2	a	0.0±0.0**	0.0±0.0**	0.0±0.0**
C2	b	0.0±0.0**	0.0±0.0**	0.0±0.0**
C2	c	0.0±0.0**	0.0±0.0**	17.6±19.8**
Stratum C2 mean	0.0**	0.0**	5.9**	
D1	a	0.0±0.0**	0.2±0.4**	95.6±2.8
D1	b	0.0±0.0**	0.0±0.0**	8.0±6.1**
D1	c	0.0±0.0**	0.0±0.0**	90.0±5.9
Stratum D1 mean	0.0**	0.1**	64.5	
Reference	n/a	93.0±1.2	93.4±3.6	92.8±2.0
D2	a	0.0±0.0**	0.0±0.0**	0.0±0.0**
D2	b	0.0±0.0**	0.4±0.5**	93.4±3.4
D2	c	0.0±0.0**	0.0±0.0**	97.2±2.2
Stratum D2 mean	0.0**	0.1**	63.5	
E	1	0.0±0.0**	0.8±1.3**	94.2±1.8
E	2	0.0±0.0**	0.0±0.0**	0.0±0.0**
E	3	0.0±0.0**	0.0±0.0**	89.3±4.8
Stratum E mean		0.0**	0.3**	59.1
F	1	0.0±0.0**	0.0±0.0**	27.4±21.4**
F	2	0.0±0.0**	0.0±0.0**	15.0±13.5**
F	3	0.0±0.0**	0.0±0.0**	0.0±0.0**
Stratum F mean		0.0**	0.0**	14.1**
G1	a	0.0±0.0**	0.0±0.0**	37.2±8.1**
G1	b	0.0±0.0**	0.0±0.0**	0.0±0.0**
G1	c	0.0±0.0**	0.2±0.4**	93.8±1.8
Stratum G1 mean	0.0**	0.1**	43.7**	
G2	a	0.0±0.0**	0.0±0.0**	0.0±0.0**
G2	b	0.0±0.0**	97.4±1.3	97.0±3.2
G2	c	0.0±0.0**	14.0±19.0**	96.6±1.8
Stratum G2 mean	0.0**	37.1**	64.5	
G3	a	0.0±0.0**	0.0±0.0**	89.0±4.5
G3	b	0.0±0.0**	35.2±17.3**	97.6±1.1
G3	c	21.8±16.0**	96.4±1.5	93.6±2.6
Stratum G3 mean	7.3**	43.9**	93.4	

Table 7 contd.

Strata	Station	100% WQAP[a]	50% WQAP[a]	25% WQAP[a]
G4	a	0.0±0.0**	0.0±0.0**	32.0±13.3**
G4	b	0.0±0.0**	0.0±0.0**	83.0±6.7
G4	c	0.0±0.0**	0.0±0.0**	0.2±0.4**
Stratum G4 mean	0.0**	0.0**	38.4**	
G5	a	0.0±0.0**	0.0±0.0**	9.6±7.8**
G5	b	0.0±0.0**	0.0±0.0**	0.0±0.0**
G5	c	0.0±0.0**	0.0±0.0**	96.0±1.6
Stratum G5 mean	0.0**	0.0**	35.2**	
G6	a	0.0±0.0**	0.0±0.0**	0.0±0.0**
G6	b	0.0±0.0**	0.0±0.0**	0.0±0.0**
G6	c	0.0±0.0**	0.0±0.0**	0.0±0.0**
Stratum G6 mean	0.0**	0.0**	0.0**	
Reference	n/a	93.0±1.2	93.4±3.6	92.8±2.0
G7	a	0.0±0.0**	0.0±0.0**	0.0±0.0**
G8	a	0.0±0.0**	17.6±20.7**	96.0±2.0
G8	b	0.0±0.0**	0.0±0.0**	0.0±0.0**
G8	c	0.0±0.0**	95.4±1.5	95.2±1.9
Stratum G8 mean	0.0*	37.7**	63.7	
G9	a	0.0±0.0**	0.0±0.0**	0.0±0.0**
G9	b	0.0±0.0**	0.0±0.0**	0.0±0.0**
G9	c	0.0±0.0**	0.0±0.0**	0.0±0.0**

[a]Water Quality Adjusted Pore water

Spatial Extent of Toxicity

Based upon a sum of the sizes of each sampling stratum measured with a planimeter, the total study area was estimated as approximately 56.8 km^2. The results of the toxicity tests were weighted to the sizes of each stratum. With these data, cumulative distribution functions were prepared for each toxicity test to determine the sum of the sizes of the strata in which toxicity was significant (i. e., test results were less than 80% of control values). The proportion of the total study area that was toxic also was determined for each test (Table 8).

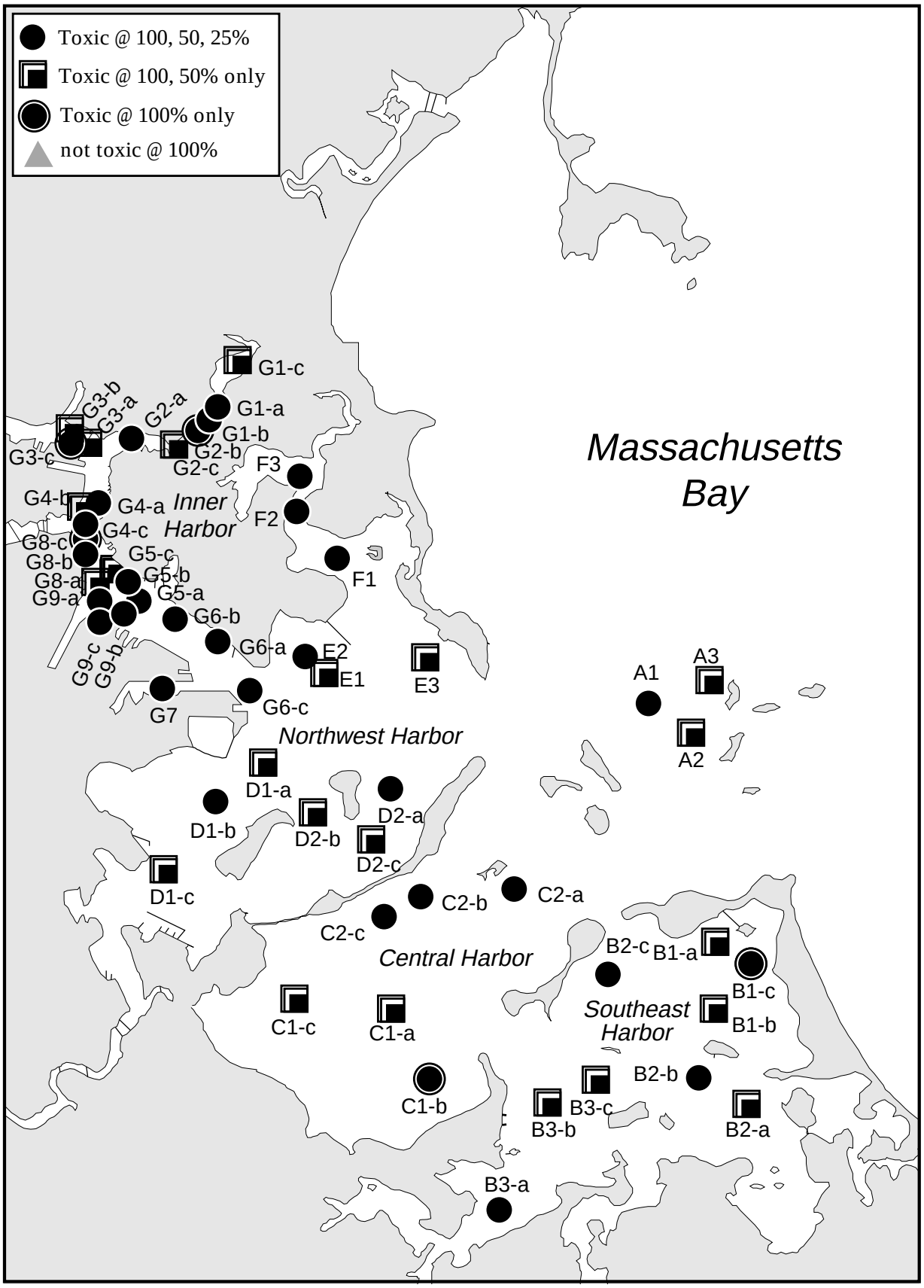

Figure 23. Sampling stations in which sediment pore water was non-toxic or was significantly toxic in sea urchin embryological development tests ($p<0.05$).

Table 8. Estimates of the spatial extent of sediment toxicity (km^2 and percent of total area) in Boston Harbor based upon cumulative distribution functions of data from each test/dilution (critical value was <80% of controls).

Toxicity Test	Kilometer^2	of Total	95% C. I.
Sea urchin development			
@ 100% pore water	56.8	100.0%	n/a
@ 50% pore water	51.7	91.0%	16.4%
@ 25% pore water	27.2	47.9%	34.8%
Sea urchin fertilization			
@ 100% pore water	3.8	6.6%	11.3%
@ 50% pore water	0.0	0.0%	n/a
@ 25% pore water	0.0	0.0%	n/a
Microbial bioluminescence	25.5	44.9%	17.6%
Amphipod survival	5.7	10.0%	12.0%

Total survey area: 56.8 km^2

Since percent normal embryological development was less than 80% of controls in all samples, the spatial extent of toxicity in this test was 100% of the survey area (56.8 km^2). The spatial extent of toxicity (51.8 km^2, 91.0% of the total) was not reduced greatly in the tests of embryological development in 50% pore water. However, in the tests of 25% pore water, approximately 27.2 km^2 were toxic (47.9% of the total). In the tests of microbial bioluminescence and amphipod survival approximately 25.5 km^2 and 5.7 km^2, respectively, were toxic. In the tests of fertilization success of urchins exposed to 100% pore water only 3.8 km^2 were toxic (i. e., the area represented by station C2(a) in stratum C2). None of the area was toxic in the tests of fertilization success performed in 50% and 25% pore water.

The data from each of the toxicity tests were examined to determine the degree of concordance or overlap in the estimates of the spatial extent of toxicity (Table 9). Based upon these data, 100% of the area was toxic in the sea urchin embryological development tests performed with 100% pore water; 91.0% was toxic at both the 100% and 50% pore water concentrations; and 47.7% was toxic at all three pore water concentrations. In addition, 23.1% of the area was toxic in the sea urchin development test in all three pore water concentrations and in the microbial bioluminescence tests. Samples that were highly toxic to amphipods and sea urchin fertilization success were not toxic to sea urchin development; thus, none of the study area was toxic to all of these tests combined.

Table 9. Concordance among different toxicity tests/ dilutions in the estimates of the spatial extent of sediment toxicity (km^2 and percent of total area) in Boston Harbor (critical value <80% of controls).

	Toxicity Test Kilometer	Percent of Total
•Sea urchin development		
@ 100% pore water	56.8	100.0%
@ 100% and 50% pore water	51.8	91.0%
@ 100%, 50%, and 25% pore water	27.1	47.7%
•Sea urchin development in all pore water concentrations and microbial bioluminescence	13.1	23.1%
• Sea urchin development in all pore water concentrations, microbial bioluminescence, and amphipod survival	0.0	0.0%
• Sea urchin development and fertilization, microbial bioluminescence, and amphipod survival	0.0	0.0%

Total area = 56.8 km^2

Concordance Among Toxicity Tests

Because of the probable differences in both the relative sensitivity of the four toxicity tests and their differential sensitivity to different toxic substances, they would not be expected to identify the same spatial patterns in toxicity. As observed in the preceding figures and tables, the four different tests did, indeed, identify different spatial patterns in toxicity in Boston Harbor. Spearman rank, two-way correlations (Rho) were calculated to quantify the relationships among these tests (Table 10).

In these correlation analyses, amphipod survival, Microtox EC50 values, sea urchin fertilization success and normal embryo development should be positively correlated with each other if they indicated similar spatial patterns in toxicity. Also, the sea urchin test results in the different pore water concentrations should be correlated with each other.

There were only three significant positive correlations among the test endpoints, all of which involved the sea urchin tests (Table 10). Percent fertilization in 100% pore water and percent normal development in 25% pore water were significantly correlated (Rho =+0.291, $p<0.05$). Percent normal development in the different pore water concentrations were significantly correlated with each other. However, the correlation between percent amphipod survival and Microtox EC50's (both expressed as percent of controls) were negatively correlated, indicating that they showed significantly different patterns in toxicity. None of the other combinations of test endpoints showed significant correlations. Therefore, the four assays, as expected, showed different patterns in toxicity.

Toxicity/Chemistry Relationships

The cause(s) of toxicity cannot be determined in an assessment such as that reported here. However, data analyses can be performed to identify the probability that some chemical(s)

Table 10. Spearman-rank correlations (rho, corrected for ties) among the results of the sea urchin, Microtox, and amphipod toxicity tests with sediments from Boston Harbor.

	Percent fertilization @100% pw[a]	Percent fertilization @50% pw[a]	Percent fertilization @25% pw[a]	Percent amphipod survival[b]	Percent EC50 value[b]	Percent normal @100% pw	Percent normal @50% pw
% fert. @50%	+0.202 ns						
% fert. @25%	-0.050 ns	-0.089 ns					
% amph. surv.[a]	+0.066 ns	+0.123 ns	+0.015 ns				
% EC50s[a]	+0.025 ns	-0.121 ns	-0.137 ns	-0.285*			
% norm. @100%	+0.083 ns	+0.114 ns	+0.021 ns	-0.165 ns	-0.073 ns		
% norm. @ 50%	+0.193 ns	+0.205 ns	+0.039 ns	-0.251 ns	+0.110 ns	+0.367*	
% norm. @ 25%	+0.291*	+0.187 ns	+0.230 ns	-0.339*	+0.103 ns	+0.164 ns	+0.700***

* p<0.05, ** p<0.001, *** p<0.0001

[a] 100%, 50%, and 25% water quality-adjusted porewater.

[b] As percent of control values.

may have contributed to toxicity. A five-step sequential process was used to identify and quantify the relationships between toxicity and the concentrations of potential toxicants in the sediments. First, a simple Spearman-rank correlation analysis was performed (Statview 4.01 software) to identify which chemicals co-varied or correlated with the measures of toxicity and which did not co-vary with toxicity. This first step was used primarily to identify which chemicals showed no pattern of co-variance with toxicity; most of those chemicals were not treated in subsequent steps of the process. Second, for those chemicals in which there appeared to be a significant correlation, the data were examined on scatterplots to determine if there was actually a reasonable pattern of co-variance. Third, the number of samples that equalled or exceeded effects-based, sediment quality guidelines or criteria were compared among each of the chemicals. Fourth, the average concentrations of chemicals in the toxic samples were compared to the average concentrations in non-toxic samples as toxic/non-toxic ratios and the ratios for each chemical were compared. Fifth, the average concentrations of chemicals in the toxic samples were compared to effects-based guidelines as toxic/guidelines ratios and the ratios were compared among chemicals. Finally, the results of all of the previous steps were compared among chemicals to form a weight of evidence regarding the relative probability that each substance contributed to toxicity.

In the following sections the apparent relationships with toxicity will be addressed for each major group of toxic substances. Summarized results of these analyses are compared in the Discussion.

Correlations with Ammonia. Concentrations of ammonia were determined in the pore water of the amphipod test chambers on the first day of toxicity tests and subsequently in the overlying water on days 4 and 8. The concentrations of the un-ionized portion of total ammonia were calculated based upon the pH and salinity of the samples. There was no significant correlation between the concentration of un-ionized ammonia on any of the sampling days and the survival of amphipods (Table 11). However, the concentrations of un-ionized ammonia in the pore water exceeded the LC50 concentration (0.830 mg/L; Kohn et al., 1994) in 6 of the 55 samples and exceeded the approximated “No Observed Effects Concentration” (NOEC) of 0.4 mg/L in 12 of the 55 samples. Two of the samples with high ammonia concentrations were very toxic to the amphipods (percent survival less than 20%).

Table 11. Spearman rank correlation coefficients (rho, corrected for ties) for amphipod survival and microbial bioluminescence versus ammonia and trace metals concentrations (n=30).

	Percent amphipod survival		Microbial bioluminescence	
Unionized NH3/Day 0	+0.151	ns		
Unionized NH3/day 4	+0.049	ns		
Unionized NH3/day 8	-0.144	ns		
Tetrabutyltin	-0.197	ns	-0.387	*
Tributyltin	-0.160	ns	-0.204	ns
Dibutyltin	-0.111	ns	-0.200	ns

Table 11 contd.	Percent amphipod survival		Microbial bioluminescence	
Monobutyltin	+0.014	ns	-0.335	ns
Total butyltins	-0.153	ns	-0.219	ns
Ag	+0.210	ns	-0.629	**
Hg	+0.143	ns	-0.421	*
As	-0.068	ns	-0.490	*
Cd	-0.132	ns	-0.555	*
Cu	-0.005	ns	-0.565	*
Ni	+0.146	ns	-0.592	*
Pb	-0.165	ns	-0.296	ns
Se	+0.060	ns	-0.583	*
Sn	-0.007	ns	-0.394	*
Zn	-0.233	ns	-0.409	*
Cr	-0.189	ns	-0.386	*
Mn	+0.137	ns	-0.351	ns
Al	+0.248	ns	-0.569	*
Fe	+0.152	ns	-0.560	*
AVS	+0.213	ns	-0.669	**
Total SEM	-0.339	ns	-0.209	ns
SEM/AVS	-0.346	ns	+0.609	**
% SAND	-0.407	*	+0.701	**
% SILT	+0.359	ns	-0.607	**
% CLAY	+0.280	ns	-0.592	*
% TOC	-0.006	ns	-0.561	*

ns = not significant ($p>0.05$) * $p<0.05$ ** $p<0.001$ *** $p<0.0001$

The correlation coefficient for the concentration of un-ionized ammonia in the overlying water on day 8 of the tests and amphipod survival was negative (Rho = -0.144), however, it was not significant (Table 11). In samples with un-ionized ammonia concentrations below the NOEC, amphipod survival ranged from 25% to over 100% of control values (Figure 24). The concentrations of un-ionized ammonia exceeded the NOEC in 6 samples and exceeded the LC50 in 3 samples. Amphipod survival was relatively high (>80%) in 4 of the samples with relatively high ammonia concentrations. However, in two of the samples, un-ionized ammonia concentrations were very high (>2.0 mg/l) and amphipod survival was very low (<20%).

In summary, there was a poor relationship between ammonia concentrations and amphipod survival. Also, these data suggest that ammonia may have contributed substantially to toxicity to amphipod survival in no more than two (3.6%) of the 55 samples.

The correlation between sea urchin fertilization success and the concentrations of un-ionized ammonia in 100% pore water was significant (Rho = -0.266, $p<0.05$, Table 12). However, this relationship was not particularly strong (Figure 25), since fertilization success was greatly depressed in only one sample and none of the ammonia concentrations equalled or exceeded the Lowest Observed Effects Concentration (LOEC) of 800 ug/L. The correlations between

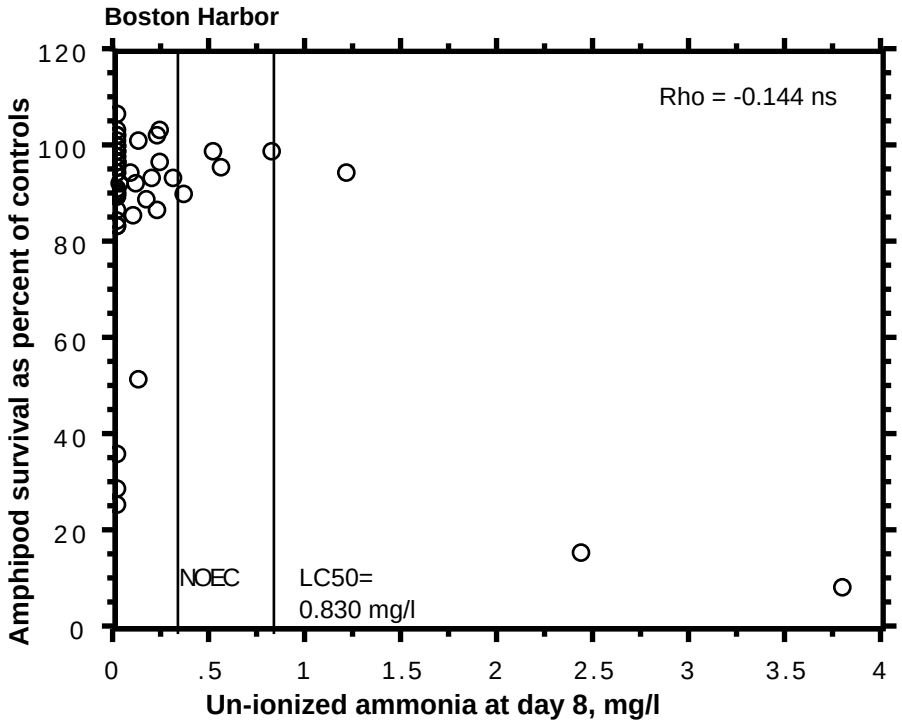

Figure 24. Relationship between the concentrations of un-ionized ammonia in the overlying water and amphipod survival (n=55).

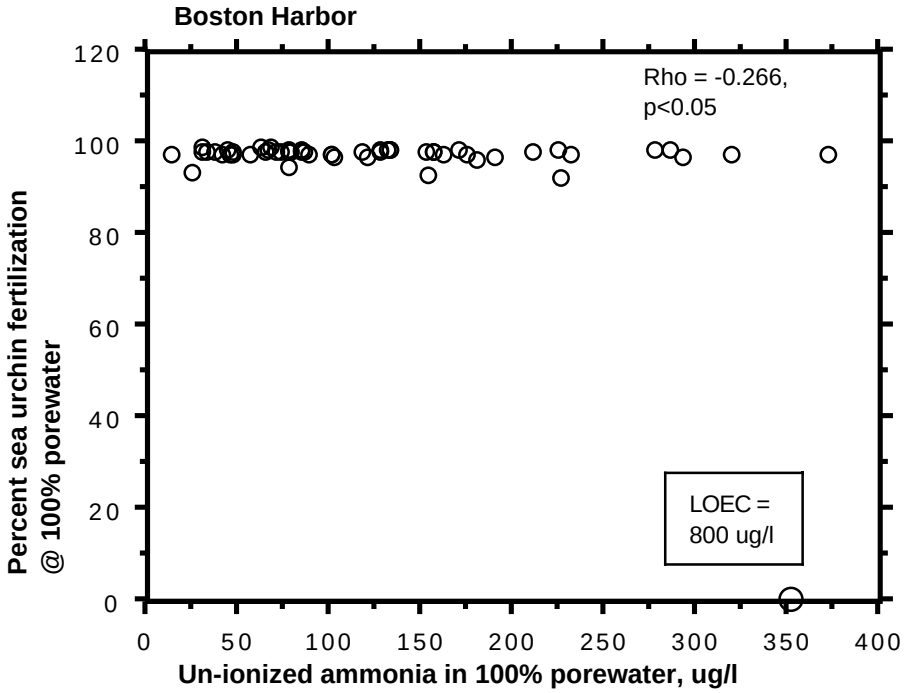

Figure 25. Relationship between sea urchin fertilization and the concentrations of un-ionized ammonia in 100% pore water (n=55).

fertilization success in the tests of 50% and 25% pore water and the concentrations of un-ionized ammonia were not significant (Rho = -0.087 and Rho = -0.117, respectively, Table 12).

Table 12. Spearman rank correlation coefficients (rho, corrected for ties) for sea urchin fertilization in 100%, 50%, and 25% pore water versus ammonia and trace metals (n=30).

	Pore water Concentration					
	@100%		**@50%**		**@25%**	
Unionized ammonia (pore water)	-0.266	*	-0.087	ns	-0.117	ns
Tetrabutyltin	-0.090	ns	+0.295	ns	-0.030	ns
Tributyltin	+0.381	*	+0.071	ns	+0.215	ns
Dibutyltin	+0.379	*	+0.108	ns	+0.287	ns
Monobutyltin	+0.303	ns	+0.063	ns	+0.259	ns
Total butyltins	+0.354	ns	+0.083	ns	+0.216	ns
Ag	+0.282	ns	+0.064	ns	+0.189	ns
Hg	+0.206	ns	+0.063	ns	+0.205	ns
As	+0.086	ns	-0.056	ns	+0.265	ns
Cd	+0.278	ns	+0.242	ns	+0.417	*
Cu	+0.258	ns	+0.045	ns	+0.324	ns
Ni	+0.217	ns	+0.038	ns	+0.383	*
Pb	+0.116	ns	-0.123	ns	+0.156	ns
Se	+0.023	ns	+0.099	ns	+0.258	ns
Sn	+0.174	ns	-0.130	ns	+0.226	ns
Zn	+0.234	ns	+0.058	ns	+0.386	*
Cr	+0.044	ns	+0.168	ns	+0.288	ns
Mn	-0.028	ns	-0.006	ns	+0.128	ns
Al	+0.126	ns	+0.082	ns	+0.255	ns
Fe	+0.138	ns	+0.077	ns	+0.221	ns
AVS	+0.107	ns	+0.288	ns	+0.173	ns
SEM/AVS	-0.082	ns	-0.417	*	-0.046	ns
Total SEM	+0.062	ns	-0.109	ns	+0.173	ns
% SAND	-0.165	ns	-0.029	ns	-0.142	ns
% SILT	+0.171	ns	+0.029	ns	+0.035	ns
% CLAY	+0.154	ns	+0.050	ns	+0.269	ns
% TOC	+0.148	ns	-0.052	ns	+0.236	ns

ns = not significant (p>0.05) * p<0.05 ** p<0.001 *** p<0.0001

In the tests of normal embryological development in 100%, 50%, and 25% pore water, the correlations with the concentrations of un-ionized ammonia were highly significant (Rho = -0.312, -0.670, -0.744, respectively, Table 13). The LOEC determined for this test is 90 ug/L and 19 of the samples from Boston Harbor exceeded that concentration in the tests of 100%

pore water. However, all of the 100% pore water samples tested were significantly toxic to embryological development regardless of the ammonia concentrations.

In the tests performed with 50% and 25% pore water, the correlations with ammonia concentrations increased in spite of the dilutions in the ammonia concentrations. All five of the samples in which percent normal development exceeded 80% had low concentrations of un-ionized ammonia (<40 ug/L, Figure 26). However, there were numerous samples with equally low ammonia concentrations that were highly toxic in this test. In addition, only three samples exceeded the un-ionized ammonia LOEC in the 50% pore water, although 91% of the samples were significantly toxic. In the tests of 25% pore water, the correlation between percent normal development and un-ionized ammonia was very strong (Rho = -0.744, p<0.0001). However, although 51% of the samples were significantly toxic in this test, none of the samples had ammonia concentrations that exceeded the LOEC of 90 ug/L (Figure 27). Only three samples equalled or exceeded the EC50 concentration and eight exceeded the NOEC, two of which were non-toxic.

In summary these data suggest that un-ionized ammonia contributed to the toxicity observed in the embryological tests, but was not the sole cause of toxicity in all samples. Ammonia concentrations were sufficiently high in the tests of 100% pore water to contribute to or cause toxicity in some samples, but toxicity was apparent also in the 50% and 25% pore water tests in which the ammonia concentrations were reduced below toxicity thresholds.

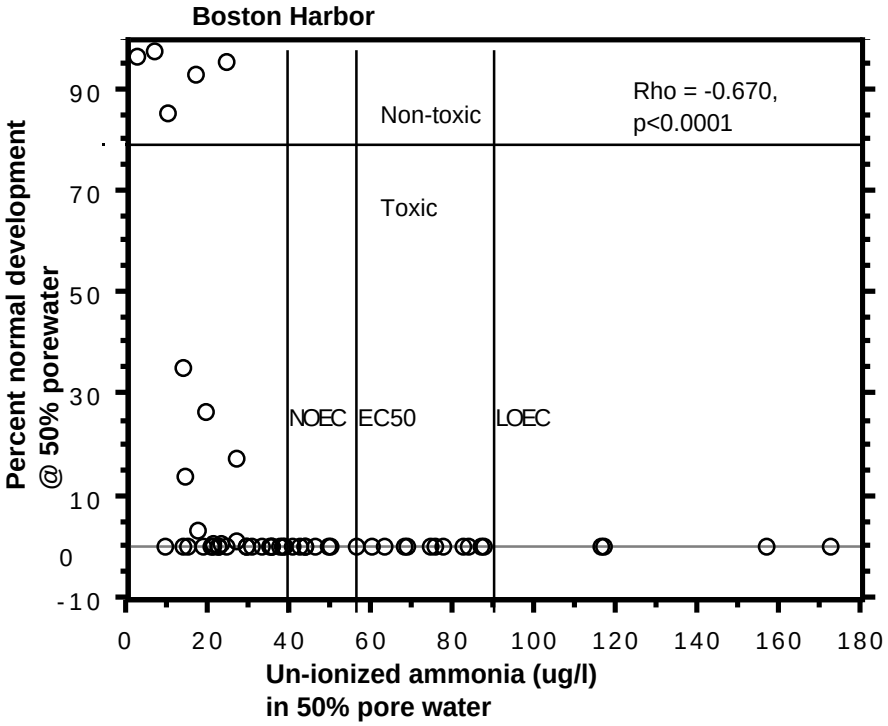

Figure 26. Relationship of sea urchin embryological development to pore water un-ionized ammonia concentrations (n=55).

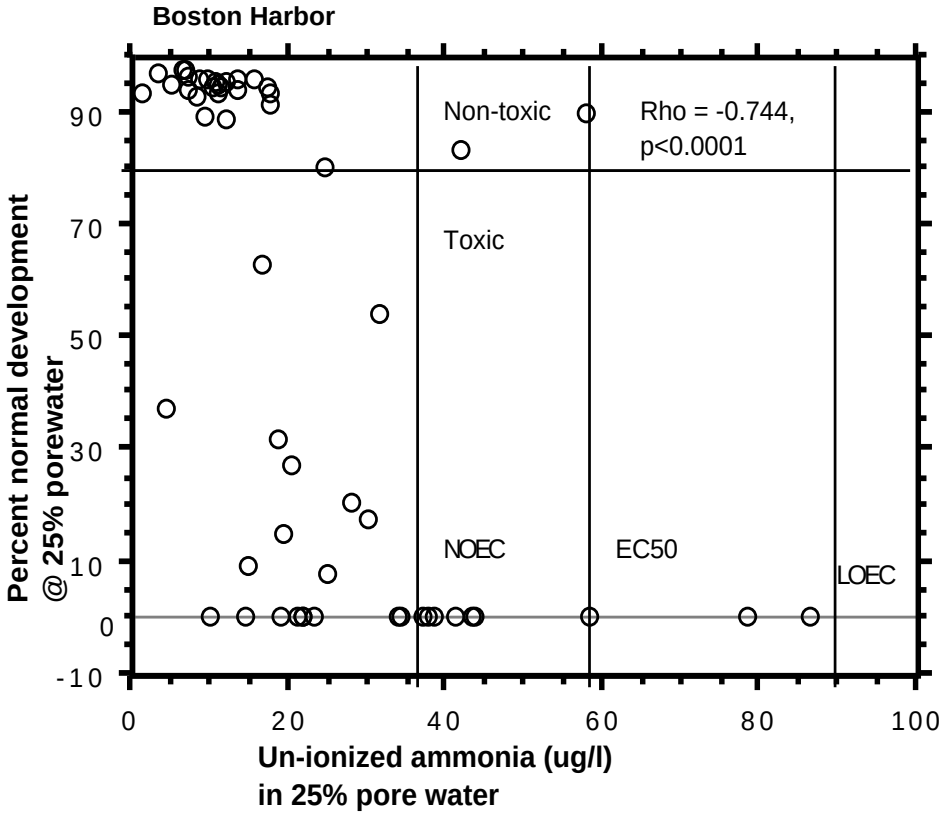

Figure 27. Relationship of sea urchin embryological development to pore water un-ionized ammonia concentrations (n=55).

Correlations with Trace Metals and Physical-Chemical Parameters. The concentrations of TOC were highly positively correlated with clay content (rho = +0.815, p<0.0001) and with silt content (rho = +0.599, p<0.05) and negatively correlated with sand content (rho = -0.761, p<0.0001). Also, the concentrations of total AVS were positively correlated with percent TOC (rho = +0.429, p<0.05), however, they were not significantly correlated with total SEM concentrations (rho = +0.156, p>0.05). As described earlier, the concentrations of trace metals were highly correlated with percent silt and with each other. These data suggest that organic carbon content co-varied with fine-grained particles, percent fines correlated with trace metals and AVS concentrations, but simultaneously-extracted metals varied independently of AVS concentrations.

The concentrations of un-ionized ammonia in the amphipod test chambers and in the pore water test chambers were significantly correlated for both the egg fertilization tests (rho = +0.504, p<0.001) and the embryological tests (rho = +0.445, p<0.05). Also, the pore water un-ionized ammonia concentrations in both of the sea urchin tests were highly correlated (rho = +0.884, p<0.0001). However, surprisingly, the un-ionized ammonia concentrations in the amphipod, urchin fertilization, and urchin embryo test chambers were not correlated with TOC content in the sediments (rho = -0.264, rho = +0.089, rho = +0.041, respectively, p>0.05).

Amphipod survival was not significantly correlated with the concentrations of any of the individual bulk trace metals, including the butyl tins (Table 11). The SEM/AVS ratios were rela-

tively high (0.94, 1.01, and 1.12) and amphipod survival was significantly reduced in three particular samples, however, this correlation was not significant (p>0.05).

Microbial bioluminescence in organic solvent extracts was significantly correlated with nearly all of the trace metals, all of the grain size parameters, the SEM/AVS ratios, and with tetrabutyl tin (Table 11). The correlations with silver, AVS, SEM/AVS ratios, and percent sand were particularly strong. These data suggest that microbial bioluminescence decreased with increasing metals concentrations, increasing percent fines, increasing AVS concentrations, and decreasing sand content. There were no significant correlations with the concentrations of lead, manganese, or total SEM.

The concentrations of mercury were significantly correlated with the results of the Microtox tests and exceeded the ERM value of 0.71 ug/g (Long et al., 1995) in many of the samples. The scatterplot of the data shows a general pattern of decreasing light production with increasing mercury concentrations (Figure 28). There was considerable variability in the Microtox data at mercury concentrations below the ERM value of 0.71 ug/g. Microtox EC50's were less than 80% of controls in 9 of 19 samples (47.4%) in which mercury concentrations were below the ERM value. In contrast, 9 of 11 samples (81.8%) were toxic in this test in samples with mercury concentrations above the ERM value. The relationship between Microtox results and silver concentrations closely paralleled that observed with mercury.

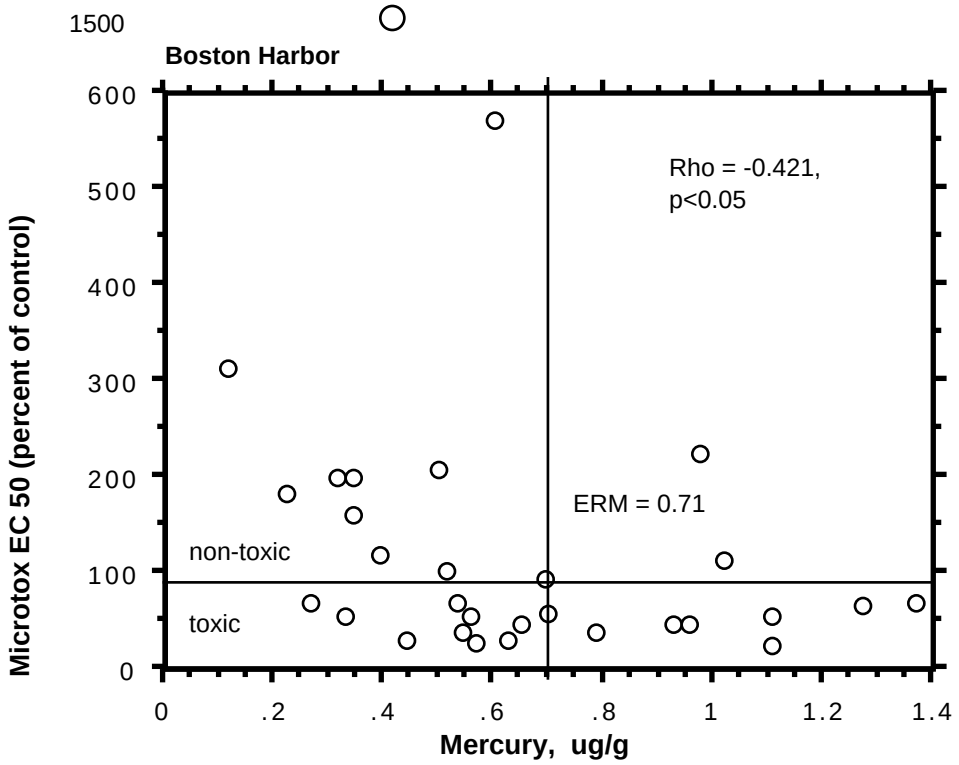

Figure 28. Relationship between microbial bioluminescence and the concentrations of mercury (ug/g, dry wt.) in Boston Harbor sediments.

In the tests of sea urchin fertilization there were no significant negative correlations with any of the individual bulk metals, organo-tins, or grain size parameters (Table 12). However, fertilization success in 50% pore water was significantly correlated with SEM/AVS ratios (Rho = -0.417, $p<0.05$). This correlative pattern was not observed in the tests of 100% or 25% pore water. Many of the correlation coefficients had positive signs.

None of the metals, organo-tins, or grain size parameters were negatively correlated with urchin embryo development, however, there was a significant positive correlation with percent sand (Table 13). Furthermore, many of the correlation coefficients had a positive sign, suggesting that there was a slight, but non-significant increase in normal embryo development with increasing metals concentrations.

Table 13. Spearman rank correlation coefficients (rho, corrected for ties) for sea urchin embryological development in 100%, 50%, and 25% pore water versus ammonia and trace metals (n=30).

	Pore water Concentration					
	@100%		**@50%**		**@25%**	
Unionized ammonia (Pore water)	-0.312	*	-0.670	***	-0.744	***
Tetrabutyltin	+0.323	ns	-0.043	ns	-0.072	ns
Tributyltin	-0.158	ns	-0.040	ns	+0.174	ns
Dibutyltin	-0.158	ns	-0.018	ns	+0.127	ns
Monobutyltin	-0.023	ns	-0.163	ns	-0.101	ns
Total Butyltins	-0.158	ns	-0.049	ns	+0.137	ns
Ag	-0.045	ns	-0.126	ns	-0.104	ns
Hg	+0.203	ns	+0.205	ns	+0.112	ns
As	+0.316	ns	-0.183	ns	-0.167	ns
Cd	+0.294	ns	+0.162	ns	+0.275	ns
Cu	+0.181	ns	-0.125	ns	-0.091	ns
Ni	+0.045	ns	-0.218	ns	-0.136	ns
Pb	+0.226	ns	+0.073	ns	-0.056	ns
Se	+0.226	ns	-0.229	ns	-0.178	ns
Sn	-0.045	ns	-0.166	ns	-0.173	ns
Zn	+0.226	ns	-0.016	ns	+0.075	ns
Cr	-0.136	ns	+0.048	ns	+0.122	ns
Mn	+0.011	ns	-0.203	ns	-0.240	ns
Al	-0.045	ns	-0.208	ns	-0.140	ns
Fe	+0.023	ns	-0.255	ns	-0.201	ns
AVS	+0.113	ns	+0.142	ns	+0.049	ns
SEM/AVS	-0.023	ns	-0.073	ns	+0.040	ns
Total SEM	+0.248	ns	-0.071	ns	-0.090	ns
% Sand	+0.097	ns	+0.369	*	+0.309	ns
% Silt	-0.118	ns	-0.282	ns	-0.252	ns
% Clay	-0.032	ns	-0.302	ns	-0.232	ns
% TOC	+0.247	ns	+0.011	ns	-0.031	ns

ns = not significant ($p>0.05$) * $p<0.05$ ** $p<0.001$ *** $p<0.0001$

Correlations with Polynuclear Aromatic Hydrocarbons (PAHs). The concentrations of 20 parent and many substituted PAHs were determined in the sediment samples. Correlations between measures of toxicity and PAH concentrations were determined for each compound and class of compounds (Tables 14-16). The concentrations of total PAHs co-varied significantly with TOC content (rho = +0.476, $p<0.05$) and with total PCB concentrations (rho = +0.647, $p<0.001$).

Table 14. Spearman rank correlation coefficients (rho, corrected for ties) for amphipod survival and microbial bioluminescence versus PAH concentrations (n=30).

	Percent amphipod survival		Microbial bioluminescence	
BIPHENYL	-0.261	ns	-0.170	ns
NAPHTHALENE	-0.291	ns	-0.228	ns
C1-NAPHTHALENES	-0.331	ns	-0.135	ns
C2-NAPHTHALENES	-0.351	ns	-0.097	ns
C3-NAPHTHALENES	-0.323	ns	-0.147	ns
C4-NAPHTHALENES	-0.304	ns	-0.199	ns
1-METHYLNAPHALENE	-0.298	ns	-0.145	ns
2-METHYLNAPHALENE	-0.334	ns	-0.141	ns
2,6-DIMETHNAPHALENE	-0.336	ns	-0.122	ns
2,3,5-TRIMETHNAPHALENE	-0.357	ns	-0.123	ns
ACENAPHTHENE	-0.223	ns	-0.199	ns
ACENAPHTHYLENE	-0.317	ns	-0.192	ns
FLUORENE	-0.208	ns	-0.198	ns
C1-FLUORENES	-0.291	ns	-0.166	ns
C2-FLUORENES	-0.336	ns	-0.145	ns
C3-FLUORENES	-0.325	ns	-0.213	ns
PHENANTHRENE	-0.075	ns	-0.304	ns
C1-PHENANTHRENE	-0.338	ns	-0.130	ns
C2-PHENANTHRENE	-0.294	ns	-0.209	ns
C3-PHENANTHRENE	-0.323	ns	-0.245	ns
C4-PHENANTHRENE	-0.311	ns	-0.300	ns
1-METHYLPHENANTHRENE	-0.253	ns	-0.194	ns
ANTHRACENE	-0.233	ns	-0.223	ns
TOTAL LMW PAH	-0.230	ns	-0.224	ns
FLUORANTHENE	-0.188	ns	-0.308	ns
PYRENE	-0.274	ns	-0.269	ns
INDENO 123cdPYRENE	-0.130	ns	-0.178	ns
DIBENZOTHIOPHENE	-0.174	ns	-0.206	ns
C1-DIBENZOTHIOPHENE	-0.228	ns	-0.262	ns
C2-DIBENZOTHIOPHENE	-0.315	ns	-0.210	ns
C3-DIBENZOTHIOPHENE	-0.254	ns	-0.244	ns
C1-FLUORANTHENE/PYRENE	-0.307	ns	-0.237	ns

Table 14 contd.

	Percent amphipod survival		Microbial bioluminescence	
BENZaANTHRACENE	-0.225	ns	-0.209	ns
CHRYSENE	-0.163	ns	-0.268	ns
C1-CHRYSENES	-0.164	ns	-0.332	ns
C2-CHRYSENES	-0.229	ns	-0.255	ns
C3-CHRYSENES	-0.128	ns	-0.354	ns
C4-CHRYSENES	-0.165	ns	-0.260	ns
BENZObFLUORANTHENE	-0.185	ns	-0.233	ns
BENZOkFLUORANTHENE	-0.097	ns	-0.265	ns
BENZOaPYRENE	-0.185	ns	-0.243	ns
BENZOePYRENE	-0.152	ns	-0.276	ns
PERYLENE	-0.048	ns	-0.320	ns
BENZghiPERYLENE	-0.209	ns	-0.220	ns
DIBENZOahANTHRACENE	-0.131	ns	-0.259	ns
TOTAL HMW PAHS	-0.218	ns	-0.288	ns
ACENAPHTHENE (ug/goc)	-0.181	ns	+0.001	ns
PHENANTHRENE (ug/goc)	+0.013	ns	-0.001	ns
FLUORANTHENE (ug/goc)	-0.131	ns	-0.083	ns
TOTAL PAH	-0.257	ns	-0.268	ns

ns = not significant (p>0.05)

None of the individual PAHs, classes of PAHs, or sums of individual PAHs were significantly correlated with either amphipod survival or microbial bioluminescence (Table 14). However, all but two of the correlation coefficients had negative signs, indicating a pattern of decreasing amphipod survival with increasing PAH concentrations.

Table 15. Spearman rank correlation coefficients (rho, corrected for ties) for sea urchin fertilization in 100%, 50%, and 25% pore water versus PAH concentrations (n=30).

	Pore water Concentration					
	@100%		@50%		@25%	
BIPHENYL	+0.120	ns	+0.030	ns	+0.205	ns
NAPHTHALENE	+0.161	ns	+0.117	ns	+0.267	ns
C1-NAPHTHALENES	+0.195	ns	+0.033	ns	+0.213	ns
C2-NAPHTHALENES	+0.199	ns	+0.020	ns	+0.211	ns
C3-NAPHTHALENES	+0.252	ns	+0.026	ns	+0.143	ns
C4-NAPHTHALENES	+0.231	ns	+0.037	ns	+0.118	ns
1-METHYLNAPHALENE	+0.231	ns	+0.012	ns	+0.165	ns
2-METHYLNAPHALENE	+0.183	ns	+0.036	ns	+0.227	ns
2,6-DIMETHNAPHALENE	+0.159	ns	+0.025	ns	+0.177	ns
2,3,5-TRIMETHNAPHALENE	+0.190	ns	+0.022	ns	+0.178	ns

Table 15 contd. **Pore water Concentration**

	@100%		@50%		@25%	
ACENAPHTHENE	+0.134	ns	+0.036	ns	+0.177	ns
ACENAPHTHYLENE	+0.105	ns	+0.185	ns	+0.243	ns
FLUORENE	+0.143	ns	+0.037	ns	+0.168	ns
C1-FLUORENES	+0.164	ns	+0.051	ns	+0.202	ns
C2-FLUORENES	+0.170	ns	+0.122	ns	+0.174	ns
C3-FLUORENES	+0.148	ns	+0.177	ns	+0.232	ns
PHENANTHRENE	+0.220	ns	+0.016	ns	+0.155	ns
C1-PHENANTHRENE	+0.057	ns	+0.056	ns	+0.001	ns
C2-PHENANTHRENE	+0.187	ns	+0.026	ns	+0.186	ns
C3-PHENANTHRENE	+0.192	ns	+0.152	ns	+0.203	ns
C4-PHENANTHRENE	+0.212	ns	+0.088	ns	+0.226	ns
1-METHYLPHENANTHRENE	+0.155	ns	+0.074	ns	+0.067	ns
ANTHRACENE	+0.240	ns	+0.165	ns	+0.200	ns
TOTAL LMW PAH	+0.164	ns	+0.109	ns	+0.173	ns
FLUORANTHENE	+0.230	ns	+0.088	ns	+0.162	ns
PYRENE	+0.160	ns	+0.100	ns	+0.205	ns
INDENO 123cdPYRENE	+0.201	ns	+0.383	*	+0.178	ns
DIBENZOTHIOPHENE	+0.147	ns	+0.026	ns	+0.086	ns
C1-DIBENZOTHIOPHENE	+0.141	ns	+0.133	ns	+0.142	ns
C2-DIBENZOTHIOPHENE	+0.232	ns	+0.152	ns	+0.179	ns
C3-DIBENZOTHIOPHENE	+0.255	ns	+0.205	ns	+0.167	ns
C1-FLUORANTHENE/PYRENE	+0.200	ns	+0.136	ns	+0.236	ns
BENZANTHRACENE	+0.158	ns	+0.160	ns	+0.186	ns
CHRYSENE	+0.209	ns	+0.149	ns	+0.231	ns
C1-CHRYSENES	+0.247	ns	+0.166	ns	+0.378	*
C2-CHRYSENES	+0.234	ns	+0.123	ns	+0.283	ns
C3-CHRYSENES	+0.113	ns	+0.239	ns	+0.159	ns
C4-CHRYSENES	+0.141	ns	+0.334	ns	+0.203	ns
BENZObFLUORANTHENE	+0.199	ns	+0.307	ns	+0.201	ns
BENZOkFLUORANTHENE	+0.173	ns	+0.298	ns	+0.134	ns
BENZOaPYRENE	+0.151	ns	+0.229	ns	+0.195	ns
BENZOePYRENE	+0.173	ns	+0.168	ns	+0.174	ns
PERYLENE	+0.131	ns	+0.155	ns	+0.119	ns
BENZghiPERYLENE	+0.215	ns	+0.210	ns	+0.211	ns
DIBENZOahANTHRACENE	+0.171	ns	+0.411	*	+0.130	ns
TOTAL HMW PAHS	+0.185	ns	+0.170	ns	+0.231	ns
ACENAPHTHENE (ug/goc)	+0.169	ns	+0.085	ns	+0.127	ns
PHENANTHRENE (ug/goc)	+0.255	ns	+0.080	ns	+0.077	ns
FLUORANTHENE (ug/goc)	+0.292	ns	+0.179	ns	+0.089	ns
TOTAL PAH	+0.163	ns	+0.158	ns	+0.195	ns

ns = not significant ($p>0.05$) * $p<0.05$

Sea urchin fertilization was not significantly negatively correlated with PAH concentrations in any of the pore water tests (Table 15). Furthermore, all of the correlation coefficients, although non-significant, had positive signs. Similarly, the results of the embryo development tests were not significantly correlated with any of the PAHs (Table 16).

Table 16. Spearman rank correlation coefficients for sea urchin embryological development in 100%, 50%, and 25% pore water versus PAH concentrations (n=30).

	Pore water Concentration					
	@100%		@50%		@25%	
BIPHENYL	+0.311	ns	+0.258	ns	+0.209	ns
NAPHTHALENE	+0.311	ns	+0.230	ns	+0.231	ns
C1-NAPHTHALENES	+0.268	ns	+0.276	ns	+0.204	ns
C2-NAPHTHALENES	+0.225	ns	+0.317	ns	+0.261	ns
C3-NAPHTHALENES	+0.247	ns	+0.268	ns	+0.274	ns
C4-NAPHTHALENES	+0.290	ns	+0.261	ns	+0.253	ns
1-METHYLNAPHALENE	+0.268	ns	+0.256	ns	+0.200	ns
2-METHYLNAPHALENE	+0.268	ns	+0.299	ns	+0.238	ns
2,6-DIMETHNAPHALENE	+0.311	ns	+0.309	ns	+0.233	ns
2,3,5-TRIMETHNAPHALENE	+0.290	ns	+0.313	ns	+0.261	ns
ACENAPHTHENE	+0.161	ns	+0.115	ns	+0.085	ns
ACENAPHTHYLENE	+0.311	ns	+0.156	ns	+0.169	ns
FLUORENE	+0.204	ns	+0.098	ns	+0.057	ns
C1-FLUORENES	+0.290	ns	+0.219	ns	+0.204	ns
C2-FLUORENES	+0.290	ns	+0.239	ns	+0.208	ns
C3-FLUORENES	+0.290	ns	+0.226	ns	+0.202	ns
PHENANTHRENE	+0.032	ns	-0.096	ns	-0.076	ns
C1-PHENANTHRENE	+0.204	ns	+0.043	ns	+0.036	ns
C2-PHENANTHRENE	+0.268	ns	+0.163	ns	+0.171	ns
C3-PHENANTHRENE	+0.290	ns	+0.211	ns	+0.200	ns
C4-PHENANTHRENE	+0.225	ns	+0.188	ns	+0.198	ns
1-METHYLPHENANTHRENE	+0.247	ns	+0.121	ns	+0.134	ns
ANTHRACENE	+0.204	ns	+0.130	ns	+0.134	ns
TOTAL LMW PAH	+0.290	ns	+0.215	ns	+0.149	ns
FLUORANTHENE	+0.118	ns	-0.004	ns	+0.042	ns
PYRENE	+0.182	ns	+0.099	ns	+0.119	ns
INDENO123cdPYRENE	+0.011	ns	-0.130	ns	-0.063	ns
DIBENZOTHIOPHENE	+0.204	ns	+0.061	ns	+0.028	ns
C1-DIBENZOTHIOPHENE	+0.290	ns	+0.111	ns	+0.093	ns
C2-DIBENZOTHIOPHENE	+0.290	ns	+0.237	ns	+0.259	ns
C3-DIBENZOTHIOPHENE	+0.290	ns	+0.197	ns	+0.208	ns
C1-FLUORANTHENE/PYRENE	+0.247	ns	+0.159	ns	+0.165	ns
BENZaANTHRACENE	+0.097	ns	+0.121	ns	+0.122	ns
CHRYSENE	+0.075	ns	+0.088	ns	+0.131	ns
C1-CHRYSENES	+0.118	ns	+0.239	ns	+0.309	ns
C2-CHRYSENES	+0.097	ns	+0.141	ns	+0.229	ns

Table 16 contd.

	Pore water Concentration					
	@100%		**@50%**		**@25%**	
C3-CHRYSENES	+0.011	ns	+0.048	ns	+0.106	ns
C4-CHRYSENES	+0.139	ns	+0.011	ns	+0.046	ns
BENZObFLUORANTHENE	+0.054	ns	-0.036	ns	+0.047	ns
BENZOkFLUORANTHENE	+0.054	ns	-0.101	ns	-0.040	ns
BENZOaPYRENE	+0.032	ns	+0.022	ns	+0.093	ns
BENZOePYRENE	+0.011	ns	+0.054	ns	+0.097	ns
PERYLENE	+0.011	ns	-0.015	ns	-0.029	ns
BENZghiPERYLENE	-0.075	ns	-0.014	ns	+0.099	ns
DIBENZOahANTHRACENE	+0.097	ns	-0.052	ns	-0.013	ns
TOTAL HMW PAHS	+0.118	ns	+0.089	ns	+0.107	ns
ACENAPHTHENE (ug/goc)	+0.075	ns	+0.099	ns	+0.120	ns
PHENANTHRENE (ug/goc)	-0.182	ns	-0.134	ns	-0.029	ns
FLUORANTHENE (ug/goc)	+0.292	ns	+0.179	ns	+0.089	ns
TOTAL PAH	+0.032	ns	-0.060	ns	+0.068	ns

ns = not significant ($p>0.05$)

Correlations with Chlorinated Organic Compounds. Concentrations of total PCBs, total DDTs, and total chlordanes were significantly correlated with TOC content (rho = +0.685, rho = +0.632, rho = +0.636, $p<0.001$, respectively). Concentrations of most chlorinated organic compounds were not significantly correlated with percent amphipod survival (Table 17). Many of the correlation coefficients, although non-significant, were positive. The exception, dieldrin, was significantly correlated with amphipod survival (rho = -0.401, $p<0.05$). The correlation coefficients for some of the isomers of chlordane and DDT had negative signs but were not significant.

Microbial bioluminescence in the tests of organic solvent extracts was significantly correlated with several individual DDT isomers, total DDT, several chlordane isomers, total chlordane, and total PCBs (Table 17). These data suggest that these compounds co-varied with each other and with the results of the Microtox tests. Two pesticides for which National sediment quality criteria have been developed (endrin, dieldrin; U. S. EPA, 1994b) were not correlated with either amphipod survival or microbial bioluminescence.

Table 17. Spearman rank correlation coefficients (rho, corrected for ties) for percent amphipod survival and microbial bioluminescence versus PCB and pesticide concentrations (n=30).

	Percent amphipod survival		Microbial bioluminescence	
2,4'DDE (O,P'DDE)	+0.097	ns	-0.172	ns
4,4'DDE (P,P'DDE)	-0.145	ns	-0.479	*
2,4'DDD (O,P'DDD)	-0.185	ns	-0.263	ns
4,4'DDD (P,P'DDD)	-0.217	ns	-0.447	*
2,4'DDT (O,P'DDT)	+0.021	ns	-0.508	*
4,4'DDT (P,P'DDT)	+0.306	ns	-0.336	ns
TOTAL DDT'S (ng/g)	-0.129	ns	-0.485	*
ALDRIN	-0.151	ns	-0.109	ns
CIS-CHLORDANE	-0.203	ns	-0.135	ns
OXYCHLORDANE	-0.329	ns	+0.245	ns
ALPHA-CHLORDANE	-0.053	ns	-0.370	*
TRANS-NONACHLOR	+0.147	ns	-0.486	*
DIELDRIN	-0.401	*	-0.150	ns
HEPTACHLOR		nd		nd
HEPTACHLOR-EPOXIDE	-0.064	ns	-0.144	ns
HEXACHLOROBENZENE	+0.047	ns	-0.282	ns
ALPHA-BHC	+0.147	ns	-0.262	ns
BETA-BHC		nd		nd
LINDANE (GAMMA-BHC)	+0.161	ns	-0.139	ns
DELTA-BHC	+0.079	ns	+0.152	ns
CIS-NONACHLOR	+0.145	ns	-0.504	*
ENDRIN	-0.161	ns	+0.225	ns
MIREX	-0.348	ns	+0.035	ns
TOTAL PCB'S (ng/g)	-0.035	ns	-0.451	*
TOTAL BHC'S (ng/g)	+0.187	ns	-0.255	ns
TOTAL CHLORDANES (ng/g)	-0.150	ns	-0.417	*
Total DDTs (ug/goc)	-0.123	ns	-0.111	ns
ENDRIN (ug/ g OC)	-0.183	ns	+0.225	ns
DIELDRIN (ug/ g OC)	-0.346	ns	-0.019	ns

ns = not signficant ($p>0.05$) * $p<0.05$

The pattern observed in the relationship between Microtox test results and the concentrations of total PCBs (Figure 29) was similar to that observed with mercury (Figure 28). In samples with PCB concentrations below the ERM value (180 ng/g, Long et al., 1995a), Microtox test results were highly variable; i.e., EC50 values were less than 80% of controls in 6 of 13 samples (46.2%). In contrast, most of the samples (11 of 17, 64.7%) with PCB concentrations in excess of the ERM level were toxic. Two samples with among the highest PCB concentrations (approximately 800 ng/g) were among the most toxic in this test.

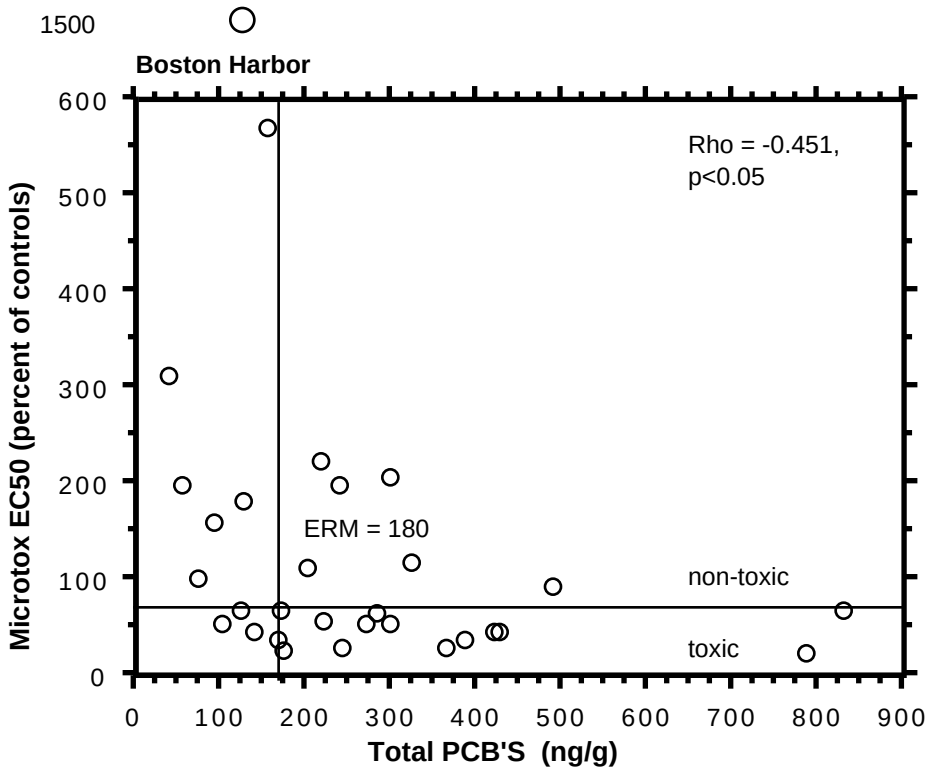

Figure 29. Relationship between microbial bioluminescence and concentrations of total PCBs (ng/g) in Boston Harbor sediments.

The results of the sea urchin fertilization tests were not significantly correlated with the concentrations of any of the chlorinated organic compounds or classes of compounds (Table 18). Furthermore, the correlation coefficients for the sums of the DDT isomers, chlordane isomers, and PCB congeners were positive.

Table 18. Spearman rank correlation coefficients (rho, corrected for ties) for sea urchin fertilization in 100%, 50%, 25% pore water versus PCB and pesticides concentrations (n=30).

	Pore water Concentrations					
	@100%		**@50%**		**@25%**	
2,4'DDE (O,P'DDE)	-0.022	ns	-0.043	ns	+0.260	ns
4,4'DDE (P,P'DDE)	+0.211	ns	-0.090	ns	+0.182	ns
2,4'DDD (O,P'DDD)	+0.181	ns	-0.048	ns	+0.001	ns
4,4'DDD (P,P'DDD)	+0.167	ns	-0.080	ns	+0.313	ns
2,4'DDT (O,P'DDT)	-0.026	ns	-0.081	ns	+0.116	ns
4,4'DDT (P,P'DDT)	+0.150	ns	-0.347	ns	+0.141	ns

Table 18 contd. **Pore water Concentrations**

	@100%		@50%		@25%	
TOTAL DDT'S (ng/g)	+0.127	ns	-0.202	ns	+0.163	ns
ALDRIN	-0.247	ns	+0.288	ns	+0.160	ns
CIS-CHLORDANE	+0.128	ns	+0.100	ns	+0.291	ns
OXYCHLORDANE	+0.030	ns	-0.019	ns	+0.339	ns
ALPHA-CHLORDANE	+0.164	ns	+0.027	ns	+0.362	ns
TRANS-NONACHLOR	+0.214	ns	-0.109	ns	+0.332	ns
DIELDRIN	-0.010	ns	+0.221	ns	+0.328	ns
HEPTACHLOR	nd		nd		nd	
HEPTACHLOR-EPOXIDE	-0.001	ns	-0.084	ns	-0.055	ns
HEXACHLOROBENZENE	+0.171	ns	+0.113	ns	+0.294	ns
ALPHA-BHC	+0.214	ns	-0.293	ns	-0.020	ns
BETA-BHC	nd		nd		nd	
LINDANE (GAMMA-BHC)	+0.205	ns	+0.239	ns	-0.011	ns
DELTA-BHC	+0.050	ns	-0.067	ns	-0.071	ns
CIS-NONACHLOR	+0.277	ns	-0.161	ns	+0.279	ns
ENDRIN	+0.087	ns	-0.293	ns	-0.011	ns
MIREX	-0.078	ns	-0.082	ns	-0.037	ns
ENDRIN (ug/g OC)	+0.087	ns	-0.293	ns	+0.011	ns
DIELDRIN (ug/g OC)	-0.019	ns	-0.055	ns	+0.255	ns
TOTAL PCB'S (ng/g)	+0.175	ns	-0.120	ns	+0.268	ns
TOTAL BHC'S (ng/g)	+0.284	ns	-0.123	ns	-0.099	ns
TOTAL CHLORDANES (ng/g)	+0.242	ns	+0.008	ns	+0.248	ns
Total DDTs (ug/goc)	+0.061	ns	-0.134	ns	-0.050	ns
ENDRIN (ug/g OC)	+0.087	ns	-0.293	ns	+0.011	ns
DIELDRIN (ug/g OC)	-0.055	ns	-0.225	ns	+0.235	ns

ns = not significant ($p>0.05$)

The results of the correlation analyses for the sea urchin embryological tests were similar to those for the fertilization tests, i. e., there were no significant negative associations between toxicity and the concentrations of chlorinated organic compounds (Table 19). In addition, many of the correlation coefficients had positive signs.

Table 19. Spearman rank correlation coefficients (rho, corrected for ties) for sea urchin embryological development and PCB and pesticide concentrations (n=30).

	Pore water Concentrations					
	@100%		**@50%**		**@25%**	
2,4'DDE (O,P'DDE)	-0.034	ns	+0.130	ns	+0.151	ns
4,4'DDE (P,P'DDE)	+0.268	ns	+0.030	ns	-0.091	ns
2,4'DDD (O,P'DDD)	+0.247	ns	-0.136	ns	-0.051	ns
4,4'DDD (P,P'DDD)	+0.204	ns	+0.086	ns	+0.186	ns
2,4'DDT (O,P'DDT)	+0.032	ns	-0.285	ns	-0.265	ns
4,4'DDT (P,P'DDT)	-0.161	ns	-0.354	ns	-0.270	ns
TOTAL DDT'S (ng/g)	+0.139	ns	-0.085	ns	-0.005	ns
ALDRIN	+0.186	ns	+0.164	ns	+0.058	ns
CIS-CHLORDANE	+0.292	ns	+0.283	ns	+0.218	ns
OXYCHLORDANE	-0.154	ns	+0.291	ns	+0.290	ns
ALPHA-CHLORDANE	-0.182	ns	+0.045	ns	+0.040	ns
TRANS-NONACHLOR	-0.204	ns	-0.153	ns	-0.045	ns
DIELDRIN	+0.312	ns	+0.264	ns	+0.260	ns
HEPTACHLOR	nd					
HEPTACHLOR-EPOXIDE	+0.526	*	+0.050	ns	-0.060	ns
HEXACHLOROBENZENE	+0.054	ns	+0.033	ns	+0.074	ns
ALPHA-BHC	+0.054	ns	-0.247	ns	-0.257	ns
BETA-BHC	nd					
LINDANE (GAMMA-BHC)	-0.034	ns	-0.154	ns	-0.032	ns
DELTA-BHC	-0.248	ns	+0.025	ns	-0.099	ns
CIS-NONACHLOR	+0.011	ns	-0.063	ns	+0.043	ns
ENDRIN	-0.034	ns	-0.154	ns	-0.075	ns
MIREX	+0.320	ns	+0.044	ns	+0.055	ns
TOTAL PCB'S (ng/g)	+0.247	ns	+0.030	ns	+0.105	ns
TOTAL BHC'S (ng/g)	-0.054	ns	+0.204	ns	-0.194	ns
TOTAL CHLORDANES (ng/g)	+0.247	ns	+0.112	ns	+0.141	ns
Total DDTs (ug/goc)	+0.032	ns	-0.187	ns	-0.039	ns
ENDRIN (ug/g OC)	+0.248	ns	+0.213	ns	+0.233	ns
DIELDRIN (ug/g OC)	-0.034	ns	-0.154	ns	-0.075	ns

ns = not significant ($p>0.05$) * $p<0.05$

Regional Correlations. Since none of the toxicity/chemistry correlations were particularly strong, additional trials were performed with subsets of the data taken from specific regions of the survey area. Specifically, since many of the inner harbor samples were highly contaminated, correlation coefficients were determined for the samples from areas E and G (n=16). However, in this data subset there were no significant negative correlations between toxicity and any of the quantified substances (except ammonia). There was no clear pattern of improvements in the correlations relative to those observed with the entire data set. The signifi-

cant negative correlations between sea urchin normal development and pore water un-ionized ammonia observed in the entire data set remained strong in this subset.

Correlations with Toxic Units. To determine if toxicity co-varied with complex mixtures of toxicants, a "toxic units" approach was attempted (Swartz et al., 1994). In this approach it was assumed that the toxicity of individual toxicants was approximately additive. Sediment contaminant concentrations were normalized using appropriate toxicity thresholds. Thus, the additive degree of contamination represented by all of the chemicals was summed to form a total estimate of cumulative risk. The chemical concentrations in each sample were divided by the respective ERM values from Long et al. (1995a) and the un-ionized ammonia concentrations were divided by the respective NOEC's. These quotients were then summed for each of the chemical classes and for all 25 substances. Then, the correlations between the sums of toxic units and the toxicity test results were determined.

Amphipod survival was not significantly correlated with any of the sums of toxic units (Table 20). Amphipod survival was most strongly associated with the cumulative total toxic units. The correlation with the cumulative total of all toxic units (-0.343, p = 0.06) indicated a negative pattern, however, the correlation was not significant. Furthermore, this association would be less significant if the correlations were adjusted for the number of variables (7) that were considered. Microbial bioluminescence was significantly correlated with the sums of the total DDTs, total PCBs, and total metals toxic units, but, not with the total PAHs toxicity units. Sea urchin fertilization was not significantly correlated with any of the chemical groups. Sea urchin embryological development was significantly correlated only with pore water un-ionized ammonia toxic units (-0.665, p<0.001).

Table 20. Spearman rank correlation coefficients (Rho, corrected for ties) for cumulative toxic units of chemical groups (chemical concentrations divided by ERM values) and four measures of sediment toxicity (n=30).

Chemical group toxic units	Amphipod survival	Microbial bioluminescence	Sea urchin fertilization @ 100% Pw	Sea urchin development @ 25% Pw
Indl. PAHs[a]	-0.144 ns	-0.282 ns	+0.105 ns	+0.028 ns
Total DDTs[b]	-0.134 ns	-0.484 *	+0.125 ns	-0.001 ns
Total PCBs[c]	-0.039 ns	-0.447 *	+0.174 ns	+0.108 ns
Total metals[d]	+0.019 ns	-0.585 *	+0.293 ns	+0.080 ns
Total toxics[e]	-0.180 ns	-0.391 *	+0.233 ns	+0.144 ns
Total UAN[f]	+0.218 ns	n/a	-0.031 ns	-0.665 **
Cum. total[g]	-0.343 ns	n/a	+0.047 ns	+0.074 ns

[a] Sum of 13 individual PAH/ERM quotients
[b] Total DDT/ERM quotient
[c] Total PCB/ERM quotient
[d] Sum of 9 metals/ERM quotients
[e] Sum of 24 toxicants/ERM quotients
[f] Un-ionized ammonia/NOEC quotients
[g] Cumulative sum of 24 toxicant/ERM and un-ionized ammonia/NOEC quotients
ns p>0.05 * p<0.05 **p<0.001

The sum of the total toxic units (sum of 24 toxicant/ERM quotients) were plotted against the Microtox test results in Figure 30. These data suggest a pattern similar to that observed with both mercury (Figure 28) and total PCBs (Figure 29). That is, as the sum of the total toxic units increases, the microbial bioluminescence (expressed as percent of controls) decreases. Samples with relatively high chemical concentrations (total toxic units > 15) invariably were toxic in this test.

The average of the total toxic units for all toxicants in the 30 samples was 11.96 units. The 13 PAHs represented 34.3% of the total, the two organo-chlorine classes (total DDT, total PCB) represented 27.6% of the total, and the 9 trace metals represented 36.8% of the total. The PCBs, which were highly elevated in concentration in many samples relative to the ERM value, made the single largest contribution to the total toxic units for all toxicants.

Comparisons with Numerical Guidelines. The concentrations of chemicals in the 30 Boston Harbor samples were compared to applicable sediment quality guidelines (SQGs) to identify which substances were most frequently elevated relative to the guidelines and to determine which samples had the greatest number of chemicals in high concentrations (Table 21). The ERM (Effects Range-Median) values of Long et al. (1995a) were used as the primary source of guideline values, since they were based upon a large compiled data base from numerous different empirical studies. The ERM values were interpreted as the chemical concentrations

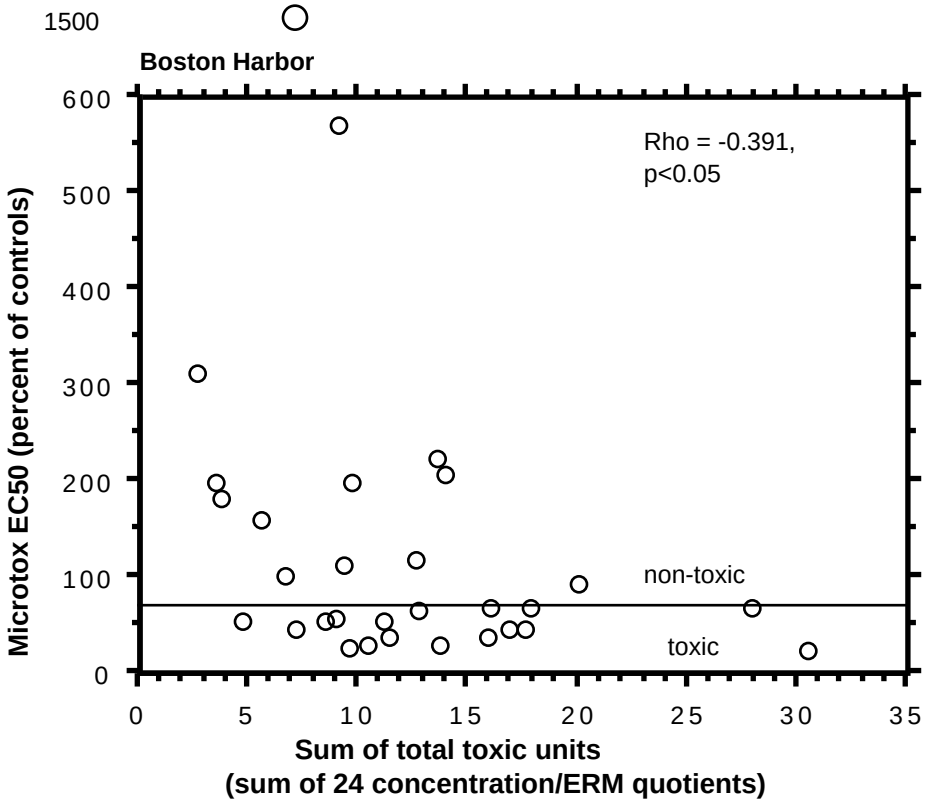

Figure 30. Relationship between microbial bioluminescence and the sum of total toxic units for metals, chlorinated organics, and PAHs.

above which adverse biological effects, such as toxicity, occurred frequently. The ERM value from Long and Morgan (1990) was used for the concentration of p, p' - DDT, since none was reported by Long et al. (1995a). Also, the proposed National sediment quality criteria (SQC) from U.S. EPA (1994b) were used for five organic carbon-normalized compounds.

Among the trace metals, the ERM values for mercury and silver were equalled or exceeded most frequently in the Boston Harbor samples (Table 21). The sums of the concentrations of the 20 PCB congeners quantified in the analytical procedures were multiplied by 2.0 to estimate the concentrations of total PCBs (based upon the results of an empirical experiment reported by NOAA, 1989). The ERM concentration for total PCBs (180 ng/g) was exceeded in 27 of the 30 samples. The concentrations of the individual non-substituted parent PAHs equalled or exceeded the respective ERM values in either none, one, two or three samples. However, the concentrations of the sum of the low molecular weight PAHs equalled or exceeded the ERM for that class of compounds in 8 samples. Also, the ERM value for total high molecular weight PAHs was equalled or exceeded in 9 of the samples. None of the proposed National criteria for five organic compounds were equalled or exceeded in any of the samples. In addition, none of the organo-chlorine compounds equalled or exceeded their respective guideline values.

Guideline exceedances were most frequent in the samples from the G and C areas (Table 21). For example, samples from strata G2, G4, G8, and C1 had several to many substances in concentrations that exceeded the guidelines. Also, samples from strata G1, G3, and G5 had relatively high concentrations of many substances. High PCB concentrations were observed in samples collected in areas A, B, C, D, and G - all of the areas except E and F in northwest harbor.

Table 21. Samples from Boston Harbor that equalled or exceeded the respective ERM or SQC guideline concentrations for each major substance or class of compounds. Stations in which the concentration exceeded the guideline by >2x are listed in bold (n = 30).

Chemical Substance	Number of Samples in which ERM or SQC values were exceeded.	Samples in which the ERM or SQC was exceeded.
Arsenic (ERM= 70 ppm [a])	0	
Cadmium (ERM=9.6 ppm [a])	0	
Chromium (ERM=370 ppm [a])	1	G2c
Copper (ERM=270 ppm [a])	0	
Lead (ERM=218 ppm [a])	3	G8c, G4c, G2a
Mercury (ERM=0.71 ppm [a])	9	G4a, G4b, G3c, G3b, C1a, C1c, G4c, D2b, G8c
Nickel (ERM=51.6 ppm [a])	0	
Silver (ERM=3.7 ppm [a])	12	C1a, B3b, E1, G4a, C2c, G5c, G4b, G4c, G8c, C1c, G7,D2b

Table 21 contd.

Chemical Substance	Number of Samples in which ERM or SQC values were exceeded.	Samples in which the ERM or SQC was exceeded.
Zinc (ERM=410 ppm [a])	1	G4c
p,p'-DDE (ERM= 27 ppb [a])	0	
p,p'-DDT (ERM= 7 ppb [b])	0	
Total DDT (ERM= 46.1 ppb [a])	0	
Dieldrin/toc (SQC= 20 mg/goc [c])		
Endrin/toc (SQC = 0.76 mg/goc [c])		
Total PCBs (ERM=180 ppb [a])	27	A1, B2a, G2c, D1b, C2a, B3b, D2a, G7, G2a, G6a, C1a, G3b, C2b, G1c, C2c, C1c, D2b, G1a, D1c, G2b, **G5a, G4a, G4b, G3c, G3a, G4c, G8c**
Acenaphthylene (ERM=640 ppb [a])	0	
Naphthalene (ERM=2100 ppb [a])	2	G3a, G3c
2-Methylnapthalene (ERM=670 ppb [a])	0	
Acenaphthene (ERM=500 ppb [a])	2	G2c, G2a
Fluorene (ERM=540 ppb [a])	1	G2a
Phenanthrene (ERM=1500 ppb [a])	3	G4c, G8c, **G2a**
Anthracene (ERM=1100 ppb [a])	1	G2c
Fluoranthene (ERM=5100 ppb [a])	0	
Pyrene (ERM=2600 ppb [a])	3	G2a, G2c, G4c
Benzo(a)anthracene (ERM=1600 ppb [a])	3	G4c, G8c, G2c
Chrysene (ERM=2800 ppb [a])	1	G4c
Benzo(a)pyrene (ERM=1600 ppb [a])	2	G2c, G4c
Dibenzo(a,h)anthracene (ERM=260 ppb [a])	0	
Total parent LMW PAH (ERM=3160 ppb [a])	8	G1a, G3b, G4c, G2c, G3c, G2a, G8c, G3a
Total parent HMW PAH (ERM=9600 ppb [a])	9	G1a, G3b, G4a, G3a, G4b, G8c, G2a, G2c, G4c
Total parent PAH (ERM=44792 ppb [a])	0	
Acenaphthene/toc (SQC = 240 mg/goc [c])	0	
Phenanthrene/toc (SQC = 240 mg/goc [c])	0	
Fluoranthene/toc (SQC =300 mg/goc [c])	0	

[a] [b] Effects Range-median values from Long et al. (1995a)
Effects Range-median values from Long and Morgan (1990)
[c] Sediment Quality Criteria from U. S. EPA (1994b)

The concentrations of total DDTs ranged from 5.1 to 41.5 ng/g dry wt., considerably lower than the suggested effective concentration of 7120 ng/g proposed by MacDonald (1994). In units of organic carbon, the total DDT concentrations ranged from 0.2 to 1.3 ug/goc, again, far below the suggested toxicity threshold for amphipods of 300 ug/goc proposed by Swartz et al. (1994).

Co-Occurrence Analyses. The average concentrations of potential toxicants in samples that were toxic were compared to the average concentrations in samples that were non-toxic to determine the ratios between the averages. This step was equivalent to the co-occurrence analyses reported by Long et al. (1995a). The populations of toxic samples were expected to have considerably higher chemical concentrations than those that were non-toxic, especially for substances that were significantly correlated with toxicity.

Among the 30 samples that were analyzed for chemistry, 22 were not significantly toxic in the amphipod tests (Table 22). Average amphipod survival in these samples was 92.0%. Also, there were 3 samples in which amphipod survival was significantly lower than the respective controls and 5 samples in which survival was less than 80% of controls.

The average concentration of un-ionized ammonia measured on day 0 in the pore water of the significantly toxic samples (0.48 mg/l) was 2.08 times higher than that measured in the non-toxic samples; whereas the average concentration in the highly toxic samples (0.82 mg/l) was elevated by a factor of 3.51 (Table 22). However, un-ionized ammonia concentrations in the overlying water at day 4 and day 8 in the significantly toxic samples were similar or lower than those in the non-toxic samples. In the highly toxic samples, the average concentrations of un-ionized ammonia in the pore water and in the overlying water on both days were considerably higher than in the non-toxic samples. Also, the average concentrations of un-ionized ammonia in the highly toxic samples in all three days exceeded the NOEC for *Ampelisca abdita* (0.677 mg/l; Kohn et al., 1994). In addition, the average concentration of un-ionized ammonia in the five highly toxic samples (1.27 mg/l) was slightly less than the LC50 concentration (1.59 mg/l; Kohn et al., 1994).

Except for chromium, none of the bulk trace metals concentrations in the significantly toxic and highly toxic samples were highly elevated above the levels in the non-toxic samples (Table 22). The average total chromium concentration in the highly toxic samples (254 ug/g) exceeded that in the non-toxic samples by a factor of 1.89, and exceeded the ERL value for chromium (81 ug/g), but was below the ERM value (370 ug/g). The average SEM/AVS ratios in the significantly toxic and highly toxic samples greatly exceeded the average concentration in the non-toxic samples (ratios of 4.68 and 6.27, respectively), however, all averages were well below 1.0.

Among the organic compounds, the average concentration of dieldrin in the highly toxic samples was elevated to the greatest degree (by a factor of 2.92) over those in the non-toxic samples (Table 22). Generally, the average concentrations of the PAHs in the highly toxic samples exceeded those in the non-toxic samples by factors of less than 2.0 and usually less than 1.5.

In summary, there was no evidence that one substance or class of toxicants was a major or dominant contributor to toxicity in the amphipod survival tests. The data do suggest, however, that un-ionized ammonia may have contributed to toxicity in a few of the samples and that a mixture of numerous elements and compounds co-varying with each other in low to moderate concentrations, also, may have contributed to toxicity.

In the Microtox tests, the average concentrations of most trace elements and organic compounds in the 16 highly toxic samples exceeded those in the 13 non-toxic samples by factors of 1.5-2.0 (Table 23). Only one sample was significantly toxic (i.e., $p<0.05$, EC50>80% of

Table 22. Average chemical concentrations (± std. dev.) in samples that were not toxic, significantly toxic (p<0.05), and highly toxic in the amphipod tests, ratios between the averages, and ratios of highly toxic averages to applicable sediment quality guidelines (SQG).

	Non-toxic (92.0±15.1% survival, n=22)	Significantly toxic (85.2±1.4% survival, n=3)	Ratio of toxic to non-toxic averages	Highly toxic (28.0±15.3%, survival, n=5)	Ratio of highly toxic to non-toxic averages	Ratio of highly toxic avg. to SQG
UAN/Pw day 0, mg/l*	0.23±0.23	0.48±0.56	2.08	0.82±1.14	3.51	1.21
UAN/day 4, max, mg/l	0.21±0.19	0.07±0.09	0.34	1.01±1.16	4.69	1.49
UAN/day 8max, mg/l	0.12±0.29	0.11±0.09	0.91	1.27±1.56	10.52	1.88
Arsenic (ppm)	14.22±5.86	14.97±6.76	1.05	11.94±1.96	0.84	0.17
Cadmium (ppm)	1.27±0.66	1.53±0.99	1.21	1.03±0.61	0.82	0.11
Chromium (ppm)	134.35±42.90	134.45±62.17	1.00	254.08±191.79	1.89	0.69
Copper (ppm)	105.16±52.70	127.62±96.68	1.21	79.43±17.49	0.76	0.29
Lead (ppm)	137.11±69.13	169.40±89.17	1.24	121.10±17.06	0.88	0.56
Mercury (ppm)	0.67±0.31	0.70±0.49	1.04	0.46±0.10	0.68	0.64
Nickel (ppm)	26.14±6.68	25.09±11.13	0.96	22.41±4.08	0.86	0.43
Selenium (ppm)	1.19±0.39	1.34±0.93	1.13	0.95±0.12	0.80	
Silver (ppm)	3.12±1.20	2.24±1.52	0.72	1.93±0.95	0.62	0.52
Tin (ppm)	12.25±4.21	9.84±5.10	0.80	11.14±4.95	0.91	
Zinc (ppm)	200.03±124.17	254.70±120.70	1.27	194.90±57.83	0.97	0.48
Aluminum (ppm)	71626.58±8647.28	64803.80±6901.47	0.90	68960.20±6105.58	0.96	
SEM/AVS	0.09±0.08	0.40±0.51	4.68	0.54±0.38	6.27	0.54
Acenaphthene (ppb)	95.88±151.82	130.38±101.53	1.36	157.31±191.57	1.64	0.31
Dieldrin (ppb)	1.03±1.01	1.46±1.00	1.42	1.71±1.19	1.66	
Endrin (ppb)	0.00±0.00	0.77±1.08	0.00	0.00±0.00	0.00	
Fluoranthene (ppb)	1061.92±914.25	1365.38±905.68	1.29	1355.11±1169.89	1.28	0.27
Phenanthrene (ppb)	703.88±686.56	1145.04±927.61	1.63	577.81±295.07	0.82	0.39
Acenaphthene (ug/goc)	4.49±10.63	3.49±2.01	0.78	8.50±10.59	1.89	0.04
Dieldrin (ug/goc)	0.03±0.03	0.04±0.01	1.30	0.10±0.08	2.92	0.00

Table 22 contd.	Non-toxic (92.0±15.1% survival, n=22)	Significantly toxic (85.2±1.4% survival, n=3)	Ratio of toxic to non-toxic averages	Highly toxic (28.0±15.3%, survival, n=5)	Ratio of highly toxic to non-toxic averages	Ratio of highly toxic avg. to SQG
Endrin (ug/goc) (ppb)	0.00±0.00	0.04±0.05	0.00	0.00±0.00	0.00	0.00
Fluoranthene (ug/goc)	42.47±53.81	41.76±27.77	0.98	71.64±66.86	1.69	0.24
Phenanthrene (ug/goc)	29.98±45.06	30.66±20.99	1.02	29.11±17.89	0.97	0.12
Acenaphthylene (ppb)	117.65±138.26	131.76±105.58	1.12	179.10±150.78	1.52	0.28
Fluorene (ppb)	118.57±133.80	150.84±105.81	1.27	138.72±115.71	1.17	0.26
1-Methylphenanthrene (ppb)	103.31±70.38	167.91±113.03	1.63	162.60±170.35	1.57	
Anthracene (ppb)	298.27±288.03	520.26±391.41	1.74	431.40±467.26	1.45	0.39
Pyrene (ppb)	970.63±755.67	1445.75±871.97	1.49	1408.72±1162.03	1.45	0.54
Benzo(a)anthracene (ppb)	758.23±707.69	1108.66±902.81	1.46	954.73±659.74	1.26	0.60
Chrysene (ppb)	770.41±709.47	1193.21±892.95	1.55	836.02±476.93	1.09	0.30
Benzo(b)fluoranthene (ppb)	456.14±393.34	337.80±262.66	0.74	566.19±285.76	1.24	
Benzo(k)fluoranthene (ppb)	530.72±427.71	377.38±293.66	0.71	624.50±317.72	1.18	
Benzo(a)pyrene (ppb)	654.34±558.10	768.53±542.48	1.17	805.57±467.32	1.23	0.50
Benzo(e)pyrene (ppb)	431.86±352.89	582.24±431.25	1.35	491.30±262.58	1.14	
Perylene (ppb)	108.69±61.55	127.75±99.00	1.18	150.47±135.08	1.38	
Benz(ghi)perylene (ppb)	345.92±277.43	381.09±276.40	1.10	433.83±219.33	1.25	
Dibenzo(a,h)anthracene (ppb)	71.53±54.24	29.96±28.10	0.42	91.15±45.87	1.27	0.35
L PAH (ppb)	4703.65±4041.58	7318.28±4848.19	1.56	6926.89±6698.60	1.47	2.19
HPAH (ppb)	8654.88±6720.15	10934.67±7497.95	1.26	11268.64±7962.56	1.30	1.17
Total PAH (ppb)	14357.28±10325.74	18252.95±12177.92	1.27	18195.54±14637.49	1.27	0.41
p,p'-DDE (ppb)	4.29±1.96	6.11±2.93	1.43	4.16±1.29	0.97	0.15
Total BHC'S (ppb)	4.62±4.15	1.93±1.78	0.42	3.91±4.05	0.85	
Total Chlordanes (ppb)	6.84±3.96	10.52±6.60	1.54	5.85±1.52	0.86	
Total DDT'S (ppb)	17.03±8.53	25.18±13.71	1.48	18.33±5.26	1.08	0.40
Total PCB'S (ppb)	256.64±170.09	419.79±300.13	1.64	197.24±75.95	0.77	1.10

* Un-ionized ammonia in porewater

Table 23. Average chemical concentrations (± std. dev.) in samples that were not toxic, significantly toxic, (p<0.05), and highly toxic in the microbial bioluminescence tests, ratios between the averages, and ratios of highly toxic averages to applicable sediment quality guidelines (SQG).

	Non-toxic (0.4±0.5 mg/ml, n=13)	Significantly toxic (0.03 mg/ml, n=1)	Ratio of toxic to non-toxic	Highly toxic (0.06±0.02 mg/ml, n=16)	Ratio of highly toxic to non-toxic averages	Ratio of highly toxic avg. to SQG
Arsenic (ppm)	11.20±3.99	15.25	**1.36**	16.04±5.91	**1.43**	0.23
Cadmium (ppm)	0.91±0.59	0.99	**1.08**	1.55±0.68	**1.70**	0.16
Chromium (ppm)	122.65±43.75	161.27	**1.31**	179.61±124.38	**1.46**	0.49
Copper (ppm)	74.81±35.44	99.72	**1.33**	126.32±61.23	**1.69**	0.47
Lead (ppm)	110.70±49.41	124.07	**1.12**	160.44±72.96	**1.45**	0.74
Mercury (ppm)	0.50±0.26	0.63	**1.26**	0.76±0.32	**1.53**	1.07
Nickel (ppm)	21.87±5.77	29.31	**1.34**	28.04±6.94	**1.28**	0.54
Selenium (ppm)	0.94±0.29	1.39	**1.48**	1.33±0.51	**1.41**	
Silver (ppm)	2.11±1.10	3.99	**1.89**	3.35±1.17	**1.59**	0.91
Tin (ppm)	10.39±4.54	15.69	**1.51**	12.74±4.22	**1.23**	
Zinc (ppm)	163.87±76.68	181.45	**1.11**	239.22±134.71	**1.46**	0.58
Aluminum (ppm)	66635.92±8397.88	77539.03	**1.16**	73199.44±7221.48	**1.10**	
SEM/AVS	0.38±0.37	0.04	**0.11**	0.05±0.03	**0.14**	0.05
Acenaphthene (ppb)	61.78±51.36	40.86	0.66	152.69±199.98	2.47	0.64
Dieldrin (ppb)	1.08±1.16	0.35	0.32	1.32±1.01	1.23	0.07
Endrin (ppb)	0.18±0.61	0.00	0.00	0.00±0.00	0.00	0.00
Fluoranthene (ppb)	756.52±508.64	837.03	1.11	1472.64±1147.65	1.95	4.91
Phenanthrene (ppb)	453.00±259.03	528.85	1.17	961.97±839.01	2.12	4.01
Acenaphthene (ug/goc)	2.85±2.11	1.20	**0.42**	7.09±13.53	**2.49**	0.01
Dieldrin (ug/goc)	0.05±0.06	0.01	**0.20**	0.04±0.03	**0.84**	
Endrin (ug/goc) (ppb)	0.00±0.03	0.00	**0.00**	0.00±0.00	**0.00**	
Fluoranthene (ug/goc)	35.22±20.86	24.55	**0.70**	58.46±71.53	**1.66**	0.01
Phenanthrene (ug/goc)	21.84±10.60	15.51	**0.71**	37.35±51.98	**1.71**	0.02

Table 23 contd.

	Non-toxic (0.4±0.5 mg/ml, n=13)	Significantly toxic (0.03 mg/ml, n=1)	Ratio of toxic to non-toxic	Highly toxic (0.06±0.02 mg/ml, n=16)	Ratio of highly toxic to non-toxic averages	Ratio of highly toxic avg. to SQG
Acenapthylene (ppb)	129.96±150.64	43.82	**0.34**	134.11±132.38	**1.03**	0.21
Fluorene (ppb)	86.19±67.93	55.09	**0.64**	161.20±156.68	**1.87**	0.30
1-Methylphenanthrene (ppb)	88.90±69.63	63.09	**0.71**	148.18±114.51	**1.67**	
Anthracene (ppb)	248.83±247.98	131.20	**0.53**	432.10±380.96	**1.74**	0.39
Pyrene (ppb)	773.68±515.93	751.31	**0.97**	1370.34±990.05	**1.77**	0.53
Benzo(a)anthracene (ppb)	611.35±487.31	473.67	**0.77**	1022.46±827.31	**1.67**	0.64
Chrysene (ppb)	596.29±443.67	429.62	**0.72**	1032.96±803.98	**1.73**	0.37
Benzo(b)fluoranthene (ppb)	367.41±287.55	374.87	**1.02**	545.52±406.56	**1.48**	
Benzo(k)fluoranthene (ppb)	407.39±318.58	418.92	**1.03**	638.46±432.99	**1.57**	
Benzo(a)pyrene (ppb)	523.84±412.65	486.59	**0.93**	839.52±592.55	**1.60**	0.52
Benzo(e)pyrene (ppb)	338.22±236.25	310.17	**0.92**	562.32±391.17	**1.66**	
Perylene (ppb)	79.12±45.46	89.78	**1.13**	150.53±93.06	**1.90**	
BghiPerylene (ppb)	280.58±204.09	294.21	**1.05**	436.30±294.56	**1.55**	
Dibenzo(a,h)anthracene (ppb)	56.36±45.27	64.19	**1.14**	82.65±55.86	**1.47**	0.32
L PAH (ppb)	4170.67±3591.84	2383.66	**0.57**	6172.72±5497.12	**1.48**	1.95
HPAH (ppb)	6869.66±5103.78	6065.93	**0.88**	11511.44±7951.51	**1.68**	1.20
Total PAH (ppb)	11040.33±8523.54	8449.59	**0.77**	19351.42±12398.55	**1.75**	0.43
4,4'DDE (P,P'DDE) (ppb)	3.51±1.64	6.16	**1.75**	5.11±2.11	**1.46**	0.19
Total BHC'S (ppb)	3.04±3.12	13.45	**4.43**	4.62±4.01	**1.52**	
Total Chlordanes (ppb)	5.26±3.20	7.49	**1.42**	8.47±4.50	**1.61**	
Total DDT'S (ppb)	13.77±7.57	26.57	**1.93**	21.02±8.95	**1.53**	0.46
Total PCB'S (ppb)	189.35±122.93	244.52	**1.29**	324.09±209.88	**1.71**	1.80

control). Relative to the other substances, the concentrations of cadmium, copper, silver, many individual PAHs, total PAHs, some chlordane isomers, and total PCBs were relatively elevated in the highly toxic samples as compared to the non-toxic samples. In most cases, however, the average concentrations in the highly toxic samples were well below the applicable sediment guidelines. Chemicals in which the average concentrations in the highly toxic samples exceeded applicable guidelines included mercury, fluoranthene, phenanthrene, sum of low molecular weight PAHs, sum of high molecular weight PAHs, and total PCBs. The concentrations of fluoranthene normalized to organic carbon content exceeded the SQC for that compound by a factor of 4.9. The concentrations of total PCBs were elevated in the highly toxic samples relative to the ERM value of 180 ng/g by a factor of 1.8. Also, the concentrations of total low molecular weight PAHs were elevated in the highly toxic samples relative to the ERM value of 3160 ng/g.

Because only two samples were significantly toxic in the sea urchin fertilization tests, co-occurrence analyses for this test were not performed. In the tests of sea urchin embryological development, 0.0% normal development was observed in all except one sample of 100% pore water. Therefore, average chemical concentrations were compared between samples that were not toxic in the tests of 50% pore water, those that were highly toxic (i.e., less than 80% of controls) in 50% pore water, and those that were highly toxic (i.e., less than 80% of controls) in both 50% and 25% pore water (Table 24). The average percent normal development listed in Table 24 was calculated from the tests of 50% pore water.

As predicted by the correlation analyses, very few of the substances were elevated in concentration in the samples that were toxic to sea urchin development (Table 24). The average concentrations of most substances, in fact, were lower in the toxic samples as compared to the non-toxic samples. The concentrations of un-ionized ammonia, acenaphthene, fluoranthene, phenanthrene, dibenzo(a,h)anthracene, and total BHC-pesticides and SEM/AVS ratios were elevated slightly in the highly toxic samples. The average concentrations of only total LPAHs and total PCBs in the highly toxic samples exceeded their respective ERM values.

DISCUSSION

In this survey, 55 surficial sediment samples were collected throughout each of the major regions of the Boston Harbor area. The distributions and concentrations of potentially toxic substances in these samples approximated information reported in historical studies (Leo et al., 1994; MacDonald, 1994) In previous studies and in this survey, chemical concentrations were most elevated in the inner harbor, intermediate in the northwest and central harbors, and lowest in southeast harbor. This pattern was observed for both trace elements and organic compounds in previous studies and was verified, again, in the present survey. Based upon these data, toxicity would be expected to follow the same pattern: High in the inner harbor, intermediate in the northwest and central harbors, and lowest in the southeast harbor and outside the harbor.

The toxicity of these samples was determined in four complementary laboratory tests. The tests involved different organisms exposed to three different phases (or components) of sediments. In all tests, toxicity responses in the Boston Harbor sediments were compared to

Table 24. Average chemical concentrations (± std. dev.) in samples that were not toxic in 50% pore water, highly toxic in 50% pore water, and highly toxic in both 50% and 25% pore water to sea urchin development, ratios between the averages, and ratios of highly toxic averages to applicable sediment quality guidelines (SQG).

	Non-toxic @50% (96.4±0.71% normal, n=3)	Toxic @50% (3.0±8.4% normal, n=27)	Ratio of toxic to non-toxic	Toxic @50% & 25% ((0.0±0.0% normal n=14)	Ratio of highly toxic to non-toxic	Ratio of highly toxic avg. to SQG
Arsenic (ppm)	20.6±5.44	13.2±5.0	**0.64**	12.5±5.4	**0.60**	0.18
Cadmium (ppm)	2.2±0.4	1.1±0.6	**0.51**	0.9±0.7	**0.42**	0.10
Chromium (ppm)	171.3±30.8	152.4±103.8	**0.89**	114.0±43.9	**0.67**	0.31
Copper (ppm)	156.8±63.9	97.1±50.7	**0.62**	88.1±60.0	**0.56**	0.33
Lead (ppm)	191.9±46.3	131.6±65.6	**0.69**	127.5±84.2	**0.66**	0.58
Mercury (ppm)	0.9±0.3	0.6±0.3	**0.67**	0.5±0.3	**0.52**	0.66
Nickel (ppm)	30.5±6.1	24.8±6.8	**0.81**	22.2±7.6	**0.73**	0.43
Selenium (ppm)	1.7±0.6	1.1±0.4	**0.65**	1.0±0.4	**0.62**	
Silver (ppm)	2.7±1.1	2.9±1.3	**1.06**	2.2±1.3	**0.91**	0.66
Tin (ppm)	11.6±3.2	11.9±4.6	**1.02**	10.4±4.7	**0.89**	
Zinc (ppm)	279.7±48.2	196.3±118.6	**0.70**	186.7±153.1	**0.67**	0.46
Aluminum (ppm)	71046±452	70439±8839	**0.99**	61610±10123	**0.87**	
SEM/AVS ratios	0.14±0.11	0.2±0.3	**1.47**	0.25±0.39	**1.88**	0.25
50% devp. UAN (ug/l)	11.3±8.1	43.6±36.2	3.86	46.1±39.2	4.08	
Acenaphthene (ppb)	157.7±61.3	104.2±162.8	**0.66**	105.4±184.0	**0.67**	0.21
Dieldrin (ppb)	3.1±0.4	1.0±0.9	**0.32**	0.8±0.9	**0.26**	
Endrin (ppb)	0.00±0.00	0.09±0.43	**0.00**	0.14±0.59	**0.00**	
Fluoranthene (ppb)	1460.1±525.7	1105.7±995.7	**0.76**	1076.7±1089.8	**0.74**	0.21
Phenanthrene (ppb)	25.7±7.3	30.4±41.4	**1.18**	33.9±54.6	**1.32**	0.14
Acenaphthene (ug/goc)	4.3±1.2	5.2±10.8	**1.21**	5.3±13.0	**1.3**	0.02
Dieldrin (ug/goc)	0.1±0.04	0.04±0.04	**0.40**	0.03±0.03	**0.29**	0.00
Endrin (ug/goc)	0.00±0.00	0.00±0.02	**0.00**	0.00±0.03	**0.00**	0.00
Fluoranthene (ug/goc)	38.3±6.2	48.2±58.2	**1.26**	46.0±66.0	**1.20**	0.15
Phenanthrene (ug/goc)	453.00±259.03	528.85	**1.17**	961.97±839.01	**2.12**	4.01

Table 24 contd.

	Non-toxic @50% (96.4±0.71% normal, n=3)	Toxic @50% (3.0±8.4% normal, n=27)	Ratio of toxic to non-toxic	Toxic @50% & 25% ((0.0±0.0% normal n=14)	Ratio of highly toxic to non-toxic	Ratio of highly toxic avg. to SQG
Acenapthylene (ppb)	314.7±128.6	108.7±122.1	**0.35**	101.2±120.6	**0.32**	0.16
Fluorene (ppb)	206.6±44.6	116.1±131.7	**0.56**	122.9±157.0	**0.60**	0.23
1-Methylphenanthrene (ppb)	200.9±82.0	110.6±99.2	**0.55**	96.1±72.8	**0.48**	
Anthracene (ppb)	635.8±214.8	310.1±337.9	**0.49**	295.1±326.3	**0.46**	0.27
Pyrene (ppb)	1712.9±416.4	1022.1±878.0	**0.60**	962.4±878.8	**0.56**	0.37
Benzo(a)anthracene (ppb)	1353.5±530.0	767.4±720.4	**0.57**	738.5±808.6	**0.55**	0.46
Chrysene (ppb)	1328.9±537.0	767.5±695.8	**0.58**	760.9±839.0	**0.57**	0.27
Benzo(b)fluoranthene (ppb)	492.4±96.2	459.3±388.7	**0.93**	451.5±419.5	**0.92**	
Benzo(k)fluoranthene (ppb)	536.6±92.4	530.4±424.6	**0.99**	532.8±446.7	**0.99**	
Benzo(a)pyrene (ppb)	890.4±171.1	668.8±567.3	**0.75**	649.9±621.7	**0.73**	0.41
Benzo(e)pyrene (ppb)	641.8±245.3	436.2±352.5	**0.68**	417.7±410.3	**0.65**	
Perylene (ppb)	151.7±58.4	113.8±84.7	**0.75**	102.7±66.3	**0.68**	
B(ghi)perylene (ppb)	404.8±71.5	359.6±283.5	**0.89**	342.2±314.3	**0.85**	
Dibenzo(a,h)anthracene (ppb)	66.8±29.8	71.1±54.8	**1.06**	68.9±52.4	**1.03**	0.26
L PAH (ppb)	11101±3493	4521±4436	**0.41**	4126±3742	**0.37**	1.31
HPAH (ppb)	13837±2826	8816±7241	**0.64**	8324±7650	**0.60**	0.87
Total PAH (ppb)	24938±5714	14325±11409	**0.57**	13910±11103	**0.56**	0.31
p,p'-DDE (ppb)	7.7±1.7	4.1±1.7	**0.53**	3.6±1.9	**0.47**	0.13
Total BHC's (ppb)	2.5±1.2	4.4±4.2	**1.78**	5.0±5.1	**2.01**	
Total Chlordanes (ppb)	12.8±3.7	6.4±3.7	**0.50**	5.6±4.0	**0.44**	
Total DDT's (ppb)	29.6±7.3	16.8±8.2	**0.57**	16.1±9.3	**0.54**	0.46
Total PCB's (ppb)	528.5±189.7	233.5±155.5	**0.44**	218.9±187.5	**0.41**	1.22

comparable responses in laboratory controls. All samples tested in the laboratory were treated in the same manner, thus significant differences between controls and field-collected samples can be attributed to some adverse factor (s) in the field.

In the amphipod survival tests of solid-phase sediments, 12 (21.8%) of the samples were significantly different from controls (Table 25). In 6 (10.9%) of the samples, amphipod survival was less than 80% of controls. The amphipod survival tests were among the least sensitive assays performed in this survey. They were performed with relatively unaltered bulk sediments under laboratory conditions in which the effects of many environmental variables were controlled. In previous surveys performed by NOAA elsewhere in the USA, the results of these tests have been highly correlated with the concentrations of toxicants in the sediments. Low amphipod survival in laboratory tests has been linked with significant alterations to resident benthic communities (e.g., Swartz et al., 1994).

Table 25. Incidence of sediment samples from Boston Harbor in which toxicity test results were statistically significantly different from controls and numerically significant (<80% of controls) in each test (n=55).

Toxicity Test	Statistically significant*	Numerically significant**
Amphipod survival	12 (21.8%)	6 (10.9%)
Microbial bioluminescence	31 (56.4%)	30 (54.5%)
Sea urchin fertilization		
100% pore water	2 (3.6%)	1 (1.8%)
50% pore water	1 (1.8%)	0
25% pore water	0	0
Sea urchin development		
100% pore water	55 (100%)	55 (100%)
50% pore water	50 (90.9%)	50 (90.9%)
25% pore water	28 (50.9%)	28 (50.9%)

***** significantly different from controls ($p<0.05$)
** test results less than 80% of controls

In several previous studies in which tests of amphipod survival were performed (SEA Plantations, Inc., 1992; Camp, Dresser and McKee, Inc., 1991; Hyland and Costa, 1994), percent survival was less than 80% in 12 of 21 samples (57%). Since the previous studies had focused mainly upon the inner harbor region, an incidence of toxicity higher than that observed in the present survey of the entire area would be expected. Amphipod survival was greater than 80% in four samples collected outside the inner harbor (Hyland and Costa, 1994).

The Microtox tests of organic extracts of the sediments were more sensitive than the amphipod tests (Table 25); 56.4% of the samples were significantly different from controls and 54.5% were numerically different (i. e., less than 80% of controls). In previous tests of microbial bioluminescence, many of the samples collected within Boston Harbor were significantly more toxic than those collected outside the harbor (DeMuth et al., 1993). This test performed with organic solvent extracts of the sediments can be viewed as a test of potential toxicity, since the complex mixtures of toxicants in the sediments are made bioavailable artificially with the solvent extraction. Also, since this test is relatively insensitive to the effects of naturally-occurring (nuisance) variables, it is highly indicative of the presence of potentially toxic substances in the samples.

Toxic chemicals dissolved or suspended in sediment pore waters are thought to be in dynamic equilibrium with chemicals bound to the sediment particles (U.S. EPA, 1994a). However, the chemicals in the pore water are much more bioavailable than those bound to the particles, thus biological tests of the pore waters would be expected to be highly sensitive to relatively small toxicant concentrations. The pore water samples extracted from the Boston Harbor sediments were tested with sea urchin gametes and embryos, life stages that are highly sensitive. The pore water tests performed with sea urchins are viewed as highly sensitive assays of the very important pore water phase of sediments.

The two independent tests performed with sea urchins exposed to sediment pore waters provided different estimates of toxicity (Table 25). In the tests of fertilization success in 100% pore water, only 3.6% of the samples were significantly different from controls. In a survey of Tampa Bay, 79% of the samples tested were toxic in the sea urchin fertilization tests (Long et al., 1994). Differences in the sperm/egg ratios may have lead to some decrease in the sensitivity of this test in the Boston Harbor study, although the responses to the positive controls (SDS) were within the expected range. In sharp contrast, the tests of embryological development indicated that all 55 samples (100%) were toxic in the tests of 100% pore water.

The reason(s) for the disparity in the results of the two sea urchin tests is (are) unknown. Relatively large disparities between the two tests have been observed in other studies (Long et al., 1990; Carr, 1993; NBS, 1994; Carr et al., in press) performed elsewhere in the U.S. These differences may be related to the different chemical-specific mechanisms of toxicity measured by the two tests. Specifically, ammonia may have contributed significantly to toxicity in the embryological development tests and not in the fertilization tests. The LOEC's for unionized ammonia are 800 ug/L and 90 ug/L, respectively, for the fertilization and embryological development tests, indicating that the latter assay is much more sensitive to ammonia. None of the anthropogenic toxicants (excluding ammonia) measured in the bulk sediments were significantly associated with the toxicity observed in either sea urchin test.

Un-ionized ammonia measured in previous surveys has always shown a strong association with the toxicity of pore water; however, in previous studies the ammonia co-varied strongly with many anthropogenic toxicants that were sufficiently elevated to cause toxicity. In the Boston Harbor survey, ammonia and the anthropogenic toxicants that were quantified may have not been sufficiently elevated to contribute to toxicity in the fertilization tests. However, in the embryological development tests ammonia may have been sufficiently elevated in concentration to have contributed to toxicity in some of the samples. Also, other un-measured

substances, possibly co-varying with ammonia, may have been primarily responsible for the toxicity observed in the embryological development tests.

There was relatively poor concordance among the amphipod, Microtox, and sea urchin test results. Each indicated somewhat different spatial patterns in toxicity. However, there was relatively good statistical concordance between the two sea urchin tests, despite the major difference in sensitivity of the two assays.

Toxicity was observed in all four toxicity tests that were performed. Of the 55 samples that were tested in this survey, 6 (10.9%) were highly toxic in the amphipod tests, 30 (54.5%) were highly toxic in the microbial bioluminescence tests, all 55 were highly toxic in the sea urchin embryological tests, and one was highly toxic in the sea urchin fertilization tests (Table 25).

A cumulative toxicity index was calculated as the sum of amphipod survival, sea urchin fertilization (in 100% pore water), and sea urchin normal development (in 25% pore water). This index was formulated with the results of the tests performed with only the invertebrates and excluded the Microtox test results, since they were viewed in this survey as a test of potential toxicity. The index had a possible range of values of 0.0 to over 300. Since the data for all three of these assays usually are significant when test results are less than 80% of control values, a cumulative score of less than 240 was used as a critical value (Figure 31). In the histograms plotted in Figure 31, the shortest bars indicate the highest toxicity.

Overall, the incidence of toxicity was highest in the samples from the inner harbor, however, samples collected throughout the entire survey area were indicated as toxic in one or more of the end-points (Figure 31). Also, several of the samples collected within the inner harbor and lower Mystic River were decidedly non-toxic in these tests. The sample from station C2(a) in the central harbor was the most toxic of the 55 samples tested, followed by the sample from station D2(a). Toxicity diminished noticeably beyond the entrance to the inner harbor channel. However, there was an apparent pattern of relatively high toxicity down the axis of the harbor, based upon data from stations D1(b), D2(a), C2(c), C2(b), C2(a), B2(c) and B2(b). Overall, toxicity was lowest in portions of northwest harbor, central harbor, and southeast harbor, and in the area sampled beyond the harbor entrance.

The survey area was estimated to cover approximately 56.8 km^2. Samples were collected at randomly chosen locations within strata identified within the survey area. Based upon the distribution functions of the data, each of the tests provided different estimates of the spatial extent of toxicity. In the amphipod and Microtox tests, approximately 10% and 45%, respectively, of the area was estimated as toxic (i. e., test results were less than 80% of controls). In the sea urchin fertilization and embryological tests of 100% pore water, 6.6% and 100% of the area, respectively, were estimated as toxic.

It was apparent from the chemical data that no single substance was the cause of toxicity in these samples. None of the individual anthropogenic substances that were quantified were strongly correlated with amphipod survival, sea urchin fertilization success or sea urchin embryological development, although there were a few relatively weak correlations with some substances. In most samples the concentrations of many of the potentially toxic substances were below the respective ERM values or other guideline concentrations. Un-ionized ammo-

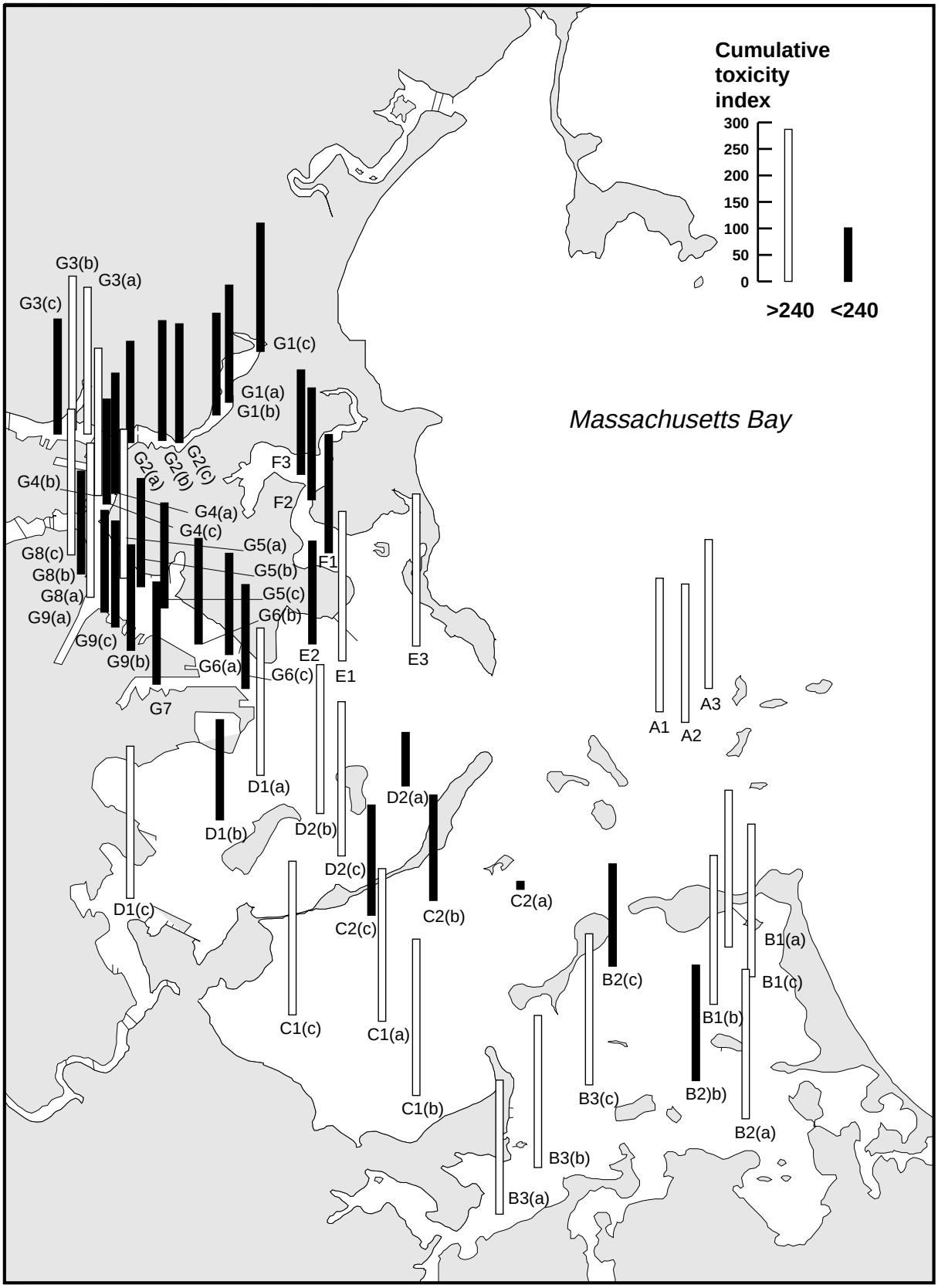

Figure 31. Cumulative toxicity index values (sum of amphipod survival, urchin fertilization in 100% pore water, urchin normal development in 25% pore water) among 55 sampling stations in Boston Harbor.

nia, however, was correlated with the results of the sea urchin embryological development tests and sufficiently elevated in concentration to have contributed to toxicity in that test.

The evidence compiled from five different sequential steps that were taken to identify toxicity/chemistry relationships is summarized in Table 26. The data compiled in Table 26 include: (1) the single-chemical Spearman rank correlations, (2) the tallies of the number of ERM exceedances, (3) the ratios in average chemical concentrations between non-toxic and highly toxic samples, and (4) the ratios in average concentrations in highly toxic samples and respective sediment quality guideline values.

The chemicals listed in Table 26 are those (apart from ammonia) that showed the strongest concordance with the measures of toxicity. For example, silver was significantly correlated with the Microtox results, exceeded the ERM for silver in 12 samples, and the average silver concentrations in samples that were toxic in the Microtox tests exceeded the average concentration in non-toxic samples by a factor of 1.59. Also, mercury was correlated with Microtox results, elevated in 9 samples above the ERM value, and occurred in relatively high concentrations in the samples that were toxic in the Microtox tests. SEM concentrations exceeded the AVS concentrations in 2 samples, SEM/AVS ratios were correlated with Microtox results, and SEM/AVS ratios were elevated in samples that were toxic to amphipods and sea urchin normal development. The concentrations of the PAHs were elevated relative to the guideline values and relative to the non-toxic samples, but the correlations with toxicity were not significant. DDT was moderately elevated in the toxic samples, but not relative to the sediment guidelines and the correlations were significant only in the Microtox test. Total PCB concentrations were much higher than sediment guidelines in many samples, were elevated in samples that were toxic in the Microtox and amphipod tests, and significantly correlated with Microtox results.

The data suggest that complex mixtures of toxic substances in the sediments contributed to the observed toxicity. Un-ionized ammonia may have been particularly important in the toxicity observed in the sea urchin embryological test. The spatial patterns in the concentrations of many chemicals were similar and the correlations among many of the different toxicant groups were significant, indicating that many substances co-varied with each other in the samples. Although only 6 of the 55 samples were highly toxic in the amphipod tests of solid-phase sediments, 30 of the samples were toxic in the Microtox tests of organic solvent extracts, and all 55 samples were toxic in the sea urchin embryo tests of pore waters.

Chemical concentrations may have been too low and most substances may have been bound sufficiently to the organic carbon and fine-grained sediment particles to preclude their bioavailability in the solid phase tests. The observations of relatively high TOC concentrations (1-7%) and the relatively low SEM/AVS ratios (<1.0 in 28 of 30 samples) suggest that most toxicants were not readily bioavailable. Thus, toxicity was not apparent in the amphipod tests of most samples. Also, none of the toxicity tests were significantly correlated with the concentrations of the potentially highly toxic PAHs. However, the low to moderate concentrations of toxicants (including the PAHs and PCBs) that were in the samples probably were extracted with the organic solvents and in sufficient concentrations to induce a response in the Microtox tests. The Microtox results were significantly correlated with the cumulative sum of all of the toxicity units, suggesting an additive response to complex mixtures of substances in the samples.

Table 26. Summary of toxicity / chemistry relationships for those chemicals most correlated with toxicity in Boston Harbor sediments.

	Correlation Coefficients					Highly toxic to non-toxic ratios			Highly toxic to SQG ratios		
	Amphipods	Microtox	Urchin Fert. @100%	Urchin Normal @ 25%	SQG Exceedances	Amphi-pods	Microtox	Urchin Normal	Amphi-pods	Micro-tox	Urchin Normal
Ag	+0.210	-0.0629**	+0.282	-0.104	12	0.62	1.59	0.91	0.52	0.91	0.66
Hg	+0.143	-0.421*	+0.206	+0.112	9	0.68	1.53	0.52	0.65	1.07	0.66
As	-0.068	-0.490*	+0.086	-0.167	0	0.84	1.43	0.60	0.17	0.23	0.18
Cd	-0.132	-0.555*	+0.278	+0.275	0	0.82	1.70	0.42	0.11	0.16	0.10
Cu	-0.005	-0.565*	+0.258	-0.091	0	0.76	1.69	0.56	0.29	0.47	0.33
Ni	+0.146	-0.592*	+0.217	-0.136	0	0.86	1.28	0.73	0.43	0.54	0.43
Zn	-0.233	-0.409*	+0.234	+0.075	1	0.97	1.46	0.67	0.48	0.58	0.46
Cr	-0.189	-0.386*	+0.044	+0.122	1	1.89	1.46	0.67	0.69	0.49	0.31
SEM/AVS	-0.346	+0.609**	+0.082	+0.040	2	6.27	0.14	1.88	0.54	0.05	0.25
LPAHs	-0.230	-0.224	+0.164	+0.149	8	1.47	1.48	0.37	2.19	1.95	1.31
HPAHs	-0.218	-0.288	+0.185	+0.107	9	1.30	1.68	0.60	1.17	1.20	0.87
tPAHs	-0.257	-.0268	+0.163	+0.068	0	1.27	1.75	0.56	0.41	0.43	0.31
DDE	-0.145	-0.479*	+0.211	-0.091	0	0.97	1.46	0.47	0.15	0.19	0.13
tDDTs	-0.129	-0.485*	+0.127	-0.005	0	1.08	1.53	0.54	0.40	0.46	0.35
tCHLs	-0.150	-0.417*	+0.242	+0.141	na	0.86	1.61	0.44	na	na	na
tPCBs	-0.035	-0.451*	+0.175	+0.105	27	0.77	1.71	0.41	1.10	1.8	1.22

Relatively high ammonia levels would be expected in organically enriched sediments and ammonia is known to be highly toxic to the invertebrates used in these tests. The concentrations of ammonia in two samples tested for amphipod survival and in many of the pore water samples tested for sea urchin embryo development may have been sufficiently high to contribute to toxicity in those assays. For example, ammonia concentrations in the sample from station C2(a) exceeded the respective toxicity thresholds for both amphipod survival and sea urchin development, and, therefore, probably was a major contributor to toxicity in that sample. However, the sediment from station C2(a) also had very high concentrations of pesticides, bulk trace metals, and simultaneously-extracted metals. Overall, the concentrations of unionized ammonia were too low to have been the sole cause of toxicity in most samples.

In summary, the chemical substances that most likely contributed to toxicity included the PCBs, other chlorinated hydrocarbons, PAHs, several trace metals, and ammonia. It is highly likely, also, that other substances not measured in the chemical analyses may have contributed to or caused toxicity in some samples.

In surveys of sediment toxicity performed by NOAA in San Francisco Bay (Long and Markel, 1992), Tampa Bay (Long et al., 1994), Long Island Sound (Wolfe et al., 1994), and the Hudson-Raritan estuary (Long et al., 1995b) relatively clear associations between toxicity and the concentrations of toxicants were observed. The specific chemicals associated with toxicity differed among these study areas, but, nevertheless, unlike Boston Harbor, there was invariably strong evidence of chemistry/toxicity concordance. Additional research would be necessary to tease out the chemistry/toxicity associations in Boston Harbor. This research would involve toxicity identification evaluations, complex procedures which involve iterative toxicity testing of chemical fractions of the mixtures of substances found in Boston Harbor sediments.

CONCLUSIONS

• Previous studies have demonstrated that potentially toxic substances in Boston Harbor sediments occur in sufficiently high concentrations to warrant concerns for their toxicological effects.

• In the present survey, toxicity was observed in Boston Harbor sediments in all four tests that were performed.

• The sea urchin test of embryological development was most sensitive, indicating significant toxicity in all 55 samples of 100% pore water. This test, performed with 100% pore water, was highly sensitive, but it was not discriminatory, since all samples were identified as toxic. Tests performed with 25% pore water were less sensitive but they identified more clearly the differences in toxicity among samples.

• The microbial bioluminescence test was the next most sensitive, indicating toxicity (i.e., significant differences from controls) in 30 of the 55 samples.

• In the amphipod survival tests, 12 samples were significantly different from controls and 6 samples were highly toxic.

• In the tests of sea urchin fertilization, only two of the samples were significantly toxic, one of which was highly toxic. The sensitivity of this test may have been reduced by a less than optimal sperm/egg ratio.

• As expected, based upon the chemical data, many of the samples collected in the inner harbor were highly toxic in at least one of the tests. However, several inner harbor samples were not toxic and toxicity was not restricted to only the inner harbor. Some samples collected in northwest harbor, central harbor, and southeast harbor were equally toxic. The two individual samples that were most toxic in the invertebrate tests were collected in the central and northwest harbor areas.

• Except for the two sea urchin tests, the correlations among the different toxicity tests were not significant.

• The estimates of the spatial extent of toxicity ranged widely depending upon the sensitivity of the four individual tests. The estimates of the extent of toxicity in the sea urchin development, microbial bioluminescence, amphipod survival, and sea urchin fertilization tests were 100%, 44.9%, 10.0%, and 6.6%, respectively.

• The chemical data from the analyses of 30 samples indicated a consistent spatial pattern among the different chemicals and chemical groups: relatively high concentrations in the inner harbor, intermediate in the northwest and central harbors, and lowest in the southeast harbor and outside the harbor entrance.

• Statistical correlations between toxicity and concentrations of anthropogenic contaminants were strongest with the results of the Microtox tests. The Microtox test showed strong associations with numerous organic compounds as well as many trace metals

• The concentrations of 17 substances either equalled or exceeded respective sediment quality guidelines in at least one sample.

• The concentrations of many toxicants were highly correlated with each other, indicating a strong pattern of co-variance among the different substances.

• The concentrations of un-ionized ammonia in the solid-phase sediments were sufficiently high in two samples to contribute substantially to toxicity to amphipod survival.

• The concentrations of un-ionized ammonia in the sediment pore waters were strongly correlated with toxicity to sea urchin embryological development and weakly associated with sea urchin fertilization success and were sufficiently high in some samples to contribute substantially to toxicity.

• Toxicity in these tests was most likely driven by complex mixtures of toxicants in the sediments, not by any single substance or class of chemicals. The chemical substances that most likely contributed to toxicity included the PCBs, other chlorinated hydrocarbons, PAHs, several trace metals, and ammonia. A highly complex toxicity identification evaluation procedure would be required to specifically identify which chemical(s) caused the observed toxicity.

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APPENDICES

Appendix A. Field notes from each sampling station: Boston Harbor.								
Strata	Station	Alternate	Station Location	Date	Time	Latitude	Longitude	Depth
No.	No.	No.						ft.
A	1	1	Massachusetts Bay	6/29/93	2:30 PM	42° 20.45' N	70° 54.45' W	46.0
	2	7		6/29/93	4:00 PM	42° 20.27' N	70° 54.31' W	50.0
	3	8		6/29/93	4:45 PM	42° 20.59' N	70° 54.11' W	53.0
B-1	a	1	Hull Bay	7/14/93	10:30 AM	42° 17.92' N	70 54.21' W	13.0
	b	2		7/14/93	11:30 AM	42° 17.36' N	70 54.17' W	18.0
	c	3		7/14/93	12:00 PM	42° 17.82' N	70° 53.55' W	11.0
B-2	a	1	Hingham Bay	6/29/93	8:45 AM	42° 16.38' N	70° 53.62' W	21.0
	b	1		6/29/93	9:45 AM	42° 16.78'N	70° 54.32' W	32.0
	c	1		6/29/93	11:00 AM	42° 17.76' N	70° 55.50' W	25.0
B-3	a	1	Weymouth Fore River	7/14/93	8:15 AM	42° 15.11' N	70° 57.13' W	41.0
	b	1		7/14/93	9:15 AM	42° 15.88' N	70° 56.45' W	16.0
	c	1		7/14/93	10:00 AM	42° 16.54' N	70° 55.58' W	17.0
C-1	a	1	Quincy Bay	7/12/93	11:45 AM	42° 17.94' N	70° 58.46' W	18.0
	b	2		7/12/93	12:45 PM	42° 16.61' N	70° 58.10' W	11.0
	c	4		7/12/93	12:00 AM	42° 17.60' N	70° 59.50' W	13.0
C-2	a	1	Nantasket Roads	6/29/93	11:45 AM	42° 18.54' N	70° 56.80' W	23.0
	b	2		6/29/93	12:30 PM	42° 18.51' N	70° 58.46' W	13.5
	c	3		6/29/93	1:30 PM	42° 18.34' N	70° 58.69' W	14.0
D-1	a	1	Dorchester Bay	6/30/93	7:45 AM	42° 19.77' N	70° 00.60' W	19.0
	b	1		6/30/93	8:40 AM	42° 19.31' N	71° 00.81' W	22.0
	c	1		6/30/93	9:30 AM	42° 18.40' N	71° 02.12' W	25.0
D-2	a	1	Sculpin Ledge	7/12/93	3:20 PM	42° 19.55' N	70° 58.58' W	17.0
	b	1		7/12/93	4:05 PM	42° 19.33' N	70° 59.55' W	19.0
	c	1		7/12/93	4:45 PM	42° 18.64' N	70° 59.30' W	17.0
E	1	3	Northwest Harbor	7/14/93	2:00 PM	42° 20.56' N	71° 00.32' W	19.0
	2	1		7/14/93	3:45 PM	42° 20.63' N	70° 59.45' W	10.0
	3	4		7/14/93	4:45 PM	42° 20.91' N	70°58.23' W	16.0

APPENDIX A contd.			
Strata No.	Station No.	Alternate No.	Sediment description
A	1	1	Sandy clay: light brown: RPD 2 cm.: lt. gray clay, no odor: small amphipod tubes abundant.
	2	7	Sandy clay: lt. brn: RPD 2 cm.: lt. gray clay, no odor: small amphipod tubes:small gelatinous masses.
	3	8	Fine, muddy, lt. brn sand; shell bits; gelatinous infauna; stones w/barnacles; no anoxia or polychaetes.
B-1	a	1	Lt. brn sandy silt in upper 1-2 cm; drk gray-blk. sandy silt below; mysids, sm. worm tubes, & shell bits.
	b	2	Lt. brn silt in upper 0.5-1 cm; dark gray silt below; amphipod tubes and worm tubes; snails on surface.
	c	3	Lt. brn sandy silt in upper 1cm; drk gray sandy silt below,rock & shell bits,snails,worm & amphi. tubes
B-2	a	1	Sandy clay; upper 1cm lt. brn, drk gray-blk below; shell bits; amphipod tubes on surface; crabs,
			skate eggs,tunicates,infaunal polychaete; no odor.
	b	1	Muddy fine sand; top 2cm olive grn/brn color; abundant epifauna and infauna, amphipods, crabs,
			shrimp, many snails, some gravel, stones, shell bits: no odor.
	c	1	Clay; no distinct RPD, sediment a bit darker below surface; no sand or gravel; no odor; amphipod tubes.
B-3	a	1	Fine silt; lt. brn top; RPD-1/4-1/2cm; snails on top; drk gray silt under RPD; some blk ooze; sulfur smell
	b	1	Lt. brn silt 1-1.5cm ; drk gray silt below; small crabs and mysids on surface; worm and amphipod tubes.
	c	1	Lt. brn silt in top 1cm; surface worm tubes, amphi. tubes; worms; dark gray silt below; sulfurous odor.
C-1	a	1	Green-brown silt in upper 1cm, grayish silt below; snails, shell bits, hermit crabs and amphipod tubes.
	b	2	Brown silt in upper 1/2cm, dark gray silt below; small worm tubes, many small rocks, shell bits.
	c	4	Brown silt in upper 1/2cm, sticky black clay beneath; some snails on surface; hermit crabs.
C-2	a	1	Well mixed brown clay; many amphipod tubes, amphipods, and gastropods
	b	2	Light brown clay; RPD approx. 2 mm; very black anoxic layer beneath RPD; small amphipod tubes.
	c	3	Light Brown clay; RPD approximately 1/2 cm; dark gray clay beneath RPd; small amphipod tubes
D-1	a	1	Sandy clay, lt. brn top 1cm; odorous blk sediment below RPD; gastropods,infaunal polychaetes,amphipod tubes
	b	1	Clay & sand, shell bits in upper 1-2cm, dark anoxic clay/sand below; gastropods, polychaetes, amphipod tubes
	c	1	Sandy mud, shell bits/gravel, a lobster; RPD 2cm; sandy mud anoxic below RPD;last drop more clay RPD <0.5cm
D-2	a	1	All brn silt,no RPD; amphipod tube mats,like a sponge; many amphipods,worms,snails; lot of interstitial water
	b	1	Brn silt in top 1-2cm; blk sticky anoxic sediment below RPD; snail, amphipod, worm tubes in surface sediment
	c	1	Fine silt, light brown in upper 0.5-1cm; black below RPD; sulfurous odor; some small tubes on surface
E	a	3	Mussel shells and shell fragments; lt. brn and drk gray silt mixed among shells; black oozy pockets; lg. worms

Appendix A contd.								
F-1	1	1	Snake Island	6/30/93	12:05 PM	42° 21.74' N	70° 59.23' W	14.0
F-2	1	1	Chelsea Point	6/30/93	11:10 AM	42° 22.13' N	70° 59.84' W	18.0
F-3	1	1	Orient Heights	6/30/93	10:40 AM	42° 22.73' N	70° 59.90' W	31.0
G-1	a	1	Upper Chelsea River	6/28/93	11:15 AM	42° 23.52' N	71° 00.99' W	35.0
	b	2		6/28/93	12:30 PM	42° 23.26'N	71° 01.21' W	33.0
	c	4		6/28/93	1:25 PM	42° 23.76' N	71° 00.78' W	33.0
G-2	a	7	Lower Chelsea River	7/13/93	8:00 AM	42° 23.14' N	71° 02.41' W	41.0
	b	1		7/13/93	9:10 AM	42° 23.14' N	71° 02.11' W	43.0
	c	2		7/13/93	10:50 AM	42° 23.13' N	71° 01.48' W	36.0
G-3	a	1	Mystic River	7/13/93	12:00 AM	42° 23.05' N	71° 03.02' W	35.0
	b	2		7/13/93	12:45 PM	42° 23.20' N	71° 03.30' W	38.0
	c	3		7/13/93	1:45 PM	42° 23.10' N	71° 03.21' W	42.0
G-4	a	1	Charleston Channel	7/15/93	11:00 AM	42° 22.42' N	71° 02.72' W	45.0
	b	2		7/15/93	11:50 AM	42° 22.36' N	71° 02.91' W	45.0
	c	3		7/15/93	12:30 PM	42° 22.35' N	71° 03.08' W	29.0
G-5	a	1	Boston Channel	6/28/93	10:00 AM	42° 21.41' N	71° 02.16' W	41.0
	b	2		6/28/93	5:05 PM	42° 21.62' N	71° 02.17' W	36.0
	c	3		6/28/93	5:45 PM	42° 21.79' N	71° 02.59' W	50.0
G-6	a	1	Channel Mouth	7/15/93	8:00 AM	42° 21.01' N	71° 00.94' W	38.0
	b	2		7/15/93	8:35 AM	42° 21.36' N	71° 01.72' W	37.0
	c	3		7/15/93	9:50 AM	42° 20.82' N	71° 01.19' W	46.0
G-7	1	1	Reserved Channel	6/28/93	4:15 PM	42° 20.55' N	71°01.80' W	36.0
G-8	a	1	Boston Wharves	6/30/93	1:45 PM	42° 21.74' N	71° 02.79' W	24.0
	b	3		6/30/93	2:30 PM	42° 21.94' N	71° 02.90' W	24.0
	c	4		6/30/93	4:00 PM	42° 21.99'N	71° 02.94'W	24.0
G-9	a	1	Fort Point	7/13/93	4:30 PM	42° 21.48' N	71° 02.76' W	30.0
	b	2		7/13/93	5:10 PM	42° 21.28' N	71° 02.44' W	39.0
	c	3		7/13/93	5:45 PM	42° 21.11' N	71° 02.48' W	48.0

APPENDIX A contd.			
			present; very difficult to isolate the sediment from shell fragments
	b	1	Lt. brn sand w/dark gray sand/silt;algae,snails,worm tubes,shell bits&stones;gray sticky clay in low sediments
	c	4	Lt. brn silt sediment in upper 1cm; dark gray silt beneath; amphipod tubes; worms, snails, shell fragments
F-1	1	1	Light brown sandy silt on surface; RPD approx. 1cm; dark gray sandy silt below RPD; hydriods, crabs gastropods,
			entromorphs, mysids, shrimp, small amphipod tubes
F-2	1	1	Silty sand, light brown on surface; abundant amphipod tubes; RPD 1cm; drk gray, organic rich, sulfurous
			underlying sediment; shrimp, hydrozoans; isolated pockets of anoxic silt below sand layer
F-3	1	1	Very fine grained clay; lt. brn at top, RPD <0.5cm; dark gray-black sulfurous beneath; no visible signs of life
G-1	a	1	Very top layer is gold-brn, fine clay, gray lower layer; no odor; clam shells, mysids and amphipods,tunicates
	b	2	Sandy mud; upper 0.5cm lt. brown; light-med petroleum sheen; silty sand anoxic layer below; sulfurous odor;
			adult crangonid shrimp, rocks, pebbles, shell fragments; some mysids and algal debris
	c	4	Mix of sandy-silt, light brown in upper 0.5cm, dark gray beneath; petroleum sheen; no odor; mysids
G-2	a	7	Mussel shells, oil sheen & droplets on surface; brown sandy silt with black sandy silt below; RPD .25-0.5cm; small
			shrimp; some pockets of black ooze with sulfurous odor
	b	1	Lt. brn sediment on top, thin layer; mix of hard drk clay, oozy blk silt & cobbles; one worm, crab, and shrimp
	c	2	Strong petro. smell; lt. brn silt in upper 0.5cm; drk gray sandy silt below; pockets of blk ooze; oil sheen; shell bits
G-3	a	1	Soft silty sediment; lt. brn in upper 0.5-1cm; drk gray below; rocks & shell bits; clumps of turicates, crab, shrimp
	b	2	Lt. brn silt in uppr 0.5cm; stratified gray clay below, lt. &drk gray sticky & soft;cobbles mix in clay layer; shrimp
	c	3	Lt. brn silt in upper .25-0.5cm;sticky gry-blk clay below;blk pockets of ooze;cobbles mix in clay;mysids;oil sheen
G-4	a	1	Lt. brn fine silt w/in 0.5cm; snail&worm tubes; drk brn-gray silt below; polychaete worms; blk silty floc. on top
	b	2	Lt. brn fine silt in upper 0.5-1cm; snails, mysids, worm tubes; gray silt beneath RPD
	c	3	Lt. brown watery silt in upper 1-2cm; some black flocculant in surface; many mysids; dark gray silt beneath RPD
G-5	a	1	Lt. brn clay in top 0.5-1cm; drk gray silt, fine grain below, anoxic sulfous smell; amphi tubes and young shrimp
	b	2	Light brown silty clay in top 0.5cm, with some ampipod tubes; lower sediment dark gray with sulfurous odor
	c	3	Silty clay in top 0.5cm; amphi tubes; drk gray anoxic sedimnt below RPD; blk with sulfur odor in lower sediments
G-6	a	1	Fine silt; lt. brn top layer, RPD <1/8cm; blk mayo-like silt below,watery; no life signs; sulfur odor;sm. tubes on top
	b	2	Lt. brn silt on surface, RPD<1/8cm; soft drk gray mayo-like silt below; some small tubes on surface
	c	3	Lt. brown silt in top 0.5cm; snails and worm tubes; dark gray silt below RPD; slight sulfurous odor
G-7	1	1	Lt. brn silty clay at the surface .25cm deep; oil sheen; black sulfurous clay beneath; no life signs; very odorous
G-8	a	1	Greenish-brown clay; RPD 3mm; no signs of life; dark gray clay below RPD no odor
	b	3	Greenish brown, fine clay; RPD 2-3cm; dark gray-black below RPD; distinct odor; no visible signs of life
	c	4	Lt. brown surface; sandy clay, small infaunal tubes, shell fragments, rpd 2-3 mm, dark gray below rpd.
G-9	a	1	Light brown upper 0.5cm, light gray below; very fine silt; some tubes on surface
	b	2	Very fine silt, mayo-like consistency; lt. brn on surface; RPD 0.25cm; drk gray beneath; no visible signs of life
	c	3	Fine silt; olive green-brn top layer, RPD<0.25cm; dark gray below; black oozy pockets, petroleum smell; shell bits

Appendix B. Sediment grain size and total organic carbon content.					
		GRAIN SIZE			TOC
Station No.	% SAND	% SILT	% CLAY	silt+clay(%)	(% DRY)
A (1)	39.99	34.71	25.3	60.01	1.78
B-1 (a)	57.39	23.97	18.64	42.61	1.45
B-2(a)	52.83	31.02	16.15	47.17	1.88
B-2 (b)	86.44	6.08	7.48	13.56	0.80
B-3 (b)	14.44	55.08	30.48	85.56	3.05
C-1 (a)	34.85	35.76	29.39	65.15	2.68
C-1 (c)	11.46	56.08	32.46	88.54	3.27
C-2 (a)	41.97	33.25	24.78	58.03	2.89
C-2 (b)	7.36	55.21	37.43	92.64	2.96
C-2 (c)	6.38	53.95	39.67	93.62	3.41
D-1 (b)	76.1	11.95	11.95	23.9	1.00
D-1 (c)	37.54	39.04	23.42	62.46	1.77
D-2 (a)	19.05	40.48	40.47	80.95	3.05
D-2 (b)	17.5	52.23	30.27	82.5	3.25
E (1)	43.23	24.64	32.13	56.77	2.39
G-1 (a)	40.89	31.34	27.77	59.11	2.12
G-1 (c)	64.79	19.5	15.71	35.21	1.53
G-2 (a)	70.01	15.62	14.37	29.99	1.41
G-2 (b)	77.41	12.51	10.08	22.59	1.72
G-2 (c)	71.96	14.27	13.77	28.04	1.83
G-3 (a)	29.5	30.95	39.55	70.5	4.45
G-3 (b)	48.13	20.07	31.8	51.87	2.29
G-3 (c)	42.96	27.27	29.77	57.04	3.74
G-4 (a)	5.7	46.02	48.28	94.3	3.31
G-4 (b)	7.57	41.43	51	92.43	3.35
G-4 (c)	3.92	36.6	59.48	96.08	4.61
G-5 (c)	10.92	43.96	45.12	89.08	3.15
G-6 (a)	3	48.51	48.49	97	2.94
G-7 (1)	15.55	49.92	34.53	84.45	2.54
G-8 (c)	36.96	30.81	32.23	63.04	6.98
Duplicates					
B-1 (a)	58.29	21.04	20.67	41.71	1.44
D-2(b)					3.24
G-2 (c)	72.04	13.45	14.51	27.96	
G-4 (b)	6.85	41.1	52.05	93.15	
G-7 (1)					2.67

Appendix C. Concentrations of trace metals, acid-volatile sulfides (AVS), and simultaneously-extracted metals (SEM).										
		SRMID	Ag	Hg	As	Cd	Cu	Ni	Pb	Se
Station No.	Lab Sample No.		ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
	MDLs		0.03	0.007	0.3	0.008	0.44	0.7	0.35	0.2
A (1)	11509		2.196	0.344	10.36	0.67	52.02	20.64	74.1	1.32
B-1 (a)	11541		1.779	0.317	6.73	0.27	37.79	17.93	62.0	0.90
B-2 (a)	11532		1.870	0.330	7.73	0.46	41.33	14.77	72.7	0.97
B-2 (b)	11533		0.693	0.118	4.11	0.18	15.48	10.33	29.6	0.55
B-3 (b)	11539		3.925	0.650	10.98	0.80	89.72	25.78	95.4	1.48
C-1 (a)	11497		3.802	1.019	11.84	0.67	92.80	25.52	138.8	0.74
C-1 (c)	11499		4.425	1.110	11.22	1.24	105.39	26.04	120.8	0.71
C-2 (a)	11535		2.804	0.409	11.23	0.19	65.03	24.32	89.3	1.17
C-2 (b)	11536		3.522	0.698	13.79	0.90	101.41	27.63	122.1	1.32
C-2 (c)	11537		3.990	0.628	15.25	0.99	99.72	29.31	124.1	1.39
D-1 (b)	11489		0.975	0.224	7.39	0.54	30.40	14.29	49.6	0.34
D-1 (c)	11490		2.243	0.561	10.29	1.25	70.95	20.76	101.7	0.45
D-2 (a)	11500		3.335	0.601	15.69	0.45	106.68	27.10	136.5	0.80
D-2 (b)	11501		4.574	1.275	13.07	1.79	156.53	29.73	158.1	0.97
E (1)	11540		3.955	0.515	8.02	1.92	98.72	25.37	96.1	1.17
G-1 (a)	11515		1.374	0.503	13.73	1.18	92.98	20.57	195.2	1.09
G-1 (c)	11517		0.924	0.345	10.09	1.25	57.32	15.42	120.1	0.89
G-2 (a)	11503		1.068	0.256	10.23	0.82	71.23	17.32	468.0	1.00
G-2 (b)	11504		1.360	0.396	11.86	1.73	88.95	24.68	135.0	0.93
G-2 (c)	11505		1.241	0.535	10.84	1.55	79.17	20.54	124.6	0.95
G-3 (a)	11506		2.948	0.695	19.37	1.78	152.65	31.45	198.8	1.43
G-3 (b)	11507		1.262	0.979	15.23	1.02	81.75	26.67	114.0	0.89
G-3 (c)	11508		2.310	0.959	26.24	2.13	122.08	26.49	177.2	1.56
G-4 (a)	11525		3.987	0.788	20.67	1.67	147.23	31.45	175.6	1.91
G-4 (b)	11526		4.081	0.921	21.50	1.51	149.39	33.90	162.4	1.75
G-4 (c)	11527		4.222	1.110	25.90	2.92	269.01	38.63	299.5	1.73
G-5 (c)	11530		4.007	0.444	18.64	2.10	149.91	33.21	143.4	1.33
G-6 (a)	11522		3.406	0.567	17.64	1.33	100.95	31.12	109.1	1.61
G-7 (1)	11531		4.516	0.546	14.15	1.52	109.15	31.30	106.0	1.17
G-8 (c)	11496		4.372	1.372	23.80	2.88	259.49	40.41	263.4	2.58

Appendix C contd.										
			Sn	Zn	Cr	Mn	Al	Fe	AVS	SEM-Cu
Station No.	Lab Sample No.	SRMID	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
	MDLs		0.1	2.2	0.1	5	440	40		0.50
A (1)	11509		8.77	103.97	107.7	497.8	68,164	30,962	283.2	7.29
B-1 (a)	11541		8.34	88.91	71.8	486.7	65,110	27,051	182.1	6.64
B-2(a)	11532		9.51	93.49	76.7	452.3	61,421	26,249	721.0	0.65
B-2 (b)	11533		5.03	54.53	37.7	320.5	46,357	16,932	125.0	6.03
B-3 (b)	11539		12.44	135.73	123.3	502.3	74,000	35,790	1822.5	0.69
C-1 (a)	11497		14.56	141.53	154.1	521.6	73,367	32,909	291.4	21.95
C-1 (c)	11499		12.77	169.18	153.3	491.7	73,516	31,028	1404.4	0.65
C-2 (a)	11535		13.78	113.47	124.9	578.5	70,188	33,946	75.9	69.35
C-2 (b)	11536		15.37	170.93	157.5	547.3	76,169	41,370	2671.3	3.02
C-2 (c)	11537		15.69	181.45	161.3	560.5	77,539	39,582	1694.0	1.62
D-1 (b)	11489		4.70	84.85	53.9	363.4	55,314	21,445	432.5	8.30
D-1 (c)	11490		8.86	147.06	103.2	509.7	68,621	28,636	597.1	<0.5
D-2 (a)	11500		19.56	178.51	157.3	574.8	78,558	33,663	92.8	86.59
D-2 (b)	11501		23.12	232.02	219.3	533.6	78,047	41,096	1541.0	8.77
E (1)	11540		15.04	174.80	146.0	434.3	60,392	28,807	1708.6	<0.5
G-1 (a)	11515		8.03	324.95	144.2	440.1	67,573	31,680	71.9	23.29
G-1 (c)	11517		5.85	173.65	166.1	414.0	62,994	35,861	104.4	2.58
G-2 (a)	11503		6.20	142.22	78.7	383.9	57,788	21,335	619.1	2.31
G-2 (b)	11504		8.18	220.66	186.5	527.8	71,293	31,531	167.9	0.71
G-2 (c)	11505		8.31	288.21	635.6	392.7	61,768	27,975	3270.0	<0.5
G-3 (a)	11506		15.61	290.94	144.1	494.7	72,027	39,732	243.6	3.02
G-3 (b)	11507		7.65	179.56	100.2	561.5	74,930	38,564	351.4	53.56
G-3 (c)	11508		9.84	264.03	122.2	512.0	70,320	35,170	1409.5	<0.5
G-4 (a)	11525		10.90	249.62	171.2	587.9	82,631	46,667	628.6	1.61
G-4 (b)	11526		11.87	239.77	167.3	581.2	80,284	46,469	1413.1	2.33
G-4 (c)	11527		19.37	698.55	190.4	512.0	78,879	51,545	3867.6	<0.5
G-5 (c)	11530		15.61	248.15	174.7	550.9	80,791	41,557	739.9	0.57
G-6 (a)	11522		9.94	189.20	161.4	574.9	78,994	44,502	4776.5	0.66
G-7 (1)	11531		12.46	201.33	136.6	577.7	75,034	42,228	2190.2	1.83
G-8 (c)	11496		16.80	354.30	205.2	474.4	71,524	43,055	2583.8	<0.5

Appendix C contd.										
			SEM-Cd	SEM-Ni	SEM-Pb	SEM-Zn	SEM-Hg	AVS	SEM-Cu	SEM-Cd
Station No.	Lab Sample No.	SRMID	ppm	ppm	ppm	ppm	ppm	mM	mM	mM
	MDLs		0.01	0.7	0.4	2.2	0.001			
A (1)	11509		0.31	2.25	41.35	38.40	0.0016	8.831	0.115	0.003
B-1 (a)	11541		0.13	1.32	28.52	26.93	0.0012	5.679	0.105	0.001
B-2(a)	11532		0.29	1.64	33.22	38.13	<0.001	22.486	0.010	0.003
B-2 (b)	11533		0.10	0.62	14.28	14.65	<0.001	3.899	0.095	0.001
B-3 (b)	11539		0.44	2.81	57.67	62.41	<0.001	56.838	0.011	0.004
C-1 (a)	11497		0.25	2.18	82.93	59.64	0.0015	9.089	0.345	0.002
C-1 (c)	11499		0.49	2.22	67.87	66.00	<0.001	43.801	0.010	0.004
C-2 (a)	11535		0.13	2.55	64.70	50.31	0.0662	2.369	1.092	0.001
C-2 (b)	11536		0.45	3.74	74.23	68.72	0.0025	81.842	0.048	0.004
C-2 (c)	11537		0.55	4.25	83.83	76.43	0.0013	52.831	0.025	0.005
D-1 (b)	11489		0.21	0.82	21.16	26.98	<0.001	13.490	0.131	0.002
D-1 (c)	11490		0.42	1.32	31.15	51.08	<0.001	18.622	<	0.004
D-2 (a)	11500		0.22	2.57	89.00	70.35	0.0227	2.893	1.363	0.002
D-2 (b)	11501		0.67	3.45	81.63	83.37	0.0019	48.062	0.138	0.006
E (1)	11540		0.20	2.49	3.74	58.60	<0.001	53.288	<	0.002
G-1 (a)	11515		0.61	2.28	95.45	107.15	0.0023	2.241	0.366	0.005
G-1 (c)	11517		0.50	1.32	46.22	63.82	<0.001	3.256	0.041	0.004
G-2 (a)	11503		0.31	2.26	57.39	88.89	<0.001	19.308	0.036	0.003
G-2 (b)	11504		0.67	2.50	52.82	86.23	<0.001	5.237	0.011	0.006
G-2 (c)	11505		0.72	2.12	47.57	220.82	<0.001	101.984	<	0.006
G-3 (a)	11506		0.87	3.69	97.91	123.48	<0.001	7.599	0.048	0.008
G-3 (b)	11507		0.57	3.89	71.38	77.67	0.0010	10.958	0.843	0.005
G-3 (c)	11508		1.07	3.06	67.62	145.17	<0.001	43.959	<	0.009
G-4 (a)	11525		0.93	4.76	99.40	123.30	<0.001	19.604	0.025	0.008
G-4 (b)	11526		0.83	4.73	97.38	110.97	<0.001	44.070	0.037	0.007
G-4 (c)	11527		1.74	7.46	167.33	538.79	<0.001	120.622	<	0.015
G-5 (c)	11530		1.05	4.65	79.49	129.22	<0.001	23.077	0.009	0.009
G-6 (a)	11522		0.89	5.26	68.54	84.82	<0.001	148.969	0.010	0.008
G-7 (1)	11531		0.83	5.27	62.35	92.29	<0.001	68.306	0.029	0.007
G-8 (c)	11496		1.20	3.74	103.17	151.64	<0.001	80.584	<	0.011

Appendix C contd.									
		SEM-Ni	SEM-Pb	SRMID	SEM-Zn	SEM-Hg	Total SEM	SEM/AVS	ADGDAT
Station No.	Lab Sample No.	mM	mM	mM	mM	Metals (mM)	ratio	Acid Dig. Date	Sample Type
	MDLs								
A (1)	11509	0.038	0.200	0.587	0.000	11509.943	1303.35	09/18/85	SAMP
B-1 (a)	11541	0.023	0.138	0.412	0.000	11541.678	2032.25	09/18/85	SAMP
B-2(a)	11532	0.028	0.160	0.583	<	11532.784	512.89	09/18/85	SAMP
B-2 (b)	11533	0.011	0.069	0.224	<	11533.399	2958.19	09/18/85	SAMP
B-3 (b)	11539	0.048	0.278	0.955	<	11540.296	203.04	09/18/85	SAMP
C-1 (a)	11497	0.037	0.400	0.912	0.000	11498.697	1265.10	09/18/85	SAMP
C-1 (c)	11499	0.038	0.328	1.010	<	11500.390	262.56	09/18/85	SAMP
C-2 (a)	11535	0.043	0.312	0.770	0.000	11537.218	4871.01	09/18/85	SAMP
C-2 (b)	11536	0.064	0.358	1.051	0.000	11537.525	140.97	09/18/85	SAMP
C-2 (c)	11537	0.072	0.405	1.169	0.000	11538.677	218.41	09/18/85	SAMP
D-1 (b)	11489	0.014	0.102	0.413	<	11489.661	851.72	09/18/85	SAMP
D-1 (c)	11490	0.023	0.150	0.781	<	11490.958	617.06	09/18/85	SAMP
D-2 (a)	11500	0.044	0.430	1.076	0.000	11502.914	3975.93	09/18/85	SAMP
D-2 (b)	11501	0.059	0.394	1.275	0.000	11502.872	239.34	09/18/85	SAMP
E (1)	11540	0.042	0.018	0.896	<	11540.959	216.58	09/18/85	SAMP
G-1 (a)	11515	0.039	0.461	1.639	0.000	11517.511	5138.42	09/18/85	SAMP
G-1 (c)	11517	0.022	0.223	0.976	<	11518.267	3537.67	09/18/85	SAMP
G-2 (a)	11503	0.038	0.277	1.360	<	11504.714	595.86	09/18/85	SAMP
G-2 (b)	11504	0.043	0.255	1.319	<	11505.634	2196.90	09/18/85	SAMP
G-2 (c)	11505	0.036	0.230	3.378	<	11508.650	112.85	09/18/85	SAMP
G-3 (a)	11506	0.063	0.473	1.889	<	11508.480	1514.50	09/18/85	SAMP
G-3 (b)	11507	0.066	0.344	1.188	0.000	11509.447	1050.33	09/18/85	SAMP
G-3 (c)	11508	0.052	0.326	2.221	<	11510.609	261.85	09/18/85	SAMP
G-4 (a)	11525	0.081	0.480	1.886	<	11527.481	588.02	09/18/85	SAMP
G-4 (b)	11526	0.081	0.470	1.698	<	11528.292	261.59	09/18/85	SAMP
G-4 (c)	11527	0.127	0.808	8.242	<	11536.192	95.64	09/18/85	SAMP
G-5 (c)	11530	0.079	0.384	1.977	<	11532.458	499.74	09/18/85	SAMP
G-6 (a)	11522	0.090	0.331	1.298	<	11523.736	77.36	09/18/85	SAMP
G-7 (1)	11531	0.090	0.301	1.412	<	11532.839	168.84	09/18/85	SAMP
G-8 (c)	11496	0.064	0.498	2.320	<	11498.892	142.70	09/18/85	SAMP

Appendix C contd.								
	SAMPTYPE	ADWT	HGDWT	AVS	SEMWT	PCTMOIS	UNITTM	UNITQUAL
Station No.	Lab Sample No.	Acid Dig. DW	Hg Dig. DW	AVS DW	SEM Wet Wt	% Moisture	Conc. Units	Wet/Dry Wt
	MDLs							
A (1)	11509	0.1995	0.1834	1.61	6.49	53.39	PPM	DRY
B-1 (a)	11541	0.215	0.2154	1.55	7.97	49.15	PPM	DRY
B-2(a)	11532	0.2105	0.2072	2.26	6.71	52.34	PPM	DRY
B-2 (b)	11533	0.2187	0.2084	2.96	8.95	34.42	PPM	DRY
B-3 (b)	11539	0.1961	0.2024	1.05	3.88	67.24	PPM	DRY
C-1 (a)	11497	0.1932	0.1848	1.95	6.92	59.45	PPM	DRY
C-1 (c)	11499	0.2021	0.1827	1.20	5.84	62.17	PPM	DRY
C-2 (a)	11535	0.204	0.2016	1.29	5.05	62.58	PPM	DRY
C-2 (b)	11536	0.2194	0.2058	0.98	3.98	70.25	PPM	DRY
C-2 (c)	11537	0.2078	0.2005	1.05	3.16	67.04	PPM	DRY
D-1 (b)	11489	0.2063	0.2039	2.23	11.97	32.45	PPM	DRY
D-1 (c)	11490	0.2271	0.1845	2.10	10.95	49.73	PPM	DRY
D-2 (a)	11500	0.2028	0.182	1.06	7.60	65.21	PPM	DRY
D-2 (b)	11501	0.1945	0.1815	1.25	5.82	64.43	PPM	DRY
E (1)	11540	0.2088	0.1975	1.86	9.42	51.53	PPM	DRY
G-1 (a)	11515	0.2058	0.1882	2.02	5.45	55.99	PPM	DRY
G-1 (c)	11517	0.21	0.1831	2.65	9.28	40.65	PPM	DRY
G-2 (a)	11503	0.2036	0.1849	2.89	4.63	43.70	PPM	DRY
G-2 (b)	11504	0.2052	0.1905	2.86	8.97	36.40	PPM	DRY
G-2 (c)	11505	0.1982	0.1866	2.18	9.54	43.10	PPM	DRY
G-3 (a)	11506	0.204	0.184	1.69	5.87	61.60	PPM	DRY
G-3 (b)	11507	0.2027	0.1952	1.78	6.13	52.16	PPM	DRY
G-3 (c)	11508	0.1971	0.1876	2.24	4.56	50.27	PPM	DRY
G-4 (a)	11525	0.2013	0.1823	1.13	3.37	69.22	PPM	DRY
G-4 (b)	11526	0.202	0.1817	1.27	2.58	68.09	PPM	DRY
G-4 (c)	11527	0.2116	0.1832	0.95	2.87	74.65	PPM	DRY
G-5 (c)	11530	0.2039	0.1818	1.35	3.57	67.78	PPM	DRY
G-6 (a)	11522	0.2059	0.1825	1.35	3.09	70.43	PPM	DRY
G-7 (1)	11531	0.2108	0.1829	1.66	3.84	63.62	PPM	DRY
G-8 (c)	11496	0.1964	0.1856	1.80	6.63	57.75	PPM	DRY

Appendix C contd.

Station No.	Lab Sample No.	SRMID	Ag ppm	Hg ppm	As ppm	Cd ppm	Cu ppm	Ni ppm	Pb ppm	Se ppm
B-2 (b)	SPIKE		0.95	0.46	11.42	4.76	23.79	190.29	11.89	42.82
B-2 (b)	11533-SPK		1.724	0.601	15.69	5.00	60.05	179.65	40.4	45.06
C-2 (c)	11537-DUP		3.945	0.683	14.66	0.99	102.71	27.75	133.6	1.38
G-2 (a)	11503-DUP		0.978	0.274	9.53	0.72	63.39	17.17	194.0	0.71
G-3 (c)	SPIKE		0.99	0.55	13.71	4.93	24.64	197.14	12.32	44.36
G-3 (c)	11508-SPK		3.459	1.440	38.59	7.10	162.27	208.57	198.1	46.02
G-4 (b)	11526-DUP		3.935	0.932	22.10	1.42	153.74	33.29	170.4	1.57
G-7 (1)	SPIKE		0.98	0.54	13.48	4.89	24.43	195.41	12.21	43.97
G-7 (1)	11531-SPK		5.548	1.059	26.15	6.54	153.69	193.82	116.7	44.91
		SRMID								
		SRMLEV	NRCC MESS2	0.18	0.092	20.7	0.24	39.3	49.3	21.9
		MESS2-C	NRCC MESS2	0.200	0.084	22.05	0.26	37.70	46.51	22.3
		MESS2-D	NRCC MESS2	0.189	0.088	20.97	0.26	38.02	45.27	22.6
		MESS2-E	NRCC MESS2	0.200	0.083	21.36	0.27	38.94	53.68	22.3
		MESS2-H	NRCC MESS2	0.159	0.081	16.99	0.20	29.29	41.62	20.2
		MESS2-I	NRCC MESS2	0.162	0.082	19.06	0.23	39.15	42.73	22.2
		BLANK-A		0.014	0.002	0.04	0.00	0.01	0.05	0.0
		BLANK-B		0.011	0.002	0.04	0.00	0.01	0.04	0.0
		BLANK-F		0.010	0.002	0.02	0.00	0.02	0.05	0.0
		BLANK-G		0.009	0.002	0.01	0.00	0.02	0.06	0.0
		BLK-SPK-F		0.233	0.097	2.64	1.10	9.51	39.36	2.5
		BLK-SPK-J		0.214	0.100	2.73	1.08	9.22	35.01	2.7
		BLK-SPK-D								
		CAL-SPK-G		0.230		2.74	1.03	9.61	39.34	2.2
		CAL-SPK-K		0.197		2.21	1.08	9.30	37.79	2.1

Appendix C contd.										
		SRMID	Sn	Zn	Cr	Mn	Al	Fe	AVS	SEM-Cu
Station No.	Lab Sample No.		ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
B-2 (b)	SPIKE		4.76	237.87	47.57	475.74			370.5	1.53
B-2 (b)	11533-SPK		9.30	278.82	82.5	797.2	48,360	18,101	443.6	6.98
C-2 (c)	11537-DUP		16.64	183.61	158.9	531.8	77,753	40,057	1025.0	1.83
G-2 (a)	11503-DUP		7.19	147.28	73.4	363.1	58,879	24,428	515.8	9.86
G-3 (c)	SPIKE		4.93	246.43	49.29	492.85			594.5	3.42
G-3 (c)	11508-SPK		14.43	505.97	168.0	902.5	72,953	35,672	2163.7	3.31
G-4 (b)	11526-DUP		11.88	242.10	166.8	592.6	82,001	46,160	1912.5	2.30
G-7 (1)	SPIKE		4.89	244.26	48.85	488.52			920.5	4.82
G-7 (1)	11531-SPK		16.18	449.43	183.6	1027.0	77,306	42,323	2966.2	6.16
		SRMID								
		SRMLEV	0.72	2.27	172	106	365	85,735	43,500	
		MESS2-C	0.75	2.58	168.21	103.6	363.1	95,753	45,420	
		MESS2-D	0.70	2.54	170.48	99.9	350.2	94,949	43,502	
		MESS2-E	0.74	2.51	170.02	101.7	356.5	93,266	43,324	
		MESS2-H	0.64	1.90	146.71	87.2	292.2	81,287	37,358	
		MESS2-I	0.75	2.52	167.63	100.0	356.5	88,502	42,972	
		BLANK-A	0.00	0.00	0.73	0.0	0.0	0	0	0.9
		BLANK-B	0.00	0.00	0.73	0.0	0.0	0	0	2.8
		BLANK-F	0.03	0.02	0.65	0.0	0.0	0	5	6.1
		BLANK-G	0.00	0.01	0.53	0.0	0.0	0	0	
		BLK-SPK-F	8.33	1.01	48.32	8.7	92.8	0	5	2473.6
		BLK-SPK-J	8.58	1.21	47.24	8.2	93.2	0	13	2314.5
		BLK-SPK-D								
		CAL-SPK-G	9.43	1.26	49.09	9.3	94.4	0	0	2812.3
		CAL-SPK-K	8.95	1.50	47.89	9.8	97.2	0	0	2841.0

Appendix C contd.										
		SRMID	SEM-Cd	SEM-Ni	SEM-Pb	SEM-Zn	SEM-Hg	AVS	SEM-Cu	SEM-Cd
Station No.	Lab Sample No.		ppm	ppm	ppm	ppm	ppm	mM	mM	mM
B-2 (b)	SPIKE		0.53	18.02	11.93	26.50	0.0010	11.556	0.024	0.005
B-2 (b)	11533-SPK		0.83	17.98	24.79	37.73	0.0019	13.835	0.110	0.007
C-2 (c)	11537-DUP		0.54	4.16	85.75	76.60	0.0016	31.968	0.029	0.005
G-2 (a)	11503-DUP		0.29	2.70	64.45	83.42	0.0012	16.086	0.155	0.003
G-3 (c)	SPIKE		1.03	34.92	23.11	51.35	0.0018	18.542	0.054	0.009
G-3 (c)	11508-SPK		3.23	42.78	81.71	207.69	0.0022	67.480	0.052	0.029
G-4 (b)	11526-DUP		0.78	4.59	100.35	112.56	0.0010	59.645	0.036	0.007
G-7 (1)	SPIKE		1.69	57.48	38.04	84.52	0.0030	28.709	0.076	0.015
G-7 (1)	11531-SPK		3.37	67.58	93.28	176.99	0.0031	92.508	0.097	0.030
		SRMID								
		SRMLEV								
		MESS2-C								
		MESS2-D								
		MESS2-E								
		MESS2-H								
		MESS2-I								
		BLANK-A	0.00	0.00	0.25	0.15	0.00	0.0016		
		BLANK-B	0.00	0.00	0.24	0.00	0.00	0.0013		
		BLANK-F	0.00	0.00	0.21	0.05	0.00	0.0012		
		BLANK-G								
		BLK-SPK-F	60.60	8.24	193.69	118.65	266.70	0.4971		
		BLK-SPK-J	61.19	8.37	191.50	117.26	269.32	0.4821		
		BLK-SPK-D	60.60	8.40	186.20	116.55	266.70	0.4696		
		CAL-SPK-G	48.20	6.32	154.83	90.76	203.22	0.3315		
		CAL-SPK-K	48.52	6.34	155.40	84.52	206.80	0.3642		

Appendix C contd.								
		SEM-Ni	SEM-Pb	SEM-Zn	SEM-Hg	Total SEM	SEM/AVS	ADGDAT
Station No.	Lab Sample No.	mM	mM	mM	mM	Metals (mM)	ratio	Acid Dig. Date
B-2 (b)	SPIKE	0.307	0.058	0.405	0.000	0.799	0.07	09/18/85
B-2 (b)	11533-SPK	0.306	0.120	0.577	0.000	1.120	0.08	09/18/85
C-2 (c)	11537-DUP	0.071	0.414	1.172	0.000	1.690	0.05	09/18/85
G-2 (a)	11503-DUP	0.046	0.311	1.276	0.000	1.791	0.11	09/18/85
G-3 (c)	SPIKE	0.595	0.112	0.786	0.000	1.555	0.08	09/18/85
G-3 (c)	11508-SPK	0.729	0.394	3.177	0.000	4.381	0.06	09/18/85
G-4 (b)	11526-DUP	0.078	0.484	1.722	0.000	2.328	0.04	09/18/85
G-7 (1)	SPIKE	0.979	0.184	1.293	0.000	2.546	0.09	09/18/85
G-7 (1)	11531-SPK	1.151	0.450	2.708	0.000	4.436	0.05	09/18/85

Appendix C contd.									
	SAMPTYPE	ADWT	HGDWT	AVS	SEMWT	PCTMOIS	UNITTM	UNITQUAL	
Station No.	Sample Type	Acid Dig. DW	Hg Dig. DW	AVS DW	SEM Wet Wt	% Moisture	Conc. Units	Wet/Dry Wt.	
B-2 (b)	SPKLEV						PPM	DRY	
B-2 (b)	MS	0.2102	0.2189	3.24	9.43	32.81	PPM	DRY	
C-2 (c)	LDUP	0.211	0.2056	1.27	2.81	66.96	PPM	DRY	
G-2 (a)	LDUP	0.1937	0.1856	2.65	3.07	42.81	PPM	DRY	
G-3 (c)	SPKLEV						PPM	DRY	
G-3 (c)	MS	0.2029	0.1824	2.38	4.87	48.37	PPM	DRY	
G-4 (b)	LDUP	0.2147	0.1853	1.36	2.61	68.09	PPM	DRY	
G-7 (1)	SPKLEV						PPM	DRY	
G-7 (1)	MS	0.2047	0.1854	1.54	2.96	63.57	PPM	DRY	
	09/18/85	SRM	0.1958	0.1884				PPM	DRY
	09/18/85	SRM	0.2001	0.1949				PPM	DRY
	09/18/85	SRM	0.1921	0.2005				PPM	DRY
	09/18/85	SRM	0.1965	0.216				PPM	DRY
	09/18/85	SRM	0.2098	0.2138				PPM	DRY
	09/18/85	BLANK	1	1				TOTMCG	DRY
	09/18/85	BLANK	1	1				TOTMCG	DRY
	09/18/85	BLANK	1	1				TOTMCG	DRY
	09/18/85	BLANK	1	1				TOTMCG	DRY
	09/18/85	BS	1	1				TOTMCG	DRY
	09/18/85	BS	1	1				TOTMCG	DRY
		BS						TOTMCG	DRY
	09/18/85	BS	1					TOTMCG	DRY
	09/18/85	BS	1					TOTMCG	DRY

Appendix D. Concentrations of polynuclear aromatic hydrocarbons (PAHs, ng/g).					
Station No.	UNITS:	BIPHENYL	NAPHTHALENE	C1-NAPHTHALENES	C2-NAPHTHALENES
MDL	MDL,ng/g	2.4	0.5		
A (1)	ng/g	9.17	64.75	57.69	51.49
B-1 (a)	ng/g	5.13	25.77	19.99	17.59
B-2(a)	ng/g	8.12	38.17	39.85	34.95
B-2 (b)	ng/g	4.39	20.27	21.81	21.30
B-3 (b)	ng/g	10.02	48.01	45.28	37.67
C-1 (a)	ng/g	73.27	122.74	299.49	445.10
C-1 (c)	ng/g	18.70	103.97	122.27	91.93
C-2 (a)	ng/g	12.36	63.89	67.82	49.72
C-2 (b)	ng/g	19.35	87.17	83.68	63.33
C-2 (c)	ng/g	17.52	103.64	93.30	80.01
D-1 (b)	ng/g	6.76	36.73	29.76	25.35
D-1 (c)	ng/g	12.64	85.75	81.62	66.36
D-2 (a)	ng/g	36.35	193.62	242.71	174.68
D-2 (b)	ng/g	33.11	208.98	283.98	200.21
E (1)	ng/g	16.16	99.14	78.93	63.73
G-1 (a)	ng/g	63.73	492.92	226.53	162.69
G-1 (c)	ng/g	28.61	261.85	155.36	133.19
G-2 (a)	ng/g	72.26	407.58	205.99	152.00
G-2 (b)	ng/g	84.46	596.85	233.64	163.74
G-2 (c)	ng/g	78.88	626.43	427.21	686.79
G-3 (a)	ng/g	122.19	2969.80	694.13	459.49
G-3 (b)	ng/g	87.03	1758.94	386.51	267.98
G-3 (c)	ng/g	185.36	3023.09	620.22	425.68
G-4 (a)	ng/g	42.76	542.60	193.37	143.81
G-4 (b)	ng/g	49.19	615.41	228.27	156.51
G-4 (c)	ng/g	85.03	755.33	478.32	254.99
G-5 (c)	ng/g	52.53	429.69	187.81	134.14
G-6 (a)	ng/g	31.90	129.22	85.24	68.83
G-7 (1)	ng/g	27.81	218.50	122.11	114.16
G-8 (c)	ng/g	69.52	1372.37	650.25	534.43
Duplicate	D-2 (b)	ng/g	31.21	191.71	330.09
Duplicate	G-7 (1)	ng/g	30.31	208.40	124.05
Proc Blank	-900	ng/g	0.47	0.29	0.49
Proc Blank	-900	ng/g	0.85	0.53	0.73
Spiked Matrix	D-2b, STA 1	% Recov	117.46	76.93	
Proc Blank	-900	ng/g	0.36	0.49	0.68
Proc Blank	-900	ng/g	0.35	0.66	0.73
Spiked Matrix	G-7, STA 1	% Recov	124.16	108.11	
SRM 1941	-850	ng/g	97.40	1104.79	533.51
SRM 1941	-850	ng/g	93.61	975.98	481.89
Lab Ref Oil	-700	ng/g	207.50	534.70	2206.46
Lab Ref Oil	-700	ng/g	204.71	548.35	2137.57

Appendix D contd.					
Station No.	UNITS:	C3-NAPHTHALENES	C4-NAPHTHALENES	1-METHYLNAPH	2-METHYLNAPH
MDL	MDL,ng/g			0.8	0.8
A (1)	ng/g	70.10	42.76	18.12	39.57
B-1 (a)	ng/g	14.36	7.36	6.73	13.26
B-2(a)	ng/g	32.08	19.02	15.68	24.18
B-2 (b)	ng/g	21.70	11.06	9.48	12.33
B-3 (b)	ng/g	30.48	22.21	14.42	30.85
C-1 (a)	ng/g	412.69	239.79	125.39	174.10
C-1 (c)	ng/g	75.76	53.39	39.36	82.91
C-2 (a)	ng/g	41.00	28.10	21.37	46.44
C-2 (b)	ng/g	57.01	44.32	28.00	55.68
C-2 (c)	ng/g	68.76	50.17	29.71	63.59
D-1 (b)	ng/g	25.58	19.83	9.77	19.99
D-1 (c)	ng/g	77.11	52.61	29.31	52.30
D-2 (a)	ng/g	122.52	68.46	75.48	167.23
D-2 (b)	ng/g	129.07	90.60	78.82	205.17
E (1)	ng/g	56.14	39.48	24.69	54.24
G-1 (a)	ng/g	161.83	125.52	81.18	145.36
G-1 (c)	ng/g	183.24	257.84	53.30	102.06
G-2 (a)	ng/g	119.34	72.23	82.50	123.49
G-2 (b)	ng/g	147.55	92.79	75.64	158.01
G-2 (c)	ng/g	1591.19	1840.57	158.60	268.61
G-3 (a)	ng/g	514.46	417.06	250.00	444.13
G-3 (b)	ng/g	252.05	215.25	146.15	240.36
G-3 (c)	ng/g	493.10	666.89	208.40	411.82
G-4 (a)	ng/g	146.06	110.14	66.49	126.88
G-4 (b)	ng/g	145.20	105.24	76.96	151.31
G-4 (c)	ng/g	198.66	176.61	177.82	300.50
G-5 (c)	ng/g	154.08	112.20	61.05	126.76
G-6 (a)	ng/g	89.55	76.14	29.19	56.05
G-7 (1)	ng/g	161.81	125.50	41.20	80.90
G-8 (c)	ng/g	574.76	497.95	236.18	414.06
Duplicate	D-2 (b)	213.17	136.33	87.08	98.38
Duplicate	G-7 (1)	107.94	155.25	173.98	41.80
Proc Blank	-900	0.00	0.00	0.00	0.24
Proc Blank	-900	0.00	0.00	0.00	0.25
Spiked Matrix	D-2b, STA 1				73.19
Proc Blank	-900	0.00	0.00	0.00	0.43
Proc Blank	-900	0.00	0.00	0.00	0.24
Spiked Matrix	G-7, STA 1				86.50
SRM 1941	-850	342.79	265.40	180.08	192.82
SRM 1941	-850	274.89	216.61	137.03	172.19
Lab Ref Oil	-700	1925.83	1426.75	871.39	1020.04
Lab Ref Oil	-700	1877.37	1400.36	805.04	961.97

Appendix D contd.					
Station No.	UNITS:	2,6-DIMETHNAPH	2,3,5-TRIMETHNAPH	ACENAPHTHENE	ACENAPHTHYLENE
MDL	MDL,ng/g	2.4	2.4	3.7	4.5
A (1)	ng/g	22.48	15.07	15.69	44.07
B-1 (a)	ng/g	9.62	4.70	6.40	10.72
B-2(a)	ng/g	19.25	10.65	30.29	16.59
B-2 (b)	ng/g	9.47	6.76	26.90	7.48
B-3 (b)	ng/g	20.26	10.26	14.27	23.91
C-1 (a)	ng/g	200.33	109.67	42.10	19.54
C-1 (c)	ng/g	45.93	21.97	40.64	27.50
C-2 (a)	ng/g	24.67	10.95	20.39	29.51
C-2 (b)	ng/g	37.73	18.24	35.67	58.53
C-2 (c)	ng/g	42.38	20.83	40.86	43.82
D-1 (b)	ng/g	14.55	8.63	9.43	4.98
D-1 (c)	ng/g	29.15	18.57	37.11	12.26
D-2 (a)	ng/g	116.49	43.28	54.96	47.80
D-2 (b)	ng/g	109.89	34.31	33.89	53.04
E (1)	ng/g	37.73	15.46	27.38	41.95
G-1 (a)	ng/g	104.71	57.98	123.83	263.46
G-1 (c)	ng/g	59.19	45.30	69.34	98.29
G-2 (a)	ng/g	79.73	32.25	743.74	83.66
G-2 (b)	ng/g	130.50	63.31	105.32	327.54
G-2 (c)	ng/g	174.42	543.99	536.55	392.37
G-3 (a)	ng/g	179.78	125.94	160.29	449.31
G-3 (b)	ng/g	128.74	78.20	141.17	344.78
G-3 (c)	ng/g	238.99	162.60	110.04	489.81
G-4 (a)	ng/g	70.13	39.38	73.62	195.12
G-4 (b)	ng/g	81.86	43.08	88.78	176.25
G-4 (c)	ng/g	144.99	58.94	244.07	223.33
G-5 (c)	ng/g	72.01	41.41	58.32	102.11
G-6 (a)	ng/g	47.46	32.31	46.74	79.59
G-7 (1)	ng/g	65.39	51.82	95.74	87.84
G-8 (c)	ng/g	124.10	83.19	257.87	126.84
Duplicate	D-2 (b)	231.73	102.70	34.48	36.72
Duplicate	G-7 (1)	82.25	58.06	49.99	84.19
Proc Blank	-900	0.25	0.42	0.38	0.36
Proc Blank	-900	0.48	0.32	0.33	0.29
Spiked Matrix	D-2b, STA 1	94.00	127.43	80.00	95.53
Proc Blank	-900	0.26	0.20	0.16	0.18
Proc Blank	-900	0.49	0.13	0.42	0.12
Spiked Matrix	G-7, STA 1	101.84	91.61	75.40	89.24
SRM 1941	-850	340.69	150.53	60.85	37.58
SRM 1941	-850	309.71	151.61	67.20	35.29
Lab Ref Oil	-700	1186.42	798.13	409.70	15.79
Lab Ref Oil	-700	1175.60	812.27	421.79	18.90

Appendix D contd.					
Station No.	UNITS:	FLUORENE	C1-FLUORENES	C2-FLUORENES	C3-FLUORENES
MDL	MDL,ng/g	2.5			
A (1)	ng/g	28.68	42.52	52.79	43.49
B-1 (a)	ng/g	10.53	9.38	11.38	12.55
B-2(a)	ng/g	34.33	23.62	24.86	22.32
B-2 (b)	ng/g	54.83	19.13	22.38	14.85
B-3 (b)	ng/g	21.71	37.02	28.91	32.00
C-1 (a)	ng/g	63.66	99.29	124.31	87.96
C-1 (c)	ng/g	55.04	35.73	50.40	52.05
C-2 (a)	ng/g	35.38	27.34	31.88	30.17
C-2 (b)	ng/g	54.80	37.30	57.13	47.45
C-2 (c)	ng/g	55.09	40.07	54.82	57.02
D-1 (b)	ng/g	16.89	15.08	18.53	19.28
D-1 (c)	ng/g	48.85	37.40	47.63	49.90
D-2 (a)	ng/g	73.89	60.62	76.56	68.80
D-2 (b)	ng/g	55.79	41.60	70.90	90.26
E (1)	ng/g	36.16	29.02	52.95	92.82
G-1 (a)	ng/g	160.05	129.78	208.03	253.76
G-1 (c)	ng/g	74.91	77.49	271.36	362.39
G-2 (a)	ng/g	627.67	156.34	109.00	152.49
G-2 (b)	ng/g	152.06	143.89	215.82	292.72
G-2 (c)	ng/g	357.37	641.84	1242.87	1099.16
G-3 (a)	ng/g	221.71	253.62	423.21	442.56
G-3 (b)	ng/g	191.74	183.89	277.26	291.55
G-3 (c)	ng/g	192.05	409.00	868.75	1001.23
G-4 (a)	ng/g	108.68	85.98	138.83	229.63
G-4 (b)	ng/g	132.89	89.79	132.18	157.93
G-4 (c)	ng/g	314.39	181.30	194.35	199.94
G-5 (c)	ng/g	86.74	82.62	117.15	132.69
G-6 (a)	ng/g	74.78	53.03	100.31	162.67
G-7 (1)	ng/g	137.96	79.12	276.27	485.42
G-8 (c)	ng/g	275.57	193.39	215.74	186.80
Duplicate	D-2 (b)	46.30	52.81	53.10	79.67
Duplicate	G-7 (1)	88.59	141.96	68.55	156.10
Proc Blank	-900	0.21	0.23	0.00	0.00
Proc Blank	-900	0.08	0.32	0.00	0.00
Spiked Matrix	D-2b, STA 1	99.67	87.75		
Proc Blank	-900	0.08	0.17	0.00	0.00
Proc Blank	-900	0.08	0.31	0.00	0.00
Spiked Matrix	G-7, STA 1	95.99	108.71		
SRM 1941	-850	84.98	71.96	80.18	200.06
SRM 1941	-850	80.65	68.09	69.89	156.16
Lab Ref Oil	-700	1.63	99.19	240.17	360.89
Lab Ref Oil	-700	1.88	87.34	201.46	322.97

Appendix D contd.					
Station No.	UNITS:	PHENANTHRENE	C1-PHENANTHR	C4-PHENANTHR	1-METHYLPHEN
MDL	MDL,ng/g	0.5			0.6
A (1)	ng/g	294.08	308.78	53.33	79.30
B-1 (a)	ng/g	94.33	55.41	19.54	12.32
B-2(a)	ng/g	252.52	134.80	28.51	28.54
B-2 (b)	ng/g	321.60	114.05	18.07	26.79
B-3 (b)	ng/g	216.34	134.41	45.87	30.02
C-1 (a)	ng/g	436.12	312.92	80.02	73.95
C-1 (c)	ng/g	601.44	327.07	92.99	165.44
C-2 (a)	ng/g	322.74	172.28	44.81	36.62
C-2 (b)	ng/g	506.90	263.52	78.96	67.43
C-2 (c)	ng/g	528.85	297.23	94.36	63.09
D-1 (b)	ng/g	157.94	950.89	36.70	24.92
D-1 (c)	ng/g	440.98	229.94	71.09	61.96
D-2 (a)	ng/g	537.06	331.32	79.10	105.32
D-2 (b)	ng/g	464.54	296.78	132.61	66.46
E (1)	ng/g	259.09	160.70	70.18	31.22
G-1 (a)	ng/g	890.31	700.16	528.54	177.52
G-1 (c)	ng/g	386.94	330.78	325.70	97.24
G-2 (a)	ng/g	3269.45	791.03	143.14	189.54
G-2 (b)	ng/g	494.23	423.67	354.61	73.87
G-2 (c)	ng/g	1148.07	1653.71	1019.71	499.93
G-3 (a)	ng/g	995.35	1106.93	424.80	262.68
G-3 (b)	ng/g	699.23	675.42	256.53	153.92
G-3 (c)	ng/g	529.14	920.20	520.70	227.42
G-4 (a)	ng/g	646.86	447.25	225.88	111.39
G-4 (b)	ng/g	934.50	542.55	266.66	114.30
G-4 (c)	ng/g	2105.07	1184.23	534.17	227.33
G-5 (c)	ng/g	616.94	437.91	294.69	113.29
G-6 (a)	ng/g	521.76	311.66	122.93	73.92
G-7 (1)	ng/g	839.59	523.34	465.14	95.79
G-8 (c)	ng/g	2386.86	1547.75	640.84	301.28
Duplicate	D-2 (b)	85.42	441.84	211.71	152.62
Duplicate	G-7 (1)	192.48	683.44	329.83	200.80
Proc Blank	-900	0.00	0.50	0.00	0.00
Proc Blank	-900	0.00	0.44	0.00	0.00
Spiked Matrix	D-2b, STA 1		124.98		
Proc Blank	-900	0.00	0.37	0.00	0.00
Proc Blank	-900	0.00	0.38	0.00	0.00
Spiked Matrix	G-7, STA 1		113.19		
SRM 1941	-850	256.68	568.48	414.98	285.66
SRM 1941	-850	241.90	480.10	326.22	221.22
Lab Ref Oil	-700	318.12	270.25	488.49	262.26
Lab Ref Oil	-700	308.53	234.44	465.90	198.31

Appendix D contd.					
Station No.	UNITS:	ANTHRACENE	FLUORANTHENE	PYRENE	I123cdPYRENE
MDL	MDL,ng/g	4.1	0.4	3.1	1.6
A (1)	ng/g	113.17	485.73	497.42	186.74
B-1 (a)	ng/g	25.13	161.47	143.42	65.19
B-2(a)	ng/g	59.60	331.73	288.39	105.71
B-2 (b)	ng/g	99.79	291.20	225.39	78.48
B-3 (b)	ng/g	63.90	393.84	350.21	168.75
C-1 (a)	ng/g	99.28	586.68	570.12	1.28
C-1 (c)	ng/g	163.54	858.92	785.15	6.79
C-2 (a)	ng/g	78.64	473.41	427.72	167.92
C-2 (b)	ng/g	134.61	816.54	702.91	287.58
C-2 (c)	ng/g	131.20	837.03	751.31	295.06
D-1 (b)	ng/g	2.28	131.98	286.17	1.61
D-1 (c)	ng/g	93.85	597.17	576.21	15.29
D-2 (a)	ng/g	128.39	761.25	721.38	330.20
D-2 (b)	ng/g	147.34	696.07	692.31	347.31
E (1)	ng/g	87.12	421.74	384.86	154.31
G-1 (a)	ng/g	610.19	1683.05	1662.17	411.79
G-1 (c)	ng/g	261.39	1041.95	923.06	375.31
G-2 (a)	ng/g	845.03	3938.03	2869.33	459.63
G-2 (b)	ng/g	341.54	832.56	1310.77	445.98
G-2 (c)	ng/g	1347.06	3666.39	3660.67	771.99
G-3 (a)	ng/g	794.84	1716.71	1688.41	540.33
G-3 (b)	ng/g	593.09	1246.97	1217.00	623.04
G-3 (c)	ng/g	617.43	1266.63	1438.95	309.77
G-4 (a)	ng/g	339.60	1345.92	1236.86	654.30
G-4 (b)	ng/g	465.22	1453.19	1422.32	657.64
G-4 (c)	ng/g	1003.83	3189.16	2936.39	1079.64
G-5 (c)	ng/g	254.29	1164.44	1167.32	269.94
G-6 (a)	ng/g	167.21	930.12	817.57	330.22
G-7 (1)	ng/g	398.69	1476.57	1383.47	339.31
G-8 (c)	ng/g	948.30	2281.12	2388.90	20.80
Duplicate	D-2 (b)	67.38	125.71	709.48	724.43
Duplicate	G-7 (1)	88.43	379.08	1234.66	1006.75
Proc Blank	-900	0.15	0.14	0.12	0.11
Proc Blank	-900	0.12	0.09	0.10	0.16
Spiked Matrix	D-2b, STA 1	78.69	93.72	80.59	94.09
Proc Blank	-900	0.07	0.12	0.17	0.10
Proc Blank	-900	0.22	0.11	0.10	0.14
Spiked Matrix	G-7, STA 1	97.64	97.81	99.57	102.92
SRM 1941	-850	97.66	203.73	1129.92	978.15
SRM 1941	-850	75.60	168.23	930.24	800.99
Lab Ref Oil	-700	181.94	2.23	4.35	11.06
Lab Ref Oil	-700	179.46	3.09	5.55	9.74

Appendix D contd.					
Station No.	UNITS:	DIBENZOTHIO	C1-DIBEN	C2-DIBEN	C3-DIBEN
MDL	MDL,ng/g				
A (1)	ng/g	17.23	39.23	62.73	44.88
B-1 (a)	ng/g	5.60	6.61	10.56	10.03
B-2(a)	ng/g	14.19	17.53	20.96	15.93
B-2 (b)	ng/g	15.71	10.95	9.93	17.92
B-3 (b)	ng/g	13.16	17.79	31.05	30.37
C-1 (a)	ng/g	32.87	57.46	86.38	63.30
C-1 (c)	ng/g	34.01	37.81	61.11	54.19
C-2 (a)	ng/g	17.14	19.68	22.08	22.48
C-2 (b)	ng/g	26.56	30.99	46.25	45.79
C-2 (c)	ng/g	31.44	36.94	58.91	53.31
D-1 (b)	ng/g	9.43	13.28	20.33	20.93
D-1 (c)	ng/g	22.86	25.85	40.71	41.11
D-2 (a)	ng/g	35.87	49.92	62.53	49.51
D-2 (b)	ng/g	29.01	39.78	68.28	69.31
E (1)	ng/g	15.47	23.51	49.82	58.91
G-1 (a)	ng/g	63.10	82.46	172.84	197.63
G-1 (c)	ng/g	35.73	63.98	227.66	253.74
G-2 (a)	ng/g	170.29	70.56	76.41	74.42
G-2 (b)	ng/g	37.45	51.47	97.04	133.30
G-2 (c)	ng/g	194.73	461.72	921.13	762.57
G-3 (a)	ng/g	107.43	186.61	414.17	441.74
G-3 (b)	ng/g	68.84	109.71	243.49	263.45
G-3 (c)	ng/g	97.83	231.28	744.97	653.43
G-4 (a)	ng/g	45.29	57.49	118.29	151.88
G-4 (b)	ng/g	62.82	71.11	130.35	158.59
G-4 (c)	ng/g	107.74	112.83	185.13	234.39
G-5 (c)	ng/g	46.28	68.20	111.55	150.00
G-6 (a)	ng/g	31.70	87.68	83.53	86.83
G-7 (1)	ng/g	53.35	66.43	169.65	333.09
G-8 (c)	ng/g	181.19	186.39	259.88	196.59
Duplicate	D-2 (b)	346.67	29.34	45.31	75.52
Duplicate	G-7 (1)	444.70	40.69	48.85	107.35
Proc Blank	-900	0.05	0.28	0.00	0.00
Proc Blank	-900	0.05	0.12	0.00	0.00
Spiked Matrix	D-2b, STA 1	81.31	73.02		
Proc Blank	-900	0.06	0.13	0.00	0.00
Proc Blank	-900	0.06	0.07	0.00	0.00
Spiked Matrix	G-7, STA 1	106.79	86.92		
SRM 1941	-850	517.72	55.44	82.26	170.38
SRM 1941	-850	393.55	46.94	67.93	128.94
Lab Ref Oil	-700	0.99	173.76	346.65	463.11
Lab Ref Oil	-700	0.95	155.45	296.73	405.41

Appendix D contd.					
Station No.	UNITS:	C1-FLUORANPYR	BENZANTHRACENE	CHRYSENE	C1-CHRYSENES
MDL	MDL,ng/g		1.4	0.5	
A (1)	ng/g	393.69	348.84	382.93	329.95
B-1 (a)	ng/g	81.83	91.43	96.38	75.01
B-2(a)	ng/g	171.62	202.67	179.98	162.44
B-2 (b)	ng/g	129.85	181.39	191.10	124.50
B-3 (b)	ng/g	200.45	231.56	241.08	1699.58
C-1 (a)	ng/g	290.15	396.21	488.79	340.02
C-1 (c)	ng/g	403.96	510.62	591.22	457.09
C-2 (a)	ng/g	231.08	274.46	251.17	207.34
C-2 (b)	ng/g	370.07	444.18	504.15	343.87
C-2 (c)	ng/g	407.95	473.67	429.62	369.60
D-1 (b)	ng/g	78.49	5.83	32.87	29.51
D-1 (c)	ng/g	262.39	112.46	338.19	312.68
D-2 (a)	ng/g	416.85	546.11	524.13	439.89
D-2 (b)	ng/g	405.31	504.78	607.54	482.05
E (1)	ng/g	232.59	269.90	255.48	215.99
G-1 (a)	ng/g	1305.41	1102.91	1341.82	1015.44
G-1 (c)	ng/g	687.26	886.13	812.01	730.87
G-2 (a)	ng/g	1278.22	1477.88	1175.94	675.29
G-2 (b)	ng/g	944.80	873.18	926.61	888.54
G-2 (c)	ng/g	2979.91	2193.75	1666.20	1702.93
G-3 (a)	ng/g	1916.85	1459.01	1346.38	1169.89
G-3 (b)	ng/g	1192.77	1512.18	1102.10	1220.36
G-3 (c)	ng/g	2017.60	970.16	855.24	943.79
G-4 (a)	ng/g	867.34	1218.03	1484.38	1087.55
G-4 (b)	ng/g	1011.66	1162.37	1462.95	1071.40
G-4 (c)	ng/g	2257.90	3176.55	3338.20	2052.75
G-5 (c)	ng/g	765.27	830.36	731.42	733.31
G-6 (a)	ng/g	475.29	547.43	666.96	444.38
G-7 (1)	ng/g	947.66	979.16	1036.60	801.24
G-8 (c)	ng/g	2083.14	2217.23	2204.94	1630.26
Duplicate	D-2 (b)	87.37	434.48	504.60	555.66
Duplicate	G-7 (1)	121.09	701.81	991.55	910.02
Proc Blank	-900	0.00	0.00	0.04	0.20
Proc Blank	-900	0.00	0.00	0.07	0.10
Spiked Matrix	D-2b, STA 1			110.24	89.27
Proc Blank	-900	0.00	0.00	0.07	0.09
Proc Blank	-900	0.00	0.00	0.11	0.10
Spiked Matrix	G-7, STA 1			70.38	87.16
SRM 1941	-850	186.98	535.63	586.23	650.36
SRM 1941	-850	148.64	428.39	574.67	483.28
Lab Ref Oil	-700	391.64	78.59	5.65	56.38
Lab Ref Oil	-700	337.81	70.24	56.22	69.56

Appendix D contd.						
Station No.	UNITS:	C2-CHRYSENES	C3-CHRYSENES	C4-CHRYSENES	BENFLUORAN	BENFLUORAN
MDL	MDL,ng/g				1.8	1.9
A (1)	ng/g	149.73	10.36	48.03	237.60	265.52
B-1 (a)	ng/g	39.82	4.93	16.97	81.13	90.66
B-2(a)	ng/g	78.09	8.48	27.05	124.01	138.59
B-2 (b)	ng/g	59.15	4.12	21.14	100.31	112.09
B-3 (b)	ng/g	99.31	11.93	37.76	204.63	228.67
C-1 (a)	ng/g	163.49	8.83	8.39	68.35	76.38
C-1 (c)	ng/g	239.47	21.96	45.18	178.44	199.41
C-2 (a)	ng/g	106.31	16.46	36.79	202.73	226.55
C-2 (b)	ng/g	174.39	58.53	66.41	360.84	403.24
C-2 (c)	ng/g	197.79	18.89	65.67	374.87	418.92
D-1 (b)	ng/g	0.00	0.00	0.00	2.57	2.53
D-1 (c)	ng/g	207.51	0.00	0.00	23.58	34.50
D-2 (a)	ng/g	228.88	17.02	74.96	383.51	428.57
D-2 (b)	ng/g	246.22	19.29	96.63	413.94	462.56
E (1)	ng/g	123.63	10.83	51.60	193.60	216.34
G-1 (a)	ng/g	573.83	38.30	129.53	643.98	719.63
G-1 (c)	ng/g	417.89	41.62	112.65	553.94	619.03
G-2 (a)	ng/g	265.47	23.83	112.65	767.16	857.30
G-2 (b)	ng/g	523.21	72.34	137.74	637.06	670.87
G-2 (c)	ng/g	820.18	84.11	224.52	1053.69	1177.49
G-3 (a)	ng/g	505.64	30.17	178.71	804.93	899.50
G-3 (b)	ng/g	526.94	39.81	190.47	866.62	968.44
G-3 (c)	ng/g	424.51	25.28	124.79	473.25	528.86
G-4 (a)	ng/g	571.78	44.43	218.81	977.23	1092.05
G-4 (b)	ng/g	544.11	41.76	191.58	935.65	1045.58
G-4 (c)	ng/g	1124.19	119.72	324.91	1613.27	1802.93
G-5 (c)	ng/g	425.53	46.19	98.30	491.04	548.74
G-6 (a)	ng/g	225.00	29.99	99.52	448.81	501.54
G-7 (1)	ng/g	514.35	72.07	108.10	578.91	645.62
G-8 (c)	ng/g	832.41	33.16	63.01	366.86	409.97
Duplicate	D-2 (b)	484.90	267.18	17.49	82.73	394.57
Duplicate	G-7 (1)	686.13	328.88	37.10	106.91	659.07
Proc Blank	-900	0.00	0.00	0.00	0.00	0.02
Proc Blank	-900	0.00	0.00	0.00	0.00	0.06
Spiked Matrix	D-2b, STA 1					79.48
Proc Blank	-900	0.00	0.00	0.00	0.00	0.05
Proc Blank	-900	0.00	0.00	0.00	0.00	0.05
Spiked Matrix	G-7, STA 1					107.28
SRM 1941	-850	548.51	340.55	30.27	157.49	860.19
SRM 1941	-850	458.44	269.46	26.13	109.58	701.71
Lab Ref Oil	-700	102.52	116.78	23.09	20.01	2.88
Lab Ref Oil	-700	94.76	101.20	24.41	26.48	2.71

Appendix D contd.							
Station No.	UNITS:	BENZOPYRENE	BENZOPYRENE	PERYLENE	BENZOPERYLENE	DIBENZOANTHRACENE	TOTAL PAH
MDL	MDL,ng/g	1.2	2.4	3.3	0.3	2.6	
A (1)	ng/g	353.48	203.94	62.37	190.99	42.15	6210.92
B-1 (a)	ng/g	101.77	67.22	21.14	66.34	12.15	1718.00
B-2(a)	ng/g	210.68	131.01	48.70	120.71	22.26	3476.56
B-2 (b)	ng/g	147.97	91.65	27.55	78.06	18.27	2902.77
B-3 (b)	ng/g	257.17	171.53	51.81	169.31	33.83	5781.25
C-1 (a)	ng/g	139.61	314.73	85.90	96.38	1.52	7952.01
C-1 (c)	ng/g	514.96	338.61	93.81	327.33	19.15	8467.93
C-2 (a)	ng/g	285.74	183.85	63.48	175.70	35.05	4830.15
C-2 (b)	ng/g	407.10	299.86	92.18	285.29	60.73	7664.28
C-2 (c)	ng/g	486.59	310.17	89.78	294.21	64.19	8449.59
D-1 (b)	ng/g	1.36	1.19	4.53	1.18	1.33	2237.77
D-1 (c)	ng/g	21.79	113.22	11.73	17.91	8.65	4717.10
D-2 (a)	ng/g	547.39	337.64	93.42	349.75	67.74	9701.54
D-2 (b)	ng/g	555.15	355.30	108.28	373.38	72.93	9921.95
E (1)	ng/g	251.76	174.56	60.44	156.59	33.21	5034.47
G-1 (a)	ng/g	1153.85	712.31	131.79	650.70	68.15	20775.25
G-1 (c)	ng/g	681.37	450.58	77.29	376.22	78.50	13992.72
G-2 (a)	ng/g	909.49	599.34	229.76	442.90	96.00	25622.49
G-2 (b)	ng/g	848.84	519.71	98.66	429.30	102.46	16007.99
G-2 (c)	ng/g	1664.50	964.74	419.50	838.16	172.00	46445.32
G-3 (a)	ng/g	1094.57	629.52	169.20	503.63	121.71	29543.97
G-3 (b)	ng/g	1202.24	709.96	132.78	572.75	150.48	22616.69
G-3 (c)	ng/g	671.86	372.45	109.44	293.77	77.62	27061.51
G-4 (a)	ng/g	1210.63	779.07	150.44	648.15	145.93	18980.01
G-4 (b)	ng/g	1197.55	754.03	189.36	629.54	143.23	19907.37
G-4 (c)	ng/g	2542.71	1696.15	244.69	1276.75	213.13	40004.15
G-5 (c)	ng/g	860.88	554.83	125.05	491.06	69.93	14132.25
G-6 (a)	ng/g	575.50	373.91	112.22	343.34	69.86	10204.16
G-7 (1)	ng/g	828.59	599.50	124.15	443.65	79.58	17031.40
G-8 (c)	ng/g	1150.39	1033.23	246.93	491.39	20.40	31745.82
Duplicate	D-2 (b)	440.93	554.14	345.59	112.83	366.52	10026.89
Duplicate	G-7 (1)	736.51	823.53	552.46	118.07	439.52	14337.68
Proc Blank	-900	0.03	0.09	0.09	0.07	0.05	
Proc Blank	-900	0.07	0.08	0.12	0.12	0.11	
Spiked Matrix	D-2b, STA 1	88.85	77.74	89.41	86.82	89.02	
Proc Blank	-900	0.06	0.15	0.15	0.52	0.03	
Proc Blank	-900	0.05	0.04	0.07	0.10	0.09	
Spiked Matrix	G-7, STA 1	85.48	83.10	72.66	82.55	114.71	
SRM 1941	-850	568.79	610.19	533.64	255.97	523.94	
SRM 1941	-850	464.00	492.19	457.61	253.87	393.97	
Lab Ref Oil	-700	3.22	2.36	9.79	2.45	4.01	
Lab Ref Oil	-700	3.03	1.90	10.36	2.42	4.41	

Appendix E. Concentrations of pesticides and PCB congeners (ng/g).						
Comment	Station No.	LAB SAMPLE #		UNITS	2,4'DDE	4,4'DDE
					o,p'-dde	p,p,'-dde
	A (1)	C11509R		ng/g	<0.28	2.69
	B-1 (a)	C11541P		ng/g	<0.28	1.51
	B-2(a)	C11532P		ng/g	<0.28	2.16
	B-2 (b)	C11533P		ng/g	<0.28	0.87
	B-3 (b)	C11539P		ng/g	0.67	2.69
	C-1 (a)	C11497P		ng/g	<0.28	4.23
	C-1 (c)	C11499P		ng/g	<0.28	4.54
	C-2 (a)	C11535P		ng/g	<0.28	2.85
	C-2 (b)	C11536P		ng/g	<0.28	5.10
	C-2 (c)	C11537P		ng/g	<0.28	6.16
	D-1 (b)	C11489P		ng/g	<0.28	2.58
	D-1 (c)	C11490P		ng/g	<0.28	4.63
	D-2 (a)	C11500P		ng/g	<0.28	2.65
	D-2 (b)	Q6107P		ng/g	<0.28	5.23
	E (1)	C11519P		ng/g	<0.28	3.41
	G-1 (a)	C11515R		ng/g	<0.28	6.00
	G-1 (c)	C11517P		ng/g	<0.28	6.05
	G-2 (a)	C11503P		ng/g	<0.28	2.23
	G-2 (b)	C11504P		ng/g	<0.28	5.01
	G-2 (c)	C11505P		ng/g	<0.28	4.26
	G-3 (a)	C11506P		ng/g	<0.28	5.54
	G-3 (b)	C11507P		ng/g	<0.28	2.24
	G-3 (c)	C11508R		ng/g	<0.28	8.22
	G-4 (a)	C11525P		ng/g	<0.28	5.20
	G-4 (b)	C11526P		ng/g	<0.28	6.29
	G-4 (c)	C11527P		ng/g	<0.28	8.26
	G-5 (c)	C11530P		ng/g	<0.28	5.84
	G-6 (a)	C11522P		ng/g	<0.28	3.72
	G-7 (1)	C11531P		ng/g	<0.28	3.73
	G-8 (c)	C11496P		ng/g	<0.28	9.75
Duplicate	G-7 (a)	Q6111P		ng/g	<0.28	3.47
Proc Blank	Q6108P	Q6108P	NA2SO4	ng/g	<0.28	<0.85
Proc Blank	Q6109P	Q6109P		ng/g	<0.28	<0.85
Matrix Spike	D-2 (b)	Q6110P		ng/g	4.58	8.95
Matrix Spike	D-2 (b)	Q6110P		%	88.00	74.00
Proc Blank	Q6112P	Q6112P	NA2SO4	ng/g	<0.28	<0.85
Proc Blank	Q6113P	Q6113P		ng/g	<0.28	<0.85
	SRM 1941	Q6115P		ng/g	<0.28	8.60
	SRM 1941	Q6116P		ng/g	<0.28	9.85
	SRM 1941	Concentrations		ng/g DRY WT.		9.71 +/- 0.17
MI = Matrix Interference						

Appendix E contd.					
LAB SAMPLE #	2,4'DDD	4,4'DDD	2,4'DDT	4,4'DDT	ALDRIN
	o,p'-ddd	p,p'-ddd	o,p'-ddt	p,p'-ddt	
C11509R	0.60	3.21	0.70	0.68	<0.25
C11541P	0.67	2.41	<0.25	2.48	<0.25
C11532P	0.41	3.65	0.66	1.99	<0.25
C11533P	0.44	1.92	0.37	1.55	<0.25
C11539P	0.56	5.38	1.10	2.91	<0.25
C11497P	0.50	4.61	0.33	0.73	<0.25
C11499P	0.92	6.72	0.36	1.40	<0.25
C11535P	1.80	6.67	1.14	4.73	<0.25
C11536P	1.40	10.84	1.89	5.84	<0.25
C11537P	1.81	12.27	2.60	3.74	<0.25
C11489P	0.28	4.12	0.72	0.29	<0.25
C11490P	0.69	7.99	0.82	1.35	<0.25
C11500P	0.60	3.95	0.23	1.39	<0.25
Q6107P	1.04	8.28	0.79	1.13	<0.25
C11519P	0.54	5.51	0.74	0.80	3.38
C11515R	1.45	12.05	1.24	5.27	<0.25
C11517P	1.78	11.92	2.69	0.69	5.63
C11503P	1.16	5.86	1.03	0.73	8.54
C11504P	1.52	13.12	2.32	1.05	5.06
C11505P	2.35	12.22	<0.25	0.69	7.13
C11506P	2.76	13.29	0.90	1.93	1.49
C11507P	1.01	7.44	0.67	1.19	0.12
C11508R	1.84	12.39	1.10	0.83	2.92
C11525P	1.24	12.38	2.59	4.11	9.26
C11526P	1.51	11.18	1.39	1.52	<0.25
C11527P	2.66	17.49	3.76	6.17	<0.25
C11530P	1.64	13.32	2.02	4.84	<0.25
C11522P	0.84	6.19	1.60	1.19	7.65
C11531P	1.17	8.59	2.53	5.02	0.39
C11496P	<0.13	27.27	1.99	2.53	<0.25
Q6111P	0.94	7.24	2.40	4.56	0.10
Q6108P	<0.13	<0.51	<0.25	<0.24	<0.25
Q6109P	<0.13	<0.51	<0.25	<0.24	<0.25
Q6110P	2.22	12.66	4.03	4.56	4.35
Q6110P	59.00	75.00	70.00	74.00	82.00
Q6112P	<0.13	<0.51	<0.25	<0.24	<0.25
Q6113P	<0.13	<0.51	<0.25	<0.24	<0.25
Q6115P	1.30	9.39	1.86	2.71	7.25
Q6116P	1.17	12.69	<0.25	7.67	0.83
Concentrations		10.3 +/- 0.10		1.11 +/- 0.05	

Appendix E contd.				
LAB SAMPLE #	CIS-CHLORDANE	OXYCHLORDANE	ALPHA-CHLORDANE	TRANS-NONACHLOR
C11509R	<0.66	<0.23	0.61	0.77
C11541P	<0.66	<0.23	0.79	0.95
C11532P	<0.66	<0.23	0.61	0.59
C11533P	<0.66	<0.23	0.21	0.13
C11539P	<0.66	<0.23	1.09	2.03
C11497P	0.99	<0.23	1.35	1.38
C11499P	1.50	0.24	1.42	1.43
C11535P	<0.66	<0.23	1.90	1.49
C11536P	<0.66	<0.23	1.86	1.89
C11537P	<0.66	<0.23	2.80	2.84
C11489P	0.50	<0.23	0.54	0.47
C11490P	1.59	0.44	1.14	1.06
C11500P	0.92	0.13	1.16	0.99
Q6107P	3.43	<0.23	3.14	2.89
C11519P	2.58	0.37	2.32	2.21
C11515R	3.90	<0.23	1.71	1.54
C11517P	1.89	1.89	1.83	0.97
C11503P	0.88	3.37	0.90	0.56
C11504P	2.31	1.69	1.89	1.00
C11505P	0.74	3.29	1.27	0.29
C11506P	2.09	3.68	2.39	1.46
C11507P	1.32	1.96	1.71	0.74
C11508R	4.78	<0.23	1.02	0.68
C11525P	1.62	<0.23	1.85	1.37
C11526P	4.28	<0.23	3.00	2.40
C11527P	3.00	<0.23	4.18	3.98
C11530P	0.35	<0.23	3.05	3.21
C11522P	1.10	<0.23	1.94	1.64
C11531P	0.86	1.55	2.01	1.13
C11496P	5.47	4.30	3.26	2.44
Q6111P	0.93	0.43	1.18	1.04
Q6108P	<0.66	<0.23	<0.23	<0.1
Q6109P	<0.66	<0.23	<0.23	<0.1
Q6110P	7.90	5.83	6.25	5.29
Q6110P	80.00	88.00	59.00	54.00
Q6112P	<0.66	<0.23	<0.23	<0.1
Q6113P	<0.66	<0.23	<0.23	<0.1
Q6115P	<0.66	<0.23	2.07	0.39
Q6116P	<0.66	<0.23	1.62	0.31
Concentrations			2.06 +/- 0.05	0.97 +/- 0.03

Appendix E contd.				
LAB SAMPLE #	DIELDRIN	HEPTACHLOR	HEPTACHLOR-EPOXIDE	HEXACHLOROBENZENE
C11509R	0.13	<0.2	<0.16	0.05
C11541P	<0.16	<0.2	<0.16	<0.37
C11532P	<0.16	<0.2	<0.16	<0.37
C11533P	<0.16	<0.2	<0.16	<0.37
C11539P	<0.16	<0.2	<0.16	0.17
C11497P	<0.16	<0.2	<0.16	0.21
C11499P	0.82	<0.2	<0.16	0.13
C11535P	0.07	<0.2	<0.16	<0.37
C11536P	<0.16	<0.2	<0.16	<0.37
C11537P	0.35	<0.2	<0.16	<0.37
C11489P	0.31	<0.2	<0.16	0.04
C11490P	0.64	<0.2	<0.16	0.12
C11500P	0.65	<0.2	<0.16	0.14
Q6107P	1.78	<0.2	<0.16	0.20
C11519P	1.15	<0.2	<0.16	0.21
C11515R	1.32	<0.2	2.40	0.31
C11517P	3.21	<0.2	<0.16	<0.37
C11503P	1.12	<0.2	<0.16	0.17
C11504P	2.69	<0.2	<0.16	<0.37
C11505P	1.93	<0.2	<0.16	0.26
C11506P	3.08	<0.2	<0.16	0.42
C11507P	1.40	<0.2	<0.16	0.15
C11508R	3.78	<0.2	4.72	0.17
C11525P	2.02	<0.2	1.85	0.35
C11526P	1.81	<0.2	2.33	1.82
C11527P	1.32	<0.2	<0.16	4.68
C11530P	0.96	<0.2	<0.16	0.08
C11522P	1.69	<0.2	<0.16	0.29
C11531P	0.54	<0.2	<0.16	<0.37
C11496P	2.74	<0.2	<0.16	0.48
Q6111P	0.63	<0.2	<0.16	<0.37
Q6108P	<0.16	<0.2	<0.16	<0.37
Q6109P	<0.16	<0.2	<0.16	0.01
Q6110P	5.47	4.78	3.34	6.20
Q6110P	67.00	88.00	71.00	103.00
Q6112P	<0.16	<0.2	<0.16	<0.37
Q6113P	<0.16	<0.2	<0.16	<0.37
Q6115P	2.63	<0.2	<0.16	30.34
Q6116P	2.18	<0.2	<0.16	3.69
Concentrations	0.63 +/- 0.03		0.23 +/- 0.02	

Appendix E contd.					
LAB SAMPLE #	ALPHA-BHC	BETA-BHC	LINDANE (GAMMA-BHC)	DELTA-BHC	CIS-NONACHLOR
C11509R	<0.22	<0.22	<0.22	<0.22	0.55
C11541P	1.02	<0.22	<0.22	3.58	0.82
C11532P	1.76	<0.22	<0.22	2.66	0.84
C11533P	2.47	<0.22	<0.22	2.62	0.15
C11539P	1.79	<0.22	<0.22	<0.22	1.32
C11497P	0.97	<0.22	<0.22	0.80	0.89
C11499P	0.59	<0.22	<0.22	0.36	0.96
C11535P	4.56	<0.22	<0.22	7.31	1.18
C11536P	3.55	<0.22	<0.22	6.67	1.51
C11537P	4.88	<0.22	<0.22	8.57	1.85
C11489P	0.16	<0.22	<0.22	<0.22	0.71
C11490P	0.43	<0.22	<0.22	0.31	0.99
C11500P	0.60	<0.22	<0.22	0.34	0.64
Q6107P	0.71	<0.22	<0.22	0.65	1.64
C11519P	0.65	<0.22	<0.22	0.60	1.04
C11515R	1.27	<0.22	<0.22	<0.22	1.40
C11517P	1.05	<0.22	<0.22	1.70	0.68
C11503P	2.03	<0.22	<0.22	1.48	0.54
C11504P	0.72	<0.22	<0.22	0.59	0.93
C11505P	<0.22	<0.22	<0.22	2.69	0.21
C11506P	2.39	<0.22	<0.22	3.07	1.29
C11507P	1.85	<0.22	<0.22	1.82	1.37
C11508R	1.78	<0.22	<0.22	<0.22	1.17
C11525P	0.77	<0.22	<0.22	0.57	1.77
C11526P	1.42	<0.22	3.90	1.29	1.72
C11527P	11.28	<0.22	<0.22	<0.22	5.19
C11530P	7.56	<0.22	<0.22	<0.22	2.56
C11522P	0.78	<0.22	<0.22	0.56	0.81
C11531P	6.71	<0.22	<0.22	9.35	1.33
C11496P	2.47	<0.22	<0.22	1.89	2.90
Q6111P	4.84	<0.22	<0.22	7.07	1.27
Q6108P	<0.22	<0.22	<0.22	<0.22	<0.1
Q6109P	<0.22	<0.22	<0.22	<0.22	<0.1
Q6110P	3.72	2.77	3.60	3.90	4.63
Q6110P	62.00	58.00	76.00	63.00	63.00
Q6112P	<0.22	<0.22	<0.22	<0.22	<0.1
Q6113P	<0.22	<0.22	<0.22	<0.22	<0.1
Q6115P	<0.22	<0.22	1.27	1.38	1.35
Q6116P	7.31	<0.22	11.32	19.65	<0.1
Concentrations					

Appendix E contd.						
LAB SAMPLE #	ENDRIN	MIREX	PCB#8	PCB#18	PCB#28	PCB#44
			cl-2	cl-3	cl-3	cl-4
C11509R	<0.22	<0.17	<0.08	<0.25	1.48	0.99
C11541P	<0.22	<0.17	<0.08	<0.25	0.98	0.59
C11532P	<0.22	<0.17	<0.08	<0.25	2.68	1.63
C11533P	<0.22	<0.17	<0.08	<0.25	1.06	0.66
C11539P	<0.22	<0.17	1.08	<0.25	1.60	2.14
C11497P	<0.22	<0.17	0.87	0.92	4.06	2.47
C11499P	<0.22	<0.17	0.56	1.00	4.90	2.95
C11535P	<0.22	<0.17	<0.08	<0.25	1.67	2.44
C11536P	<0.22	<0.17	<0.08	<0.25	3.75	3.36
C11537P	<0.22	<0.17	<0.08	<0.25	2.88	4.94
C11489P	<0.22	0.19	0.24	0.31	1.68	1.63
C11490P	<0.22	<0.17	1.64	3.21	10.41	7.89
C11500P	<0.22	<0.17	0.61	0.64	3.18	1.58
Q6107P	<0.22	<0.17	0.50	2.48	8.41	5.92
C11519P	<0.22	<0.17	<0.08	1.01	4.62	3.02
C11515R	2.30	0.60	<0.08	3.57	2.85	3.15
C11517P	<0.22	1.70	<0.08	3.25	4.12	4.15
C11503P	<0.22	0.45	<0.08	6.50	2.30	1.98
C11504P	<0.22	<0.17	<0.08	6.07	9.54	7.61
C11505P	<0.22	1.13	<0.08	6.84	1.33	1.69
C11506P	<0.22	4.10	<0.08	8.62	9.08	7.56
C11507P	<0.22	<0.17	<0.08	4.59	3.89	3.30
C11508R	<0.22	1.53	<0.08	9.41	6.72	8.33
C11525P	<0.22	1.38	<0.08	2.70	4.71	3.95
C11526P	<0.22	0.58	<0.08	5.12	6.63	5.87
C11527P	<0.22	<0.17	3.01	<0.25	8.36	11.60
C11530P	<0.22	<0.17	2.18	<0.25	5.25	6.41
C11522P	<0.22	<0.17	<0.08	0.88	3.70	2.17
C11531P	<0.22	<0.17	1.99	<0.25	2.78	5.72
C11496P	<0.22	1.07	<0.08	9.27	16.65	15.29
Q6111P	<0.22	<0.17	1.20	<0.25	1.68	3.54
Q6108P	<0.22	<0.17	<0.08	<0.25	<0.09	<0.09
Q6109P	<0.22	<0.17	<0.08	<0.25	<0.09	<0.09
Q6110P	5.76	3.67	9.56	9.62	13.56	12.53
Q6110P	111.00	75.00	121.00	113.00	86.00	92.00
Q6112P	<0.22	<0.17	<0.08	<0.25	<0.09	<0.09
Q6113P	<0.22	<0.17	<0.08	<0.25	<0.09	<0.09
Q6115P	<0.22	<0.17	<0.08	5.42	15.37	10.87
Q6116P	<0.22	<0.17	4.29	<0.25	15.52	18.12
Concentrations				9.90 +/- 0.25	16.1 +/- 0.40	

Appendix E contd.				
LAB SAMPLE #	PCB#52	PCB#66	PCB#101	PCB#105 (CL5)
	cl-4	cl-4	cl-5	cl-5
C11509R	1.85	1.91	3.43	1.90
C11541P	0.81	2.06	1.50	2.06
C11532P	2.09	3.83	3.48	2.95
C11533P	0.84	1.75	1.08	1.41
C11539P	1.15	5.25	5.67	3.49
C11497P	6.10	6.87	6.81	7.06
C11499P	5.19	7.53	8.79	8.98
C11535P	2.27	6.40	3.13	4.93
C11536P	4.78	6.37	8.85	6.86
C11537P	5.48	7.44	9.36	8.28
C11489P	3.05	2.94	6.64	6.13
C11490P	11.60	12.16	12.87	10.98
C11500P	5.76	4.38	4.75	5.68
Q6107P	8.85	9.01	11.42	10.09
C11519P	5.66	4.28	6.68	5.44
C11515R	10.11	5.30	13.20	5.71
C11517P	9.95	4.90	12.85	8.73
C11503P	6.54	3.24	6.94	5.87
C11504P	14.02	8.88	17.11	11.86
C11505P	3.91	3.35	4.89	3.52
C11506P	17.11	13.14	23.73	18.37
C11507P	7.33	5.70	11.18	9.43
C11508R	15.65	9.81	23.36	8.98
C11525P	11.25	7.01	17.20	15.75
C11526P	16.03	9.05	21.62	16.18
C11527P	32.07	13.81	44.22	15.74
C11530P	14.24	7.76	17.22	9.02
C11522P	7.01	5.22	6.68	6.19
C11531P	6.66	5.19	7.24	5.13
C11496P	31.36	18.26	48.11	34.16
Q6111P	6.10	3.98	7.75	4.64
Q6108P	<0.09	<0.14	<0.13	<0.1
Q6109P	<0.09	<0.14	<0.13	<0.1
Q6110P	15.07	14.04	15.08	14.57
Q6110P	86.00	78.00	62.00	76.00
Q6112P	<0.09	<0.14	<0.13	<0.1
Q6113P	<0.09	<0.14	<0.13	<0.1
Q6115P	16.13	16.13	18.55	11.25
Q6116P	24.90	18.54	20.32	12.54
Concentrations	10.4 +/- 0.40	22.4 +/- 0.70	22.0 +/- 0.70	5.76 +/- 0.23

Appendix E contd.					
LAB SAMPLE #	PCB#110/77	PCB#118/108/149	PCB#128	PCB#138	PCB#126
	cl4/5	cl5/5/6	cl6	cl6	cl5
C11509R	10.11	5.16	2.55	5.75	1.34
C11541P	8.42	3.35	1.08	3.33	0.00
C11532P	10.45	5.74	1.58	6.76	0.00
C11533P	8.86	2.19	0.30	1.52	0.00
C11539P	12.28	7.42	0.94	9.67	0.00
C11497P	15.97	11.08	2.83	14.58	0.00
C11499P	18.53	12.99	3.31	16.50	0.00
C11535P	19.09	6.37	1.90	7.26	0.00
C11536P	20.60	11.44	3.70	13.39	0.00
C11537P	22.69	12.37	4.89	14.23	0.00
C11489P	10.99	8.44	1.99	10.74	0.00
C11490P	20.93	17.15	3.39	15.35	0.00
C11500P	12.70	8.11	2.18	9.46	0.00
Q6107P	22.16	15.53	3.68	17.81	0.00
C11519P	13.14	8.68	1.81	7.80	0.00
C11515R	40.14	13.91	7.61	18.83	0.00
C11517P	21.54	12.57	2.89	20.45	0.00
C11503P	19.96	8.63	1.96	9.84	0.00
C11504P	25.53	16.85	3.72	19.77	0.00
C11505P	16.15	6.58	<0.13	6.61	0.00
C11506P	41.16	26.34	5.41	33.70	0.00
C11507P	22.98	12.69	2.60	14.56	0.00
C11508R	64.89	23.13	16.90	25.73	8.27
C11525P	32.44	21.73	5.35	22.22	0.00
C11526P	35.34	21.17	4.94	27.25	0.00
C11527P	42.73	35.11	10.65	52.42	0.00
C11530P	24.50	16.53	6.15	23.31	0.00
C11522P	18.33	8.70	2.29	8.97	0.00
C11531P	21.46	7.22	<0.13	10.76	2.14
C11496P	59.70	46.36	12.79	54.50	0.00
Q6111P	17.90	8.35	<0.13	13.07	0.00
Q6108P	0.00	<0.12	<0.13	<0.18	0.00
Q6109P	0.00	<0.12	<0.13	<0.18	0.00
Q6110P	26.98	19.67	8.78	20.95	7.45
Q6110P	73.00	68.00	76.00	51.00	113.00
Q6112P	0.00	<0.12	<0.13	<0.18	0.00
Q6113P	0.00	<0.12	<0.13	<0.18	0.00
Q6115P	38.92	19.29	3.80	21.44	0.00
Q6116P	46.72	18.27	4.58	19.42	0.00
Concentrations		15.2 +/- 0.70		24.9 +/- 1.80	

Appendix E contd.						
LAB SAMPLE #	PCB#153	PCB#170	PCB#180	PCB#187/	PCB#195	PCB#206
	cl6	cl7	cl7	cl7/7/6	cl8	cl 9
C11509R	6.48	3.40	3.63	1.55	0.43	0.43
C11541P	2.43	2.53	1.88	0.62	<0.25	0.56
C11532P	6.02	3.90	2.94	1.25	0.35	0.31
C11533P	1.61	3.07	0.93	0.33	<0.25	<0.09
C11539P	8.73	5.03	5.85	2.22	0.78	0.54
C11497P	10.10	2.18	6.61	3.43	1.21	1.43
C11499P	14.50	9.25	13.92	7.41	2.20	1.75
C11535P	6.44	6.98	8.25	2.15	<0.25	<0.09
C11536P	12.55	7.71	8.98	2.81	1.37	1.06
C11537P	13.83	9.57	9.97	2.89	1.02	0.76
C11489P	7.11	MI	3.81	2.11	0.31	<0.09
C11490P	11.99	3.42	6.29	3.52	1.06	1.21
C11500P	7.23	2.26	5.43	2.61	1.31	1.81
Q6107P	13.90	4.29	8.03	4.77	1.37	1.37
C11519P	7.71	MI	4.80	4.48	0.63	0.56
C11515R	19.99	12.71	9.77	4.76	1.29	1.28
C11517P	9.92	MI	5.33	6.97	0.64	2.17
C11503P	8.43	MI	5.72	7.35	0.75	1.17
C11504P	13.93	MI	6.93	6.96	0.85	3.27
C11505P	4.38	MI	3.21	6.16	0.53	2.13
C11506P	25.94	MI	17.88	8.24	1.98	6.15
C11507P	11.36	MI	7.36	4.13	0.50	<0.09
C11508R	25.53	MI	9.53	3.77	1.30	1.91
C11525P	23.18	MI	18.08	15.37	2.06	4.23
C11526P	22.64	5.90	14.40	7.17	1.94	3.15
C11527P	55.62	22.48	24.20	14.63	4.39	5.22
C11530P	22.78	12.82	10.57	5.60	1.74	1.32
C11522P	8.79	MI	8.79	7.52	0.76	0.60
C11531P	9.57	<0.81	5.97	2.22	0.32	0.68
C11496P	39.71	9.82	19.48	11.04	2.91	5.75
Q6111P	11.99	<0.81	8.43	4.39	0.73	1.64
Q6108P	<0.12	<0.81	<0.16	<0.14	<0.25	<0.09
Q6109P	<0.12	<0.81	<0.16	<0.14	<0.25	<0.09
Q6110P	18.39	16.66	10.72	9.41	5.83	6.82
Q6110P	43.00	MI	59.00	69.00	71.00	81.00
Q6112P	<0.12	4.38	<0.16	<0.14	<0.25	<0.09
Q6113P	<0.12	1.60	<0.16	<0.14	<0.25	<0.09
Q6115P	17.99	<0.81	13.24	13.41	1.68	2.15
Q6116P	22.38	MI	14.01	10.42	2.48	2.23
Concentrations	22.0 +/- 1.4	7.29 +/- 0.26	3 +/- 0.30	5 +/- 0.60	1 +/- 0.10	1 +/- 0.15

Appendix E contd.					
LAB SAMPLE #	PCB#209	TOTAL BHC'S	TOTAL CHLORDANES	TOTAL DDT'S	TOTAL PCB'S
	cl 10				
C11509R	0.69	0.00	1.93	7.88	93.37
C11541P	0.31	4.60	2.55	7.07	54.96
C11532P	0.82	4.42	2.04	8.86	103.67
C11533P	0.42	5.09	0.49	5.16	39.79
C11539P	1.23	1.79	4.44	13.30	139.70
C11497P	2.78	1.77	4.62	10.39	202.35
C11499P	2.02	0.95	5.55	13.93	273.20
C11535P	1.39	11.87	4.57	17.18	137.08
C11536P	2.79	10.22	5.26	25.07	220.70
C11537P	2.74	13.45	7.49	26.57	244.52
C11489P	0.28	0.16	2.23	7.99	127.92
C11490P	1.32	0.74	5.23	15.48	298.86
C11500P	3.39	0.93	3.84	8.82	156.34
Q6107P	2.00	1.36	11.10	16.47	285.61
C11519P	0.21	0.60	4.13	5.33	73.74
C11515R	1.42	1.27	10.95	26.02	298.84
C11517P	0.43	2.75	7.25	23.13	241.57
C11503P	0.25	3.51	6.26	11.00	171.90
C11504P	0.29	1.31	7.81	23.01	325.54
C11505P	1.24	2.69	5.80	19.52	125.64
C11506P	0.41	5.46	10.92	24.42	491.98
C11507P	<0.78	3.67	7.10	12.54	218.12
C11508R	4.14	1.78	12.36	24.37	427.51
C11525P	1.11	1.34	8.46	25.52	387.42
C11526P	2.41	6.61	13.73	21.90	421.46
C11527P	4.70	11.28	16.34	38.34	786.73
C11530P	2.73	7.56	9.17	27.66	364.90
C11522P	0.83	1.34	5.49	13.54	175.41
C11531P	1.31	16.06	6.88	21.04	161.54
C11496P	3.72	4.36	18.37	41.55	832.61
Q6111P	3.13	11.91	4.86	18.61	178.75
Q6108P	<0.78	0.00	0.00	0.00	2.19
Q6109P	<0.78	0.00	0.00	0.00	2.19
Q6110P	6.70	13.99	38.01	37.02	501.39
Q6110P	73.00				79.00
Q6112P	<0.78	0.00	0.00	0.00	11.78
Q6113P	<0.78	0.00	0.00	0.00	5.69
Q6115P	5.53	2.65	3.81	23.86	423.18
Q6116P	6.09	38.28	1.93	31.39	471.11
Concentrations	8.36 +/- 0.21				

Appendix F. Concentrations of butyltins (Sn ng/g).							
File No.	Station No.	Tetrabutyltin ng Sn/g	Tributyltin ng Sn/g	Dibutyltin ng Sn/g	Monobutyltin ng Sn/g	Total butyl tins, ng/g	%TPT Rec.
11509	A (1)	0.5	13.9	4.1	1.1	19.6	68.2%
11541	B-1 (a)	0.1	5.5	3.1	0.8	9.6	71.6%
11532	B-2 (a)	0.3	19.1	3.4	1.4	24.2	74.1%
11533	B-2 (b)	0.1	9.2	1.7	0.9	11.9	66.4%
11539	B-3 (b)	0.1	23.0	8.8	2.9	34.8	63.3%
11497	C-1 (a)	0.1	37.7	11.1	3.4	52.3	53.3%
11499	C-1 (c)	0.2	33.1	11.8	3.0	48.0	58.6%
11535	C-2 (a)	0.1	16.7	5.9	2.9	25.5	61.9%
11536	C-2 (b)	0.0	26.0	7.9	2.4	36.3	60.3%
11537	C-2 (c)	0.1	19.2	7.4	3.4	30.1	56.8%
11489	D-1 (b)	0.1	13.1	0.0	0.0	13.2	61.3%
11490	D-1 (c)	0.0	27.2	6.7	0.5	34.3	57.4%
11500	D-2 (a)	0.2	27.0	12.6	3.5	43.3	60.4%
11501	D-2 (b)	0.3	50.2	23.1	7.1	80.7	66.3%
11519	E (1)	0.3	65.0	13.9	3.0	82.3	60.1%
11515	G-1 (a)	0.3	126.9	25.0	3.8	155.9	63.7%
11517	G-1 (c)	0.3	122.4	14.3	1.7	138.7	62.0%
11503	G-2 (a)	0.3	49.0	13.0	3.1	65.4	67.5%
11504	G-2 (b)	0.4	24.2	7.2	1.3	33.1	56.0%
11505	G-2 (c)	0.1	243.6	21.8	1.7	267.3	66.7%
11506	G-3 (a)	0.0	128.4	31.7	9.0	169.1	63.1%
11507	G-3 (b)	0.0	66.1	22.5	9.6	98.2	66.4%
11508	G-3 (c)	0.6	20.1	6.9	2.9	30.6	63.5%
11525	G-4 (a)	0.5	74.0	20.3	6.9	101.7	66.8%
11526	G-4 (b)	0.4	68.8	20.3	8.1	97.6	58.1%
11527	G-4 (c)	0.3	98.9	32.7	8.9	140.8	65.1%
11530	G-5 (c)	0.5	114.2	18.8	6.9	140.4	68.7%
11522	G-6 (a)	0.5	24.5	7.4	4.0	36.5	56.8%
11531	G-7 (1)	0.5	86.7	16.8	4.2	108.1	57.1%
11496	G-8 (c)	0.4	92.1	24.7	7.2	124.4	61.4%
1959	B-2 (b) (dup)	0.1	9.0	1.6	0.8	11.6	60.2%
1827	G-2 (b) (dup)	0.4	24.8	7.5	1.4	34.1	81.6%
1864	G-3 (c) (dup)	0.6	20.6	6.9	3.2	31.3	56.5%
			Reference Material				
1828	PACS-1	9.9	1272.8	1136.0	298.5		78.1%
1865	PACS-1	7.1	1299.0	1069.4	248.7		61.3%
1960	PACS-1	10.5	1309.7	1117.9	277.3		59.7%
Certified Conc. (micrograms Sn/g		* * *	1.27_.22	1.16_.18	0.28_.17		* * *
			Spike Blanks				
1830	Spike Blank	108.2%	107.7%	100.2%	68.4%		61.0%
1867	Spike Blank	104.3%	109.5%	97.7%	83.1%		67.7%
1962	Spike Blank	101.6%	107.0%	100.0%	77.3%		49.7%
			Blanks				
1829	Blank	0.0	0.0	0.0	0.0		66.4%
1866	Blank	0.0	0.0	0.0	0.1		60.3%
1961	Blank	0.0	0.0	0.1	0.1		57.2%


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