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Final Report

SEDIMENT QUALITY OF THE NY/NJ HARBOR SYSTEM

**An Investigation under the Regional Environmental Monitoring and Assessment Program
(R-EMAP)**

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FOREWORD

The Environmental Monitoring and Assessment Program (EMAP) is a long-term, interagency environmental monitoring and research program overseen by EPA's Office of Research and Development (ORD). Its goal is to provide the public, scientists and Congress with information that can be used to evaluate the overall condition of the Nation's ecological resources. The program is designed to operate on a broad geographic scale.

EMAP has entered into partnerships with EPA Regional offices, other Federal agencies and States to assess environmental quality at smaller, regional or local scales. These Regional EMAP (REMAP) projects adapt the EMAP approach to assess specific areas more precisely than can be accomplished by existing data or EMAP alone. These projects also provide the opportunity to apply EMAP's statistical design and ecological indicators at localized scales. The REMAP project for the New York-New Jersey Harbor complex is one of ten REMAP efforts in the country (U.S.EPA, 1993a).

The study results presented in this report are based on a REMAP proposal which was jointly developed by U.S.EPA-Region 2 and NY-NJ Harbor Estuary Program (HEP) participants. The study was jointly funded by U.S. EPA/ORD/EMAP, the NY-NJ HEP and U.S.EPA-Region 2.

EXECUTIVE SUMMARY

A number of studies have documented high concentrations of contaminants in sediments of the New York-New Jersey Harbor and Bight Apex. Based on these findings, U.S.EPA-Region 2 and the New York-New Jersey Harbor Estuary Program (NY-NJ HEP) identified the development of a sediment management and monitoring strategy as an integral part of the Comprehensive Conservation and Management Plan (CCMP) for the Harbor and Bight Apex. An unbiased baseline of sediment quality was needed to measure progress of management actions. Existing data were insufficient for developing this baseline.

To provide the baseline data needed to evaluate progress, 168 sites in the Harbor and Bight Apex were sampled in the summers of 1993 and 1994, using a stratified random design. Fourteen sampling sites were allocated in each year to each of six sub-basins (Newark Bay, Lower Harbor, Upper Harbor, Jamaica Bay, western Long Island Sound, and the Bight Apex). Surficial sediment contaminant concentrations, two sediment toxicity tests (*Ampelisca abdita* and Microtox™), and benthic macrofaunal community structure were measured at each site.

Contamination was widespread, with most of the Harbor samples (102 of 112) having at least one chemical exceeding an ERL (Effects Range-Low) concentration, a threshold at which biological effects are possible, and 50% of the Harbor exceeding at least one ERM (Effects Range-Median) concentration, a threshold above which biological effects are more likely. A toxicological response was also observed for 45% of the Harbor. Newark Bay was the most contaminated sub-basin, with 92% of its area exceeding an ERM concentration and 49% of its area showing a toxicological response. In contrast, only 7% of the area in the Bight Apex exceeded ERM concentrations and toxicity was only observed at one Bight Apex location, which was located near an area of historical dredged material disposal.

Contamination was distributed across chemical classes. At least one pesticide, one metal and total PCBs were present at concentrations above ERM for one-third of the Harbor area. The ERL for Total PCB was exceeded at 87% of the Harbor. Mercury and chlordane were the only individual chemicals for which more than 25% of the area in the Harbor exceeded an ERM concentration. Twenty-six individual chemicals had mean concentrations for the entire Harbor that exceeded their ERL concentrations. Mercury, DDT and total PCBs were the only chemicals for which average concentrations exceeded ERM values.

The condition of benthic communities was strongly associated with chemical contamination. At the 66% of the Harbor area where impacted benthic communities were observed, there also was a toxicological response and/or at least one chemical exceeding its ERM concentration. In contrast, only 14% of the Harbor area without a toxicological response and without a chemical exceeding ERM concentration had impacted benthic macroinvertebrates.

The sampling design and methods used in this study were compatible with those of EPA's Environmental Monitoring and Assessment Program-Estuaries (EMAP-E), allowing unbiased comparison of conditions in the NY-NJ Harbor with those in the entire mid-Atlantic region. Based on comparisons with EMAP-E data collected from 1990 through 1993 from the Virginian Province (coastal area from Cape Cod to, and including Chesapeake Bay), the NY-NJ Harbor was found to have higher average sediment concentrations for 58 of the 59 chemicals measured in this study. NY-NJ Harbor sediments are responsible for more than 90% of the spatial extent of exceedances of the total PCBs ERM and 69% of the mercury ERM exceedances in the Virginian Province, even though the Harbor constitutes only 4% of the area in the Province.

An index of benthic quality specific to the Harbor was developed as a tool to evaluate the health of benthic macroinvertebrates. This Benthic Index of Biotic Integrity (B-IBI) was similar to the IBIs developed for freshwater biota. It was developed for four different salinity and grain-size habitat combinations. Five measures were ultimately used in the index; number of taxa, abundance, biomass, abundance of pollution-indicative taxa and abundance of pollution-sensitive taxa. Overall, the B-IBI was able to distinguish correctly 93% of the stressed sites from reference sites.

Sediment quality in the Harbor has undoubtedly improved due to actions taken as a result of recent environmental legislation and improved stewardship. Further major improvements cannot be expected immediately, and will probably be more subtle than improvements to date. The Harbor bottom will continue to integrate loadings of contaminants, organic materials and sediments from the watersheds and airsheds surrounding it. The most obvious "next steps" are to estimate how rapidly sediment quality and associated biological health improve under current watershed protection and pollution prevention activities. Some of these steps are included in the NY-NJ HEP CCMP. Other efforts are being undertaken as a subsequent REMAP investigation.

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DEDICATION

This report is dedicated to the memory of Dr. Barbara Metzger, Director of the Environmental Services Division, until her untimely death on February 14, 1996. This report strives to represent her dedication to protection of the environment and her conviction that the U.S.EPA use sound scientific practices to achieve that goal.

TABLE OF CONTENTS

	Page
FOREWORD	iii
EXECUTIVE SUMMARY	iv
ACKNOWLEDGMENTS	vi
DEDICATION	vii
1.0 INTRODUCTION	1-1
1.1 BACKGROUND	1-1
1.2 OBJECTIVES	1-3
1.3 RELATIONSHIP TO THE CCMP	1-4
1.4 ORGANIZATION OF THE REPORT	1-4
2.0 METHODS	2-1
2.1 DESIGNATION OF STUDY AREA	2-1
2.2 STUDY DESIGN	2-1
2.3 SAMPLING PROCEDURES	2-3
2.3.1 Water Column	2-3
2.3.2 Sediment	2-4
2.3.3 Benthos	2-4
2.4 PHYSICAL/CHEMICAL/BACTERIOLOGICAL LABORATORY METHODS	2-4
2.4.1 Major and Trace Elements	2-7
2.4.2 Organic Compounds	2-7
2.4.3 Sediment Physical Parameters	2-8

2.4.4	Bacteriological Analysis	2-9
2.5	TOXICITY METHODS	2-9
2.5.1	Amphipod Sediment Toxicity Tests	2-9
2.5.2	Microtox™ Assays	2-10
2.6	BENTHIC MACROINVERTEBRATE ASSEMBLAGES	2-10
2.7	DATA ANALYSIS	2-11
2.7.1	Chemical Data	2-11
2.7.2	Toxicity Data	2-11
2.7.3	Benthic Macroinvertebrate Data	2-11
2.7.4	Condition Estimates	2-13
	2.7.4.1 Mean Condition	2-13
	2.7.4.2 Mass Estimates	2-15
	2.7.4.3 Percent of Area Estimates	2-16
2.8	SELECTION OF THRESHOLD VALUES	2-17
2.8.1	Physical Data Thresholds	2-17
2.8.2	Chemical Data Thresholds	2-17
2.8.3	Sediment Toxicity Thresholds	2-18
2.8.4	Benthic Index Thresholds	2-18
3.0	PHYSICAL PARAMETERS	3-1
3.1	BACKGROUND	3-1
3.2	CHARACTERIZATION OF THE HARBOR	3-1

3.2.1	Depth	3-1
3.2.2	Percent Silt-Clay	3-2
3.2.3	Total Organic Carbon (TOC)	3-2
3.2.4	Water Column Profile	3-2
3.3	CHARACTERIZATION OF WESTERN LONG ISLAND SOUND AND THE BIGHT APEX	3-5
3.3.1	Depth	3-5
3.3.2	Percent Silt-Clay	3-5
3.3.3	Total Organic Carbon (TOC)	3-5
3.3.4	Water Column Profile	3-6
3.4	COMPARISON TO PREVIOUS STUDIES	3-6
4.0	SEDIMENT CHEMISTRY	4-1
4.1	BACKGROUND	4-1
4.2	CHARACTERIZATION OF THE HARBOR	4-3
4.2.1	Mean Condition	4-3
4.2.2	Areal Extent	4-3
4.2.3	Dioxins and Furans	4-6
4.3	CHARACTERIZATION OF WESTERN LONG ISLAND SOUND AND THE BIGHT APEX	4-16
4.3.1	Mean Condition	4-16
4.3.2	Areal Extent	4-16
4.4	ALTERNATIVE THRESHOLDS	4-16
4.4.1	Proposed Sediment Quality Criteria	4-17

4.4.2	Acid Volatile Sulfides	4-17
4.4.3	Aluminum-Normalization	4-20
4.5	RELATIONSHIP BETWEEN CHEMISTRY AND GRAIN SIZE	4-22
4.6	COMPARISON TO PREVIOUS STUDIES	4-22
4.7	COMPARISON TO A LARGER GEOGRAPHIC AREA	4-24
5.0	SEDIMENT TOXICITY	5-1
5.1	BACKGROUND	5-1
5.2	CHARACTERIZATION OF THE HARBOR	5-1
5.2.1	Mean Condition	5-1
5.2.2	Areal Extent	5-2
5.3	CHARACTERIZATION OF WESTERN LONG ISLAND SOUND AND THE BIGHT APEX	5-6
5.3.1	Mean Condition	5-6
5.3.2	Areal Extent	5-6
5.4	RELATIONSHIP BETWEEN TOXICITY AND GRAIN SIZE	5-8
5.5	COMPARISON TO PREVIOUS STUDIES	5-8
6.0	BENTHIC MACROINVERTEBRATES	6-1
6.1	BACKGROUND	6-1
6.2	CHARACTERIZATION OF THE HARBOR	6-2
6.2.1	Diversity and Taxonomic Composition	6-2
6.2.2	Abundance and Biomass	6-5
6.2.3	Benthic Index	6-6

6.3	CHARACTERIZATION OF WESTERN LONG ISLAND SOUND AND THE BIGHT APEX	6-9
6.3.1	Diversity and Taxonomic Composition	6-9
6.3.2	Abundance and Biomass	6-9
6.3.3	Benthic Index	6-9
6.4	COMPARISON TO PREVIOUS STUDIES	6-9
7.0	ASSOCIATIONS	7-1
7.1	BACKGROUND	7-1
7.2	ASSOCIATION BETWEEN CHEMISTRY AND BENTHIC CONDITION	7-1
7.3	ASSOCIATION BETWEEN CHEMISTRY AND TOXICITY	7-4
7.4	ASSOCIATION AMONG CHEMISTRY, TOXICITY AND BENTHIC COMMUNITY STRUCTURE	7-4
8.0	DISCUSSION	8-1
9.0	LITERATURE CITED	9-1

APPENDICES

A	Sampling station maps
B	Analytical detection limits
C	Development of the Benthic Index of Biotic Integrity (B-IBI)
D	Aluminum-normalization procedure
E	Tables: E-1) Area-weighted mean concentrations for all sediment contaminants E-2) Percent of area exceeding ERM values for all sediment contaminants
F	Dioxin bioaccumulation calculation

- G Area-weighted mean abundances of benthic macroinvertebrate species
- H *Clostridium perfringens* results
- I Benthic Index values for individual stations

LIST OF FIGURES

2-1	Map of the six study sub-basins	2-2
3-1	Percent of area distribution of substrate type (as % silt-clay)	3-3
3-2	Percent of area distribution of total organic carbon levels (as % TOC)	3-4
4-1	Percent of area with any chemical or chemicals within groups exceeding an ERL or ERM in the Harbor	4-4
4-2	Percent of area greater than ERL and ERM values for individual metals in the Harbor	4-5
4-3	Percent of area greater than ERL and ERM values for individual or classes of organics in the Harbor	4-7
4-4	Percent of area exceeding the mercury ERL and ERM	4-8
4-5	Percent of area exceeding the chlordane ERL and ERM	4-9
4-6	Distribution of mercury concentrations by station	4-10
4-7	Distribution of total PCB concentrations by station	4-11
4-8	Distribution of total PAH concentrations by station	4-12
4-9	Total area (km ²) above the mercury and total PCB ERMs	4-13
4-10	Total mass (kg) of mercury and total PCB in surficial sediments of the Harbor	4-14
4-11	Comparison of percent of area in the Harbor exceeding a proposed Sediment Quality Criterion or an ERM value	4-18
4-12	Comparison of percent of area with SEM in excess of AVS (SEM-AVS>0) and percent of area with any metal greater than ERM	4-19

4-13	Relationship between substrate type (sand# 40% silt-clay, mud \$ 40% silt-clay) and percent of area in the Harbor with at least one chemical greater than ERM	4-23
4-14	Contribution of the NY/NJ Harbor to percent of area in the Virginian Province with ERM exceedances	4-29
5-1	Percent of area exhibiting <i>Ampelisca abdita</i> toxicity	5-3
5-2	Distribution of stations with <i>Ampelisca abdita</i> toxicity	5-4
5-3	Percent of area toxic in the Microtox™ assay	5-5
5-4	Distribution of stations toxic to Microtox™ luminescence	5-6
5-5	Relationship between substrate type (sand # 40% silt-clay, mud \$ 40% silt-clay) and percent of area in the Harbor with toxicity to <i>A. abdita</i> , Microtox™ or <i>A. abdita</i> and/or Microtox™	5-9
6-1	Numbers of benthic macrofaunal species, by major taxon	6-4
6-2	Percent of area with impacted benthos (B-IBI<3)	6-7
6-3	Distribution of stations by Benthic Index of Biotic Integrity (B-IBI) values	6-8
7-1	Association between benthos and percent of area with one or more contaminants greater than an ERM	7-2
7-2	Association between <i>Ampelisca abdita</i> toxicity and percent of area with one or more contaminants greater than an ERM value	7-5
7-3	Association between sediment toxicity (<i>A. abdita</i> or Microtox™), benthic community structure (using the B-IBI) and sediment chemistry (as one or more contaminants greater than an ERM value)	7-7
7-4	Percent of area considered degraded because of impacted benthos, sediment toxicity and sediment chemistry concentrations	7-8

LIST OF TABLES

2-1	Sub-basin areas and percent of study areas	2-1
-----	--	-----

2-2	Summary of physical/chemical analytical methods	2-5
2-3	Analytical measurements for sediment samples	2-6
2-4	Individual benthic macroinvertebrate measures assessed	2-12
2-5	B-IBI habitat categories	2-12
3-1	Area-weighted means of depth and sediment physical parameters	3-1
3-2	Area-weighted means of water column physical parameters	3-5
4-1	ERL and ERM concentrations for sediment trace metals and organic compounds	4-2
4-2	Mean concentrations of 2,3,7,8-TCDD in sediments of three sub-basins	4-15
4-3	Environmental concentrations associated with TCDD risk to aquatic life and associated wildlife	4-15
4-4	Percent of area with anthropogenically enriched levels of metals	4-21
4-5	Comparison of mean sediment contaminant concentrations between the Virginian Province and the NY-NJ Harbor	4-29
5-1	Mean % survival for <i>Ampelisca abdita</i> and mean % Microtox™ bioluminescence inhibition	5-2
5-2	Percent of area toxic in the <i>A. abdita</i> and Microtox™ assays	5-6
6-1	Species richness (total number of species)	6-2
6-2	Means of benthic variables	6-3
6-3	Pollution-sensitive and pollution-indicative taxa	6-5
6-4	Percent of area within B-IBI categories	6-4
7-1	Individual chemicals associated with impacted benthos	7-3
7-2	Individual chemicals associated with sediment toxicity (<i>Ampelisca abdita</i>)	7-6
8-1	Relative ranking of sub-basins by % of area	8-1

8-2	Association between Harbor means of benthic metrics and number of chemicals > ERM	8-2
8-3	Percent of Harbor area which exceeded selected thresholds	8-3

1.0 INTRODUCTION

1.1 BACKGROUND

The New York-New Jersey Harbor system is an important economic, recreational, and aesthetic resource supporting many kinds of habitat and species. Among the many important species of fish and shellfish in this estuarine and coastal system are striped bass, white perch, tomcod, and blue crabs in the estuarine portion; and sea bass, bluefish, menhaden, herring, sturgeon, shad, hake, winter flounder, lobster, clams and oysters in the marine portion. Historically, the Harbor supported several large commercial and recreational fisheries. Currently, there remain some isolated, small-scale commercial fisheries (e.g., clams, crabs, menhaden) and a large recreational fishery (MacKenzie, 1992). Since the Estuary is on the Atlantic flyway, it is also an important resting and feeding area for migrating birds. Many birds, both migratory and regional, utilize the Harbor environs for feeding and raising young. Birds commonly found in the region include herons, egrets, ducks, plovers, sandpipers, gulls and geese. Bald eagles and peregrine falcons, both federally-listed endangered species, are less common inhabitants.

The land uses above and surrounding the New York-New Jersey Harbor Estuary make the Harbor particularly susceptible to toxic contamination. For more than a century, it has been the recipient of pollutants generated by the human activities that exist around it. The Harbor is surrounded by a population of more than 20 million people and concentrated refining and manufacturing industries. It is also one of the most heavily utilized shipping ports on the east coast. Sources of toxicants found in the Harbor include municipal and industrial discharges, atmospheric inputs, non-point source runoff, hazardous waste sites, landfills, combined sewer overflows and accidental spills. Additionally, Harbor sediments are contaminant reservoirs which can function as secondary sources. Since the Bight Apex and Long Island Sound receive Harbor outflow, both are affected by Harbor contaminants. One dedesignated (dredged material) and several inactive (acid waste, cellar dirt and sewage sludge) dumpsites also are located in the Bight Apex.

Contaminated sediments pose a substantial threat to Harbor resources and are a management challenge. Dredging and disposal of contaminated sediments are controversial issues. Adverse changes in the biota of the system have been documented, and many of these changes have been linked to toxic contamination (Mayer, 1982; U.S.EPA, 1990a). The consequences of contamination in the NY-NJ Harbor are extensive. The states around the Harbor advise restricted consumption of striped bass, bluefish and blue claw crabs from large portions of the Estuary because the levels of PCB and/or dioxins exceed guidelines for human consumption. Areas that were once productive shellfish beds no longer exist or have reduced populations that are restricted for harvesting (MacKenzie, 1992). Bioaccumulation of contaminants in fish, shellfish and crustacea has been documented (Belton et al., 1985; NYSDEC, 1988; Hauge et al., 1990; Zongwei et al., 1994; NOAA, 1996). Benthic macroinvertebrate communities appear to be impacted by sediment contaminants (Franz and Harris, 1988; Steimle and Caracciolo-Ward,

1989). Other investigations have described elevated levels of contaminants in sediments (NOAA, 1991; Huntley et al., 1993; Bonnevie et al., 1995) and sediment toxicity (Scott et al., 1990; Schimmel et al., 1994; Long et al., 1995b).

Most studies of toxic contamination in the NY-NJ Harbor system have focused on measuring the concentrations of contaminants in the sediment. Characterizing sediment condition is a logical way to describe toxic contamination in an estuarine system because the sediment is both a sink for contaminants that adsorb to fine particles, and a source for toxic contaminants that are rereleased to the water column when sediments are disturbed by natural events (e.g., seasonal turnover, bioturbation, violent storms) or human activity (e.g., dredging, vessel traffic). In addition, the food chains for many estuarine species begin in the sediment; therefore, contaminants in the sediment can be propagated widely throughout an estuarine ecosystem.

Existing studies have been useful in establishing concern about contaminants in the NY/NJ Harbor system. In a review of historical data on toxic contamination, Squibb et al. (1991) identified 12 metals and 43 organic chemicals that are present in the Harbor water, biota or sediments at concentrations that may affect the integrity of the system. NOAA's National Status and Trends program, which has conducted sampling in the NY-NJ Harbor, identified it as having some of the highest metals concentrations found nationwide. Based on these data and the integral relationship between contaminated sediments and the health of the Estuary, the Harbor Estuary Program, U.S.EPA-Region 2, states and local governments have made addressing the biological effects of contaminated sediments a high priority (U.S.EPA-Region 2, 1996).

While these existing data are sufficient for the purpose they were designed for and to raise concerns about sediment contamination in the Harbor, they are insufficient for developing an effective contaminant strategy for the NY-NJ Harbor complex for several reasons:

- < Much of the existing data is limited, outdated, or unreliable, causing Squibb et al. (1991) to recommend characterizing the problem further before acting to correct it.
- < Data from historic studies are insufficient for evaluating the areal extent of toxic contamination throughout the NY/NJ Harbor and in each of its sub-basins because most studies of sediment contamination in the system were initiated to resolve site-specific problems rather than to support regional management decisions. Sampling has been limited to specific "hot-spots" around known or assumed contaminant sources. These data cannot be extrapolated to unsampled areas, which would be necessary to reliably characterize the condition of the entire system and specific sub-basins. Although Squibb et al. (1991) were able to identify a large number of contaminants in the Harbor, they were unable to evaluate pervasiveness of the contamination.
- < There is little opportunity to assess from existing data the biological effect of contaminants that were measured in the sediment, or whether the effects differ in

different portions of the estuary complex. This is because sediment contaminant data were collected independently of biological data.

These shortcomings are major impediments to developing a management strategy. Information about the distribution of the contamination problems among sub-basins is necessary for determining whether the management emphasis should be focused on a regional, watershed, or a local site-specific scale. Developing management strategies on the basis of “hot spot” information alone may result in misdirection of management efforts, particularly if the problem is more widespread than limited “hot spot” data would suggest. Also, information on biological effects of contaminants is critical to identifying the scope of the problem and determining the resources appropriate to remediate it. The ecological significance of contaminant levels documented from purely chemical surveys is unknown in the absence of information on direct toxicity of those contaminants and/or data documenting the relative status of biological communities, such as the benthos, exposed to these materials. Areas where contaminant levels are high but biological availability and toxicity are low may be addressed best with management strategies different from those appropriate for areas where significant impacts to biota are evident.

1.2 OBJECTIVES

This project was designed to support resource management decisions related to pollution control and remediation throughout the NY-NJ Harbor and Bight Apex and to assist the Harbor Estuary Program (HEP) in developing a contaminant monitoring strategy to be followed as part of the Comprehensive Conservation and Management Plan (CCMP) for the NY-NJ Harbor system. This investigation was designed around several objectives:

Objective 1. Estimate with known confidence the percent of area in each of six major sub-basins of the NY-NJ Harbor system in which the benthic environment is "degraded", "not degraded", or "not evidently degraded" with respect to benthic macroinvertebrate assemblages, sediment toxicity, and concentrations of sediment contaminants, and,

Objective 2. Identify statistical associations among particular chemical contaminants and degraded benthos or toxic sediments.

A third objective was identified because the HEP and the Region recognized that a tool to represent benthic quality was needed:

Objective 3. Develop and validate a managerially useful index of benthic quality for the NY/NJ Harbor system, based on the condition of benthic macroinvertebrate assemblages.

1.3 RELATIONSHIP TO THE CCMP

The New York-New Jersey Harbor Estuary Program (HEP) has prepared a Comprehensive Conservation and Management Plan (New York-New Jersey Harbor Estuary Program, 1996). The CCMP included a section on management of toxic contamination. The goals of the HEP plan for toxics are:

- ! To establish and maintain a healthy and productive Harbor/Bight ecosystem, with no adverse ecological effects due to toxics.
- ! To ensure that fish, crustacea and shellfish caught in the Harbor/Bight are safe for unrestricted human consumption.
- ! To ensure that dredged sediments in the Harbor are safe for unrestricted ocean disposal.

In order to take steps toward attainment of these goals, the HEP plan includes actions to reduce continuing inputs of toxic chemicals to the Harbor and Bight from sources such as municipal discharges, industrial discharges, combined sewer overflows, storm water discharges, and non-point sources.

The data from this investigation will be used to support the HEP goals. For example, the benthic index and toxicity tests will be interpreted in relation to a "no adverse effects" level. Also, where available, numeric criteria and tests used in regulatory decision-making will be used to interpret the data. This investigation's surficial sediment sampling represents recently deposited sediments and contaminants. Therefore, interpretation of the *A. abdita* toxicity test results, sediment chemistry and benthic macroinvertebrate structure information will help managers assess the potential future distribution of dredged material unsuitable for ocean disposal. This information, combined with an evaluation of the causes of toxicity, also will help focus strategies to control continuing sources of contamination.

1.4 ORGANIZATION OF THE REPORT

The purpose of this report is to present summarized data and interpretation to address the three objectives that were defined at the start of the project.

The report has nine chapters. Chapter 2 defines the indicators that were used and how they were measured. Chapters 3, 4, 5 and 6 report results from each of the indicator classes, both in terms of mean condition and percent of area above or below specified threshold values, and relates these to previous studies in the Harbor. Chapter 7 analyzes the associations between the various indicators and Chapter 8 provides discussion of the results in terms of management implications. Chapter 9 contains all references cited in the report. Several appendices are included: A - sampling station locations and maps, B - analytical detection limits, C - benthic index

development, D - aluminum-normalization procedure, E - tables of means and % of area exceedances of ERMs for all chemicals measured in the study, F - dioxin bioaccumulation calculations, G - mean abundances of all benthic species, H - *Clostridium perfringens* results, and I - benthic index values for individual stations. Appendix J contains explanatory information for the data disk that is included inside the back cover. The disk, in Excel format, contains unmanipulated data from this investigation.

2.0 METHODS

2.1 DESIGNATION OF STUDY AREA

Based on hydrogeography and similar source characteristics, the study area was divided into six sub-basins (Figure 2-1): Upper Harbor, Newark Bay, Lower Harbor (includes Raritan and Sandy Hook Bays), Jamaica Bay, western Long Island Sound and the New York Bight Apex. The New York-New Jersey Harbor, for purposes of this investigation, includes the lower portions of the Hudson, Passaic, Harlem, Hackensack and Raritan Rivers, upstream to a near-bottom salinity of 15 ppt, the East River to Long Island Sound, and Lower Harbor to the Atlantic Ocean. The New York Bight Apex is defined as the area of ocean bounded on the northwest by the transect from Sandy Hook, NJ to Rockaway Point, NY, the east by 73° 30' W longitude, and the south by 40 10' N latitude. The eastern boundary of the western Long Island Sound sub-basin is 73° 24' W longitude (from Eaton's Neck Point, NY to Norwalk, CT). The area of each sub-basin was determined using Geographic Information System (GIS) ARCInfo software (Table 2-1).

Table 2-1
Sub-basin Areas and Percent of Study Areas

Sub-basin	Area (km²)	% of Study Area
Lower Harbor	318	11.1
Upper Harbor	104	3.7
Jamaica Bay	47	1.7
Newark Bay	32	1.1
W. Long Island Sound	476	16.6
Bight Apex	1883	65.8
Harbor Total*	501	17.6
Study Area Total	2861	100.0

*The Harbor Total includes Lower and Upper Harbors, Jamaica Bay and Newark Bay.

2.2 STUDY DESIGN

There are two different strategies for sampling to estimate characteristics of the field. Often sampling sites are selected by their anticipated ability to reflect regional characteristics. Samples are presumed *a priori* to be “representative” of their surrounding areas. This is termed judgmental or purposive sampling. The alternative strategy, termed probabilistic, ensures that

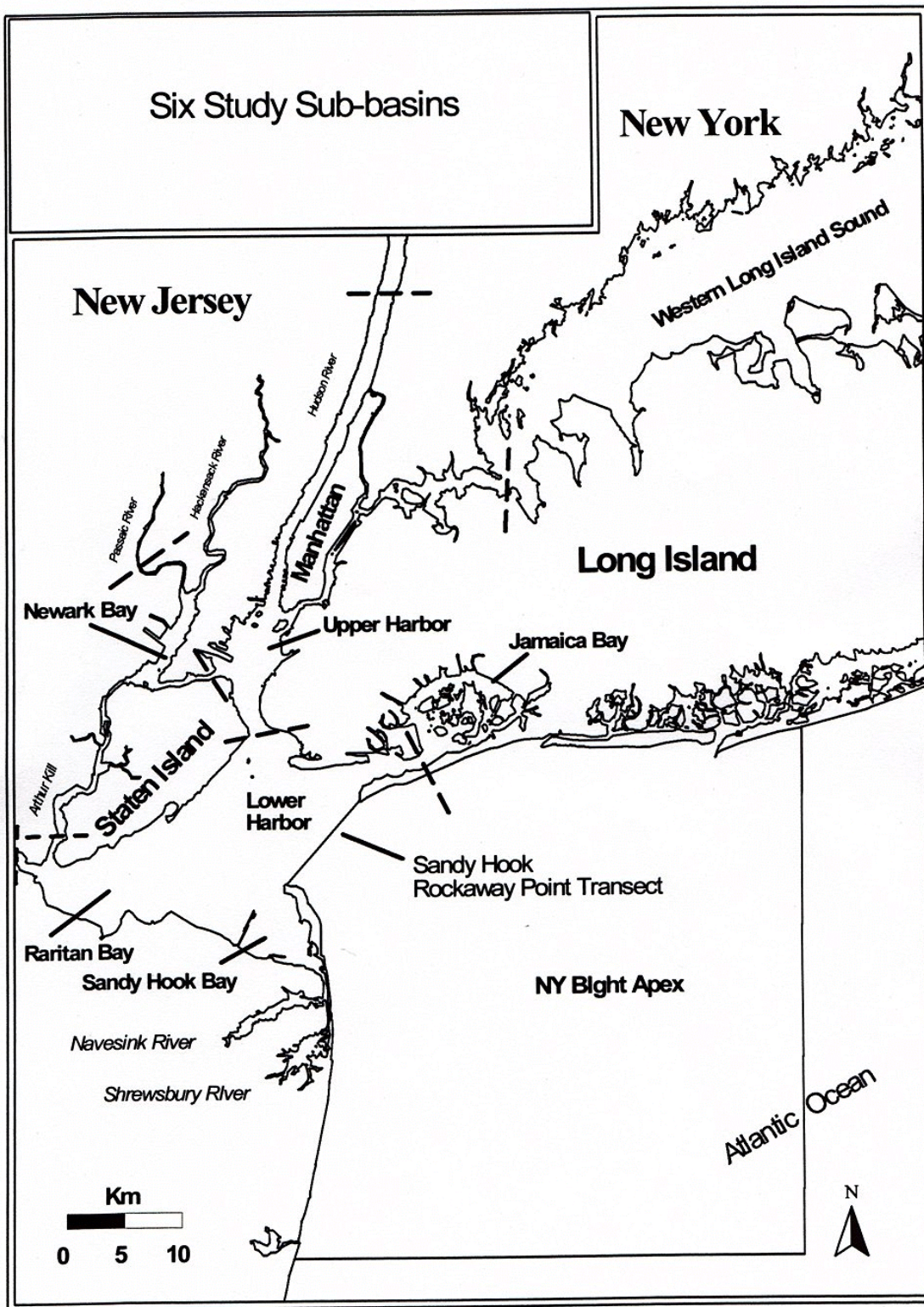


Figure 2-1. Map of the six study sub-basins: Upper Harbor, Newark Bay, Lower Harbor (includes Raritan and Sandy Hook Bays), Jamaica Bay, western Long Island Sound and the New York Bight Apex.

every element in the population sampled has some chance of actually being sampled. For instance, in the present investigation, every potential benthic grab sample in the study area could have been sampled (i.e., potential grabs not sampled were excluded only by chance, not by judgement). While this probability sampling is not the most appropriate in all situations, it does have important advantages over purposive sampling. Probability samples can provide unbiased estimates of population characteristics with specified confidence limits. These confidence limits become smaller as sample size is increased.

Sampling stations for the present investigation were selected probabilistically using a stratified random approach. The strata corresponded to each of six sub-basins where independent estimates of condition were needed. Fourteen stations were assigned to each sub-basin in each of the two years of sampling, for a total of 28 stations in each sub-basin (Appendix A). Each year, sites were selected by randomly placing a grid structure over the study area, selecting 14 grid cells at random from each stratum, and selecting a random location from within the selected cells. Cells were of equal area within strata, except for the Newark Bay stratum, where grid cell size was altered to ensure sampling in the Arthur Kill, Passaic River, and the Hackensack River.

Sampling was conducted between late July and late September of 1993 and 1994. A summer index period was chosen for several reasons. This time period has been identified as most appropriate for this area (Holland, 1990). Pollution stress is expected to be at its highest because dissolved oxygen values are low and contaminant exposure is at its maximum due to high temperatures and low dilution flows. Benthic organisms are usually more abundant, which increases the success of sampling. While some indicators vary between July and September, most of the measures that this investigation focused on, such as benthos, toxicity and chemistry, are stable during that time period. The U.S.EPA Environmental Monitoring and Assessment Program (EMAP) evaluated benthic response and found it did not vary unacceptably between late July and September (Weisberg et al., 1993). A summer index period also ensures compatibility with EMAP, which is useful since it allows comparison to those results and referencing to EMAP benthic macroinvertebrate data for the development of a benthic index.

2.3 SAMPLING PROCEDURES

The U.S.EPA vessels, R/V CLEAN WATERS and OSV PETER W. ANDERSON, were used for sample collection. Sampling stations were located using LORAN-C and a Global Positioning System (GPS) or Differential-GPS (D-GPS). Depth of the water column was determined using sonar. Field procedures followed Reifsteck et al. (1993).

2.3.1 Water Column

A SeaBird model SBE 25 “Sealogger” CTD unit was used to obtain a vertical profile of depth, dissolved oxygen, pH, temperature, and salinity at each station. Measurements were made from within a meter of the water surface to approximately a meter above the sediment/water interface.

Water clarity was measured using a 20-cm Secchi disk. Dissolved oxygen, temperature and salinity at the surface were measured using a Winkler titration, NBS thermometer and a refractometer, respectively, and compared with the CTD results.

2.3.2 Sediment

A 0.04-m² or 0.1-m², stainless steel, Young-modified van Veen grab was used to collect surficial sediment for chemical analysis and toxicity testing. Multiple grabs were required to collect enough volume for analysis. Overlying water was carefully drained by allowing suspended floc to settle for approximately one minute and then carefully suctioning off the overlying water with a clean section of Tygon® tubing. For Acid Volatile Sulfide (AVS)/Simultaneously Extracted Metals (SEM) analysis, aliquots of the top 2 cm were taken from the undisturbed surface of multiple individual grabs using a 60-cc syringe which had the narrow end removed to create a mini-corer. AVS samples were not homogenized. When a sample container was filled to the top, it was sealed with Teflon® tape and immediately frozen. The remaining top 2 cm of sediment from each grab were removed using clean stainless steel spoons. A composite of all grabs was homogenized in a clean glass mixing bowl for 10 minutes. Subsamples were removed for metals, organics, grain size, TOC and toxicity tests, and transferred to clean sample containers that were stored on ice. The van Veen grab was rinsed with ambient seawater between grabs at a station and thoroughly cleaned with detergent and water between stations.

2.3.3 Benthos

Three benthic macroinvertebrate grabs per sampling station were collected using the 0.04-m² Young-modified van Veen grab. Benthic grabs were alternated with sediment chemistry/toxicity grabs. Benthic samples were gently washed through a 0.5 mm mesh sieve. The material that remained was preserved in a 10% buffered formaldehyde-rose bengal solution.

2.4 PHYSICAL/CHEMICAL/BACTERIOLOGICAL LABORATORY METHODS

Methods used for chemical analyses are summarized in Table 2-2. Individual chemical parameters are listed in Table 2-3 and detection limits are in Appendix B. PAHs, TOC, grain size, and total recoverable metals were analyzed at the U.S.EPA-Region 2 Laboratory in Edison, NJ. PCB, pesticides and butyltins were analyzed, under contract to the Hudson River Foundation (HRF), by the Geochemical and Environmental Research Group (GERG) of Texas A&M University, College Station, TX. Acid volatile sulfide (AVS), simultaneously extracted metals (SEM) and total metals were analyzed by the Trace Element Research Laboratory (TERL) of Texas A&M. Selected samples for dioxins and furans were analyzed by Battelle Labs, Columbus, OH. The GERG and TERL laboratories both participated in the NOAA Status and Trends Interlaboratory Comparison exercise.

Table 2-2
Summary of Physical/Chemical Analytical Methods

Parameter	Method	Reference
PAHs	Methylene chloride extraction; determination by GC/MS	TSB SOP C-48 (U.S.EPA-Region 2, 1994a)
PCB/Pesticides	Methylene chloride extraction; determination by HRGC/ECD	GERG SOPs-ST02, ST04
Major and Trace Elements	Total metals: HNO ₃ and HF acid digestion: Hg-CVAAS; Cu, Ni, Pb, Cr, Sb, Sn, As, Se, Ag, Cd-GFAAS; Al, Fe, Mn, Si, Zn-FAAS	GERG SOPs-ST08, ST09, ST10, ST11
Major and Trace Elements	Total recoverable metals: HNO ₃ /H ₂ O ₂ or microwave digestion: Hg-CVAF; Cu, Ni, Cr, Ag, Al, Fe, Mn, Sb (1993); Zn-ICP; Pb, Cd, As (1993), Se-GFAAS; As (1994), Sb (1994)-HYDAAS	TSB SOPs C-5, C-8, C-72, C-73, C-74 (U.S.EPA-Region 2, 1994b-f)
Hexavalent Chromium	Chelation with APDC, extraction with MIBK; determination by FAAS	MCAWW 218.4 (U.S.EPA, 1983)
Dioxins and Furans	Extraction with toluene; determination by HRGC/HRMS; second column confirmation for 2,3,7,8-TCDD	Method 1613 - Rev. A (U.S.EPA, 1990b)
AVS/SEM	AVS-selective generation of H ₂ S, gravimetric, colorimetric or titrametric determination; SEM-filtration of AVS digestate, determination by FAAS, ICPAES or CVAAS	GERG SOPs-9130, ST11, ST09, ST10
Butyltins	Tropolone extraction; determination by HRGC/FPD or HRGC/MS	GERG SOP-9013
TOC	Acidification with H ₃ PO ₄ ; determination using a CO ₂ analyzer	MCAWW 415.1 (U.S.EPA, 1983)
Grain size	Sieving and pipette analysis	U.S.EPA, 1993b

All analyses employed appropriate quality assurance samples. Quality assurance goals were developed and followed for each analysis (Adams and Hunt, 1993). Except in isolated instances, all quality assurance goals were met or exceeded. Data were entered into two separate databases and then compared electronically to ensure accuracy in data entry.

Table 2-3
Analytical Measurements for Sediment Samples

Polyaromatic Hydrocarbons (PAHs)			
Acenaphthene	Biphenyl	1-Methylnaphthalene	
Acenaphthylene	Chrysene	1-Methylphenanthrene	
Anthracene	Dibenz(a,b)anthracene	Naphthalene	
Benz(a)anthracene	2,6-Dimethylnaphthalene	Perylene	
Benzo(b,k)fluoranthene	Fluoranthene	Phenanthrene	
Benzo(g,h,i)perylene	Fluorene	Pyrene	
Benzo(a)pyrene	Ideno(1,2,3-c,d)pyrene	2,3,5-Trimethylnaphthalene	
Benzo(e)pyrene	2-Methylnaphthalene		
DDT and its Metabolites		Chlorinated Pesticides other than DDT	
o,p'-DDD	p,p'-DDE	Aldrin	Heptachlor
p,p'-DDD	o,p'-DDT	Alpha-Chlordane	Heptachlor epoxide
o,p'-DDE	p,p'-DDT	Trans-Nonachlor	Hexachlorobenzene
		Dieldrin	Lindane ((-BHC)
		Endrin	Mirex
Major Elements		Trace Elements	
Aluminum	Antimony	Copper	Selenium
Iron	Arsenic	Lead	Silver
Manganese	Cadmium	Mercury	Tin
Silicon	Chromium	Nickel	Zinc
PCB Congeners (20)			
No.	Congener Name	No.	Congener Name
8	2,4'-dichlorobiphenyl	118	2,3',4,4',5-pentachlorobiphenyl
18	2,2',5-trichlorobiphenyl	126	3,3',4,4',5-pentachlorobiphenyl
28	2,4,4'-trichlorobiphenyl	128	2,2',3,3',4,4'-hexachlorobiphenyl
44	2,2',3,5-tetrachlorobiphenyl	138	2,2',3,4,4',5'-hexachlorobiphenyl
52	2,2',5,5'-tetrachlorobiphenyl	153	2,2',3,4,4',5'-hexachlorobiphenyl
66	2,3',4,4'-tetrachlorobiphenyl	170	2,2',4,4',5,5'-hexachlorobiphenyl
101	2,2',4,5,5'-pentachlorobiphenyl	180	2,2',3,3',4,4',5-heptachlorobiphenyl
105	2,3,3',4,4'-pentachlorobiphenyl	187	2,2',3,4,4',5,5'-heptachlorobiphenyl
110/77	2,3,3',4',6-pentachlorobiphenyl/ 3,3',4,4'-trichlorotetrabiphenyl	195	2,2',3,3',4,4',5,6-octachlorobiphenyl
		206	2,2',3,3',4,4',5,5',6-nonachlorobiphenyl
		209	2,2',3,3',4,4',5,5',6,6'-decachlorobiphenyl
Dioxin and Furan Congeners*			
2,3,7,8-TCDD	1,2,3,4,6,7,8-HpCDD	2,3,7,8-TCDF	2,3,4,6,7,8-HxCDF
1,2,3,7,8-PeCDD	OCDD	1,2,3,7,8-PeCDF	1,2,3,4,6,7,8-HpCDF
1,2,3,4,7,8-HxCDD		2,3,4,7,8-PeCDF	1,2,3,4,7,8,9-HpCDF
1,2,3,6,7,8-HxCDD		1,2,3,4,7,8-HxCDF	OCDF
1,2,3,7,8,9-HxCDD		1,2,3,7,8,9-HxCDF	
Other Measurements			
AVS/SEM	Grain Size	<i>Clostridium</i>	TOC
			Butyltins

*only analyzed on Upper Harbor, Jamaica Bay, & Lower Harbor samples

2.4.1 Major and Trace Elements

Sediment samples were prepared for bulk metals analyses using two procedures: 1) digestion with nitric and hydrofluoric acids (total metals) and 2) digestion with nitric acid (total recoverable metals). Subsequent data analyses are based on total metals results. Mercury was analyzed by cold vapor atomic absorption (CVAA). Copper, nickel, lead, chromium, hexavalent chromium, antimony, tin, arsenic, selenium, silver and cadmium were analyzed by graphite furnace atomic absorption spectroscopy (GFAAS). Other metals (aluminum, iron, manganese, silicon and zinc) were determined by flame atomic absorption spectroscopy (FAAS). Metal concentrations are reported on a dry weight basis. The sediment SRM used was National Research Council of Canada (NRCC) MESS2.

2.4.2 Organic Compounds

For analysis of pesticides and PCBs, aliquots of sediment were dried using sodium sulfate and soxhlet extracted using methylene chloride for six hours. The extract was concentrated using a Kuderna-Danish technique and the methylene chloride replaced with hexane. Extracts were cleaned up with a silica gel/alumina column eluting with a 50:50 mixture of pentane and methylene chloride. This fraction, which was primarily the aromatic and chlorinated hydrocarbons, was again concentrated using a Kuderna-Danish technique and the mixed solvent was replaced with hexane. The chlorinated pesticides and PCBs were quantified using high resolution capillary gas chromatography with electron capture detection (GC/ECD). The GC column used was a 30 m, 0.25 mm I.D. fused silica column with a DB-5 bonded phase. The data are reported in ng/g dry weight. The sediment SRM used with these samples was National Institute of Technology (NIST) 1941a.

Twenty-two polycyclic aromatic hydrocarbons (PAHs) were measured (U.S.EPA-Region 2, 1994a). A 10-g aliquot of sediment was dried with anhydrous sodium sulfate and soxhlet extracted with methylene chloride for 16 hours. The extract was dried by using a sodium sulfate drying column and concentrated using a Kuderna-Danish apparatus to 1 ml. A GC/MS with a 30 m, 0.25 mm I.D. DB-5 fused silica capillary column was used for analysis. A mass range of 33 to 450 amu was used. Results are reported as ug/kg, dry weight. The SRMs used were NIST 1941a and 2260.

Butyltin analysis included mono-, di-, tri- and tetrabutyltin. Samples were freeze-dried and extracted using 0.2% tropolone in methylene chloride on a roller table for three hours. The extract was concentrated using a Kuderna-Danish apparatus and treated with Grignard reagent to hexylate the butyltins. Extracts were neutralized and cleaned up with a silica gel/alumina column. The fraction was again concentrated using Kuderna-Danish techniques and the mixed solvent was replaced with hexane. Final volume of the extract was 1.0 ml. Butyltin quantification was done on a high resolution capillary gas chromatograph with either flame photometric detection (HRGC/FPD), equipped with a tin selective 610 nm filter or a mass

spectrometer (HRGC/MS). The GC column used was a 30 m, 0.32 mm I.D. fused silica capillary column with DB-5 or DB-5MS bonded phase. A mass of 121 m/z was monitored for quantification with a secondary ion of 191 m/z monitored for confirmation. The standard reference material, NRCC PACS-1, also was analyzed.

The analytical method for AVS analysis employed selective generation of hydrogen sulfide and gravimetric, colorimetric or titrametric determination (depending on the expected concentration of sulfide). Following AVS analysis and digestate filtration, SEM analysis was performed for cadmium, copper, lead, mercury, nickel and zinc using FAAS, ICPAES or CVAAS. Results are reported as $\mu\text{mol/g}$ (dry wt.).

Analysis of selected sediments for seventeen dioxin and furan congeners was done according to Method 1613-Revision A (U.S.EPA, 1990b). Frozen sediment samples were thawed and centrifuged to remove excess water. Approximately 10 g of sediment was used for determination of percent solids. Another 10 g was combined with quartz sand for extraction. All samples were spiked with isotopically labeled analogs of 15 of the 17 2,3,7,8-substituted PCDDs/PCDFs prior to extraction. The samples then were extracted for 20 hours using toluene in a Soxhlet/Dean Stark apparatus. Extracts were spiked with $^{37}\text{Cl}_4$ -2,3,7,8-TCDD cleanup standard, partitioned against base and acid solutions, and processed through acid/base silica, basic alumina, and carbon AX-21/Celite cleanup columns. The carbon AX-21 Celite columns were back eluted with 30 mL toluene rather than the method-specified 20 mL as the laboratory has found that the extra toluene has increased the recovery of OCDD/F in the past. Extracts were spiked with 1,2,3,4-TCDD- $^{13}\text{C}_{12}$ /1,2,3,7,8,9-HxCDD- $^{13}\text{C}_{12}$ recovery standard and concentrated to a final volume of 20 μL . These extracts were analyzed by high resolution gas chromatography/high resolution mass spectrometry (HRGC/HRMS) in the selected ion monitoring mode on a DB-5 capillary column at an instrument resolution of approximately 10,000 (10% valley). Most samples were diluted to reduce chromatographic interference problems. Because 2,3,7,8-TCDF is not completely resolved from other tetrachlorinated isomers on the DB-5 column, second column confirmation of 2,3,7,8-TCDF levels above 1 ng/kg dry wt. was performed on a DB-Dioxin column. The standard reference material, EDF-2513 (Cambridge Isotope Laboratories), was processed with each batch of samples.

2.4.3 Sediment Physical Parameters

Grain size analysis was performed according to U.S.EPA (1993b), except samples were not digested with hydrogen peroxide. Samples were treated with sodium hexametaphosphate as a dispersant. Sand was defined as the fraction that was retained on a 63- μ sieve. Percent silt and percent clay were determined using pipette analysis of the filtrate. Percent moisture was obtained by accurately weighing 10 g of sediment, drying overnight at 105°C and reweighing. The total organic carbon (TOC) method was based on the U.S.EPA method MCAWW 415.1 (U.S.EPA, 1983), modified for sediment using a boat sampling module.

2.4.4 Bacteriological Analysis

Concentrations of *Clostridium perfringens* spores have been used as an indicator of sewage contamination (Hill et al., 1993; O'Reilly et al., 1995). *C. perfringens* is a obligate anaerobe bacterium found in fecal material. It can survive extreme environmental conditions. This study evaluated the concentrations of the spores in Harbor sediments. The membrane filter method of Emerson and Cabelli (1982) was used. Mean concentrations of *C. perfringens* spores are expressed as confirmed counts per gram (wet weight) of sediment

2.5 TOXICITY METHODS

2.5.1 Amphipod Sediment Toxicity Tests

Batches of a tube-dwelling amphipod, *Ampelisca abdita*, were supplied by East Coast Amphipod of Kingston, Rhode Island. The amphipods and control sediment were collected from the Narrow River, Rhode Island and the U.S. Army Corps of Engineers Long Island Sound (LIS) reference station. Control sediment was press-sieved through a 0.5 mm mesh stainless steel sieve to remove resident amphipods and debris. Test sediment was press-sieved through a 2.0 mm stainless steel sieve to remove large debris and predaceous organisms. If amphipods were present, the test sediments were press-sieved through a 1.0 mm stainless steel sieve. Organisms were acclimated at 20°C and 30 ppt salinity prior to testing. Temperature and salinity did not change by more than 3°C and 3 ppt, respectively, during any 24 consecutive hours of acclimation. Amphipods were fed the marine alga, *Phaeodactylum tricorutum*, during acclimation. Ten-day acute, static, non-renewal sediment toxicity tests were conducted according to ASTM (1991, 1992) and U.S.EPA (1993b) test protocols. For each toxicity test, 200 ml of composited, press-sieved sample were placed in 1 L glass test chambers and covered with 600 ml of seawater. Five replicate test chambers were used for each sample. Each replicate contained 20 organisms.

Post-test enumeration of amphipods was performed without knowledge of sample identity to prevent bias. If less than 20 amphipods were found, the test sediment was stored in the dark for up to 48 hours to encourage emergence of any remaining amphipods. Final organism counts were confirmed by a second scientist. Minimum control survival for satisfying test performance criteria was 90%. Sodium dodecyl sulfate (SDS) was used as a reference toxicant to evaluate the sensitivity of each batch of amphipods. Reference toxicant results were all within the acceptable range for this species. *A. abdita* assays were conducted by the U.S.EPA-Region 2 Bioassay Laboratory in Edison, NJ and SAIC, Narragansett, RI. These two laboratories participated in an interlaboratory comparison which showed that the laboratories produced comparable results.

2.5.2 Microtox™ Assays

The Microtox™ assay for marine sediments is considered to be a rapid screening alternative to standard acute toxicity testing with fish or invertebrates (Giesy and Hoke, 1990) and has been recommended as a first stage assay in a tiered testing arrangement (Sloof, 1985). In this investigation it was used to supplement the *Ampelisca abdita* acute amphipod assay. The Microtox™ assay is based on the inhibition of light emission by the luminescent bacterium *Photobacterium phosphoreum* in the presence of toxicants. Freeze-dried luminescent bacteria are reconstituted in control and test solutions and incubated, then luminescence is measured on serial dilutions after 5 to 15 minute exposures. The percent inhibition of light transmission, converted to an EC₅₀ value, is the measure of toxicity. Microtox™ assays were conducted by ToxScan, Watsonville, CA.

The solvent extraction method adapted from Long and Markel (1992) was employed. Before extraction, excess water from the top of the samples was decanted and discarded. The sediment was homogenized and a 3.3 g wet weight sample was weighed into a 50-ml Pyrex centrifuge tube with a Teflon-lined screw cap. Samples were dried by and extracted with dichloromethane (DCM). Solvent exchange and concentration were performed using a Kuderna-Danish flask attached to a Snyder column. Extracts were tested in duplicate following Micobics Corp. recommended procedures (1992). The sediment extracts were diluted 1:100 with Microtox™ diluent. Serial dilutions of 100, 50, 25, 12.5, 6.25, 3.13 and 0 percent of this stock solution were made using Microtox™ diluent. The 0% dilution is a reagent blank used to measure spontaneous decay in bacterial luminescence of any treatment. Percent decrease in luminescence relative to the reagent blank was calculated and these data were used to obtain the 50% inhibition concentration (i.e., EC₅₀). Results were converted to mg dry wt./ml.

Control sediment from the U.S. Army Corps of Engineers Long Island Sound (LIS) reference station was tested along with the Harbor samples. Ethanol reagent blanks with no sediment and extraction blanks were prepared and tested. Reference toxicant testing using phenol was conducted with each set of sediment assays and results were acceptable according to the test protocols.

2.6 BENTHIC MACROINVERTEBRATE ASSEMBLAGES

Three replicate grabs for benthic macroinvertebrate community structure were obtained at each station. The grabs were processed by being washed through a 0.5 mm screen on-board the sampling vessel. Invertebrates from two of the replicates were sorted and identified, the third replicate was archived. Procedures for sorting, identifying, and measuring the biomass of benthic macroinvertebrates followed EMAP-E procedures (Klemm et al., 1993; Frithsen et al., 1994). The macrobenthos were identified to the lowest practical taxonomic category. Rare or previously undocumented specimens from the Harbor were put aside in a reference collection. Ten percent of all samples were reprocessed and subjected to a second QA evaluation.

Taxonomic identifications were verified using reference organisms obtained from EMAP's reference collection. Sample processing was conducted by Versar, Inc. (Columbia, MD) and Cove Corporation (Lusby, MD). Species identifications and enumerations were done by Cove Corporation and biomass measurements were done by Versar, Inc.

Organisms were grouped by taxa for biomass determination. To standardize the biomass measurements, all samples were preserved in a 10% solution of buffered formaldehyde for at least two months before the biomass measurement. Hard-bodied organisms (bivalves <2cm and gastropods) were acidified in 10% HCL until all visible traces of shell material were removed.

Bivalves larger than 2 cm were shucked before determination of biomass. Biomass was determined as dry wt. after drying for at least 48 hours at 60°C.

2.7 DATA ANALYSIS

2.7.1 Chemical Data

For several classes of compounds, data analyses were performed on summed results. Total PCBs were the sum of the concentrations of the 20 congeners in Table 2-3 multiplied by 2.0 (NOAA, 1989). Total PAHs were the sum of the concentrations of the 23 individual PAHs. Total chlordane was the sum of the concentrations of heptachlor, heptachlor-epoxide, oxychlordane, gamma-chlordane, alpha-chlordane, trans-nonachlor and cis-nonachlor. Non-detects were not included in the calculation of total concentrations.

Data analyses for metals were based on total metals results.

2.7.2 Toxicity Data

Amphipod survival data were not transformed, since an examination of a large historical data set from SAIC has shown that *A. abdita* percentage survival data meet the requirement of normality (Thursby et al., 1997).

For Microtox™ analyses, the concentration and response data were log-transformed before using analysis of covariance (ANCOVA) to conduct a pair-wise comparison to determine significant differences between samples from each station and control sediment.

2.7.3 Benthic Macroinvertebrate Data

Nine individual measures (Table 2-4) and one composite index (benthic index of biotic integrity or B-IBI) were used to evaluate the condition of benthic assemblages in the study area. Diversity

was evaluated by using species richness (number of species) and the Shannon-Wiener diversity index (Shannon and Weaver, 1949).

A multi-metric benthic index of biotic integrity (B-IBI) was developed for the NY/NJ Harbor (Appendix C). The EMAP-E 1990-1993 Virginian Province data, excluding Chesapeake Bay and site with salinities less than 15 ppt, were used to develop the index. The B-IBI incorporated five of the benthic macroinvertebrate metrics in Table 2-4 into a single value that described the condition of the benthos. These five metrics were those which most effectively distinguished normal sites from all others. The metrics were evaluated for four different salinity and grain size habitats (Table 2-5) and threshold values were defined for each.

Table 2-4
Individual Benthic Macroinvertebrate Measures Assessed

Species Diversity	Species Composition
Number of taxa (#)*	Abundance of pollution-indicative taxa (%)*
Shannon-Wiener Diversity (H')	Abundance of pollution-sensitive taxa (%)*
Abundance and Biomass	Trophic Composition
Abundance (#/m ²)*	Abundance of deposit feeding taxa (%)
Biomass (g/m ²)*	Abundance of suspension feeding taxa (%)
	Abundance of carnivores/omnivores (%)

* Measures used in B-IBI.

Table 2-5
B-IBI Habitat Categories

Habitat	
Salinity Class	Sediment Type
Polyhaline (15-28 ppt)	Mud (>40% silt+clay)
	Sand (<40% silt+clay)
Euhaline (28-35 ppt)	Mud (>40% silt+clay)
	Sand (<40% silt+clay)

The index was calculated by scoring each selected metric as 5, 3, or 1 depending on whether its value at a site approximated, deviated slightly from, or deviated greatly from conditions at the

best reference sites. The B-IBI value for each station is calculated as the mean score of the five metrics. A mean score of 5 indicated that the site was approximately equivalent to the best reference sites. A score of 3 or 1 indicated that the site slightly deviated or greatly deviated from conditions at the best reference sites and would be considered to have impacted benthos. The overall validation efficiency of the B-IBI was 93%. The average difference between replicates was 0.32. Ninety-one percent of the replicates at the same site scored similarly. At most of the sites where the replicates scored differently, the replicates had similar numerical values, but were on either side of the index threshold of 3.

2.7.4 Condition Estimates

Two types of characterizations were done for this investigation. Individual sub-basins were separately characterized for each parameter, resulting in six characterizations. The “Harbor” characterization includes four of the six sub-basins that are commonly known as the Harbor proper; Jamaica Bay, Newark Bay, Lower Harbor and Upper Harbor. The watersheds, sources, physical and hydrological characteristics of western Long Island Sound and the Bight Apex were significantly different from the Harbor proper.

The condition of each stratum and the Harbor as a whole was assessed in two ways: 1) mean condition and, 2) percent of area exceeding threshold (or critical) values for selected parameters. The spatial distribution of degraded and non-degraded stations was also evaluated using GIS (Geographic Information System) display of individual station results.

This investigation used specific terminology to distinguish different bases for determining “sediment quality.” Sediments with unusually high chemical concentrations were considered “contaminated.” Significant results of sediment toxicity tests indicated “toxic” sediments. Measurable departures from normal benthic macroinvertebrate assemblages indicated “impacted” or “abnormal” benthic assemblages. Only when two or three of these sediment quality indications were abnormal, were the sediments described as “degraded.”

2.7.4.1 Mean Condition

Since the sampling stations within each stratum or sub-basin (except Newark Bay) were selected with equal inclusion probabilities, the mean parameter values for a stratum, h , and its variance were calculated as:

$$\bar{Y}_h = \frac{\sum_{i=1}^{n_h} Y_{ih}}{n_h} \quad (1)$$

$$S_h^2 = \frac{\sum_{i=1}^{n_h} (Y_{ih} - \bar{Y}_h)^2}{n_h - 1} \quad (2)$$

where

y_{ih} was the variable of interest (e.g., concentration of mercury), and

n_h was the number of samples collected from stratum h .

The weighted mean value for L strata with combined area A is given by

$$\bar{Y}_{st} = \sum_{h=1}^L W_h \bar{Y}_h \quad (3)$$

where the weighting factors, $W_h = A_h/A$, ensure that each stratum h is weighted by its fraction of the combined area for all L strata. An estimator for the variance of the stratified mean (3) is

$$V(\bar{Y}_{st}) = \sum_{h=1}^L W_h^2 \text{Var}(Y_h) \quad (4)$$

Strata were combined to develop estimates for the study area as a whole and for the New York/New Jersey Harbor, which includes all strata except western Long Island Sound and the Bight Apex, following Holt and Smith (1979). Confidence intervals were calculated as 1.64 times the standard error, where the standard error was the square root of the variance.

The samples from Newark Bay were treated as a cluster sample, in which the cells formed clusters (areas) of unequal size. Mean parameter values were calculated as area-weighted means:

$$\bar{q} = \frac{\sum_{i=1}^{n_h} c_i Y_{ih}}{C} \quad (5)$$

where

c_i was the area of sampling cell i ,

C was the combined area of all the cells sampled,

y_{ih} was the variable of interest (e.g., concentration of mercury), and

n was the number of cells sampled.

The standard error was calculated using the jackknife estimator (Cochran 1977; Efron and Gong 1983):

$$F_j = \{[(n-1)/n]E(:_{(i)} - :_{(j)})^2\}^{1/2}$$

where

$$\mu_{(i)} = \frac{\sum_{j \neq i} c_j \bar{y}_j}{(C - c_i)}$$

was the weighted mean value deleting the j th cell and

$$\mu_{(\cdot)} = \sum \mu_{(i)} / n$$

was the jackknife estimate of the mean y for the n cells.

2.7.4.2 Mass Estimates

Total mass of contaminants in surficial sediments were estimated from bulk density and volume of sediment, and contaminant concentration. Wet sediment bulk density was calculated as:

$$D = (1-p)r_s + pr_w$$

where: p = porosity (mean of 0.4 assumed)

r_s = density of sediment (quartz, etc.) particles (2.65 g/cm³)
 r_w = density of water (1 g/cm³).

So, $D \approx (1-0.4) \times 2.65 + 0.4 = 2 \text{ g/cm}^3$, or $4 \text{ g/cm}^2 (= 40 \times 10^6 \text{ kg/m}^2)$ in the top two centimeters of sediment. The concentration of mercury, for example, averaged over surficial sediments in the Harbor was 0.74 ppm, dry weight (Table E-1). So, mean mercury concentration $\approx 0.74 \times (1-p) = 0.74 \times 0.6 = 0.44 \text{ ppm}$, wet weight. Therefore, the mass of mercury in surficial sediments of the Harbor was approximately:

$$\begin{aligned}
 & \text{mercury concentration} \times \text{unit mass of sediment} \times \text{Harbor surface area} \\
 &= 0.44 \text{ mg/kg} \times 40 \times 10^6 \text{ kg/km}^2 \times 501 \text{ km}^2 \\
 &= 8,800 \text{ kg Hg.}
 \end{aligned}$$

2.7.4.3 Percent of Area Estimates

Estimates of percent of area exceeding selected thresholds (e.g., mercury concentration greater than ERM) were calculated as $p = B/n$ (except in Newark Bay), where B was number of samples exceeding the threshold and n was the total number of samples in the stratum. For strata with equal inclusion probability, the exact confidence intervals for p were calculated from the binomial distribution using the formula of Hollander and Wolfe (1973). Below detection limit values were included as zero for percent of area estimates.

The confidence interval for combined strata was calculated using the normal approximation to the binomial, with the 90% confidence interval of stratified estimates of proportions, p_{st} , estimated as:

$$p_{st} \pm 1.64[\text{Var}(p_{st})]^{1/2},$$

where

$$p_{st} = \sum_{h=1}^L W_h p_h$$

$$\text{Var}(p_{st}) = \sum_{h=1}^L W_h^2 \text{Var}(p_h)$$

The formulas for estimating means and variances for Newark Bay also were used to estimate the percentage of area in Newark Bay with y values that fell into some defined class. An indicator variable, I_i , was assigned the value 1 if the value of y_i fell in a specified class, and 0 otherwise. The sample mean and variance of I_i was an estimate of the proportion of area in Newark Bay that had y values within the specified class.

2.8 SELECTION OF THRESHOLD VALUES

To conduct the data analyses needed to produce percent of area estimates, threshold values or “levels of concern” were required. The threshold values used were either proposed (proposed SQC), established by regulation or Agency guidance (e.g., *Ampelisca abdita* toxicity), or were screening guidelines (e.g., contaminant ERLs and ERMs).

2.8.1 Physical Data Thresholds

For grain size, a value of 40% silt-clay was used to distinguish between sand (<40% silt-clay) and mud (>40% silt-clay) substrate. This cut-off was established using cluster analysis on Environmental Monitoring and Assessment Program (EMAP) data from 525 randomly selected sites, sampled between 1990 and 1993 in the Virginian Province.

2.8.2 Chemical Data Thresholds

For chemical contaminants, three conventions were evaluated: 1) the “Effects Range-Low (ERL)” and “Effects Range-Median (ERM)” values of Long and Morgan (1991) and Long et al. (1995a); 2) two conventions which incorporate equilibrium partitioning theory (U.S.EPA, 1994): Proposed Sediment Quality Criteria (SQC) and Acid Volatile Sulfides (AVS); and, 3) aluminum normalization for metals (Appendix D).

For determination of potential biological effects, this study’s chemical data, except dioxins and furans, were evaluated using the effects-based guidelines of Long and Morgan (1991) and Long et al. (1995a). This approach utilizes data from laboratory spiked bioassays, equilibrium partitioning models and synoptic chemical and biological data from field surveys. Ranges of chemical concentrations are determined that are usually associated with biological effects (Effects Range-Median or ERM), and at which biological effects begin to be seen (Effects Range-Low or ERL). New York State has adopted some of these ERLs and ERMs for Sediment Guidance Criteria (NYSDEC, 1994 and 1996). The Long and Morgan (1991) and Long et al. (1995a) values were used because they include thresholds for most of the chemicals that were measured, allowing this study to provide an integrated contaminant response. Alternative thresholds and evaluation methods, such as proposed sediment quality criteria (U.S.EPA, 1994),

SEM-AVS (DiToro et al., 1990; NOAA, 1995) and aluminum normalization (Appendix D) also were applied.

Concentrations of seventeen dioxin and furan congeners also were measured in sediments of three sub-basins: Jamaica Bay, Lower Harbor and Upper Harbor. Sediments that are contaminated with dioxins and furans contain a complex mixture of congeners. Individual congeners differ greatly in their toxicity and carcinogenicity and although specific individual congeners may not be present in concentrations of concern, the combined effect of existing concentrations may be toxicity. A “toxicity equivalency factor (TEF)” was applied to each congener, then summed across all dioxin and furan congeners to give “toxicity equivalents (TEQ)”. This permitted estimation of total dioxin/furan toxicity (U.S.EPA, 1989; Cura et al., 1995). The TEQs calculated were for human health application. TEFs for aquatic organisms are still in the development stage and do not address all congeners. Therefore, comparison to interim guidelines was made for 2,3,7,8-TCDD risk to aquatic life and associated wildlife. A level of 100 pg/g 2,3,7,8,-TCDD has been suggested as interim guidance for high risk to sensitive fish species (U.S.EPA, 1993c).

2.8.3 Sediment Toxicity Thresholds

Significant toxicity for the amphipod, *A. abdita*, was defined as survival less than or equal to 80% of the mean control survival and statistically different ($p < 0.05$) from controls (U.S.EPA/U.S.ACE, 1991). For Microtox™, a significant effect was defined as an EC_{50} statistically less ($p < .05$) than the performance control and 70% or less of the control EC_{50} . This 70% criterion is used by the Puget Sound Dredge Disposal Analysis (PSDDA, 1989).

2.8.4 Benthic Index Thresholds

Threshold values for each measure (metric) in the NY/NJ Harbor Benthic Index of Biotic Integrity (B-IBI) were established based on the distribution of its values at reference sites. Similar to the Index of Biotic Integrity (IBI) approach (Kerans and Karr, 1994), each measure was scored as 5, 3, or 1 based on whether its value at a site approximated, deviated slightly from, or deviated greatly from conditions at the best reference sites. Threshold values were established at the 5th and 50th (median) values for reference sites in each habitat. Metric values below the 5th percentile compared to the reference sites were scored as a 1; values between the 5th and 50th percentile were scored as a 3; and values above the 50th percentile were scored as a 5. An index value for a location was calculated by taking the mean of the scores for the individual measures at a location. If the mean of all the benthic index metrics at a location was less than or equal to 3, the location was considered to have impacted benthos.

3.0 PHYSICAL PARAMETERS

3.1 BACKGROUND

Many factors potentially influence chemical and biological measurements. The measurement of physical parameters provides information necessary to interpret chemical and biological data accurately. Sediment grain size and total organic carbon content can determine the magnitude and distribution of contaminants (Burton, 1995). Fine-grained sediments generally retain more contamination than sands because of the greater surface area to volume ratio of fine particles and surface electric charges that can render them more chemically and biologically reactive (Plumb, 1981; Power and Chapman, 1995). Physical characteristics, such as salinity, sediment type and depth, are important parameters because they can influence the distribution and abundance of benthic assemblages (Snelgrove and Butman, 1994; Holland et al., 1989).

At each site where sediment was collected, water column depth, temperature, salinity, and dissolved oxygen were measured. The water column measurements consisted of a single CTD profile at each station. Physical characteristics of the sediments included grain size (as % silt-clay) and total organic carbon (TOC) content.

3.2 CHARACTERIZATION OF THE HARBOR

3.2.1 Depth

All Harbor sub-basins, except the Upper Harbor, had similar mean depths (Table 3-1). The Upper Harbor mean at 10 m, was 3-4 m deeper than other sub-basins in the Harbor. The mean

Table 3-1
Area-Weighted Means of Depth and Sediment Physical Parameters
 (± 90% confidence interval)

	Harbor	Jamaica Bay	Newark Bay	Lower Harbor	Upper Harbor	W.LI. Sound	Bight Apex
Depth (m)	6.9 ±0.9	6.4 ±1.1	6.7 ±1.5	5.9 ±1.2	10.1 ±1.8	16.6 ±2.4	22.2 ±2.8
% Silt-Clay	34.8 ±6.1	30.3 ±9.7	68.1 ±8.6	26.8 ±8.8	51.0 ±10.1	63.2 ±10.5	7.7 ±3.4
% TOC	1.9 ±0.3	1.9 ±0.7	2.3 ±0.6	1.7 ±0.4	2.5 ±0.5	2.3 ±0.7	1.2 ±0.4

depth for the entire Harbor was 7 m. Portions of the Harbor are dredged to maintain shipping channels.

3.2.2 Percent Silt-Clay

The mean percent silt-clay varied greatly among sub-basins (Figure 3-1). Average percent silt-clay in sediments of the entire Harbor was 35%. Newark Bay was the muddiest sub-basin with 68% silt-clay and Lower Harbor was the sandiest with only 26% silt-clay. These same patterns were also apparent when results are expressed as areal extent. In terms of spatial extent, 39% of the Harbor is predominantly mud (>40% silt-clay). Eighty-five percent of Newark Bay was dominated by mud compared to 29% of Jamaica Bay and Lower Harbor.

3.2.3 Total Organic Carbon (TOC)

The average total organic carbon (TOC) in Harbor sub-basins ranged from 1.7 to 2.5%, with the sub-basins not significantly different from one another (Table 3-1). When TOC was examined on an areal basis, the sub-basins were not as similar, with Upper Harbor, Newark Bay and Lower Harbor having a considerable percent of area with TOC exceeding 1.5% (Figure 3-2). Sixty-two percent of the sediments in the Harbor contained between 0.5 and 3.4% TOC. There also were no sites in Newark Bay where TOC was less than 0.5%, whereas TOC less than 0.5% occurred over at least 10% of the area in every other sub-basin.

3.2.4 Water Column Profile

The water column results are all based on a single measurement at each station during the study period.

All sub-basins were similar to one another with regard to mean bottom water temperature during the sampling timeframe (Table 3-2). Means ranged from 20.8°C in Jamaica Bay to 23.4°C in Newark Bay. Mean bottom water temperature for the entire Harbor was 22.0°C.

Mean bottom salinity for the entire Harbor was 26.2 ppt. Newark Bay had an average salinity of 22.4 ppt, which was significantly lower ($p < 0.01$) than any of the other systems. The lowest salinity value measured during the study was 1.3 ppt in the Passaic River; all other values exceeded 12 ppt.

In general, dissolved oxygen concentrations are extremely variable temporally and spatially. This study obtained a single measurement of dissolved oxygen at each station. New York City has a more complete dissolved oxygen data set (Brosnan and O'Shea, 1994; 1995) which was

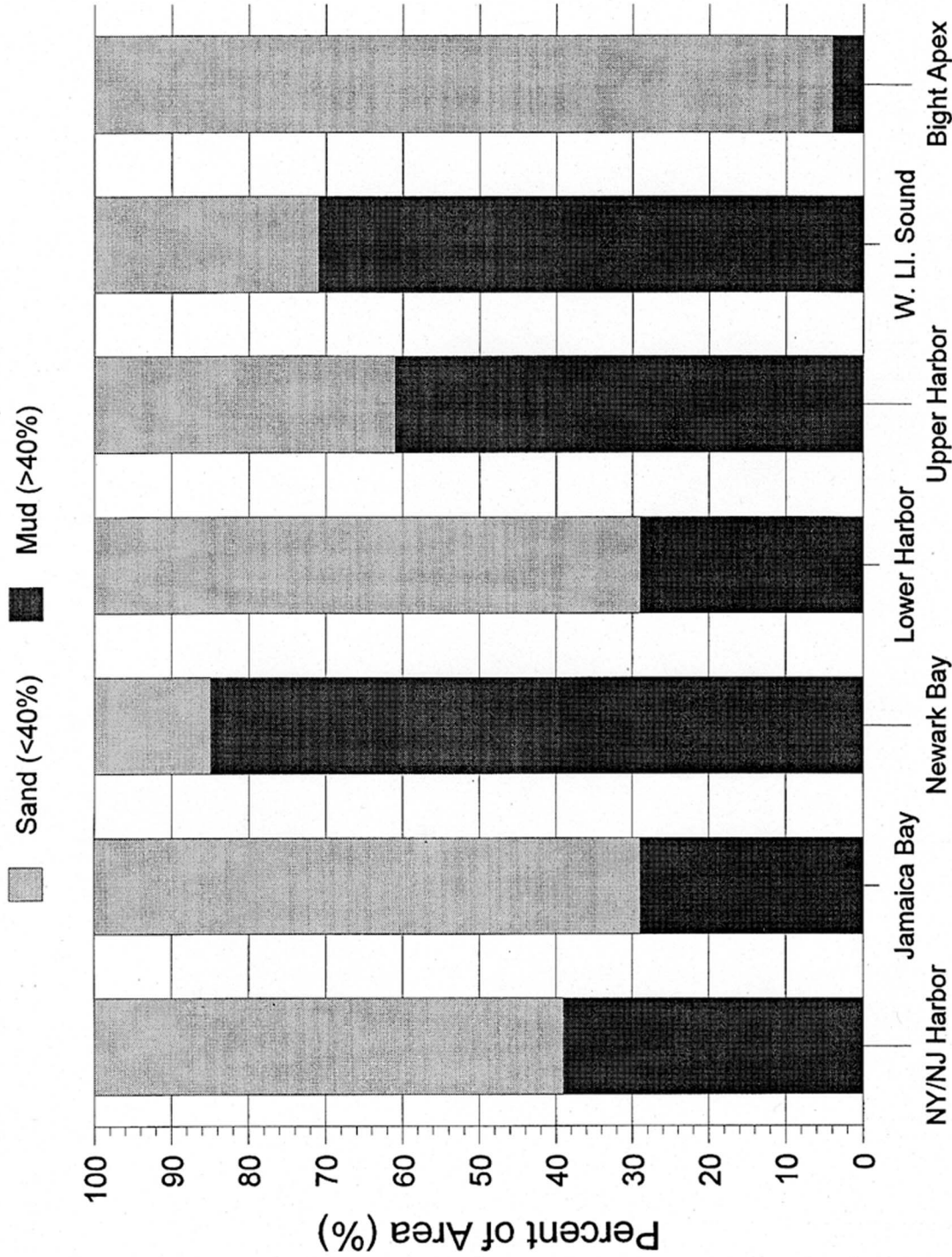


Figure 3-1. Percent of area distribution of substrate type (as % silt/clay).

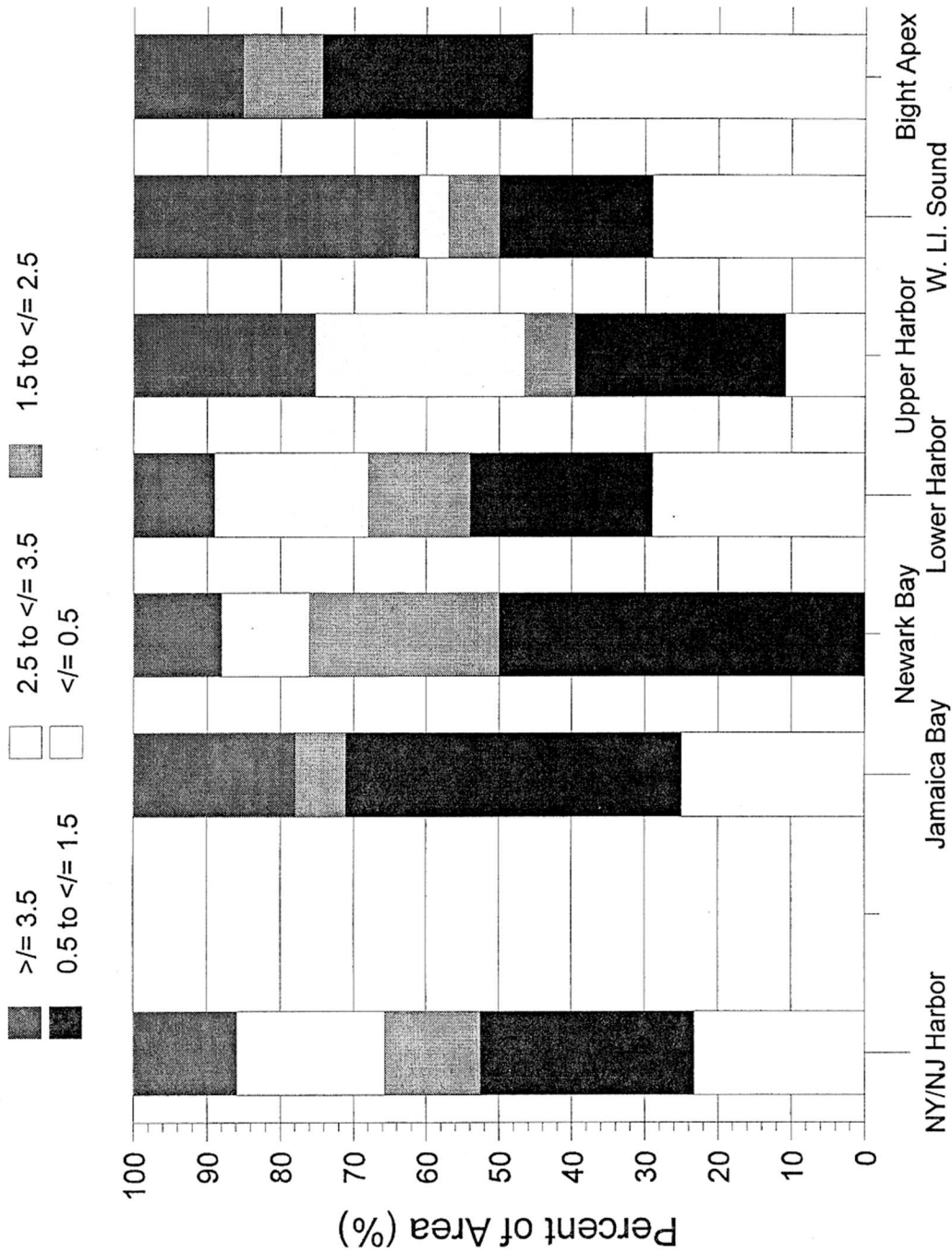


Figure 3-2. Percent of area distribution of total organic carbon levels (%).

used for developing the benthic index. Therefore, dissolved oxygen results from this investigation were not reported here.

Table 3-2
Area-Weighted Means of Water Column Physical Parameters
 (± 90% confidence interval)

	Harbor	Jamaica Bay	Newark Bay	Lower Harbor	Upper Harbor	W.L.I. Sound	Bight Apex
Bottom Temp. (°C)	22.0 ±0.5	20.8 ±0.5	23.4 ±0.8	22.3 ±0.7	21.3 ±0.9	17.5 ±0.6	11.1 ±1.2
Bottom Salinity (ppt)	26.2 ±0.4	27.1 ±0.5	22.4 ±0.8	26.9 ±0.5	24.8 ±1.5	28.7 ±0.6	33.6 ±0.9

3.3 CHARACTERIZATION OF WESTERN LONG ISLAND SOUND AND THE BIGHT APEX

3.3.1 Depth

Western Long Island Sound and the Bight Apex were both, on average, about 20 m deeper than the Harbor (Table 3-1).

3.3.2 Percent Silt-Clay

The Bight Apex had a low mean % silt-clay compared to the Harbor (8% versus 35%) and was the sandiest sub-basin in the study (Figure 3-1). The mean % silt-clay in western Long Island Sound (63%) was comparable to Newark Bay (68%) and approximately double that of the Harbor. Fifty percent of the area of western Long Island Sound was mud compared to 4% of the Bight Apex (Figure 3-1).

3.3.3 Total Organic Carbon (TOC)

TOC levels in the Bight Apex were significantly less than in the Harbor (Table 3-1). The Bight Apex had a mean of 1.2 % TOC. The mean in western Long Island Sound was comparable to Newark Bay and Upper Harbor. Forty-six percent of the area in the Bight Apex had less than 0.5% TOC, compared to 29% in western Long Island Sound (Figure 3-2).

3.3.4 Water Column Profile

The average bottom water temperature in the Bight Apex, at 11.1°C, was 11°C less than the Harbor mean and the lowest of all the sub-basins (Table 3-2). The average for western Long Island Sound was 17.5°C.

The Bight Apex had an average salinity of 34.6 ppt, and western Long Island Sound, 28.7 ppt (Table 3-2). Both were higher than the Harbor mean or other sub-basins.

Because of the spatial and temporal variability of dissolved oxygen levels and the fact that this investigation obtained a single dissolved oxygen measurement at each station, those results are not included here.

3.4 COMPARISON TO PREVIOUS STUDIES

Several other investigations and monitoring programs have produced physical data for the Harbor and/or Bight Apex. TOC and grain size in the Harbor have been measured as part of other contaminant investigations (Long et al., 1995b; Strobel et al., 1995) and as study objectives (Suszkowski, 1978; Jones et al., 1979; Coch, 1986). The most spatially and temporally extensive database for dissolved oxygen, temperature and salinity is that of the New York City Department of Environmental Protection (NYCDEP) which sampled 52 stations at least bi-monthly year-round (weekly in the summer) in the Harbor in 1993 and 1994 (Brosnan and O'Shea, 1994; 1995). U.S.EPA conducted monitoring of dissolved oxygen and temperature in the Bight Apex (U.S.EPA-Region 2, 1994g; 1995). The data from the present study were collected to aid in interpretation of other study parameters and were not intended to represent comprehensive temporal coverage.

Physical data collected during this investigation was similar to historical data. The Harbor mean TOC for the present study was 1.9%. The Long et al. (1995b) investigation (using similar sub-basin boundaries to the present investigation) produced a range of 0.07% to 5.0% and a mean of 2.6%. Long et al. found a range of 0.0% to 76.7% silt-clay in the Harbor, with a mean of 39.3% silt-clay as compared to a mean of 34.8% in the present investigation. An earlier study by Coch (1978), incorporating data from Suszkowski (1978), showed that Newark Bay was 66% silt-clay; this study produced an estimate of 68%. The area that is approximately Upper Harbor in the present study had 51% of its area predominantly mud, compared to 34% in the Coch investigation. Other basin boundaries in the Coch investigation were significantly different to preclude direct comparison with the present investigation. Additionally, grain size and TOC distributions in the Harbor may have substantially changed.

Salinity and temperature measurements were similar between this and other investigations.

4.0 SEDIMENT CHEMISTRY

4.1 BACKGROUND

Chemically contaminated sediments, directly and indirectly, pose a significant threat to Harbor resources. Striped bass, bluefish and blue claw crabs from large portions of the estuary should not be consumed because the levels of PCBs and/or dioxins exceed guidelines (NY-NJ HEP, 1996). Areas that were once productive shellfish beds no longer exist or have reduced populations that are restricted for harvesting. Bioaccumulation of contaminants and effects on benthic macroinvertebrate communities also have been observed. Dredging and disposal of contaminated sediments is a major management issue because of the potential adverse biological effects that could result in disposal areas.

For determination of potential biological effects, chemical data, except that for dioxins and furans, were evaluated using the aquatic effects-based guidelines of Long and Morgan (1991) and Long et al. (1995a). This approach utilizes data from laboratory spiked bioassays, equilibrium partitioning models and synoptic chemical and biological data from field surveys. Two concentrations are determined for each chemical that are associated with incidence of biological effects in the dataset that was used for development (Table 4-1). The Effects Range-Low (ERL) value is the concentration at which adverse biological effects begin to be seen, and the Effects Range-Median (ERM) concentration is that usually associated with adverse biological effects. New York State has adopted some of the ERLs and ERMs for Sediment Guidance Criteria (NYSDEC, 1994 and 1996). The Long and Morgan (1991) and Long et al. (1995a) values were used because they include thresholds for most of the chemicals that were measured, allowing this study to provide an integrated contaminant response. Alternative thresholds and evaluation methods, such as proposed sediment quality criteria (U.S.EPA, 1994), SEM-AVS (DiToro et al., 1990; NOAA, 1995) and aluminum normalization also were applied.

Concentrations of seventeen dioxin and furan congeners were measured in sediments of three sub-basins: Jamaica Bay, Lower Harbor and Upper Harbor. Sediments that are contaminated with dioxins and furans contain a complex mixture of congeners. Individual congeners differ greatly in their toxicity and although individual congeners may not be present in concentrations of concern, their combined concentrations may be toxic. A “toxicity equivalency factor (TEF)” was applied to each congener, then summed across all dioxin and furan congeners to give “toxicity equivalents (TEQ)”. This permits estimation of total dioxin/furan toxicity, expressed as an equivalent amount of 2,3,7,8-TCDD (U.S.EPA, 1989; Cura et al., 1995). TEFs for aquatic organisms are still in the development stage and do not address all congeners. A level of 100 pg/g 2,3,7,8-TCDD has been suggested as interim guidance for high risk to sensitive fish species (U.S.EPA, 1993c).

Table 4-1
ERL and ERM Concentrations for Sediment Trace Metals and Organic Compounds
 (Long and Morgan, 1991; Long et al., 1995a)

Chemical Analyte	ERL Concentration	ERM Concentration
Trace Elements (ppm)		
Antimony	2	25
Arsenic	8.2	70
Cadmium	1.2	9.6
Chromium	81	370
Copper	34	270
Lead	46.7	218
Mercury	0.15	0.71
Nickel	20.9	51.6
Silver	1	3.7
Zinc	150	410
Polychlorinated Biphenyls (ppb)		
Total PCBs	22.7	180
DDT and Metabolites (ppb)		
DDT	1	7
DDD	2	20
p,p'-DDE	2.2	27
DDE	2	15
Total DDT	1.58	46.1
Other Pesticides (ppb)		
Chlordane	0.5	6
Dieldrin	0.02	8
Endrin	0.02	45
Polynuclear Aromatic Hydrocarbons (ppb)		
Acenaphthene	16	500
Acenaphthylene	44	640
Anthracene	85.3	1100
Benzo(a)anthracene	261	1600
Benzo(a)pyrene	430	1600
Chrysene	384	2800
Dibenz(a,h)anthracene	63.4	260
Fluoranthene	600	5100
Fluorene	19	540
2-Methylnaphthalene	70	670
Naphthalene	160	2100
Phenanthrene	240	1500
Low molecular weight PAHs	552	3160
High molecular weight PAHs	1700	9600
Pyrene	665	2600
Total PAH	4022	44792

4.2 CHARACTERIZATION OF THE HARBOR

4.2.1 Mean Condition

Chemical contamination was found to be pervasive in the Harbor. The mean values for every contaminant for which ERL and ERM thresholds exist, except cadmium, were above ERL levels (Appendix E). The Harbor means for mercury, parent DDT and total PCBs exceeded ERM values.

Of the Harbor sub-basins, Newark Bay had the highest average concentration of all the metals measured, except for manganese and silicon (Appendix E).

The Upper Harbor had the highest mean concentrations of individual and total PAHs and endrin, but for all other organic contaminants, Newark Bay had the highest mean concentration. For chemicals in the DDT family (e.g., parent DDT, DDD, DDE and total DDT), Newark Bay had a mean concentration that was 10 or more times higher than the next highest sub-basin.

The mean concentration of tributyltins in the Harbor was 30.1 ppb. Mean concentrations in Jamaica Bay and Upper Harbor were similar (38.6 and 32.5 ppb). Newark Bay's average concentration was about twice as high (69.3 ppb). Tributyltin threshold concentrations for biological effects have not been defined.

4.2.2 Areal Extent

Chemical contamination was present throughout the Harbor. When expressed on an area basis, 87% of the Harbor exceeded an ERL concentration for at least one contaminant, and 50% of the Harbor exceeded an ERM concentration for at least one contaminant (Figure 4-1).

Within the Harbor, Newark Bay and the Upper Harbor had the most pervasive contaminant problem, with 92% and 79% of their areas, respectively, exceeding an ERM value for at least one chemical. These two sub-basins, at 98% and 100%, also had the highest percent of area exceeding at least five ERLs. The entire Harbor exceeded five or more ERLs at 57% of its area.

Estimates of the percent of area in the Harbor that exceeded an ERL and/or ERM for any metal, pesticide, PAH and total PCBs showed that all contaminant groups appeared to contribute to Harbor contamination (Figure 4-1). No single contaminant group predominated. Metals, pesticides and total PCBs contaminated approximately the same percentages of the Harbor at ERM levels.

Examination of the individual chemicals showed that mercury, chlordane and total PCBs were the most pervasive at levels above ERMs. The most ubiquitous metal was mercury, with 75% of the area of the Harbor exceeding the ERL and 34% exceeding the ERM (Figure 4-2). All other

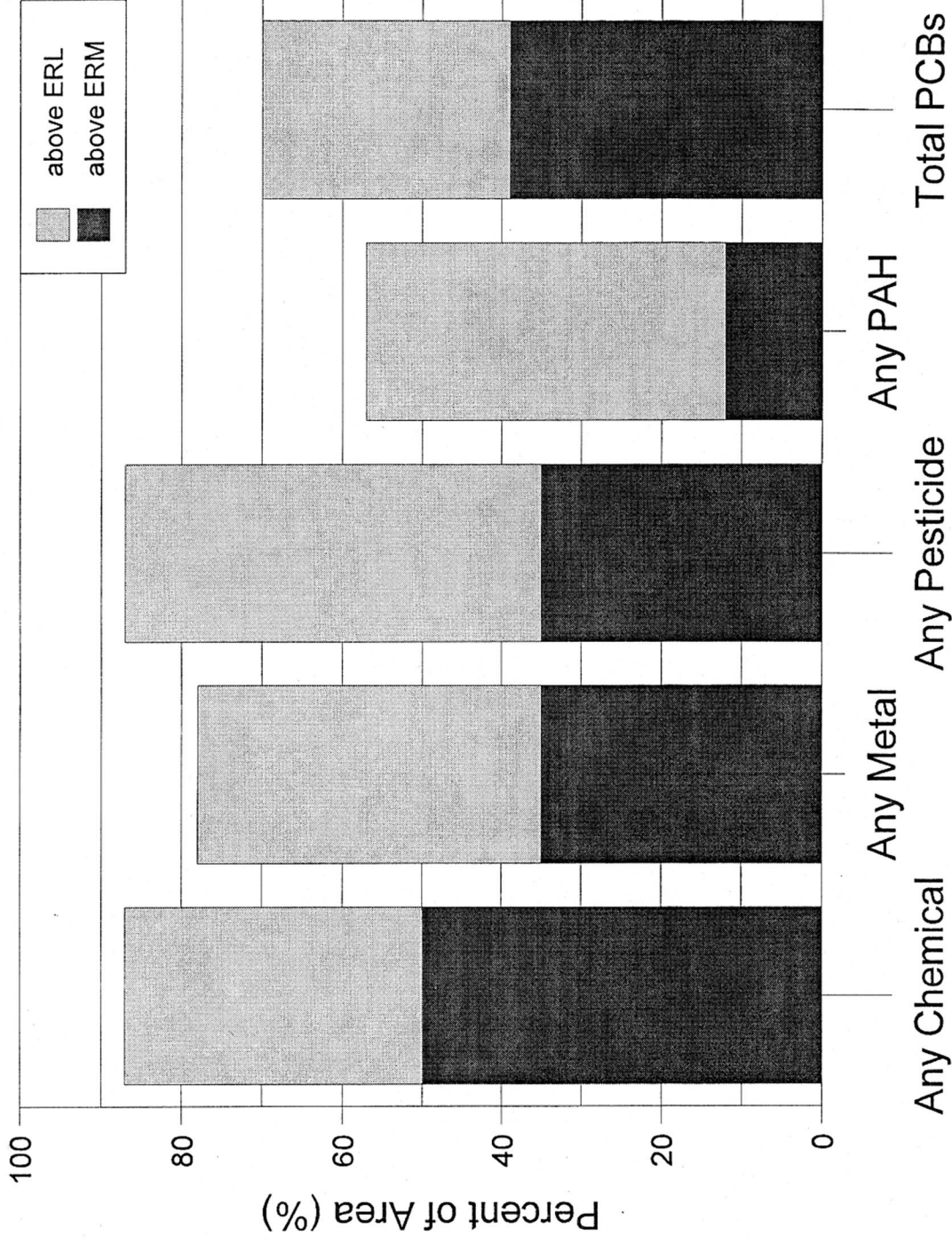


Figure 4-1. Percent of area (%) with any chemical or chemicals within groups exceeding an ERL or ERM (Long & Morgan, 1991; Long et al., 1995a) in the Harbor.

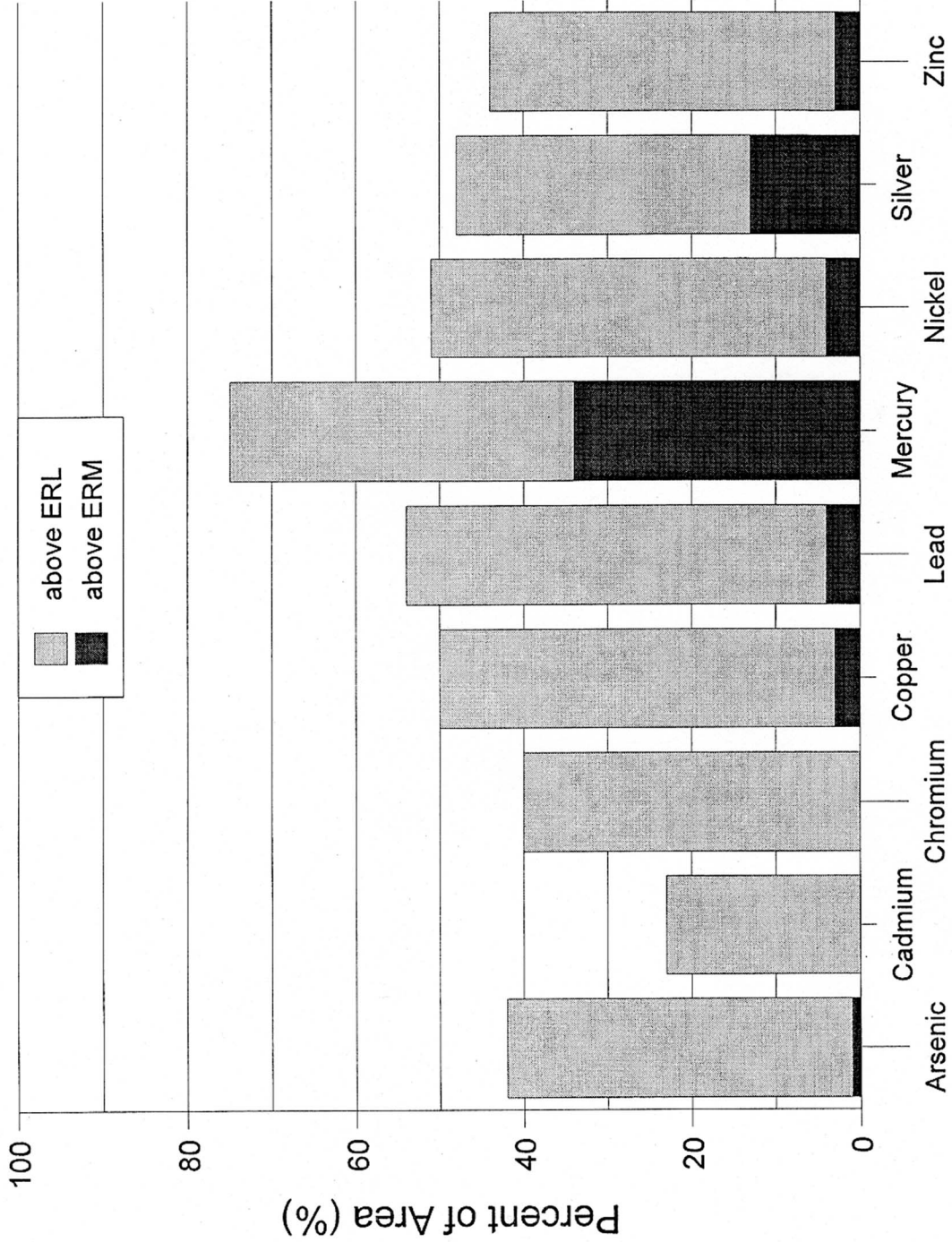


Figure 4-2. Percent of area (%) greater than ERL and ERM values (Long & Morgan, 1991; Long et al., 1995a) for individual metals in the Harbor.

metals also caused significant amounts of area, ranging from 23 to 54%, to exceed an ERL value. Of the pesticides, chlordane resulted in the greatest percent area (32%) above an ERM (Figure 4-3). Organic contaminants above ERL values affected from 56% to 83% of the Harbor area.

The distribution of individual chemicals was not uniform across sub-basins (Appendix E). Many of the individual chemicals were sub-basin specific. Several, such as mercury and chlordane, were ubiquitous. Mercury had the highest percent area of all the metals exceeding an ERM. Focusing on mercury in each of the sub-basins showed that 91% of the area in Newark Bay and 46% of the area in the Upper Harbor exceeded the ERM concentration (Figure 4-4). Chlordane, the most prevalent pesticide Harbor-wide at a level that has probable biological effects, exceeded the ERM in 91% of Newark Bay. All sub-basins had some area above the ERM concentration for chlordane (Figure 4-5).

It was possible to distinguish some general patterns of chemical distribution in sediments. The pattern of mercury distribution in the Harbor indicated that a possible source or sources exist in or above Newark Bay (Figure 4-6). Concentrations were elevated down the Arthur Kill across Raritan Bay to Sandy Hook Bay, following the circulation pattern for this part of the Harbor. Total PCBs (Figure 4-7) and total PAHs (Figure 4-8) exhibited similar patterns.

The actual area above and below specified threshold levels was calculated, in addition to percent of area. Approximately 436 of the Harbor's 501 km² were above the ERL for at least one contaminant and approximately 250 km² were above the ERM for a least one contaminant. The total area for specific contaminants also was estimated. Mercury and total PCBs concentrations above ERMs affected approximately the same total area of the Harbor (Figure 4-9). Although Newark Bay had pervasive, elevated levels of these contaminants, because of its small relative size, it did not contribute as much as other sub-basins to the total contaminated area.

Total mass of contaminants in the surficial sediments was also calculated. As an example, the estimated mass of mercury in the Harbor was more than three times that of total PCBs (Figure 4-10). Comparing sub-basins, a higher quantity of mercury and total PCBs was estimated for the Bight Apex, despite the low concentration of these chemicals in that sub-basin.

4.2.3 Dioxins and Furans

Concentrations of seventeen congeners of dioxins and furans were measured at each station in Jamaica Bay, Lower Harbor and Upper Harbor. The biotic effects of dioxins and furans are roughly additive, although congeners differ greatly in their toxicity and carcinogenicity. These features were of concern because most sediments, if contaminated with dioxins and furans, have them present as complex mixtures and although individual congeners may not be present in concentrations of concern, their combined concentrations may be toxic. A "toxicity equivalency factor" has been quantified for each congener, allowing estimation of total dioxin/furan toxicity, expressed as "toxicity equivalents" (U.S.EPA, 1989; Cura et al., 1995).

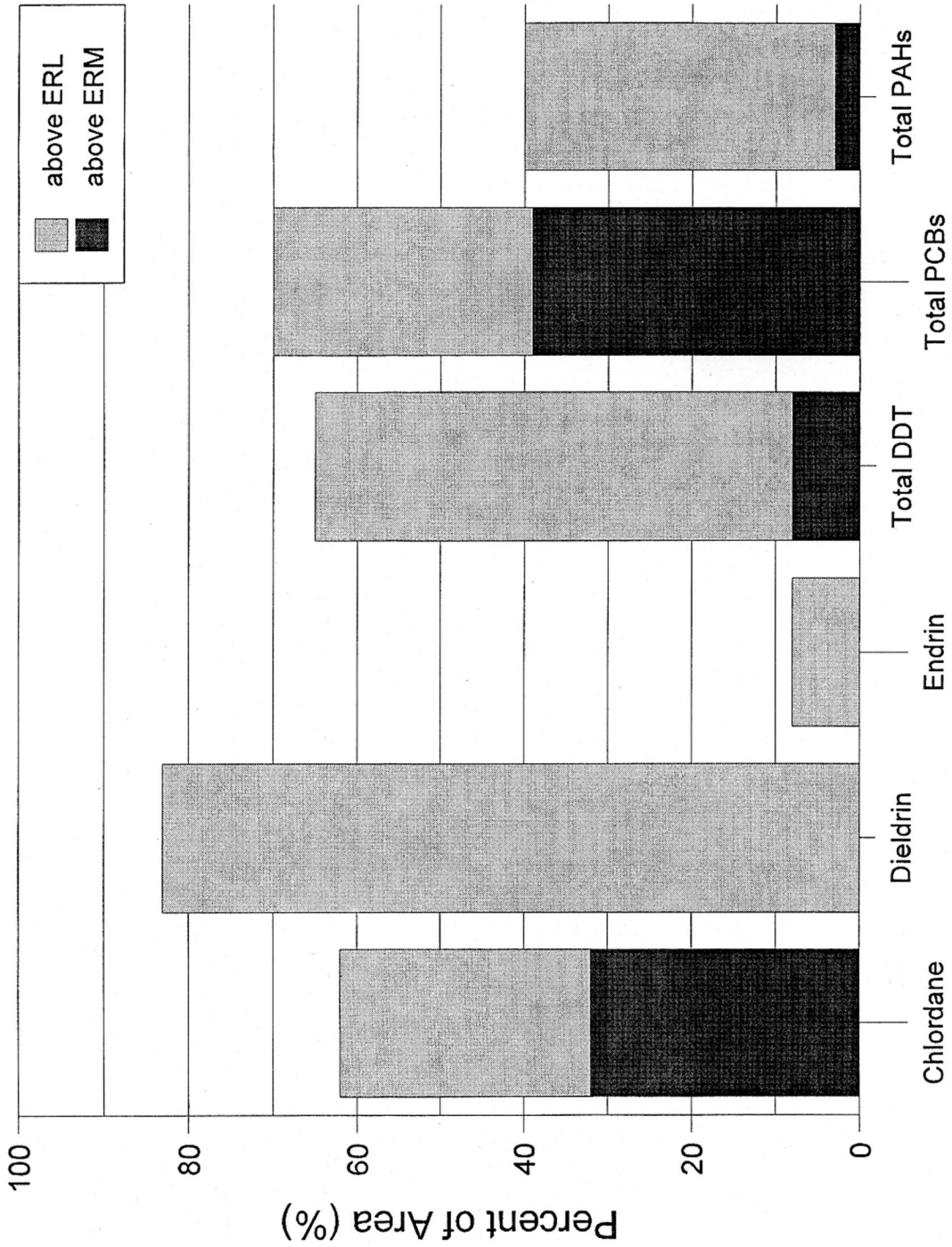


Figure 4-3. Percent of area (%) greater than ERL and ERM values (Long & Morgan, 1991; Long et al., 1995a) for individual or classes of organics in the Harbor.

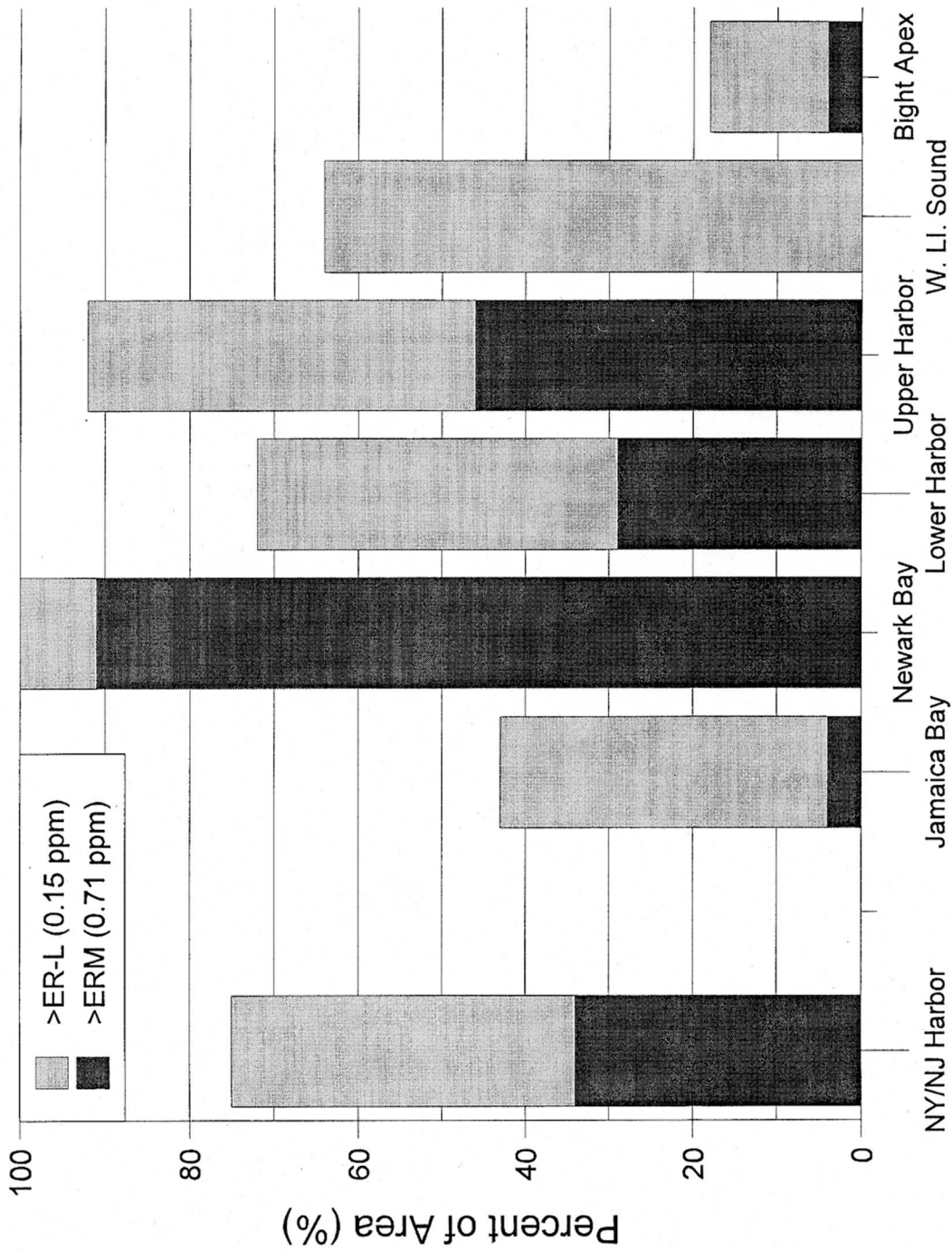


Figure 4-4. Percent of area (%) exceeding the mercury ERL and ERM (Long & Morgan, 1991; Long et al., 1995a).

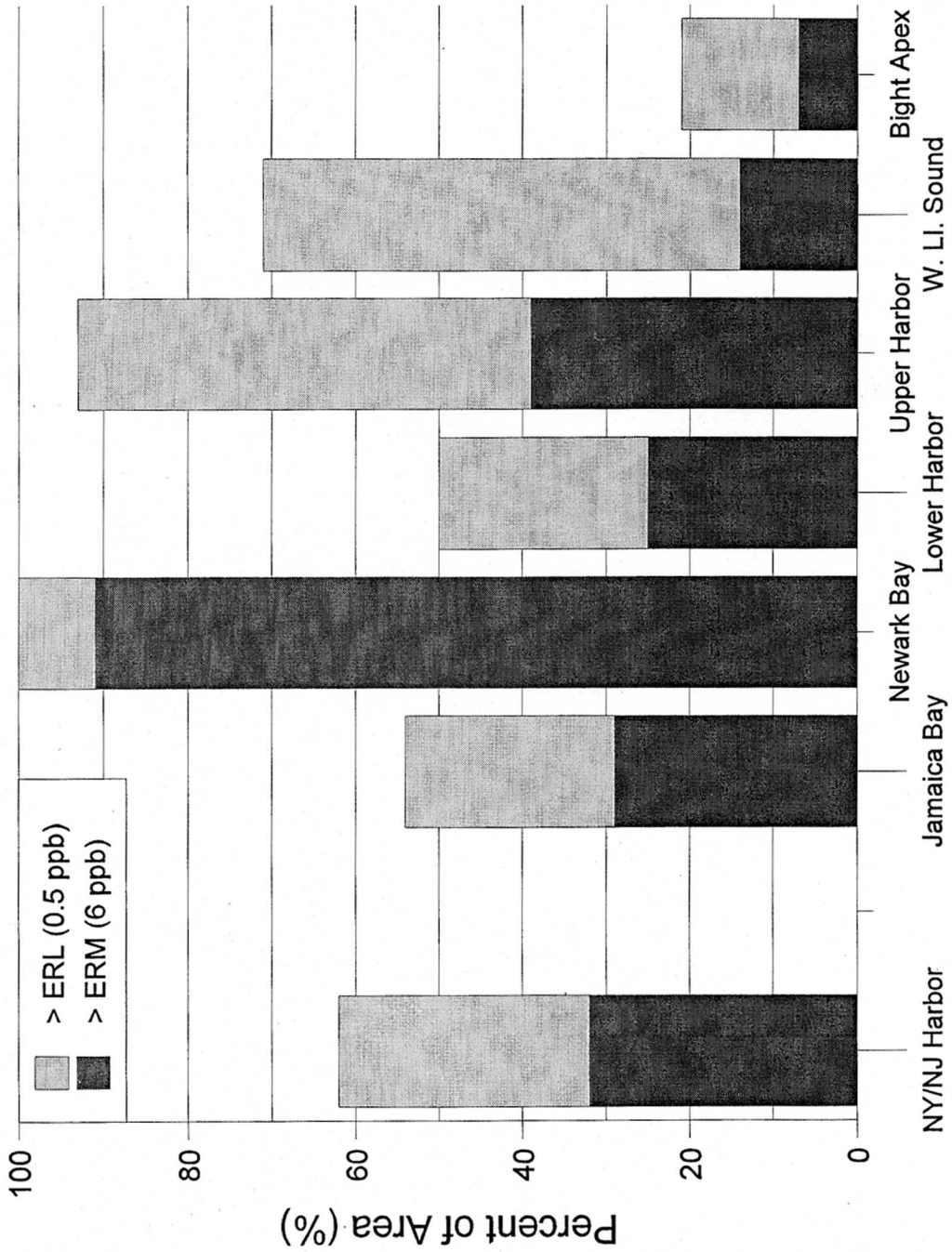


Figure 4-5. Percent of area (%) exceeding the chlordane ERL and ERM (Long & Morgan, 1991; Long et al., 1995a).

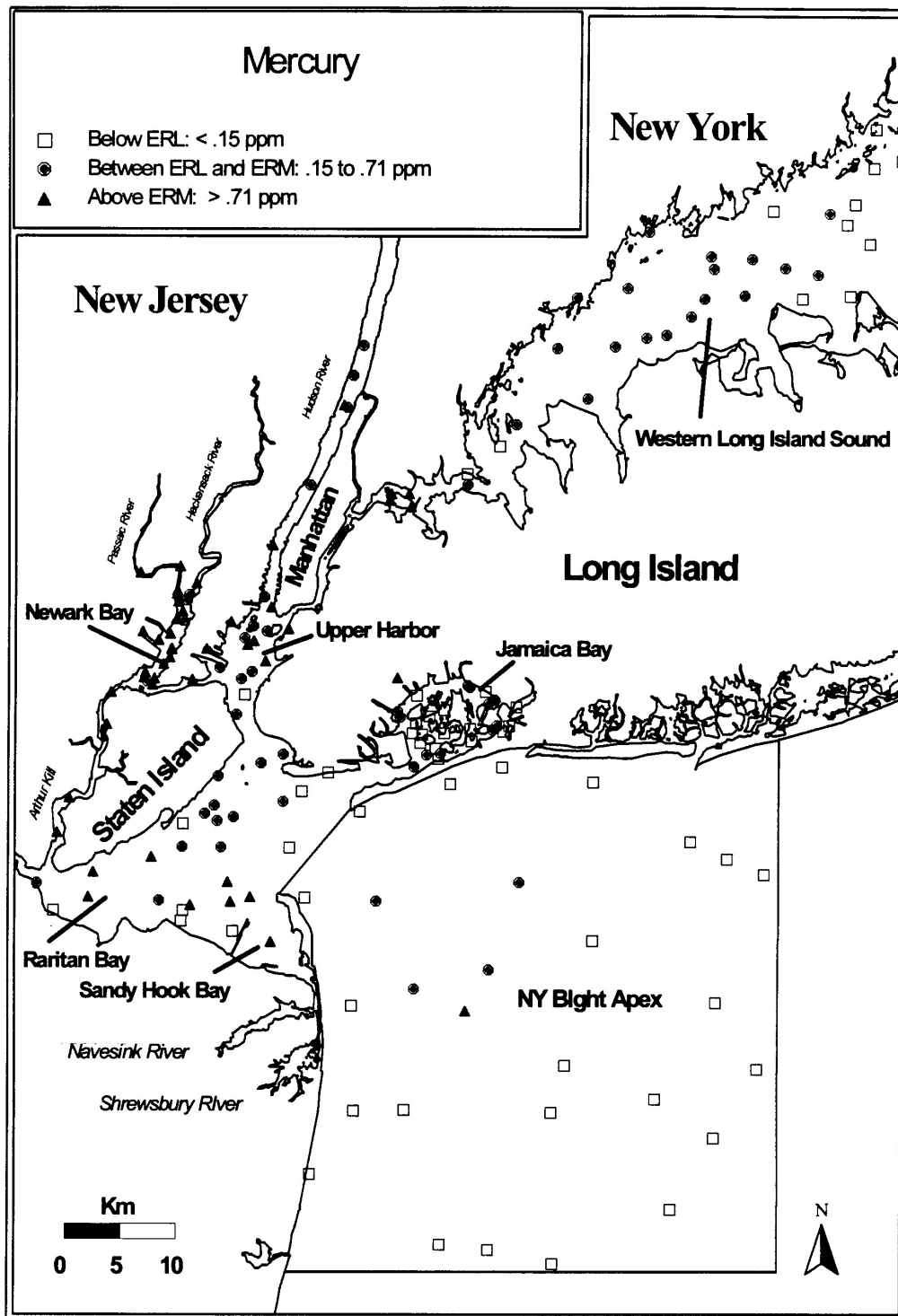


Figure 4-6. Distribution of sediment mercury concentrations by station. ERL and ERM values (Long et al., 1995a) are equivalent to NY State Sediment Guidance Criteria lowest and severe effects levels (NYSDEC, 1994 and 1996).

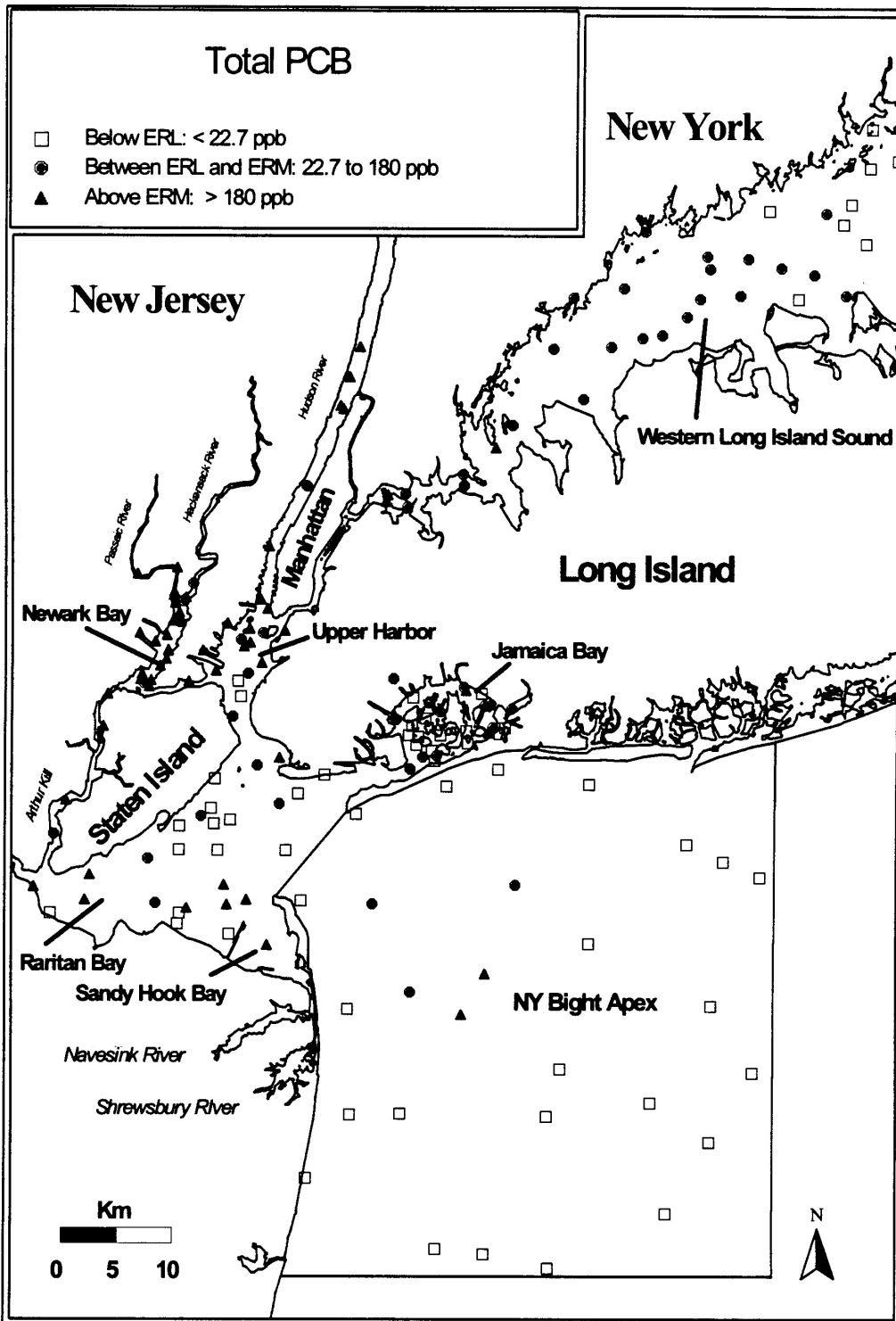


Figure 4-7. Distribution of sediment Total PCB concentrations by station. TPCB is the product of the sum of the 20 congeners in Table 2-3 and 2.0 (NOAA, 1989). ERL and ERM values are according to Long et. al. (1995a).

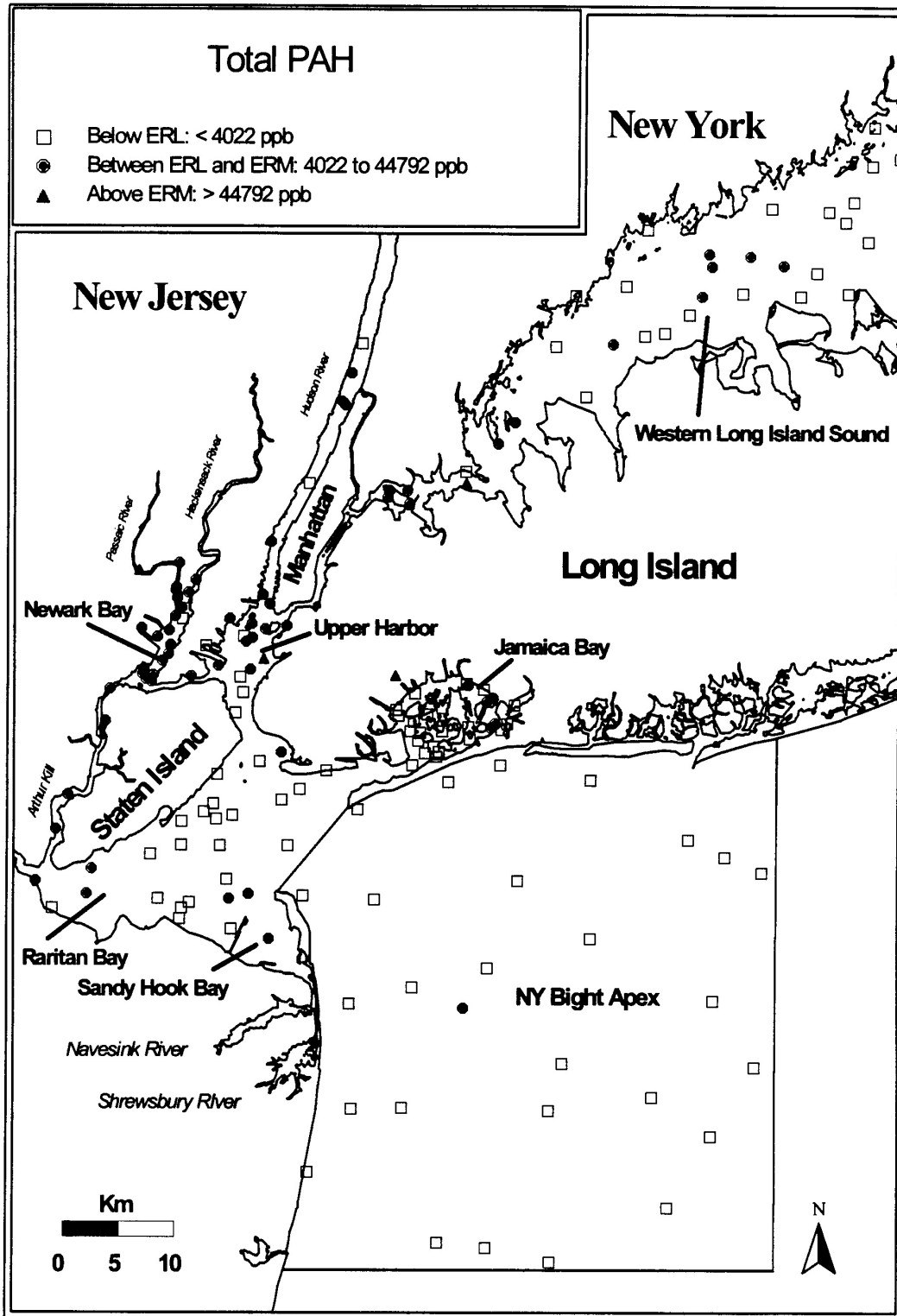


Figure 4-8. Distribution of sediment Total PAH concentrations by station. TPAH is the sum of the 23 individual PAHs in Table 2-3. ERL and ERM values are according to Long et. al. (1995a).

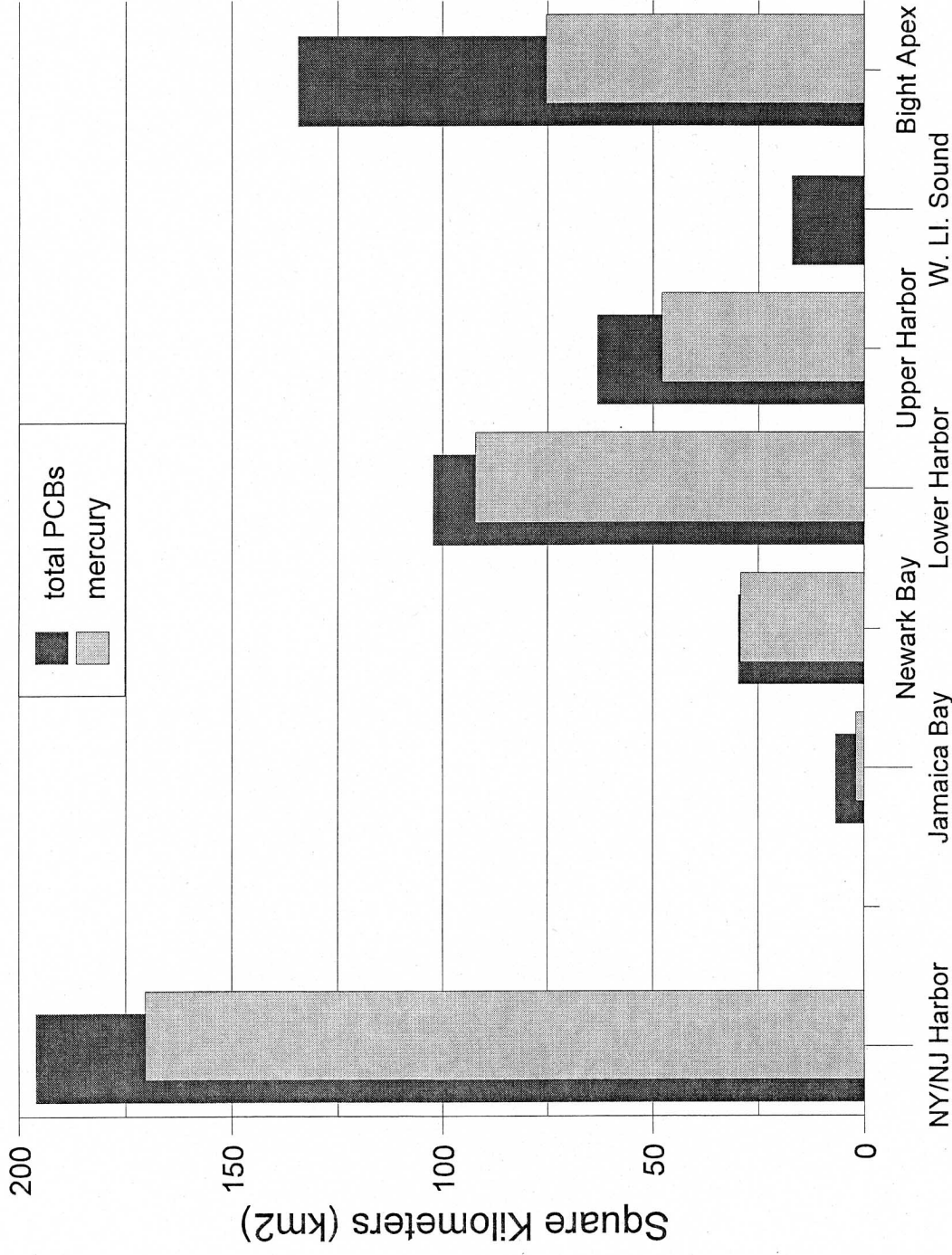


Figure 4-9. Total area (km²) above the mercury and total PCB ERMs (Long et al., 1995a). The area of the Harbor is 501 km².

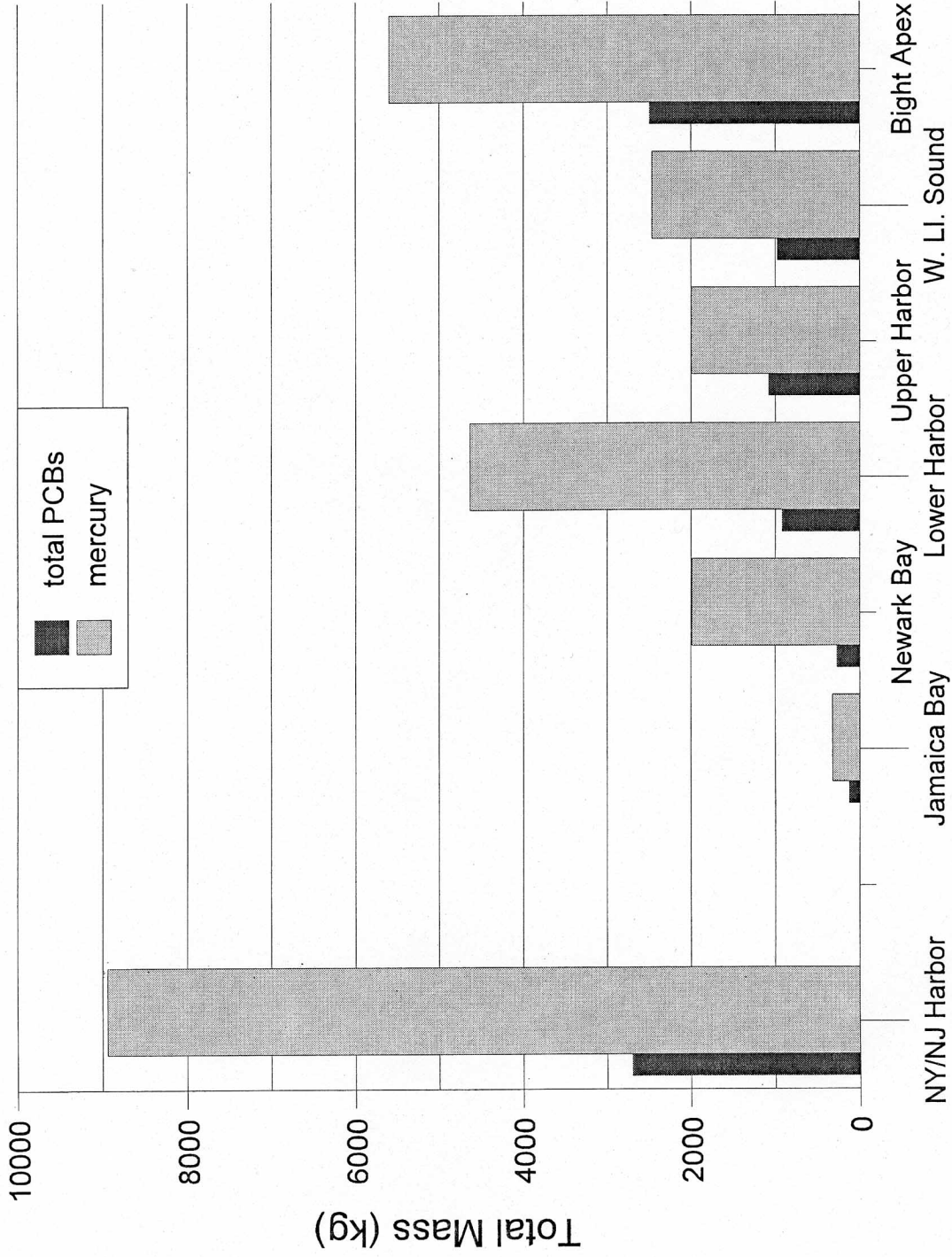


Figure 4-10. Total mass (kg) of mercury and total PCBs in surficial sediments of the Harbor (based on area-weighted mean concentrations).

Among the three sub-basins where dioxins were measured, mean concentrations of the most toxic dioxin congener, 2,3,7,8-TCDD, were highest in Lower Harbor (Table 4-2). Similarly, incorporating all congeners into the calculation of TEQs resulted in the Upper Harbor having a significantly higher amount of 2,3,7,8-TCDD equivalents than the other two sub-basins.

Table 4-2
Mean Concentrations Of 2,3,7,8-TCDD In Sediments Of Three Sub-Basins
 (± 90% confidence limits)

	2,3,7,8-TCDD (ng/kg, dry wt.)	Human Health Toxicity Equivalents
Jamaica Bay	4.0 ±2.6	16.4±9.1
Lower Harbor	7.5 ±3.4	17.0±7.1
Upper Harbor	5.5 ±1.8	22.2±5.7

Using the Biota to Sediment Accumulation Factor (BSAF) approach, EPA has derived interim guidance (U.S.EPA, 1993c) for assessing risk of 2,3,7,8-TCDD only, to aquatic life and associated wildlife (Table 4-3). Comparison of the values presented in the interim guidance to

Table 4-3
Interim Environmental Concentrations Associated With TCDD Risk To Aquatic Life And Associated Wildlife (table adapted from U.S.EPA, 1993c)

Organism	Sediment Concentration (pg/g dry wt.)
Low Risk	
Fish	60
Mammalian Wildlife	2.5
Avian Wildlife	21
High Risk to Sensitive Species	
Fish	100
Mammalian Wildlife	25
Avian Wildlife	210
<small>Fish lipid of 8% and sediment organic carbon of 3% assumed where needed. For risk to fish, BSAF of 0.3 used; for risk to wildlife, BSAF of 0.1 used. Low risk concentrations are derived from no-effects thresholds for reproductive effects (mortality in embryos and young) in sensitive species. High risk concentrations are derived from TCDD doses expected to cause 50 to 100% mortality in embryos and young of sensitive species.</small>	

the 2,3,7,8-TCDD sediment concentrations found in this study indicated less than low risk to fish and avian wildlife, with low risk to mammalian wildlife.

Using a Theoretical Bioaccumulation Approach (TBP) (U.S.EPA, 1993c), this study estimated that concentrations of 3 ppt and 21 ppt (as toxicity equivalents), would be representative of low and high risk, respectively, to mammalian wildlife consuming food contaminated with dioxins and furans (Appendix F). Applying these values to the data from the three sub-basins indicated that none of the mean concentrations found would be considered “high risk” to mammalian or avian wildlife.

4.3 CHARACTERIZATION OF WESTERN LONG ISLAND SOUND AND THE BIGHT APEX

4.3.1 Mean Condition

Overall, the Bight Apex was relatively uncontaminated when compared to the Harbor (Appendix E). Western Long Island Sound had the lowest mean for total chlordane. For all other contaminants measured, the Bight Apex had the lowest mean concentrations.

4.3.2 Areal Extent

Exceedances of at least one ERM were not as common in western Long Island Sound and the Bight Apex (21% and 7%), but western Long Island Sound exceeded at least one ERL in 100% of its area. The Bight Apex, which exceeded more than five ERLs in 18% of its area, did not have as pervasive a pattern of ERL exceedances as the Harbor.

The percent of area above specific ERL and ERM values in the Bight Apex and western Long Island Sound also was estimated. These two sub-basins had 4% and 0% of area exceeding the mercury ERM value, but 18% and 64%, respectively, exceeded the ERL. The Bight Apex had 21% of its area above the ERL concentration for total chlordane and 7% above the ERM.

4.4 ALTERNATIVE THRESHOLDS

The results presented in the last two sections have been based largely on interpreting the chemical concentrations relative to the thresholds suggested by Long et al. (1995a). The Long and Morgan (1991) and Long et al. (1995a) values are emphasized because they include thresholds for most of the chemicals that were measured, allowing this study to provide an integrated contaminant response. Other thresholds and approaches for interpreting sediment chemistry data for a more limited set of chemicals have been suggested. This section interprets the data in the context of some of those alternatives.

4.4.1 Proposed Sediment Quality Criteria

The U.S.EPA has proposed Sediment Quality Criteria (SQC) for five chemicals (U.S.EPA, 1994). This approach was based on equilibrium partitioning theory to establish individual chemical concentrations in interstitial water that do not exceed water quality criteria (WQC) (DiToro et al., 1991). SQC are normalized to the TOC content of the sediment. The approach assumes that water quality criteria are protective of infaunal organisms, chemical concentrations in the interstitial water are in equilibrium with that adsorbed to the sediment particles, and porewater is the primary route of organism exposure. The calculation incorporates an organic carbon normalization step.

Exceedances of SQC's were rare, with none of the chemicals exceeding the SQC threshold for more than 3% of the area in the Harbor (Figure 4-11). For dieldrin and endrin, no samples exceeded SQC's. In addition, none of the samples from the Bight Apex or Western Long Island Sound exceeded SQC for any chemical.

The interpretation based on SQC's was very similar to that based on the ERM thresholds for these chemicals. For three of the five chemicals, there was complete agreement between the two approaches (Figure 4-11). For fluoranthene and phenanthrene, the estimates for percent of the Harbor with exceedances between the two approaches differed by less than 3% and were not significantly different. If comparing SQC to ERL thresholds, there was no agreement, as four of the five chemicals exceed nearly 100% of the Harbor area at the ERL concentrations.

4.4.2 Acid Volatile Sulfides

Equilibrium partitioning theory also has been applied with regard to acid volatile sulfides in sediments. AVS in combination with simultaneously extracted metals (SEM) is used to indicate when several divalent metals (Cd, Cu, Ni, Pb, Zn) would not be bioavailable (DiToro, 1990). If the difference between the molar concentrations of SEM and AVS ($SEM - AVS$) is <0 , the theory states that the sulfides should be binding all of the metal and none should be available to cause toxicity (NOAA, 1995). When SEM is in excess ($SEM - AVS > 0$), the sediments are described as potentially toxic. This theory does not take into account other contaminants that could be causing an effect.

Thirty-six percent of the Harbor was found to have SEM in excess of AVS (Figure 4-12). Within the Harbor, excess SEM was most prevalent in Lower Harbor, where it occurred over 54% of the area. Excess SEM occurred in only 7% of western Long Island Sound, but occurred for more than half of the Bight Apex.

The SEM-AVS results were highly inconsistent with the ERM or ERL based metals results (Figure 4-12). Based on ERL/ERM, it appeared that metal toxicity should have been highest (or metal non-toxicity lowest) in Newark Bay, where ERM metals concentrations were exceeded for

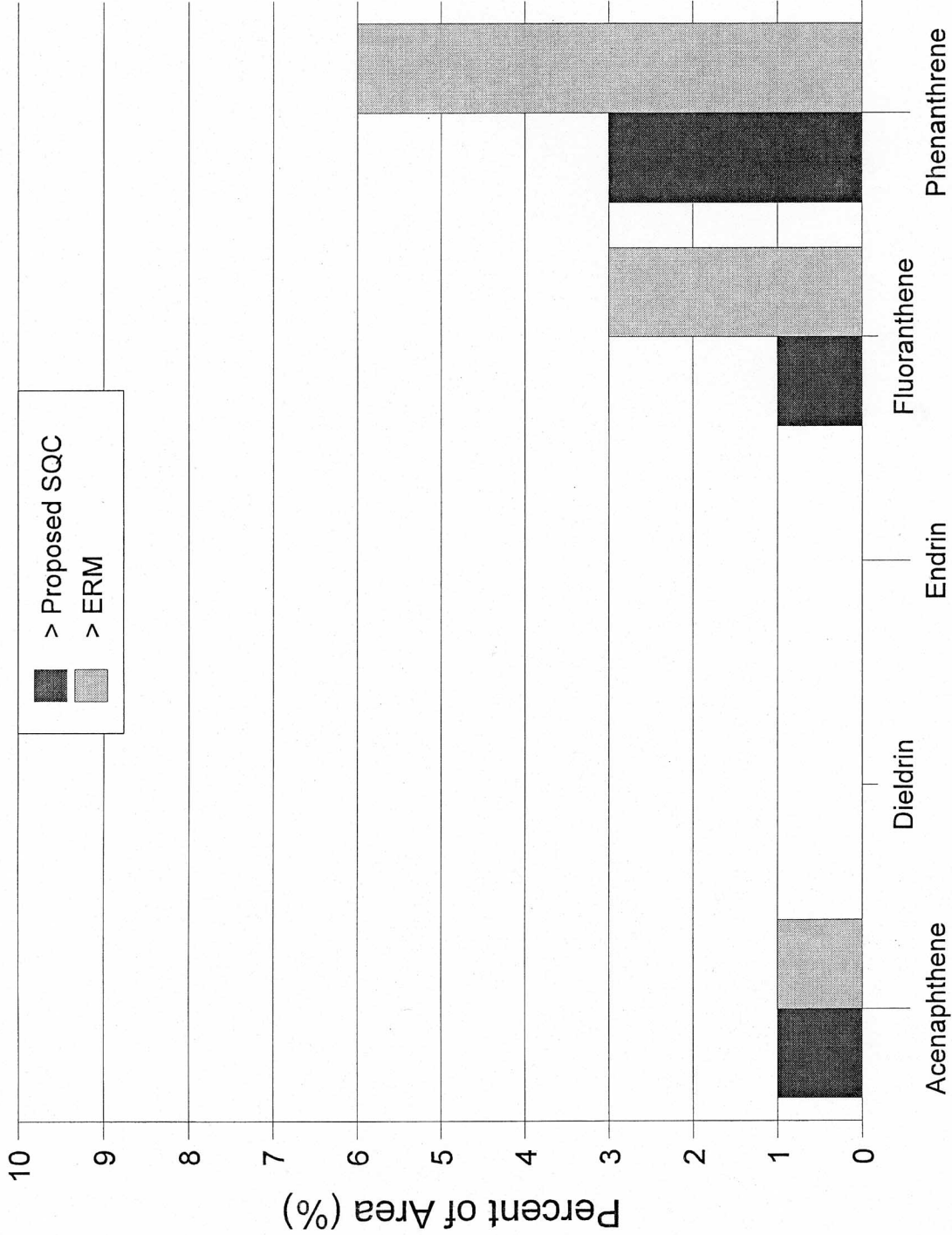


Figure 4-11. Comparison of percent of area (%) in the Harbor exceeding a proposed Sediment Quality Criterion (U.S. EPA, 1994) or an ERM value (Long and Morgan, 1991; Long et al., 1995a). Note: the y axis is 0-10 %.

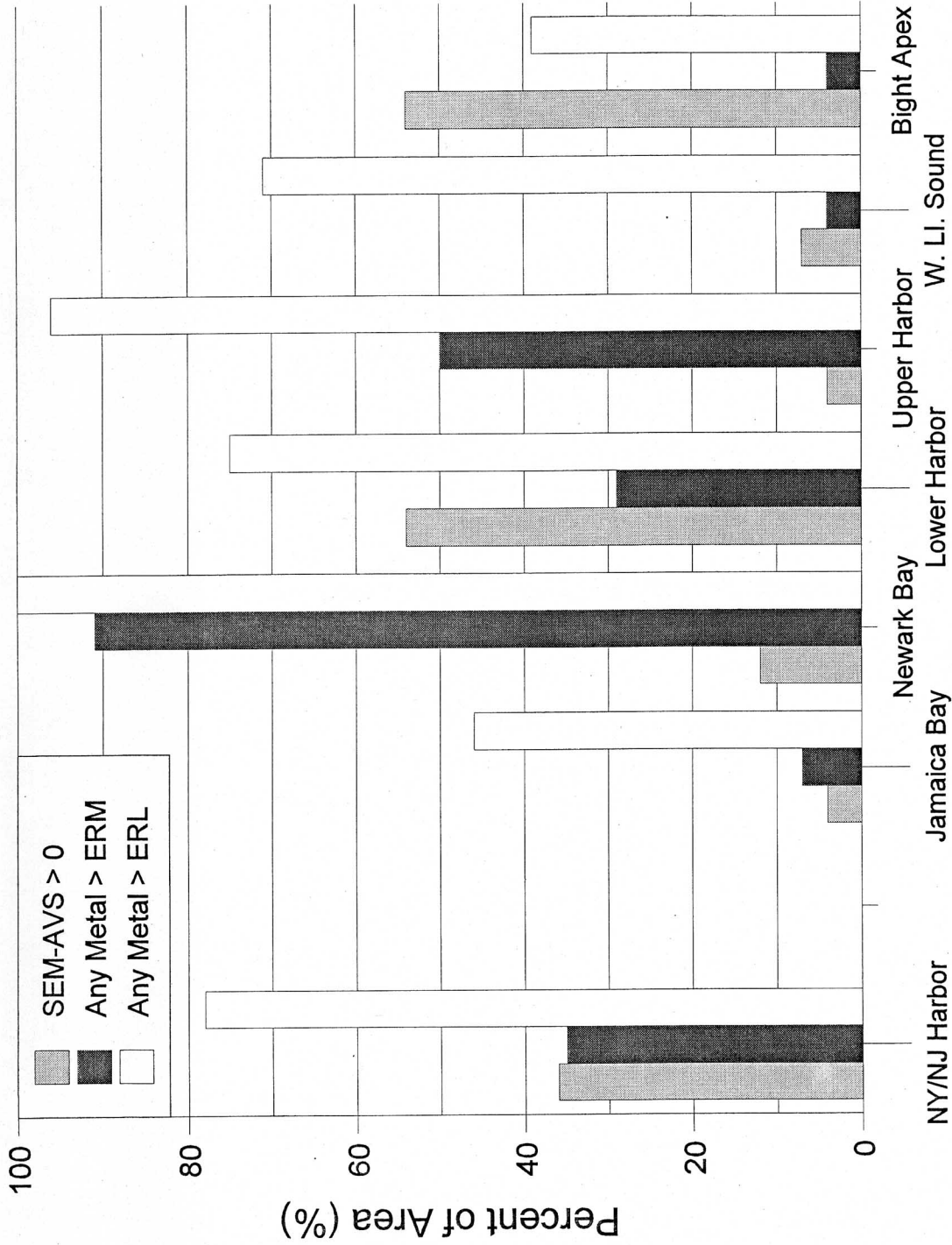


Figure 4-12. Comparison of percent of area (%) with SEM in excess of AVS (SEM-AVS>0) and percent of area with any metal greater than ERM (Long & Morgan, 1991; Long et al., 1995a).

91% of the area. But SEM in excess of AVS occurred at only 13% of Newark Bay's area. In other words, SEM-AVS theory would predict that 87% of Newark Bay should have been non-toxic. However, metal ERLs and ERMs, indicated that 0% and 25%, respectively, was non-toxic. Similarly, in the Upper Harbor, 50% of the area exceeded ERM, whereas only 4% had excess SEM. In contrast, only a single station in the Bight Apex exceeded an ERM for metals, whereas 54% of the area in the Bight Apex had excess SEM.

4.4.3 Aluminum-Normalization

Analyses so far have focused on identifying amount of area where contaminants are at concentrations of biological concern, but another relevant question was what percent of the Harbor has been subjected to anthropogenic enrichment for each chemical compound. Most organic contaminants are of anthropogenic origin, so detection and enrichment are synonymous. However, a portion of the metals in sediments results from natural weathering of crustal rocks, with naturally higher concentrations of metals occurring in fine-grained, depositional sediments. One challenge in accurately assessing the spatial extent of contamination is separating the anthropogenic contribution to observed concentrations of metals from concentrations attributable to natural mineral weathering.

Several techniques have been developed to address this concern (Luoma, 1990, Schropp et al. 1990), the most popular of which is aluminum-normalization (Daskalakis and O'Connor, 1995; Hanson et al., 1993; Loring, 1991; Schropp et al., 1990). Using this approach, aluminum is treated as a conservative tracer of crustal decomposition, since anthropogenic contributions of aluminum are small relative to natural pools in sediment. A set of non-contaminated sites are identified and statistical relationships between each metal and aluminum are established for those sites. Significant deviation from those relationships indicate anthropogenic enrichment. This investigation used the relationships derived by Weisberg et al. (in prep.) for identifying sites with anthropogenic metal enrichment (Appendix D).

Most of the Harbor was found to be enriched in at least one metal (Table 4-4). Nine of the 12 metals measured were enriched over more than 50% of the area of the Harbor. Zinc (80%), mercury (75%), lead and silver (both 70%), were the metals enriching the most Harbor area.

Newark Bay had the highest number of metals enriching greater than 50% of its area (11 out of the 12). The only metal for which Newark Bay did not have the highest percent of enriched area was silver. Upper Harbor had the most enriched area (96%) for this metal. Upper Harbor also was comparable to Newark Bay for enrichment by copper, tin and mercury.

Compared to the Harbor, the Bight Apex had an almost equivalent percent of area enriched with antimony and arsenic. All other values were substantially below the Harbor values. Only one metal, arsenic at 54%, was enriched in more than 50% of the Bight Apex's area. Western Long Island Sound was more similar to the Harbor, with eight of the 12 metals enriching greater than

50% of its area. Copper (93%) and zinc (86%) were the most pervasive in western Long Island Sound, with the extent of copper enrichment being comparable to that found in Newark Bay.

Table 4-4
Percent of Area With Anthropogenically Enriched Levels of Metals
 (parentheses represent 90% confidence intervals)

	Harbor	Jamaica Bay	Newark Bay	Lower Harbor	Upper Harbor	W. LI Sound	Bight Apex
Antimony	54 (32-53)	32 (20-46)	85 (72-97)	54 (40-67)	54 (40-67)	14 (6-27)	46 (33-60)
Arsenic	52 (41-62)	25 (14-38)	88 (79-97)	50 (36-64)	57 (43-70)	18 (9-31)	54 (40-67)
Cadmium	46 (36-56)	36 (24-50)	94 (88-100)	36 (24-50)	68 (54-80)	46 (33-60)	7 (2-18)
Chromium	66 (56-76)	43 (30-57)	89 (80-98)	64 (50-76)	75 (62-86)	57 (43-70)	18 (9-31)
Copper	66 (56-77)	50 (36-64)	97 (93-101)	57 (43-70)	93 (82-98)	93 (82-98)	14 (6-27)
Lead	70 (60-80)	50 (36-64)	95 (90-100)	68 (54-80)	79 (65-88)	68 (54-80)	25 (14-38)
Mercury	75 (66-84)	43 (30-57)	98 (94-101)	71 (58-83)	93 (82-98)	54 (40-67)	18 (9-31)
Nickel	7 (3-11)	4 (0-13)	48 (26-70)	4 (0-13)	7 (2-18)	0 (0-8)	4 (0-13)
Silver	70 (60-80)	54 (40-67)	94 (89-100)	61 (47-73)	96 (87-100)	71 (58-83)	18 (9-31)
Selenium	63 (52-73)	54 (40-67)	80 (65-95)	61 (47-73)	68 (54-80)	54 (40-67)	21 (12-35)
Tin	38 (28-49)	29 (17-42)	51 (30-73)	36 (24-50)	46 (33-60)	32 (20-46)	14 (6-27)
Zinc	80 (72-88)	50 (36-64)	96 (91-101)	82 (69-91)	82 (69-91)	86 (73-84)	25 (14-38)

4.5 RELATIONSHIP BETWEEN CHEMISTRY AND GRAIN SIZE

Grain size is a controlling factor in the adsorption of contaminants onto sediments. Fine sediments typically accumulate higher levels of contaminants than coarse sediments, due to a higher surface area to volume ratio and surface charges that cause these particles to be more chemically and biologically reactive than coarser particles (Power and Chapman, 1995). Depositional areas, which accumulate fine particles, frequently have higher levels of contaminants than coarse sediment zones.

The 39% of the Harbor that was predominantly mud (>40% silt/clay) had 95% exceedance of at least one ERM (Figure 4-13). This can be compared to the sand portion of the Harbor where only 16% of the area exceeded a contaminant ERM.

4.6 COMPARISON TO PREVIOUS STUDIES

No other investigations have sampled the Harbor for sediment contaminants using a probabilistic sampling approach. Therefore, while the results of other investigations can be compared to the present investigation to confirm general magnitude and variety of contaminants, other investigations cannot be used to compare the areal extent of contaminants from the present investigation. However, the ranges of concentrations and specific contaminants determined for the present investigation generally agree with those obtained from other investigations in the Harbor.

Another sediment quality investigation (Long et al, 1995), took place during approximately the same time period as this investigation but sampled in the winter season. The primary purpose of the Long et al. investigation was to evaluate sediment toxicity and the investigation was conducted in two phases. The first phase sampled Harbor-wide and selected samples for chemical analysis after toxicity test results were examined. The second phase focused on Newark Bay and selected stations prior to sampling for chemical analysis to represent a gradient of contamination.

Mercury in the Long et al. investigation of the entire Harbor, generally ranged from 1.0 to 5.0 ppm, with a few samples from the East River at around 5.0 ppm, and one sample from the Arthur Kill at 15 ppm. The present investigation had mercury concentrations ranging from non-detected to 6.7 ppm with a mean of 1.0 ppm. The highest mercury values (5.4 and 6.7 ppm) were found in the Arthur Kill.

In the Long et al. investigation, total PCBs (sum of 20 congeners) generally ranged from 100 to 200 ppb. Several stations in the Arthur Kill and East River were above 450 ppb. The East River had a high value of 1973 ppb. This investigation had a range of .03 to 2482 ppb PCBs (sum of 20 congeners) with a mean of 205 ppb. In the Upper Harbor sub-basin, three stations in the East River had PCBs concentrations ranging from 373 to 430 ppb. A single station east of Governor's

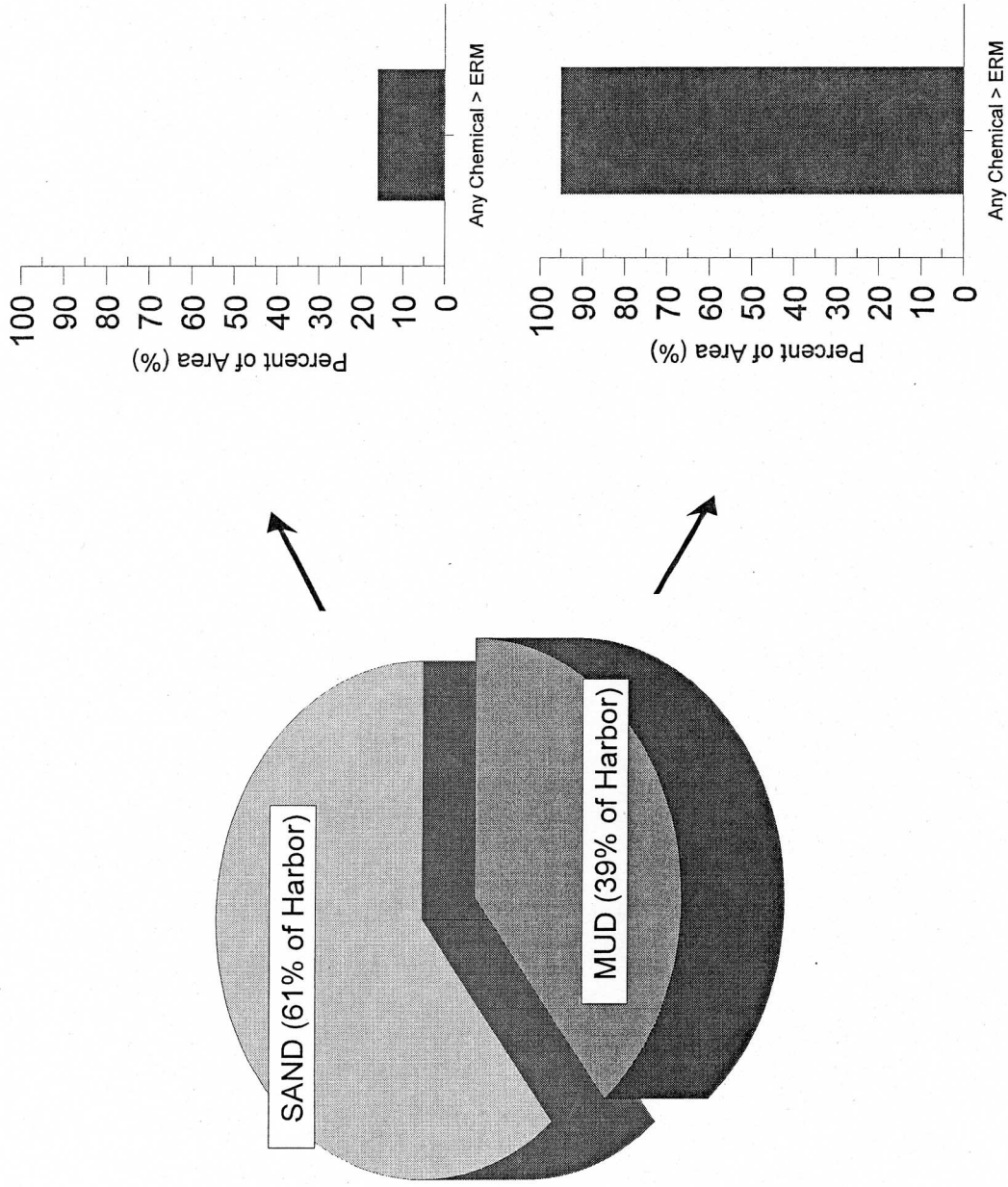


Figure 4-13. Relationship between substrate type (sand \leq 40% silt/clay, mud \geq 40%) and percent of area in the Harbor with at least one chemical greater than ERM (Long & Morgan, 1991; Long et al., 1995a).

Island had 425 ppb. One station in the Lower Hudson River was measured at 403 ppb and an Upper Hudson River station had a concentration of 947 ppb. In the Newark Bay sub-basin, a station in the Elizabeth Ship Channel had a value of 1435 ppb. Three stations in the Passaic River were above 650 ppb, with one having the investigation's high concentration of 2481 ppb.

In the Long et al. investigation, total PAHs (sum of 24 congeners) generally ranged from 4,000 to 20,000 ppb. Five sites from the East River and one from the Kill van Kull exceeded 20,000 ppb. The highest concentration of total PAHs was 1,123,355 ppb in the East River.

Concentrations of 2,3,7,8 TCDD (as TEQs) ranged from 13 pg/g at a single reference station in Upper Harbor to 874 pg/g in the lower Passaic River.

Earlier investigations are summarized in a review by Squibb et al. (1991). They concluded that many portions of the Harbor exceeded the ERM values that existed at that time.

4.7 COMPARISON TO A LARGER GEOGRAPHIC AREA

The probabilistic design, sampling methods and laboratory procedures used for the present investigation were the same as those used by the U.S.EPA Environmental Monitoring and Assessment Program (EMAP). This compatibility allowed direct comparison of the data obtained under EMAP and this investigation. The EMAP Virginian Province effort encompassed the coastal zone of the east coast from Cape Cod south to the mouth of Chesapeake Bay. It included the NY-NJ Harbor Estuary.

Comparison to the Virginian Province indicated that the NY-NJ Harbor is heavily and extensively contaminated. The NY-NJ Harbor had a statistically higher ($p < 0.10$) mean sediment contaminant concentration than the Virginian Province for 50 of the 59 chemicals measured (Table 4-5). In addition, for several chemicals, specifically mercury and total PCBs, the Harbor had a large portion (69% and 100%, respectively) of the areal extent of ERM exceedances in the Virginian Province, even though the Harbor constitutes only 4% of the area in the Province (Figure 4-14).

East Coast tributyltin concentrations from purposive sediment sampling ranged from <10 to 770 ppb (Krone, Stein and Varanasi 1996). The levels measured by the present investigation were comparable to the low end of the East Coast range. EMAP, using a probabilistic approach, obtained a similar range for the Virginian Province (12 to 764 ng/g).

Table 4-5

Comparison of Mean Sediment Contaminant Concentrations between the Virginian Province (1990-1993) and the NY/NJ Harbor (1993-1994)

(\pm represents 90% confidence intervals for NY/NJ Harbor data; \pm for Virginian Province data represents the standard error)

	NY/NJ Harbor	Virginian Province	Harbor Larger
METALS (ppm)			
Aluminum	43456 \pm 4229	35697 \pm 1238	T
Antimony	1.49 \pm 0.48	0.54 \pm 0.024	T
Arsenic	10.33 \pm 2.05	6.60 \pm 0.30	T
Cadmium	0.79 \pm 0.13	0.21 \pm 0.01	T
Chromium	78.09 \pm 10.11	37.82 \pm 1.73	T
Copper	72.53 \pm 17.40	19.57 \pm 1.55	T
Iron	23483.6 \pm 2897.0	19664 \pm 729	T
Lead	78.84 \pm 12.83	38.29 \pm 1.31	T
Manganese	495.26 \pm 44.14	556.45 \pm 46.56	
Mercury	0.74 \pm 0.14	0.09 \pm 0.01	T
Nickel	24.07 \pm 2.90	14.39 \pm 0.87	T
Selenium	3.82 \pm 1.02	0.27 \pm 0.02	T

Silver	1.59 ±0.30	0.24 ±0.03	T
Tin	4.96 ±1.54	2.34 ±0.14	T
Zinc	170.06 ±25.56	79.65 ±4.61	T
ORGANICS (ppb)			
Total PCBs = (3 congeners) x 2	224.35 ±42.25	17.57 ±3.72	T
Parent DDT	9.57 ±9.38	0.58 ±0.07	T
DDD	14.16 ±5.98	0.99 ±0.21	T
DDE	8.53 ±2.54	1.31 ±0.24	T
Total DDT	31.59 ±16.64	2.62 ±0.45	T
Aldrin	0.50 ±0.05	0.02 ±0.01	T
Alpha Chlordane	1.15 ±0.22	0.29 ±0.09	T
Chlordane	5.11 ±1.01	0.47 ±0.15	T
Dieldrin	0.80 ±0.12	0.31 ±0.08	T
Heptachlor	0.45 ±0.06	0.06 ±0.02	T
Heptachlor epoxide	0.39 ±0.05	0.08 ±0.03	T
Hexachlorobenzene	0.46 ±0.15	0.03 ±0.01	T

Lindane	0.43 ±0.07	0.06 ±0.02	T
Mirex	0.56 ±0.17	0.02 ±0.01	T
Trans-Nonachlor	0.71 ±0.14	0.12 ±0.056	T
Acenaphthene	82.78 ±65.43	23.80 ±13.83	T
Acenaphthylene	122.93 ±41.89	6.96 ±1.69	T
Anthracene	365.05 ±220.76	51.86 ±29.99	T
Benzo(a)anthracene	486.83 ±129.35	99.59 ±46.19	T
Benzo(a)pyrene	433.96 ±116.40	87.25 ±28.38	T
Benzo(e)pyrene	302.69 ±72.98	66.62 ±18.71	T
Benzo(k)fluoranthene	781.78 ±177.51	173.74 ±52.91	T
Benzo(g,h,i)perylene	303.05 ±83.12	65.65 ±17.93	T
Biphenyl	32.16 ±11.74	11.19 ±2.28	T
Chrysene	544.76 ±145.85	110.17 ±45.25	T
Dibenz(a,h)anthracene	79.42 ±31.10	9.99 ±1.49	T
2,6-Dimethylnaphthalene	198.15 ±57.34	22.50 ±4.24	T
Fluoranthene	743.25 ±278.61	217.00 ±105.53	T

Fluorene	176.41 ±182.11	33.82 ±14.93	T
Ideno(1,2,3-c,d)pyrene	291.62 ±90.08	71.22 ±19.49	T
2-Methylnaphthalene	89.91 ±42.02	40.11 ±8.28	T
1-Methylnaphthalene	46.37 ±24.30	18.75 ±4.25	T
1-Methylphenanthrene	156.10 ±88.28	24.46 ±9.84	T
Naphthalene	163.96 ±100.34	47.25 ±10.23	T
Perylene	333.54 ±113.69	85.44 ±11.57	T
Phenanthrene	628.06 ±520.48	194.25 ±117.15	T
Pyrene	767.60 ±269.73	232.29 ±113.38	T
2,3,5- Trimethylnaphthalene	47.00 ±29.87	10.39 ±2.81	T
Total PAHs	7177.4 ±2607.9	1704.30 ±653.64	T
Monobutyltin	5.32 ±1.37	2.23 ±0.33	T
Dibutyltin	16.33 ±6.04	5.11 ±0.76	T
Tributyltin	30.08 ±8.52	8.29 ±0.95	T
Total Butyltin	55.90 ±15.35	15.62 ±1.44	T

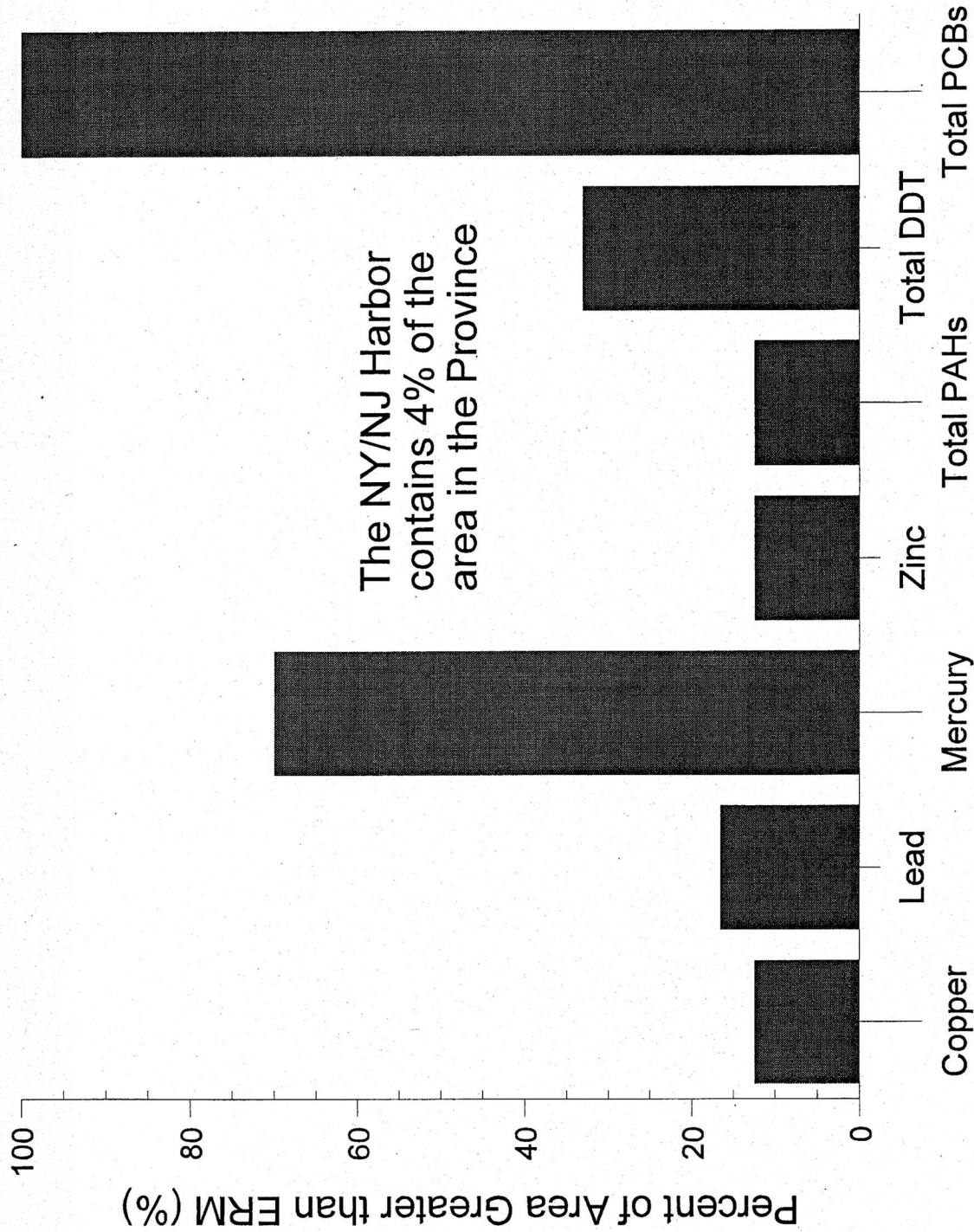


Figure 4-14. Contribution of the NY/NJ Harbor to percent of area in the Virginian Province with ERM exceedances.

5.0 SEDIMENT TOXICITY

5.1 BACKGROUND

The analysis and interpretation of chemical data to determine potential biological response must assume that there is a particular association between chemical contamination and biological effects. Toxicity tests can provide this information directly and can control confounding factors, such as temperature, salinity and dissolved oxygen. They also integrate the effects of complex mixtures of chemicals in sediment, including chemicals that are not measured. However, toxicity tests should not be used alone because individual species of test organisms vary in their sensitivity to chemicals and the relevance of toxicity test results to field conditions is difficult to establish (Chapman, 1995). The value of toxicity tests is best realized when they are interpreted in conjunction with chemistry and in situ biological response (e.g., benthic macroinvertebrate community structure).

This investigation used two measures of toxicity: (1) survival of the amphipod, *Ampelisca abdita*, as a percentage of control survival, and (2) inhibition of light emission by the bacterium, *Photobacterium phosphoreum*, when exposed to organic extracts of test sediment relative to control sediment. Grain size analysis was used to examine the association between toxicity and substrate type.

Sediments at a station were considered toxic using the *Ampelisca abdita* toxicity test if percent survival was less than 80% compared to control. These criteria are similar to U.S.EPA/U.S.ACE (1991). Sediments were considered “highly toxic” if *A. abdita* survival was less than 60% compared to survival in control sediments.

Sediments were considered toxic using the Microtox™ assay if the EC₅₀ was 70% or less and significantly different ($p < .05$) from the control EC₅₀ (PSDDA, 1989). The degree of Microtox™ toxicity is measured as the dry weight of sediment that provides enough organic extract to inhibit normal bacterial luminescence by 50%, i.e., EC₅₀, (Long and Markel, 1992). Measured Microtox™ toxicity is expressed as a percentage of control EC₅₀ (0.12 and 0.22 mg dry wt/ml in this study). Therefore, EC₅₀ values and percentages of control values are inversely proportional to sediment toxicity.

5.2 CHARACTERIZATION OF THE HARBOR

5.2.1 Mean Condition

Mean percent survival of *Ampelisca abdita* (as percent of control survival) was comparable within each sub-basin of the Harbor except Newark Bay (Table 5-1). Mean survival within

Newark Bay was significantly less ($p < .10$) than the Harbor as a whole. Lower Harbor exhibited the highest mean survival.

Mean Microtox™ values varied substantially among Harbor sub-basins, but Newark Bay also exhibited the greatest toxicity relative to the entire Harbor ($p < .05$). Jamaica Bay and Upper Harbor were similar to one another. Lower Harbor had the least percent of area toxic in the Microtox™ assay.

Table 5-1
**Mean % Survival for *Ampelisca abdita* and
 Mean % Microtox™ Bioluminescence Inhibition**
 (± 90% confidence intervals)

	Harbor	Jamaica Bay	Newark Bay	Lower Harbor	Upper Harbor	W. Long Is. Sound	Bight Apex
<i>Ampelisca abdita</i> *	87.9 ±4.1	84.9 ±7.7	66.5 ±15.1	91.0 ±5.9	86.6 ±6.3	97.0 ±1.4	94.9 ±1.9
Microtox™ *	365 ±86	257 ±100	122 ±56	452 ±132	224 ±96	237 ±113	765 ±119

* Adjusted for control survival or control bioluminescence inhibition.

5.2.2 Areal Extent

Out of a total area of 501 km², an estimated 75 km² (15%) of the Harbor proper was toxic to *A. abdita* and 40 km² (8% of the total area) was highly toxic (Figure 5-1). Newark Bay and Jamaica Bay have more widespread toxic sediments (46 and 25%, respectively) than the rest of the Harbor. However, only Newark Bay has a larger percent area of highly toxic sediments than other Harbor sub-basins ($p < .10$). Although relatively large percentages of Newark and Jamaica Bay sediments were toxic, these were the smallest Harbor sub-basins. The total toxic area of these sub-basins (26 km²) was approximately 1/3 of the acreage of toxic sediments in the entire Harbor. Individual stations toxic to *A. abdita* were concentrated in the Kills (Newark Bay sub-basin) and the mouth of Jamaica Bay (Figure 5-2). Highly toxic stations exhibited a similar pattern, with the addition of several stations in the back bay portion of Jamaica Bay.

Based on the Microtox™ assay, 38% (190 km²) of the Harbor area was found to be toxic (Figure 5-3). Sub-basins in the Harbor were similar with regard to percent of area toxic in the Microtox™ assay. The estimated percentages of sub-basins considered toxic using Microtox™ ranged from 39% in Upper Harbor to 50% in Jamaica Bay. Over the Harbor proper, the Microtox™ assay characterized 2.5 times more area as toxic than the *A. abdita* assay (Table 5-2).

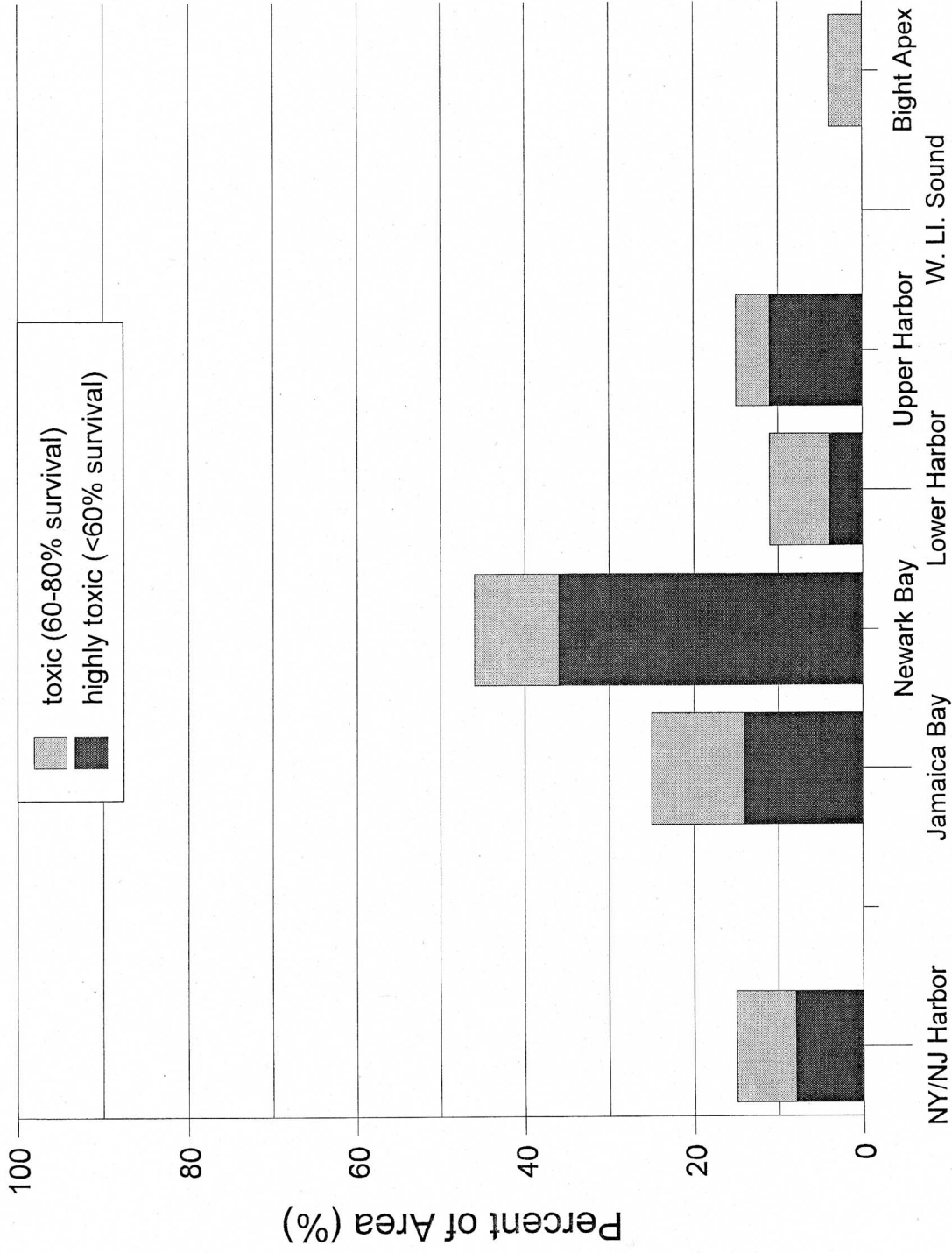


Figure 5-1. Percent of area exhibiting *Ampelisca abdita* toxicity.

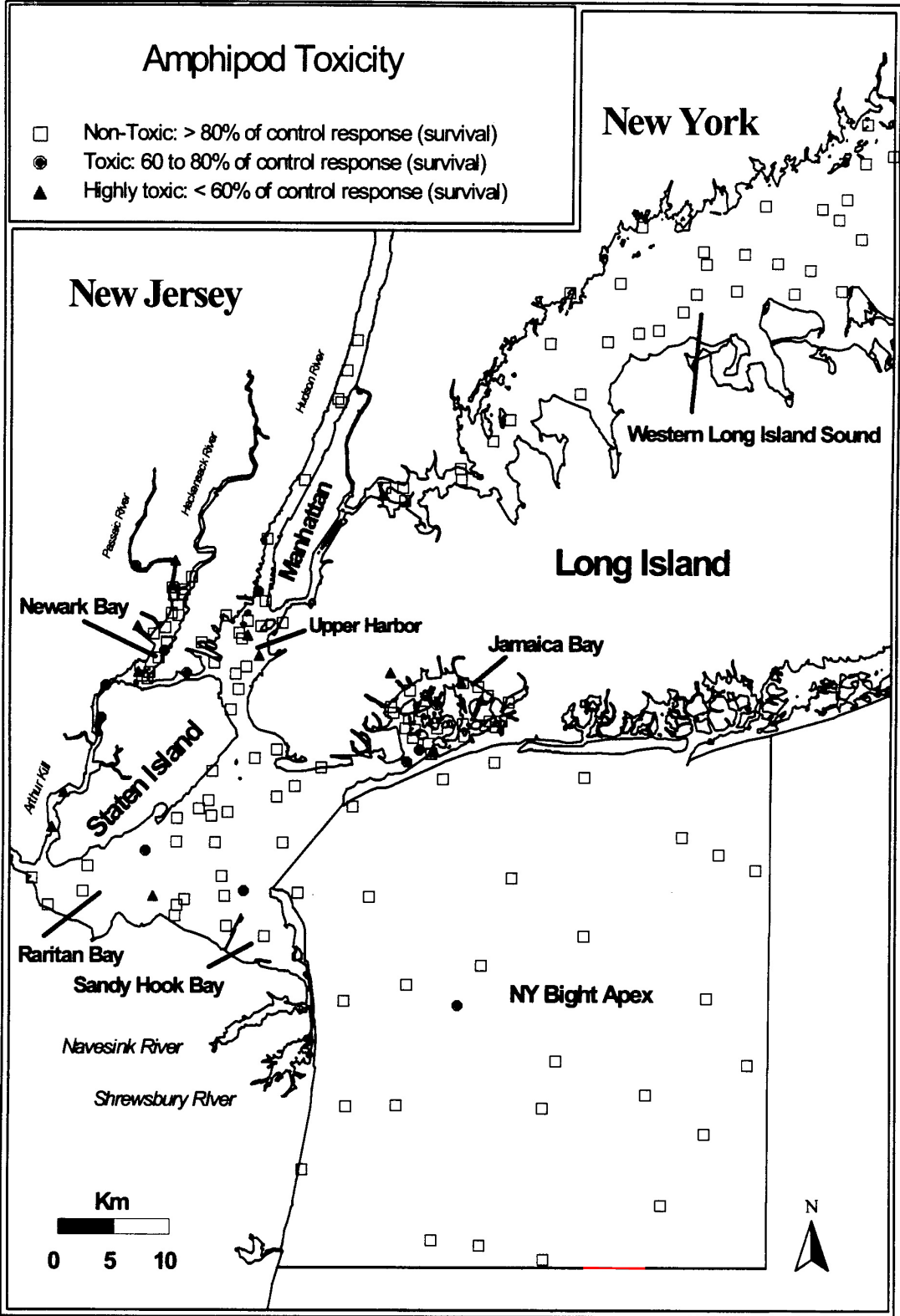


Figure 5-2. Distribution of stations toxic in amphipod (*Ampelisca abdita*) survival assays.

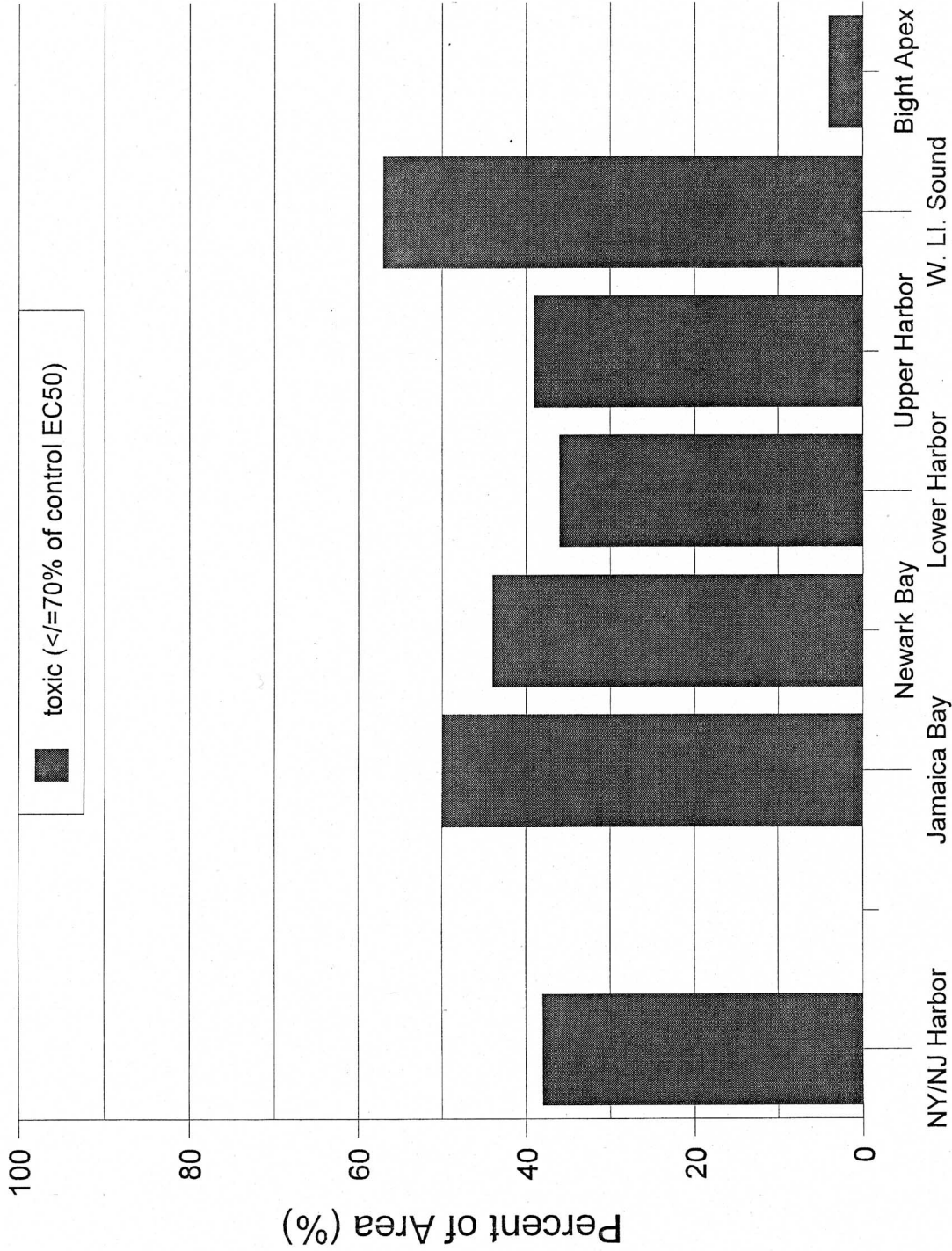


Figure 5-3. Percent of area toxic in the Microtox™ assay.

The majority of the toxic stations for Microtox™ were clustered on the south shore of Lower Harbor, the perimeter of Jamaica Bay, the Kills and the Passaic River (Figure 5-4).

Using a positive result in either assay as an indication of toxic conditions, resulted in 45% of the Harbor considered toxic (Table 5-2).

Table 5-2
Percent of Area Toxic in the *A. abdita* and Microtox™ Assays
 (± 90% confidence intervals)

	Harbor	Jamaica Bay	Newark Bay	Lower Harbor	Upper Harbor	W. LI Sound	Bight Apex
<u><i>Ampelisca abdita</i></u> *	15 (8-22)	28 (15-39)	46 (23-68)	11 (0-18)	15 (2-23)	0 (0-8)	4 (0-8)
Microtox™**	38 (28-49)	50 (36-64)	44 (22-67)	36 (24-50)	39 (27-53)	57 (43-70)	4 (0-13)
<u><i>Ampelisca abdita</i></u> or Microtox™	45 (34-55)	50 (36-64)	49 (28-71)	43 (30-57)	46 (33-60)	57 (43-70)	4 (0-13)

* Significant toxicity is percent survival # 80% mean control survival (U.S.EPA, 1991).

** Significant toxicity is an EC₅₀ statistically less than the control and #70% of the control EC₅₀ (PSDDA, 1989).

5.3 CHARACTERIZATION OF WESTERN LONG ISLAND SOUND AND THE BIGHT APEX

5.3.1 Mean Condition

Mean *A. abdita* survival was higher in Bight Apex and western Long Island Sound sediments than in Harbor sediments. Mean survival in these two areas also was higher than any of the individual Harbor sub-basins (Table 5-1).

The least toxic sediments using mean Microtox™ results were in the Bight Apex. Mean western Long Island Sound toxicity was above that for the Harbor as a whole, but was comparable to Jamaica Bay, Upper Harbor and Newark Bay.

5.3.2 Areal Extent

Based upon *A. abdita* assays, the Harbor as a whole and each Harbor sub-basin had proportionately more toxic area than either western Long Island Sound or the Bight Apex (Figure

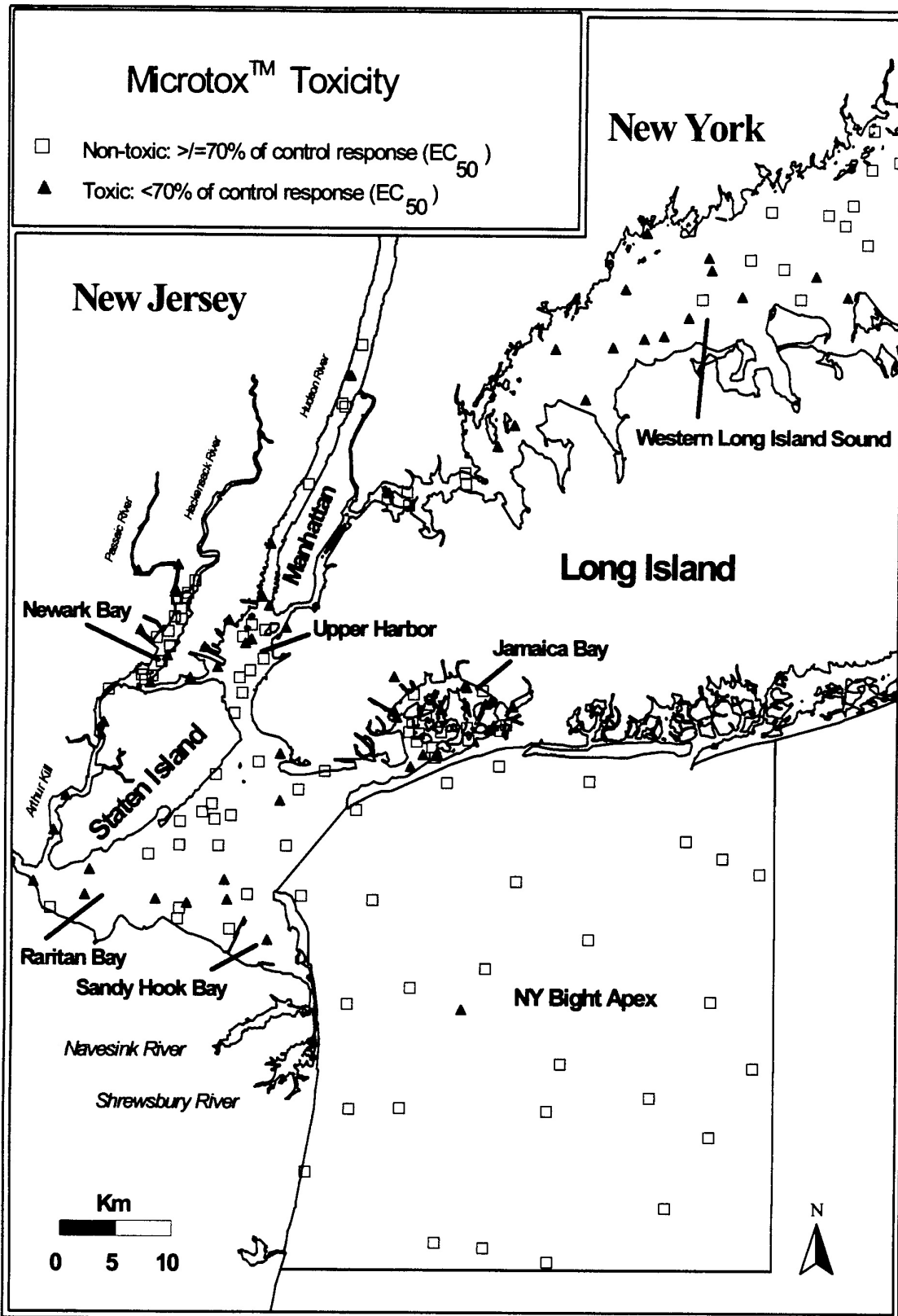


Figure 5-4. Distribution of stations inhibiting Microtox™ bioluminescence.

5-1). There was no significant difference between the percent of toxic sediments estimated in western Long Island Sound and the Bight Apex. However, the areal estimate of toxic sediments in the Bight Apex was 67 km², nearly as much toxic area as estimated for the Harbor. The single toxic site in the Bight Apex was located in an area of historical dredged material disposal. Western Long Island Sound had no sites that exhibited *A. abdita* toxicity (Figure 5-2).

More area in western Long Island Sound was characterized as toxic in the Microtox™ assay than in the Harbor as a whole or any other sub-basin. Only 4% of the Bight Apex was classified as toxic. The Microtox™ assay indicates the same extent of toxicity in the Bight Apex as is indicated by the *A. abdita* assay. Individual toxic sites were clustered in the portion of western Long Island Sound closest to the Harbor and at a single location in the Bight Apex (Figure 5-4). The Bight Apex site was also toxic to *A. abdita*. Microtox™ and *A. abdita* results for western Long Island Sound substantially disagree, as 17 sites (57% of the area) were toxic in the Microtox™ assay but none were toxic to *A. abdita*.

5.4 RELATIONSHIP BETWEEN TOXICITY AND GRAIN SIZE

Generally, sediment toxicity is expected to be greater and more prevalent in finer grained substrates (Power and Chapman, 1995). The percent of area in the Harbor with *A. abdita* toxicity was examined by substrate category (Figure 5-5). Of the 39% of the Harbor sediments that were mud (>40% silt-clay), approximately 26% was toxic to *A. abdita* and 76% toxic to Microtox™. Conversely, the sand portion (<40% silt-clay) of the Harbor (61%) exhibited toxicity to *A. abdita* and Microtox™ at 7% and 14% of its area, respectively. Overall, *A. abdita* toxicity was slightly more predominant in mud than sand, but Microtox™ toxicity was significantly higher in mud than sand. Regression analyses of toxicity vs. grain size at individual stations showed that *A. abdita* toxicity was not related to the fraction of silt-clay in sediments ($P = .05$), but Microtox™ toxicity was significantly greater as the fraction of silt-clay increased.

5.5 COMPARISON TO PREVIOUS STUDIES

Previous studies of sediment toxicity in the Harbor generally have used non-random sampling strategies. Although useful for other purposes, these non-probabilistic approaches prevent reliable characterization of the Harbor, or even portions of the Harbor. This is true no matter how reliably the sediment toxicity tests assayed the sampled sediment. However, the intensive sampling of Newark Bay in the Long et al. (1995b) investigation did identify “hot spots” more fully than the present investigation.

This study’s sediment toxicity results were broadly similar to those of Long et al. (1995b). That investigation and the present investigation both conclude that: (1) less than 50% of the entire Harbor was toxic to *Ampelisca* survival or to Microtox™ luminescence, and (2) the Newark Bay

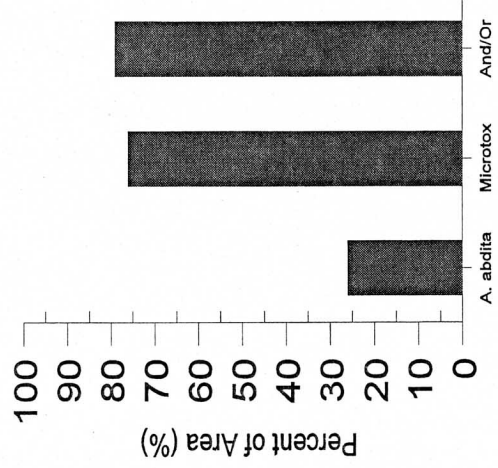
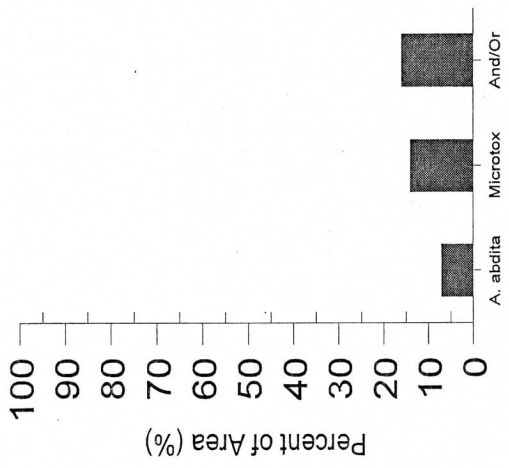
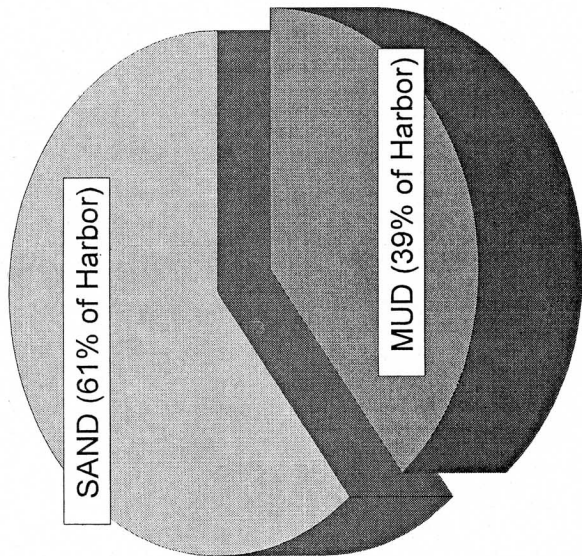


Figure 5-5. Relationship between substrate type (sand $\leq 40\%$ silt/clay, mud $\geq 40\%$) and percent of area in the Harbor with toxicity to *A. abdita*, Microtox™, or *A. abdita* and /or Microtox™.

sub-basin is the most toxic region of the Harbor. Both investigations had similar study areas; the Long et al. (1995b) investigation did not include Jamaica Bay.

However, the Long et al. investigation and this study estimated somewhat different areas of sediment toxicity in the individual sub-basins. Based upon *Ampelisca* survival tests, this study estimated that 46% (23-68%) of the Newark Bay sub-basin was toxic (Figure 5-1), whereas Long et al. (1995b) estimated that 85% of this sub-basin was toxic.

Approximately 40% of the Long et al. study area was toxic to Microtox™ luminescence. The present investigation estimated that less than 20% of the Long et al.'s study area was toxic in the Microtox™ assay, although 38% (28-49%) of the Harbor exhibited Microtox™ toxicity (Figure 5-1).

6.0 BENTHIC MACROINVERTEBRATES

6.1 BACKGROUND

Although sediment chemistry and toxicity assays provide useful insights into sediment quality, they provide only limited understanding of ecological damage (Keeler and McLemore, 1996). For most management purposes, a principal goal is protection and remediation of biological resources. This goal requires a reliable understanding of biological effects of contaminants.

Because of several attributes, bottom-dwelling invertebrates (benthos) provide useful indications of biological response to environmental conditions. Since the ultimate disposition of many contaminants is into sediments where benthic macroinvertebrates live and feed, they are directly exposed to contaminant effects. Because they are relatively sedentary and cannot avoid exposure, benthos can provide an accurate indication of local environmental conditions. Bottom dwelling organisms (benthos) are also relatively long-lived and, as an essential component of the food web, are an important link between primary producers and higher trophic levels (Diaz, 1995). Additionally, benthos significantly affect oxygen, nutrient, and carbon cycles (Blackburn and Henriksen, 1983). They exhibit a broad diversity of sizes, feeding modes and life history characteristics, with a range of responses to environmental stress, making them especially suitable as integrators of contaminant effects (Frithsen & Holland, 1992).

Many measures have been suggested for describing benthic communities. This study assessed several individual structural measures to quantify the status of benthic macroinvertebrate assemblages (Table 2-4). Species diversity, a measure of community structure, is indicative of the species utilizing the available habitat. It is expressed here as number of species (species richness) and as the Shannon-Wiener composite index (Shannon and Weaver, 1949). Evenness (distribution among species) is a basic characteristic of benthic community structure. Biomass also is an integral component of community structure, since it is the basis for energy flow and has been shown to be responsive to pollution stress (Warwick, 1986; Dauer and Connor, 1980; Luckenbach et al., 1990; Pearson and Rosenberg, 1978). Total abundance is also used as an indicator for contaminant effects (Becker et al., 1990) and, along with biomass, is a measure of total biological activity at a site. The use of benthic species that are pollution-tolerant or pollution-sensitive has also been used to determine the ecological health of a location (Grassle and Grassle, 1974 and 1976).

However, more than one measure or indicator, combined into an index of benthic invertebrate structure, can distinguish more effectively than individual measures between normal and abnormal benthic assemblages (Pearson and Rosenberg, 1978; Gray, 1995). A multi-metric benthic index of biotic integrity (B-IBI), similar to the fresh water Index of Biotic Integrity (IBI) (Karr, 1991; Kerans and Karr, 1994) was developed for the NY/NJ Harbor (Appendix C). Five metrics which most effectively distinguished normal sites from all others were selected for the B-IBI (Table 2-4). These metrics were evaluated for four different salinity and grain size habitats

(Table 2-5). The index was calculated by scoring each selected metric as 5, 3, or 1 depending on whether its value at a site approximated, deviated slightly from, or deviated greatly from conditions at the best reference sites. The B-IBI value for each station is calculated as the mean score of the five metrics. A mean score of 5 indicated that the site was approximately equivalent to the best reference sites. A score of 3 or 1 indicated that the site slightly deviated or greatly deviated from conditions at the best reference sites and would be considered to have impacted benthos. These scoring criteria defined normal and abnormal benthic assemblages.

The overall validation efficiency of the B-IBI was 93%. The average difference between replicates was 0.32. Ninety-one percent of the replicates at the same site scored similarly. At most of the sites where the replicates scored differently, the replicates had similar numerical values, but were on either side of the index threshold of 3.

6.2 CHARACTERIZATION OF THE HARBOR

6.2.1 Diversity and Taxonomic Composition

A total of 239 infaunal species were represented in the Harbor (Table 6-1). The mean number of species per sample in the entire Harbor was 19.2 (Table 6-2). Mean species diversity (Shannon-Wiener) in the Harbor was 2.3 (Table 6-2). Shannon-Wiener diversity was similar in all sub-basins, but taxonomic composition varied greatly among sub-basins.

Table 6-1
Species Richness (Total Number of Species)

	Harbor	Jamaica Bay	Newark Bay	Lower Harbor	Upper Harbor	W. LI. Sound	Bight Apex
Number of Species	239	137	91	166	152	180	231

One difference among sub-basins of the Harbor was the relatively few species present in Newark Bay (Figure 6-1). The mean numbers of species per sample (species richness) was not significantly less ($p > 0.1$) in Newark Bay than in Jamaica Bay (the next least species-rich sub-basin). However, Newark Bay species richness was significantly less ($p < .05$) than any of the other three Harbor sub-basins. Nearly half the total number of species was polychaetes, consistently in each sub-basin (Figure 6-1). Molluscs and arthropods were represented by roughly equal numbers of species in each sub-basin. Depending upon the sub-basin, amphipod species constituted from 10 to 18% of all species identified. Three taxa (Amphipoda, Mollusca, and Polychaeta) include about 85% of all taxa identified (Figure 6-1). Area-weighted mean abundances for all benthic macroinvertebrate species identified in the study also were calculated (Appendix G).

Table 6-2
Means of Benthic Variables
 (± 90% confidence interval)

	Harbor	Jamaica Bay	Newark Bay	Lower Harbor	Upper Harbor	W. LI. Sound	Bight Apex
Abundance (# organisms/m ²)	40,000 ±14,000	39,000 ±15,000	11,000 ±4,700	52,000 ±22,000	12,000 ±3,600	19,000 ±7,400	32,000 ±8,200
Species Richness (as # species/sample)	19.2 ±1.7	17.7 ±2.7	14.1 ±2.6	20.6 ±2.6	17.1 ±2.3	20.6 ±2.8	28.9 ±3.6
Pollution-Sensitive Species (%)	13 ±5.6	3.6 ±2.0	0.3 ±0.3	18 ±8.6	6.8 ±5.6	8.1 ±4.7	50 ±9.2
Pollution-Indicative Species (%)	31 ±3.5	46 ±8.4	65 ±7.1	20 ±5.0	49 ±6.3	28 ±8.3	3.0 ±1.0
Biomass (g/m ²)	31 ±11	10 ±5.1	5.4 ±2.0	50 ±31	56 ±35	22 ±7.4	29 ±15
Species Diversity (Shannon-Wiener)	2.3 ±0.17	2.1 ±0.20	2.1 ±0.3	2.4 ±0.26	2.5 ±0.15	2.4 ±0.29	2.3 ±0.23

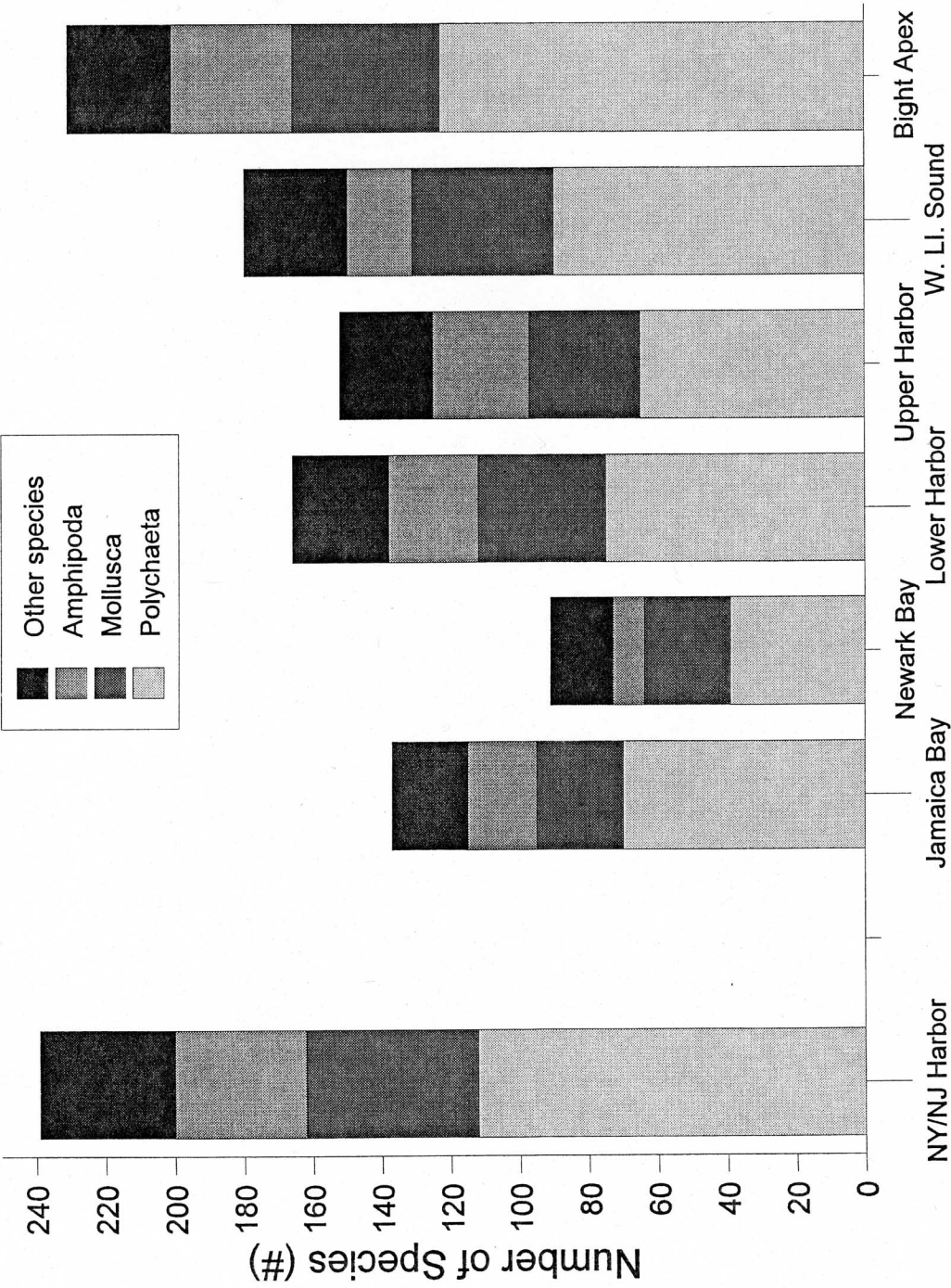


Figure 6-1. Numbers of benthic macrofaunal species, by major taxon.

Lists of pollution-sensitive and pollution-indicative species (Table 6-3) were developed by comparing relative abundance of taxa between reference sites and degraded sites in the EMAP-E Virginian Province data. Pollution-indicative taxa were those for which average abundance, average percent of abundance, and frequency of occurrence were all higher at degraded versus reference sites. Pollution-sensitive taxa were those for which average abundance, average percent of abundance, and frequency of occurrence were all higher at reference than degraded sites, and for which percent of abundance at reference sites averaged at least 0.2%.

Table 6-3
Pollution-Sensitive and Pollution-Indicative Taxa

Pollution-Sensitive Taxa		
Mollusca	Polychaeta	
<i>Acteocina canaliculata</i>	<i>Ampharete arctica</i>	<i>Ninoe nigripes</i>
<i>Tellina agilis</i>	<i>Aricidea catherinae</i>	<i>Polygordius spp.</i>
<i>Spisula solidissima</i>	<i>Caulleriella spp.</i>	<i>Sabaco elongatus</i>
Arthropoda	<i>Clymenella torquata</i>	<i>Scalibregma inflatum</i>
<i>Ampelisca agassizi</i>	<i>Glycinde solitaria</i>	<i>Spiophanes bombyx</i>
<i>Ampelisca verrilli</i>	<i>Levinsenia gracilis</i>	
<i>Byblis serrata</i>	<i>Macroclymene zonalis</i>	
<i>Rheopoxynius hudsoni</i>	<i>Nephtys picta</i>	
Pollution-Indicative Taxa		
Mollusca	Polychaeta	
<i>Mulinia lateralis</i>	<i>Capitella spp.</i>	
Oligochaeta	<i>Polydora cornuta</i>	
Oligochaetes	<i>Streblospio benedicti</i>	

6.2.2 Abundance and Biomass

The mean abundance and biomass for the Harbor was 40,000 organisms/m² and 31 g/m², respectively (Table 6-2).

The mean abundance of benthos was significantly lower ($p < .01$) in both Newark Bay and Upper Harbor than in any other Harbor sub-basin (Table 6-2). Pollution-sensitive species were significantly less abundant ($p < .05$) in Newark Bay than elsewhere in the Harbor, and significantly more abundant in Lower Harbor ($p < .05$) than elsewhere in the Harbor. Pollution-indicative species were generally distributed inversely to pollution-sensitive species: i.e., pollution-indicative species were least abundant in Lower Harbor and most abundant in Newark Bay ($p < .05$). Biomass of the benthos was significantly lower ($p < .05$) in Jamaica and Newark Bays than in Lower and Upper Harbors.

6.2.3 Benthic Index

A multi-metric benthic index of biotic integrity (B-IBI), similar to the fresh water Index of Biotic Integrity (Karr, 1991; Kerans and Karr, 1994), was developed for the NY/NJ Harbor (Appendix C). Values of the benthic index (B-IBI) at a sampling site can range from one (impacted assemblage) to five (normal assemblage). Benthic structure in about half (53%) of the entire Harbor area exhibited measurable departure from the structure at reference sites (Table 6-4). Most of this area (47%) was in a category indicative of intermediate impact (B-IBI values of 2 to 3).

Measurable benthic impacts ($B-IBI < 3$) were most widespread in Newark Bay, Upper Harbor and Jamaica Bay (Figure 6-2). Estimates of impacted benthic area ranged from 39% for Lower Harbor to 98% for Newark Bay (Table 6-4). The distribution of individual stations with impacted benthos (Figure 6-3) shows the most highly impacted sites were located in the Newark Bay sub-basin and in the back bay portion of Jamaica Bay. Newark Bay had only one station of 28 that was comparable to reference conditions.

Table 6-4
Percent of Area within B-IBI categories
 (90% confidence intervals are in parentheses)

	Harbor	Jamaica Bay	Newark Bay	Lower Harbor	Upper Harbor	W. LI Sound	Bight Apex
1 to <2 impacted	6 (3-9)	18 (9-31)	18 (0-38)	0 (0-8)	14 (6-27)	7 (2-18)	0 (0-8)
2 to 3 moderately impacted	47 (37-57)	46 (33-60)	80 (60-100)	39 (27-53)	61 (47-73)	46 (33-60)	0 (0-8)
\$3-5 unimpacted	47 (37-58)	36 (24-50)	2 (0-6)	61 (47-73)	25 (14-38)	46 (33-60)	100 (92-100)

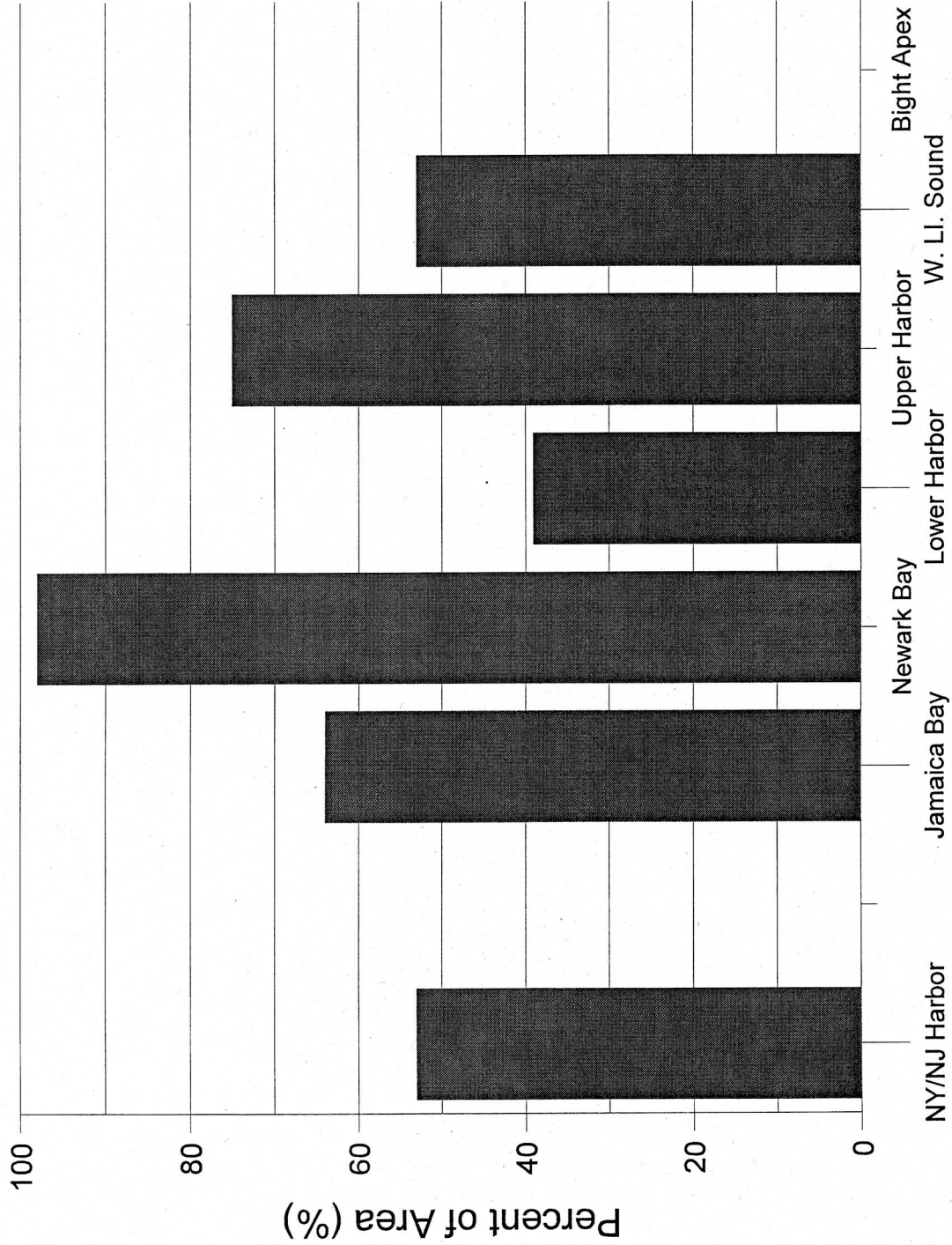


Figure 6-2. Percent of area with impacted benthos (B-IBI < 3).

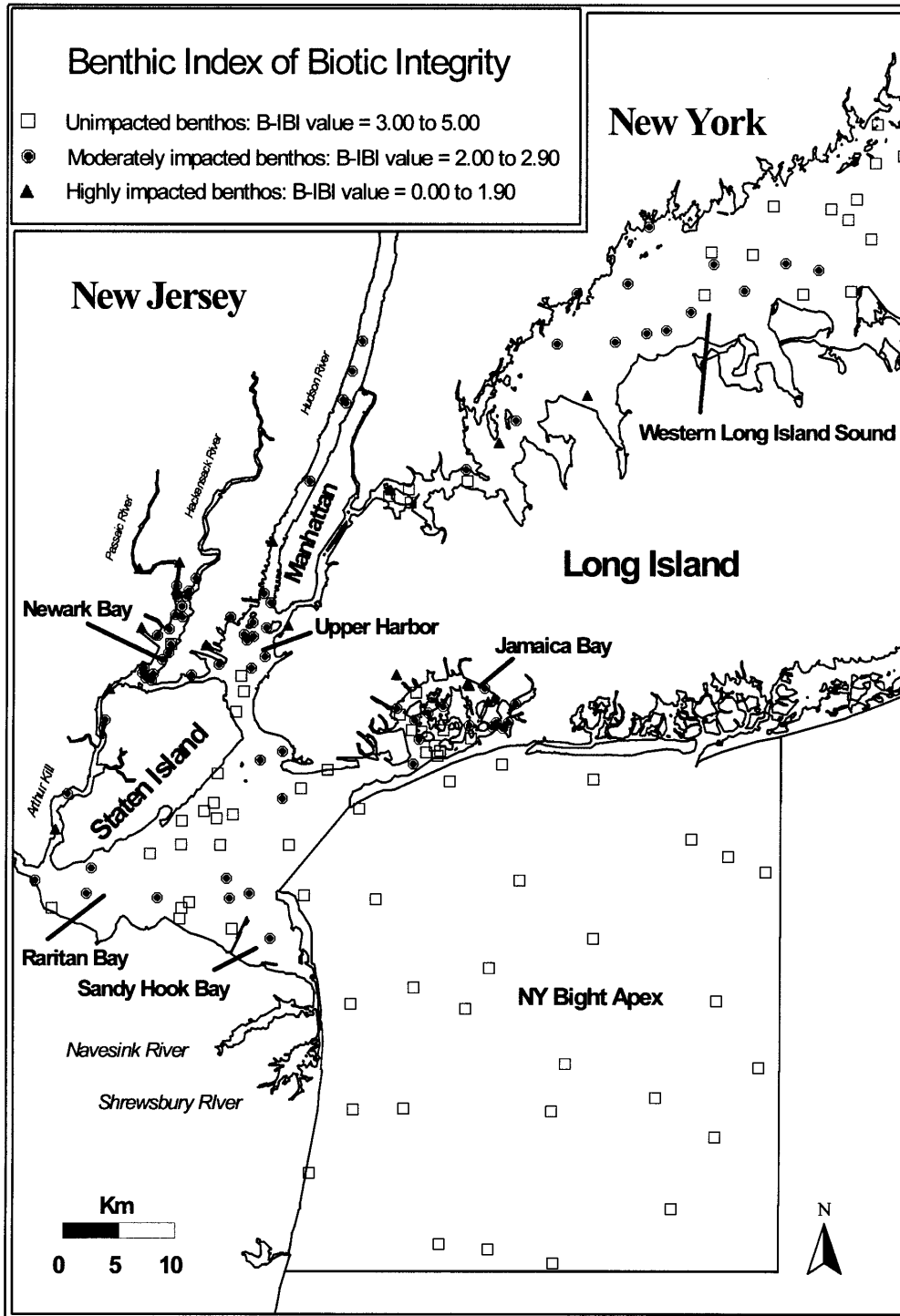


Figure 6-3. Distribution of stations by Benthic Index of Biotic Integrity (B-IBI) values.

6.3 CHARACTERIZATION OF WESTERN LONG ISLAND SOUND AND THE BIGHT APEX

6.3.1 Diversity and Taxonomic Composition

More species were identified in western Long Island Sound and in the Bight Apex, than in any of the Harbor sub-basins. The relative abundance of amphipods, molluscs and polychaetes was similar in coastal waters and the Harbor (Figure 6-1). The mean number of benthic species per station in the Bight Apex (28.9) was greater than in western Long Island Sound or within any sub-basin of the Harbor ($p < .05$).

6.3.2 Abundance and Biomass

The mean abundance of benthos did not differ significantly ($p = .05$) between western Long Island Sound, the Bight Apex and the Harbor. However, pollutant-indicative species in the Apex were significantly less abundant than in any other sub-basin ($p < .05$). Conversely, pollution-sensitive species were more abundant in the Apex than in any other sub-basin ($p < .01$). Benthic biomass in both western Long Island Sound and the Apex was intermediate between sub-basins of the Harbor (Table 6-2).

6.3.3 Benthic Index

The percent of area in each category of the benthic index was similar between the Harbor and western Long Island Sound (Table 6-4). Nearly 50% of the area in each would be considered to have impacted benthos, but most of the 50% was in the intermediate category of the B-IBI. The Bight Apex had approximately 100% of its area in the highest category (similar to reference conditions) of the B-IBI.

6.4 COMPARISON TO PREVIOUS STUDIES

Previous studies of benthic invertebrate structure in the Harbor primarily have used non-random sampling strategies. Although useful for other purposes, these non-probabilistic data prevent reliable generalizations beyond the specific locations sampled. However, some broad comparisons have been made to the current investigation.

Comparisons between this investigation and other studies regarding benthic structure must consider both natural and sampling variability, and differences in techniques. Uncertainty due to natural and sampling variability tends to decrease as less specific structural features are compared. For example, comparisons of abundance for a species, e.g., the amphipod *Ampelisca abdita*, are less certain (and less ecologically significant) than comparative abundance of all

amphipods, or of several amphipods which function similarly. Unfortunately, differences in techniques cause the greatest problems in comparisons among studies. They preclude most quantitative comparisons of even reliably estimable parameters. For instance, differences in methods among studies within the Harbor would make most biomass comparisons less than useful, although regional comparisons can be made.

This study's estimates of mean macrofaunal benthic abundance (# organisms/m²) were also not quantitatively comparable with other studies in the Harbor. This investigation's estimate of abundance for Lower Harbor was substantially higher (52,000/m²) than that (660/m²) of another study in Lower Harbor (Steimle and Caracciolo-Ward 1989). Two probable reasons for this disparity are: (1) entirely summer sampling by this investigation versus primarily winter collections, when benthic densities are minimal, by Steimle and Caracciolo-Ward, and (2) use of 0.5 mm mesh benthic sieves in the present investigation versus 1.0 mm mesh sieves used by Steimle and Caracciolo-Ward. Additional methodological contributions to this disparity are possible. Similar sieve-size differences also probably contributed to this study's higher estimates of mean abundance in Newark Bay (11,000/m²) versus 2,300/m² in August samples from the southern portion of Newark Bay (Cerrato 1986). The same sieve-size difference, plus differences in grab size, precluded useful comparisons of species richness (species per benthic grab) between Cerrato (1986) and the present investigation.

Within the Bight Apex, mean macrofaunal abundance as estimated by this investigation (32,000/m² ±8,200) was similar to an October 1994 estimate of 26,000/m² within a 79 km² rectangle surrounding the existing dredged material dumpsite (Hunt, 1996).

Several authors have postulated that benthic structural quality in the Harbor or parts of it has degraded, or improved, since the late 1950s. After correcting and enlarging the available benthic macrofaunal data set from 1957-60 and 1973-74 surveys, Steimle and Caracciolo-Ward (1989) questioned the significance of all benthic structural differences presumably indicative of negative trends in Lower Bay. An even more extensive benthic survey of Lower Harbor in 1986-87 (Cerrato, Bokuniewicz and Wiggins, 1988) did not indicate substantial changes in benthic structure from the 1957-60 or 1973-74 surveys interpreted by Steimle and Caracciolo-Ward (1989). Indeed, the mean, 1986-87 structural parameters estimated by Cerrato et al. reflected normal conditions or deviated only slightly from them, as defined by this study's benthic index. These observations were consistent with apparent improvements in summer minima of dissolved oxygen concentrations. Although dissolved oxygen monitoring is limited to New York waters of Lower Bay, improvements in summer bottom oxygen concentrations of Lower Harbor became evident (depending upon the site) from 1945 to the late 1970s. Once improvements became evident, they continued improving to 1995 (T.M. Brosnan, 1995, personal communication).

A number of benthic faunal surveys were conducted since 1972 in the Newark Bay area. These data sets included less than 30 stations per survey and were confounded by differences in sampling and analysis techniques, sampling locations and seasons, interannual variability, etc. Hypothesized hypoxic impacts on the Newark Bay benthos, particularly in deeper areas, do not

appear to have been evaluated during periods of extreme hypoxia (Cerrato, 1986). Despite the limitations of these data, analyses indicated that total abundance and species diversity were unusually low, at least until the May and August 1985 sampling of Cerrato (1986). Cerrato (1986) concluded that data from two seasonal cruises may or may not indicate real, temporary or long-term, differences from prior benthic structure which is itself inferred from limited, purposeful sampling.

Cautious but interesting observations on the benthic infauna of Jamaica Bay were based upon sampling during 1981 and 1982 (Franz and Harris 1988). The authors emphasized within-Bay associations. The only strong, evident pollutant influence on benthic structure were total organic carbon content of sediments. *A. abdita* was also sampled at three sites in Jamaica Bay during spring and summer of 1988-89 (Franz and Tanacredi, 1992). This work documents the existence of two productive cohorts in the Bay. The authors indicated that productivity of *A. abdita*, at least at the sites sampled, was comparable to the total macrobenthic production for several North Atlantic estuaries. These authors also suggested that the large amounts of particulate organic carbon in Bay sediments stimulated this high *Ampelisca* productivity.

It seems probable that the principal departures from historically "normal" benthic structure in the Harbor area had already taken place before the late 1950s, perhaps much earlier.

7.0 ASSOCIATIONS

7.1 BACKGROUND

Along with areal extent of contamination, an additional goal of this investigation was to determine if the contaminants in the NY/NJ Harbor and Bight Apex system were associated with biological effects. This was done most effectively by an integrated assessment. This type of assessment provides more information concerning the ecological significance of contamination than any of the measures can supply individually. An integrated assessment can include two or more of the following components: sediment toxicity tests, sediment chemical analyses, tissue chemical analyses, pathological studies, and community structure analyses (Chapman et al., 1995). This investigation used three of the five components: sediment toxicity tests, sediment chemical analyses and community structure analyses. This type of integrated assessment is commonly known as the Sediment Quality Triad approach (Chapman, 1990).

The Sediment Quality Triad has had multiple estuarine and marine applications (Long and Chapman, 1985; Chapman et al., 1987; Chapman et al., 1991). It offers several advantages that are not realized when using a one or two component approach. In a complex sediment mixture, such as is found in the NY/NJ Harbor, the triad approach incorporates interactions among contaminants (such as additivity, antagonism and synergism) and the effects of any unidentified chemicals. It is more comprehensive than individual measures, but does not assess non-sedimentary ecosystem components such as fish and mammals or human health. Associations are assessed here using a weight-of-evidence approach.

7.2 ASSOCIATION BETWEEN CHEMISTRY AND BENTHIC CONDITION

Contamination by chemical constituents appears to be a prominent factor affecting the health of benthic macroinvertebrate assemblages in the NY-NJ Harbor. The percent of area with impacted benthos was closely related to the level of contaminants in sediments of the Harbor. In the 53% of the Harbor that had abnormal benthic assemblages, 79% of this area exceeded an ERM for at least one contaminant (Figure 7-1). Only 16% of the area with normal benthic assemblages exceeded an ERM for any toxicant.

Three individual chemicals or classes exceeded their ERM values in more than 50% of the impacted benthic area (Table 7-1). Because these toxicants (mercury, chlordane and total PCBs) exceeded their ERM values at relatively few sites without evidence of benthic degradation (16% of the Harbor area), they were strongly associated with impacted benthos. No other chemicals measured were half as widespread in association with impacted benthos at concentrations likely to cause biotic effects.

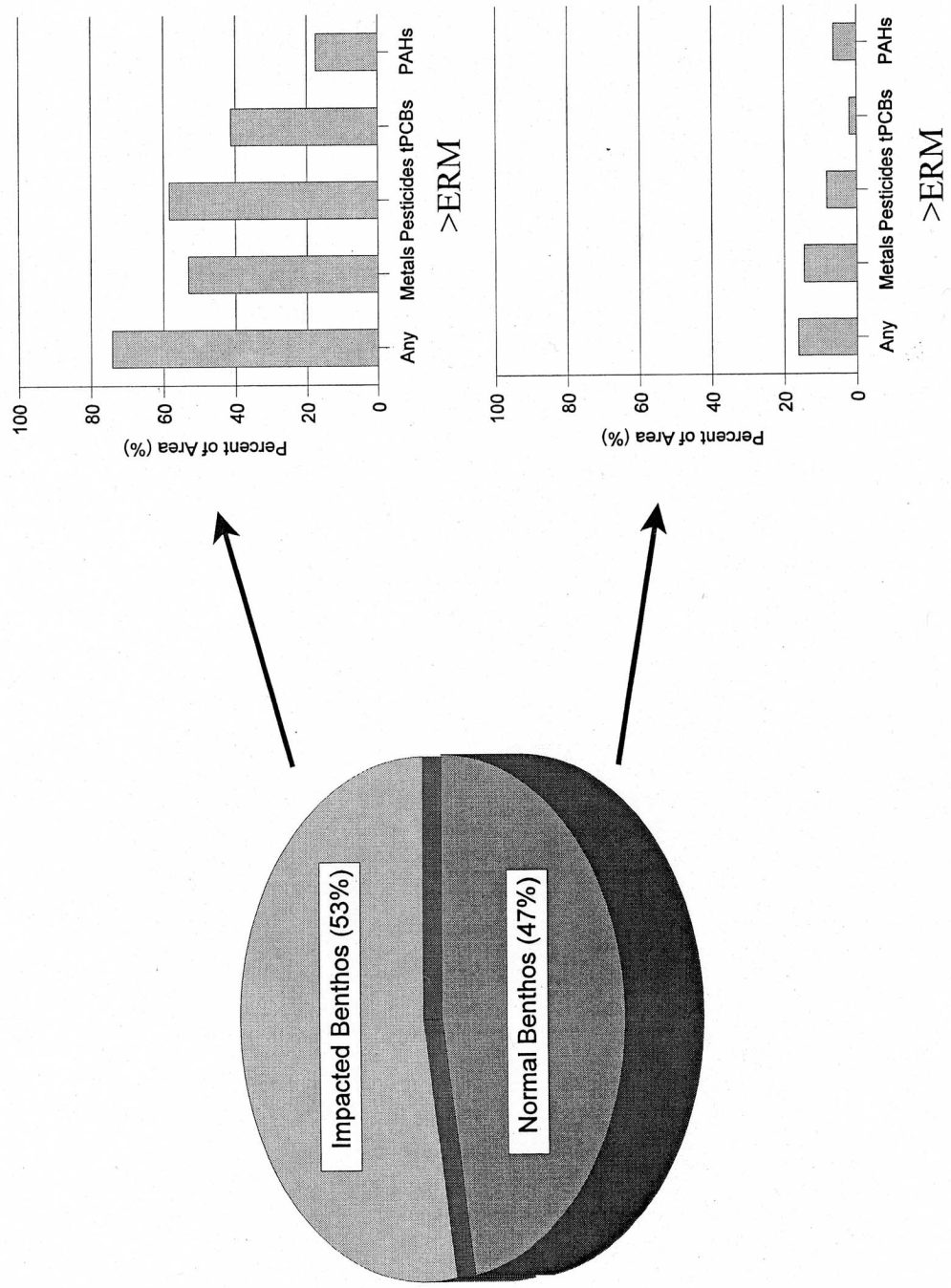


Figure 7-1. Association between benthos and percent of area with one or more contaminants greater than ERM (Long & Morgan, 1991; Long et al., 1995a)

Table 7-1
Individual Chemicals Associated with Impacted Benthos

	% of Impacted Area at which a Contaminant > ERM	% of Non- Impacted Area at which a Contaminant > ERM	% of Impacted Area at which a Contaminant > ERL	% of Non- Impacted Area at which a Contaminant > ERL
Metals				
Mercury	51.1	14.6	92.8	55.1
Silver	23.6	1.6	78.8	14.5
Nickel	8.3	0	82.0	16.2
Lead	6.3	1.6	82.0	22.4
Zinc	4.9	0	67.5	17.9
Copper	4.5	1.6	78.5	17.6
Antimony	1.5	0	33.4	6.7
Arsenic	1.5	0	69.0	12.2
Cadmium	0.2	0	41.5	1.9
Chromium	0	0	66.2	11.5
Organics				
Total PCBs	69.6	6.7	95.2	26.4
Total Chlordane	55.6	6.7	95.5	25.4
Total DDE	24.0	0.3	83.4	13.8
Total DDD	19.9	3.5	90.5	16.9
High Molec. Wt. PAHs	17.4	6.3	76.9	20.1
Total DDT	13.3	1.9	95.5	31.1
Low Molec. Wt. PAHs	11.0	6.3	81.6	15.1
Benzo(a)anthracene	7.4	6.3	63.9	6.6
Anthracene	6.3	4.7	71.0	12.1
Phenanthrene	6.3	4.7	57.0	8.2
Dibenz(a,h)anthracene	6.0	3.2	55.6	11.4
p,p'-DDE	5.8	0.3	77.1	13.1
Pyrene	5.8	6.3	34.4	6.6
Benzo(a)pyrene	5.6	6.3	41.6	6.6
Total parent DDT	5.2	0.3	51.1	38.3
Chrysene	4.9	3.2	59.4	6.6
Total PAHs	3.5	1.6	69.0	6.6
Fluoranthene	3.5	1.6	40.0	6.6
Acenaphthylene	2.9	3.2	79.9	14.4
Fluorene	2.1	1.6	86.9	18.3
Acenaphthene	2.1	0	81.2	13.7
2-Methylnaphthalene	2.1	0	48.9	6.6
Naphthalene	1.4	0	31.0	6.6
Endrin	0	0	100.0	99.3
Dieldrin	0	0	99.4	85.6

7.3 ASSOCIATION BETWEEN CHEMISTRY AND TOXICITY

Similar to the association between chemistry and benthic community structure, contaminants also were associated with sediment toxicity. Within the 15% of the Harbor where *A. abdita* toxicity was observed, 92% exceeded at least one ERM (Figure 7-2). Conversely, an ERM was exceeded in 42% of the non-toxic area. Metals were most often associated with toxicity, and total PAHs the least often associated.

The same three individual contaminants or classes (mercury, total chlordane, and total PCBs) that were most strongly associated with benthic impacts also appeared to be associated with toxicity (Table 7-2). However, all three also appeared to be, although less frequently, found in non-toxic areas at concentrations above ERMs.

7.4 ASSOCIATION AMONG CHEMISTRY, TOXICITY AND BENTHIC COMMUNITY STRUCTURE

Incorporating all three components of the Sediment Quality Triad strengthened the association between contaminants and biological effects, and demonstrated that a high degree of consistency existed among the components. This association was examined by partitioning the Harbor areas with impacted benthic structure into percentages of these areas with and without one or more toxicant concentrations exceeding ERM values, and percentages with or without evidence of sediment toxicity based upon *A. abdita* or Microtox™ assays (Figure 7-3). Most of the area with impacted benthic structure also had evidence of both sediment toxicity and toxicant concentrations likely to cause biological effects (66%). Approximately 86% of the area with impacted benthic structure had evidence of sediment toxicity or toxicants likely to impact benthic structure. Conversely, only 18% of those areas with normal benthos exhibited evidence of sediment toxicity or any sediment toxicant exceeding its ERM value. Consequently, it is apparent that most departures from normal benthic structure were associated with sediment toxicity or unusually high toxicant concentrations in sediments.

At only 14 of the 168 Harbor stations were abnormal benthic assemblages observed without evidence of: (1) potential biological effects (at least one chemical concentration greater than its ERM value), or (2) actual sediment toxicity (Microtox™ or *A. abdita*). Environmental stresses other than, or coincident with, toxicants could have been responsible for these abnormal benthic index values. To assess the possibility of low dissolved oxygen induced benthic impacts, existing dissolved oxygen data from the New York City Department of Environmental Protection (Brosnan and O'Shea, 1994; 1995) were evaluated. Severe hypoxic stress (< 2 mg/l D.O.) was probable at only three of the 14 stations. Several of the remaining 11 stations were exposed to exceptionally great scouring by strong currents, a stressor known to impact benthic structure.

The estimated prevalence of high toxicant concentrations (i.e., sediments with one or more toxicant concentrations exceeding ERM values) was consistent with the estimates of areas with

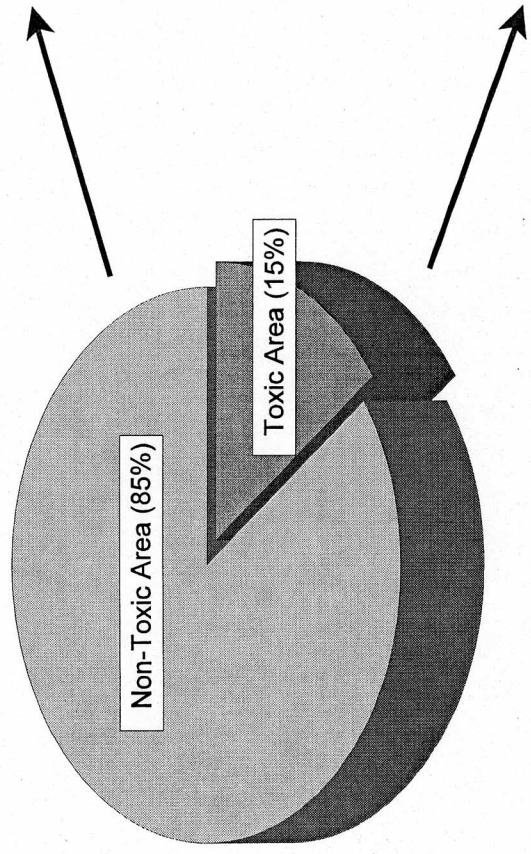
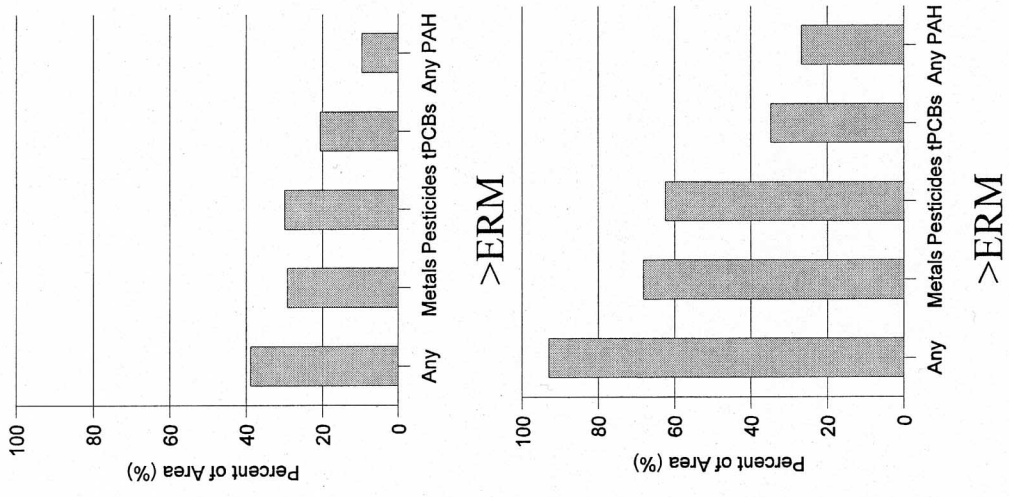
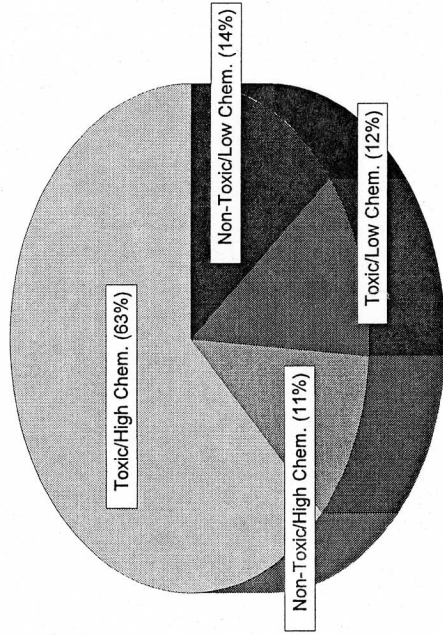


Figure 7-2. Association between *Ampelisca abdita* toxicity and one or more contaminants greater than ERM (Long & Morgan, 1991; Long et al., 1995a).

Table 7-2
Individual Chemicals Associated with Sediment Toxicity (*Ampelisca abdita*)

	% of Toxic Area at which a Contaminant > ERM	% of Non-Toxic Area at which a Contaminant > ERM	% of Toxic Area at which a Contaminant > ERL	% of Non-Toxic Area at which a Contaminant > ERL
Metals				
Mercury	68.8	28.0	100.0	70.7
Silver	21.2	11.8	94.6	40.5
Lead	17.3	1.8	95.4	46.7
Zinc	16.8	0.1	90.8	36.0
Copper	16.1	0.9	95.4	41.9
Nickel	15.2	2.5	75.4	46.7
Antimony	5.3	0	33.2	18.6
Arsenic	5.3	0	70.4	37.3
Cadmium	0.7	0	52.2	17.8
Chromium	0	0	73.1	34.7
Organics				
Total Chlordane	57.3	28.2	100.0	56.0
Total PCBs	49.5	37.3	100.0	65.5
High Molec. Wt. PAHs	26.7	9.7	82.3	44.5
Total DDD	24.7	10.0	95.4	49.0
Anthracene	17.5	3.5	82.3	36.4
Total DDE	16.9	12.1	95.4	42.8
Total DDT	14.6	6.8	100.0	59.1
Low Molec. Wt. PAHs	12.9	8.0	84.6	44.3
Benzo(a)pyrene	12.9	4.7	37.3	23.0
p,p'-DDE	12.8	1.6	90.8	39.3
Benzo(a)anthracene	12.4	6.0	57.8	33.2
Pyrene	12.4	4.9	29.8	19.8
Phenanthrene	12.4	4.4	56.0	30.2
Total parent DDT	12.0	1.3	58.0	42.8
Dibenz(a,h)anthracene	11.1	3.5	39.4	34.0
Chrysene	7.4	3.5	57.8	30.5
Total PAHs	7.4	1.8	60.1	36.0
Fluoranthene	7.4	1.7	42.7	21.1
Acenaphthylene	5.1	2.7	77.7	44.1
Fluorene	2.3	1.8	84.6	49.3
Acenaphthene	2.3	0.9	82.3	43.7
2-Methylnaphthalene	2.3	0.9	57.8	24.0
Naphthalene	0	0.9	40.7	15.8
Endrin	0	0	100.0	99.6
Dieldrin	0	0	100.0	91.6



Impacted Benthos (53% of Harbor)

Non-Impacted Benthos (47% of Harbor)

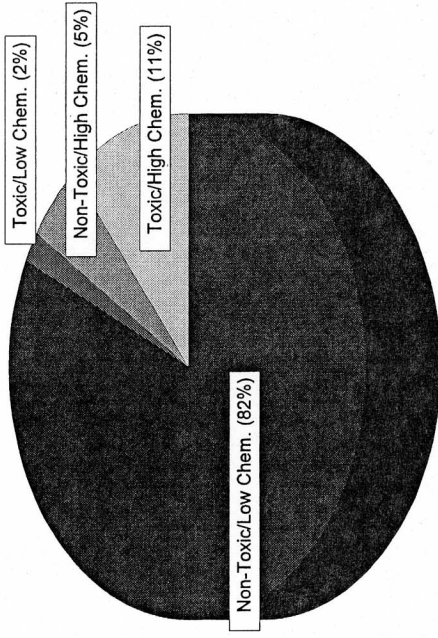


Figure 7-3. Association between sediment toxicity (*A. Abditia* or Microtox™), benthos (using the B-IBI) and sediment chemistry as one or more contaminants greater than ERM (Long & Morgan, 1991; Long et al., 1995a).

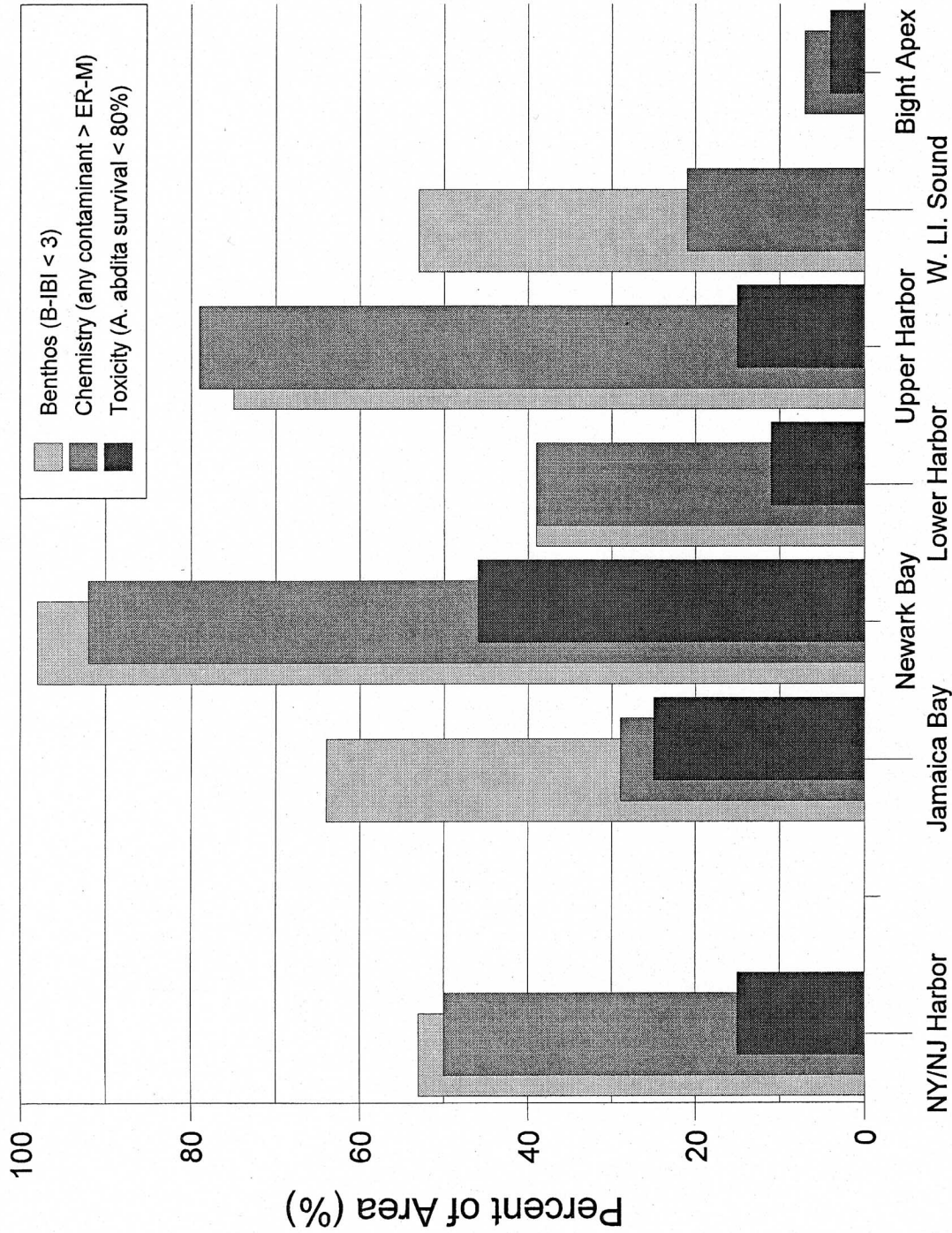


Figure 7-4. Percent of area considered degraded because of impacted benthos, sediment toxicity and sediment chemical contamination.

impacted benthos. Both indicators estimated that about 50% of the Harbor sediments were affected on average, and provided similar results even within sub-basins (Figure 7-4). However, sediments from a relatively small area of the Harbor (15%) reduced laboratory survival of *A. abdita*. The *A. abdita* test detected sediment toxicity in only about 25% of the Harbor area with ecologically significant chemical contamination and/or measured degradation of benthic assemblages. This indicated that the *A. abdita* acute sediment toxicity test was a less sensitive indicator of sediment quality than the B-IBI or ERM sediment chemistry concentrations. This difference was significant for the Harbor as a whole ($P < 0.01$) and was consistent within each Harbor sub-basin and western Long Island Sound ($P < 0.05$). The only exception was the lack of a significant difference between the estimated areas with ecologically significant chemical contamination and *A. abdita* toxicity within Jamaica Bay (Figure 7-4). These findings indicated that benthic structure was measurably impacted, and was predictable by chemical contamination, before acute toxicity of *A. abdita* became evident.

8.0 DISCUSSION

Previous studies have documented that sediment chemical contamination is intensive within selected portions of the NY/NJ Harbor (NOAA, 1995). This study expands on these findings by documenting the pervasiveness of the contamination. Nearly every sample collected in the Harbor, as part of this investigation, had at least one chemical exceeding an ERL concentration and one-half of the area in the Harbor had at least one chemical exceeding an ERM concentration. Contamination was pervasive across chemical groups. More than one-third of the Harbor had chemical concentrations exceeding ERM concentrations for each of the metals, pesticides and PCBs chemical groups; there were 14 individual chemicals which exceeded their ERL concentration over more than 25% of the Harbor area.

Examining a simple ranking of the sub-basins by areal extent of biologically significant levels of contaminants, toxicity and abnormal benthic communities (Table 8-1) shows that Newark Bay is consistently the most degraded sub-basin in the Harbor and Lower Harbor the least degraded. The Bight Apex and western Long Island Sound appear relatively unaffected.

Table 8-1
Relative Ranking of Sub-basins by % of Area
 (1 is most degraded, 5 is least degraded)

	Jamaica Bay	Newark Bay	Lower Harbor	Upper Harbor	W. LI Sound	Bight Apex
Chemistry ¹	4	1	3	2	5	6
Toxicity ²	2	1	4	3	6	5
Benthos ³	3	1	5	2	4	6
Mean Ranking	3	1	4	2	5	6

¹ One or more contaminants > ERM.

² Significant toxicity to *A. abdita* (% survival <= 80% and statistically different from controls).

³ Benthic index value <3.

Biological effects were found to be associated with chemical contamination. At 66% of the area where impacted benthic communities were observed, there also was a toxicological response and/or at least one chemical exceeding its ERM concentration. In contrast, only 14% of the area without a toxicological response and without a chemical exceeding an ERM concentration had impacted benthic communities.

The conclusions regarding the strong relationship between high chemical concentrations and biological response are based largely on an index that integrates multiple measures of the benthic community into a single value. Some authors have raised concern about analyses based solely on

integrative indices (Elliott, 1994). The index approach was chosen for this investigation because the integration provides a threshold for identifying degraded assemblages and allows analysis based on areal extent of a problem. This investigation's conclusion regarding coupling of chemistry and benthic response, though, appears to be independent of the index. There were relationships between average values for several of the individual benthic metrics used in the index and presence of high chemical concentrations (Table 8-2).

Table 8-2
Association between Harbor Means of Benthic Metrics and Number of Chemicals > ERM
 (± represent 90% confidence interval)

	1 or more chemicals > ERM*	2 - 5 chemicals > ERM*	6 or more chemicals > ERM*
Abundance (# organisms/m ²)	98,497 ±64,798	76,976 ±27,915	21,477 ±3108
Species Richness (as # species/sample)	24.33 ±4.63	21.24 ±1.97	18.15 ±2.43
Pollution-Indicative Species (%)	18.37 +8.07	34.08 +6.58	58.31 +4.99

* May also have 1 or more contaminants >ERL.

This study's conclusions are also based on interpreting chemical concentrations relative to the thresholds suggested by Long and Morgan (1991) and Long et al. (1995a). Some authors have suggested that the likelihood of contaminant-related biological effects is more appropriately assessed using equilibrium partitioning for organic chemicals (DiToro, 1991; U.S.EPA, 1994) and acid-volatile sulfides for metals (DiToro et al., 1990, 1992), although other authors have questioned these approaches (Iannuzzi et al., 1995). The Long et al. (1995a) values were used for this investigation because they included thresholds for most of the chemicals that were measured, allowing an integrated contaminant response to be provided. The other approaches have been developed for a relatively small number of chemicals, and rely almost entirely on theoretical considerations without field assessment. When the two approaches were compared for chemicals for which thresholds are available from both approaches, the Long et al. approach consistently predicted a greater extent of contamination occurring at biologically relevant concentrations (Table 8-3). The coincidence between chemistry, toxicity and biological response was also greater for the Long et al. approach, suggesting that the partitioning approaches may underestimate the availability of contaminants, but this may be partially a function of the lesser number of chemicals for which thresholds have been developed. Re-examination of which chemical groups are leading to biological and toxicological responses may be advisable as the equilibrium partitioning approach is applied to a larger group of chemicals. The use of cumulative distribution functions, inherent with a probability-based sampling design, provides

flexibility in applying different thresholds to the same data set without recollecting samples or recalculating data.

Table 8-3
Percent of Harbor Area Which Exceeded Selected Thresholds

	Percent of Area Exceeding Threshold (%)
ERM (Long & Morgan, 1991; Long et al., 1995a)	50
Proposed SQC (U.S.EPA, 1994)*	3
AVS (DiToro, 1990, 1992)**	12

* Proposed SQC exist for 3 aromatic hydrocarbons and 2 pesticides. Normalized for TOC.

**Applies to 5 divalent metals.

The most prevalent contaminants at levels of biological concern appeared to be mercury, chlordane and total PCBs, which were consistent with findings of previous studies (Long et al., 1995a) and data syntheses (Squibb et al., 1991) for NY/NJ Harbor. However, this study's conclusions were based on associations which do not necessarily result from cause/effect relationships. Correlations with other chemicals, or with mixes of other chemicals, can confound the patterns that were observed. Associations identifying which chemicals are not causing effects are more robust to confounding than are associations that imply cause. Still, mercury, chlordane and total PCBs each were found at concentrations exceeding ERM levels at more than half of the sites in the Harbor where impacted benthic assemblages were observed, but were not observed at most sites which contained healthy assemblages, which is a compelling spatial coincidence.

The chemistry problems in the NY/NJ Harbor present a difficult management challenge as each of the major chemicals of concern appears to originate from a combination of point- and non-point sources. For instance, most of the mercury input to Newark Bay has been estimated to come from point sources on the Hackensack and Passaic Rivers (Olsen et al., 1984), which is consistent with the spatial patterns this investigation observed for mercury in the Harbor. Mercury was mostly concentrated in Newark Bay and the mercury exceedances in places like Raritan Bay followed a spatial pattern suggesting flow from Newark Bay as a source. In contrast, HydroQual (1991) has estimated that 50% of the inputs for total PCBs enters from tributaries and most of the chlordane (Bopp et al., 1982) is non-point in origin. The distribution of total PCBs and chlordane was pervasive throughout the Upper Harbor, Newark Bay and Jamaica Bay, each of which has a distinct watershed.

While this study assessed which chemicals were site- or basin-specific problems within the Harbor complex, it did not address which chemicals had sources that were ubiquitous at scales beyond the boundaries of the Harbor complex. The field methods, laboratory methods and QA protocols used in the Harbor were modeled after those of EPA's Environmental Monitoring and

Assessment Program (EMAP), facilitating comparisons between the NY/NJ Harbor and the remainder of the mid-Atlantic coastal estuaries sampled by EMAP (Strobel et al., 1995), and allowing assessment of which chemicals are NY/NJ specific problems and which are issues on a wider geographic scale. Conducting the comparison with EMAP, this study found that the Harbor had higher average concentrations for 58 of the 59 chemicals measured (Table 4-4). For several chemicals, specifically mercury and total PCBs, the Harbor also had a large portion (69% and 100%, respectively) of the areal extent of ERM exceedances in the Virginian Province, even though the Harbor constitutes only 4% of the area in the Province (Figure 4-14). These findings suggest that for these chemicals the spatial scale of management action should be focused on the Harbor.

This study was focused on evaluating the relationship between contaminants and benthic community condition, but findings from other studies suggested that there also may be contaminant related food chain effects in the Harbor. Benthic macroinvertebrates are important food for fish and birds. Some of the same contaminants this study found prevalent in the sediments were also present in fish, shellfish and crustacea (Belton et al., 1985; NYSDEC, 1988; Hauge et al., 1990; Zongwei et al., 1994) and bird feathers (Burger and Gochfeld, 1993) within and near the Harbor and Bight Apex.

While this study's data were sufficient to indicate a contaminant problem in the Harbor, this study did not distinguish historical from current inputs. Crawford et al. (1995) has suggested that inputs to systems like Newark Bay have decreased by 90% over the last decade. This investigation sampled only the top two centimeters and it has been suggested that average deposition rates in the Harbor are as high as 0.3 cm per year (Olsen et al., 1984). Based on this estimate, most of the material this investigation sampled would have been deposited in the last seven years, suggesting that inputs to the system are still a problem even after substantial reductions. Better estimation of deposition rates and sediment transport within each sub-basin is a necessary precursor for determining the most appropriate management strategy to address the contaminant problem, whether it is pollution prevention, remediation, no action or a combination of strategies.

This study assessed the quality of surficial sediments in 1993-94, but these qualities will persist in potential dredged materials of the future. This investigation was principally concerned with fine-grained particles (silts and clays, <63 μ in diameter) because most toxicants are strongly attached to them -- so strongly that the fines carry the toxicants with them when transported (Olsen et al. 1982). Although the dynamics of fine particles and their associated toxicants are complex functions of several processes, the locations of maximal net sedimentation (the fastest deposition) are predictable. Deposition is fastest wherever bottom currents are slow and little wave energy reaches the bottom: in coves and channels, around piers, and near the ends of salinity intrusions (Olsen et al. 1978, 1984; Abood et al. 1992).

Human intervention to improve sediment quality in the Harbor presumes at least broad understanding of where sediments and contaminants come from, and their movements within the

Harbor. Despite large uncertainties, usefully precise estimates of fine sediment fluxes exist. On average, $1.5 \pm 0.5 \times 10^6$ metric tons of fine particles accumulate in the Harbor annually. About 3/4 of this material is riverborne, 1/4 comes from marine sources, and very small contributions are from sewage solids, water column productivity and shore erosion (Olsen et al. 1984). These estimates are comparable to those of Ellsworth (1986) and Bokuniewicz and Ellsworth (1986), but a resulting fine-sediment budget did not balance. Bokuniewicz and Ellsworth suspect that existing measurements underestimate oceanic fluxes into the Harbor, and up rivers and into Jamaica Bay (by factors of about 2.5 to 4). Most of the newly introduced fines tend to mix with fines already in the Harbor, and accumulate in dredged areas of Upper Bay, Newark Bay, and Raritan Bay, at 10 to 100 times the accumulation rates elsewhere (Olsen et al., 1984; Abood et al., 1992). Dredging is the principal mechanism for removing fine-grained sediment from the Harbor. Lateral fine sediment mixing appears to be rapid throughout the Harbor (Bokuniewicz and Ellsworth, 1986). These extensive fluxes rapidly scavenge toxicants from the water column and tend to homogenize their concentrations in fine sediments. Sediments of shallow, wide areas of the Harbor are generally in equilibrium with sea level rise, and have net sedimentation rates of only 1-3mm/yr. These areas have little or no net accumulation of fine particles. However, these fines and their associated contaminants are continually resuspended, facilitating their lateral transport throughout the Harbor (Olsen et al., 1984).

These dynamics explain why today's fine surficial sediments scavenge toxicants from Harbor waters and store them in deep and protected areas such as channels and coves. As a consequence most chemical properties of the surficial sediments measured by this investigation in 1993-94 will persist in channels until these sediments are dredged. Similarly, the qualities of future dredged materials will reflect toxicant concentrations of fine sediments accumulated in previous years. Consequently, significant improvements in dredged material quality will require significant reductions in total toxicant loadings on the Harbor, wherever they come from.

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APPENDICES FOR:

**SEDIMENT QUALITY OF THE NY/NJ
HARBOR SYSTEM**

EPA/902-R-98-001

Darvene A. Adams
U.S. Environmental Protection Agency - Region 2
Edison, NJ

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U.S. Environmental Protection Agency - Region 2
New York, NY

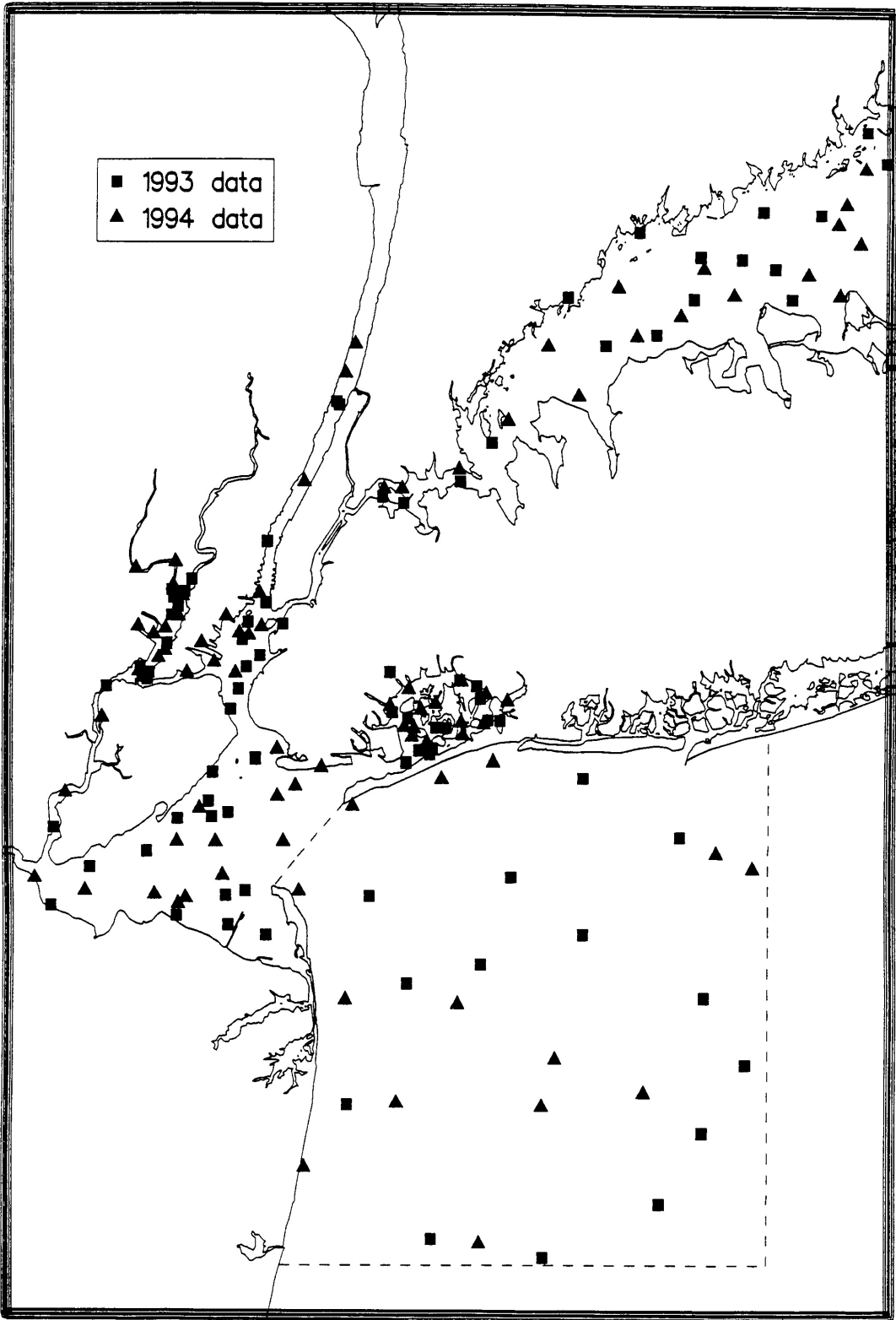
Stephen B. Weisberg
Southern California Coastal Water Research Project
Westminster, CA

March 1998

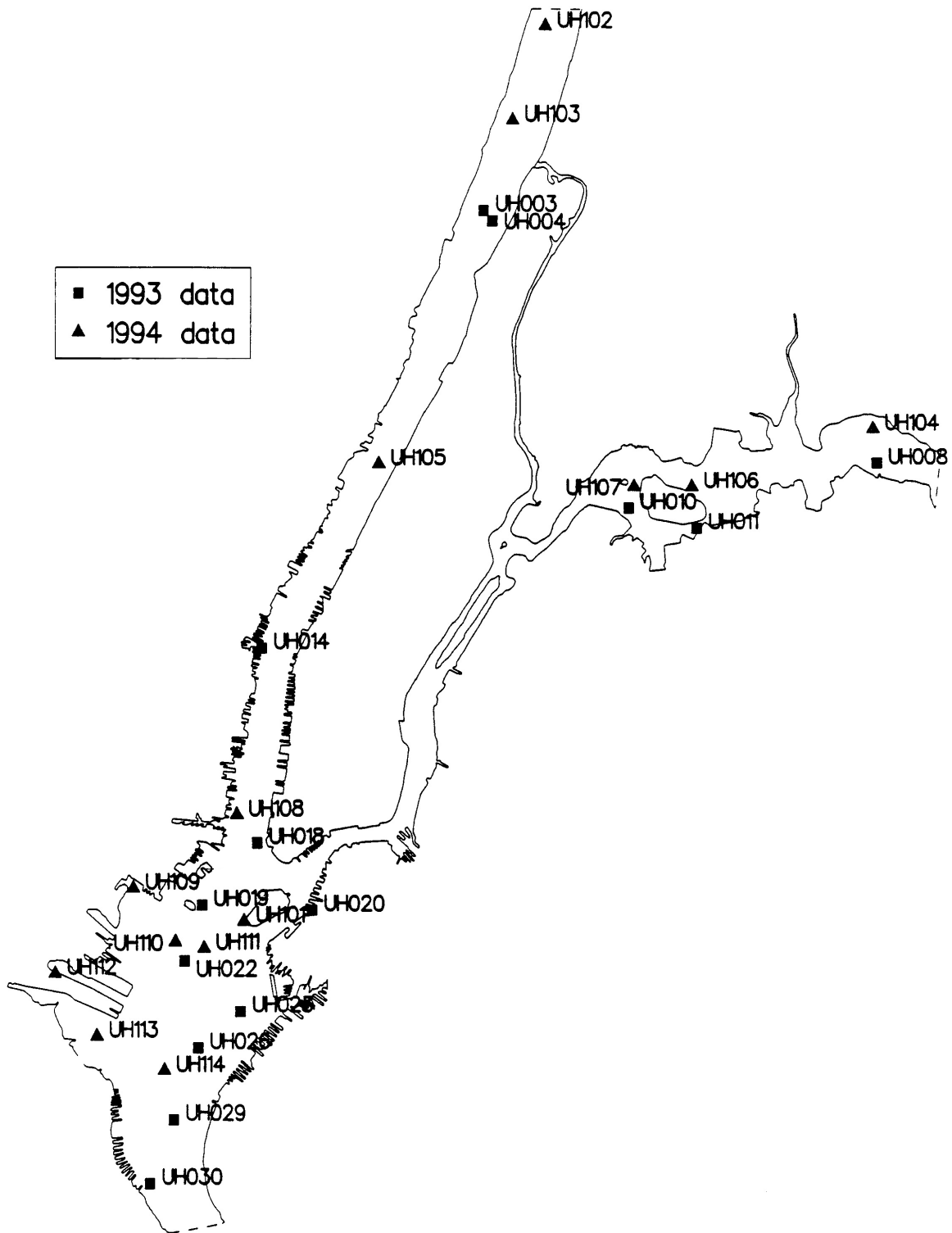
Appendix A

Sampling station maps

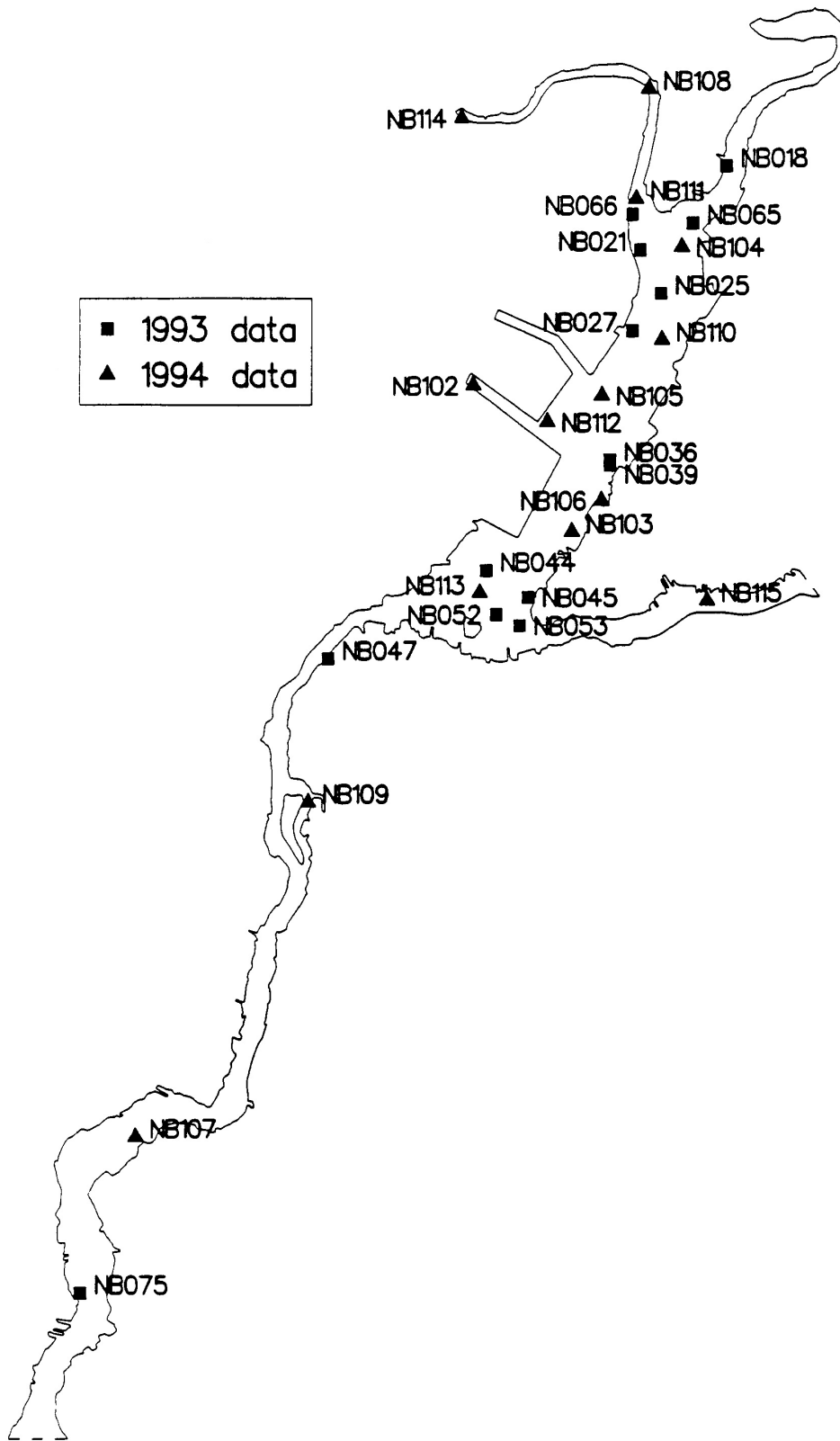
R-EMAP SUMMER 1993 AND 1994 SAMPLING LOCATIONS, NY/NJ HARBOR



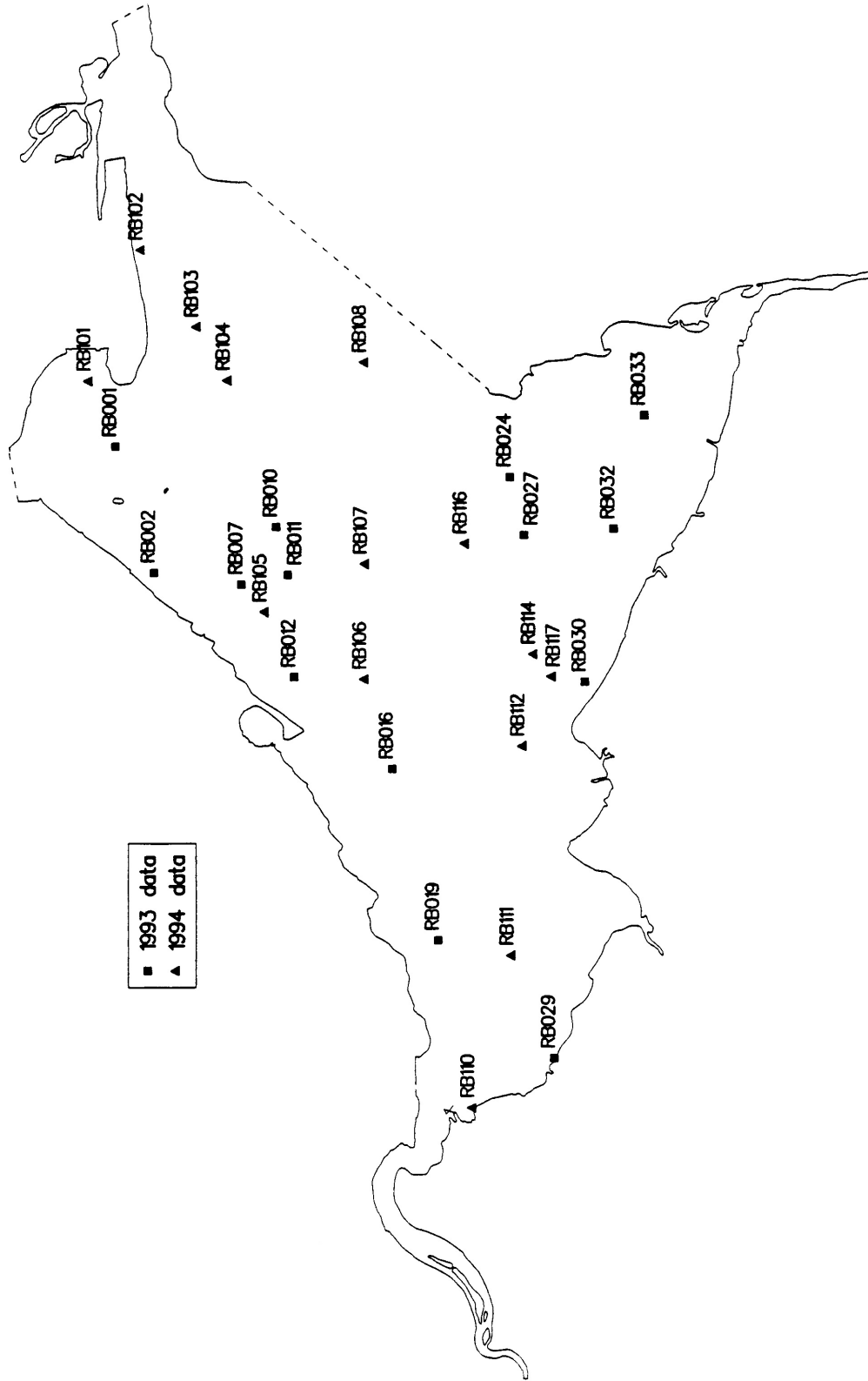
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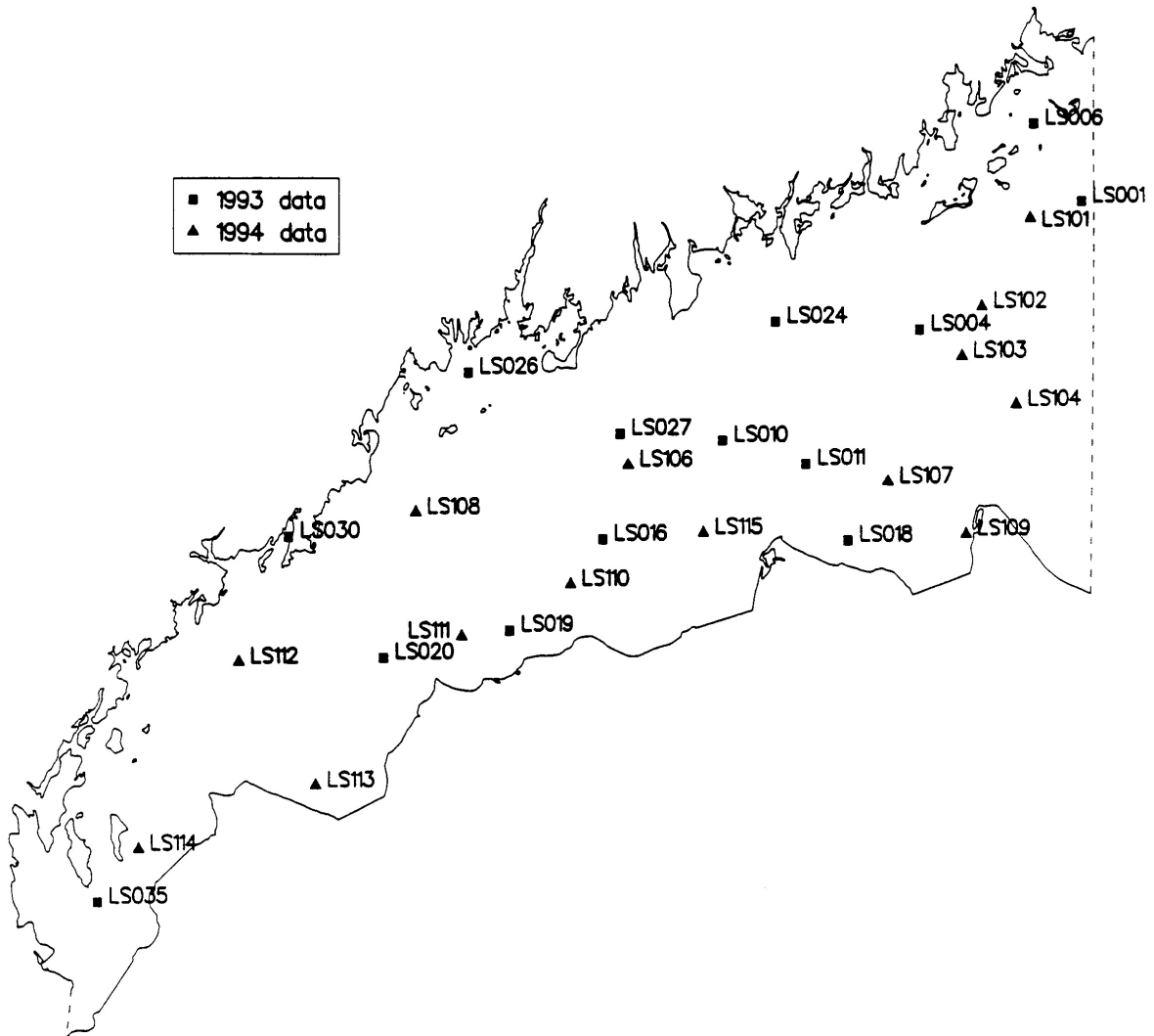
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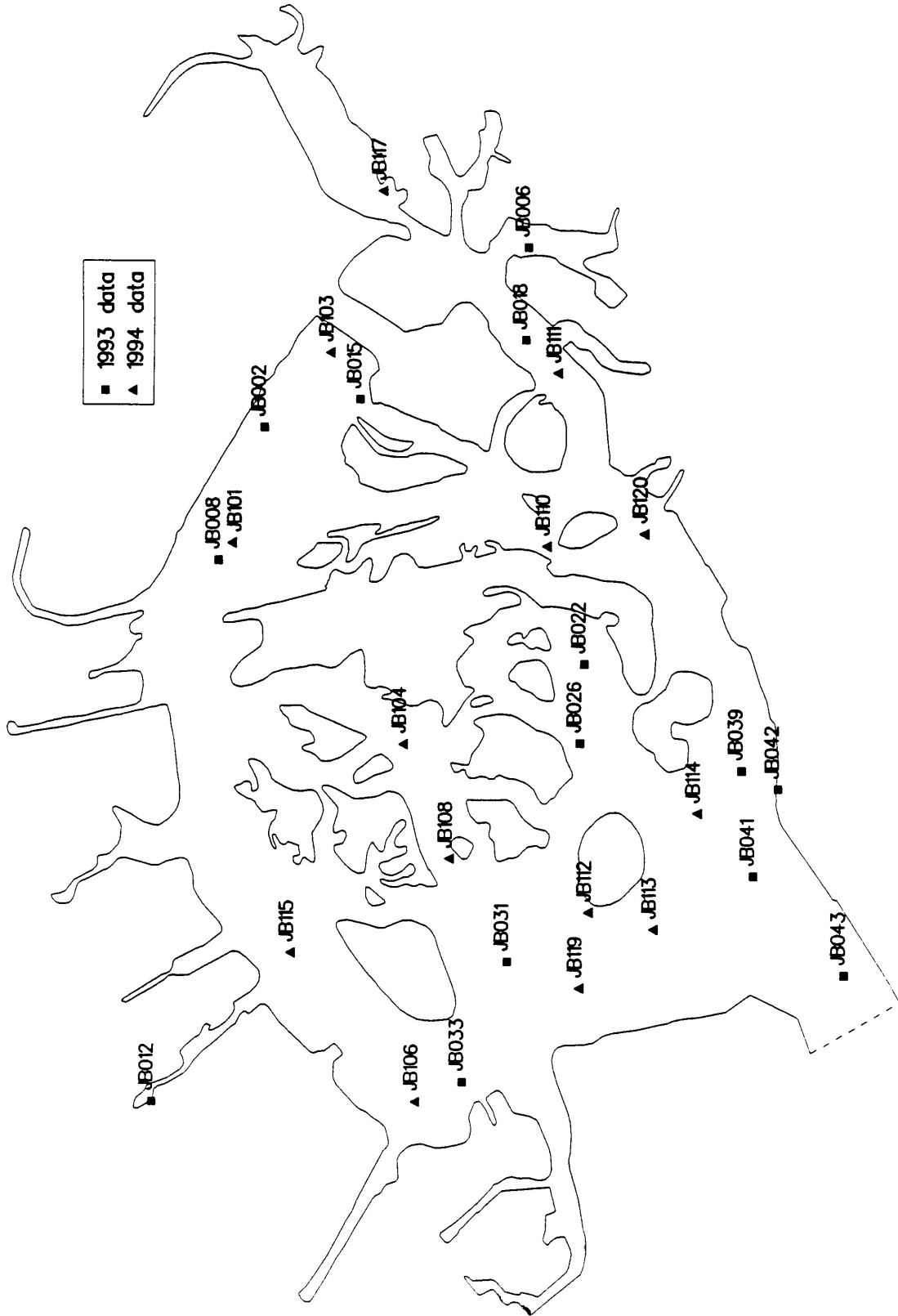
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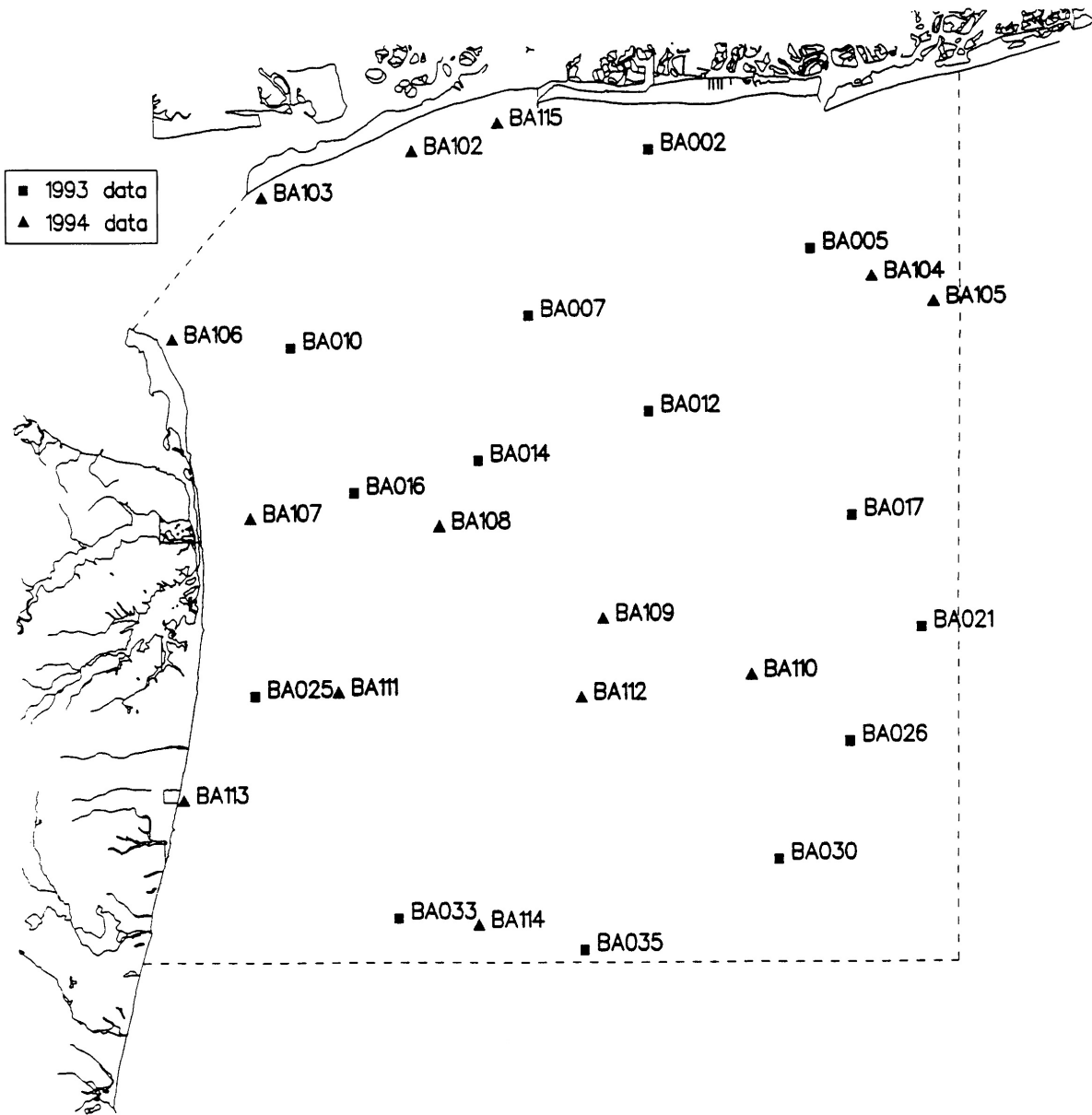
R-EMAP SUMMER 1993 AND 1994 SAMPLING LOCATIONS, WESTERN LONG ISLAND SOUND



R-EMAP SUMMER 1993 AND 1994 SAMPLING LOCATIONS, JAMAICA BAY



R-EMAP SUMMER 1993 AND 1994 SAMPLING LOCATIONS, NEW YORK BIGHT APEX



Appendix B

Analytical detection values

Analytical Detection Values for Sediment Samples

Parameter	DL	Parameter	DL
PAHs (ug/kg, dry wt.)		Major and Trace Elements (ug/g, dry wt.)	
Acenaphthene	12,24	Aluminum (Al)	200
Acenaphthylene	12	Antimony (Sb)	0.1
Anthracene	12	Arsenic (As)	0.24
Benzo(a)anthracene	12	Cadmium (Cd)	0.018
Benzo(b,k)fluoranthene	12,31	Chromium (Cr)	0.1
Benzo(g,h,i)perylene	12,25	Copper (Cu)	0.44
Benzo(a)pyrene	12	Iron (Fe)	40
Benzo(e)pyrene	12	Lead (Pb)	0.15
Biphenyl	12,24	Manganese (Mn)	3.5
Chrysene	12	Mercury (Hg)	0.01
Dibenz(a,h)anthracene	12,32	Nickel (Ni)	0.4
2,6-Dimethylnaphthalene	12	Selenium (Se)	0.1
Fluoranthene	12	Silver (Ag)	0.013
Fluorene	12,24	Tin (Sn)	0.1
Indeno(1,2,3-C,D)pyrene	12,30	Zinc (Zn)	1.5
2-Methylnaphthalene	12		
1-Methylnaphthalene	12,24	PCBs (ng/g, dry wt.)	
1-Methylphenanthrene	12,30	2,4'-dichlorobiphenyl (8)	2
Naphthalene	12	2,2',5'-trichlorobiphenyl (18)	2
Perylene	12	2,4,4'-trichlorobiphenyl (28)	2
Phenanthrene	12	2,2',3,5'-tetrachlorobiphenyl (44)	2
Pyrene	12	2,2',5,5'-tetrachlorobiphenyl (52)	2
2,3,5-Trimethylnaphthalene	12,33	2,3',4,4'-tetrachlorobiphenyl (66)	2
		2,2',4,5,5'-pentachlorobiphenyl (101)	2
Pesticides (ng/g, dry wt.)		2,3,3',4,4'-pentachlorobiphenyl (105)	2
o,p'-DDD	1	2,3',4,4',5-pentachlorobiphenyl (118)	2
p,p'-DDD	1	2,2',3,3',4,4'-hexachlorobiphenyl (128)	2
o,p'-DDE	1	2,2',3,4,4',5'-hexachlorobiphenyl (153)	2
p,p'-DDE	1	2,2',4,4',5,5'-heptachlorobiphenyl (170)	2
o,p'-DDT	1	2,2',3,3',4,4',5-heptachlorobiphenyl (180)	2
p,p'-DDT	1	2,2',3,3',4,4',5,5'-heptachlorobiphenyl (187)	2
Aldrin	1	2,2',3,3',4,4',5,6-octachlorobiphenyl (195)	2
alpha-Chlordane	1	2,2',3,3',4,4',5,5',6-nonachlorobiphenyl (206)	2
trans-Nonachlor	1	2,2',3,3',4,4',5,5',6,6'-decachlorobiphenyl (209)	2
Dieldrin	1		
Heptachlor	1	Butyltins (ng/g, dry wt.)	
Heptachlor epoxide	1	Monobutyltin	5
Hexachlorbenzene	1	Dibutyltin	5
Lindane (gamma-BHC)	1	Tributyltin	5
Mirex	1	Tetrabutyltin	5
AVS/SEM (ug/g, dry wt.)		Dioxin & Furan Congeners (ng/kg, dry wt.)	
AVS	5	Detection limits for dioxins and furans varied by	
SEM-Cd	0.2	sample. See accompanying data disk for	
SEM-Cu	0.5	detection	
SEM-Hg	0.07	limits.	
SEM-Ni	0.5		
SEM-Pb	1		
SEM-Zn	5		

Two values for a detection limit represent values achieved for 1993 and 1994 samples, respectively.

Appendix C

Development of the Benthic Index of Biotic Integrity (B-IBI)

Running Head: NY/NJ Harbor B-IBI

A BENTHIC INDEX OF BIOTIC INTEGRITY (B-IBI) FOR THE
NEW YORK/NEW JERSEY HARBOR

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ABSTRACT

A multi-metric benthic index of biotic integrity (B-IBI) for the New York/New Jersey Harbor was developed by comparing the response of nine candidate measures of benthic condition (metrics) between a set of minimally-affected reference sites and a set of sites with known anthropogenic stress. The index was developed independently for each of four habitats defined by salinity and substrate. All nine candidate metrics differed significantly between reference sites and stressed sites in the calibration data set for at least one habitat. Six metrics differed significantly between reference and stressed sites in all habitats: species richness, species diversity, biomass, percent of abundance as pollution-sensitive taxa, percent of abundance as pollution-tolerant taxa, and percent of abundance as carnivores/omnivores. The index was calculated by scoring each of five selected metrics as 5, 3, or 1 depending on whether its value approximated, deviated slightly from, or deviated greatly from conditions at the best reference sites. Validation using independent data from 72 sites in the NY/NJ Harbor complex showed that the index was 93% effective at distinguishing anthropogenically stressed sites from reference sites.

INTRODUCTION

Numerous studies have documented a high degree of toxic contamination of sediments in the New York/New Jersey Harbor complex (Ianuzzi et al. 1995, Huntley et al 1993, Bonnevie et al. 1993, Williams et al. 1978). Billions of dollars have been spent to reduce source loads, which have declined by more than 90% in the last decade (Crawford et al. 1995). The proximal goal of these expenditures has been reduction of toxic contaminant inputs and ambient sediment concentrations, but the ultimate goal is protection of biological and human health resources. Few studies, though, have examined the extent of contaminant effects on the quality of biological assemblages (Steimle and Caracciolo-Ward 1989, Franz et al. 1988); most biological assessments conducted in the New York Harbor have focused on food chain effects of contaminants in tissues (Stainken and Rollwagen 1979, Burger and Gochfeld 1993, Zongwei et al. 1994, Peven et al. 1996).

The condition of benthic macrofaunal invertebrate assemblages is a good candidate for assessing the present condition and future changes in biotic condition of the NY/NJ Harbor. Benthos have limited mobility and cannot avoid adverse conditions (Gray 1979) so their condition accurately reflects local environmental conditions. Benthos live in sediments, where exposure to contaminant and hypoxia stress is generally most

severe. Benthos are an important component of the food web, serving as an important link between primary producers and higher trophic levels (Holland et al. 1980, Baird and Ulanowicz 1989). Benthos also significantly affect oxygen, nutrient, and carbon cycles and may control the coupling of benthic and pelagic processes (Rhoads and Young 1970, Kemp and Boynton 1981, Blackburn and Henriksen 1983).

One factor limiting use of benthos for assessing condition of New York Harbor sediment is a lack of clear expectations for benthic assemblage characteristics in non-stressed habitats. These expectations are a necessary first step in using benthic community measures in assessments because expectations establish criteria for distinguishing between non-stressed sites and those with varying degrees of anthropogenic alteration. Such criteria could also be used to identify areas most in need of restoration and provide a quantitative endpoint for restoration.

One approach that has been used extensively in fresh water to define expectations at non-stressed sites is the Index of Biotic Integrity (IBI) (Kerans and Karr 1994, Simon and Lyons 1995). This approach defines community characteristics expected at sites free from anthropogenic stress, and scores metrics that quantify those expectations based upon observations at non-stressed reference sites. Characteristics of biota at other sites are then compared with these expectations to provide an

assessment of site conditions. In this paper, we use that approach to develop a benthic index of biotic integrity (B-IBI) for application to summer estuarine benthic communities of the New York/New Jersey Harbor complex.

METHODS

Data Sources

The B-IBI was developed using data from EPA's Environmental Monitoring Assessment Program (EMAP), which collected benthos, sediment chemistry and sediment toxicity samples at 525 randomly selected sites in the Virginian biogeographic province in August and September between 1990 and 1993 (Paul et al 1992). At each site, triplicate samples of benthic macrofaunal communities were collected using a 440-cm², stainless steel, Young-modified VanVeen grab, and sieved in the field using a 0.5-mm screen and preserved in a 10% solution of buffered formaldehyde stained with rose bengal. A 50-ml core from each grab was frozen in a plastic bag for analysis of silt-clay content. Sediment samples for analysis of sediment chemistry and toxicity and were also collected using the VanVeen grab. A teflon spoon was used to remove the top 2 cm of sediment to a clean glass jar with a teflon lid, which was stored frozen. Dissolved oxygen and salinity were measured near the bottom of each site using a SeaBird CTD.

In the laboratory, macroinvertebrates were identified to the lowest practical taxonomic level and counted. Biomass was measured for 30 dominant species; other taxa were combined by feeding type and major taxonomic group (i.e., subsurface,

deposit-feeding polychaetes). Biomass was determined as shell-free dry weight after drying at 60 °C for 48 hours. Bivalves longer than 2 cm were shucked and smaller shells removed by acidification in 10% HCl before determining biomass. Percent sand in the sediment was estimated as the fraction retained on a 63 u sieve. Percent silt and percent clay were determined using pipette analysis of the filtrate.

Sediment samples were analyzed for the NOAA Status and Trends Program list of chemicals (O'Connor and Ehler 1991) using standard methodologies (Table 1). Sediment toxicity was measured using the ten-day acute, static, non-renewal Ampelisca abdita test following ASTM (1990) protocols. For each toxicity test, 200 ml of composited, press-sieved sample was placed in 1 L glass test chambers and covered with 600 ml of seawater. Five replicate test chambers were used for each sample, with 20 organisms placed into each replicate.

The index was validated using independent data from 168 randomly selected sites in the New York/New Jersey Harbor complex between August and September in 1993 and 1994. The validation data set included the same variables collected using the same field and laboratory methods as described above, except that only two benthic macrofaunal samples were processed for each site.

Index Development

The B-IBI was developed by testing and quantifying previously established principles that benthic assemblages respond to improvements in habitat quality in at least four ways: (1) species diversity increases as new taxa that are unable to tolerate poor habitat quality flourish (Pearson and Rosenberg 1978); (2) the abundance and biomass of organisms increases (Pearson and Rosenberg 1978, Warwick and Clarke 1991); (3) the dominant species at the site change from pollution-tolerant to pollution-sensitive (Boesch 1973, Warwick 1986, Dauer 1993); and 4) the diversity of feeding guilds increases (Brown et al. in press). These hypotheses were tested by comparing benthic assemblages at reference sites with those at anthropogenically stressed sites, selecting attributes that differed significantly between the two groups for inclusion in the index, and establishing thresholds for the selected attributes based on the range of attribute values at the reference sites.

Reference sites were selected by eliminating locations near known point-source discharges, and selecting from the remaining sites those where bioassay survival exceeded 80% of controls, and no contaminant exceeded Long et al.'s (1995) Effects Range-Median (ER-M) concentration, and no more than two contaminants exceeded Long et al.'s Effects Range-Low (ER-L) concentration, and total organic content of the sediment was less than 2.5%, and dissolved

oxygen concentration at the time of sampling exceeded 5 ppm. Sites were also screened to exclude those that occurred in areas of known frequent hypoxia, such as western Long Island Sound. The anthropogenically stressed sites used for comparison of response were identified as sites where any sediment contaminant exceeded Long et al.'s (1995) ER-M concentration and survival in sediment toxicity tests was less than 80% of control, or dissolved oxygen content was below 2 ppm.

Two criteria were used to compare attribute values between reference and stressed sites. First, a Mann-Whitney U-test was used to test for difference in median. Second, the Kolmogorov-Smirnov two-sample test was used to test for other distributional differences. The latter is particularly important for attributes such as abundance and biomass, for which the anticipated response at stressed sites could be higher or lower than at reference sites, depending on the severity of the stress.

Nine candidate metrics from the four categories of benthic response were tested (Table 2). The feeding guild and pollution-sensitivity metrics required classification of collected species into groups. Feeding modes were assigned using literature descriptions of feeding behavior (Jorgensen 1966; Bousfield 1973; Fauchald and Jumars 1979; Dauer et al. 1981). Lists of pollution-indicative (Table 3) and pollution-sensitive (Table 4) taxa were developed by comparing relative abundance of taxa

between the reference sites and stressed sites in the calibration data set. Pollution-indicative taxa were selected as those for which average abundance, average percent of abundance, and frequency of occurrence were all higher at stressed than reference sites (Table 3). Pollution-sensitive taxa were selected as those for which average abundance, average percent of abundance, and frequency of occurrence were all higher at reference than stressed sites, and for which percent of abundance at reference sites averaged at least 0.2% (Table 4).

Attributes were tested separately for each of four habitats defined by salinity and substrate type (Table 5). The four habitats were established using cluster analysis (Bray-Curtis similarity coefficient, flexible sorting, $\beta = -0.25$) on species abundances in the calibration data set to identify major site groupings, followed by ANOVA to determine whether salinity, grain size or depth differed significantly among the site groupings (Ranasinghe et al. in prep). Results from the cluster analysis were also used to identify geographical limitations for selection of reference sites; reference sites were selected from estuarine and coastal areas between Chincoteague Bay and Cape Cod, because euhaline and polyhaline benthic assemblages within the Virginian Province, except for Chesapeake Bay, exhibited a high degree of similarity (Ranasinghe et al. in prep).

Thresholds for each selected metric were established based on the distribution of its values at the reference sites. The IBI approach involves scoring each metric as 5, 3, or 1, depending on whether its value at a site approximates, deviates slightly from, or deviates greatly from conditions at the best reference sites (Karr et al. 1986). Threshold values were established as approximately the 5th and 50th (median) percentile values for reference sites in each habitat. For each metric, values below the 5th percentile were scored as 1; values between the 5th and 50th percentiles were scored as 3, and values above the 50th percentile were scored as 5. The scored values of the metrics were combined into an index by computing the mean attribute score across all selected metrics. Assemblages with an index score less than 3 are considered stressed, as they have metric values that on average are less than that at the poorest reference sites.

Two of the attributes, abundance and biomass, respond to stress bimodally, where the response can be greater than reference at sites with moderate degrees of stress and less than reference at sites with high degrees of stress (Pearson and Rosenberg 1978, Dauer and Conner 1980, Stull et al. 1986, Ferraro et al. 1991). These two attributes were scored as 5 for those values falling between the 25th and 75th percentile response at reference sites, and as a 3 for those values between the 5-25th and 75-95th percentiles at reference sites. Abundance values

lower than the 5th percentile or higher than the 95th percentile were scored as a 1; biomass values higher than the 95th percentile were scored as a 3 since high biomass can occur naturally at non-stressed sites where biomass is dominated by large bivalves.

Index validation was conducted in three ways. First, we examined index values at reference sites and anthropogenically-stressed sites in the validation data set, which was independent of the data set used to develop the index. Our criteria for defining reference sites and known stressed sites from the validation data set were the same as those for the calibration data set; our hypothesis was that reference sites should have index values of three or greater, while stressed sites should have values less than three. Second, we examined the relationship between the index and TOC concentration, hypothesizing that stressed assemblages would occur at higher concentrations of TOC. We examined the B-IBI relationship with TOC in a correlative, rather than in a categorical, fashion because threshold levels for anticipated biological response to TOC levels are not well established. Third, we calculated the correlation between replicates in the validation data set to examine stability of the index over small spatial scales.

RESULTS

One hundred and twenty-five sites from the calibration data set met our criteria for reference sites. There were at least 25 reference sites for each habitat class, except for the polyhaline mud habitat, for which only eleven reference sites were available (Table 5). Twenty-five sites met our criteria as anthropogenically-stressed (Figure 1), though only two were identified for the euhaline sand habitat (Table 5).

All nine candidate metrics differed significantly between reference sites and stressed sites for at least one habitat in the calibration data set (Table 2). Species richness (number of species per sample), species diversity, biomass, percentage of abundance as pollution-sensitive taxa, percent of abundance as pollution-indicative taxa, and percent of abundance as carnivore/omnivores significantly differentiated reference and stressed sites in all four habitats.

Our initial list of metrics selected for the B-IBI, and their thresholds, are presented in Table 6. In developing the index, we chose to include the abundance metric in the index for all habitats even though it statistically distinguished reference and stressed sites in only three of the four habitats; we did so because the pattern of response was similar in all habitats, and the response in the fourth habitat was significant at $p = 0.2$.

We excluded species diversity from the index because it was highly correlated with species richness, and species richness was slightly more effective at differentiating reference and stressed sites.

Validation

The initial index developed from the calibration data set classified 89% of the validation sites correctly, with classification efficiency equalling or exceeding 80% in each habitat except polyhaline sand (Table 7). When we examined the validation efficiency of each metric individually, we found that the proportion of abundance as carnivore/omnivores was the least effective metric for differentiating reference from stressed sites and was the metric that differed most in classification efficiency between the calibration and validation data sets (Table 8). We also found that when the carnivore/omnivore metric was removed from the index, classification efficiency of the index at validation sites improved slightly (Tables 7). Therefore, we removed this metric from the index, improving overall validation efficiency to 93%.

The final index was significantly correlated with total organic carbon in both the calibration ($r = -0.50$) and validation ($r = -0.54$) data sets. Ninety-two percent of the samples for which TOC exceeded 3%, and all of the samples for which TOC

exceeded 4%, had an index value less than 3, indicating a stressed benthic assemblage.

Index scores were significantly correlated ($r = 0.84$) between replicates; average difference in index scores between replicates was 0.32. Ninety-one percent of replicates at the same site classified the same; at most sites where replicates classified differently, the replicates had similar index values, but were close to, and on either side of, the index threshold value of 3.

DISCUSSION

The premise of the IBI approach is that there are selected quantifiable characteristics of biotic assemblages which are held in common at reference sites and which differ from those at anthropogenically stressed sites. Our study found that this was the case for at least five different metrics, each of which was effective at discriminating stressed sites in all of the habitats we studied. Cumulatively, these metrics were 93% effective at differentiating reference and stressed sites.

Another premise of the IBI approach is that biotic communities respond to stress in numerous ways, often in a staged fashion, and that multiple metrics are required to appropriately integrate these responses (Barbour et al. 1995). Pearson and Rosenberg (1978) erected a paradigm along these lines for marine benthos, with different metrics providing better discrimination of effect at varying distances from sources of stress. Our results are consistent with the multi-metric premise, as we found that the combination of metrics provided greater discrimination than any of the metrics alone (Tables 7 and 8).

We found the most efficient metrics were those based on pollution-tolerance of species occurring at the sites (Table 8). Our empirical approach to defining pollution-indicative taxa differs from most previous efforts at categorizing marine species

groups, in which pollution tolerance has been largely inferred from life history characteristics (Dauer 1993). The two approaches are not inconsistent, as indicated by the similarity of our list of pollution-indicative taxa and the lists of opportunistic taxa from other studies of east coast benthic macrofauna (Grassle and Grassle 1974, McCall 1977, Dauer 1993). One possible reason for the similarity in lists is that our approach for identifying pollution-indicative taxa does not discriminate between pollution-tolerant taxa and those that recolonize quickly following stress events. The similarity of the lists suggests that the latter is the predominant mechanism.

Our list of pollution-sensitive taxa is less consistent with previously developed lists of equilibrium taxa. Perhaps the difference results from incomplete knowledge of life histories for many benthic organisms, as Seitz and Schaffner (1995) have suggested. Despite this difference, the pollution-sensitive taxa metric had a higher classification efficiency than the pollution-indicative taxa metric for the validation sites. Perhaps this is because the pollution-indicative taxa are ubiquitous colonizing taxa, and their presence alone is not necessarily an indicator of poor habitat conditions at the site; only when the pollution-indicative taxa constitute a sizable portion of the assemblage do they become reliable indicators. In contrast, the pollution-sensitive taxa show a high fidelity to reference sites and may be the first to die or leave the site as stress occurs.

In developing the index, we chose a species richness metric in preference to species diversity. We did so because the richness metric was more effective at distinguishing reference from stressed sites in the calibration (and subsequently in the validation) data set. Species richness has the disadvantage, though, of being gear-specific, whereas diversity is less so (Ewing et al. 1988). We felt comfortable including richness because we used the same sampling device at all of our sites. If the index is applied to historical data, or to data collected using a different gear type, we recommend substituting a diversity metric in place of species richness. The thresholds for the diversity metric based on our calibration data set were 1.9 and 3.2 for all habitats. In our validation data set, substituting the diversity metric for species richness reduced validation efficiency to 89%.

Biomass is a metric in our index that is not measured by some benthic programs because of cost. We found it to be the least effective of our metrics at distinguishing stressed sites. It was also the metric that varied most among replicates (Table 9), probably because it can be so easily skewed by a single large individual. Calculating the final index without the biomass metric, as if these data were not available, reduced validation efficiency to 89%.

Although index development was conducted on a habitat-specific basis, the metric response values at reference sites were largely habitat-independent. Applying metric threshold values averaged across habitat reduced classification efficiency of the index by only 2% in the calibration data set and not at all in the validation data set. Weisberg et al. (In press), conducting a similar effort to establish thresholds for benthic assemblage response variables at reference sites in Chesapeake Bay, also found consistency in response among higher salinity habitats. Lopez (1988) suggested that many of the factors that structure benthic communities are similar over gradients as sharp as those from freshwater to saltwater. Such cross-habitat comparative studies are rare in benthic ecology; the consistency of our assemblage metric thresholds across habitats, despite substantial differences in species composition in the different habitats, suggests that further comparative work is warranted.

There has been recent debate as to whether the condition of benthic communities is more appropriately assessed using multivariate examination of individual species responses, or by using assemblage level metrics, as was used here (Norris 1995, Gerritsen 1995). We suggest that these approaches are not mutually exclusive and may be best employed together; multivariate approaches are sensitive enough to illuminate even minor changes in species composition, whereas the assemblage level approach provides perspective on the importance of those

changes. The multivariate approach, though, may be harder to employ. Both approaches require description of reference condition. Assemblage level metrics appear to be relatively robust to physical habitat variation; species composition is not. The high degree of habitat specificity of individual species may lead to difficulty in defining reference condition for the multivariate approach, with false positives resulting if there are minor differences in natural physical habitat between the reference and potentially affected sites.

While our B-IBI was validated using data only from the NY/NJ Harbor, it was developed based on data from a large portion of the mid-Atlantic coast. One issue that remains unresolved is whether it is applicable over the larger geographic scale of the calibration data set, which will be difficult to address because there are few independent data sets from the east coast with concurrently collected benthic and stressor data that could be used for validation. One such data set, to which we applied the B-IBI, was collected from the Delmarva peninsula (Chaillou and Weisberg 1995) located at the southern boundary of our calibration data set. We found that the index validated at all sixteen sites in that data set that met our criteria as reference or stressed sites, suggesting that the index is applicable to at least the southern portion of the province. In contrast to our NY/NJ Harbor validation, however, the percent of abundance as pollution-sensitive taxa was only 69% efficient at discriminating

sites, indicating that either the taxa list, or the thresholds used for this metric, may not be uniformly applicable at extreme ends of the province. Attempts at validation with data sets from other areas will be required to assess the degree of index modification necessary to assure that the index is applicable to the remainder of the Virginian Province.

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Table 1. Physical/Chemical Analytical Methods

Parameter	Method
PAHs	Methylene chloride extraction; determination by GC/MS
PCBs/Pesticides	Methylene chloride extraction; determination by HRGC/ECD
Major and Trace Elements	HNO ₃ and HF acid digestion: Hg - CVAAS; Cu, Ni, Pb, Cr, Sb, Sn, As, Se, Ag, Cd - GFAAS; Al, Fe, Mn, Si, Zn - FAAS
Dioxins & Furans	Extraction with toluene; determination by HRGC/HRMS; second column confirmation for 2,3,7,8-TCDD
TOC	Acidification with H ₃ PO ₄ ; determination using a CO ₂ analyzer
Grain size	Sieving and pipette analysis

Table 2. Mean benthic assemblage values at reference sites (top number) and stressed sites (bottom number). Top number shaded indicates pair is different by Mann-Whitney test; bottom number shaded indicates different by Kolmogorov-Smirnov test.

	Polyhaline Sand	Polyhaline Mud	Euhaline Sand	Euhaline Mud
Species Diversity				
Number of Taxa	19.5	21.2	28.3	24.0
	15.4	6.0	14.7	7.5
Shannon-Weiner	2.58	2.81	3.04	2.73
	2.15	1.01	0.85	1.11
Abundance and Biomass				
Abundance (#/m ²)	9111	7319	11686	83
	8656	6638	14027	7234
Biomass (g dry)	4.9	6.8	7.4	14.4
	15.2	22.1	1.7	36.6
Species Composition				
Percent of abundance as pollution- indicative taxa	11.4	15.1	12.4	14.6
	68.1	79.3	52.2	90.5
Percent of abundance as pollution- intolerant taxa	18.5	18.3	30.2	8.8
	1.9	0.1	0.2	0.1
Trophic Composition				
Percent of abundance as carnivore/ omnivores	17.0	14.8	13.2	13.1
	5.5	5.2	0.5	2.0
Percent of abundance as deposit feeders	42.1	40.6	27.1	53.5
	34.6	24.7	27.8	56.3
Percent of abundance as suspension feeders	40.4	44.6	59.5	33.3
	59.8	66.5	38.4	41.7

Table 3. Mean abundance percent of abundance, and frequency of occurrence of pollution-indicative taxa at reference and stressed sites in the calibration data set

	Abundance (#/m ²)		% of Abundance		Frequency of Occurrence	
	Reference Sites	Stressed Sites	Reference Sites	Stressed Sites	Reference Sites	Stressed Sites
<i>Streblospio benedicti</i>	332	2299	3.1	32.7	38.8	66.7
<i>Capitella</i> spp.	26	42	0.3	5.5	12.9	14.8
<i>Polydora cornuta</i>	92	355	1.0	2.5	29.8	42.6
<i>Mulinia lateralis</i>	84	2786	2.0	15.8	28.6	46.3
<i>Oligochaetes</i>	524	738	7.1	24.9	77.7	77.8

Table 4. Mean abundance, percent of abundance, and frequency of occurrence of pollution-sensitive taxa at reference and stressed sites in the calibration data set

	Abundance (#/m ²)		Percent of Abundance		Frequency of Occurrence	
	Reference Sites	Stressed Sites	Reference Sites	Stressed Sites	Reference Sites	Stressed Sites
Polychaeta						
<i>Ampharete arctica</i>	42.5	0.0	0.4	0.0	16.9	0.0
<i>Aricidea catherinae</i>	176.5	0.8	2.1	0.0	33.7	1.9
<i>Caulierella</i> spp.	9.4	0.0	0.3	0.0	15.7	0.0
<i>Clymenella torquata</i>	25.6	0.0	0.2	0.0	13.7	0.0
<i>Glycinde solitaria</i>	45.4	6.7	0.7	0.1	25.9	13.0
<i>Levinsenia gracilis</i>	93.3	0.0	0.7	0.0	13.3	0.0
<i>Macroclymene zonalis</i>	16.0	0.0	0.2	0.0	17.6	0.0
<i>Nephtys picta</i>	30.9	0.0	1.0	0.0	29.0	0.0
<i>Ninoe nigripes</i>	27.8	0.0	0.4	0.0	14.1	0.0
<i>Polygordius</i> spp.	53.7	0.0	0.6	0.0	15.7	0.0
<i>Sabaco elongatus</i>	32.9	0.4	0.5	0.0	16.5	1.9
<i>Scalibregma inflatum</i>	61.2	0.0	0.5	0.0	8.2	0.0
<i>Spicophanes bombyx</i>	82.3	0.0	1.5	0.0	31.4	0.0
Mollusca						
<i>Spisula solidissima</i>	28.3	0.0	0.7	0.0	18.8	0.0
<i>Tellina agilis</i>	313.4	15.6	4.4	0.4	54.9	18.5
<i>Acteocina canaliculata</i>	88.7	1.3	1.6	0.0	32.6	3.7
Arthropoda						
<i>Ampelisca agassizi</i>	68.3	0.0	0.3	0.0	3.5	0.0
<i>Ampelisca verrilli</i>	224.5	0.0	2.1	0.0	26.3	0.0
<i>Byblis serrata</i>	40.5	0.0	0.2	0.0	5.9	0.0
<i>Rhepoxynius hudsoni</i>	23.1	0.4	0.7	0.0	11.8	1.9

Table 5. Number of sites in calibration data set

Salinity Class	Habitat		Environmental Conditions	
	Sediment Type	Reference Sites	Stressed Sites	
Polyhaline (15-28 ppt)	Mud (>40% silt/clay)	11	12	
	Sand (<40% silt/clay)	28	6	
Euhaline (28-35 ppt)	Mud (>40% silt/clay)	26	5	
	Sand (<40% silt/clay)	60	2	

Table 6. Thresholds used to score each metric of the NY-NJ Harbor B-IBI

	Scoring Criteria		
	5	3	1
Number of Species			
Polyhaline Sand	> 20	15 - 20	< 15
Polyhaline Mud	> 20	15 - 20	< 15
Euhaline Sand	> 25	15 - 25	< 15
Euhaline Mud	> 25	15 - 25	< 15
Abundance (#/m²)			
Polyhaline Sand	2,500 - 10,000	1,000 - 2,500 or 10,000 - 25,000	< 1,000 or > 25,000
Polyhaline Mud	3,000 - 10,000	1,500 - 3,000 or 10,000 - 20,000	< 1,500 or > 20,000
Euhaline Sand	3,000 - 10,000	1,500 - 3,000 or 10,000 - 50,000	< 1,500 or > 30,000
Euhaline Mud	3,500 - 10,000	2,000 - 3,500 or 10,000 - 25,000	< 2,000 or > 25,000
Biomass			
Polyhaline Sand	2 - 8	0.8 - 2 or > 8	< 0.8
Polyhaline Mud	3 - 10	1 - 3 or > 10	< 1
Euhaline Sand	2 - 10	0.8 - 2 or > 10	< 0.8
Euhaline Mud	4 - 10	1 - 4 or > 10	< 1
Abundance of Pollution-Indicative Taxa (%)			
Polyhaline Sand	< 10	10 - 40	> 40
Polyhaline Mud	< 10	10 - 40	> 40
Euhaline Sand	< 10	10 - 40	> 40
Euhaline Mud	< 10	10 - 40	> 40

Table 6. Continued

	Scoring Criteria		
	5	3	1
Abundance of Pollution-Sensitive Taxa (%)			
Polyhaline Sand	> 15	3 - 15	< 3
Polyhaline Mud	> 15	3 - 15	< 3
Euhaline Sand	> 15	3 - 15	< 3
Euhaline Mud	> 10	2 - 10	< 2
Abundance of Carnivores/Omnivores (%)			
Polyhaline Sand	> 15	3 - 15	< 3
Polyhaline Mud	> 15	4 - 15	< 4
Euhaline Sand	> 10	2 - 10	< 2
Euhaline Mud	> 10	3 - 10	< 3

Table 7. Percent of sites in the validation data set correctly classified by the B-IBI, with and without the carnivore/omnivore metric

Habitat	Number of Sites	Percent Correctly Classified	Percent Correctly Classified Without Carnivore/Omnivore Metric
Polyhaline Sand	19	74	79
Polyhaline Mud	20	100	100
Euhaline Sand	23	96	100
Euhaline Mud	10	80	90
Overall	72	88.9	93.1

Table 8. Classification efficiency (%) of reference and stressed sites for the individual metrics

Metric	Calibration Data Set	Validation Data Set
Number of Taxa	84.7	68.1
Shannon-Weiner Diversity	78.2	58.3
Abundance	75.3	63.9
Biomass	81.3	63.9
% of Abundance as Pollution-indicative Taxa	90.0	77.8
% of Abundance as Pollution-sensitive Taxa	83.3	88.9
% of Abundance as Carnivores/Omnivores	81.3	56.9

Table 9. Correlation between replicate samples for each of the metric values in the index

Metric	Correlation Coefficient
Number of Species	0.89
Shannon-Weiner Diversity	0.84
Abundance	0.84
Biomass	0.62
Percent Abundance as Pollution-Indicative Taxa	0.86
Percent Abundance as Pollution-Sensitive Taxa	0.95

Appendix D

Aluminum-normalization procedure

Comparison of sediment metal:aluminum relationships between the
eastern and gulf coasts of the United States

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INTRODUCTION

Metal contamination of sediments is a concern to the normal function of estuarine and nearshore systems [1,2]. A portion of the metals in sediments comes from natural weathering of crustal rocks, with naturally higher concentrations of metals occurring in finer-grained fractions of sediments. One challenge in assessing the spatial extent of metal contamination is separating anthropogenic contributions of metals from natural contributions.

Several techniques have been developed for making this distinction [3], the most popular of which is aluminum-normalization [4,5,6,7,8,9]. Using this approach, aluminum is treated as a conservative tracer of the natural metal-bearing phases (i.e., aluminosilicates) in the fine sediment fraction. Anthropogenic contributions to aluminum concentrations are trivial compared to the natural contribution, and the natural metal-to-aluminum ratio should be relatively constant within a region and similar to the crustal ratio [10] or to the ratio observed in source rocks in the regional watershed. Using the normalization approach, a set of uncontaminated sites are identified, and statistical relationships between each metal and aluminum are identified for those sites. Significant deviation from those relationships indicates anthropogenic enrichment.

Metal-to-aluminum ratios have been determined on several spatial scales ranging from individual estuarine systems [11,12,13]

to entire countries [7,8,14]. Differences in metal-to-aluminum ratios have been found among studies conducted on these different spatial scales, which could be explained by regional differences in the ratios within source rocks or by differences in the fractionation of metals between soluble and particulate phases during weathering. These geologic explanations, though, are confounded by differences in data analysis approaches used by various investigators in defining the relationships. The most important methodological differences among such studies are in the assumed functional form of the relationship and in the means of ensuring that only non-contaminated sites are included in the data sets used to derive the relationships.

The uncertainty concerning differences in normalization techniques among studies hampers inter-regional comparisons of anthropogenic influence. If the metal-to-aluminum ratios in crustal or source rock, or weathering characteristics differ between regions, then locally derived aluminum relationships would be the most appropriate basis for such comparisons. Alternatively, if differences in metal-to-aluminum ratios are artifacts of data analysis techniques used to define the relationship, then using locally derived relationships would bias inter-regional comparisons. This paper addresses these concerns by applying a common analytical methodology to data collected on the Atlantic and Gulf coasts to identify the most appropriate spatial scales for developing aluminum-normalization curves.

METHODS

Data Sources

Sampling was conducted in two biogeographical provinces: the Virginian Province, extending from Cape Cod to Cape Henry on the Atlantic coast (Figure 1), and the Louisianian Province, extending from Tampa Bay to the Mexican border along the Gulf Coast (Figure 2). Sampling in the Virginian Province was conducted from late July to early September annually between 1990 and 1993. Sampling in the Louisianian Province was conducted from July 1 through August 30 annually between 1991 and 1994. Between 100 and 160 sites were sampled in each province each year. Sampling sites were selected using a stratified random design in which the estuaries were classified as large estuaries (surface area $>250 \text{ km}^2$); large tidal rivers (surface area $>250 \text{ km}^2$ with an aspect ratio of 18:1 or greater); and small estuarine systems, which included all other systems with a surface area of at least 2.5 km^2 . Sampling sites within each stratum were selected randomly.

Sediment samples were collected at each site using a 440-cm^2 Young-modified VanVeen grab. A teflon spoon was used to remove the top 2 cm of sediment to a clean glass jar with a teflon lid, which was stored frozen. Metals were analyzed in the laboratory by HF/HNO₃ digestion, followed by inductively coupled plasma mass emission spectrometry (Ag, Al, Cr, Cu, Fe, Ni, Pb, Zn), microwave

digestion using HNO₃/HCl followed by graphite furnace atomic absorption spectrophotometry (Cd, Sb, Se, Sn), or cold vapor atomic absorption spectrophotometry (Hg). Silver, antimony, selenium, and tin were measured in the Virginian Province only during the last three years. Reagent and procedural blanks were analyzed to check for laboratory contamination during processing. Approximately every tenth sample was split and processed as a laboratory duplicate. In addition, National Research Council of Canada Certified Reference Material BCSS-1 was analyzed with approximately every 10 samples to assess accuracy and precision.

Data Analysis

The relationship between the concentration of aluminum and a response metal was estimated based on a linear model:

$$Y = \beta * Al + m + e$$

where,

Y = concentration of the response metal

β = slope relating the response metal to aluminum

Al = aluminum concentration

m = intercept

e = random measurement error

Anthropogenically contaminated sites were removed from the data set by comparing the residual of the regression with an estimate of laboratory measurement error. This approach was based on the premise that if the data set did not include anthropogenically enriched sites, the mean square error (MSE) from the regression would equal measurement error. If the MSE exceeded measurement error, the site with the highest residual in the model was removed, and the model was reparameterized. This procedure was repeated until the MSE was no greater than measurement error. Laboratory measurement error was estimated based on repeated measurements from blind laboratory duplicates and standard reference materials.

To compare metal-to-aluminum relationships between the two provinces, we applied our estimation method separately to data from each year, providing four independent slope and intercept estimates for each province. These annual estimates for each province served as replicates to test whether the intercept differed significantly from zero, and whether slope or intercept differed between provinces, based on a t-test ($\alpha=0.05$). Initial applications of the model included an intercept term. If the average intercept for a given metal did not differ significantly from zero in our initial runs, the regression was recalculated with a no-intercept model. If the intercepts were significantly different from zero, but not different between provinces, the regression was recalculated after setting the intercept equal to the average intercept between

provinces. If the intercepts for both provinces were equivalent, the four independent yearly estimates were used to assess whether slopes differed significantly between provinces.

RESULTS

Mean and maximum aluminum concentrations differed between the two provinces by about 15%. Mean concentration of other metals differed by a substantially greater margin, with differences of 100% or more for 5 of the 12 metals examined (Table 1). For every metal except aluminum, the mean and maximum observed concentrations were higher in the Virginian Province.

Six of the 10 metals we examined had intercepts that differed significantly from zero in at least one of the provinces (Table 2). In all cases where the intercept was significant, the intercepts were positive values. For only three metals did the intercept differ significantly between provinces. Most intercept values were small compared with the mean value for the province; however, for silver in the Louisianian Province and selenium in the Virginian Province the intercept values were almost half of the mean values for the province.

Of the six metals that had an equivalent intercept between provinces, only three (Hg, Pb, Ni) had significantly different slopes (Table 3). For each of these metals the slope was higher in the Virginian Province than in the Louisianian Province. For nickel, the slope difference was only 30%; for lead and mercury, the difference was almost 100% (Table 3).

The number of samples removed from the regression based on deviation greater than measurement error differed substantially among chemicals and between the provinces (Table 4). Thirty-six percent of the sites in the Virginian Province and 22% in the Louisianian Province were eliminated from the regression for at least one chemical. Most of the sites that were eliminated for one chemical were eliminated for several chemicals (Table 5). The spatial pattern of eliminated sites was highly clustered, with most sites occurring around the major cities of New York, Philadelphia, Baltimore, Galveston, Mobile, and New Orleans (Figures 1 and 2).

DISCUSSION

Most of the differences in metal-to-aluminum ratios between the mid-Atlantic and Gulf coasts of the United States were small. Slopes differed by more than 30% only for mercury, lead, silver, and selenium, and comparisons for the latter two were confounded by differences in intercept. Differences in slope or intercept were mostly limited to metals with small natural concentrations; there were no significant differences in slope or intercept for the naturally most abundant metals (e.g., copper, zinc, chromium).

We used a new approach for ensuring that only unenriched sites were used to estimate the natural metal-to-aluminum relationships within a province. Previous authors have used a variety of techniques for accomplishing this objective. Some authors have removed sites with large concentrations or sites where biological effects are suspected [9]. This may lead to a shallower slope if naturally occurring high concentrations are removed from the regression. Other authors have screened their sites based on the uses of the surrounding land by equating low population density or absence of known point sources with a lack of anthropogenic input [5,7,8,14]. This approach is probably suitable for sparsely populated areas, but becomes highly subjective in densely populated areas such as the Virginian Province.

Our approach is most similar to that of Schropp et al. [5], in which sites were sequentially eliminated from the regression until the residuals were distributed normally. Our approach, however, uses additional information to identify a quantitative stopping rule for data removal; Schropp et al.'s approach of examining kurtosis is more subjective. Our approach, though, requires an unbiased estimate of measurement error, which can be hard to develop because many laboratories fail to quantify error or do so as part of a performance evaluation in which the analyst knows which samples are being used for the test.

Our approach also assumes that the study area encompasses enough unenriched sites to define a baseline relationship. This may not be the case for lead in the Virginian Province because atmospheric deposition is a primary source of lead. If atmospheric deposition enhanced concentrations equally everywhere, then our approach would quantify the deposited lead as an addition to the intercept term. If atmospheric inputs varied within a region, or if these additions bound disproportionately to the fine-grained sediment, our approach would quantify the additional lead as an increase in slope. The higher slope we observed in the Virginian Province probably reflects widespread enrichment, and the lead-to-aluminum relationship we defined for the Virginian Province may underestimate enrichment.

An alternate approach for obtaining reliable baseline conditions for defining metal-to-aluminum relationships is to sample deep sediments that were deposited before the industrial period. Obtaining such samples requires expensive coring equipment and specialized techniques for dating the sediments accurately. Such data records are few, and they typically do not include a sufficient range of aluminum concentrations to identify metal-to-aluminum relationships. The available coring data, however, provide a benchmark for validating the relationships we identified in other ways. For the Virginian Province, we compared our metal-to-aluminum relationships with those in pre-industrial sediment cores collected by Goldberg et al. in Chesapeake Bay [15] and Narragansett Bay [16]. For copper, cadmium, nickel and zinc, the historic data matched our findings well; all of the historic samples were bisected by and within the measurement error of our regression line (Figure 3). Our relationship for lead was steeper than suggested by the deep sediment samples, confirming our concern that widespread contamination has caused us to overestimate the underlying relationship. Our relationship for chromium had a shallower slope than suggested by the deep sediment samples.

For the Louisianian Province, we compared our findings to ratios in pre-industrial cores from the Mississippi River [17] and Texas [18]. Data for all metals, except copper, were mostly within the measurement error of our metal-to-aluminum relationships (Figure 4). For copper, our data matched the data from Texas well

but had a shallower slope than the data from the Mississippi River. Our shallower slope for copper than in sediments from the Mississippi River is not an artifact of our data analysis because we eliminated very few data points in identifying the relationship between copper and aluminum.

We also compared our metal-to-aluminum relationships with those identified by other authors working in our geographic study areas and found considerable similarity for all metals except lead in the Virginian Province. For lead, most previous studies suggested a relationship more similar to the slope we found for the Louisianian Province. Interestingly, all of the previous studies found slopes for chromium in the Virginian Province that were equivalent to or less than those we found in the pre-industrial cores (Figure 5). It is unclear why samples of pre-industrial sediment contained larger chromium-to-aluminum ratios than those estimated in all other studies, but suggests the earlier data may contain a systematic analytical error. Standard reference materials were not readily available during the earlier studies; therefore, researchers had no way to assess the quality of their data, and because of its refractory nature, chromium is a difficult metal to analyze accurately. Perhaps our disagreement with copper data for the Mississippi River can be explained similarly.

One substantial difference between the relationships we defined and those defined in other studies is the magnitude and

sign of the intercept term. We found the intercept to be nonsignificant in more than half of the cases we examined; when the intercept was significant, it was always a positive value. Many previous studies have reported negative intercepts. We believe the theoretical basis for a negative intercept is weak. The model of the metal-to-aluminum relationship is based on conservative mixing of aluminosilicates, which naturally contain large concentrations of metals, with quartz or other low metal-bearing phases such as carbonates. The intercept term should be equal to the concentration of the dependent metal in the low-metal phase end member.

In many of the previous studies, the negative intercept values were small enough to have resulted from random measurement error, which we were able to assess because we had four independent intercept estimates. Negative intercepts can also be analytical artifacts introduced when concentrations of the dependent metals fall below detection limits. An artificial negative slope would occur if samples with concentrations below detection limits were treated as zeros and combined with positive aluminum measurements (concentrations of aluminum typically exceed detection limits). Conversely, setting values of undetected dependent metals equal to detection limits of the analytical technique would artificially create a positive intercept. In our study, we chose to remove samples with values below the detection limit from analyses.

One shortcoming of our analytical approach is that we were unable to incorporate a measurement error term for aluminum. To determine if our results were sensitive to this shortcoming, we used the same analytical approach employing iron, which is also abundant in crustal rock, as the conservative tracer and tested to see if the same samples fell outside the background relationship. Eighty-three percent of the samples that we identified as enriched by aluminum-normalization were also identified as enriched by normalizing to iron. Another 9% were identified as enriched by the iron analyses only. Re-running our models, eliminating only samples that were identified as enriched in both the iron and aluminum analyses, had a negligible effect on the slopes of our metal-to-aluminum relationships.

One issue that we chose not to address in our analysis was mean-to-variance relationships. The data suggested a small mean-to-variance relationship in laboratory measurement error for most metals. Adjusting our model to exclude points based on a mean-to-variance relationship resulted in eliminating most samples closest to the origin. This difficulty arose because measurement error was not a linear function of concentration; rather there was a "nugget effect" in which measurement error relative to the mean increased at lower concentrations. We had too few replicate data at low concentrations to quantify the nugget effect. Modelling measurement error would be a fruitful area for refining our approach.

One advantage of our approach for examining metal-to-aluminum relationships is that our results can be applied easily to other data sets that either are too small or are collected from geographic areas that are too enriched to identify metal-to-aluminum relationships. Within our study areas, the base metal-to-aluminum relationship is constant for most metals. The only thing that changes among studies is the allowable deviation from these relationships. We suggest that there are three components of allowable deviation: (1) variance of the slope estimate, which can be estimated from the variability among our four independent slope estimates (Table 6); (2) variance of the intercept (where appropriate), which also can be estimated from our four yearly estimates (Table 6); and (3) measurement variance of the specific study. The probability that a sample has an enriched concentration of a metal can be estimated by dividing the difference between the observed and predicted concentrations of the metal by the square root of the sum of the three sources of error and comparing the quotient to standard normal critical values. Samples with quotients exceeding 1.96 have a 95% probability of enrichment.

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Table 1.

Mean and maximum concentrations (ppm, except for aluminum, which is percent) of metals measured in each province. Table is based on all data collected.

	Mean Concentration		Maximum Concentration	
	Virginian Province	Louisianian Province	Virginian Province	Louisianian Province
Aluminum	4.1	4.6	9.8	13.8
Silver	0.4	0.1	9.7	0.9
Cadmium	0.5	0.2	8.0	1.5
Chromium	48.2	43.5	365.0	149.0
Copper	30.9	11.3	680.0	104.0
Mercury	0.1	0.1	3.3	0.4
Nickel	18.3	16.7	136.0	51.2
Lead	62.6	16.4	13,600.0	610.0
Antimony	1.0	0.6	152.0	3.8
Selenium	0.4	0.3	9.1	1.8
Tin	3.3	1.4	48.7	13.5
Zinc	115.6	64.3	1,090.0	625.1

Table 2. Annual intercept estimates for each province (ND = no data). Asterisk indicates the mean intercept value was significantly different from zero in the Virginia Province; Δ indicates the same for the Louisianian Province.

Metal	Virginian Province				Louisianian Province			
	90	91	92	93	91	92	93	94
Ag _Δ	ND	-0.005	0.029	-0.008	0.083	0.019	0.055	0.049
Cd* _Δ	0.098	0.114	0.107	0.262	0.058	-0.004	0.085	0.086
Cr	-0.694	-1.762	0.976	-4.85	5.340	3.009	-0.488	1.389
Cu	-1.48	-1.07	-1.21	0.137	0.203	-0.359	-0.957	0.448
Hg* _Δ	0.013	0.017	0.007	0.000	0.018	0.012	0.015	0.000
Ni	-5.88	-2.04	3.31	-4.29	-0.381	0.334	-1.18	2.36
Pb* _Δ	6.97	2.85	1.58	-0.41	3.11	1.19	1.40	2.57
Sb* _Δ	ND	0.066	0.158	0.265	0.216	0.083	0.162	0.160
Se* _Δ	ND	0.159	0.179	0.352	0.057	0.062	0.056	0.106
Sn*	ND	0.087	0.210	0.225	0.081	0.010	0.189	-0.040
Zn	6.47	-3.57	3.05	-2.05	1.28	0.89	4.01	0.63

Table 3. Annual slope estimates for each province and the intercept values used in estimating the slopes.

Metal	Virginian Province				Louisianian Province				Intercept Values		
	90	91	92	93	91	92	93	94	VP	LP	
Ag	ND	0.0247	0.0382	0.0360	0.0140	0.0186	0.0121	0.0135	0	0	0.0514
Cd	0.0447	0.0337	0.0426	0.0147	0.0265	0.0440	0.0172	0.0321	0.1008	0.1008	0.1008
Cr	8.970	9.084	10.627	9.238	10.353	8.821	9.470	7.391	0	0	0
Cu	2.257	3.213	3.657	2.624	2.406	2.394	2.203	2.407	0	0	0
Hg	0.0152	0.0122	0.0193	0.0187	0.0074	0.0073	0.0083	0.0099	0.0103	0.0103	0.0103
Ni	4.633	4.813	5.115	4.171	3.932	3.709	3.500	3.225	0	0	0
Pb	5.218	5.016	5.193	5.193	2.996	2.787	2.992	2.514	2.0954	2.0954	2.0954
Sb	ND	0.0817	0.0762	0.0529	0.0963	0.0905	0.0780	0.676	0.1586	0.1586	0.1586
Se	ND	0.0429	0.0286	0.0208	0.0460	0.0394	0.0499	0.0186	0.2296	0.2296	0.0703
Sn	ND	0.5233	0.5096	0.4700	0.3282	0.3190	0.2134	0.3222	0.1732	0.1732	0
Zn	13.527	14.028	15.403	12.212	11.992	13.424	12.919	10.765	0	0	0

Table 4. Percent of sites removed from the regression for each metal in each province.

	Virginian Province	Louisianian Province
Silver	20.0	0.0
Cadmium	12.5	0.0
Chromium	17.4	6.1
Copper	41.8	0.8
Mercury	13.7	0.0
Nickel	0.5	0.0
Lead	32.9	0.3
Antimony	10.5	2.8
Selenium	35.7	17.1
Tin	12.5	0.0
Zinc	51.6	11.2

Table 5. Frequency distribution of number of metals removed from the regression

Number of Metals Removed	Percent of Sites	
	Virginian Province	Louisianian Province
0	41.4	66.1
1	14.9	18.6
2	11.5	9.2
3	7.5	2.0
4	5.3	1.4
5	3.6	0.9
6	4.3	0.8
7	3.8	0.2
8	2.8	0.2
9	3.2	0.0
10	1.3	0.0
11	0.4	0.0

Table 6. Variance associated with parameter estimates for the metal:aluminum models in each province

Metal	Province	Slope	Intercept	Slope	Intercept
				Variance	Variance
Silver	Louisianian	0.0146	0.0514	0.0	0.0002
Silver	Virginian	0.0330	-	0.0	0
Cadmium	Both	0.0323	0.1008	0.0	0.0007
Chromium	Both	9.2442	-	0.1233	-
Copper	Both	2.6451	-	0.0338	-
Mercury	Louisianian	0.0082	0.0103	0.0	0.0
Mercury	Virginian	0.0164	0.0103	0.0	0.0
Nickel	Louisianian	3.5914	-	0.0227	-
Nickel	Virginian	4.6826	-	0.0390	-
Lead	Louisianian	2.8223	2.0954	0.0129	0.5509
Lead	Virginian	4.6600	2.0954	0.2461	0.5509
Antimony	Both	0.0776	0.1586	0.0	0.0007
Selenium	Louisianian	0.0385	0.0703	0.0001	0.0001
Selenium	Virginian	0.0308	0.2296	0.0	0.0038
Tin	Louisianian	0.2957	-	0.0008	-
Tin	Virginian	0.5009	0.1737	0.0003	0.0019
Zinc	Both	13.0336	-	0.2485	-

Figure 1. Number of metals found to be anthropogenically enriched at study sites in the Virginian Province.

Figure 2. Number of metals found to be anthropogenically enriched at study sites in the Louisianian Province.

Figure 3. Metal-to-aluminum relationships in pre-industrial sediment cores from the Virginian Province and samples used in the present study. Dashed lines represent 95% confidence intervals based on laboratory measurement error. Circles are from Goldberg et al.'s Core #1314 [16]. Squares are from Goldberg et al.'s Core #1411 [16]. Asterisks are from Goldberg et al.'s Core #7408 [15].

Figure 4. Metal-to-aluminum relationships in pre-industrial sediment cores from the Louisianian Province and those from the present study. Dashed lines represent 95% confidence intervals based on laboratory measurement error. Squares are data from the Mississippi River [17]. Asterisks are data from Texas [18].

Figure 5. Chromium-to-aluminum relationships among several studies and in deep sediment cores. Symbols are the same as in Figure 3.

Appendix E

Tables:

- E-1) Area-weighted mean concentrations
- E-2) Percent of area exceeding ERM values

Table E-1
Area-Weighted Mean Sediment Contaminant Concentrations
 (± represent 90% confidence intervals)

	Harbor	Jamaica Bay	Newark Bay	Lower Harbor	Upper Harbor	W. Long Is. Sound	Bight Apex
METALS (ppm)							
Aluminum	43456 ±4229	31862 ±3761	64633 ±4207	38706 ±6466	56705 ±4551	62745 ±4324	26345 ±3376
Antimony	1.49 ±0.48	0.84 ±0.52	6.27 ±6.80	1.24 ±0.30	1.11 ±0.18	0.70 ±0.11	0.81 ±0.19
Arsenic	10.33 ±2.05	5.07 ±1.26	25.51 ±20.15	10.01 ±2.49	9.04 ±1.14	7.05 ±0.84	8.48 ±2.12
Cadmium	0.79 ±0.13	0.95 ±0.53	2.52 ±0.58	0.54 ±0.18	0.93 ±0.18	0.70 ±0.14	0.17 ±0.10
Chromium	78.09 ±10.11	50.96 ±9.17	137.31 ±14.08	71.48 ±15.32	92.44 ±12.27	80.66 ±10.70	35.74 ±9.46
Copper	72.53 ±17.40	55.15 ±35.09	226.69 ±105.28	47.29 ±16.01	110.12 ±57.65	70.43 ±11.63	9.26 ±5.23
Iron	23483.6 ±2897.0	16883.4 ±3230.7	33980.2 ±3830.8	22170.9 ±4405.9	27269.04 ±3208.9	28149.3 ±2665.1	16066.0 ±3447.2
Lead	78.84 ±12.83	63.29 ±37.42	193.92 ±60.70	63.78 ±17.47	96.55 ±18.40	57.38 ±9.39	21.69 ±5.71
Manganese	495.26 ±44.14	390.86 ±66.24	427.94 ±53.12	481.32 ±63.71	605.71 ±78.59	988.18 ±120.43	483.18 ±98.54

Table E-1 Continued.	Harbor	Jamaica Bay	Newark Bay	Lower Harbor	Upper Harbor	W. Long Is. Sound	Bight Apex
Mercury	0.74 ±0.14	0.29 ±0.13	2.59 ±0.58	0.61 ±0.21	0.80 ±0.16	0.22 ±0.04	0.12 ±0.10
Nickel	24.07 ±2.90	17.80 ±10.31	50.81 ±8.72	20.08 ±4.03	30.92 ±3.80	26.92 ±3.45	8.69 ±2.50
Selenium	3.82 ±1.02	1.34 ±0.56	10.98 ±4.14	3.60 ±1.50	3.41 ±1.28	2.16 ±0.73	0.85 ±0.71
Silicon	354788 ±16077	349968 ±26009	315399 ±16061	367569 ±24327	330116 ±17836	300703 ±19640	412862 ±12327
Silver	1.59 ±0.30	1.14 ±0.42	2.98 ±0.61	1.29 ±0.44	2.28 ±0.46	1.19 ±0.32	0.23 ±0.14
Tin	4.96 ±1.54	2.84 ±1.43	15.29 ±13.27	3.43 ±1.40	7.45 ±4.44	2.98 ±0.96	1.57 ±0.66
Zinc	170.06 ±25.56	134.89 ±74.55	308.04 ±55.85	162.56 ±37.38	166.68 ±26.28	177.34 ±24.25	47.02 ±10.06
ORGANICS (ppb)							
Total PCBs = (Σ congeners) x 2	224.35 ±42.25	112.34 ±67.57	755.62 ±270.28	120.46 ±43.88	428.74 ±124.62	85.51 ±22.11	55.26 ±40.98
Parent DDT	9.57 ±9.38	0.92 ±0.15	132.97 ±147.29	1.28 ±0.31	0.99 ±0.19	0.97 ±0.20	1.33 ±0.57
Total DDD	14.16 ±5.98	2.83 ±1.32	122.41 ±89.49	5.71 ±2.60	11.94 ±3.60	3.00 ±0.65	1.75 ±1.30

Table E-1 Continued.	Harbor	Jamaica Bay	Newark Bay	Lower Harbor	Upper Harbor	W. Long Is. Sound	Bight Apex
DDE	8.53 ±2.54	3.18 ±1.60	65.20 ±35.68	4.04 ±1.66	7.32 ±2.04	2.72 ±0.54	1.18 ±0.69
Total DDT	31.59 ±16.64	5.95 ±2.90	320.31 ±256.91	10.28 ±4.52	19.84 ±5.07	6.38 ±1.30	2.78 ±2.63
Chlordane	5.11 ±1.01	5.19 ±2.50	21.64 ±2.83	2.95 ±1.21	6.60 ±1.77	2.65 ±0.74	14.32 ±22.58
Dieldrin	0.80 ±0.12	0.73 ±0.35	2.34 ±0.36	0.53 ±0.13	1.19 ±0.33	0.69 ±0.17	0.28 ±0.10
Endrin	0.67 ±0.19	0.47 ±0.04	0.76 ±0.42	0.51 ±0.05	1.22 ±0.90	1.56 ±1.44	0.41 ±0.07
Acenaphthene	82.78 ±65.43	45.05 ±48.02	92.82 ±30.15	17.81 ±5.69	294.62 ±312.96	28.21 ±12.24	10.57 ±4.38
Acenaphthylene	122.93 ±41.89	50.00 ±34.26	202.46 ±30.69	40.84 ±14.13	381.64 ±195.75	95.05 ±40.25	16.86 ±11.72
Anthracene	365.05 ±220.76	151.36 ±144.73	511.49 ±163.77	63.54 ±26.52	1335.14 ±1054.25	105.14 ±45.35	26.86 ±19.85
Benzo(a)anthracene	486.83 ±129.35	231.11 ±185.03	905.11 ±199.37	141.74 ±50.53	1525.6 ±593.1	395.20 ±320.69	49.34 ±39.34
Benzo(a)pyrene	303.05 ±83.12	138.96 ±111.32	516.92 ±79.50	113.25 ±40.94	889.96 ±375.20	194.09 ±52.38	33.19 ±24.55
Benzo(k)fluoranthene	781.78 ±177.51	531.68 ±415.14	1669.94 ±264.54	294.28 ±99.79	2107.79 ±769.94	518.25 ±164.81	94.86 ±68.05

Table E-1 Continued.	Harbor	Jamaica Bay	Newark Bay	Lower Harbor	Upper Harbor	W. Long Is. Sound	Bight Apex
Benzo(g,h,i)perylene	302.69 ±72.98	186.48 ±173.51	579.08 ±101.00	112.75 ±41.96	849.14 ±315.35	173.15 ±67.70	30.65 ±19.81
Biphenyl	32.16 ±11.74	38.86 ±42.83	45.73 ±7.67	15.02 ±4.21	77.14 ±51.31	17.01 ±4.11	9.06 ±3.10
Chrysene	544.76 ±145.85	313.48 ±271.91	1076.9 ±217.0	161.69 ±56.44	1653.2 ±664.7	311.20 ±123.95	51.54 ±41.17
Dibenz(a,h)anthracene	79.42 ±31.10	17.32 ±6.72	146.12 ±25.41	26.66 ±9.59	247.84 ±146.29	34.93 ±10.65	13.00 ±8.15
2,6-Dimethylnaphthalene	198.15 ±57.34	582.37 ±382.91	181.20 ±52.59	135.41 ±62.49	219.79 ±95.74	116.40 ±34.59	17.25 ±11.02
Fluoranthene	743.25 ±278.61	568.79 ±481.83	1280.0 ±397.6	201.34 ±80.22	2308.0 ±1292.0	325.36 ±109.31	65.51 ±51.71
Fluorene	176.41 ±182.11	77.62 ±87.06	107.72 ±23.17	28.20 ±13.07	693.43 ±873.05	37.15 ±13.42	12.32 ±5.96
Ideno(1,2,3-c,d)pyrene	291.62 ±90.08	132.04 ±106.36	575.81 ±74.23	117.62 ±42.01	806.89 ±409.94	195.27 ±60.61	35.54 ±27.73
2-Methylnaphthalene	89.91 ±42.02	95.08 ±122.30	114.36 ±21.63	33.04 ±13.05	253.21 ±189.86	43.72 ±12.86	14.33 ±7.65
1-Methylnaphthalene	46.37 ±24.30	59.61 ±81.69	47.24 ±6.97	15.16 ±4.83	135.10 ±109.67	19.08 ±5.86	9.71 ±3.65
1-Methylphenanthrene	156.10 ±88.28	130.93 ±187.12	150.03 ±84.70	9.65 ±3.57	615.18 ±414.55	29.18 ±27.49	6.00 ±0.00

Table E-1 Continued.	Harbor	Jamaica Bay	Newark Bay	Lower Harbor	Upper Harbor	W. Long Is. Sound	Bight Apex
Naphthalene	163.96 ±100.34	96.04 ±92.26	217.87 ±28.42	48.90 ±16.84	528.57 ±477.41	82.89 ±24.35	26.32 ±12.43
Perylene	333.54 ±113.69	113.98 ±55.94	608.35 ±173.42	127.84 ±47.68	975.43 ±523.23	169.73 ±67.87	37.83 ±43.06
Phenanthrene	628.06 ±520.48	363.98 ±412.31	417.30 ±61.09	116.85 ±45.44	2368.6 ±2489.5	197.89 ±69.24	48.20 ±35.82
Pyrene	767.60 ±269.73	508.73 ±440.02	1144.7 ±288.8	202.19 ±77.94	2491.0 ±1255.0	364.17 ±141.09	69.63 ±57.35
2,3,5-Trimethylnaphthalene	47.00 ±29.87	183.02 ±287.39	70.47 ±37.44	9.82 ±2.60	91.21 ±57.89	10.70 ±3.60	7.29 ±1.48
Total PAHs	7177.4 ±2607.9	4838.5 ±4279.8	11471 ±1836.3	2179.2 ±723.5	22141 ±12165	3749.7 ±1310.2	730.0 ±521.7
Monobutyltin	5.32 ±1.37	8.51 ±5.13	11.74 ±3.92	4.48 ±1.93	4.46 ±1.38	1.21 ±0.24	2.77 ±1.28
Dibutyltin	16.33 ±6.04	11.25 ±6.78	38.95 ±22.07	15.45 ±9.06	14.39 ±5.02	2.45 ±0.46	6.08 ±3.33
Tributyltin	30.08 ±8.52	38.64 ±19.50	69.31 ±23.39	24.07 ±11.77	32.50 ±16.17	23.98 ±8.02	19.54 ±9.35
Tetrabutyltin	4.17 ±0.52	4.99 ±2.18	5.39 ±2.28	3.95 ±0.66	4.11 ±0.88	3.75 ±0.40	3.61 ±0.45

Table E-2
Percent of Area Exceeding Sediment Contaminant ERMs (Long & Morgan, 1991; Long et al., 1995a)
 values in parentheses represent 90% confidence intervals

	Harbor	Jamaica Bay	Newark Bay	Lower Harbor	Upper Harbor	W. Long Is. Sound	Bight Apex
METALS							
Antimony	1 (-1-2)	0 (0-8)	12 (-8-32)	0 (0-8)	0 (0-8)	0 (0-8)	0 (0-8)
Arsenic	1 (-1-2)	0 (0-8)	12 (-8-32)	0 (0-8)	0 (0-8)	0 (0-8)	0 (0-8)
Cadmium	0 (0-0)	0 (0-8)	2 (-1-4)	0 (0-8)	0 (0-8)	0 (0-8)	0 (0-8)
Chromium	0 (0-0)	0 (0-8)	0 (0-0)	0 (0-8)	0 (0-8)	0 (0-8)	0 (0-8)
Copper	3 (1-5)	4 (0-13)	32 (8-56)	0 (0-8)	4 (0-13)	0 (0-8)	7 (0-8)
Lead	4 (2-6)	4 (0-13)	35 (11-59)	0 (0-8)	7 (2-18)	0 (0-8)	0 (0-8)
Mercury	34 (24-44)	4 (0-13)	91 (82-99)	29 (17-42)	46 (33-60)	0 (0-8)	4 (0-13)
Nickel	4 (2-6)	4 (0-13)	52 (30-73)	0 (0-8)	4 (0-13)	0 (0-8)	0 (0-8)
Silver	13 (6-20)	7 (2-18)	32 (8-56)	11 (4-22)	18 (9-31)	4 (0-13)	0 (0-8)

Table E-2 Continued.	Harbor	Jamaica Bay	Newark Bay	Lower Harbor	Upper Harbor	W. Long Is. Sound	Bight Apex
Zinc	3 (1-4)	4 (0-13)	35 (11-59)	0 (0-8)	0 (0-8)	0 (0-8)	0 (0-8)
ORGANICS							
Total PCBs = (Σ congeners) x 2	39 (35-43)	14 (3-25)	75 (51-93)	32 (18-46)	61 (46-76)	4 (0-10)	7 (0-15)
Parent DDT	3 (2-4)	0 (0-8)	46 (24-67)	0 (0-8)	0 (0-8)	0 (0-8)	4 (0-13)
Total DDD	12 (6-18)	0 (0-8)	73 (52-94)	7 (2-18)	14 (6-27)	0 (0-8)	4 (0-13)
p,p'-DDE	3 (2-5)	0 (0-8)	51 (29-73)	0 (0-8)	0 (0-8)	0 (0-8)	0 (0-8)
Total DDE	13 (7-19)	4 (0-13)	79 (58-99)	7 (2-18)	14 (6-27)	0 (0-8)	0 (0-8)
Total DDT	8 (4-12)	0 (0-8)	65 (44-87)	4 (0-13)	7 (2-18)	0 (0-8)	0 (0-8)
Chlordane	32 (23-42)	29 (17-42)	91 (82-99)	25 (14-38)	39 (27-53)	14 (6-27)	7 (2-18)
Dieldrin	0 (0-0)	0 (0-8)	0 (0-0)	0 (0-8)	0 (0-8)	0 (0-8)	0 (0-8)
Endrin	0 (0-0)	0 (0-8)	0 (0-0)	0 (0-8)	0 (0-8)	0 (0-8)	0 (0-8)

Table E-2 Continued.	Harbor	Jamaica Bay	Newark Bay	Lower Harbor	Upper Harbor	W. Long Is. Sound	Bight Apex
Acenaphthene	1 (0-2)	4 (0-13)	1 (0-1)	0 (0-8)	4 (0-13)	0 (0-8)	0 (0-8)
Anthracene	6 (3-9)	4 (0-13)	12 (-7-32)	0 (0-8)	21 (12-35)	0 (0-8)	0 (0-8)
Acenaphthylene	3 (1-5)	0 (0-8)	1 (0-1)	0 (0-8)	14 (6-27)	4 (0-13)	0 (0-8)
Benzo(a)anthracene	7 (4-10)	4 (0-13)	10 (0-20)	0 (0-8)	29 (17-42)	4 (0-13)	0 (0-8)
Benzo(a)pyrene	6 (3-9)	4 (0-13)	6 (0-11)	0 (0-8)	25 (14-38)	4 (0-13)	0 (0-8)
Chrysene	4 (2-7)	4 (0-13)	1 (0-1)	0 (0-8)	18 (9-31)	0 (0-8)	0 (0-8)
Dibenz(a,h)anthracene	5 (2-7)	0 (0-8)	3 (0-6)	0 (0-8)	21 (12-35)	0 (0-8)	0 (0-8)
Fluoranthene	3 (0-5)	4 (0-13)	0 (0-0)	0 (0-8)	11 (4-22)	0 (0-8)	0 (0-8)
Fluorene	2 (0-4)	4 (0-13)	1 (0-1)	0 (0-8)	7 (2-18)	0 (0-8)	0 (0-8)
2-Methylnaphthalene	1 (0-2)	4 (0-13)	1 (0-1)	0 (0-8)	4 (0-13)	0 (0-8)	0 (0-8)
Naphthalene	1 (0-2)	0 (0-8)	0 (0-8)	0 (0-8)	4 (0-13)	0 (0-8)	0 (0-8)

Table E-2 Continued.	Harbor	Jamaica Bay	Newark Bay	Lower Harbor	Upper Harbor	W. Long Is. Sound	Bight Apex
Phenanthrene	6 (3-8)	4 (0-13)	1 (0-1)	0 (0-8)	25 (14-38)	0 (0-8)	0 (0-8)
Pyrene	6 (3-9)	4 (0-13)	7 (-2-17)	0 (0-8)	25 (14-38)	0 (0-8)	0 (0-8)
Low Molec. Wt. PAHs	9 (5-12)	0 (0-8)	4 (0-8)	0 (0-8)	39 (27-53)	4 (0-13)	0 (0-8)
High Molec. Wt. PAHs	12 (9-16)	4 (0-13)	46 (23-68)	0 (0-8)	43 (30-57)	7 (2-18)	0 (0-8)
Total PAHs	3 (0-5)	4 (0-13)	1 (0-1)	0 (0-8)	11 (4-22)	0 (0-8)	0 (0-8)

Appendix F

Dioxin bioaccumulation calculation

Theoretical Bioaccumulation Potential (TBP) Calculation

Because the relative toxicity of congeners to humans may differ from toxicity to aquatic organisms, different toxicity equivalents have been defined for humans and for [aquatic] "ecological systems." Human toxicity equivalents are probably closer to those of other mammals and birds than the equivalents for aquatic organisms. Preliminary efforts to define toxicity equivalency factors for aquatic "ecological systems" are based solely upon laboratory mortalities of early life-stage fishes (U.S. EPA 1993; Cura, Heiger-Bernays and Bucholz 1995, p.2-11). These preliminary toxicity equivalency factors for aquatic ecosystems are so uncertain (indeed, completely unknown for several congeners) that they are not used here. Further, it is clear that fish-eating birds and mammals, including humans, are at much greater risk from dioxins/furans than the benthos (U.S. EPA 1993; Cura, Heiger-Bernays and Bucholz 1995). Consequently this investigation attempts to estimate dioxin/furan concentrations in sediments which would not be a risk to humans or fish-eating wildlife.

Measured concentrations of 2,3,7,8-TCDD and the "human health toxicity equivalents" of all dioxin/furan congeners - expressed as weighted additive equivalents - are summarized in Table 4.3.1. The biotic effects of 2,3,7,8-TCDD alone are not interpretable. Concentrations of this single isomer are shown only because they are comparable to commonly reported 2,3,7,8-TCDD values.

We attempt to estimate a "safe" concentration of dioxins/furans (expressed as human health toxicity equivalents) in sediments, based upon a presumably protective range of concentrations in fishes, and an estimated relationship between sediment and fish concentrations. First, we specify dioxins/furans concentrations in fishes that seem to pose low and high risks to humans and wildlife. The range of 0.7 to 7 pptr dioxins/furans in fishes is presumed to embrace low to high risks for piscivorous mammals - probably the organisms at greatest potential risk (U.S. EPA 1993, Table E-1). Following the NYS Department of Health, we presume that 10 pptr in fishes protects against effects of dioxins/furans in adult humans unless exceptionally large quantities of fishes are eaten. Thus we consider a protective range for mammalian wildlife of one pptr (low risk) to 7 pptr mean fish concentration (high risk), and presume that 7 pptr is also a low risk to most adult humans.

We then work down the food web from fishes to estimate a "safe" range of dioxins/furans in sediments. Wide ranges have been measured for dioxin/furan biomagnification from benthic invertebrates to fishes. We use an intermediate value of two (U.S. EPA 1993; Cura, Heiger-Bernays and Buckolz 1995). Thus, our "high risk" concentration of 7 pptr in fishes would result from $7/2 = 3.5$ pptr in the benthos. Dioxin/furan concentrations in the benthos are estimated from: (1) the "accumulation factor" of dioxin/furan transfer from sediment to benthos, (2) dioxin/furan concentration in sediment, (3) lipid content of the benthos, and (4) fraction of organic carbon in the sediments. This relationship has been expressed as an estimator of "theoretical bioaccumulation potential" (TBP) of benthic infaunal organisms (U.S. EPA 1993):

$$\text{TBP} = \text{AF}(C_s @ \%L) / \% \text{TOC}$$

where: TBP = 2,3,7,8-TCDD human health equivalents in benthic tissue (pptr, wet wt), AF = accumulation factor, or dioxin/furan concentration in benthos as fraction of concentration in sediment,

C_s = dioxin/furan concentration in sediments,

%L = percent lipid in fishes, and

%TOC = percent total organic carbon in sediments.

In our “high risk” case, TBP=3.5 pptr. Measured accumulation of 2,3,7,8-TCDD and 2,3,7,8-TCDF from sediments to marine invertebrates has ranged from 0.24 to 1.0 times the sediment concentration (Pruell et al. 1993). We assume an intermediate sediment to polychaete “accumulation factor” (AF) of 0.5. Percentages of lipid in the benthos are typically near 1%, and 3% total organic carbon is common in Harbor sediments.

Using these assumed and typical values, we can solve for a range of presumably safe, but mammalian wildlife “high risk” dioxin/furan concentrations in sediments:

$$3.5 \text{ pptr} = 0.5(C_s \cdot 0.01) / 0.03$$

$$C_s = 21 \text{ pptr.}$$

Similarly, our estimate of “low risk” concentration in the benthos (TBP) is half the low risk protective concentration in fishes ($1/2=0.5$ pptr). So, low risk sediment concentrations are:

$$0.5 \text{ pptr} = 0.5(C_s \cdot 0.01) / 0.03$$

$$C_s = 3.$$

As mentioned above, we presume that even the high risk sediment concentrations (21 pptr) pose low risks for most adult humans. Hence these sediment concentrations apply to piscivorous birds and mammals. Several major uncertainties are inescapable in estimating these presumably “high” and “low” risk sediment concentrations for wildlife. Some uncertainties are so great that we can not even rank their severity. One obvious uncertainty is variability in wildlife exposures to dioxins/furans, and assimilation efficiencies, from foods, sediments and water. This obviously varies with the top carnivore involved, food available to the carnivore, differential bioaccumulation in the food web, etc. (U.S. EPA 1993). Also, dose-response relationships such as the above equation for theoretical bioaccumulation potential have little empirical support from few environments. Even if the TBP equation is robust, all the predictor variables are spatially heterogeneous, probably ensuring imprecise estimates of mean dioxin/furan concentrations in the benthos even if field measurements were extensive. Further, there are few direct measurements of variability in the most important variables, e.g., concentrations of dioxins/furans in commercial and recreational fishes. Hence, there is little basis for estimating the distributions of these variables.

Appendix G

Area-weighted mean abundances of all
benthic macroinvertebrate species (mean #/.04 m²)

1/46

Taxon Group	Taxon Name	Bight Apex	West. Long Island Sound	Newark Bay	Raritan Bay	Upper Harbor	Jamaica Bay
Cnidaria : Anthozoa	Anthozoa	0.3214	0.0179	0.2857	0.0517	4.5714	0.0000
Cnidaria : Anthozoa	Ceriantheopsis americanus	4.3393	0.1429	0.0000	0.3276	0.0357	0.0000
Platyhelminthes : Turbellaria	Turbellaria	0.0000	0.3571	0.3571	1.2931	0.2679	6.6071
Nemertinea	Malacobdella grossa	0.0000	0.0179	0.0000	0.0000	0.0000	0.0000
Nemertinea	Nemertinea	4.1964	7.6250	1.4107	0.6379	1.3571	0.1786
Annelida : Polychaeta	Aglaophamus circinata	0.3036	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	Amastigos caperatus	0.5179	0.0000	0.0000	0.0517	0.0000	0.0000
Annelida : Polychaeta	Ampharete arctica	0.6607	0.3750	0.0000	0.0172	0.3036	0.0000
Annelida : Polychaeta	Ampharetidae	103.2321	0.2679	1.0179	0.8621	2.0714	0.1964
Annelida : Polychaeta	Ancistrosyllis hartmanae	0.0357	0.3393	0.0000	0.0000	0.0179	0.0000
Annelida : Polychaeta	Anobothrus gracilis	0.0536	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	Aphelochaeta spp.	12.8036	0.1429	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	Aphrodita hastata	0.0179	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	Apoprionospio pygmaea	0.0357	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	Aricidea catherinae	21.8393	1.1071	0.0000	29.5690	2.1071	2.1071
Annelida : Polychaeta	Aricidea cerrutti	0.0714	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	Aricidea spp.	0.0179	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	Aricidea wassi	2.3571	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	Asabellides oculata	11.8036	0.0714	1.6429	0.9310	1.6071	0.1429

Taxon Group	Taxon Name	Bight Apex	West. Long Island Sound	Newark Bay	Raritan Bay	Upper Harbor	Jamaica Bay
Annelida : Polychaeta	<i>Autolytus</i> spp.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0179
Annelida : Polychaeta	<i>Brada villosa</i>	0.0357	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	<i>Brania clavata</i>	0.0179	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	<i>Brania</i> spp.	0.0000	0.0000	0.0000	0.0172	0.0000	0.0000
Annelida : Polychaeta	<i>Brania wellfleetensis</i>	0.0000	0.0357	0.0000	0.3793	0.0000	0.0000
Annelida : Polychaeta	<i>Capitella</i> spp.	0.5536	0.0714	0.2321	0.0000	0.0000	7.1964
Annelida : Polychaeta	Capitellidae	0.0714	0.0000	0.0179	0.3448	0.0179	0.0000
Annelida : Polychaeta	<i>Carazziella hobsonae</i>	0.0000	0.0179	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	<i>Caulerliella</i> sp. B Blake	3.6607	0.0179	0.0000	3.8966	0.0179	13.5536
Annelida : Polychaeta	<i>Chaetopterus variopectatus</i>	0.0000	0.0179	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	<i>Chone infundibuliformis</i>	1.5179	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	Cirratulidae	8.8036	0.4643	0.0000	0.0345	0.0000	5.2500
Annelida : Polychaeta	<i>Cirriformia grandis</i>	0.0000	0.0000	0.0000	0.0172	1.5714	0.0357
Annelida : Polychaeta	<i>Cirrophorus</i> sp. A Morris	0.0000	0.0357	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	<i>Clymenella torquata</i>	2.6964	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	<i>Cossura longocirrata</i>	10.4464	10.8393	0.0000	0.0000	0.0179	0.0179
Annelida : Polychaeta	<i>Demonax microphthalmus</i>	0.0000	0.0714	0.0000	0.0345	0.3036	0.0714
Annelida : Polychaeta	<i>Diopatra cuprea</i>	0.0000	0.0000	0.0000	0.0345	0.0000	0.0000
Annelida : Polychaeta	<i>Dispio uncinata</i>	0.0000	0.0000	0.0000	0.0172	0.0000	0.0000

Taxon Group	Taxon Name	Bight Apex	West. Long Island Sound	Newark Bay	Raritan Bay	Upper Harbor	Jamaica Bay
Annelida : Polychaeta	Dodecaceria fimbriata	0.0000	0.1071	0.0000	0.0000	0.0714	0.0000
Annelida : Polychaeta	Dorvillea rudolphi	0.0000	0.0000	0.0000	0.0000	0.0536	0.0714
Annelida : Polychaeta	Dorvilleidae sp. A Hilbig	0.0357	0.2679	0.0000	0.0517	0.0000	0.0000
Annelida : Polychaeta	Driloneireis longa	0.3571	0.0000	0.0000	0.1379	0.0000	0.0000
Annelida : Polychaeta	Euchone elegans	0.1250	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	Euchone incolor	14.7143	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	Euchone spp.	0.1964	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	Eumida sanguinea	0.3571	0.5179	0.1071	4.1724	4.6071	5.0536
Annelida : Polychaeta	Exogone dispar	0.0893	0.0357	0.0000	1.2931	0.0000	14.3750
Annelida : Polychaeta	Exogone hebes	9.1607	0.0000	0.0179	0.0000	0.0000	0.0000
Annelida : Polychaeta	Exogone spp.	0.0357	0.0179	0.0000	0.0345	0.0000	0.0536
Annelida : Polychaeta	Exogone verugera	0.0714	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	Flabelligeridae	3.5893	0.0179	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	Glycera americana	0.0000	0.3393	0.1607	1.6034	0.7857	0.1429
Annelida : Polychaeta	Glycera dibranchiata	0.6964	0.0714	0.0000	0.5345	0.0000	0.3571
Annelida : Polychaeta	Glycera spp.	0.3929	0.6607	1.7143	0.8966	1.1250	0.6071
Annelida : Polychaeta	Goniada maculata	0.0179	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	Goniadella gracilis	2.2679	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	Goniadidae	0.1607	0.0000	0.0000	0.0000	0.0000	0.0000

Taxon Group	Taxon Name	Bight Apex	West. Long Island Sound	Newark Bay	Raritan Bay	Upper Harbor	Jamaica Bay
Annelida : Polychaeta	Harmothoe extenuata	0.0000	0.0000	0.0000	0.1034	0.7143	0.0536
Annelida : Polychaeta	Harmothoe imbricata	0.0000	0.0000	0.0000	0.0172	0.2679	0.1964
Annelida : Polychaeta	Hemipodus roseus	0.0714	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	Hesionidae	0.0000	0.0000	0.0000	0.0172	0.0000	0.0536
Annelida : Polychaeta	Heteromastus filiformis	0.0000	0.0179	6.8571	30.5517	7.8036	0.5357
Annelida : Polychaeta	Hobsonia florida	0.0000	0.0000	0.0179	0.0000	0.0000	0.0000
Annelida : Polychaeta	Hydroides dianthus	0.0000	0.0536	0.0000	0.0000	0.0000	14.1786
Annelida : Polychaeta	Hydroides protulicola	0.0000	0.0000	0.0000	0.0000	0.0000	0.0357
Annelida : Polychaeta	Hydroides spp.	0.0000	0.0179	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	Hypereteone foliosa	0.0893	0.0000	0.0893	0.0690	0.0000	0.0000
Annelida : Polychaeta	Hypereteone heteropoda	0.0000	0.5179	3.2500	10.9138	2.9821	7.0357
Annelida : Polychaeta	Hypereteone longa	0.0357	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	Laonereis culveri	0.0000	0.0000	2.5357	0.0000	0.0000	0.0000
Annelida : Polychaeta	Laonice spp.	0.0357	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	Leitoscoloplos robustus	0.3036	0.3571	23.9286	1.4483	5.4464	0.5357
Annelida : Polychaeta	Leitoscoloplos spp.	0.4107	1.9643	10.3214	2.8793	7.3929	1.8929
Annelida : Polychaeta	Lepidonotus spp.	0.0000	0.0179	0.0000	0.0690	0.1786	0.0000
Annelida : Polychaeta	Lepidonotus squamatus	0.0000	0.0000	0.0000	0.0000	0.0179	0.0000
Annelida : Polychaeta	Lepidonotus sublevis	0.0000	0.0179	0.0000	0.0517	0.0000	0.0179

Taxon Group	Taxon Name	Bight Apex	West. Long Island Sound	Newark Bay	Raritan Bay	Upper Harbor	Jamaica Bay
Annelida : Polychaeta	<i>Levinsenia gracilis</i>	18.5893	0.0179	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	<i>Loimia medusa</i>	0.0000	0.0536	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	Lumbrineridae	14.9107	0.2143	0.0000	0.0000	0.0000	0.0357
Annelida : Polychaeta	<i>Lumbrinerides acuta</i>	0.6607	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	<i>Lumbrinerides</i> spp.	0.0179	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	<i>Macroclymene zonalis</i>	0.0179	1.9464	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	<i>Magelona</i> spp.	1.3571	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	Maldanidae	1.8929	4.7500	0.0000	0.0172	0.0000	0.0000
Annelida : Polychaeta	<i>Marenzelleria viridis</i>	0.0000	0.0000	1.2143	0.0690	0.1607	0.0000
Annelida : Polychaeta	<i>Marphysa belli</i>	0.0179	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	<i>Mediomastus ambiseta</i>	5.1250	131.5000	13.7321	511.4483	97.9643	79.1071
Annelida : Polychaeta	<i>Mediomastus</i> spp.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0536
Annelida : Polychaeta	<i>Microphthalmus aberrans</i>	0.0000	0.0000	0.0000	0.0000	0.0000	0.0179
Annelida : Polychaeta	<i>Microphthalmus fragilis</i>	0.4107	0.0000	0.0000	0.0000	0.0179	0.0000
Annelida : Polychaeta	<i>Microphthalmus sczelkowi</i>	0.1786	0.0536	0.7679	0.2414	0.2321	0.0000
Annelida : Polychaeta	<i>Microphthalmus similis</i>	3.6071	0.0000	0.0000	0.0000	0.2500	0.1429
Annelida : Polychaeta	<i>Microphthalmus</i> spp.	0.0000	0.0000	0.0000	0.0172	0.0000	0.0000
Annelida : Polychaeta	<i>Monticellina baptistae</i>	5.4286	0.0536	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	<i>Neanthes arenaceodentata</i>	0.0000	0.0000	0.0000	0.0345	0.1429	5.8929

Taxon Group	Taxon Name	Bight Apex	West. Long Island Sound	Newark Bay	Raritan Bay	Upper Harbor	Jamaica Bay
Annelida : Polychaeta	<i>Neanthes succinea</i>	0.0179	3.1964	0.3393	0.9310	4.2143	2.0000
Annelida : Polychaeta	<i>Neanthes virens</i>	0.0000	0.0000	0.0000	0.0000	0.2857	0.0000
Annelida : Polychaeta	Nephtyidae	4.7500	2.3214	0.0179	0.0690	0.1250	0.0714
Annelida : Polychaeta	<i>Nephtys bucera</i>	0.0714	0.0000	0.0000	0.0172	0.0000	0.0000
Annelida : Polychaeta	<i>Nephtys incisa</i>	1.5179	4.0714	0.0357	0.0345	0.0714	0.0000
Annelida : Polychaeta	<i>Nephtys picta</i>	0.8929	0.1429	0.0000	1.0517	0.5000	0.4821
Annelida : Polychaeta	<i>Nephtys</i> spp.	0.0000	0.0179	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	Nereididae	0.0714	0.0179	0.0536	0.0690	1.4107	0.3750
Annelida : Polychaeta	<i>Nereis grayi</i>	0.0536	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	<i>Nicolea zostericola</i>	0.0179	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	<i>Ninoe nigripes</i>	2.8393	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	<i>Notocirrus spiniferus</i>	0.0000	0.0000	0.0000	0.0000	0.0000	0.0179
Annelida : Polychaeta	<i>Notomastus</i> spp.	0.0357	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	<i>Odontosyllis fulgurans</i>	0.0000	0.0179	0.0000	0.0000	0.0179	0.0000
Annelida : Polychaeta	Onuphidae	0.0179	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	Opheliidae	0.0179	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	<i>Ophelina acuminata</i>	0.0714	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	<i>Owenia fusiformis</i>	0.0536	4.1964	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	Oweniidae	0.0000	0.4643	0.0000	0.0000	0.0000	0.0000

Taxon Group	Taxon Name	Bight Apex	West. Long Island Sound	Newark Bay	Raritan Bay	Upper Harbor	Jamaica Bay
Annelida : Polychaeta	<i>Paradoneis</i> sp. A Morris	0.0179	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	<i>Paradoneis</i> sp. B Morris	1.3929	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	<i>Parabesione luteola</i>	0.0000	0.0000	0.0000	0.0000	0.0000	0.0179
Annelida : Polychaeta	<i>Paranaitis speciosa</i>	0.0536	0.0357	0.0179	0.3793	0.2143	0.0179
Annelida : Polychaeta	<i>Paronion fulgens</i>	0.0536	0.0000	0.0000	0.0690	0.0000	0.0000
Annelida : Polychaeta	<i>Paronion pygoenigmatica</i>	0.4286	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	<i>Parapionosyllis longicirrata</i>	0.4643	0.0357	0.0000	0.0690	0.0000	0.0000
Annelida : Polychaeta	<i>Parougia caeca</i>	3.9286	0.0179	0.0179	0.0000	0.0000	0.0000
Annelida : Polychaeta	<i>Pectinaria gouldii</i>	0.0357	4.7321	0.7500	2.3793	2.5000	2.1964
Annelida : Polychaeta	<i>Pectinaria</i> spp.	0.0000	0.0000	0.3214	0.0000	0.0000	0.0000
Annelida : Polychaeta	<i>Pherusa affinis</i>	1.5893	0.7857	0.0000	0.0517	0.0179	0.0357
Annelida : Polychaeta	<i>Pherusa</i> spp.	0.0536	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	<i>Pholoe minuta</i>	0.1429	0.1964	0.0000	0.0000	0.0179	0.0000
Annelida : Polychaeta	<i>Phyllodoce arenae</i>	0.3750	0.0714	0.0536	0.2414	0.1250	0.1786
Annelida : Polychaeta	<i>Phyllodoce mucosa</i>	0.5357	0.0357	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	Pilargidae	0.0000	0.0000	0.0000	0.0000	0.0179	0.0000
Annelida : Polychaeta	<i>Pisione remota</i>	0.1607	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	<i>Podarke obscura</i>	0.0000	0.0536	0.0000	0.0000	0.4643	10.0000
Annelida : Polychaeta	<i>Podarkeopsis levifuscina</i>	0.0000	0.0536	0.1071	3.0862	0.1786	0.8571

Taxon Group	Taxon Name	Bight Apex	West. Long Island Sound	Newark Bay	Raritan Bay	Upper Harbor	Jamaica Bay
Annelida : Polychaeta	Polychaeta: Unidentified	0.0000	0.0000	0.0000	0.0000	0.0000	0.0179
Annelida : Polychaeta	Polycirrus eximius	0.0000	0.7500	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	Polycirrus spp.	0.6429	2.7143	0.0000	0.3103	0.5714	0.5179
Annelida : Polychaeta	Polydora aggregata	0.0000	0.0357	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	Polydora caulleryi	0.6607	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	Polydora cornuta	0.1250	1.9286	3.2143	31.5517	15.5893	19.2500
Annelida : Polychaeta	Polydora quadrilobata	0.6250	0.0000	0.0000	0.1207	0.0179	0.0000
Annelida : Polychaeta	Polydora socialis	3.6250	0.0893	0.0000	0.2069	0.1429	0.0179
Annelida : Polychaeta	Polydora spp.	0.0714	0.0536	0.0536	0.1207	0.0179	2.8571
Annelida : Polychaeta	Polydora websteri	0.0000	0.0000	0.0000	0.6379	0.0179	0.3571
Annelida : Polychaeta	Polygordius spp.	551.8929	7.2321	0.5893	0.2759	0.8571	0.0000
Annelida : Polychaeta	Polynoidae	0.1071	0.1786	0.0000	0.0862	0.9464	0.0179
Annelida : Polychaeta	Praxillura ornata	0.0893	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	Prionospio spp.	0.0000	0.0357	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	Prionospio steenstrupi	222.5893	1.0714	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	Proceræa cornuta	0.0000	0.1250	0.0000	0.0000	0.0536	0.1071
Annelida : Polychaeta	Pseudopotamilla reniformis	0.0000	0.0357	0.0000	0.1207	0.0714	0.1250
Annelida : Polychaeta	Pygospio elegans	0.0000	0.0000	0.3929	0.1897	0.0000	0.0000
Annelida : Polychaeta	Sabaco elongatus	0.0000	0.2143	0.0000	0.0345	0.0000	0.0000

Taxon Group	Taxon Name	Bight Apex	West. Long Island Sound	Newark Bay	Raritan Bay	Upper Harbor	Jamaica Bay
Annelida : Polychaeta	<i>Sabellaria vulgaris</i>	0.0536	0.7679	0.4821	2.8276	18.2143	39.1607
Annelida : Polychaeta	Sabellariidae	0.0000	0.0357	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	Sabellidae	0.4107	0.0714	0.0000	0.0517	0.8750	0.5357
Annelida : Polychaeta	<i>Scalibregma inflatum</i>	4.8393	0.0893	0.0000	0.0172	0.0000	0.0000
Annelida : Polychaeta	<i>Scolelepis bousfieldi</i>	0.0000	0.0893	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	<i>Scolelepis</i> spp.	0.0000	0.0179	0.0000	0.1034	0.0000	0.0357
Annelida : Polychaeta	<i>Scolelepis squamata</i>	0.7143	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	<i>Scolelepis texana</i>	0.0000	0.0000	0.0179	0.1379	0.0000	0.4286
Annelida : Polychaeta	<i>Scoletoma acicularum</i>	0.2500	0.0714	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	<i>Scoletoma hebes</i>	3.4286	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	<i>Scoletoma tenuis</i>	0.0000	0.0179	0.0000	0.0000	0.0000	0.0357
Annelida : Polychaeta	<i>Scoloplos rubra</i>	0.0000	0.0357	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	<i>Scoloplos</i> spp.	0.0893	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	<i>Sigalion arenicola</i>	0.0536	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	Sigalionidae	0.0357	0.0000	0.0000	0.0000	0.0536	0.0000
Annelida : Polychaeta	<i>Sigambra tentaculata</i>	0.0000	1.6607	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	<i>Sphaerosyllis</i> spp.	0.0179	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	<i>Spio filicornis</i>	0.9821	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	<i>Spio setosa</i>	1.2679	0.0000	2.2143	4.1897	7.8571	1.2321

Taxon Group	Taxon Name	Bight Apex	West. Long Island Sound	Newark Bay	Raritan Bay	Upper Harbor	Jamaica Bay
Annelida : Polychaeta	Spio spp.	0.0357	0.0000	0.0000	0.1207	0.0000	0.0000
Annelida : Polychaeta	Spiochaetopterus costarum	0.0536	0.5357	0.0179	0.5345	0.2321	0.1250
Annelida : Polychaeta	Spionidae	0.0000	0.0179	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	Spiophanes bombyx	7.6607	0.4286	0.0000	0.8966	0.4286	0.0357
Annelida : Polychaeta	Sthenelais boa	0.0000	0.0714	0.0000	0.0000	0.1250	0.0000
Annelida : Polychaeta	Sthenelais limicola	0.0893	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	Sthenelais spp.	1.8214	0.0179	0.0000	0.0000	0.0357	0.0000
Annelida : Polychaeta	Streblospio benedicti	0.0893	36.3750	309.8393	262.7586	148.6786	339.9464
Annelida : Polychaeta	Streptosyllis pettiboneae	0.3750	0.0000	0.0536	0.1724	0.0357	0.0536
Annelida : Polychaeta	Syllidae	0.2500	0.0000	0.0000	0.0000	0.0000	0.1071
Annelida : Polychaeta	Syllides convoluta	1.3929	0.0000	0.0000	0.0000	0.0000	0.0179
Annelida : Polychaeta	Syllides verrilli	0.0893	0.0000	0.0000	0.0000	0.0000	0.0714
Annelida : Polychaeta	Terebellides stroemi	0.2143	0.0000	0.0000	0.0000	0.0000	0.0000
Annelida : Polychaeta	Tharyx acutus	6.0179	0.1429	0.0000	0.0000	0.0000	0.0179
Annelida : Polychaeta	Tharyx sp. A Morris	17.4464	2.2679	8.3214	25.8621	26.5357	14.7679
Annelida : Polychaeta	Travisia sp. A Morris	0.3393	0.0000	0.0000	0.0345	0.0000	0.0000
Annelida : Polychaeta	Typosyllis alternata	0.0357	0.0000	0.0000	0.0000	0.0000	0.2857
Annelida : Oligochaeta	Oligochaeta	38.7500	27.5179	50.8036	71.9483	137.8571	48.5357
Mollusca : Gastropoda	Acteocina canaliculata	0.0179	4.9107	0.0000	0.1034	0.0179	0.0000

Taxon Group	Taxon Name	Bight Apex	West. Long Island Sound	Newark Bay	Raritan Bay	Upper Harbor	Jamaica Bay
Mollusca : Gastropoda	<i>Alvania</i> spp.	0.0179	0.0000	0.0000	0.0000	0.0000	0.0000
Mollusca : Gastropoda	<i>Boonea bisuturalis</i>	0.0000	0.0179	0.0357	1.3448	0.1964	5.4107
Mollusca : Gastropoda	Buccinidae	0.0000	0.0000	0.0000	0.0172	0.0000	0.0000
Mollusca : Gastropoda	<i>Colus pygmaeus</i>	0.1250	0.0000	0.0000	0.0000	0.0000	0.0000
Mollusca : Gastropoda	<i>Cratena pilata</i>	0.0000	0.1429	0.0000	0.0000	0.0000	0.0000
Mollusca : Gastropoda	<i>Crepidula convexa</i>	0.0000	0.0893	0.0000	0.0000	0.4464	0.0000
Mollusca : Gastropoda	<i>Crepidula fornicata</i>	0.0000	0.0000	0.0000	1.5517	0.5893	2.7143
Mollusca : Gastropoda	<i>Crepidula maculosa</i>	0.0000	0.0357	0.0000	2.7241	0.0000	2.6786
Mollusca : Gastropoda	<i>Crepidula plana</i>	0.0357	0.0179	0.0000	0.9828	0.1607	0.0000
Mollusca : Gastropoda	<i>Crepidula</i> spp.	0.5536	0.5179	0.0357	1.7414	1.1071	2.6786
Mollusca : Gastropoda	<i>Cyllichnella bidentata</i>	0.0000	0.0536	0.0179	0.0000	0.0000	0.0000
Mollusca : Gastropoda	<i>Doridella obscura</i>	0.0000	0.0357	0.0357	0.0690	0.0714	0.1250
Mollusca : Gastropoda	<i>Epitonium rupicola</i>	0.0000	0.0000	0.0357	0.0000	0.0000	0.0000
Mollusca : Gastropoda	<i>Eupleura caudata</i>	0.0000	0.0000	0.0000	0.1034	0.0000	0.0179
Mollusca : Gastropoda	Gastropoda: Other	0.0179	0.0357	0.1071	0.3621	0.1071	0.0714
Mollusca : Gastropoda	<i>Haminoea solitaria</i>	0.0000	1.4286	4.0536	0.0000	0.0000	0.0000
Mollusca : Gastropoda	Hydrobia spp.	0.0000	0.0000	0.0536	0.0000	0.0000	0.0000
Mollusca : Gastropoda	<i>Ilyanassa obsoleta</i>	0.0000	0.0714	0.2857	2.1207	0.0357	12.6786
Mollusca : Gastropoda	Muricidae	0.0000	0.0000	0.0000	0.0172	0.0000	0.0179

Taxon Group	Taxon Name	Bight Apex	West. Long Island Sound	Newark Bay	Raritan Bay	Upper Harbor	Jamaica Bay
Mollusca : Gastropoda	<i>Nassarius trivittatus</i>	0.2500	16.9643	0.0357	10.9655	1.4821	0.0536
Mollusca : Gastropoda	<i>Nassarius vibex</i>	0.0000	0.0000	0.1964	0.0690	0.0000	0.0714
Mollusca : Gastropoda	<i>Nudibranchia</i>	0.0000	0.0000	0.0000	0.0000	0.0000	0.0714
Mollusca : Gastropoda	<i>Odostomia engonia</i>	0.0000	0.0000	0.8214	0.0000	0.0179	0.0000
Mollusca : Gastropoda	<i>Odostomia</i> spp.	0.0000	2.1429	1.1607	3.8276	1.8393	0.2321
Mollusca : Gastropoda	<i>Polinices duplicata</i>	0.0179	0.0000	0.0000	0.0000	0.0000	0.0000
Mollusca : Gastropoda	<i>Pyramidellidae</i>	0.0179	0.0000	0.0000	0.0000	0.0357	0.0179
Mollusca : Gastropoda	<i>Rictaxis punctostriatus</i>	0.0357	13.0357	2.3571	5.9828	2.2500	1.2321
Mollusca : Gastropoda	<i>Turbonilla interrupta</i>	0.0179	4.0893	0.0000	0.1379	0.0000	0.0000
Mollusca : Gastropoda	<i>Turbonilla</i> spp.	0.0000	0.0357	0.0000	0.0172	0.0000	0.0000
Mollusca : Gastropoda	<i>Urosalpinx cinerea</i>	0.0000	0.0000	0.0000	0.0345	0.0000	0.0000
Mollusca : Bivalvia	<i>Aligea elevata</i>	0.0357	0.0000	0.0000	0.0000	0.0000	0.0000
Mollusca : Bivalvia	<i>Anadara transversa</i>	0.0000	0.2679	0.0000	0.0172	0.0000	0.1250
Mollusca : Bivalvia	<i>Anomia simplex</i>	0.0000	0.0536	0.0000	0.0000	0.0179	0.0000
Mollusca : Bivalvia	<i>Anomia</i> spp.	0.0000	0.0357	0.0000	0.0000	0.0000	0.0000
Mollusca : Bivalvia	<i>Astarte castanea</i>	0.0357	0.1429	0.0000	0.0000	0.0000	0.0000
Mollusca : Bivalvia	<i>Astarte</i> spp.	0.1250	0.0000	0.0000	0.0000	0.0000	0.0000
Mollusca : Bivalvia	<i>Astarte undata</i>	0.3929	0.0714	0.0000	0.0000	0.0000	0.0000
Mollusca : Bivalvia	<i>Asthenothaerus hemphilli</i>	0.4286	0.0000	0.0000	0.0000	0.0000	0.0000

Taxon Group	Taxon Name	Bight Apex	West. Long Island Sound	Newark Bay	Raritan Bay	Upper Harbor	Jamaica Bay
Mollusca : Bivalvia	Bivalvia: Other - Suspension Feeders	0.1429	0.0357	0.0179	0.0862	0.0714	0.1250
Mollusca : Bivalvia	Bivalvia: Other - Unidentified	0.2857	0.0000	0.0179	0.0517	0.0000	0.0000
Mollusca : Bivalvia	Bushia elegans	0.0179	0.0000	0.0000	0.0000	0.0000	0.0000
Mollusca : Bivalvia	Cerastoderma pinnulatum	0.4821	0.0000	0.0000	0.0000	0.0000	0.0000
Mollusca : Bivalvia	Crassostrea virginica	0.0000	0.0000	0.0000	0.0000	0.0357	0.0000
Mollusca : Bivalvia	Crenella decussata	0.0357	0.0000	0.0000	0.0000	0.0000	0.0000
Mollusca : Bivalvia	Crenella glandula	0.0357	0.0000	0.0000	0.0000	0.0000	0.0000
Mollusca : Bivalvia	Crenella spp.	0.0179	0.0000	0.0000	0.0000	0.0000	0.0000
Mollusca : Bivalvia	Cyclocardis borealis	0.0536	0.0000	0.0000	0.0000	0.0000	0.0000
Mollusca : Bivalvia	Ensis directus	0.2857	0.1071	0.2143	3.4655	0.0357	0.0536
Mollusca : Bivalvia	Gemma gemma	0.7143	0.1071	0.0179	11.2414	1.1250	32.4286
Mollusca : Bivalvia	Lyonsia arenosa	0.0179	0.1250	0.0000	0.1379	0.0357	0.0000
Mollusca : Bivalvia	Lyonsia hyalina	0.0000	0.0000	0.0000	0.0517	0.0000	0.0000
Mollusca : Bivalvia	Lyonsia spp.	0.1429	0.1607	0.0179	0.4483	0.1429	0.0000
Mollusca : Bivalvia	Macoma balthica	0.0000	0.0000	0.9464	0.0172	0.2500	0.0000
Mollusca : Bivalvia	Macoma tenta	0.0000	11.9107	0.0000	0.0000	0.0000	0.0000
Mollusca : Bivalvia	Mercenaria mercenaria	0.0179	0.3036	0.0000	1.7069	0.0536	4.5536
Mollusca : Bivalvia	Mulinia lateralis	0.0179	128.1786	7.8214	7.8276	1.9107	0.0000

Taxon Group	Taxon Name	Bight Apex	West. Long Island Sound	Newark Bay	Raritan Bay	Upper Harbor	Jamaica Bay
Mollusca : Bivalvia	Musculus niger	0.0536	0.0000	0.0000	0.0000	0.0000	0.0000
Mollusca : Bivalvia	Mya arenaria	0.0000	0.0357	2.5714	67.6897	2.8929	0.4643
Mollusca : Bivalvia	Mysella planulata	0.0000	0.0000	0.0000	0.0000	0.0000	0.3214
Mollusca : Bivalvia	Mytilidae	0.0179	0.0179	0.0000	0.0000	0.0000	0.0000
Mollusca : Bivalvia	Mytilus edulis	0.0536	0.1071	0.0893	0.1379	46.4643	0.0000
Mollusca : Bivalvia	Nucula annulata	198.1786	179.9643	0.0179	62.6724	1.1250	8.7857
Mollusca : Bivalvia	Nucula delphinodonta	0.6250	0.0000	0.0000	0.0000	0.0000	0.0000
Mollusca : Bivalvia	Nucula spp.	1.5714	0.0000	0.0000	0.0000	0.0000	0.0000
Mollusca : Bivalvia	Pandora gouldiana	0.0000	0.3393	0.0000	0.0000	0.0000	0.0000
Mollusca : Bivalvia	Pandora spp.	0.0357	0.5893	0.0000	0.0000	0.0000	0.0000
Mollusca : Bivalvia	Parvilucina multilincata	0.0179	0.0000	0.0000	0.0000	0.0000	0.0000
Mollusca : Bivalvia	Petricola pholadiformis	0.0357	0.2143	0.0000	1.3621	0.0893	0.8214
Mollusca : Bivalvia	Pitar morrhuanus	0.3393	0.3750	0.0000	0.1552	0.0000	0.0000
Mollusca : Bivalvia	Spisula solidissima	6.1786	1.9464	0.0000	2.0517	0.0179	0.0000
Mollusca : Bivalvia	Tellina agilis	7.2857	12.8393	0.3036	8.4828	11.1071	2.3571
Mollusca : Bivalvia	Tellinidae	0.0000	0.0000	0.0000	0.0000	0.0179	0.0000
Mollusca : Bivalvia	Yoldia limatula	0.4643	22.6071	0.0000	0.0000	0.0179	0.0000
Arthropoda : Merostomata	Limulus polyphemus	0.0000	0.0000	0.0000	0.0000	0.0000	0.0179
Arthropoda : Cephalocarida	Hutchinsoniella macracantha	0.0179	0.1250	0.0000	0.0000	0.0000	0.0000

Taxon Group	Taxon Name	Bight Apex	West. Long Island Sound	Newark Bay	Raritan Bay	Upper Harbor	Jamaica Bay
Arthropoda : Cirripedia	Balanus improvisus	0.0000	0.0357	4.3750	0.0000	6.1607	0.0000
Arthropoda : Cirripedia	Balanus spp.	0.0000	0.2500	0.0179	0.1034	0.0357	0.0000
Arthropoda : Cirripedia	Balanus venustus	0.0000	0.0714	0.0000	0.0000	0.0000	0.0000
Arthropoda : Stomatopoda	Squilla empusa	0.0000	0.0179	0.0000	0.0000	0.0000	0.0000
Arthropoda : Mysidacea	Heteromysis formosa	0.0000	0.1964	0.0000	0.9483	0.2321	0.2500
Arthropoda : Mysidacea	Neomysis americana	0.0357	0.0536	0.7321	0.3621	0.2143	0.1964
Arthropoda : Cumacea	Diastylis quadrispinosa	0.0179	0.0000	0.0000	0.0000	0.0000	0.0000
Arthropoda : Cumacea	Diastylis spp.	0.0536	0.0000	0.0000	0.0000	0.0000	0.0000
Arthropoda : Cumacea	Eudorella pusilla	0.5357	0.0000	0.0000	0.0000	0.0000	0.0000
Arthropoda : Cumacea	Leucon americanus	0.0000	0.7679	8.0536	0.0000	3.1071	0.0000
Arthropoda : Cumacea	Oxyurostylis smithi	0.1786	0.1250	0.2321	0.7759	0.2857	0.1071
Arthropoda : Cumacea	Pseudoleptocums minor	0.1071	0.0000	0.0000	0.0000	0.0000	0.0000
Arthropoda : Tanaiidacea	Tanaisius psammophilus	2.2143	0.0000	0.0000	0.0862	0.0000	0.0000
Arthropoda : Isopoda	Anthuridae	0.0000	0.0000	0.0000	0.0172	0.0000	0.0000
Arthropoda : Isopoda	Chiridotes spp.	0.0536	0.0000	0.0000	0.0000	0.0000	0.0000
Arthropoda : Isopoda	Cyathura barbancki	0.0000	0.0000	0.0179	0.4138	0.1786	0.0536
Arthropoda : Isopoda	Cyathura polita	0.0000	0.0000	0.9107	0.1207	0.3571	0.0000
Arthropoda : Isopoda	Edotea triloba	0.7321	0.1429	1.6786	2.1207	3.2143	0.0179
Arthropoda : Isopoda	Pleurogonium inerme	0.1071	0.0000	0.0000	0.0000	0.0000	0.0000

Taxon Group	Taxon Name	Bight Apex	West. Long Island Sound	Newark Bay	Raritan Bay	Upper Harbor	Jamaica Bay
Arthropoda : Isopoda	<i>Pleurogonium spinosissimum</i>	0.0179	0.0000	0.0000	0.0000	0.0000	0.0000
Arthropoda : Isopoda	<i>Politolana polita</i>	0.0357	0.0000	0.0000	0.0000	0.0000	0.0000
Arthropoda : Isopoda	<i>Ptilanthura tenuis</i>	0.5179	0.0000	0.0000	0.0000	0.0000	0.0000
Arthropoda : Amphipoda	<i>Acanthohaustorius millisi</i>	0.0536	0.0000	0.0000	0.0172	0.0000	0.0000
Arthropoda : Amphipoda	<i>Acanthohaustorius similis</i>	0.0357	0.0000	0.0000	0.0345	0.0000	0.0000
Arthropoda : Amphipoda	<i>Acanthohaustorius spp.</i>	0.0536	0.0000	0.0000	0.0000	0.0000	0.0000
Arthropoda : Amphipoda	<i>Aeginina longicornis</i>	0.0179	0.0000	0.0000	0.0000	0.0000	0.0000
Arthropoda : Amphipoda	<i>Ampelisca abdita</i>	0.0000	55.0357	0.3393	443.2414	1.0179	405.4464
Arthropoda : Amphipoda	<i>Ampelisca abdita-vadorum</i> complex	0.0536	97.4286	0.6071	596.7586	1.2857	606.4821
Arthropoda : Amphipoda	<i>Ampelisca agassizi</i>	11.9464	0.0000	0.0000	0.0000	0.0000	0.0000
Arthropoda : Amphipoda	<i>Ampelisca spp.</i>	1.3393	0.0000	0.0000	0.0000	0.0000	0.0000
Arthropoda : Amphipoda	<i>Ampelisca vadorum</i>	0.0000	0.2143	0.0000	0.0000	0.0000	29.0179
Arthropoda : Amphipoda	<i>Ampelisca verrilli</i>	3.9286	0.5179	0.0000	0.0000	0.0000	0.0000
Arthropoda : Amphipoda	<i>Ampithoe valida</i>	0.0000	0.0000	0.0000	0.0000	0.0893	0.0000
Arthropoda : Amphipoda	Ampithoidae	0.0000	0.0000	0.0000	0.0000	0.0179	0.0000
Arthropoda : Amphipoda	Aoridae	0.0000	0.0000	0.0000	0.0000	0.0000	0.0179
Arthropoda : Amphipoda	<i>Argissa hamatipes</i>	0.0714	0.0000	0.0000	0.0000	0.0000	0.0000
Arthropoda : Amphipoda	<i>Byblis serrata</i>	0.0714	0.0000	0.0000	0.0000	0.0000	0.0000

Taxon Group	Taxon Name	Bight Apex	West. Long Island Sound	Newark Bay	Raritan Bay	Upper Harbor	Jamaica Bay
Arthropoda : Amphipoda	Caprella penantis	0.0000	0.0179	0.0000	0.0000	0.6429	0.1071
Arthropoda : Amphipoda	Caprellidae	0.0000	0.0000	0.0000	0.0172	0.0000	0.0000
Arthropoda : Amphipoda	Casco bigelowi	0.0893	0.0000	0.0000	0.0000	0.0000	0.0000
Arthropoda : Amphipoda	Cerapus tubularis	0.0000	0.0179	0.0000	0.0000	0.0000	0.0000
Arthropoda : Amphipoda	Corophium schersicum	0.0000	0.0000	0.0000	0.0000	0.4821	0.0000
Arthropoda : Amphipoda	Corophium bonellii	0.0000	0.0000	0.0000	0.0000	0.0179	0.0000
Arthropoda : Amphipoda	Corophium crassicorne	1.3214	0.0000	0.0000	0.0000	0.0000	0.0000
Arthropoda : Amphipoda	Corophium insidiosum	0.0000	0.0000	0.0000	0.0000	0.6071	0.0000
Arthropoda : Amphipoda	Corophium spp.	0.0714	0.0000	0.0179	0.0345	0.7857	0.0536
Arthropoda : Amphipoda	Corophium tuberculatum	0.0179	0.0000	0.0000	283.0517	0.2143	220.8214
Arthropoda : Amphipoda	Dyopodos monacanthus	0.4464	0.0000	0.0000	0.0000	0.0000	0.0000
Arthropoda : Amphipoda	Elasmopus laevis	0.0357	0.0000	0.0000	6.6724	3.0000	94.4643
Arthropoda : Amphipoda	Eobroglus spinosus	0.0000	0.0000	0.0000	0.4483	9.0179	14.5714
Arthropoda : Amphipoda	Erichthonius brasiliensis	0.0000	0.0714	0.0179	0.2241	1.3393	0.9107
Arthropoda : Amphipoda	Gammarus annulatus	0.1250	0.0000	0.0000	0.4828	0.0000	0.0714
Arthropoda : Amphipoda	Gammarus daiberi	0.0000	0.0000	10.3750	0.0000	0.0000	0.0000
Arthropoda : Amphipoda	Gammarus spp.	0.0714	0.0000	0.0000	0.1379	0.0000	0.0000
Arthropoda : Amphipoda	Harpinia propinqua	1.2143	0.0000	0.0000	0.0000	0.0000	0.0000
Arthropoda : Amphipoda	Hippomedon serratus	0.0357	0.0000	0.0000	0.0000	0.0000	0.0000

Taxon Group	Taxon Name	Bight Apex	West. Long Island Sound	Newark Bay	Raritan Bay	Upper Harbor	Jamaica Bay
Arthropoda : Amphipoda	<i>Jassa marmorata</i>	0.0000	0.0536	0.0000	0.0000	0.0179	0.0000
Arthropoda : Amphipoda	<i>Leptocheirus pinguis</i>	0.6607	0.0714	0.0000	0.0000	0.0000	0.0000
Arthropoda : Amphipoda	<i>Listriella clymenellae</i>	0.0000	0.0179	0.0000	0.0000	0.0000	0.0000
Arthropoda : Amphipoda	<i>Luconcia incerta</i>	0.0000	0.0536	0.0000	0.0000	0.0000	0.0000
Arthropoda : Amphipoda	<i>Lysianopsis alba</i>	0.0000	0.0000	0.0000	0.0172	1.1250	19.1964
Arthropoda : Amphipoda	<i>Melita nitida</i>	0.0000	0.0000	0.3929	0.5862	2.8571	2.0536
Arthropoda : Amphipoda	<i>Microdeutopus gryllotalpa</i>	0.0000	0.3036	0.0000	0.0345	1.8393	263.1429
Arthropoda : Amphipoda	<i>Microtopotus raneyi</i>	0.0000	0.0179	0.0000	0.0000	0.0000	0.0000
Arthropoda : Amphipoda	<i>Monoculodes</i> sp. 1 Watling	0.0000	0.0000	0.0000	0.2759	0.2679	0.0000
Arthropoda : Amphipoda	<i>Mucrogammarus mucronatus</i>	0.0000	0.0000	0.0000	0.0000	0.3393	0.0000
Arthropoda : Amphipoda	<i>Orchomenella minuta</i>	0.0714	0.0000	0.0000	0.0000	0.0000	0.0000
Arthropoda : Amphipoda	<i>Paracaprella tenuis</i>	0.0000	0.0893	0.0536	0.4828	5.3750	0.5179
Arthropoda : Amphipoda	<i>Parametopella cypris</i>	0.0000	0.3929	0.0000	0.0690	1.1786	0.0000
Arthropoda : Amphipoda	<i>Parapleustes aestuarius</i>	0.0000	0.0000	0.0000	0.0000	0.0536	0.0000
Arthropoda : Amphipoda	<i>Photis dentata</i>	0.0714	0.0000	0.0000	0.0000	0.0000	0.0000
Arthropoda : Amphipoda	<i>Photis pollex</i>	1.2500	0.0000	0.0000	0.0000	0.0000	0.0000
Arthropoda : Amphipoda	<i>Phoxocephalus holbolli</i>	0.0357	1.6964	0.0000	0.3448	0.0714	0.0000
Arthropoda : Amphipoda	<i>Protohaustorius</i> cf. <i>deichmannae</i>	2.5714	0.0000	0.0000	0.0000	0.0000	0.0000

Taxon Group	Taxon Name	Bight Apex	West. Long Island Sound	Newark Bay	Raritan Bay	Upper Harbor	Jamaica Bay
Arthropoda : Amphipoda	<i>Protohaustorius wigleyi</i>	0.0357	0.0000	0.0000	0.0000	0.0000	0.0000
Arthropoda : Amphipoda	<i>Pseudohaustrorius borealis</i>	0.0179	0.0000	0.0000	0.0000	0.0000	0.0000
Arthropoda : Amphipoda	<i>Pseudunciola obliquua</i>	6.1964	0.0000	0.0000	0.0000	0.0000	0.0000
Arthropoda : Amphipoda	<i>Rhepoxynius epistomus</i>	0.0000	0.0000	0.0000	0.0172	0.0000	0.0000
Arthropoda : Amphipoda	<i>Rhepoxynius hudsoni</i>	2.7679	0.0000	0.0000	1.2759	0.0179	0.0357
Arthropoda : Amphipoda	<i>Stenothoe minuta</i>	0.0357	0.0000	0.0000	0.0345	0.0179	0.0714
Arthropoda : Amphipoda	<i>Synchelidium americanum</i>	0.0179	0.0000	0.0000	0.0000	0.0000	0.0000
Arthropoda : Amphipoda	<i>Unciola dissimilis</i>	0.0000	0.0000	0.0000	0.8793	0.0179	0.4107
Arthropoda : Amphipoda	<i>Unciola inermis</i>	0.2857	0.0000	0.0000	0.0000	0.0000	0.0000
Arthropoda : Amphipoda	<i>Unciola irrorata</i>	2.8750	0.3929	0.0000	0.1552	0.0000	0.0000
Arthropoda : Amphipoda	<i>Unciola serrata</i>	0.0000	0.0179	0.8750	1.3276	12.1071	0.8214
Arthropoda : Amphipoda	<i>Unciola</i> spp.	1.7857	0.4464	0.2321	2.1207	4.0893	0.9107
Arthropoda : Decapoda	<i>Callinectes sapidus</i>	0.0000	0.0000	0.0179	0.0000	0.0000	0.0000
Arthropoda : Decapoda	<i>Cancer irroratus</i>	0.3214	0.1071	0.0000	0.2586	0.1071	0.0179
Arthropoda : Decapoda	Caridea	0.0000	0.0000	0.0000	0.0172	0.0000	0.0000
Arthropoda : Decapoda	<i>Crangon septemspinosus</i>	0.3214	0.3393	0.2857	0.3793	0.5000	0.1786
Arthropoda : Decapoda	<i>Dyspanopeus sayi</i>	0.0000	0.0179	0.0000	2.0690	0.2679	4.7143
Arthropoda : Decapoda	<i>Hexapanopeus angustifrons</i>	0.0000	0.0000	0.0000	0.0172	0.0536	0.0000
Arthropoda : Decapoda	<i>Libinia</i> spp.	0.0000	0.0536	0.0000	0.0172	0.0000	0.0357

Taxon Group	Taxon Name	Bight Apex	West. Long Island Sound	Newark Bay	Raritan Bay	Upper Harbor	Jamaica Bay
Arthropoda : Decapoda	<i>Ovalipes ocellatus</i>	0.0000	0.0357	0.0000	0.0862	0.0000	0.0536
Arthropoda : Decapoda	<i>Pagurus longicarpus</i>	0.0536	0.0714	0.0000	0.7069	0.0357	0.2321
Arthropoda : Decapoda	<i>Pagurus spp.</i>	0.0536	0.0357	0.0000	0.0172	0.1250	0.0357
Arthropoda : Decapoda	<i>Palaemonetes intermedius</i>	0.0000	0.0000	0.0000	0.0000	0.0000	0.0179
Arthropoda : Decapoda	<i>Palaemonetes vulgaris</i>	0.0000	0.0000	0.0000	0.0000	0.0000	0.3750
Arthropoda : Decapoda	<i>Panopeus herbstii</i>	0.0000	0.0000	0.0000	0.0000	0.1607	0.0000
Arthropoda : Decapoda	<i>Pinnixa spp.</i>	0.0000	0.0536	0.0000	0.0000	0.0000	0.0179
Arthropoda : Decapoda	<i>Rhithropanopeus harrisi</i>	0.0000	0.0000	1.1786	0.0000	0.7321	0.0000
Arthropoda : Decapoda	<i>Upogebia affinis</i>	0.0000	0.0357	0.0000	0.0000	0.0000	0.0000
Arthropoda : Decapoda	Xanthidae	0.0000	0.2500	0.0893	0.1897	0.2321	0.0536
Arthropoda : Chironomidae	Chironomidae	0.0000	0.0000	0.0000	0.0000	0.0000	0.0179
Sipuncula	Sipuncula	0.1786	0.0000	0.0000	0.0000	0.0000	0.0000
Phoronida	Phoronis spp.	3.2679	5.0536	0.0000	0.1207	0.0357	0.0000
Echinodermata : Asteroidea	Asteroidea	0.1429	0.0179	0.0000	0.0862	0.0357	0.0000
Echinodermata : Echinoidea	Echinarachnius parma	0.4286	0.0000	0.0000	0.0000	0.0000	0.0000
Echinodermata : Echinoidea	Echinoidea	10.1429	0.0000	0.0000	0.0000	0.0000	0.0000
Echinodermata : Holothuroidea	Havelockia scabra	0.0179	0.0000	0.0000	0.0000	0.0000	0.0000
Hemichordata	Saccoglossus kowalevskii	0.0714	0.1250	0.0000	0.0000	0.0000	0.0000
Chordata : Ascidiacea	Ascidiacea	0.0357	0.0000	0.0536	0.0345	0.6429	0.0000

Taxon Group	Taxon Name	Bight Apex	West. Long Island Sound	Newark Bay	Raritan Bay	Upper Harbor	Jamaica Bay
Chordata : Ascidiacea	Molgula manhattensis	0.0000	0.0179	0.0893	0.0862	4.5357	0.0000

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Appendix H

Clostridium perfringens results

Clostridium perfringens results

Concentrations of *Clostridium perfringens* spores have been used as an indicator of sewage contamination (Hill et al., 1993; O'Reilly et al., 1995). *C. perfringens* is an obligate anaerobe bacterium found in fecal material. It can survive extreme environmental conditions. This study evaluated the concentrations of the spores in Harbor sediments. The laboratory procedure was the membrane filter method of Emerson and Cabelli (1982). Mean concentrations of *C. perfringens* spores are expressed as confirmed counts per gram (wet weight) of sediment.

The Lower Harbor had the lowest mean spore count of the sub-basins in the Harbor (Table J-1). The other three sub-basins of the Harbor all had similar mean spore concentrations, although variability was high. The mean spore concentration in western Long Island Sound was an order of magnitude lower than the Harbor mean.

Table J-1
Area-weighted Mean Concentrations of *C. perfringens*
 (± represent 90% confidence intervals)

	Harbor	Jamaica Bay	Newark Bay	Lower Harbor	Upper Harbor	W. LI. Sound	Bight Apex
Mean number of <i>C. perfringens</i> spores (# spores/g-wet weight)	2440 716	4171 5187	5977 3335	935 355	5156 2015	237 67	556 536

Background concentrations of *C. perfringens* in surficial sediments from the outer New York Bight continental shelf of Georges Bank are 10-20 spores/g (dry weight) (Cabelli and Pedersen, 1982). Mean concentrations in the Harbor, western Long Island Sound and the Bight Apex were significantly above background (even after converting from wet weight to dry weight).

Literature Cited

Cabelli, V.J., and D. Pedersen. 1982. The movement of sewage sludge from the New York Bight dumpsite as seen from *Clostridium perfringens* spore densities. *In* Oceans '82 conference record, p. 995-999. Inst. Electr. Electron. Eng., Piscataway, New Jersey.

Emerson, D.J., and V.J. Cabelli. 1982. Extraction of *Clostridium perfringens* spores from bottom sediment samples. *Appl. Environ. Microbiol.* **44**:1144-1149.

Hill, R.T., I.T. Knight, M.S. Anikis, and R.R. Colwell. 1993. Benthic distribution of sewage sludge indicated by *Clostridium perfringens* at a deep-ocean dump site. *Appl. Environ.*

Microbiol. **59**(1):47-51.

O'Reilly, J.E., I. Katz, and A.F.J. Draxler. 1995. Changes in the abundance and distribution of *Clostridium perfringens*, a microbial indicator, related to cessation of sewage sludge dumping in the New York Bight, p. 113-132. *In* U.S. Dept. Of Commerce NOAA Technical Report NMFS 124.

Appendix I

Benthic Index (B-IBI) values for individual stations

OBS	STATION	RINDEX52
1	BA002	3.4
2	BA005	4.0
3	BA007	3.2
4	BA010	3.2
5	BA012	3.4
6	BA014	3.8
7	BA016	4.4
8	BA017	3.8
9	BA021	4.6
10	BA025	4.4
11	BA026	4.0
12	BA030	3.4
13	BA033	4.2
14	BA035	3.8
15	BA102	3.4
16	BA103	3.4
17	BA104	4.4
18	BA105	4.4
19	BA106	3.4
20	BA107	4.6
21	BA108	3.8
22	BA109	4.4
23	BA110	4.6
24	BA111	4.2
25	BA112	4.0
26	BA113	3.0
27	BA114	4.6
28	BA115	4.0
29	JB002	2.4
30	JB006	2.4
31	JB008	1.4
32	JB012	1.4
33	JB015	1.2
34	JB018	2.4
35	JB022	2.0
36	JB026	3.0
37	JB031	2.2
38	JB033	3.0
39	JB039	3.0
40	JB041	3.0
41	JB042	3.8
42	JB043	2.6
43	JB101	1.8
44	JB103	1.0
45	JB104	2.6
46	JB106	2.6
47	JB108	2.2
48	JB110	2.8
49	JB111	2.6
50	JB112	3.0
51	JB113	2.8
52	JB114	3.0
53	JB115	3.4

Benthic Index 11:12 Tuesday, February 13, 1996

OBS	STATION	RINDEX52
54	JB117	2.8
55	JB119	3.2
56	JB120	3.2
57	LS001	5.0
58	LS004	3.2
59	LS006	3.8
60	LS010	3.4
61	LS011	2.6
62	LS016	3.0
63	LS018	3.4
64	LS019	2.8
65	LS020	2.4
66	LS024	4.2
67	LS026	2.4
68	LS027	3.0
69	LS030	2.8
70	LS035	1.6
71	LS101	4.2
72	LS102	3.2
73	LS103	4.2
74	LS104	4.2
75	LS106	2.4
76	LS107	2.6
77	LS108	2.0
78	LS109	3.2
79	LS110	2.8
80	LS111	2.2
81	LS112	2.4
82	LS113	1.8
83	LS114	2.8
84	LS115	2.4
85	NB018	2.2
86	NB021	2.0
87	NB025	2.4
88	NB027	2.2
89	NB036	3.0
90	NB039	2.6
91	NB044	2.4
92	NB045	2.6
93	NB047	1.2
94	NB052	2.6
95	NB053	2.0
96	NB065	2.4
97	NB066	1.6
98	NB075	1.2
99	NB102	1.8
100	NB103	2.6
101	NB104	2.4
102	NB105	2.0
103	NB106	2.6
104	NB107	2.6
105	NB108	1.8
106	NB109	2.2

Benthic Index 11:12 Tuesday, February 13, 1996

OBS	STATION	RINDEX52
107	NB110	2.8
108	NB111	2.4
109	NB112	2.2
110	NB113	2.4
111	NB114	1.6
112	NB115	2.6
113	RB001	2.8
114	RB002	3.6
115	RB007	3.2
116	RB010	4.0
117	RB011	4.6
118	RB012	4.4
119	RB016	3.0
120	RB019	2.6
121	RB024	2.8
122	RB027	2.8
123	RB029	3.0
124	RB030	4.4
125	RB032	3.8
126	RB033	2.6
127	RB101	2.8
128	RB102	3.0
129	RB103	3.0
130	RB104	2.6
131	RB105	3.4
132	RB106	4.8
133	RB107	3.4
134	RB108	3.0
135	RB110	2.2
136	RB111	2.2
137	RB112	2.8
138	RB114	3.0
139	RB116	2.6
140	RB117	3.0
141	UH003	2.0
142	UH004	2.8
143	UH008	4.0
144	UH010	3.2
145	UH011	3.2
146	UH014	1.8
147	UH018	2.6
148	UH019	2.4
149	UH020	1.4
150	UH022	2.2
151	UH023	2.6
152	UH026	2.6
153	UH029	3.2
154	UH030	4.0
155	UH101	2.2
156	UH102	2.2
157	UH103	2.2
158	UH104	2.8
159	UH105	2.6

UPDATED 93/94 NY/NJ DATA

Benthic Index 11:12 Tuesday, February 13, 1996

OBS	STATION	RINDEX52
160	UH106	3.4
161	UH107	1.4
162	UH108	2.2
163	UH109	2.2
164	UH110	2.0
165	UH111	2.6
166	UH112	1.8
167	UH113	2.4
168	UH114	3.4

Appendix J

Data disk explanatory information

CONTENTS PROCEDURE

—Alphabetic List of Variables and Attributes—

#	Variable	Type	Len	Pos	Format	Label
74	ACENTHE	Num	8	596		Acenaphthene (ppb)
73	ACENTHY	Num	8	588		Acenaphthylene (ppb)
48	AG	Num	8	390		Silver (ppm)
93	AG_RECOV	Num	8	748		Silver partial (ppm)
60	AL	Num	8	486		Aluminum (ppm)
119	ALDRIN	Num	8	956		Aldrin (ppb)
120	ALPHACHL	Num	8	964		Alpha-chlordane (ppb)
94	AL_RECOV	Num	8	756		Aluminum partial (ppm)
172	AMB_DO	Num	8	1380		Amb DO (mg/L)
170	AMB_SAL	Num	8	1364		Amb Salinity (ppt)
171	AMB_TEMP	Num	8	1372		Amb Temp. (C)
77	ANTHRA	Num	8	620		Anthracene (ppb)
49	AS	Num	8	398		Arsenic (ppm)
95	AS_RECOV	Num	8	764		Arsenic partial (ppm)
33	AVS	Num	8	270		AVS (ppm)
40	AVS_MM	Num	8	326		AVS (mmol)
65	BASAREA	Num	8	526		Total Basin Area (sq km)
1	BASINCOD	Char	2	0		Basin Code
80	BENANTH	Num	8	644		Benzo[a]anthracene (ppb)
82	BENAPY	Num	8	660		Benzo[a]pyrene (ppb)
86	BENEPY	Num	8	692		Benzo[e]pyrene (ppb)
110	BENZOFI	Num	8	884		Benzo[b,k]fluoranthene (ppb)
85	BENZOP	Num	8	684		Benzo[g,h,i]perylene (ppb)
108	BIO10DS1	Num	8	868		
87	BIPHENYL	Num	8	700		Biphenyl (ppb)
165	BT_TOT	Num	8	1324		Total Butyl tins (ppb)
175	B_BAC	Num	8	1404		Bottom BAC
176	B_COND	Num	8	1412		Bottom Conductivity (mS/cm)
21	B_DEPTH	Num	8	174		Bottom depth (m)
22	B_DO	Num	8	182		Bottom DO (mg/L)
26	B_ORP	Num	8	214		Bottom ORP (mV)
24	B_PH	Num	8	198		Bottom pH
23	B_SAL	Num	8	190		Bottom Salinity (ppt)

* biomass
* abundance

g/sample (0.04 m² grab)
organisms/sample

* note that there are 2 replicates for each of these and they are separate sheets on the spreadsheet.

CONTENTS PROCEDURE

#	Variable	Type	Len	Pos	Format	Label
25	B_TEMP	Num	8	206		Bottom Temp (C)
50	CD	Num	8	406		Cadmium (ppm)
96	CD_RECOV	Num	8	772		Cadmium partial (ppm)
69	CHAN_TYP	Char	8	558		Channel Type
121	CHL_TOTC	Num	8	972		Total Chlordane (ppb)
81	CHRYSENE	Num	8	652		Chrysene (ppb)
109	CLOSTR	Num	8	876		Clostridium (#/gm)
51	CR	Num	8	414		Chromium (ppm)
97	CR_RECOV	Num	8	780		Chromium partial (ppm)
52	CU	Num	8	422		Copper (ppm)
98	CU_RECOV	Num	8	788		Copper partial (ppm)
3	DATE	Num	8	12	DATE7.	Date
159	DBT	Num	8	1276		Dibutyltin (ppb)
168	DDD_TOT	Num	8	1348		Total DDD (ppb)
167	DDE_TOT	Num	8	1340		Total DDE (ppb)
169	DDT_STOT	Num	8	1356		Total DDT parent (ppb)
122	DDT_TOT	Num	8	980		Total DDT (ppb)
7	DEPTH	Num	8	61		Depth (m)
84	DIBENZ	Num	8	676		Dibenz[a,h]anthracene (ppb)
123	DIELDRIN	Num	8	988		Dieldrin (ppb)
88	DIMETH	Num	8	708		2,6-Dimethylnaphthalene (ppb)
124	ENDRIN	Num	8	996		Endrin (ppb)
61	FE	Num	8	494		Iron (ppm)
99	FE_RECOV	Num	8	796		Iron partial (ppm)
78	FLUORANT	Num	8	628		Fluoranthene (ppb)
75	FLUORENE	Num	8	604		Fluorene (ppb)
125	HEPTACHL	Num	8	1004		Heptachlor (ppb)
126	HEPTAEPO	Num	8	1012		Heptachlor Epoxide (ppb)
127	HEXACHL	Num	8	1020		Hexachlorobenzene (ppb)
63	HG	Num	8	510		Mercury (ppm)
101	HG_RECOV	Num	8	812		Mercury partial (ppm)
83	INDENO	Num	8	668		Indeno[1,2,3-C,D]pyrene (ppb)
4	LAT	Char	20	20		
128	LINDANE	Num	8	1028		Lindane - Gamma-BHC (ppb)
5	LONG	Char	20	40		
160	MBT	Num	8	1284		Monobutyltin (ppb)
89	MENAP1	Num	8	716		1-Methylnaphthalene (ppb)
72	MENAP2	Num	8	580		2-Methylnaphthalene (ppb)
90	MEPHEN1	Num	8	724		1-Methylphenanthrene (ppb)
129	MIREX	Num	8	1036		Mirex (ppb)
59	MN	Num	8	478		Manganese (ppm)
100	MN_RECOV	Num	8	804		Manganese partial (ppm)
71	NAPH	Num	8	572		Naphthalene (ppb)
53	NI	Num	8	430		Nickel (ppm)
102	NI_RECOV	Num	8	820		Nickel partial (ppm)
130	OPDDD	Num	8	1044		o,p, DDD (ppb)
131	OPDOE	Num	8	1052		o,p, DDE (ppb)
132	OPDDT	Num	8	1060		o,p, DDT (ppb)
163	OPDDTTOT	Num	8	1308		Total OPDDT (ppb)
117	PAH_HMWC	Num	8	940		High Molecular Wt PAHs (ppb)
116	PAH_LMWC	Num	8	932		Low Molecular Wt PAHs (ppb)
118	PAH_TOTC	Num	8	948		Total PAHs (ppb)
54	PB	Num	8	438		Lead (ppm)

CONTENTS PROCEDURE

#	Variable	Type	Len	Pos	Format	Label
103	PB RECOV	Num	8	828		Lead partial (ppm)
152	PCB8	Num	8	1220		PCB Congener 8 (ppb)
142	PCB18	Num	8	1140		PCB Congener 18 (ppb)
148	PCB28	Num	8	1188		PCB Congener 28 (ppb)
149	PCB44	Num	8	1196		PCB Congener 44 (ppb)
150	PCB52	Num	8	1204		PCB Congener 52 (ppb)
151	PCB66	Num	8	1212		PCB Congener 66 (ppb)
133	PCB101	Num	8	1068		PCB Congener 101 (ppb)
134	PCB105	Num	8	1076		PCB Congener 105 (ppb)
136	PCB118	Num	8	1092		PCB Congener 118 (ppb)
137	PCB126	Num	8	1100		PCB Congener 126 (ppb)
138	PCB128	Num	8	1108		PCB Congener 128 (ppb)
139	PCB138	Num	8	1116		PCB Congener 138 (ppb)
140	PCB153	Num	8	1124		PCB Congener 153 (ppb)
141	PCB170	Num	8	1132		PCB Congener 170 (ppb)
143	PCB180	Num	8	1148		PCB Congener 180 (ppb)
144	PCB187	Num	8	1156		PCB Congener 187 (ppb)
145	PCB195	Num	8	1164		PCB Congener 195 (ppb)
146	PCB206	Num	8	1172		PCB Congener 206 (ppb)
147	PCB209	Num	8	1180		PCB Congener 209 (ppb)
135	PCB11077	Num	8	1084		PCB Congener 110/77 (ppb)
166	PCB_TOTC	Num	8	1332		Total PCBs (ppb)
29	PCTCON_A	Num	8	238		Ampelisca Surv as % of Control
32	PCTCON_M	Num	8	262		Microtox Surv as % of Control
30	PCTSUR_A	Num	8	246		Ampelisca % Survival
91	PERYLENE	Num	8	732		Perylene (ppb)
76	PHENANTH	Num	8	612		Phenanthrene (ppb)
6	POSEQUIP	Char	1	60		Pos Unit
153	PPDDD	Num	8	1228		p,p, DDD (ppb)
154	PPDDE	Num	8	1236		p,p, DDE (ppb)
155	PPDDT	Num	8	1244		p,p, DDT (ppb)
164	PPDDTTOT	Num	8	1316		Total PPDDT (ppb)
79	PYRENE	Num	8	636		Pyrene (ppb)
179	RINDEX45	Num	8	1437		RGI Analogue # 2 Value
70	SAMPLE	Char	6	566		Sample ID
177	SAMPTYPE	Char	9	1420		Sample Type
55	SB	Num	8	446		Antimony (ppm)
104	SB_RECOV	Num	8	836		Antimony partial (ppm)
57	SE	Num	8	462		Selenium (ppm)
11	SEAS	Char	10	92		Sea condition
9	SECCHI	Num	8	70		Secchi depth (m)
66	SEGAREA	Num	8	534		Segment Area (sq km) (NB only)
27	SEGMENT	Num	8	222		Segment (NB only)
34	SEM_CD	Num	8	278		SEM Cd (ppm)
41	SEM_CD_M	Num	8	334		SEM Cd (mmol)
35	SEM_CU	Num	8	286		SEM Cu (ppm)
42	SEM_CU_M	Num	8	342		SEM Cu (mmol)
39	SEM_HG	Num	8	318		SEM Hg (ppm)
46	SEM_HG_M	Num	8	374		SEM Hg (mmol)
37	SEM_NI	Num	8	302		SEM Ni (ppm)
44	SEM_NI_M	Num	8	358		SEM Ni (mmol)
36	SEM_PB	Num	8	294		SEM Pb (ppm)
43	SEM_PB_M	Num	8	350		SEM Pb (mmol)

CONTENTS PROCEDURE

#	Variable	Type	Len	Pos	Format	Label
47	SEM_TOT	Num	8	382		Total SEM (mmol)
38	SEM_ZN	Num	8	310		SEM Zn (ppm)
45	SEM_ZN_M	Num	8	366		SEM Zn (mmol)
105	SE_RECOV	Num	8	844		Selenium partial (ppm)
62	SI	Num	8	502		Silicon (ppm)
28	SIG_AMP	Num	8	230		Ampelisca Significance (1=signif)
31	SIG_MIC	Num	8	254		Microtox Significance (1=sig)
64	SILTCLAY	Num	8	518		Percent Siltclay Content
56	SN	Num	8	454		Tin (ppm)
2	STATION	Char	10	2	\$F8.	Station Identifier
67	STA_LAT	Num	8	542		Station Latitude
68	STA_LNG	Num	8	550		Station Longitude
18	S_AMBDO	Num	8	150		
14	S_AMBSAL	Num	8	118		
16	S_AMBTMP	Num	8	134		
173	S_BAC	Num	8	1388		Surface BAC
174	S_COND	Num	8	1396		Surface Conductivity (mS/cm)
12	S_DEPTH	Num	8	102		Surface depth (m)
17	S_DO	Num	8	142		Surface DO (mg/L)
20	S_ORP	Num	8	166		Surface ORP (mV)
19	S_PH	Num	8	158		Surface pH
13	S_SAL	Num	8	110		Surface Salinity (ppt)
15	S_TEMP	Num	8	126		Surface Temp (C)
111	T2PAHC	Num	8	892		2-Ring PAHs (ppb)
112	T3PAHC	Num	8	900		3-Ring PAHs (ppb)
113	T4PAHC	Num	8	908		4-Ring PAHs (ppb)
114	T5PAHC	Num	8	916		5-Ring PAHs (ppb)
115	T6PAHC	Num	8	924		6-Ring PAHs (ppb)
158	TBT	Num	8	1268		Tributyltin (ppb)
161	TCDD	Num	8	1292		Dioxin (2,3,7,8-TCDD) (ng/kg)
162	TCDF	Num	8	1300		Furan (2,3,7,8-TCDF) (ng/kg)
157	TETBT	Num	8	1260		Tetrabutyltin (ppb)
156	TNONCHL	Num	8	1252		Trans-Nonachlor (ppb)
107	TOC	Num	8	860		Total Organic Carbon (ppm)
8	TRASH	Char	1	69		Trash?
92	TRI235	Num	8	740		2,3,5 Trimethylnaphthalene (ppb)
10	WEATHER	Char	14	78		Weather cond.
178	YEAR	Num	8	1429		
58	ZN	Num	8	470		Zinc (ppm)
106	ZN_RECOV	Num	8	852		Zinc partial (ppm)