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SEDIMENT QUALITY OF THE NY/NJ HARBOR SYSTEM: A 5-Year Revisit

1993/4 - 1998

An Investigation under the Regional Environmental Monitoring and Assessment Program (REMAP)

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Disclaimer

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.

EXECUTIVE SUMMARY

The Comprehensive Conservation and Management Plan (CCMP) for the NY/NJ Harbor requires specific management actions to maintain and restore the Harbor environment. It also specifies that the progress of these management actions on the improvement of sediment quality and biological condition in the Harbor be measured. To do this requires initially establishing a baseline of condition of the Harbor sediment that is objective and of known statistical confidence. The next logical step is to periodically determine whether conditions have improved, declined or remained the same from the baseline. Existing studies either were conducted in a biased manner, did not cover all portions of the Harbor or did not concurrently collect the biological and chemical information to do be able to provide the baseline or subsequent trend assessment.

A previous investigation (Adams et al., 1998) provided a baseline of the areal extent of chemical contamination and biological effects in the NY/NJ Harbor system. That investigation, done in 1993 and 1994, also defined the extent of specific biological effects, such as degraded benthic macroinvertebrate communities and amphipod toxicity, and determined that these effects were associated with specific contaminants found in the sediments of the Harbor.

To begin to define trends in sediment quality and biological health of the Harbor, EPA-Region 2 conducted a followup investigation in 1998. The design, parameters measured, and methods were identical to, or comparable to, the 1993/1994 investigation. Synoptic measurements of benthic macroinvertebrate assemblages, sediment toxicity and sediment chemical concentrations were collected in four sub-basins of the Harbor, encompassing 28 sampling stations in each sub-basin. Surficial sediment contaminant concentrations, sediment toxicity (*Ampelisca abdita*) and benthic macrofaunal community structure were measured at each station.

Some improvements in the mean values for chemical contaminants in the Harbor's sediment have occurred between 1993/4 and 1998. Sediment chemistry results show the Harbor is still extensively contaminated but the mean values for cadmium, chromium and chlordane have declined. However, the Harbor means for mercury and DDT still exceed ERMs and all chemicals that have ERLs exceeded these thresholds in the Harbor, except antimony and cadmium. Newark Bay is still the most highly affected sub-basin but mean values for silver and chlordane showed a significant decrease. In Upper Harbor, the total DDT mean had a statistically significant decrease.

In terms of areal extent, chemical contamination is still widespread. In 1998, 45% of the Harbor exceeded an ERM (compared to 50% in 1993/4), and 86% exceeded an ERL (87% in 1993/4). While metals levels have remained the same, pesticide levels appear to be declining. Mercury still is the most ubiquitous chemical at levels of concern. In 1998, 68% of the Harbor was above the mercury ERL (75% in 1993/4) and 42% was above the ERM (34% in 1993/4). Newark Bay is still the most extensively chemically contaminated sub-basin by area, followed by Upper Harbor.

Sediment toxicity has remained the same between studies. In 1998, 12% of the Harbor was considered toxic to the amphipod, *Ampelisca abdita*, compared to 15% in 1993/4. There have been no statistically significant changes in sediment toxicity in any of the sub-basins. Newark Bay and Jamaica Bay still have the most area of toxic sediments.

Some aspects of the benthic community health in the Harbor have improved between 1993/4 and 1998. The total number of species and species diversity have increased. The percent of pollution-indicative species has significantly declined but the percent of pollution-sensitive species has not shown a significant change. Benthic abundance and biomass have decreased from 1993/4. The number of species increased in individual sub-basins, except for Upper Harbor. Upper Harbor also saw a significant decrease in biomass.

Application of the benthic index developed in the baseline investigation (Adams et al., 1998) showed that 31% of the area of the Harbor would be considered to have impacted benthic communities, compared to 53% in 1998. While the amount of area in the most impacted category has remained the same from 1993/4 to 1998, there is significantly more area of the Harbor that is considered similar to reference in 1998. In the individual sub-basins (except for Newark Bay), a shift is seen of area from the moderately impacted category to the least impacted. Newark Bay had significantly more area move to the most impacted category in 1998 than in 1993/4.

It appears that some aspects of the sediment quality of the Harbor are beginning to improve slightly. Future monitoring and research should focus on continuing the assessment of change in Harbor sediment quality. There also should be emphasis on development and evaluation of indicators that are more sensitive to the more subtle changes that may occur in the future and identifying and controlling contaminants other than those currently measured that might be responsible for the biological effects that have been seen.

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Any investigation that involves a range of activities, in this case planning, design, implementation, data analysis and interpretation, by necessity has the support and involvement of many people.

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INTRODUCTION

The New York/New Jersey (NY/NJ) Harbor system has been impacted by over 100 years of industrial and human population growth. It has a watershed that encompasses over 42,000 km^2 , portions of 5 states and a population of over 20 million people. As one of the most heavily utilized shipping ports on the east coast, it also has considerable refining and manufacturing industry. Sources of contaminants in the Harbor include municipal and industrial discharges, atmospheric inputs, non-point source runoff, hazardous waste sites, landfills, combined sewer overflows and accidental spills. Many of the contaminants present in these sources find their way into the sediments of the Harbor.

Despite substantial perturbations, the NY/NJ Harbor system still is an essential economic, recreational, and aesthetic resource. Some commercial fishing for clams, crabs and menhaden still exists, although it is not as extensive as it was historically. A large recreational fishery still remains. The Harbor environs are also important resting and feeding areas for migrating birds and provide habitat for local birds.

To ensure restoration and maintenance of uses of the Harbor, the Harbor Estuary in 1987 was designated as a National Estuary of Concern. The NY/NJ Harbor Estuary Program (HEP) was established to provide goals and activities to achieve the objective of maintaining/restoring the Harbor resources. The New York-New Jersey Harbor Estuary Program (HEP) has prepared a CCMP or Comprehensive Conservation and Management Plan (U.S. EPA-Region 2, 1996), which provides goals for the protection and restoration of Harbor resources and actions required to achieve them. The CCMP includes 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, crustaceans 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.

The current investigation is especially useful to address the first goal of the CCMP toxics section. In addition, in order to take steps toward attaining all the goals, the HEP plan includes actions to reduce continuing inputs of toxic chemicals to the Harbor and Bight from multiple sources such as municipal discharges, industrial discharges, combined sewer overflows, storm water discharges, surface runoff, and atmospheric deposition. Essential to achieving these goals is the need to estimate with accuracy the status and change in condition of the Harbor resources.

A previous investigation by Adams et al. (1998) provided baseline information for the Harbor. A probabilistic design allowed sediment toxicity, chemical, and benthic macroinvertebrate data to be collected for the Harbor and individual sub-basins. The current investigation takes the next step and begins to assess, with known confidence, whether biological health and sediment quality are improving, declining or remaining the same. The use of trend assessment has tremendous utility for managers to evaluate whether management actions are having an environmental benefit.

OBJECTIVE

This project was designed to support resource management decisions related to pollution control and remediation throughout the NY/NJ Harbor and to assist the Harbor Estuary Program (HEP) in evaluating the contaminant monitoring strategy portion of the CCMP for the NY/NJ Harbor system. This investigation was designed around a primary objective, with two sub-objectives:

Begin Trend Assessment

- Estimate with known confidence the percent of area in each of the 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,
- Evaluate statistically whether the percent of area that is degraded or not degraded in each of the sub-basins has increased, decreased, or remained the same compared to the baseline investigation (1993/1994 Sediment Quality of the NY/NJ Harbor).

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 1 states the objective of the report. 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 the baseline investigation 5 years earlier in the Harbor. Chapter 7 provides discussion of the results in terms of management implications. Chapter 8 contains all references cited in the report. Several appendices are included: A - sampling station locations and maps; B - tables of means and % of area exceedances of ERMs for all chemicals measured in the study; C - lists of pollution-tolerant and pollution-sensitive benthic organisms in the Harbor; and D - benthic index values for individual stations.

METHODS

Field and laboratory methods, as well as data analysis/interpretation procedures used in 1998 were either identical or comparable to methods used in the 1993/4 baseline investigation of the Harbor. A more detailed description of methods can be found in the report from the 1993/4 investigation, *Sediment Quality of the NY/NJ Harbor System* (Adams et al., 1998).

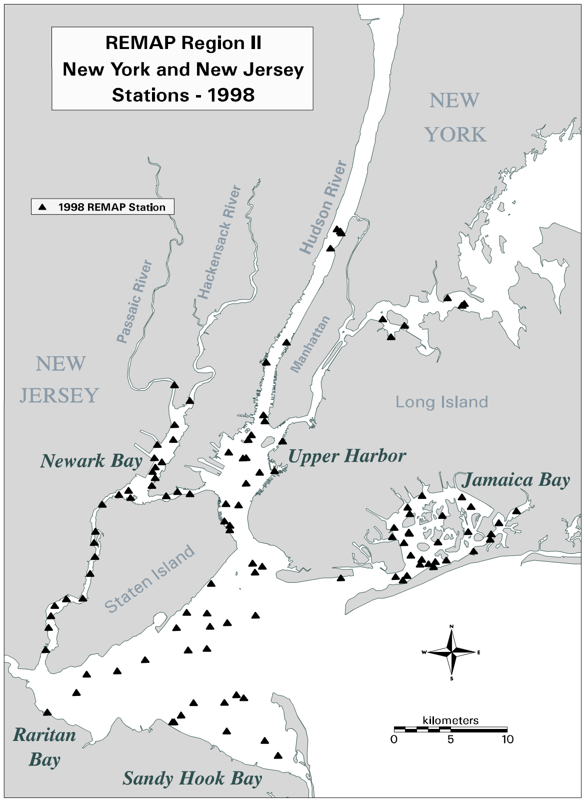

Figure 2-1. Stations in the study area.

STUDY AREA

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 study area was divided into four sub-basins, based on hydrogeography and similar source characteristics (Figure 2-1): Upper Harbor, Newark Bay, Lower Harbor (includes Raritan and Sandy Hook Bays) and Jamaica Bay. The area of each sub-basin was determined using Geographic Information System (GIS) ARCInfo software (Table 2-1).

Table 2-1. **Sub-basin Areas**

Sub-basin	**Area (km^2)**	**% of Study Area**
Lower Harbor	318	63.5
Upper Harbor	104	20.8
Jamaica Bay	47	9.4
Newark Bay	32	6.4
Total	501	100

STUDY DESIGN

A stratified random approach was used to probabilistically select sampling stations. The strata corresponded to each of four sub-basins where independent estimates of condition were needed. Twenty-eight stations were assigned to each sub-basin (Appendix A). Fourteen stations corresponded to stations from the 1993/1994 investigation, and 14 were chosen specifically for this sampling event. All sites were selected by randomly placing a grid structure over the study area, selecting grid cells at random from each stratum, and selecting a random location from within the selected cells. Cells were of equal area within strata. Sampling was conducted between late July and early September of 1998.

SAMPLING PROCEDURES

The U.S.EPA-Region 2 vessel, R/V CLEAN WATERS, was used for sample collection. Sampling stations were located using 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).

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.

Sediment

A 0.04-m^2 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. The 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.

Benthos

Three benthic macroinvertebrate grabs were collected per sampling station using the 0.04-m^2 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.

LABORATORY METHODS

Standard methods were used for chemical analyses (Table 2-2). Individual chemical parameters are listed in Table 2-3. PCBs, pesticides, PAHs, TOC, grain size, and total recoverable metals were analyzed at the U.S.EPA-Region 2 Laboratory in Edison, NJ. Total metals, coplanar PCBs, and dioxin/furans were analyzed, under contract to NOAA, by the Geochemical and Environmental Research Group (GERG) of Texas A&M University, College Station, TX. Benthic macroinvertebrate samples were processed by Barry Vittor & Associates, Inc., Mobile, AL. *Ampelisca abdita* assays were conducted by the U.S.EPA-Region 2 Bioassay Laboratory in Edison, NJ and SAIC in Narragansett, RI. An interlaboratory comparison conducted in 1993 and 1994 showed comparable results between these two bioassay laboratories.

Table 2-2. Summary of Physical/Chemical Analytical Methods

Parameter	Method	Reference
PAHs	Methylene chloride extraction; determination by GC/MS	SW846 3540 and 8270
PCBs*/Pesticides	Methylene chloride extraction; determination by HRGC/ECD	SW846 3540, 8081/8082; Lauenstein and Cantillo, 1993a
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	Lauenstein and Cantillo, 1993b
Major and Trace Elements	Total recoverable metals: HNO_3/H_2O_2 or microwave digestion: Hg-CVAF;Cu, Ni, Cr, Ag, Al, Fe, Mn,; Zn-ICP; Pb, Cd, Se-GFAAS; As, Sb-HYDAAS	SW846 3015 and MCAWW 200.7; Hg - SW846 7471 and MCAWW 245.1
Dioxins and Furans	Extraction with toluene; determination by HRGC/HRMS; second column confirmation for 2,3,7,8-TCDD	Chambers et al., 1998
TOC	Acidification with H_3PO_4; determination using a CO_2 analyzer	MCAWW 415.1 (U.S.EPA, 1983)
Grain size	Sieving and pipette analysis	U.S.EPA, 1995

*The quality of the PCB data was indeterminate at the time of this report, so those data do not appear in this report.

All analyses employed appropriate quality assurance samples. Quality assurance goals were developed and followed for each analysis (Adams, 1998). The quality of the PCB data were indeterminate at the time of this report; therefore, those data do not appear in this report. For all other parameters, except for isolated instances, all quality assurance goals were met or exceeded. The laboratory that conducted the dioxin/furan and total metal analyses participated in the NOAA Status and Trends Interlaboratory Comparison exercise. 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
Acenaphthylene
Anthracene
Benz(a)anthracene
Benzo(b,k)fluoranthene
Benzo(g,h,i)perylene
Benzo(a)pyrene
Benzo(e)pyrene
Biphenyl
Chrysene
Dibenz(a,b)anthracene
2,6-Dimethylnaphthalene
Fluoranthene
Fluorene
Ideno(1,2,3-c,d)pyrene
2-Methylnaphthalene
1-Methylnaphthalene
1-Methylphenanthrene
Naphthalene
Perylene
Phenanthrene
Pyrene
2,3,5-Trimethylnaphthalene

DDT and its Metabolites

o,p'-DDD
p,p'-DDD
o,p'-DDE
p,p'-DDE
o,p'-DDT
p,p'-DDT

Chlorinated Pesticides other than DDT

Aldrin
Alpha-Chlordane
Trans-Nonachlor
Dieldrin
Endrin
Heptachlor
Heptachlor epoxide
Hexachlorobenzene
Lindane (γ-BHC)
Mirex

Major Elements

Aluminum
Iron**
Manganese
Silicon

Trace Elements

Antimony
Arsenic
Cadmium
Chromium
Lead
Mercury
Nickel
Selenium
Silver
Tin
Zinc
Copper**

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

Dioxin and Furan Congeners

2,3,7,8-TCDD
1,2,3,7,8-PeCDD
1,2,3,4,7,8-HxCDD
1,2,3,6,7,8-HxCDD
1,2,3,7,8,9-HxCDD
1,2,3,4,6,7,8-HpCDD
OCDD
2,3,7,8-TCDF
1,2,3,7,8-PeCDF
2,3,4,7,8-PeCDF
1,2,3,4,7,8-HxCDF
1,2,3,7,8,9-HxCDF
2,3,4,6,7,8-HxCDF
1,2,3,4,6,7,8-HpCDF
1,2,3,4,7,8,9-HpCDF
OCDF

Other Measurements

Grain Size
TOC

* The quality of the PCB data was indeterminate at the time of this report; therefore, those data do not appear in this report.

** Results are total recoverable values versus total values for other metals.

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). Total analysis was done to provide comparability with the USEPA-Office of Research and Development (ORD) National Coastal Assessment (NCA) and with the database used to develop ERLs and ERMs (Long et al, 1995). Total recoverable analysis provided the possibility for comparison to historical data. Subsequent data analyses are based on total metals results, except for aluminum, copper, iron, manganese, and selenium. 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 Standard Reference Material (SRM) used was National Research Council of Canada (NRCC) MESS2.

Organic Compounds

For analysis of pesticides and PCBs, aliquots of sediment were dried and extracted. The chlorinated pesticides and PCBs were quantified using high resolution capillary gas chromatography with electron capture detection (GC/ECD). The data are reported in ng/g dry weight. The sediment SRM used with these samples was National Institute of Technology (NIST) 1941a. The PCB data do not appear in this report because of QA concerns.

Twenty-two polycyclic aromatic hydrocarbons (PAHs) were measured (U.S.EPA, 1998). Aliquots of sediment were dried and extracted. Gas chromatography/mass spectrometry (GC/MS) was used for analysis. Results are reported as ug/kg, dry weight. The SRMs used were NIST 1941a.

Analysis of sediments for seventeen dioxin and furan congeners was completed using a method developed by NOAA (Chambers et al., 1998). Frozen sediment samples were thawed and centrifuged to remove excess water. Approximately 10 g of sediment were used for determination of percent solids. Another 10 g were combined with quartz sand for extraction. The extracts were analyzed by high resolution gas chromatography/high resolution mass spectrometry (HRGC/HRMS).

Sediment Physical Parameters

Grain size analysis was conducted according to U.S.EPA (1995), except samples were not digested with hydrogen peroxide. Sand was defined as the fraction that was retained on a 63-u 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). The laboratory control sediment was BCSS Marine Sediment.

Toxicity Methods

Ampelisca abdita Assays

Ten-day acute, static, non-renewal sediment toxicity tests were conducted using the amphipod, *Ampelisca abdita* (ASTM, 1993). Batches of *A. 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. 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.

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 procedures (U.S. EPA, 1995; Frithsen et al., 1994). Sample processing, as well as species identifications, enumerations and biomass measurements were done by Barry Vittor & Associates, Inc. (Mobile, AL). The macrobenthos were identified to the lowest practical taxonomic category. Rare or previously undocumented specimens from the Harbor were put aside in a specimen voucher collection. A minimum of 10% of all samples were resorted by a different technician. Ten percent of all samples were also subjected to a second identification and enumeration by a different taxonomist.

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 <2 cm 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 weight after drying for at least 48 hours at 60°C.

DATA ANALYSIS

Chemical Data

For several classes of compounds, data analyses were performed on summed results. 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, except for aluminum, copper, iron, manganese and selenium which are total recoverable.

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).

Benthic Macroinvertebrate Data

Benthic macroinvertebrate data from the two replicates were averaged and used in subsequent analyses. Nine individual measures 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).

Table 2-4. **Benthic Macroinvertebrate Measures Included in B-IBI**

Abundance and Biomass	**Species Composition**
Abundance (#/m^2)	Abundance of pollution-indicative taxa (%)
Biomass (g/m^2)	Abundance of pollution-sensitive taxa (%)
Species Diversity	
Number of Taxa (#)	

A multi-metric benthic index of biotic

integrity (B-IBI) was developed for the NY/NJ Harbor (Adams et al., 1998). The B-IBI incorporated the five benthic macroinvertebrate metrics (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 two salinity regimes (polyhaline and euhaline) and two sediment types (mud and sand), and threshold values were defined for each.

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%.

B-IBI score	Interpretation
5	Similar to reference
3	Slightly different from reference
1	Very different from reference

The EMAP-VP benthic index, which was developed for the east coast of the U.S. from Cape Cod to the mouth of Chesapeake Bay, was also applied. The three measures that are incorporated into this index are: salinity-normalized Gleason's D for infaunal and epifaunal species, salinity-normalized expected number of tubificids, and abundance of spionids (Strobel et al., 1995). This index had a classification efficiency of approximately 90% on a test data set.

Condition Estimates

Two types of characterizations were produced for this investigation. The condition of each stratum and the Harbor as a whole were 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 a Geographic Information System (GIS) display of individual station results. Individual sub-basins were separately characterized for each parameter, resulting in four characterizations. An additional characterization, the "Harbor", combines all four of the sub-basins that are commonly known as the Harbor proper (i.e., Jamaica Bay, Newark Bay, Lower Harbor and Upper Harbor).

Mean Condition

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

$$\bar{y}_h = \sum_{i=1}^{n_h} \frac{y_{ih}}{n_h} \qquad \textbf{(1)}$$

$$s_h^2 = \sum_{i=1}^{n_h} \frac{(y_{ih} - \overline{y}_h)^2}{n_h - 1} \quad \textbf{(2)}$$

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

$$\overline{y}_{st} = \sum_{h=1}^{L} W_h \overline{y}_h \quad \textbf{(3)}$$

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

$$V(\overline{y}_{st}) = \sum_{h=1}^{L} W_h^2 Var(y_h) \quad \textbf{(4)}$$

Strata were combined to develop estimates for the study area as a whole and for the New York/New Jersey Harbor, 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.

T-test comparisons were made for samples collected in 1993 and in 1998 to evaluate whether they were significantly different. Single variables (e.g. silver) were compared between years for the Harbor estimates and the sub-basin estimates using SAS v6.12 software package (SAS, 1989). Options within the SAS software allow t-test comparisons of data which have either equal or unequal variances. The first step was to determine whether the data had equal variances. When the variances of the two years of data were equal, they were compared using the Cochran and Cox approximation of the *t* statistic, and when unequal, they were compared using the Satterthwaite approximation.

Percent of Area Estimates

Estimates of percent of area exceeding selected thresholds (e.g., mercury concentration greater than ERM) were calculated as $p = B/n$, 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:

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

where

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

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 established by regulation or Agency guidance (e.g., *Ampelisca abdita* toxicity), were screening guidelines (e.g., contaminant ERLs and ERMs) or were developed based on previous investigations (e.g., B-IBI and EMAP benthic index).

Physical Data

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.

Chemical Data

For determination of potential biological effects, this study's chemical data, except dioxins and furans, were evaluated using the effects-based guidelines (Table 2-5) of Long and Morgan (1991)

Table 2-5. **ERL and ERM Concentrations for Sediment Trace Metals and Organic Compounds** (Long and Morgan, 1991; Long et al., 1995).

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
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

and Long et al. (1995). 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, 1999). The Long and Morgan (1991) and Long et al. (1995) values were used because they include thresholds for most of the chemicals that were measured, allowing this study to provide an integrated contaminant response. Consensus-based sediment quality guidelines for PAHs (Swartz, 1999) were also evaluated. Additional 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, were applied in the 1993/4 investigation (Adams et al., 1998) but were not repeated for the current investigation.

Concentrations of 17 dioxin and furan congeners also were measured in sediments. 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)”. TEFs permit estimation of total dioxin/furan toxicity, expressed as an equivalent amount of 2,3,7,8-TCDD. Previously only TEFs to address human toxicity had been developed (U.S.EPA, 1989; Cura et al., 1995). Recently, however, TEFs were proposed that could be used to calculate toxic effects of dioxins and furans on fish and wildlife (U.S.EPA, 2001).

Sediment Toxicity Data

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).

Benthic Index

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.

PHYSICAL PARAMETERS

Physical measurements of sediment and water matrices provide information useful to the interpretation of chemical and biological data, as well as understanding of the natural conditions of the Harbor. Physical characteristics of the sediments included grain size (as % silt-clay) and total organic carbon (TOC) content. Water parameters, including water column depth, temperature, salinity, and dissolved oxygen, were measured at each sampling location using a single CTD profile.

Depth

The mean depth for the entire Harbor was 8.0 m. Mean depths were similar for all Harbor sub-basins, except the Upper Harbor (Table 3-1). The Upper Harbor mean at 10.8 m, was 2-3 m deeper than other sub-basins.

The mean depth for the Harbor is significantly different between 1993/1994 and 1998. The mean was 1.5 m higher in 1998. This may be due to additional dredging that took place between the investigations. Portions of the Harbor are dredged to maintain shipping channels. The mean depths of the individual sub-basins are statistically similar to the 1993/1994 investigation.

Table 3-1. **Area-Weighted Means for Depth**

	Harbor	Jamaica Bay	Newark Bay	Lower Harbor	Upper Harbor
Depth (m) (± 90% C.I.)	8.0 ±1.4	7.6 ±1.1	9.0 ±1.3	7.0 ±1.7	10.8 ±1.8

Percent Silt-Clay

Average percent silt-clay in sediments of the entire Harbor was 34.3%. Mean percent silt-clay varied among sub-basins (Table 3-2). Lower Harbor was the sandiest with only 27% silt-clay. Upper Harbor and Newark Bay were the muddiest sub-basins with 50.4% and 46.9% silt-clay, respectively.

The mean percent silt-clay is nearly identical for the Harbor from 1993/4 to 1998. The sub-basins also were similar, except for Newark Bay, which was significantly different in 1998 (46.9%) versus 1993/4 (68.1%). Overall, variability in percent silt-clay values appeared to be lower in 1998 than in 1993/4.

Table 3-2. **Area-Weighted Means of % Silt-Clay** (± 90% C.I.)

	1993/4	1998
Harbor	34.8 ±6.1	34.3 ±3.1
Jamaica Bay	30.3 ±9.7	37.5 ±8.7
Newark Bay	68.1 ±8.6	46.9 ±7.3
Lower Harbor	26.8 ±8.8	27.3 ±7.8
Upper Harbor	51.0 ±10.1	50.4 ±8.0

A sub-basin pattern similar to the average silt-clay results was also apparent when results are expressed as areal extent (Figure 3-1). In terms of spatial extent, 43% of the Harbor is predominantly mud (>40% silt-clay). Sixty-one percent of Newark Bay was comprised of mud compared to 32% of Lower Harbor, 50% of Jamaica Bay and 68% of Upper Harbor.

The percent of area estimates between 1993/4 and 1998 were similar in all sub-basins except Newark Bay. This may be due to the influence of dredging in Newark Bay. or reduced input of fine sediments from land or upstream contributions.

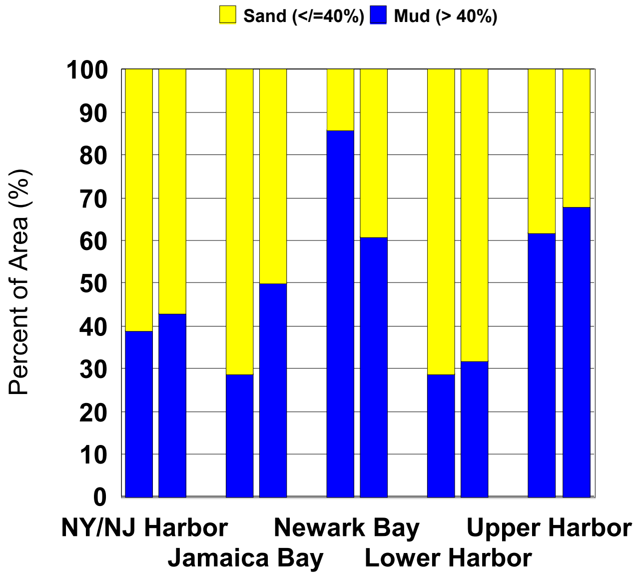

Figure 3-1. Percent of area distribution of substrate type.

Total Organic Carbon (TOC)

The mean total organic carbon (TOC) in Harbor sediments was 2.3%. TOC means in the sub-basins ranged from 1.7 to 3.8%, with the Upper Harbor significantly different from the other sub-basins (Table 3-3).

Table 3-3. **Area-Weighted Means of % TOC**

	Harbor	Jamaica Bay	Newark Bay	Lower Harbor	Upper Harbor
% TOC, dry wt. (± 90% C.I.)	2.3 ±0.8	2.6 ±0.7	2.5 ±0.4	1.7 ±0.5	3.8 ±0.7

When TOC was examined on an areal basis (Table 3-4), the sub-basins were very similar, with Upper Harbor and Newark Bay having similar and considerable percent of area with TOC exceeding 1.5%.

Table 3-4. **Percent of Area Distribution of % TOC** (90% C.I.)

	Harbor	Jamaica Bay	Newark Bay	Lower Harbor	Upper Harbor
< 0.5%	24.8 ±4.0	39.3 ±15.1	0	32.1 ±14.5	3.6 ±5.8
0.5 to </= 1.5%	24.1 ±4.1	3.6 ±5.8	17.9 ±11.9	32.1 ±14.5	10.7 ±9.6
1.5 to </= 2.5%	8.8 ±2.8	10.7 ±9.6	39.3 ±15.1	3.6 ±5.8	14.3 ±10.9
2.5 to </= 3.5%	10.3 ±3.2	7.1 ±8.0	21.4 ±12.7	7.1 ±8.0	17.9 ±11.9
> 3.5%	32.1 ±4.1	39.3 ±15.1	21.4 ±12.7	25.0 ±13.4	53.6 ±15.5

There were no sites in Newark Bay where TOC was less than 0.5%, whereas Jamaica Bay and the Lower Harbor had a third of their areas with TOC less than 0.5%. Highly organically-enriched areas ranged from 21.4% of Newark Bay to 53.6% of Upper Harbor.

The percent of area distribution of TOC in 1998 was similar to 1993/4 for the Harbor (Figure 3-2). A significant shift was seen between the three categories of TOC greater than 1.5%. This also may be attributed to the effect of dredging. Individual sub-basins also were similar between 1993/4 and 1998,

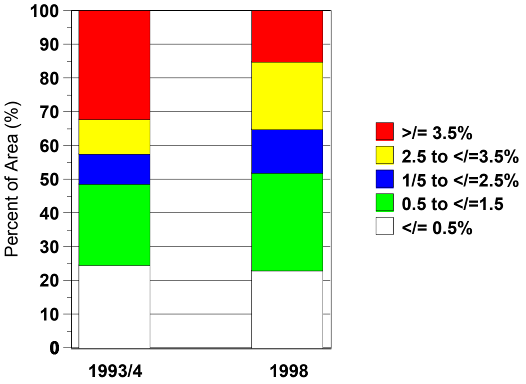

Figure 3-2. Percent of area distribution of TOC for the Harbor.

although there was some shifting between the intermediate TOC categories.

Water Column Profile

Mean bottom water temperature during the sampling period was similar in all the sub-basins (Table 3-5). Means ranged from 21.0°C in Lower Harbor to 24.3°C in Newark Bay. Mean bottom water temperature for the entire Harbor was 21.7°C. For the Harbor overall, there was no significant difference in mean bottom temperature between 1993/4 and 1998.

Table 3-5. **Area-Weighted Means of Water Column Physical Parameters**

	Harbor	Jamaica Bay	Newark Bay	Lower Harbor	Upper Harbor
Bottom Temp. (°C) (± 90% C.I.)	21.7 ±1.1	24.1 ±0.4	24.3 ±0.6	21.0 ±1.1	22.2 ±1.0
Bottom Salinity (ppt) (± 90% C.I.)	24.8 ±1.0	27.2 ±0.3	21.1 ±0.6	25.8 ±0.7	22.0 ±2.0
Bottom D.O. (mg/l) (± 90% C.I.)	7.0 ±0.8	6.5 ±0.9	5.4 ±0.4	7.7 ±0.6	5.7 ±0.6

Mean bottom salinity for the entire Harbor was 24.8 ppt. Newark Bay and Upper Harbor were significantly lower ($p<0.01$) than the other two systems. The lowest salinity value measured during the study was 5.6 ppt in the Hudson River; all other values exceeded 12 ppt. There was a slight difference in Harbor mean bottom salinity between 1993/4 (26.2± 0.4) and 1998, with 1998 being lower.

Dissolved oxygen concentrations are typically highly variable both temporally and spatially, and NY/NJ Harbor is no exception. This study obtained a single measurement of dissolved oxygen at each station. New York City DEP has a more spatially and temporally complete dissolved oxygen data set for 1998 (NYCDEP, 1999). It should be noted that, although mean D.O. values did not fall into a category of impaired, this may not be the case at individual stations. Each sub-basin had stations with D.O. measurements that were below 3 mg/l.

SEDIMENT CHEMISTRY

The direct measurement of the concentration and kind of chemicals present in sediment provides insight into the ecological effects that might be present, as well as suggesting possible sources of contaminants. However, there needs to be an interpretative step to “translate” those chemical data into indication of ecological impact.

This investigation used the aquatic effects-based guidelines of Long and Morgan (1991) and Long et al. (1995) to evaluate the chemical data (except for dioxins and furans). 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 data set that was used for development. 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, 1999). The ERM and ERL values were used because they include thresholds for most of the chemicals that were measured, allowing this study to provide an integrated contaminant response.

Concentrations of 17 dioxin and furan congeners also were measured in sediments of the study area. 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)”. TEFs permit estimation of total dioxin/furan toxicity, expressed as an equivalent amount of 2,3,7,8-TCDD.

Mean Condition

Chemical contamination is pervasive in the Harbor. The mean values for 7 of 10 trace elements for which ERL and ERM thresholds exist were at or above ERL levels (Appendix B). Cadmium, and antimony were the only ERLs not exceeded, and chromium was present at a mean concentration equal to the ERL. The Harbor mean for mercury exceeded the ERM value. With regard to organic chemical contaminants, the ERL value was exceeded for the Harbor mean concentrations of total chlordane, total DDT, DDT, total PAHs and high molecular weight PAHs, as well as several of the individual PAHs. The ERM value was exceeded for DDT.

A comparison of 1993/4 and 1998 shows that, among the major groups of contaminants, the Harbor mean for total chlordane experienced a statistically significant decrease in the five years from 1993/4 to 1998 (Table 4-1). Mean values for most other individual contaminants in the Harbor decreased only slightly during that time period, if at all (Appendix B).

Table 4-1. **Comparison of Harbor Mean Sediment Concentrations (± 90% C.I.).**

	1993/4	1998	statistical difference (p<0.10)
Mercury (ppm)	0.74 ±0.14	0.86 ±0.54	
Silver (ppm)	1.59 ±0.30	1.57 ±0.74	
Total Chlordane (ppb)	5.11 ±1.01	0.64 ±0.70	T (93/94 higher)
Total DDT (ppb)	31.59 ±16.64	20.87 ±2.12	
Total PAHs (ppb)	7177.4 ±2607.9	5327.08 ±47.55	

Concentrations of some sediment contaminants in the individual sub-basins decreased enough to be statistically significant (Table 4-2). Total chlordane decreased in all the sub-basins except Upper Harbor. Significant decreases also were seen for silver in Newark Bay as well as for total DDT in Upper Harbor.

Table 4-2. **Statistically Significant Decreases in Sub-basin Mean Contaminant Sediment Concentrations (p<0.10)**

	Jamaica Bay	Newark Bay	Lower Harbor	Upper Harbor
Silver		T		
Total Chlordane	T	T	T	

Of the Harbor sub-basins, Newark Bay had the highest average concentration of all the metals measured, except for silver, manganese and aluminum, which were higher in Upper Harbor (Appendix B). Upper Harbor had the highest mean concentrations of total chlordane and total PAHs, as well as for most of the individual PAHs, except for 2,6-dimethylnaphthalene which was highest in Jamaica Bay. Newark Bay had a mean concentration of parent DDT that was 200 times higher and a mean total DDT that was 50 times higher than the next highest sub-basin.

Areal Extent

Chemical contamination was present throughout the Harbor. When expressed on an area basis, 86% (± 4) of the Harbor exceeded an ERL concentration for at least one contaminant, and 45% (±4) of the Harbor exceeded an ERM concentration for at least one contaminant (Figure 4-1). This is very similar to conditions measured in 1993/4.

Estimates of the percent of area in the Harbor that exceeded an ERL and/or ERM for any metal, pesticide, and PAH showed that all contaminant groups appeared to contribute to Harbor contamination (Figure 4-1). In 1998, while the extent of metals contamination remained constant, pesticide levels have declined from 1993/4.

Evaluation of the individual chemicals showed that mercury was the most ubiquitous chemical. Sixty-eight percent (± 4) of the area of the Harbor exceeded the ERL and 42% (± 4) exceeded the ERM for mercury (Figure 4-2). Between 1993/4 and 1998 metals levels have remained approximately the same. The area of the Harbor affected by low-level cadmium contamination has significantly decreased.

Organic contaminants above ERL values affected between <1% to 47% of the Harbor. Total DDT, high molecular weight PAHs, and several individual PAHs had the highest percent of areas above ERLs. The percent of area above organic ERMs was low, ranging from <1% to 8%. In 1993/4, organic contaminants above ERL values affected from 56% to 83% of the Harbor area, and chlordane resulted in the greatest percent area (32%) of an organic contaminant above an ERM (Figure 4-3).

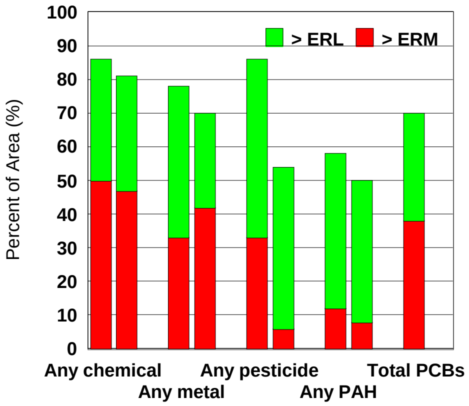

Figure 4-1. Percent of area exceeding ERLs and ERMs for individual chemical groups in 1993/4 (1st bar) and 1998 (2nd bar). (Quality of 1998 PCB data were indeterminate at time of publication.)

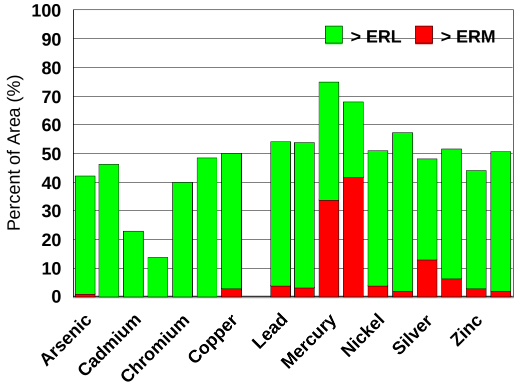

Figure 4-2. Percent of area greater than ERL and ERM values for 1993/4 (1st bar) and 1998 (2nd bar) for metals in the Harbor. (Total copper was not analyzed in 1998.)

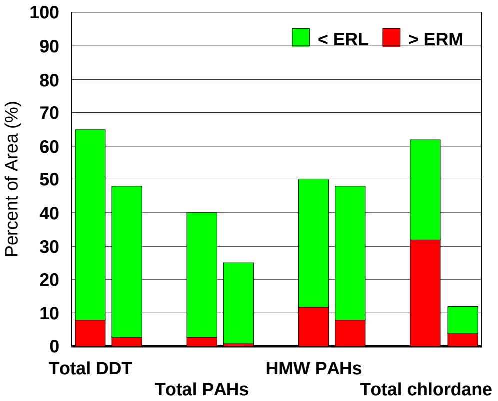

Figure 4-3. Percent of Harbor area greater than ERL and ERM values for 1993/4 (1st bar) and 1998 (2nd bar) for organics in the Harbor.

Within the Harbor, Newark Bay and the Upper Harbor had the most widespread and diverse contaminant problems, with 96% (± 6) and 82% (± 12) of their areas exceeding an ERM value for at least one chemical (Figure 4-4). These two sub-basins, at 100% and 93% (± 8), also had the highest percent of area exceeding at least five ERLs. The entire Harbor exceeded five or more ERLs at 60% (± 4) of its area. Approximately 8% (± 1) of the Harbor exceeded at least 5 ERMs with Newark Bay having 50% (± 16) and UH 25% (± 13) exceedances in 1998. Jamaica Bay and Lower Harbor had no stations with 5 or more ERMs exceeded.

Mercury had the highest percent area of all the metals exceeding an ERM in the Harbor (42%). Focusing on mercury in each of the sub-basins showed that in 1998, 96% of the area in Newark Bay and 71% of the area in the Upper Harbor exceeded the ERM concentration (Figure 4-4). One hundred percent of Newark Bay and 96% of the Upper Harbor exceeded the ERL for mercury. This is compared to 100% and 93%, respectively, in 1993/4.

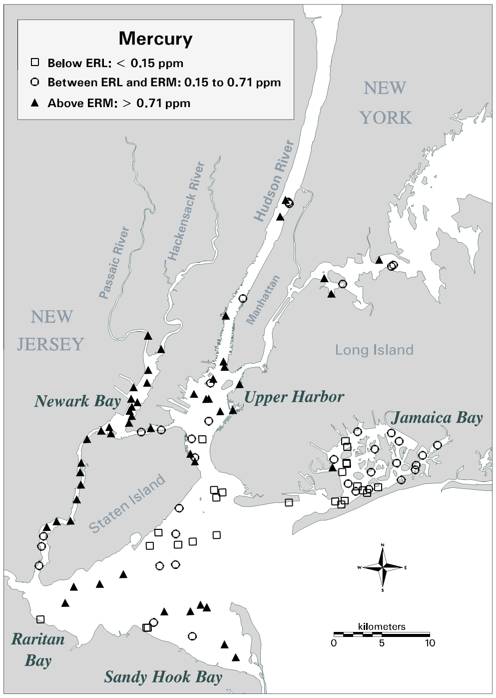

Figure 4-5. Distribution of mercury concentrations in 1998 by station.

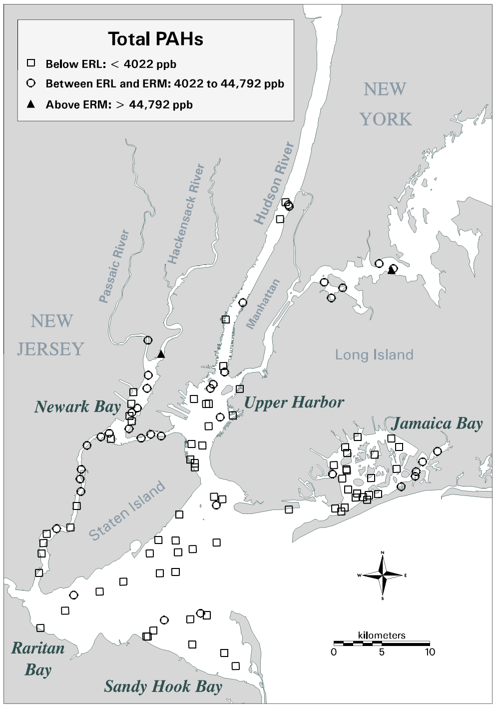

Figure 4-6. Distribution of total PAH concentrations in 1998 by station.

It was possible to distinguish some general patterns of chemical distribution in sediments. The pattern of mercury distribution in the Harbor may indicate that a possible source or sources exist in or above Newark Bay and Upper Harbor (Figures 4-5). 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 PAHs exhibited a similar pattern (Figure 4-6). These observations are similar to those from 1993/4.

Dioxins and Furans

Concentrations of seventeen congeners of dioxins and furans were measured at each station in Newark Bay, Jamaica Bay, Lower Harbor, and Upper Harbor. Most sediments, if contaminated with dioxins and furans, have them present as complex mixtures. 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 in fish and birds, expressed as "toxicity equivalents" or TEQs (U.S.EPA, 2001).

Table 4-3. **Mean Sediment Concentrations of 2,3,7,8-TCDD and dioxin/furan TEQs** (± 90% confidence limits)

	2,3,7,8-TCDD (ng/kg, dry wt.)		TEQs (fish)	TEQs (birds)
	1993/4	1998	1998	1998
Harbor	-	6.5 ±1.6	9.7 ±2.0	22.5 ±3.1
Jamaica Bay	4.0 ±2.6	1.6 ±0.9	2.5 ±1.2	12.3 ±5.0
Lower Harbor	7.5 ±3.4	3.0 ±1.7	5.0 ±2.8	15.1 ±7.4
Upper Harbor	5.5 ±1.8	6.4 ±2.7	12.4 ±3.7	32.5 ±9.1
Newark Bay	not analyzed	49.0 ±24.6	57.1 ±26.7	78.1 ±31.9

Low levels of dioxins and furans were found in all sub-basins. The mean concentration of the most toxic dioxin congener, 2,3,7,8-TCDD, was highest in Newark Bay (Table 4-3), with concentrations in the other sub-basins substantially lower but similar to one another. Incorporating all congeners into the calculation of TEQs also resulted in the Newark Bay having a significantly higher mean of 2,3,7,8-TCDD equivalents than the other three sub-basins.

Comparison of 2,3,7,8-TCDD levels in 1993/4 and 1998 show that, while levels in some sub-basins appear to be declining, these changes are not statistically significant.

SEDIMENT TOXICITY

Sediment toxicity tests, which involve the exposure of organisms to sediments in a laboratory setting, are useful because they provide a direct indication of the effects of sediment contaminants. Because the tests are done in a laboratory, confounding factors such as temperature, salinity, and dissolved oxygen can be controlled. Toxicity tests also integrate the effects of complex mixtures of chemicals in sediment, including chemicals that were not measured. However, two disadvantages of toxicity tests are that individual species of test organisms can vary in their sensitivity to chemicals, and the relevance of toxicity test results to field conditions is difficult to establish. For these reasons, toxicity tests are best used as in conjunction with sediment chemistry and some measure of in situ biological response (e.g., benthic macroinvertebrate community structure).

This investigation used survival of the amphipod, *Ampelisca abdita*, to indicate sediment toxicity. Sediments at a station were considered toxic using the *Ampelisca abdita* toxicity test if percent survival was less than 80% compared to controls. These criteria are similar to those in 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.

Table 5-1. **Mean % Survival for *A. abdita*** * (± 90% C.I.)

	1993/4	1998
Harbor	87.9 ±4.1	89.8 ±2.8
Jamaica Bay	84.9 ±7.7	77.0 ±9.9
Newark Bay	66.5 ±15.1	63.7 ±10.7
Lower Harbor	91.0 ±5.9	96.0 ±5.9
Upper Harbor	86.6 ±6.3	84.5 ±10.0

* Adjusted for control survival.

Mean Condition

Mean percent survival of *Ampelisca abdita* (as percent of control survival) for 1998 was fairly high for the Harbor overall (Table 5-1). Mean survival was comparable within each sub-basin of the Harbor except Newark Bay where it was significantly less than the Harbor as a whole. Lower Harbor exhibited the highest mean survival.

A comparison between the investigations of 1993/4 and 1998 shows that mean percent survival was very similar for the Harbor and across the sub-basins. There were no statistically significant changes.

Areal Extent

In 1998, out of a total area of 501 km^2, approximately 60 km^2 (12%) of the Harbor proper was toxic to *A. abdita* and 48 km^2 of that (9.5% of the total area) was highly toxic (Figure 5-1). Newark Bay and Jamaica Bay have more widespread toxic sediments (50 and 32%, respectively) than the rest of the Harbor. Newark Bay also has a larger percent area of highly toxic sediments (36%) than other Harbor sub-basins. 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 (31 km^2) was ½ of the acreage of toxic sediments in the entire Harbor.

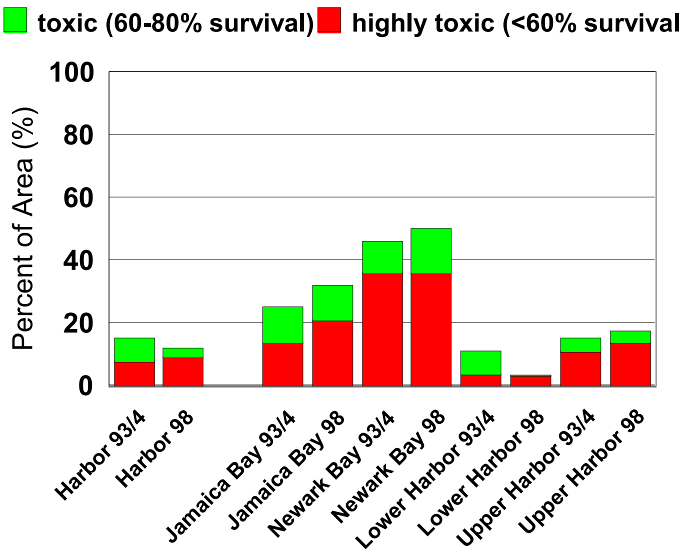

Figure 5-1. Percent of area with *Ampelisca* toxicity.

Individual stations toxic to *A. abdita* were scattered around the Newark Bay, Upper Harbor and Jamaica Bay sub-basins (Figure 5-2). Highly toxic stations were concentrated in the Arthur Kill (Newark Bay sub-basin) and throughout Jamaica Bay. The Upper Harbor had two stations on the western Long Island Sound side of the East River with highly toxic sediments. The one station in the Lower Harbor that exhibited toxicity was near the entrance to Jamaica Bay.

Comparing 1998 with 1993/4 shows that the overall prevalence (Figure 5-1) and distribution of toxicity in the Harbor remains similar. Overall, the Harbor extent of toxicity was identical between 1993/4 and 1998. There also were no sub-basins with statistically significant changes in the extent of toxicity.

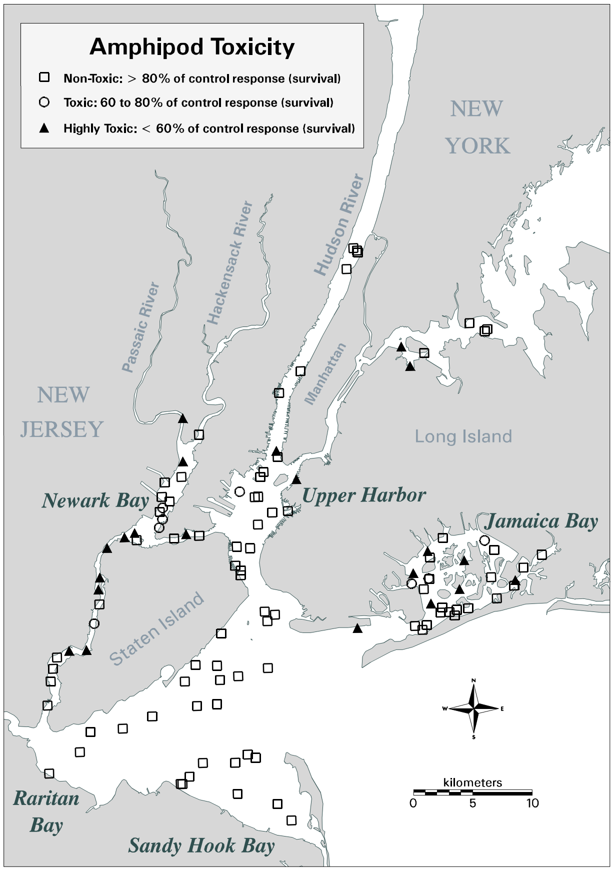

Figure 5-2. Distribution of stations with A. abdita toxicity.

Individual stations with measurable toxicity varied slightly between 1993/4 and 1998 (Figure 5-2). The lower Passaic River and Arthur Kill still had many toxic and highly toxic stations. The Lower Harbor still had the least number of toxic stations.

BENTHIC MACROINVERTEBRATES

Sediment chemistry data and toxicity data provide indications of sediment quality, but only indirect estimates of ecological impact. A goal of the Harbor management plan is to establish and maintain a healthy and productive ecosystem. Achieving this requires an understanding of the effects of contaminants on indigenous communities, as well as the extent and magnitude of those effects.

Bottom-dwelling invertebrates (benthos) have several characteristics that make them useful indicators of biological response to environmental conditions. Because they live and feed in the sediments, they are directly exposed to contaminant effects. Benthos are relatively sedentary and cannot avoid exposure, therefore they can provide an accurate indication of local environmental conditions. Bottom dwelling organisms are also relatively long-lived and are an important link between primary producers and higher trophic levels. Additionally, benthos 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.

There are many individual measures that have been developed for describing benthic communities. This study used several structural measures to quantify the status of benthic macroinvertebrate assemblages (Table 2-4). Species diversity is indicative of site biodiversity. Biodiversity is measured here as the number of species present (i.e., species richness) and species diversity (Shannon-Wiener index). Evenness (distribution among species in the community) is incorporated in the Shannon-Weiner index (Shannon and Weaver, 1949). Biomass 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; Luckenbach et al., 1990). Total abundance is 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 been used to determine the ecological health of a location (Grassle and Grassle, 1974 and 1976). In the previous investigation (Adams et al.,1998), lists of pollution-sensitive and pollution-indicative species were developed for the Harbor (Appendix C).

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. 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 (Adams et al., 1998). Five metrics which most effectively distinguished normal sites from all others were selected for the B-IBI; these metrics were evaluated for four different salinity and grain size habitats. 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.

Diversity and Taxonomic Composition

A total of 278 infaunal species were represented in the Harbor in 1998 (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 2.6 (Table 6-2). Pollution sensitive species accounted for 9.2 % of the Harbor benthic organisms, while pollution-indicative species comprised 19.7 % of the benthos (Table 6-2).

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

	Harbor		Jamaica Bay		Newark Bay		Lower Harbor		Upper Harbor	
	1993/4	1998	1993/4	1998	1993/4	1998	1993/4	1998	1993/4	1998
Number of Species	239	278	137	161	91	125	166	218	152	144

Newark Bay has the least number of species of all the sub-basins and Lower Harbor the most (Table 6-1). Shannon-Wiener diversity was similar in all sub-basins, but taxonomic composition varied greatly among sub-basins.

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

	Harbor		Jamaica Bay		Newark Bay		Lower Harbor		Upper Harbor	
	1993/4	1998	1993/4	1998	1993/4	1998	1993/4	1998	1993/4	1998
Species Richness (as # species/ sample)	19.2 ±1.7	24.5 ±2.0	17.7 ±2.7	20.6 ±4.0	14.1 ±2.6	17.1 ±3.1	20.6 ±2.6	27.4 ±3.4	17.1 ±2.3	19.8 ±3.4
Pollution-Sensitive Species (%)	13 ±5.6	9.2 ±2.4	3.6 ±2.0	6.4 ±2.1	0.3 ±0.3	1.1 ±1.0	18 ±8.6	11.2 ±4.8	6.8 ±5.6	6.8 ±4.6
Pollution-Indicative Species (%)	31 ±3.5	19.7 ±2.2	46 ±8.4	27.3 ±3.8	65 ±7.1	46.6 ±6.4	20 ±5.0	11.4 ±3.5	49 ±6.3	33.4 ±8.6
Species Diversity (Shannon-Wiener)*	2.3 ±0.17	2.6 ±0.58	2.1 ±0.20	2.1 ±0.17	2.1 ±0.3	2.5 ±0.16	2.4 ±0.26	2.7 ±0.22	2.5 ±0.15	2.5 ±0.21

* natural log calculation

Between 1993/4 and 1998, the total number of species and the mean number of species per sample in the Harbor, as well as in each of the sub-basins, slightly increased. Species diversity in the Harbor and its sub-basins remained the same or slightly increased. The percentage of pollution-indicative species showed statistically significant decreases across the Harbor sub-basins, while pollution-sensitive species remained similar between sampling periods. Dependent on the sub-basin, there were no statistically significant changes in pollution-sensitive species between 1993/4 and 1998. In 1998, pollution-sensitive species were significantly less abundant in Newark Bay than elsewhere in the Harbor, and more abundant in Lower Harbor.

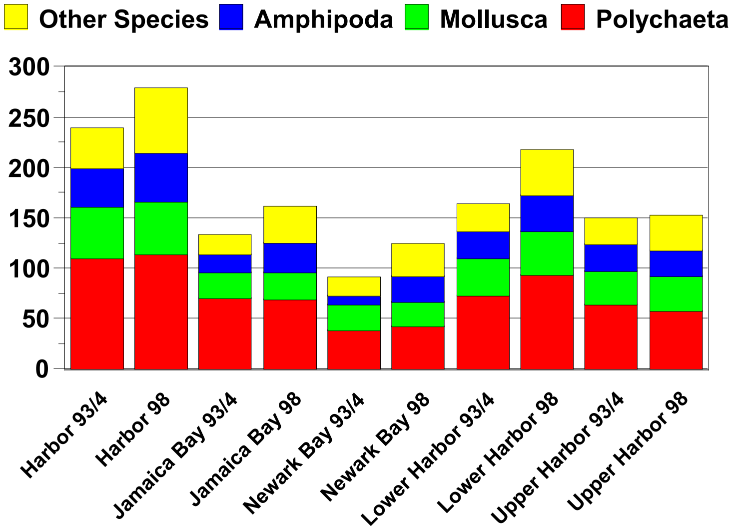

Figure 6-1. Numbers of benthic macrofaunal species, by major taxon.

In the Harbor and in each sub-basin, one-third to one-half of the total number of species were consistently polychaetes (Figure 6-1). Molluscs and arthropods were represented by approximately equal numbers of species in each sub-basin. Among the sub-basins, amphipod species comprised 17 to 21% of all species identified. Three taxa (Amphipoda, Mollusca, and Polychaeta) include about 77% of all Harbor taxa identified (Figure 6-1).

Abundance and Biomass

The mean abundance and biomass for the Harbor in 1998 were 18,000 organisms/m^2 and 10.2 g/m^2, respectively (Table 6-3). These numbers are both significantly less than those recorded in 1993/4.

The mean abundance was significantly lower in both Newark Bay and Upper Harbor than in any other Harbor sub-basin in 1998 (Table 6-3). Biomass of the benthos was lowest in Newark Bay. Comparison of 1998 to 1993/4 shows mean abundance and biomass have significantly decreased in the Harbor and in individual sub-basins. Jamaica Bay showed the least change in abundance with a slight increase in biomass. Lower Harbor had a large decrease in organism abundance, while both the Lower Harbor and Upper Harbor saw a significant decrease in biomass.

Table 6-3. **Abundance and Biomass Means** (± 90% confidence interval)

	Harbor		Jamaica Bay		Newark Bay		Lower Harbor		Upper Harbor	
	1993/4	1998	1993/4	1998	1993/4	1998	1993/4	1998	1993/4	1998
Abundance (# organisms/m^2)	40,000 ±14,000	18,000 ±98	39,000 ±15,000	34,000 ±17,000	11,000 ±4,700	5,900 ±2,000	52,000 ±22,000	20,000 ±8,000	12,000 ±3,600	8,000 ±2,000
Biomass (g/m^2)	31 ±11	10 ±4	10 ±5	13 ±5	5 ±2	5 ±7	50 ±31	11 ±12	56 ±35	9 ±7

Benthic Index

Approximately 31 % of the Harbor area exhibited measurable departure from the structure at reference sites (Table 6-4). Most of this area (20%) was in a moderately impacted category (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 18% for Lower Harbor to 89% 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 three stations of 28 that were comparable to reference conditions (Appendix D).

A comparison with 1993/4 data shows that for the Harbor overall the percent of area with the most impacted benthic communities has remained similar between studies. However, there has been a shift of significant portions of the Harbor from the moderately impacted category to the unimpacted category. Within the sub-basins, this shift is also seen, except in Newark Bay.

Table 6-4. **Percent of Area within B-IBI categories** (± 90% C.I.)

	Harbor		Jamaica Bay		Newark Bay		Lower Harbor		Upper Harbor	
	1993/4	1998	1993/4	1998	1993/4	1998	1993/4	1998	1993/4	1998
1 to <2 impacted	6 (3-9)	11.1 ±1.5	18 (9-31)	14.3 ±10.9	18 (0-38)	60.7 ±15.1	0 (0-8)	0	14 (6-27)	28.0 ±14.7
2 to <3 moderately impacted	47 (37-57)	20.3 ±3.9	46 (33-60)	32.1 ±14.5	80 (60-100)	28.6 ±14.0	39 (27-53)	17.9 ±11.9	61 (47-73)	20.0 ±13.1
≥3-5 unimpacted	47 (37-58)	68.6 ±3.9	36 (24-50)	53.6 ±15.5	2 (0-6)	10.7 ±9.6	61 (47-73)	82.1 ±11.9	25 (14-38)	52.0 ±16.4

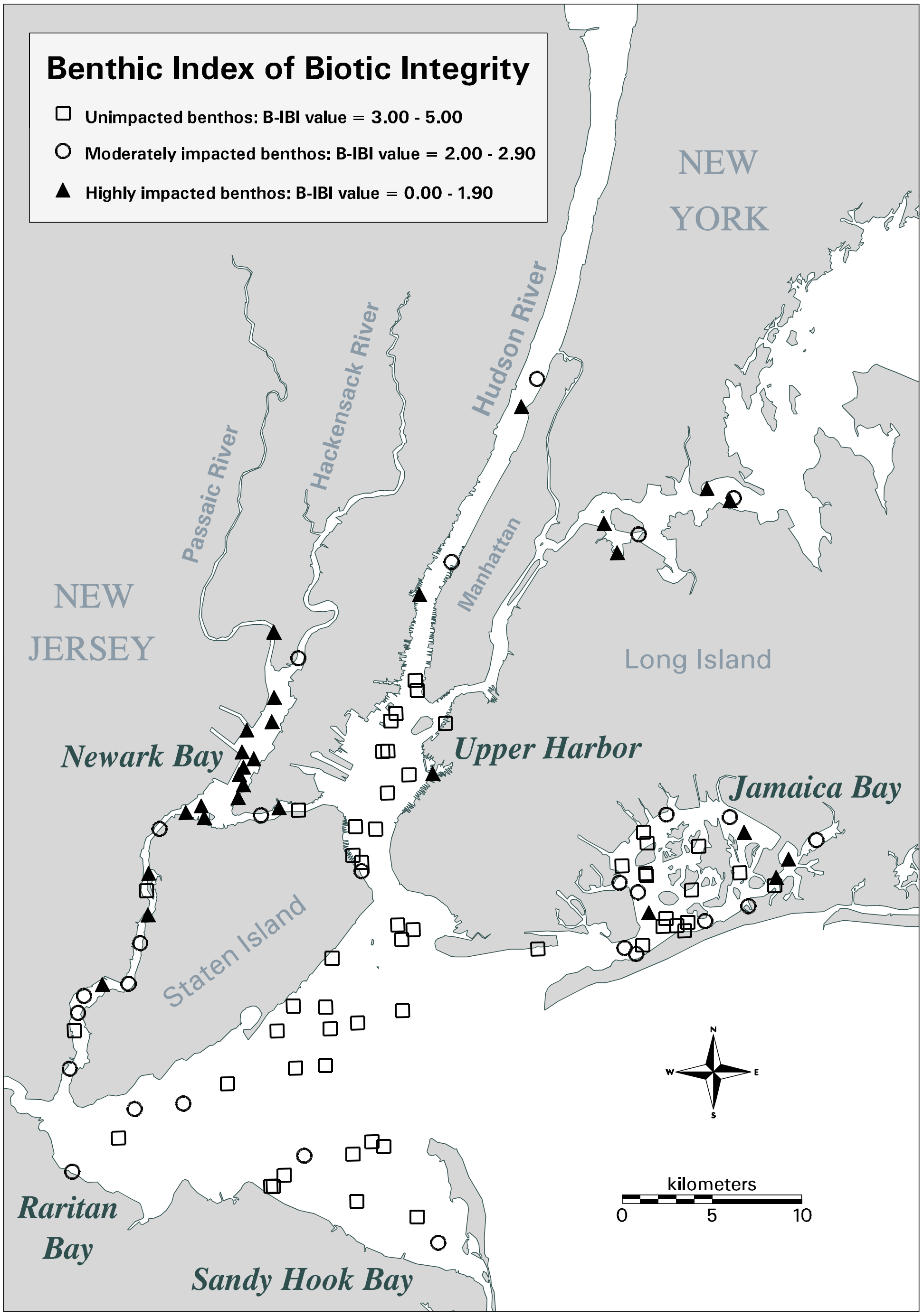

Figure 6-2. B-IBI scores of individual stations.

SUMMARY and RECOMMENDATIONS

Summary

The CCMP for the NY/NJ Harbor (1996) set out goals for the protection and restoration of the NY/NJ Harbor system. Key to achieving these goals are understanding of the current chemical and ecological condition of the system and how the system responds over time to the management actions that have been implemented and the natural changes that have occurred.

A previous investigation (Adams et al., 1998) developed a baseline of chemical, biological, and toxicity estimates for the Harbor and each of its sub-basins. The current investigation took place five years after the baseline and measured the same parameters to determine how conditions were changing in the Harbor. During each investigation, twenty-eight probabilistically selected stations were sampled in four sub-basins of the Harbor: Jamaica Bay, Newark Bay, Upper Harbor, and Lower Harbor.

While some aspects of sediment quality in the Harbor have remained the same, some have shown improvement.

- The Harbor is still extensively contaminated with chemical substances at levels of concern but there has been improvement:
    - Harbor means for mercury and DDT exceeded ERMs (similar to 1993/4)
    - Harbor means for all chemicals exceeded or equaled their ERLs, except antimony and cadmium (similar to 1993/4 except for antimony which did not exceed its ERL then)
    - Total chlordane means have had a statistically significant decrease in all sub-basins, except the Upper Harbor
    - Dioxin and furan concentrations have not significantly changed
    - Forty-five percent of the Harbor exceeded an ERM for at least one contaminant (compared to 50% in 1993/4)

  - Mercury is the most ubiquitous contaminant at a level of concern
    - 68% of the Harbor exceeded the ERL, 42% exceeded the ERM (75% and 34% in 1993/4)
  - Areal PAH contamination has not significantly changed between 1993/4 and 1998
- Benthic (bottom dwelling) organisms and associated measures have shown mixed results
  - Sixty-nine percent of the Harbor had un-impacted benthic communities (compared to 47% in 1993/4)
    - Newark Bay had the most area with impacted benthos (89%) in 1998, compared to 98% in 1993/4)
    - Most sub-basins (except Newark Bay) have had a shift of area from the moderately impacted category to the unimpacted column
  - Pollution-indicative species were generally distributed inversely to pollution-sensitive species
    - Pollution-indicative species were least abundant in Lower Harbor and most abundant in Newark Bay
  - Benthic abundance and biomass have decreased or stayed the same Harbor-wide and in the sub-basins from 1993/4 to 1998
- The extent and distribution of sediment toxicity in the Harbor has remained stable
  - Twelve percent of the Harbor was toxic to *Ampelisca abdita* (15% in 1993/4)
  - Newark Bay has the most toxic area (50%), compared to 46% in 1993/4

Recommendations

Evaluate the sampling interval (currently 5 years).

It is very likely that major changes in the Harbor had already occurred before the 1993/4 and 1998 investigations. Five years may not be long enough to distinguish additional change.

Add an additional measure of sediment toxicity.

The *Ampelisca abdita* assay has been criticized as lacking sensitivity. Sediment porewater toxicity tests have been shown to be more sensitive than *Ampelisca* (Carr and Chapman, 1992; Carr et al., 2000) and have excellent correspondence with bulk sediment contaminant concentrations (Carr et al., 1996).

Evaluate the addition of analytes that are not currently measured but may be responsible for biological effects.

PCB15 has been linked with toxicity in the Harbor but is not measured with the present list of PCBs.

Nonylphenol is a persistent organic with endocrine disrupting potential that has been found in sediments of the Harbor in high concentrations.

Organomercury compounds are highly toxic, bioaccumulative and have been found in the Harbor.

Planar PCBs exhibit toxicity similar to dioxins and also have been found in the Harbor.

Intensify sampling for some parameters.

In situ dissolved oxygen monitoring could provide temporally comprehensive measurement of condition.

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