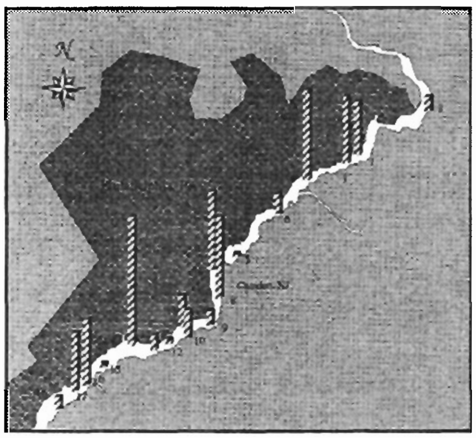
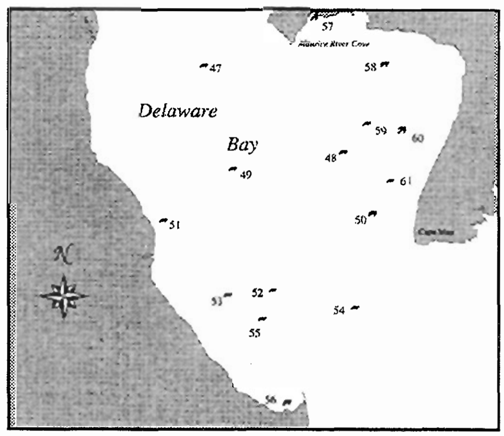
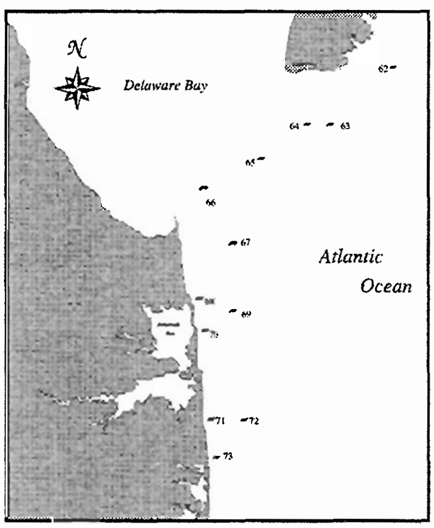
NOAA Technical Memorandum NOS NCCOS CCMA 148

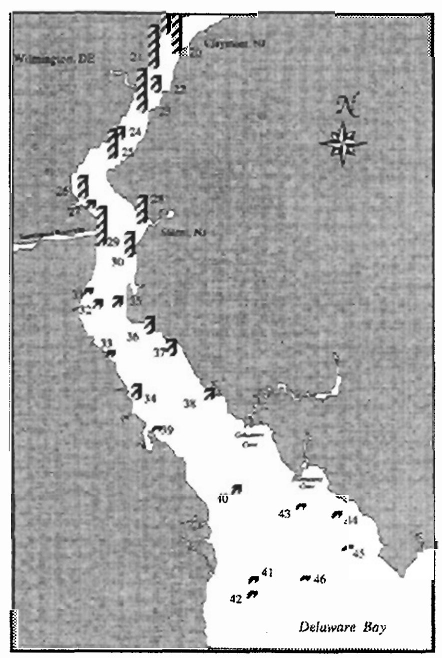
National Status and Trends Program
for Marine Environmental Quality

Magnitude and Extent of Contaminated Sediment and Toxicity in Delaware Bay









Silver Spring, Maryland
June 2001

US Department of Commerce

noaa National Oceanic and Atmospheric Administration

Centers for Coastal Monitoring and Assessment
National Centers for Coastal Ocean Science

Centers for Coastal Monitoring and Assessment
National Centers for Coastal Ocean Science
National Ocean Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce
NSI 1, SSMC4
1305 East-West Highway
Silver Spring, MD 20910

Notice

NOAA Technical Memorandum NOS ORCA 148

Magnitude and Extent of Contaminated Sediment and Toxicity in Delaware Bay

S. Ian Hartwell, Jawed Hameedi, and Michelle Harmon
National Oceanic and Atmospheric Administration

Contributors

R. Scott Carr
U.S. Geological Survey

Cornelia Mueller and John Scott
Science Applications International Corp.

Jack Anderson and Jennifer Jones
Columbia Analytical Services

Carl Way
Barry A. Vittor & Assoc. Inc.

Terry Wade
Texas A&M University

David Carter
Delaware Dept. of Natural Resources and Environmental Control

Edward Santoro
Delaware River Basin Commission

Silver Spring, Maryland
June 2001

United States
Department of Commerce

Donald L. Evans
Secretary

National Oceanic and
Atmospheric Administration

Scott B. Gudes, Acting
Under Secretary

National Ocean Service

Margaret Davidson, Acting
Assistant Administrator

Centers for Coastal Monitoring and Assessment
National Centers for Coastal Ocean Science
National Ocean Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce
NSI 1, SSMC4
1305 East-West Highway
Silver Spring, MD 20910

Notice

Table of Contents

List of Tables

List of Figures

EXECUTIVE SUMMARY

This report summarizes the results of NOAA's 1997 sediment toxicity, chemistry, and benthic community studies in the Delaware Bay estuary and contiguous areas as a component of the National Status and Trends (NS&T) Program for marine environmental quality. Sediment contamination in U.S. coastal areas is a major environmental issue because of its potential toxic effects on biological resources and often, indirectly, on human health. Contaminants in the sediments often pose both ecological and human-health risks through degraded habitats, loss of fauna, propagation of contaminants in the coastal ecosystem, and human consumption of contaminated fish and wildlife. Thus, characterizing and delineating areas of sediment contamination and toxicity are viewed as important goals of coastal resource management.

Delaware Bay is one of the largest coastal plain estuaries on the U.S. east coast. The major source of freshwater input is the Delaware River. The watershed drains portions of New York, Pennsylvania, New Jersey, and Delaware. Major metropolitan centers are located in the freshwater and estuarine portions of the watershed, including Philadelphia, PA, Trenton, NJ, Camden, NJ, and Wilmington, DE. These localities contain numerous municipal point and non-point source releases, industrial and petrochemical discharges, and extensive commercial and naval ship traffic and port facilities. Three of the basin States maintain fish consumption advisories due to PCBs and chlorinated pesticides. Salinity steadily increases in the downstream direction from Philadelphia. In the estuarine portion of the system, the water column may exhibit salinity stratification but is usually well mixed to the bottom. Most of the bay is less than 10 m deep. At the mouth of the bay, Cape May shoals restrict the entrance to the bay on the north side, with characteristic flood tidal shoals behind it. Dilution of sea water by fresh water flow is evident on the continental shelf beyond the mouth of the estuary. Sediments in the central bay are characteristically fine grained sand. Broad flat shoals in the south and the large north-east expanse of the bay are characteristically muddy.

A standard stratified-random design was used for selection of sampling sites to determine the spatial extent of sediment toxicity in Delaware Bay with a quantifiable degree of confidence. To characterize the entire system, samples were taken from offshore stations on the continental shelf north and south of the bay mouth, throughout the open bay, up the estuary into tidal fresh areas, and up to the fall line. The system was divided into well-defined sampling strata and sampling sites within each substratum. Strata boundaries were established in consultation with regional scientists and resource mangers and were based on bathymetric, hydrographic, and regional environmental considerations. Several tributary sampling stations were also established to assist in local investigations and site specific evaluations.

Sediment samples were taken using rigorous procedures for chemical analyses, toxicity bioassays, and benthic community assessment. Chemical analyses included a wide array of organic and trace metal analyses including major classes of environmental contaminants (heavy metals, PCBs, PAHs, DDT and other chlorinated pesticides, and TBT). Current use pesticides were not analyzed. NOAA uses a suite of sediment toxicity tests, ranging from intact animals tested in whole sediments, to enzyme mediated reactions to chemical extracts of sediment contaminants, for assessment of different modes of contaminant exposure to a variety of species and different assessment end-points. Benthic ambient toxicity studies have a history of use in regional estuarine monitoring programs and have been proven to serve as an effective indicator for describing the extent and magnitude of pollution impacts in estuarine ecosystems, as well as for assessing the effectiveness of management actions. Since toxicity test results are not necessarily axiomatic and biological effects of contaminants occur at different levels of biological organization, i.e., from cells to ecosystems, results from the toxicity tests are used in the "weight of evidence" context to infer the incidence and severity of environmental toxicity in conjunction with the chemical and ecological data. Benthic community samples were carefully examined to identify patterns of resident species for assessment of contaminant impact. Benthic communities are particularly important as ecological links in food webs for juvenile fish and crustaceans, water quality, and ecosystem productivity. Responses of some species are indicative of changes in sediment quality. Benthic species composition and abundance are also influenced by natural habitat conditions. Information on changes in benthic population and community parameters due to habitat characteristics can be useful for separating natural variation from changes associated with pollutant effects

The tidal-fresh portion of the study area in the vicinity of Philadelphia was heavily contaminated with metals, pesticides, PCBs and PAHs. Selected portions of the upper estuarine zone and downstream to below the C&D canal were also contaminated. Contaminant concentrations varied greatly from station to station, depending on exact location. In general, the concentrations of all chemical constituents were either relatively high or low at a given site, that is, where organic contaminant concentrations were high, metals were high. Examples of stations with contamination by one class of chemicals but not others were rare. Most of the freshwater sites exceeded one or more ERL concentration for PCBs and/or PAHs. While the total dioxin and furan concentrations were relatively high in the estuarine sites, the vast majority was in the form of the octachlorinated compounds that are three orders of magnitude less toxic than the tetrachloro congeners. The concentration of DDT and it's breakdown products showed a similar distribution as PCBs, but elevated concentrations were not distributed as far downstream. All but two samples from the freshwater zone exceeded the ERL for p,p'DDE. Seven samples exceeded the ERM. Eleven samples in the estuarine zone exceeded the ERL, of which two exceeded the ERM. The concentration of other chlorinated pesticides was dominated by chlordane and related cyclodienes. These compounds were found over a more widespread area than DDT. Metals contamination followed the same pattern as organic contaminants, with selected stations exhibiting elevated concentrations of multiple metals. Metals concentrations were frequently above ERL concentrations in the freshwater and upper estuarine zone. Mercury, nickel and, zinc exceeded ERMs in some locations.

Bioassay results were highly variable. Significantly elevated amphipod mortality was observed at only 3 stations, which were among the most polluted with heavy metals and PAHs. Significant toxicity in the sea urchin fertilization test was limited to saline stations. The Microtox® results were the most variable of the toxicity bioassays both in terms of response level and distribution of significant responses. The most extreme values were from the vicinity of the C&D canal. The P-450 results were significant primarily in the freshwater strata and upper estuarine stations. This bioassay tracked very closely with PAH concentrations and chlorinated dioxins, furans, and/or PCBs regardless of salinity.

A total of 20,060 organisms, representing 239 taxa, were identified from the all sites, including the small watershed, special study samples. A small proportion of stations contained a large number of species that were very limited in spatial distribution. This makes interpretation of the data difficult using conventional statistical methods. Organism density was highly skewed with respect to the density of individual taxa within stations, and between stations as a whole. High density stations were generally dominated by very large numbers of an individual taxon. There was no apparent pattern, with high and low density stations in all salinity zones. Most of the freshwater stations were dominated by Tubificids and/or *Limnodrilus hoffmeisteri,* which are commonly regarded as pollution indicator taxa. Species diversity and abundance were generally lowest in the freshwater/saltwater interface zone.

Because chemical concentrations tended to be either high or low for all constituents at a given station, interpretation of benthic community and toxicological results is difficult. Direct statistical correlations of toxicity with individual chemical constituents were only discernable where concentrations were at the extremes of observed concentrations. Significant bioassay results tended to be highest at stations with high pollutant concentrations, but not all stations with high concentrations showed high responses. This was interpreted as an indication that organisms can tolerate chemical contamination up to a certain threshold level, beyond which effects are observable. Below these levels, the relationships are influenced by a myriad of other factors.

Species richness was strongly correlated with grain size. The majority of the biologically diverse stations were found on the continental shelf in coarse grained sediment, with some estuarine stations demonstrating this trend also. This relationship between species richness and sediment texture may prove to be a useful modifying factor in assessing coastal community indices, similar to how TOC and grain size are used to normalize organic contaminants and metals concentrations. Animal abundance however, did not follow the trend, but rather peaked in fine grained sediments. The relationship between sediment texture and abundance or number of species did not apply in the freshwater strata. This may be due to a combination of factors ranging from altered grain size characteristics due to dredging to altered species composition due to contaminant impacts and structural habitat alterations.

INTRODUCTION

This report summarizes the results of NOAA's sediment toxicity, chemistry, and benthic community studies in the Delaware Bay estuary and contiguous areas. It is a component of the National Status and Trends (NS&T) Program for marine environmental quality. This program encompasses a broad spectrum of research and monitoring studies to evaluate sediment contamination and toxicity in U.S. coastal waters, including the long-term, nationwide monitoring of contaminant levels in sediments and bivalves; sediment toxicity assessments in specific coastal areas; the evaluation and application of biomarkers; and the development of ecological indices (NOAA, 1998). The National Status and Trends Program has conducted sediment toxicity assessment studies in coastal water bodies since 1991. The sites for sediment toxicity assessment studies are selected based on a variety of parameters, including: (1) a high level of contamination in oysters or mussels as determined by NOAA's NS&T Program; (2) the likelihood of adverse biological effects of contamination based on state and local environmental data; and (3) collaboration with other federal, state, and local agencies.

Sediment contamination in U.S. coastal areas is a major environmental issue because of its potential toxic effects on biological resources and often, indirectly, on human health. A large variety of contaminants from industrial, agricultural, urban, and maritime activities are associated with bottom sediments, including synthetic organic chemicals, polycyclic aromatic hydrocarbons (PAHs), and trace metals.

Critical habitats and food chains supporting many estuarine fish and wildlife species involve the benthic environment. Contaminants in the sediments often pose both ecological and human-health risks through degraded habitats, loss of fauna, propagation of contaminants in the coastal ecosystem, and human consumption of contaminated fish and wildlife. In many instances, fish consumption advisories are coincident with severely degraded sediments in coastal water bodies. Thus, characterizing and delineating areas of sediment contamination and toxicity are viewed as important goals of coastal resource management.

Macrobenthic organisms play an important role in the estuarine environment. As major secondary consumers in the estuarine ecosystem, they represent an important link between primary producers and higher trophic levels for both planktonic and detritus-based food webs. They are a particularly important food source for juvenile fish and crustaceans. Macrobenthic filter feeding activities can remove large amounts of particulate material from the water, especially in shallow (<10 m) estuaries, improving water quality by increasing water clarity and limiting phytoplankton production. Benthic assemblages are composed of diverse taxa with a variety of reproductive modes, feeding guilds, life history characteristics, and physiological tolerances to environmental stressors, both natural and anthropogenic. Responses of some species (e.g., organisms that burrow in or feed on sediments) are indicative of changes in sediment quality. Benthic species composition, abundance, and biomass also are influenced by habitat conditions including salinity and sediment type. Distributions of benthic organisms, however, are predictable along estuarine gradients and are characterized by similar groups of species over broad latitudinal ranges. Information on changes in benthic population and community parameters due to habitat characteristics can be useful for separating natural variation from changes associated with human activities. Furthermore, most benthic species have limited mobility and cannot physically avoid stressful environmental conditions. Benthic assemblages thus cannot avoid and must respond to many stressors such as toxic pollution, eutrophication, sediment quality, habitat modification, and seasonal climate changes. Benthic community studies have a history of use in regional estuarine monitoring programs and have been proven to serve as an effective indicator for describing the extent and magnitude of pollution impacts in estuarine ecosystems, as well as for assessing the effectiveness of management actions.

NOAA uses a suite of sediment toxicity tests to assess different modes of contaminant exposure (bulk sediment, sediment porewater, and chemical extracts of contaminants from sediment) to a variety of species (invertebrates, bacteria, and vertebrate cells) and different assessment end-points (i.e., mortality, impaired reproduction, physiological stress, and enzymatic response). Since the test results are not necessarily axiomatic and biological effects of contaminants occur at different levels of biological organization, i.e., from cells to ecosystems, results from a suite of toxicity tests are used in the "weight of evidence" context to infer the incidence and severity of environmental toxicity (Chapman, 1996). Typically, the amphipod mortality test, the sea urchin fertilization impairment test, the Microtox test, and, in recent years, a Human Reporter Gene System (HRGS) test are used in each study area. Other tests -- based on promising new techniques, full life-cycle tests, and genotoxicity – have also been used in some area on a trial basis or in response to a specific information need.

SITE DESCRIPTION

Delaware Bay is one of the largest drowned river valley coastal plain estuaries on the US east coast. To characterize the entire system, samples were taken from offshore stations on the continental shelf north and south of the bay mouth, throughout the open bay, up the estuary into tidal fresh areas and up to the fall line. Dilution of sea water by fresh water flow is evident on the continental shelf beyond the mouth of the bay. Within the bay, salinity is generally above 20 ppt up to the region where the bay begins to narrow near Money Island. Salinity steadily decreases in the upstream direction toward Philadelphia. The water column may exhibit salinity stratification but is generally well mixed to the bottom, even in the channel areas during storms. From southern Philadelphia upstream, the river is tidal fresh. Outside of three relict river channels and actively dredged areas, most of the bay is less than 10 m deep. The ancient river channels range from less than 10 to 46 m deep and run north-west from the mouth of the bay. At the mouth of the bay, Cape May shoals restrict the entrance to the bay on the north side, with characteristic flood tidal shoals behind it. Tidal flow velocities are strongest in the channels, and net sediment flux is actually in the upstream direction in the main bay area because ebb tidal velocities are relatively weaker due to the shoreline configuration and Coriolis effects (Knebel, 1989). Sediments in the central bay are characteristically coarser in grain size, and the bathymetry exhibits distinct sand wave and sand ribbon patterns perpendicular to channels and boundary shoals from prehistoric river levees. Broad flat shoals in the south and the large north-east expanse of the bay are characteristically fine grained depositional zones with few bathymetric features. Further upstream, the estuary narrows significantly and the influence of lateral water movement on depositional patterns is reduced.

The major source of freshwater input is from the Delaware River. The watershed drains portions of New York, Pennsylvania, New Jersey and Delaware. The largest tributary is the Schuylkill River, which joins the Delaware River in Philadelphia. It is a major source of both conventional and toxic contaminants, including PCBs. Philadelphia is one of the oldest and largest urban centers on the US east coast with a metropolitan area population over 1.5 million. Philadelphia has numerous municipal point and non-point source releases, industrial and petrochemical discharges, and extensive commercial and naval ship traffic and port facilities. Trenton, NJ, Camden, NJ, and Wilmington, DE are also industrial centers with numerous municipal and industrial contaminant sources. Three of the basin's States maintain fish consumption advisories due to PCBs and chlorinated pesticides.

Methods

SAMPLING DESIGN

NOAA uses a stratified-random design for selection of sampling sites to determine the spatial extent of sediment toxicity in US coastal waters. The study area is divided into well-defined sampling strata (or sub-populations) and sampling sites within each substratum are selected on a random basis. This type of sampling allows some control of spacing of samples in the study area. Data generated within each stratum can be attributed to the dimensions of the stratum. Therefore, these data can be used to estimate the spatial extent of toxicity with a quantifiable degree of confidence (Heimbuch et al., 1995). Strata boundaries were established by NOAA in consultation with regional scientists and resource mangers, including the Delaware River Basin Commission, and were based on bathymetric, hydrographic, regional environmental considerations and, previous studies (e.g. EMAP). In large study areas with considerable heterogeneity, the number of strata can be quite large. The minimum number of sampling sites within each stratum is three. Three randomly selected alternate sites were also selected for each primary sampling site. In well-studied areas, such as Delaware Bay, sampling strata are defined after consideration of several environmental factors. Such factors included knowledge of geochemical reservoirs, sediment grain size distribution, hydrographic model results, organic carbon and total sulfur maps, distribution patterns of benthic fauna, occurrence of seasonally anoxic conditions, and regional contamination databases indicating potential problem areas. Even with several factors such as these, water depth and sediment grain size predominate in the separation of strata.

The study area, including the contiguous continental shelf and freshwater reaches up to the fall line, was divided into 20 strata (Figure 1). The upper six strata (19, 20 and, 1-4) contained 18 sampling stations in the tidal freshwater zone above and below Philadelphia (Figure 2). Strata 5-12 encompass the mixing zone (Figure 3) and exhibit steadily increasing salinities in the downstream direction and into the open portion of Delaware Bay. Strata 13 and 14 (Figure 4) comprise the wide portion of the main bay. Strata 15-18 were located on the continental shelf (Figure 5), and contained stations from above Cape

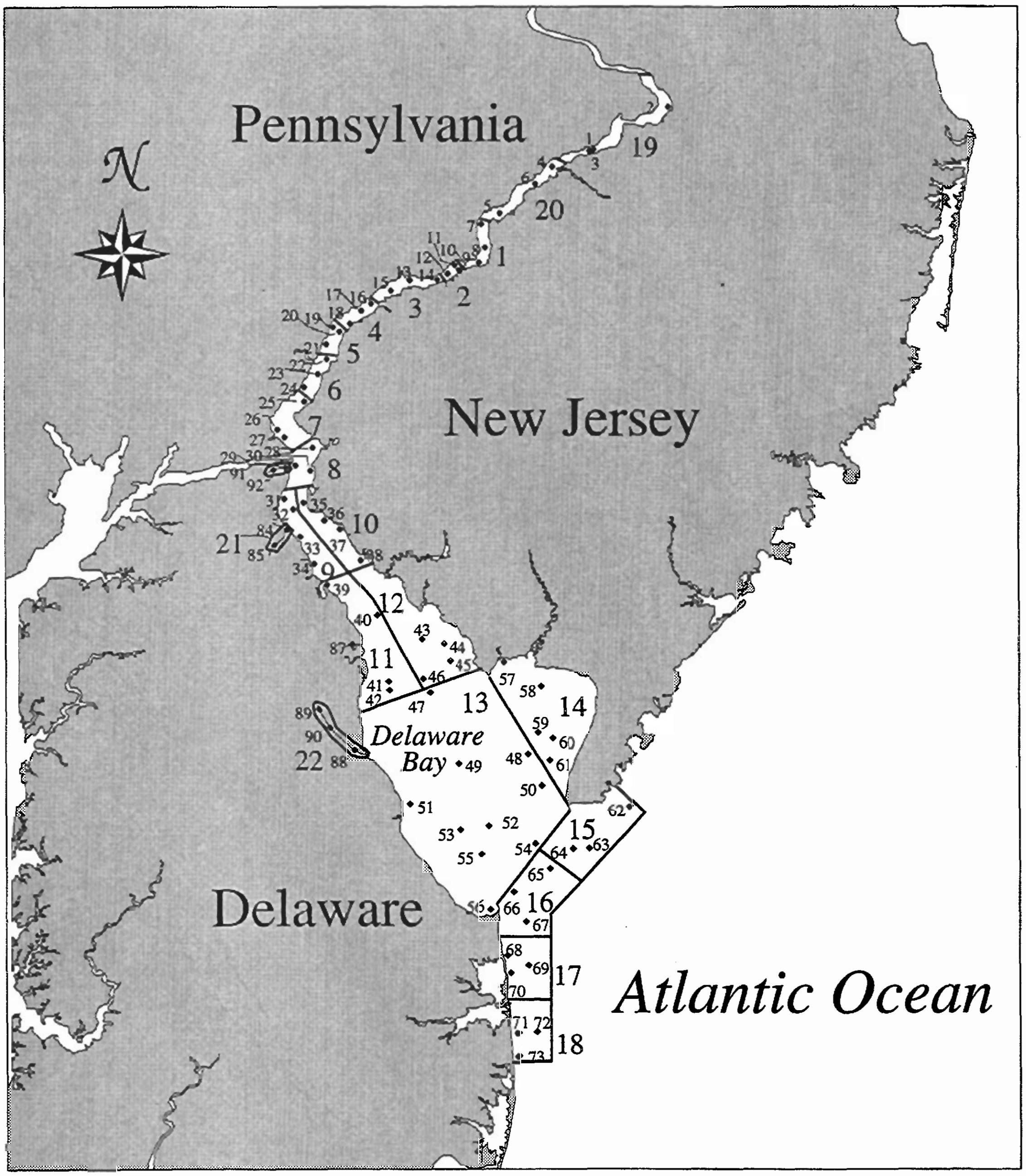


Figure 1. Sample strata and stations in Delaware Bay and surrounding areas.

Delaware Bay Sampling Stations

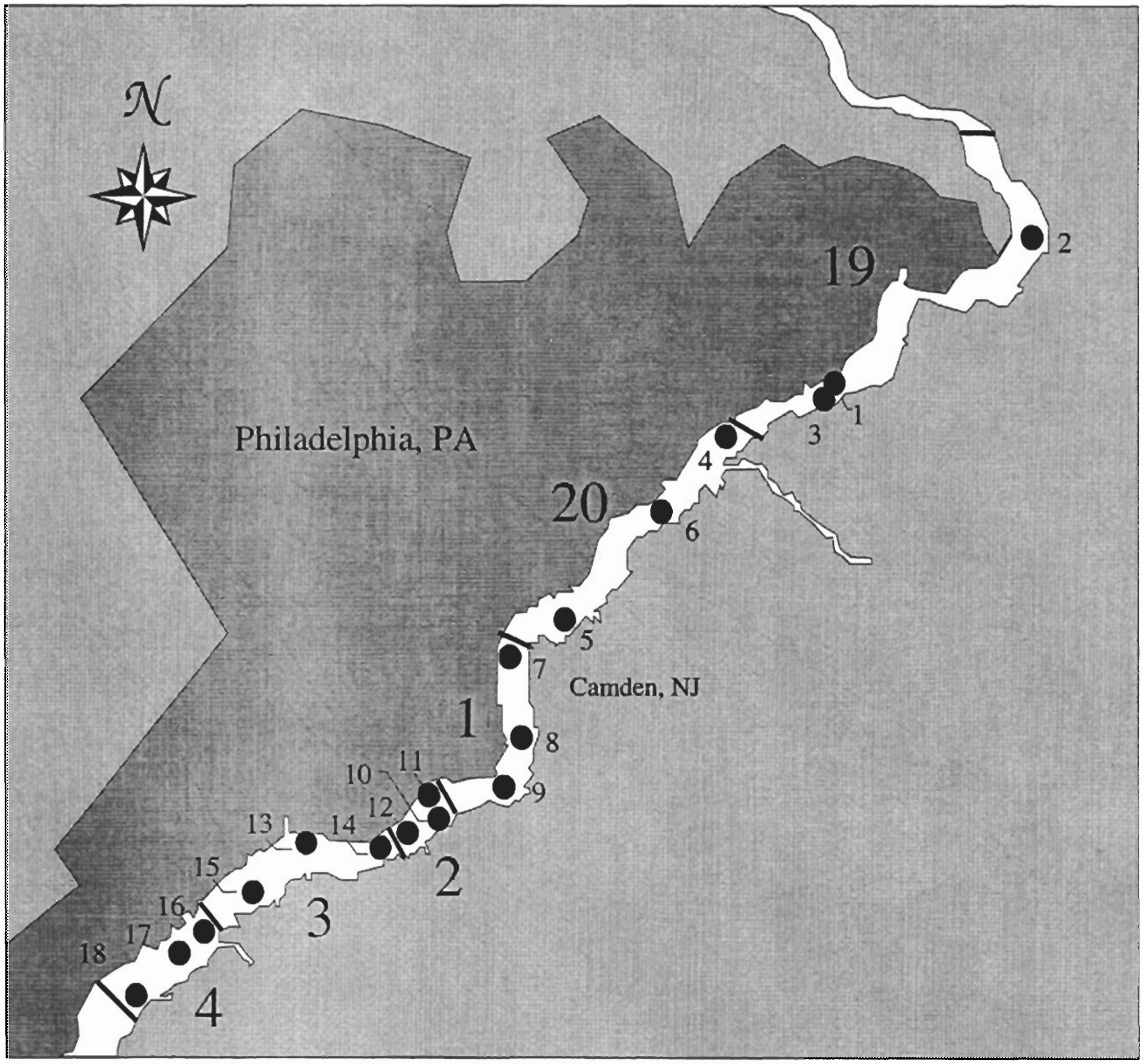


Figure 2. Sample stations in strata 1 through 4, 19 and 20.

Delaware Bay Sampling Stations

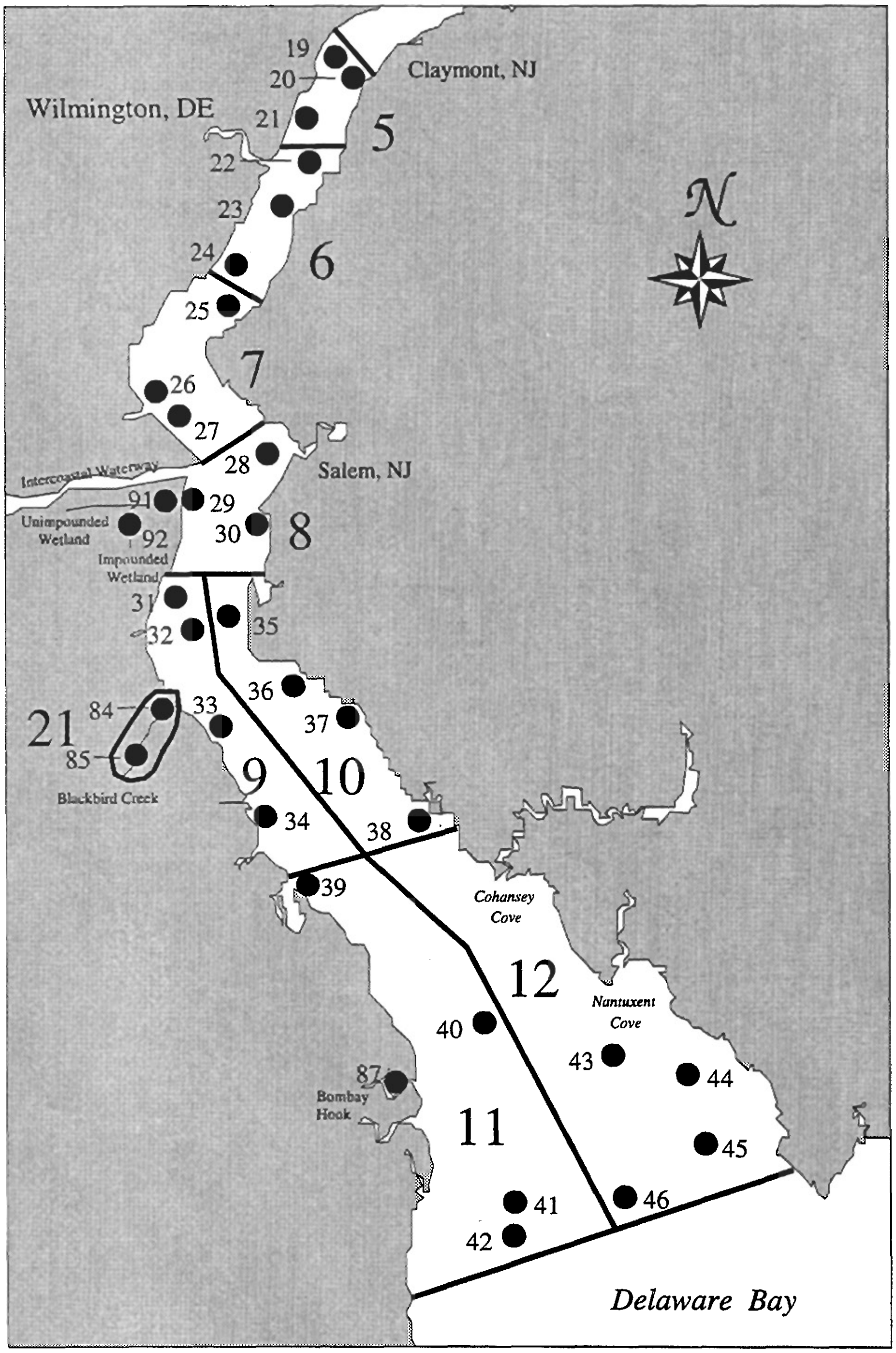


Figure 3. Sample stations in strata 5 through 12 and 21.

Delaware Bay Sampling Stations

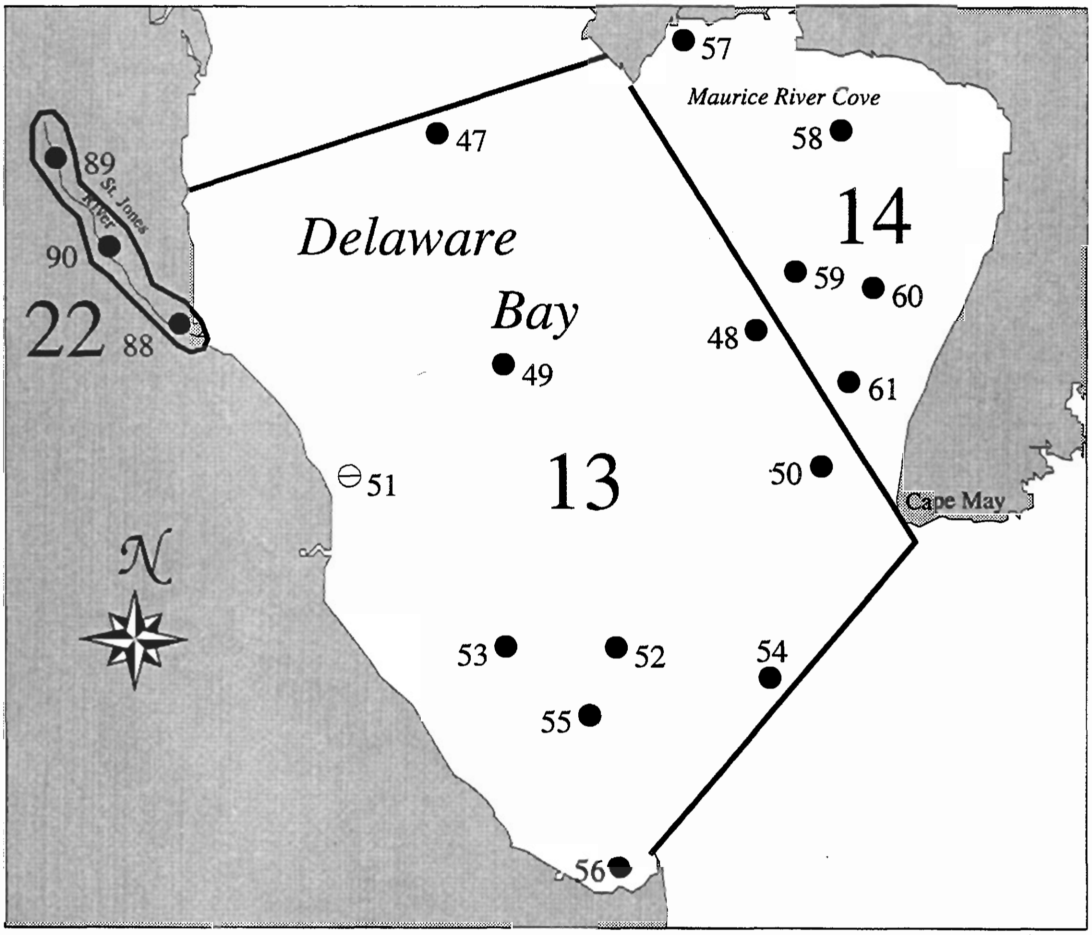


Figure 4. Sample stations in strata 13, 14 and 22.

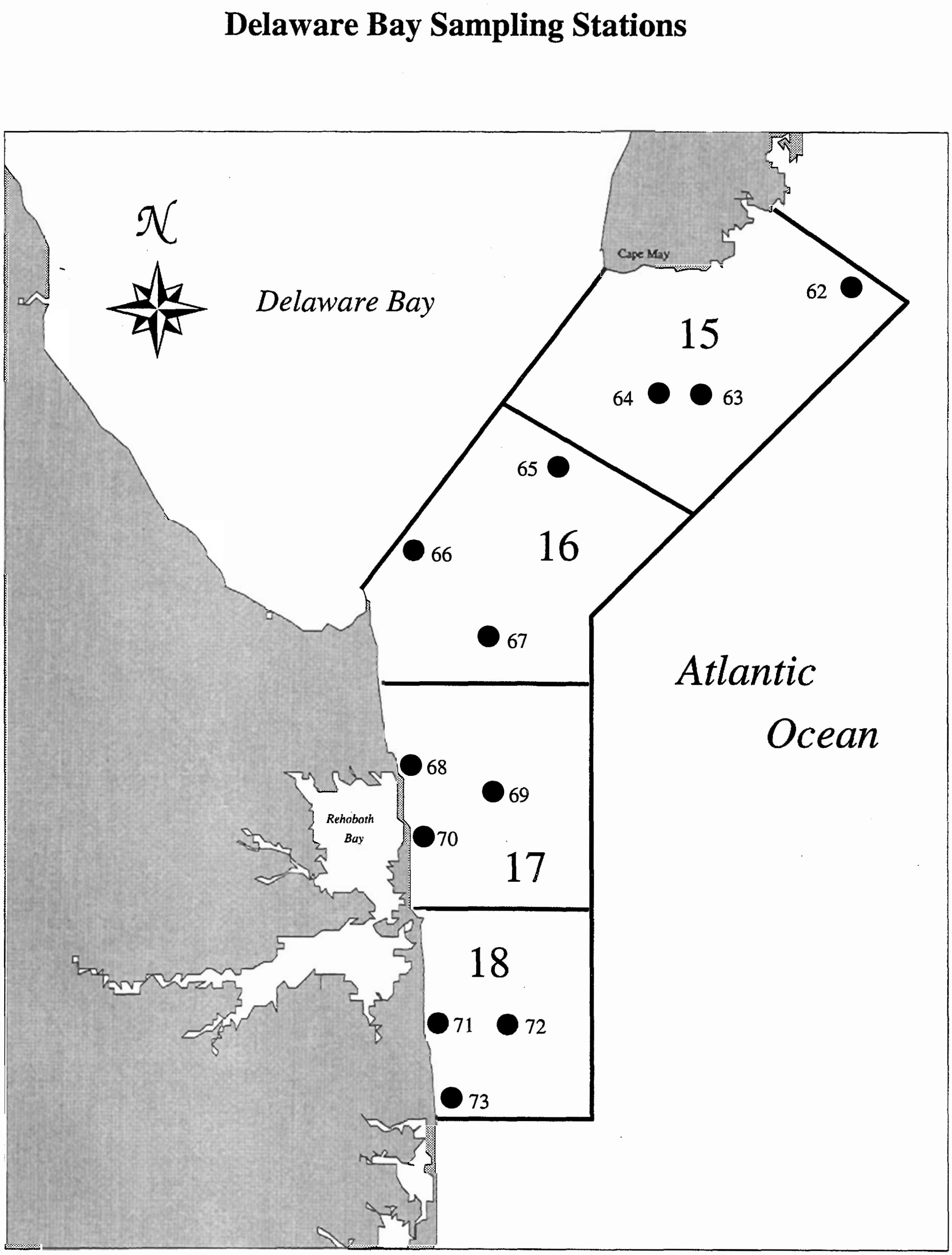


Figure 5. Sample stations in strata 15 through 18.

May to the north of the mouth of the bay, to below Cape Henlopen beyond the Rehoboth and Indian River Bays.

In addition, small watershed sampling sites are also included in the sampling design. These sampling stations were included in the field sampling program as special project areas to address site-specific inquiries. As such, they do not represent main-bay strata, and are not the prime consideration in this report except as contrasted with mainstem conditions. These areas included a pair of wetland areas (sites 90 and 91), one impounded and one not, which were selected to assess the relative contribution of suspended particulates versus other sources to sediment contaminant loads in the estuarine shallows. St Jones Creek and Blackbird Creek (sites 88-90 and 84-85 respectively) make up the Delaware NOAA Estuarine Research Reserves. St Jones creek is heavily impacted by the city of Dover, Del. and Dover Air Force Base. Bombay Hook (site 87) was selected to represent a relatively pristine site, as a large portion of the watershed estuarine is a wildlife refuge. While the ecological importance of small sub-estuaries is recognized, the prime focus of the sampling effort was the mainstem, and smaller tributaries did not receive the comprehensive coverage necessary to assess the condition of the shallow tidal component of the system.

This sampling approach, even though geographically comprehensive, does not account for temporal variability. Sampling was conducted during the July-September period when the flora and fauna, notably juveniles and adults, are most abundant, and between-year variability during this period is likely to be low. This is consistent with the Environmental protection Agency's approach for the Environmental Monitoring and Assessment Program for estuaries (Paul, et al., 1999).

FIELD SAMPLING PROCEDURES

Three sediment samples were taken at each site in addition to a CTD profile or YSI readings at the surface and bottom of the water column. Samples were collected with a modified Van Veen grab sampler. At each site the sampler was rinsed with acetone and seawater prior to sampling.

The first sample was used to determine sediment characteristics and subsamples were taken from the top 3 cm for total organic carbon (TOC), grain size and, water content analyses. A second sample was taken for benthic community analysis. The entire sample was sieved on site through 0.5mm mesh. All organisms were retained in 500/2500 ml plastic Nalgene bottles and preserved in buffered formalin containing Rose Bengal. Additional grab samples were taken and the top 3 cm of sediment was collected and composited until sufficient volume (7-8 L) of sediment for all the toxicity bioassays and chemical analyses was collected. This composite sample was thoroughly homogenized on site, and subdivided for distribution to various testing laboratories. All subsamples were either stored on ice or frozen, as appropriate, prior to shipment.

On occasion, when the primary site could not be sampled, the alternative sites were sampled. Reasons for not sampling the primary sites included the site being too shallow, manmade obstructions, the location had no depositional sediments, or there was no dredging or anchoring allowed in the area.

SEDIMENT TOXICITY BIOASSAYS

A summary of the toxicity bioassay methods is presented below. Detailed methods are found in Hameedi , 2000. All methods are based on standard methods promulgated by the EPA, ASTM, and/or APHA.

Amphipod Survival Test

This test is commonly used in North America for assessing sediment quality, in part because the test integrates the effects of complex contaminant mixtures in relatively unaltered sediment and also because amphipods are fairly common and ecologically important species in coastal waters. *Ampelisca abdita* is the most commonly used species in NOAA's studies. This euryhaline species occurs in fine sediments from the intertidal zone to a depth of 60 m, with a distribution range that extends from Newfoundland to south-central Florida, and includes the eastern Gulf of Mexico, and portions of the California coast. *Ampelisca abdita* builds soft, membranous tubes and feeds on surface deposited particles as well as particles in suspension.

The tests are conducted in accordance with a standard guide for conducting 10-day static sediment toxicity tests with amphipods (ASTM 1992) and additional guidance developed for testing four different amphipod species (EPA 1994). Briefly, amphipods are exposed to test and control sediments for 10 days under static conditions. The bioassays include 5 replicates, with 20 animals per replicate. During the test, the animals are exposed to constant light in filtered, aerated seawater. The test chambers are quart-sized (ca. 1 L), glass vessels, containing 200 mL of sediment. The vessels were monitored daily for water temperature and condition of test organisms. Measurements for salinity, dissolved oxygen, ammonia, and pH are made at least twice during the course of the experiment. On occasion, hydrogen sulfide in sediment pore water is also measured.

A positive control, or reference toxicant test, was used to document the sensitivity of each batch of test organisms. In most instances, a commonly used industrial chemical, sodium dodecyl sulfate (SDS), also known as sodium lauryl sulfate, was used in 96-hour water-only exposure bioassay as a control test. The LC_{50} results were recorded in a control chart, and are expected to be within 2 standard deviations of the mean of the previous 20 positive control tests.

Based on statistical analyses of amphipod survival data, including power analysis, two criteria are used to declare a sample mean LC_{50} to be different from the control mean: first, the t-test must show that the sample survival is statistically lower than in the control (marginally toxic), and second, the sample's mean survival must also be equal to less than 20% of that in the control (highly toxic) (Thursby, et al., 1997)

Sea Urchin Fertilization Toxicity Test

This test is used extensively in assessments of ambient water quality, toxicity of industrial and municipal effluents, and sediment toxicity in coastal waters. It combines the features of testing sediment pore waters (the phase of sediments in which dissolved toxicants may be bioavailable) and exposures to gametes or early life stages of invertebrates which often are more sensitive than the adult forms.

Pore water is extracted from the sediment by using a pneumatic extraction device. The extractor is made of polyvinyl chloride and uses a 5 µm polyester filter. After extraction the sample is centrifuged, and the supernatant collected and frozen at –20 °C. Prior to commencing the experiment, samples are thawed in a water bath, and water quality measurements are made (dissolved oxygen, pH, sulfide, and ammonia). Each porewater sample is tested in a dilution series (100%, 50% and 25%) with five replicates per treatment. A reference porewater sample collected from Redfish Bay, Texas is included with each test as a negative control.

The sea urchin (*Arbacia punctulata*) fertilization toxicity test (also known as the sperm cell test) involves exposing sea urchin sperm to pore water followed by the addition of eggs. At the test's conclusion, the fraction of fertilized eggs (eggs showing fertilization membrane) is recorded. Sodium dodecyl sulfate (SDS) is used as a positive control toxicant. Reduction in mean fertilization success after exposure to pore water, in comparison with the negative control, is the experimental end-point. A general outline of the pore water extraction procedure and testing protocol is given by Carr (1998).

Statistical treatments of data include analysis of variance and Dunnett's one-tailed t-test on the arcsine square root transformed data. The trimmed Spearman-Karber method with Abbott's correction is used to calculate EC_{50} (concentration that is effective in causing a 50% response in a toxicity test) values based on dilution series tests. In addition to statistically significant differences with control sediment, a detectable significance criterion is used to determine the 95% confidence value based on power analysis of data from similar tests. This value is the percent minimum significant difference from the reference that is necessary to detect a difference from the reference: at ($\alpha = 0.05$, it is 15.5%, and at $\alpha = 0.01$, it is 19% (Carr and Biedenbach, 1999).

Microtox ®Test

This test is based on the premise that in a particular strain of the bacterium *Vibrio fischeri* (B-11177), bioluminescence is closely tied to cellular respiration, and any inhibition of cellular activity results in a decreased rate of respiration and a corresponding decrease in luminescence. The test has certain advantages: it is simple, rapid, reproducible and inexpensive; there are published data on the Microtox® response (EC_{50} values) upon exposure to over 1,000 chemicals (for a sampling, see Johnson and Long, 1998). For these reasons, this test is used worldwide, mostly as a screening test but in some instances as a government-approved regulatory test as well, such as testing of oil well drilling fluid toxicity (Qureshi, Bulich, and Isenberg, 1998).

NOAA uses Microtox® response to an organic extract of surficial sediment. Sediment is extracted and processed within 10 days following collection in accordance with the EPA Method 3550. Details of the extraction procedure are provided elsewhere (EPA, 1996; Johnson and Long, 1998). Briefly, after removal of debris and pebbles, the sediment is homogenized, dried with anhydrous sodium sulfate, and 20 g of sediment is extracted by sonication with dichloromethane (DCM). The extract is concentrated under nitrogen, and exchanged into mixture of dimethylsulfoxide (DMSO), toluene and isopropyl alcohol (2:1:1) to achieve a final volume of 2 mL. The 2 mL extracts are split into two 1 mL vials for testing with the Microtox® and P450 HRGS assays (below). Before testing, the extracts are diluted 1:10 with DMSO to produce the proper dilution series. The extraction procedure is well suited for extraction of neutral, non-ionic organic compounds, such as aromatic and chlorinated hydrocarbons. Extraction of other classes of toxicants, such as metals and polar organic compounds, is not efficient. DMSO is compatible these tests because of its low toxicity and high solvent properties with a broad spectrum of nonpolar chemicals.

Light emission is measured with a luminometer after 5 minutes of incubation. Percent decrease in luminescence relative to the reagent blank is calculated. The standard dose-response curve method is used to determine EC_{50} values: EC_{50} denotes the concentration that is effective in causing a 50% reduction in light production and expressed as mg equivalent sediment wet weight/mL. All EC_{50} values are based on average readings with 95% confidence intervals for the replicates. Each sample was tested in triplicate.

A negative control (extraction blank) was prepared using DMSO, the test carrier solvent. Tests of sediment extract from Redfish Bay, Texas were used as a reference standard. A phenol spiked Redfish Bay extract was used as negative control standard. Sample EC_{50} s were normalized to the Redfish Bay extract EC_{50}. Any sample with an EC_{50} significantly ($P \leq 0.05$) lower than the controls indicated marginal toxicity. Samples with an EC_{50} significantly below the phenol-spiked standard were considered highly toxic.

Human Reporter Gene System (Cytochrome P450) Response

This test is used to determine the presence of organic compounds that bind to the Ah (aryl hydrocarbon) receptor and induce the CYP1A locus on the vertebrate chromosome. Under appropriate test conditions, induction of CYP1A is evidence that the cells have been exposed to one or more of these xenobiotic organic compounds, including dioxins, furans, planar PCBs, and several polycyclic aromatic hydrocarbons. Differences in the ability of the P450 enzyme to metabolize chlorinated and non-chlorinated compounds allow for differentiation between these classes of compounds in environmental samples. Since most PAHs are rapidly metabolized, they exhibit a maximum response in 6 hours, at which point the response begins to fade. Chlorinated hydrocarbons (dioxins, furans, and certain PCBs), on the other hand, are not degraded and continue to induce CYP1A and do not show a maximum response until 16 hours after exposure.

The details of this test are provided as a standard method, Method 4425, of the US Environmental Protection Agency (EPA, 1999), the American Public Health Association (APHA, 1998) and American Society of Testing and Material (ASTM, 1999). The test uses a transgenic cell line (101L), derived from the human hepatoma cell line (HepG2), in which the flanking sequences of the CYP1A gene, containing the xenobiotic response elements (XREs), have been stably linked to the firefly luciferase gene (Postlind, et al. 1993). As a result, the enzyme luciferase is produced in the presence of compounds that bind the XREs. Briefly, a small amount of organic extract of sediment, prepared as described for the Microtox® test, is applied to cell cultures. Detection of enzyme induction in this assay is relatively rapid and simple to measure since binding of a xenobiotic with the Ah receptor results in the production of luciferase.

After 16 hours of incubation with the extract, the cells are washed and lysed. Cell lysates are centrifuged, and the supernatant is mixed with buffering chemicals. Enzyme reaction is initiated by injection of luciferin. The resulting luminescence is measured with a luminometer and is expressed in relative light units (RLUs). A solvent blank and a reference toxicant (TCDD at a concentration of 1 ng/mL) are used with each batch of samples.

The relative increase in RLU over background (enzyme fold induction) is calculated as the mean RLU of the test solution divided by the mean RLU of the solvent blank. From the standard concentration-response curve for benzo[a]pyrene (B[a]P), the HRGS response to 1 μg/mL is approximately 60. Data are converted to μg of B[a]P equivalents per g of sediment using this factor. Since testing at only one time interval (16 h) does not allow discrimination between PAHs and chlorinated hydrocarbons, the data are also expressed as Toxic Equivalents (TEQs) in ng/g based on a standard curve with a dioxin/furan mixture.

Quality control tests are run with clean extracts spiked with tetrachlorodibenzo-p-dioxin (TCDD) and B[a]P to ensure compliance with results of previous tests. Tests are rerun if the coefficient of variation for replicates is greater than 20%, and if fold induction is over the linear range (100 fold). Sediment extracts from Redfish Bay, Texas, were used as a negative control. For samples in which fold induction (=sample/solvent blank) was 100 or greater, a dilution series was conducted to obtain final response values. In addition, these tests were evaluated at both 6 and 16 hrs incubation to assess the relative contribution of PAHs as opposed to chlorinated dioxins, furans and, PCBs to the observed responses.

There are no clearly defined assessment end-points for P450 induction that signify a threshold of biological damage, and statistical procedures must be employed to arrive at decision points. Two parameters that have been employed are confidence intervals and prediction intervals.

Anderson, et al. (1999a) calculated the mean and 95% confidence interval of HRGS values from 527 sampling points in the NOAA biological effects database to be 22.7 $\pm$ 10.1 (CI=12.6-32.8) mg B[a]PEq/kg. Hence, values less than 12.6, forming the tail of the distribution in the direction of low induction (or impact), could be interpreted as a minimal (background) level. This is consistent with data from pristine sites in Alaska and California where HRGS values did not exceed 10.4 mg B[a]PEq/kg (Anderson, et al., 1999b; Fairey, et al., 1996).

Excluding the upper 10% of the NOAA data points (considered impacted) the upper 80% prediction limit (Hahn and Meeker, 1991) is 11.12 mg B[a]PEq/kg. That is, there is an 80% probability that a future observation from the distribution will be less than 11.12. Given these observations, it can be surmised that HRGS induction values below 10 mg B[a]PEq/kg represent background conditions in estuarine waters. Fairey et al. (1996) also demonstrated that HRGS values above 60 mg B[a]PEq/kg were highly correlated with degraded benthic communities in San Diego and Mission Bays and also PAH concentrations above the 9,600 ug/kg Probable Effects Level (PEL) guideline (McDonald, 1993). Based on these data, HRGS values greater than 10 and 60 mg B[a]PEq/kg were considered to represent marginal and highly contaminated thresholds, respectively.

CHEMICAL ANALYSES

Metals

Sediment samples were stored frozen until processing and analysis. Samples were prepared for atomic absorption analysis and activation analysis by freeze drying and wet digestion. Dried sediment samples were homogenized, weighed and digested in a sequence of heating steps in Teflon bombs with HNO_3, HF and, boric acid. Analyses were performed using either flame or graphite furnace atomic absorption spectroscopy (AAS), (Table 1). A 20-fold dilution was made for flame AAS analysis of Al, Fe, Mn, Si, and Zn. Digested solution was diluted 20:1 with an acidified seawater solution containing 2:1:17 proportions of seawater:HNO_3:deionized water for graphite furnace AAS analyses of the remaining analytes except Hg. Recalibration standards were run every 12 samples, and matrix modifiers were used as necessary.

For analysis of Hg, sediment samples were digested using a modified version of EPA method 245.5, using a concentrated H_2SO_4 and HNO_3 digestion, followed by addition of $KMnO_4$, and $K_2S_2O_8$, and the samples were again digested. Before analysis, 5 mL of 10% (w/w) $NH_2OH \cdot HCl$ were added to reduce excess permanganate and the volume brought to 40 mL with distilled water.

TBT

An aliquot of freeze dried sediment was weighed and appropriate amounts of surrogate standards (approximately 10 times the method detection limit, MDL) were added to all samples, matrix spikes, and blanks. Samples were extracted three times by agitation with tropolone in dichloromethane. The sample extract was concentrated in a hot water bath, and the extract was centrifuged and further concentrated. The solvent was exchanged to hexane and concentrated to a final volume of about 10 - 20 mL at which point only hexane remained. Hexylmagnesium bromide (2 M; Grignard reagent) was added to the sample extract under nitrogen and heated to hexylate the sample. After separation from the organic phase, pentane:CH_2Cl_2 (3/1, v/v) was added to the aqueous phase and the

Table 1. Elemental quantification techniques by matrix.

Analyte	Method
Mercury	CVAA
Aluminum	FAA
Iron	FAA
Manganese	FAA
Zinc	FAA
Arsenic	GFAA
Cadmium	GFAA
Chromium	GFAA
Copper	GFAA
Lead	GFAA
Nickel	GFAA
Selenium	GFAA
Silver	GFAA

CVAA - Cold vapor atomic absorption
FAA - Flame atomic absorption
GFAA - Graphite furnace atomic absorption

sample shaken vigorously. The pentane:CH_2Cl_2 extraction was done twice. The hexylated extract was dried by addition of anhydrous Na_2SO_4 and then concentrated. The extract was purified using silica gel/alumina column chromatography. The eluent was collected and concentrated on a water bath.

The quantitative method was based on high resolution, capillary gas chromatography using flame photometric detection (GC/FPD). This method quantitatively determined tetrabutyltin (4BT), tributyltin (TBT), dibutyltin (DBT) and monobutyltin (MBT).

Quality control samples were processed in a manner identical to actual samples. A method blank was run with every 20 samples, or with every sample set, whichever was more frequent. If corrected blank concentrations for any component were above three times MDL, the whole sample set was re-extracted and reanalyzed. If insufficient sample was available for re-extraction, the data was reported and appropriately qualified. Matrix spike/matrix spike duplicate (MS/MSD) samples were run with every 20 samples, or with every sample set, whichever was more frequent. The appropriate spiking level was ten times the MDL. Reference materials were extracted with each set of sample and were analyzed when available. The method detection limit was determined following the procedures outlined in CFR 40, part 136 (1999).

Organics (PAHs, PCBs, chlorinated pesticides, furans and dioxins)

Sediment was collected and stored in precleaned glass jars and frozen. Samples were shipped frozen to the laboratory and stored at -20 °C until analysis. An aliquot of approximately 1 g of sample was weighed and oven dried at 63 - 56 °C to constant weight to determine wet/dry weight.

For analyses, an aliquot of homogenized sample was chemically dried with sodium sulfate. After samples were spiked with surrogates the samples were extracted in a Soxhlet apparatus with dichloromethane on a hot sand bath for 8 hr. If sediment or other particulates were present in the sample extract, the extracts were filtered through a funnel containing glass wool and sodium sulfate. The sample extract was then concentrated and solvent changed to about 2 mL of hexane. Silica gel/alumina column chromatography was utilized to concentrate and purify the samples before analysis. Quality control samples were processed with each batch of samples in a manner identical to the samples, including matrix spikes. Extracts were stored in the dark at or below 4 °C.

A method blank was run with every 20 samples, or with every sample set, whichever was more frequent. If blank levels for any component were above three times MDL, samples analyzed in that sample set were re-extracted and reanalyzed. If insufficient sample was available for extraction, the data was reported and appropriately qualified. Matrix spike/matrix spike duplicate samples were run with every 20 samples, or with every sample set, whichever was more frequent. Surrogate standards were spiked into every sample and quality control sample.

Quantitation of PAHs and their alkylated homologues was performed by gas chromatography mass spectrometry (GC/MS) in the selected ion monitoring (SIM) mode. Target analytes are listed in Table 2. The compounds in the surrogate solution were deuterated naphthalene-d_8, acenaphthene-d_{10}, phenanthrene-d_{10}, chrysene-d_{12} and perylene-d_{12}. The internal standards were fluorene-d_{10}, and benzo[a]pyrene-d_{12} at 4 µg/mL and were prepared with a certified standard (NIST or equivalent). The GC conditions were set so that the internal standards were resolved, but would elute in close proximity to, the analytes of interest.

A solution containing 2- to 5-ring PAH compounds was used to fortify matrix spike samples. A certified solution (NIST SRM 2260) was diluted to the appropriate working concentration. Dibenzothiophene was not present in the SRM and was added to the solution by weighing neat material to make a concentration of 1.00 µg/µL. The spiking solution was used to fortify samples to a final concentration of approximately ten times the MDL. A solution of a laboratory reference oil was analyzed as an instrument reference solution with each analytical batch. After every 8 - 10 samples, the mass spectrometer response for each PAH relative to the internal standard was determined using check standards. Daily response factors for each compound were compared to the

Table 2. Polynuclear aromatic hydrocarbons analyzed in Delaware Bay sediment samples.

Low Weight ($\leq$ 3 rings) PAHs	**High weight ($\geq$ 4 rings) PAHs**
Naphthalene	Fluoranthene
1-Methylnaphthalene*	Pyrene
2-Methylnaphthalene*	C1-Fluoranthenes/Pyrenes
2,6-Dimethylnaphthalene*	Benzo(a)anthracene
1,6,7-Trimethylnaphthalene*	Chrysene
C1-Naphthalenes	C1-Chrysenes
C2-Naphthalenes	C2-Chrysenes
C3-Naphthalenes	C3-Chrysenes
C4-Naphthalenes	C4-Chrysenes
Biphenyl	Benzo(b)fluoranthene
Acenaphthylene	Benzo(k)fluoranthene
Acenaphthene	Benzo(e)pyrene
Fluorene	Benzo(a)pyrene
C1-Fluorenes	Perylene
C2-Fluorenes	Indeno(1,2,3-c,d)pyrene
C3-Fluorenes	Dibenzo(a,h)anthracene
Phenanthrene	Benzo(g,h,i)perylene
Anthracene	
C1-Phenanthrenes/Anthracenes	
C2-Phenanthrenes/Anthracenes	
C3-Phenanthrenes/Anthracenes	
C4-Phenanthrenes/Anthracenes	
1-Methylphenanthrene	
Dibenzothiophene	
C1-Dibenzothiophenes	
C2-Dibenzothiophenes	
C3-Dibenzothiophenes	

* Individual substituted naphthalenes were not double counted with non-specific substituted naphthalenes.

initial calibration curve and recalibration was repeated when necessary. The standard reference oil was analyzed with all analytical batches.

When available, a standard reference material was extracted and analyzed with each batch of samples. Target concentrations were defined as the range of the certified value plus or minus the 95% confidence intervals found in the SRM certification. The measured concentration was within ±30% of the target concentration on average for all analytes either certified or non-certified with concentrations greater than 10 times the MDL. The actual analytical method detection limit (MDL) was determined following procedures outlined in CFR 40, part 136 (1999).

Chlorinated hydrocarbons (chlorinated pesticides and PCBs, Table 3) were quantitatively determined by capillary gas chromatography with an electron capture detector (ECD). If the response for any peak exceeded the highest calibration solution, the extract was diluted, a known amount of surrogate and tetrachloro-m-xylene (TCMX) solution added, and the sample reanalyzed for those analytes that exceeded the calibration range. Analyte concentrations in the samples were based on calculations using the PCB 103 surrogate. The internal standard (TCMX) was used to calculate surrogate recoveries. 4,4'-dibromooctafluorobiphenyl (DBOFB) or PCB 198 was used to calculate selected analytes concentrations, if it was demonstrated that they produced more reliable data (i.e., if matrix interference occurs with PCB 103) based on percent recoveries in spiked blanks, matrix spikes, or reference materials. The calibration solutions that were analyzed as part of the analytical GC/ECD run were preceded by no more than six samples and no more than six samples were run between calibration mixtures.

An acceptable method blank contained no more than two target compounds at concentrations three times greater than the MDL. All samples and quality control samples were spiked with DBOFB, PCB 103 and PCB 198. The surrogate standard solution was spiked into the samples prior to extraction in an attempt to minimize individual sample matrix effects associated with sample preparation and analysis. A matrix spike and a duplicate were analyzed with each sample set or every 20 field samples, whichever was

Table 3. Chlorinated pesticides and PCBs analyzed in Delaware Bay sediment samples.

Pesticides	PCBs
Hexachlorobenzene	PCB8_5
Alpha HCH	PCB18_17
Gamma HCH	PCB28
Heptachlor	PCB52
Heptachlor Epoxide	PCB44
Oxychlordane	PCB66
Alpha Chlordane	PC101_90
Gamma Chlordane	PCB118
Cis-Nonachlor	PCB153_132
Trans-Nonochlor	PCB105
Aldrin	PCB138 _160
Dieldrin	PCB187
Endrin	PCB128
Mirex	PCB180
Endsulfan II	PCB170_190
2,4'-DDE	PCB195_208
4,4'-DDE	PCB206
2,4'-DDD	PCB209
4,4'-DDD	
2,4'-DDT	**Planar PCBs***
4,4'-DDT	PCB77
	PCB126
	PCB169

*selected stations only

more frequent. The acceptable matrix spike recovery criteria were 50 - 125% recovery for at least 80% of the analytes. Criterion for duplicates was ≤30% relative percent difference (RPD). The method detection limit was determined following the procedures outlined in CFR 40, part 136 (1999). Most target compounds, surrogates and internal standard were resolved from one another and from interfering compounds. When they were not, coelutions were documented. A standard reference material sample was analyzed per batch of samples or every 20 samples whichever was more frequent

Selected samples were analyzed for chlorinated dibenzofurans and dioxins (Table 4). Samples were spiked with fifteen $^{13}C_{12}$- labeled PCDD and PCDF standards for isotope dilution quantitation. Sample cleanup and concentration was accomplished by Soxhlet extraction with toluene, followed by sequential partition of the final hexane extract against concentrated sulfuric acid, aqueous sodium chloride, aqueous potassium hydroxide, and sodium chloride again. Following drying with anhydrous sodium sulfate the sample was concentrated to near dryness on a rotary evaporator. The sample was passed through a silica gel/alumina column chromatography sequence, followed by addition of methylene chloride. The samples were then run through an activated carbon column purification step and eluted with toluene followed by addition of a nonane recovery standard solution containing the recovery standards $^{13}C_{12}$ -1,2,3,4-TCDD and $^{13}C_{12}$ -1,2,3,7,8,9-HxCDD. The analytical method was high-resolution gas chromatography and high-resolution mass spectrometry (HRGC/HRMS). Four mainstem samples were analyzed for dioxins and furans with a matrix spike and duplicate samples.

BENTHIC COMMUNITY ASSESSMENT

<u>Community Indices</u>

Benthic infauna samples were sieved through a 0.5-mm mesh screen and preserved with 10% formalin on-board. In the laboratory, samples were inventoried, rinsed gently through a 0.5 mm mesh sieve to remove preservatives and residual sediment, stained with Rose Bengal, and stored in 70% isopropanol solution until processing. Sample material (sediment, detritus, organisms) was placed in white enamel trays for sorting under Wild

Table 4. Chlorinated dibenzodioxins and dibenzofurans analyzed in selected Delaware Bay sediment samples.

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
1,2,3,6,7,8-HxCDF
2,3,4,6,7,8-HxCDF
1,2,3,7,8,9-HxCDF
1,2,3,4,6,7,8-HpCDF
1,2,3,4,7,8,9-HpCDF
OCDF

M-5A dissecting microscopes. All macroinvertebrates were carefully segregated into major taxonomic group (e.g. Polychaeta, Mollusca, Arthropoda). All sorted macroinvertebrates were identified to the lowest practical identification level (LPIL), which in most cases was to species level unless the specimen was a juvenile, damaged, or otherwise unidentifiable. The number of individuals of each taxon, excluding fragments, was recorded.

Data were reduced to a data summary report for each site, which included a taxonomic species list and benthic community parameters information. Archive data files of species identification and enumeration were prepared. At a minimum, 10 percent of all samples were resorted and recounted on a regular basis. The minimum acceptable sorting efficiency was 95%. Ten percent of samples were randomly selected and re-identified. The minimum acceptable taxonomic efficiency was 95%. A voucher collection composed of representative individuals of each species encountered in the project was accumulated and retained.

Since taxa are distributed along environmental gradients, there are generally no distinct boundaries between communities. However, the relationships between habitats and taxa assemblages reflect the interactions of physical and biological factors and indicate major ecological trends. Quantitative benthic community characterizations included enumeration of density, species richness, evenness, and diversity, followed by pattern and classification analysis for delineation of taxa assemblages. Density was calculated as the total number of individuals per square meter. Taxa richness is reported as the total number of taxa represented at a given site. Taxa diversity, was calculated with the Shannon-Weiner Index (Shannon and Weaver, 1949), using the following formula:

$$H' = -\sum_{i=1}^{S} p_i (\ln p_i)$$

where, S = is the number of taxa in the sample,

i is the i_{th} taxa in the sample, and

p_i is the number of individuals of the i_{th} taxa divided by the total number of individuals in the sample.

Evenness of taxa diversity for a given station was calculated as Pielou's Index J' (Pielou, 1966);

$$J' = H'/ln\ S$$

where 1n S = H'max,

When all taxa are represented by the same number of individuals, $J' = H'/H'_{max}$

Regression Statistics

Summary statistics for all parameters were calculated on a site by site basis, and averaged by strata. Simple scatter plots were produced for all community indices versus toxicity data and chemical constituents, and between toxicity results and contaminants to assess gross correspondence of parameters. Stepwise regression was run in pairwise fashion on benthic community indices, toxicity endpoints and chemical parameters. Toxicity data were log or arc-sine transformed, as appropriate. Contaminant concentration data were run as both linear and log transformed variables. The chemical data were run as broad classes (e.g. metals, PAHs, PCBs, etc.) and in subgroups including individual metals, low and high weight PAHs, alkyl substituted and parent compound PAHs, DDT and metabolites, chlordane and related compounds, TBT, HCH and, HCB. Analyses were run on a matrix of data sets, included the entire data set and data subsets (e.g. fresh, estuarine, oceanic).

RESULTS

Summaries for all data sets are included in the appendices in tabular and location map form. The data are grouped by strata, roughly from upstream to downstream, and then by site number. Not all sites proceed from upstream to downstream, because some alternate sites were sampled due to difficulty at the primary site and some strata are adjacent sections of the estuary. Contaminant data are presented by chemical class. Data are summarized into total concentrations of all parameters measured. Benthic community data are presented on a site by site basis. Biomass was not measured. Bioassay data is presented in map form in only those sections where significant impacts were detected. Conventional sediment characteristics (e.g. grain size, TOC, etc.) and water quality parameters are also presented. Data from additional small watershed sampling sites are also included in the appendices.

HABITAT CONDITIONS

Sediment grain size data for the 73 mainstem sites are shown in Figure 6. Sediment composition varied considerably from 73% silt at site 3 to ≥99% sand at nine sites. The coastal zone sites were primarily sand with some gravel, and the lower estuarine sites were predominantly sand or silty sand. Sites 5, 6 and 15 in the tidal freshwater zone were 99% sand and site 2 was 96% sand. Approximately half of the freshwater and upper estuarine sites were dominated by silt/clay material. In terms of strata, sand dominated in 14 of the 22 strata however, the variability of sediment components of the sites within each stratum is high. Stratum 3 contained the highest percentage of sand at 94.45%. Site 56, near the mouth of the Bay has an unusually large proportion of fine grained material. It is a protected area behind Cape Henlopen, near a temporary anchorage with a constructed breakwater, for ships waiting to proceed to points north.

The total organic carbon (TOC) fraction of the sediment ranged from 0.07% at site 64 to 3.28% at site 29 (Figure 7). Only 17 sites had TOC concentrations above 2%. Site 5 had a TOC value of 2.12% despite being composed of 99% sand. AVS varied widely among sites from a high of 15.1 at site 26 to zero at many sites (Figure 8). AVS concentrations

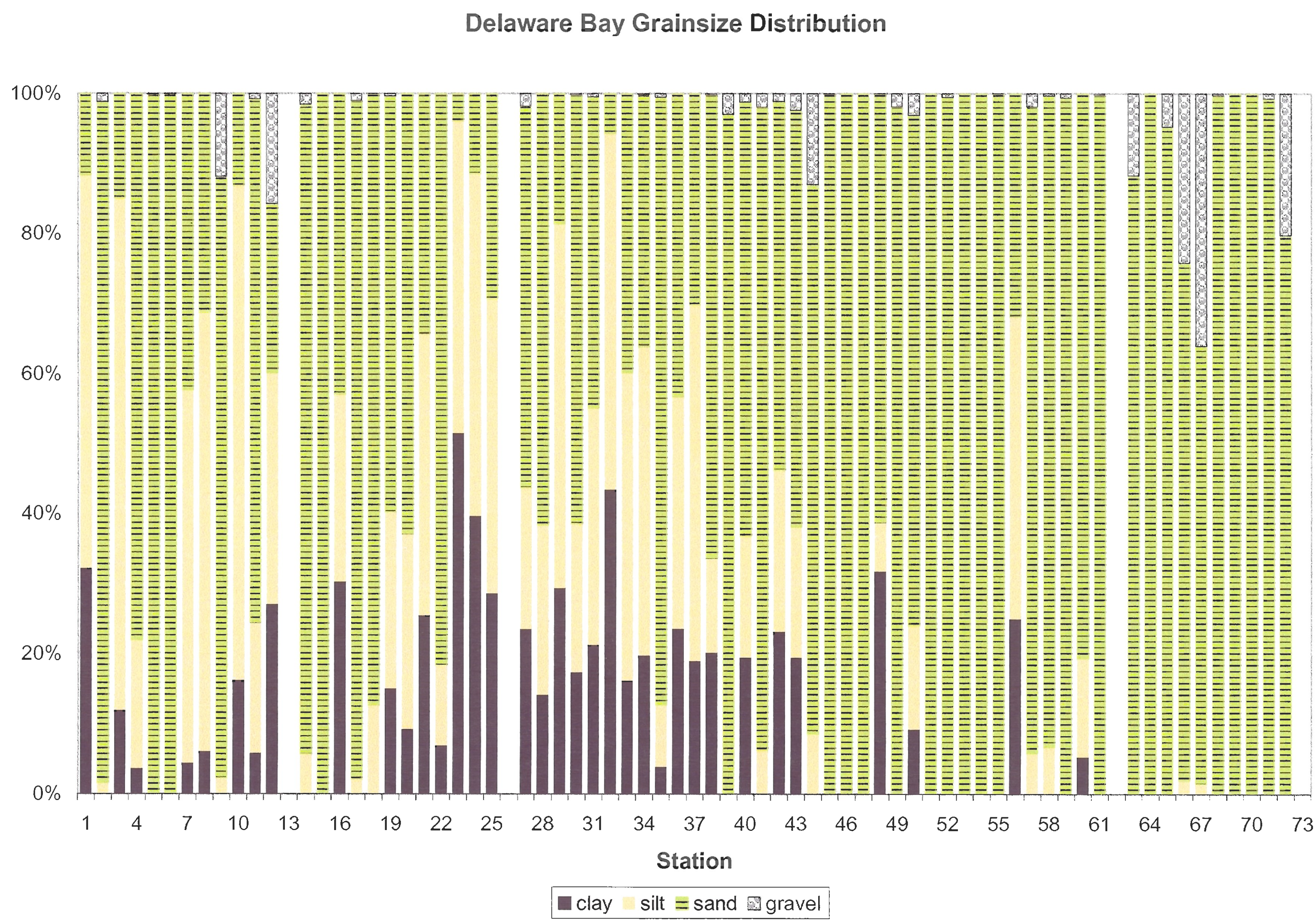


Figure 6. Grain size distribution at Delaware Bay sampling stations, expressed as percent of total.

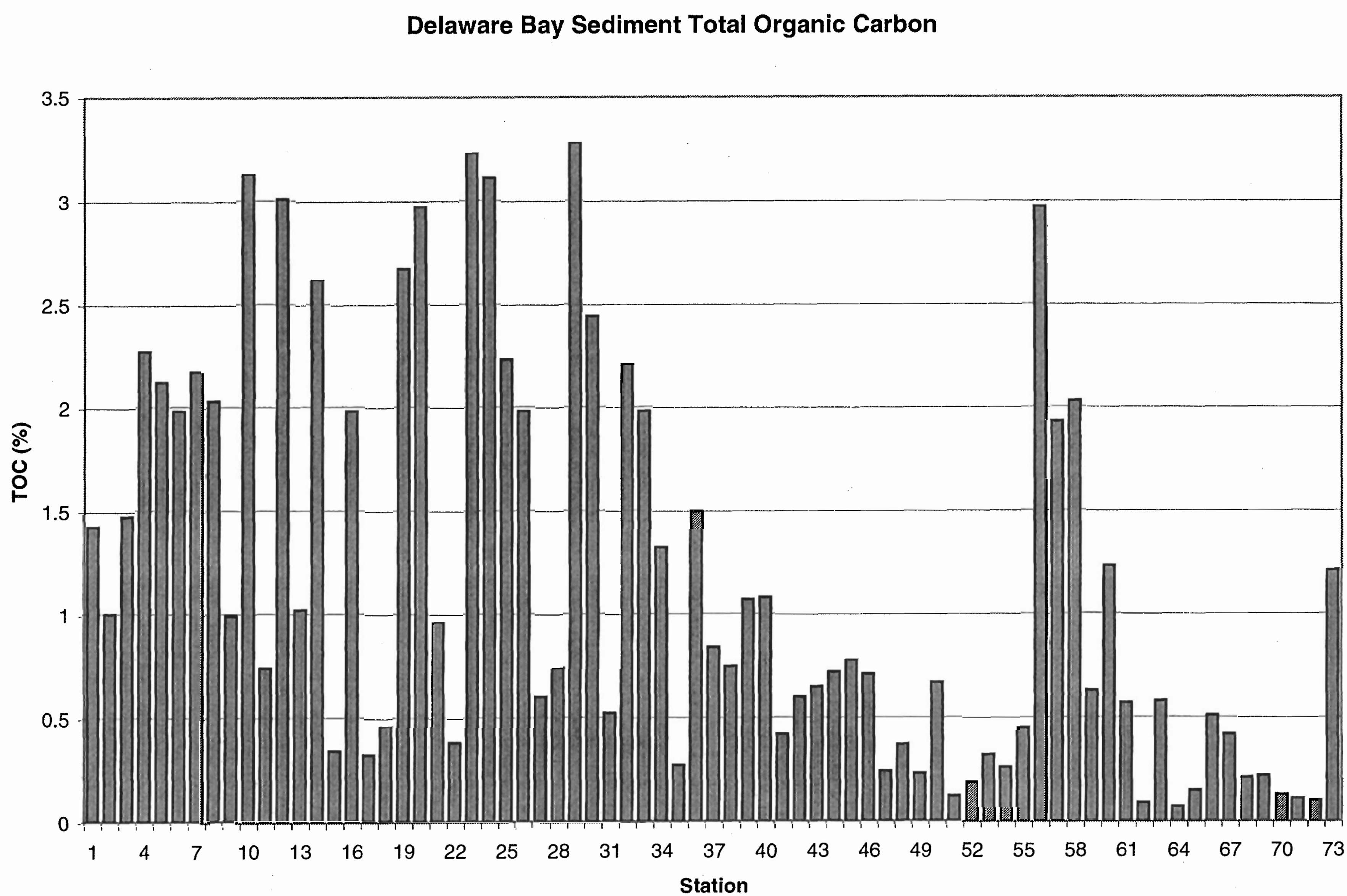


Figure 7 Total organic carbon content at Delaware Bay sampling stations.

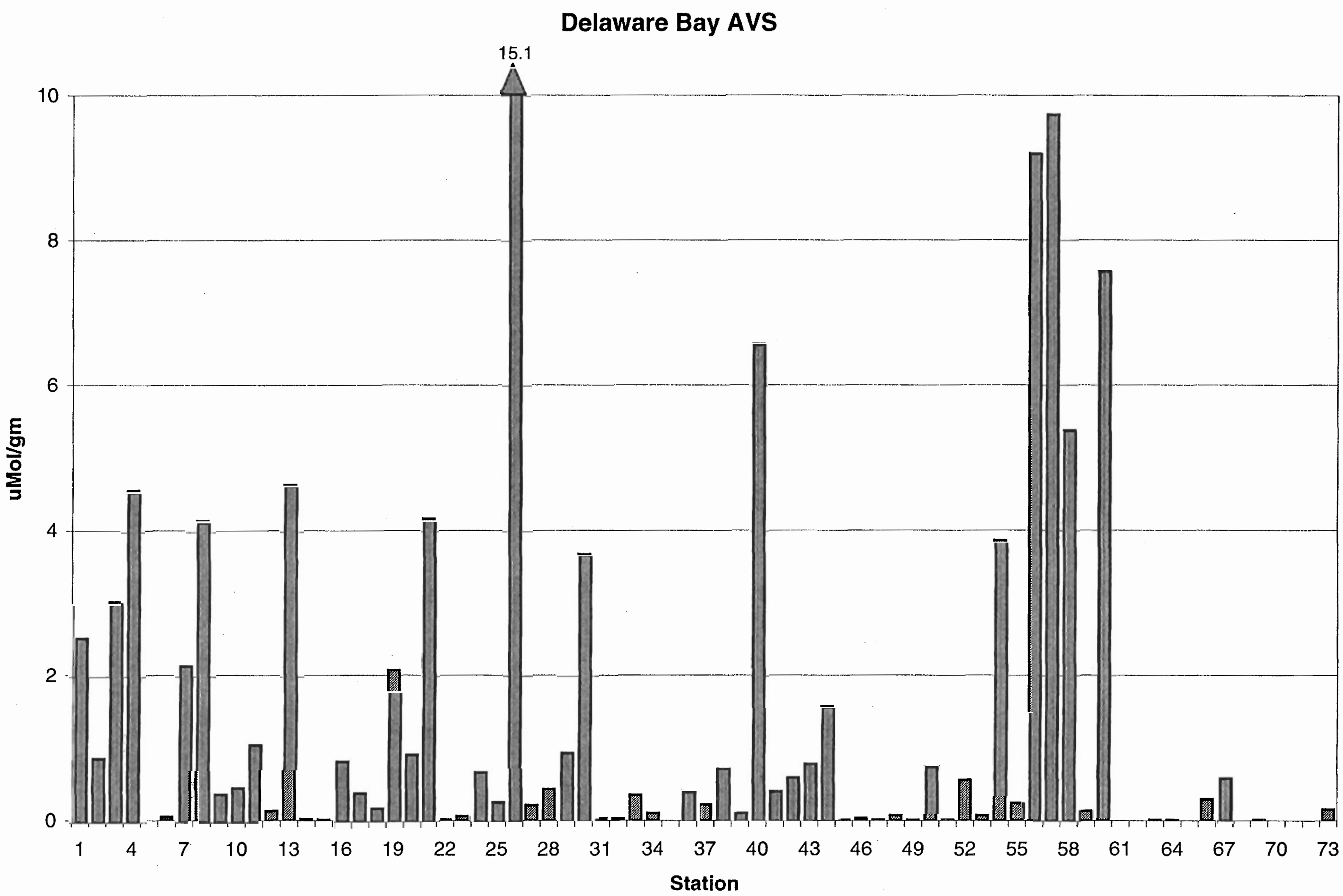


Figure 8 Acid volatile sulfide content at Delaware Bay sampling stations.

did not correlate with grain size or contaminants distributions. The eastern lobe of the lower Bay (stratum 14) exhibited relatively high AVS concentrations, but the values varied on a site specific basis.

The water column data is incomplete due to equipment failure, but the partial record is sufficient to describe conditions on a system-wide basis. The water column was essentially fresh water down through stratum 4 (stations 1-18) (Figure 9). Salinity increased steadily through the estuary to the middle portion of the Bay. The water column was slightly diluted ocean water throughout the lower Bay and extending out onto the continental shelf. Temperature was relatively uniform throughout the system (Fig 10) and stressful dissolved oxygen conditions were not observed at any station, with the exception of borderline conditions at station 22 (Fig 11). The weather during the sampling period was stormy, and the salinity, DO and temperature data all indicate a well mixed water column, typical for Delaware Bay, which is a relatively shallow, well flushed system.

CHEMICAL CONTAMINATION

The tidal-fresh portion of the study area was heavily contaminated with metals, pesticides, PCBs and PAHs. Selected portions of the upper estuarine zone were also contaminated in the vicinity of Philadelphia, and below the C&D canal. Contaminant concentrations varied greatly from station to station, depending on exact location. In general, the concentrations of all chemical constituents were either relatively high or low at a given site (Fig 12). TBT was the exception to this trend, and was found at elevated concentrations at station 17 and 57, and at low concentrations at other stations, in contrast to other constituents (Fig 12). Sandy sites had generally lower concentrations of contaminants than sites with a significant proportion of silt/clay. Chemical concentrations at the other main bay, and coastal zone stations outside of the bay proper, were basically uncontaminated beyond trace levels.

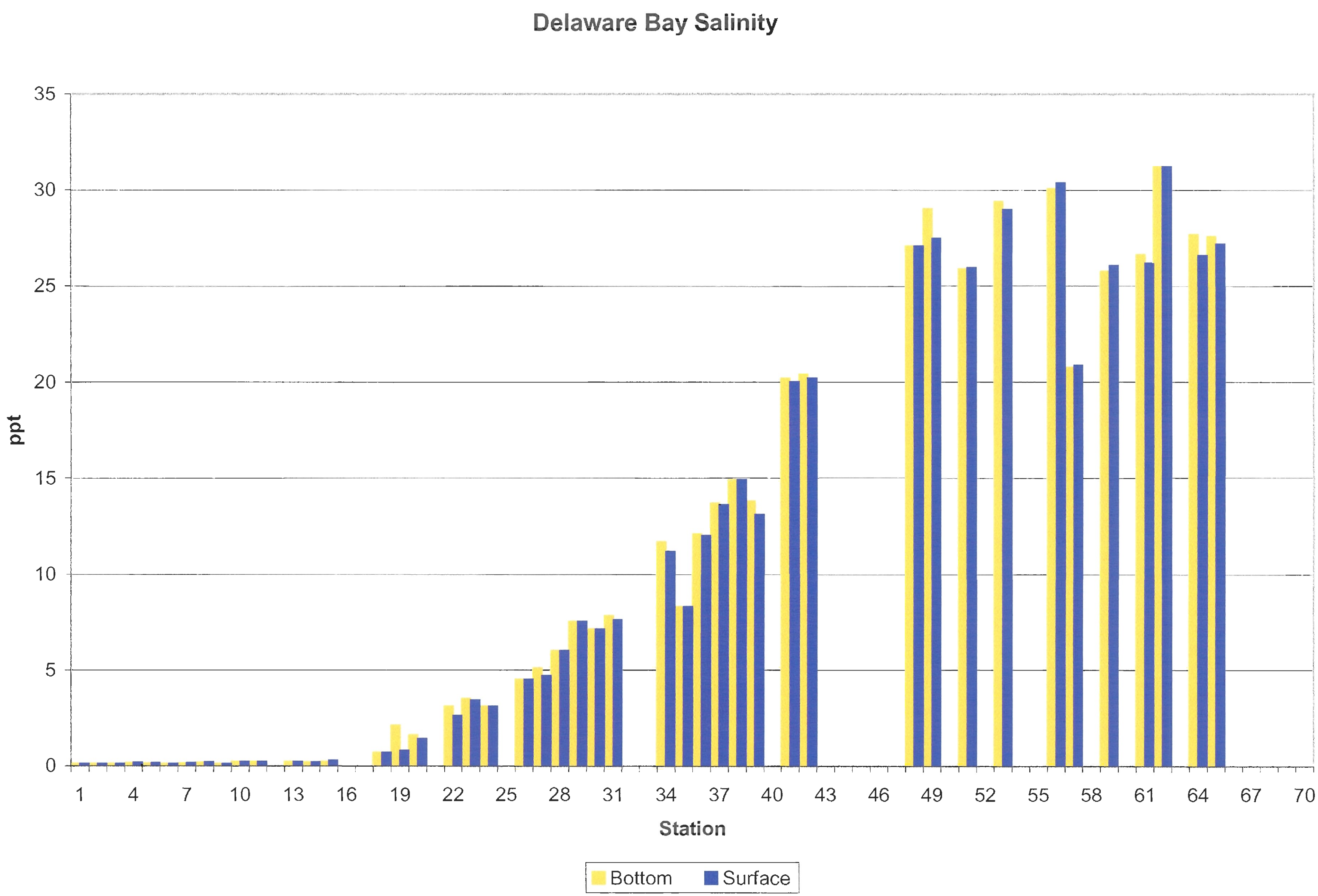


Figure 9 Surface and bottom salinity at Delaware Bay sampliung stations.

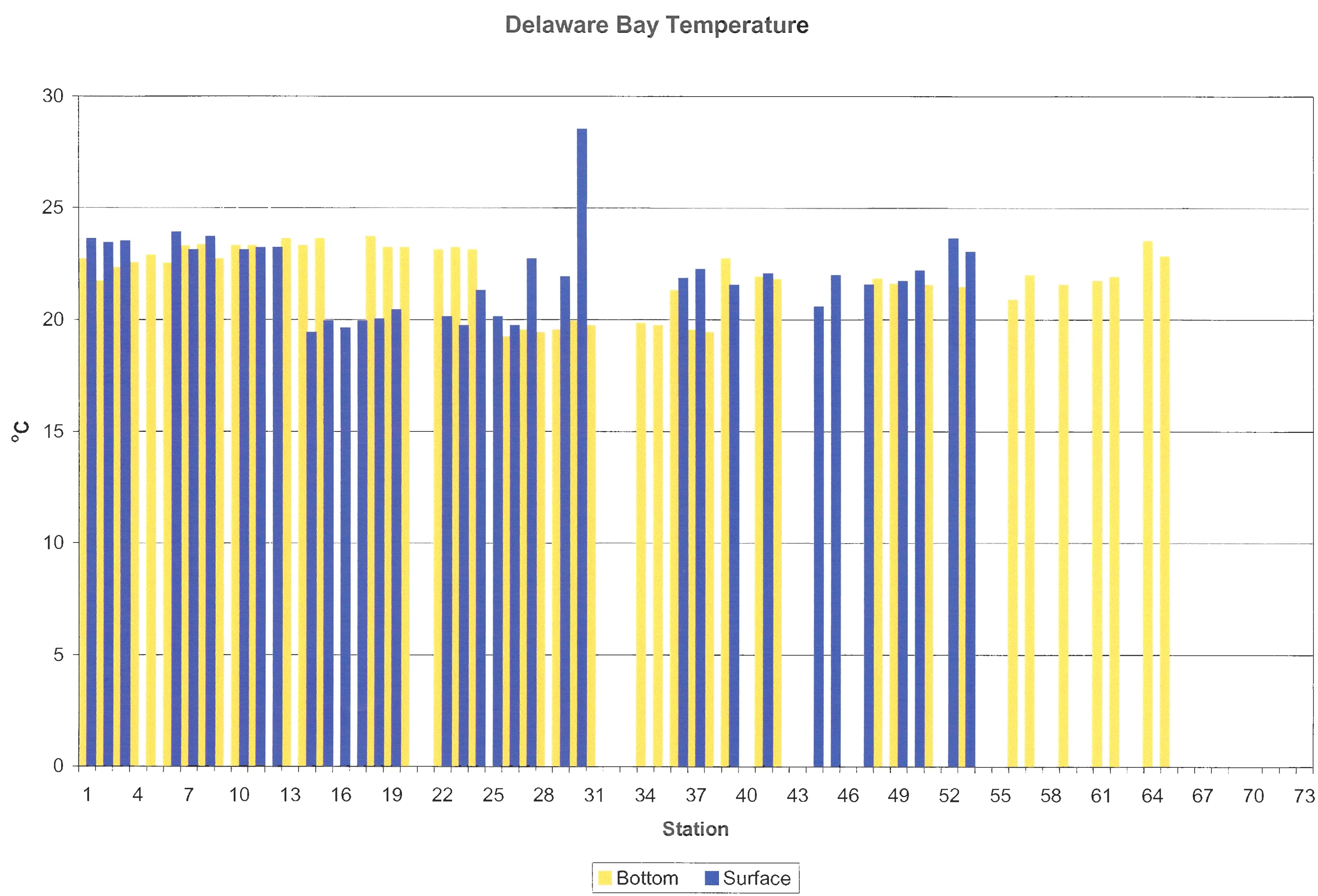


Figure 10 Surface and bottom water temperature at Delaware Bay sampling stations.

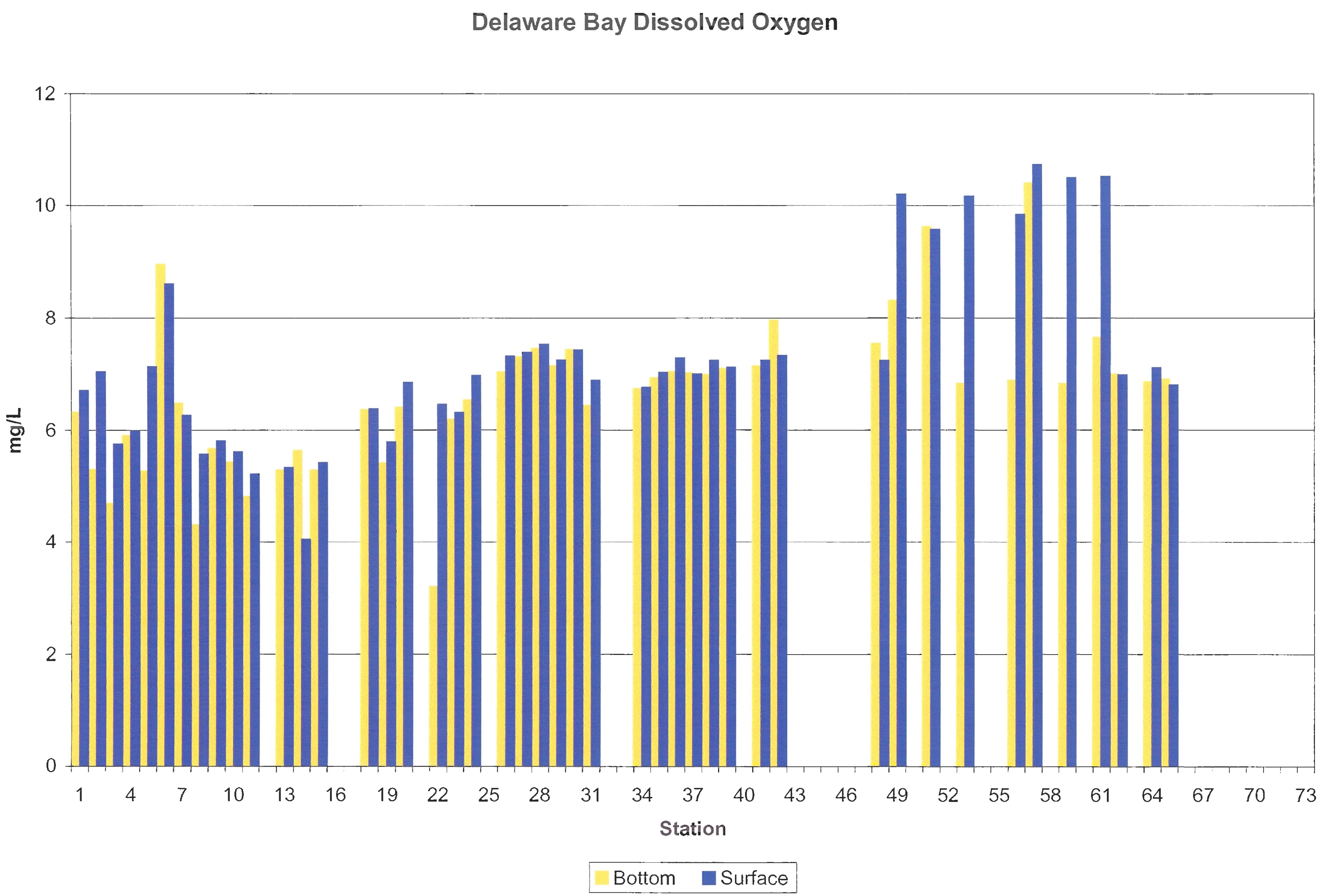


Figure 11 Surface and bottom dissolved oxygen at Delaware Bay sampling stations.

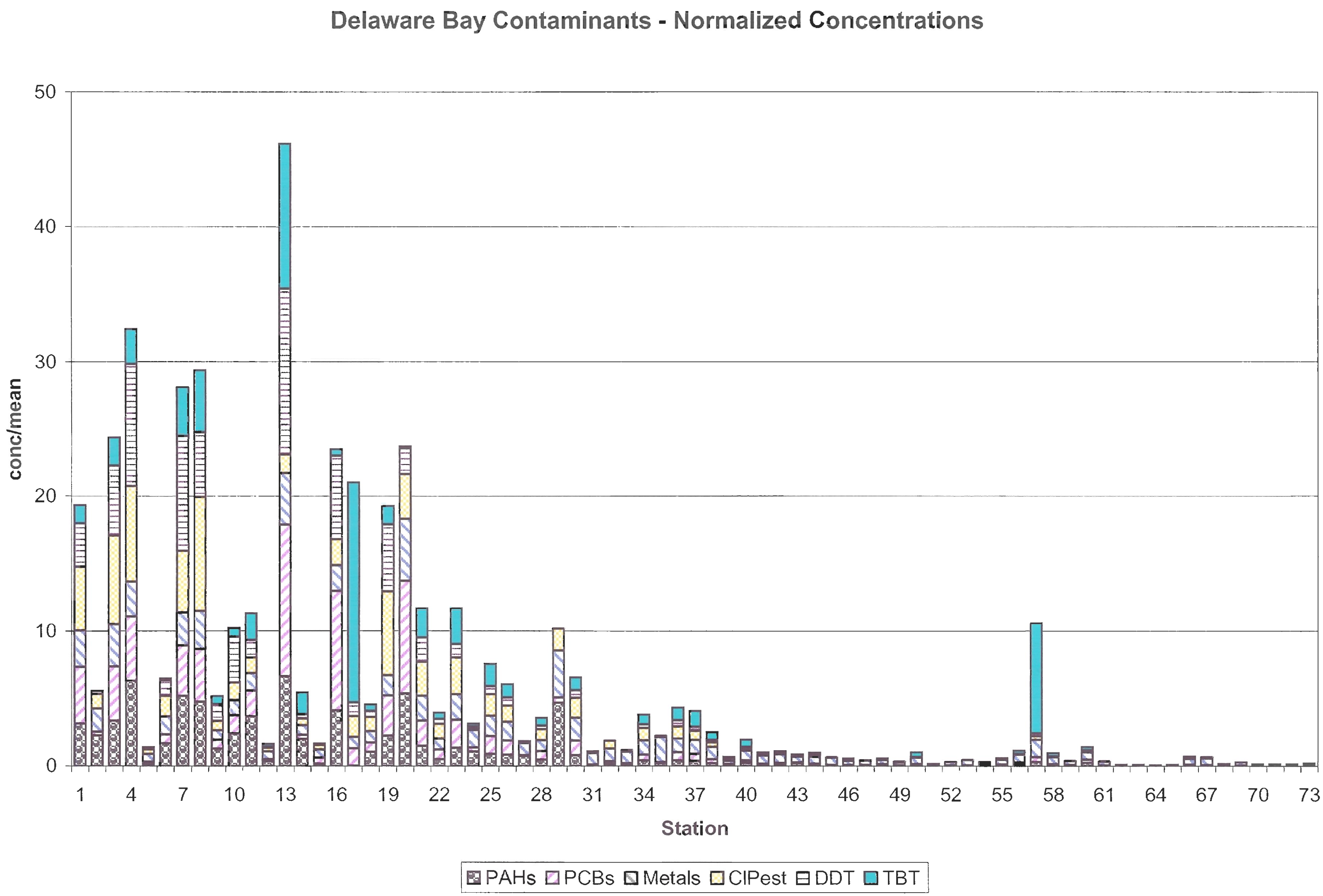


Figure 12 Normalized contaminant concentrations at Delaware Bay sampling stations. Concentrations are normalized to the mean for each chemical class.

Concentrations of measured PAHs were highly variable, ranging from 5 to over 18,000 ug/kg (Figure 13). Station 17 had a concentration over 153,000 ug/kg, but this sample is suspected of being spurious. The site location was in the dredged portion of a ship turning basin in a highly industrialized section of the waterway. Every PAH analyzed had extremely high concentrations in this sample. Because sediment samples were homogenized by hand on-board the sampling boat, a small clump of coal or other organic mass may have contaminated the individual sample split. A separate subsample from the composite was used for the toxicity bioassays. The P450 Reporter Gene System (RGS) bioassay, which is specifically designed to respond to PAHs, did not indicate extraordinarily high concentrations of PAHs at this site. Other contaminants (except TBT) were found at relatively low concentrations at site 17.

Low weight ($\leq$3 rings) and high weight ($\geq$ 4 rings) PAHs were generally present in equal concentrations on a mass basis (Figure 13). Alkyl-substituted PAHs were much more prevalent in the low weight category (Figure 14) than in the high weight category (Figure 15). This indicates a pyrogenic source for the high weight PAHs, whereas the low weight PAHs are likely a mixture of pyrogenic sources and fuel spills. However, it may also be an artifact of the analytical scheme which emphasizes the lower weight substituted compounds. For those chemicals for which ERLs and ERMs exist (Table 5), most of the freshwater sites exceeded one or more ERLs (Table 6). About half of the sites exceeded the ERL for individual high weight PAHs. The ERM for aggregate low-weight PAHs was exceeded at several stations, but the benchmark was not derived for as large a set of compounds as are in the current data set. Individual and/or total high weight PAH concentrations exceeded the respective ERLs at 4-12 of the stations in the fresh water zone, and at 1-4 stations in the estuarine zone. The latter sites were primarily in the vicinity of south Philadelphia and below the C&D canal. Fluorene was found at concentrations above the ERL at 14 of the 18 freshwater stations and 10 of the upper 12 estuarine stations.

PCB concentrations parallel the PAH data, with selected stations exhibiting elevated concentrations, and other stations having low concentrations (Figure 16). This pattern

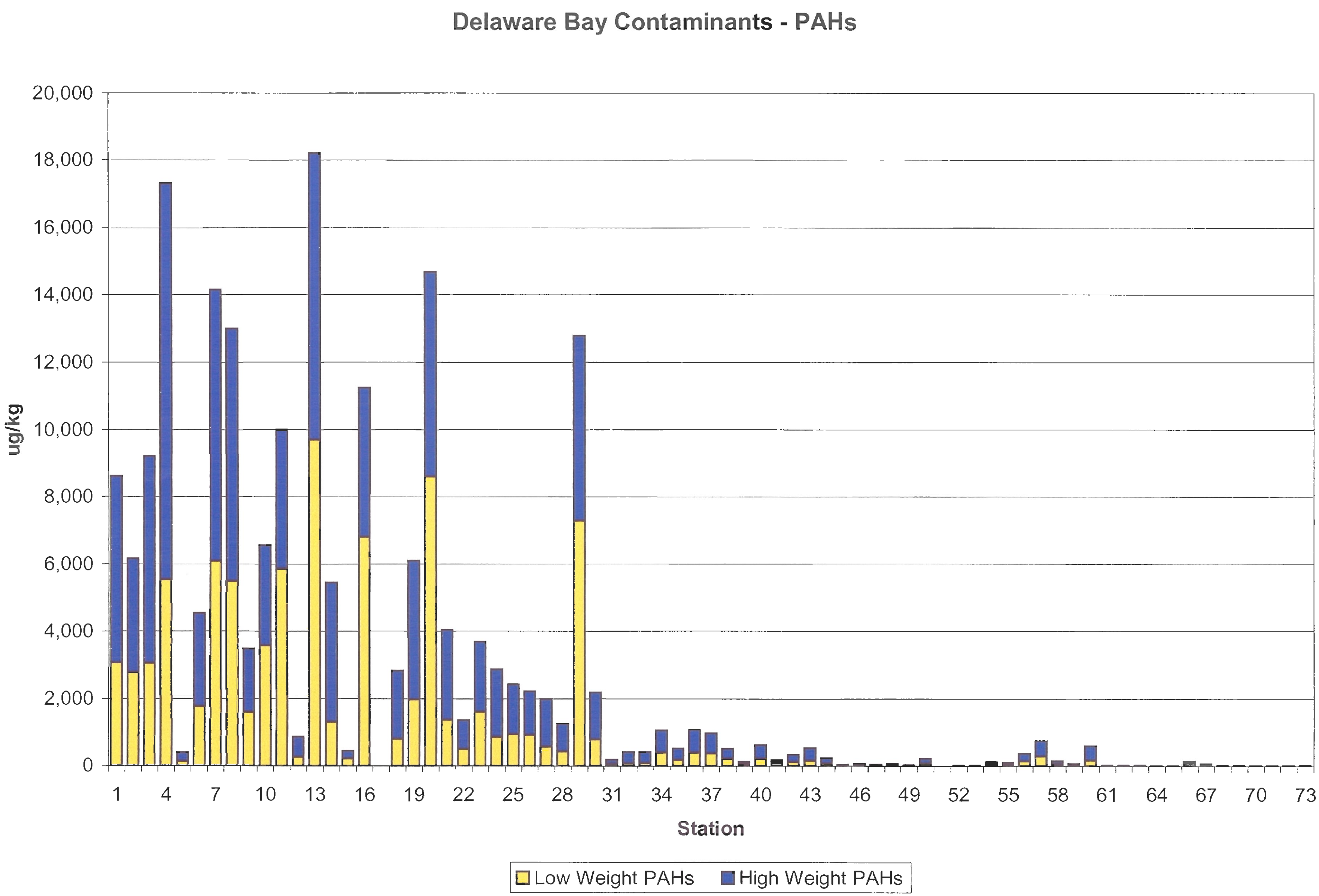


Figure 13 Summed concentration of all measured PAHs at Delaware Bay sampling stations. (Low weight PAHs = ≤ 3 rings; High weight PAHs = ≥ 4 rings)

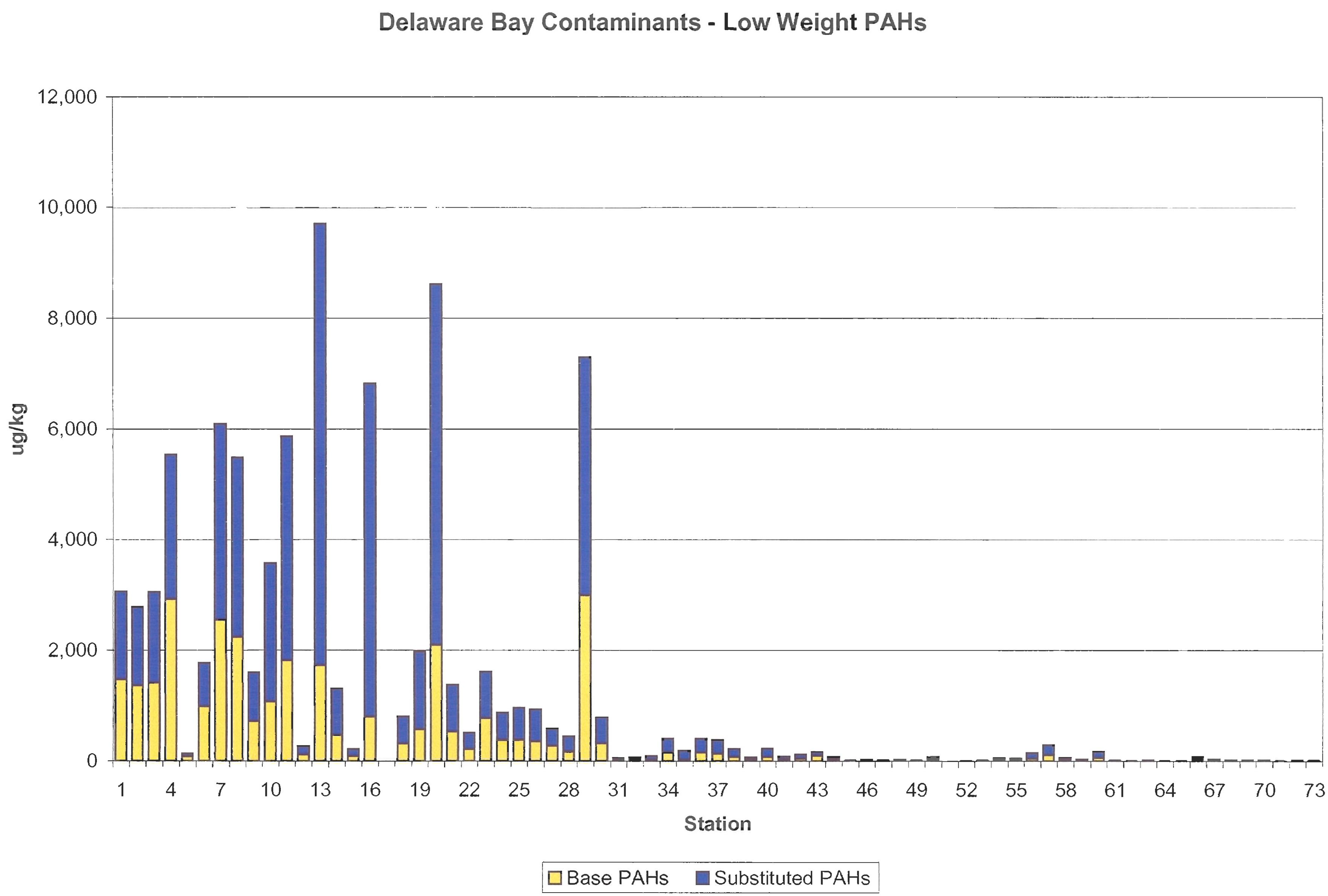


Figure 14 Measured concentrations of low weight base and alkyl-substituted PAHs at Delaware Bay sampling stations.

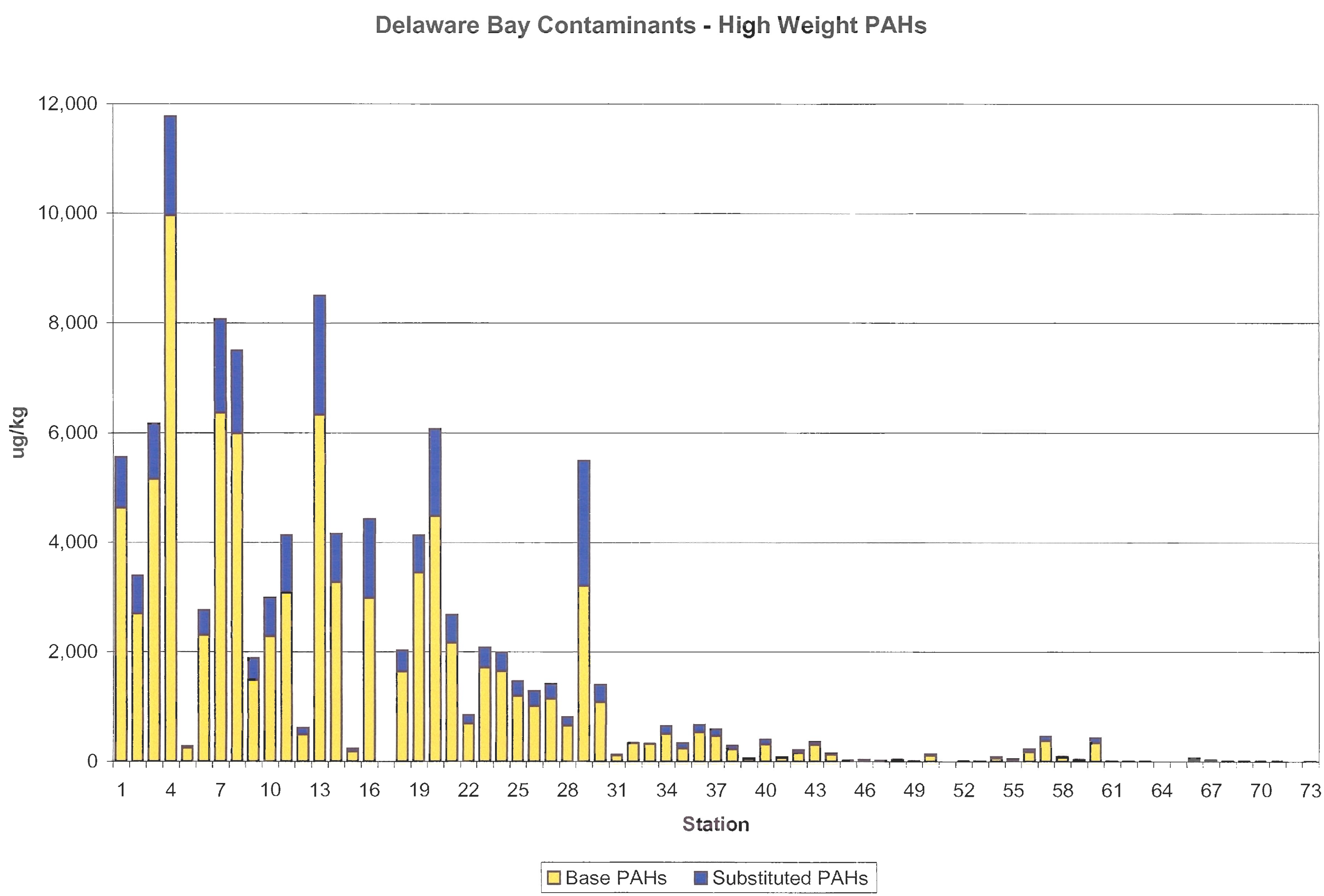


Figure 15 Measured concentrations of high weight base and alkyl-substituted PAHs at Delaware Bay sampling stations.

Table 5. Chemicals and chemical groups for which ERLs and ERMs have been derived (ppb, dry weight).

	ERL	ERM
Total DDT	1.58	46.1
pp'-DDE	2.2	27
Total PCBs	22.7	180
Total PAHs	4022	44792
High weight PAHs ($\geq$ 4 rings)	1700	9600
Low weight PAHs ($\leq$ 3 rings)	552	3160
Acenaphthene	16	500
Acenaphthylene	44	640
Anthracene	85.3	1100
Flourene	19	540
2-Methyl Naphthalene	70	670
Naphthalene	160	2100
Phenanthrene	240	1500
Benzo-a-anthracene	261	1600
Benzo-a-pyrene	430	1600
Chrysene	384	2800
Dibenzo(a,h)anthracene	63.4	260
Fluoranthene	600	5100
Pyrene	665	2600
As	8.2	70
Cd	1.2	9.6
Cr	81	370
Cu	34	270
Pb	46.7	218
Hg	0.15	0.71
Ni	20.9	51.6
Ag	1.0	3.7
Zn	150	410

Table 6. Number of ERL/ERM exceedances at Delaware Bay sampling stations. Stations without exceedances are not listed.

Station	#>ERL	#>ERM
1	25	1
2	16	
3	26	1
4	26	1
5	1	
6	14	
7	26	2
8	26	1
9	9	
10	12	
11	15	
13	28	2
14	9	
16	19	1
17	6	
18	6	
19	18	1
20	25	2
21	14	
22	4	
23	16	
24	7	
25	8	
26	7	
27	4	
28	2	
29	22	1
30	10	
31	2	
32	2	
33	2	
34	4	
35	3	
36	4	
37	3	
38	1	
57	5	
69	1	

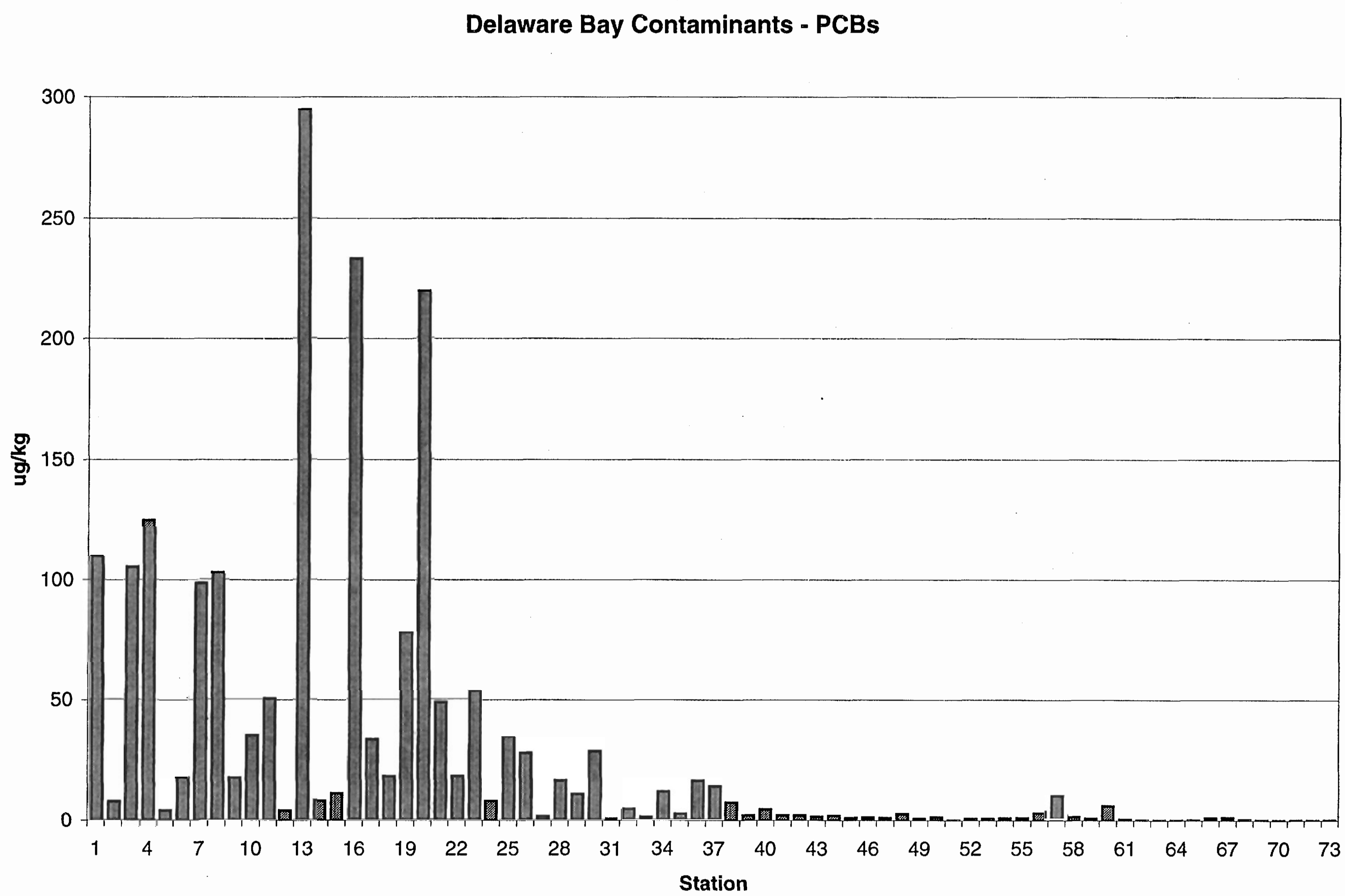


Figure 16 Summed concentrations of all measured PCBs (excluding planar PCBs) at Delaware sampling stations.

was strongly influenced by sediment grain size. Total PCB concentrations exceeded the ERL at 10 of the 18 freshwater stations and 7 of the estuarine stations, including three stations which exceeded the ERM. Again, the estuarine stations were in the vicinity of southern Philadelphia, and the C&D canal. These values do not include the measured concentrations of the planar PCBs -77, 126 and, 169 (Figures 17 & 18). The concentration of PCB77 was extremely high at station 13.

Tetrachlorodibenzodioxin (TCDD) was not detected in the four mainstem samples analyzed for dioxins and furans (Figure 19 a & b). Tetrachlorodibenzofuran (TCDF) was detected at low levels at two stations. While the total dioxin and furan concentrations were relatively high in the estuarine sites, the vast majority was in the form of the octachlorinated compounds which are three orders of magnitude less toxic than the tetrachloro congeners.

The concentration of DDT and it's breakdown products showed a similar distribution as PCBs, but elevated concentrations were not distributed as far downstream (Figure 20). All but two samples from the freshwater zone exceeded the ERL for p,p'DDE. Seven samples exceeded the ERM. Eleven samples in the estuarine zone exceeded the ERL, of which two exceeded the ERM. The concentration of other chlorinated pesticides was dominated by chlordane and related cyclodienes (Figure 21). These compounds were found over a more widespread area than DDT, but were at relatively low levels in strata 2-4.

Metals contamination followed the same pattern as organic contaminants, with selected stations exhibiting elevated concentrations of multiple metals. In general, these stations corresponded to the same locations exhibiting elevated organic contaminants (Figure 22). Concentrations were frequently above ERL concentrations in the freshwater and upper estuarine zone, but ERM exceedances were rare. Excluding aluminum, iron and manganese, the metal of highest concentration was zinc, on both a mass and molar basis. There were high concentrations of zinc throughout the fresh water zone, in contrast to the other metals which were concentrated in the sediments nearer to the freshwater-estuarine interface. Chromium, Cd, Cu, Hg, Ni, Pb, and Zn were all enriched above normalized

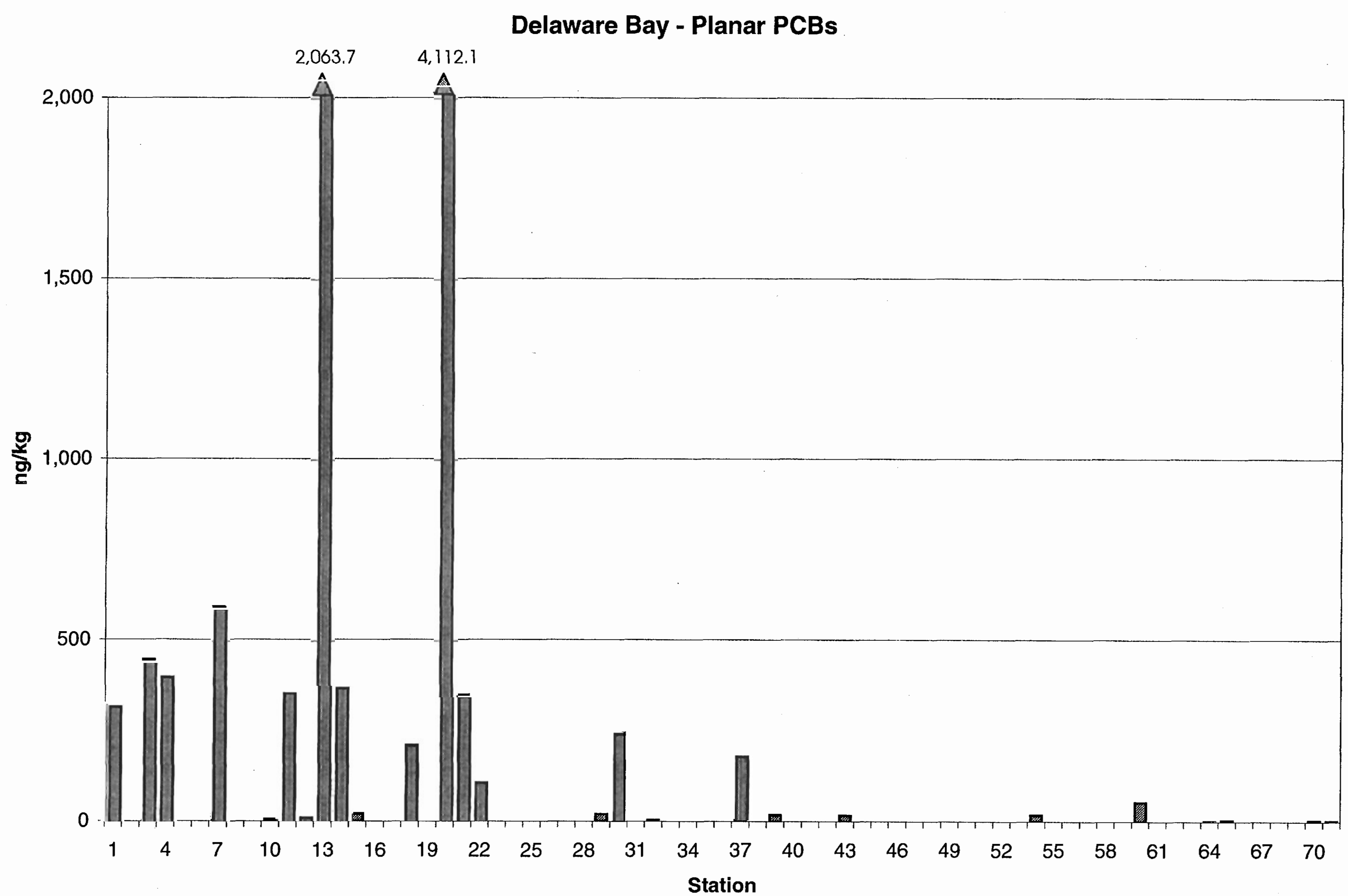


Figure 17 Summed concentrations of measured planar PCBs (77, 126, 169) at selected stations in Delaware Bay.

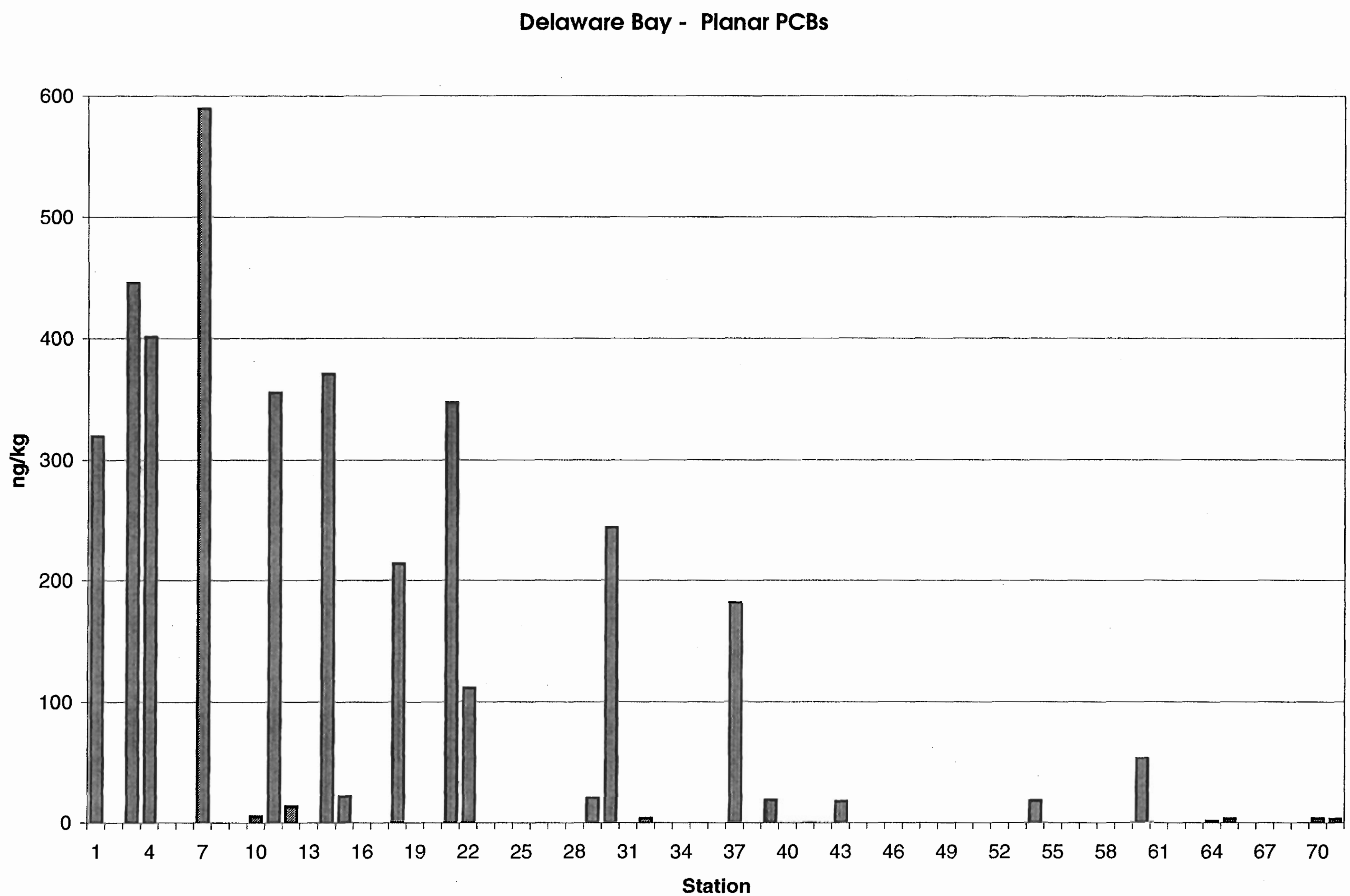
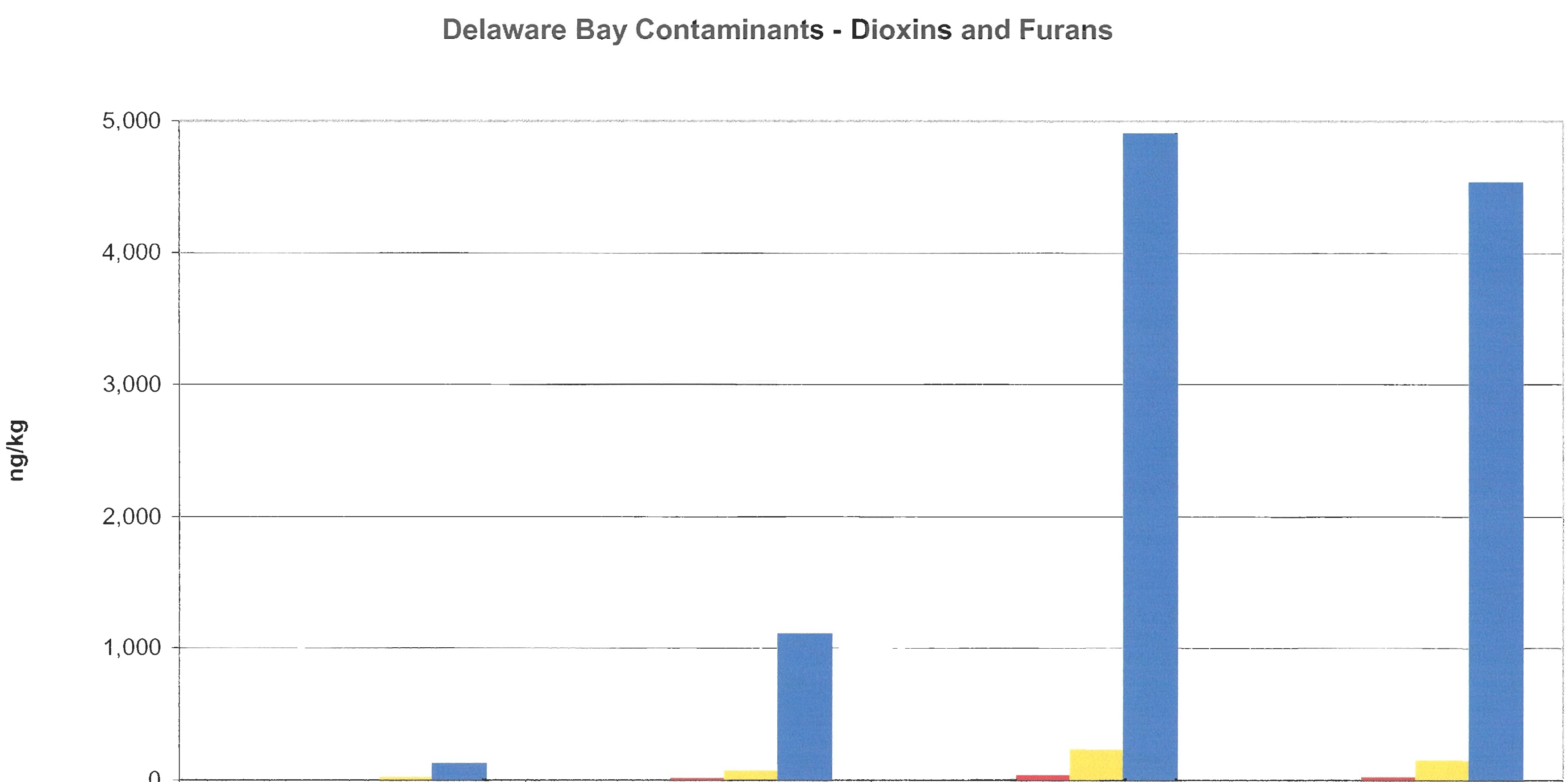
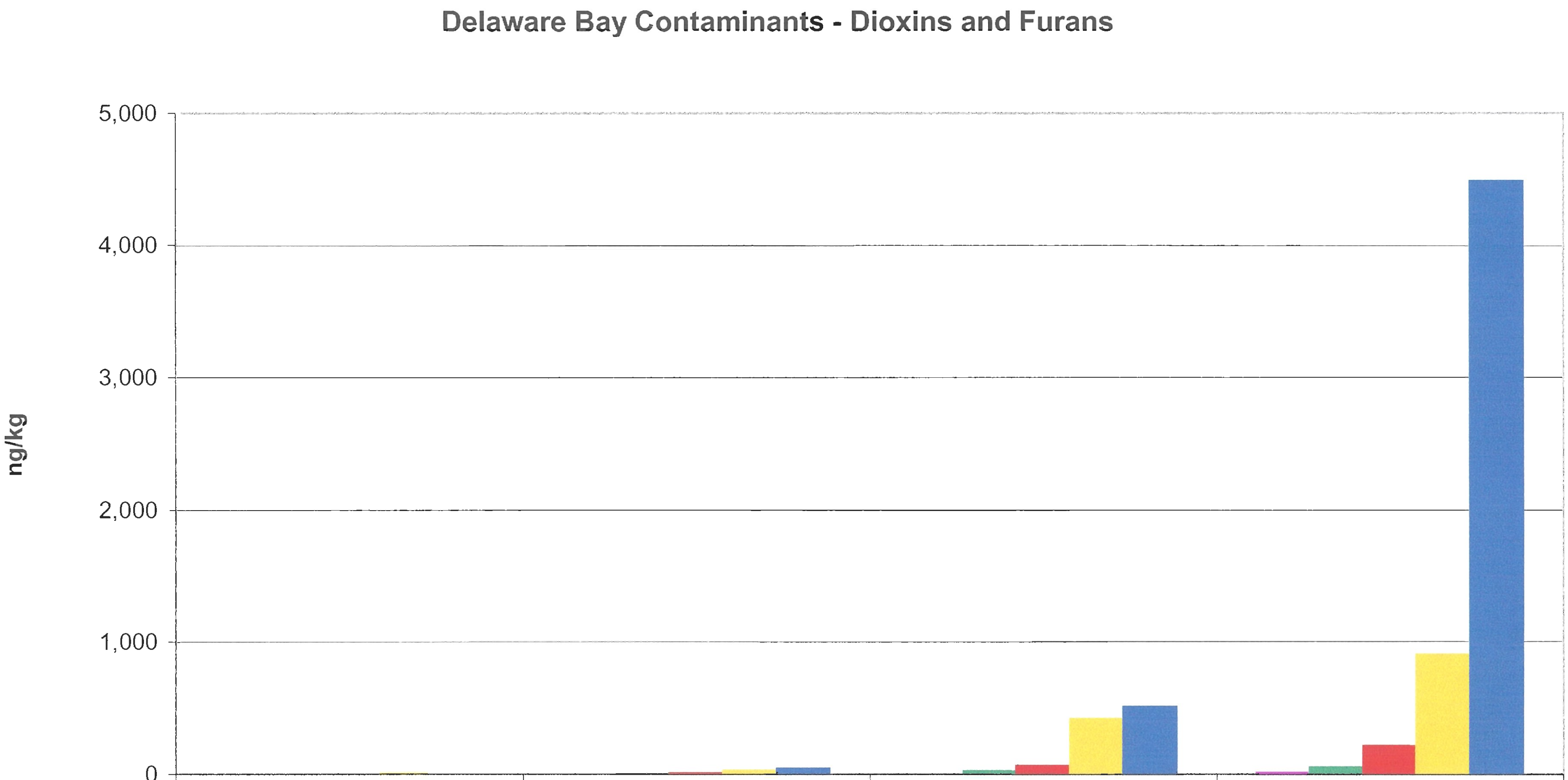


Figure 18 Summed concentrations of measured planar PCBs (77, 126, 169) at selected stations in Delaware Bay (without stations 13 and 20).



Station	10	11	20	29
TCDD	0	0	0	0
PeCDD	0	0	4.121	0
HxCDD	0.313	6.649	28.433	14.247
HpCDD	14.085	62.131	222.039	137.976
OCDD	117.971	1103.977	4902.631	4530.753

Figure 19(a) Measured concentrations of chlorinated dibenzo dioxins in selected Delaware Bay sampling stations. (chlorination level - T=tetra, Pe=penta, Hx=hexa, Hp=hepta, O=octa)



Station	10	11	20	29
TCDF	0.456	0	0	9.857
PeCDF	0.498	3.936	20.918	49.347
HxCDF	0	7.739	61.985	213.177
HpCDF	1.947	25.949	421.95	902.537
OCDF	0	39.436	512.646	4488.924

Figure 19(b) Measured concentrations of chlorinated dibenzo furans at selected Delaware Bay sampling stations. (chlorination level - T=tetra, Pe=penta, Hx=hexa, Hp=hepta, O=octa)

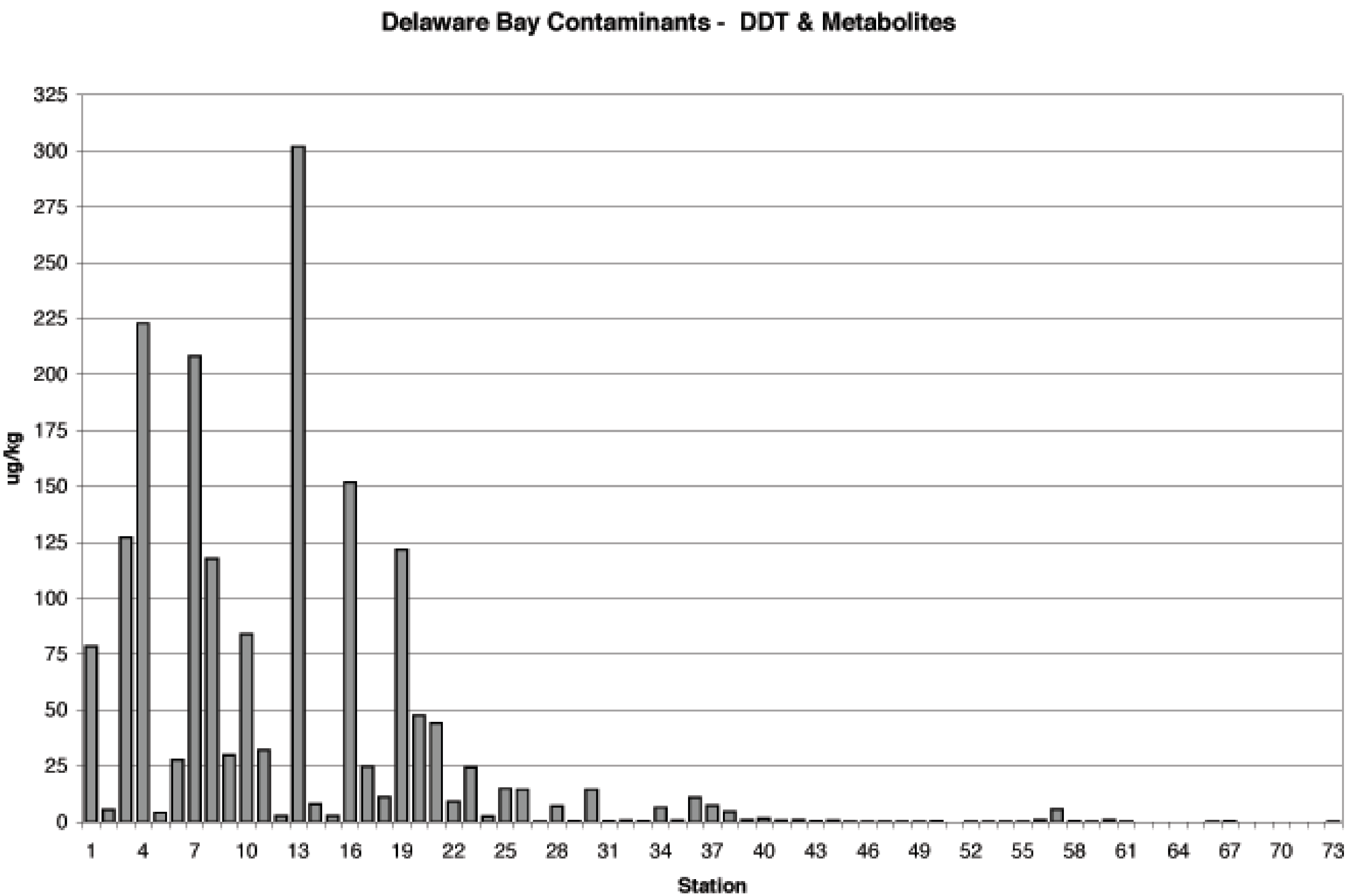


Figure 20 Summed concentrations of DDT and metabolites at Delaware Bay sampling stations.

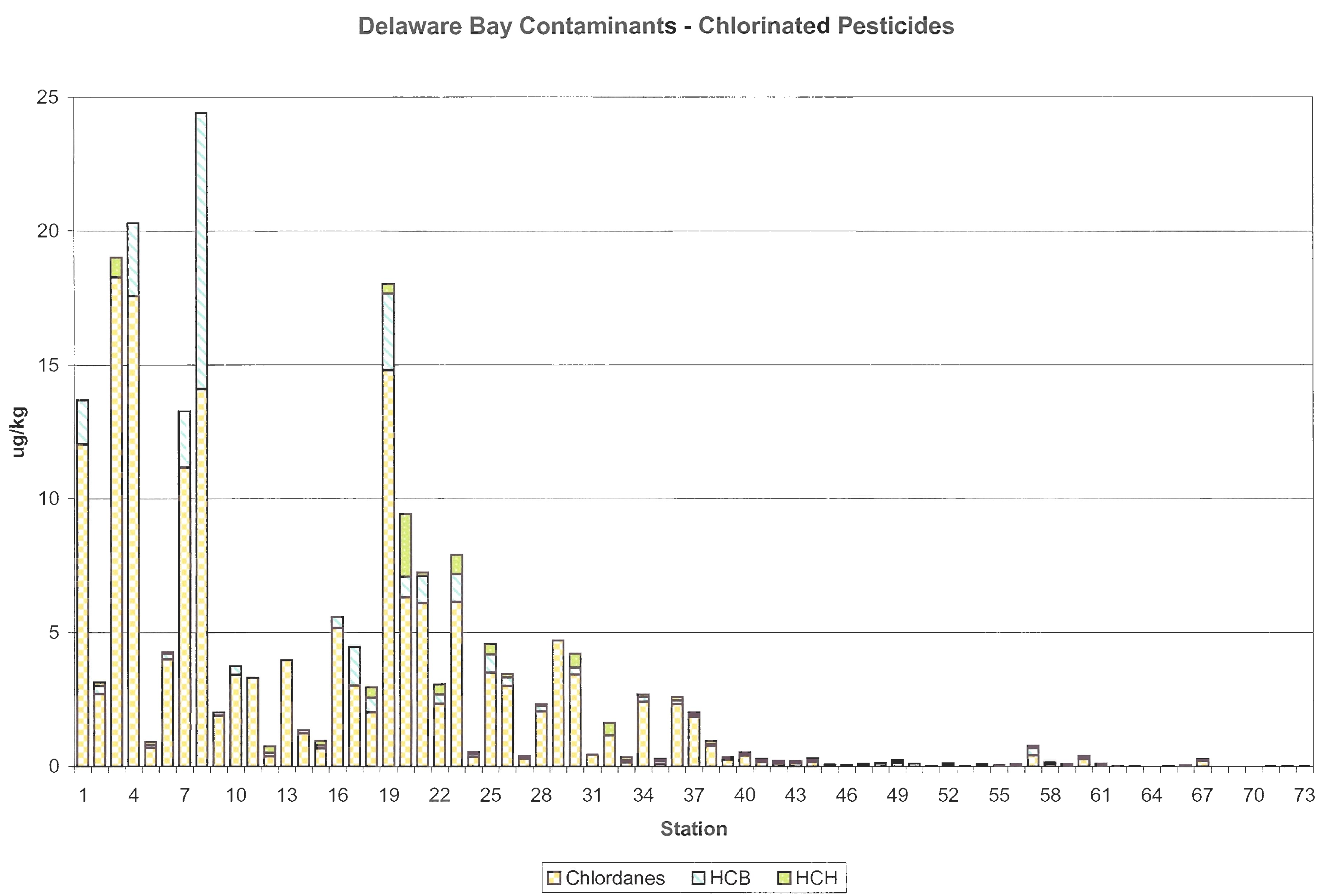


Figure 21 Concentrations of chlorinated pesticides at Delaware Bay sampling stations. (Chlordanes include chlordane-related compounds and other cyclodiene pesticides.)

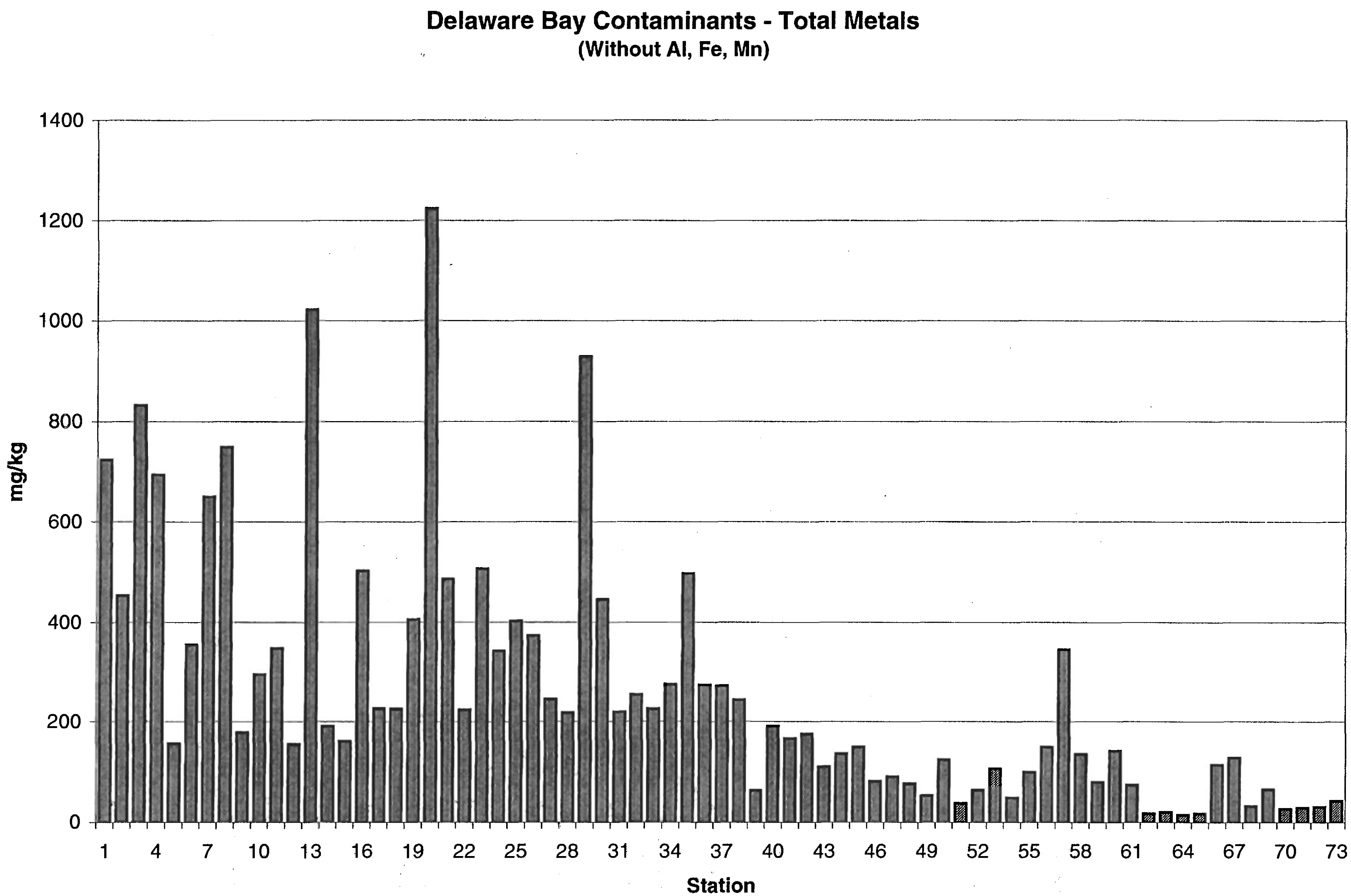


Figure 22 Summed concentrations of metals (excluding Al, Fe and Mn) at Delaware Bay sampling stations.

levels (Schropp and Windom, 1988) in the freshwater and upper estuarine zones. Butyl tins were detected at most of the freshwater and upper estuarine stations. Tributyltin tin was the dominant compound at all locations. It was particularly high at stations 13 and 17, plus a large spike at station 57 (Figure 23). Other contaminants showed a small but consistent increase in the vicinity of stations 57 and 58, which are influenced by discharge from Dividing Creek and Maurice River.

SEDIMENT TOXICITY

Bioassay results were highly variable. Significantly elevated amphipod mortality greater than 20% over controls was observed at only 3 stations (Figure 24), comprising only 1% of the total area. Mortality was elevated above 20% at station 52, but was not statistically significant from controls. Seven stations were marginally toxic. Calculated aerial extent of toxicity is shown in Tables 7 & 8. Mortality was elevated at stations 40, 47 and 57, but results were not statistically significant. Station 13 was the only station in the freshwater zone which demonstrated toxicity to amphipods. The 3 stations exhibiting high toxicity were among the most polluted with heavy metals and PAHs. (Figures 25 & 26). However, other stations with high contaminant loads were not toxic. The freshwater stations had high levels of contaminants, but were not toxic to amphipods. Significant toxicity in the sea urchin fertilization test was also limited to saline stations (Figure 27). Sediment from stations which were toxic to amphipods were different than the stations that exhibited toxicity in the sea urchin bioassays. The highest response in the sea urchin fertilization bioassay was at station 56, behind Cape Henlopen. A total of 6 stations demonstrated statistically significant fertilization reductions at the 100% pore water tests, which comprised 10.6% of the total area. Pore water from station 56 also resulted in significant reduction at the 50% level. Pore water from station 21 was marginally toxic at a 50% dilution. None of the 25% dilutions demonstrated toxicity.

The Microtox® results were the most variable of the toxicity bioassays both in terms of response level and distribution of significant responses (Figure 28). Several stations in

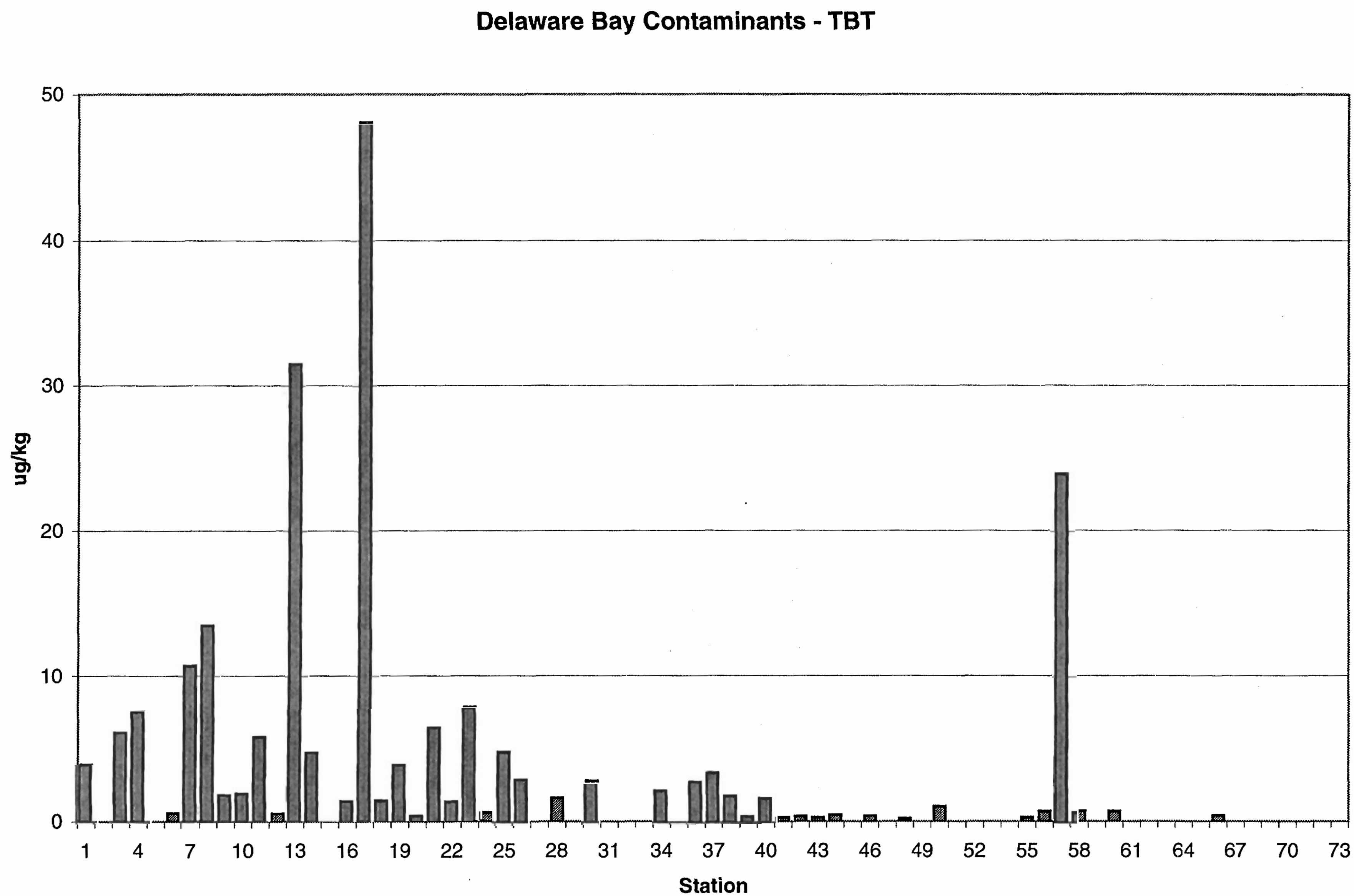


Figure 23 Summed concentrations of butyl tin compounds(tetra-, tri-, di-, and mono-BT) at Delaware Bay sampling stations.

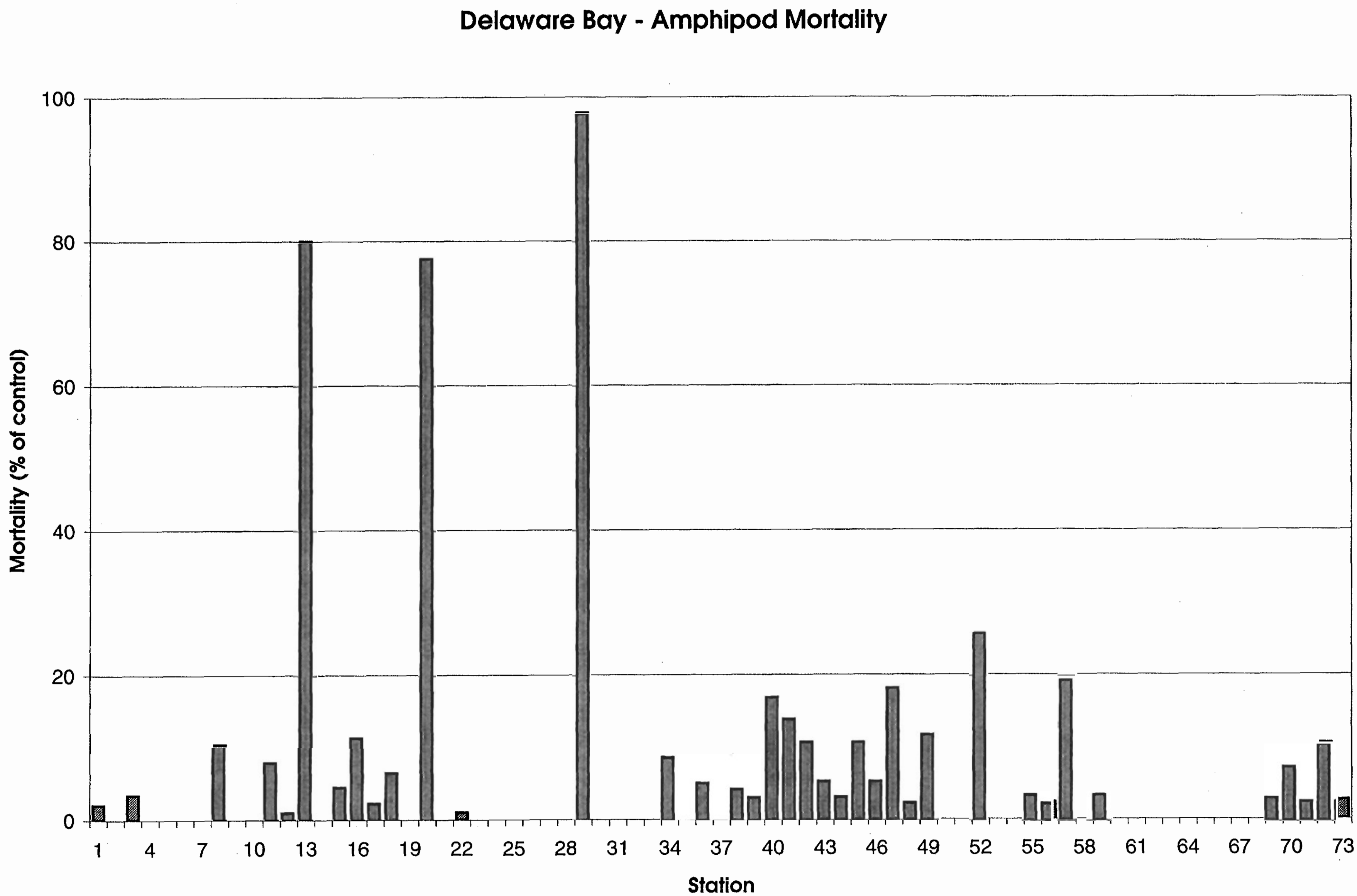


Figure 24 Mortality rates of amphipods (*Ampelisca abdita*) in whole sediment toxicity bioassays from Delaware Bay sampling stations.

Table 7. Spatial extent of marginal sediment toxicity by stratum in Delaware Bay (square kilometers and percent of study area), as estimated by laboratory bioassay tests.

Stratum	Total Area	Amphipod Mortality	Sea Urchin Fertilization	Microtox	P450 B[a]P eq
19	13.90	0	0	13.9	9.26
20	13.90	0	0	4.63	4.63
1	7.09	2.36	0	7.09	0
2	10.87	3.62	0	10.87	0
3	18.33	0	0	18.33	0
4	16.81	0	0	16.81	5.6
5	14.23	0	4.76	9.52	0
6	21.81	0	0	21.81	0
7	35.75	0	0	35.75	0
8	38.77	0	0	38.77	0
9	55.37	0	0	55.37	0
10	69.57	0	0	52.17	0
11	247.71	123.86	0	247.71	0
12	210.95	105.18	0	158.22	0
13	891.29	89.13	0	713.04	0
14	336.16	0	0	268.92	0
15	96.52	0	0	32.17	0
16	97.41	0	0	64.94	0
17	83099	0	0	28.00	0
18	66.32	0	0	22.11	0
Total km^2	2346.78	324.45 (13.83%)	4.76 (0.20%)	1,842.22 (78.50%)	19.49 (0.83%)

Table 8. Spatial extent of highly toxic sediment in Delaware Bay by stratum (square kilometers and percent of study area), as estimated by laboratory bioassay tests.

Stratum	Total Area	Amphipod Mortality	Sea Urchin Fertilization	Microtox	P450 B[a]P eq
19	13.90	0	0	0	4.63
20	13.90	0	0	4.63	4.63
1	7.09	0	0	2.36	4.72
2	10.87	0	0	7.24	7.24
3	18.33	6.11	0	6.11	6.11
4	16.81	0	0	5.60	11.20
5	14.23	4.76	4.76	9.52	9.52
6	21.81	0	7.27	14.54	0
7	35.75	0	11.92	11.92	0
8	38.77	12.92	0	12.92	12.92
9	55.37	0	0	27.68	0
10	69.57	0	0	52.17	0
11	247.71	0	0	185.79	0
12	210.95	0	0	105.48	0
13	891.29	0	89.13	445.65	0
14	336.16	0	134.46	268.92	0
15	96.52	0	0	32.17	0
16	97.41	0	0	64.94	0
17	83099	0	0	0	0
18	66.32	0	0	0	0
Total km^2	2346.78	23.79 (1.01%)	247.54 (10.55%)	1312.06 (55.91%)	60.97 (2.6%)

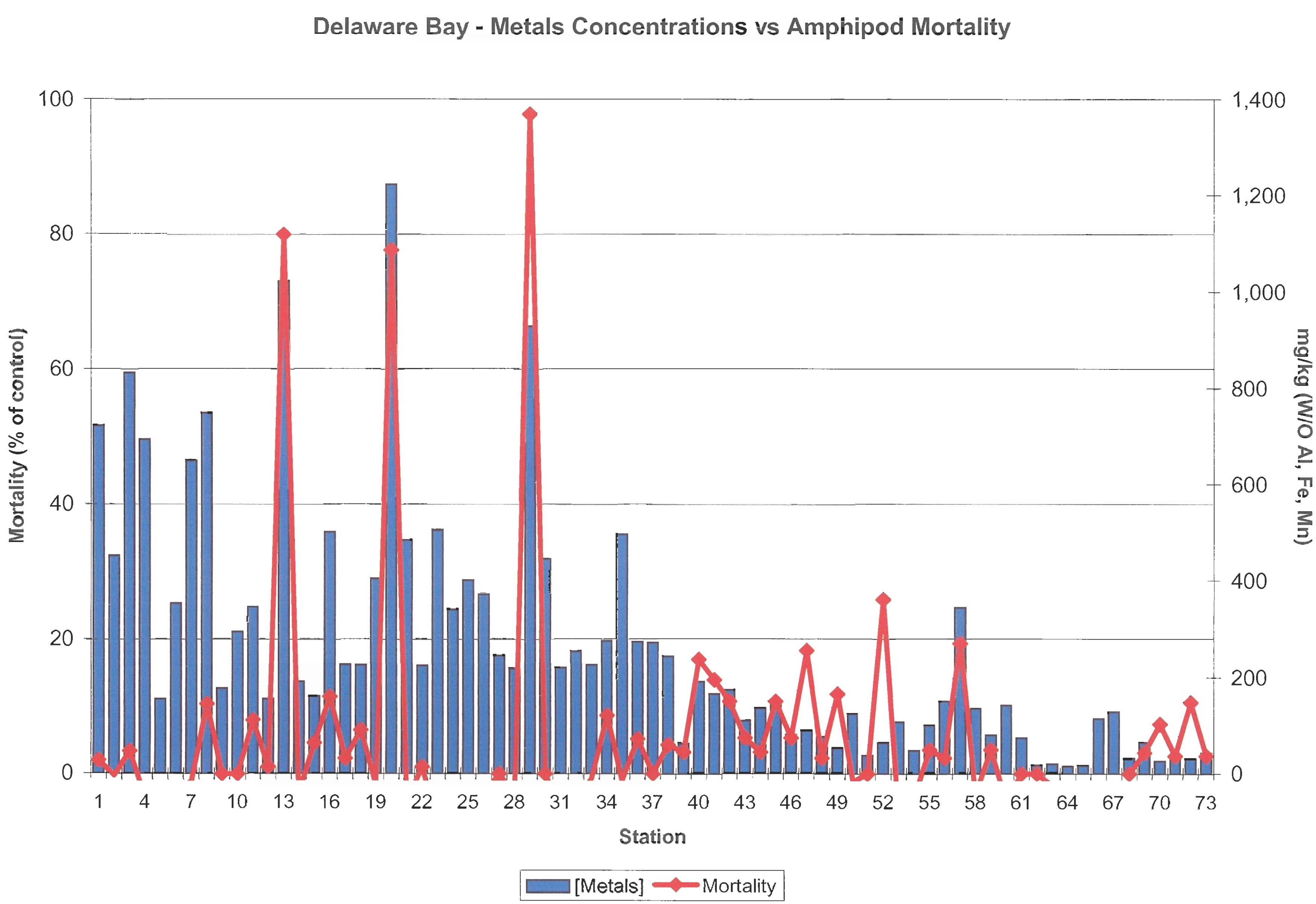


Figure 25 Delaware Bay sediment metals concentrations and amphipod sediment toxicity bioassay mortality rates.

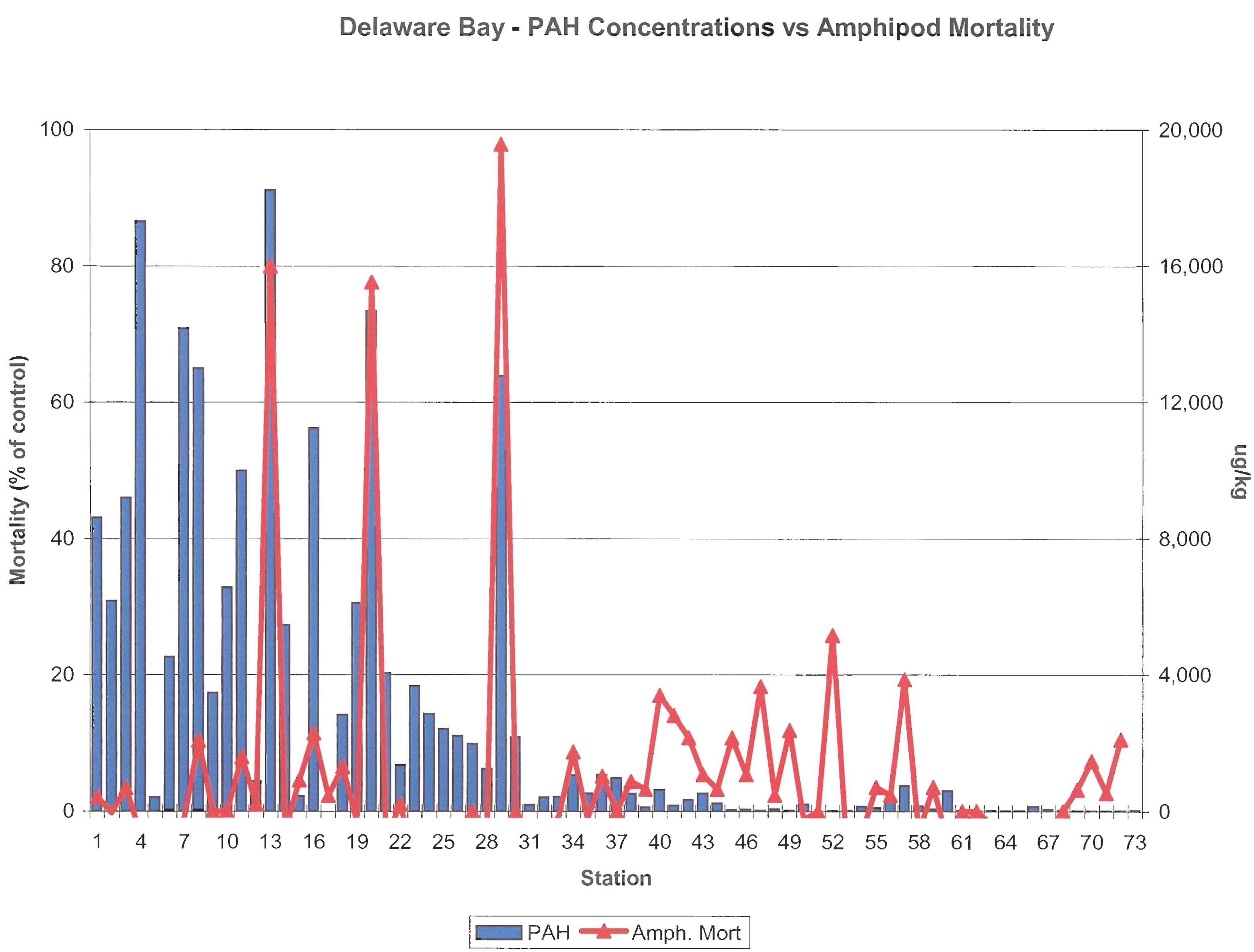


Figure 26 Delaware Bay sediment PAH concentrations and amphipod sediment toxicity bioassay mortality rates.

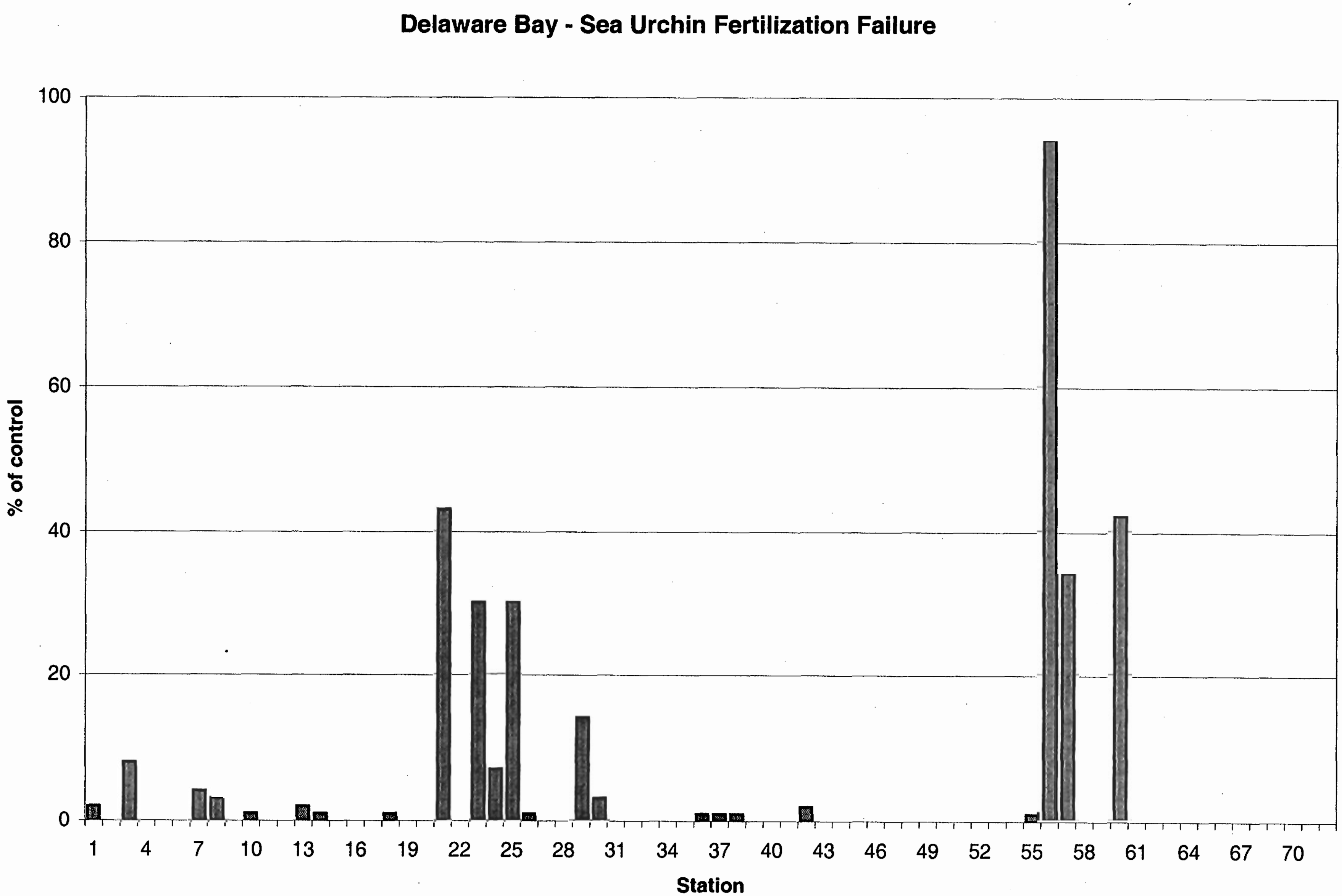


Figure 27 Fertilization failure rates of sea urchin (*Arbacia punctulata*) eggs in sediment pore water toxicity bioassays from Delaware Bay sampling stations.

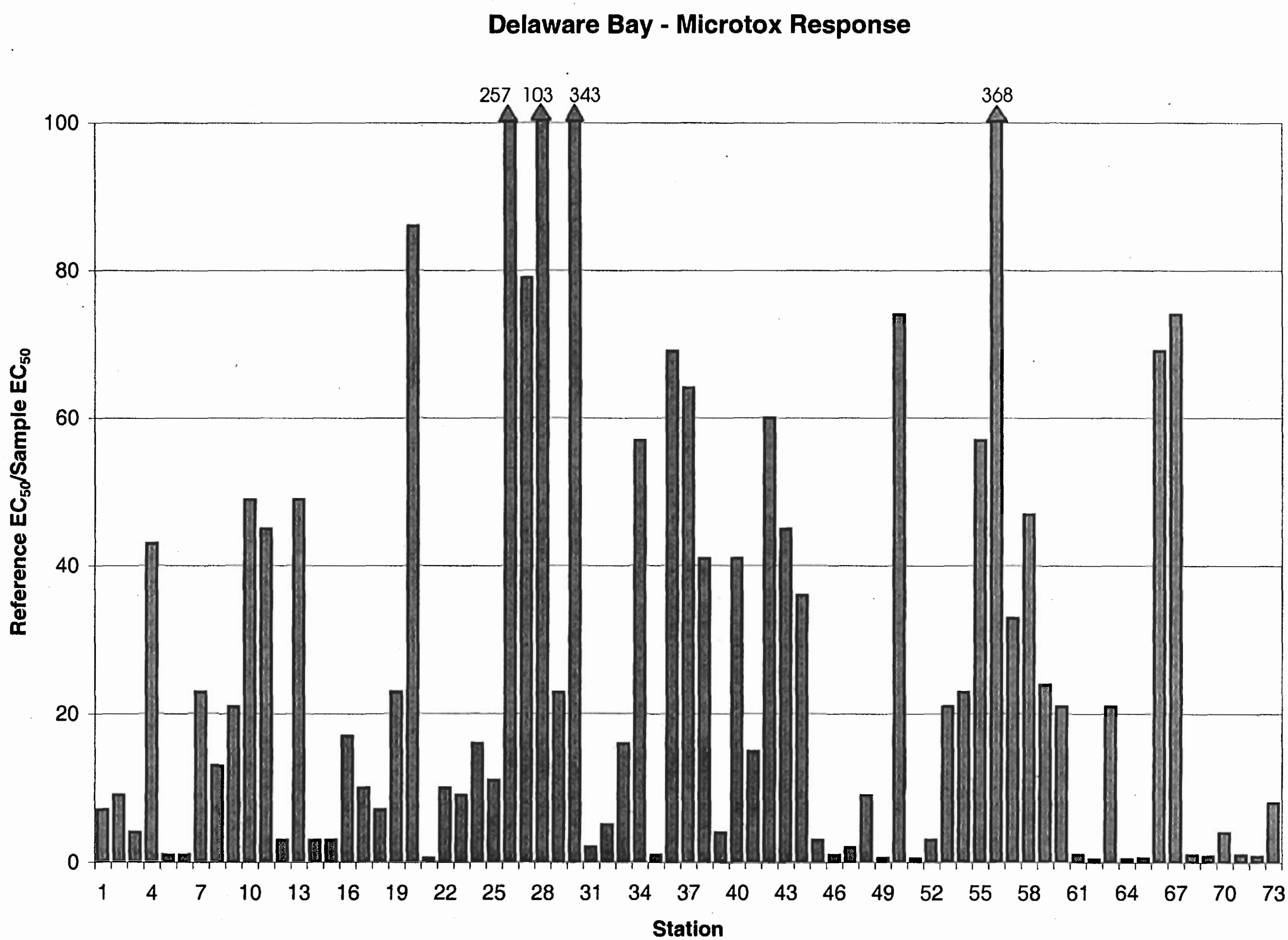


Figure 28 Microtox[R] bioassay EC_{50} response rates relative to control EC_{50}s in sediment extract toxicity bioassays from Delaware Bay sampling stations.

strata 1 and 2 were highly significant. Station 20 demonstrated a highly significant response, consistent with the amphipod mortality response. The most extreme values were from strata 7 and 8, in the vicinity of the C&D canal. The test EC_{50} was as low as 0.3% of the reference. Similar results were seen at station 56. Eight stations exhibited EC_{50}s of less than 1% of the reference value. A total of 58 stations demonstrated marginal depression of EC_{50}s, comprising 78.5% of the total area. A total of 40 stations demonstrated statistically significant depression relative to the phenol-spiked reference standard (Figure 29), comprising 55.9% of the area.

The P-450 results were significant primarily in the freshwater strata and upper estuarine stations (Figure 30). With the exception of station 11 this bioassay tracked very closely with PAH concentrations, regardless of salinity (Figure 31). Eighteen stations in 11 strata exhibited B[a]P equivalency factors above 32 ug/g. Results from station 11 were over 1,500 while the next highest value was 344 ug/g B[a]P equivalents. In the 6 and 16 hrs timed sequence of experiments, performed to distinguish between PAHs and chlorinated compounds, stations 2, 10, 17 and, 19 indicated contribution of chlorinated dioxins, furans, and/or PCBs to the observed results (Figure 32). Results from stations 11,16 and 20 indicated a predominant contribution of chlorinated contaminants to the responses (Figures 32 & 33). Station 11 was notable in that results showed a significant contribution of chlorinated compounds even at a 1:100 dilution, which effectively diluted the other station samples to concentrations below induction thresholds. Stations 13, 16 and, 20 had the highest measured PCB concentrations. Also, station 13 had a very high concentration of planar PCBs, specifically PCB77. Chlorinated dibenzofurans and dioxins were analyzed only at mainstem stations 10, 11, 20 and, 29. The aerial extent of toxicity as measured by the P450 bioassay was 2.6%.

BENTHIC COMMUNITY CHARACTERIZATION

The appendices provide a complete species listing for all sites with taxa abundance and density data. A total of 20,060 organisms, representing 239 taxa, were identified from all sites, including the small watershed special study samples. Polychaetes were the most

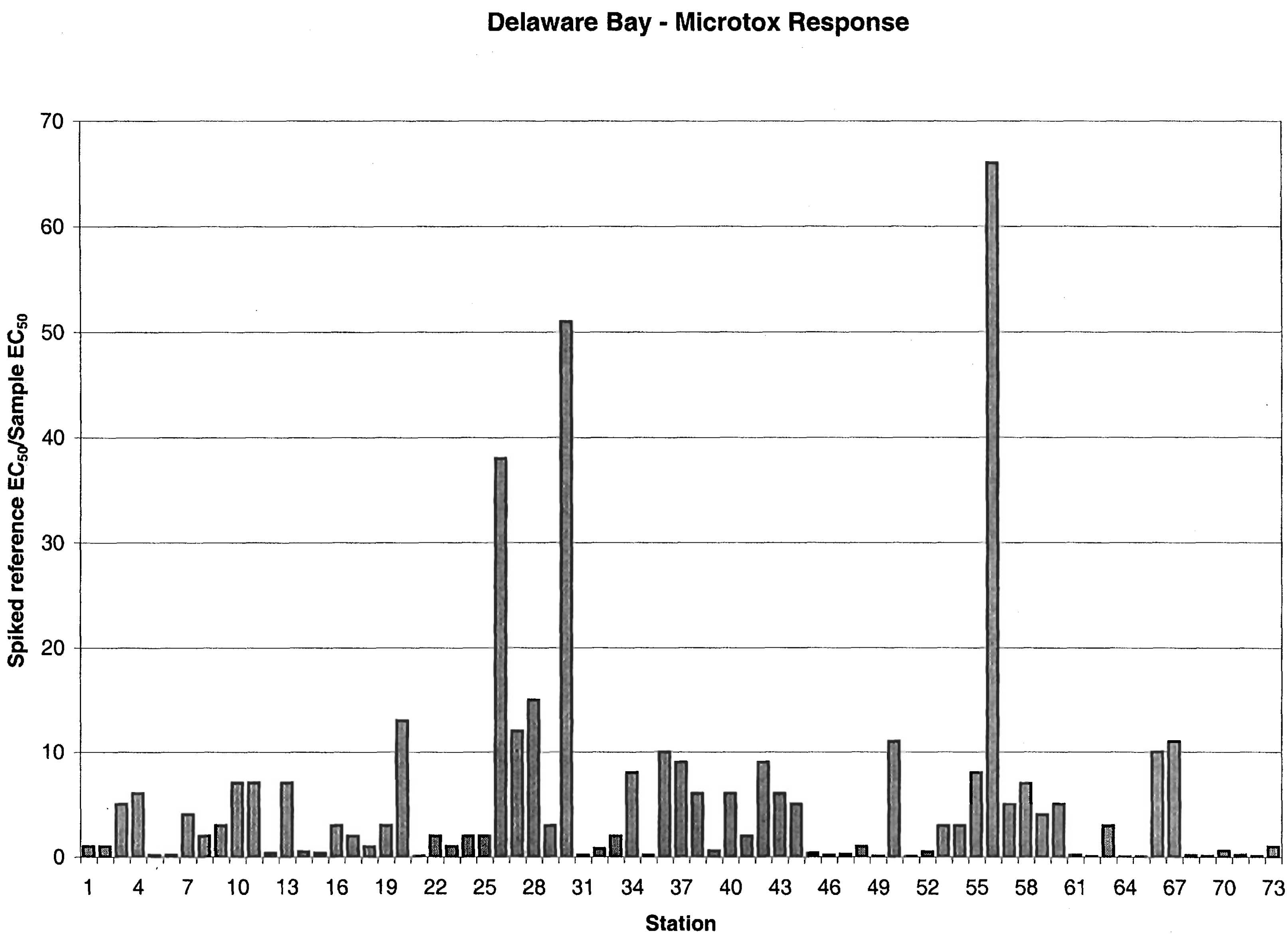


Figure 29 Microtox[R] bioassay EC_{50} response rates relative to phenol spiked reference EC_{50}s in sediment extract toxicity bioassays from Delaware Bay sampling stations.

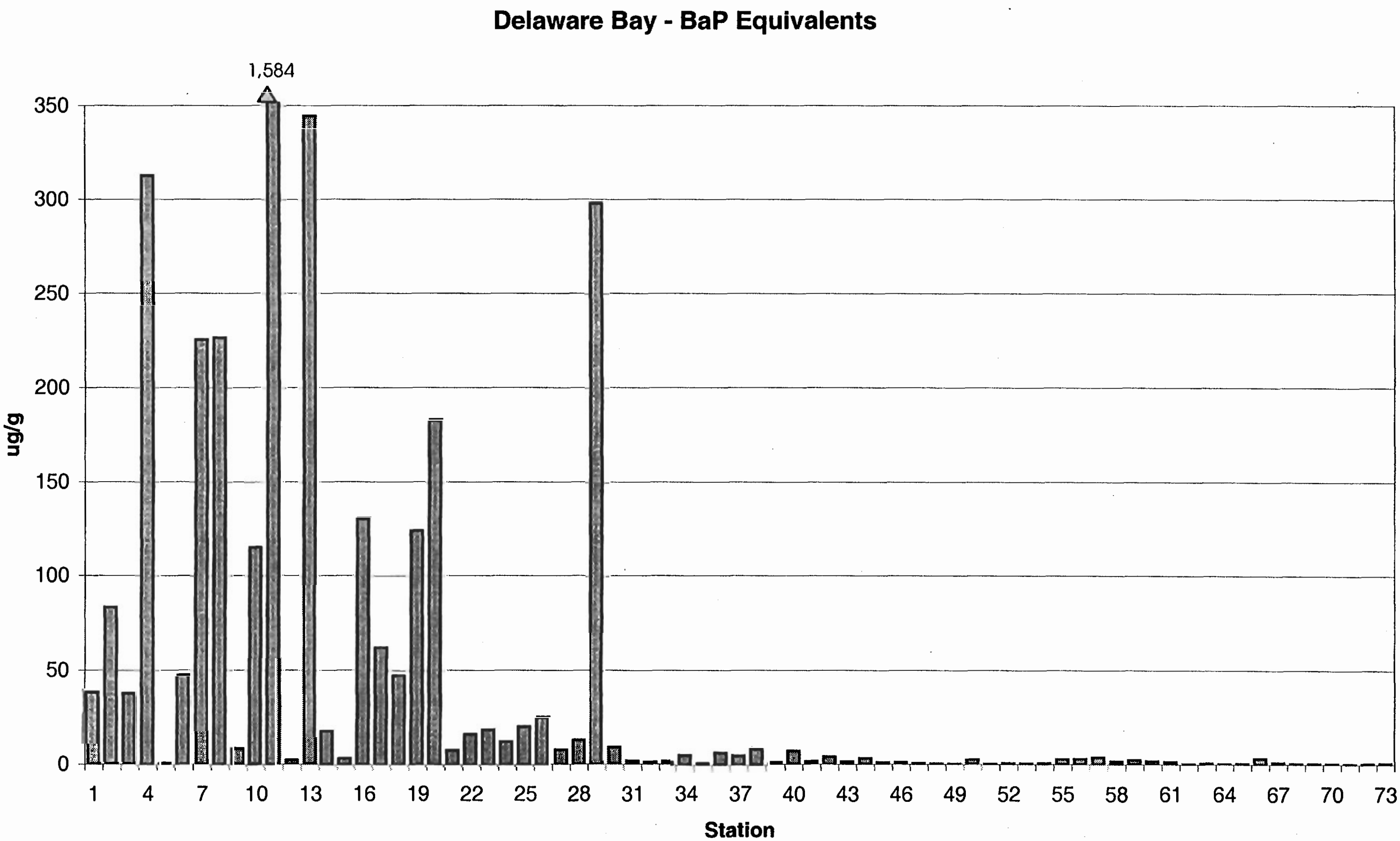


Figure 30 P450 response rates expressed as Benzo-a-Pyrene equivalents in sediment extract bioassays from Delaware Bay sampling stations.

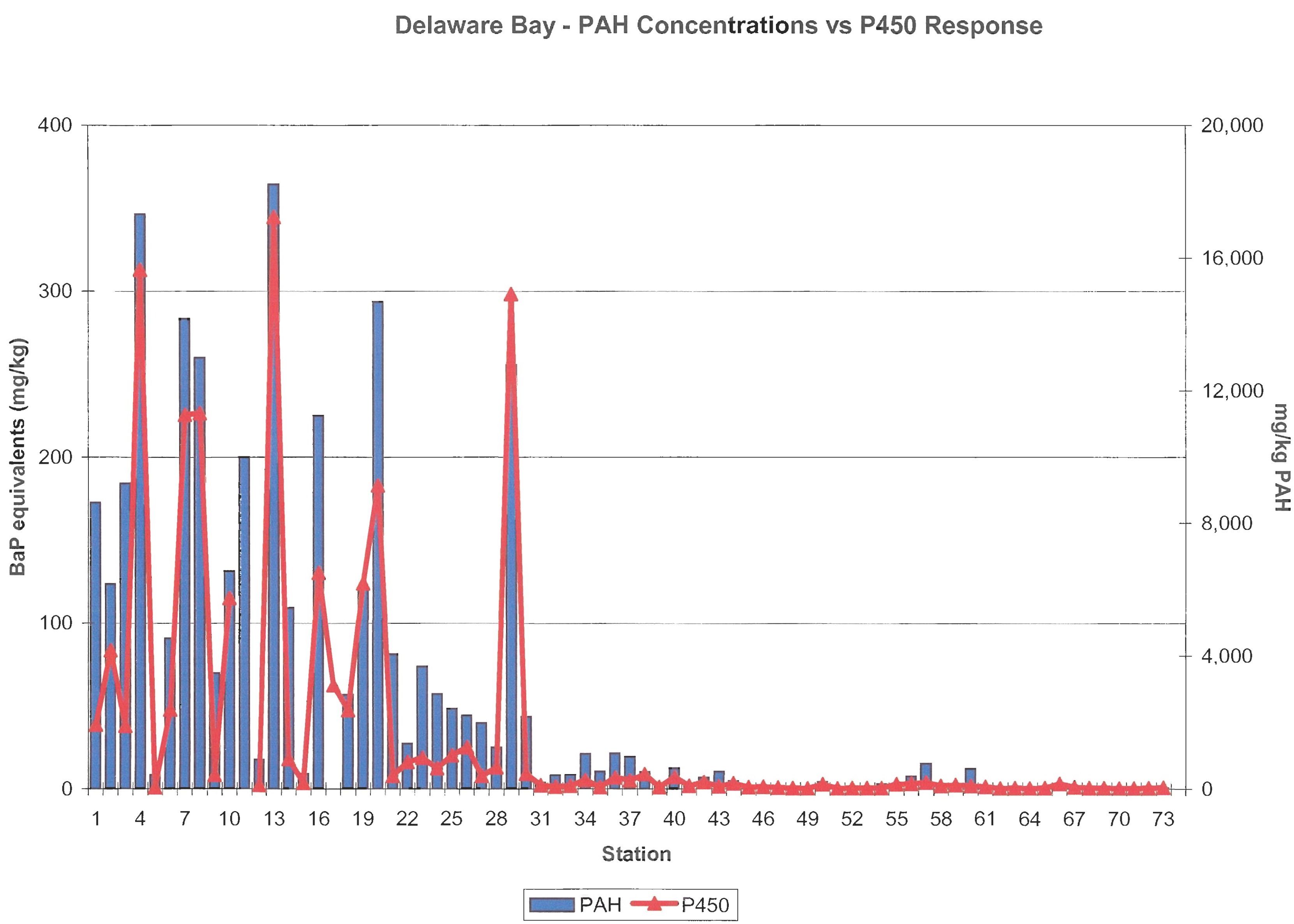


Figure 31 Delaware Bay sediment PAH concentrations and P450 response, as BaP equivalents (without station 11 P450 response = 1584mg/kg).

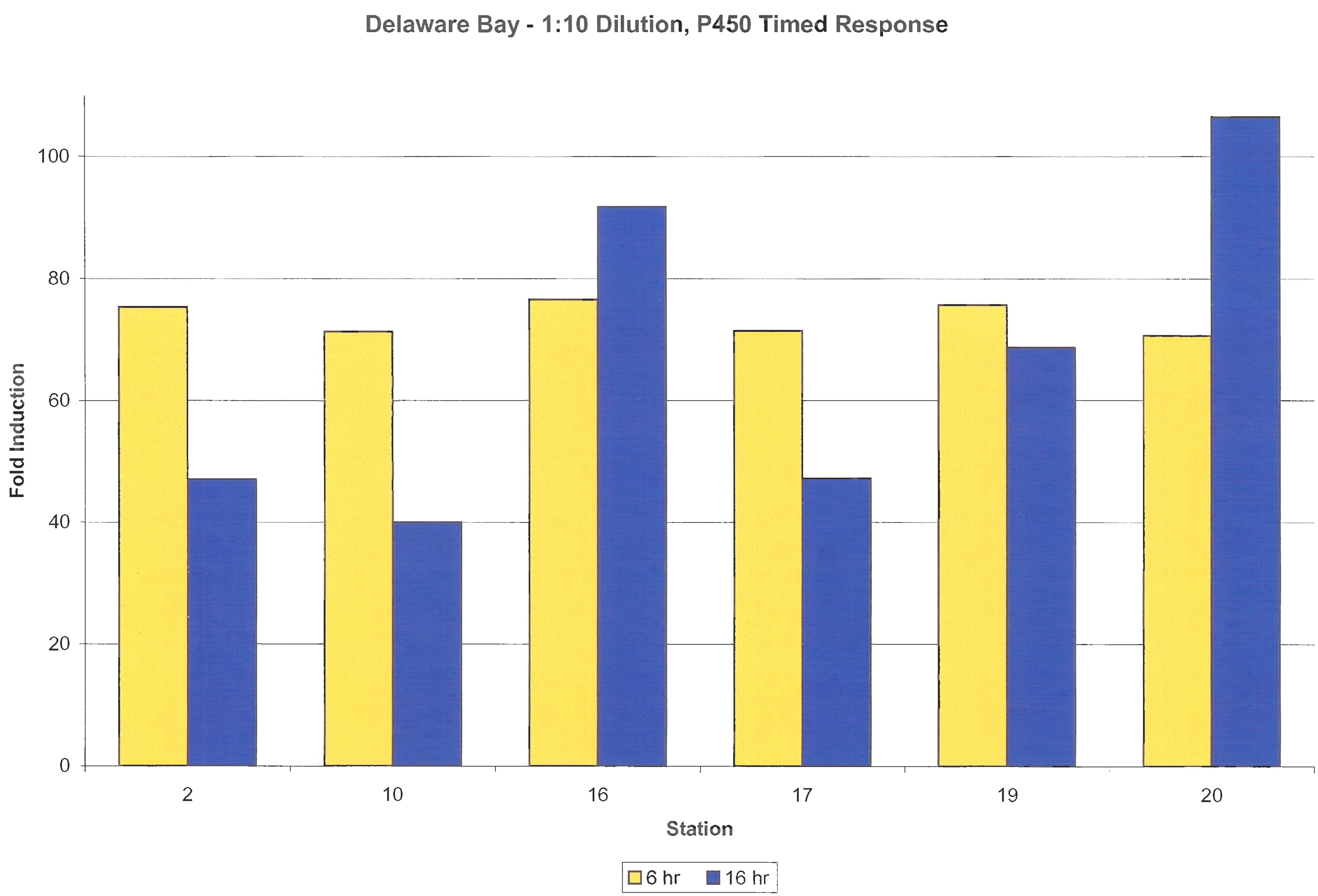


Figure 32 Fold induction (relative increase in P450 activity) results for selected Delaware Bay samples diluted by 1:10 and measured after 6 and 16 hrs.

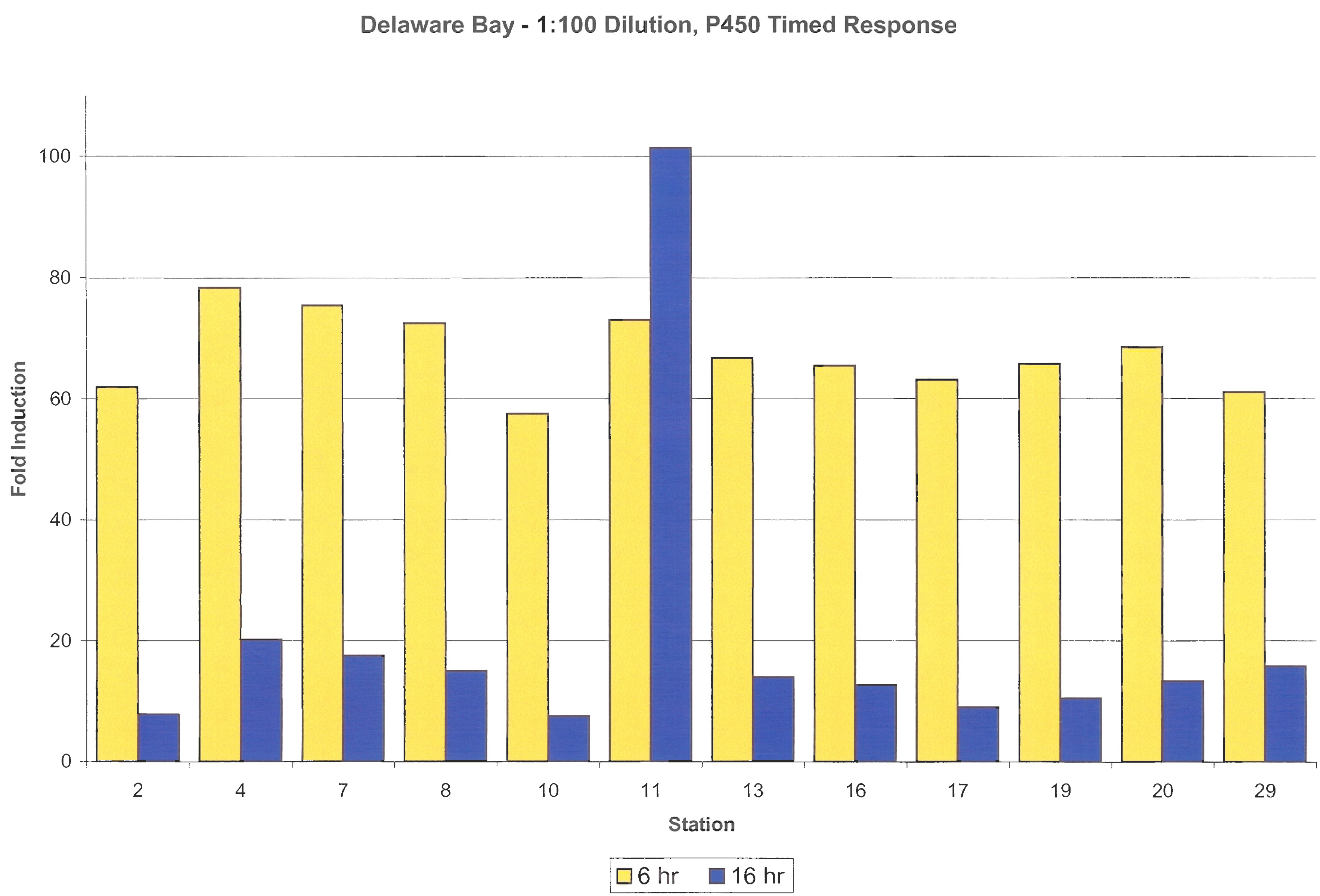


Figure 33 Fold induction (relative increase in P450 activity) results for selected Delaware Bay samples diluted by 1:100 and measured after 6 and 16 hrs.

numerous taxa present representing 34.7% of the total species assemblage, followed by malacostracans (31.4%) and gastropods (9.6%). In terms of abundance, malacostracans represented 36.1 % of the total number of individuals, followed by polychaetes (28.0%), oligochaetes (25.5%), and bivalves (4.6%). The dominant taxa collected from the samples was the amphipod, *Ampelisca abdita* which accounted for 19.38% of all individuals, but occurred at only 24.7% of the sites. The next most abundant taxon was the oligochaete Family Tubificidae at 17.88% of all individuals identified. This taxon was also the most widespread occurring at 61.7% of the sites. The isopod, *Cyathura polita,* Phylum Rhynchocoela, the oligochaete *Limnodrilus hoffmeisteri,* the cumacean *Leucon americanus* and the class Oligochaeta (LPIL) were the next most widespread occurring at 40.7%, 32.1%, 28.4%, 24.7% and 23.5% respectively. The polychaete genus *Mediomastus* accounted for 10.42% of all individuals and was identified at 27.2% of the sites. All other taxa accounted for less than 6.0% of the total number of individuals.

Total number of taxa, organism density, diversity and evenness are shown for individual stations in Figures 34 – 37, and by stratum in Figures 38-41. There were a total of 231 taxa enumerated in the mainstem. Of these, 131 were identified down to species. Among all stations, 81 taxa were found at to be unique to one station (i.e. found only at one station and no other). The number of unique taxa varied from station to station. Stations 72, 67, 66, 63, and 44 had high proportions of taxa that were unique to only those stations. Also, these stations had high proportions of rare taxa which were found at only two stations (Table 9). Of the 10 species found at station 67 and only one other station, 9 of the taxa were shared by station 66. Eight stations had 25 or more taxa (72, 67, 66, 63, 58, 44, 43, 42). The presence of unique and rare taxa were major contributors to the high taxa counts at these stations.

Organism density was highly skewed with respect to the density of individual taxa within stations, and between stations as a whole. Densities ranged from 59,700 organisms/M^2 at station 58 to 75 organisms/M^2 at station 24 (Figure 35). The high density stations were generally dominated by very large numbers of an individual taxon. Station 58 had 1.5X more animals that the next highest station. The density of *Ampelisca abdita* was almost

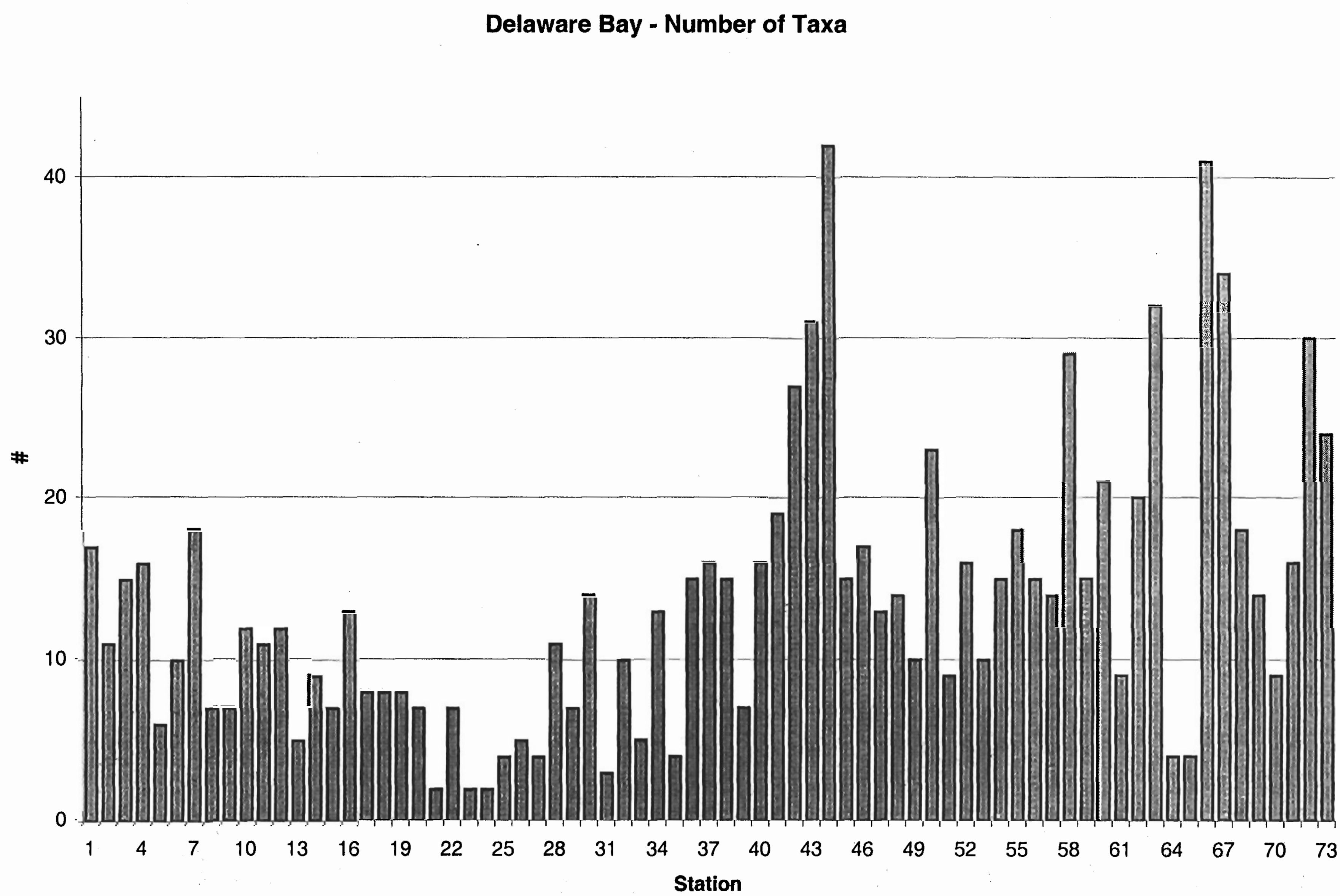


Figure 34 Number of macroinvertebrate taxa identified in Delaware Bay sediment samples.

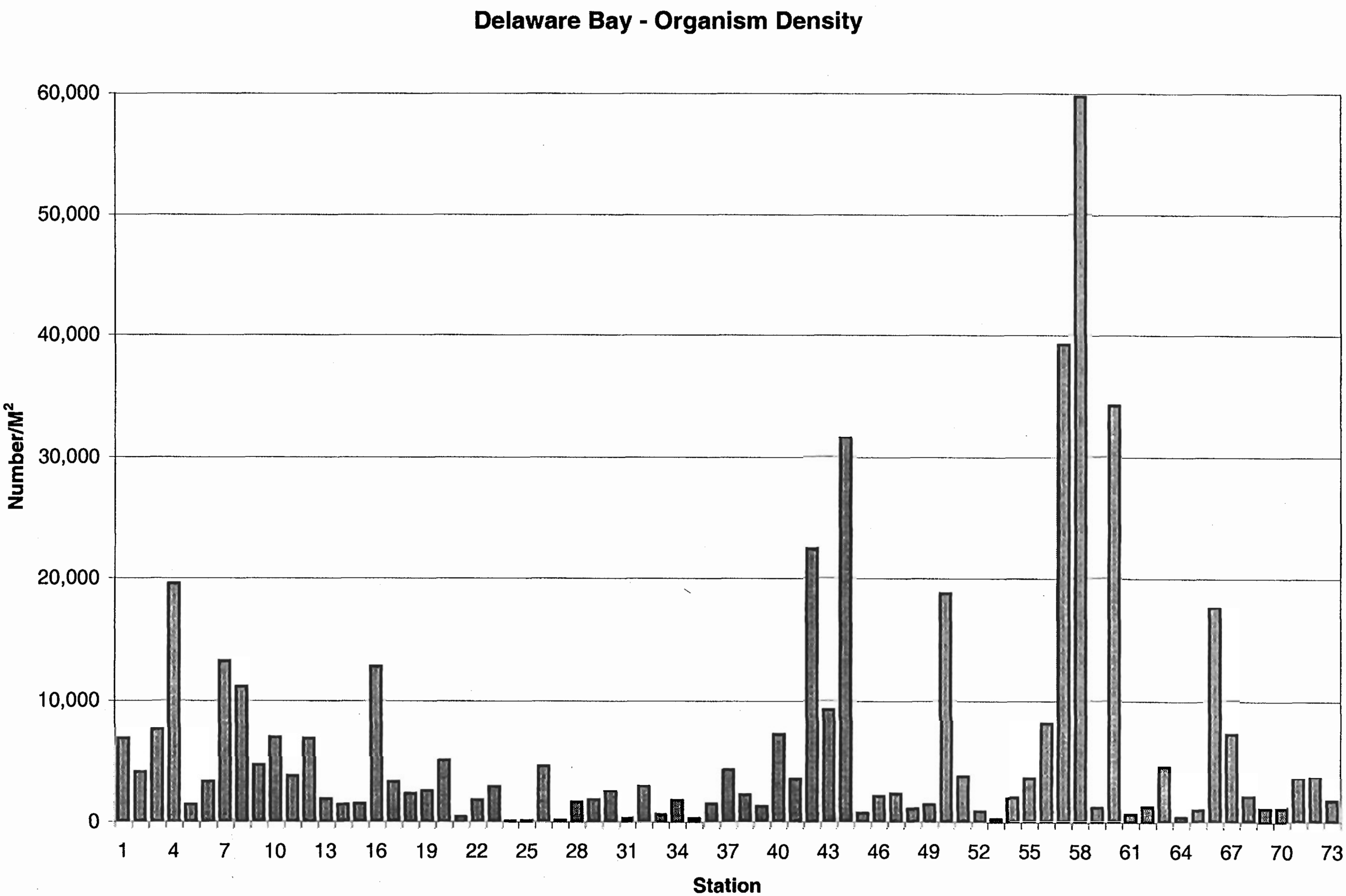


Figure 35 Density of macroinvertebrate organisms found in Delaware Bay sediment samples.

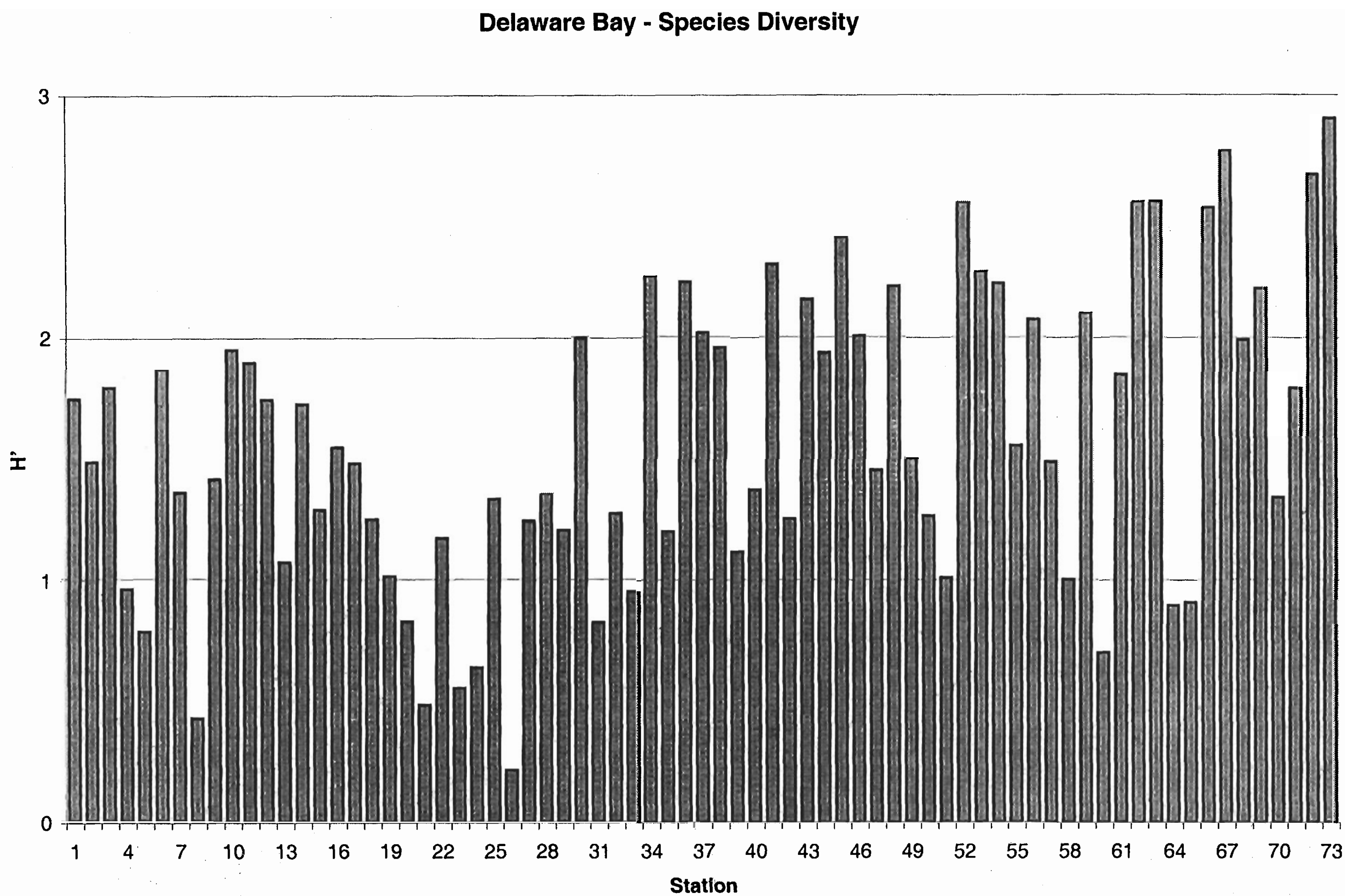


Figure 36 Macroinvertebrate species diversity in Delaware Bay sampling stations.

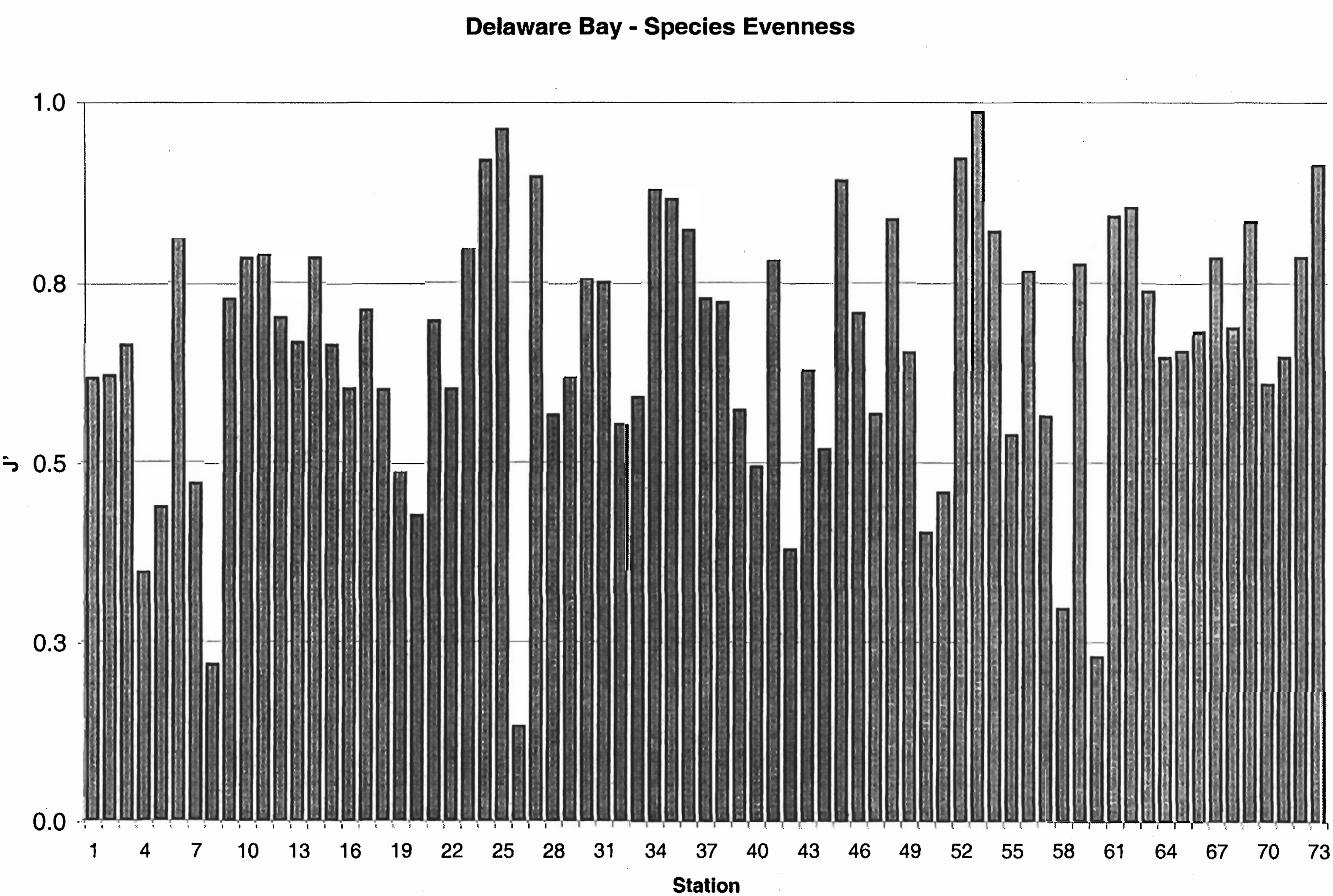


Figure 37 Macroinvertebrate species evenness in Delaware Bay sediment samples.

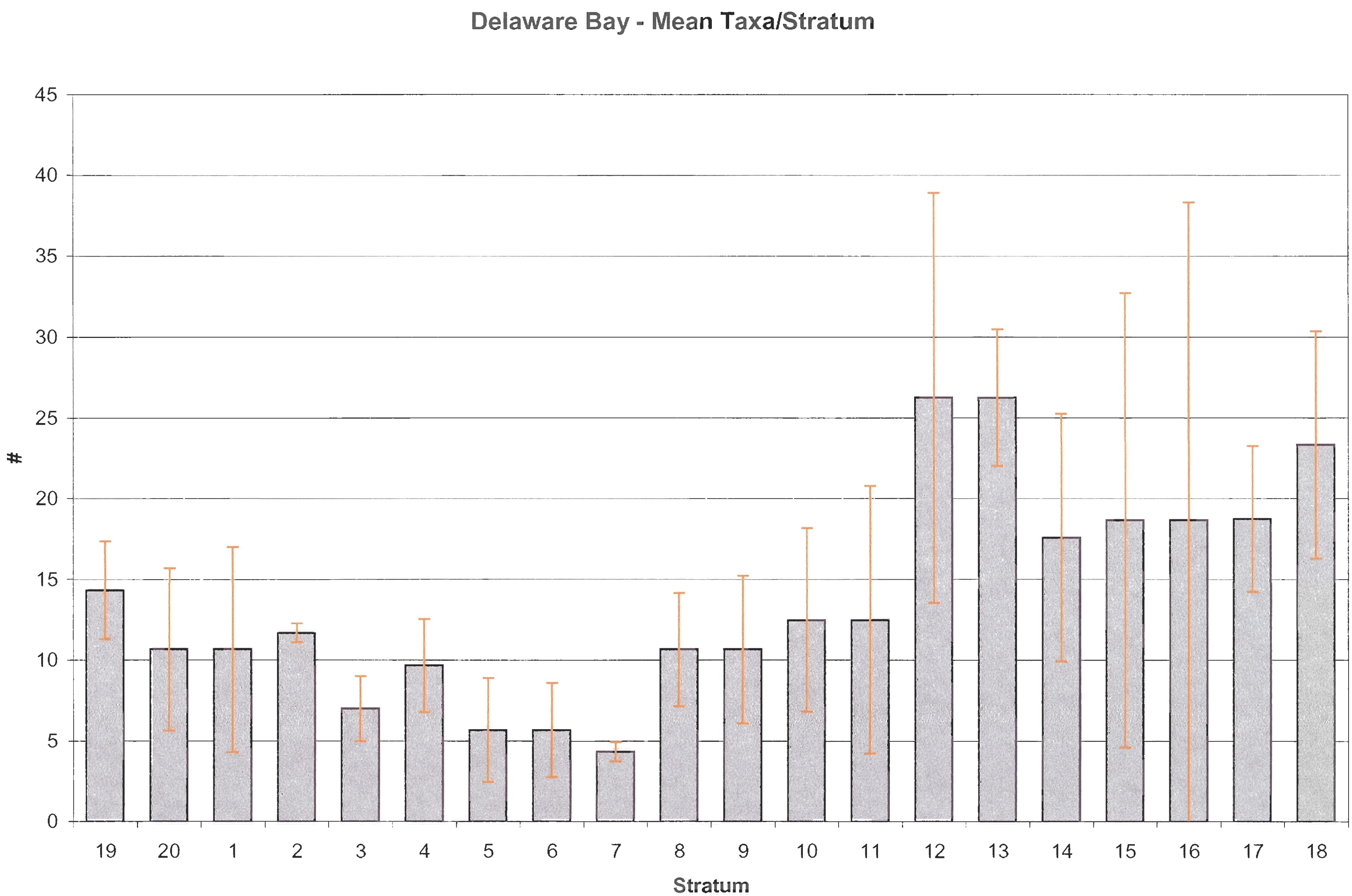


Figure 38 Mean number of macroinvertebrate taxa per stratum in Delaware Bay sediment samples. Error bars are ± one standard deviation.

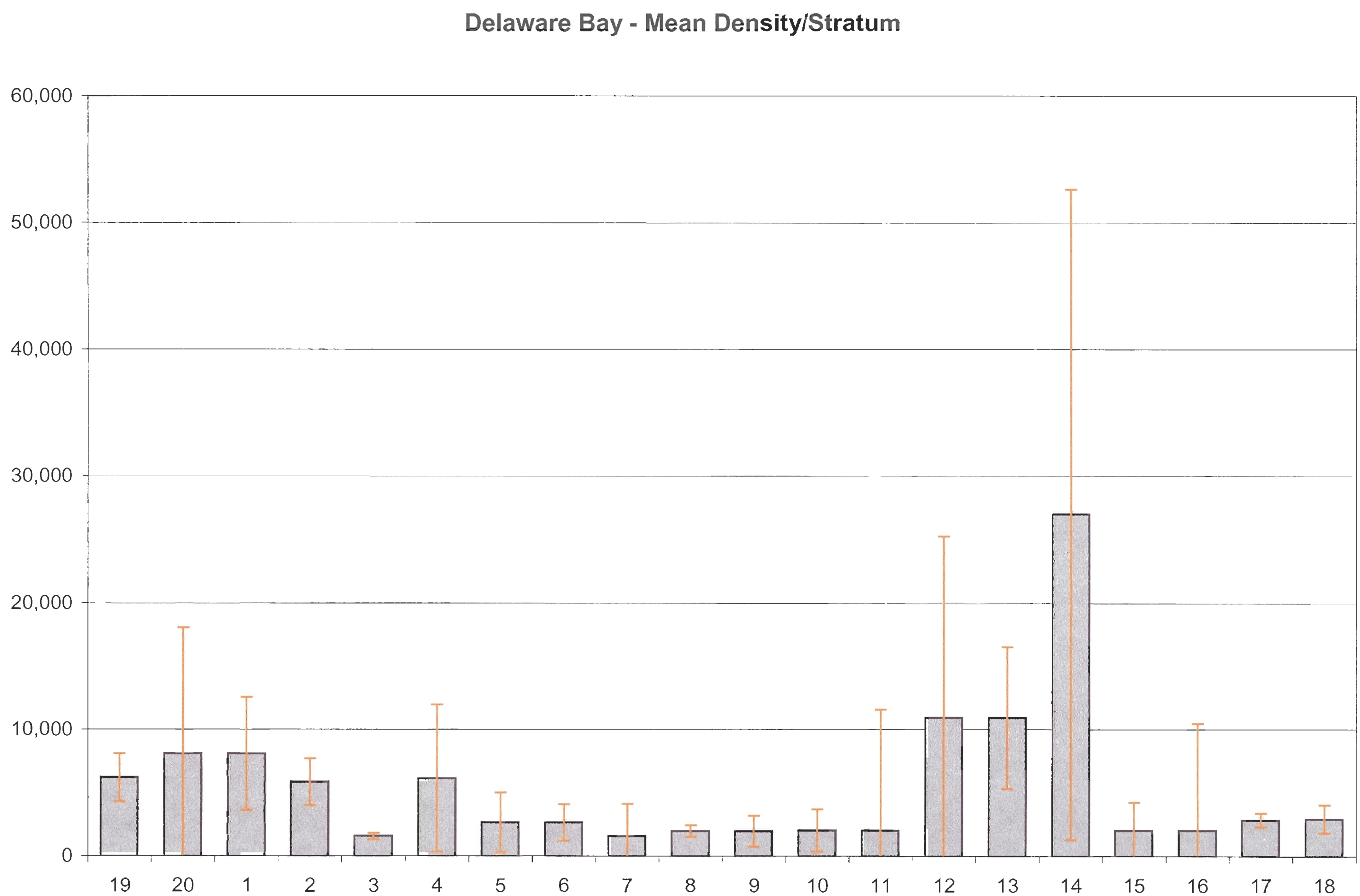


Figure 39 Mean density of macroinvertebrate organisms per stratum in Delaware Bay sediment samples. Error bars are ± one standard deviation.

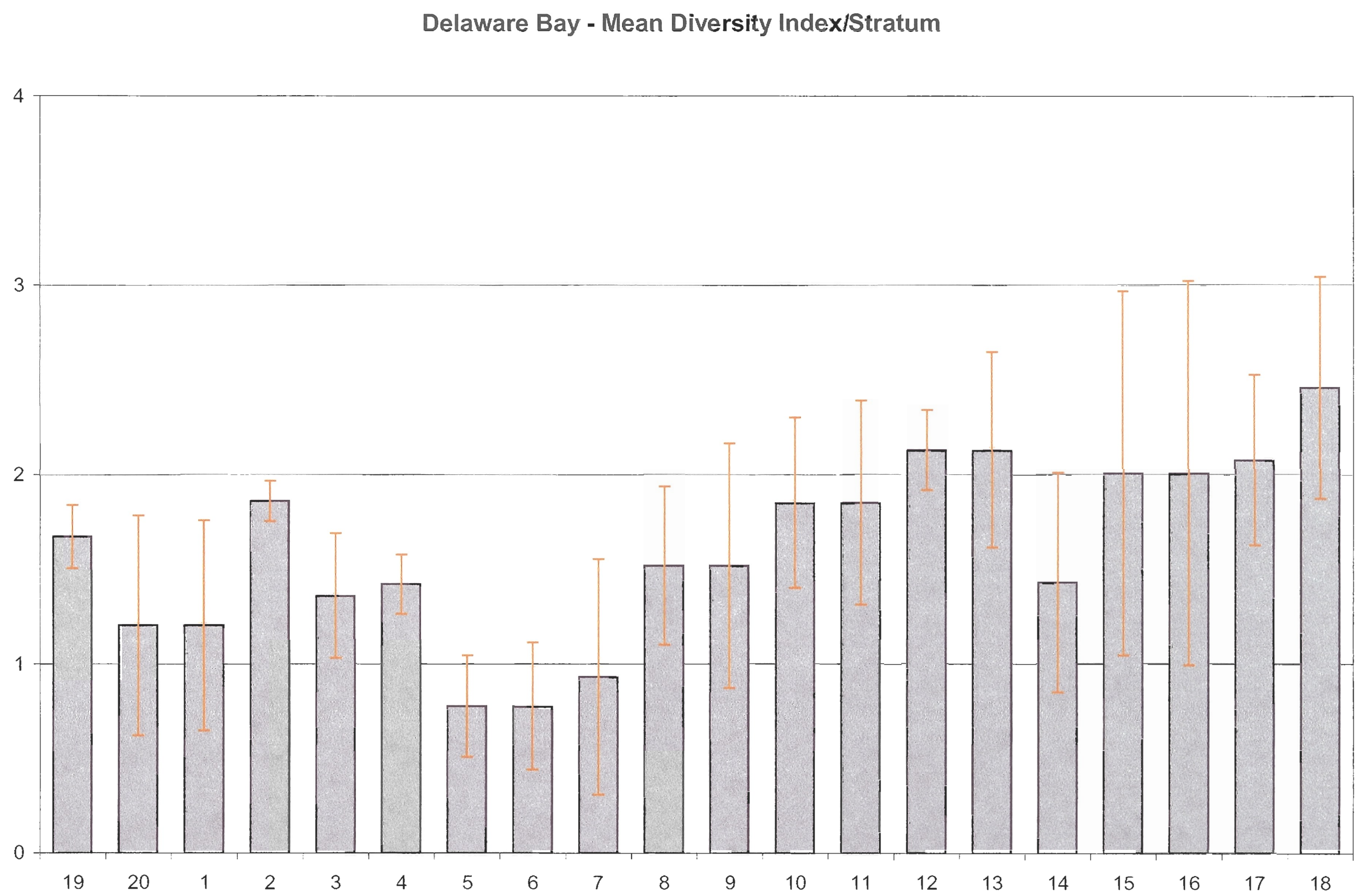


Figure 40 Mean species diversity per stratum in Delaware Bay sediment samples. Error bars are ± one standard deviation.

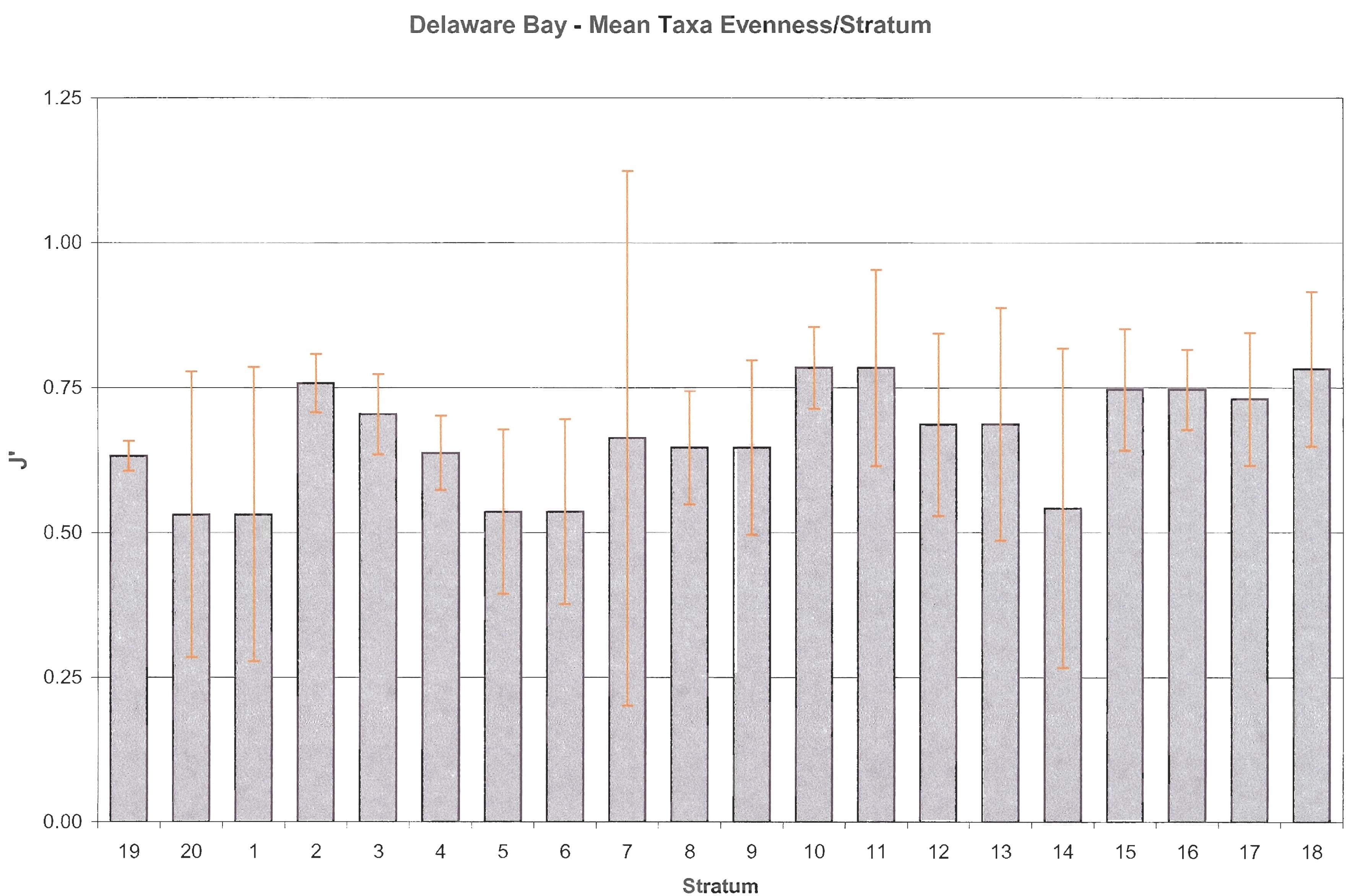


Figure 41 Mean species evenness per stratum in Delaware Bay sediment samples. Error bars are ± one standard deviation.

Table 9 Number of unique (occurring at only one station) and rare (occurring at only 2 stations) species from Delaware Bay sampling sites.

Station	#Unique	# Rare	Total
1	1	3	4
3	3	1	4
4	0	1	1
5	1	0	1
7	2	3	5
8	1	1	2
12	0	1	1
15	1	0	1
16	0	2	2
19	2	0	2
20	1	1	2
27	0	1	1
28	0	2	2
30	2	1	3
32	1	1	2
36	0	2	2
38	1	0	1
39	1	0	1
40	1	1	2
41	1	1	2
42	1	1	2
43	2	4	6
44	5	5	10
45	0	1	1
47	2	0	2
48	2	1	3
49	0	1	1
50	2	1	3
51	2	0	2
52	0	1	1
53	2	0	2
55	3	1	4
56	1	0	1
58	1	3	4
59	2	1	3
60	0	3	3
61	1	0	1
62	5	2	7
63	4	5	9
64	2	1	3
66	9	12	21
67	6	10	16
68	0	1	1
69	0	2	2
70	0	1	1
71	1	0	1
72	8	5	13
73	1	2	3

42,000/M^2 at station 58, which accounts for 70% of the organisms counted there. Mediomastus accounted for 21% of the count. *A. abdita* accounted for 85% and 73% of the organisms at station 60 and 42, respectively. Stations 57, 50 and 44 were dominated by *Leucon americanus* (50%), Mediomastus (59%), and *Sabellaria vulgaris* (56%), respectively. Station 4 had 77% Tubificids. Station 66, which had the second highest number of taxa, was dominated by unspecified Oligochaete species (30%). Stations 57, 58 and 60 showed the three highest densities, and stratum 14 (Maurice River Cove) had the highest mean density of all strata. However, in the same stratum, stations 61 and 59 demonstrated the 10th and 17th lowest densities. The highly skewed distribution of organism density can be seen in Figure 42, which depicts the density of individual taxa at all stations. Figure 43 illustrates the distribution of density values at stations with organism densities below 15,000/M^2. There is no apparent pattern, with high and low density stations in all zones. Most of the freshwater stations were dominated by Tubificids and/or *Limnodrilus hoffmeisteri.* When viewed on the basis of strata (Figure 39) only stratum 14 stands out, as a consequence of stations 57 and 58, and the variability is evident.

Mean density for all stations was 451/M^2. The mean density for freshwater, estuarine and, oceanic stations was 588, 523, and 184/M^2 for, respectively (Table 10). Excluding the top 10th percentile of stations (66, 60, 58, 57, 50, 44, 42, 4) the mean density for total, freshwater, estuarine and, oceanic stations was 265, 530, 215, 135/M^2, respectively. Organism densities at non-toxic sites were 345, 378, 426 and 184/M^2 for total, freshwater, estuarine and, oceanic stations respectively. Mean density at stations exhibiting significant toxicity was 798/M^2 (666 and 991/M^2 at fresh and estuarine stations, respectively). These values include data from the extreme stations of 57 and 60. Without the high count stations, the mean density was 516/M^2. Excluding Tubificids and *Limnodrilus hoffmeisteri,* from all toxic stations, the mean density actually rises to 550/M^2 due to a smaller sample size, but the density value for the freshwater stations falls to 278. Without *A. abdita* at station 60 and *L. americanus* at station 57, the mean density at toxic estuarine stations was 314/M^2. The details of species richness and density

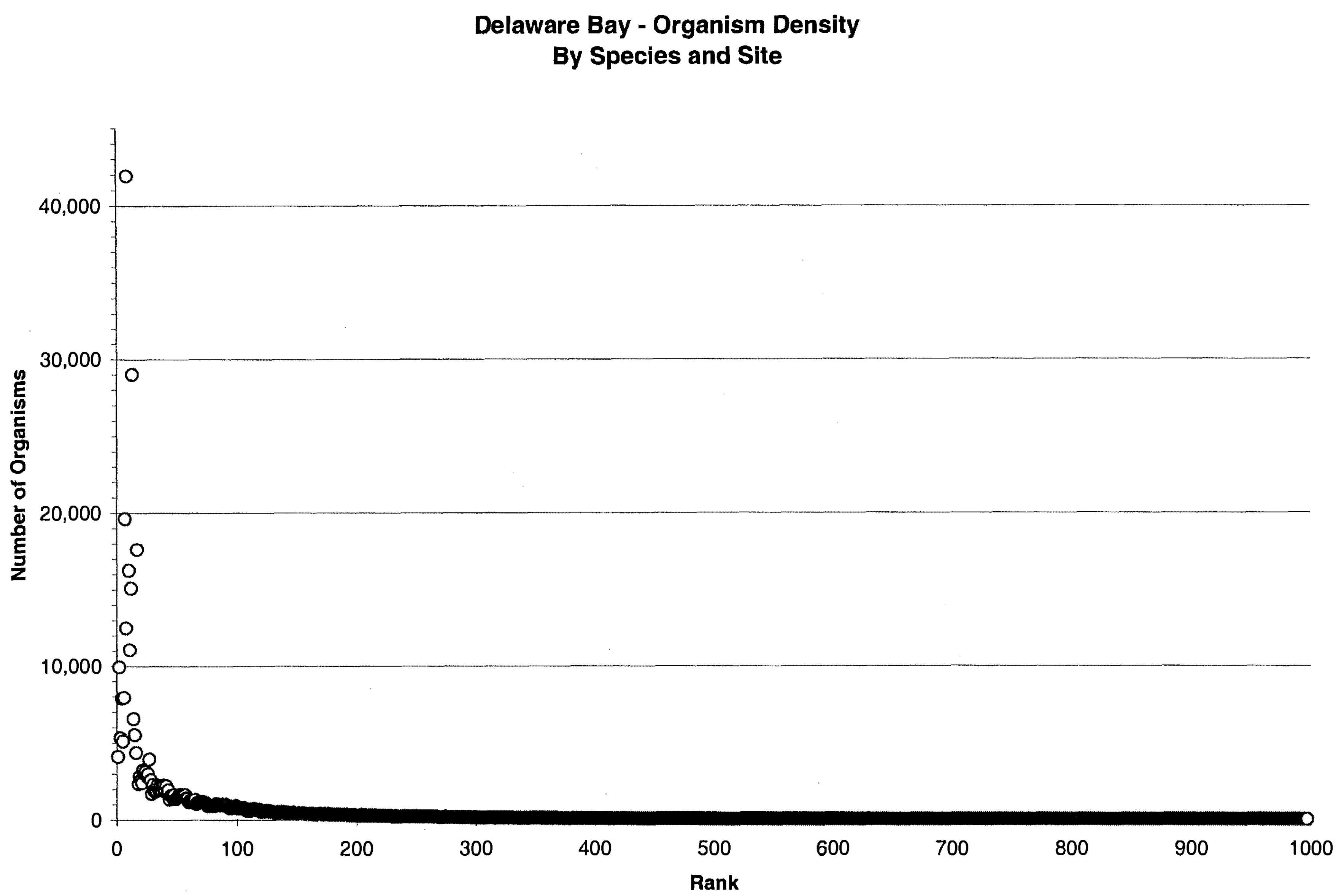


Figure 42 Density of individual species at each site, plotted in rank order from highest to lowest.

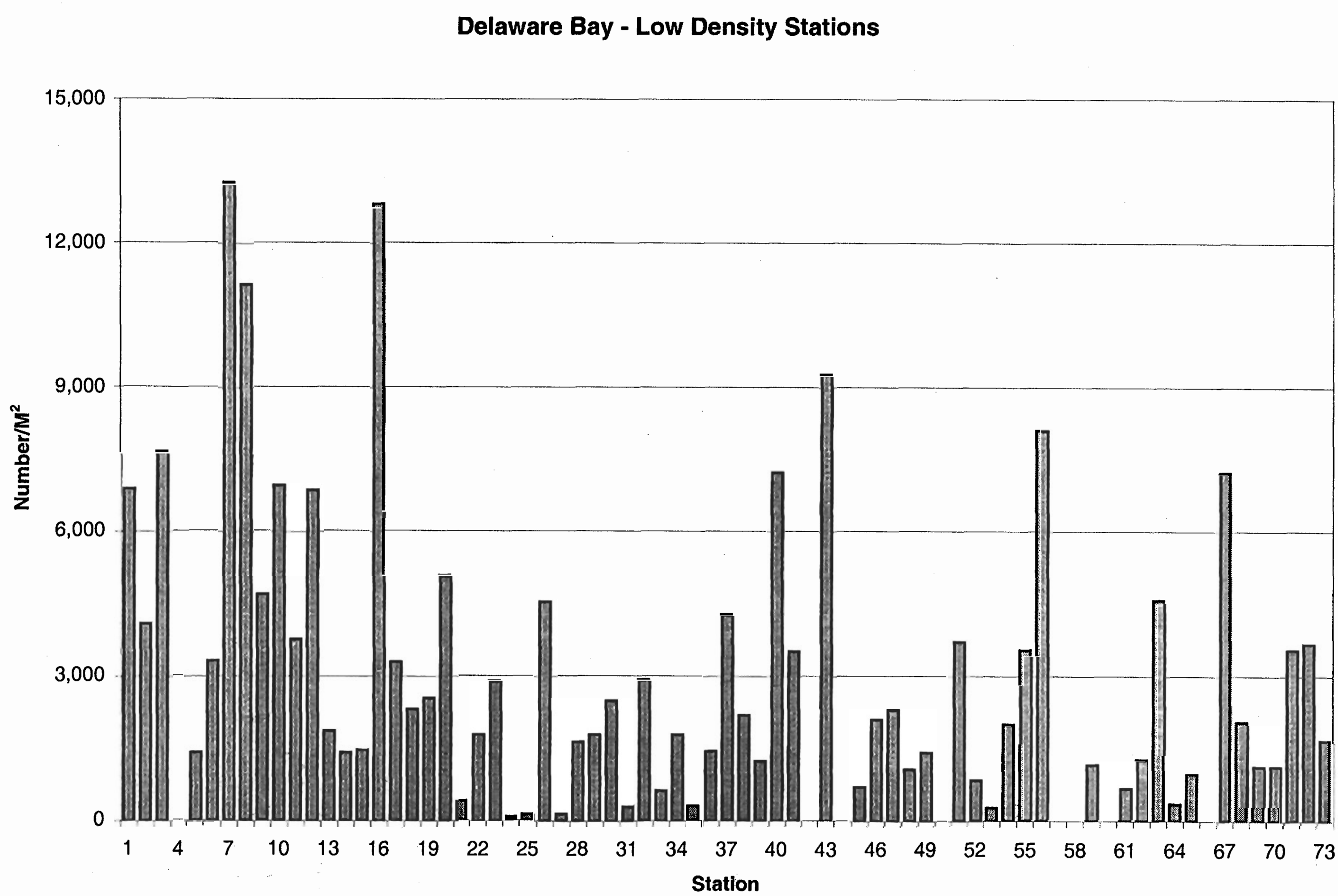


Figure 43 Density of macroinvertebrate organisms found in Delaware Bay sediment samples, without stations over 15,000 organisms/M^2.

Table 10. Mean densities of Delaware Bay stations with and without various extreme values of stations and/or taxa.

Zone	All Taxa All Sites	All Taxa 90% Sites	Non-Toxic All Sites	Non-Toxic 90% Sites	Toxic All Sites	Toxic 90% Sites	Toxic W/O species*	Toxic W/O Species#
All	451	265	345	187	798	516	550	264
Fresh	523	530	378	378	666	594	278	/
Estuarine	588	215	426	190	991	357	920	314
Ocean	184	135	184	135	/	/	/	/

* excluding Tubificidae and *Limnodrilus hoffmeisteri*
\# excluding Tubificidae and *Limnodrilus hoffmeisteri* plus *Ampelisca abdita* from #60 and *Leucon americanus* from # 57

are important to understanding the derived values of diversity and evenness. Species diversity was generally lowest in the freshwater/saltwater interface zone as a consequence of low species richness. Mean strata diversity was higher in the oceanic and estuarine sites below the mixing zone, but individual station values were highly variable in all zones. Diversity and evenness were low at stations 8 and 26. These stations had relatively low species richness and density and, were dominated by Tubificids. In contrast, station 60 had low diversity and evenness in spite of high species richness and density, due to the enormous number of *Ampelisca abdita* (over 29,000/M^2) found at that site. Stations 24, 25 and, 53 had the highest evenness values because they had a relatively low number of taxa, but organism density levels were among the lowest of all stations. Evenness was more uniform than diversity on a stratum by stratum basis.

REGRESSION ANALYSES

Stepwise regressions resulted in several statistically significant relations between variables, but correlation coefficients were generally low for linear regressions. Log transformation of contaminant concentration data resulted in improved correlations between concentration and toxicity and benthic community indices for selected variables (Tables 11 - 13). Examination of the data from the freshwater and estuarine strata, where virtually all of the samples with significant contaminant concentrations and toxicity responses were observed, does not reveal consistent relationships. Also, most of the contaminant concentrations rose and fell in unison, especially PAHs and metals (Figure 44), so identifying specific relationships would be difficult under any circumstances, even for bioassays that are reasonably chemical specific, such as the P450 assay. Stepwise regression results are summarized in Figures 45 & 46 for freshwater and estuarine zones respectively. Regressions calculated on individual subsets of chemical classes (e.g. low weight, high weight, low weight alkyl-substituted, high weight alkyl-substituted PAHs) did not substantially improve results. Even the P450/PAH regression results only achieved an R^2 of 46.2%. Addition of PCBs to the regressions did not improve the results. The regression between Amphipod mortality and a combination of (log transformed) trans-nonachlor, alpha chlordane and, endosulfan resulted in an R^2 of

Table 11. Stepwise regression results of contaminant concentrations and log transformed concentrations on community indices and toxicity results for stations in the freshwater zone.

Variable	Contaminant Class	R^2		Log[]Contaminant Class	R^2
Total Taxa	HCH	15.95		HCH	21.14
Density	HCH**	44.69		HCH* Chlordanes*	33.03 20.03
Diversity	Chlordanes*	36.70		Chlordanes	17.43
Evenness	Chlordanes* HCB	36.77 11.40		Chlordanes* HCH	25.41 17.54
Amphipod Mortality	PAHs	15.21		Chlordanes*	29.84
Microtox EC50	/			/	
Sea Urchin Fertilization	/			TBT PAHs** PCBs HCH	18.09 37.22 12.32 6.84
P450	PAHs DDT*	20.55 27.17		HCH	16.79

Significance levels ** = P≤ 0.01, * = P≤ 0.05, none = P≤ 0.15
/ = No chemical variable regression was statistically significant.

Table 12. Stepwise regression results of contaminant concentrations and log transformed concentrations on community indices and toxicity results for stations in the estuarine zone.

Variable	Contaminant Class	Partial R^2	Log[]Contaminant Class	Partial R^2
Total Taxa	PCBs**	18.83	HCH**	30.98
Density	TBT**	15.56	Chlordanes*	5.25
	Chlordanes*	12.94	TBT	8.30
	DDT	6.13		
Diversity	PCBs**	26.69	PCBs**	36.04
	TBT*	10.02	Metals	3.59
Evenness	TBT	7.22		
Amphipod Mortality	DDT*	13.76	/	
	Metals*	10.19		
Microtox EC50	HCH	6.59	/	
	Metals*	9.26		
Sea Urchin Fertilization	HCH	7.11	/	
P450	Chlordanes**	33.72	PAHs**	46.20
			HCB*	7.68
			Metals*	4.38
			TBT	3.68

Significance levels ** = $P \leq 0.01$, * = $P \leq 0.05$, none = $P \leq 0.15$
/ = No chemical variable regression was statistically significant.

Table 13. Stepwise regression results of contaminant concentrations and log transformed concentrations on community indices and toxicity results using the entire data set.

Variable	Contaminant Class	Partial R^2	Log[]Contaminant Class	Partial R^2
Total Taxa	Metals**	12.74	Chlordanes** HCH	25.50 2.55
Density	/		/	
Diversity	HCH** Chlordanes**	18.15 9.88	Chlordanes** HCH*	33.14 5.69
Evenness	Chlordanes*	8.91	Chlordanes*	5.95
Amphipod Mortality	/		/	
Microtox EC50	/		PAHs	3.40
Sea Urchin Fertilization	HCH*	7.89	/	
P450	Chlordanes** Metals	19.84 3.15	DDT** TBT* Metals PAHs** HCH	45.56 4.34 1.74 5.00 2.31

Significance levels ** = $P \leq 0.01$, * = $P \leq 0.05$, none = $P \leq 0.15$
/ = No chemical variable regression was statistically significant.

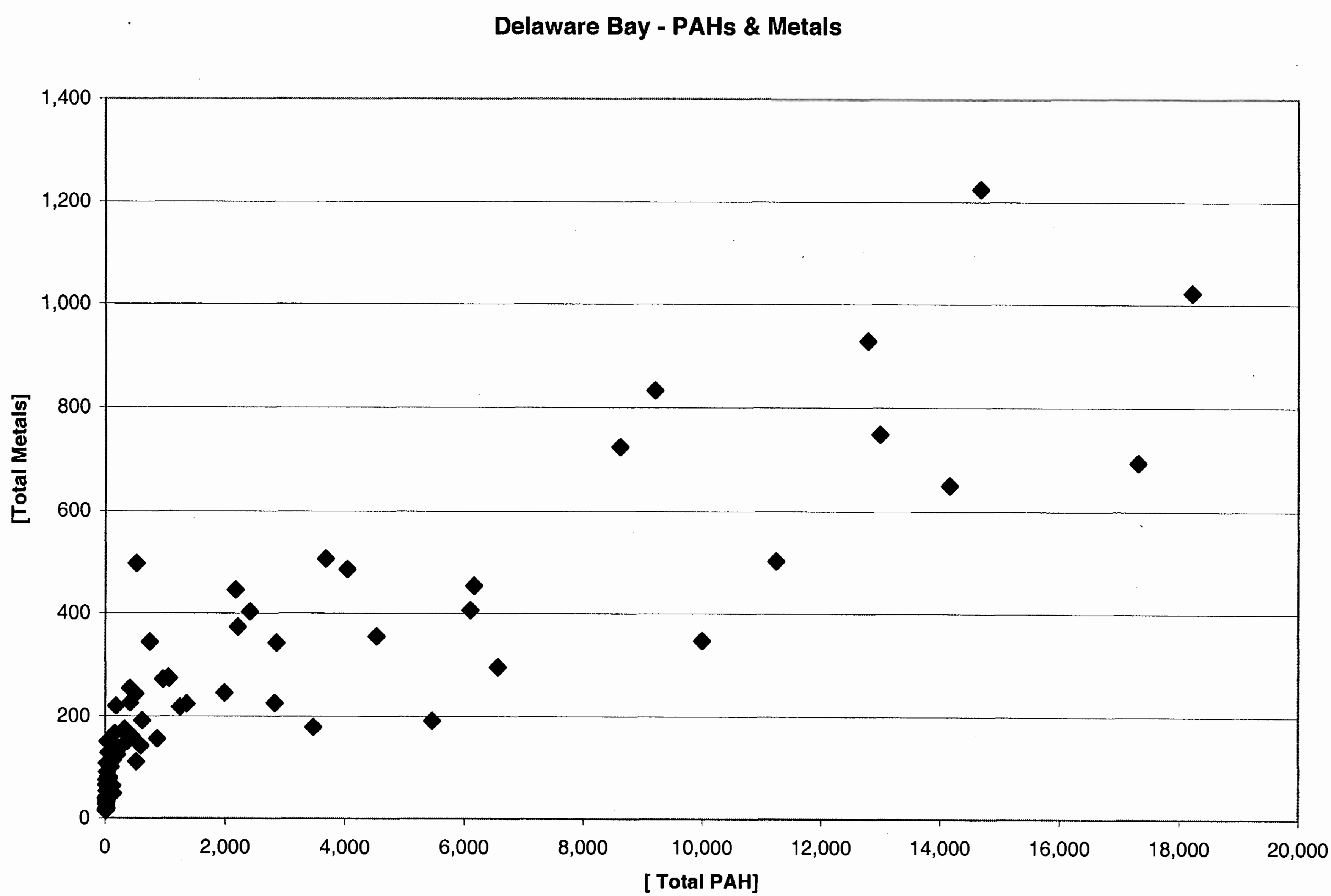


Figure 44 Concentrations of PAHs vs metals in Delaware Bay sediment samples.

Significant Regression Relationships Between Toxicity, Contaminants, and Community Indices

Freshwater Strata

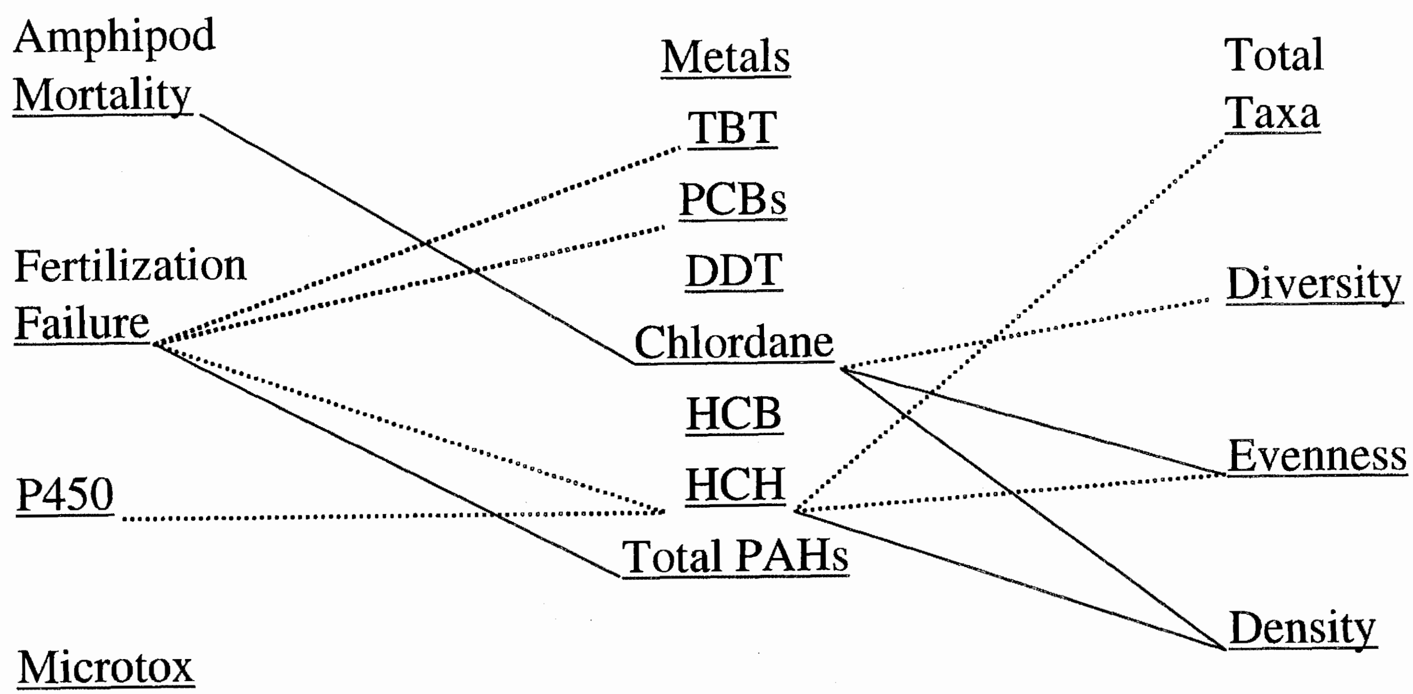


Figure 45 Significant regression relationships between toxicity bioassay results, benthic community indices and, sediment contaminants from Delaware Bay samples in the freshwater strata. Solid lines are for significant regressions at $P \leq 0.05$. Dashed lines are for significant regressions at $0.15 \geq P \leq 0.05$.

Significant Regression Relationships Between Toxicity, Contaminants, and Community Indices

Estuarine Strata

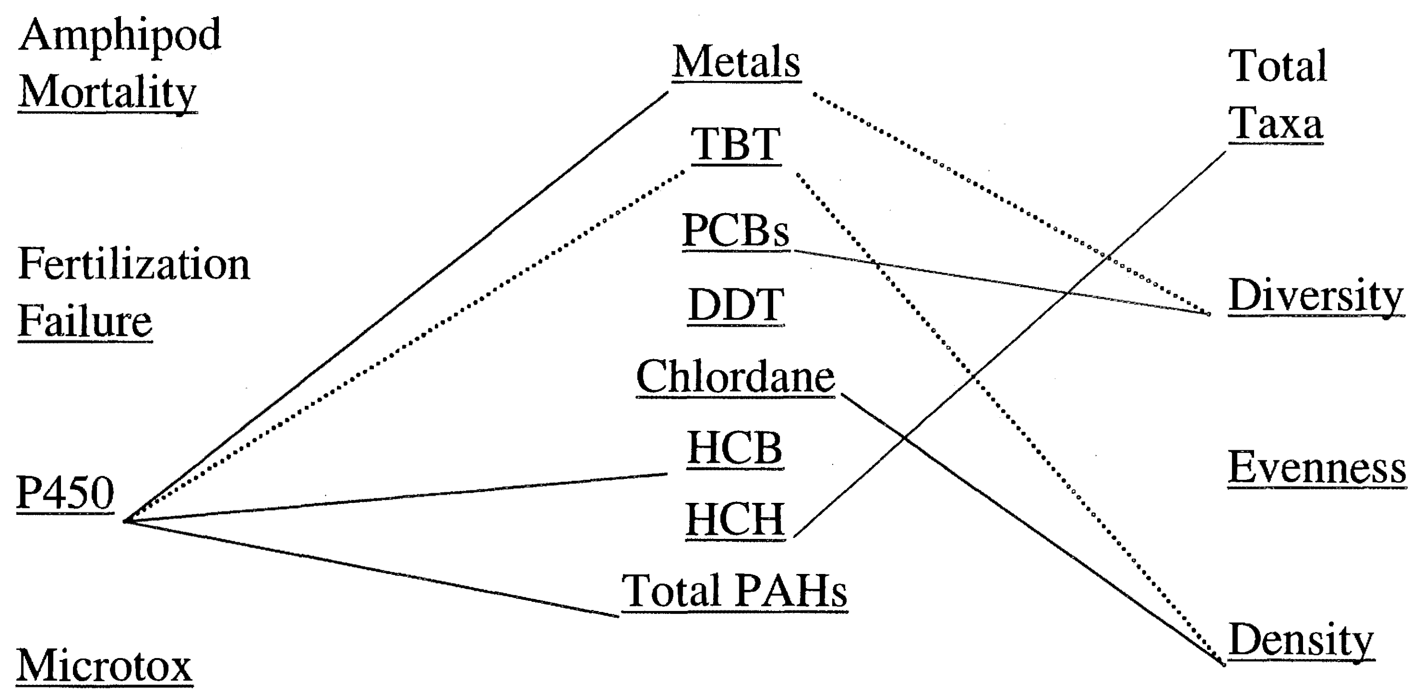


Figure 46 Significant regression relationships between toxicity bioassay results, benthic community indices and, sediment contaminants from Delaware Bay samples in the estuarine strata. Solid lines are for significant regressions at P≤ 0.05. Dashed lines are for significant regressions at 0.15≥P≤ 0.05.

55.24% in the freshwater strata but these results are largely driven by outliers. Similar results were seen with metals concentrations, where correlation coefficients for individual metals were seldom above 20% for toxicity bioassay or community indices. The relationships between benthic community indices and toxicity results were equally unclear (Table 14). Only two correlation coefficients for a community index/individual bioassay result were above 20%. Results are summarized in Figure 47.

Table 14. Stepwise regression results of toxicity bioassay results on community indices.

Variable	Bioassay (Freshwater)	Partial R^2	Bioassay (Estuarine)	Partial R^2
Total Taxa	Amphipod	15.58	Microtox*	9.61
	P450*	23.51	P450**	21.98
	Fertilization	13.52	Amphipod	4.05
Density	Microtox	19.93	Microtox	6.86
	Amphipod	13.32		
	Fertilization	10.52		
Diversity	/		P450**	16.20
			Microtox*	10.22
			Amphipod*	8.27
Evenness	/		Microtox	5.52

Significance levels ** = $P \leq 0.01$, * = $P \leq 0.05$, none = $P \leq 0.15$
/ = No chemical variable regression was statistically significant.

Significant Regression Relationships Between Toxicity and Community Indices

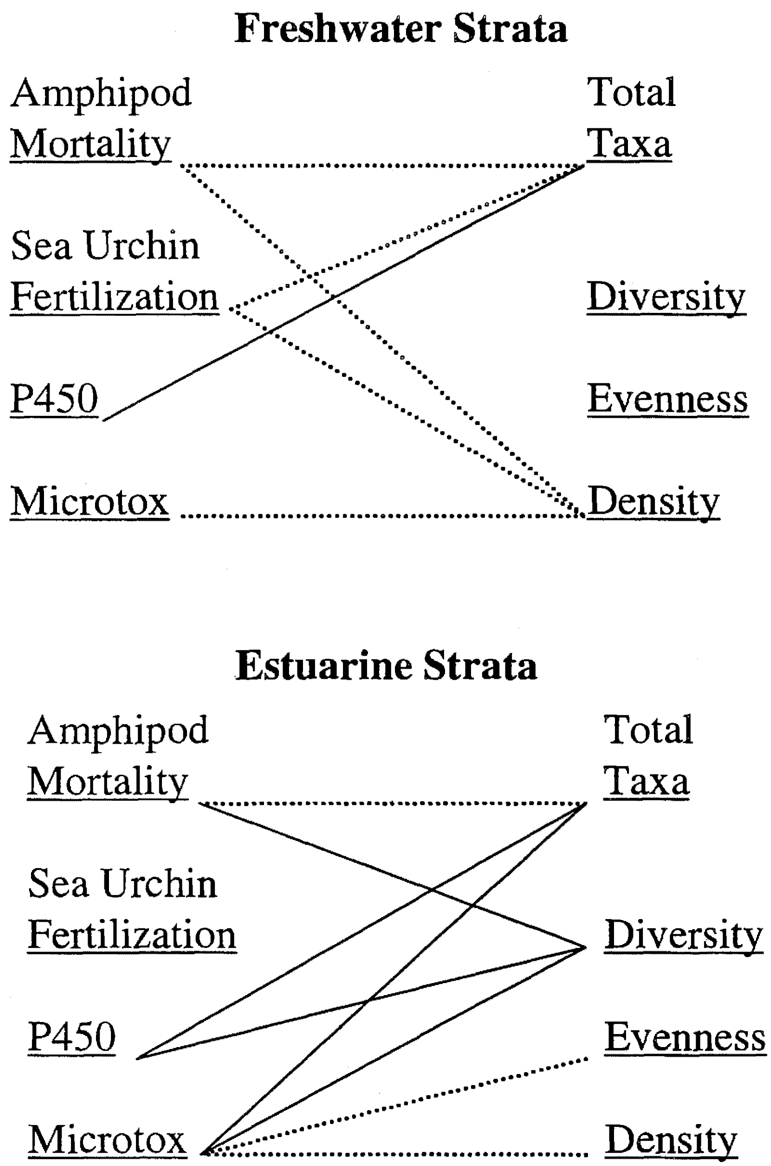


Figure 47 Significant regression relationships between toxicity bioassay results and benthic community indices from Delaware Bay samples. Solid lines are for significant regressions at $P \leq 0.05$. Dashed lines are for significant regressions at $0.15 \geq P \leq 0.05$.

DISCUSSION

The fact that chemical concentrations tended to be either high or low for all constituents at a given station makes interpretation of benthic community and toxicological results difficult. Because contaminant concentrations were confounded, specific assignment of cause and effect between chemical constituents, toxicity results and benthic community indices are impossible, even in the absence of other modifying parameters such as salinity or grain size gradients. Direct statistical correlations with individual chemical constituents were only discernable where concentrations were at the extremes of observed concentrations. Example scatter plots of chemical constituents and toxicity (Figure 48) show a correlation only at extreme levels if at all. The same was true for the benthic community indices. This can be interpreted as an indication that organisms can tolerate chemical contamination up to a certain threshold level, beyond which effects are observable. Below these levels, the relationships are influenced by a myriad of other factors.

Amphipod mortality tended to be highest at stations with high metals concentrations, but not all stations with high metals showed high mortality. Also, there were stations which demonstrated elevated toxicity, but which did not have elevated metals concentrations. High concentrations of metals and PAHs corresponded to amphipod mortality in estuarine stations, but not in the freshwater stations except for station 13. It may be that the process of salinity adjustment in the laboratory alters the chemical availability of contaminants in the short term. Toxicity in the sea urchin fertilization test did not show toxicity at the freshwater sites either.

The P-450 bioassay, which is essentially a chemical specific response test, tracked PAHs very well at all stations. The high value at station 11 is likely driven by chlorinated compounds (Figure 33). PCB concentrations at station 11 were not the highest observed in the data set. Dioxins and furans were detected at station 11, but planar PCBs were not analyzed in this sample. The station is located adjacent to an industrial zone in southern Philadelphia. It is immediately downstream from the confluence of the Schuylkill River,

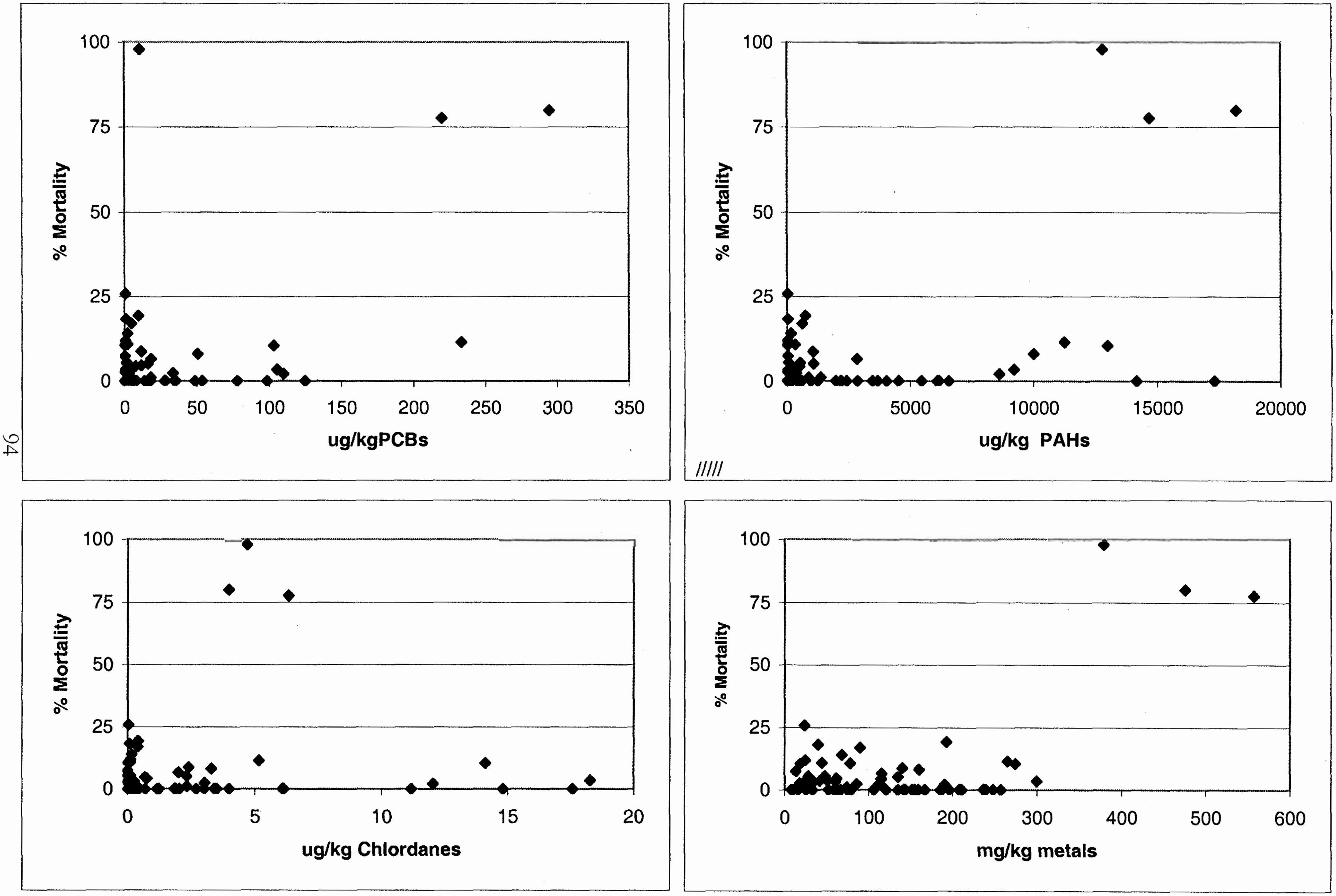


Figure 48 Scatter plots of selected contaminants and amphipod mortality.

which is a known source of contaminants, and just upstream from the Philadelphia International Airport. The next highest P450 value was reported from station 13. Amphipod mortality was also significant at this station. This station was by far the most contaminated of all the sites. The highest concentrations of PAHs, PCBs, coplanar PCBs, and DDT were found in that sample, as well as the second highest concentrations of metals and TBT. The station was located in a marina near the mouth of Darby creek in a heavily industrialized area.

A report prepared for the US Army Corps of Engineers (Versar, Inc., 1997), reported PCB concentrations at several stations near the NOAA stations. The data sets are not strictly comparable because the NOAA data includes fewer congeners than the Versar document. However, the data sets are in agreement that PCB contamination is prevalent in the tidal fresh and upper estuarine zone, but not in the main Bay. One of the objectives of the Versar study was to assess the relative contamination levels in the channel and compare that data to values for shoal areas as reported in a 1994 Delaware Estuary Program study (Little, Inc, 1994). The NOAA data are in general agreement with the conclusion that shoal areas have higher concentrations than the channels, but due to larger number of sample sites, some exceptions were found (Table 15). The NOAA data is also in agreement with the 1994 report that some of the worst pollution for a variety of contaminants is in the vicinity of the Schuylkill River and Little Tinicum Island, as well as locations above Philadelphia. Whether the PCBs accumulation rates in the channel are lower, or the sediment-bound material has been removed by previous dredging and is prevented from settling due to shipping activities and maintenance dredging has not been addressed. According to the most recent Monitoring Report from the Delaware River Basin Commission (DRBC, 1998), concentrations of PCBs and chlorinated pesticides have not declined to acceptable levels in recent years, and inputs continue from municipal and non-point releases.

More than 90% of the Virginian EMAP Province were below the ERL for total PCBs (EPA,1994), whereas 55% of the freshwater stations in the Delaware River exceeded the ERL. Similarly, concentrations of chlordane and DDT in the tidal fresh reaches of the

Table 15. Comparison of PCB concentrations at selected locations in the Delaware estuary. NOAA sites were randomly chosen within strata and occur in the channel or in shoals, and Versar sites were all in the channel, but depths were not provided.

NOAA Site	Depth (ft)	Latitude	Longitude	Measured PCBs	Versar Site	Latitude	Longitude	Measured PCBs
7	6.4	39 56.737	75 07.945	98.30	DRV-1	39 55.70	75 08.27	14.22
8	5.4	39 54.431	75 07.951	103.10				
9	15	39 52.700	75 08.977	17.59	DRV-2	39 53.02	75 08.55	0.0
10	12	39 51.970	75 12.206	35.22	DRV-3	39 52.50	75 12.28	12.07
11	18.5	39 51.950	75 12.478	50.36				
13	8.5	39 51.644	75 17.911	294.86	DRV-4	39 50.90	75 17.02	23.63
14	28	39 51.131	75 16.078	8.16				
15	18.8	39 50.227	75 21.050	11.32	DRV-5	39 50.68	75 20.57	0.1
16	49	39 49.0789	75 23.0548	233.13	DRV-6	39 48.52	75 24.58	74.71
17	46	39 48.5311	75 24.1906	33.38	NA			
21	36	39 44.7136	75 29.5081	48.75	NA			
25	23	39 39.4505	75 32.9156	34.40	DRV-7	39 39.33	75 32.68	18.48
26	9	39 36.030	75 35.329	27.61	DRV-8	39 36.68	75 34.57	0.0
40	40	39 16.69	75 21.90	4.66	DRV-11	39 17.55	75 22.28	0.01

Delaware estuary were routinely above the 90th percentile of observed concentrations. Because metals have naturally occurring sources, the concentration of metals which constitutes anthropogenic enrichment (normalized to Al) is element specific. Also, the data are highly variable from station to station, but selected locations in the upper reaches of Delaware Bay are enriched with As, Cd, Cu Hg, Pb, Sn, and Zn, compared to the Virginian Province database (EPA, 1994). Chromium and Ni showed borderline enrichment levels. Riedel and Sanders (1998) concluded that seston (phytoplankton and other suspended particulate material and/or microorganisms) were substantially enriched with Pb and Zn and moderately enriched with As, Se and Cd in Delaware Bay. The DRBC (1994) identified multiple sources for metals contamination, and concluded that for Cd, Cu, Pb, Ag, and Zn, natural sources are unlikely to account for the observed distribution of these metals. They also concluded the Delaware and Schuylkill Rivers are not the predominant source, but that point sources on the mainstem and smaller tributaries, and non-point sources were the major sources of metals contamination.

Low weight ($\leq$3 rings) and high weight ($\geq$ 4 rings) PAHs were generally present in equal concentrations on a mass basis (Figure 13). Alkyl-substituted PAHs were much more prevalent in the low weight category (Figure 14) than in the high weight category (Figure 15). This indicates a pyrogenic source for the high weight PAHs, whereas the low weight PAHs are likely a mixture of pyrogenic sources and fuel spills. However, it may also be influenced by an artifact of the analytical scheme which emphasizes the lower weight substituted compounds. Regardless of potential analytical bias, measurement of alkyl substituted PAHs reveals that the mass of PAHs in the sediment are much higher than previously documented, and it is certain that concentrations would be shown to be even higher if all forms (other than just alkyl substitutions) were considered.

Station 56 is an anomalous site with respect to the surrounding region. The sediment grain size characteristics are much more fine grained that the surrounding area. Organic carbon content of the sediment was also high. Clearly this is a consequence of the physical constraints on current velocity imposed by the natural shoals behind Cape Henlopen and the artificial breakwater constructed to provide protected anchorage for ships in transit. The actual sampling site is adjacent to, but not in the anchorage area. Contaminant levels are elevated above other stations in the stratum, but only slightly, and all concentrations are low. However, both the Microtox® and sea urchin fertilization bioassays showed significant responses. The Microtox® bioassay is performed on an organic extract of the sediment, while the fertilization bioassay is performed in the pore water. No explanation for the results is readily apparent, but this area may warrant further investigation.

An interesting relationship was noted with respect to the distribution of taxa and sediment characteristics. As noted in the results section, certain stations exhibited highly exceptional species composition, with respect to rare and unusual species. Species can be rare in spatial distribution, or species can be rare in numerical abundance. Both aspects affect measures of species diversity and evenness. Current efforts to develop benthic community indicators follow one of two approaches. One is to deal only with those species that occur at widespread stations and at abundance levels above some arbitrary level (EPA/CBP, 1994). The rationale is that rare and/or low abundance species do not provide information about the condition of the habitat over extensive areas because they do not occur over extensive areas, and only serve to muddle complex mathematical manipulations of the data. The other approach is that all species contribute to the dynamics of the ecosystem, the presence of rare and unusual species is an indicator of a robust habitat, and to exclude them is to arbitrarily exclude a significant indicator of habitat function (Pielou, 1966). These conflicting approaches are particularly difficult to reconcile in an environment as variable and physiologically challenging as an estuary. In an effort to deal with these issues, and explore novel multivariate statistical approaches to reconcile benthic community indices and toxicological results (to be reported later), a relationship between the presence of unique taxa and substrate grain size was found in the saline portions of the study area. Grain size classifications were arbitrarily assigned a value from 1 to 10 corresponding to the range from finest to coarsest grain size (Table 16). A few stations did not fit into the scheme (e.g. gravely mud). Taxa richness is strongly correlated with texture scores (Figure 49). The majority of the highly diverse

Table 16. Numerical classifications of grain size texture used to address relationships between species composition and sediment grain size.

Grain_Size	Numerical Rank
clay	1
clayey silt	2
silty clay	3
silt	4
sandy clay	4.5
sandy silt	5
clayey sand	6
silty sand	7
sand	8
gravely sand	9
sandy gravel	10

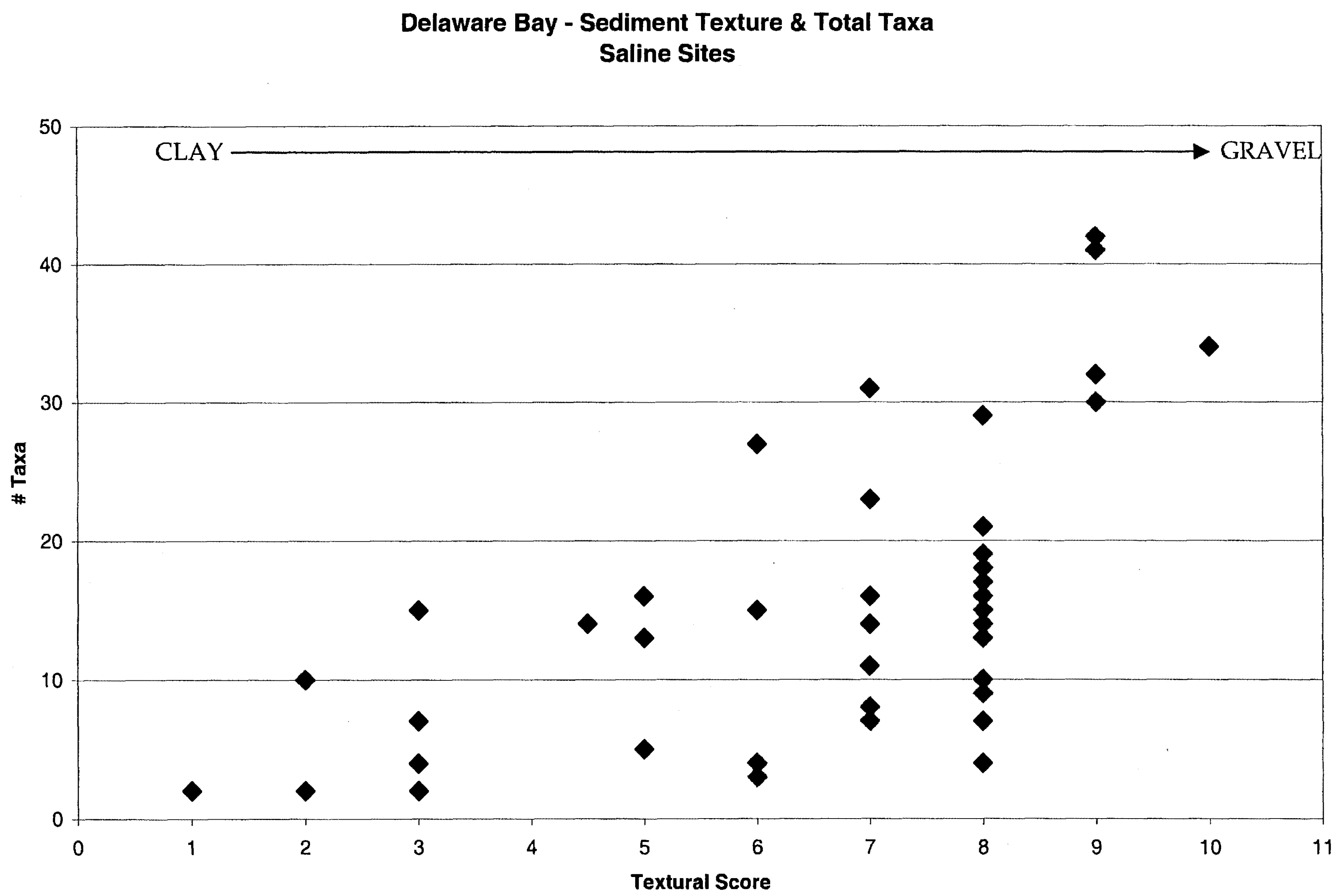


Figure 49. Sediment textural score vs number of taxa in saline Delaware Bay sampling stations.

stations were found on the continental shelf, but the estuarine stations followed the trend. Diversity (H'), being a product of species richness and abundance followed the same trend. Species abundance however, did not follow the trend, but rather peaked at a textural score of 8 and then declined. This relationship between species richness and sediment texture may prove to be a useful modifying factor in assessing coastal community indices, similar to how TOC and grain size are used to normalize organic contaminants and metals concentrations. The relationship between sediment texture and number of species did not apply in the freshwater strata. This may be due to a combination of factors ranging from altered grain size characteristics due to dredging to altered species composition due to contaminant impacts and structural habitat alterations.

ACKNOWLEDGEMENTS

This study is one among a series of sediment toxicity assessment studies that have been carried out by NOAA's National Status and Trends Program in coastal waters and estuaries of the United States. This study is also a key component of the Mid-Atlantic Integrated Assessment (MAIA) program, a demonstration project for an inter-disciplinary, multi-agency approach to provide integrated scientific information on the current conditions, stressors, and vulnerabilities of the region's estuaries. The MAIA program was developed as a "proof of concept" in view of recommendations by the President' Committee on the Environment and Natural Resources (CENR), National Science and Technology Council, to integrate and coordinate federal environmental monitoring, assessment and related research through collaborative and complementary efforts. As such, the study has benefited from considerable cooperation and information exchange with US Environmental Protection Agency, State of Delaware, the Delaware River Basin Commission (DRBC), the Delaware Estuary Program, regional port authorities, and a number of citizens groups.

We are pleased to acknowledge scientific advice and fieldwork assistance by a number of individuals and organizations as well as scientific support from contractors and cooperating laboratories for sample analyses and reporting of results. Susan Love, Jennifer Lukens, Carl Yetter, and David McQuaide of the Department of Natural Resources and Environmental Control, State of Delaware, provided considerable information on areas of particular environmental concern to the state and assisted in field operations, including use of vessels for sampling in shallow waters. Dr. Tom Fikslin, DRBC, was very helpful in providing background information and reports on previous studies on environmental toxicants in the region and for arranging dialogue with the commission's Toxics Advisory Committee. The officers and crew of the NOAA ship *Ferrel* provided excellent ship support, including small vessel operations, despite inclement weather that affected field activities during the entire sampling period. The ship also hosted a news media and public outreach event during the course of field operations.

REFERENCES

Anderson, J.W., Jones, J.M., Steinert, S., Sanders, B., Means, J., McMillin, D., Vu, T., Tukey, R. 1999a. Correlation of CYP1A1 induction, as measured by the P450 RGS biomarker assay, with high molecular weight PAHs in mussels deployed at various sites in San Diego Bay in 1993 and 1995. Marine Environmental Research, 48:389-405.

Anderson, J.W., Jones, J.M., Hameedi, J., Long, E., and Tukey, R.H. 1999b. Comparative analysis of sediment extracts from NOAA's Bioeffects Studies by the biomarker, P450 RGS. Marine Environmental Research, 48:407-425.

APHA. 1998. P450 Reporter Gene Response to Dioxin-like Organics. Method 8070. In: Standard Methods for the Examination of Water and Wastewater, 20th Ed, American Public Health Association, Washington, DC.

ASTM. 1999. E 1853M-98 Standard Guide for Measuring the Presence of Planar Organic Compounds which Induce CYP1A, Reporter Gene Test Systems. In: Biological Effects and Environmental Fate; Biotechnology; Pesticides, 1999 Annual Book of ASTM Standards, Volume 11.05 - Water and Environmental Technology. American Society for Testing and Materials, West Conshohocken, PA.

ASTM. 1992. Standard guide for conducting 10-day static sediment toxicity test with marine and estuarine amphipods. Designation E-1367-92. Annual Book of Standards, 11.04. American Society of Testing and Materials, Philadelphia, PA.

Carr, R.S. 1998. Marine and estuarine porewater toxicity testing, pp. 523-538. In: Microscale Testing in Aquatic Toxicology (P.G. Wells, K. Lee, and C. Blaise, eds), CRC Press, Boca Raton, FL

Carr, R.S., and M. Biedenbach. 1999. Use of power analysis to develop detectable significance criteria for sea urchin toxicity tests. Aquatic Ecosystem Health Management 2: 413-418

CFR 40. (1999). Guidelines for Establishing Test procedures for the Analysis of Pollutants Under the Clean Water Act. CFR 40, part 136, app. A, pp114-328.

Chapman, P.M. 1996. Presentation and interpretation of sediment quality triad data. Ecotoxicology 5: 327-339.

DRBC. 1994. Sediment Contaminants of the Delaware Estuary. Delaware River Basin Commission Report, March, 1993, DRBC, Philadelphia, PA.

EPA. 1994. Methods for assessing the toxicity of sediment-associated contaminants with estuarine and marine amphipods. EPA-600/R-94/025. Office of Research and Development, U.S. Environmental Protection Agency, Narragansett, RI.

EPA. 1994. Statistical Summary, EMAP-Estuaries Virginian Province – 1991. U.S. EPA, ORD EMAP. EPA/620/R-94/005.

EPA. 1999. Method 4425: Screening Extracts Of Environmental Samples For Planar Organic Compounds (PAHS, PCBS, PCDDS/PCDFS) By A Reporter Gene On A Human Cell Line. EPA Office of Solid Waste, SW 846 Methods, Update IVB, Washington, DC.

EPA. 1996. Method 3550: Extraction of soils and sediment by sonication. In: Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW-846, Third Edition and Update III. EPA Office of Solid Waste, Washington, DC

EPA/CPB. 1994. Chesapeake Bay Benthic Community Restoration Goals. U.S. Environmental Protection Agency, Chesapeake Bay Program, CBP/TRS 107/94. 69pp.

Fairey, R., C. Bretz, S. Lamerdin, J. Hunt, B. Anderson, S. Tudor, C.J. Wilson, F. LaCaro, M. Stephenson, M. Puckett, and E. R. Long. 1996. Chemistry, toxicity and benthic community conditions in sediments of the San Diego Bay region. State of California Water Resources Control Board Final Report to NOAA, 169 p. plus appendices

Hahn, G.J. and W.Q. Meeker. 1991. Statistical Intervals: A Guide for Practitioners. John Wiley & Sons, Inc., N.Y. 392 pp.

Heimbuch, D., H. Wilson, J. Seibel, and S. Weisberg. 1995. R-EMAP data analysis approach for estimating the portion of area that is subnominal. Report prepared for US Environmental Protection Agency, Research Triangle Park, NC, 22 p.

Johnson, B. T., and E.R. Long. 1998. Rapid toxicity assessment of sediment from estuarine ecosystems: a new tandem in vitro testing approach. Environmental Toxicology and Chemistry, 17: 1099-1106.

Kenebel, H.J. 1989. Modern Sedimentary Environments in a Large Tidal Estuary, Delaware Bay. Marine Geol., 86: 119-136.

Little, A.D., Inc. 1994. Distributions of Chemical Contaminants and Acute Toxicity in Delaware Estuary Sediments. Final Report to US. EPA and Delaware River Basin Commission, June , 1994. Ref#42976-00.

MacDonald, D.D. 1993. Development of an Approach to the Assessment of Sediment Quality in Florida Coastal Waters. Report to Florida Dept. Environ. Reg. Vol 1, 128 pp, Vol 2, 117pp. MacDonald Environ. Sci., Ltd., Ladysmith, B.C., Canada.

National Oceanic and Atmospheric Administration (NOAA).1998. The National Status and Trends Program for Marine Environmental Quality. Silver Spring, MD: NOAA, National Ocean Service, National Centers for Coastal Ocean Science. 32 pp.

Paul, J.F., J. H. Gentile, K.J. Scott, S.C. Schimmel, D.E. Campbell, and R.W. Latimer. 1999. EMAP-Virginian Province Four-Year Assessment. EPA/620/R-99/004, US Environmental Protection Agency, Narragansett, RI, 119 p.

Pielou, E.C. 1966. The Measurement of /diversity in Different Types of Biological Collections. J. Theoretical Biology, 13:131-144.

Postlind, H., T.P. Vu, R.H. Tukey, and L.C. Quattrochi. 1993. Response of human CYP1-luciferase plasmids to 2,3,7,8,-tetrachlorodibenzo-p-dioxin and polycyclic aromatic hydrocarbons. Toxicol. App. Pharm., 118: 255-262

Qureshi, A.A., A.A. Bulich, and D.L. Isenberg. 1998. Microtox toxicity test systems – where they stand now, pp. 185-199. In: Microscale Testing in Aquatic Toxicology (P.G. Wells, K. Lee, and C. Blaise, eds), CRC Press, Boca Raton, FL

Riedel, G.F. and J.G. Sanders. 1998. Trace Element Speciation and Behavior in the Tidal Delaware River. Estuaries, 21(1): 78-90.

Schropp, S.J. and H.L. Windom. 1988. A Guide to the Interpretation of Metal Concentrations in Estuarine Sediments. Report to the Office of Water Policy, Florida Dept. of Environ. Protection, Tallahassee, FL. 51pp.

Shannon, L.C. and W. Weaver. 1949. The Mathematical Theory of Communication. Univ. of Illinois Press, Urbana, Ill.

Thursby, G. B., J. Heltshe, and K.J. Scott. 1997. Revised approach to toxicity test acceptability criteria using a statistical performance assessment. Environmental Toxicity and Chemistry, 16: 1322-1329

Versar, Inc. 1997. Delaware River Philadelphia to the Sea Project High Resolution PCB Analysis of Channel Sediments. Prepared for U.S. ACoE, Philadelphia Dist., Phila., PA.

List of Appendices

APPENDIX A

Sample Site Locations

Appendix A - Station Locations

STRATUM	SITE	LOCATION	DATE	TIME	LATITUDE (N)	LONGITUDE (W)
19	1	South of Trenton	9/15/97	1555	40° 04.106	74° 54.640
19	2	South of Trenton	9/15/97	1350	40° 08.820	74° 43.380
19	3	South of Trenton	9/15/97	1020	40° 04.120	74° 54.604
20	4	North of Philadelphia	9/15/97	1040	40° 03.207	74° 58.510
20	5	North of Philadelphia	9/15/97	0852	39° 58.481	75° 05.125
20	6	North of Philadelphia	9/15/97	0915	40° 01.645	75° 00.387
1	7	Phily & Camden Waterfront	9/15/97	1330	39° 56.737	75° 07.945
1	8	Phily & Camden Waterfront	9/15/97	1500	39° 54.431	75° 07.951
1	9	Phily & Camden Waterfront	9/16/97	0827	39° 52.700	75° 08.977
2	10	South of Philadelphia	9/16/97	1200	39° 51.970	75° 12.206
2	11	South of Philadelphia	9/16/97	1345	39° 51.950	75° 12.478
2	12	South of Philadelphia	9/12/97	1406	39° 51.402	75° 14.642
3	13	Little Tinicum & Chester Is.	9/17/97	1040	39° 51.644	75° 17.911
3	14	Little Tinicum & Chester Is.	9/16/97	0923	39° 51.131	75° 16.078
3	15	Little Tinicum & Chester Is.	9/16/97	1105	39° 50.227	75° 21.050
4	16	Marcus Hook Bar	9/12/97	1215	39° 49.079	75° 23.055
4	17	Marcus Hook Bar	9/12/97	1050	39° 48.531	75° 24.191
4	18	Marcus Hook Bar	9/12/97	1305	39° 47.059	75° 26.112
5	19	Cherry Island Flats	9/12/97	0933	39° 46.320	75° 28.674
5	20	Cherry Island Flats	9/12/97	1115	39° 46.245	75° 27.485
5	21	Cherry Island Flats	9/12/97	0915	39° 44.7136	75° 29.508
6	22	Cherry Island Range	9/11/97	0834	39° 43.234	75° 29.308
6	23	Cherry Island Range	9/11/97	1130	39° 41.566	75° 30.674
6	24	Cherry Island Range	9/11/97	1300	39° 40.070	75° 32.844
7	25	Bulkhead Shoal/Pea Patch Is.	9/10/97	1325	39° 39.451	75° 32.916
7	26	Bulkhead Shoal/Pea Patch Is.	10/6/97	0925	39° 36.030	75° 35.329
7	27	Bulkhead Shoal/Pea Patch Is.	10/6/97	1105	39° 35.548	75° 35.367
8	28	Salem Cove/Ready Is.	10/6/97	1255	39° 34.309	75° 32.080
8	29	Salem Cove/Ready Is.	10/6/97	1550	39° 32.575	75° 33.827
8	30	Salem Cove/Ready Is.	10/6/97	1420	39° 32.178	75° 31.842
9	31	E. of Baker/Liston R.	10/8/97	1050	39° 28.851	75° 35.037
9	32	E. of Baker/Liston R.	9/10/97	1100	39° 27.986	75° 33.848
9	33	E. of Baker/Liston R.	9/10/97	0945	39° 26.121	75° 32.534
9	34	E. of Baker/Liston R.	10/7/97	1045	39° 22.864	75° 31.069
10	35	W. of Baker/Liston R.	10/8/97	0925	39° 28.460	75° 32.661
10	36	W. of Baker/Liston R.	9/23/97	0935	39° 26.820	75° 30.360
10	37	W. of Baker/Liston R.	10/7/97	1440	39° 25.639	75° 28.482
10	38	W. of Baker/Liston R.	10/7/97	1245	39° 22.823	75° 26.101
11	39	East side - mouth of Del Bay	9/9/97	1400	39° 20.627	75° 29.095
11	40	East side - mouth of Del Bay	9/8/97	1630	39° 16.690	75° 21.900
11	41	East side - mouth of Del Bay	9/9/97	1310	39° 10.783	75° 21.233
11	42	East side - mouth of Del Bay	9/9/97	0930	39° 09.756	75° 21.026
12	43	West side - mouth of Del Bay	9/9/97	1545	39° 14.993	75° 17.271
12	44	West side - mouth of Del Bay	9/9/97	1247	39° 14.381	75° 14.032
12	45	West side - mouth of Del Bay	9/9/97	1050	39° 12.309	75° 13.415
12	46	West side - mouth of Del Bay	9/8/97	1500	39° 10.387	75° 16.106
13	47	Central Delaware Bay	9/8/97	1335	39° 07.707	75° 15.090
13	48	Central Delaware Bay	9/6/97	1100	39° 03.127	75° 04.164

Appendix A - Station Locations

STRATUM	SITE	LOCATION	DATE	TIME	LATITUDE (N)	LONGITUDE (W)
13	49	Central Delaware Bay	9/8/97	1145	39° 02.510	75° 13.640
13	50	Central Delaware Bay	9/5/97	1455	38° 59.142	75° 02.177
13	51	Central Delaware Bay	9/5/97	1502	38° 59.143	75° 17.879
13	52	Central Delaware Bay	9/8/97	1130	38° 55.360	75° 07.456
13	53	Central Delaware Bay	9/5/97	1304	38° 55.200	75° 12.597
13	54	Central Delaware Bay	9/5/97	1707	38° 52.8442	75° 01.833
13	55	Central Delaware Bay	9/5/97	1250	38° 52.633	75° 08.212
13	56	Central Delaware Bay	9/5/97	1007	38° 48.270	75° 07.020
14	57	Eastern Central Delaware Bay	9/8/97	1002	39° 12.029	75° 06.457
14	58	Eastern Central Delaware Bay	9/6/97	1150	39° 08.878	75° 01.000
14	59	Eastern Central Delaware Bay	9/6/97	0920	39° 04.35	75° 02.291
14	60	Eastern Central Delaware Bay	9/6/97	0955	39° 04.011	74° 59.484
14	61	Eastern Central Delaware Bay	9/6/97	1331	39° 01.710	75° 00.855
15	62	Cape May - outside	9/2/97	0908	38° 55.548	74° 48.8201
15	63	Cape May - outside	9/2/97	1040	38° 53.218	74° 53.988
15	64	Cape May - outside	9/2/97	1345	38° 53.165	74° 56.386
16	65	Cape Henlopen - outside	9/2/97	1535	38° 50.718	75° 00.047
16	66	Cape Henlopen - outside	9/5/97	1050	38° 49.490	75° 04.617
16	67	Cape Henlopen - outside	9/3/97	1114	38° 46.344	75° 02.751
17	68	Rehoboth	9/2/97	1355	38° 43.204	75° 04.055
17	69	Rehoboth	9/3/97	1303	38° 42.013	75° 01.756
17	70	Rehoboth	9/3/97	1353	38° 40.133	75° 03.599
18	71	Bethany	9/4/97	1310	38° 33.703	75° 02.538
18	72	Bethany	9/4/97	1054	38° 33.660	75° 00.240
18	73	Bethany	9/4/97	1200	38° 31.003	75° 01.964
21	84	Blackbird Creek	9/23/97	1108	39° 26.400	75° 34.260
21	85	Blackbird Creek	9/23/97	1230	39° 23.661	75° 36.494
/	87	Bombay Hook	9/23/97	1445	39° 14.400	75° 25.440
22	88	St. Jones River	9/22/97	1120	39° 04.040	75° 24.239
22	89	St. Jones River	9/22/97	1250	39° 07.757	75° 30.167
22	90	St. Jones River	9/22/97	1410	39° 05.132	75° 27.615
/	91	Unimpounded wetlands	10/6/97	1105	39° 32.566	75° 34.268
/	92	Impounded wetlands	10/6/97	1500	39° 32.195	75° 35.816

APPENDIX B

Sample Site Water Quality

Appendix B - Water quality conditions

			SURFACE				BOTTOM			
STRATUM	SITE	DEPTH (feet)	TEMP. (°C)	SALINITY (PPT)	DISSOLVED OXYGEN (mg/L)	CONDUCTIVITY (umhos)	TEMP. (°C)	SALINITY (PPT)	DISSOLVED OXYGEN (mg/L)	CONDUCTIVITY (umhos)
19	1	6.6	22.8	0.1	6.7	254.2	22.7	0.1	6.3	243.20
19	2	12.0	21.7	0.1	7.0	166.0	21.1	0.1	5.3	164.00
19	3	3.5	22.3	0.1	5.7	235.6	22.3	0.1	4.7	238.90
20	4	10.8	22.5	0.2	6.0		22.5	0.1	5.9	
20	5	19.0	22.9	0.2	7.1		22.9	0.1	5.3	
20	6	18.0	22.5	0.1	5.6	252.3	22.5	0.1	6.0	252.40
1	7	6.4	23.3	0.1	6.3		23.3	0.1	6.5	
1	8	5.4	23.4	0.2	5.6		23.3	0.2	4.3	
1	9	15.0	22.8	0.1	5.8	297.7	22.7	0.1	5.7	304.10
2	10	12.0	23.5	0.2	5.6	360.3	23.3	0.2	5.4	363.30
2	11	18.5	23.5	0.2	5.2	388.9	23.3	0.2	4.8	392.70
2	12	45.0								
3	13	8.5	23.6	0.2	5.3	397.8	23.6	0.2	5.3	407.10
3	14	28.0	23.4	0.2	4.0		23.3	0.2	5.6	
3	15	18.8	23.5	0.3	5.4		23.5	0.3	5.2	
4	16	49.0								
4	17	46.0								
4	18	6.7	23.9	0.7	6.4	1303.0	23.7	0.7	6.4	1332.00
5	19	6.6	23.1	0.8	5.8	1621.0	23.2	2.1	5.4	3788.00
5	20	14.0	23.7	1.4	6.8	2869.0	23.2	1.6	6.4	2928.00
5	21	36.0								
6	22	13.0	23.1	2.6	6.5	47.2	23.1	3.1	3.2	5.61
6	23	21.0	23.2	3.4	6.3	6.0	23.2	3.5	6.2	6.14
6	24	16.0	23.2	3.1	7.0	5.7	23.1	3.1	6.5	5.53
7	25	23.0								
7	26	9.0	19.4	4.5	7.3	7.3	19.2	4.5	7.0	7.54
7	27	15.0	19.9	4.7	7.4	7.7	19.5	5.1	7.3	8.07
8	28	10.0	19.6	6.0	7.5	9.4	19.4	6.0	7.5	9.35
8	29	13.0	19.9	7.5	7.2	11.7	19.5	7.5	7.1	11.57
8	30	11.0	20.0	7.1	7.4	11.1	19.9	7.1	7.4	11.11
9	31	6.0	20.4	7.6	6.9	13.2	19.7	7.8	6.4	13.45

Blank cells indicate no data.

Appendix B - Water quality conditions

			SURFACE				BOTTOM			
STRATUM	SITE	DEPTH (feet)	TEMP. (°C)	SALINITY (PPT)	DISSOLVED OXYGEN (mg/L)	CONDUCTIVITY (umhos)	TEMP. (°C)	SALINITY (PPT)	DISSOLVED OXYGEN (mg/L)	CONDUCTIVITY (umhos)
9	32	33.0								
9	33	38.0								
9	34	1.3	20.1	11.2	6.8	18.8	19.8	11.7	6.7	19.56
10	35	15.0	19.7	8.3	7.0	14.3	19.7	8.3	6.9	14.26
10	36	5.0	21.3	12.0	7.3	20.1	21.3	12.1	7.0	20.17
10	37	16.0	20.1	13.6	7.0	22.5	19.5	13.7	7.0	22.67
10	38	20.0	19.7	14.9	7.2	24.4	19.4	14.9	7.0	24.36
11	39	8.8	22.7	13.1	7.1	20.8	22.7	13.2	7.1	20.91
11	40	40.0								
11	41	13.0	21.9	20.0	7.2	30.2	21.9	20.2	7.1	30.39
11	42	13.0	28.5	20.2	7.3	32.2	21.8	20.4	8.0	30.59
12	43	22.0								
12	44	19.3								
12	45	14.5								
12	46	47.0								
13	47	23.0								
13	48	27.0	21.8	27.1	7.2		21.8	27.1	7.5	
13	49	28.0	22.2	27.5	10.2		21.6	29.0	8.3	
13	50	40.0								
13	51	7.0	21.5	26.0	9.6		21.5	25.9	9.6	
13	52	54.0								
13	53	15.0	22.0	29.0	10.2		21.4	29.4	6.8	
13	54	33.0								
13	55	64.0								
13	56	30.0	20.6	30.4	9.8		20.9	30.1	6.9	
14	57	6.3	22.0	20.9	10.7		22.0	20.8	10.4	
14	58	15.0								
14	59	14.8	21.5	26.1	10.5		21.5	25.8	6.8	
14	60	19.0								
14	61	15.4	21.7	26.2	10.5		21.7	26.6	7.7	
15	62	14.8	22.2	31.2	7.0		21.9	31.2	7.0	

Blank cells indicate no data.

Appendix B - Water quality conditions

			SURFACE				BOTTOM			
STRATUM	SITE	DEPTH (feet)	TEMP. (^oC)	SALINITY (PPT)	DISSOLVED OXYGEN (mg/L)	CONDUCTIVITY (umhos)	TEMP. (^oC)	SALINITY (PPT)	DISSOLVED OXYGEN (mg/L)	CONDUCTIVITY (umhos)
15	63	14.4								
15	64	14.0	23.6	26.6	7.1	41.5	23.5	27.7	6.9	42.06
16	65	16.0	23.0	27.2	6.8	40.6	22.8	27.6	6.9	41.10
16	66	64.0								
16	67	62.0								
17	68	33.0								
17	69	42.0								
17	70	24.0								
18	71	35.0								
18	72	40.0								
18	73	46.0								
21	84	4.0	20.4	8.0	6.0	13.9	20.4	8.1	5.9	13.88
21	85	5.9	20.6	7.4	6.6	12.8	20.5	7.4	6.6	12.82
/	87	8.0	20.5	16.6	6.2	27.0	20.5	16.7	6.4	27.05
22	88		20.0	19.4	5.0	31.3	19.9	19.8	4.8	31.79
22	89	2.3	19.6	4.4	10.6	7.9	19.6	4.4	9.6	7.14
22	90	2.6	20.3	19.1	4.1	30.6	20.1	19.2	4.1	30.83
/	91	3.0	20.2	6.2	7.7	10.9	20.0	6.2	7.4	10.86
/	92	1.6	25.1	4.1	over range	7.3	25.0	4.0	over range	7.31

Blank cells indicate no data.

APPENDIX C

Sediment Characteristics

Appendix C - Sediment Characteristics

STRATUM	SITE	% GRAVEL	% SAND	% SILT	% CLAY	% SOLIDS	TEXTURE	AVS (umol/g)	%TOTAL ORGANIC CARBON
19	1	0.00	11.76	55.99	32.24	43.25	silty clay	2.54	1.40
19	2	1.24	96.18	1.56	0.00	62.97	sand	0.88	1.00
19	3	0.00	14.99	73.05	11.96	38.70	sandy silt	3.02	1.47
20	4	0.00	78.05	18.22	3.72	53.68	silty sand	4.55	2.27
20	5	0.15	99.04	0.00	0.00	78.63	sand	0.00	2.12
20	6	0.09	99.26	0.00	0.00	73.67	sand	0.05	1.98
1	7	0.00	42.38	53.13	4.49	50.89	sandy silt	2.15	2.17
1	8	0.00	31.35	62.49	6.16	51.10	sandy silt	4.13	2.03
1	9	11.81	84.56	2.25	0.00	77.09	gravelly sand	0.38	0.99
2	10	0.00	13.24	70.48	16.28	56.14	sandy silt	0.47	3.13
2	11	0.85	74.72	18.54	5.89	70.46	silty sand	1.06	0.74
2	12	15.86	24.08	32.93	27.12	72.65	gravelly mud	0.13	3.01
3	13					51.70		4.63	1.02
3	14	1.53	89.81	5.51	0.00	74.60	sand	0.02	2.62
3	15	0.00	99.08	0.00	0.00	72.98	sand	0.01	0.34
4	16	0.00	43.03	26.65	30.32	60.12	sandy clay	0.83	1.98
4	17	1.09	95.98	2.05	0.00	80.20	sand	0.39	0.32
4	18	0.07	84.57	12.20	0.00	65.87	sand	0.18	0.46
5	19	0.41	59.38	25.14	15.07	51.29	silty sand	2.07	2.67
5	20	0.00	62.87	27.83	9.30	54.60	silty sand	0.92	2.97
5	21	0.00	34.42	40.11	25.48	39.32	clayey silt	4.16	0.96
6	22	0.00	81.65	11.39	6.97	62.99	sand	0.01	0.38
6	23	0.00	4.01	44.50	51.49	30.82	clay	0.06	3.23
6	24	0.00	11.49	48.87	39.64	45.74	silty clay	0.68	3.11
7	25	0.00	29.28	42.06	28.66	44.40	clayey silt	0.27	2.23
7	26					40.79		15.10	1.98
7	27	1.83	54.53	20.10	23.54	61.78	clayey sand	0.21	0.60
8	28	0.00	61.65	24.18	14.17	60.48	silty sand	0.43	0.74
8	29	0.00	18.63	52.03	29.34	51.29	clayey silt	0.95	3.28
8	30	0.22	61.24	21.16	17.37	41.80	silty sand	3.67	2.44
9	31	0.51	44.44	33.78	21.27	60.79	clayey sand	0.03	0.52
9	32	0.00	5.77	50.81	43.42	47.27	silty clay	0.03	2.21
9	33	0.00	39.91	43.89	16.20	48.71	sandy silt	0.35	1.98
9	34	0.16	36.04	44.01	19.79	53.65	sandy silt	0.10	1.32
10	35	0.57	86.76	8.76	3.92	80.79	sand	0.00	0.27
10	36	0.00	43.36	33.06	23.58	45.73	clayey sand	0.40	1.50
10	37	0.00	30.26	50.72	19.02	51.60	sandy silt	0.22	0.84
10	38	0.25	66.08	13.47	20.20	60.32	clayey sand	0.72	0.75
11	39	2.98	95.22	0.00	0.00	76.40	sand	0.11	1.07
11	40	1.26	61.92	17.37	19.45	59.57	silty sand	6.56	1.08
11	41	1.96	90.59	6.18	0.00	68.17	sand	0.41	0.42
11	42	1.20	52.59	23.02	23.19	62.50	clayey sand	0.60	0.60
12	43	2.46	59.41	18.65	19.47	75.20	silty sand	0.79	0.65
12	44	12.89	76.95	8.42	0.00	70.32	gravelly sand	1.57	0.72
12	45	0.09	99.09	0.00	0.00	79.88	sand	0.01	0.78
12	46	0.00	98.97	0.00	0.00	73.71	sand	0.03	0.71
13	47	0.00	99.97	0.00	0.00	79.02	sand	0.01	0.24
13	48	0.03	61.18	6.97	31.82	74.90	sandy clay	0.07	0.37
13	49	1.93	97.94	0.00	0.00	74.11	sand	0.01	0.23
13	50	3.15	72.78	14.80	9.27	68.19	silty sand	0.74	0.67

Blank cells indicate no data.

Appendix C - Sediment Characteristics

STRATUM	SITE	% GRAVEL	% SAND	% SILT	% CLAY	% SOLIDS	TEXTURE	AVS (umol/g)	%TOTAL ORGANIC CARBON
13	51	0.00	99.78	0.00	0.00	81.00	sand	0.01	0.12
13	52	0.57	98.58	0.00	0.00	76.03	sand	0.56	0.19
13	53	0.00	96.25	0.00	0.00	69.43	sand	0.07	0.32
13	54	0.00	97.52	0.00	0.00	72.78	sand	3.86	0.26
13	55	0.03	97.35	0.00	0.00	66.21	sand	0.24	0.45
13	56	0.00	31.93	43.07	25.00	60.36	clayey silt	9.20	2.97
14	57	1.85	90.34	5.74	0.00	26.81	sand	9.74	1.93
14	58	0.35	91.07	6.60	0.00	65.87	sand	5.38	2.03
14	59	0.62	95.71	0.00	0.00	71.23	sand	0.13	0.63
14	60	0.00	80.67	13.94	5.39	64.27	sand	7.56	1.23
14	61	0.24	98.42	0.00	0.00	73.25	sand	0.00	0.57
15	62					80.88		0.00	0.09
15	63	11.75	87.87	0.00	0.00	82.02	gravelly sand	0.01	0.58
15	64	0.00	99.07	0.00	0.00	80.91	sand	0.01	0.07
16	65	4.77	94.68	0.00	0.00	81.85	sand	0.00	0.15
16	66	24.12	73.51	1.93	0.00	64.27	gravelly sand	0.29	0.51
17	67	35.81	61.99	1.45	0.00	76.80	sandy gravel	0.58	0.42
17	68	0.31	98.76	0.00	0.00	83.86	sand	0.00	0.21
17	69	0.00	99.53	0.00	0.00	80.04	sand	0.01	0.22
17	70	0.00	99.81	0.00	0.00	80.75	sand	0.00	0.13
18	71	0.76	98.45	0.00	0.00	83.20	sand	0.00	0.11
18	72	20.25	79.57	0.00	0.00	83.07	gravelly sand	0.00	0.10
18	73					76.79		0.15	1.21
21	84	0.00	12.64	65.21	22.16	37.05	clayey silt	24.7	2.36
21	85	0.00	0.17	57.13	42.70	31.03	silty clay	38	5.85
/	87	0.10	7.81	50.96	41.14	44.07	clayey silt	6.01	1.75
22	88	0.10	9.20	55.39	35.32	34.85	silty clay	2.05	5.07
22	89	0.00	1.45	39.14	59.42	11.13	clay	28.3	20.50
22	90	0.00	3.01	67.36	29.63	29.80	clayey silt	7.92	3.90
/	91					34.52		4.99	3.45
/	92	0.58	89.27	6.95	0.00	23.26	sand	104	5.85

Blank cells indicate no data.

APPENDIX D

Polynuclear Aromatic Hydrocarbon Concentrations

Appendix D - Polynuclear aromatic hydrocarbons (PAHs) in ug/kg

STRATUM	SITE NUMBER	TOTAL LOW WEIGHT PAHs*	ALKYL SUBSTITUTED	WITHOUT ALKYL SUBSTITUTION	TOTAL HIGH WEIGHT PAHs*	ALKYL SUBSTITUTED	WITHOUT ALKYL SUBSTITUTION	TOTAL PAHs
19	1	3,061.3	1,594.1	1,467.2	5553.3	928.0	4,625.3	8,614.6
19	2	2,777.3	1,415.2	1,362.1	3390.9	697.3	2,693.6	6,168.2
19	3	3,049.3	1,640.1	1,409.2	6158.1	1,002.4	5,155.7	9,207.4
20	4	5,539.9	2,613.7	2,926.2	11768.5	1,801.3	9,967.2	17,308.4
20	5	128.7	48.4	80.3	273.3	32.6	240.7	402.0
20	6	1,765.6	782.3	983.3	2764.2	463.1	2,301.1	4,529.8
1	7	6,091.4	3,538.3	2,553.1	8067.3	1,705.0	6,362.3	14,158.7
1	8	5,486.8	3,245.6	2,241.2	7501.5	1,521.1	5,980.4	12,988.3
1	9	1,595.2	876.1	719.1	1877.1	399.0	1,478.1	3,472.3
2	10	3,571.6	2,501.7	1,069.9	2990.6	713.5	2,277.1	6,562.2
2	11	5,866.7	4,052.9	1,813.8	4130.3	1,042.9	3,087.4	9,997.0
2	12	263.0	148.0	115.0	607.6	118.4	489.2	870.6
3	13	9,707.1	7,981.2	1,725.9	8506.8	2,180.3	6,326.5	18,213.9
3	14	1,304.8	831.0	473.8	4157.3	875.5	3,281.8	5,462.1
3	15	210.9	120.7	90.2	231.0	53.8	177.2	441.9
4	16	6,814.7	6,010.1	804.6	4426.5	1,440.0	2,986.5	11,241.2
4	17	42,110.8	14,112.8	27,998.0	115327.8	16,627.8	98,700.0	157,438.6
4	18	801.8	486.3	315.5	2023.0	390.6	1,632.4	2,824.8
5	19	1,971.8	1,401.0	570.8	4132.6	679.8	3,452.8	6,104.4
5	20	8,616.8	6,522.4	2,094.4	6064.9	1,575.9	4,489.0	14,681.7
5	21	1,365.5	838.4	527.1	2675.8	513.7	2,162.1	4,041.3
6	22	509.7	294.2	215.5	844.3	156.6	687.7	1,354.0
6	23	1,606.2	834.2	772.0	2071.0	362.9	1,708.1	3,677.2
6	24	869.4	487.0	382.4	1986.1	344.2	1,641.9	2,855.5
7	25	954.6	574.0	380.6	1457.5	267.8	1,189.7	2,412.1
7	26	927.4	570.8	356.6	1278.2	272.9	1,005.3	2,205.6
7	27	578.7	303.8	274.9	1403.8	260.6	1,143.2	1,982.5
8	28	438.0	270.3	167.7	806.7	158.8	647.9	1,244.7
8	29	7,292.3	4,292.8	2,999.5	5487.3	2,280.7	3,206.6	12,779.6
8	30	784.2	465.6	318.6	1388.3	304.3	1,084.0	2,172.5
9	31	54.8	37.5	17.3	124.7	13.6	111.1	179.5
9	32	67.4	43.3	24.1	342.1	8.8	333.3	409.5
9	33	86.9	63.0	23.9	327.4	12.2	315.2	414.3
9	34	399.1	248.3	150.8	646.8	141.3	505.5	1,045.9

* See text for specific compounds.

Appendix D - Polynuclear aromatic hydrocarbons (PAHs) in ug/kg

STRATUM	SITE NUMBER	TOTAL LOW WEIGHT PAHs*	ALKYL SUBSTITUTED	WITHOUT ALKYL SUBSTITUTION	TOTAL HIGH WEIGHT PAHs*	ALKYL SUBSTITUTED	WITHOUT ALKYL SUBSTITUTION	TOTAL PAHs
10	35	183.0	160.8	22.2	333.2	95.9	237.3	516.2
10	36	395.1	240.5	154.6	669.4	134.3	535.1	1,064.5
10	37	377.7	242.9	134.8	582.8	116.1	466.7	960.5
10	38	214.7	140.3	74.4	288.9	66.0	222.9	503.6
11	39	63.3	36.3	27.0	57.1	10.0	47.1	120.4
11	40	218.5	141.6	76.9	398.3	85.0	313.3	616.8
11	41	80.2	47.8	32.4	83.5	14.9	68.6	163.7
11	42	118.8	77.1	41.7	204.4	48.2	156.2	323.2
12	43	162.2	67.2	95.0	356.2	50.9	305.3	518.4
12	44	74.9	43.9	31.0	150.4	26.5	123.9	225.3
12	45	15.2	8.3	6.9	22.7	5.4	17.3	37.9
12	46	22.6	12.5	10.1	32.4	6.0	26.4	55.0
13	47	14.5	8.0	6.5	17.0	4.5	12.5	31.5
13	48	22.5	12.3	10.2	39.4	8.5	30.9	61.9
13	49	12.1	4.8	7.3	10.6	0.5	10.1	22.7
13	50	74.2	43.0	31.2	128.0	23.4	104.6	202.2
13	51	2.6	0.0	2.6	2.4	0.0	2.4	5.0
13	52	7.5	2.7	4.8	11.4	1.8	9.6	18.9
13	53	17.5	12.6	4.9	10.8	3.4	7.4	28.3
13	54	55.9	32.6	23.3	78.5	15.7	62.8	134.4
13	55	50.2	36.1	14.1	47.6	13.9	33.7	97.8
13	56	143.4	95.7	47.7	221.5	50.8	170.7	364.9
14	57	287.2	178.1	109.1	454.6	82.9	371.7	741.8
14	58	61.3	38.8	22.5	88.8	16.8	72.0	150.1
14	59	26.2	13.5	12.7	37.3	8.8	28.5	63.5
14	60	167.3	109.9	57.4	423.6	88.1	335.5	590.9
14	61	11.7	6.0	5.7	7.4	0.0	7.4	19.1
15	62	10.7	8.5	2.2	7.5	2.9	4.6	18.2
15	63	15.6	12.2	3.4	7.3	2.2	5.1	22.9
15	64	7.7	6.6	1.1	1.3	0.9	0.4	9.0
16	65	8.9	6.9	2.0	3.2	1.0	2.2	12.1
16	66	81.3	66.5	14.8	56.1	18.7	37.4	137.4
16	67	27.2	18.3	8.9	29.2	7.0	22.2	56.4
17	68	11.7	8.9	2.8	7.5	2.1	5.4	19.2

* See text for specific compounds.

Appendix D - Polynuclear aromatic hydrocarbons (PAHs) in ug/kg

STRATUM	SITE NUMBER	TOTAL LOW WEIGHT PAHs*	ALKYL SUBSTITUTED	WITHOUT ALKYL SUBSTITUTION		TOTAL HIGH WEIGHT PAHs*	ALKYL SUBSTITUTED	WITHOUT ALKYL SUBSTITUTION		TOTAL PAHs
17	69	11.8	9.0	2.8		6.8	2.2	4.6		18.6
17	70	12.3	9.6	2.7		4.4	1.6	2.8		16.7
18	71	10.6	8.1	2.5		4.6	1.2	3.4		15.2
18	72	13.3	10.7	2.6		3.3	1.4	1.9		16.6
18	73	17.9	12.3	5.6		9.4	2.1	7.3		27.3
21	84	515.7	301.3	214.4		799.8	157.6	642.2		1,315.5
21	85	596.5	341.5	255.0		889.2	184.6	704.6		1,485.7
/	87	83.7	53.9	29.8		226.6	24.2	202.4		310.3
22	88	492.8	318.5	174.3		685.1	148.4	536.7		1,177.9
22	89	3,116.2	2,191.3	924.9		7860.3	1,851.6	6,008.7		10,976.5
22	90	713.8	464.1	249.7		1028.2	204.2	824.0		1,742.0
/	91	819.8	472.6	347.2		1286.8	284.7	1,002.1		2,106.6
/	92	1,030.7	569.6	461.1		1020.5	311.9	708.6		2,051.2

* See text for specific compounds.

APPENDIX E

Polychlorinated Biphenyls, Dioxins/Furans, and Chlorinated Pesticide Concentrations

Appendix E - Polychlorinated biphenyls (PCBs), dioxins, furans and, chlorinated pesticides in ug/kg (planar PCBs and dioxins/furans in ng/kg)

STRATUM	SITE NUMBER	MEASURED PCBs*	TOTAL PLANAR PCBs*	DIOXINS	FURANS	TOTAL DDTs*	TOTAL CHLORDANES*	TOTAL HCH	HEXACHLORO-BENZENE
19	1	109.59	319.6			78.49	12.03	0.00	1.66
19	2	7.67				5.43	2.70	0.13	0.31
19	3	105.18	445.7			127.21	18.27	0.75	0.00
20	4	124.63	41.2			222.94	17.57	0.00	2.73
20	5	3.97				4.14	0.69	0.11	0.11
20	6	17.64				27.83	3.99	0.07	0.21
1	7	98.30	589.2			208.23	11.17	0.00	2.09
1	8	103.10				117.75	14.10	0.00	10.30
1	9	17.59				29.90	1.89	0.01	0.12
2	10	35.22	5.2	132.37#	2.90	84.04	3.41	0.00	0.33
2	11	50.36	355.5	1,172.76	77.06	32.08	3.30	0.00	0.00
2	12	4.11	13.4			2.71	0.38	0.24	0.13
3	13	294.86	263.7			301.94	3.97	0.00	0.00
3	14	8.16	37.8			7.91	1.23	0.00	0.12
3	15	11.32	21.4			2.75	0.68	0.18	0.10
4	16	233.13				151.89	5.16	0.00	0.42
4	17	33.38				24.72	3.02	0.00	1.44
4	18	18.11	213.5			11.12	2.01	0.41	0.54
5	19	77.72				121.72	14.80	0.36	2.87
5	20	219.94	4112.1	5,157.22	1,017.50	47.63	6.33	2.35	0.76
5	21	48.75	347.7			44.22	6.10	0.14	1.02
6	22	18.17	111.3			9.11	2.33	0.38	0.36
6	23	53.51				24.36	6.14	0.71	1.05
6	24	8.09				2.47	0.36	0.08	0.10
7	25	34.40				14.88	3.50	0.39	0.68
7	26	27.61				14.48	3.01	0.13	0.31
7	27	1.45	30.0#			0.21	0.28	0.07	0.04
8	28	16.29				7.06	2.04	0.07	0.21
8	29	10.74	20.0#	4,682.98	5,663.84	0.40	4.70	0.00	0.00
8	30	28.28	244.1			14.48	3.43	0.53	0.25
9	31	0.75				0.41	0.44	0.00	0.01
9	32	4.42	3.6			0.73	1.16	0.47	0.00
9	33	0.99				0.31	0.15	0.13	0.07
9	34	11.50				6.51	2.40	0.10	0.19

blanks indicate no analyses

* See text for specific compounds.

Some isomers were below method detection limit.

Appendix E - Polychlorinated biphenyls (PCBs), dioxins, furans and, chlorinated pesticides in ug/kg (planar PCBs and dioxins/furans in ng/kg)

STRATUM	SITE NUMBER	MEASURED PCBs*	TOTAL PLANAR PCBs*	DIOXINS	FURANS	TOTAL DDTs*	TOTAL CHLORDANES*	TOTAL HCH	HEXACHLORO-BENZENE
10	35	2.34				0.71	0.09	0.08	0.12
10	36	16.00				10.87	2.32	0.14	0.13
10	37	13.70	181.9			7.33	1.84	0.10	0.08
10	38	7.41				4.49	0.76	0.12	0.07
11	39	2.10	18.0			0.93	0.25	0.04	0.05
11	40	4.66				1.64	0.40	0.05	0.08
11	41	2.13				0.69	0.17	0.03	0.08
11	42	2.17				0.89	0.11	0.03	0.08
12	43	1.53	17.0			0.48	0.12	0.01	0.08
12	44	1.91				0.71	0.17	0.06	0.07
12	45	0.99				0.21	0.06	0.02	0.00
12	46	1.21				0.19	0.01	0.04	0.01
13	47	1.05				0.15	0.07	0.03	0.01
13	48	2.77				0.18	0.11	0.00	0.03
13	49	0.67				0.12	0.12	0.05	0.07
13	50	1.31				0.28	0.10	0.00	0.00
13	51	0.15				0.02	0.00	0.00	0.03
13	52	0.58				0.10	0.04	0.04	0.04
13	53	0.59				0.19	0.03	0.00	0.00
13	54	0.94	17.5			0.23	0.06	0.03	0.00
13	55	1.05				0.24	0.04	0.00	0.00
13	56	3.06				0.89	0.03	0.04	0.02
14	57	9.52				5.55	0.41	0.10	0.26
14	58	1.56				0.47	0.09	0.03	0.04
14	59	0.76				0.08	0.04	0.00	0.05
14	60	6.05	53.2			0.96	0.27	0.05	0.07
14	61	0.54				0.10	0.04	0.04	0.03
15	62	0.10				0.03	0.01	0.00	0.00
15	63	0.14				0.02	0.03	0.00	0.00
15	64	0.06	1.6			0.00	0.00	0.00	0.00
16	65	0.25	3.3			0.01	0.01	0.00	0.00
16	66	1.14				0.22	0.04	0.00	0.00
16	67	1.23				0.49	0.20	0.08	0.00
17	68	0.36				0.05	0.00	0.00	0.00

blanks indicate no analyses

* See text for specific compounds.

Some isomers were below method detection limit.

Appendix E - Polychlorinated biphenyls (PCBs), dioxins, furans and, chlorinated pesticides in ug/kg (planar PCBs and dioxins/furans in ng/kg)

STRATUM	SITE NUMBER	MEASURED PCBs*	TOTAL PLANAR PCBs*	DIOXINS	FURANS	TOTAL DDTs*	TOTAL CHLORDANES*	TOTAL HCH	HEXACHLORO-BENZENE
17	69	0.23				0.04	0.00	0.00	0.00
17	70	0.08	3.4			0.01	0.00	0.00	0.00
18	71	0.10	3.0			0.04	0.00	0.00	0.01
18	72	0.09				0.02	0.02	0.00	0.00
18	73	0.23	12.0			0.06	0.00	0.00	0.01
21	84	18.67	200#			10.38	2.13	0.23	0.17
21	85	16.58				9.16	1.51	0.32	0.14
/	87	2.03	40#			1.39	0.69	0.00	0.00
22	88	11.60				9.32	2.12	0.23	0.10
22	89	415.70	526.7	13,923.31	242.06	169.95	74.61	1.15	0.80
22	90	50.39	120#			30.92	6.62	0.00	0.12
/	91	32.64	487.4			18.86	2.75	0.29	0.25
/	92	6.99	254.3			14.01	0.62	0.21	0.00

blanks indicate no analyses
* See text for specific compounds.
# Some isomers were below method detection limit.

APPENDIX F

Metals Concentrations

Appendix F - Metals concentrations in mg/kg (Butyl tins in ug/kg)

STRATUM	SITE	SILVER	ALUMINUM	ARSENIC	CADMIUM	CHROMIUM	COPPER	IRON	MERCURY	MANGANESE
19	1	0.81	55,621	11.30	2.07	66.0	56.0	35,606	0.19	1,657
19	2	0.19	30,844	15.10	0.57	45.0	46.0	39,091	0.12	479
19	3	1.04	58,840	13.10	2.47	74.0	68.0	38,616	0.30	2,062
20	4	0.34	48,466	9.40	1.94	63.0	50.0	31,821	0.19	882
20	5	0.05	12,287	2.90	0.16	15.4	4.1	10,444	0.02	307
20	6	0.11	30,489	5.60	0.44	37.0	21.6	18,510	0.12	381
1	7	0.68	48,183	9.90	2.11	61.0	56.0	28,801	0.26	907
1	8	0.95	53,159	10.60	2.49	68.0	59.0	32,465	0.20	1,392
1	9	0.11	16,284	4.20	0.59	25.5	12.5	12,756	0.18	224
2	10	0.26	29,577	6.60	0.52	42.0	39.0	30,676	0.15	330
2	11	0.29	38,987	11.40	0.90	45.0	32.0	20,041	0.14	453
2	12	0.05	22,156	5.70	0.18	33.0	5.1	19,653	0.04	769
3	13	2.03	65,111	21.80	3.25	129.0	102.0	41,489	0.59	1,047
3	14	0.09	16,135	5.10	0.20	25.1	9.1	12,101	0.05	282
3	15	0.05	20,830	5.90	0.23	21.8	6.4	14,943	0.03	367
4	16	0.58	45,275	22.20	1.00	78.0	43.0	29,376	0.30	729
4	17	0.07	31,330	6.30	0.15	37.0	22.8	23,944	0.07	321
4	18	0.14	46,934	10.30	0.28	41.0	13.1	20,171	0.08	720
5	19	0.29	55,229	10.30	0.72	68.0	37.0	28,335	0.17	956
5	20	1.06	61,392	44.30	2.73	164.0	108.0	36,857	1.88	760
5	21	0.47	65,815	18.30	0.65	87.0	34.0	39,025	0.20	1,871
6	22	0.17	43,059	6.20	0.27	41.0	12.2	20,278	0.09	573
6	23	0.45	73,234	17.00	0.61	89.0	35.0	42,510	0.22	2,062
6	24	0.16	68,457	17.60	0.17	84.0	23.5	37,150	0.20	1,103
7	25	0.34	64,932	13.40	0.54	73.0	27.7	36,546	0.14	1,598
7	26	0.30	66,819	13.80	0.43	72.0	26.0	34,841	0.05	1,122
7	27	0.09	58,985	15.40	0.14	62.0	17.3	33,222	0.12	932
8	28	0.13	50,769	8.00	0.28	43.0	12.9	21,486	0.09	546
8	29	0.34	64,690	38.90	1.17	114.0	64.0	32,389	0.69	931
8	30	0.42	58,164	16.80	0.63	73.0	33.0	35,401	0.17	750
9	31	0.04	60,586	10.00	0.09	57.0	8.7	33,584	0.04	641
9	32	0.05	71,392	11.20	0.12	76.0	12.7	41,232	0.03	814
9	33	0.05	65,434	11.00	0.10	70.0	10.2	39,501	0.02	1,032
9	34	0.23	48,609	11.40	0.36	56.0	18.3	28,219	0.15	604
10	35	0.03	8,840	11.30	0.27	8.0	9.7	7,266	0.02	10,918

Appendix F - Metals concentrations in mg/kg (Butyl tins in ug/kg)

STRATUM	SITE	NICKEL	LEAD	ANTIMONY	SELENIUM	TIN	THALLIUM	ZINC	BUTYL TINS
19	1	33.5	76.40	1.25	0.77	7.77	0.50	467.0	3.95
19	2	21.5	47.80	0.86	0.71	7.44	0.27	268.0	0.00
19	3	39.4	88.60	1.27	0.99	9.77	0.52	533.0	6.13
20	4	33.4	82.60	0.91	0.71	5.20	0.41	446.0	7.56
20	5	13.5	14.50	0.38	0.09	1.07	0.10	104.0	0.00
20	6	26.2	47.20	0.61	0.19	15.60	0.24	200.0	0.58
1	7	30.5	70.30	1.20	0.62	6.46	0.40	411.0	10.73
1	8	35.1	87.90	1.49	0.80	7.32	0.35	475.0	13.47
1	9	12.6	20.30	0.67	0.20	1.97	0.25	99.0	1.82
2	10	19.5	45.50	1.14	0.44	11.80	0.23	128.0	1.93
2	11	22.5	43.40	0.93	0.49	3.06	0.32	187.0	5.83
2	12	12.8	15.40	0.23	0.17	1.29	0.21	81.0	0.55
3	13	49.3	151.00	2.71	1.61	11.70	0.61	547.0	31.49
3	14	14.5	19.10	0.37	0.16	1.08	0.19	116.0	4.77
3	15	12.2	13.80	0.22	0.15	0.92	0.23	99.0	0.00
4	16	29.9	82.50	1.31	1.33	4.72	0.43	237.0	1.43
4	17	21.7	22.10	0.38	0.20	1.57	0.24	114.0	48.09
4	18	17.7	27.70	1.28	0.27	3.77	0.36	110.0	1.46
5	19	28.1	45.00	1.20	0.59	4.24	0.42	210.0	3.93
5	20	38.7	181.00	2.32	2.28	10.20	0.61	667.0	0.42
5	21	38.2	51.30	0.77	0.79	4.55	0.47	249.0	6.48
6	22	18.3	36.30	0.55	0.27	2.22	0.32	106.0	1.40
6	23	43.5	64.20	0.81	0.87	4.88	0.52	249.0	7.86
6	24	39.3	39.60	0.51	0.50	4.64	0.44	132.0	0.62
7	25	35.0	52.10	0.67	0.61	3.91	0.49	195.0	4.83
7	26	29.8	39.50	0.65	0.62	3.63	0.48	186.0	2.91
7	27	25.5	27.40	0.52	0.40	2.58	0.39	94.0	0.00
8	28	16.0	22.70	0.50	0.25	1.88	0.36	112.0	1.60
8	29	36.2	109.00	1.70	1.23	10.80	0.71	550.0	0.00
8	30	31.6	47.80	0.99	0.96	3.80	0.42	236.0	2.80
9	31	51.9	13.40	0.37	0.24	1.54	0.41	76.0	0.00
9	32	35.2	21.00	0.38	0.44	1.77	0.44	95.0	0.00
9	33	29.9	17.80	0.60	0.31	1.52	0.37	84.0	0.00
9	34	20.5	29.90	0.55	0.50	2.35	0.32	135.0	2.15
10	35	55.4	34.90	8.06	0.17	0.70	0.33	368.0	0.00

Appendix F - Metals concentrations in mg/kg (Butyl tins in ug/kg)

STRATUM	SITE	SILVER	ALUMINUM	ARSENIC	CADMIUM	CHROMIUM	COPPER	IRON	MERCURY	MANGANESE
10	36	0.23	49,612	9.90	0.39	53.0	17.4	26,358	0.11	433
10	37	0.20	58,087	8.00	0.32	55.0	17.9	26,623	0.12	492
10	38	0.16	46,035	9.40	0.29	44.0	13.8	22,063	0.08	475
11	39	0.03	13,717	2.23	0.06	9.7	2.9	5,550	0.03	125
11	40	0.11	46,595	6.33	0.21	38.0	7.9	20,357	0.06	547
11	41	0.06	44,159	4.75	0.31	31.0	3.5	15,424	0.04	416
11	42	0.09	52,205	4.11	0.33	34.0	5.0	18,844	0.04	493
12	43	0.06	34,061	2.02	0.28	19.5	3.3	10,900	0.03	261
12	44	0.07	34,714	3.52	0.44	25.0	4.4	12,493	0.04	281
12	45	0.02	29,506	2.78	0.09	16.1	2.0	11,395	0.02	265
12	46	0.00	11,596	2.92	0.04	9.8	2.5	8,537	0.02	198
13	47	0.02	36,418	4.39	0.06	14.1	1.7	9,988	0.02	242
13	48	0.01	10,458	2.69	0.06	9.1	1.7	6,858	0.01	104
13	49	0.00	13,741	2.92	0.01	9.3	1.3	7,045	0.02	118
13	50	0.10	45,030	4.85	0.14	30.0	4.3	15,830	0.07	300
13	51	0.00	7,833	3.52	0.00	3.3	1.0	3,635	0.00	94
13	52	0.00	9,573	3.82	0.02	8.4	1.5	9,116	0.01	95
13	53	0.02	47,628	5.00	0.07	29.6	2.0	15,869	0.01	361
13	54	0.02	28,624	1.96	0.02	9.1	1.5	5,343	0.01	81
13	55	0.05	37,203	4.43	0.08	21.1	2.5	12,195	0.02	201
13	56	0.16	39,813	8.13	0.17	35.0	8.9	17,041	0.07	283
14	57	0.26	62,194	17.50	0.51	80.0	20.0	40,673	0.15	963
14	58	0.08	34,085	3.87	0.43	28.6	4.3	15,626	0.05	390
14	59	0.01	41,053	4.27	0.04	17.6	2.3	9,709	0.01	150
14	60	0.10	49,058	4.15	0.20	36.0	5.1	18,332	0.06	380
14	61	0.02	27,167	3.41	0.05	12.5	1.5	8,193	0.02	150
15	62	0.00	3,497	0.71	0.00	3.3	0.7	1,234	0.00	61
15	63	0.01	10,264	0.85	0.00	1.7	1.0	1,594	0.01	61
15	64	0.00	5,901	1.67	0.00	1.9	0.5	1,005	0.00	19
16	65	0.00	6,016	0.95	0.00	2.4	0.8	1,444	0.00	79
16	66	0.09	21,124	3.93	0.18	25.5	6.6	14,391	0.05	307
16	67	0.13	22,054	4.25	0.20	28.0	6.9	15,046	0.06	262
17	68	0.01	10,235	2.78	0.00	3.9	0.9	3,251	0.01	73
17	69	0.01	11,934	12.80	0.02	7.3	1.4	10,909	0.00	111
17	70	0.00	6,673	2.53	0.00	3.2	0.7	2,884	0.00	72

Appendix F - Metals concentrations in mg/kg (Butyl tins in ug/kg)

STRATUM	SITE	NICKEL	LEAD	ANTIMONY	SELENIUM	TIN	THALLIUM	ZINC	BUTYL TINS
10	36	22.0	28.20	0.72	0.56	2.06	0.37	139.0	2.76
10	37	21.2	28.50	0.71	0.44	2.34	0.33	137.0	3.40
10	38	19.7	24.30	0.56	0.38	1.89	0.36	129.0	1.81
11	39	4.2	10.20	0.23	0.04	0.53	0.16	33.0	0.41
11	40	13.1	22.00	0.40	0.18	1.51	0.17	101.0	1.65
11	41	9.3	17.30	0.30	0.07	1.20	0.23	98.0	0.29
11	42	12.6	20.10	0.30	0.10	1.52	0.28	96.0	0.37
12	43	7.6	14.20	0.15	0.04	0.85	0.19	62.0	0.28
12	44	10.0	15.20	0.20	0.09	1.05	0.18	76.0	0.46
12	45	7.7	14.50	0.28	0.06	0.71	0.21	105.0	0.00
12	46	3.7	8.35	0.19	0.12	0.69	0.12	53.0	0.39
13	47	5.5	13.00	0.22	0.01	0.62	0.22	50.0	0.00
13	48	2.9	6.44	0.16	0.05	0.52	0.18	53.0	0.21
13	49	3.4	7.33	0.00	0.00	0.36	0.06	28.0	0.00
13	50	10.4	14.90	0.62	0.09	1.20	0.25	57.0	1.03
13	51	1.4	6.25	0.07	0.01	0.17	0.07	22.0	0.00
13	52	2.9	6.60	0.06	0.01	0.43	0.08	40.0	0.00
13	53	8.5	12.00	0.26	0.03	0.99	0.23	48.0	0.00
13	54	3.2	8.71	0.24	0.00	0.42	0.20	23.0	0.00
13	55	7.0	14.20	0.28	0.07	0.90	0.28	49.0	0.29
13	56	12.4	18.70	0.30	0.19	1.38	0.27	64.0	0.71
14	57	32.5	37.50	0.67	0.82	2.23	0.42	152.0	23.99
14	58	8.8	15.00	0.22	0.17	1.32	0.20	72.0	0.70
14	59	6.0	10.40	0.23	0.00	0.60	0.25	38.0	0.00
14	60	10.6	17.30	0.36	0.13	1.47	0.23	66.0	0.71
14	61	3.3	11.30	0.24	0.05	0.56	0.22	41.0	0.00
15	62	2.1	3.00	0.04	0.02	0.13	0.00	7.7	0.00
15	63	1.1	5.04	0.07	0.00	0.19	0.12	10.0	0.00
15	64	0.7	2.95	0.17	0.00	0.07	0.07	6.8	0.00
16	65	0.7	3.25	0.00	0.00	0.10	0.06	8.9	0.00
16	66	8.3	13.20	0.15	0.13	0.77	0.18	55.0	0.40
16	67	10.3	14.60	0.18	0.21	0.97	0.22	62.0	0.00
17	68	1.3	6.63	0.13	0.00	0.23	0.11	16.0	0.00
17	69	3.0	9.68	0.20	0.00	0.45	0.11	30.0	0.00
17	70	1.1	5.43	0.00	0.00	0.38	0.05	13.0	0.00

Appendix F - Metals concentrations in mg/kg (Butyl tins in ug/kg)

STRATUM	SITE	SILVER	ALUMINUM	ARSENIC	CADMIUM	CHROMIUM	COPPER	IRON	MERCURY	MANGANESE
18	71	0.00	18,777	1.82	0.00	5.1	0.8	2,128	0.00	68
18	72	0.01	23,586	2.41	0.00	4.6	0.7	2,708	0.00	60
18	73	0.00	24,493	2.47	0.00	6.0	0.9	5,228	0.02	72
21	84	0.32	58,849	18.60	0.57	102.0	26.5	44,734	0.21	876
21	85	0.35	70,031	14.70	0.53	91.0	29.2	39,749	0.29	1,141
/	87	0.08	71,712	13.70	0.10	81.0	13.1	43,793	0.01	843
22	88	0.42	57,926	21.60	0.43	67.0	23.7	36,199	0.22	1,125
22	89	0.61	56,735	16.00	1.44	75.0	38.0	40,313	0.67	616
22	90	0.50	68,778	17.60	0.57	86.0	28.5	39,985	0.31	722
/	91	0.41	69,224	21.10	0.64	83.0	35.0	41,639	0.30	1,117
/	92	0.24	65,108	22.80	0.61	92.0	38.0	48,472	0.44	603

Appendix F - Metals concentrations in mg/kg (Butyl tins in ug/kg)

STRATUM	SITE	NICKEL	LEAD	ANTIMONY	SELENIUM	TIN	THALLIUM	ZINC	BUTYL TINS
18	71	1.1	8.49	0.07	0.01	0.27	0.22	11.0	0.00
18	72	1.4	9.51	0.01	0.00	0.13	0.23	12.0	0.00
18	73	1.4	10.30	0.09	0.00	0.31	0.23	21.0	0.00
21	84	30.9	44.50	1.12	0.90	3.25	0.46	229.0	5.86
21	85	34.9	48.80	0.99	0.90	4.27	0.54	235.0	2.73
/	87	33.0	17.60	0.26	0.42	1.79	0.43	103.0	0.41
22	88	28.7	41.00	0.45	0.78	2.74	0.45	167.0	3.62
22	89	36.4	82.80	0.60	1.91	5.68	0.54	359.0	7.41
22	90	35.2	59.10	0.65	1.07	3.97	0.45	215.0	2.22
/	91	35.6	59.80	1.07	0.88	4.57	0.46	302.0	14.60
/	92	34.3	71.80	1.32	0.98	4.81	0.61	310.0	0.00

Delaware Bay Contamination Levels

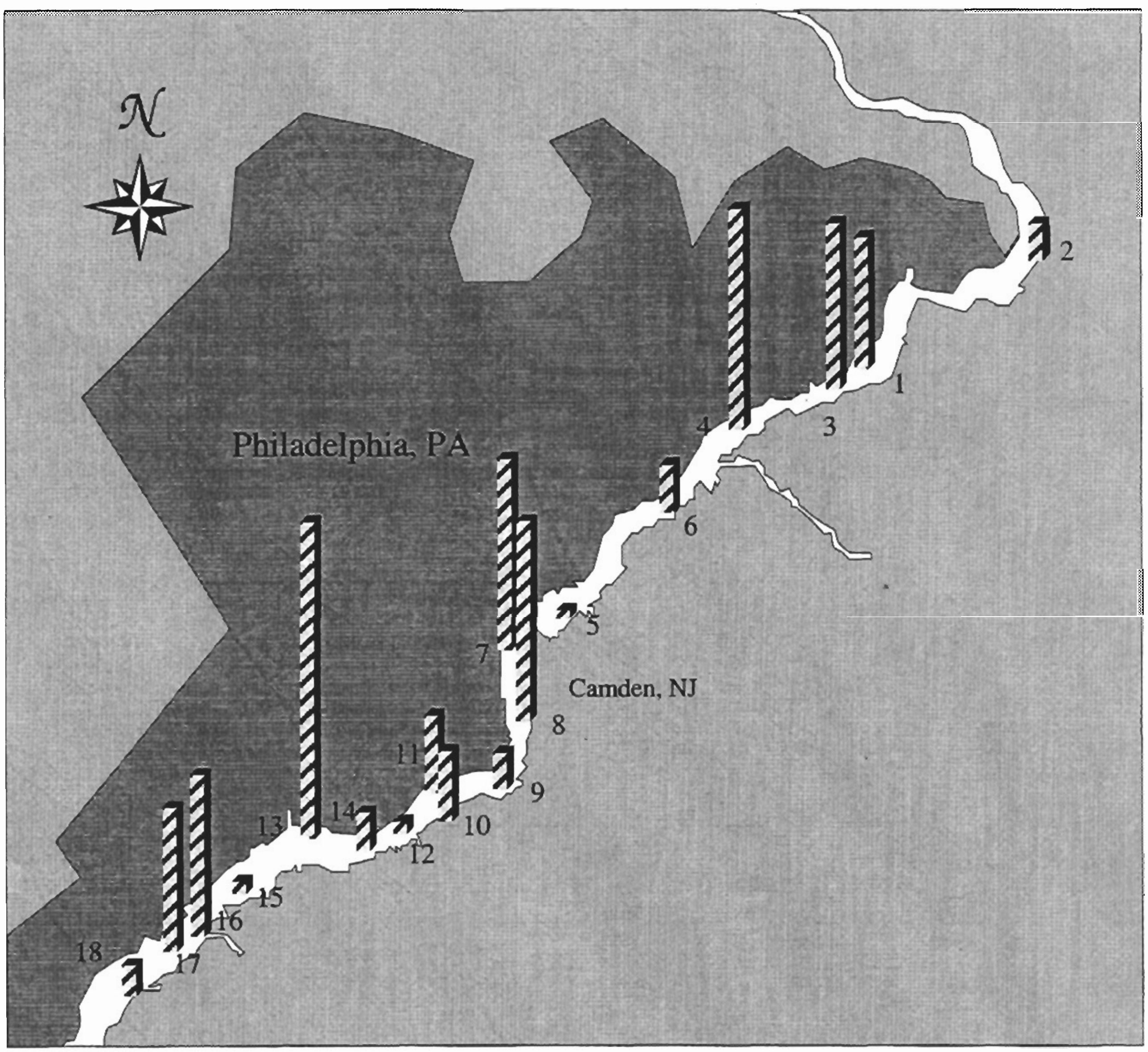


Figure F-1. Chemical contamination at freshwater sample stations 1 through 18. Height of bars indicate relative degree of combined contaminant concentrations (Σ PCBs + PAHs + 10 metals + TBT + DDTs + chlorinated pesticides, divided by their respective means).

Delaware Bay Contamination Levels

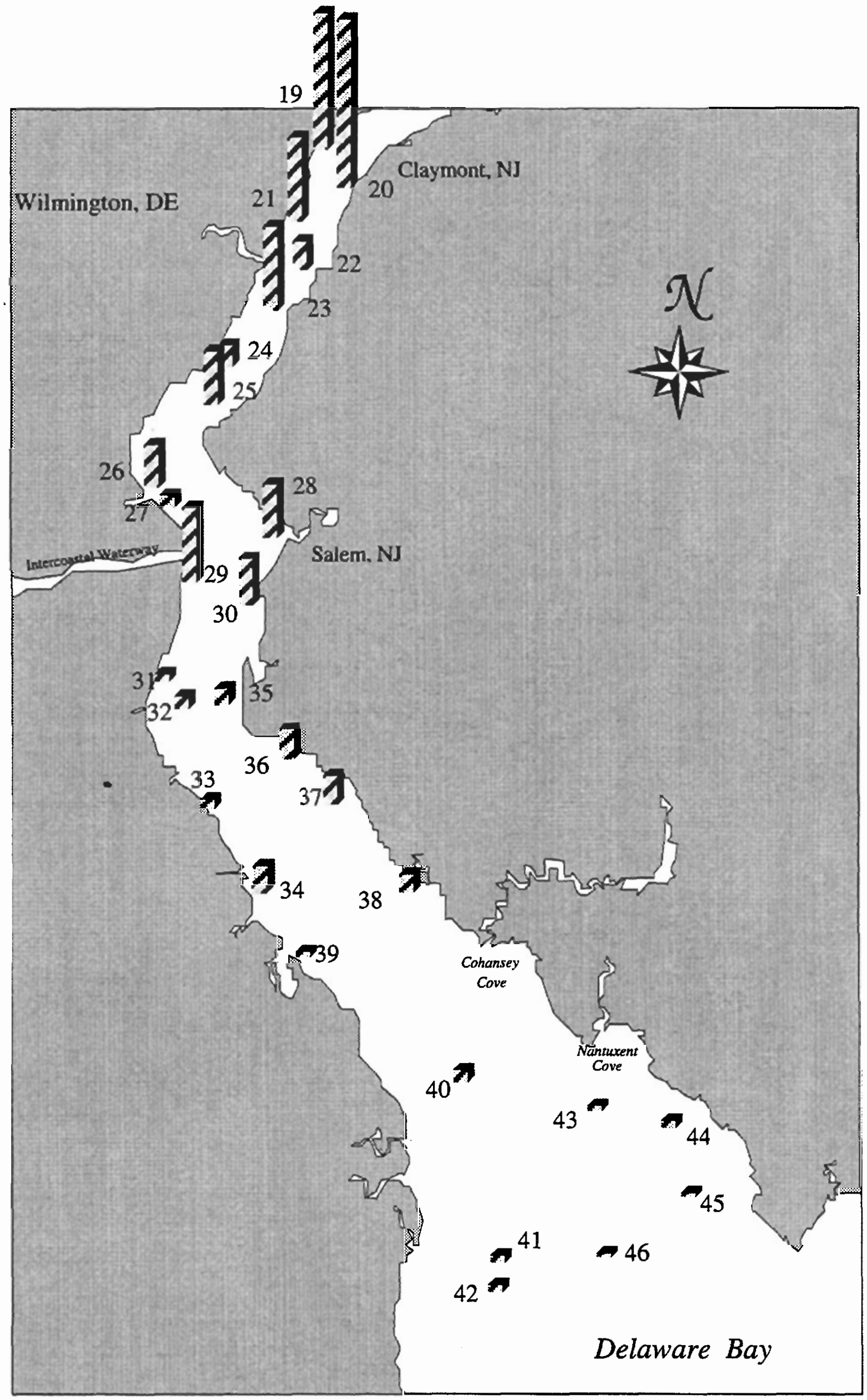


Figure F-2. Chemical contamination at sample stations 19 through 46. Height of bars indicate relative degree of combined contaminant concentrations (Σ PCBs + PAHs + 10 metals + TBT + DDTs + chlorinated pesticides, divided by their respective means).

Delaware Bay Contamination Levels

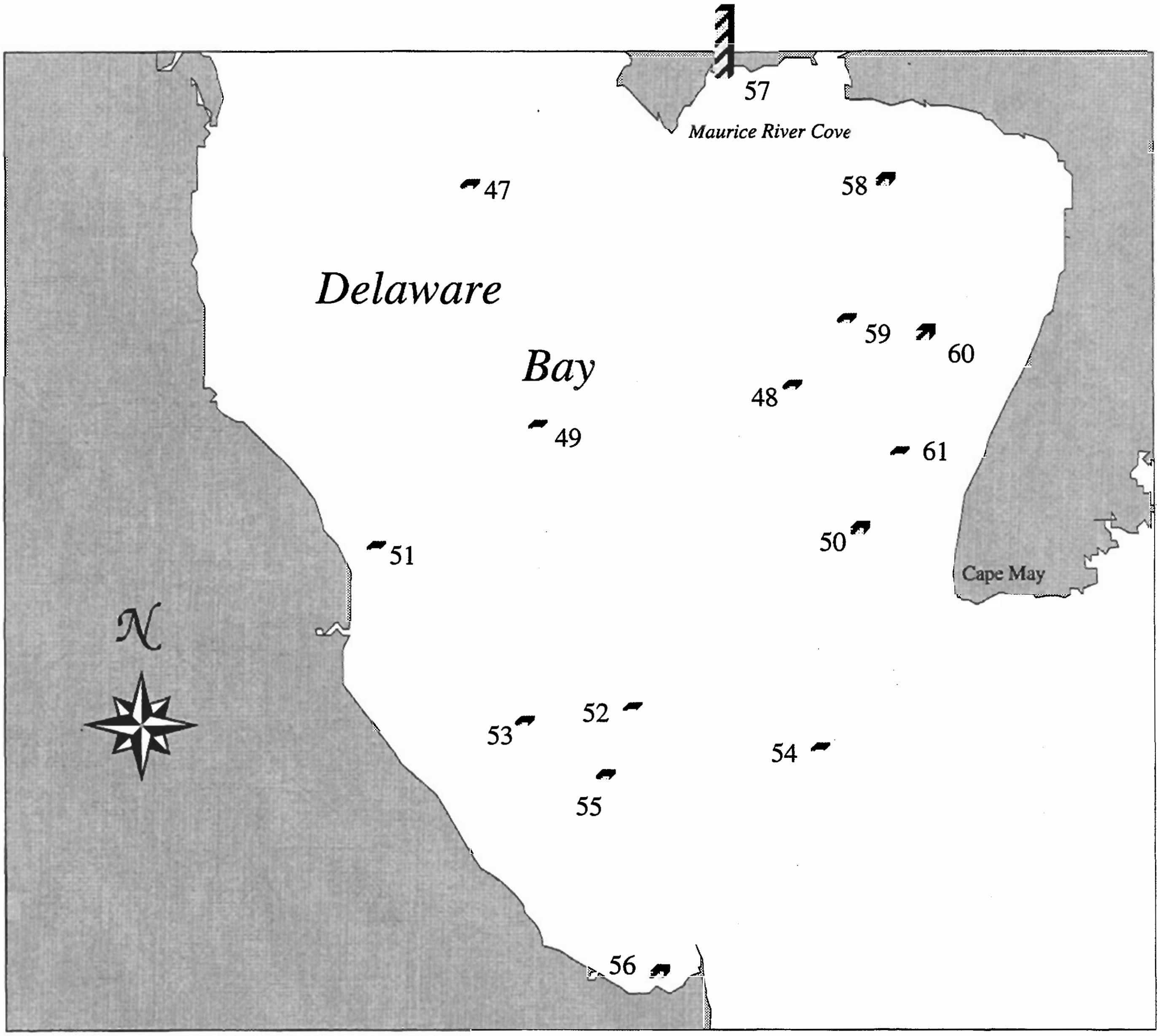


Figure F-3. Chemical contamination at sample stations 47 through 61. Height of bars indicate relative degree of combined contaminant concentrations (Σ PCBs + PAHs + 10 metals + TBT + DDTs + chlorinated pesticides, divided by their respective means).

Delaware Bay Contamination Levels

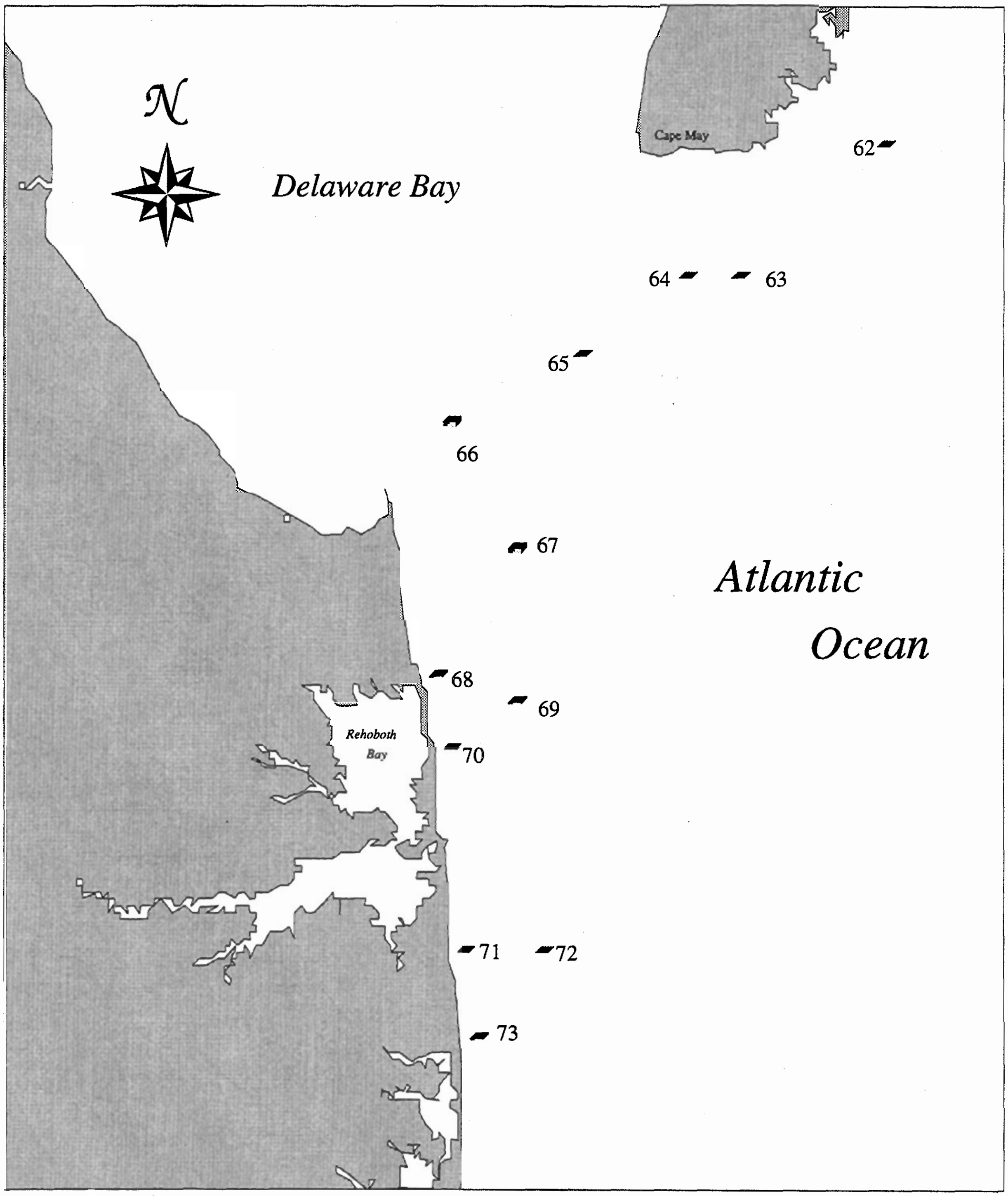


Figure F-4. Chemical contamination at sample stations 62 through 73. Height of bars indicate relative degree of combined contaminant concentrations (Σ PCBs + PAHs + 10 metals + TBT + DDTs + chlorinated pesticides, divided by their respective means).

APPENDIX G

Toxicity Bioassay Results

Appendix G - Toxicity results

		Amphipod Survival		Microtox™ Response			Sea Urchin Fertilization						P450 RGS	
Stratum	Site	% Survival	% of Control	Mean EC_{50}	Ref./ Sample	Phenol Ref./ Sample	% Fert. (100%) [a]	% of Control	% Fert. (50%) [a]	% of Control	% Fert. (25%) [a]	% of Control	B[a]P Equivalents (ug/g)	TEQ (ng/g)
19	1	94[R]	97.92	14.1	7 **	1	90.8	98	94.4	100	94.6	101	38.41	2.30
19	2	96.3[R]	100.26	11.1	9 **	1	94.4	102	95.0	101	94.2	100	83.28	5.00
19	3	85	96.59	28.6	4 **	5	85.6	92 **	91.6	97	91.4	97	37.86	2.27
20	4	91	103.41	2.4	43 **	6 **	94.4	102	93.0	99	96.8	103	313.01	18.78
20	5	97	110.23	91.5	1	0.2	94.6	102	94.4	100	95.0	101	.72	0.04
20	6	90	102.27	97.7	1	0.2	94.2	102	93.8	99	93.2	99	47.59	2.86
1	7	89	101.14	4.4	23 **	4 **	88.8	96	95.2	101	94.4	101	225.52	13.53
1	8	86[R]	89.58*	8.1	13 **	2 **	89.8	97	93.2	99	92.8	99	226.59	13.60
1	9	88	100.00	5.0	21 **	3 **	95.2	103	93.8	99	96.0	102	8.40	0.50
2	10	92	100.00	2.1	49 **	7 **	92.2	99	94.0	100	94.8	101	115.12	6.91
2	11	89[R]	92.00*	2.3	45 **	7 **	94.8	102	95.0	101	94.4	101	1,583.99	95.40
2	12	95[R]	98.96	36.0	3 **	0.4	92.6	100	95.4	101	93.4	100	2.36	0.14
3	13	17	20.00**	2.1	49 **	7 **	90.6	98	92.6	98	96.0	102	344.65	20.68
3	14	91	103.00	31.0	3 **	0.5	92.2	99	94.6	100	94.2	100	17.95	1.08
3	15	84	95.45	33.6	3 **	0.4	96.0	104	93.8	99	96.6	103	3.42	0.21
4	16	85[R]	88.54	6.1	17 **	3 **	92.8	100	95.8	102	94.6	101	130.58	7.83
4	17	85	97.70	10.0	10 **	2	92.6	100	95.0	101	93.8	100	62.29	3.74
4	18	86	93.48	14.8	7 **	1	91.6	99	94.4	100	94.6	101	47.36	2.84
5	19	97.5[R]	101.56	4.5	23 **	3 **	93.4	101	91.8	97	95.4	102	124.19	7.45
5	20	19	22.35**	1.2	86 **	13 **	94.4	102	93.8	99	92.8	99	183.08	10.98
5	21	100[R]	104.17	187.2	0.5	0.1	53.0	57 **	78.6	83 *	93.2	99	7.93	0.48
6	22	95[R]	98.96	9.8	10 **	2 *	94.4	102	94.0	100	92.2	98	16.32	0.98
6	23	85	107.59	12.0	9 **	1	64.6	70 **	82.6	88 **	93.0	99	18.84	1.13
6	24	97.5[R]	101.56	6.3	16 **	2 **	86.6	93 *	91.6	97	92.0	94	12.54	0.75
7	25	91	115.19	9.7	11 **	2 *	64.8	70 **	89.8	95	92.2	98	20.41	1.22
7	26	95	103.26	0.4	257 **	38 **	91.4	99	90.4	96	95.6	102	25.18	1.51

(R) - repeated assay
* significant at $\alpha \leq 0.05$
** significant at $\alpha \leq 0.01$
na - not available
a - porewater concentration

Appendix G - Toxicity results

		Amphipod Survival		Microtox™ Response			Sea Urchin Fertilization						P450 RGS	
Stratum	Site	% Survival	% of Control	Mean EC_{50}	Ref./ Sample	Phenol Ref./ Sample	% Fert. (100%) [a]	% of Control	% Fert. (50%) [a]	% of Control	% Fert. (25%) [a]	% of Control	B[a]P Equivalents (ug/g)	TEQ (ng/g)
7	27	92	100.00	1.3	79 **	12 **	92.8	100	93.8	99	94.8	101	7.87	0.47
8	28	95	103.26	1.0	103.09 **	15 **	92.4	100	93.6	99	94.8	101	12.97	0.78
8	29	2	2.17**	4.4	23 **	3 **	79.8	86 **	93.4	99	92.8	99	298.41	17.90
8	30	92	100.00	0.3	343 **	51 **	90.2	97	94.8	101	95.0	101	9.25	0.56
9	31	100	105.26	64.7	2 *	0.2	97.0	105	96.0	102	95.0	101	1.93	0.12
9	32	100[R]	104.17	19.0	5 **	0.8	94.6	102	95.0	101	96.2	103	1.30	0.08
9	33	96.7[R]	100.69	6.3	16 **	2 **	95.6	103	94.4	100	95.4	102	1.73	0.10
9	34	84	91.30	1.8	57 **	8 **	93.2	101	94.4	100	94.8	101	5.34	0.32
10	35	96	101.05	105.4	1	0.2	95.2	103	95.0	101	95.4	102	1.05	0.06
10	36	92	94.85	1.5	69 **	10 **	91.4	99	93.8	99	93.0	99	6.86	0.41
10	37	95	100.00	1.6	64 **	9 **	92.2	99	94.8	101	93.8	100	5.20	0.31
10	38	88	95.65	2.5	41 **	6 **	91.4	99	94.8	101	93.2	99	8.89	0.53
11	39	90	96.77	24.2	4 **	0.6	94.2	102	93.6	99	97.2	104	1.08	0.06
11	40	77	83.00	2.5	41 **	6 **	93.0	100	95.6	101	94.8	101	7.20	0.43
11	41	80	86.02*	6.9	15 **	2 **	94.6	102	96.6	102	95.2	101	1.81	0.11
11	42	83	89.25*	1.7	60 **	9 **	91.0	98	92.6	98	92.6	99	4.17	0.25
12	43	88	94.62*	2.3	45 **	6 **	96.4	102	95.6	100	96.0	100	1.46	0.09
12	44	90	96.77	2.9	36 **	5 **	97.8	103	96.8	101	97.6	101	3.38	0.20
12	45	83	89.25	34.2	3 **	0.4	97.2	103	97.0	102	97.0	101	1.04	0.06
12	46	88	94.62*	72.9	1	0.2	96.4	102	97.4	102	96.0	100	1.19	0.07
13	47	76	81.72	48.9	2 **	0.3	97.8	103	97.2	102	97.8	102	.68	0.04
13	48	83	97.65*	11.2	9 **	1	97.6	103	97.0	102	95.6	99	.41	0.02
13	49	82	88.17	161.0	0.6	0.1	95.6	101	96.0	101	97.8	102	.33	0.02
13	50	86	101.18*	1.4	74 **	11 **	94.2	100	97.0	102	97.4	101	2.73	0.16
13	51	85	100.00	189.5	0.5	0.08	96.0	101	98.0	103	97.8	102	.22	0.01
13	52	69	74.19	31.7	3 **	0.5	97.0	103	97.8	103	95.6	99	.58	0.03

(R) - repeated assay
* significant at $\alpha \leq 0.05$
** significant at $\alpha \leq 0.01$
na - not available
a - porewater concentration

Appendix G - Toxicity results

		Amphipod Survival		Microtox™ Response			Sea Urchin Fertilization						P450 RGS	
Stratum	Site	% Survival	% of Control	Mean EC_{50}	Ref./ Sample	Phenol Ref./ Sample	% Fert. (100%) [a]	% of Control	% Fert. (50%) [a]	% of Control	% Fert. (25%) [a]	% of Control	B[a]P Equivalents (ug/g)	TEQ (ng/g)
13	53	90	105.88**	4.8	21 **	3 **	94.4	100	95.0	100	95.4	99	.60	0.04
13	54	88	103.53	4.5	23 **	3 **	95.0	100	97.2	102	95.8	99	.62	0.04
13	55	82	96.47	1.8	57 **	8 **	93.8	99	95.6	100	96.4	100	2.78	0.17
13	56	83	97.65	0.3	368 **	66 **	6.0	6 **	35.0	37 **	93.2	97	2.95	0.18
14	57	75	80.65	3.1	33 **	5 **	62.2	66 **	91.0	95 *	97.0	101	3.74	0.22
14	58	99[R]	103.13	2.2	47 **	7 **	94.2	100	95.6	100	97.0	101	1.66	0.10
14	59	82	96.47	4.2	24 **	4 **	96.4	102	96.8	101	97.2	101	2.34	0.14
14	60	100[R]	104.17	3.3	21 **	5 **	54.6	58 **	94.8	99	96.0	100	1.79	0.11
14	61	96[R]	100.00	71.4	1	0.2	96.2	102	96.6	101	96.2	100	1.32	0.08
15	62	95[R]	100.00	228.3	0.4	0.07	95.2	101	97.8	103	95.8	99	.24	0.01
15	63	96.66[R]	101.75	4.8	21 **	3 **	95.2	101	96.2	101	98.0	102	.52	0.03
15	64	84	112.00	272.5	0.4	0.06	96.0	101	96.8	101	97.8	102	.24	0.01
16	65	98[R]	103.16	199.7	0.6	0.08	96.6	102	96.0	101	96.6	100	.44	0.03
16	66	98.33[R]	103.51	1.5	69 **	10 **	97.4	103	97.2	102	97.2	101	3.02	0.18
16	67	na[R]	na	1.4	74 **	11 **	95.0	100	97.0	102	97.4	101	.99	0.06
17	68	95[R]	100.00	102.1	1	0.2	96.2	102	96.6	101	97.2	101	.42	0.03
17	69	92[R]	96.84	123.1	0.8	0.1	97.2	103	97.2	102	97.6	101	.42	0.03
17	70	88[R]	92.63	26.4	4 **	0.6	96.6	102	97.6	102	97.4	101	.37	0.02
18	71	92.5[R]	97.37	99.2	1	0.2	97.0	103	97.8	103	97.8	102	.32	0.02
18	72	85[R]	89.47	127.7	0.8	0.1	96.8	102	98.6	103	97.0	101	.43	0.03
18	73	92.5[R]	97.37	13.2	8 **	1	97.6	103	99.0	104	97.0	101	.70	0.04
21	84	91	93.81	0.5	187 **	28 **	97.6	103	95.8	100	95.8	99	14.33	0.86
21	85	88	96.70	0.7	139 **	21 **	92.4	98	95.8	100	97.6	101	48.14	2.89
/	87	95	104.40	3.7	28 **	4 **	96.6	102	96.8	101	96.6	100	3.78	0.23

(R) - repeated assay
* significant at $\alpha \leq 0.05$
** significant at $\alpha \leq 0.01$
na - not available
a - porewater concentration

Appendix G - Toxicity results

		Amphipod Survival		Microtox™ Response			Sea Urchin Fertilization						P450 RGS	
Stratum	Site	% Survival	% of Control	Mean EC_{50}	Ref./ Sample	Phenol Ref./ Sample	% Fert. (100%) [a]	% of Control	% Fert. (50%) [a]	% of Control	% Fert. (25%) [a]	% of Control	B[a]P Equivalents (ug/g)	TEQ (ng/g)
22	88	84	86.60	0.8	122 **	18 **	95.6	101	95.2	100	98.0	102	6.65	0.40
22	89	87	89.69	1.2	85 **	13 **	73.4	78 **	87.2	91 **	96.4	100	396.85	23.81
22	90	94	96.91*	1.0	107 **	16 **	97.4	103	96.4	101	95.8	99	28.32	1.70
/	91	88	95.65*	1.3	79 **	12 **	97.2	103	95.6	100	97.2	101	27.80	1.67
/	92	91	98.91	0.4	257 **	38 **	85.0	90 **	91.8	96	96.0	100	15.49	0.93

(R) - repeated assay
* significant at $\alpha \leq 0.05$
** significant at $\alpha \leq 0.01$
na - not available
a - porewater concentration

Delaware Bay Amphipod Mortality

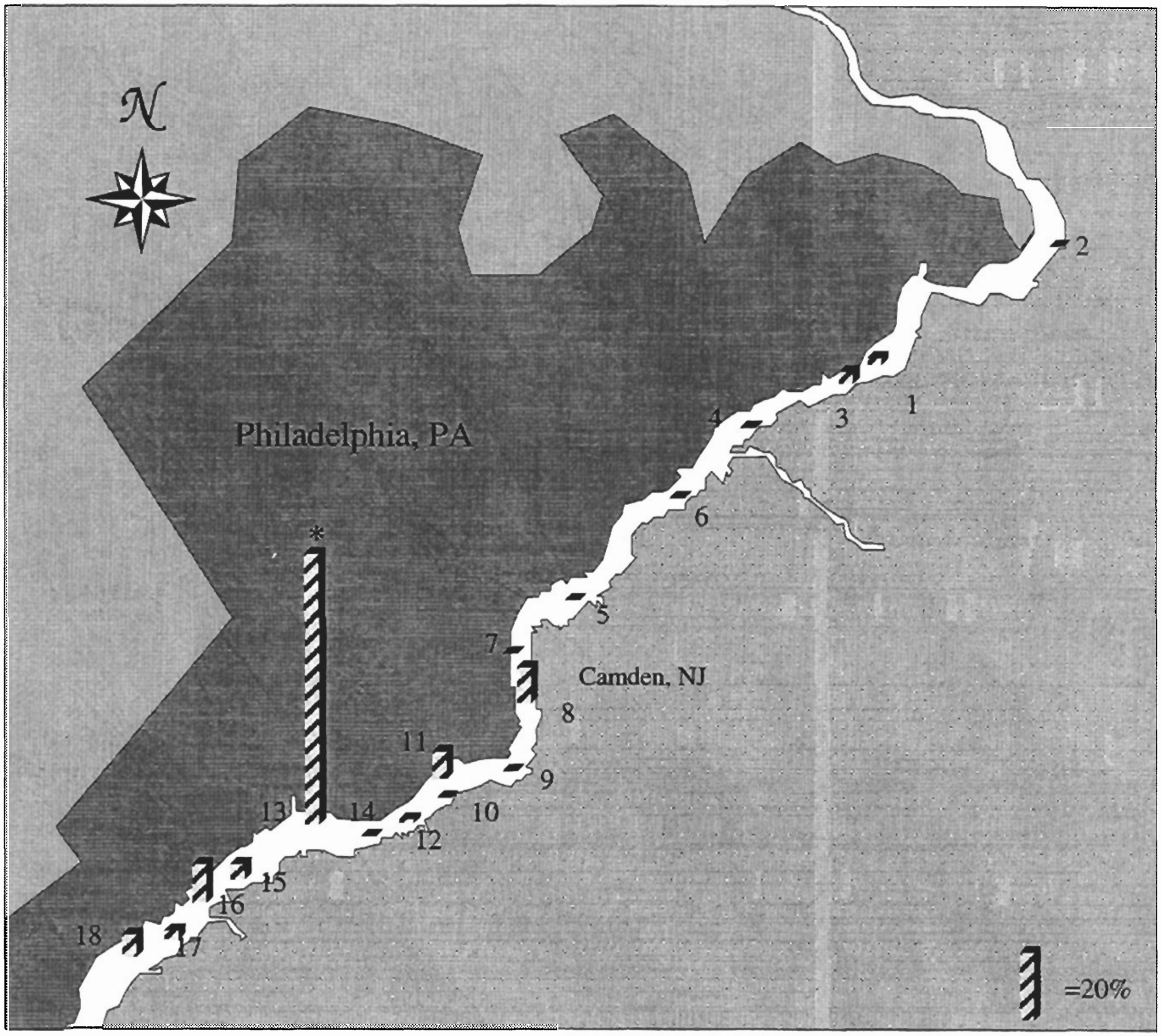


Figure G-1. Toxicity test results at freshwater sample stations 1 through 18. Height of bars indicate relative amphipod mortality response. (* = statistically significant)

Delaware Bay Amphipod Mortality

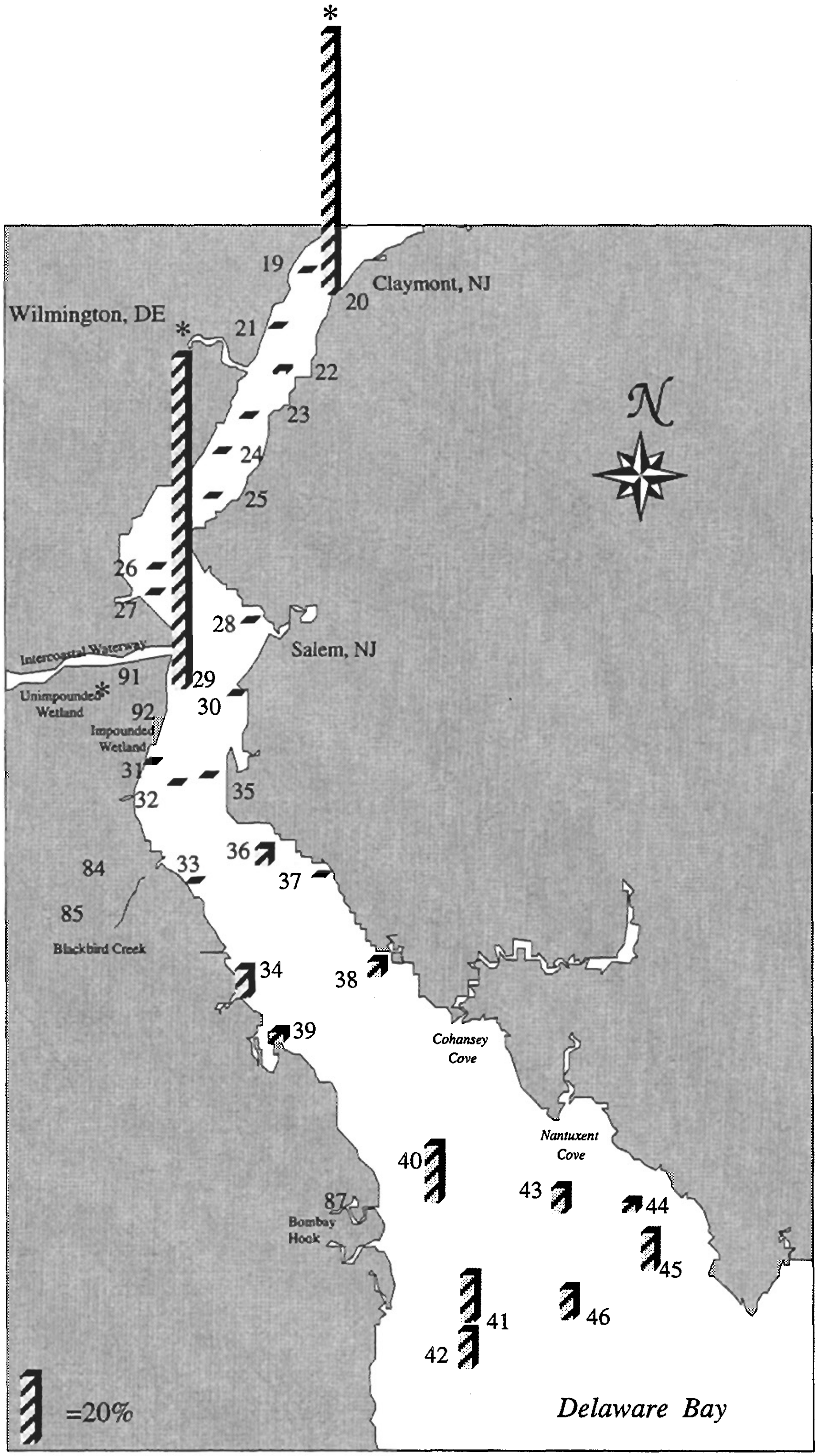


Figure G-2. Toxicity test results at sample stations 19 through 46. Height of bars indicate relative amphipod mortality response. (* = statistically significant)

Delaware Bay Sea Urchin Fertilization Failure

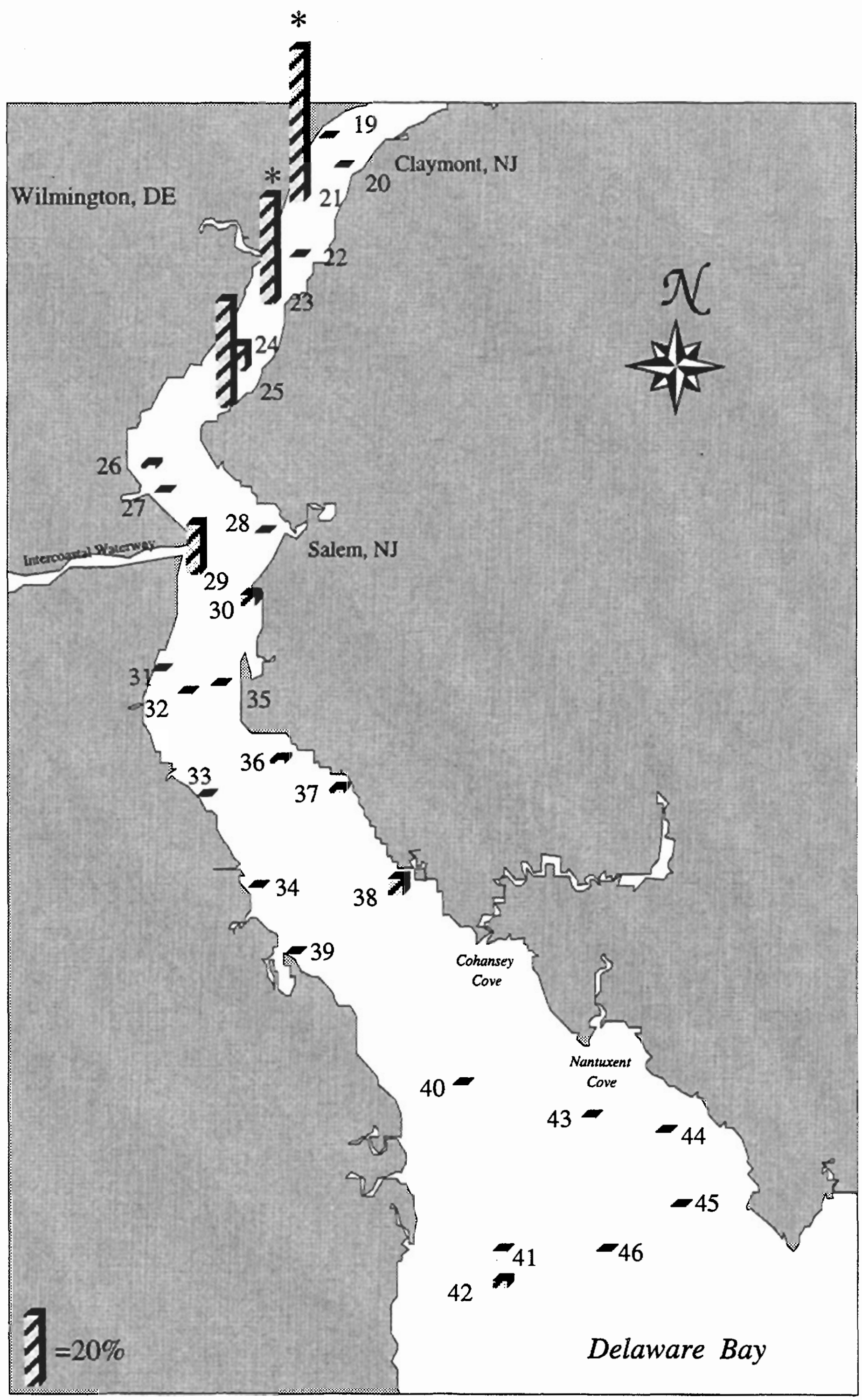


Figure G-3. Toxicity test results at sample stations 19 through 46. Height of bars indicate relative degree of sea urchin fertilization failure response. (* = statistically significant)

Delaware Bay Sea Urchin Fertilization Failure

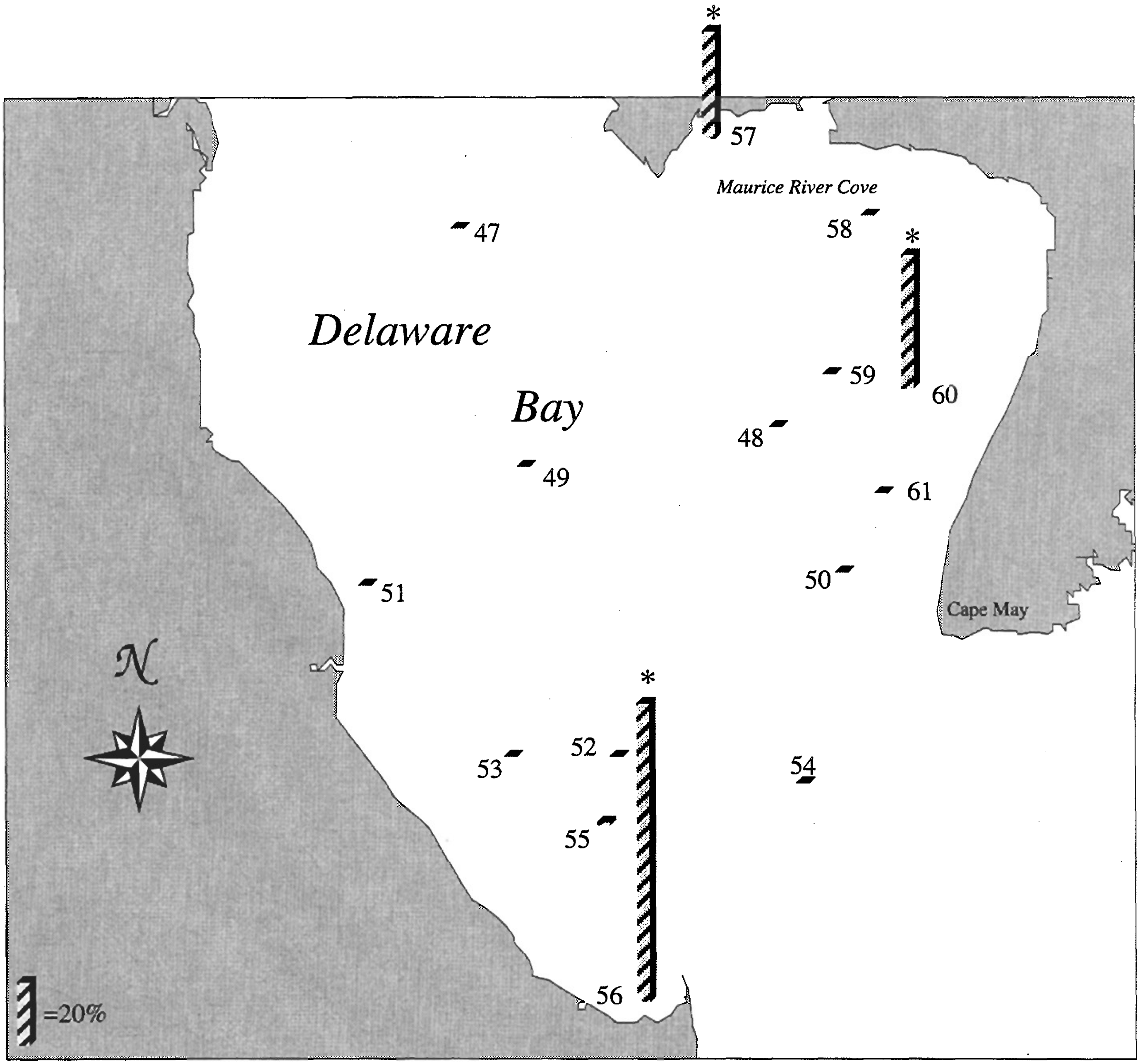


Figure G-4. Toxicity test results at sample stations 47 through 61. Height of bars indicate relative sea urchin fertilization failure response. (* = statistically significant)

Delaware Bay Microtox Response

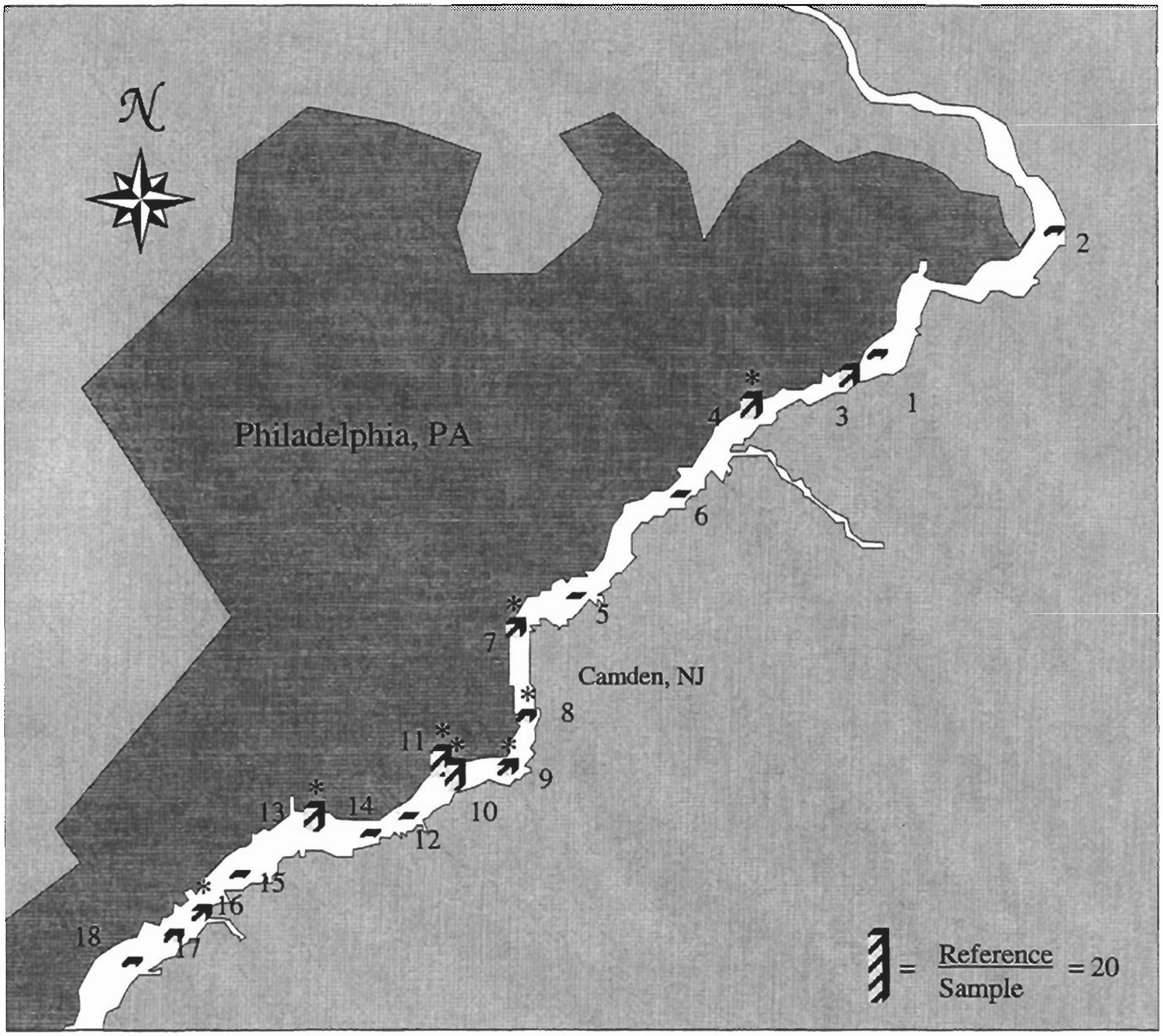


Figure G-5. Toxicity test results at freshwater sample stations 1 through 18. Height of bars indicate degree of Microtox EC50 response relative to the phenol spiked control. (* = statistically significant)

Delaware Bay Microtox Response

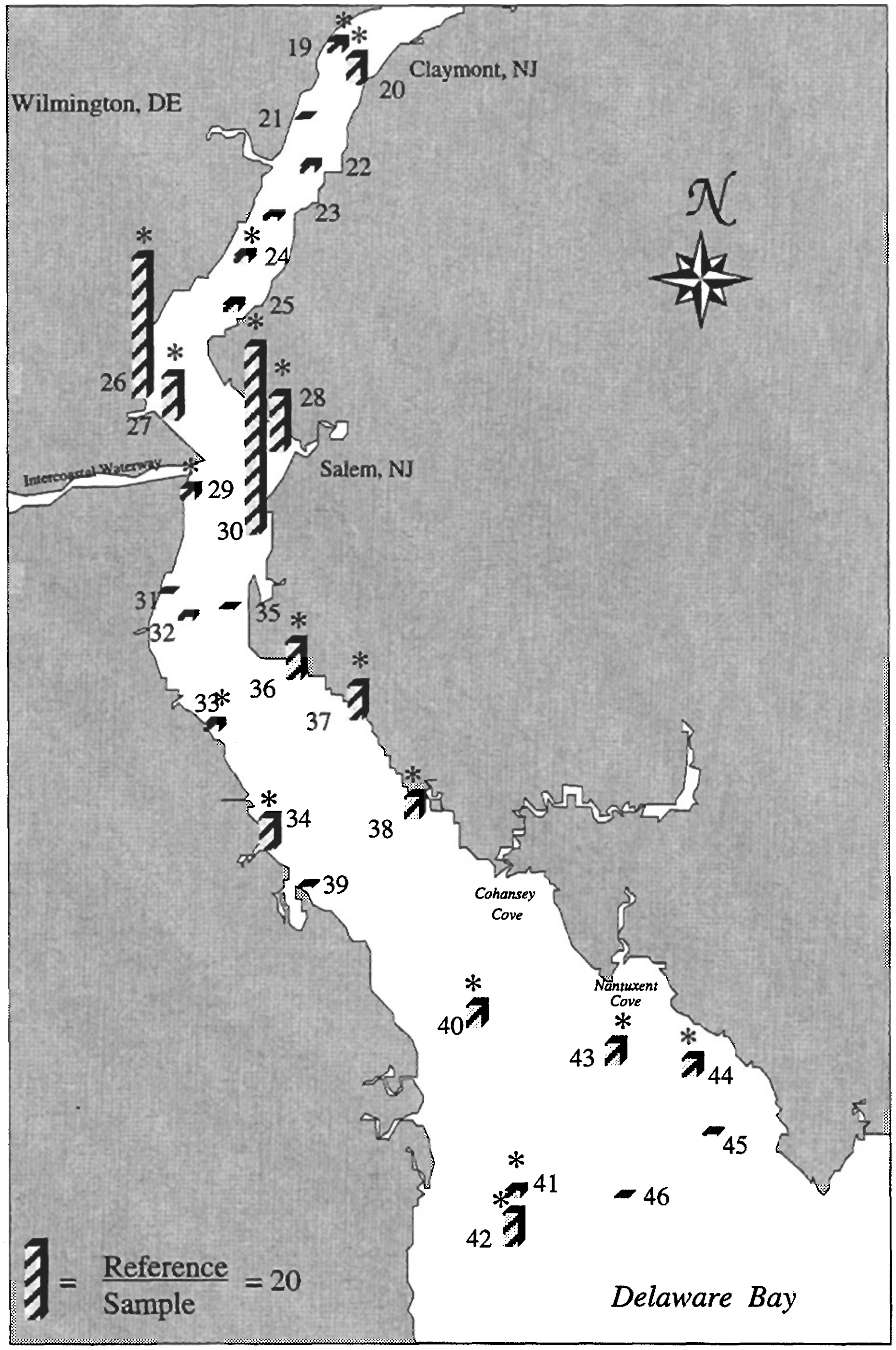


Figure G-6. Toxicity test results at sample stations 19 through 46. Height of bars indicate degree of Microtox EC50 response relative to the phenol spiked control. (* = statistically significant)

Delaware Bay Microtox Response

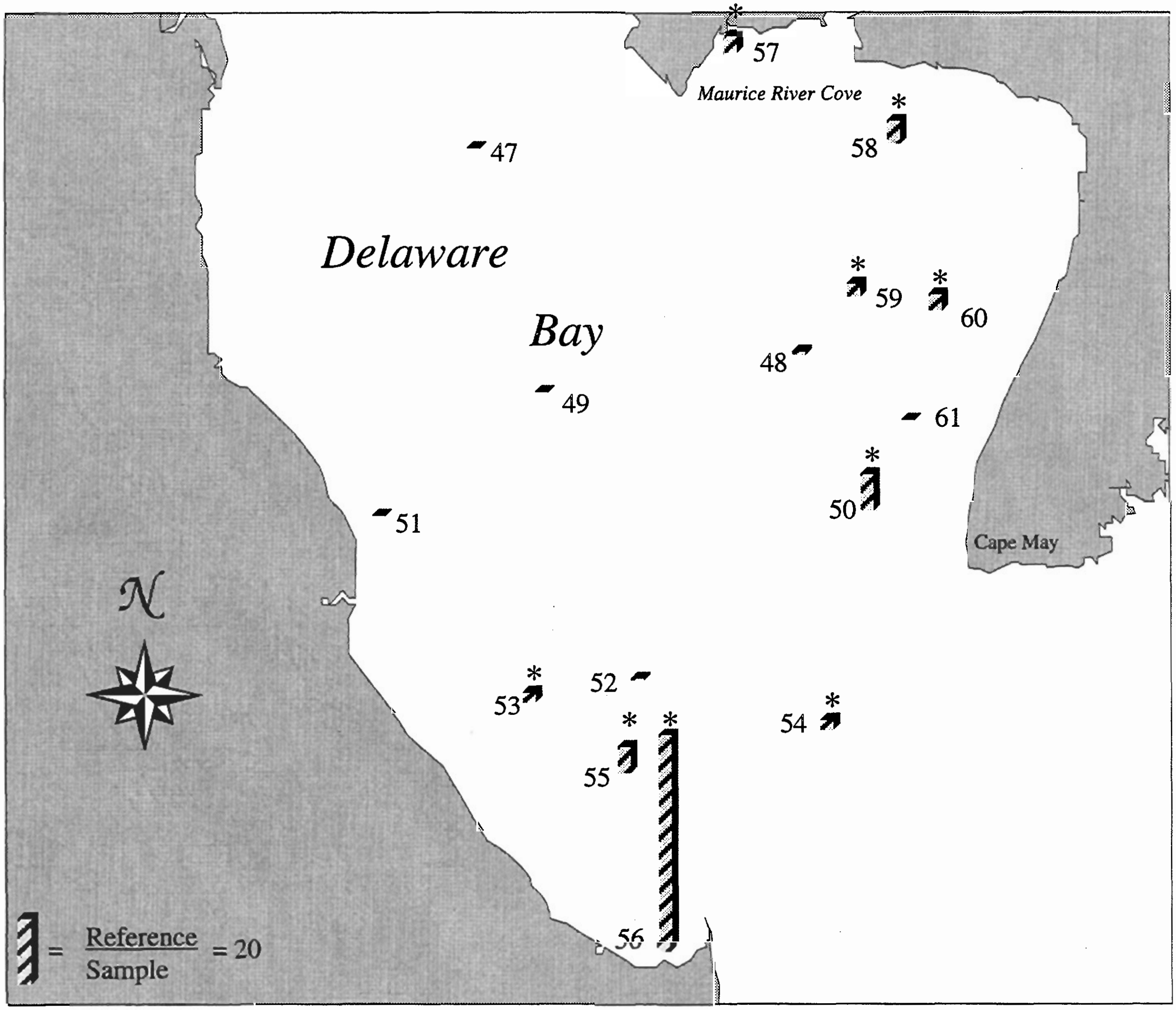


Figure G-7. Toxicity test results at sample stations 47 through 61. Height of bars indicate degree of Microtox EC50 response relative to the phenol spiked control. (* = statistically significant)

Delaware Bay Microtox Response

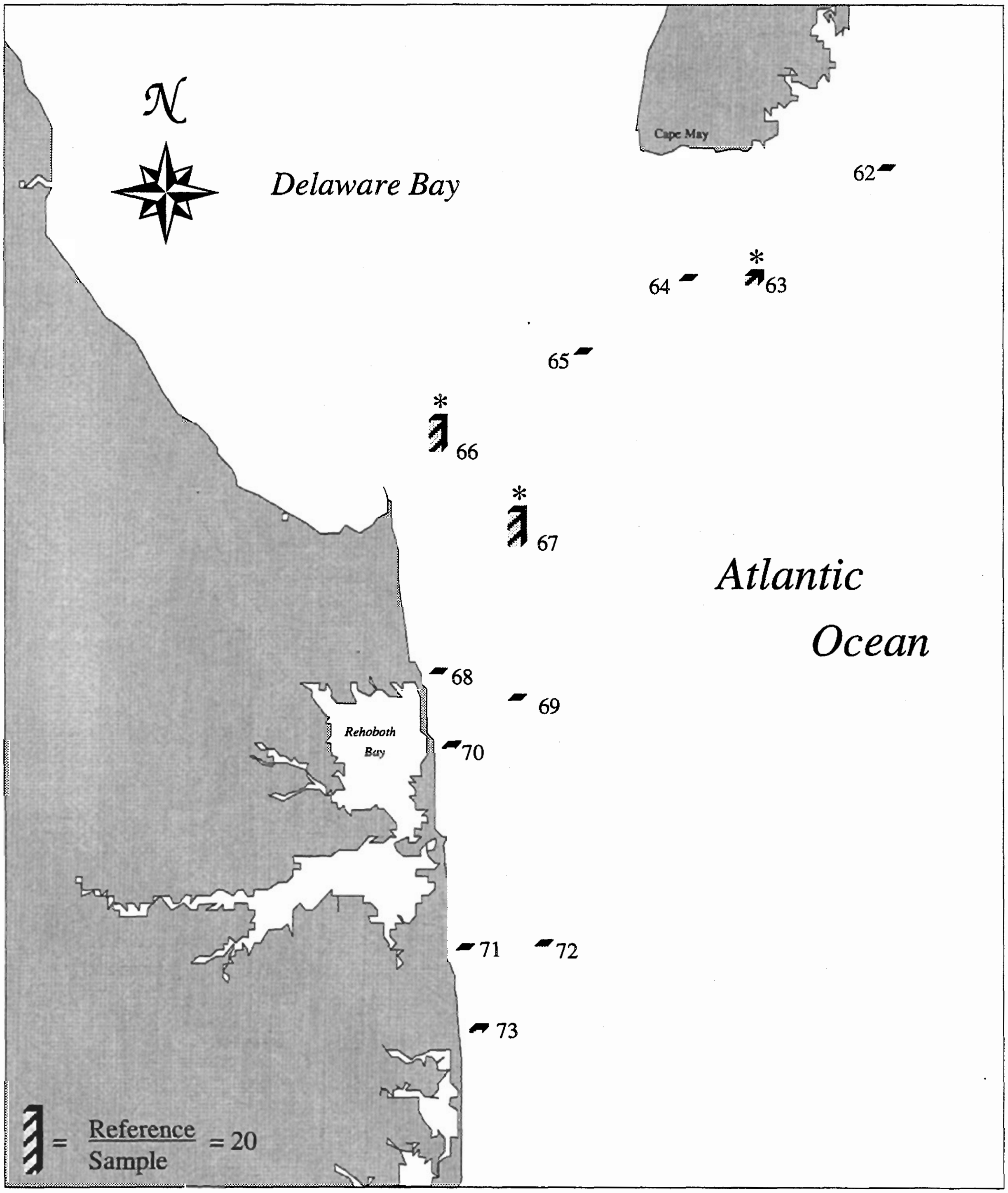


Figure G-8. Toxicity test results at sample stations 62 through 73. Height of bars indicate degree of Microtox EC50 response relative to the phenol spiked control. (* = statistically significant)

Delaware Bay P450 B[a]P Equivalents

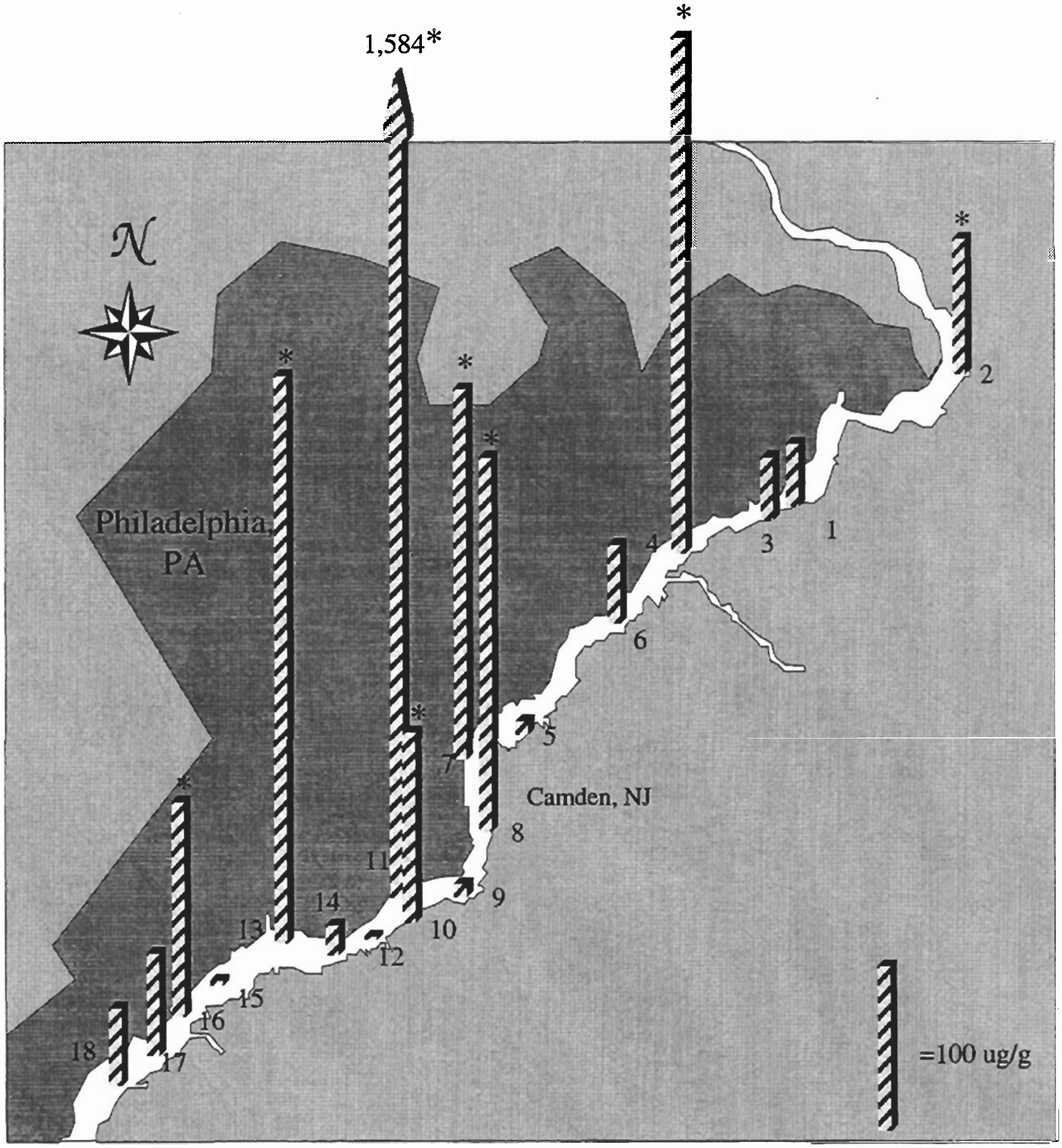


Figure G-9. Toxicity test results at freshwater sample stations 1 through 18. Height of bars indicate relative degree of P450/HRG response expressed in terms of B[a]P equivalents. (* = statistically significant)

Delaware Bay P450 B[a]P Equivalents

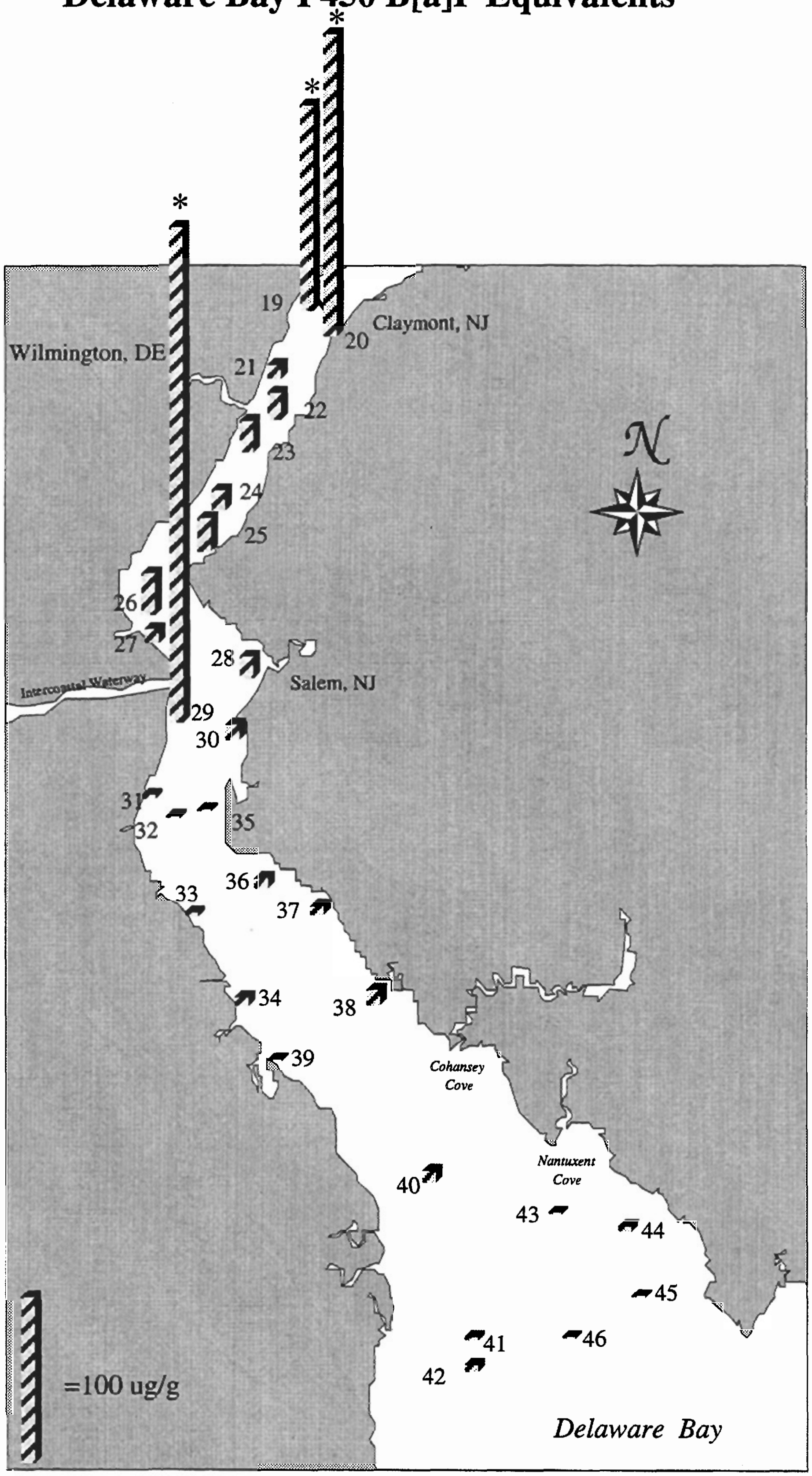


Figure G-10. Toxicity test results at sample stations 19 through 46. Height of bars indicate relative degree of P450/HRG response expressed in terms of B[a]P equivalents. (* = statistically significant)

APPENDIX H

Macroinvertebrate Community Parameters

Appendix H - Benthic community metrics

Stratum	Site	Total Taxa	Abundance (#/M^2)	Diversity Index	Evenness Index
19	1	17	6900	1.74	0.62
19	2	11	4100	1.49	0.62
19	3	15	7650	1.79	0.66
20	4	16	19525	0.96	0.35
20	5	6	1425	0.78	0.44
20	6	10	3325	1.87	0.81
1	7	18	13250	1.36	0.47
1	8	7	11150	0.42	0.22
1	9	7	4700	1.41	0.73
2	10	12	6975	1.95	0.78
2	11	11	3775	1.89	0.79
2	12	12	6875	1.74	0.70
3	13	5	1875	1.07	0.67
3	14	9	1425	1.72	0.78
3	15	7	1475	1.29	0.66
4	16	13	12800	1.54	0.60
4	17	8	3300	1.48	0.71
4	18	8	2325	1.25	0.60
5	19	8	2550	1.01	0.49
5	20	7	5075	0.83	0.43
5	21	2	400	0.48	0.70
6	22	7	1800	1.17	0.60
6	23	2	2900	0.55	0.80
6	24	2	75	0.64	0.92
7	25	4	125	1.33	0.96
7	26	5	4550	0.21	0.13
7	27	4	150	1.24	0.90
8	28	11	1650	1.36	0.57
8	29	7	1800	1.20	0.62
8	30	14	2500	1.99	0.76
9	31	3	300	0.82	0.75
9	32	10	2925	1.27	0.55
9	33	5	625	0.95	0.59
9	34	13	1800	2.25	0.88
10	35	4	300	1.20	0.86
10	36	15	1450	2.23	0.82
10	37	16	4275	2.02	0.73
10	38	15	2200	1.96	0.72
11	39	7	1250	1.12	0.57
11	40	16	7225	1.37	0.49
11	41	19	3525	2.30	0.78
11	42	27	22400	1.25	0.38
12	43	31	9275	2.16	0.63
12	44	42	31625	1.94	0.52
12	45	15	700	2.41	0.89
12	46	17	2100	2.01	0.71
13	47	13	2300	1.46	0.57
13	48	14	1075	2.21	0.84
13	49	10	1425	1.50	0.65
13	50	23	18750	1.26	0.40

Appendix H - Benthic community metrics

Stratum	Site	Total Taxa	Abundance (#/M^2)	Diversity Index	Evenness Index
13	51	9	3725	1.01	0.46
13	52	16	850	2.55	0.92
13	53	10	275	2.27	0.99
13	54	15	2000	2.22	0.82
13	55	18	3550	1.56	0.54
13	56	15	8100	2.07	0.77
14	57	14	39175	1.49	0.56
14	58	29	59700	1.00	0.30
14	59	15	1175	2.10	0.78
14	60	21	34200	0.70	0.23
14	61	9	675	1.85	0.84
15	62	20	1275	2.56	0.85
15	63	32	4575	2.56	0.74
15	64	4	350	0.90	0.65
16	65	4	975	0.91	0.65
16	66	41	17600	2.53	0.68
16	67	34	7225	2.77	0.79
17	68	18	2050	1.99	0.69
17	69	14	1125	2.20	0.83
17	70	9	1125	1.34	0.61
18	71	16	3550	1.79	0.65
18	72	30	3675	2.67	0.79
18	73	24	1675	2.90	0.91
21	84	10	2150	1.92	0.83
21	85	9	1000	0.99	0.45
/	87	14	4150	0.99	0.38
22	88	14	29500	1.11	0.42
22	89	8	1850	1.44	0.69
22	90	16	3825	1.34	0.48
/	91	6	5550	0.76	0.42
/	92	6	2900	0.53	0.30

Delaware Bay Species Richness

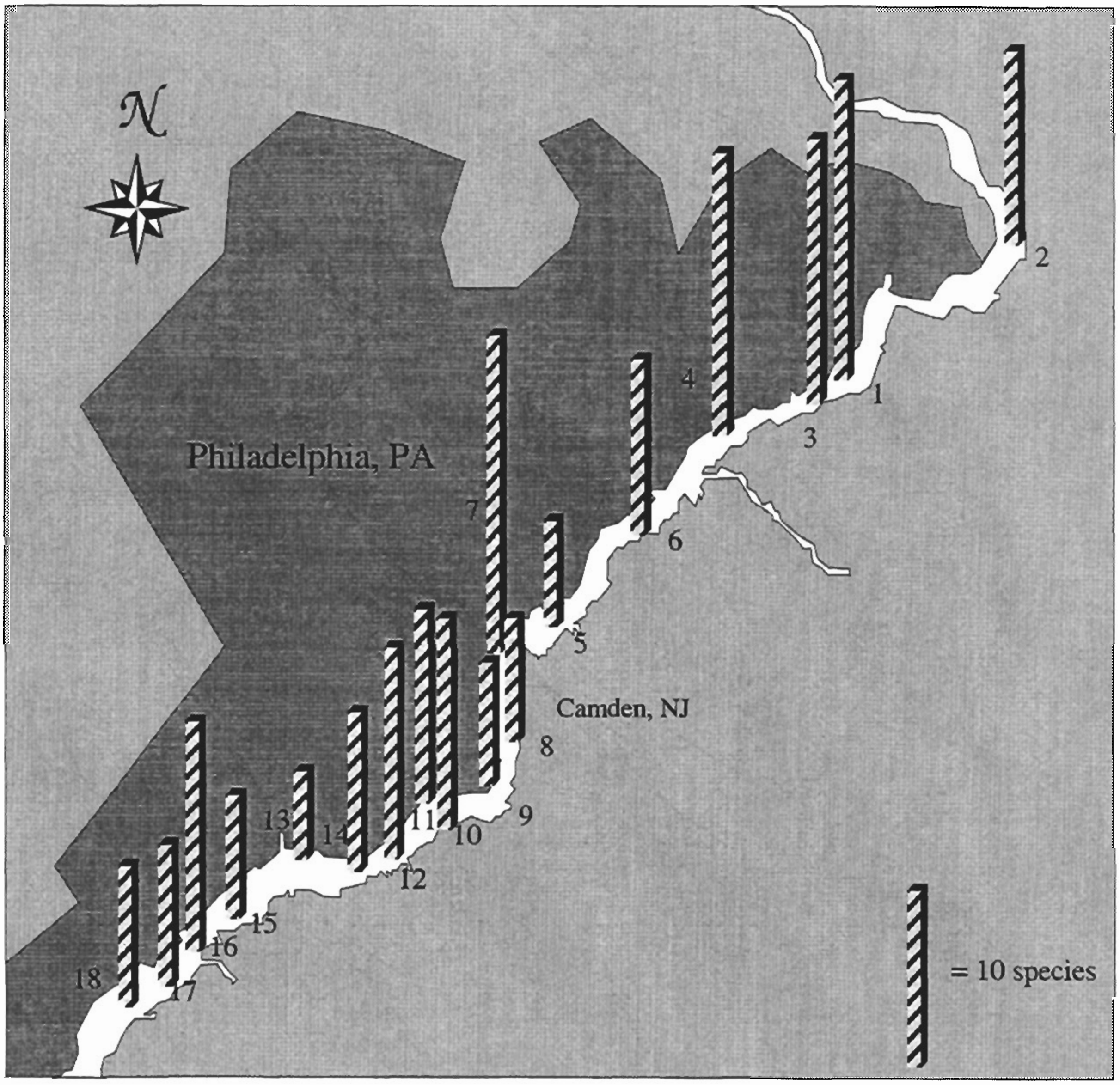


Figure H-1. Species richness at freshwater sample stations 1 through 18. Height of bars indicate relative number of species.

Delaware Bay Species Richness

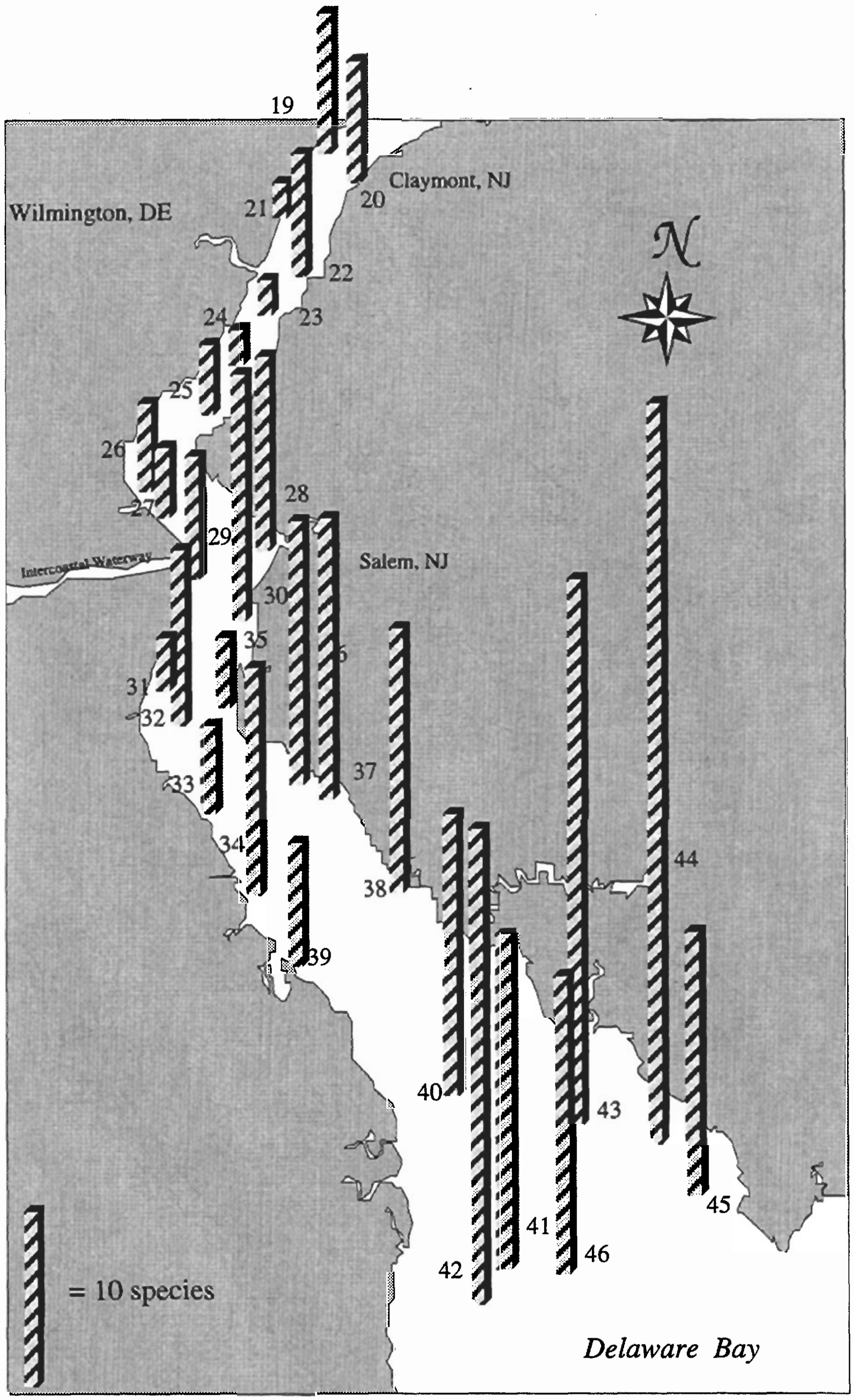


Figure H-2. Species richness at sample stations 19 through 46. Height of bars indicate relative number species.

Delaware Bay Species Richness

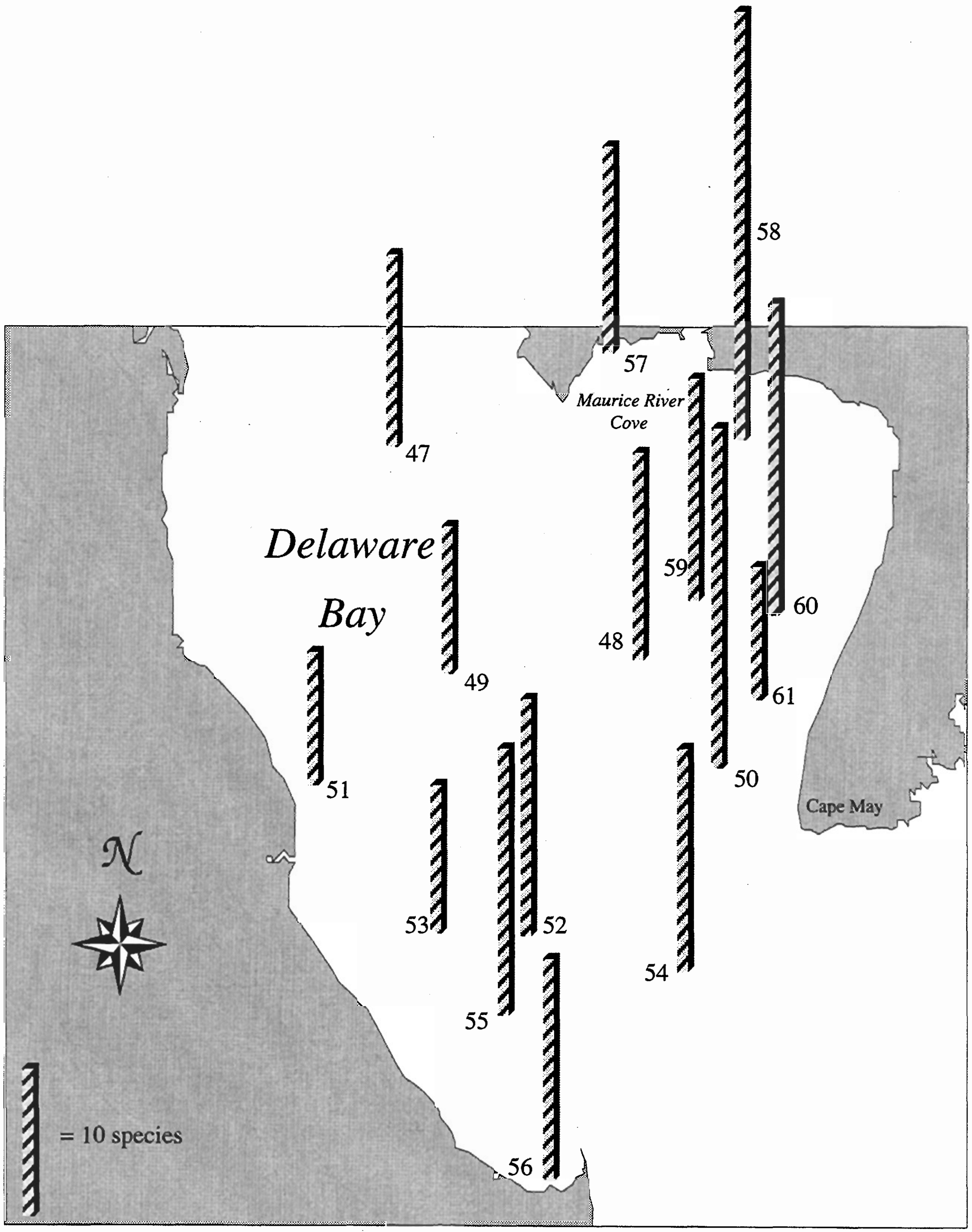


Figure H-3. Species richness at sample stations 47 through 61. Height of bars indicate relative number of species.

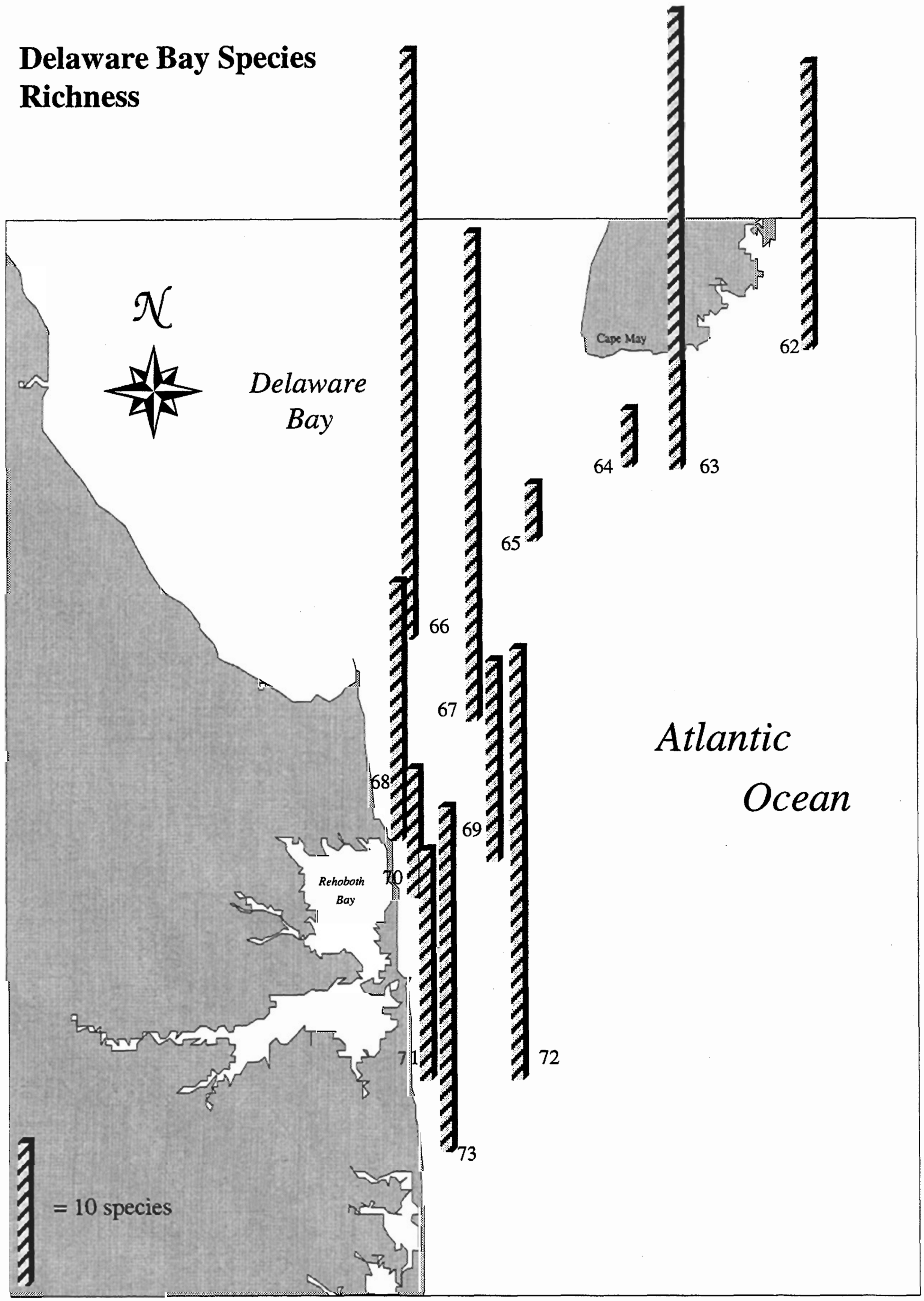


Figure H-4. Species richness at sample stations 62 through 73. Height of bars indicate relative number of species.

Delaware Bay Macroinvertebrate Abundance

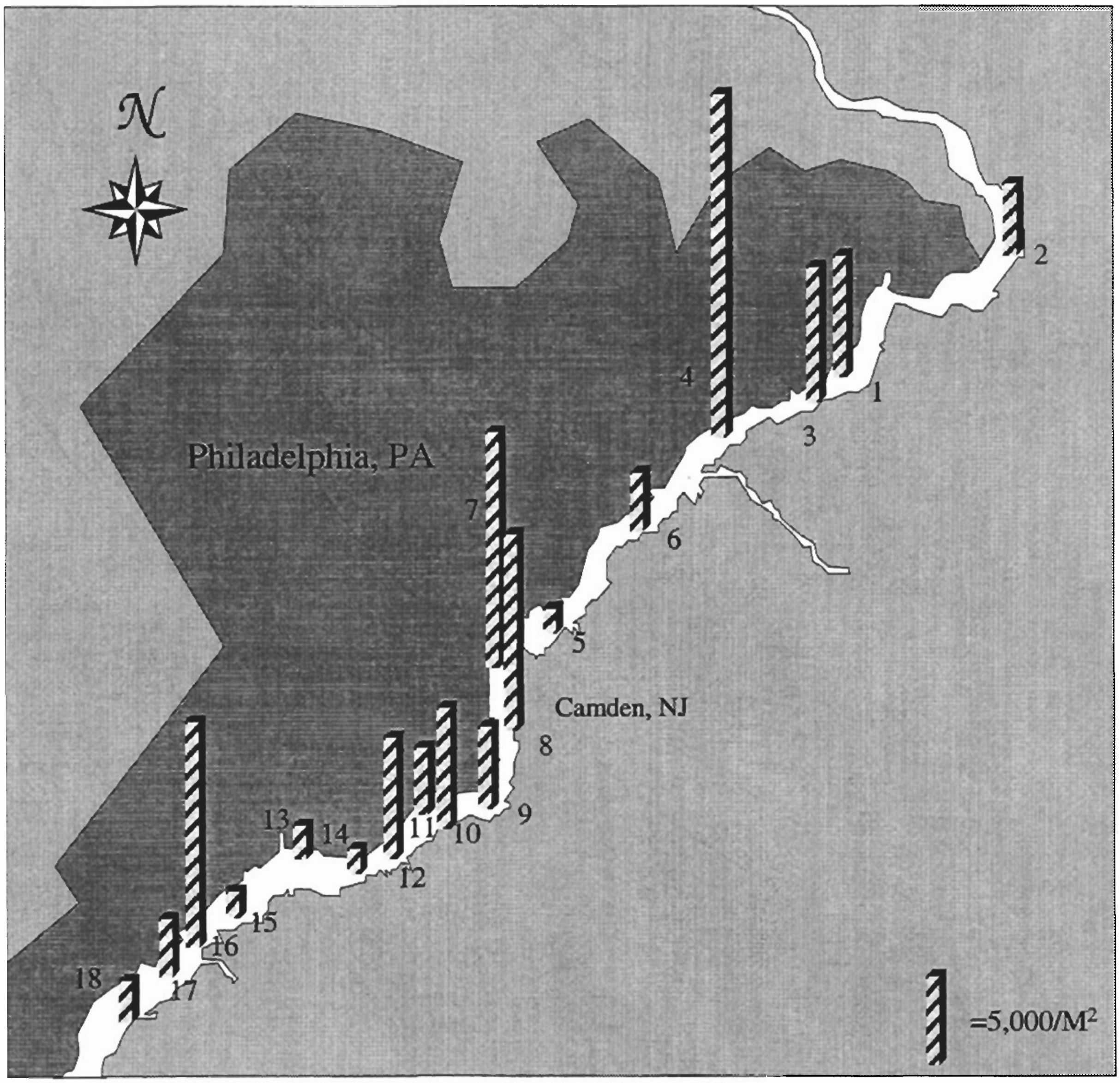


Figure H-5. Macroinvertebrate abundance (#/M^2) at freshwater sample stations 1 through 18. Height of bars indicate relative number of organisms.

Delaware Bay Macroinvertebrate Abundance

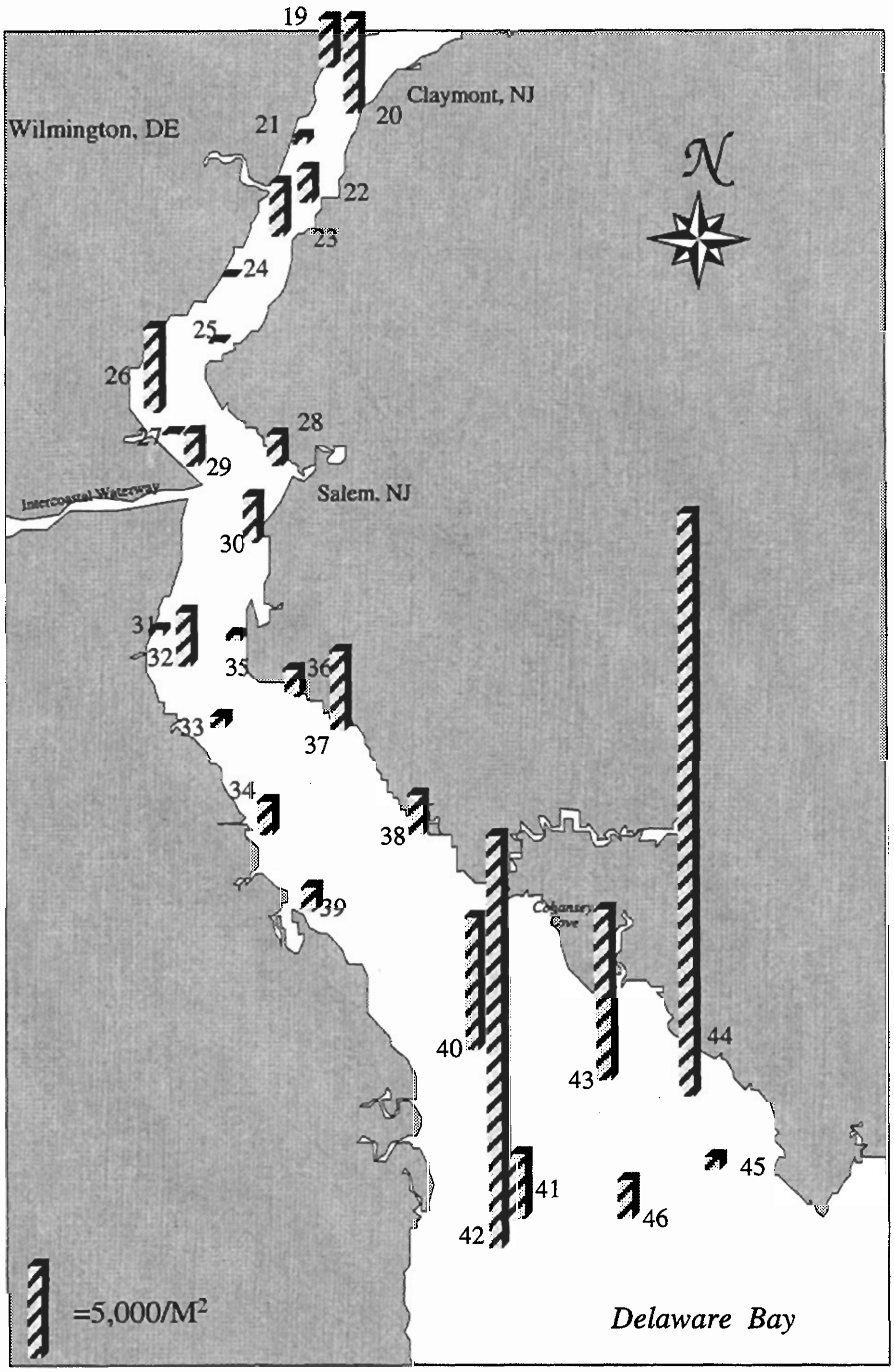


Figure H-6. Macroinvertebrate abundance (#/M^2) at sample stations 19 through 46. Height of bars indicate relative number organisms.

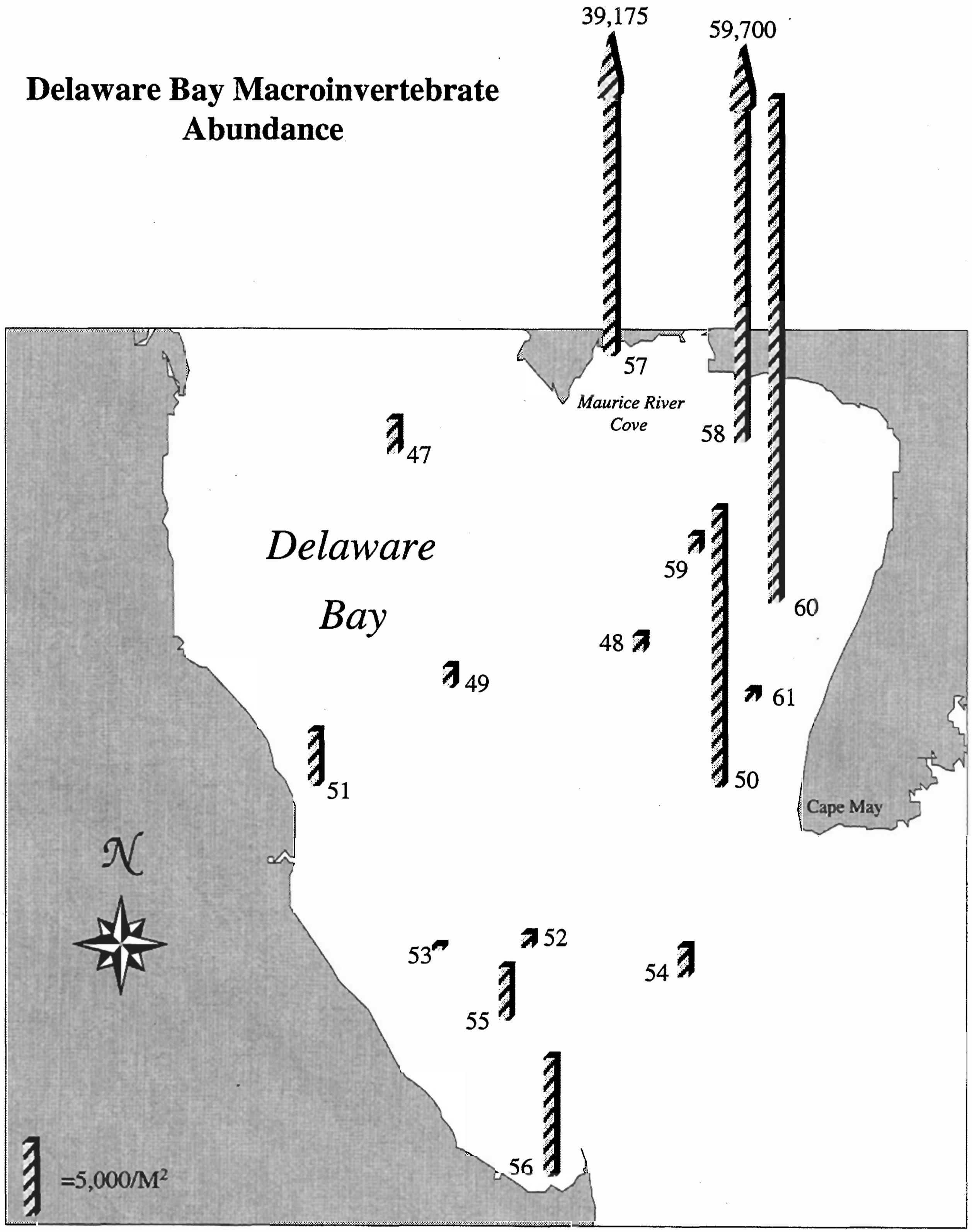


Figure H-7. Macroinvertebrate abundance (#/M^2) at sample stations 47 through 61. Height of bars indicate relative number of organisms.

Delaware Bay Macroinvertebrate Abundance

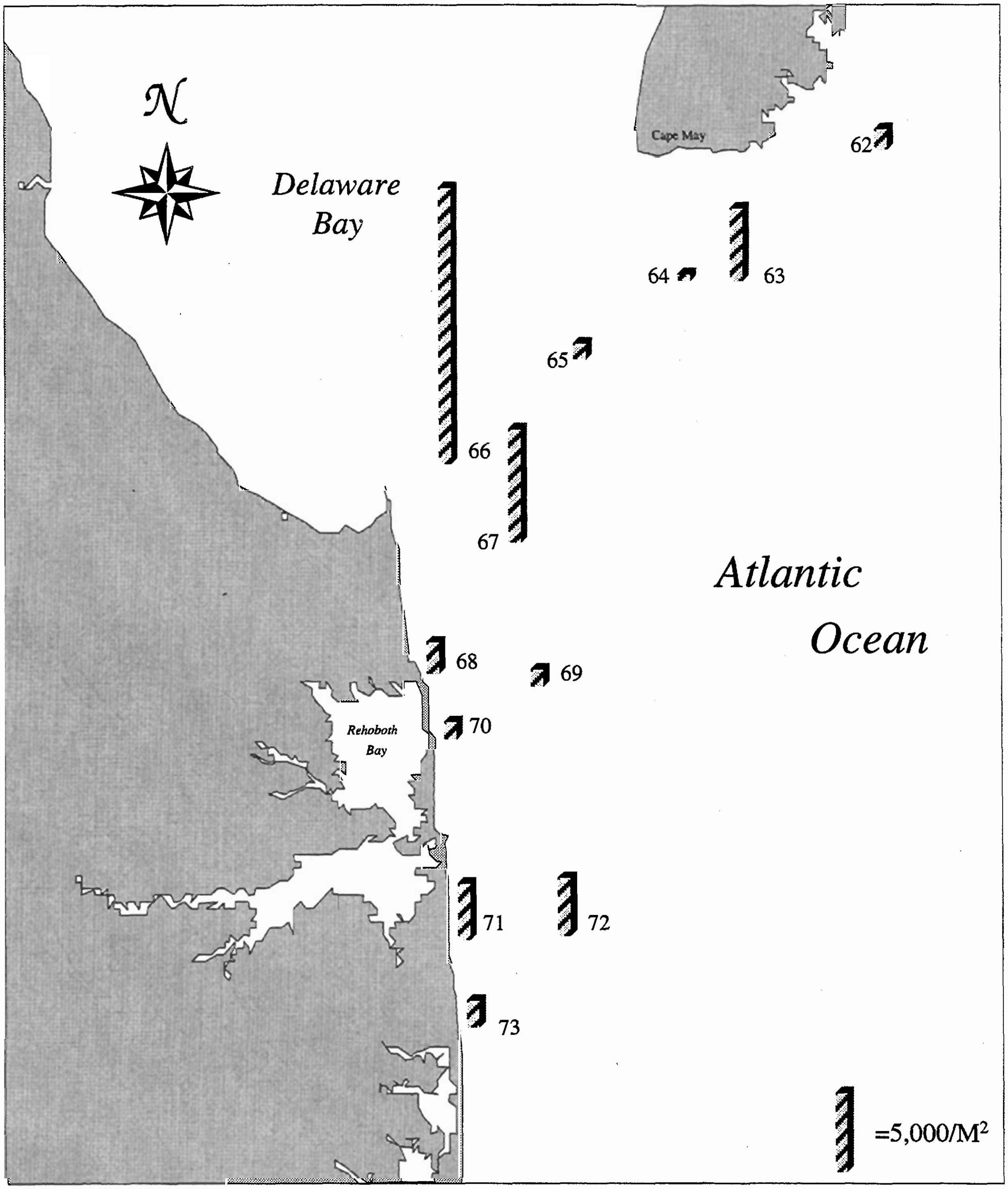


Figure H-8. Macroinvertebrate abundance (#/M^2) at sample stations 62 through 73. Height of bars indicate relative number of organisms.

Delaware Bay Species Diversity

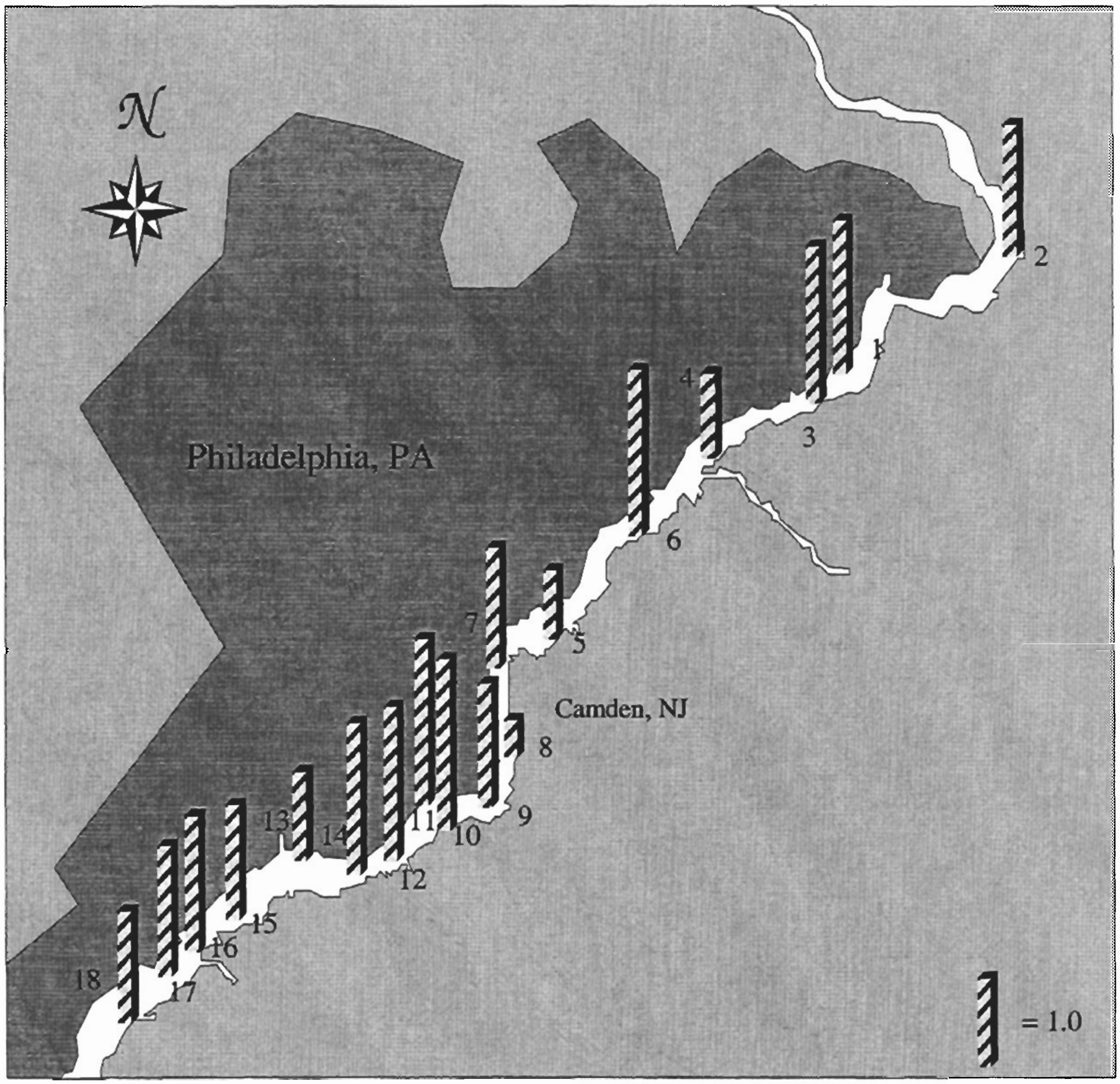


Figure H-9. Species diversity at freshwater sample stations 1 through 18. Height of bars indicate relative index value.

Delaware Bay Species Diversity

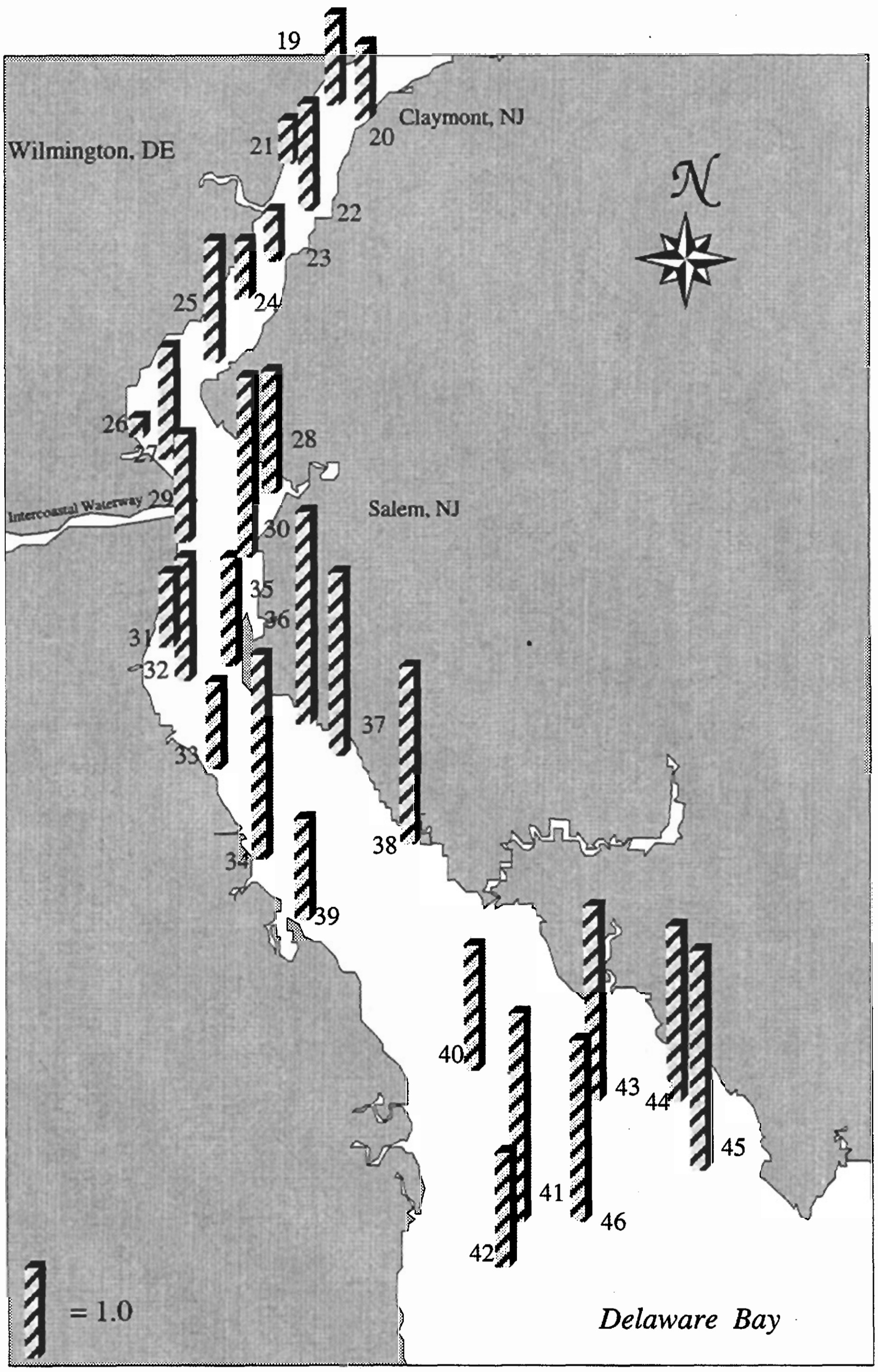


Figure H-10. Species diversity at sample stations 19 through 46. Height of bars indicate relative index value.

Delaware Bay Species Diversity

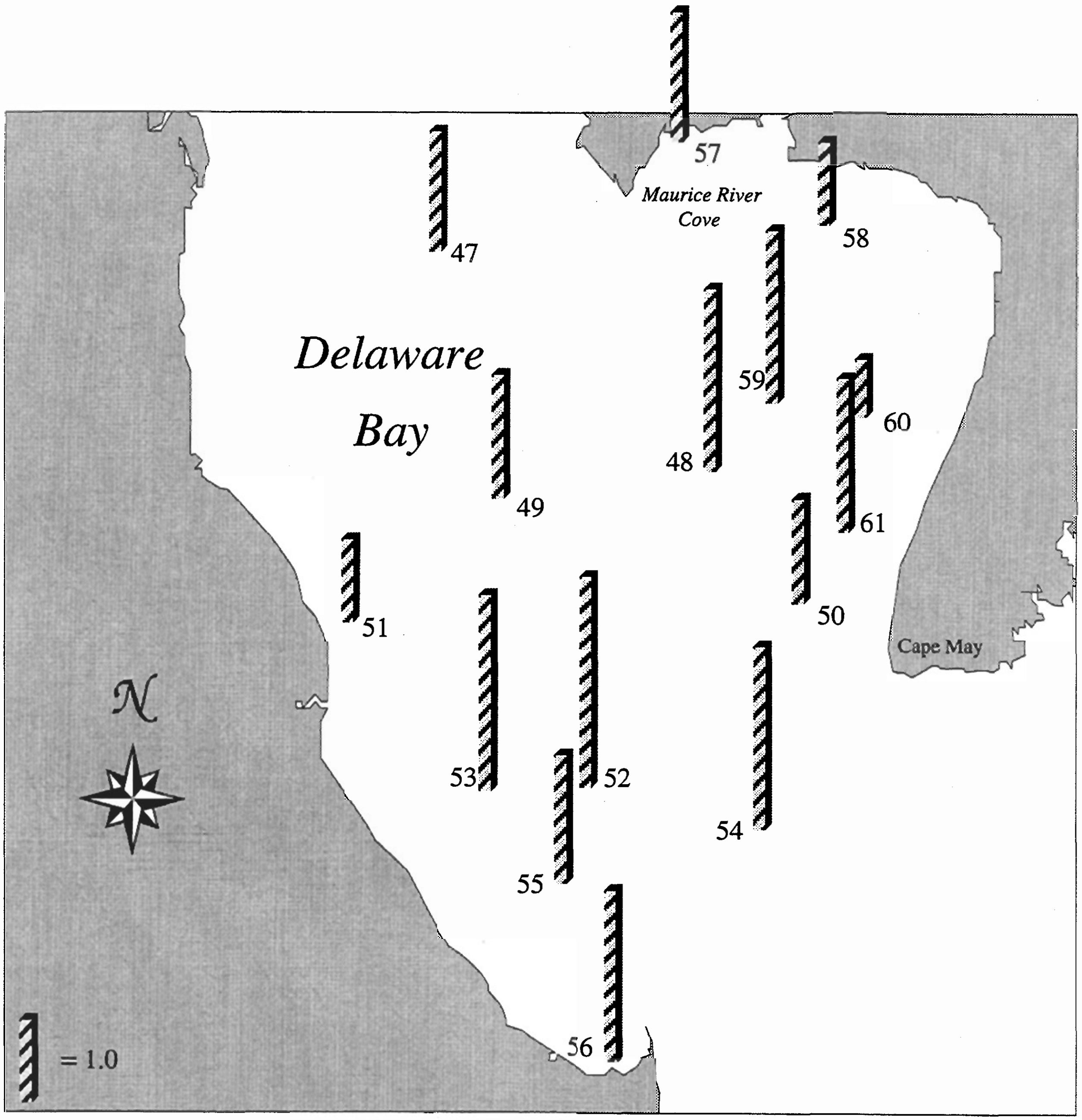


Figure H-11. Species diversity at sample stations 47 through 61. Height of bars indicate relative index value.

Delaware Bay Species Diversity

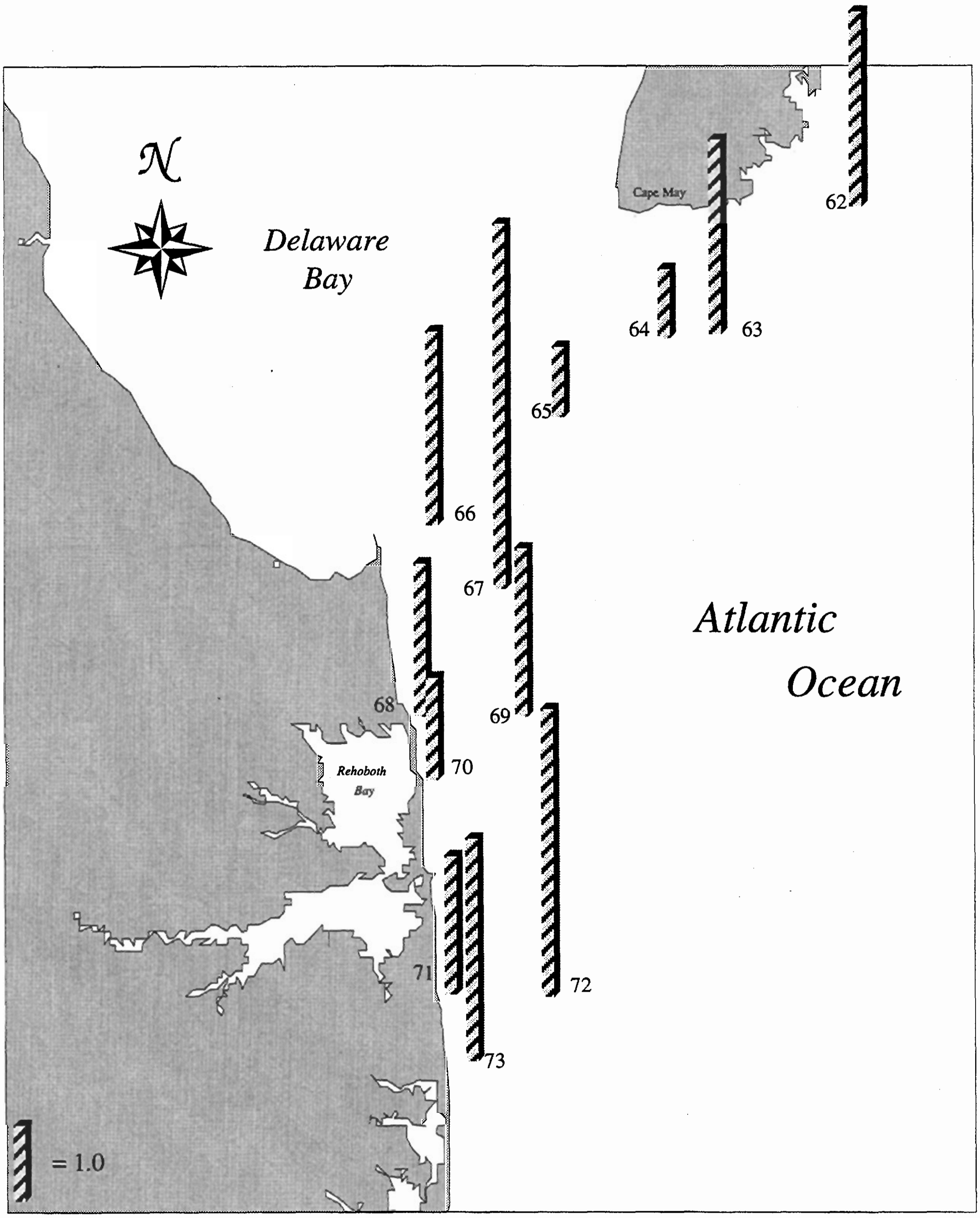


Figure H-12. Species diversity at sample stations 62 through 73. Height of bars indicate relative index value.

Delaware Bay Species Evenness

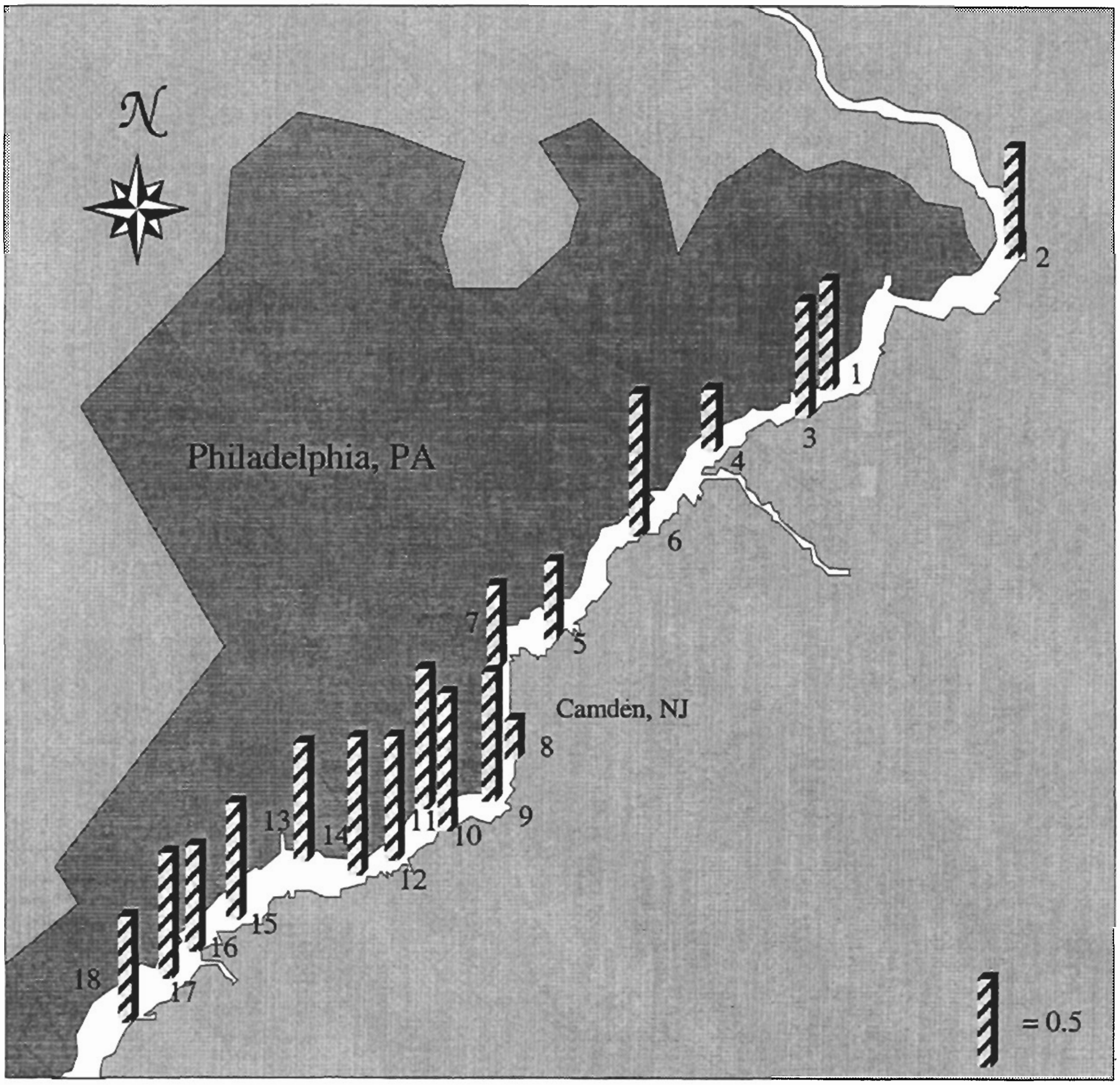


Figure H-13. Species evenness at freshwater sample stations 1 through 18. Height of bars indicate relative index value.

Delaware Bay Species Evenness

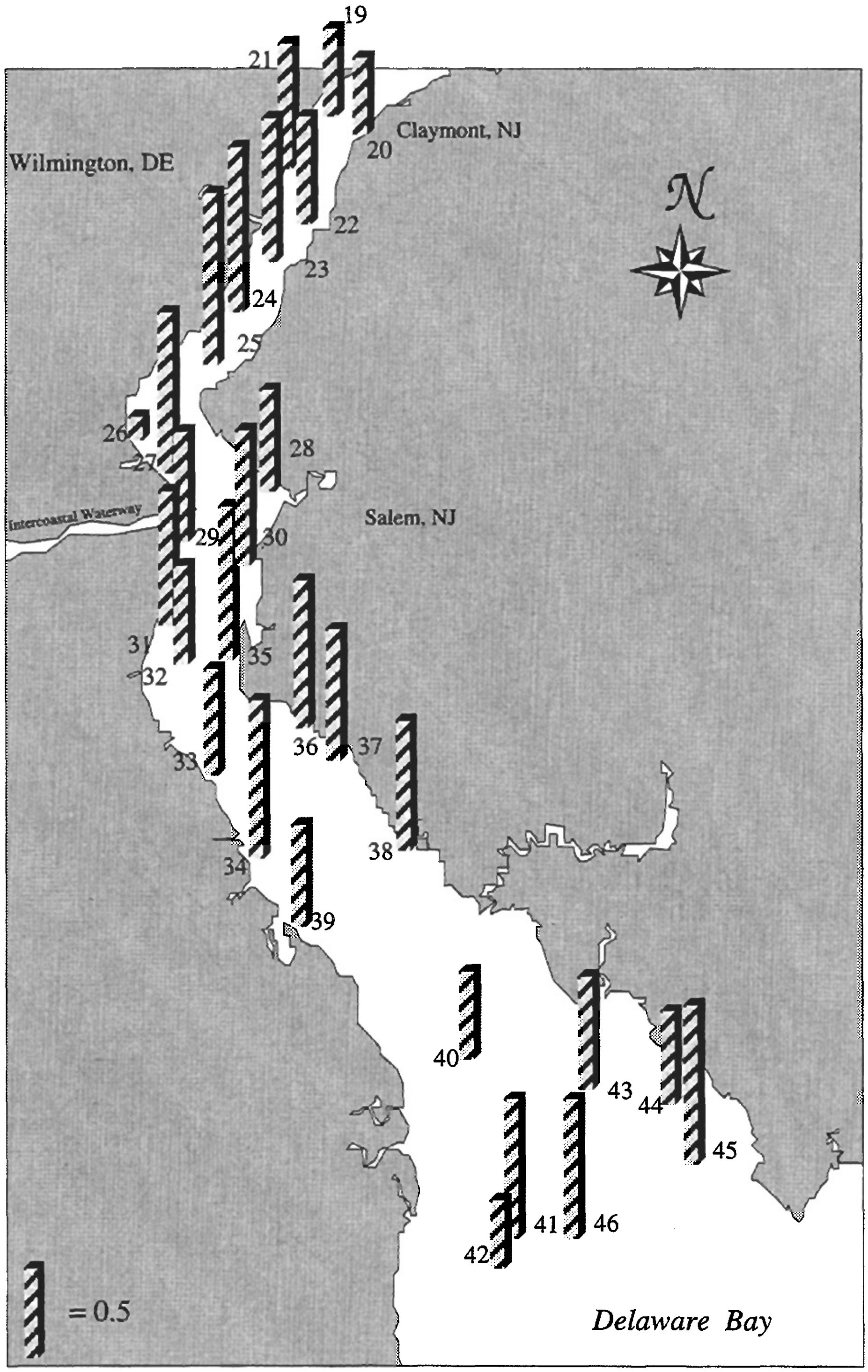


Figure H-14. Species evenness at sample stations 19 through 46. Height of bars indicate relative index value.

Delaware Bay Species Evenness

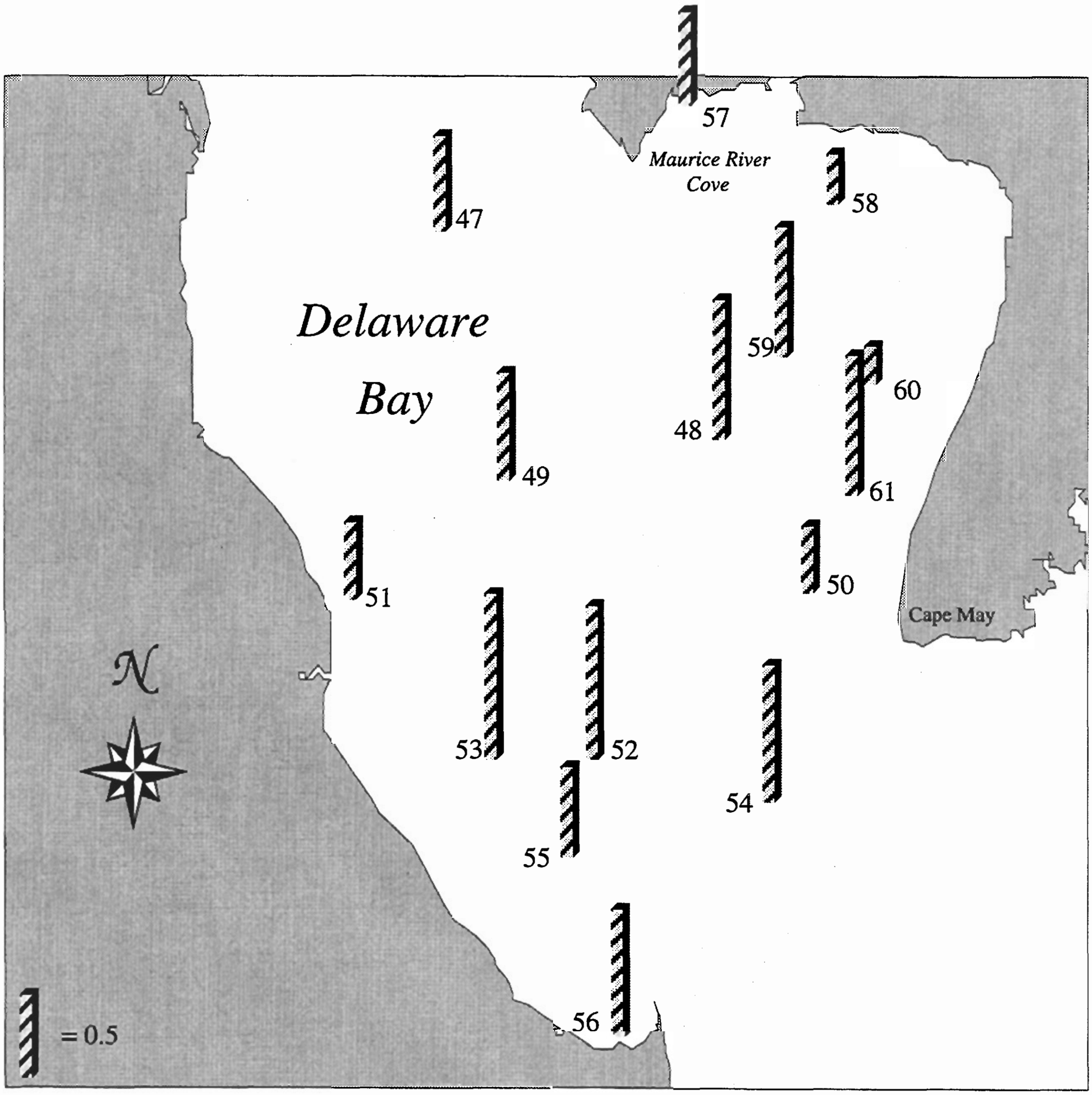


Figure H-15. Species evenness at sample stations 47 through 61. Height of bars indicate relative index value.

Delaware Bay Species Evenness

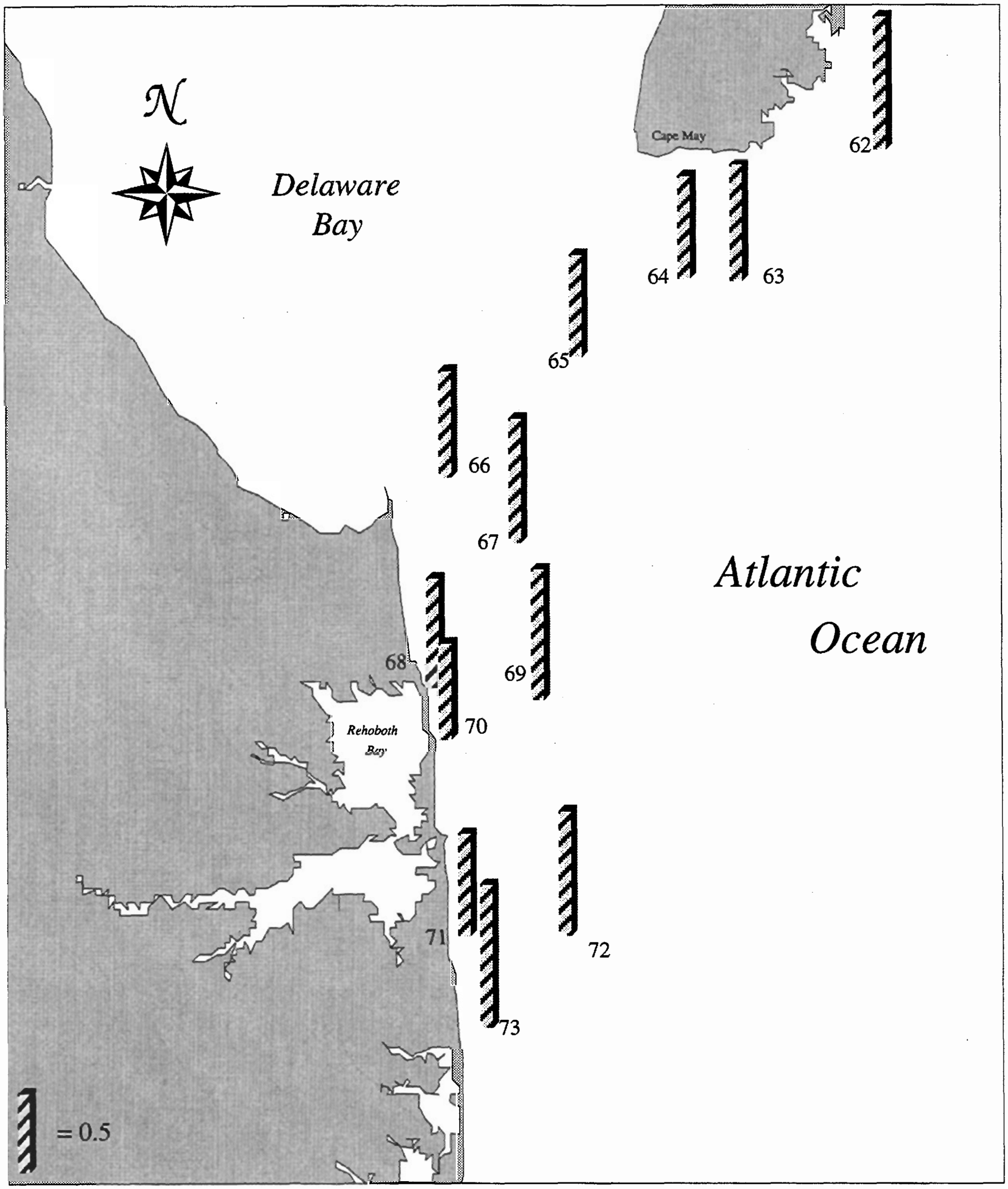


Figure H-16. Species evenness at sample stations 62 through 73. Height of bars indicate relative index value.

APPENDIX I

Species Composition

Appendix I - Benthic fauna species list, by sample site

STRATUM	SITE	TAXA NAME	ABUNDANCE #/M^2
19	1	TUBIFICIDAE (LPIL)	3,150
19	1	LIMNODRILUS HOFFMEISTERI	1,625
19	1	ANCYLIDAE (LPIL)	625
19	1	PISIDIUM COMPRESSUM	300
19	1	QUISTADRILUS MULTISETOSUS	300
19	1	PROCLADIUS (LPIL)	175
19	1	SPHAERIUM (LPIL)	175
19	1	CORBICULA MANILENSIS	125
19	1	FERRISSIA (LPIL)	125
19	1	CHIRONOMUS (LPIL)	50
19	1	GASTROPODA (LPIL)	50
19	1	GILLIA ALTILIS	50
19	1	TANYTARSUS (LPIL)	50
19	1	DICROTENDIPES (LPIL)	25
19	1	GAMMARUS (LPIL)	25
19	1	PLACOBDELLA PAPILLIFERA	25
19	1	POLYPEDILUM (LPIL)	25
19	2	CORBICULA MANILENSIS	2,125
19	2	CYATHURA POLITA	775
19	2	TUBIFICIDAE (LPIL)	575
19	2	LIMNODRILUS HOFFMEISTERI	225
19	2	GAMMARUS TIGRINUS	150
19	2	SPHAERIUM (LPIL)	75
19	2	FERRISSIA (LPIL)	50
19	2	GAMMARUS (LPIL)	50
19	2	ALMYRACUMA PROXIMOCULI	25
19	2	POLYPEDILUM (LPIL)	25
19	2	QUISTADRILUS MULTISETOSUS	25
19	3	TUBIFICIDAE (LPIL)	2,825
19	3	LIMNODRILUS HOFFMEISTERI	1,925
19	3	PISIDIUM COMPRESSUM	950
19	3	QUISTADRILUS MULTISETOSUS	925
19	3	GILLIA ALTILIS	200
19	3	PROCLADIUS (LPIL)	200
19	3	CHIRONOMIDAE (LPIL)	150
19	3	FERRISSIA (LPIL)	100
19	3	GAMMARUS TIGRINUS	100
19	3	CORBICULA MANILENSIS	75
19	3	AULODRILUS PIGUETI	50
19	3	DICROTENDIPES (LPIL)	50
19	3	GASTROPODA (LPIL)	50
19	3	OECETIS (LPIL)	25
19	3	RHEOTANYTARSUS (LPIL)	25
20	4	TUBIFICIDAE (LPIL)	15,100
20	4	LIMNODRILUS HOFFMEISTERI	2,250
20	4	QUISTADRILUS MULTISETOSUS	400
20	4	SPHAERIUM (LPIL)	400
20	4	LIMNODRILUS UDEKEMIANUS	200
20	4	BIVALVIA (LPIL)	175
20	4	PISIDIUM (LPIL)	175
20	4	CHIRONOMIDAE (LPIL)	150

(LPIL) - Lowest possible identification level

Appendix I - Benthic fauna species list, by sample site

STRATUM	SITE	TAXA NAME	ABUNDANCE #/M^2
20	4	CYATHURA POLITA	150
20	4	GAMMARUS (LPIL)	125
20	4	PISIDIUM COMPRESSUM	100
20	4	CORBICULA MANILENSIS	75
20	4	CRYPTOCHIRONOMUS (LPIL)	75
20	4	POLYPEDILUM (LPIL)	75
20	4	PROCLADIUS (LPIL)	50
20	4	ALMYRACUMA PROXIMOCULI	25
20	5	TUBIFICIDAE (LPIL)	1,150
20	5	CHIRIDOTEA TUFTSI	100
20	5	BEZZIA COMPLEX (LPIL)	50
20	5	CYATHURA POLITA	50
20	5	GAMMARUS (LPIL)	50
20	5	GAMMARUS TIGRINUS	25
20	6	CHIRONOMIDAE (LPIL)	900
20	6	LIMNODRILUS HOFFMEISTERI	650
20	6	POLYPEDILUM (LPIL)	525
20	6	TUBIFICIDAE (LPIL)	500
20	6	CYATHURA POLITA	450
20	6	ALMYRACUMA PROXIMOCULI	100
20	6	GAMMARUS (LPIL)	100
20	6	CRYPTOCHIRONOMUS (LPIL)	50
20	6	CORBICULA MANILENSIS	25
20	6	TANYTARSUS (LPIL)	25
1	7	TUBIFICIDAE (LPIL)	7,875
1	7	LIMNODRILUS HOFFMEISTERI	2,850
1	7	GAMMARUS TIGRINUS	925
1	7	LIMNODRILUS UDEKEMIANUS	350
1	7	SPHAERIUM (LPIL)	275
1	7	QUISTADRILUS MULTISETOSUS	250
1	7	FERRISSIA (LPIL)	175
1	7	ANCYLIDAE (LPIL)	125
1	7	NANOCLADIUS (LPIL)	100
1	7	GAMMARUS (LPIL)	75
1	7	CYATHURA POLITA	50
1	7	POLYPEDILUM (LPIL)	50
1	7	CASSIDINIDEA OVALIS	25
1	7	CHIRONOMIDAE (LPIL)	25
1	7	GILLIA ALTILIS	25
1	7	LAEVAPEX FUSCUS	25
1	7	PISIDIUM (LPIL)	25
1	7	SPHAERIIDAE (LPIL)	25
1	8	TUBIFICIDAE (LPIL)	9,925
1	8	LIMNODRILUS HOFFMEISTERI	1,000
1	8	QUISTADRILUS MULTISETOSUS	125
1	8	CHIRONOMUS (LPIL)	25
1	8	HYDROBIIDAE (LPIL)	25
1	8	PROCLADIUS (LPIL)	25
1	8	SPHAERIIDAE (LPIL)	25
1	9	LIMNODRILUS HOFFMEISTERI	1,625
1	9	TUBIFICIDAE (LPIL)	1,500

(LPIL) - Lowest possible identification level

Appendix I - Benthic fauna species list, by sample site

STRATUM	SITE	TAXA NAME	ABUNDANCE #/M^2
1	9	POLYPEDILUM (LPIL)	1,100
1	9	GAMMARUS TIGRINUS	275
1	9	GAMMARUS (LPIL)	100
1	9	CRYPTOCHIRONOMUS (LPIL)	75
1	9	CORBICULA MANILENSIS	25
2	10	LIMNODRILUS HOFFMEISTERI	2,350
2	10	ALMYRACUMA PROXIMOCULI	1,400
2	10	TUBIFICIDAE (LPIL)	1,125
2	10	CYATHURA POLITA	375
2	10	SPHAERIUM (LPIL)	375
2	10	CHIRONOMIDAE (LPIL)	350
2	10	POLYPEDILUM (LPIL)	325
2	10	POLYPEDILUM HALTERALE GROUP	250
2	10	POLYPEDILUM ILLINOENSE GROUP	250
2	10	SPHAERIIDAE (LPIL)	100
2	10	CRYPTOCHIRONOMUS (LPIL)	50
2	10	PISIDIUM (LPIL)	25
2	11	ALMYRACUMA PROXIMOCULI	975
2	11	CYATHURA POLITA	950
2	11	CHIRONOMIDAE (LPIL)	650
2	11	POLYPEDILUM (LPIL)	300
2	11	POLYPEDILUM ILLINOENSE GROUP	300
2	11	LIMNODRILUS HOFFMEISTERI	275
2	11	TUBIFICIDAE (LPIL)	225
2	11	CERATOPOGONIDAE (LPIL)	25
2	11	CRYPTOCHIRONOMUS (LPIL)	25
2	11	SPHAERIIDAE (LPIL)	25
2	11	TANYTARSUS (LPIL)	25
2	12	LIMNODRILUS HOFFMEISTERI	3,000
2	12	TUBIFICIDAE (LPIL)	1,125
2	12	CHIRONOMIDAE (LPIL)	1,025
2	12	CHIRIDOTEA TUFTSI	475
2	12	POLYPEDILUM HALTERALE GROUP	400
2	12	GAMMARUS TIGRINUS	325
2	12	POLYPEDILUM ILLINOENSE GROUP	250
2	12	CYATHURA POLITA	100
2	12	POLYPEDILUM (LPIL)	100
2	12	CIRROPHORUS (LPIL)	25
2	12	SPHAERIIDAE (LPIL)	25
2	12	SPIONIDAE (LPIL)	25
3	13	LIMNODRILUS HOFFMEISTERI	925
3	13	TUBIFICIDAE (LPIL)	725
3	13	QUISTADRILUS MULTISETOSUS	150
3	13	OLIGOCHAETA (LPIL)	50
3	13	CRYPTOCHIRONOMUS (LPIL)	25
3	14	POLYPEDILUM HALTERALE GROUP	475
3	14	POLYPEDILUM (LPIL)	375
3	14	CHIRONOMIDAE (LPIL)	275
3	14	LIMNODRILUS HOFFMEISTERI	75
3	14	POLYPEDILUM ILLINOENSE GROUP	75
3	14	CYATHURA POLITA	50

(LPIL) - Lowest possible identification level

Appendix I - Benthic fauna species list, by sample site

STRATUM	SITE	TAXA NAME	ABUNDANCE #/M^2
3	14	TUBIFICIDAE (LPIL)	50
3	14	CHIRIDOTEA TUFTSI	25
3	14	SPHAERIIDAE (LPIL)	25
3	15	CHIRIDOTEA TUFTSI	925
3	15	LIMNODRILUS HOFFMEISTERI	150
3	15	POLYGORDIUS (LPIL)	125
3	15	GAMMARUS (LPIL)	100
3	15	GAMMARUS TIGRINUS	75
3	15	TUBIFICIDAE (LPIL)	75
3	15	ARICIDEA SUECICA	25
4	16	GAMMARUS TIGRINUS	6,550
4	16	TUBIFICIDAE (LPIL)	2,175
4	16	COROPHIUM LACUSTRE	1,825
4	16	CYATHURA POLITA	750
4	16	LIMNODRILUS HOFFMEISTERI	650
4	16	CHIRIDOTEA TUFTSI	200
4	16	POLYPEDILUM (LPIL)	175
4	16	CHIRONOMIDAE (LPIL)	150
4	16	POLYPEDILUM HALTERALE GROUP	150
4	16	FERRISSIA (LPIL)	75
4	16	CASSIDINIDEA OVALIS	50
4	16	ECHINOIDEA (LPIL)	25
4	16	JASSA FALCATA	25
4	17	CHIRIDOTEA TUFTSI	1,650
4	17	CHIRONOMIDAE (LPIL)	450
4	17	POLYPEDILUM (LPIL)	425
4	17	TUBIFICIDAE (LPIL)	425
4	17	POLYPEDILUM ILLINOENSE GROUP	250
4	17	LIMNODRILUS HOFFMEISTERI	50
4	17	GAMMARUS TIGRINUS	25
4	17	POLYGORDIUS (LPIL)	25
4	18	TUBIFICIDAE (LPIL)	1,025
4	18	LIMNODRILUS HOFFMEISTERI	950
4	18	JASSA FALCATA	125
4	18	GAMMARUS (LPIL)	100
4	18	CYATHURA POLITA	50
4	18	ALMYRACUMA PROXIMOCULI	25
4	18	CERATOPOGONIDAE (LPIL)	25
4	18	POLYPEDILUM ILLINOENSE GROUP	25
5	19	TUBIFICIDAE (LPIL)	1,275
5	19	LIMNODRILUS HOFFMEISTERI	1,100
5	19	CRYPTOCHIRONOMUS (LPIL)	50
5	19	AMPHIPODA (LPIL)	25
5	19	CYATHURA (LPIL)	25
5	19	CYATHURA POLITA	25
5	19	EDOTIA TRILOBA	25
5	19	POLYPEDILUM (LPIL)	25
5	20	TUBIFICIDAE (LPIL)	3,000
5	20	LIMNODRILUS HOFFMEISTERI	1,925
5	20	SPHAERIUM (LPIL)	50
5	20	ANTHURIDAE (LPIL)	25

(LPIL) - Lowest possible identification level

Appendix I - Benthic fauna species list, by sample site

STRATUM	SITE	TAXA NAME	ABUNDANCE #/M^2
5	20	JASSA FALCATA	25
5	20	MONOCULODES (LPIL)	25
5	20	MONOCULODES EDWARDSI	25
5	21	CHIRIDOTEA TUFTSI	325
5	21	TUBIFICIDAE (LPIL)	75
6	22	TUBIFICIDAE (LPIL)	1,100
6	22	LIMNODRILUS HOFFMEISTERI	400
6	22	CYATHURA POLITA	125
6	22	JASSA FALCATA	75
6	22	MULINIA LATERALIS	50
6	22	GAMMARUS (LPIL)	25
6	22	POLYPEDILUM ILLINOENSE GROUP	25
6	23	TUBIFICIDAE (LPIL)	2,200
6	23	LIMNODRILUS HOFFMEISTERI	700
6	24	TUBIFICIDAE (LPIL)	50
6	24	SPIONIDAE (LPIL)	25
7	25	TUBIFICIDAE (LPIL)	50
7	25	CERATOPOGONIDAE (LPIL)	25
7	25	CHIRIDOTEA TUFTSI	25
7	25	MARENZELLARIA VIRIDIS	25
7	26	TUBIFICIDAE (LPIL)	4,375
7	26	LEUCON AMERICANUS	75
7	26	TELLINA (LPIL)	50
7	26	CYATHURA POLITA	25
7	26	EDOTIA TRILOBA	25
7	27	SPIONIDAE (LPIL)	75
7	27	COROPHIUM (LPIL)	25
7	27	CYATHURA POLITA	25
7	27	LINEIDAE (LPIL)	25
8	28	TUBIFICIDAE (LPIL)	975
8	28	CYATHURA POLITA	325
8	28	RHYNCHOCOELA (LPIL)	150
8	28	CHIRONOMIDAE (LPIL)	25
8	28	EDOTIA TRILOBA	25
8	28	LAEONEREIS CULVERI	25
8	28	MARENZELLARIA VIRIDIS	25
8	28	MONOCULODES (LPIL)	25
8	28	MONOCULODES EDWARDSI	25
8	28	POLYPEDILUM (LPIL)	25
8	28	SPIONIDAE (LPIL)	25
8	29	DIPOLYDORA SOCIALIS	1,150
8	29	CYATHURA POLITA	250
8	29	SPIONIDAE (LPIL)	150
8	29	COROPHIUM LACUSTRE	125
8	29	NEREIS SUCCINEA	75
8	29	GAMMARUS (LPIL)	25
8	29	MARENZELLARIA VIRIDIS	25
8	30	TUBIFICIDAE (LPIL)	900
8	30	LEPTOCHEIRUS PLUMULOSUS	525
8	30	LEPTOCHEIRUS (LPIL)	250
8	30	MARENZELLARIA VIRIDIS	225

(LPIL) - Lowest possible identification level

Appendix I - Benthic fauna species list, by sample site

STRATUM	SITE	TAXA NAME	ABUNDANCE #/M^2
8	30	CYATHURA POLITA	125
8	30	EDOTIA TRILOBA	125
8	30	LEUCON AMERICANUS	75
8	30	RHYNCHOCOELA (LPIL)	75
8	30	CRYPTOCHIRONOMUS (LPIL)	50
8	30	TELLINA (LPIL)	50
8	30	CHIRONOMIDAE (LPIL)	25
8	30	GAMMARUS (LPIL)	25
8	30	MELITIDAE (LPIL)	25
8	30	MULINIA LATERALIS	25
9	31	CYATHURA POLITA	200
9	31	MARENZELLARIA VIRIDIS	75
9	31	NEREIS (LPIL)	25
9	32	DIPOLYDORA SOCIALIS	1,875
9	32	COROPHIUM LACUSTRE	475
9	32	CYATHURA POLITA	125
9	32	MELITA (LPIL)	125
9	32	COROPHIUM (LPIL)	100
9	32	NEREIS SUCCINEA	100
9	32	RHITHROPANOPEUS HARRISII	50
9	32	DECAPODA REPTANTIA (LPIL)	25
9	32	GASTROPODA (LPIL)	25
9	32	NEOPANOPE SAYI	25
9	33	DIPOLYDORA SOCIALIS	450
9	33	CYATHURA POLITA	75
9	33	CHIRIDOTEA TUFTSI	50
9	33	NEREIS SUCCINEA	25
9	33	PHYLLODOCIDAE (LPIL)	25
10	34	LEUCON AMERICANUS	375
10	34	TUBIFICIDAE (LPIL)	325
10	34	RHYNCHOCOELA (LPIL)	275
10	34	HETEROMASTUS FILIFORMIS	175
10	34	CYATHURA POLITA	150
10	34	STREBLOSPIO BENEDICTI	125
10	34	CHIRIDOTEA TUFTSI	100
10	34	GASTROPODA (LPIL)	75
10	34	AMPELISCA ABDITA	50
10	34	MARENZELLARIA VIRIDIS	50
10	34	NEREIS SUCCINEA	50
10	34	NEREIDIDAE (LPIL)	25
10	34	NEREIS (LPIL)	25
10	35	MARENZELLARIA VIRIDIS	150
10	35	CHIRIDOTEA TUFTSI	75
10	35	LEUCON AMERICANUS	50
10	35	RHYNCHOCOELA (LPIL)	25
10	36	TUBIFICIDAE (LPIL)	325
10	36	MARENZELLARIA VIRIDIS	250
10	36	HETEROMASTUS FILIFORMIS	225
10	36	CHIRIDOTEA TUFTSI	200
10	36	CYATHURA POLITA	150
10	36	LEUCON AMERICANUS	50

(LPIL) - Lowest possible identification level

Appendix I - Benthic fauna species list, by sample site

STRATUM	SITE	TAXA NAME	ABUNDANCE #/M^2
10	36	RHYNCHOCOELA (LPIL)	50
10	36	BIVALVIA (LPIL)	25
10	36	DECAPODA REPTANTIA (LPIL)	25
10	36	LAEONEREIS CULVERI	25
10	36	MEDIOMASTUS (LPIL)	25
10	36	NEREIDIDAE (LPIL)	25
10	36	NEREIS (LPIL)	25
10	36	NEREIS SUCCINEA	25
10	36	PHYLLODOCIDAE (LPIL)	25
10	37	TUBIFICIDAE (LPIL)	1,300
10	37	MARENZELLARIA VIRIDIS	950
10	37	STREBLOSPIO BENEDICTI	775
10	37	ODOSTOMIA (LPIL)	275
10	37	HETEROMASTUS FILIFORMIS	175
10	37	LEUCON AMERICANUS	175
10	37	RHYNCHOCOELA (LPIL)	175
10	37	CYATHURA POLITA	150
10	37	GASTROPODA (LPIL)	75
10	37	MACOMA BALTHICA	50
10	37	NEREIS SUCCINEA	50
10	37	AMPELISCA (LPIL)	25
10	37	BIVALVIA (LPIL)	25
10	37	CAPITELLIDAE (LPIL)	25
10	37	EDOTIA TRILOBA	25
10	37	GLYCINDE SOLITARIA	25
10	38	ASTARTE CASTANEA	750
10	38	TUBIFICIDAE (LPIL)	600
10	38	GLYCINDE SOLITARIA	175
10	38	CYATHURA POLITA	150
10	38	LEUCON AMERICANUS	150
10	38	AMPELISCA (LPIL)	100
10	38	ODOSTOMIA (LPIL)	50
10	38	TELLINA AGILIS	50
10	38	AMPELISCA ABDITA	25
10	38	CAPITELLIDAE (LPIL)	25
10	38	CRANGON SEPTEMSPINOSA	25
10	38	HETEROMASTUS FILIFORMIS	25
10	38	MACOMA BALTHICA	25
10	38	MULINIA LATERALIS	25
10	38	PRIONOSPIO (LPIL)	25
11	39	HETEROMASTUS FILIFORMIS	825
11	39	CYATHURA POLITA	225
11	39	RHYNCHOCOELA (LPIL)	75
11	39	CAPITELLIDAE (LPIL)	50
11	39	BODOTRIIDAE (LPIL)	25
11	39	MACOMA BALTHICA	25
11	39	STREBLOSPIO BENEDICTI	25
11	40	LEUCON AMERICANUS	3,950
11	40	TUBIFICIDAE (LPIL)	1,850
11	40	MEDIOMASTUS (LPIL)	700
11	40	GLYCINDE SOLITARIA	150

(LPIL) - Lowest possible identification level

Appendix I - Benthic fauna species list, by sample site

STRATUM	SITE	TAXA NAME	ABUNDANCE #/M^2
11	40	MEDIOMASTUS AMBISETA	125
11	40	AMPELISCA (LPIL)	75
11	40	ODOSTOMIA (LPIL)	75
11	40	ACTEOCINA CANALICULATA	50
11	40	ENSIS DIRECTUS	50
11	40	PARASTEROPE POLLEX	50
11	40	MULINIA LATERALIS	25
11	40	NEVERITA DUPLICATA	25
11	40	RICTAXIS PUNCTOSTRIATUS	25
11	40	SPIOCHAETOPTERUS OCULATUS	25
11	40	STREBLOSPIO BENEDICTI	25
11	40	TELLINA AGILIS	25
11	41	MEDIOMASTUS (LPIL)	950
11	41	GLYCINDE SOLITARIA	525
11	41	ACTEOCINA CANALICULATA	500
11	41	AMPELISCA ABDITA	425
11	41	COROPHIUM TUBERCULATUM	225
11	41	STREBLOSPIO BENEDICTI	175
11	41	ILYANASSA OBSOLETA	125
11	41	LEUCON AMERICANUS	125
11	41	ODOSTOMIA (LPIL)	125
11	41	AMPHARETIDAE (LPIL)	50
11	41	CREPIDULA MACULOSA	50
11	41	MYSIDACEA (LPIL)	50
11	41	TUBIFICIDAE (LPIL)	50
11	41	ASABELLIDES OCULATA	25
11	41	EUSARSIELLA ZOSTERICOLA	25
11	41	LEITOSCOLOPLOS (LPIL)	25
11	41	MELITA (LPIL)	25
11	41	PAGURUS (LPIL)	25
11	41	SPIOCHAETOPTERUS OCULATUS	25
11	42	AMPELISCA ABDITA	16,250
11	42	MEDIOMASTUS (LPIL)	1,750
11	42	GLYCINDE SOLITARIA	1,225
11	42	ACTEOCINA CANALICULATA	575
11	42	STREBLOSPIO BENEDICTI	375
11	42	CERAPUS TUBULARIS	325
11	42	LEUCON AMERICANUS	275
11	42	EDOTIA TRILOBA	250
11	42	COROPHIUM TUBERCULATUM	200
11	42	EUSARSIELLA ZOSTERICOLA	200
11	42	PARASTEROPE POLLEX	175
11	42	ODOSTOMIA (LPIL)	125
11	42	MITRELLA LUNATA	100
11	42	SPIOCHAETOPTERUS OCULATUS	100
11	42	AMPHARETIDAE (LPIL)	75
11	42	TUBIFICIDAE (LPIL)	75
11	42	CYCLASPIS VARIANS	50
11	42	GASTROPODA (LPIL)	50
11	42	ASABELLIDES OCULATA	25
11	42	ASCIDIACEA (LPIL)	25

(LPIL) - Lowest possible identification level

Appendix I - Benthic fauna species list, by sample site

STRATUM	SITE	TAXA NAME	ABUNDANCE #/M^2
11	42	GEMMA GEMMA	25
11	42	HETEROMASTUS FILIFORMIS	25
11	42	KURTZIELLA CERINA	25
11	42	LEITOSCOLOPLOS (LPIL)	25
11	42	RICTAXIS PUNCTOSTRIATUS	25
11	42	TELLINA AGILIS	25
11	42	TUBULANUS (LPIL)	25
12	43	SABELLARIA VULGARIS	4,100
12	43	POLYDORA CORNUTA	1,625
12	43	COROPHIUM TUBERCULATUM	500
12	43	ASCIDIACEA (LPIL)	475
12	43	MEDIOMASTUS (LPIL)	375
12	43	CYATHURA POLITA	225
12	43	LYONSIA HYALINA	225
12	43	MELITA (LPIL)	225
12	43	GLYCINDE SOLITARIA	200
12	43	CREPIDULA MACULOSA	125
12	43	OLIGOCHAETA (LPIL)	125
12	43	BATEA CATHARINENSIS	100
12	43	EUSARSIELLA ZOSTERICOLA	100
12	43	HETEROMASTUS FILIFORMIS	100
12	43	ERICHTHONIUS BRASILIENSIS	75
12	43	NEREIS (LPIL)	75
12	43	NEREIS SUCCINEA	75
12	43	RHITHROPANOPEUS HARRISII	75
12	43	ACTINIARIA (LPIL)	50
12	43	GLYCERIDAE (LPIL)	50
12	43	MULINIA LATERALIS	50
12	43	PAGURUS (LPIL)	50
12	43	SPIOCHAETOPTERUS OCULATUS	50
12	43	UROSALPINX CINERA	50
12	43	ACTEOCINA CANALICULATA	25
12	43	AMPHARETIDAE (LPIL)	25
12	43	CERAPUS TUBULARIS	25
12	43	COROPHIUM (LPIL)	25
12	43	EUPLEURA CAUDATA	25
12	43	GRUBEOSYLLIS CLAVATA	25
12	43	ILYANASSA OBSOLETA	25
12	44	SABELLARIA VULGARIS	17,600
12	44	POLYDORA CORNUTA	2,600
12	44	OLIGOCHAETA (LPIL)	2,275
12	44	PARACAPRELLA TENUIS	1,700
12	44	MEDIOMASTUS (LPIL)	1,150
12	44	GLYCINDE SOLITARIA	725
12	44	COROPHIUM TUBERCULATUM	600
12	44	MITRELLA LUNATA	550
12	44	HETEROMASTUS FILIFORMIS	525
12	44	ACTEOCINA CANALICULATA	350
12	44	UNCIOLA SERRATA	350
12	44	ASCIDIACEA (LPIL)	325
12	44	RHYNCHOCOELA (LPIL)	325

(LPIL) - Lowest possible identification level

Appendix I - Benthic fauna species list, by sample site

STRATUM	SITE	TAXA NAME	ABUNDANCE #/M^2
12	44	ODOSTOMIA (LPIL)	300
12	44	LEITOSCOLOPLOS (LPIL)	275
12	44	ERICHTHONIUS BRASILIENSIS	200
12	44	SCOLOPLOS RUBRA	200
12	44	EUSARSIELLA ZOSTERICOLA	175
12	44	RHITHROPANOPEUS HARRISII	175
12	44	LYONSIA HYALINA	150
12	44	NEREIS (LPIL)	150
12	44	AMPELISCA ABDITA	125
12	44	XANTHIDAE (LPIL)	100
12	44	ASABELLIDES OCULATA	75
12	44	MELITA (LPIL)	75
12	44	AMPHARETIDAE (LPIL)	50
12	44	AORIDAE (LPIL)	50
12	44	RICTAXIS PUNCTOSTRIATUS	50
12	44	STREBLOSPIO BENEDICTI	50
12	44	UROSALPINX CINERA	50
12	44	ACTINIARIA (LPIL)	25
12	44	BATEA CATHARINENSIS	25
12	44	EDOTIA TRILOBA	25
12	44	GASTROPODA (LPIL)	25
12	44	GLYCERA SP.D	25
12	44	LIBINIA DUBIA	25
12	44	MELITIDAE (LPIL)	25
12	44	MULINIA LATERALIS	25
12	44	NEREIDIDAE (LPIL)	25
12	44	PECTINARIA GOULDII	25
12	44	PHYLLODOCIDAE (LPIL)	25
12	44	PLEUSTIDAE (LPIL)	25
12	45	ACTEOCINA CANALICULATA	175
12	45	HETEROMASTUS FILIFORMIS	100
12	45	RHYNCHOCOELA (LPIL)	75
12	45	TELLINA (LPIL)	75
12	45	ARICIDEA (LPIL)	25
12	45	CAPITELLIDAE (LPIL)	25
12	45	GLYCERA SP.D	25
12	45	LINEIDAE (LPIL)	25
12	45	MEDIOMASTUS (LPIL)	25
12	45	MITRELLA LUNATA	25
12	45	NEPHTYS BUCERA	25
12	45	NEVERITA DUPLICATA	25
12	45	ODOSTOMIA (LPIL)	25
12	45	OXYUROSTYLIS SMITHI	25
12	45	PAGURUS (LPIL)	25
12	46	COROPHIUM TUBERCULATUM	900
12	46	TELLINA AGILIS	325
12	46	SABELLARIA VULGARIS	200
12	46	ASCIDIACEA (LPIL)	175
12	46	AMPELISCA ABDITA	100
12	46	NEOMYSIS AMERICANA	50
12	46	OXYUROSTYLIS SMITHI	50

(LPIL) - Lowest possible identification level

Appendix I - Benthic fauna species list, by sample site

STRATUM	SITE	TAXA NAME	ABUNDANCE #/M^2
12	46	POLYDORA CORNUTA	50
12	46	RHYNCHOCOELA (LPIL)	50
12	46	CIRRATULIDAE (LPIL)	25
12	46	EUSARSIELLA ZOSTERICOLA	25
12	46	GLYCERA SP.D	25
12	46	GONIADIDAE (LPIL)	25
12	46	LEITOSCOLOPLOS (LPIL)	25
12	46	MEDIOMASTUS (LPIL)	25
12	46	PAGURUS (LPIL)	25
12	46	RHITHROPANOPEUS HARRISII	25
13	47	RHEPOXYNIUS HUDSONI	1,425
13	47	PROTOHAUSTORIUS SP.B	300
13	47	CAPITELLIDAE (LPIL)	150
13	47	GEMMA GEMMA	100
13	47	ACTEOCINA CANALICULATA	50
13	47	MONOCULODES EDWARDSI	50
13	47	SYNAPTIDAE (LPIL)	50
13	47	THARYX ACUTUS	50
13	47	ARICIDEA WASSI	25
13	47	LEITOSCOLOPLOS ROBUSTUS	25
13	47	NEPHTYS BUCERA	25
13	47	RHYNCHOCOELA (LPIL)	25
13	47	TELLINA AGILIS	25
13	48	CAPITELLIDAE (LPIL)	225
13	48	TELLINA AGILIS	225
13	48	TELLINA (LPIL)	175
13	48	GLYCERA SP.D	150
13	48	AMPELISCA ABDITA	50
13	48	PAGURUS (LPIL)	50
13	48	CHAETOPTERIDAE (LPIL)	25
13	48	CIRRATULIDAE (LPIL)	25
13	48	COLUMBELLIDAE (LPIL)	25
13	48	OLIGOCHAETA (LPIL)	25
13	48	PINNIXA (LPIL)	25
13	48	RHEPOXYNIUS HUDSONI	25
13	48	RHYNCHOCOELA (LPIL)	25
13	48	SPIONIDAE (LPIL)	25
13	49	PROTOHAUSTORIUS SP.B	800
13	49	TELLINA (LPIL)	225
13	49	RHEPOXYNIUS HUDSONI	125
13	49	NEPHTYS PICTA	75
13	49	ANCINUS DEPRESSUS	50
13	49	NEPHTYS BUCERA	50
13	49	ARICIDEA TAYLORI	25
13	49	LEITOSCOLOPLOS (LPIL)	25
13	49	LEUCON AMERICANUS	25
13	49	OXYUROSTYLIS SMITHI	25
13	50	MEDIOMASTUS (LPIL)	11,075
13	50	AMPELISCA ABDITA	5,100
13	50	LEUCON AMERICANUS	925
13	50	NUCULA PROXIMA	225

(LPIL) - Lowest possible identification level

Appendix I - Benthic fauna species list, by sample site

STRATUM	SITE	TAXA NAME	ABUNDANCE #/M^2
13	50	GLYCERA SP.D	200
13	50	LEITOSCOLOPLOS ROBUSTUS	200
13	50	OLIGOCHAETA (LPIL)	175
13	50	ACTEOCINA CANALICULATA	125
13	50	EDOTIA TRILOBA	125
13	50	TUBULANUS (LPIL)	100
13	50	CIRRATULIDAE (LPIL)	75
13	50	GLYCINDE SOLITARIA	75
13	50	HETEROMASTUS FILIFORMIS	50
13	50	OXYUROSTYLIS SMITHI	50
13	50	RICTAXIS PUNCTOSTRIATUS	50
13	50	AMPHARETIDAE (LPIL)	25
13	50	CERAPUS (LPIL)	25
13	50	GASTROPODA (LPIL)	25
13	50	GONIADIDAE (LPIL)	25
13	50	LOIMIA MEDUSA	25
13	50	PARACAPRELLA TENUIS	25
13	50	SPIOCHAETOPTERUS OCULATUS	25
13	50	THARYX ACUTUS	25
13	51	GEMMA GEMMA	2,575
13	51	RHEPOXYNIUS HUDSONI	700
13	51	ACANTHOHAUSTORIUS INTERMEDIUS	200
13	51	AMPELISCA ABDITA	125
13	51	LEUCON AMERICANUS	25
13	51	OSTRACODA (LPIL)	25
13	51	TANAISSUS PSAMMOPHILUS	25
13	51	TELLINA (LPIL)	25
13	51	TELLINA AGILIS	25
13	52	POLYGORDIUS (LPIL)	175
13	52	RHEPOXYNIUS HUDSONI	100
13	52	TELLINA AGILIS	100
13	52	ANCINUS DEPRESSUS	50
13	52	ARICIDEA (LPIL)	50
13	52	CAULLERIELLA SP.J	50
13	52	GEMMA GEMMA	50
13	52	OLIGOCHAETA (LPIL)	50
13	52	SPIOPHANES BOMBYX	50
13	52	ARICIDEA CATHERINAE	25
13	52	CAPITELLIDAE (LPIL)	25
13	52	CIRRATULIDAE (LPIL)	25
13	52	ILYANASSA TRIVITTATA	25
13	52	NEPHTYS PICTA	25
13	52	PARAONIDAE (LPIL)	25
13	52	PROTOHAUSTORIUS WIGLEYI	25
13	53	TELLINA (LPIL)	50
13	53	AMPELISCA ABDITA	25
13	53	BIVALVIA (LPIL)	25
13	53	CALLIANASSIDAE (LPIL)	25
13	53	ILYANASSA TRIVITTATA	25
13	53	LEUCON AMERICANUS	25
13	53	MEDIOMASTUS (LPIL)	25

(LPIL) - Lowest possible identification level

Appendix I - Benthic fauna species list, by sample site

STRATUM	SITE	TAXA NAME	ABUNDANCE #/M^2
13	53	MYSIDAE (LPIL)	25
13	53	OEDICEROTIDAE (LPIL)	25
13	53	PROTOHAUSTORIUS SP.B	25
13	54	PROTOHAUSTORIUS SP.B	500
13	54	MEDIOMASTUS (LPIL)	425
13	54	TELLINA (LPIL)	325
13	54	MACTRIDAE (LPIL)	125
13	54	CAPITELLIDAE (LPIL)	100
13	54	NEPHTYS PICTA	100
13	54	RHEPOXYNIUS HUDSONI	75
13	54	TELLINA AGILIS	75
13	54	CIRRATULIDAE (LPIL)	50
13	54	ILYANASSA TRIVITTATA	50
13	54	NEOMYSIS AMERICANA	50
13	54	RHYNCHOCOELA (LPIL)	50
13	54	AMPELISCA (LPIL)	25
13	54	LEITOSCOLOPLOS ROBUSTUS	25
13	54	OXYUROSTYLIS SMITHI	25
13	55	MEDIOMASTUS (LPIL)	2,250
13	55	TELLINA (LPIL)	275
13	55	CREPIDULA PLANA	200
13	55	NUCULA PROXIMA	175
13	55	TELLINA AGILIS	125
13	55	DORIDELLA OBSCURA	100
13	55	CIRRATULIDAE (LPIL)	75
13	55	ARICIDEA CATHERINAE	50
13	55	ILYANASSA TRIVITTATA	50
13	55	POLYDORA CORNUTA	50
13	55	GLYCERA SP.D	25
13	55	HARMOTHOE EXTENUATA	25
13	55	HOLOTHUROIDEA (LPIL)	25
13	55	MYSIDAE (LPIL)	25
13	55	NEPHTYS PICTA	25
13	55	PAGURUS POLLICARIS	25
13	55	SABELLARIA VULGARIS	25
13	55	THARYX ACUTUS	25
13	56	LEUCON AMERICANUS	1,925
13	56	MEDIOMASTUS (LPIL)	1,625
13	56	CREPIDULA PLANA	1,500
13	56	OLIGOCHAETA (LPIL)	800
13	56	TUBIFICIDAE (LPIL)	775
13	56	TELLINA AGILIS	475
13	56	NUCULA PROXIMA	325
13	56	AMPELISCA ABDITA	225
13	56	ACTEOCINA CANALICULATA	200
13	56	GONIADIDAE (LPIL)	75
13	56	RHYNCHOCOELA (LPIL)	75
13	56	GLYCERA SP.D	25
13	56	ILYANASSA TRIVITTATA	25
13	56	NEPHTYS INCISA	25
13	56	STREBLOSPIO BENEDICTI	25

(LPIL) - Lowest possible identification level

Appendix I - Benthic fauna species list, by sample site

STRATUM	SITE	TAXA NAME	ABUNDANCE #/M^2
14	57	LEUCON AMERICANUS	19,625
14	57	MEDIOMASTUS (LPIL)	7,925
14	57	TUBIFICIDAE (LPIL)	5,525
14	57	EDOTIA TRILOBA	2,400
14	57	STREBLOSPIO BENEDICTI	1,425
14	57	MULINIA LATERALIS	1,250
14	57	AMPHARETIDAE (LPIL)	375
14	57	RHYNCHOCOELA (LPIL)	225
14	57	AMPELISCA (LPIL)	100
14	57	AMPELISCA ABDITA	100
14	57	PHYLLODOCIDAE (LPIL)	100
14	57	ACTEOCINA CANALICULATA	50
14	57	EUSARSIELLA ZOSTERICOLA	50
14	57	MYSIDAE (LPIL)	25
14	58	AMPELISCA ABDITA	41,925
14	58	MEDIOMASTUS (LPIL)	12,500
14	58	ACTEOCINA CANALICULATA	1,600
14	58	GLYCINDE SOLITARIA	1,025
14	58	LEITOSCOLOPLOS ROBUSTUS	525
14	58	TUBIFICIDAE (LPIL)	400
14	58	MITRELLA LUNATA	350
14	58	RICTAXIS PUNCTOSTRIATUS	175
14	58	PARASTEROPE POLLEX	150
14	58	AMPHARETIDAE (LPIL)	100
14	58	EUSARSIELLA ZOSTERICOLA	100
14	58	GONIADIDAE (LPIL)	100
14	58	LYONSIA HYALINA	100
14	58	ODOSTOMIA (LPIL)	100
14	58	LEUCON AMERICANUS	75
14	58	ORBINIIDAE (LPIL)	75
14	58	STREBLOSPIO BENEDICTI	75
14	58	QUISTADRILUS MULTISETOSUS	50
14	58	CERAPUS TUBULARIS	25
14	58	CIRRATULIDAE (LPIL)	25
14	58	CREPIDULA (LPIL)	25
14	58	GLYCERA SP.D	25
14	58	HETEROMASTUS FILIFORMIS	25
14	58	MACTRIDAE (LPIL)	25
14	58	PHYLLODOCE ARENAE	25
14	58	PINNIXA (LPIL)	25
14	58	PINNIXA CHAETOPTERANA	25
14	58	SPIOCHAETOPTERUS OCULATUS	25
14	58	TELLINA (LPIL)	25
14	59	TELLINA AGILIS	475
14	59	AMPELISCA VADORUM	175
14	59	ACTEOCINA CANALICULATA	75
14	59	AMPELISCA ABDITA	75
14	59	MEDIOMASTUS (LPIL)	75
14	59	CIRRATULIDAE (LPIL)	50
14	59	CREPIDULA PLANA	50
14	59	AMPHARETIDAE (LPIL)	25

(LPIL) - Lowest possible identification level

Appendix I - Benthic fauna species list, by sample site

STRATUM	SITE	TAXA NAME	ABUNDANCE #/M^2
14	59	COROPHIUM TUBERCULATUM	25
14	59	EUSARSIELLA (LPIL)	25
14	59	GLYCERA SP.D	25
14	59	LEITOSCOLOPLOS (LPIL)	25
14	59	MONOCULODES EDWARDSI	25
14	59	PAGURIDAE (LPIL)	25
14	59	RHYNCHOCOELA (LPIL)	25
14	60	AMPELISCA ABDITA	29,025
14	60	GLYCINDE SOLITARIA	1,950
14	60	MEDIOMASTUS (LPIL)	1,625
14	60	COROPHIUM TUBERCULATUM	400
14	60	TUBIFICIDAE (LPIL)	325
14	60	ACTEOCINA CANALICULATA	250
14	60	EUSARSIELLA ZOSTERICOLA	100
14	60	KURTZIELLA CERINA	75
14	60	PHYLLODOCE ARENAE	75
14	60	RHYNCHOCOELA (LPIL)	75
14	60	MICROPROTOPUS RANEYI	50
14	60	CERAPUS TUBULARIS	25
14	60	CRANGON SEPTEMSPINOSA	25
14	60	DIPOLYDORA SOCIALIS	25
14	60	LEITOSCOLOPLOS (LPIL)	25
14	60	MAJIDAE (LPIL)	25
14	60	MITRELLA LUNATA	25
14	60	MULINIA LATERALIS	25
14	60	PARASTEROPE POLLEX	25
14	60	PECTINARIA GOULDII	25
14	60	SPIOCHAETOPTERUS OCULATUS	25
14	61	TELLINA (LPIL)	275
14	61	RHEPOXYNIUS HUDSONI	75
14	61	RHYNCHOCOELA (LPIL)	75
14	61	TELLINA AGILIS	75
14	61	LEITOSCOLOPLOS (LPIL)	50
14	61	LEITOSCOLOPLOS ROBUSTUS	50
14	61	AMERICHELIDIUM AMERICANUM	25
14	61	ANCINUS DEPRESSUS	25
14	61	ILYANASSA TRIVITTATA	25
15	62	BRANIA WELLFLEETENSIS	300
15	62	PARAPIONOSYLLIS LONGICIRRATA	200
15	62	OLIGOCHAETA (LPIL)	125
15	62	PROTOHAUSTORIUS WIGLEYI	125
15	62	TUBIFICIDAE (LPIL)	75
15	62	ANCINUS DEPRESSUS	50
15	62	BATHYPOREIA PARKERI	50
15	62	SPISULA SOLIDISSIMA	50
15	62	CAULLERIELLA SP.J	25
15	62	CIRROPHORUS ILVANA	25
15	62	HAUSTORIIDAE (LPIL)	25
15	62	MACTRIDAE (LPIL)	25
15	62	NEVERITA DUPLICATA	25
15	62	POLYGORDIUS (LPIL)	25

(LPIL) - Lowest possible identification level

Appendix I - Benthic fauna species list, by sample site

STRATUM	SITE	TAXA NAME	ABUNDANCE #/M^2
15	62	RHEPOXYNIUS HUDSONI	25
15	62	SIGALION ARENICOLA	25
15	62	SIGAMBRA BASSI	25
15	62	TANAISSUS PSAMMOPHILUS	25
15	62	TELLINA (LPIL)	25
15	62	TELLINA AGILIS	25
15	63	TELLINA (LPIL)	1,200
15	63	CIRRATULIDAE (LPIL)	900
15	63	POLYGORDIUS (LPIL)	425
15	63	ARICIDEA (LPIL)	275
15	63	MITRELLA LUNATA	250
15	63	SABELLARIA VULGARIS	225
15	63	DEUTELLA INCERTA	200
15	63	MEDIOMASTUS (LPIL)	175
15	63	CAULLERIELLA SP.J	125
15	63	RHEPOXYNIUS HUDSONI	100
15	63	GLYCERIDAE (LPIL)	75
15	63	BIVALVIA (LPIL)	50
15	63	ILYANASSA TRIVITTATA	50
15	63	OLIGOCHAETA (LPIL)	50
15	63	SPIONIDAE (LPIL)	50
15	63	AEGINELLIDAE (LPIL)	25
15	63	ARCIDAE (LPIL)	25
15	63	CREPIDULA (LPIL)	25
15	63	CREPIDULA MACULOSA	25
15	63	CREPIDULA PLANA	25
15	63	EDOTIA TRILOBA	25
15	63	ERICHTHONIUS BRASILIENSIS	25
15	63	LEITOSCOLOPLOS (LPIL)	25
15	63	MAJIDAE (LPIL)	25
15	63	MICROPROTOPUS RANEYI	25
15	63	NEPHTYIDAE (LPIL)	25
15	63	OVALIPES (LPIL)	25
15	63	PHYLLODOCIDAE (LPIL)	25
15	63	PINNIXA CHAETOPTERANA	25
15	63	RHYNCHOCOELA (LPIL)	25
15	63	SPIOPHANES BOMBYX	25
15	63	UNCIOLA (LPIL)	25
15	64	PARAHAUSTORIUS ATTENUATUS	250
15	64	HAUSTORIIDAE (LPIL)	50
15	64	POLYDORA (LPIL)	25
15	64	TANAISSUS PSAMMOPHILUS	25
16	65	CHIRIDOTEA TUFTSI	600
16	65	GEMMA GEMMA	300
16	65	RHYNCHOCOELA (LPIL)	50
16	65	TELLINA (LPIL)	25
16	66	OLIGOCHAETA (LPIL)	5,325
16	66	LYSIANOPSIS ALBA	3,225
16	66	SABELLARIA VULGARIS	1,350
16	66	ARICIDEA (LPIL)	1,325
16	66	ARICIDEA CATHERINAE	875

(LPIL) - Lowest possible identification level

Appendix I - Benthic fauna species list, by sample site

STRATUM	SITE	TAXA NAME	ABUNDANCE #/M^2
16	66	CYATHURA POLITA	725
16	66	MEDIOMASTUS (LPIL)	675
16	66	CIRRATULIDAE (LPIL)	450
16	66	SCOLETOMA TENUIS	425
16	66	AUTOLYTUS (LPIL)	375
16	66	CREPIDULA PLANA	350
16	66	POLYCIRRUS EXIMIUS	250
16	66	RHEPOXYNIUS HUDSONI	250
16	66	RHITHROPANOPEUS HARRISII	200
16	66	ECHINOIDEA (LPIL)	175
16	66	UNCIOLA SERRATA	175
16	66	DIPOLYDORA SOCIALIS	150
16	66	TEREBELLIDAE (LPIL)	125
16	66	POLYNOIDAE (LPIL)	100
16	66	SERPULIDAE (LPIL)	100
16	66	HARMOTHOE EXTENUATA	75
16	66	HARMOTHOE IMBRICATA	75
16	66	MARGINELLA APICINA	75
16	66	NEOMYSIS AMERICANA	75
16	66	NUCULA PROXIMA	75
16	66	RHYNCHOCOELA (LPIL)	75
16	66	ARICIDEA TAYLORI	50
16	66	HYDROIDES DIANTHUS	50
16	66	HYDROIDES PROTULICOLA	50
16	66	LEPIDONOTUS SUBLEVIS	50
16	66	MICROPHTHALMUS (LPIL)	50
16	66	PHYLLODOCIDAE (LPIL)	50
16	66	AMPHARETIDAE (LPIL)	25
16	66	BHAWANIA HETEROSETA	25
16	66	CRANGON SEPTEMSPINOSA	25
16	66	GLYCERA AMERICANA	25
16	66	LUMBRINERIDAE (LPIL)	25
16	66	MALDANIDAE (LPIL)	25
16	66	MICROPHTHALMUS HARTMANAE	25
16	66	POLYDORA CORNUTA	25
16	66	POLYGORDIUS (LPIL)	25
16	67	ARICIDEA CATHERINAE	1,400
16	67	ARICIDEA (LPIL)	1,125
16	67	CYATHURA BURBANCKI	600
16	67	SABELLARIA VULGARIS	600
16	67	UNCIOLA SERRATA	475
16	67	TUBIFICIDAE (LPIL)	450
16	67	LYSIANOPSIS ALBA	375
16	67	NUCULA PROXIMA	325
16	67	HYDROIDES PROTULICOLA	275
16	67	UNCIOLA (LPIL)	250
16	67	POLYCIRRUS EXIMIUS	175
16	67	TEREBELLIDAE (LPIL)	150
16	67	SCOLETOMA TENUIS	125
16	67	DIPOLYDORA SOCIALIS	100
16	67	QUISTADRILUS MULTISETOSUS	100

(LPIL) - Lowest possible identification level

Appendix I - Benthic fauna species list, by sample site

STRATUM	SITE	TAXA NAME	ABUNDANCE #/M^2
16	67	LUMBRINERIDAE (LPIL)	75
16	67	BRANIA WELLFLEETENSIS	50
16	67	CIRRATULIDAE (LPIL)	50
16	67	DRILONEREIS LONGA	50
16	67	EUCERAMUS PRAELONGUS	50
16	67	MEDIOMASTUS (LPIL)	50
16	67	PHYLLODOCE ARENAE	50
16	67	POLYGORDIUS (LPIL)	50
16	67	AMPHARETIDAE (LPIL)	25
16	67	ANOMIA SIMPLEX	25
16	67	CREPIDULA MACULOSA	25
16	67	DECAPODA NATANTIA (LPIL)	25
16	67	LEPIDONOTUS SUBLEVIS	25
16	67	MARGINELLA APICINA	25
16	67	MYSIDAE (LPIL)	25
16	67	PARASTEROPE POLLEX	25
16	67	PHOXOCEPHALIDAE (LPIL)	25
16	67	PHYLLODOCIDAE (LPIL)	25
16	67	SERPULIDAE (LPIL)	25
17	68	TELLINA AGILIS	775
17	68	RHEPOXYNIUS HUDSONI	525
17	68	CAPITELLIDAE (LPIL)	175
17	68	POLYGORDIUS (LPIL)	125
17	68	CIRRATULIDAE (LPIL)	75
17	68	GEMMA GEMMA	50
17	68	LEITOSCOLOPLOS ROBUSTUS	50
17	68	ASABELLIDES OCULATA	25
17	68	ECHINARACHNIUS PARMA	25
17	68	GLYCERA SP.D	25
17	68	GLYCERIDAE (LPIL)	25
17	68	ILYANASSA TRIVITTATA	25
17	68	LYONSIA HYALINA	25
17	68	NEPHTYIDAE (LPIL)	25
17	68	NEREIDIDAE (LPIL)	25
17	68	OLIGOCHAETA (LPIL)	25
17	68	SPIONIDAE (LPIL)	25
17	68	THARYX ACUTUS	25
17	69	POLYGORDIUS (LPIL)	350
17	69	BIVALVIA (LPIL)	175
17	69	TUBIFICIDAE (LPIL)	125
17	69	ARICIDEA (LPIL)	100
17	69	NEPHTYIDAE (LPIL)	75
17	69	TELLINA (LPIL)	75
17	69	OLIGOCHAETA (LPIL)	50
17	69	BRANCHIOSTOMA (LPIL)	25
17	69	CAPITELLIDAE (LPIL)	25
17	69	ENSIS DIRECTUS	25
17	69	GLYCERA SP.D	25
17	69	LYONSIA HYALINA	25
17	69	NUCULA PROXIMA	25
17	69	SPIOCHAETOPTERUS OCULATUS	25

(LPIL) - Lowest possible identification level

Appendix I - Benthic fauna species list, by sample site

STRATUM	SITE	TAXA NAME	ABUNDANCE #/M^2
17	70	TELLINA AGILIS	600
17	70	GEMMA GEMMA	325
17	70	ANCINUS DEPRESSUS	50
17	70	ECHINARACHNIUS PARMA	25
17	70	MELITA (LPIL)	25
17	70	OLIGOCHAETA (LPIL)	25
17	70	POLYGORDIUS (LPIL)	25
17	70	PROTOHAUSTORIUS WIGLEYI	25
17	70	SPIOPHANES BOMBYX	25
18	71	TELLINA AGILIS	1,575
18	71	TANAISSUS PSAMMOPHILUS	750
18	71	PROTOHAUSTORIUS WIGLEYI	325
18	71	RHEPOXYNIUS HUDSONI	325
18	71	SABELLARIA VULGARIS	125
18	71	ASTARTE CASTANEA	75
18	71	CAULLERIELLA SP.J	75
18	71	POLYGORDIUS (LPIL)	75
18	71	ANCINUS DEPRESSUS	50
18	71	ARICIDEA (LPIL)	25
18	71	NEPHTYS PICTA	25
18	71	OXYUROSTYLIS SMITHI	25
18	71	PHYLLODOCE ARENAE	25
18	71	RHYNCHOCOELA (LPIL)	25
18	71	SPIONIDAE (LPIL)	25
18	71	TURBONILLA (LPIL)	25
18	72	PSEUDUNCIOLA OBLIQUUA	1,000
18	72	ARICIDEA CERRUTII	500
18	72	GEMMA GEMMA	300
18	72	STREPTOSYLLIS ARENAE	300
18	72	PROTOHAUSTORIUS WIGLEYI	200
18	72	TANAISSUS PSAMMOPHILUS	175
18	72	POLYGORDIUS (LPIL)	150
18	72	TELLINA AGILIS	125
18	72	BRANIA WELLFLEETENSIS	100
18	72	CIRRATULIDAE (LPIL)	100
18	72	BRANCHIOSTOMA (LPIL)	75
18	72	OLIGOCHAETA (LPIL)	75
18	72	CAULLERIELLA SP.J	50
18	72	CIRROPHORUS (LPIL)	50
18	72	RHEPOXYNIUS HUDSONI	50
18	72	SYLLIDAE (LPIL)	50
18	72	TRAVISIA PARVA	50
18	72	AMPELISCA ABDITA	25
18	72	ARICIDEA (LPIL)	25
18	72	ASCIDIACEA (LPIL)	25
18	72	CARDIIDAE (LPIL)	25
18	72	CHIRIDOTEA TUFTSI	25
18	72	ISCHYROCERIDAE (LPIL)	25
18	72	MONTICELLINA DORSOBRANCHIALIS	25
18	72	PARAONIDAE (LPIL)	25
18	72	PAROUGIA CAECA	25

(LPIL) - Lowest possible identification level

Appendix I - Benthic fauna species list, by sample site

STRATUM	SITE	TAXA NAME	ABUNDANCE #/M^2
18	72	SIGALION ARENICOLA	25
18	72	SPIOPHANES BOMBYX	25
18	72	TUBIFICIDAE (LPIL)	25
18	72	UNCIOLA SERRATA	25
18	73	CIRRATULIDAE (LPIL)	225
18	73	POLYGORDIUS (LPIL)	200
18	73	GLYCERA SP.D	150
18	73	TELLINA (LPIL)	150
18	73	ARICIDEA CATHERINAE	100
18	73	CAPITELLIDAE (LPIL)	100
18	73	ARICIDEA (LPIL)	75
18	73	PAGURIDAE (LPIL)	75
18	73	THARYX ACUTUS	75
18	73	AMPELISCA ABDITA	50
18	73	CAULLERIELLA SP.J	50
18	73	GEMMA GEMMA	50
18	73	OLIGOCHAETA (LPIL)	50
18	73	PHYLLODOCE ARENAE	50
18	73	RHEPOXYNIUS HUDSONI	50
18	73	ANCINUS DEPRESSUS	25
18	73	APOPRIONOSPIO PYGMAEA	25
18	73	ASTARTE CASTANEA	25
18	73	EDOTIA TRILOBA	25
18	73	NEPHTYIDAE (LPIL)	25
18	73	PECTINARIA GOULDII	25
18	73	SPIOCHAETOPTERUS OCULATUS	25
18	73	TRAVISIA PARVA	25
18	73	TUBULANUS (LPIL)	25
21	84	LEUCON AMERICANUS	775
21	84	BIVALVIA (LPIL)	275
21	84	OLIGOCHAETA (LPIL)	275
21	84	TUBIFICIDAE (LPIL)	275
21	84	RHYNCHOCOELA (LPIL)	175
21	84	MARENZELLARIA VIRIDIS	150
21	84	CYATHURA POLITA	75
21	84	EDOTIA TRILOBA	75
21	84	HETEROMASTUS FILIFORMIS	50
21	84	MULINIA LATERALIS	25
21	85	TUBIFICIDAE (LPIL)	775
21	85	PROCLADIUS (LPIL)	50
21	85	ARICIDEA (LPIL)	25
21	85	CHIRONOMIDAE (LPIL)	25
21	85	CYATHURA POLITA	25
21	85	MULINIA LATERALIS	25
21	85	NEMATONEREIS HEBES	25
21	85	OLIGOCHAETA (LPIL)	25
21	85	RHYNCHOCOELA (LPIL)	25
/	87	AMPELISCA ABDITA	3,300
/	87	DIPOLYDORA SOCIALIS	175

(LPIL) - Lowest possible identification level

Appendix I - Benthic fauna species list, by sample site

STRATUM	SITE	TAXA NAME	ABUNDANCE #/M^2
/	87	CYATHURA POLITA	100
/	87	EDOTIA TRILOBA	100
/	87	HYPERETEONE HETEROPODA	100
/	87	ERICHTHONIUS BRASILIENSIS	75
/	87	NEREIS SUCCINEA	75
/	87	ACTINIARIA (LPIL)	50
/	87	ASABELLIDES OCULATA	50
/	87	PARACAPRELLA TENUIS	25
/	87	PLEUSYMTES GLABER	25
/	87	POLYDORA CORNUTA	25
/	87	RHITHROPANOPEUS HARRISII	25
/	87	SPIONIDAE (LPIL)	25
22	88	STREBLOSPIO BENEDICTI	16,875
22	88	MEDIOMASTUS (LPIL)	8,800
22	88	TUBIFICIDAE (LPIL)	2,550
22	88	HYPERETEONE HETEROPODA	425
22	88	LEUCON AMERICANUS	325
22	88	SPISULA SOLIDISSIMA	175
22	88	AMPELISCA ABDITA	100
22	88	EDOTIA TRILOBA	50
22	88	ILYANASSA OBSOLETA	50
22	88	RHYNCHOCOELA (LPIL)	50
22	88	CIRRATULIDAE (LPIL)	25
22	88	GLYCINDE SOLITARIA	25
22	88	SPIOCHAETOPTERUS OCULATUS	25
22	88	UROSALPINX CINERA	25
22	89	TUBIFICIDAE (LPIL)	950
22	89	LIMNODRILUS HOFFMEISTERI	350
22	89	GAMMARUS TIGRINUS	250
22	89	EDOTIA TRILOBA	150
22	89	CYATHURA POLITA	50
22	89	LAEONEREIS CULVERI	50
22	89	ASABELLIDES OCULATA	25
22	89	LEUCON AMERICANUS	25
22	90	TUBIFICIDAE (LPIL)	2,475
22	90	SPIONIDAE (LPIL)	625
22	90	OLIGOCHAETA (LPIL)	150
22	90	HETEROMASTUS FILIFORMIS	125
22	90	DIPOLYDORA SOCIALIS	100
22	90	AMPELISCA ABDITA	75
22	90	STREBLOSPIO BENEDICTI	50
22	90	AMPHARETIDAE (LPIL)	25
22	90	CAPITELLIDAE (LPIL)	25
22	90	CIRROPHORUS LYRA	25
22	90	COROPHIUM TUBERCULATUM	25
22	90	CYATHURA POLITA	25
22	90	MAGELONA PAPILLICORNIS	25
22	90	MALDANIDAE (LPIL)	25
22	90	MEDIOMASTUS (LPIL)	25
22	90	PHYLLODOCIDAE (LPIL)	25

(LPIL) - Lowest possible identification level

Appendix I - Benthic fauna species list, by sample site

STRATUM	SITE	TAXA NAME	ABUNDANCE #/M²
/	91	TUBIFICIDAE (LPIL)	4,325
/	91	LAEONEREIS CULVERI	775
/	91	TUBIFICOIDES HETEROCHAETUS	275
/	91	CERATOPOGONIDAE (LPIL)	100
/	91	RHYNCHOCOELA (LPIL)	50
/	91	ASABELLIDES OCULATA	25
/	92	TUBIFICIDAE (LPIL)	2,550
/	92	NAIDIDAE (LPIL)	150
/	92	LIMNODRILUS HOFFMEISTERI	100
/	92	OLIGOCHAETA (LPIL)	50
/	92	DERO DIGITATA	25
/	92	DICROTENDIPES (LPIL)	25

(LPIL) - Lowest possible identification level