Ecological Condition of Coastal Ocean Waters Along the U.S. Mid-Atlantic Bight: 2006

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December 2009

Office of Research and Development
U.S. Environmental Protection Agency
Washington, DC 20460

U.S. Department of Commerce
National Oceanic and
    Atmospheric Administration
National Ocean Service
Silver Spring, MD 20910

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Preface

This document presents the results of an assessment of ecological condition and potential stressor impacts in coastal-ocean waters of the mid-Atlantic Bight (MAB), along the eastern U.S. continental shelf from Cape Cod, MA to Cape Hatteras, NC, based on sampling conducted in May 2006. The project was a collaborative effort by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA). It represents one of a series of studies, similar in protocol and design to EPA's Environmental Monitoring and Assessment Program (EMAP) and subsequent National Coastal Assessment (NCA), which extend these prior efforts in estuaries and inland waters out to the coastal shelf, from navigable depths along the shoreline seaward to the shelf break (approximate 100 m depth contour).

The appropriate citation for this report is:

Disclaimer

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List of Acronyms

CDF	Cumulative Distribution Function
Chl *a*	Chlorophyll-*a*
CTD	Conductivity-Temperature-Depth
CVAA	Cold Vapor Atomic Absorption
CWA	Clean Water Act
DDE	Dichlorodiphenyldichloroethylene
DDT	Dichlorodiphenyltrichloroethane
DIN	Dissolved Inorganic Nitrogen
DIP	Dissolved Inorganic Phosphorus
DIN:DIP	Ratio of DIN to DIP
DO	Dissolved Oxygen
EAM	Ecosystem Approach to Management
EMAP	Environmental Monitoring and Assessment Program
EPA	Environmental Protection Agency
ERL	Effects Range Low
ERM	Effects Range Median
GC/MS	Gas Chromatography/Mass Spectrometry
GED	Gulf Ecology Division
GFAA	Graphite Furnace Atomic Absorption
GRTS	Generalized Random-Tessellation Stratified
IEA	Integrated Ecosystem Assessment
ICP-MS	Inductively Coupled Plasma-Mass Spectrometry
LME	Large Marine Ecosystem
MAB	Mid-Atlantic Bight
MIT	Massachusetts Institute of Technology
MITIS	Marine Invader Tracking Information System
NBI	National Benthic Inventory
NAS	Nonindigenous Aquatic Species
NCA	National Coastal Assessment
NCCOS	National Centers for Coastal Ocean Science
NEFSC	Northeast Fisheries Science Center
NEMESIS	National Exotic Marine and Estuarine Species Information System
NHEERL	National Health and Environmental Effects Research Laboratory
NM	Nautical Mile
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
PAH	Polycyclic Aromatic Hydrocarbon
PBDE	Polybrominated Diphenyl Ether
PCB	Polychlorinated Biphenyl
PSU	Practical Salinity Units
SAB	South Atlantic Bight
SBE	Seabird Electronics
SQG	Sediment Quality Guideline
TOC	Total Organic Carbon
TSS	Total Suspended Solids
USGS	United States Geological Survey

Executive Summary

In May 2006, the NOAA National Ocean Service (NOS), in conjunction with the EPA National Health and Environmental Effects Laboratory (NHEERL), conducted an assessment of the status of ecological condition of soft-bottom habitat and overlying waters throughout the mid-Atlantic Bight (MAB) portion of the eastern U.S. continental shelf. The study area encompassed the region from Cape Cod, MA and Nantucket Shoals in the northeast to Cape Hatteras in the south, and was defined using a one nautical mile buffer of the shoreline extended seaward to the shelf break (~100-m depth contour). A total of 50 stations were targeted for sampling using standard methods and indicators applied in prior NOAA coastal studies and EPA's Environmental Monitoring and Assessment Program (EMAP) and National Coastal Assessment (NCA). A key feature adopted from these studies was the incorporation of a random probabilistic sampling design. Such a design provides a basis for making unbiased statistical estimates of the spatial extent of ecological condition relative to various measured indicators and corresponding thresholds of concern. Indicators included multiple measures of water quality, sediment quality, and biological condition (benthic fauna). Through coordination with the NOAA Fisheries Service/Northeast Fisheries Science Center (NFS/NEFSC), samples of summer flounder (*Paralichthys dentatus*) also were obtained from 30 winter 2007 bottom-trawl survey stations in overlapping portions of the study area and used for analysis of chemical-contaminant body burdens.

Depths ranged from 14 – 98 m throughout the study area. About 92 % of the area had sediments composed of sands (< 20 % silt-clay), 6 % of the area was composed of intermediate muddy sands (20 – 80 % silt-clay), and 2 % of the sampled area consisted of mud (> 80 % silt-clay). About 92 % of the area had sediment TOC concentrations < 5 mg/g and all sites had levels of TOC < 20 mg/g, which is well below the range potentially harmful to benthic fauna (> 50 mg/g).

Surface salinities ranged from 30 to 35.3 psu, with the majority of the study region (approximately 80 % of the area) having surface salinities between 31 and 33 psu. Bottom salinities varied between 30 and 35 psu, with fewer sites (representing about 65 % of the area) having bottom salinities between 31 and 33 psu. A greater number of sites (about 31 % area) had salinities > 33 psu in near-bottom waters compared to the surface (10 % area). Surface-water temperatures varied between 7.8 and 17.9 ºC, while near-bottom waters ranged in temperature from 6.5 – 15.2 ºC. The coldest bottom-water temperatures were recorded in the area of the "cold pool", an area of colder, low-salinity water originating in the Gulf of Maine and Georges Bank that flows around Cape Cod and south-westward along the shelf. An index of density stratification ($\Delta\sigma_t$) indicated that the waters of the MAB shelf were well-mixed at the time of sampling, with no evidence of strong water-column stratification.

Levels of dissolved oxygen (DO) were confined to a fairly narrow range in surface (7.7 – 9.7 mg/L) and bottom (8.1 – 9.9 mg/L) waters throughout the survey area. These levels are within the range considered indicative of good water quality (> 5 mg/L) with respect

to DO. None of these waters had DO at low levels (< 2 mg/L) potentially harmful to benthic fauna and fish.

Total suspended solids (TSS) in surface waters ranged from 0.9 – 13.5 mg/L, with slightly higher values observed in bottom waters (1.1 – 36.4 mg/L). One site at the entrance to Delaware Bay had concentrations of bottom-water TSS of 36.4 mg/L, with all remaining sites having values ≤ 16.3 mg/L.

Dissolved inorganic nitrogen (DIN: nitrogen as nitrate + nitrite + ammonium) in coastal shelf surface waters of the MAB ranged from 0.01 mg/L to 0.20 mg/L and averaged 0.04 mg/L. Bottom water concentrations of DIN tended to be higher than surface DIN concentrations, particularly along the outer shelf. This observation is consistent with other published descriptions of the MAB, which have found nutrient levels to be higher in bottom waters than in surface waters. In comparison to these offshore waters, estuaries of the region tend to have higher levels of DIN, with values ranging from 0.01 – 3.0 mg/L in surface waters and averaging 0.17 mg/L (NCA 2006). Similarly, bottom-water concentrations of DIN in estuaries ranged from 0.01 – 2.2 mg/L and averaged 0.15 mg/L. Concentrations of dissolved inorganic phosphorus (DIP) in surface waters of the MAB ranged between 0.02 mg/L and 0.06 mg/L and averaged 0.04 mg/L. Bottom-water concentrations of DIP were somewhat higher than those measured in surface waters, ranging from 0.02 mg/L to 0.12 mg/L and averaging 0.05 mg/L. DIP concentrations in MAB shelf waters were slightly higher than those observed in estuaries, but these levels appear to be comparable to results from other studies in offshore areas of the MAB. DIN:DIP ratios in surface waters ranged from 0.43 to 6.25, which are strongly indicative of nitrogen limitation (DIN:DIP < 16). Surface-water concentrations of chlorophyll a, an indicator of phytoplankton biomass and abundance, ranged from 0.01 µg/L to 3.30 µg/L and averaged 0.23 µg/L. Bottom-water concentrations of chlorophyll a were similar to concentrations in surface waters, ranging between 0.01 µg/L and 3.02 µg/L and averaging 0.3 µg/L. Chlorophyll a concentrations in offshore waters were much lower than in corresponding estuaries.

Shelf sediments of the MAB appeared to be relatively uncontaminated. No contaminants were found in excess of their corresponding Effects-Range Median (ERM) sediment quality guideline values. The entire survey region was rated in good condition (no chemicals above corresponding ERM values and < 5 chemicals above corresponding Effects-Range Low (ERL) values). Arsenic was one of only three chemicals that exceeded their corresponding ERL guidelines. The ERL exceedances for arsenic occurred at three sites, representing 6.3 % of the survey area. The overall range of concentrations for arsenic was within the range typical of uncontaminated near-shore marine sediments and reflects its natural presence at low to moderate concentrations in crustal rocks of the region. Similarly, one site, representing 2.1 % of the study area, had nickel concentrations that just exceeded the ERL value of 20.9 µg/g. Concentrations of total DDT (sum of 2,4′-DDD, 4,4′-DDD, 2,4′-DDE, 4,4′-DDE, 2,4′-DDT, and 4,4′-DDT) were detectable in sediment samples at eight sites and exceeded the ERL guideline of 1.58 ng/g at five sites, which represent 10 % of the study area. Total DDT levels were below the limit of detection at all of the remaining 40 sites where sediment samples were

collected. Many of the other chemicals measured in this study also were below method detection limits.

Because none of the species of fish targeted for chemical contaminant analysis were collected on the core May 2006 survey, samples of summer flounder (*Paralichthys dentatus*) were obtained from a subsequent winter bottom-trawl survey conducted February 6 – March 2, 2007 by the NOAA Fisheries Service, Northeast Fisheries Science Center (NFS/NEFSC) and used for this purpose. Fish samples were taken from 30 bottom-trawl locations in shelf waters between Sandy Hook, NJ and Cape Hatteras, NC. Concentrations of a suite of metals, pesticides, and PCBs were measured in edible tissues (fillets) of 30 individual summer flounder, one each from the 30 trawl sites, and compared to risk-based EPA advisory guidelines for recreational fishers. None of the 30 stations where fish were measured had chemical contaminants in fish tissues above the corresponding upper human-health endpoints. Thus none of these stations were rated as "poor" with respect to contaminant body burdens. Three stations had total PCB concentrations in tissues that were between the corresponding lower and upper endpoints and thus were rated as "fair." All other stations had concentrations of contaminants that were below corresponding lower endpoints and thus were rated as "good."

Benthic taxonomic richness was relatively high in MAB shelf assemblages, ranging from $9 - 50$ per 0.04-m^2 grab and averaging 28 taxa grab^{-1}. Diversity (Shannon H′ (log$_2$)) averaged 3.4 overall, varying between 1.9 and 4.4 throughout the study area, and tended to be higher among outer shelf sites compared to the inner shelf. A total of 381 taxa were identified (215 to species) in 95 grabs collected during the course of the survey. Polychaetes, crustaceans, and molluscs were the dominant taxa both by percent abundance (46 %, 36 %, and 10 %, respectively) and percent of taxa (43 %, 31 %, and 19 %, respectively). Densities ranged from $675 - 29,263$ m^{-2} and averaged 6,067 m^{-2}.

The 10 dominant (most abundant) taxa, in decreasing order of abundance, included the amphipod *Ampelisca agassizi*, the polychaetes *Polygordius* spp. and *Acmira catherinae*, tubuficid oligochaetes (Tubificidae), the amphipod *Unciola irrorata*, the polychaete *Spiophanes bombyx*, the tanaid *Tanaissus psammophilus*, the polychaetes *Exogone hebes* and *Goniadella gracilis*, and maldanid polychaetes (Maldanidae). Some of these dominant taxa (*Polygordius* spp., *Acmira catherinae*, Tubificidae, *Tanaissus psammophilus*) were more abundant on the inner shelf compared to the middle and outer shelf, while others (*A. agassizi*, *U. irrorata*, *S. bombyx*) were more abundant on the middle and outer shelf. The composition of offshore assemblages was markedly different from estuaries, with six of the ten offshore dominants either under-represented (found in < 10 % of samples) or completely absent from estuaries. The reverse also was true, with seven of the ten estuarine dominants being found either in low numbers (occurring in < 10 % of samples) or not at all offshore.

There were no non-indigenous species identified in samples collected in coastal shelf sediments of the MAB, although some (*Harmothoe imbricata*, *S. bombyx*) are considered to be cryptogenic, or of unknown origin. By comparison, a few cryptogenic (*Boccardiella ligerica*, *Monocorophium acherusicum*) and non-indigenous (*Branchiura*

sowerbyi, *Corbicula fluminea*) benthic infaunal species were identified in samples collected throughout mid-Atlantic estuaries as part of the U.S. EPA's National Coastal Assessment in 2005-2006. The above estuarine non-indigenous species would not be expected to occur offshore, however, since the shelf environment would be outside their normal (lower) salinity ranges.

This study found no evidence of biological impacts linked to measured stressors. In fact, no indications of poor sediment or water quality relative to published evaluation thresholds were observed. These results suggest that coastal shelf waters of the MAB are in good condition, with lower-end values of biological attributes representing parts of a normal reference range controlled by natural factors. Some influence of depth on diversity and taxonomic richness was observed, with deeper sites having slightly higher values for these measures.

Alternatively, it is possible that for some of these sites the lower values of benthic variables reflect symptoms of disturbance induced by other unmeasured stressors. In efforts to be consistent with the underlying concepts and protocols of earlier EMAP and NCA programs, the indicators in this study included measures of stressors, such as chemical contaminants and symptoms of eutrophication, which are often associated with adverse biological impacts in shallower estuarine and inland ecosystems. However, there may be other sources of human-induced stress in these offshore systems, particularly those causing physical disruption of the seafloor (e.g., commercial bottom trawling, cable placement, minerals extraction), that pose greater risks to living resources and which have not been adequately captured. Future monitoring efforts in these offshore areas should include indicators of such alternative sources of disturbance.

1.0 Introduction

The National Oceanic and Atmospheric Administration (NOAA) and the Environmental Protection Agency (EPA) each perform a broad range of research and monitoring activities designed to assess the status of coastal ecosystems and the potential effects of natural and human impacts. Authority to conduct such work is given by several legislative mandates including the Clean Water Act (CWA) of 1977 (33 U.S.C. §§ 1251 et seq.), National Coastal Monitoring Act of 1992 (Title V of the Marine Protection, Research, and Sanctuaries Act, 33 U.S.C. §§ 2801-2805), and the National Marine Sanctuary Act of 2000. To the extent possible, the two agencies have sought to coordinate related activities through partnerships with states and other institutions to prevent duplication of effort and to bring together complementary resources to fulfill common research and management goals. Accordingly, in May 2006, NOAA and EPA combined efforts to conduct a joint survey of ecological conditions throughout coastal shelf waters of the mid-Atlantic Bight (MAB). The MAB lies between Cape Cod and Nantucket Shoals to the northeast and Cape Hatteras to the south (Allen 1983) and is a sub-region of the Northeast U.S. Continental Shelf Large Marine Ecosystem (LME), one of 10 LMEs of the United States (U.S. Commission on Ocean Policy 2004) (Figure 1).

The present survey is part of a series of studies being conducted by NOAA and EPA to assess the condition of aquatic resources throughout coastal-ocean waters of the U.S. using multiple indicators of ecological condition. The protocols and design of these studies are similar to those used in EPA's Environmental Monitoring and Assessment Program (EMAP) and subsequent National Coastal Assessment (NCA), both of which have focused mainly on estuarine and inland waters. The offshore series extends these prior efforts onto the continental shelf, from approximately one nautical mile of the shoreline seaward to the shelf break (~100-m depth contour). Where applicable, sampling has been included in NOAA's National Marine Sanctuaries (NMS) to provide a basis for comparing conditions in these protected areas to surrounding non-sanctuary waters. To date such surveys have been conducted throughout the western U.S. continental shelf, from the Straits of Juan de Fuca, WA to the U.S./Mexican border (see Nelson et al. 2008 for final report); shelf waters of the South Atlantic Bight (SAB) from Cape Hatteras, NC to West Palm Beach, FL (see Cooksey 2004 for cruise report); the continental shelf off southern Florida, from West Palm Beach in the Atlantic Ocean to Anclote Key in the Gulf of Mexico (see Cooksey and Hyland 2007 for cruise report); and shelf waters of the mid-Atlantic Bight (MAB) from Cape Hatteras to Cape Cod, MA (the present assessment). There are plans to continue these surveys throughout the central and western portions of the Gulf of Mexico in summer 2010 and throughout the remainder of the North Atlantic coast of the U.S., from Cape Cod to the Canadian border, in 2011.

The purpose of the present study was to assess the current status of ecological condition and stressor impacts throughout the MAB region and to provide this information as a framework for evaluating future changes due to natural or human-induced disturbances. To address this objective, the study incorporated standard methods and indicators applied in previous coastal EMAP/NCA projects (U.S. EPA 2001a, 2004, 2008) including

multiple measures of water quality, sediment quality, and biological condition (benthic community health and fish tissue contamination). Synoptic sampling of the various indicators provided an integrative weight-of-evidence approach to assessing condition at each station and a basis for examining potential associations between presence of stressors and biological responses. Another key feature was the incorporation of a probabilistic sampling design with stations (49 in total) positioned randomly throughout the study area. The probabilistic sampling design provided a basis for making unbiased statistical estimates of the spatial extent of condition relative to the various measured indicators and corresponding thresholds of concern. Other surveys in the current coastal-ocean series have applied stratified random sampling designs, with stations stratified by NMS vs. non-sanctuary status. However, the boundaries of the present MAB study did not encompass NMSs, thus the assessment of condition relative to these various indicators did not include sanctuary vs. non-sanctuary comparisons.

Because the protocols and indicators are consistent with those used in previous EMAP/NCA estuarine surveys, comparisons can be made between conditions in offshore waters and those observed in neighboring estuarine habitats, thus providing a more holistic account of ecological conditions and processes throughout the inshore and offshore resources of the region. Such information should provide valuable input for future National Coastal Condition Reports, which historically have included limited coverage in offshore areas (e.g., U.S. EPA 2001a, 2004, 2008).

Results of this study should also provide valuable support to evolving interests within the U.S. and other parts of the world to move toward an ecosystem approach to management (EAM) of coastal resources (Murawski 2007; Marine Ecosystems and Management 2007). Integrated Ecosystem Assessments (IEAs) have been identified as an important component of an EAM strategy (Murawski and Menashes 2007; Levin et al. 2008, 2009). An IEA is a synthesis and quantitative analysis of information on relevant natural and socio-economic factors in relation to specified ecosystem management goals (Levin et al. 2008, 2009). Initial steps in the IEA process include the assessment of baseline conditions defining the status of the system as well as the assessment of stressor impacts and their links to source drivers and pressures. Results of the present study will be available to support such initial steps in the development of any future IEA for the Northeast U.S. Continental Shelf LME. While the focus of the present study is on indicators of ecological condition, some human-dimension indicators have been included as well (e.g., fish contaminant levels relative to human-health guidelines, water clarity, marine debris, foul odors, oil slicks), which can be used to help address common public concerns such as "Are the fish safe to eat?" or "Is the water clean enough to swim in?" Humans are considered as both sources and receptors of ecosystem impacts in the IEA and EAM process.

2.0 Methods

2.1 Sampling Design and Field Collections

The sampling frame for this study was based on a generalized random-tessellation stratified (GRTS) design. The GRTS design represents a unified strategy for selecting spatially balanced probability samples of natural resources, in which sampling sites are more or less evenly dispersed over the extent of the resource (Stevens & Olsen 2004). Sampling was conducted from May 13 – 21, 2006 at 49 stations located throughout coastal shelf waters of the MAB region, from Cape Cod to Cape Hatteras and within approximately 1 nautical mile (NM) of shore seaward to the 100-m isobath (Figure 1, Appendix A). The study is one of a series of assessments being conducted in coastal-ocean waters of the U.S., using consistent methods and indicators to support national comparisons.

Vertical water-column profiles of conductivity/salinity, temperature, depth, dissolved oxygen, and pH were conducted at each station using a Sea-Bird Electronics (SBE) Conductivity-Temperature-Depth (CTD) profiler, equipped with supplemental dissolved oxygen and pH sensors. The CTD was an SBE 9Plus with an 11Plus deck unit that provided real-time data recording of the vertical profile. The CTD was incorporated into a frame that included a rosette of 12 Nisken bottles used to collect water samples at discrete depths (near-surface, mid-depth, and near-bottom). Water samples were analyzed for nutrients, total suspended solids (TSS), and chlorophyll *a*.

The CTD was lowered into the water until completely submerged and held just beneath the surface for three minutes while the water pump was allowed to purge any air from the system. The unit was then lowered to within one meter of the bottom at a rate of approximately 1 m s^{-1}. Four Nisken bottles were fired at approximately 1 m below the surface, four at mid-depth, and the remaining four at near-bottom (approximately 1 m off the bottom).

Sediment samples were collected using a 0.04-m^2 Young-modified Van Veen grab sampler. Two replicate grab samples were retained for analysis of benthic infaunal composition, sieved onboard through a 0.5-mm screen, and preserved in 10% buffered formalin with rose bengal stain. The upper 2 – 3 cm of sediment from additional grabs (typically 1 or 2) was combined to yield a sediment composite, which was then homogenized and sub-sampled for analysis of metals, organic contaminants (pesticides, PCBs, PAHs), grain size (% silt-clay), and total organic carbon (TOC). Sediment samples (other than infauna) were kept frozen onboard the ship and later transferred to the respective analytical laboratories for analysis.

Hook-and-line fishing was attempted at all 49 stations. Targeted species included members of the families Bothidae (flatfish), Serranidae (seabass), Sparidae (scup), and Gadiformes (hake). Unfortunately, none of the targeted species were collected during the May 2006 sampling effort. However, through collaboration with the NOAA Fisheries Service/Northeast Fisheries Science Center (NFS/NEFSC) winter 2007 bottom-trawl

survey (NFS/NEFSC 2007), specimens of summer flounder (*Paralichthys dentatus*) were obtained from 30 of their stations in overlapping portions of the study area (Fig 1B). Edible tissue (fillets) from these specimens was analyzed for metals, pesticides, PAHs, PCBs, and PBDEs. While these fish were not collected during the May 2006 survey, they should help to provide an indication of the levels of contaminants in edible fish tissues likely to be encountered in the MAB region.
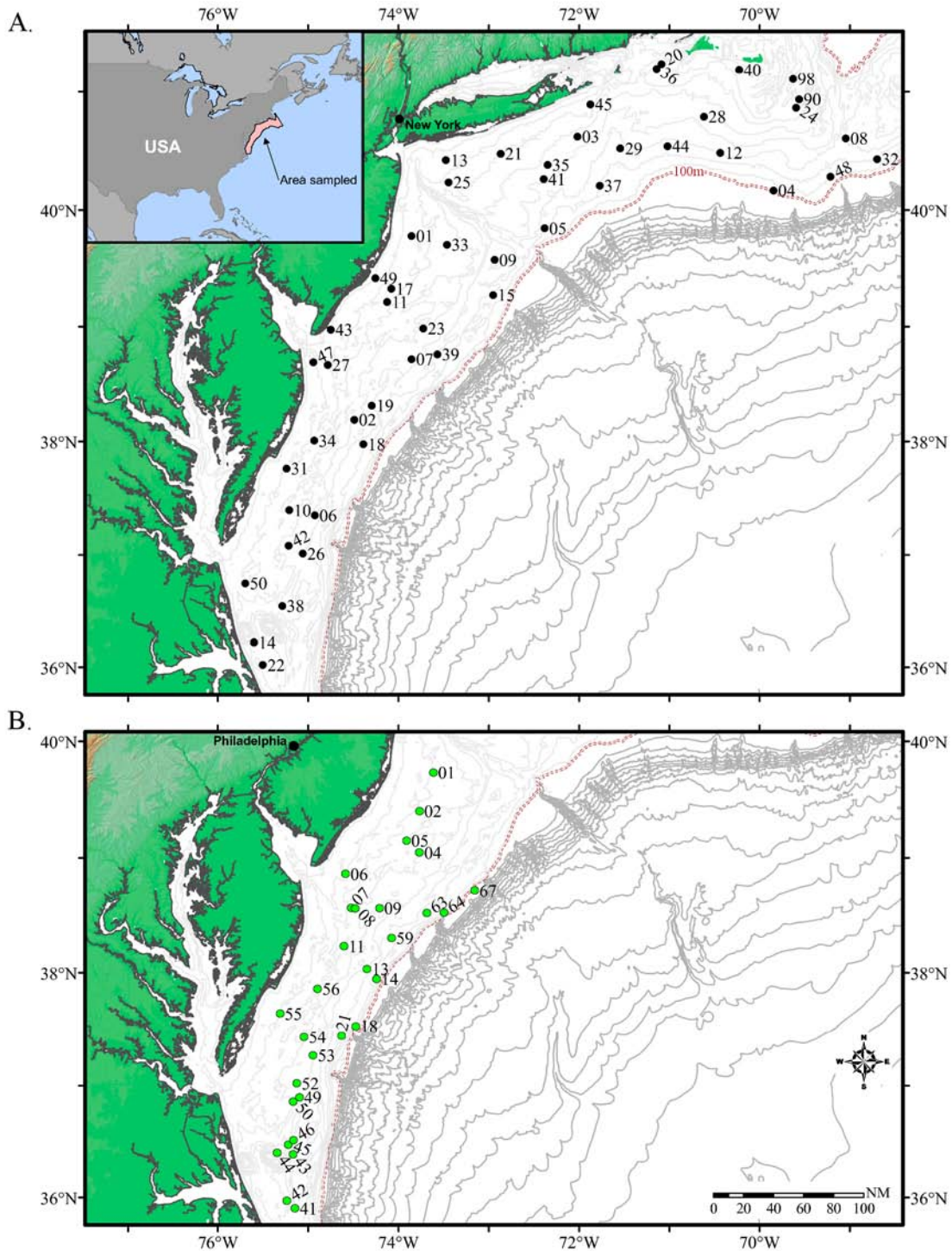
Figure 1. A. Map of study area and station locations. B. Map showing location of 2007 NFS/NEFSC trawl locations used for fish tissue contaminant analysis.

2.2 Water Quality Analysis

Readings of temperature, conductivity/salinity, dissolved oxygen, depth, and pH were recorded directly from the CTD unit during its descent and ascent through the water column. An index of density stratification ($\Delta\sigma_t$) was calculated as the difference between the computed bottom and surface density (σ_t) values, where σ_t is the density of a parcel of water with a given salinity and temperature relative to atmospheric pressure (Fofonoff and Millard 1983). Dissolved inorganic nutrients, including nitrate (NO_3^-), nitrite (NO_2^-), orthophosphate (HPO_4^{2-}), silicate ($HSiO_3^-$), and ammonium (NH_4^+); chlorophyll *a*; and total suspended solids (TSS) were sampled at discrete water depths (near surface, mid-water, and near-bottom) and analyzed following standard methods (U.S. EPA 1997; U.S. EPA 1995). Only surface and bottom values for these various indicators are presented in this report. Data for all depths are included in the study database and are available on request to the authors.

2.3 Sediment TOC and Grain Size Analysis

Samples for grain size analysis were homogenized and diluted to a suspended slurry with the aid of a chemical dispersant and the suspension was passed through a 63µm sieve. The fine fraction passing through the sieve (< 63µm) and the coarse fraction retained on the sieve (> 63µm) were separately dried and weighed (see U.S. EPA 1995). Total organic carbon (TOC) was determined by combusting pre-acidified samples at high temperature and measuring the volume of carbon dioxide gas produced (U.S. EPA 1995).

2.4 Sediment Contaminant Analysis

Sediments were analyzed for a suite of metals and organic pollutants using analytical methods from the NOAA NS&T Program (Lauenstein and Cantillo 1993) or described in the EMAP Laboratory Methods Manual (U.S. EPA 1995). Quality assurance/quality control principles followed those outlined for the EMAP/NCA (U.S. EPA 2001b).

Sediment samples were extracted and analyzed for the presence of most metals (Ag, Al, As, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Sb, Se, Sn, Zn) using hydrofluoric acid digestion and inductively-coupled plasma mass spectrometry (ICP-MS) using EPA method 6020A (U.S. EPA 2006). Analysis of sediment samples for Hg was conducted using cold vapor atomic absorption spectrometry (CVAA) consistent with EPA method 7471A (U.S. EPA 2006).

Samples for analysis of semi-volatile organic compounds (PAHs) were extracted using EPA method 3550B (U.S. EPA 2006) and analyzed by gas chromatography/mass spectrometry (GC/MS) using a modified low-level method 8270C (U.S. EPA 2006). Samples were extracted and analyzed for pesticides following EPA method 8081A (U.S. EPA 2006). The sample extracts underwent florisil cleanup. Sample extraction and analysis for PCBs used EPA method 8082A (U.S. EPA 2006). The sample extracts underwent sulfur and acid cleanup procedures.

2.5 Fish Tissue Analysis

Fish tissues were analyzed for a suite of metals and organic contaminants using methods previously described by Cooksey et al. (2008). Fish fillets were homogenized using a ProScientific homogenizer in 500mL Teflon containers. The well-homogenized samples were split into separate aliquots for inorganic and organic contaminant analysis.

Tissue samples for all inorganic analytes except silver and mercury were analyzed using nitric acid digestion and inductively-coupled plasma mass spectrometry (ICP-MS). Silver was analyzed using Graphite Furnace Atomic Absorption (GFAA). Analysis of tissues for mercury was conducted using a Milestone DMA-80 Direct Mercury Analyzer.

Aliquots of tissue homogenates for organic contaminant analysis were mixed with anhydrous sodium sulfate to form a dry powder and then extracted in methylene chloride using Accelerated Solvent Extraction (ASE). Following extraction, the residual water was removed by passing the extract through phase separation paper containing a small amount of sodium sulfate. After drying, the extracted sample was concentrated to 1000 µL on an automatic concentrator (TurboVap). Lipid and other high molecular weight components were then removed by size exclusion chromatography (SEC). Following SEC, the volume was reduced to about 1000 µL and the extract was split into two equal aliquots (~500 µL each) for subsequent cleanup and analysis.

Following cleanup using silica solid-phase extraction columns, tissue sample extracts were analyzed for PCBs, PBDEs, and DDTs using an Agilent 6890/5973N GC/MS operating in the electron impact ionization (EI) mode. Additional organochlorine pesticides (eg. aldrin, dieldrin, heptachlor, mirex) were analyzed using similar instrumentation in the negative chemical ionization (NCI) mode. Analysis for PAHs was conducted using a Varian 4000 GC/MS. Spiked blank, reagent blank, and appropriate standard reference materials were included with each set (18) of samples to ensure the integrity of the analytical method.

2.6 Benthic Community Analysis

The status of benthic communities was assessed using standard measures of abundance (density/m^2), richness (number of taxa), and diversity (Shannon H′; Shannon 1948, Hayek and Buzas 1997). H′ was calculated using base-2 logarithms. Total faunal abundance was used to rank dominant taxa. Taxa were grouped according to higher taxonomic classifications to determine relative percentages (by abundance and number of taxa) of major groups of organisms (i.e., polychaetes, crustaceans, molluscs, echinoderms, other taxa). The full list of identified taxa was examined to evaluate the incidence of non-indigenous species vs. native species or ones with indeterminate status relative to invasiveness.

2.7 Quality Assurance

2.7.1 Quality Assurance and Quality Control

The quality assurance/quality control (QA/QC) program followed during the Mid-Atlantic Bight assessment is described in the "Environmental Monitoring and Assessment Program (EMAP): National Coastal Assessment Quality Assurance Project Plan 2001-2004" (U.S. EPA 2001b). A performance-based approach was employed, featuring the following standard practices: 1) continuous laboratory evaluation through the use of Certified Reference Materials (CRMs), Laboratory Control Materials (LCMs), or Standard Reference Material (SRM); 2) laboratory spiked sample matrices; 3) laboratory reagent blanks; 4) calibration standards; 5) analytical surrogates; and 6) laboratory and field replicates. The objective of this performance-based approach was to assist the laboratories in meeting desired Data Quality Objectives (DQOs) as defined in the EMAP Quality Assurance Project Plan (U.S. EPA 2001b). The subsequent sections provide details of the QA procedures followed by analytical laboratories conducting analyses in this report.

2.7.2 Water Quality Analyses

Nutrient analyses were conducted by B&B Laboratories, College Station, Texas. The QA/QC procedures included the analyses of a method blank, spike/recovery check sample and every 10 to 15 samples. Method blanks were used to determine that sample preparation and analyses are free of contaminants. The duplicate sample was used to determine the precision of the analysis. Spike/recovery samples were used to verify analytical accuracy. All blanks and spike/recovery samples were subject to the identical preparation and analysis steps as samples. The QA criterion for duplicate samples was 30% relative percent difference (RPD), and 10% of the true value for spike recovery check sample. All analyses conducted for this assessment successfully met QA/QC criteria.

2.7.3 Sediment Contaminant Analyses

Analyses of marine sediment samples were performed by GPL Laboratories of Frederick, MD and CRG Laboratories of Torrance, CA. Both laboratories have well-defined QA/QC guidelines described in their respective Quality Assurance Program Plan documents. The QA program plans met or exceeded EPA recommended guidelines with quality control samples accounting for at least 20% of the total number of samples analyzed. The Quality Assurance Manager ensured that facilities, equipment, personnel methods, records, and Quality Control procedures were in conformance with Standard Operating Procedures (SOPs) as well as with applicable EPA QC guidelines.

Laboratories applied the following QA/QC procedures during the analyses:

BATCH: Quality Assurance Program Documents defined a batch as a group of 20 or fewer samples of similar matrix, processed together under the same conditions and with

the same reagents. Quality control samples were associated with each batch and were used to assess the validity of the sample analyses. Batch sizes of 10-15 samples were typically used.

PROCEDURAL BLANKS: Laboratory contamination was controlled through the analysis of procedural blanks on a minimum frequency of 1 per batch. Quality Assurance Program Plan documents required that all procedural blanks be below 10 times the MDL and all detectable constituents in the blanks be flagged in the sample results.

ACCURACY: Accuracy of the project data was indicated by analysis of matrix spikes, surrogate spikes, certified reference materials, and/or laboratory control materials on a minimum frequency of 1 per batch. Quality Assurance Program Plan documents required that 95% of the target compounds greater than 10 times the MDL be within the specified acceptance limits. The requirements for PAHs, PCBs, and pesticides are that the "Lab's value should be within ± 30% of true value on average for all analytes, not to exceed ± 35% of true value for more than 30% of individual analytes" (U.S. EPA 2001b). For metals and other inorganic compounds, the laboratory's value for each analyte should be within ± 20% of the true value of the CRM, LCM, or SRM.

PRECISION: Precision of the project data was determined by analysis of duplicate matrix spikes, blank spikes, and/or duplicate test sample analysis on a minimum frequency of 1 per batch. Quality Assurance Program Plan documents required that for 95% of the compounds > 10 times the MDL, the Relative Percent Difference (RPD) should be within the specified acceptance range: RPD or CV should be <30%. The RPD for the duplicate test sample analysis can be affected significantly by the homogeneity of the sample matrix within the sample container itself, causing additional variability in the analytical results. In these cases, the QA/QC Acceptance Limits may be exceeded.

In all cases of QA reports for batches, procedural blanks and certified reference materials passed the stated accuracy and reproducibility criteria. However, failures of two types were commonly reported: 1) The Relative Percent Difference (RPD) of unspiked duplicate samples was out of control because the concentrations of PAHs, PCBs, or pesticides in the sample were too small for reliable analysis (less than 10 times the MDL, which is comparable to the Reporting Limit commonly used to evaluate precision in samples with complex matrix effects); 2) Often for Al and Fe, spike recovery and RPD control limits did not apply because the concentration in the sample exceeded the spike concentration (i.e., the metals were not truly trace elements). The Quality Control Manager determined that neither of these failures affected the goals of the program and the batch data were accepted.

2.7.4 Benthic Taxonomy

Identification and enumeration of benthic fauna was performed by Barry A. Vittor & Associates, Inc., Mobile, Alabama. Only skilled taxonomists conducted organism identification. A minimum of 10% of samples were rechecked by other qualified taxonomists for accuracy in identification and enumeration. Species lists from different

labs were cross-checked, with external experts consulted for difficult identifications. Judged accuracy rates were well above standard levels for sorting and taxonomy (quality control reworks all $\geq$ 95 %).

2.7.5 Tissue Contaminant Analyses

QA/QC procedures for tissue contaminant analyses were similar to those described above for sediment contaminants. Spiked blank, reagent blank, and appropriate standard reference materials were included with each set of samples to ensure the integrity of the analytical method.

2.8 Data Analysis

The probabilistic sampling design used in this study allows calculation of estimates of the percent area of the resource that corresponds to specified values of a given parameter under consideration. Estimated cumulative distribution functions (CDFs), point estimates, and 95% confidence intervals were developed for water quality, sediment, and biological parameters measured in this study using formulas described in the EMAP statistical methods manual (Diaz-Ramos 1996). Calculation of CDFs was facilitated using algorithms (*spsurvey* package; Kincaid 2008) developed for R, a language and environment for statistical computing and graphics (R Development Core Team 2008).

Measured parameters were compared to established thresholds of concern, where available (Tables 1–3), and the corresponding percentiles of the estimated CDFs were reported. Where no such recommended levels of concern exist (e.g., benthic metrics), common distributional properties are reported (e.g., lower or upper percentiles).

Results of this study are compared, where appropriate, to results for estuaries from the U.S. Environmental Protection Agency's National Coastal Assessment 2005-2006 database (NCA 2006). Many of the same parameters measured in the current study also were measured as part of the NCA in estuaries of the Virginian Province, which includes the coastal region of the northeast United States from Cape Cod, MA to the mouth of Chesapeake Bay. The Virginian Province includes Chesapeake Bay which, in terms of area, represents 62 % of the Province (NCA 2006). The Chesapeake Bay system also experiences conditions which are distinctly different from other estuaries in the Province (U.S. EPA 2008). Hence, some comparisons with the NCA 2005-2006 data are further subdivided into Chesapeake Bay and non-Chesapeake Bay portions of the Province.

Table 1. Thresholds used for classifying samples relative to various environmental indicators.

Indicator	Threshold	Reference
Water Quality		
Salinity (psu)	< 5 = Oligohaline 5 – 18 = Mesohaline >18 – 30 = Polyhaline > 30 = Euhaline	Carriker 1967
$\Delta \sigma_t$	> 2 = strong vertical stratification	Nelson et al. 2008
DO (mg/L)	< 2 = Low (Poor) 2 – 5 = Moderate (Fair) > 5 = High (Good)	USEPA 2008; Diaz and Rosenberg 1995
DIN/DIP	> 16 = phosphorus limited < 16 = nitrogen limited	Geider and La Roche 2002
Sediment Quality		
Silt-Clay Content (%)	> 80 = Mud 20 – 80 = Muddy Sand < 20 = Sand	USEPA 2008
TOC Content (mg/g)	> 50 = High (Poor) 20 – 50 = Moderate (Fair) < 20 = Low (Good)	USEPA 2008
	> 36 = High (Poor)	Hyland et al. 2005
Overall chemical contamination of sediments	≥ 1 ERM value exceeded = High (Poor); ≥ 5 ERL values exceeded = Moderate (Fair); No ERMs exceeded and < 5 ERLs exceeded = Low (Good)	USEPA 2008
Individual chemical contaminant concentrations in sediments	> ERM High probability of bioeffects < ERL = Low probability of bioeffects	Long et al. 1995a; Table 2 herein

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Table 1 (continued).

Indicator	Threshold	Reference
<u>Biological Condition</u>		
Reduced benthic taxonomic richness, diversity, or abundance	$\leq$ lower 10th percentile of all values for corresponding variable	Nelson et al. 2008
Chemical Contaminants in Fish Tissues	$\geq$ 1 chemical exceeded Human Health upper limit = High (Poor) $\geq$ 1 chemical within Human Health risk range = Moderate (Fair) All chemicals below Human Health lower risk limit = Low (Good)	USEPA 2008
Individual chemical contaminants in fish tissues	Non-cancer (chronic systemic effects) endpoints based on consumption of four 8-ounce meals per month (general adult population). Cancer risk endpoints (1 in 100,000 risk level) based on consumption of four 8-ounce meals per month (general adult population).	USEPA 2000; Table 3 herein

Table 2. ERM and ERL guideline values in sediments (Long et al. 1995a).

Chemical	ERL	ERM
Metals (µg/g)		
Arsenic	8.2	70
Cadmium	1.2	9.6
Chromium	81	370
Copper	34	270
Lead	46.7	218
Mercury	0.15	0.71
Nickel	20.9	51.6
Silver	1	3.7
Zinc	150	410
Organics (ng/g)		
Acenaphthene	16	500
Acenaphthylene	44	640
Anthracene	85.3	1100
Fluorene	19	540
2-Methylnaphthalene	70	670
Naphthalene	160	2100
Phenanthrene	240	1500
Benzo[a]anthracene	261	1600
Benzo[a]pyrene	430	1600
Chrysene	384	2800
Dibenz[a,h]Anthracene	63.4	260
Fluoranthene	600	5100
Pyrene	665	2600
Low molecular weight PAHs	552	3160
High molecular weight PAHS	1700	9600
Total PAHs	4020	44800
4,4-DDE	2.2	27
Total DDT	1.58	46.1
Total PCBs	22.7	180

Table 3. Risk-based EPA advisory guidelines for recreational fishers (USEPA 2000a).

	EPA Advisory Guidelines Concentration Range[a]	Health Endpoint
Metals (μg/g)		
Arsenic (inorganic)[b]	0.35 – 0.70	non-cancer
Cadmium	0.35 – 0.70	non-cancer
Mercury (methylmercury)[c]	0.12 – 0.23	non-cancer
Selenium	5.9 – 12.0	non-cancer
Organics (ng/g)		
Chlordane	590 – 1200	non-cancer
DDT (total)	59 – 120	non-cancer
Dieldrin	59 – 120	non-cancer
Endosulfan	7000 – 14000	non-cancer
Endrin	350 – 700	non-cancer
Heptachlor epoxide	15 – 31	non-cancer
Hexachlorobenzene	940 – 1900	non-cancer
Lindane	350 – 700	non-cancer
Mirex	230 – 470	non-cancer
Toxaphene	290 – 590	non-cancer
PAHs (benzo[a]pyrene)	1.6 – 3.2	cancer[d]
PCB (total)	23 – 47	non-cancer

[a] Range of concentrations associated with non-cancer and cancer health endpoint risk for consumption of four 8-oz meals per month.
[b] Inorganic arsenic, the form considered toxic, estimated as 2% of total arsenic.
[c] Because most mercury present in fish and shellfish tissue is present primarily as methylmercury and because of the relatively high cost of analyzing for methylmercury, the conservative assumption was made that all mercury is present as methylmercury (U.S. EPA, 2000a).
[d] A non-cancer concentration range for PAHs does not exist.

3.0 Results and Discussion

Not all of the originally targeted 50 stations could be sampled for all parameters. Two stations (16 and 46) off of Cape Cod were located in waters that were hazardous to navigation, and were replaced with alternate stations 90 and 98, respectively. Station 98 was over rocky, hard-bottom habitat and only water samples were collected at the site. The last station to be sampled during the survey cruise was station 30, but due to vessel problems which used up the remaining cruise time, this station could not be sampled. In all, sediment samples were collected at 48 of the original 50 sites; water quality samples were collected at 49 sites.

3.1 Depth and Water Quality

3.1.1 Depth

Bottom depths for the 49 stations sampled in coastal shelf waters of the MAB ranged from 13.6 m to 98.3 m (Table 4, Figure 2). The shallowest sites were located in near-coastal waters off of Delaware and New Jersey (stations 27, 43, 47, and 49), while the deepest sites were seaward of Nantucket Shoals near the 100 m depth contour. The mean depth of all sites sampled was 45 m.

Table 4. Summary of depth and water-column characteristics for near-bottom (lower 3 m) and near-surface (0.5 - 4 m) waters.

	Near-bottom water					Near-surface water				
	Mean	Range	CDF 10th pctl	CDF 50th pctl	CDF 90th pctl	Mean	Range	CDF 10th pctl	CDF 50th pctl	CDF 90th pctl
Depth (m)	44.9	13.6 – 98.3	18.9	40.3	75.2	—	—	—	—	—
$\Delta\sigma_t$	0.66	0.00 – 1.81	0.06	0.65	1.21	—	—	—	—	—
Temperature (°C)	10. 2	6.5 – 13.9	7.3	10.0	13.5	11.6	7.8 – 17.9	9.3	11.1	14.4
Salinity (psu)	32.8	30.0 – 35.0	31.5	32.5	34.4	32.2	30.0 – 35.3	31.1	32.2	33.0
DO (mg/L)	9.1	8.4 – 9.9	8.5	9.0	9.7	8.9	7.7 – 9.7	8.4	8.9	9. 3
pH	8.3	8.0 – 8.6	8.1	8.3	8.6	8.4	8.1 – 8.6	8.1	8.4	8.6
DIN (mg/L)	0.13	0.01 – 0.54	0.02	0.04	0.29	0.04	0.01 – 0.20	0.01	0.03	0.06
DIP (mg/L)	0.05	0.02 – 0.12	0.03	0.05	0.08	0.04	0.02 – 0.06	0.03	0.04	0.05
DIN/DIP	3.83	0.68 – 10.88	0.84	2.26	8.50	1.91	0.43 – 6.25	0.80	1.52	3.55
Chl *a* (µg/L)	0.30	0.01 – 3.02	0.02	0.08	0.77	0.23	0.01 – 3.30	0.02	0.09	0.57
TSS (mg/L)	6.9	1.1 – 36.4	2.0	5.6	12.0	5.6	0.9 – 13.5	2.2	4.9	10.1

3.1.2 General Water Characteristics: Temperature, Salinity, Water-Column Stratification, DO, pH, TSS

Temperatures of surface water (0.5 to 4 m) ranged from 7.8 ℃ to 17.9 ℃ (Table 4). Fifty percent of the area sampled had surface temperatures $\leq$ 11.1 ℃, and only 10 % of the area had temperatures greater than 14.4 ℃ (CDF 90th percentile, Table 4). Bottom-water temperatures (lower 3 m of the water column) were slightly cooler, ranging from 6.5 ℃ to 13.9 ℃, with 50 % of the area being $\leq$ 10 ℃ and 10 % exceeding 13.5 ℃. The coldest bottom-water temperatures were observed in association with the "cold pool", an area of cold, low-salinity water supplied by the Gulf of Maine and Georges Bank (Beardsley et al. 1976). The "cold pool" occupies a region of the middle shelf along the southern flank of Georges Bank and Nantucket Shoals, flowing westward and then south, roughly parallel to the shoreline. It is bounded by an area of warmer, more saline slope water along the shelf break.

Surface salinities varied between 30 psu and 35.3 psu. The mean and 50th percentile (based on area) were 32.2 psu, with 10 % of the area having surface salinities between 33 psu and 35.3 psu. The majority of sites (representing approximately 80 % of the area) had surface salinities between 31 and 33 psu. Bottom salinities varied between 30 and 35 psu, with fewer sites (representing about 65 % of the area) having bottom salinities between 31 and 33 psu. A greater number of sites (about 31 % area) had salinities > 33 psu in near-bottom waters compared to the surface (10 % area). Ten percent of the study area had bottom salinities > 34.4 psu, compared to only 4.1 % of area for surface waters.

Little evidence of density stratification was observed among the stations sampled in this study. Computed values of $\Delta\sigma_t$ indicate that coastal shelf waters of the MAB at the time of this sampling were well-mixed, with 83.7 % of the survey area having values of $|\Delta\sigma_t| \leq$ 1. Values of $\Delta\sigma_t$ ranged from 0 to 1.81, which are below the range considered to be indicative of strong vertical stratification ($\Delta\sigma_t > 2$; Nelson et al. 2008).

Consistent with the previous observations that the coastal shelf waters of the MAB were well-mixed vertically, DO levels indicated that the waters also were well-oxygenated. Measured DO concentrations occupied a fairly narrow range for both surface and bottom waters, with surface DO concentrations ranging between 7.7 mg/L and 9.7 mg/L and bottom water concentrations between 8.4 mg/L and 9.9 mg/L. None of these waters had DO at low levels (< 2 mg/L) potentially harmful to benthic fauna and fish (Table 4, Figure 2). DO levels in coastal shelf waters were relatively uniform compared to estuarine waters of the mid-Atlantic region, which have been shown to be highly variable, ranging from 0.4 – 12.7 mg/L in estuarine surface waters and 0.2 – 11.4 mg/L in bottom waters (NCA 2006).

Due to technical problems with the CTD, pH was measured at less than half (n = 23) of the 49 stations sampled during this survey. At the stations where pH was measured, the range of values was 8.1 – 8.6 for surface waters, and 8.0 – 8.6 for bottom waters, which falls approximately within the normal range for seawater of 7.5 – 8.5 (Pinet 2006).

Total suspended solids (TSS) ranged between 0.9 mg/L to 13.5 mg/L in surface waters. Fifty percent of the area had TSS values $\leq$ 4.9 mg/L, and 90 % of the area had surface TSS values $\leq$ 10.1 mg/L. With few exceptions, TSS concentrations in bottom waters were similar to those of surface waters. The area-weighted 50th and 90th percentiles were 5.6 mg/L and 12.0 mg/L, respectively. One station at the entrance to Delaware Bay (station 47) had a bottom-water TSS concentration of 36.4 mg/L. All other stations had TSS concentrations $\leq$ 16.3 mg/L. In comparison, suspended solids in estuaries were considerably higher than offshore, and more variable. TSS values for surface waters in estuaries ranged from 0.1 – 240 mg/L (mean of 17.2 mg/L) and bottom-water TSS averaged 20.9 and ranged from 0.1 – 314 mg/L (NCA 2006).

The full range of values across all stations, summarized above, is depicted as CDF plots in Figs. 2 and 3. The mean values by station (average of multiple CTD measurements for near-surface and near-bottom waters for each station) appear in Appendices B and C.
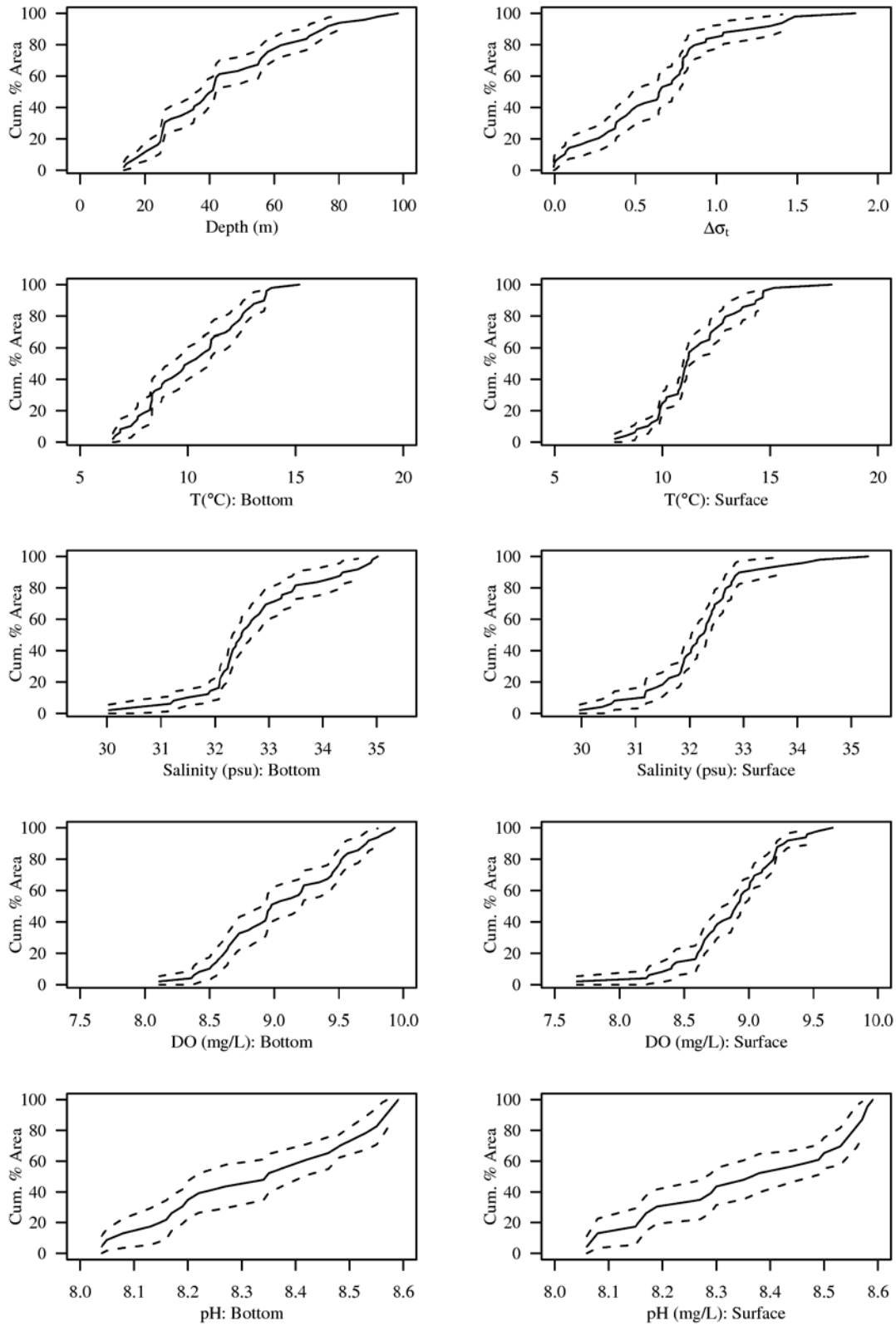
Figure 2. Percent area (and 95% confidence intervals) of MAB shelf waters *vs.* selected water-quality characteristics.
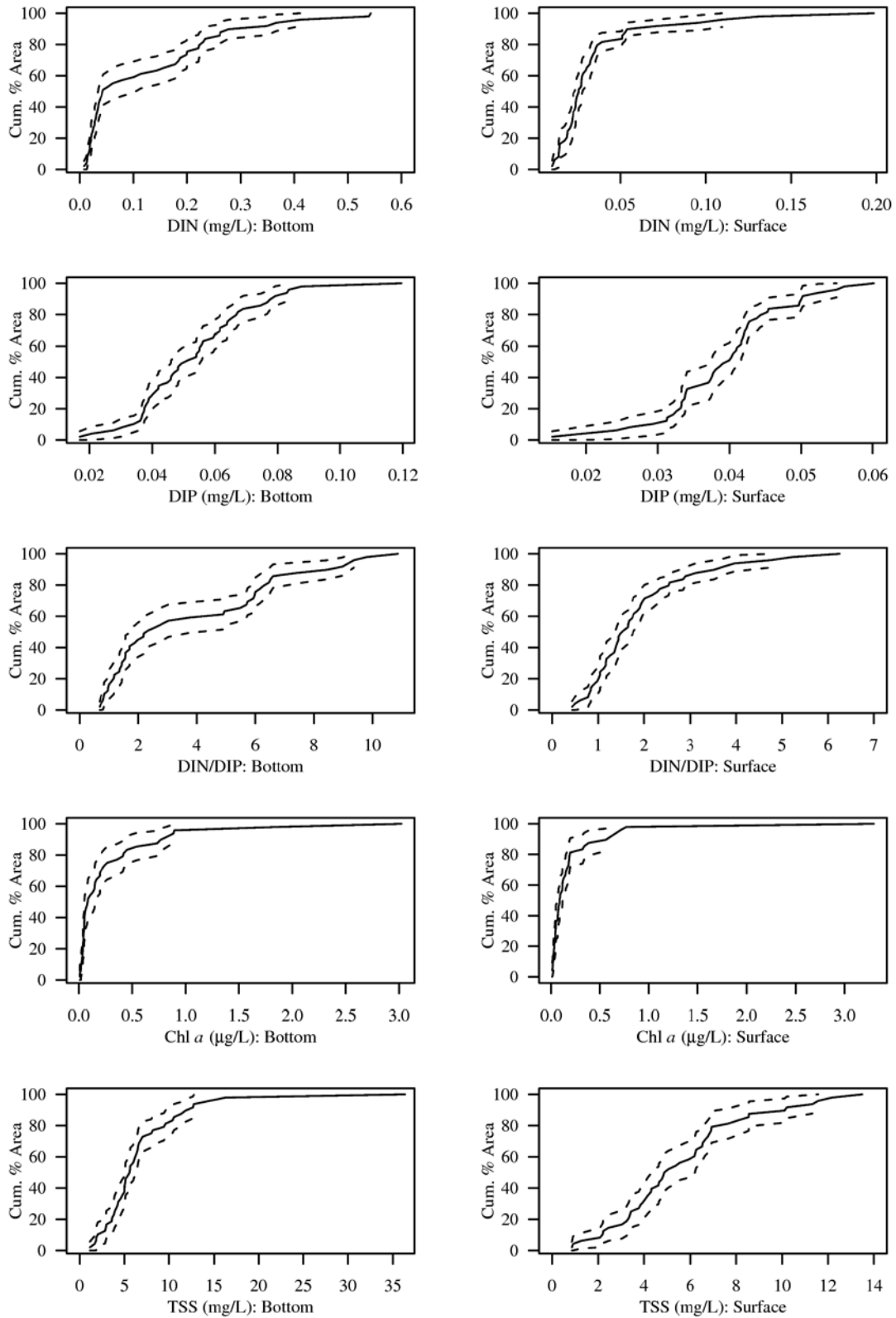
Figure 3. Percent area (and 95% confidence intervals) of MAB shelf waters *vs.* nutrient, chlorophyll, and TSS concentrations.

3.1.3 Nutrients and Chlorophyll

The concentration of dissolved inorganic nitrogen (DIN: nitrogen as nitrate + nitrite + ammonium) in surface waters ranged from 0.01 mg/L to 0.20 mg/L and averaged 0.04 mg/L (Table 4, Figure 3). Ninety percent of the study area surface waters had DIN concentrations $\leq$ 0.06 mg/L. Bottom water concentrations of DIN tended to be higher than surface concentrations. For example, only about 50% of bottom waters had DIN $\leq$ 0.06 mg/L and the average concentration was 0.13 mg/L (range of 0.01 – 0.54 mg/L). While there are no published water-quality guidelines for DIN in offshore waters, Figure 4 shows the spatial distribution of DIN in bottom waters relative to evaluation cutpoints established for neighboring estuaries (USEPA 2008). The figure depicts a clear pattern of higher bottom-water DIN levels along the outer shelf in comparison to inner-shelf sites. This observation is consistent with other published descriptions of the MAB, which have found nutrient levels to be higher in bottom waters than in surface waters, particularly along the outer shelf. Matte and Waldhauer (1984) found that concentrations of nutrients, particularly nitrate, in bottom waters of the shelf exhibit a general increase seaward and tend to remain high year-round. They suggest that slope waters rich in nutrients represent a reservoir of nitrogen that can replace nitrogen utilized from inshore waters. In comparison to these offshore waters, estuaries of the region tend to have higher levels of DIN, with values ranging from 0.01 – 3.0 mg/L in surface waters and averaging 0.17 mg/L (NCA 2006, results not shown). Similarly, bottom-water concentrations of DIN in estuaries ranged from 0.01 – 2.2 mg/L and averaged 0.15 mg/L.

Concentrations of dissolved inorganic phosphorus (DIP) in surface waters ranged between 0.02 mg/L and 0.06 mg/L and averaged 0.04 mg/L (Table 4). Ninety percent of the study area surface waters had DIP concentrations $\leq$ 0.05 mg/L. Bottom-water concentrations of DIP were slightly higher than those measured in surface waters, ranging from 0.02 mg/L to 0.12 mg/L and averaging 0.05 mg/L (Table 4). A much smaller portion of the study area (about 50 %) had bottom-water concentrations of DIP $\leq$ 0.05 mg/L. These DIP concentrations in bottom waters of the MAB coastal shelf are higher than those observed in estuaries of the region (e.g., 82 % of estuarine area with $\leq$ 0.05 mg/L of DIP; NCA 2006). While levels of DIP above 0.05 mg/L are considered high for estuaries and an indication of poor water quality (USEPA 2008), a similar interpretation may be inappropriate for offshore waters. There are no published water-quality guidelines for DIP in offshore waters, thus DIP > 0.05 mg/L in 50% of the study area is not necessarily an indication of abnormally high phosphate levels and deteriorating water quality.

Other studies of nutrient and chlorophyll distributions in offshore waters of the MAB region have found levels similar to those presented here. In their description of chlorophyll enhancement at the shelf break of the MAB, Ryan et al. (1999) noted that upwelling or vertical mixing to near-surface waters was required for the chlorophyll enhancement that they detected by remote sensing, since their study (May/June) occurred after the period of nutrient depletion and onset of stratified conditions that follow the well-mixed and nutrient-rich winter water-column conditions. Matte and Waldhauer (1984) reported that upwelling can be expected to occur during periods of southwesterly

winds; the mean wind direction for the period of May 13 – 21, 2006 (this study) was 207 degrees (calculated from NOAA National Buoy Data Center data). Cross-frontal mixing events between slope and shelf waters also are important in nutrient fluxes in the MAB (Townsend et al. 2005). Hence, nutrient levels observed during the present study appear to be comparable to results from other studies in the MAB region.

The ratio of DIN to DIP was calculated as an index of nutrient limitation. A DIN:DIP ratio > 16 is considered to be indicative of phosphorus limitation, while values of DIN:DIP < 16 suggest that nitrogen is the limiting factor for primary production (Geider and La Roche 2002). DIN:DIP ratios (Table 4) ranged from 0.43 to 6.25 (mean of 1.91) in surface waters, and from 0.68 to 10.88 (mean of 3.83) in bottom waters, which are strongly indicative of nitrogen limitation. In comparison, estuaries of the region tend to be less nitrogen-limited, or in some cases phosphorus-limited, with DIN:DIP ratios ranging from 0.12 – 24.1 (mean of 4.5) in bottom waters and from 0.01 – 112 (mean of 7.0) in surface waters (NCA 2006).

Surface-water concentrations of chlorophyll *a*, an indicator of phytoplankton biomass and abundance, ranged from 0.01 µg/L to 3.30 µg/L and averaged 0.23 µg/L (Table 4). Bottom-water concentrations of chlorophyll *a* were similar to concentrations in surface waters, ranging between 0.01 µg/L and 3.02 µg/L and averaging 0.3 µg/L. These levels tended to be lower than those observed in estuaries of the region, with surface-water concentrations in estuaries ranging from 0.1 – 302 µg/L (mean of 11.8 µg/L) and bottom-water concentrations ranging from 0.1 – 87.2 µg/L and averaging 5.9 µg/L.
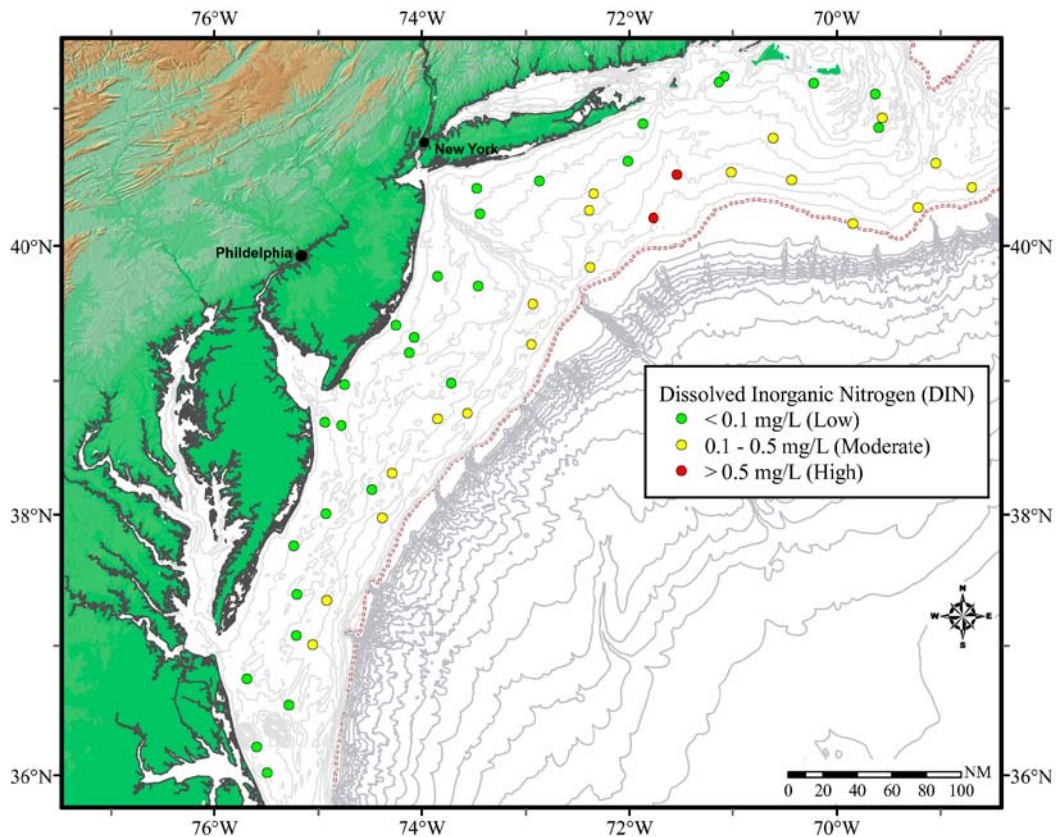
Figure 4. Map of study area showing distribution of DIN in bottom water.

3.2 Sediment Quality

3.2.1 Grain Size and TOC

The majority of the survey area (92 % area) consisted of bottom sediments composed of sands (< 20 % silt-clay content). Three sites had sediments composed of intermediate muddy sands (20 – 80 % silt-clay), and only one site had sediments classified as muds (> 80 % silt-clay). This is consistent with other studies (e.g., Rabalais and Boesch 1987) that have found shelf surface sediments to be composed of sands (> 75 % and mostly > 90 %) or gravelly sands to water depths of at least 200 m. Results from the present study are summarized in Table 5 and Figure 5.

TOC content of sediments was low, ranging from 0.27 – 16.04 mg/g and averaging 1.92 mg/g throughout the region (Table 5). Most of the study area (92 %) had sediment TOC concentrations < 5 mg/g and all sites (100% of the area) had concentrations < 20 mg/g, below levels associated with a moderate to high incidence of effects on benthic fauna (Figure 6).

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Table 5. Summary of sediment characteristics.

Parameter	Mean	Range	CDF 10th pctl	CDF 50th pctl	CDF 90th pctl
TOC (mg/g)	1.92	0.27 – 16.04	0.33	0.72	4.77
% silt-clay	6.6	0.2 – 86.9	0.3	0.9	19.3
Mean ERM-Q	0.007	0.001 – 0.031	0.001	0.005	0.011
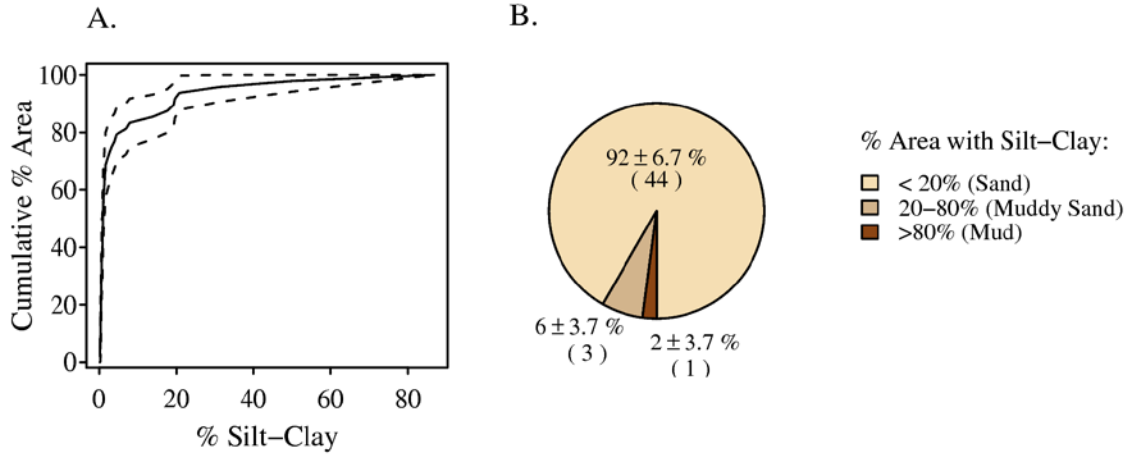
Figure 5. (A) Percent area (and 95% CI) represented by varying levels of the % silt-clay content of sediment, and (B) percent area having silt-clay content within specified ranges.
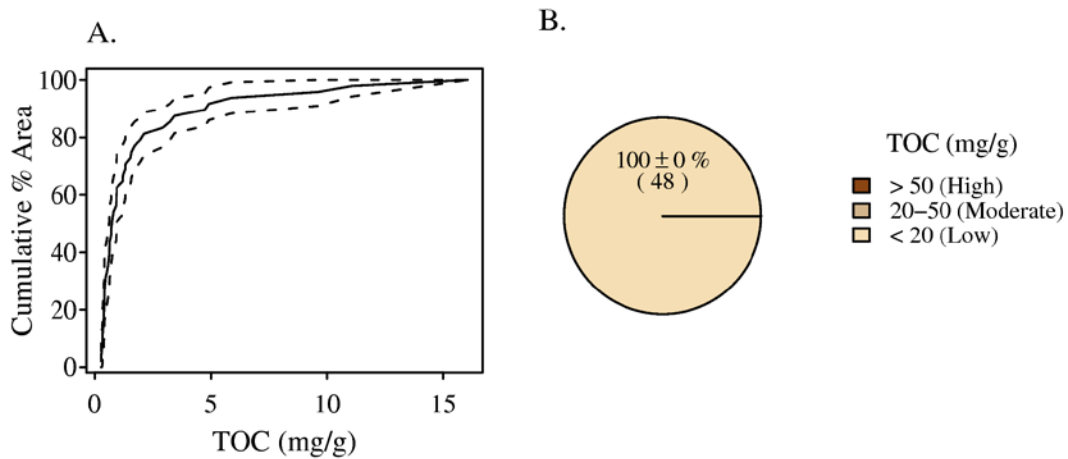
Figure 6. (A) Percent area (and 95% CI) represented by varying levels of TOC content of sediment (mg/g), and (B) percent area having TOC content within specified ranges.

3.2.2 Chemical Contaminants in Sediments

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The biological significance of chemical contamination of sediments was evaluated by comparing measured contaminant concentrations to sediment quality guidelines (SQGs) developed by Long et al. (1995a). Effects-Range Low (ERL) values represent lower bioeffect limits, below which adverse effects of contaminants on sediment-dwelling organisms are not likely to occur (the ERL corresponds to an expected incidence of toxicity of about 10%). Effects-Range Median (ERM) values are mid-range concentrations above which adverse biological effects are more likely to occur (the ERM is the concentration corresponding to an expected incidence of toxicity of about 50%). Any site having one or more chemicals in excess of their corresponding ERM values (see Table 2) was rated as having poor sediment quality; any site with five or more chemicals between the corresponding ERL and ERM values was rated as fair; any site with no ERMs exceeded and < 5 ERLs exceeded was rated as having good sediment quality (*sensu* U.S. EPA 2008). Overall sediment contamination from multiple chemicals also was expressed through the use of mean ERM quotients *(sensu* Long et al. 1998; Hyland et al. 1999, 2003). The mean ERM quotient (mean ERM-Q) is the mean of the ratios of individual chemical concentrations in a sample relative to corresponding published ERM values (using all chemicals in Table 2 except nickel, low- and high-molecular-weight PAHs, and total PAHs). A useful feature of this method is that overall contamination in a sample from mixtures of multiple chemicals present at varying concentrations can be expressed as a single number that can be compared to values calculated the same way for other samples (either from other locations or sampling occasions).

The overall mean, range, and area-weighted percentiles of mean ERM-Qs are shown in Table 5. These values are nearly an order of magnitude lower than values calculated for northeast estuaries (area-weighted 10th, 50th, and 90th percentiles of 0.01, 0.04, and 0.12, respectively; NCA 2006), suggesting that concentrations of chemical contaminants in shelf sediments of the MAB are at relatively low background levels. None of the stations had mean ERM-Qs high enough to suggest significant risks of adverse effects on benthic fauna. Hyland et al. (2003) reported the highest incidence of impaired benthic assemblages (85% of samples) in mid-Atlantic (Virginian Province) estuaries at mean ERM-Qs above a critical point of 0.473 and a low incidence of effects (9% of samples) at mean ERM-Qs ≤ 0.022. Although in the present study we are dealing with offshore benthic fauna, none of the stations had mean ERM-Qs in this upper bioeffect range (which are the most applicable data known to us for comparison). Except for one station with a mean ERM-Q of 0.031 (Table 5), the majority of stations (97.9 % of the study area) had values that were well within the reported low-risk range.

No contaminants were found in excess of their corresponding ERMs (Table 6). Only three chemicals, arsenic, nickel, and total DDT, exceeded their corresponding ERL guidelines. The ERL exceedances for arsenic occurred at three sites: Stations 12, 13, and 17 with concentrations of 8.2, 11, and 8.5 µg/g, respectively. These three sites represented only 6.3 % of the survey area. The overall range of concentrations for arsenic (0 – 11 µg/g dry mass) was within the range typical of uncontaminated near-shore marine sediments (5 – 15 µg/g dry weight total arsenic) reported by Neff (1997) and reflects its natural presence at low to moderate concentrations in crustal rocks of the region. Similarly, concentrations of nickel at one site (21 µg/g dry mass, station 29),

representing 2.1 % of the study area, barely exceeded the ERL guideline of 20.9 µg/g. Concentrations of total DDT (sum of 2,4′-DDD, 4,4′-DDD, 2,4′-DDE, 4,4′-DDE, 2,4′-DDT, and 4,4′-DDT) were detectable in sediment samples at eight sites and exceeded the ERL guideline of 1.58 ng/g at five sites (Figure 7), which represent 10 % of the study area. Exceedances for total DDT were driven by 4,4′-DDT (four sites) and 2,4′-DDE (one site). DDT and its metabolites have been detected in major estuaries of the region, including Chesapeake Bay (Hartwell and Hameedi 2007), Delaware Bay (Hartwell et al. 2001), the Hudson-Raritan Estuary (Long et al. 1995b), and Long Island Sound (Wolfe et al. 1994). While some of these contaminants have been able to make their way onto the shelf, currently they appear to be present at low concentrations in the sediment. Total DDT levels were below the limit of detection at all of the remaining 40 sites where sediment samples were collected. Many of the other chemicals measured in this study also were below method detection limits.

Compared to overall sediment contaminant concentrations in estuaries of the region, shelf sediments have much lower levels (Figure 8). For example, contaminant levels measured in sediments of the Virginian Province, analyzed as part of the U.S. EPA National Coastal Assessment (NCA 2006), indicated that 5 % of estuarine sediments in the region were in poor condition ($\geq$ 1 ERM exceeded), 15 % were rated as fair ($\geq$ 5 ERLs exceeded), and 80 % were in good condition (no ERMs exceeded and fewer than 5 ERLs exceeded). Similarly, using the above criteria, the third National Coastal Condition Report (U.S. EPA 2008) concluded that 9 % of coastal and estuarine sediments in the northeast region of the U.S., inclusive of the MAB states, were in poor condition with respect to sediment contaminant concentrations and 12 % were fair. The remaining 79 % of area was rated as good. In contrast, all of the sites sampled in this study (100 % of the study area) were rated as good.

Table 6. Summary of chemical contaminant concentrations in sediments ('N.D.' = not detected; '-' = no corresponding ERL or ERM available).

Analyte	Mean (Std. Dev.)	Range	Concentration ≥ ERL, < ERM		Concentration ≥ ERM	
			# Stations	% Area	# Stations	% Area
Metals (% dry)						
Aluminum	1.374 (0.680)	0.186 – 3.650	-	-	-	-
Iron	0.936 (0.633)	0.121 – 2.840	-	-	-	-
Trace Metals (µg/g dry mass)						
Antimony	0.138 (0.219)	0 - 0.83	-	-	-	-
Arsenic	3.479 (2.198)	0.75 - 11	3	6.3	0	0
Cadmium	0.130 (0.2)	0 - 0.7	0	0	0	0
Chromium	12.921 (12.329)	1 - 57	0	0	0	0
Copper	1.719 (2.178)	0 - 10.5	0	0	0	0
Lead	9.348 (5.858)	2.6 - 30.6	0	0	0	0
Manganese	214.760 (134.235)	30.7 - 643	-	-	-	-
Mercury	0.006 (0.015)	0 - 0.085	0	0	0	0
Nickel	4.285 (4.412)	0.66 - 21	1	2.1	0	0
Selenium	0.128 (0.345)	0 - 1.3	-	-	-	-
Silver	0.031 (0.045)	0 - 0.15	0	0	0	0
Tin	3.558 (0.745)	2.8 - 6.4	-	-	-	-
Zinc	19.148 (14.639)	4.2 - 66.3	0	0	0	0
PAHs (ng/g dry)						
Acenaphthene	N.D.	N.D.	0	0	0	0
Acenaphthylene	N.D.	N.D.	0	0	0	0
Anthracene	N.D.	N.D.	0	0	0	0
Benz[a]anthracene	0.469 (1.895)	0 - 10	0	0	0	0
Benzo[a]pyrene	0.125 (0.866)	0 - 6	0	0	0	0
Benzo[b]fluoranthene	0.323 (1.586)	0 - 9	-	-	-	-
Benzo[g,h,i]perylene	N.D.	N.D.	-	-	-	-
Benzo[k]fluoranthene	N.D.	N.D.	-	-	-	-
Biphenyl	N.D.	N.D.	-	-	-	-
Chrysene	0.677 (2.769)	0 - 14	0	0	0	0
Dibenz[a,h]anthracene	N.D.	N.D.	0	0	0	0
Dibenzothiophene	N.D.	N.D.	-	-	-	-
Fluoranthene	1.552 (4.083)	0 - 18	0	0	0	0
Fluorene	N.D.	N.D.	0	0	0	0
Indeno[1,2,3-c,d]pyrene	N.D.	N.D.	-	-	-	-
Naphthalene	N.D.	N.D.	0	0	0	0
1-Methylnaphthalene	N.D.	N.D.	-	-	-	-

Table 6 (continued).

Analyte	Mean (Std. Dev.)	Range	Concentration ≥ ERL, < ERM		Concentration ≥ ERM	
			# Stations	% Area	# Stations	% Area
2-Methylnaphthalene	N.D.	N.D.	0	0	0	0
2,6-Dimethylnaphthalene	N.D.	N.D.	-	-	-	-
2,3,5-Trimethylnaphthalene	N.D.	N.D.	-	-	-	-
Phenanthrene	0.156 (1.083)	0 - 7.5	0	0	0	0
1-Methylphenanthrene	N.D.	N.D.	-	-	-	-
Pyrene	0.604 (2.083)	0 - 10	0	0	0	0
Low Molecular Weight PAHs	0.156 (1.083)	0 – 7.5	0	0	0	0
High Molecular Weight PAHs	3.750 (11.330)	0 - 51	0	0	0	0
Total PAHs[a]	3.906 (12.026)	0 - 58.5	0	0	0	0
PCBs (ng/g dry)						
Total PCBs[b]	0.714 (1.68)	0 - 7.24	0	0	0	0
Pesticides (ng/g dry)						
2,4'-DDD (o,p'-DDD)	N.D.	N.D.	-	-	-	-
2,4'-DDE (o,p'-DDE)	0.038 (0.26)	0 - 1.8	-	-	-	-
2,4'-DDT (o,p'-DDT)	N.D.	N.D.	-	-	-	-
4,4'-DDD (p,p'-DDD)	0.009 (0.061)	0 - 0.42	-	-	-	-
4,4'-DDE (p,p'-DDE)	0.023 (0.096)	0 - 0.55	0	0	0	0
4,4'-DDT (p,p'-DDT)	0.270 (0.719)	0 - 3.1	-	-	-	-
Aldrin	N.D.	N.D.	-	-	-	-
alpha-Chlordane	N.D.	N.D.	-	-	-	-
Dieldrin	N.D.	N.D.	-	-	-	-
Endosulfan I	N.D.	N.D.	-	-	-	-
Endosulfan II (beta-Endosulfan)	N.D.	N.D.	-	-	-	-
Endosulfan sulfate	N.D.	N.D.	-	-	-	-
Endrin	N.D.	N.D.	-	-	-	-
gamma-HCH (g-BHC, lindane)	N.D.	N.D.	-	-	-	-
Heptachlor	N.D.	N.D.	-	-	-	-
Heptachlor epoxide	N.D.	N.D.	-	-	-	-
Hexachlorobenzene (HCB)	0.013 (0.092)	0 - 0.64	-	-	-	-
Mirex	N.D.	N.D.	-	-	-	-
Total DDTs[c]	0.340 (0.836)	0 - 3.1	5	10.4	0	0
trans-Nonachlor	N.D.	N.D.	-	-	-	-

[a] Sum of 23 measured PAHs.
[b] Sum of 21 measured PCB congeners.
[c] Sum of 2,4′-DDD, 4,4′-DDD, 2,4′-DDE, 4,4′-DDE, 2,4′-DDT, and 4,4′-DDT.
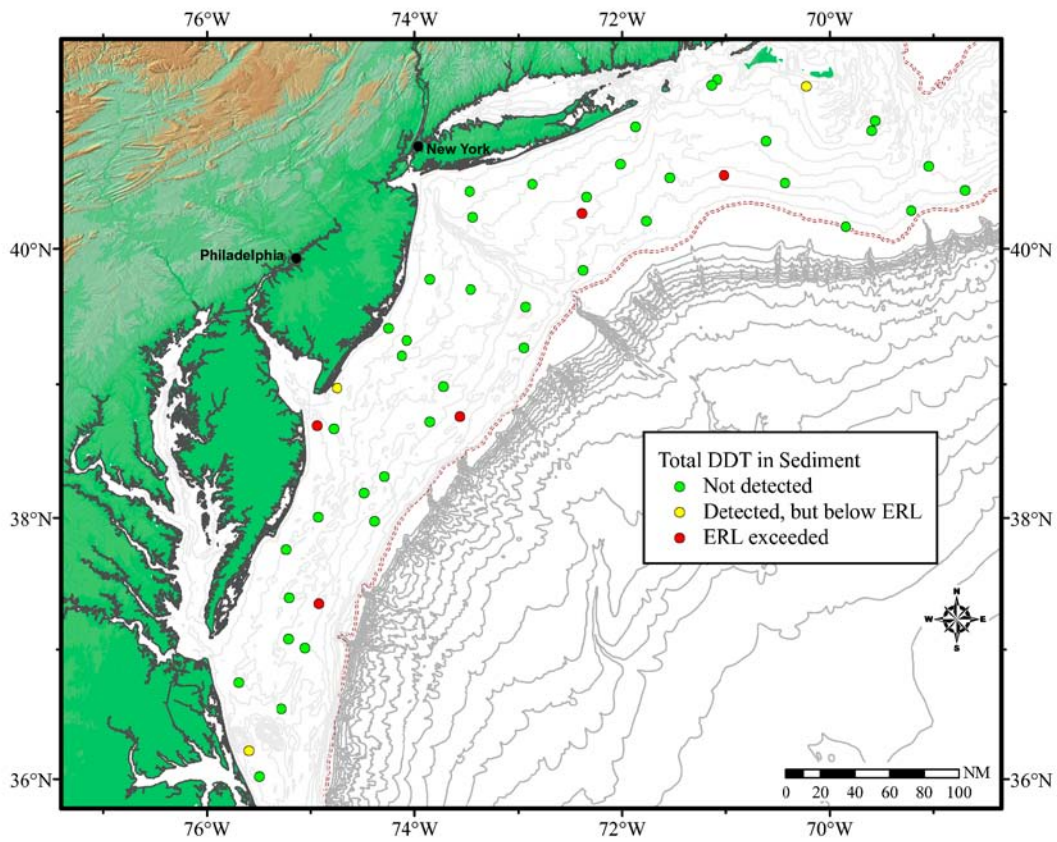
Figure 7. Map of study area showing distribution of total DDT in sediments. Red symbol: concentration exceeded the ERL value of 1.58 ng/g but was below the ERM value of 46.1 ng/g (from Long et al. 1995a).
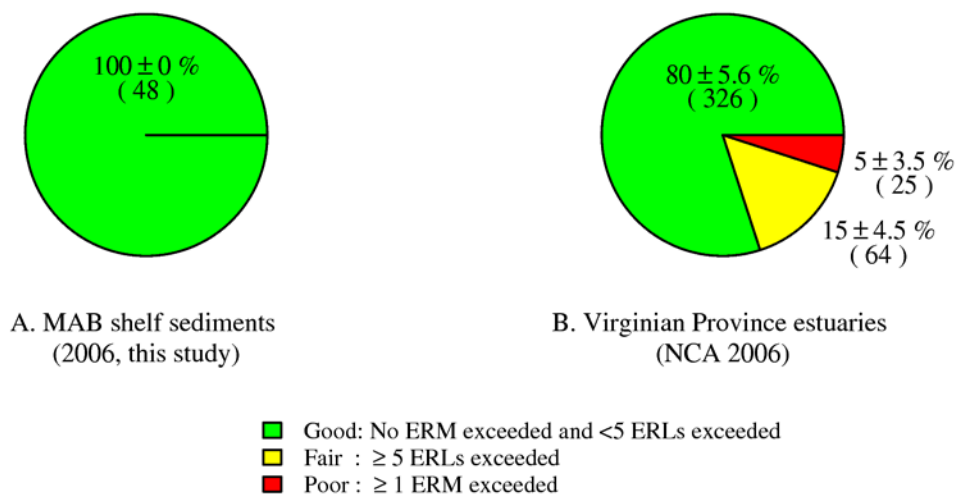
Figure 8. Comparison of contamination in MAB shelf sediments (2006, this study) vs. estuaries of the Virginian Province (NCA 2006).

3.3 Chemical Contaminants in Fish Tissues

Because none of the species of fish targeted for chemical contaminant analysis were collected on the core May 2006 survey, samples of summer flounder (*Paralichthys dentatus*) were obtained from a subsequent winter bottom-trawl survey conducted February 6 – March 2, 2007 by the NOAA Fisheries Service, Northeast Fisheries Science Center (NFS/NEFSC) and used for this purpose. Fish samples were taken from 30 bottom-trawl locations in shelf waters between Sandy Hook, NJ and Cape Hatteras, NC (Figure 1B). Although these samples were not part of the core probabilistic sampling design and thus should not be used for CDF calculations and spatial estimates of condition, they provide a good indication of the range of chemical contaminant levels likely to be encountered in edible tissues from bottom fish in the MAB study area.

Concentrations of a suite of metals, pesticides, and PCBs were measured in edible tissues (fillets) of 30 individual summer flounder, one each from the 30 trawl sites, and compared to risk-based EPA advisory guidelines for recreational fishers (Table 3). The guidelines selected for this analysis were endpoints associated with an average consumption rate of four 8-oz fish meals per month (from USEPA 2000a), which is consistent with the comparison basis used currently in the National Coastal Condition Report (USEPA 2008) and by States for setting fish advisories. A station was rated as "good" if all chemical contaminants listed in Table 3 had concentrations below the corresponding lower endpoints, "fair" if at least one contaminant fell within the

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corresponding lower and upper endpoints, and "poor" if at least one contaminant occurred at a concentration above the upper endpoint (USEPA 2008).

None of the 30 stations where fish were measured had chemical contaminants in fish tissues above the corresponding upper human-health endpoints (Table 7, Figure 9). Thus none of these stations were rated as "poor" with respect to contaminant body burdens. Three stations – NFS/NEFSC 14, 21, and 53 – had total PCB concentrations in tissues (26.6, 42.4, and 38.6 ng/g respectively) that were between the corresponding lower and upper endpoints and thus were rated as "fair." One of the above stations (21) and an additional station (59) had total mercury concentrations (assumed to be all methylmercury, *sensu* U.S. EPA 2000a) between the corresponding lower and upper endpoints for methylmercury. All other stations had concentrations of contaminants listed in Table 3 that were below corresponding lower endpoints and thus were rated as "good."

As a side note, total PCBs and inorganic arsenic were both present in fish tissues at slightly elevated levels, though below the (non-cancer) human-health risk endpoints, consistently at 16 of the remaining 27 stations in the case of total PCBs and across all 30 stations in the case of inorganic arsenic. To be consistent with methods used in the National Coastal Condition Report III (USEPA 2008), non-cancer human-health risk endpoints were used in this report as the basis for comparisons with observed fish tissue contaminant levels (with the exception of benzo(a)pyrene, for which only cancer risk endpoints exist). However, USEPA (2000a) also provides risk-based cancer endpoints for nine of the remaining 15 contaminants listed in Table 3. For example, based on an average consumption of four 8-oz fish meals per month and an acceptable risk level of 1 in 100,000, the lower to upper cancer-risk endpoints would be 5.9 – 12.0 ng/g for total PCBs and 0.0078 – 0.016 µg/g for inorganic arsenic (USEPA 2000a). Though below even the lower non-cancer endpoint, inorganic arsenic concentrations exceeded both of these cancer-risk endpoints at all 30 stations where fish were measured (data not reflected in tables). Concentration of total PCBs exceeded its corresponding upper cancer endpoint at eight stations and was between the lower and upper endpoints at an additional 11 stations.

Table 7. Summary of contaminant concentrations (wet weight) measured in tissues of summer flounder, *P. dentatus*. A total of 30 fish (one each from 30 stations) were analyzed. All measured contaminants are included. Concentrations are compared to human-health guidelines where available (from US EPA 2000a, also see Table 3 herein). ('N.D.' = Not detected; 'N.M.' = Not measured; '-' = no corresponding guideline available).

Analyte	Mean	Range	No. of fish exceeding health endpoints	
			$\geq$ Lower & $\leq$ Upper	> Upper
Metals (µg/g wet weight)				
Aluminum	1.628	0.000 - 4.330	-	-
Antimony	0.049	0.000 - 0.092	-	-
Arsenic	3.194	0.942 - 7.890	-	-
Arsenic (Inorganic)[a]	0.064	0.019 - 0.158	0	0
Barium	0.013	0.000 - 0.032	-	-
Beryllium	N.D.	N.D.	-	-
Cadmium	0.001	0.000 - 0.001	0	0
Chromium	0.293	0.198 - 0.442	-	-
Cobalt	0.000	0.000 - 0.012	-	-
Copper	0.211	0.177 - 0.256	-	-
Methylmercury (estimated)[b]	0.075	0.015 - 0.152	2	0
Iron	8.101	6.720 - 10.000	-	-
Lead	0.094	0.000 - 0.891	-	-
Lithium	0.010	0.000 - 0.019	-	-
Manganese	0.174	0.104 - 0.292	-	-
Nickel	0.003	0.000 - 0.020	-	-
Selenium	0.653	0.556 - 0.858	0	0
Silver	N.D.	N.D.	-	-
Thallium	N.D.	N.D.	-	-
Tin	0.000	0.000 - 0.007	-	-
Uranium	N.D.	N.D.	-	-
Vanadium	0.086	0.030 - 0.139	-	-
Zinc	4.893	3.500 - 7.000	-	-
PAHs (ng/g wet weight)				
Acenaphthene	N.D.	N.D.	-	-
Acenaphthylene	N.D.	N.D.	-	-
Anthracene	N.D.	N.D.	-	-
Benz[a]anthracene	N.D.	N.D.	-	-
Benzo[a]pyrene	N.D.	N.D.	0	0
Benzo[b]fluoranthene	N.D.	N.D.	-	-
Benzo[e]pyrene	N.D.	N.D.	-	-
Benzo[g,h,i]perylene	N.D.	N.D.	-	-
Benzo[j,k]fluoranthene	N.D.	N.D.	-	-
Biphenyl	N.D.	N.D.	-	-
Chrysene+Triphenylene	N.D.	N.D.	-	-
Dibenz[a,h]anthracene	N.D.	N.D.	-	-
Dibenzothiophene	N.D.	N.D.	-	-
Flouranthene	N.D.	N.D.	-	-
Flourene	N.D.	N.D.	-	-
Indeno[1,2,3-c,d]pyrene	N.D.	N.D.	-	-
Napthalene	N.D.	N.D.	-	-
1-Methylnaphthalene	N.D.	N.D.	-	-
2-Methylnaphthalene	N.D.	N.D.	-	-
2,6-Dimethylnaphthalene	N.D.	N.D.	-	-

Table 7 (continued).

Analyte	Mean	Range	≥ Lower & ≤ Upper	> Upper
1,6,7-Trimethylnaphthalene	N.D.	N.D.	-	-
Perylene	N.D.	N.D.	-	-
Phenanthrene	N.D.	N.D.	-	-
1-Methylphenanthrene	N.D.	N.D.	-	-
Pyrene	N.D.	N.D.	-	-
Total PAH	N.D.	N.D.	-	-
PBDEs (ng/g wet weight)				
PBDE 100	N.D.	N.D.	-	-
PBDE 138	N.D.	N.D.	-	-
PBDE 153	N.D.	N.D.	-	-
PBDE 154	N.D.	N.D.	-	-
PBDE 17	N.D.	N.D.	-	-
PBDE 183	N.D.	N.D.	-	-
PBDE 190	N.D.	N.D.	-	-
PBDE 28	N.D.	N.D.	-	-
PBDE 47	1.033	0.000 - 5.320	-	-
PBDE 66	N.D.	N.D.	-	-
PBDE 71	N.D.	N.D.	-	-
PBDE 85	N.D.	N.D.	-	-
PBDE 99	0.074	0.000 - 1.160	-	-
PCBs (ng/g wet weight)				
Total PCBs[c]	11.133	1.300 - 42.400	3	0
Pesticides (ng/g wet weight)				
2,4' - DDD (o,p' - DDD)	N.D.	N.D.	-	-
2,4' - DDE (o,p' - DDE)	0.021	0.000 - 0.348	-	-
2,4' - DDT (o,p' - DDT)	0.251	0.000 - 2.136	-	-
4,4' - DDD (p,p' - DDD)	0.209	0.000 - 1.461	-	-
4,4' - DDE (p,p' - DDE)	1.925	0.000 - 5.974	-	-
4,4' - DDT (p,p' - DDT)	N.D.	N.D.	-	-
Aldrin	N.D.	N.D.	-	-
Chlorpyrifos	N.D.	N.D.	-	-
cis-Chlordane (alpha-Chlordane)	N.D.	N.D.	-	-
Dieldrin	0.034	0.000 - 0.271	0	0
Endosulfan	N.D.	N.D.	0	0
Endosulfan I	N.D.	N.D.	-	-
Endosulfan II	N.D.	N.D.	-	-
Endosulfan sulfate	N.D.	N.D.	-	-
Endrin	N.M.	N.M.	-	-
Heptachlor	N.D.	N.D.	-	-
Heptachlor epoxide	N.D.	N.D.	0	0
Hexachlorobenzene	N.D.	N.D.	0	0
Lindane	N.D.	N.D.	0	0
Mirex	2.406	0.000 - 9.920	0	0
Total DDT	N.D.	N.D.	0	0
Total Chlordane	N.D.	N.D.	0	0
Toxaphene	N.M.	N.M.	-	-
trans-Nonachlor	N.D.	N.D.	-	-

[a] Estimated as 2% of the measured total arsenic.
[b] Measured as total mercury and assumed to be all methylmercury.
[c] Sum of 79 measured PCB congeners.
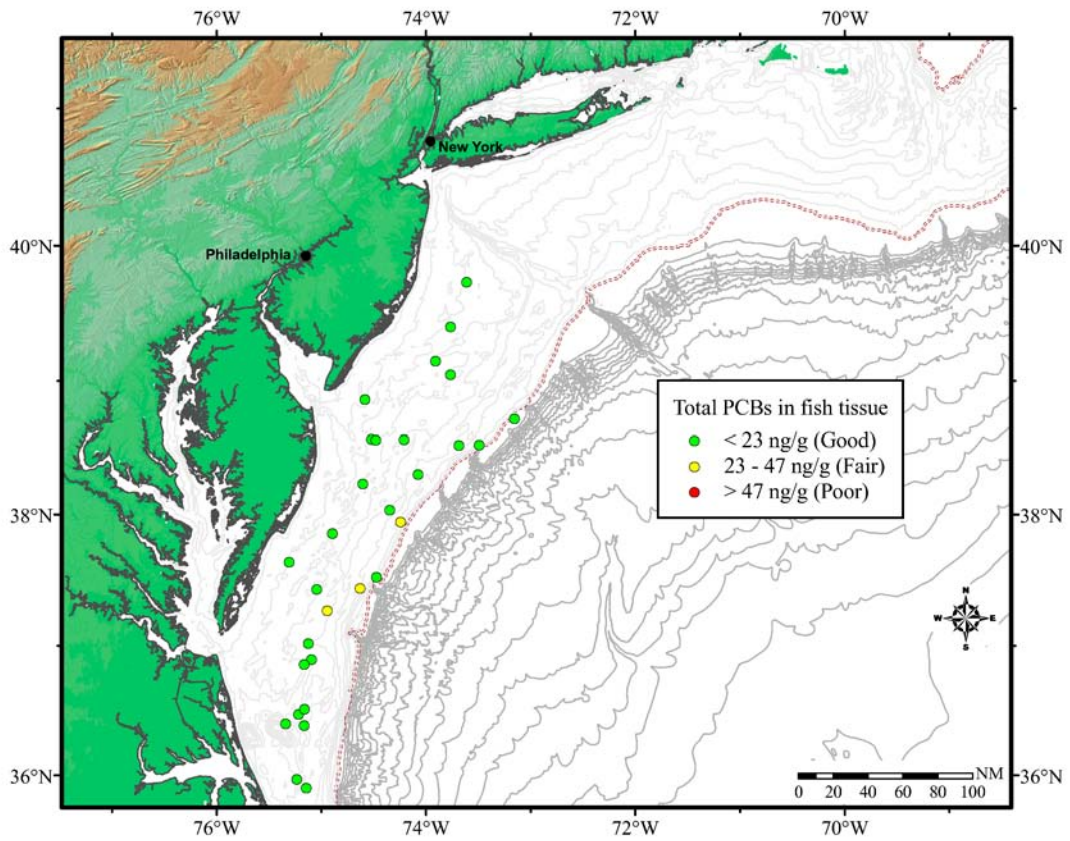
Figure 9. Distribution of PCB concentrations in fish tissues (fillets) relative to EPA (2000a) non-cancer human-health guidelines.

3.4 Status of Benthic Communities

Macrobenthic infauna (those retained on a 0.5-mm sieve) were sampled at a total of 48 stations throughout the study region. Two grabs (0.04 m^2 each) were collected at every station except station 14, where a single grab was collected, resulting in a total of 95 grabs. Measures of taxonomic diversity and abundance were calculated separately for each of the 95 grabs and averaged by station where indicated (e.g., *mean* # taxa/0.04 m^2, *mean* H′/0.04 m^2). The resulting data here are used to assess the status of benthic community characteristics (taxonomic composition, diversity, abundance, and dominant taxa), the incidence of non-indigenous species, and potential linkages to ecosystem stressors throughout the coastal shelf waters of the MAB from Cape Cod, MA to Cape Hatteras, NC.

The status of benthic communities in shelf sediments of the MAB is also compared to estuaries of the Virginian Province, sampled in 2005-2006 as part of the U.S. EPA National Coastal Assessment (NCA 2006). The NCA benthic data represent 353 stations, with a single 0.04-m^2 grab sample collected at each site (with the exception of 20 sites in Delaware Bay, which were sampled using a 0.1-m^2 grab). Of the 353 NCA estuarine benthic samples, 205 were analyzed by Barry Vittor & Associates, who also analyzed the samples from the MAB (this study). Maryland estuarine benthic samples (n=48) were analyzed for the NCA by Versar, Inc. Virginia NCA benthic samples (n=100) were analyzed by the benthic ecology laboratory at Old Dominion University in Norfolk, VA. While some differences in the level of taxonomic identification may exist among benthic laboratories, all samples were processed in accordance with methods outlined in the EMAP Laboratory Methods Manual (U.S. EPA 1995).

3.4.1 Taxonomic Composition

A total of 381 taxa were identified throughout the study area, of which 215 were identified to the species level. Polychaetes were the dominant taxa (Figure 10, Table 8), both by percent of taxa (43 %) and percent abundance (46 %). Crustaceans and molluscs were the second and third dominant taxa, respectively, both by percent of taxa (31 % crustaceans, 19 % mollusks) and percent abundance (36 % crustaceans, 10 % mollusks). Collectively, these three groups represented 92 % of total taxa and 93 % of total faunal abundance. Crustaceans were represented primarily by amphipods (66 identifiable taxa, 17.3 % of the total number of taxa), followed by cumaceans (19 taxa, 5 % of total taxa), ostracods (15 taxa, 3.9 % of total taxa), and isopods (10 taxa, 2.6 % of total taxa; Table 8). Molluscs were represented mainly by bivalves (51 taxa, 13.4 % of total taxa), followed by gastropods (19 taxa, 5 % of total taxa).

Macrobenthic composition also was examined in relation to bathymetric zones by dividing the survey area into inner (~14 – 30 m), middle (30 – 50 m), and outer (50 – 100 m) shelf (*sensu* Boesch 1979). Numbers of taxa (as percent of total) for the major taxonomic groups identified in Figure 10A remained fairly constant across inner, middle, and outer shelf habitats. However, the relative abundance of major taxonomic groups varied (Figure 10B), with the inner shelf dominated by polychaetes (53% *versus* 40% and

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44% for middle and outer shelf, respectively). Crustaceans (primarily amphipods) were most abundant (44%) on the outer shelf relative to the inner (24%) and middle (38%) shelf habitats. Molluscs represented a much smaller percentage of total taxonomic abundance on the outer shelf (5%) relative to middle (17%) and inner (11%) shelf habitats. Echinoderms also were more abundant on the outer shelf (3%) relative to the middle (0.5%) and inner (0.4%) shelf.

Also shown in Figure 10 are the relative percentages (by numbers of taxa and abundance) of taxonomic groups in estuaries of the Virginian Province. While the relative percentages of most taxonomic groups (as percent of taxa) were similar, estuaries had fewer polychaete taxa (34% vs. 43% in shelf waters) and higher numbers of 'Other' taxa, mainly due to Oligochaetes and insect larvae found in low salinity estuarine habitats (Table 8). In terms of percent of abundance, the relative percentage of polychaetes was similar for estuaries and shelf waters (49% vs. 46%, respectively). However, relative abundance (m^{-2}) of crustaceans was much lower for estuaries (22% vs. 36% for shelf waters), while molluscs were more abundant in estuaries (18% vs. 11%). While the relative percent abundance of taxonomic groups varied among inner, mid, and outer shelf waters, the taxonomic composition of estuaries, in terms of relative percent of abundance, most resembled that of inner shelf waters.
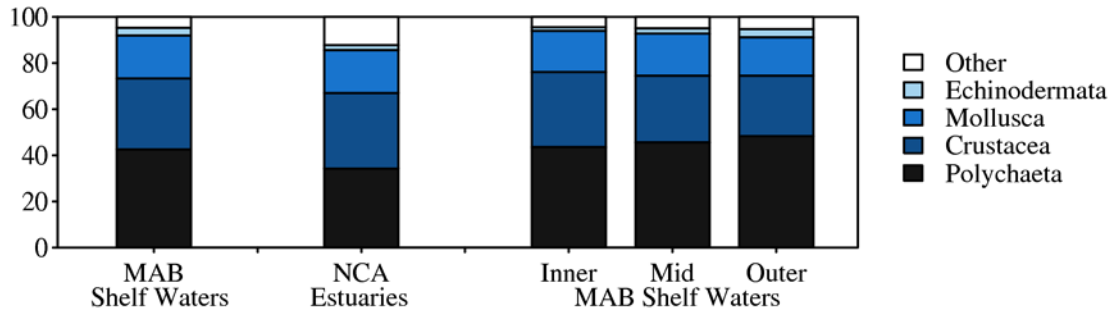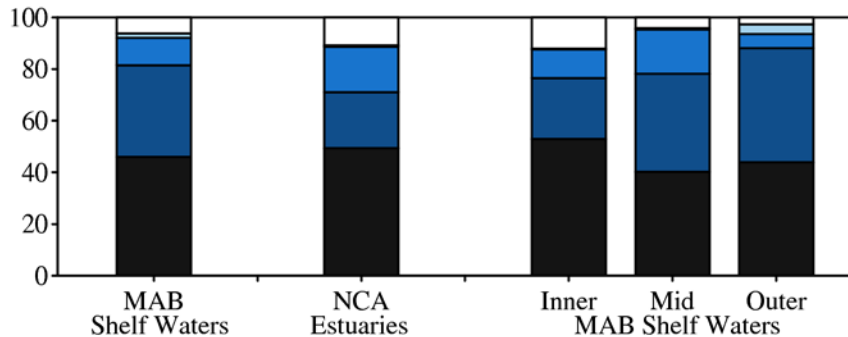
Figure 10. Relative percent composition of major taxonomic groups expressed as percent of total taxa (A) and percent of abundance (B). Bar charts compare taxonomic composition throughout MAB shelf waters with estuaries of the Virginian Province, sampled in 2005-2006 as part of the U.S. EPA's National Coastal Assessment (NCA 2006). Additionally, MAB shelf waters are further subdivided by depth into inner (~14–30 m), mid (30–50 m), and outer (50–100 m) shelf, illustrating the transition from estuaries to outer shelf.

Table 8. Summary of major taxonomic groups of benthic infauna and corresponding numbers of identifiable taxa in samples (95 0.04-m^2 grabs) from shelf waters of the MAB compared to northeastern estuaries (353 0.04-m^2 grabs[†]; NCA 2006).

	MAB 2006		NCA 2005-2006	
Taxonomic Group	No. of identifiable taxa	% of total identifiable taxa	No. of identifiable taxa	% of total identifiable taxa
Phylum Annelida				
Class Polychaeta	162	42.5	207	34.9
Class Clitellata				
Subclass Oligochaeta*	2	0.5	16	2.7
Phylum Arthropoda				
Subphylum Chelicerata*	2	0.5	5	0.9
Subphylum Crustacea				
Class Malacostraca				
Order Amphipoda	66	17.3	98	16.5
Order Cumacea	19	5.0	9	1.5
Order Decapoda	4	1.0	39	6.6
Order Isopoda	10	2.6	23	3.9
Order Lophogastrida	0	0	1	0.2
Order Mysida	0	0	6	1.0
Order Tanaidacea	3	0.8	3	0.5
Class Ostracoda	15	3.9	12	2.0
Class Thoracica*	0	0	1	0.2
Subphylum Hexapoda				
Class Insecta*	0	0	31	5.2
Phylum Chordata*	2	0.5	3	0.5
Phylum Cnidaria				
Class Anthozoa*	2	0.5	3	0.5
Class Hydrozoa*	0	0	1	0.2
Phylum Echinodermata				
Class Asteroidea	4	1.0	5	0.8
Class Echinoidea	3	0.8	1	0.2
Class Holothuroidea	3	0.8	7	1.2
Class Ophiuroidea	3	0.8	0	0
Phylum Ectoprocta*	1	0.3	0	0
Phylum Hemichordata*	1	0.3	2	0.4
Phylum Mollusca				
Class Aplacophora	1	0.3	0	0
Class Bivalvia	51	13.4	59	9.9
Class Gastropoda	19	5.0	47	7.9
Class Polyplacophora	0	0	1	0.2
Class Scaphopoda	0	0	1	0.2
Phylum Nemertea*	3	0.8	6	1.0
Phylum Phoronida*	1	0.3	1	0.2
Phylum Platyhelminthes*	1	0.3	3	0.5
Phylum Sipuncula*	3	0.8	2	0.3
Total	*381*	*100*	*593*	*100*

[†] With the exception of 20 sites in Delaware Bay, sampled with a 0.1-m^2 grab.
* Taxonomic groups followed by an asterisk were assigned to the group 'Other' in Figure 11.

3.4.2 Abundance and Dominant Taxa

A total of 23,044 individuals were collected across the 48 stations (95, 0.04 m^2 grabs) sampled for benthos. Densities ranged from 675 – 29,263 m^{-2} and averaged 6,067 m^{-2} (Table 9, Appendix E). On an area-weighted basis, 50 % of the survey area had mean densities > 4,438 m^{-2} and 10 % of the area (upper 10th percentile) had mean densities > 11,843 m^{-2} (Table 9, Figure 11). The mean density of benthic macrofauna was fairly consistent across the three depth zones (Figure 12B), although slightly higher (6,301 m^{-2}) for outer-shelf stations relative to middle- and inner-shelf stations (5,506 m^{-2} and 6,295 m^{-2}, respectively). While the mean infaunal density in MAB coastal shelf waters (6,067 m^{-2}) was similar to the mean density observed in northeast estuaries (6,052 m^{-2}; NCA 2006), shelf densities were less variable (675 – 29,263 m^{-2} compared to 0 – 185,885 m^{-2} for estuaries).

The 50 most abundant taxa collected throughout shelf waters in the MAB are listed in Table 10. The top 10 dominants, in decreasing order of abundance, included the amphipod *Ampelisca agassizi*, the polychaetes *Polygordius* spp. and *Acmira catherinae*, tubuficid oligochaetes (Tubificidae), the amphipod *Unciola irrorata*, the polychaete *Spiophanes bombyx*, the tanaid *Tanaissus psammophilus*, the polychaetes *Exogone hebes* and *Goniadella gracilis*, and maldanid polychaetes (Maldanidae).

Some cross-shelf trends in benthic dominance were noted (Figure 13). For example, the overall top dominant, *A. agassizi*, did not appear in samples collected from the inner shelf, but was the most abundant species in deeper mid- to outer-shelf waters. Mean density of *A. agassizi* increased from 565 m^{-2} to 1,551 m^{-2} in mid- and outer-shelf sediments, respectively. The second dominant taxon overall (*Polygordius* spp.) was the top dominant on the inner shelf, second dominant mid-shelf, and 29th on the outer shelf (mean densities of 855 m^{-2}, 430 m^{-2}, and 41 m^{-2}, respectively). *Acmira catherinae*, the third dominant overall, decreased in abundance from inner- (second dominant) to mid- (21st) to outer- (22nd) shelf sediments, with mean densities of 718 m^{-2}, 64 m^{-2}, and 61 m^{-2}, respectively. Tubificid oligochaetes and the tanaid *Tanaissus psammophilus* decreased monotonically from the inner to outer shelf, while *Unciola irrorata* and *Spiophanes bombyx* showed the reverse trend.

Patterns of dominance were markedly different for these offshore assemblages in comparison to estuaries (Table 11). The top two offshore dominants (the amphipod *Ampelisca agassizi* and the polychaete *Polygordius* spp.) were not found in estuaries. Similarly, several of the remaining offshore dominants were found either in lower densities in estuaries (*Spiophanes bombyx*: < 15 % of stations; *Unciola irrorata*, *Exogone hebes*: < 10 % of stations) or rarely at all (*Tanaissus psammophilus*, *Goniadella gracilis*: < 1 % of stations). Conversely, the top two dominants in estuaries (the bivalve *Gemma gemma* and the polychaete *Streblospio benedicti*) were not found at any sites in shelf waters of the MAB. The amphipod *Ampelisca abdita* was rare at MAB sites, found at only one site in very low densities (outer shelf, 3 specimens in one 0.04 m^2 grab). *Mediomastus ambiseta* and unidentified *Mediomastus* spp. were ranked as fourth and fifth most abundant in estuaries, while the genus was much less common in offshore

sediments (e.g., not among the 50 most abundant taxa). Tubificid oligochaetes as a group were common to both offshore and estuarine sites, as was the bivalve *Nucula proxima*. The remaining members of the ten highest ranked estuarine dominants were found either in lower densities offshore (*Tharyx acutus*: 20 % of stations) or rarely if at all (*Ampelisca vadorum*, *Parasterope pollex*: < 5 % of stations).

3.4.3 Diversity

A total of 381 taxa were identified (215 to species) in 95 grabs collected throughout the study area. Taxonomic richness, expressed as the mean number of taxa present in replicate 0.04 m^2 grabs at a station, ranged from 9 to 50 taxa $grab^{-1}$, with an overall mean and median of 28 and 27 taxa $grab^{-1}$, respectively (Table 9). Area-weighted percentiles also are given in Table 9, and the full distribution of area-weighted estimates is illustrated in Figure 11. Numbers of taxa in estuaries of the region typically were lower than offshore waters, but varied by estuarine sub-region. For example, the number of taxa in samples collected throughout estuaries of the Virginian Province averaged 18 taxa $grab^{-1}$ and ranged from 0 – 62 taxa $grab^{-1}$ (NCA 2006). However, the mean number of taxa at sites exclusive of Chesapeake Bay was equal to 23 taxa $grab^{-1}$, compared to only 12 taxa $grab^{-1}$ for Chesapeake Bay sites only (Table 9). This pattern also is reflected in the other parameters presented in Table 9. Because of the large area of Chesapeake Bay in relation to the rest of the Virginian Province (it represents 62 % of the area of the Province), it tends to have a strong influence on calculated parameters (NCA 2006). Hence, benthic parameters are presented in Table 9 for the estuaries of the region overall, for estuaries exclusive of Chesapeake Bay, and for Chesapeake Bay only.

Numbers of taxa in coastal shelf sediments of the MAB were similar for inner (26 taxa $grab^{-1}$) and middle (25 taxa $grab^{-1}$) shelf habitats, and highest among outer shelf sites (33 taxa $grab^{-1}$). Diversity (H′) generally increased seaward from inner (3.1) to middle (3.3) to outer (3.6) shelf (Figure 12). Except for the similar numbers of taxa between inner- and mid-shelf locations, these observations are consistent with those of Boesch (1979), who found that both taxonomic richness and Shannon diversity increased across the shelf, with the highest diversity occurring on the outer shelf.

The spatial distribution of values for taxonomic richness, density, and H′ diversity in relation to frequency-based percentiles (lower, mid, and upper quartiles) are shown in Figs. 14 A, B, and C. Though there is some degree of variability in the data, most of the low to intermediate values for taxonomic richness occurred along the middle and inner shelf, with the majority of high values (above the upper quartile) occurring along the outer shelf, as previously illustrated by the mean values shown in Figure 12A. Though on average infaunal densities were slightly lower along the middle shelf, a clear density pattern fails to emerge due to the large amount of variability that exists, as seen in the overlapping confidence limits in Figure 12B. Most of the lowest values of H′ diversity (within the lower 10th percentile) occurred along the inner shelf, with higher diversity along the outer shelf.

Table 9. Mean, range, and selected distributional properties of key benthic variables. The MAB benthic measures represent 95 0.04-m^2 grabs collected at 48 sites (2 replicate grabs at every station except for station 14). The NCA benthic metrics represent 353 sites (one 0.04-m^2 grab[†] collected at each station).

	Overall Mean	Overall Range	Area-based Percentiles[a]			Frequency-based percentiles[b]				
			CDF 10th pctl	CDF 50th pctl	CDF 90th pctl	10th	25th	50th	75th	90th
MAB (this study) [c]										
Mean # Taxa/0.04 m^2	28	9 – 50	16	27	43	13	21	27	36	44
Total # Taxa/0.08 m^2	42	15 – 77	24	41	66	19	32	40	54	67
Mean Density (#/m^2)	6,067	675 – 29,263	1,091	4,438	11,843	1,050	2,006	4,438	7,850	12,938
Mean H′/0.04 m^2	3.4	1.9 – 4.4	2.5	3.5	4.1	2.5	3.0	3.4	3.8	4.1
Mid-Atlantic Estuaries (NCA 2006)										
# Taxa/0.04 m^2	18	0 – 62	1	13	33	4	8	16	27	36
Density (#/m^2)	6,052	0 – 185,885	45	1,932	8,660	300	864	2,637	6,501	14,047
H′ /0.04 m^2	2.6	0 – 4.7	0.8	2.6	3.8	1.3	2.0	2.7	3.3	3.9
Mid-Atlantic Estuaries, Excluding Chesapeake Bay (NCA 2006)										
# Taxa/0.04 m^2	23	0 – 62	7	24	40	7	13	24	32	40
Density (#/m^2)	8,842	0 – 185,885	773	4,546	15,547	659	1,682	4,251	10,001	21,866
H′ /0.04 m^2	2.87	0.46 – 4.7	1.74	3.04	4.18	1.52	2.23	2.95	3.54	4.03
Mid-Atlantic Estuaries, Chesapeake Bay Only (NCA 2006)										
# Taxa/0.04 m^2	12	0 – 36	1	10	19	2	6	10	16	24
Density (#/m^2)	2,300	0 – 12,261	23	1,157	5,398	68	523	1,454	2,932	6,205
H′ /0.04 m^2	2.32	0 – 4.25	0.31	2.37	3.41	0.92	1.84	2.43	3.04	3.53

[†] With the exception of 20 sites in Delaware Bay, sampled with a 0.1-m^2 grab.

[a] Value of benthic variable corresponding to the designated cumulative % area of the estimated CDF.

[b] Corresponding lower 10th percentile, lower quartile, median, upper quartile, and upper 10th percentile of all values for each benthic variable.

[c] Mean # taxa, mean density, and mean H′ represent the average of each of those measures calculated separately for the two grabs at sites where replicates were taken. Total # taxa is the total number of taxa in both replicate grabs combined (0.08 m^2), except for station 14.

Table 10. Fifty most abundant benthic taxa in the MAB 2006 survey region-wide. Mean density (m^{-2}), and percent frequency of occurrence are based on 95 0.04-m^2 grabs. Classification: Native = native species; Crypto = cryptogenic species (of uncertain origin); Indeter = indeterminate taxon (not identified to a level that would allow determination of origin).

Taxon Name	Group	Classification	Mean Density	Frequency (%)
Ampelisca agassizi	Amphipod	Native	754.2	21.1
Polygordius spp.	Polychaete	Indeter	422.1	68.4
Acmira catherinae	Polychaete	Native	276.3	44.2
Tubificidae	Oligochaete	Indeter	241.3	60.0
Unciola irrorata	Amphipod	Native	212.4	47.4
Spiophanes bombyx	Polychaete	Crypto	210.3	44.2
Tanaissus psammophilus	Tanaid	Native	178.9	44.2
Exogone hebes	Polychaete	Native	168.2	41.1
Goniadella gracilis	Polychaete	Native	164.5	35.8
Maldanidae	Polychaete	Indeter	143.2	58.9
Cirratulidae	Polychaete	Indeter	103.9	64.2
Protohaustorius wigleyi	Amphipod	Native	98.4	22.1
Rhepoxynius hudsoni	Amphipod	Native	97.1	46.3
Ampeliscidae	Amphipod	Indeter	92.1	10.5
Leptocheirus pinguis	Amphipod	Native	91.6	14.7
Tellina agilis	Bivalve	Native	89.2	4.2
Nucula proxima	Bivalve	Native	86.3	12.6
Prionospio pygmaea	Polychaete	Native	85.0	9.5
Chone spp.	Polychaete	Indeter	85.0	26.3
Lumbrinerides acuta	Polychaete	Native	79.7	23.2
Aricidea spp.	Polychaete	Indeter	72.9	52.6
Unciola spp.	Amphipod	Indeter	67.6	17.9
Scalibregma inflatum	Polychaete	Native	63.4	43.2
Bivalvia	Bivalve	Indeter	63.4	57.9
Ericthonius brasiliensis	Amphipod	Native	62.4	13.7
Asabellides oculata	Polychaete	Native	58.7	8.4
Nemertea	Nermertean	Indeter	53.2	50.5
Nucula aegeensis	Bivalve	Native	50.8	5.3
Amphiuridae	Echinoderm	Indeter	46.6	5.3
Cirrophorus spp.	Polychaete	Indeter	46.1	26.3
Tellina spp.	Bivalve	Indeter	46.1	15.8
Nephtyidae	Polychaete	Indeter	43.2	50.5
Ampelisca spp.	Amphipod	Indeter	39.2	13.7
Solemya velum	Bivalve	Native	38.9	3.2
Levinsenia gracilis	Polychaete	Native	36.6	15.8
Byblis serrata	Amphipod	Native	34.5	28.4
Ninoe nigripes	Polychaete	Native	33.9	17.9
Acanthohaustorius millsi	Amphipod	Native	33.2	9.5
Aricidea wassi	Polychaete	Native	32.6	18.9
Ophiuroidea	Echinoderm	Indeter	32.6	9.5
Spionidae	Polychaete	Indeter	28.9	26.3
Caulleriella spp.	Polychaete	Indeter	27.6	28.4
Ampharetidae	Polychaete	Indeter	27.1	36.8
Protohaustorius spp.	Amphipod	Indeter	27.1	1.1
Aricidea cerrutii	Polychaete	Native	26.6	15.8
Parapionosyllis longicirrata	Polychaete	Native	26.3	26.3
Astarte spp.	Bivalve	Indeter	25.8	5.3
Crassicorophium crassicorne	Amphipod	Native	25.3	7.4
Euchone incolor	Polychaete	Native	25.3	11.6
Enchytraeidae	Oligochaete	Indeter	24.7	24.2

Table 11. Fifty most abundant benthic taxa collected in northeast estuaries in 2005-2006 (NCA 2006). Mean density (m^{-2}), and percent frequency of occurrence are based on 353 0.04-m^2 grabs[†]. Classification: Native = native species; Crypto = cryptogenic species (of uncertain origin); Indeter = indeterminate taxon (not identified to a level that would allow determination of origin).

Taxon Name	Group	Classification	Mean Density	Frequency (%)
Gemma gemma	Bivalve	Native	578.8	9.5
Streblospio benedicti	Polychaete	Native	478.6	40.3
Ampelisca abdita	Amphipod	Native	456.5	17.9
Mediomastus ambiseta	Polychaete	Native	434.5	45.5
Mediomastus spp.	Polychaete	Indeter	327.4	39.8
Tubificidae	Oligochaeta	Indeter	311.4	42.7
Nucula proxima	Bivalve	Native	189.8	17.0
Tharyx acutus	Polychaete	Native	183.9	23.6
Ampelisca vadorum	Amphipod	Native	136.8	11.2
Parasterope pollex	Ostracod	Native	119.5	14.4
Crepidula fornicata	Gastropod	Native	108.8	7.5
Heteromastus filiformis	Polychaete	Native	100.3	35.2
Schizobranchia insignis	Polychaete	Native	84.7	4.6
Acmira catherinae	Polychaete	Native	81.7	13.5
Ampelisca verrilli	Amphipod	Native	77.5	13.3
Ennucula tenuis	Bivalve	Native	71.1	1.7
Ampelisca spp.	Amphipod	Indeter	68.8	18.2
Spiochaetopterus oculatus	Polychaete	Native	65.7	16.7
Glycinde solitaria	Polychaete	Native	62.9	37.8
Polydora cornuta	Polychaete	Native	62.7	17.9
Levinsenia gracilis	Polychaete	Native	62.6	10.1
Bivalvia	Bivalve	Indeter	53.8	28.0
Acteocina canaliculata	Gastropod	Native	52.9	24.2
Nephtys incisa	Polychaete	Native	52.0	17.3
Crepidula spp.	Gastropod	Indeter	48.6	7.8
Neanthes succinea	Polychaete	Native	47.5	24.8
Leitoscoloplos spp.	Polychaete	Indeter	44.0	28.0
Tubificoides spp.	Oligochaete	Indeter	43.9	9.5
Leptocheirus plumulosus	Amphipod	Native	40.3	8.6
Scoloplos robustus	Polychaete	Native	39.2	20.2
Sabellaria vulgaris	Polychaete	Native	39.1	7.5
Corophium lacustre	Amphipod	Native	36.0	2.0
Lumbrineris tenuis	Polychaete	Native	35.9	12.7
Paraprionospio pinnata	Polychaete	Native	35.3	21.9
Maldanidae	Polychaete	Indeter	34.9	20.5
Capitella capitata	Polychaete	Native	33.9	8.4
Cirratulidae	Polychaete	Indeter	31.6	17.0
Mulinia lateralis	Bivalve	Native	31.3	11.8
Cerapus tubularis	Amphipod	Native	31.1	4.3
Limnodrilus spp.	Oligochaeta	Indeter	29.3	2.9
Tellina agilis	Bivalve	Native	28.9	17.0
Mytilus edulis	Bivalve	Native	27.0	2.3
Microdeutopus gryllotalpa	Amphipod	Native	26.6	4.0
Pygospio elegans	Polychaete	Native	25.9	2.0
Elasmopus laevis	Amphipod	Native	25.8	8.4
Nephtys spp.	Polychaete	Indeter	25.5	13.0
Leptocheirus pinguis	Amphipod	Native	23.6	4.3
Eusarsiella zostericola	Ostracod	Native	21.2	17.3
Cyathura polita	Isopod	Native	20.4	14.7
Polydora socialis	Polychaete	Native	19.9	5.5

[†] With the exception of 20 sites in Delaware Bay, sampled with a 0.1-m^2 grab.
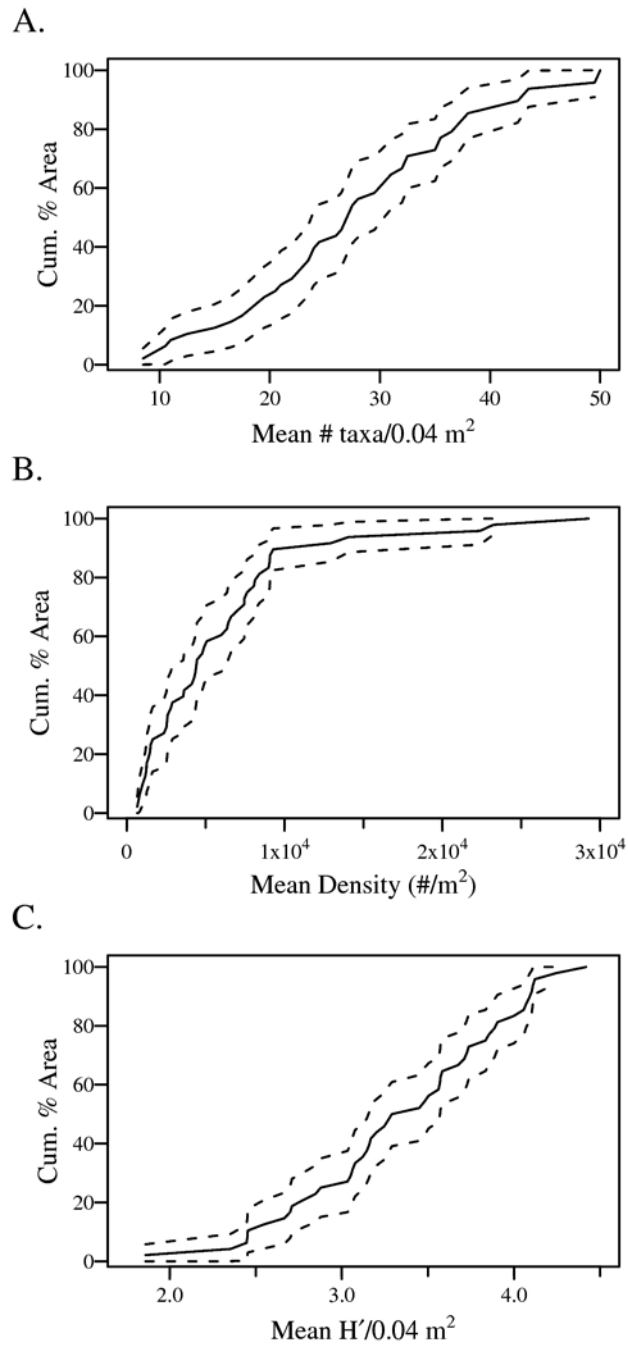
Figure 11. Percent area (and 95% C.I.) of MAB shelf waters vs. benthic infaunal taxonomic richness (A), density (B), and H' diversity (C).
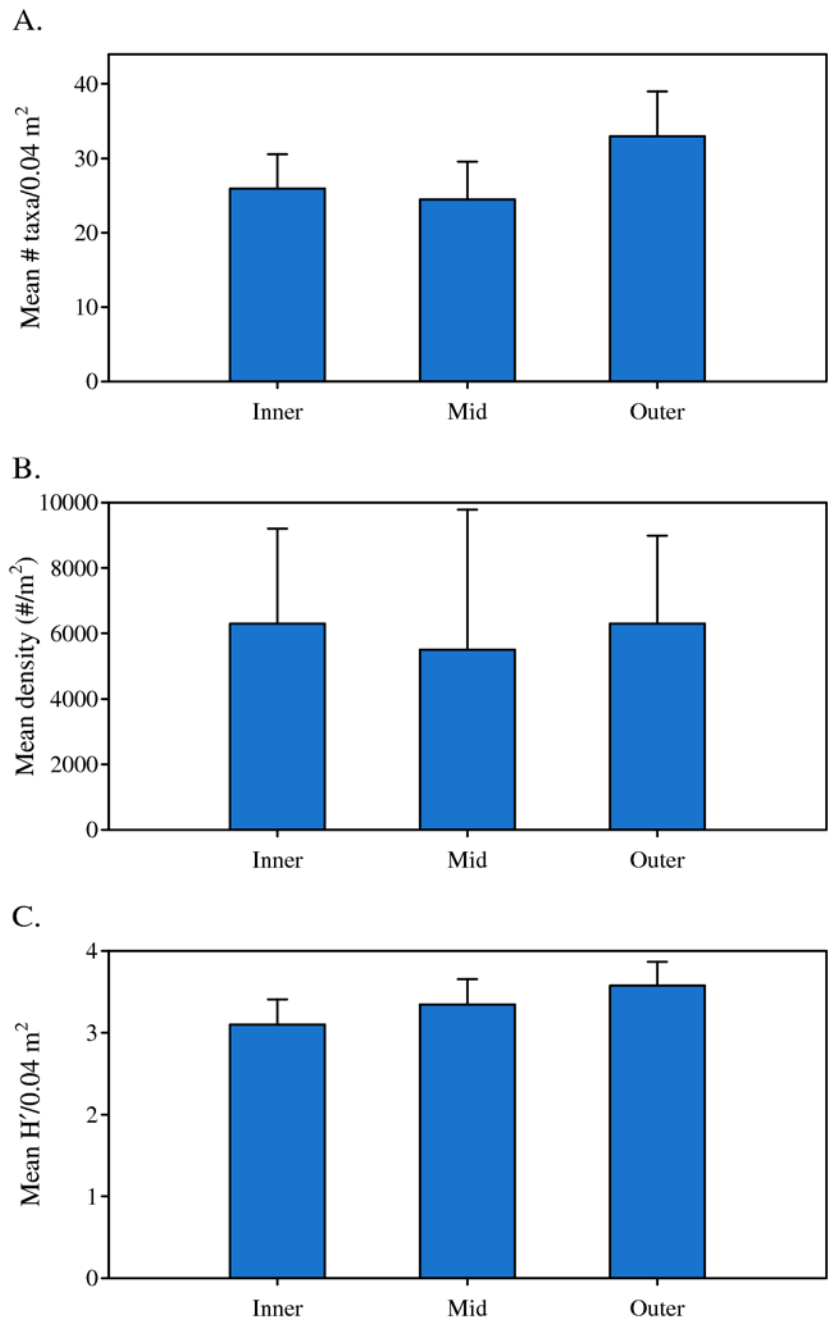
Figure 12. Comparison of A) benthic taxonomic richness (mean # taxa/0.04 m^2), B) density (mean # individuals/m^2), and C) diversity (mean H′/0.04 m^2) among inner, middle, and outer shelf locations. Whiskers represent upper 95% confidence limits for the sample mean.
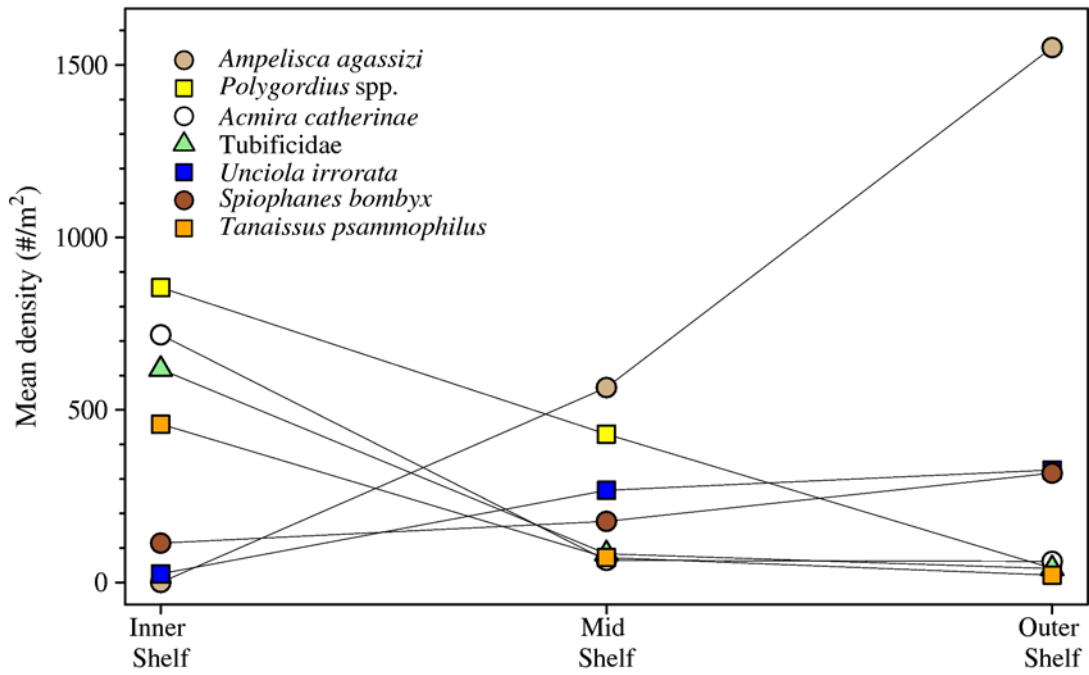
Figure 13. Trends in mean densities (#/m^2) of dominant taxa collected in sediments from relatively shallow ($\leq$ 30 m) inner-shelf waters to deeper mid- (30 – 50 m) and outer- (> 50 m) shelf waters of the MAB.
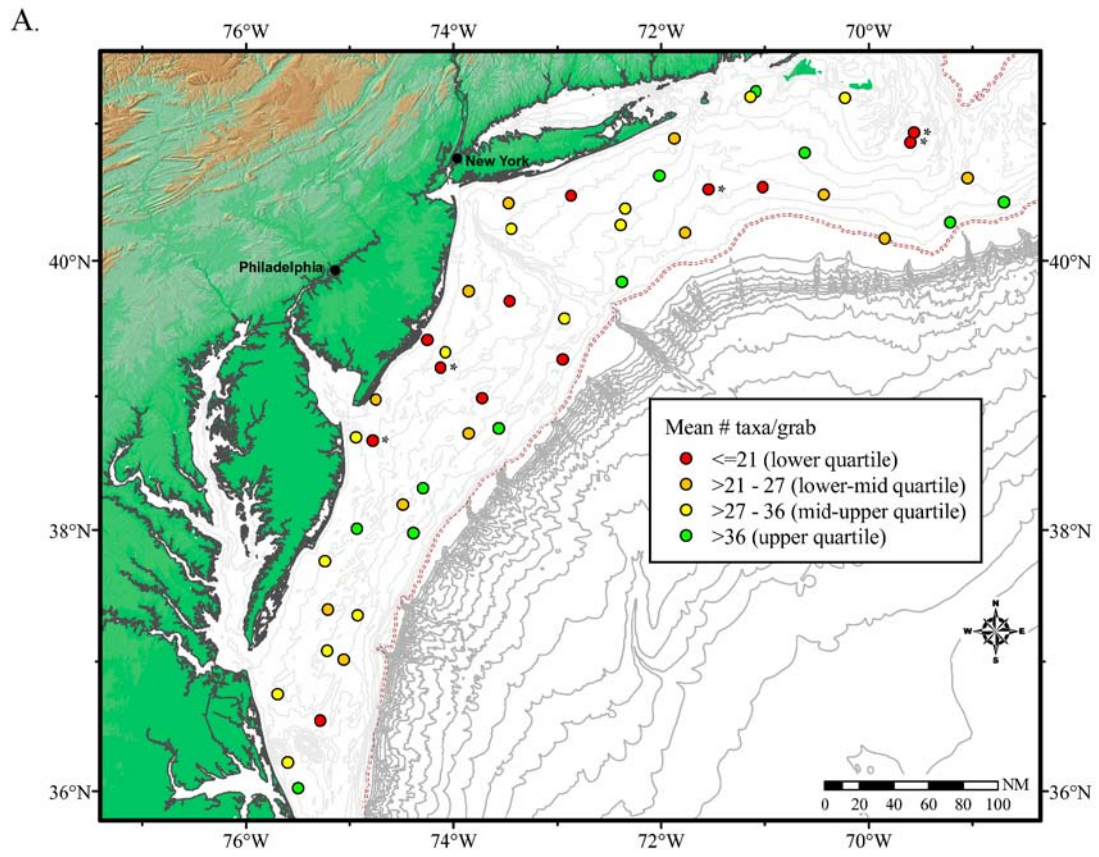
Figure 14. A. Spatial distribution of benthic taxonomic richness (mean # taxa/0.04 m^2). Values within the lower 10th percentile of all values are also flagged with an asterisk (*).
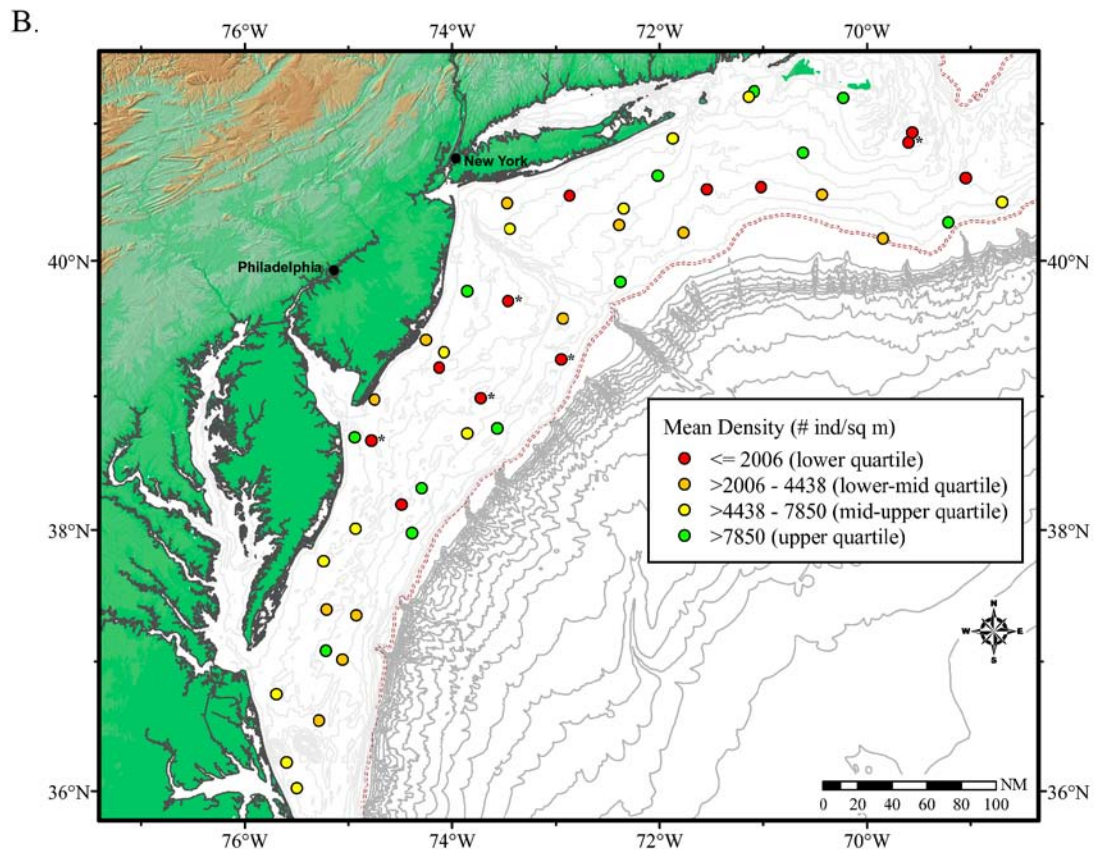
Figure 14. B. Spatial distribution of benthic infaunal density (mean # individuals/m^2). Values within the lower 10th percentile of all values are also flagged with an asterisk (*).
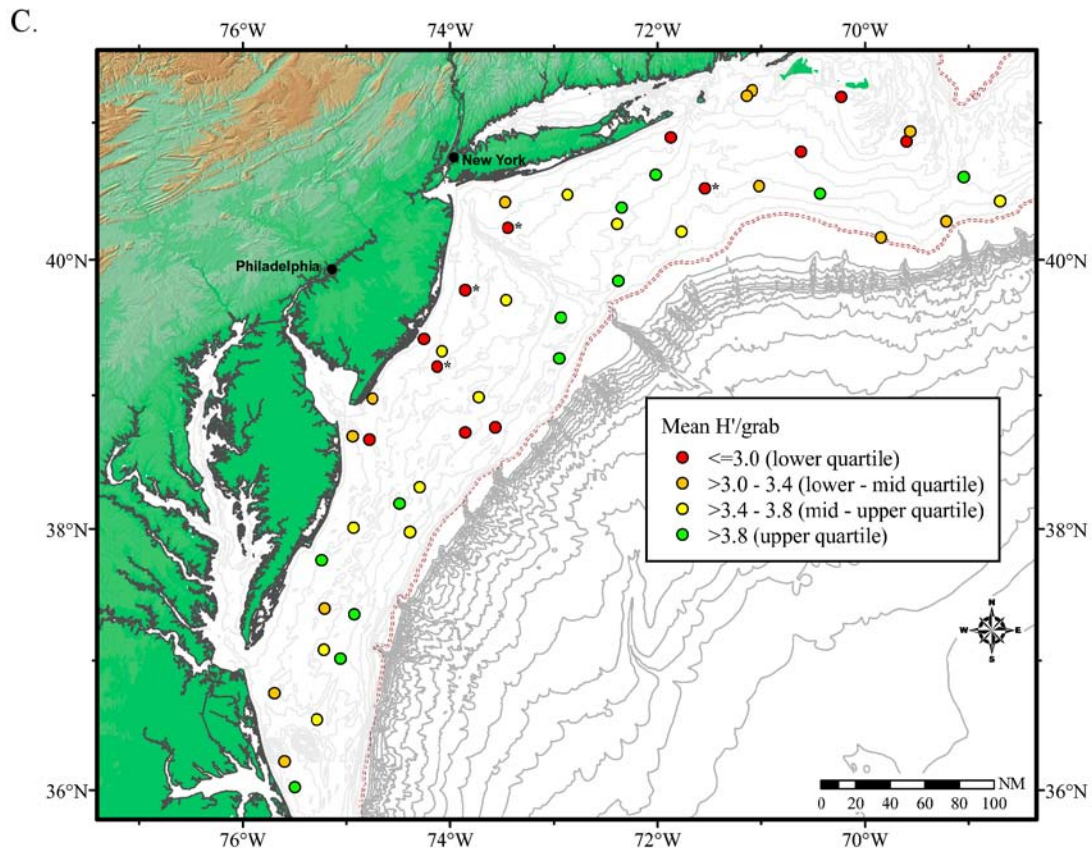
Figure 14. C. Spatial distribution of benthic taxonomic diversity (mean H′/0.04 m^2). Values within the lower 10th percentile of all values are also flagged with an asterisk (*).

3.4.4 Non-indigenous Species

The list of taxa collected in coastal shelf waters of the MAB was examined for the occurrence of non-native and exotic species by searching NISbase, a distributed database on non-indigenous species that queries a number of different information systems. Databases that are part of NISbase include the U.S. Geological Survey (USGS) National Aquatic Species Database (NAS, U.S. Geological Survey 2004), the Smithsonian National Exotic Marine and Estuarine Species Information System (NEMESIS, Fofonoff et al. 2003), the Massachusetts Institute of Technology Sea Grant Program Marine Invader Tracking Information System (MITIS, MIT 2008), and the NOAA National Benthic Inventory (NBI 2004), among others. While a small number of species collected as part of the 2006 MAB survey (*Harmothoe imbricata*, *Spiophanes bombyx*, and possibly *Leptochelia dubia*, but not identified to species) are considered to be cryptogenic (Ruiz et al. 2000), none were found unequivocally to be non-indigenous to the area.

By comparison, a few cryptogenic (*Boccardiella ligerica*, *Corophium acherusicum*) and non-indigenous (*Branchiura sowerbyi*, *Corbicula fluminea*) benthic infaunal species were identified in mid-Atlantic estuaries (NCA 2006). These estuarine non-indigenous species would not be expected to occur offshore since the shelf environment would be outside of their normal (lower) salinity ranges.

3.5 Potential Linkage of Biological Condition to Stressor Impacts

Multi-metric benthic indices are commonly used to summarize and classify benthic habitat conditions along the continuum from non-degraded to degraded (see review by Diaz et al. 2004) and have been developed for a variety of estuarine applications (Engle et al. 1994, Weisberg et al. 1997, Van Dolah et al. 1999, Llansó et al. 2002a, 2002b, Hale and Heltshe 2008). A desired characteristic of these indices is the ability to discriminate between impaired *versus* unimpaired benthic condition, based on key biological attributes (e.g., numbers of species, diversity, abundance, biomass, relative proportion of pollution-sensitive or pollution-tolerant species), while taking into account natural controlling factors. Such indices have been developed for estuaries of the mid-Atlantic states and Chesapeake Bay (Weisberg et al. 1997, Llansó et al. 2002a, 2002b). An index is being developed for near-coastal NJ (to 3 km; Strobel et al. 2008), but no such index exists for coastal shelf waters of the mid-Atlantic region.

In the absence of a benthic index, we attempted to assess potential stressor impacts in the present study by evaluating linkages between reduced values of biological attributes (numbers of taxa, diversity, and abundance) and synoptically measured indicators of poor sediment or water quality. Using the lower 10th percentile as a basis for defining 'low' values, we looked for co-occurrences of low values of biological attributes with indications of poor sediment or water quality defined as follows (*sensu* U.S. EPA 2000b for dissolved oxygen, U.S. EPA 2004 for other indicators): ≥ 1 chemical in excess of ERMs (from Long et al. 1995a), TOC > 50 mg/g, and DO in near-bottom water < 2.0 mg/L.

The analysis found no association of low values of biological attributes (as defined above) with indicators of poor sediment or water quality. In fact, no indications of poor sediment or water quality were observed based on these criteria. The highest observed TOC concentration was 16 mg/g (Appendix A), well below 50 mg/g as well as the more conservative bioeffect threshold of 35 mg/g TOC published in Hyland et al. (2005). DO concentrations in bottom waters were at least 8.1 mg/L (Appendix B) and no ERM exceedances were observed (Appendix D). These results suggest that coastal shelf waters of the MAB are in good condition, with lower-end values of biological attributes (Appendix E) representing parts of a normal reference range controlled by natural factors. Multiple linear regression was used to assess the relationship of each of the benthic variables to various abiotic environmental factors (depth, latitude, percent fines). Appropriate data transformations were applied where needed (i.e., $\log_{10}$ for density) to meet analysis assumptions. While none of the relationships were significant for either density or taxonomic richness, all three abiotic factors showed a significant effect on H′ diversity (at $\alpha = 0.05$ level of significance). Benthic diversity was higher among deeper sites (p = 0.0001), lower latitudes (p = 0.0164), and lower percent fines (p = 0.0010).

Alternatively, it is possible that for some of these sites the lower values of benthic variables reflect symptoms of disturbance induced by other unmeasured stressors. In efforts to be consistent with the underlying concepts and protocols of earlier EMAP and NCA programs, the indicators in this study included measures of stressors, such as chemical contaminants and symptoms of eutrophication, which are often associated with adverse biological impacts in shallower estuarine and inland ecosystems. However, there may be other sources of human-induced stress in these offshore systems, particularly those causing physical disruption of the seafloor (e.g., commercial bottom trawling, cable placement, minerals extraction), that pose greater risks to living resources and which have not been adequately captured. Future monitoring efforts in these offshore areas should include indicators of such alternative sources of disturbance.

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5.0 Appendices

Appendix A. Locations (latitude, longitude), depth, and sediment characteristics of sampling stations.

Station	Latitude	Longitude	Depth (m)	TOC mg/g	% Sand	% Silt-clay
01	39.77623	-73.85195	26.0	0.46	99.5	0.5
02	38.19041	-74.48682	42.0	0.38	99.5	0.6
03	40.62198	-72.01708	55.4	0.62	98.8	1.2
04	40.16709	-69.84248	98.3	3.42	79.3	20.7
05	39.84345	-72.38011	75.0	1.96	93.0	7.0
06	37.35055	-74.92469	39.6	0.76	99.7	0.3
07	38.71867	-73.71866	48.8	0.94	98.4	1.6
08	40.60671	-69.04485	71.0	0.52	99.0	1.1
09	39.57371	-72.93307	62.0	0.60	98.6	1.4
10	37.39598	-75.20685	28.1	0.80	99.1	0.9
11	39.21100	-74.12418	24.0	0.41	49.8	50.2
12	40.48423	-70.43420	70.0	9.63	99.5	0.5
13	40.42264	-73.47158	24.8	0.93	99.4	0.6
14	36.22157	-75.59648	26.3	1.32	96.1	3.9
15	39.27211	-72.94964	70.0	1.21	98.7	1.4
17	39.32492	-74.07539	24.0	1.23	99.6	0.4
18	37.96872	-74.38807	56.0	1.59	97.9	2.1
19	38.31449	-74.29424	51.6	1.54	97.4	2.6
20	41.23268	-71.08608	42.0	4.91	82.4	17.6
21	40.47603	-72.86645	42.0	0.95	99.0	1.0
22	36.02088	-75.49837	26.0	0.70	99.2	0.8
23	38.98426	-73.72332	43.0	0.91	99.1	0.9
24	40.86574	-69.59671	37.0	0.56	99.6	0.4
25	40.23471	-73.44134	35.3	0.72	99.2	0.8
26	37.01197	-75.05770	41.0	0.63	99.8	0.2
27	38.66862	-74.77945	14.3	0.40	99.6	0.4
28	40.78832	-70.61688	57.0	5.86	68.8	31.2
29	40.52200	-71.54149	76.6	11.07	80.8	19.2
31	37.76414	-75.23725	20.5	0.39	99.1	0.9
32	40.43062	-68.69903	88.0	2.12	95.6	4.4
33	39.70231	-73.45761	33.2	0.31	99.5	0.5
34	38.00765	-74.92921	26.0	0.36	99.4	0.6
35	40.38298	-72.34644	55.0	0.33	99.1	0.9
36	41.19415	-71.13901	38.0	0.63	99.4	0.6
37	40.20558	-71.77030	80.0	4.74	80.5	19.6
38	36.54718	-75.28401	25.0	0.27	99.6	0.5
39	38.75957	-73.56624	60.0	1.72	96.8	3.2
40	41.18448	-70.22600	26.0	0.42	99.1	0.9
41	40.26110	-72.39044	58.0	0.69	98.4	1.6
42	37.08104	-75.21376	35.0	1.34	98.9	1.2
43	38.97416	-74.74604	13.6	0.33	99.8	0.3
44	40.53967	-71.01903	75.0	16.04	13.2	86.9
45	40.89256	-71.87329	38.7	0.41	99.7	0.3
47	38.69160	-74.94115	17.6	2.92	86.1	13.9
48	40.28228	-69.21308	92.2	3.23	92.0	8.0
49	39.41574	-74.25471	16.0	0.34	99.7	0.3
50	36.74786	-75.69260	20.5	0.44	99.4	0.7
90	40.93569	-69.55392	42.0	0.28	99.8	0.3
98	41.10785	-69.62802	31.2	–	–	–

Appendix B. Near-bottom water characteristics by station.

Station	Temp. (ºC)	Salinity (psu)	DO (mg/L)	pH	DIP (mg/L)	DIN (mg/L)	Nitrate+ Nitrite (µg/L)	Ammonium (µg/L)	N/P	Silicate (µg/L)	Chlorophyll a (µg/L)	TSS (mg/L)
01	10.4	31.9	9.1	8.1	0.036	0.032	22.6	9.2	2.35	294.8	0.216	6.0
02	9.8	32.9	9.2	–	0.046	0.027	27.0	0.4	0.97	354.5	0.075	8.2
03	7.4	32.5	9.7	8.4	0.055	0.054	51.1	2.5	1.70	454.7	0.018	4.3
04	13.2	35.0	8.4	8.5	0.069	0.412	405.9	5.8	9.82	631.1	0.041	6.5
05	12.3	34.3	8.6	8.3	0.064	0.234	231.2	2.5	6.00	592.9	0.051	1.8
06	9.5	33.5	9.2	–	0.056	0.101	98.4	2.5	3.04	388.2	0.732	5.6
07	11.0	34.1	8.9	–	0.065	0.222	218.7	3.8	5.69	562.1	–	–
08	7.3	32.6	9.7	8.5	0.067	0.187	160.4	27.0	5.93	469.6	0.896	3.0
09	7.9	33.2	9.6	–	0.083	0.230	200.7	29.3	5.74	714.8	0.238	3.6
10	11.0	32.5	9.0	–	0.037	0.024	20.8	3.1	1.35	261.2	0.412	7.0
11	10.8	32.3	9.0	–	0.039	0.025	24.3	0.7	1.10	228.6	0.147	6.8
12	7.7	33.0	9.6	8.5	0.067	0.159	116.0	43.4	6.15	446.2	0.827	9.6
13	10.1	31.2	9.2	8.2	0.046	0.037	26.6	10.9	2.18	468.6	0.164	3.9
14	11.7	32.5	8.9	–	0.039	0.027	26.7	0.8	1.18	394.8	0.886	5.7
15	12.9	34.7	8.5	–	0.060	0.221	210.9	10.2	6.60	588.3	0.081	3.8
17	11.2	32.4	8.9	–	0.042	0.019	18.2	0.4	0.73	164.9	0.104	5.0
18	13.6	35.0	8.4	–	0.049	0.142	131.7	10.6	5.48	414.4	0.196	3.0
19	11.0	34.1	8.9	–	0.064	0.184	179.1	5.0	4.91	481.7	0.028	9.4
20	8.3	32.3	8.4	8.0	0.056	0.042	31.5	10.4	1.87	495.4	0.050	4.1
21	8.5	32.1	9.5	8.2	0.054	0.044	40.0	3.9	1.56	393.2	0.034	5.1
22	12.0	32.4	8.8	–	0.047	0.034	28.8	5.3	1.57	209.0	0.058	8.0
23	8.3	32.8	9.5	–	0.062	0.079	69.8	8.9	2.59	359.3	0.043	3.6
24	8.3	32.3	9.5	8.6	0.048	0.062	51.2	10.4	2.82	300.4	0.037	1.1
25	9.2	32.1	9.4	8.2	0.048	0.030	28.9	0.6	1.01	326.6	0.034	11.4
26	9.7	33.2	9.2	–	0.055	0.114	106.7	7.1	3.75	358.1	0.267	5.6
27	13.1	31.5	8.7	–	0.028	0.014	9.1	4.6	1.44	210.3	0.038	10.6
28	6.9	32.7	9.8	8.4	0.074	0.178	134.0	43.9	5.97	662.1	0.008	12.8
29	6.9	33.3	9.8	8.3	0.120	0.539	464.6	74.0	9.37	1239.4	0.051	4.8
31	12.7	31.9	8.7	–	0.037	0.016	11.6	4.6	1.17	254.9	0.053	14.5
32	8.2	33.4	9.5	8.5	0.077	0.349	310.7	37.9	8.99	578.6	0.065	2.0

Appendix B (continued).

Station	Temp. (ºC)	Salinity (psu)	DO (mg/L)	pH	DIP (mg/L)	DIN (mg/L)	Nitrate+ Nitrite (µg/L)	Ammonium (µg/L)	N/P	Silicate (µg/L)	Chlorophyll a (µg/L)	TSS (mg/L)
33	8.9	32.2	9.4	–	0.054	0.035	28.1	7.3	1.55	305.1	0.450	5.0
34	12.5	32.1	8.7	–	0.031	0.021	13.3	7.4	1.98	241.0	0.761	5.4
35	6.6	32.6	9.9	8.2	0.084	0.262	231.8	30.5	6.28	664.9	0.144	5.0
36	8.3	32.3	8.6	8.0	0.037	0.018	16.0	2.1	0.98	171.3	0.019	4.3
37	12.6	34.9	8.6	8.3	0.079	0.542	539.9	2.5	10.88	766.3	0.359	1.6
38	11.1	32.9	8.9	–	0.040	0.019	18.3	0.6	0.80	485.7	0.085	6.2
39	13.5	34.9	8.4	–	0.051	0.199	181.7	17.3	7.43	466.9	0.049	6.1
40	9.8	32.1	8.9	8.1	0.038	0.013	11.1	1.5	0.68	252.2	0.046	11.8
41	6.5	32.5	9.9	8.2	0.088	0.278	241.4	36.3	6.51	759.7	0.022	2.9
42	11.1	32.7	9.0	–	0.041	0.021	20.6	0.3	0.84	392.5	0.009	5.1
43	13.6	30.6	8.6	–	0.021	0.008	6.9	1.1	0.83	123.0	0.422	12.7
44	12.1	34.4	8.7	8.5	0.062	0.261	232.7	28.4	8.45	482.8	0.043	1.8
45	8.8	32.2	9.4	–	0.045	0.030	17.3	13.0	2.18	270.8	0.036	6.4
47	13.9	31.2	8.5	–	0.034	0.040	12.6	27.9	4.95	240.2	3.023	36.4
48	8.3	33.5	9.5	8.6	0.078	0.366	329.1	36.6	9.18	614.5	0.540	16.3
49	13.6	30.0	8.6	–	0.017	0.014	13.6	0.5	1.45	118.1	0.129	10.4
50	12.4	32.1	8.7	–	0.037	0.022	14.5	7.4	1.70	223.3	1.829	6.5
90	7.7	32.3	9.7	8.6	0.059	0.200	181.7	18.6	6.46	384.2	0.150	4.6
98	8.8	32.2	9.5	8.6	0.042	0.034	32.7	0.9	1.38	252.3	0.195	6.6

Appendix C. Near-surface water characteristics by station.

Station	Temp. (ºC)	Salinity (psu)	DO (mg/L)	pH	DIP (mg/L)	DIN (mg/L)	Nitrate+ Nitrite (µg/L)	Ammonium (µg/L)	N/P	Silicate (µg/L)	Chlorophyll a (µg/L)	TSS (mg/L)
01	11.8	31.6	8.9	8.2	0.034	0.026	21.6	4.1	1.65	417.0	0.342	4.9
02	11.0	32.8	9.0	–	0.042	0.037	27.5	9.0	2.17	277.3	0.043	5.4
03	10.0	32.4	9.2	8.4	0.033	0.027	26.0	1.1	1.44	617.4	0.146	5.1
04	17.9	35.3	7.7	8.6	0.024	0.053	43.1	9.7	5.23	312.6	0.187	4.6
05	10.9	32.3	9.0	8.3	0.038	0.026	22.6	3.1	1.39	149.8	0.195	3.4
06	11.2	32.9	8.9	–	0.043	0.032	23.2	9.1	2.01	239.6	0.044	4.2
07	11.1	32.8	8.9	–	0.040	0.039	36.2	3.1	1.85	497.6	–	–
08	8.7	32.4	9.4	8.6	0.055	0.096	95.1	0.7	2.84	349.8	0.387	0.9
09	10.9	32.1	9.0	–	0.040	0.036	25.6	10.0	2.34	187.2	0.177	6.9
10	12.8	32.3	8.6	–	0.034	0.034	33.6	0.5	1.67	755.6	0.085	6.8
11	11.6	32.0	8.9	–	0.036	0.025	24.7	0.1	1.12	259.3	0.562	3.3
12	9.8	32.4	9.2	8.5	0.038	0.030	23.4	6.4	1.91	113.5	0.094	6.6
13	10.7	31.2	9.1	8.2	0.044	0.022	22.4	0.1	0.85	741.1	0.047	11.3
14	14.3	31.2	8.4	–	0.033	0.033	30.7	1.8	1.75	396.7	0.033	6.3
15	14.7	34.1	8.2	–	0.033	0.024	21.7	2.6	1.48	660.2	0.185	4.7
17	12.2	31.6	8.8	–	0.042	0.035	30.4	4.8	1.77	250.9	0.070	3.8
18	12.2	33.7	8.7	–	0.038	0.022	17.8	4.2	1.35	248.1	0.018	2.5
19	11.2	32.8	8.9	–	0.044	0.031	30.0	0.6	1.17	413.5	0.068	4.2
20	11.0	31.9	8.8	8.1	0.042	0.028	25.7	2.0	1.25	228.4	0.091	3.4
21	10.7	31.4	9.1	8.2	0.042	0.019	18.3	0.8	0.81	787.3	0.032	6.3
22	12.9	31.8	8.7	–	0.039	0.054	49.8	4.0	2.53	167.7	0.049	11.6
23	10.9	32.6	9.0	–	0.043	0.024	20.6	3.4	1.18	206.9	0.039	4.3
24	8.3	32.3	9.5	8.6	0.050	0.071	54.6	16.8	3.53	315.2	0.022	0.9
25	10.8	31.9	9.0	8.2	0.042	0.027	26.1	1.3	1.17	299.5	0.163	3.2
26	12.4	32.6	8.7	–	0.037	0.019	17.9	1.0	0.91	214.6	0.076	8.1
27	13.6	31.5	8.6	–	0.031	0.014	12.2	2.2	1.04	634.2	0.660	13.5
28	10.2	32.5	9.1	8.6	0.034	0.010	9.2	0.9	0.61	165.7	0.708	8.6
29	9.8	32.5	9.2	8.4	0.042	0.021	20.3	0.9	0.98	505.9	0.012	3.9
31	14.3	31.8	8.4	–	0.033	0.033	15.1	18.1	3.73	650.9	0.112	7.7
32	9.5	32.7	9.3	8.6	0.050	0.110	102.6	7.1	3.97	377.6	0.118	1.3

Appendix C (continued).

Station	Temp. (ºC)	Salinity (psu)	DO (mg/L)	pH	DIP (mg/L)	DIN (mg/L)	Nitrate+ Nitrite (µg/L)	Ammonium (µg/L)	N/P	Silicate (µg/L)	Chlorophyll a (µg/L)	TSS (mg/L)
33	11.4	31.8	8.9		0.040	0.021	14.5	6.0	1.37	227.1	0.066	2.1
34	12.8	32.0	8.7		0.029	0.022	12.0	10.4	2.55	260.5	0.049	4.0
35	9.9	32.2	9.2	8.3	0.052	0.014	13.8	0.1	0.43	224.7	0.181	4.3
36	11.2	31.9	8.7	8.1	0.050	0.024	19.8	3.9	1.05	285.6	0.115	2.2
37	9.9	32.4	9.2	8.4	0.056	0.051	29.1	21.8	2.90	461.3	0.129	3.0
38	12.2	32.8	8.7		0.041	0.027	17.4	9.9	1.96	494.8	0.012	5.9
39	14.7	34.4	8.2		0.034	0.019	17.5	1.0	1.01	514.3	0.086	5.6
40	10.1	31.9	8.9	8.1	0.045	0.022	14.2	7.6	1.41	338.6	0.024	4.8
41	9.9	32.1	9.2	8.3	0.037	0.011	11.4	0.1	0.50	221.5	0.028	4.8
42	12.8	32.6	8.6		0.039	0.014	12.1	2.1	0.78	199.2	0.025	12.2
43	13.6	30.6	8.6		0.020	0.014	11.7	2.2	1.56	626.8	0.150	10.1
44	11.0	33.3	8.9	8.5	0.032	0.017	10.6	6.7	1.65	108.1	0.042	2.2
45	11.1	31.2	9.0		0.045	0.024	17.9	6.2	1.44	830.4	0.017	8.5
47	14.7	30.5	8.4		0.031	0.028	21.3	6.9	2.28	409.5	3.303	6.9
48	9.3	32.7	9.3	8.5	0.050	0.132	124.1	7.6	4.74	378.7	0.116	10.2
49	13.7	30.0	8.6		0.015	0.014	12.8	1.6	1.93	94.5	0.325	6.5
50	15.2	30.4	8.3		0.026	0.011	9.7	1.2	0.84	157.8	0.767	6.9
90	7.8	32.3	9.7	8.6	0.060	0.199	181.3	17.3	6.25	374.5	0.610	6.7
98	8.8	32.2	9.4	8.6	0.041	0.051	39.1	12.0	3.14	437.7	0.074	6.2

Appendix D. Summary by station of mean ERM quotients and the number of contaminants that exceeded corresponding ERL or ERM values (from Long et al. 1995a).

Station	# of ERLs Exceeded	# of ERMs Exceeded	Mean ERM-Q
01	0	0	0.002
02	0	0	0.002
03	0	0	0.009
04	0	0	0.009
05	0	0	0.007
06	0	0	0.001
07	0	0	0.004
08	0	0	0.001
09	0	0	0.008
10	0	0	0.005
11	0	0	0.003
12	1	0	0.018
13	1	0	0.010
14	0	0	0.011
15	0	0	0.004
17	1	0	0.009
18	0	0	0.006
19	0	0	0.005
20	0	0	0.008
21	0	0	0.002
22	0	0	0.001
23	0	0	0.002
24	0	0	0.001
25	0	0	0.008
26	0	0	0.001
27	0	0	0.003
28	0	0	0.008
29	0	0	0.019
31	0	0	0.006
32	0	0	0.004
33	0	0	0.007
34	0	0	0.005
35	0	0	0.003
36	0	0	0.002
37	0	0	0.007
38	0	0	0.003
39	0	0	0.006
40	0	0	0.001
41	0	0	0.003
42	0	0	0.006
43	0	0	0.001
44	0	0	0.026
45	0	0	0.002
47	0	0	0.017
48	0	0	0.007
49	0	0	0.001
50	0	0	0.003
90	0	0	0.001

Appendix E. Summary by station of benthic macroinfaunal (>0.5mm) characteristics. Two replicate benthic grabs (0.04m^2 each) were processed from each station, except for station 14 (see text). H′ derived using base 2 logarithms. (*Values within lower 25th percentile of all values of a specific benthic variable; **values within lower 10th percentile.)

Station	Mean # Taxa per Grab	Total # Taxa	Mean Density (# / m^2)	Mean H′ per Grab
01	27	38	9288	2.4**
02	24	36	1188*	4.1
03	44	56	8138	4.2
04	25	38	4275	3.1
05	50	77	9000	4.0
06	35	54	4125	4.1
07	27	42	4788	2.7*
08	22	33	1650*	4.1
09	33	51	2900	4.4
10	21	34	4363	3.2
11	11**	16**	1513*	1.9**
12	27	44	2788	4.1
13	23	36	3638	3.3
14	32	32*	6350	3.1
15	20*	31*	825**	4.1
17	30	44	5075	3.8
18	43	63	9063	3.7
19	37	61	8413	3.4
20	43	69	29263	3.2
21	20*	32*	1250*	3.6
22	38	61	5988	3.9
23	15*	24*	750**	3.5
24	11**	17**	1050**	2.7*
25	30	47	7450	2.4**
26	24	36	2363	3.9
27	9**	15**	675**	2.5*
28	50	71	22388	2.8*
29	11**	19**	1488*	2.4**
31	36	53	4900	3.9
32	44	67	7638	3.6
33	18*	25*	938**	3.7
34	37	59	7463	3.5
35	36	52	4463	4.1
36	28	39	6438	3.3
37	24	42	2600	3.7
38	21*	34	2525	3.6
39	38	56	8063	2.8*
40	31	45	23238	2.5*
41	28	40	4413	3.7
42	31	31*	9088	3.6
43	23	34	3588	3.1
44	17*	31*	1263*	3.2
45	26	40	7013	2.9*
47	33	47	12938	3.2
48	50	77	14063	3.0
49	20*	29*	2563	2.7*
50	28	41	6613	3.1
90	13**	17**	1388*	3.1

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