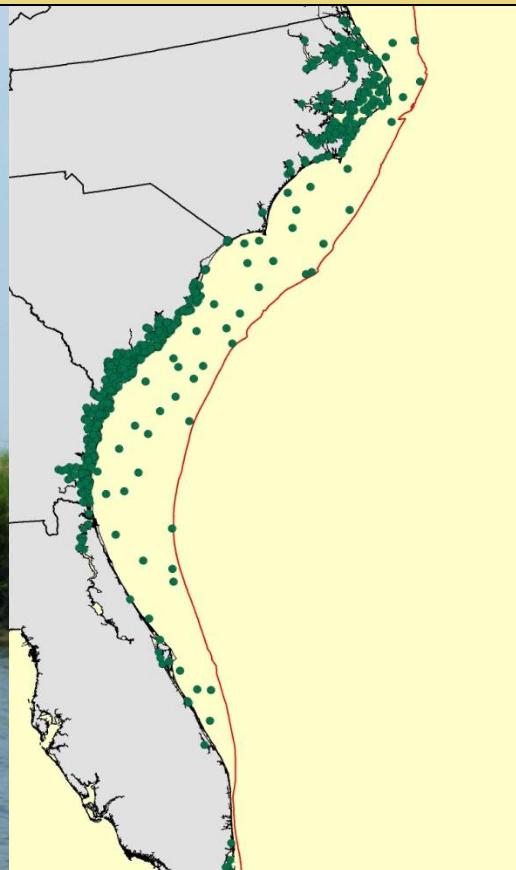
EPA United States Environmental Protection Agency



Ecological Condition of Coastal Ocean and Estuarine Waters of the U.S. South Atlantic Bight: 2000 – 2004

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May 2010

Office of Research and Development
U.S. Environmental Protection Agency
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National Oceanic and
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National Ocean Service
Silver Spring, MD 20910

Ecological Condition of Coastal Ocean and Estuarine Waters of the U.S. South Atlantic Bight: 2000 - 2004

May 2010

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Preface

This document provides an assessment of ecological condition in coastal ocean and estuarine waters of the U.S. South Atlantic Bight from Cape Henry, Virginia, through the southern end of the Indian River Lagoon along the east coast of Florida. Data are from sampling conducted in open shelf waters during March-April 2004 and in estuaries each year from 2000 to 2004. The project was a large collaborative effort by the U.S. Environmental Protection Agency (EPA), the National Oceanic and Atmospheric Administration (NOAA), and Southeast U.S. Coastal States (Florida, Georgia, South Carolina, North Carolina, Virginia). It also represents one of a series of assessments conducted under EPA's National Coastal Assessment (NCA) program. The NCA is the coastal component of the nationwide Environmental Monitoring and Assessment Program (EMAP). The NCA program is administered through the EPA and implemented through partnerships with a variety of federal and state agencies, universities, and the private sector. The 2004 South Atlantic Bight (SAB) coastal ocean shelf assessment involved the participation and collaboration of NOAA, EPA, and the State of Florida/Florida Fish and Wildlife Conservation Commission (FFWCC).

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Executive Summary

In March-April 2004, the National Oceanic and Atmospheric Administration (NOAA), U.S. Environmental Protection Agency (EPA), and State of Florida (FL) conducted a study to assess the status of ecological condition and stressor impacts throughout the South Atlantic Bight (SAB) portion of the U.S. continental shelf and to provide this information as a baseline for evaluating future changes due to natural or human-induced disturbances. The boundaries of the study region extended from Cape Hatteras, North Carolina to West Palm Beach, Florida and from navigable depths along the shoreline seaward to the shelf break (~100m). The study incorporated standard methods and indicators applied in previous national coastal monitoring programs — Environmental Monitoring and Assessment Program (EMAP) and National Coastal Assessment (NCA) — including multiple measures of water quality, sediment quality, and biological condition. 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. A probabilistic sampling design, which included 50 stations distributed randomly throughout the region, was used to provide a basis for estimating the spatial extent of condition relative to the various measured indicators and corresponding assessment endpoints (where available).

Conditions of these offshore waters are compared to those of southeastern estuaries, based on data from similar EMAP/NCA surveys conducted in 2000-2004 by EPA, NOAA, and partnering southeastern states (Florida, Georgia, South Carolina, North Carolina, Virginia) (NCA database for estuaries, EPA Gulf Ecology Division, Gulf Breeze FL). Data from a total of 747 estuarine stations are included in this database. As for the offshore sites, the estuarine samples were collected using standard methods and indicators applied in previous coastal EMAP/NCA surveys including the probabilistic sampling design and multiple indicators of water quality, sediment quality, and biological condition (benthos and fish).

The majority of the SAB had high levels of DO in near-bottom water (> 5 mg L^{-1}) indicative of "good" water quality. DO levels in bottom waters exceeded this upper threshold at all sites throughout the coastal-ocean survey area and in 76% of estuarine waters. Twenty-one percent of estuarine bottom waters had moderate levels of DO between 2 and 5 mg L^{-1} and 3% had DO levels below 2 mg L^{-1}. The majority of sites with DO in the low range considered to be hypoxic (< 2 mg L^{-1}) occurred in North Carolina estuaries. There also was a notable concentration of stations with moderate DO levels (2 – 5 mg L^{-1}) in Georgia and South Carolina estuaries.

Approximately 58% of the estuarine area had moderate levels of chlorophyll *a* (5-10 µg L^{-1}) and about 8% of the area had higher levels, in excess of 10 µg L^{-1}, indicative of eutrophication. The elevated chlorophyll *a* levels appeared to be widespread throughout the estuaries of the region. In contrast, offshore waters throughout the region had relatively low levels of chlorophyll *a* with 100% of the offshore survey area having values < 5 µg L^{-1}.

Estuaries of the SAB displayed a wide range of sediment types from mud to sands, while the offshore environment consisted largely of sands with typically < 5% silt-clay. Total Organic Carbon (TOC) also exhibited a wide range of values across the region, with the highest levels occurring in estuaries. About 19% of the estuarine survey area had TOC at moderate levels (20-50 mg g^{-1}) and 7% had values in the high range (> 50 mg g^{-1}) associated with a high risk of adverse effects on benthic fauna. In comparison, offshore sediments had moderate levels of TOC in about 10% of the survey area (only three of the 50 stations) and none of the stations had TOC in the upper range. TOC levels tended to be highest in the upstream portions of estuaries and along the shelf break in the case of the offshore environment. All three offshore stations with TOC in excess of 20 mg g^{-1} were located along the shelf break.

In general, sediment contaminants were at relatively low levels throughout most of the region. Chemical contaminants in offshore sediments were mostly at low, background levels and there were no chemicals in excess of Effects-Range Median (ERM) values and < 5 chemicals in excess of Effects-Range Low (ERL) values at all stations. Sediment contamination was more extensive in estuaries, though moderate levels (≥ 5 ERL values exceeded) to high levels (≥ 1 ERM value exceeded) were still limited to only 4% of the total estuarine survey area.

Previous surveys of the estuarine portions of the SAB in the 1990s found that Polychlorinated Biphenyls (PCB) and pesticides were the most pronounced contaminant groups for this region. The current study found that PCBs and pesticide contamination have become less pronounced since the earlier surveys. The most prevalent contaminants in the present estuarine survey area were three metals (arsenic, nickel, and cadmium) and total Dichlorodiphenyltrichloroethane (DDT). Though spatially extensive, all of these except nickel were present at only moderate levels between corresponding ERL and ERM guideline values. Nickel in addition to five other contaminants (mercury, silver, zinc, total PCBs, and 4,4′ Dichlorodiphenyldichloroethylene (DDE)) were present in estuarine sediments at concentrations above the corresponding ERM values though only at four of 747 stations. For the offshore environment, there were three metals (arsenic, cadmium, and silver) found at moderate concentrations between corresponding ERL and ERM values, but no chemicals were found in excess of the higher-threshold ERM values and none of the offshore stations had more than one chemical that exceeded its corresponding ERL value.

Of the 20 offshore samples of fish that were collected and analyzed for chemical contaminants, only two had tissue contaminant concentrations (i.e., mercury) in the moderate range with respect to non-cancer human-health risks and there were none with contaminants in the upper range. In contrast, of the 166 fish samples from estuaries, three had total PCB concentrations that exceeded the lower non-cancer effects threshold, one had total PCBs in excess of the corresponding higher threshold, and three had total PAHs that exceeded both the lower (1.6 ng g^{-1}) and upper (3.2 ng g^{-1}) cancer effects thresholds (a non-cancer concentration range for PAHs does not exist) .

The relative proportions of major benthic taxonomic groups were fairly consistent between the offshore and estuarine habitats. Polychaete worms, followed by crustaceans, were the dominant taxa both by percent abundance and percent species throughout the region. However, the total number of species per unit of sampling effort was much higher for the offshore waters. For example, while a total of 948 benthic taxa were identified from 746 estuarine sites, almost half that amount (462 taxa or 49%) was identified from only 50 offshore sites (6.7% of the estuarine sites).

There was little overlap of dominant benthic taxa between the estuarine and coastal-ocean habitats. Specifically, only five taxa were common to both the offshore and estuarine lists of fifty most abundant taxa. These taxa were the amphipod *Ampelisca abdita*, the polychaete *Mediomastus* spp., Actiniaria, Nemertea, and Tubificidae. Diversity of benthic macroinfauna, as measured by species richness and the Shannon-Weiner diversity index H′, was higher in the offshore than in estuarine portions of the region. As an example, species richness averaged 38 taxa grab^{-1} in offshore waters and was less than half that number (16 taxa grab^{-1}) in estuaries. Only three of the 50 offshore stations, representing about 10% of the offshore survey area, had ≤ 16 taxa grab^{-1} (the estuarine mean).

Benthic species lists were examined for presence of non-indigenous species by comparison to the USGS Non-indigenous Aquatic Species database (nas.er.usgs.gov). There were no non-indigenous species found in benthic samples from any of the 50 offshore sites. Three non-indigenous species — *Corbicula fluminea* (Asian clam), *Petrolisthes armatus* (green porcelain crab), and *Rangia cuneata* (Atlantic rangia) — were identified in benthic samples from SAB estuaries sampled as part of the NCA efforts in 2000 – 2004. Still, these three species represented a relatively small proportion (< 0.01%) of the total 408 taxa that were identified to species level from the analysis of 1,039 estuarine grab samples (0.04-m^2 each). The SAB benthos appears to be less invaded than some other coastal regions such as the Pacific Coast benthos, where non-indigenous species are common in estuaries and occur offshore as well though in more limited numbers.

Multi-metric benthic indices are an important tool for detecting pollution-induced signals of a degraded benthos and have been developed for a variety of estuarine applications including SAB estuaries. Of the estuarine area represented in the present SAB study, 7% of the total area was rated as having poor benthic condition (index scores ≤ 1.5), 9% was rated fair (1.5 – 3.0), and 84% was rated good (≥ 3.0) based on the Benthic-Index of Biological Integrity (B-IBI) for southeastern estuaries. No such index exists for the coastal-ocean portion of the SAB. However, because there were no major indications of poor sediment or water quality in the offshore environment (i.e., DO < 2 mg/L, TOC > 50 mg/g, or ≥ 1 chemical contaminant in excess of ERMs), there was no evidence of a linkage between such potential degraded environmental conditions and impaired benthic communities. Thus, lower values of key biological attributes (numbers of taxa, diversity, and abundance), defined as the lower 10th percentile of observed values, appeared to represent parts of a normal reference range controlled by natural factors. Alternatively, it is possible that for some of these offshore sites the lower values of benthic variables reflect symptoms of disturbance induced by other unmeasured stressors, particularly those causing physical disruption of the seafloor (e.g., commercial bottom trawling, cable placement, minerals extraction), which may pose greater risks to offshore living resources and have not been adequately captured. Future monitoring efforts in these offshore areas should include indicators of such alternative sources of disturbance.

Overall the SAB appears to be in fair to good ecological condition. However, this assessment also indicates that there are measurable portions, particularly in estuaries compared to the offshore environment, which are under some chemical or physical stress. It would be prudent to use such information as an early warning signal and justification for implementing effective coastal management practices in order to prevent potential growth of future environmental risks from increasing human activities in the region. In addition, the SAB region provides many important ecosystem goods and services across a variety of categories. As coastal development continues throughout the southeastern region, the component estuarine and coastal-ocean environments should be treated as a connected ecosystem if we are to better understand and manage these important resources and the functions they provide.

1.0 Introduction

The National Oceanic and Atmospheric Administration (NOAA) and the U.S. Environmental Protection Agency (EPA) both perform a broad range of research and monitoring activities to assess the status and potential effects of human activities on the health of coastal ecosystems and to promote the use of this information in protecting and restoring the Nation's coastal resources. Authority to conduct such work is provided through several legislative mandates including the Clean Water Act (CWA) of 1977 (33 U.S.C. §§ 1251 et seq.), National Coastal Monitoring Act (Title V of the Marine Protection, Research, and Sanctuaries Act, 33 U.S.C. §§ 2801-2805), and the National Marine Sanctuary Act of 2000. Where possible the two agencies have sought to coordinate related activities through partnerships with states and other institutions to prevent duplications of effort and bring together complementary resources to fulfill common research and management goals. Accordingly, in March-April 2004, NOAA, EPA, and the State of Florida combined efforts to conduct a joint survey of ecosystem condition in near-coastal waters of the U.S. South Atlantic Bight (SAB) using multiple indicators of ecological condition.

The study is an expansion of EPA's Environmental Monitoring and Assessment Program (EMAP) which assesses condition of the Nation's environmental resources within a variety of coastal and terrestrial resource categories. The coastal component of EMAP along the southeastern U.S. began in 1994 and continued in subsequent years with a focus on estuaries later becoming known as the National Coastal Assessment (NCA) (Hyland et al. 1996, 1998; U.S. EPA 2001, 2004, 2008). The current assessment expands this work to near-coastal shelf waters (depths of ~10 m -100 m), from Nags Head, North Carolina (NC) to West Palm Beach, Florida (FL) (see Figure 2.1.1 below), and includes comparisons with adjacent estuaries of the region, based on NCA data collected from 2000-2004 by EPA, NOAA and partnering southeastern states – FL, Georgia (GA), South Carolina (SC), NC, and Virginia (VA) (NCA database for estuaries, EPA Gulf Ecology Division, Gulf Breeze FL).

The SAB refers to coastal waters along the southeastern U.S., generally defined as extending from Cape Hatteras, NC to West Palm Beach, FL (e.g., Alegria et al. 2000) though some authors have used Cape Canaveral as the southern boundary (e.g., Allen et al. 1983), and encompassing aquatic habitats from estuaries seaward to the outer edge of the continental shelf (delineated here by the 100-m isobath). This region is also roughly equivalent to the Southeast U.S. Continental Shelf Large Marine Ecosystem (LME), one of 10 LMEs of the U.S. that provide a framework for managing ocean resources at ecosystem scales (U.S. Commission on Ocean Policy 2004). The majority of the SAB continental shelf is a sandy environment with infrequent rock outcrops and other hard bottom habitats (Powles and Barans 1980, Parker et al. 1983). Inshore the SAB contains large riverine estuaries, bar-built sounds and lagoons, as well as extensive salt marshes (Dame et al. 2000). SAB estuaries are dominated by un-vegetated soft-bottom habitats with higher proportions of silts and clays in lower-energy environments and sands in higher-energy environments (Dardeau et al. 1992). The estuaries of the SAB discharge vast quantities (66 km^3 yr^{-1}) of low-salinity water creating a coastal frontal zone along the inner shelf (Menzel et al. 1993), while the Gulf Stream acts as a major influence on the middle and outer portions of the shelf (Verity et al. 1993).

The purpose of the present study was to assess the current status of ecological condition and stressor impacts throughout the SAB region and to provide this information as a baseline 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 2001c, 2004, 2008) including multiple measures of water quality, sediment quality, and biological condition (benthos and fish). 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 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.

Assessments of status relative to these various indicators are presented for both coastal-ocean and estuarine waters, thus providing a 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 focused on estuaries (U.S. EPA 2001c, 2004, 2008). Results of this study should also provide valuable support to other growing environmental priorities, such as Ecosystem Based Approaches to Management (EAM) of coastal resources (Murawski 2007; Marine Ecosystems and Management 2007) and relevant Marine Spatial Planning (MSP) actions, especially with respect to the Southeast U.S. Continental Shelf LME.

1.1 Coastal Ocean

Shelf waters of the SAB are valuable reservoirs of both living and mineral resources and include one of NOAA's marine sanctuaries, the Gray's Reef National Marine Sanctuary (GRNMS) off the coast of Georgia. In the spring of 2004, sampling was conducted at 50 stations in shelf waters throughout the SAB, using the random probabilistic sampling design of EMAP/NCA. Accordingly, the resulting data can be used to make unbiased statistical estimates of the spatial extent of the region's health with respect to the various measured indicators, and to provide this information as a baseline for determining how environmental conditions may be changing in the future. This is the first such baseline for the near-coastal (shelf) waters of the SAB region. Scientists involved in the present study also have conducted surveys, using similar protocols and indicators, to assess the status of ecological condition and stressor impacts within the boundaries of the GRNMS itself (Cooksey et al. 2004, Hyland et al. 2006, Balthis et al. 2007). Thus, condition and characteristics of sanctuary resources can be compared to those of the surrounding SAB ecosystem.

The offshore survey involved the cooperation of multiple organizations. NOAA/Office of Marine and Aviation Operations provided the research ship (NOAA ship Nancy Foster). Funds for the project were provided by NOAA's National Ocean Service (NOS) /National Centers for Coastal Ocean Science (NCCOS) /Center for Coastal Environmental Health and Biomolecular Research (CCEHBR) (sampling supplies and equipment) and by EPA's National Health and Environmental Effects Research Laboratory (NHEERL)/Gulf Ecology Division (GED) (sample processing). Representatives from NOAA/NOS/NCCOS headquarters and two of its Centers

(CCEHBR and Center for Coastal Monitoring and Assessment), EPA/NHEERL/GED, and the State of Florida (Florida Wildlife Research Institute) participated on the cruise as members of the scientific staff. Additional partners involved in the overall program included the NOAA/GRNMS Office, South Carolina Department of Natural Resources (SCDNR), and the Georgia Department of Natural Resources (GADNR).

The present offshore survey is part of a series of Regional Ecological Assessments to evaluate condition of living resources and ecosystem stressors throughout coastal ocean waters of the U.S. 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 mid-Atlantic Bight (MAB) from Cape Hatteras to Cape Cod, MA (see Balthis et al. 2009 final 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 South Atlantic Bight (SAB) from Cape Hatteras, NC to West Palm Beach, FL (the present assessment). There are plans to complete similar surveys throughout the remaining portions of the Gulf of Mexico and North Atlantic coasts of the U.S. by 2012.

1.2 Estuaries

The estuaries addressed in the present study extend from Cape Henry, VA through the southern end of the Indian River Lagoon along the east coast of FL. These estuarine resources are diverse and extensive, covering an estimated 4,487 square miles and featuring a variety of habitats such as salt marshes, tidal rivers, coastal lagoons, and open-water embayments and sounds. They also provide a wealth of ecological and societal services including buffers against storms and sea-level rise; corridors for maritime transportation and trade, as exemplified by busy shipping ports in Miami, Jacksonville, Savannah, and Charleston; reservoirs of marine biodiversity; protected areas (e.g., National Estuarine Research Reserve System sites) to promote marine research, education, and conservation; habitat for various migratory birds and protected species; important commercial and recreational fisheries; and tourism. North Carolina contains the Albemarle-Pamlico Estuarine System (APES), the second largest estuary in the U.S. APES represents North Carolina's key resource base for commercial fishing, recreational fishing, and tourism. Similarly, the coastal resources of other southeastern states support corresponding fishing and tourism industries and generate vast amounts of sales tax income for those states as well. There is an increasing need for effective management of these economically and ecologically valuable resources given the predicted influx of people and businesses to southeastern coastal states over the next few decades and the ensuing pressures on the coastal zone of this region. Culliton et al. (1990) estimated that the coastal population in the southeastern United States will have increased by 181% over the 50 -year period from 1960 to 2010.

Estuarine data used to support the present inshore-offshore comparisons are from NCA surveys conducted in 2000 to 2004 by EPA, NOAA, and partnering States of FL, GA, SC, NC, and VA (NCA database for estuaries, EPA Gulf Ecology Division, Gulf Breeze FL). The data represent a total of 747 sampling sites (Figure 2.1.1). As for the offshore sites, the samples were collected using standard methods and indicators applied in previous coastal EMAP/NCA projects (U.S. EPA 2001c, 2004, 2008) including the probabilistic sampling design and multiple indicators of water quality, sediment quality, and biological condition (benthos and fish). The data were produced through funding provided principally by EPA (Office of Research and Development, National Health and Environmental Effects Research Laboratory).

2.0 Methods

At each station, samples were obtained for characterization of: (1) community structure and composition of benthic macroinfauna (fauna retained on a 0.5-mm sieve); (2) concentration of chemical contaminants in sediments (metals, pesticides, PCBs, PAHs); (3) sediment toxicity using the 10-day amphipod survival assay (estuarine samples only); (4) water clarity/turbidity measured by light attenuation (estuaries only);(5) other general habitat conditions (water depth, dissolved oxygen, conductivity, temperature, chlorophyll *a*, water-column nutrients and total suspended solids, % silt-clay versus sand content of sediment, organic-carbon content of sediment); and (6) condition of targeted demersal fish and macroinvertebrate species (contaminant body burdens and visual evidence of pathological disorders). The following section describes methods used for the collection, processing, and analysis of each of these sample types, which were adopted from the protocols developed for EPA's National Coastal Assessment (USEPA 2001a, 2001b).

2.1 Sampling Design and Field Collections

2.1.1 Coastal Ocean

Sampling was conducted March 30 - April 11, 2004 at 50 stations positioned randomly throughout shelf waters of the SAB, from about 1 nautical mile offshore (water depth of ~10 m) seaward to the shelf break (100 m isobath) between Nags Head, NC and West Palm Beach, FL (Figure 2.1.1). One of the 50 stations was located within GRNMS. The sampling frame for positioning stations 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 and Olsen 2004). Sampling for the survey was conducted on NOAA ship Nancy Foster, Cruise NF-04-08-CL. The cruise consisted of two legs: Leg 1 for the northern section of the sampling area (Charleston, SC to Nags Head, NC, March 30 - April 5); and Leg 2 for the southern section of the sampling area (Charleston, SC to West Palm Beach, FL, April 6 - April 11).

Bottom sediments were collected at each station with a $0.04 m^2$, Young modified van Veen grab and used for analysis of macroinfaunal communities, concentration of chemical contaminants, % silt-clay, and organic-carbon content. A grab sample was deemed successful when the grab unit was >75% full (with no major slumping). Two replicate grab samples were collected for benthic infaunal analysis. Each replicate was 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 multiple grabs (usually at least two) were taken at each station, combined into a single station composite, and then sub-sampled for analysis of metals, organic contaminants (PCBs, pesticides, PAHs), total organic carbon (TOC), and grain size.

Both a Seabird 9/11 and Seabird 19 CTD unit, supplied by the NOAA Ship Nancy Foster, were used to acquire continuous profiles of salinity, temperature, dissolved oxygen, and depth during the descent and ascent through the water column. The Seabird 9/11 also was equipped with 12 Nisken bottles to acquire discrete water samples at three designated water depths: 1 m below sea surface, mid-water column, and 1 m off seabed. The water samples were processed for nutrients, total suspended solids, and chlorophyll.

Hook-and-line fishing methods (up to six fishing rods) were attempted at all 50 stations in an effort to capture demersal fishes for inspection of external pathologies and for subsequent analysis of chemical contaminants in tissues. Any captured fish were identified and inspected for gross external pathologies. A total of 20 fish collected among seven species from 17 of the 50 stations were selected for analysis as follows:

- 7 sand perch (*Diplectrum formosum*)
- 6 black seabass (*Centropristis striata*)
- 3 dusky flounder (*Syacium papillosum*)
- 1 whitebone porgy (*Calamus leucosteus*)
- 1 red porgy (*Pagrus pagrus*)
- 1 lizardfish (*Synodus foetens*)
- 1 snake fish (*Trachinocephalus myops*)

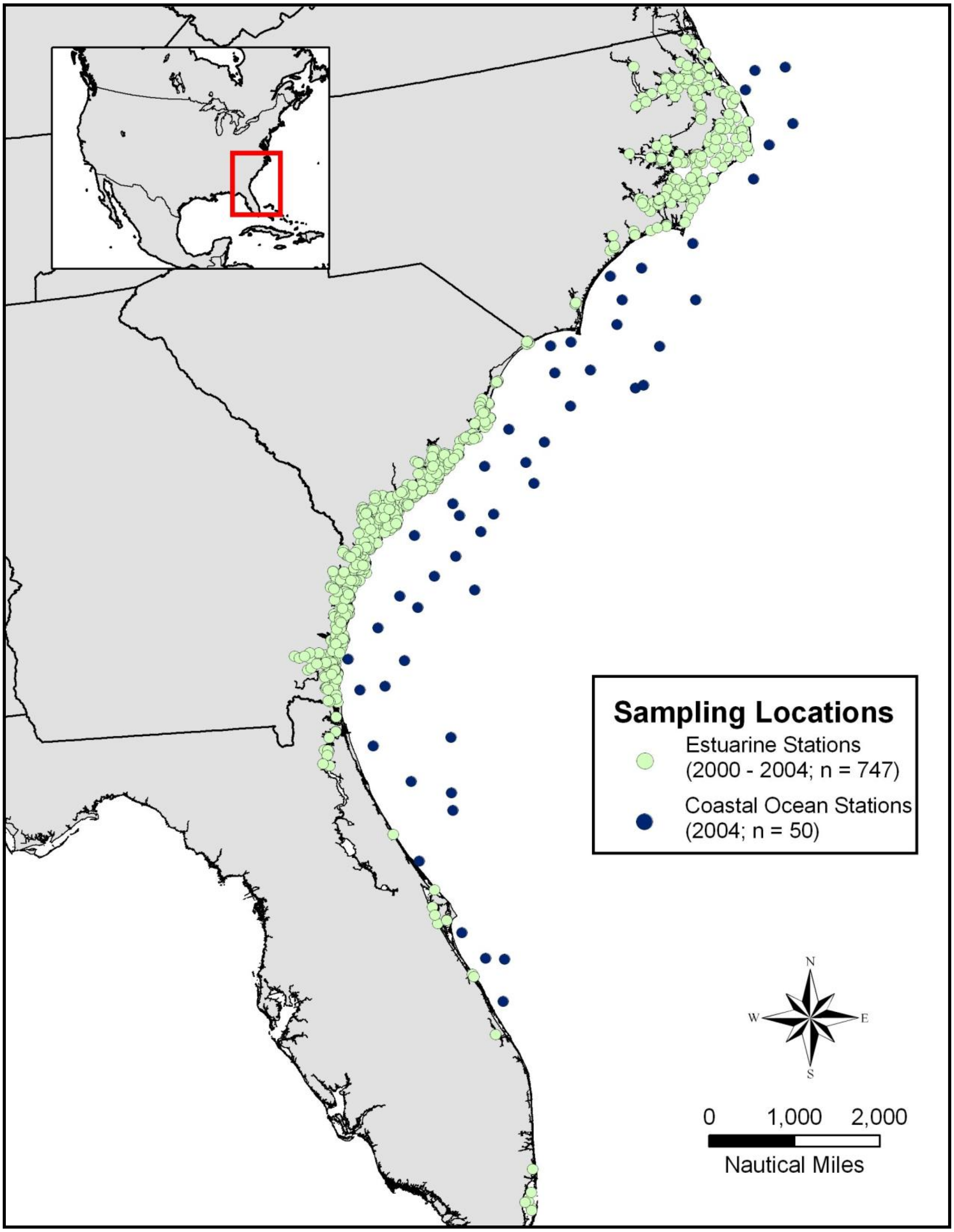

Figure 2.1.1 – Map of South Atlantic Bight study area and station locations. Green dots indicate National Coastal Assessment estuarine stations (sampled 2000 – 2004; n = 747), and blue dots indicate coastal ocean stations (sampled 2004; n = 50).

2.1.2 Estuaries

Similar to the off-shore component, the GRTS survey design strategy was used to select approximately 150 estuarine sites per year for sampling years 2000 to 2004 (Table 2.1.1) The southeastern estuarine target population represented all boatable areas from the head-of-tide upland out toward the open ocean encompassing all waters within coastal embayments, lagoons, tidal rivers and creeks, and intracoastal waterways. Stations were sampled once in the summer months between July and September when coastal conditions are expected to be under the greatest influence of environmental stress (Summers et al. 1995).

Bottom sediments were collected at each station with a $0.04m^2$, Young modified van Veen grab. Contents of each grab were used for analysis of macroinfaunal communities, concentration of chemical contaminants, % silt-clay, and organic-carbon content. Consistent with the offshore survey, a grab sample was deemed successful when the grab unit was >75% full and without major slumping. A single grab was collected from the majority of sites for benthic infaunal analysis. Benthic sample sediments were sieved on site 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 were subsequently taken at each station, homogenized into a single station composite, and then sub-sampled for analysis of metals, organic contaminants (PCBs, pesticides, PAHs), total organic carbon (TOC), and grain size.

A hand-held water column profiler, such as a Hydrolab® or YSI® sonde, was used at each site to collect instantaneous measures of temperature, salinity, pH, and dissolved oxygen (DO). The water column was measured from 0.5m below surface, at 1m intervals throughout the water column, and within 0.5m from bottom. Instruments were calibrated daily using known solutions, pre- and post-deployment comparisons, and weekly air-saturated water tests. Photosynthetically active radiation (PAR) readings were taken using a LICOR® datalogger equipped with both ambient and submersible 2pi light sensors just beneath the surface at 1m intervals through water column, and near the bottom. Secchi disk readings were also taken while on station. Water samples for nutrient and chlorophyll *a* analysis were collected at 3 prescribed depths (surface, mid-water, bottom) using horizontal water samplers. At some sites, only surface samples were collected. These samples were acquired by submerging a pre-cleaned 1-liter Nalgene® bottle upside down then inverting it to fill.

Fishes and shrimp were collected for analysis of tissue contaminants and visual evidence of pathological disorders. Tissue samples were typically collected using either a 6.1m high-rise otter trawl with a 2.5 cm mesh cod end or 21.3m center bag seine with a 0.31cm bar mesh. In South Carolina, a 15-foot four-seam trawl with 1.9 cm mesh was used to collect tissue samples. Trawl nets were towed for 10 minutes against the current between 0.7 and 1.0 $m\ s^{-1}$. At sites too shallow to trawl, a seine net was deployed to acquire the necessary fish tissue samples. All organisms caught were counted and identified to species. As many as 30 individuals from each species caught were measured to the nearest millimeter. A prescribed list of target species was used to cull samples from the catch for contaminant analysis. Up to ten individuals of each target species were reserved for subsequent laboratory analysis. When no target species were available, species that best represented the catch were selected as surrogates for analysis. Specimens were labeled, frozen, and shipped to the appropriate processing laboratory where they were stored and frozen until analyses could be performed. For this assessment, 166 fish-only specimens were represented in the tissue contaminant results from the 2000-2004 estuarine surveys. Eighty-two percent of analyses results were based on target species. The complete list of tissue contaminant species follows (target species are identified with “*”):

- 70 Atlantic croaker (*Micropogonias undulatus**)
- 47 spot (*Leiostomus xanthurus**)
- 16 pinfish (*Lagodon rhomboides**)
- 12 weakfish (*Cynoscion regalis*)
- 4 silver perch (*Bairdiella chrysoura*)
- 4 hogfish (*Lachnolaimus maximus*)
- 3 southern flounder (*Paralichthys lethostigma**)
- 2 white perch (*Morone americana*)
- 2 striped mullet (*Mugil cephalus*)
- 2 pigfish (*Orthopristis chrysoptera*)
- 1 hardhead catfish (*Ariopsis felis*)
- 1 southern kingfish (*Menticirrhus americanus*)
- 1 white mullet (*Mugil curema*)
- 1 summer flounder (*Paralichthys dentatus*)

Table 2.2.1 Number of SAB stations sampled by resource category, institution, and year.

Resource Category	Institution	2000	2001	2002	2003	2004	All Years
Estuaries	Florida Fish and Wildlife Research Institute	7	6	4	5	8	30
	Georgia Department of Natural Resources	50	50	50	50	50	250
	North Carolina Department of Environmental and Natural Resources	34	34	35	34	35	172
	South Carolina Department of Natural Resources	60	55	60	60	60	295
Coastal Ocean	NOAA National Ocean Service, Charleston, SC					50	50
Totals		151	145	159	149	153	797

2.2 Water Quality Analysis

Preliminary processing of water samples for nutrients, chlorophyll, and TSS was conducted in the field at the end of each sampling day (estuaries) or immediately after collection onboard the research ship (coastal ocean). A portion of the water (~0.5 - 1.0 L) from each station was vacuum-filtered using microfiltration glassware and a GF/F 47mm filter. The filtered water sample was then transferred to a polypropylene bottle, frozen (< -20°C), and analyzed within 30 days for dissolved nutrients including ammonium (NH_{4-} +), nitrate/nitrite ($NO_{2/3}$), orthophosphate ($PO_{4-}{}^{3-}$), silicate (Si), total dissolved phosphorus (TDP), and total dissolved nitrogen (TDN)). The filter was folded and wrapped in a foil pouch, frozen, and analyzed within 30 days for chlorophyll *a*. An additional sample of water (~0.5 – 1.0 L) was filtered on a pre-weighed GF/F 47mm filter for analysis of total suspended solids (TSS). Whole water samples were frozen in polypropylene bottles and later analyzed for total nitrogen (TN) and total phosphorus (TP).

Water chemistry was measured with autoanalyzers using standard EPA methods (USEPA methods 349.0, 353.4, 365.5). Chlorophyll *a* samples were extracted using a modified Welshmeyer (buffered methanol) method and analyzed on a Turner Designs® fluorometer (USEPA method 445.0m). Total suspended solids was measured using the methods outlined in EMAP - Estuaries Laboratory Methods Manual Volume 1 - Biological and Physical Analyses, Section 6 - Residue, Non-Filterable (Suspended Solids) (USEPA 1995).

2.3 Sediment TOC and Grain Size Analysis

Sediment characterization included analyses for TOC and silt-clay content. TOC analysis followed USEPA Method 9060. A minimum of 5g (wet weight) of sediment was initially dried for 48 h. Weighed subsamples were ground to fine consistency and acidified to remove sources of inorganic carbon (e.g., shell fragments). The acidified samples were ignited at 950ºC and the carbon dioxide evolved was measured with an infrared gas analyzer. Silt-clay samples were prepared by sieve separation followed by timed pipette extractions as described in Plumb (1981). Results for both analyses were reported as percent of sample.

2.4 Contaminant Analysis

Both offshore and estuarine sediment and tissue samples were examined for inorganic and organic contaminants. The list (Table 2.4.1) comprises 25 polycyclic aromatic hydrocarbons (PAHs), 21 polychlorinated biphenyls (PCBs), 20 chlorinated pesticides, and 15 metals.

2.4.1 Sample Preparation

2.4.1.1 Sediments

Samples were stored on ice while on station then shipped (overnight) to a laboratory where samples were kept at ≤ -20°C until analyzed. A 24-hour thawing period was used to bring sample temperature to approximately +4°C. Composited sediment samples were re-homogenized prior to obtaining sample aliquots. Separate aliquots were drawn for each of the contaminant tests

(Table 2.4.1). For metals analysis, sediments were prepared using microwave-assisted extraction (EPA Method 3052) while organic samples were prepared using ultrasonic extraction (EPA Method 3550a). All results were reported in dry weight units.

2.4.1.2 Tissues

Fish samples were stored on ice while on station then shipped (overnight) to a laboratory where samples were kept at ≤-20°C until analyzed. Samples were partially thawed prior to dissection and individuals were filleted for muscle tissue with skin and scales intact. Fillets from a single species collected from a site were blended together to create a homogenate from which aliquots were retrieved. A separate aliquot was drawn for each contaminant group (Table 2.4.1). Microwave-assisted extraction was used for metals analysis preparation (EPA Method 3052). Solvent extraction (EPA Method 3540c) was used to prepare samples for organic analysis. All results reported in wet weight units.

2.4.2 Analytical Methods

The same analytical methods were used to examine both tissue and sediment samples for contaminants. These were:

Trace: Inductively Coupled Plasma Mass Spectrometry
Heavy metals (except mercury): Inductively Coupled Plasma Emission Spectrometry or Graphite Furnace Atomic Absorption Spectrometry
Mercury: Graphite- or Cold-Vapor Atomic Absorption Spectrometry
PAHs: Gas Chromatography/Mass-Spectrometry Selected Ion Monitoring
PCBs and Pesticides: Gas Chromatography/Mass-Spectrometry or Electron Capture Detection

2.5 Toxicity Analysis

Sediment toxicity, measured only during the estuarine studies, was assessed using the standard 10-day, solid-phase test for survival of the marine amphipod *Ampelisca abdita* (ASTM, 1993). Tests were performed at each station using the same sediment homogenates on which analysis of chemical contaminants and other abiotic sediment variables were conducted. Tests were run on five replicate samples of sediment from each site under static conditions at 20ºC and 30 ppt. Samples were considered toxic if mean survival relative to a corresponding negative control (sediment from a reference site) was < 80% and statistically different at $\alpha = 0.05$.

Table 2.4.1. List of target contaminants analyzed in coastal-ocean and estuarine sediment and tissue samples.

Polycyclic Aromatic Hydrocarbons (PAHs)	***C.A.S.***	***Polychlorinated Biphenyls (PCBs)***	***C.A.S.***
1-Methylnaphthalene	90-12-0	2,2',3,3',4,4',5,5',6-Nonachlorobiphenyl	40186-72-9
1-Methylphenanthrene	832-69-9	2,2',3,3',4,4'-Hexachlorobiphenyl	38380-07-3
2,3,5-Trimethylnaphthalene	2245-38-7	2,2',3,4,4',5,5'-Heptachlorobiphenyl	35065-29-3
2,6-Dimethylnaphthalene	581-42-0	2,2',3,4,4',5'-Hexachlorobiphenyl	35065-28-2
2-Methylnaphthalene	91-57-6	2,2',3,5'-Tetrachlorobiphenyl	41464-39-5
Acenaphthene	83-32-9	2,2',4,4',5,5'-Hexachlorobiphenyl	35065-27-1
Acenaphthylene	208-96-8	2,2',5,5'-Tetrachlorobiphenyl	35693-99-3
Anthracene	120-12-7	2,2',5-Trichlorobiphenyl	37680-65-2
Benz[a]anthracene	56-55-3	2,3,3',4,4'-Pentachlorobiphenyl	32598-14-4
Benzo[a]pyrene	50-32-8	2,3',4,4'-Tetrachlorobiphenyl	32598-10-0
Benzo[b]fluoranthene	205-99-2	2,4,4'-Trichlorobiphenyl	7012-37-5
Benzo[e]pyrene	192-97-2	3,3',4,4',5-Pentachlorobiphenyl	57465-28-8
Benzo[g,h,i]perylene	191-24-2	3,3',4,4'-Tetrachlorobiphenyl	32598-13-3
Benzo[k]fluoranthene	207-08-9	2,2',3,3',4,4',5,5',6,6'-Decachlorobiphenyl	2051-24-3
Biphenyl	92-52-4	PCB 110/77	38380-03-9
Chrysene	218-01-9	PCB congener 101/90	37680-73-2
Dibenz[a,h]anthracene	53-70-3	PCB congener 118/108/149	31508-00-6
Dibenzothiophene	132-65-0	PCB congener 170/190	35065-30-6
Fluoranthene	206-44-0	PCB congener 187/182/159	52663-68-0
Fluorene	86-73-7	PCB congener 195/208	52663-78-2
Indeno[1,2,3-c,d]pyrene	193-39-5	PCB congener 8/5	34883-43-7
Naphthalene	91-20-3		
Perylene	198-55-0		
Phenanthrene	85-01-8		
Pyrene	129-00-0		
Pesticides	***C.A.S.***	***Metals***	***C.A.S.***
2,4'-DDD	53-19-0	Aluminum	7429-90-5
2,4'-DDE	3424-82-6	Antimony	7440-36-0
2,4'-DDT	789-02-6	Arsenic	7440-38-2
4,4'-DDD	72-54-8	Cadmium	7440-43-9
4,4'-DDE	72-55-9	Chromium	7440-47-3
4,4'-DDT	50-29-3	Copper	7440-50-8
Aldrin	309-00-2	Iron	7439-89-6
Alpha-chlordane	5103-71-9	Lead	7439-92-1
BHC-alpha	319-84-6	Manganese (sediment only)	7439-96-5
Endosulfan I	959-98-8	Mercury	7439-97-6
Endosulfan II	33213-65-9	Nickel	7440-02-0
Dieldrin	60-57-1	Selenium	7782-49-2
Endosulfan	115-29-7	Silver	7440-22-4
Endosulfan Sulfate	1031-07-8	Tin	7440-31-5
Endrin	72-20-8	Zinc	7440-66-6
Heptachlor	76-44-8		
Heptachlor epoxide	1024-57-3		
Hexachlorobenzene	118-74-1		
Lindane	58-89-9		
Mirex	2385-85-5		
Toxaphene	8001-35-2		
Trans-nonachlor	39765-80-5		

2.6 Benthic Community Analysis

Once in the laboratory, samples were transferred from formalin to 70% ethanol. Macroinfaunal invertebrates were sorted from the sample debris under a dissecting microscope and identified to the lowest practical taxon (usually species). Data were used to compute density (m^{-2}) of total fauna (all species combined), densities of numerically dominant species (m^{-2}), numbers of species, H' diversity (Shannon and Weaver 1949) derived with base-2 logarithms, and estimates of condition based on the Southeastern benthic index of biotic integrity for estuarine stations (B-IBI, Van Dolah et al. 1999). Computation of the B-IBI was based on the procedures and habitat designations of Van Dolah et al. (1999). B-IBI scoring criteria are presented here in Table 2.7.1. A B-IBI has not been developed yet for the coastal ocean portion of the SAB.

2.7 Data Analysis

A probabilistic, stratified-random sampling design was used in these surveys in order to provide a basis for making unbiased statistical estimates of the spatial extent of condition, with 95 % confidence intervals, of the coastal and estuarine waters of the SAB based on the status of various measured ecological indicators and corresponding thresholds of interest (Table 2.7.1). A similar approach has been applied throughout EPA's EMAP, related NCA programs, and other coastal-ocean surveys (e.g., Summers et al. 1995; Strobel et al. 1995; Hyland et al. 1996; USEPA 2004, 2006; Nelson et al. 2008). Results of the above type of spatial estimates are presented throughout this report as the percent area of the SAB within specified ranges of a particular indicator. Thresholds defining such ranges (see Table 2.7.1) include, where possible, those having known biological significance (e.g., dissolved oxygen < 2 mg L^{-1}). Additional data summaries presenting key distributional properties (e.g., mean, range) and other basic data tabulations are provided as well. Data presented graphically in this report are primarily in the form of cumulative distribution functions (CDFs) and pie charts. These are useful tools for portraying the percentage of coastal area corresponding to varying levels of a given indicator across the full range of its observed values and for estimating the percentage of area falling below or above some designated threshold of interest. This is a useful feature for management applications; for example, if valid thresholds can be defined for a particular indicator or suite of indicators, they could be used as ecosystem quality targets for tracking how well the system is doing and for triggering any necessary management actions.

The biological significance of sediment contamination was evaluated by comparing measured chemical concentrations in sediments to corresponding Effects Range-Low (ERL) and Effects Range-Median (ERM) sediment quality guideline (SQG) values developed by Long et al. (1995) and listed here in Table 2.7.2. The ERL values are lower-threshold bioeffect limits, below which adverse effects on sediment–dwelling organisms are not expected to occur. ERM values represent upper-threshold concentrations, above which bioeffects are likely to occur in some sediment-dwelling species. Overall sediment contamination from multiple chemicals was expressed as the mean ERM quotient (ERM-Q) (Long et al. 1998; Long and MacDonald 1998; Hyland et al. 1999), which is the mean of the ratios of individual chemical concentrations in a sample relative to corresponding ERM values. Mean ERM-Qs ≤ 0.018 and > 0.057 have been associated with a low and high incidence of stress, respectively, in benthic communities of southeastern estuaries (Hyland et al. 2003).

The biological significance of fish and shrimp tissue contamination was evaluated from a human-health perspective using risk-based consumption limits for cancer and non-cancer (chronic systemic effects) endpoints derived by U.S. EPA (2000) for a variety of organic and inorganic contaminants (Table 2.7.3). Concentrations of contaminants measured in fish tissues were compared to the corresponding endpoints for cancer and chronic health risks associated with the consumption of four 8-ounce meals per month for the general adult population. Fish tissue contamination data were only available for a subset of stations; therefore, tissue contaminant data were not evaluated on a percent areal basis.

For estuarine data only, a water quality index was developed based on evaluations stemming from dissolved oxygen, DIN, DIP, and Chl *a* analysis and a sediment quality index was created by combining results from sediment contaminant, TOC, and toxicity data evaluations. Methods used for the development of these two indices are consistent with methods used in the National Coastal Condition Reports (USEPA 2001c, 2004, 2006, 2008).

Table 2.7.1 Thresholds used for classifying samples relative to various environmental indicators.

Indicator	***Estuaries Threshold***	***Coastal Ocean Threshold***	***Reference***
Water Quality			
Salinity (PSU)	< 5 = Oligohaline 5 – 18 = Mesohaline >18 – 30 = Polyhaline > 30 = Euhaline	< 5 = Oligohaline 5 – 18 = Mesohaline >18 – 30 = Polyhaline > 30 = Euhaline	Carriker 1967
Chlorophyll *a* (µg/L)	Low: < 5.0 Moderate: 5.0 – 10.0 High: >10.0	Potentially Elevated: ≥ upper 90th percentile	U.S.EPA 2008
Dissolved Oxygen (mg/L)	Good: >5.0 Moderate: 2.0 - 5.0 Poor: < 2.0	Good: >5.0 Moderate: 2.0 - 5.0 Poor: < 2.0	U.S. EPA 2008
Dissolved Inorganic Phosphorus (mg/L)	Low: < 0.01 Moderate: 0.01-0.05 High: > 0.05	Potentially Elevated: ≥ upper 90th percentile	U.S. EPA 2008; Nelson et al. 2008
Dissolved Inorganic Nitrogen (mg/L)	Low: <0.1 Moderate: 0.1 - 0.5 High: >0.5	Potentially Elevated: ≥ upper 90th percentile	U.S. EPA 2008; Nelson et al. 2008
DIN/DIP	Phosphorus Limitation: > 16 Nitrogen Limitation: < 16	Phosphorus Limitation: > 16 Nitrogen Limitation: < 16	Geider and LaRoche 2002
Water Clarity (light penetration @ 1 m)	Less Turbid: >20% Mod. Turbid: 10 – 20% High. Turbid: <10%	Data not available	Smith et al. 2007
$\Delta\delta_T$	Strong Vertical Stratification: > 2	Strong Vertical Stratification: > 2	Nelson et al. 2008
Sediment Quality			
Overall Chemical Contamination of Sediments (ERM-Q): Potential Benthic Risk Levels	Very High: > 0.196 High: >0.057-0.196 Moderate: > 0.018-0.057 Low: ≤ 0.018	Very High: > 0.196 High: >0.057-0.196 Moderate: > 0.018-0.057 Low: ≤ 0.018	Hyland et al. 2003

Indicator	*Estuaries Threshold*	*Coastal Ocean Threshold*	*Reference*
Overall Chemical Contamination of Sediments (# ERL/ERM exceeded): Probability of adverse biological affect	High: ≥ 1 ERM exceeded Moderate: ≥ 5 ERLs exceeded and no ERMs exceeded Low: < 5 ERLs and no ERMs exceeded	High: ≥ 1 ERM Moderate: ≥ 5 ERLs Low: < 5 ERLs	US. EPA 2008
Individual chemical contaminant concentrations in sediments	Bioeffects likely: > ERM Bioeffects not likely: < ERL	Bioeffects likely: > ERM Bioeffects not likely: < ERL	Long et al. 1995
Sediment Toxicity (% *A. abdita* control corrected survival)	Not Toxic: > 80	Data not available	U.S. EPA 2008
TOC (mg/g)	Low: < 20 Moderate: 20 - 50 High: > 50	Low: < 20 Moderate: 20 - 50 High: > 50	U.S. EPA 2008;
		High: > 35	Hyland et al. 2005
<u>Biological Condition</u>			
Benthic Community (potential degraded condition)	SE Benthic Index Healthy Benthos: ≥ 3.0 Some Stress: 1.5 – 3.0 Degraded Benthos: ≤ 1.5	Potentially Degraded Benthos: ≤ lower 10^{th} percentile for key benthic variables	U.S. EPA 2008; Nelson et al. 2008; Van Dolah et al. 1999
Tissue Contaminants (# guidelines exceeded)	Any contaminant concentration: High: Exceeded range Moderate: within range Low: below range	Any contaminant concentration: High: Exceeded range Moderate: within range Low: below range	U.S. EPA 2000

Table 2.7.2. ERM and ERL guidance values in sediments (Long et al. 1995).

	ERL	*ERM*		*ERL*	*ERM*
Metals (ppm)			***PAHs (ppb)***		
Arsenic*†	8.2	70	Acenaphthene*	16	500
Cadmium*†	1.2	9.6	Acenaphthylene*	44	640
Chromium*	81	370	Anthracene*	85.3	1100
Copper*	34	270	Benzo[a]anthracene*	261	1600
Lead *	46.7	218	Benzo[a]pyrene*	430	1600
Mercury *	0.2	0.71	Chrysene*	384	2800
Nickel*	20.9	51.6	Dibenz[a,h,]anthracene	63.4	260
Silver*†	1	3.7	Fluoranthene*	600	5100
Zinc*	150	410	Fluorene*	19	540
			2-Methylnaphthalene*	70	670
Pesticides (ppb)			Naphthalene*	160	2100
			Phenanthrene*	240	1500
4,4'-DDE (p,p♣-DDE)*	2.2	27	Pyrene*	665	2600
Total DDTs*	1.6	46.1	Total PAHs	4020	44800
			PCBs (ppb)		
			Total PCBs*	22.7	180

ERL exceeded: *- Estuaries † - Coastal Ocean

Table 2.7.3. Risk based EPA advisory guidelines for recreational fishers (US EPA 2000). Concentration ranges represent the non-cancer health endpoint risk for four 8-ounce fish meals per month.

	Lower	*Upper*		*Lower*	*Upper*
Metals (ppm)			*Pesticides (continued)*		
Arsenic (inorganic)[1]	0.35	0.70	Heptachlor epoxide	15	31
Cadmium	0.35	0.70	Hexachlorobenzene	940	1900
Mercury (methylmercury)[2]	0.12	0.23	Lindane	350	700
Selenium	5.9	12.0	Mirex	230	470
			Toxaphene	290	590
Pesticides (ppb)					
Chlordane	590	1200	***PCBs (ppb)***		
Total DDTs	59	120	Total PCBs	23	47
Dieldrin	59	120			
Endosulfan	7000	14000	***PAHs (ppb)***		
Endrin	350	700	Total PAHs[3]	1.6	3.2

1. Inorganic arsenic estimated as 2% of total arsenic.

2. Conservative assumption was made that all mercury is present as methylmercury because most mercury in fish and shellfish is present primarily as methylmercury.

3. Cancer concentration range used, a non-cancer concentration range for PAHs does not exist.

3.0 Results and Discussion

3.1 Depth and Water Quality

3.1.1 Depth and General Water Characteristics: temperature, salinity, water-column stratification, DO, pH, water clarity

Coastal Ocean

Key bottom-water characteristics, as measured during the 2004 survey, throughout the coastal ocean waters of the SAB (Figure 3.1.1, Table 3.1.1, Appendix A, B, C) can be summarized as follows: (1) water depths ranging from 8.9 – 68.1 m and averaging 29.4 m (water depths were not corrected to Mean Low Low Water); (2) a narrow range of euhaline bottom salinity (PSU) values of 32.9 – 36.5 (overall mean of 35.6); (3) high bottom DO levels ranging from 6.8 – 9.9 mg L^{-1} and averaging 7.8 mg L^{-1}; (4) bottom temperatures ranging from 6.4 – 23.7 °C and averaging 17.1 °C; (5) a narrow range of pH levels from 8.2 – 8.6 and averaging 8.4; and (6) low levels of surface-water total suspended solids (TSS) ranging from 0.97 – 15.93 mg L^{-1} and averaging 3.64 mg L^{-1}.

Water-column stratification expressed as $\Delta\sigma_t$, an index of the variation between surface and bottom water densities, was calculated from temperature and salinity data. The index is the difference between the computed bottom and surface σ_t values, where σ_t is the density of a parcel of water with a given salinity and temperature relative to atmospheric pressure (Nelson et al. 2008). The $\Delta\sigma_t$ index ranged from 0.003 to 1.715. One hundred percent of the area of waters of the SAB shelf had $\Delta\sigma_t$ index values less than 2, indicating weak vertical stratification of the water column (Table 2.7.1). These results agree with previous assessments that have shown October through May to be periods of low vertical stratification for coastal-ocean waters of the SAB (Martins and Pelegri 2006).

Estuaries

A summary of key water-column characteristics is presented in Table 3.1.2 for estuarine waters of the SAB. Bottom-water salinities ranged from oligohaline (< 5 ppt) to euhaline (> 30 ppt), with the average salinity (23.5 ppt) falling in the polyhaline range of 18 – 30 ppt. Bottom DO varied widely from 0.2 to 11.6 mg L^{-1} and averaged 4.9 mg L^{-1}. Bottom-water pH also exhibited a wide range (4.8 – 9.2) and averaged 7.6. Water clarity as measured by the light attenuation coefficient ranged from 0.3 to 23.3 and averaged 2.3.

Seventy-four percent of southeast estuaries had low turbidity (indicative of high water clarity). Conversely, 12% of the area exhibited considerably higher turbidity. Twenty-six percent of the survey area did not meet the light-penetration threshold (≥ 20% transmissivity @ 1m) associated with optimum growth conditions of submerged aquatic vegetation (SAV) (Figure 3.1.3).

SAB Region-wide

The majority of the SAB had bottom-water DO levels in the high range (> 5 mg L^{-1}) considered good for marine life (Figure 3.1.4, Table 2.7.1). DO levels in bottom-waters exceeded this upper threshold at all coastal-ocean stations and in 76% of the estuarine waters. Twenty-one percent of the estuarine bottom-waters had moderate levels of DO between 2 and 5 mg L^{-1} and 3% had DO levels below 2 mg L^{-1}. The majority of the lowest DO levels (< 2 mg L^{-1}) occurred in North Carolina waters where low-DO conditions have previously been reported (Figure 3.1.4; Hyland et al. 2000). There is an interesting cluster of moderate DO levels (2 – 5 mg L^{-1}) in the estuaries of Georgia and South Carolina, which corresponds to results of Verity et al. (2006) indicating a long-term trend of declining DO throughout Georgia estuaries.

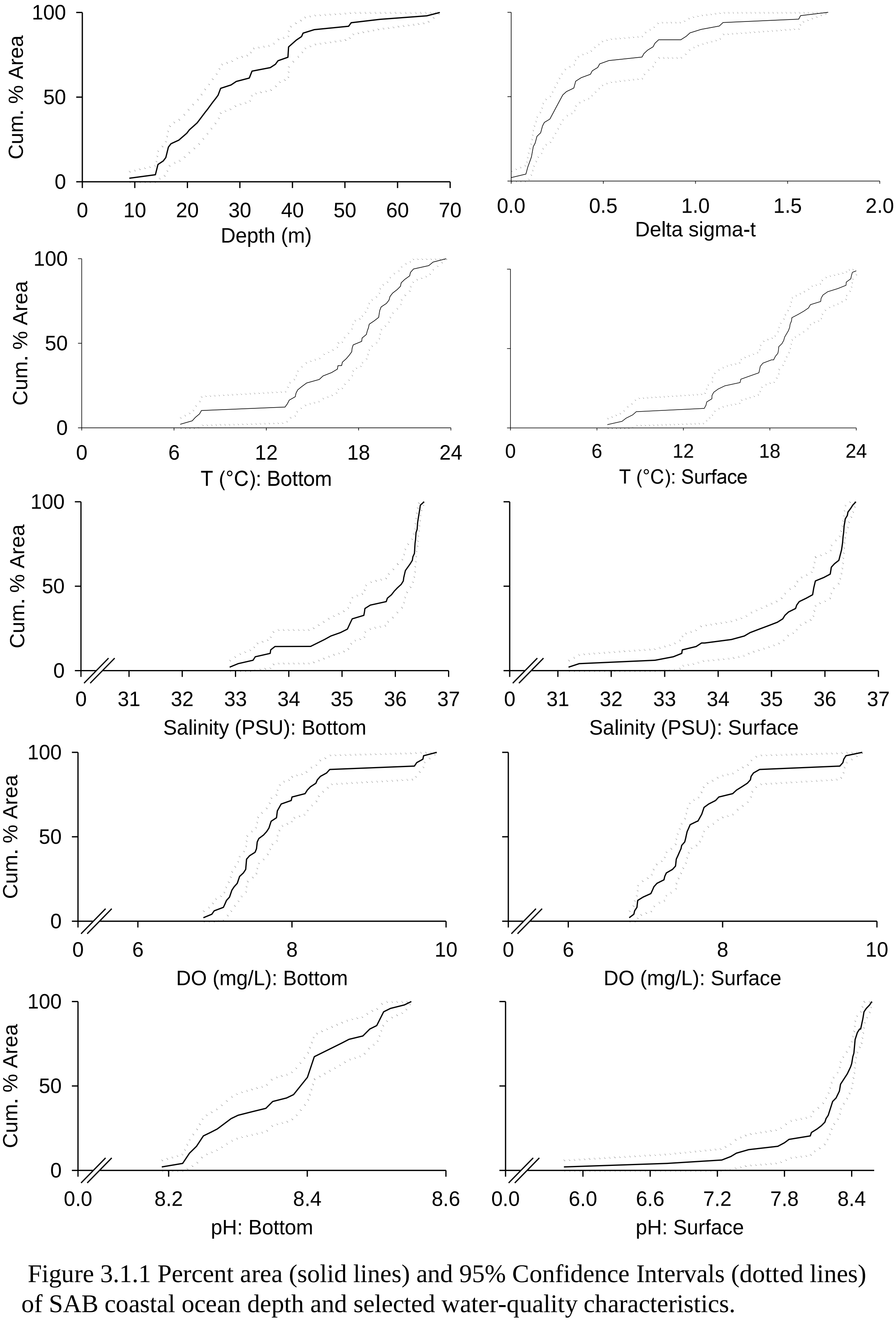

Figure 3.1.1 Percent area (solid lines) and 95% Confidence Intervals (dotted lines) of SAB coastal ocean depth and selected water-quality characteristics.

Table 3.1.1. Summary of depth and water-column characteristics for near-bottom and near-surface SAB coastal ocean waters.

	Near-Bottom Water					Near-Surface Water				
	Mean	Range	CDF 10^{th}%	CDF 50^{th}%	CDF 90^{th}%	Mean	Range	CDF 10^{th}%	CDF 50^{th}%	CDF 90^{th}%
Depth (m)	29.4	8.9 - 68.1	14.3	25.7	44.5	N/A	N/A	N/A	N/A	N/A
$\Delta\delta_T$	0.472	0.003 - 1.715	0.097	0.275	1.048	N/A	N/A	N/A	N/A	N/A
DO (mg L^{-1})	7.8	6.8 - 9.9	7.1	7.6	8.9	7.7	6.8 - 9.8	6.9	7.5	8.7
Salinity (PSU)	35.6	32.9 - 36.5	33.5	36	36.4	35.3	31.2 - 36.6	33.2	35.8	36.3
Temperature (°C)	17.1	6.4 - 23.7	7.8	17.9	21.3	17.7	6.7 - 24.3	8.7	18.6	23.2
pH	8.4	8.2 - 8.6	8.2	8.3	8.5	8.2	5.8 - 8.6	7.3	8.3	8.5
DIN (mg L^{-1})	0.045	0.012 - 0.269	0.012	0.026	0.064	0.038	0.011 - 0.232	0.015	0.028	0.043
DIP (mg L^{-1})	0.024	0.010 - 0.080	0.011	0.017	0.031	0.028	0.010 - 0.110	0.011	0.017	0.037
DIN/DIP	4.01	1.07 - 8.46	2.74	3.75	6.01	3.69	0.53 - 9.00	1.92	3.81	5.23
Chl *a* (µg L^{-1})	0.67	0.15 - 2.83	0.23	0.41	1.39	0.44	0.09 - 2.02	0.15	0.26	1.08
TSS (mg L^{-1})	3.30	0.27 - 24.9	1.17	2.17	5.76	3.64	0.97 - 15.93	1.4	3.18	6.21

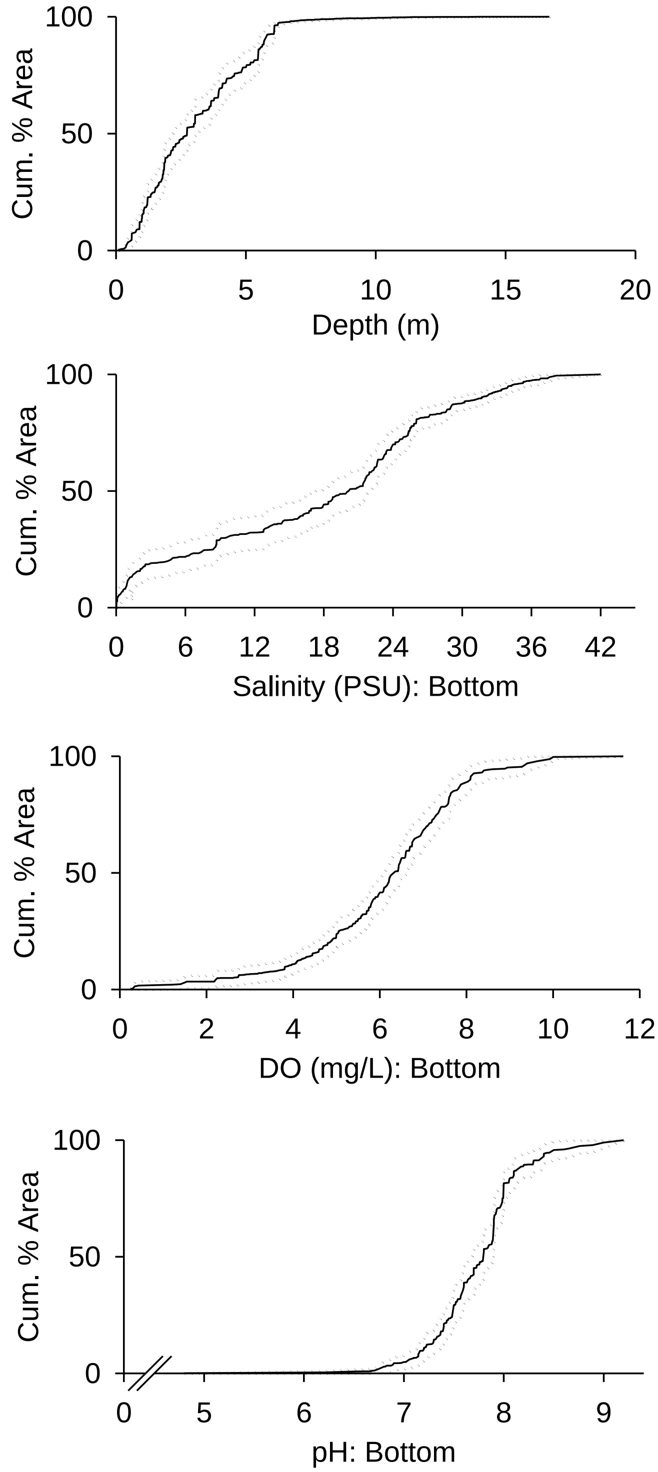

Figure 3.1.2. Percent area (solid lines) and 95% Confidence Intervals (dotted lines) of SAB estuarine depth and selected bottom water-quality characteristics.

Table 3.1.2. Summary of depth and selected water column characteristics for SAB estuarine waters.

	Mean	Range	CDF 10th%	CDF 50th%	CDF 90th%
Depth (m)	3.5	0.1 - 16.7	0.9	2.7	5.7
Bottom DO (mg L^{-1})	4.9	0.2 - 11.6	3.9	6.3	8.1
Bottom Salinity (PPT)	23.5	0 - 42	0.9	20.2	31.7
Bottom pH	7.6	4.8 - 9.2	7.2	7.8	8.3
DIN (mg L^{-1})	0.099	0 - 1.388	0	0.022	0.131
DIP (mg L^{-1})	0.042	0 - 1.07	0.001	0.012	0.054
Chl *a* (µg L^{-1})	10.16	0.26 - 97.74	2.3	6.75	17.45
Water Clarity (light attenuation co-efficient)	2.3	0.3 - 23.3	0.7	1.3	2.5

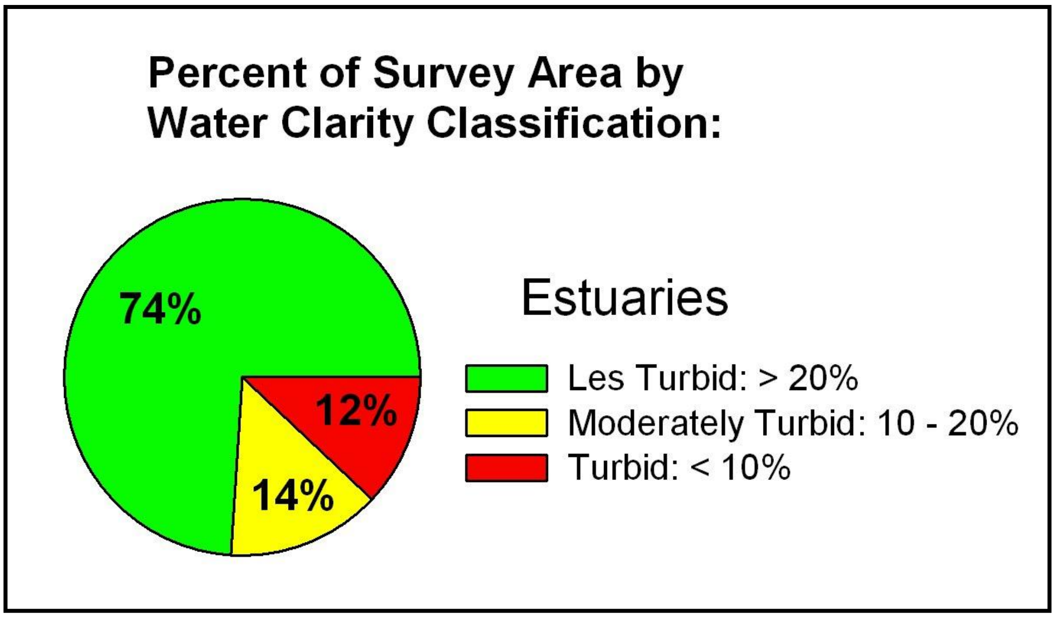

Figure 3.1.3. Percent area of SAB estuarine waters within specified ranges of water clarity.

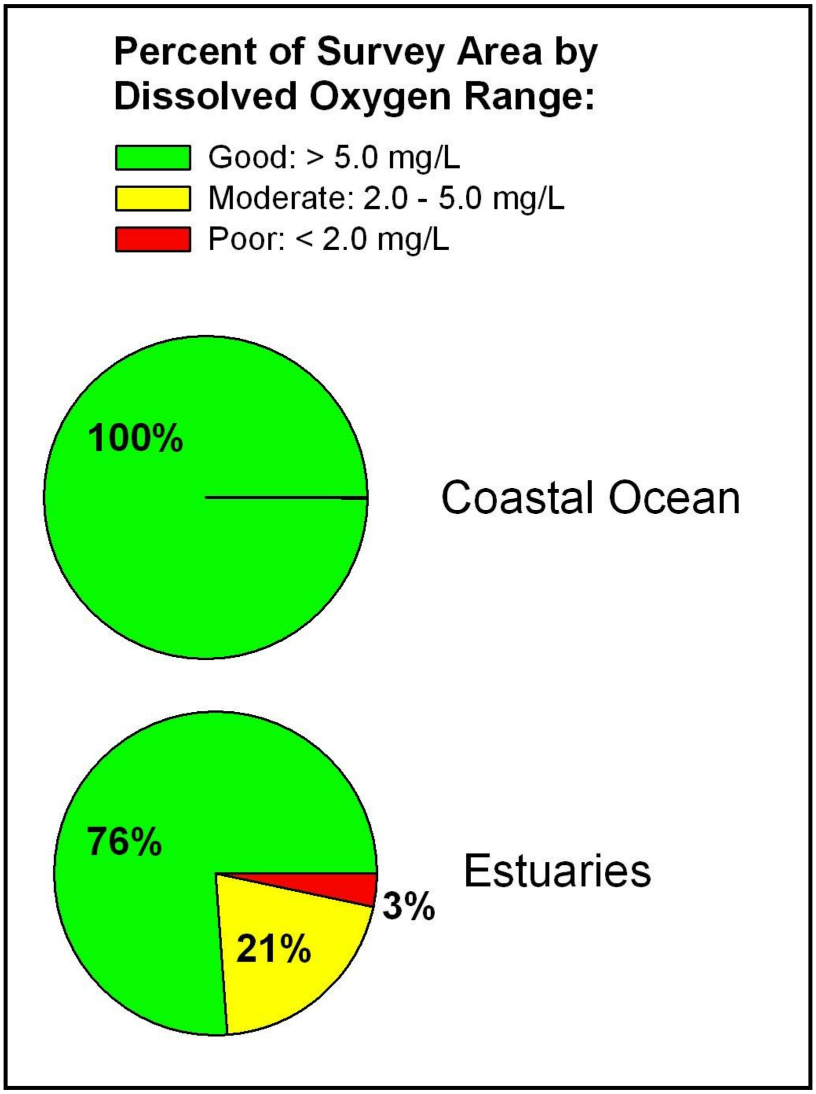

Figure 3.1.4. Percent area of SAB coastal ocean and estuarine near-bottom waters within specified ranges of DO concentrations.

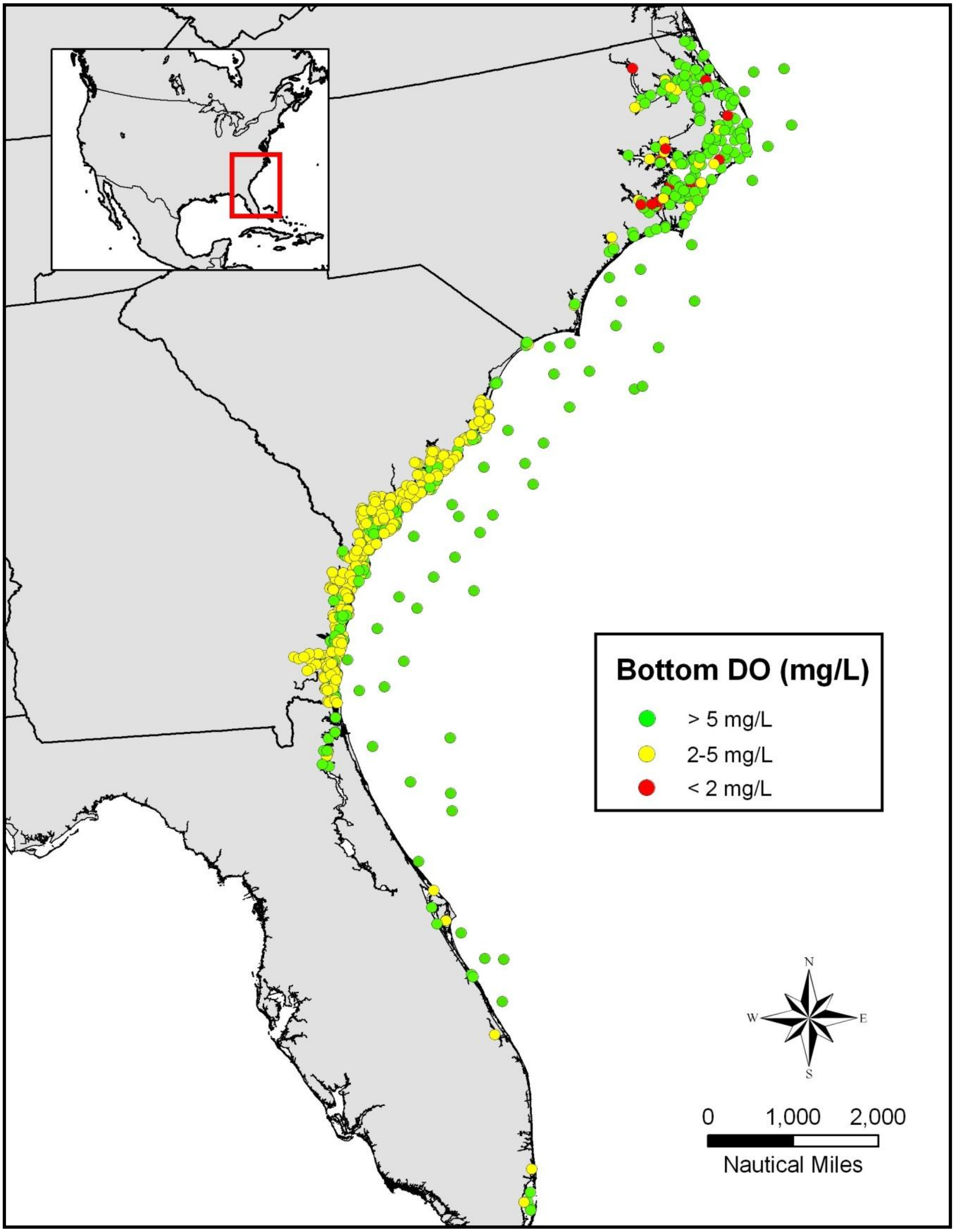

Figure 3.1.5. Spatial distribution of bottom dissolved oxygen levels in SAB coastal ocean and estuarine waters.

3.1.2 Nutrients and Chlorophyll

Coastal Ocean

Surface-water concentrations of total dissolved inorganic nitrogen (DIN: nitrate + nitrite + ammonium as nitrogen) ranged from 0.011 – 0.232 mg L^{-1} and averaged 0.038 mg L^{-1} (Figure 3.1.6, Table 3.1.1, Appendix C). The 50th percentile of the surface-water sampling area corresponded to a DIN concentration of 0.028 mg L^{-1} and the 90th percentile corresponded to a DIN concentration of 0.043 mg L^{-1}. Surface-water concentrations of dissolved inorganic phosphate (DIP: orthophosphate as phosphate) ranged from 0.010 – 0.110 mg L^{-1} and averaged 0.028 mg L^{-1} (Figure 3.1.6, Table 3.1.1). The 50th percentile of the surface-water sampling area corresponded to a DIP concentration of 0.017 mg L^{-1} and the 90th percentile corresponded to a DIP concentration of 0.037 mg L^{-1}.

The ratio of DIN concentration to DIP concentration (N/P ratio) was calculated as an indicator of which nutrient may be controlling primary production. A ratio above 16 is generally considered indicative of phosphorus limitation, and a ratio below 16 is considered indicative of nitrogen limitation (Geider and La Roche 2002). The N/P ratio in surface waters ranged from 0.53 to 9.0 and averaged 3.69. One hundred percent of the offshore survey area had N/P ratios < 16, indicative of a nitrogen limited environment. The SAB coastal ocean has previously been reported as being primarily nitrogen limited (Pomeroy et al. 1993; Verity et al. 1993).

DIN and DIP thresholds developed for evaluation purposes in estuarine habitats are not applicable to the coastal-ocean environment and thus are not used in this report for evaluating the offshore nutrient data (Table 2.7.1). Estuaries experience a continuum of nitrogen and phosphate cycling and if the estuarine thresholds were applied to the nitrogen-limited offshore environment, the result might indicate erroneously that a large percentage of coastal ocean waters have "high" levels of DIP. Specifically, nearly 100% of the coastal ocean area exceeded the moderate DIP threshold for estuarine waters (0.01 mg L^{-1}) and approximately 8% of the coastal ocean area exceeded the high threshold for estuarine waters (0.05 mg L^{-1}). In contrast, only 2% of the coastal-ocean area exceeded the moderate DIN threshold for estuarine waters (0.1 mg L^{-1}) and none of the coastal-ocean area exceeded the high DIN threshold for estuarine waters (0.5 mg L^{-1}). The baseline data collected in the 2004 coastal-ocean survey may be used to develop applicable nutrient thresholds in the future.

Chlorophyll *a* (Chl *a*) levels in surface waters ranged from 0.09 – 2.02 μg L^{-1} and averaged 0.44 μg L^{-1} (Figure 3.1.5, Table 3.1.1, Appendix C). The 50th percentile of the surface-water sampling area corresponded to a Chl *a* concentration of 0.26 μg L^{-1} and the 90th percentile corresponded to a Chl *a* concentration of 1.08 μg L^{-1}. All offshore stations, representing 100% of the offshore survey area, had Chl *a* below the 5.0 μg L^{-1} threshold used to denote the beginning of the high range for estuarine waters (U.S. EPA 2004). These data are in good agreement with prior studies of Chl *a* levels in coastal-ocean waters off South Carolina (Verity et al. 1998) and Georgia (Paffenhöfer et al. 1994).

The amount of TSS in the water column has a direct effect on turbidity (a measure of water clarity) by causing the attenuation or scattering of light, though TSS itself is not a measure of turbidity. Generally as TSS increases, the water becomes murkier or more turbid. Excessively high turbidity and TSS may be harmful to marine life (e.g., by reducing light penetration and photosynthesis, increasing biological oxygen demand of high organic content, interfering with normal respiratory and feeding activities) and distract from the aesthetic value of a coastal area. TSS levels in both surface- and bottom-waters of the coastal ocean portion of the SAB were relatively low (Figure 3.1.6, Table 3.1.1). The 50^{th} percentile of the survey area had a TSS concentration of 3.18 mg L^{-1} for surface-waters and 2.17 mg L^{-1} for bottom-waters.

Estuaries

Surface water concentrations of total dissolved inorganic nitrogen (DIN: nitrate + nitrite + ammonium as nitrogen) ranged from 0.0 – 1.388 mg L^{-1} and averaged 0.099 mg L^{-1} (Figure 3.1.7, Table 3.1.2). The 50th percentile of the surface water sampling area in estuaries corresponded to a DIN concentration of 0.022 mg L^{-1} and the 90th percentile corresponded to a DIN concentration of 0.131 mg L^{-1}. Surface-water concentrations of dissolved inorganic phosphate (DIP: orthophosphate as phosphate) ranged from 0.0 – 1.07 mg L^{-1} and averaged 0.042 mg L^{-1} (Figure 3.1.7, Table 3.1.2). The 50th percentile of the surface-water sampling area corresponded to a DIP concentration of 0.012 mg L^{-1} and the 90th percentile corresponded to a DIP concentration of 0.054 mg L^{-1}.

Less than 1% of the SAB estuarine area had DIN concentrations that exceeded 0.5 mg L^{-1}, considered a high level of DIN, while 15% had moderate levels of DIN (0.1 – 0.5 mg L^{-1}) (Figure 3.1.8, Table 2.7.1). DIP concentrations exceeded 0.05 mg L^{-1}, considered a high level of DIP, in 11% of the estuarine area and moderate levels of DIP (0.01 – 0.05 mg L^{-1}) were detected in 45% of the estuarine area (Figure 3.1.8).

Chlorophyll *a* (Chl *a*) levels in SAB estuarine surface waters ranged from 0.26 – 97.74 μg L^{-1} and averaged 10.16 μg L^{-1} (Figure 3.1.7, Table 3.1.2). The 50th percentile of the surface-water sampling area corresponded to a Chl *a* concentration of 6.75 μg L^{-1} and the 90th percentile corresponded to a Chl *a* concentration of 17.45 μg L^{-1}. Sixty-six percent of the southeast coastal estuarine area had chlorophyll *a* concentrations in the moderate to high range in excess of 5 μg L^{-1} (Figure 3.1.9, Table 3.1.2).

SAB Region-Wide

Estuaries throughout the SAB have shown symptoms of low to moderate eutrophication with some areas reported as being highly eutrophic (Mallin et al. 2000, Bricker et al. 2007). Such assessments are supported by the results presented here, which suggest that about 58% of the estuarine area is experiencing moderate levels of Chl *a* (5-10 μg L^{-1}) and 8% of the area is experiencing higher levels in excess of 10 μg L^{-1} (Figure 3.1.9). The elevated Chl *a* levels are widespread throughout the estuaries of the region (Figure 3.1.10). In contrast, at the time of sampling, coastal-ocean waters throughout the region had relatively low levels of Chl *a* with 100% of the offshore survey area having values < 5 μg L^{-1} (Figure 3.1.10).

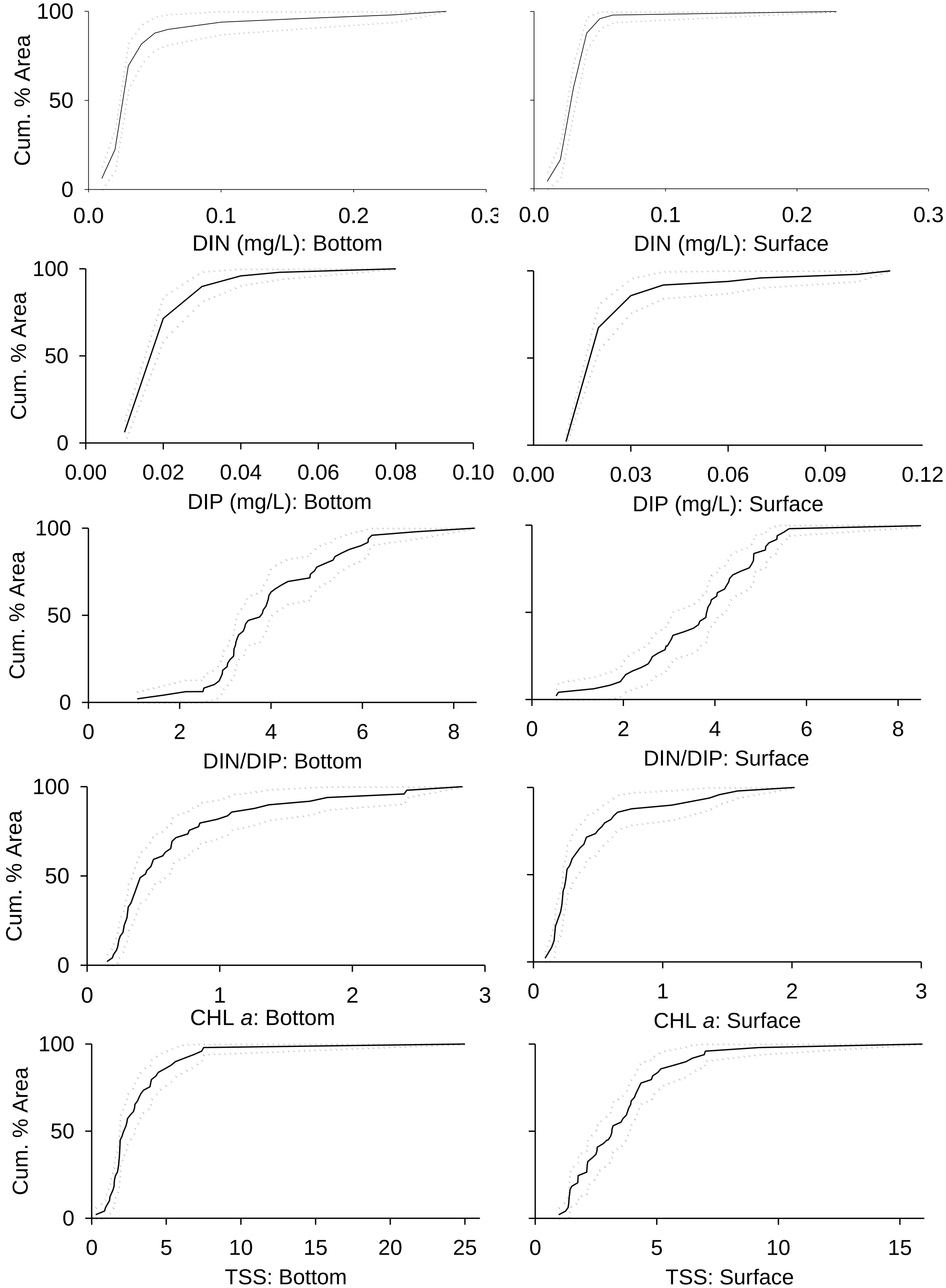

Figure 3.1.6. Percent area (solid lines) and 95% Confidence Intervals (dotted lines) of SAB coastal ocean waters for nurtients, chlorophyll *a* and TSS concentrations.

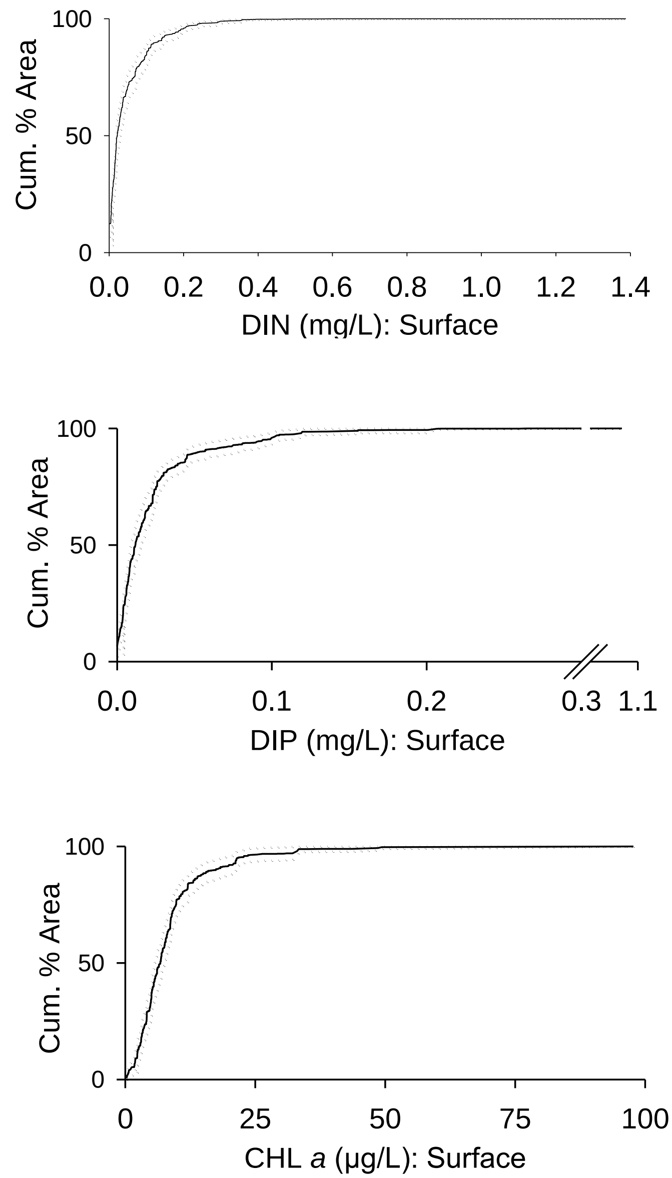

Figure 3.1.7. Percent area (solid lines) and 95% Confidence Intervals (dotted lines) of SAB estuarine surface water nutrients, chlorophyll *a* and TSS concentrations.

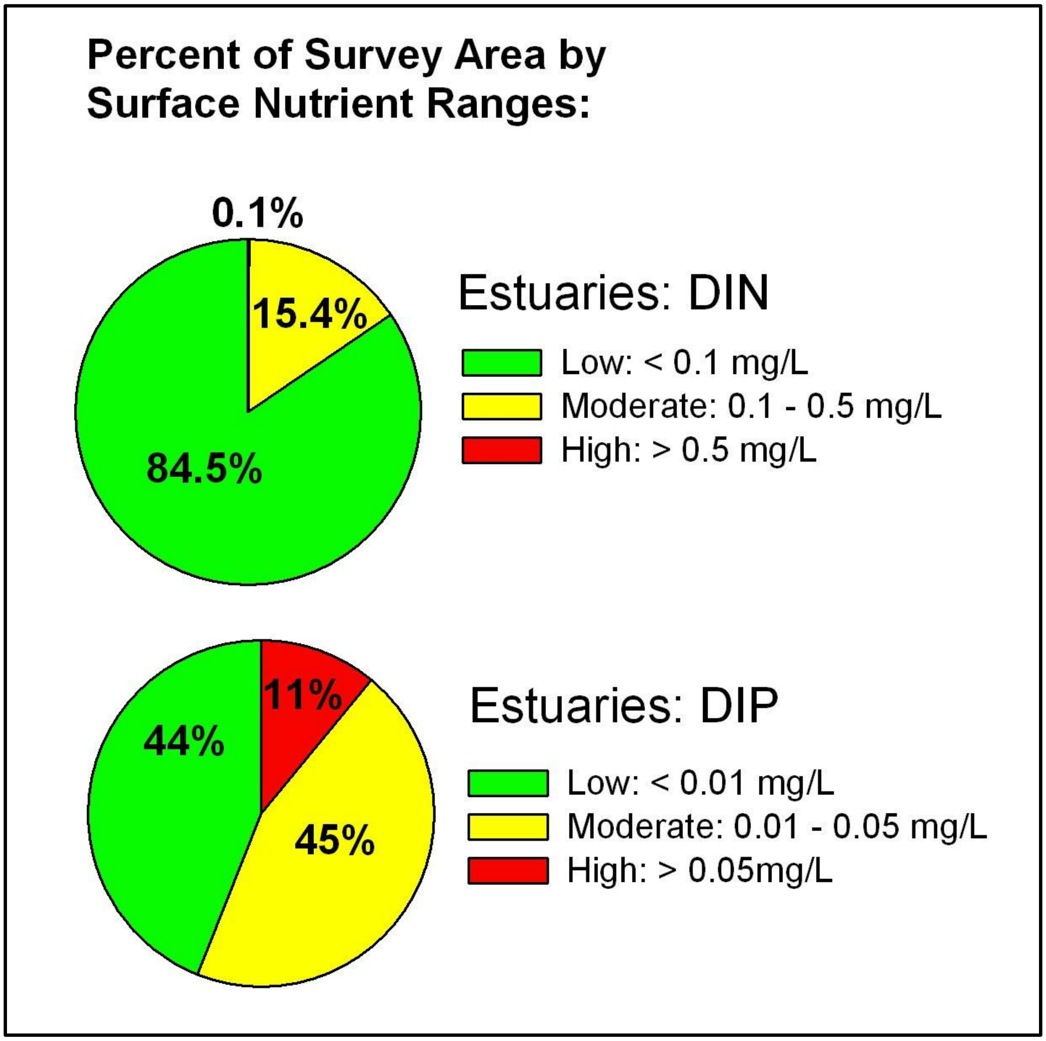

Figure 3.1.8. Percent area of SAB within specified ranges of DIN and DIP for near-surface estuarine waters only.

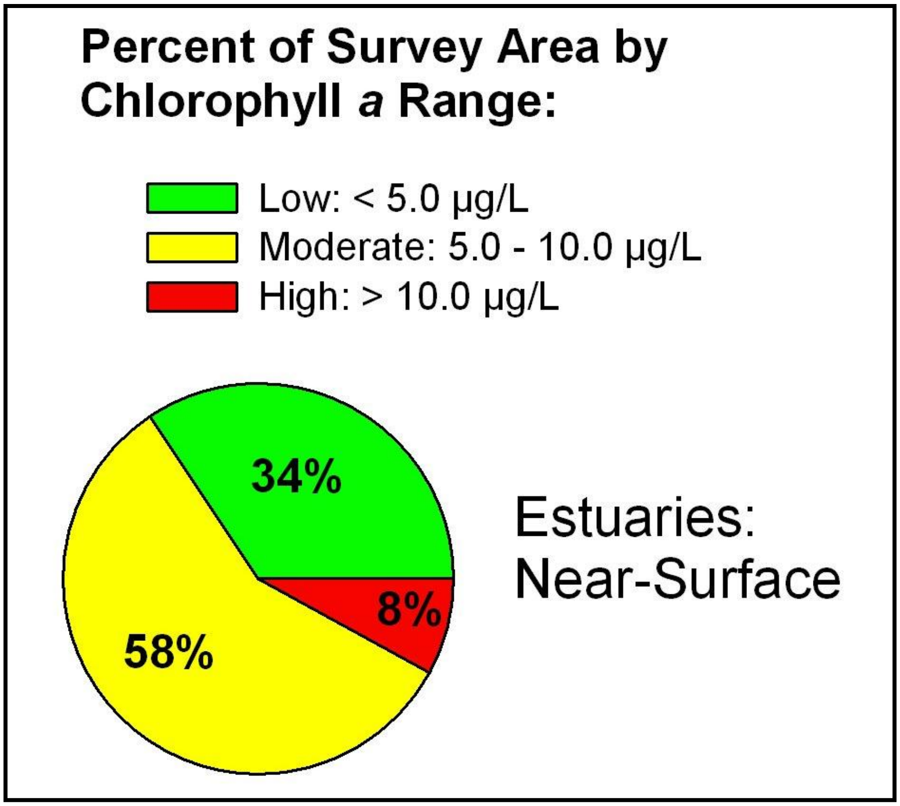

Figure 3.1.9. Percent area of SAB within specified ranges of chlorophyll *a* for near-surface estuarine waters only.

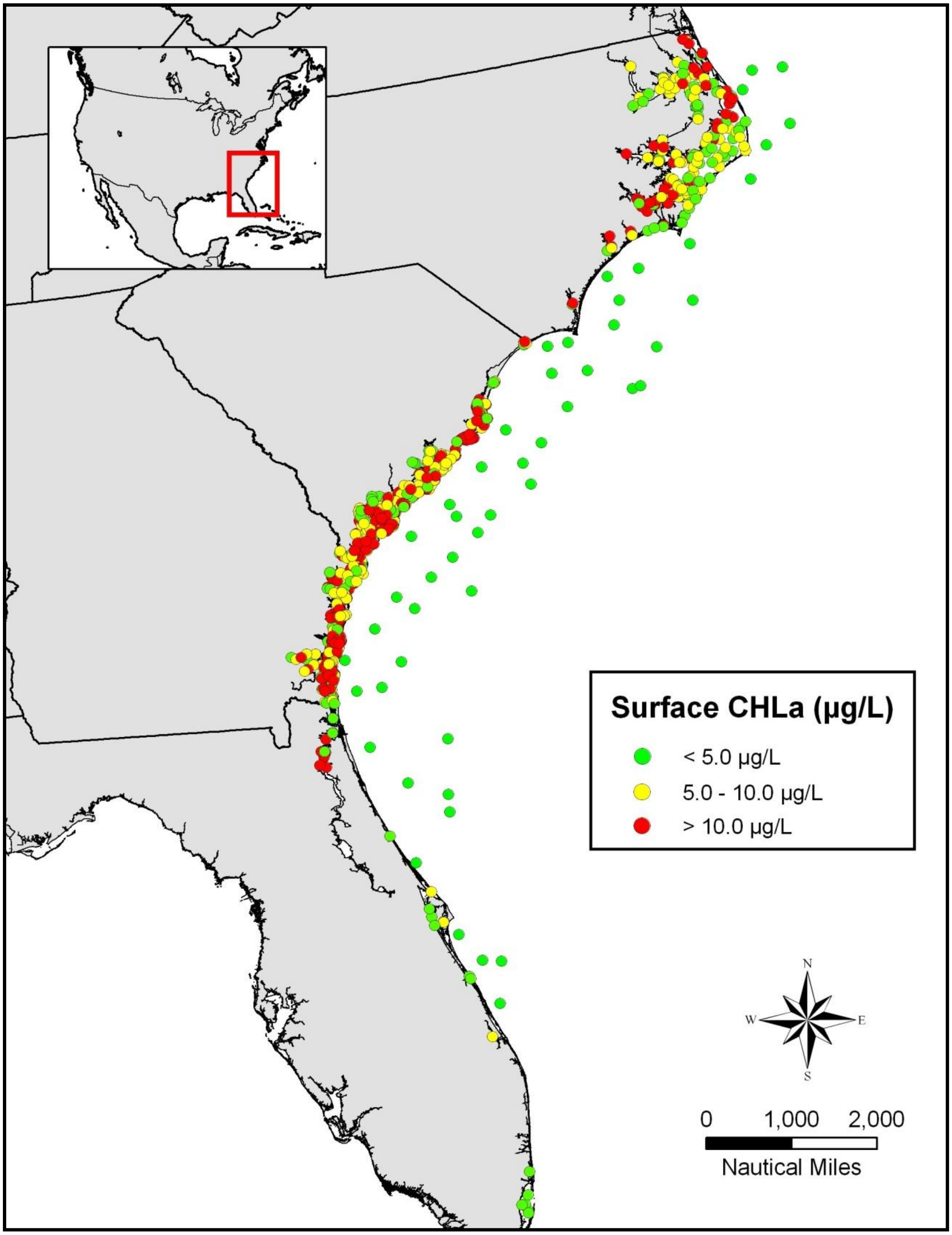

Figure 3.1.10. Spatial distribution of surface chlorophyll *a* levels in SAB coastal ocean and estuarine waters.

3.2 Sediment Quality

3.2.1 Grain Size and TOC

Coastal Ocean

The percentage of silt-clay in sediments ranged from 0.4% to 11.5% and averaged 1.9% throughout the survey area (Table 3.2.1, Appendix A). One hundred percent of the overall coastal-ocean survey area had sediments composed of sands (< 20% silt-clay). None of the stations were composed of muds (> 80% silt-clay; Figure 3.2.1).

Total organic carbon (TOC) in sediments exhibited a wide range (0.01 to 39.94 mg g^{-1}) throughout the SAB region (Table 3.2.1). The majority of the coastal-ocean survey area (90%) had relatively low TOC levels of < 20 mg g^{-1} and none had high levels (> 50 mg g^{-1}) associated with a high risk of adverse effects on benthic fauna. About 10% of the offshore survey area, represented by three stations located consistently along the outer shelf, had intermediate levels of TOC (20-50 mg g^{-1}) (Figure 3.2.3).

Estuaries

The percentage of silt-clay in sediments ranged widely from 0.1% to 98.8% and averaged 25.3% throughout the survey area (Table 3.2.1). Approximately 54% of the estuarine survey area had sediments composed of sands (< 20% silt-clay), 41% was composed of intermediate muddy sands (20-80% silt-clay), and 5% was composed of muds (> 80% silt-clay).

TOC exhibited a wide range of 0 to 166.54 mg g^{-1} and averaged 11.40 mg g^{-1} (Table 3.2.1). Seventy-four percent of the estuarine survey area had low levels of TOC (< 20 mg g^{-1} and only 7% had high levels (> 50 mg g^{-1}). These data are similar to those recorded for SAB estuaries during earlier surveys, although the maximum reported here (166.54 mg g^{-1}) is slightly higher than the maximum (148 mg g^{-1}) previously reported by Hyland et al. (1996, 1998).

SAB Region-Wide

Estuaries of the SAB are characterized by a wide range of sediment types from muds to sands, while the coastal-ocean environment consists largely of sands with typically < 5% silt-clay (Figure 3.2.1). TOC also exhibited a wide range of values across the SAB, with the highest levels occurring in estuaries (Table 3.2.1, Figure 3.2.2 and 3.2.3). About 19% of the estuarine survey area had TOC at moderate levels (20-50 mg g^{-1}) and 7% had values in the high range (> 50 mg g^{-1}) associated with a high risk of adverse effects on benthic fauna (U.S. EPA 2008). In comparison, offshore sediments had moderate levels of TOC in about 10% of the survey area and did not exhibit evidence of TOC in the upper range. The lower and upper thresholds of 20 and 50 mg g^{-1} used here for evaluating the biological significance of sediment TOC content are adopted from earlier EPA National Coastal Condition Reports (e.g., U.S. EPA 2004, 2008). Hyland et al. (2005) also identified TOC concentrations > 35 mg g^{-1} as an upper range associated with a high risk of degraded benthic condition from multiple coastal areas around the world. The portion of the present offshore survey area with TOC in excess of this slightly more conservative cut point also was relatively small, 5%, represented by one station along the shelf break west of Cape Fear. For comparison, estuaries had TOC > 35 mg g^{-1} in about 11% of the survey area.

TOC levels tended to be the highest in the upstream portions of estuaries and along the shelf break in the case of the offshore environment (Figure 3.2.4). All three offshore stations with TOC in excess of 20 mg g^{-1}, inclusive of the one station off Cape Fear with TOC > 35 mg g^{-1}, were located along the shelf break. The offshore pattern is consistent with results observed previously along a cross-shelf transect off the coast of Georgia (Hyland et al. 2006) and may be related to intrusions of deep, nutrient-rich water onto the continental shelf (Verity et al. 1993).

Table 3.2.1. Summary of sediment characteristics for SAB coastal ocean waters (A) and estuarine waters (B).

A.

	Mean	Range	CDF 10th%	CDF 50th%	CDF 90th%
TOC (mg g^{-1})	3.53	0.01 - 39.94	0.07	0.53	18.2
% silt-clay	1.9	0.4 - 11.5	0.72	0.98	5.8
Mean ERM-Q	0.008	0.003 - 0.028	0.003	0.006	0.013

B. Estuaries

	Mean	Range	CDF 10th%	CDF 50th%	CDF 90th%
TOC (mg g^{-1})	11.40	0 – 166.54	0.46	5.9	35.8
% silt-clay	25.3	0.1 – 98.8	1.2	13.3	73.7
Mean ERM-Q	0.019	0 – 0.968	0.003	0.013	0.076

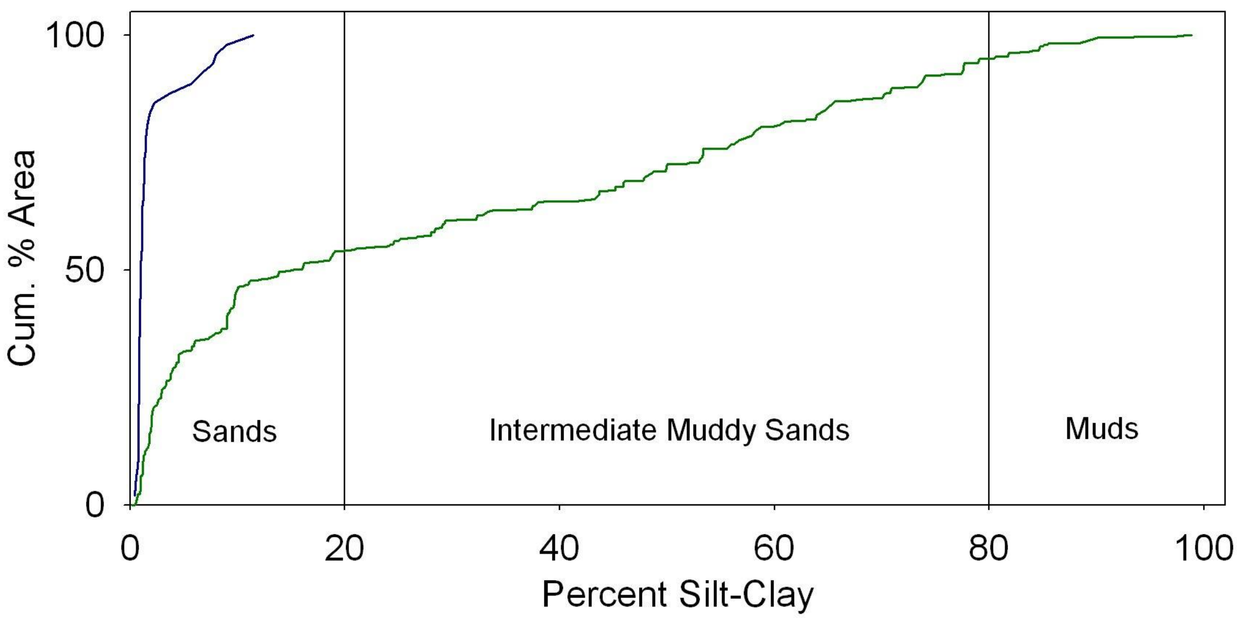

Figure 3.2.1. Percent area of SAB coastal ocean (blue line) and estuarine (green line) vs. percent silt-clay of sediment.

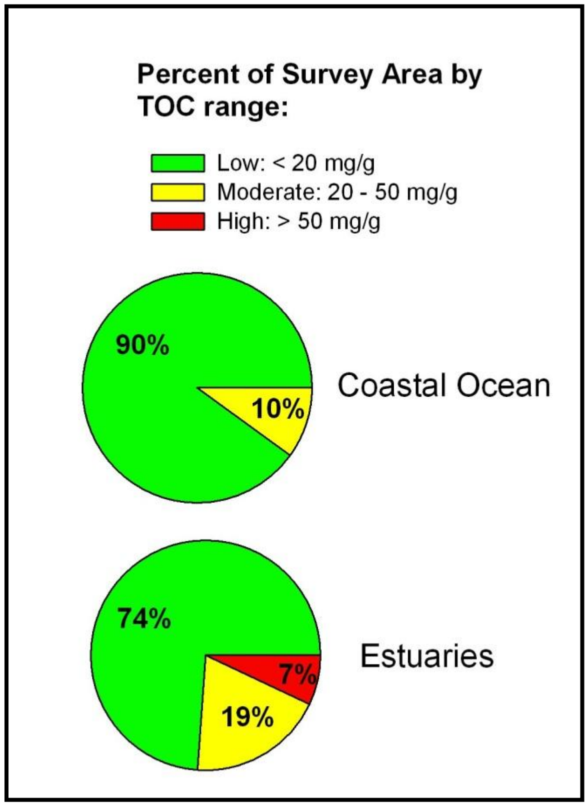

Figure 3.2.2. Percent area of SAB near-bottom waters within specified ranges of TOC levels.

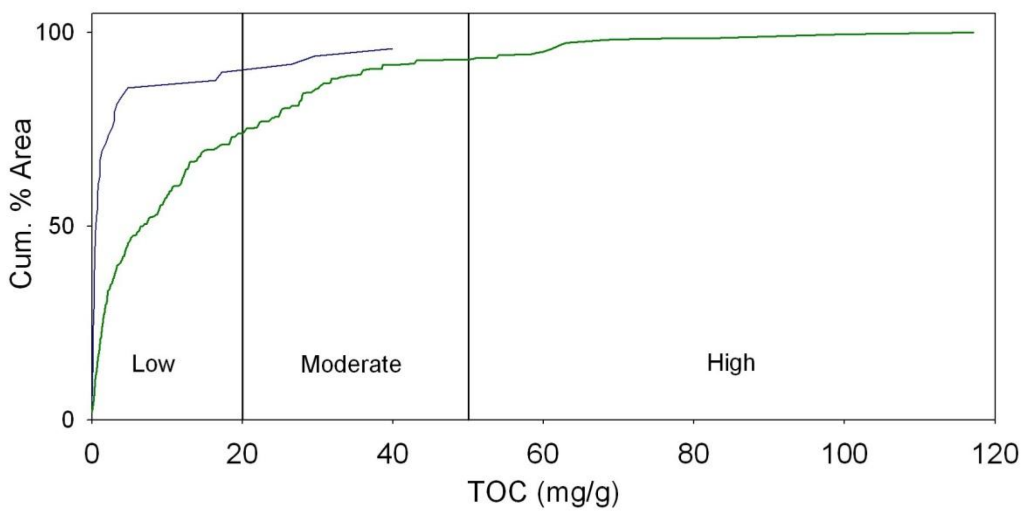

Figure 3.2.3. Percent area of SAB coastal ocean (blue line) and estuarine (green line) area vs. TOC levels of sediment.

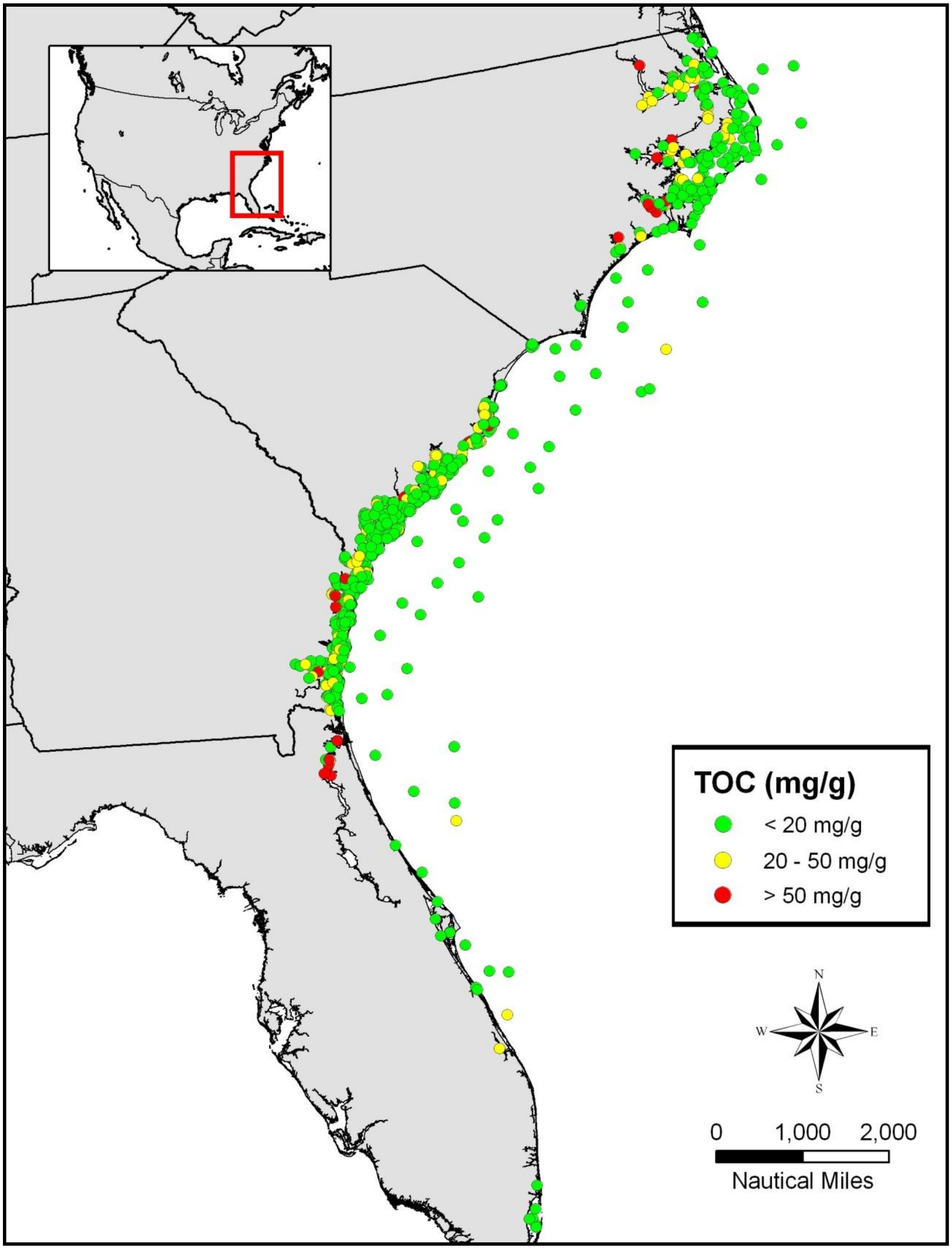

Figure 3.2.4. Spatial distribution of total organic carbon (TOC) levels in SAB coastal ocean and estuarine sediments.

3.2.2 Chemical Contaminants in Sediments

Effects Range-Low (ERL) and Effects Range-Median (ERM) sediment quality guideline (SQG) values from Long et al. (1995) were used to help interpret the biological significance of observed chemical contaminant levels in sediments. ERL values are lower-threshold bioeffect limits, below which adverse effects of the contaminants on sediment-dwelling organisms are not expected to occur. In contrast, ERM values represent mid-range concentrations of chemicals above which adverse effects are more likely to occur. A list of 26 chemicals, or chemical groups, for which ERL and ERM guidelines have been developed is provided in Table 2.7.2 along with the corresponding SQG values (from Long et al. 1995). Any site with one or more chemicals that exceeded corresponding ERM values was rated as having poor sediment quality, any site with five or more chemicals between corresponding ERL and ERM values was rated as fair, and any site that had less than five ERLs exceeded and no ERMs exceeded was rated as good (sensu USEPA 2004).

Overall sediment contamination from multiple chemicals also was expressed as the mean ERM quotient (ERM-Q) (Long et al. 1998; Long and MacDonald 1998; Hyland et al. 1999), which is the mean of the ratios of individual chemical concentrations in a sample relative to corresponding ERM values (using all chemicals in Table 2.7.2 except nickel and total PAH). Mean ERM-Qs ≤ 0.018 and > 0.058 have been associated with a low and high incidence of stress, respectively, in benthic communities of southeastern estuaries (Hyland et al. 2003).

Coastal Ocean

Sediments throughout the coastal-ocean survey area were relatively uncontaminated with all stations (100%) having contaminant concentrations in the low range (Table 3.2.2, Figure 3.2.5, Appendix D). Three trace metals (arsenic, cadmium, and silver) were found at moderate concentrations between corresponding ERL and ERM values, but no chemicals were found in excess of the higher-threshold ERM values (Table 3.2.2). ERL values were exceeded by these metals only at nine of the 50 offshore stations and none of these stations had more than one ERL exceedance. Mean ERM-Q values were also low throughout SAB coastal ocean sediments, ranging from 0.003 to 0.028 and averaging 0.008 (Table 3.2.1, Appendix D). Values in the moderate range (> 0.018-0.057) were found at three stations representing approximately 5% of the offshore survey area (Figure 3.2.5). None of the offshore sediments had mean ERM-Qs in the high to very high range (i.e., >0.057). Arsenic, cadmium, and silver are naturally occurring trace metals in crustal rocks, thus it is likely that the moderately elevated levels are due to natural geological conditions (Kimbrough et al. 2008).

Estuaries

Sediment contamination in estuaries was also fairly limited, although individual chemical contaminants exceeded their corresponding ERL values at many of the stations and ERM values at a few stations (Table 3.2.3). Overall, about 96% of the estuarine survey area had sediments with contaminants at low levels, 2% at moderate levels, and 2% at high levels based on numbers of ERL and ERM values exceeded (Figure 3.2.6). Three metals (arsenic, nickel, and cadmium) and total DDT were the predominant contaminants in estuarine sediments. Out of the 747 estuarine stations where sediment contaminants were measured, lower-level ERL values were exceeded at 131 stations for arsenic, 70 stations for nickel, 35 stations for cadmium, and 30 stations for total DDT. Arsenic, cadmium, and total DDT did not exceed their corresponding, higher-threshold ERM values at any of the estuarine sites. As with the offshore environment, arsenic, nickel, and cadmium are naturally occurring trace elements in crustal rocks, thus it is likely that the moderately elevated levels are due to natural geological conditions (Kimbrough et al. 2008). The higher-level ERM values were exceeded for six contaminants (mercury, nickel, silver, zinc, total PCBs, and 4,4′ DDE) at four of the estuarine stations. One station, FL04-0050, located in Doctors Lake, Florida on the St. John's River, accounted for the majority of this contamination. For example, mercury, nickel, and 4,4′ DDE exceeded their corresponding ERM values only at this station. Additionally, ERM levels for zinc and total PCBs were exceeded at Station FL04-0050. This area of the St. John's River, FL has been reported previously as containing high levels of chemical contaminants (Cooksey and Hyland 2007).

Mean ERM-Qs for estuarine sediments ranged from 0.0 to 0.968 and averaged 0.019 (Table 3.2.1). Values in the low range (≤ 0.018) accounted for about 59% of the estuarine survey area, values in the moderate range (> 0.018-0.057) accounted for about 30% of the area, values in the high range (> 0.057-0.196) accounted for about 10% of the area, and values in the very high range (> 0.196) accounted for about 1% of the area (Figure 3.2.5).

SAB Region-Wide

In general, sediment contamination across the majority of the SAB was at low levels. Chemical contaminants in offshore sediments were at low, background levels throughout the entire survey area. Sediment contamination, expressed as number of ERL and ERM values exceeded, was more extensive in estuarine sediments, though moderate to high levels were still limited to 4% of the total estuarine survey area (Figure 3.2.6). The spatial extent of sediment contamination in estuaries was somewhat higher, however, if expressed as mean ERM-Qs, with about 11% of the estuarine survey area having mean ERM-Qs in the high to very high range (Figure 3.2.5). Specific areas of high sediment contamination were located in Biscayne Bay and St. John's River, FL, and Winyah Bay, SC (Figure 3.2.7).

Hyland et al. (1996, 1998) previously completed surveys of environmental quality of estuaries of the SAB, in 1994 and 1995, using methodology nearly identical to that used in the current survey. They found that PCBs (1994) and pesticides (1995) were the most pronounced contaminant groups for this region. The current survey finds that PCBs and pesticide contamination have become less pronounced during the five to ten years between the earlier surveys and the data presented here. The most prevalent contaminants in the present estuarine survey area were three metals (arsenic, nickel, and cadmium) and total DDT. Though spatially extensive, all of these except nickel were present at moderate levels between corresponding ERL and ERM guideline values. Nickel and five other contaminants (mercury, silver, zinc, total PCBs, and 4,4′ DDE) were present in estuarine sediments at concentrations above the corresponding ERM values. However, areas with elevated chemical contaminant concentrations were spatially limited; ERM values were exceeded at only four of 747 stations. For the offshore environment, there were three metals (arsenic, cadmium, and silver) found at moderate concentrations between corresponding ERL and ERM values, but no chemicals were found in excess of the higher-threshold ERM values and none of the offshore stations had more than one chemical that exceeded its corresponding ERL value.

Table 3.2.2. Summary of chemical contaminant concentrations in SAB coastal ocean sediments ('N/A' = no corresponding ERL or ERM available).

Analyte	Mean	Range	Concentration > ERL < ERM # Stations	Concentration > ERM # Stations
Metals (% dry wt.)				
Aluminum	0.28	0 - 1.3	N/A	N/A
Iron	0.41	0.11 - 2.1	N/A	N/A
Trace Metals (µg/g)				
Antimony	0.0318	0 - 0.48	N/A	N/A
Arsenic	5.2	1.1 - 20.8	7	0
Cadmium	0.114	0 - 1.5	1	0
Chromium	11.17	1.6 - 24.9	0	0
Copper	1.0884	0 - 4.8	0	0
Lead	4.33	1.6 - 12.1	0	0
Manganese	98.15	26.1 - 603	N/A	N/A
Mercury	0.00088	0 - 0.025	0	0
Nickel	2.0968	0.76 - 8.2	0	0
Selenium	0.4022	0 - 0.93	N/A	N/A
Silver	0.06976	0.011 - 1.9	1	0
Tin	3.772	3 - 14.9	N/A	N/A
Zinc	7.28	2.3 - 34.3	0	0
PAHs (ng/g)				
Acenaphthene	0	0 - 0	0	0
Acenaphthylene	0	0 - 0	0	0
Anthracene	0	0 - 0	0	0
benz[a]anthracene	0	0 - 0	0	0
benzo[a]pyrene	0	0 - 0	0	0
benzo[b]fluoranthene	0	0 - 0	N/A	N/A
Benzo[g,h,i]perylene	0	0 - 0	N/A	N/A
Benzo[k]fluoranthene	0	0 - 0	N/A	N/A
Biphenyl	0	0 - 0	N/A	N/A
Chrysene	0	0 - 0	0	0
Dibenz[a,h]Anthracene	0	0 - 0	0	0
Dibenzothiophene (Synfuel)	0	0 - 0	N/A	N/A
2,6-Dimethylnaphthalene	0	0 - 0	N/A	N/A
Fluoranthene	0	0 - 0	0	0
Fluorene	0	0 - 0	0	0
Indeno[1,2,3-c,d]Pyrene	0	0 - 0	N/A	N/A
Naphthalene	0	0 - 0	0	0
2-Methylnaphthalene	0	0 - 0	0	0
1-Methylnaphthalene	0	0 - 0	N/A	N/A
1-Methylphenanthrene	0	0 - 0	N/A	N/A
Phenanthrene	0	0 - 0	0	0
Pyrene	0	0 - 0	0	0
2,3,5-Trimethylnaphthalene	0	0 - 0	N/A	N/A
Total PAHs	0	0 – 0	0	0
PCBs (ng/g)				
Total PCBs	0	0 - 0	N/A	N/A
Pesticides (ng/g)				
2,4′-DDD	0	0 - 0	N/A	N/A

Analyte	Mean	Range	Concentration > ERL < ERM # Stations	Concentration > ERM # Stations
2,4′-DDE	0	0 - 0	0	0
2,4′-DDT	0	0 - 0	N/A	N/A
4,4′-DDD	0	0 - 0	N/A	N/A
4,4′-DDE	0	0 - 0	N/A	N/A
4,4′-DDT	0	0 - 0	N/A	N/A
Total DDT	0	0 – 0	0	0
Aldrin	0	0 - 0	N/A	N/A
Alpha-Chlordane	0	0 - 0	N/A	N/A
Atrazine	0	0 - 0	N/A	N/A
Dieldrin	0	0 - 0	N/A	N/A
Endosulfan I	0	0 - 0	N/A	N/A
Endosulfan II	0	0 - 0	N/A	N/A
Endosulfan Sulfate	0	0 - 0	N/A	N/A
Endrin	0	0 - 0	N/A	N/A
Gamma-BHC (Lindane)	0	0 - 0	N/A	N/A
Heptachlor	0	0 - 0	N/A	N/A
Heptachlor Epoxide	0	0 - 0	N/A	N/A
Hexachlorobenzene	0	0 - 0	N/A	N/A
Mirex	0	0 - 0	N/A	N/A
Toxaphene	0	0 - 0	N/A	N/A
Trans-Nonachlor	0	0 - 0	N/A	N/A

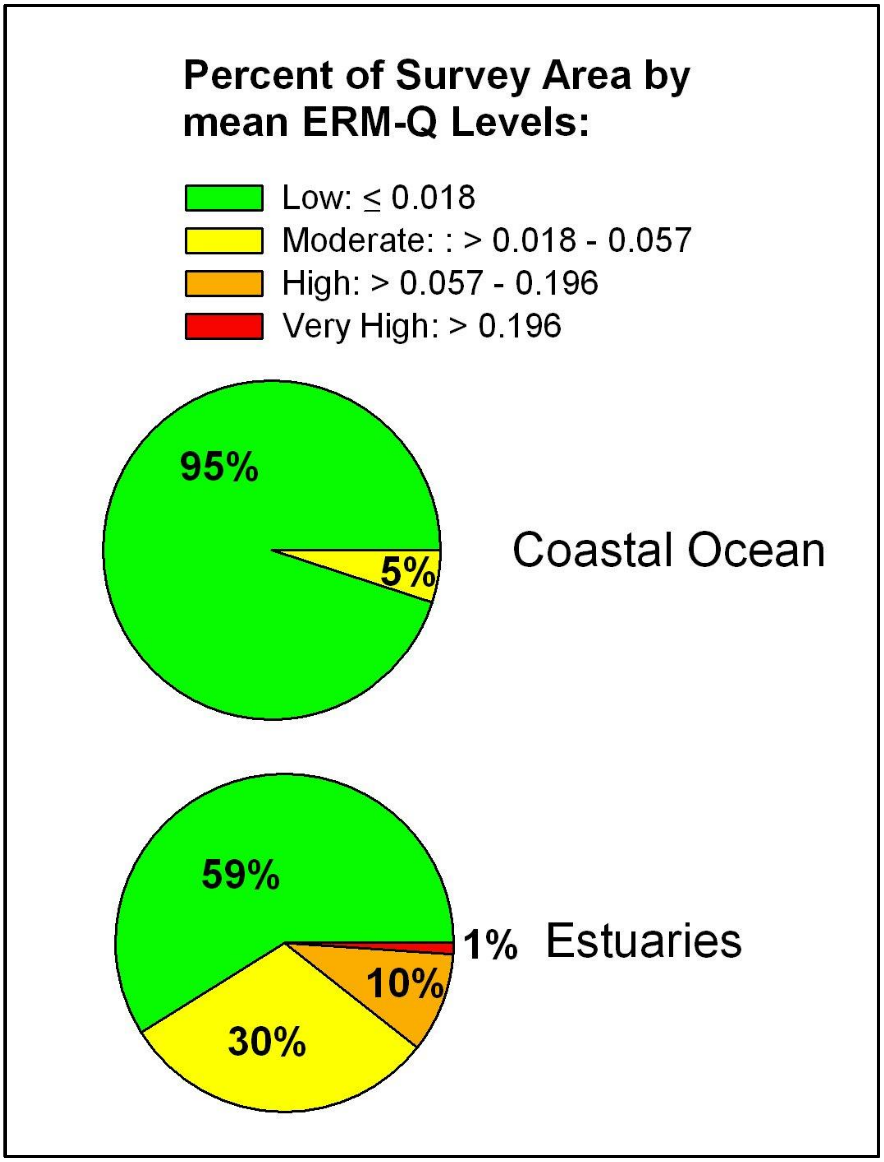

Figure 3.2.5. Percent area of SAB sediment contamination, expressed as mean ERM-Q, levels within specified ranges.

Table 3.2.3. Summary of chemical contaminant concentrations in SAB estuarine sediments ('N/A' = no corresponding ERL or ERM available).

Analyte	Mean	Range	Concentration > ERL < ERM # Stations	Concentration > ERM # Stations
Metals (µg/g)				
Aluminum	21464.11	0 - 180000	N/A	N/A
Iron	13846.71	0 - 100000	N/A	N/A
Antimony	0.22161	0 - 5.4	N/A	N/A
Arsenic	4.81	0 - 26.8	131	0
Cadmium	0.2221	0 - 4.85	35	0
Chromium	24.281	0 - 250	21	0
Copper	5.8	0 - 130	7	0
Lead	11.92	0 - 180	10	0
Manganese	197.59	0 - 1426.9	N/A	N/A
Mercury	0.026676	0 - 1.2	15	1
Nickel	7.7511	0 - 90	70	1
Selenium	0.4543	0 - 46	N/A	N/A
Silver	0.0647	0 - 5.8	4	1
Tin	3.087	0 - 248.2	N/A	N/A
Zinc	31.66	0 - 628	7	2
PAHs (ng/g)				
Acenaphthene	0.604	0 - 123.1	9	0
Acenaphthylene	0.782	0 - 96	4	0
Anthracene	2.075	0 - 442	4	0
Benz[a]anthracene	5.558	0 - 602	3	0
Benzo[a]pyrene	5.182	0 - 640	2	0
Benzo[b]fluoranthene	6.966	0 - 770	N/A	N/A
Benzo[e]pyrene	4.307	0 - 389	N/A	N/A
Benzo[g,h,i]perylene	3.236	0 - 700	N/A	N/A
Benzo[j+k]fluoranthene	8.246	0 - 487	N/A	N/A
Benzo[k]fluoranthene	3.231	0 - 690	N/A	N/A
Biphenyl	0.809	0 - 97.9	N/A	N/A
Chrysene	4.971	0 - 560	1	
Dibenz[a,h]anthracene	0.125	0 - 5.9	0	0
Dibenzothiophene	0.285	0 - 91	N/A	N/A
2,6-Dimethylnaphthalene	0.848	0 - 91	N/A	N/A
Fluoranthene	13.044	0 - 1100	2	0
Fluorene	0.840	0 - 93	7	0
Indeno[1,2,3-c,d]pyrene	2.973	0 - 560	N/A	N/A
1-Methylnaphthalene	1.033	0 - 92	N/A	N/A
2-Methylnaphthalene	1.383	0 - 88	3	0
1-Methylphenanthrene	0.364	0 - 100	N/A	N/A
Naphthalene	2.562	0 - 470	1	0
Perylene	45.119	0 - 1813.5	N/A	N/A
Phenanthrene	4.355	0 - 330	2	0
Pyrene	12.860	0 - 1200	1	0
2,3,5-Trimethylnaphthalene	0.241	0 - 90	N/A	N/A
Total PAHs	97.450	0 - 7580	2	0
PCBs (ng/g)				
Total PCBs	4.640	0 - 2526	1	2

Analyte	Mean	Range	Concentration > ERL < ERM # Stations	Concentration > ERM # Stations
Pesticides (ng/g)				
2,4'-DDD	0.015	0 - 1.7	N/A	N/A
2,4'-DDE	0.004	0 - 0.66	N/A	N/A
2,4'-DDT	0.003	0 - 0.82	N/A	N/A
4,4'-DDD	0.058	0 - 5.7	N/A	N/A
4,4'-DDE	0.173	0 - 35	4	1
4,4'-DDT	0.0308	0 - 5.8	N/A	N/A
Total DDT	0.280	0 - 35	30	0
Aldrin	0.120	0 - 88	N/A	N/A
Alpha-Chlordane	0.005	0 - 0.58	N/A	N/A
Dieldrin	0.048	0 - 30.28	N/A	N/A
Endosulfan I	0.002	0 - 0.69	N/A	N/A
Endosulfan II	0.007	0 - 2.6	N/A	N/A
Endosulfan Sulfate	0.026	0 - 8.5	N/A	N/A
Endrin	0.0072899	0 - 1	N/A	N/A
Gamma-BHC (Lindane)	0.011	0 - 1.2	N/A	N/A
Heptachlor	0.002	0 - 0.34	N/A	N/A
Heptachlor Epoxide	0.003	0 - 1	N/A	N/A
Hexachlorobenzene	0.053	0 - 7.7	N/A	N/A
Mirex	0.019	0 - 3.3	N/A	N/A
Toxaphene	0	0 - 0	N/A	N/A
Trans-Nonachlor	0.001	0 - 0.25	N/A	N/A

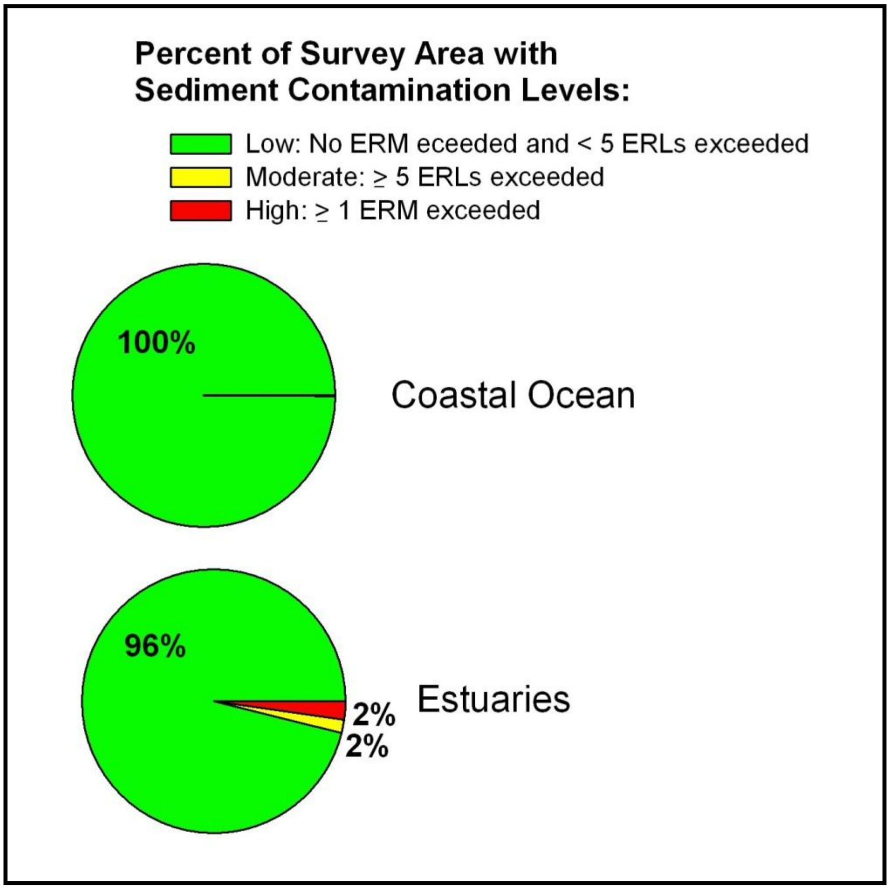

Figure 3.2.6. Percent area of SAB sediment contamination levels, expressed as number of ERL and ERM values exceeded, within specified ranges.

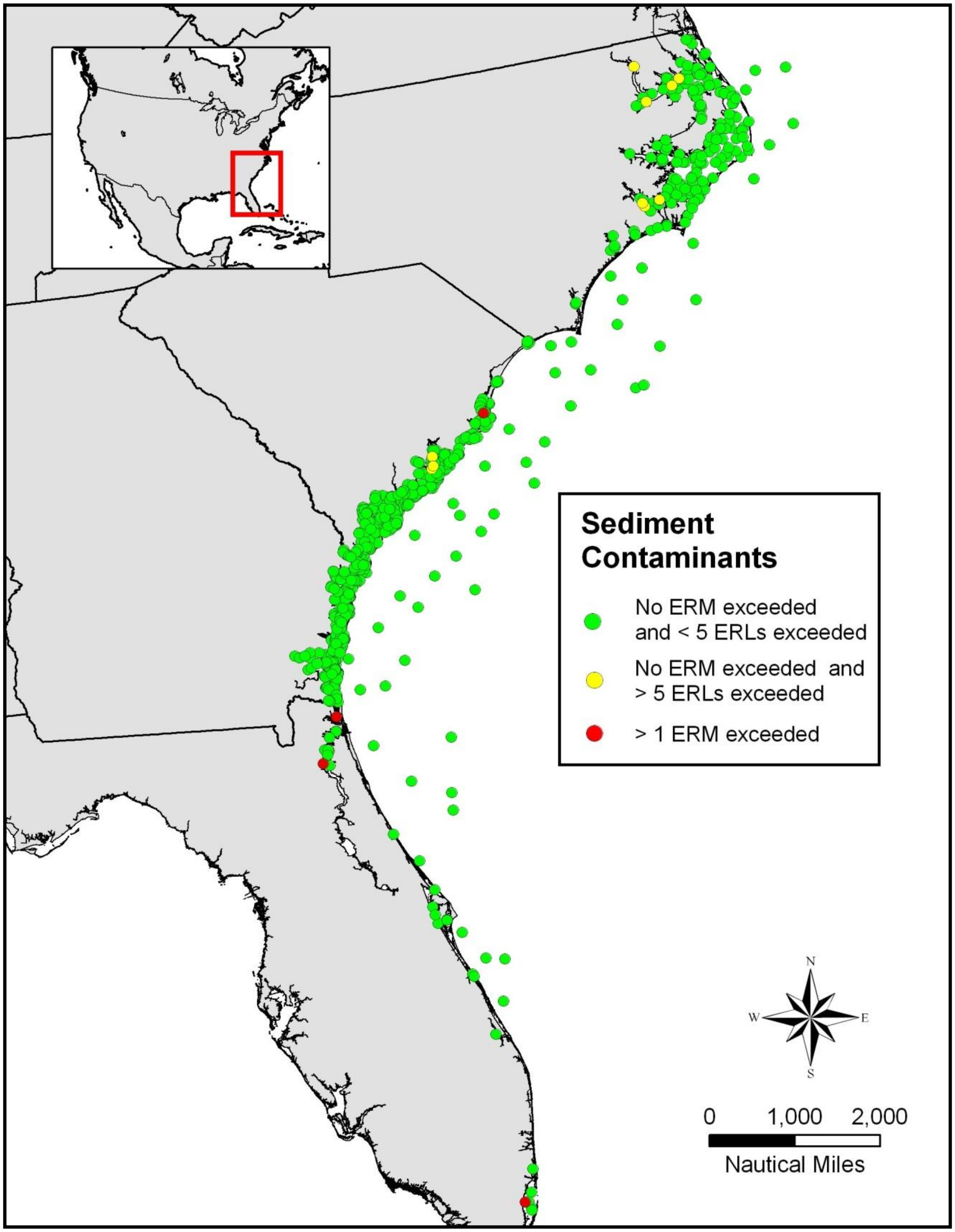

Figure 3.2.7. Spatial distribution of sediment contaminant levels in SAB coastal ocean and estuarine sediments.

3.2.3 Sediment Toxicity (Estuaries Only)

Ninety-five percent of the estuarine survey area showed no signs of sediment toxicity based on the 10-day survival assay with the marine amphipod *Ampelisca abdita*, (Figure 3.2.6). This low incidence of sediment toxicity is consistent with results from previous surveys of sediment quality throughout the southeastern estuaries (Hyland et al. 1996, 1998).

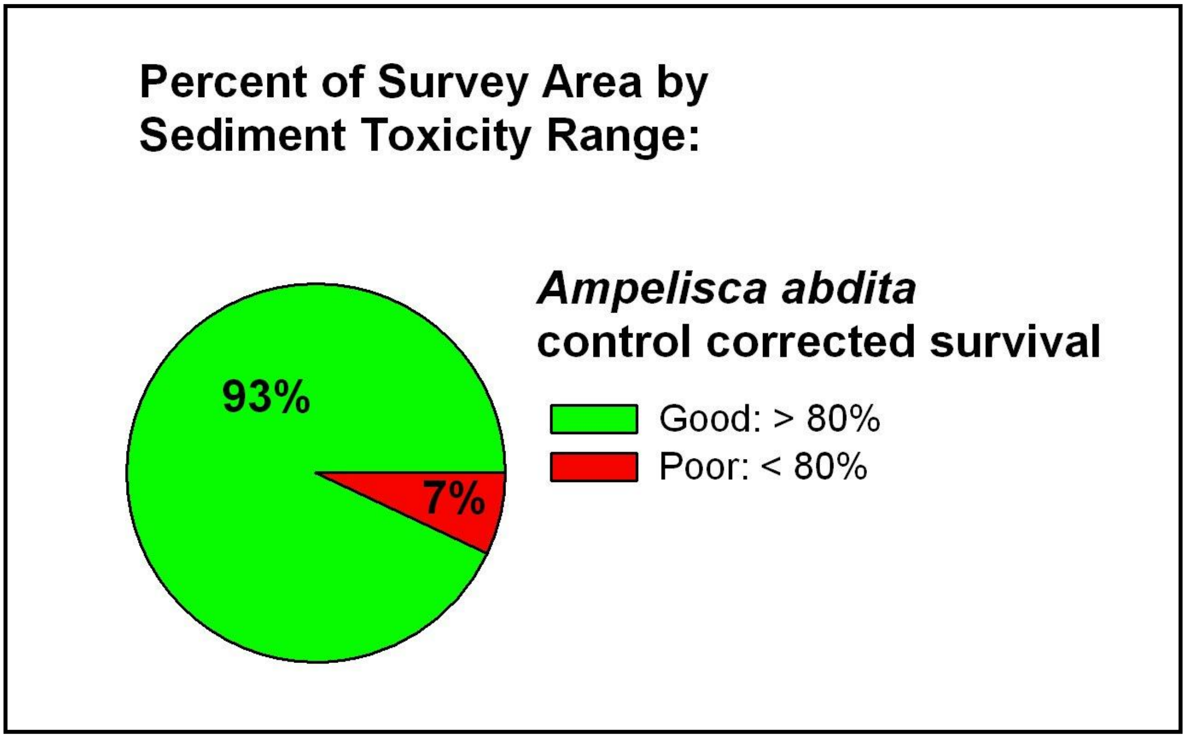

Figure 3.2.8. Percent area of SAB estuarine toxicity levels within specified ranges.

3.3 Chemical Contaminants in Fish Tissues

Coastal Ocean

Analysis of chemical contaminants in fish tissues was performed on homogenized fillets (including skin) from 20 samples of seven fish species collected from 17 stations. The fish species were sand perch (*Diplectrum formosum*), black seabass (*Centropristis striata*), dusky flounder (*Syacium papillosum*), whitebone porgy (*Calamus leucosteus*), red porgy (*Pagrus pagrus*), lizardfish (*Synodus foetens*), and snake fish (*Trachinocephalus myops*). Many of the measured contaminants in these samples were below corresponding minimum detection limits (MDL)(Table 3.3.1). However, 16 of the 22 inorganic trace metals that were measured (Al, As, Ba, Cr, Cu, Fe, Pb, Mn, Ni, Hg, Se, Ag, Sr, Ti, V, and Zn) were present at detectable levels and nine of the 26 measured PAHs were present at detectable levels. Additionally, there were several other organic contaminants that were present at detectable levels including total PCBs and 4,4'-DDT.

USEPA (2000) developed human-health consumption limits for cancer and non-cancer (chronic systemic) health endpoints for a variety of contaminants (Table 2.7.3). Measured contaminant concentrations (Table 3.3.1) fell well below the non-cancer consumption limits for most chemicals. However, one red porgy (Station 42) and one sand perch (Station 2) had mercury levels that exceeded the lower threshold for non-cancer effects (0.12 $\mu g\ g^{-1}$), but did not exceed the higher non-cancer effects threshold (0.23 $\mu g\ g^{-1}$).

Estuaries

Analysis of chemical contaminants in fish issues was performed on whole bodies from 166 samples of 14 fish species collected from 153 estuarine stations. Nearly all of the measured contaminants were found at detectable levels in at least a portion of the samples (Table 3.3.2). However, most samples had contaminants below both the lower and upper thresholds for non-cancer human-health risks. Four fish samples had mercury concentrations between the lower and upper thresholds (0.12 $\mu g\ g^{-1}$ and 0.23 $\mu g\ g^{-1}$, respectively). Three fish samples had total PCB concentrations that exceeded the lower threshold (23 $\mu g\ g^{-1}$) and one fish had total PCBs in excess of the corresponding higher threshold (47 ng/g). Three fish samples also had total PAHs that exceeded both the lower (1.6 $\mu g\ g^{-1}$) and upper (3.2 $\mu g\ g^{-1}$) cancer effects thresholds.

SAB Region-Wide

Of the seventeen coastal-ocean stations where fish were collected and analyzed for chemical contaminants, only two (12% of sites) had moderate levels of tissue contaminants, between lower and upper non-cancer effect thresholds, and none of the measured fish had high levels of tissue contaminants above the upper threshold (Table 2.7.1). At estuarine sites, in contrast, six stations (4% of sites) had high levels of tissue contaminants, exceeding the upper end of the human-health guideline range, and eight stations (5% of sites) had moderate levels of tissue contaminants (Figure 3.3.1).

Table 3.3.1 Summary of chemical contaminant concentrations (wet weight) measured in tissues of 20 fish (from 17 coastal ocean stations). Concentrations are compared to human health guidelines where available (from US EPA 2000, Table 2.7.3 here in). 'N/A' = no corresponding human health guideline available.

			No. of Fish Exceeding Non-Cancer Endpoints	
Analyte	Mean	Range	Lower	Upper
Trace Metals (μg g^{-1})				
Aluminum (Al)	2	1 - 5	N/A	N/A
Antimony (Sb)	0	0 - 0	N/A	N/A
Arsenic (As)	4.92	0.7 - 14.3	0	0
Inorganic Arsenic	0.098	0.014 - 0.286	N/A	N/A
Cadmium (Cd)	0	0 - 0	0	0
Chromium (Cr)	0.82	0.1 - 1.7	N/A	N/A
Copper (Cu)	0.3	0.2 - 0.67	N/A	N/A
Iron (Fe)	7.35	3 - 10	N/A	N/A
Lead (Pb)	0.029	0.01 - 0.09	N/A	N/A
Manganese (Mn)	0.31	0.1 - 0.7	N/A	N/A
Mercury (Hg)	0.068	0.025 - 0.158	2	0
Nickel (Ni)	0.1	0.1 - 0.1	N/A	N/A
Selenium (Se)	0.415	0.3 - 0.8	0	0
Silver (Ag)	0.1	0.1 - 0.1	N/A	N/A
Tin (Sn)	0	0 - 0	N/A	N/A
Zinc (Zn)	5.2	4 - 7	N/A	N/A
PAHs (ng g^{-1})				
Total Detectable PAHs[1]	0.545	0 - 4.15	0	0
PCBs (ng g^{-1})				
Total Detectable PCBs	0.06	0 - 1.19	0	0
Pesticides (ng g^{-1})				
2,4'-DDD	0	0 - 0	N/A	N/A
2,4'-DDE	0	0 - 0	N/A	N/A
2,4'-DDT	0	0 - 0	N/A	N/A
4,4'-DDD	0	0 - 0	N/A	N/A
4,4'-DDE	0	0 - 0	N/A	N/A
4,4'-DDT	0.3	0.3 - 0.3	N/A	N/A
Aldrin	0	0 - 0	N/A	N/A
BHC-alpha	0	0 - 0	N/A	N/A
Chlordane-alpha	0	0 - 0	N/A	N/A
Dieldrin	0	0 - 0	0	0
Endosulfan Sulfate	0	0 - 0	N/A	N/A
Endosulfan-I	0	0 - 0	0	0
Endosulfan-II	0	0 - 0	N/A	N/A
Endrin	0	0 - 0	0	0
Heptachlor	0	0 - 0	N/A	N/A
Heptachlor Epoxide	0	0 - 0	0	0
Hexachlorobenzene	0	0 - 0	0	0
Lindane	0	0 - 0	0	0
Mirex	0	0 - 0	0	0
Toxaphene	0	0 - 0	0	0
trans-Nonachlor	0	0 - 0	N/A	N/A
Total Detectable DDTs	0.015	0 - 0.3	0	0

1. Cancer concentration range used, a non-cancer concentration range for PAHs does not exist.

Table 3.3.2 Summary of chemical contaminant concentrations (wet weight) measured in tissues of 166 fish samples (from 153 estuarine stations). Concentrations are compared to human health guidelines where available (from US EPA 2000, Table 2.7.3 here in). 'N/A' = no corresponding human health guideline available.

			No. of Fish Exceeding Non-Cancer Endpoints	
Analyte	Mean	Range	Lower	Upper
Trace Metals ($\mu g\ g^{-1}$)				
Aluminum (Al)	9.934	0 - 121	N/A	N/A
Antimony (Sb)	0.059	0 - 0.580	N/A	N/A
Arsenic (As)	1.097	0 - 5.0	0	0
Inorganic Arsenic	0.02194	0 – 0.1	N/A	N/A
Cadmium (Cd)	0.004	0 - 0.080	0	0
Chromium (Cr)	0.355	0 - 9.9	N/A	N/A
Copper (Cu)	0.642	0.2 – 7.93	N/A	N/A
Iron (Fe)	21.211	1.9 - 273	N/A	N/A
Lead (Pb)	0.285	0 - 23.9	N/A	N/A
Manganese (Mn)	3.409	0.27 - 37.3	N/A	N/A
Mercury (Hg)	0.029	0 - 0.2	4	0
Nickel (Ni)	0.043	0 - 0.730	N/A	N/A
Selenium (Se)	0.690	0.25 - 1.3	0	0
Silver (Ag)	0.003	0 - 0.085	N/A	N/A
Tin (Sn)	1.555	0 - 17.2	N/A	N/A
Zinc (Zn)	10.624	4.05 - 32	N/A	N/A
PAHs ($ng\ g^{-1}$)				
Total Detectable PAHs[1]	13.934	0 - 460	0	3
PCBs (ng/g)				
Total Detectable PCBs	4.789	0 - 54.0	3	1
Pesticides ($ng\ g^{-1}$)				
Aldrin	0.060	0 – 2.0	N/A	N/A
Chlordane-alpha	0.060	0 - 2.0	N/A	N/A
Dieldrin	0.076	0 - 2.0	0	0
Endosulfan	0.181	0 - 6.0	N/A	N/A
Endrin	0.060	0 - 2.0	0	0
Heptachlor	0.060	0 - 2.0	N/A	N/A
Heptachlor Epoxide	0.060	0 - 2.0	0	0
Hexachlorobenzene	0.069	0 - 2.0	0	0
Lindane	0.060	0 - 2.0	0	0
Mirex	0.076	0 - 2.0	0	0
Toxaphene	7.530	0 - 250	0	0
trans-Nonachlor	0.060	0 -2.0	N/A	N/A
Total Detectable DDTs	1.379	0 - 16.00	0	0

1. Cancer concentration range used, a non-cancer concentration range for PAHs does not exist.

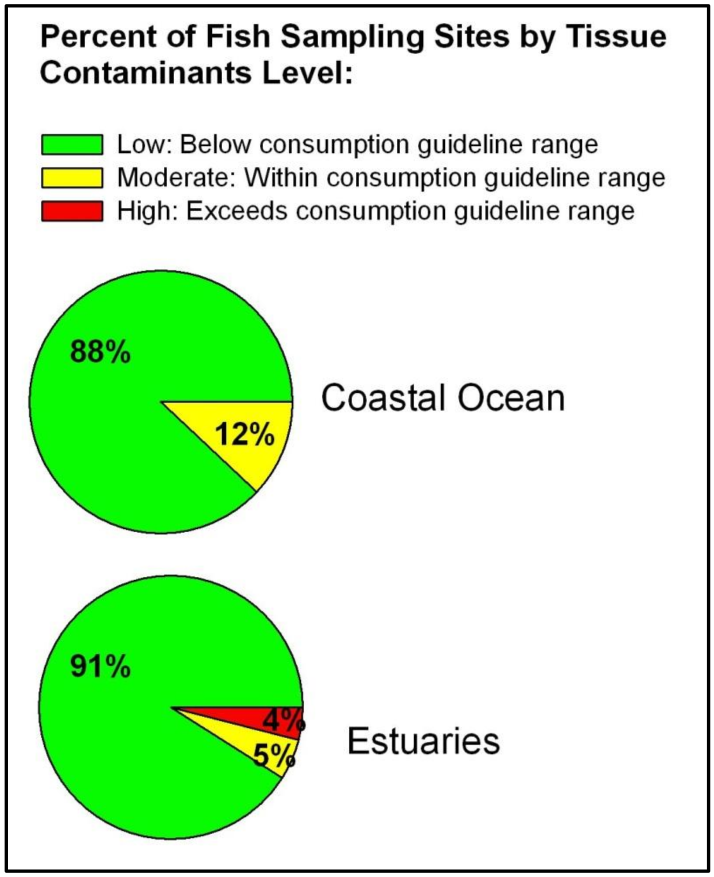

Figure 3.3.1. Percent of sites of SAB fish tissue contamination levels within consumption guideline ranges.

3.4 Status of Benthic Communities

Macrobenthic infauna (> 0.5 mm) were sampled at a total of 50 coastal ocean stations and 746 estuarine stations throughout the SAB. A single grab (0.04 m^2) was collected at all stations except for South Carolina estuaries, at which duplicates were taken, thus resulting in a total of 1,039 benthic grabs. The duplicate samples were averaged for the calculation of CDFs and other analysis purposes. The resulting data are used here to assess the status of benthic community characteristics (taxonomic composition, diversity, abundance and dominant species), biogeographic patterns, incidence of non-indigenous species, and potential linkages to ecosystem stressors.

3.4.1 Taxonomic Composition

Coastal Ocean

A total of 462 taxa were identified across the coastal ocean portion of the SAB, of which 313 were identified to the species level. Polychaetes were the dominant taxa, both by percent abundance (47%) and percent taxa (47%; Figure 3.4.1, Table 3.4.1). Crustaceans were the second most dominant taxa, both by percent abundance (28%) and percent taxa (30%). Collectively, these two groups represented 75% of the total faunal abundance and 77% of the taxa throughout these offshore waters. Crustaceans were represented mostly by amphipods (65 identifiable taxa, 14% of the total number of taxa). Mollusca accounted for 17% of taxa identified in coastal ocean samples, but only 9% of total faunal abundance. Echinoderms accounted for a small portion of total fauna by both percent abundance (2%) and percent taxa (2%).

Estuaries

A total of 948 taxa were identified across the estuarine portion of the SAB, of which 545 were identified to the species level. Polychaetes were the dominant taxa, both by percent abundance (58%) and percent taxa (37%; Figure 3.4.1, Table 3.4.2). Crustaceans were the second most dominant taxa, both by percent abundance (18%) and percent taxa (29%). Collectively, these two groups represented 76% of the total faunal abundance and 66% of the taxa throughout the estuaries of the SAB. Crustaceans were represented mostly by amphipods (124 identifiable taxa, 13.1% of the total number of taxa). Mollusca accounted for 25% of taxa identified in coastal ocean samples, but only 9% of total faunal abundance.

SAB Region-Wide

Taxonomic composition, based on major taxonomic groups, was very consistent between the coastal-ocean and estuarine portions of the SAB survey area (Figure 3.4.1). Polychaetes, followed by crustaceans, were the dominant taxa both by percent abundance and percent taxa across the region. However, the total number of taxa per unit of sampling effort was much higher for the offshore waters. For example, while a total of 948 benthic taxa were identified from 746 estuarine sites, almost half the number of taxa (462 or 49%) were identified from only

50 offshore sites (6.7% of the estuarine sites). This observation is consistent with the observed patterns of species diversity discussed below.

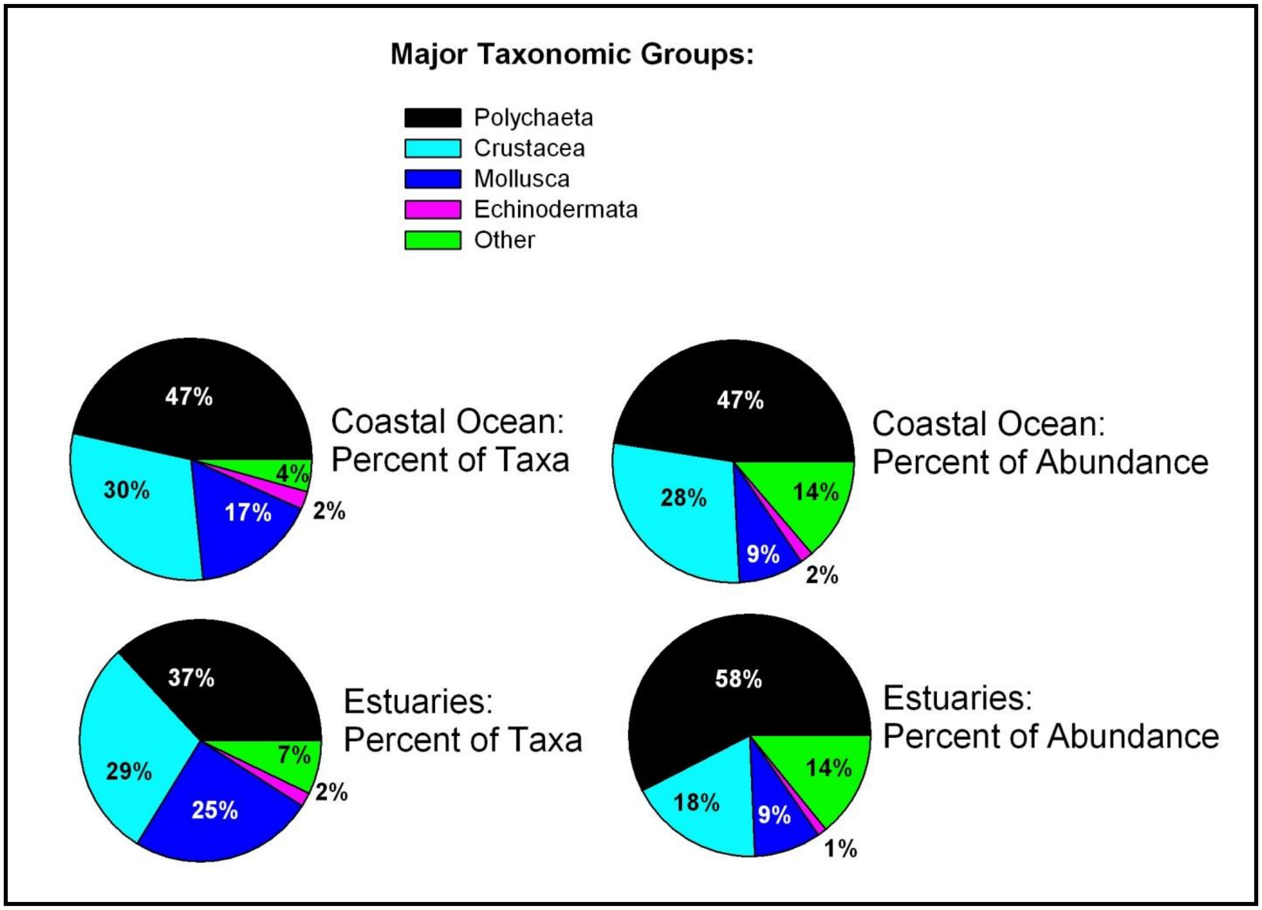

Figure 3.4.1. Relative percent composition of major taxonomic groups expressed as (A) percent of total taxa and (B) percent of abundance for coastal ocean and estuarine waters.

Table 3.4.1. Summary of major taxonomic groups of benthic infauna and corresponding numbers of identifiable taxa in samples from SAB coastal ocean sites.

Taxonomic Group	Number identifiable taxa	% Total identifiable taxa
Phylum Cnidaria	1	0.2
Class Anthozoa	1	0.2
Phylum Platyhelminthes	1	0.2
Phylum Nemertea	3	0.6
Phylum Sipuncula	6	1.3
Phylum Annelida		
Class Polychaeta	215	46.5
Class Clitellata	2	0.4
Phylum Arthropoda		
Subphylum Crustacea		
Class Malacostraca		
Order Stomatopoda	1	0.2
Order Decapoda	18	3.9
Order Mysidacea	1	0.2
Order Cumacea	11	2.4
Order Tanaidacea	9	1.9
Order Isopoda	14	3.0
Order Amphipoda	65	14.1
Class Ostracoda	20	4.3
Subphylum Chelicerata		
Class Arachnida	1	0.2
Phylum Mollusca		
Class Polyplacophora	1	0.2
Class Gastropoda	24	5.2
Class Bivalvia	45	9.7
Class Scaphopoda	7	1.5
Phylum Phoronida	1	0.2
Phylum Ectoprocta	1	0.2
Phylum Brachiopoda	1	0.2
Phylum Echinodermata		
Class Asteroidea	2	0.4
Class Ophiuroidea	4	0.9
Class Echinoidea	3	0.6
Class Holothuroidea	2	0.4
Phylum Chordata	2	0.4
Total	*462*	*100*

Table 3.4.2 Summary of major taxonomic groups of benthic infauna and corresponding numbers of identifiable taxa in samples from SAB estuarine sites.

Taxonomic Group	Number identifiable taxa	% Total identifiable taxa
Phylum Porifera	1	0.1
Phylum Cnidaria	1	0.1
Class Hydrozoa	5	0.5
Class Anthozoa	3	0.3
Phylum Platyhelminthes	3	0.3
Phylum Nemertea	7	0.7
Phylum Sipuncula	2	0.2
Phylum Annelida	1	0.1
Class Polychaeta	350	36.9
Class Clitellata	11	1.2
Phylum Arthropoda	1	0.1
Subphylum Crustacea	1	0.1
Class Malacostraca		
Order Leptostraca	1	0.1
Order Stomatopoda	1	0.1
Order Decapoda	74	7.8
Order Mysidacea	13	1.4
Order Lophogastridae	1	0.1
Order Cumacea	15	1.6
Order Tanaidacea	13	1.4
Order Isopoda	35	3.7
Order Amphipoda	124	13.1
Subphylum Hexapoda		
Class Insecta	18	1.9
Subphylum Chelicerata		
Class Pycnogonida	9	0.9
Phylum Mollusca		
Class Polyplacophora	3	0.3
Class Gastropoda	108	11.4
Class Bivalvia	122	12.9
Class Scaphopoda	1	0.1
Phylum Phoronida	2	0.2
Phylum Brachiopoda	1	0.1
Phylum Echinodermata		
Class Asteroidea	2	0.2
Class Ophiuroidea	9	0.9
Class Holothuroidea	7	0.7
Phylum Chaetognatha	1	0.1
Phylum Hemichordata	2	0.2
Total	*948*	*100*

3.4.2 Abundance and Dominant Taxa

Coastal Ocean

A total of 6,236 individual specimens were collected across the 50 coastal-ocean stations (50, 0.04 m^{-2} grab samples). Densities ranged from 275 to 23,650 m^{-2} and averaged 3,118 m^{-2} (Figure 3.4.2, Table 3.4.3, Appendix E). Thus there were no offshore samples that were devoid of benthic fauna. Spatially, 90% of the shelf area had densities ≥ 635 m^{-2} and 50% of the shelf area had densities ≥ 2350 m^{-2} (Table 3.4.3). The average densities reported from this survey for the entire coastal-ocean portion of the SAB are similar to densities previously reported for the continental shelf off Georgia, inclusive of GRNMS, where inner-shelf densities averaged 4958 m^{-2}, middle-shelf densities averaged 5901 m^{-2}, and outer-shelf densities averaged 1550 m^{-2} (Hyland et al. 2006). There were no apparent patterns of increasing or decreasing abundance in relation to depth or latitudinal variation in the current survey.

The 50 most abundant taxa found in shelf waters throughout the region are listed in Table 3.4.4. The 10 most abundant taxa on this list include the polychaetes *Spiophanes bombyx*, *Protodorvillea kefersteini*, *Mediomastus* spp., *Synelmis ewingi*, and *Exogone lourei*; the amphipods *Ampelisca abdita* and *Protohaustorius wigleyi*; tubificid oligochaetes; the chordate *Branchiostoma* spp.; and the Nemertea. *Ampelisca abdita* was the most abundant taxon overall, although it was only found at one station located north of Cape Hatteras (station 37) in very high numbers. The three taxa with the highest frequency of occurrence were the Nemertea, the Tubificidae, and the polychaete *S. bombyx*. Four of the top-five dominant taxa (*S.bombyx*, *P. wigleyi*; tubificid oligochaetes; and *Branchiostoma* spp.) found in the current survey were also among the dominant taxa previously reported at GRNMS and nearby shelf waters (Hyland et al. 2006).

Estuaries

A total of 160,378 individual specimens were collected across 746 estuarine stations (1,039 0.04 m^{-2} grab samples). Densities ranged from 0 to 103,350 m^{-2} and averaged 3,525 m^{-2} (Figure 3.4.3, Table 3.4.3). Eleven stations, accounting for 1.9% of estuarine area, were devoid of benthic fauna. Spatially, 90% of the estuarine area had densities ≥ 180, and 50% of the estuarine area had densities ≥ 1610 m^{-2} (Table 3.4.3). The overall mean density reported here for SAB estuaries during 2000-2004 is in good agreement with previously reported mean densities for the same region — 4,125 m^{-2} in 1994 and 3,100 m^{-2} in 1995 (Hyland et al. 1996; Hyland et al. 1998).

The fifty most abundant taxa found in SAB estuaries are listed in Table 3.4.5. The ten most abundant taxa on the list include several polychaetes: *Streblospio benedicti*, *Mediomastus* spp., *Lumbrineris tenuis*, *Caulleriella* spp., *Tharyx acutus*, and *Exogone* spp. Two oligochaete taxa, Tubificidae and *Tubificoides wasselli*, and two amphipod taxa, *Ampelisca abdita* and *Ampelisca vadorum*, are also among the top ten dominants. The most abundant taxon overall, *S. benedicti*, also had the highest frequency of occurrence (52%). Two of the current dominant taxa, *S. benedicti* and *Mediomastus* spp., were also among the top five dominant taxa during previous surveys of benthic fauna from southeastern estuaries (Hyland et al. 1996, 1998).

SAB Region-Wide

Mean densities were similar between the coastal-ocean and estuarine environments, i.e. 3,118 m^{-2} and 3,525 m^{-2} respectively (Table 3.4.3). Inner-quartile ranges (middle 25th to 75th percentile of observed values) were similar as well, i.e. 1400 m^{-2} to 3725 m^{-2} and 650 m^{-2} to 4250 m^{-2} for offshore and estuarine waters respectively. However, the overall range of densities among stations was much larger for estuaries (0 to 103,350 m^{-2}) than for the offshore waters (275 to 23,650 m^{-2}). The low end of the density range for estuaries included azoic conditions at 11 of the stations.

There was little overlap of dominant benthic taxa between the estuarine and coastal-ocean environments. Specifically, only five taxa were common to both the offshore and estuarine lists of fifty most abundant taxa. These taxa were the amphipod *Ampelisca abdita*, the polychaete *Mediomastus* spp., Actiniaria, Nemertea, and Tubificidae. As noted earlier, although *A. abdita* is the dominant taxon in the coastal-ocean environment, it was only collected at one station where it was found in very high numbers. No taxa identified to the species level, other than *A. abdita*, were among the fifty most abundant taxa in both the estuarine and coastal-ocean environments.

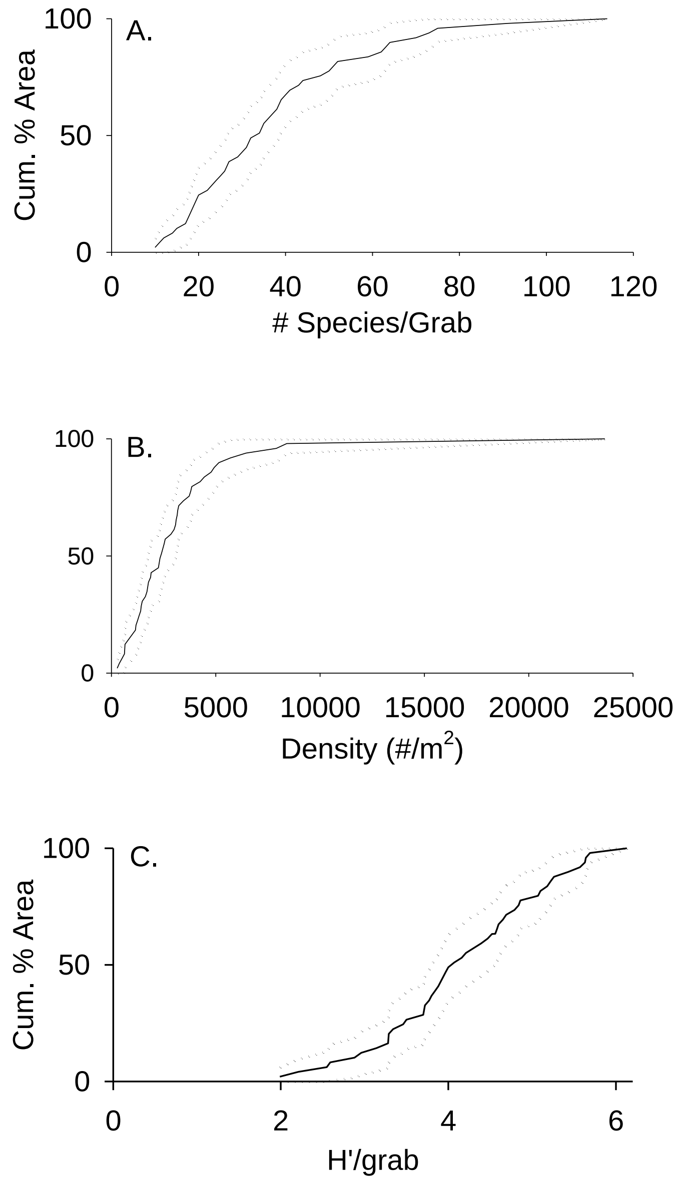

Figure 3.4.2. Percent area (solid lines) and 95% Confidence Intervals (dotted lines) of SAB coastal ocean benthic infaunal species richness (A), density (B), and H′ diversity (C).

Table 3.4.3. Mean, range, and selected distributional properties of key benthic variables for (A) coastal ocean and (B) estuarine sediments.

A. Coastal Ocean

	Overall Mean	Overall Range	Areal-Based Percentiles[1]: CDF 10th %	CDF 50th %	CDF 90th %	Frequency-Based Percentiles[2] 10th	25th	50th	75th	90th
# Taxa per grab	38	10 - 114	15	34	64	16	23	34	48	67
Density (#/m^2)	3118	275 - 23650	635	2350	5150	650	1400	2362	3725	5425
H′ per grab	4.17	1.98 – 6.13	2.88	4.07	5.43	2.92	3.50	4.12	4.84	5.50

B. Estuaries

	Overall Mean	Overall Range	Areal-Based Percentiles[1]: CDF 10th %	CDF 50th %	CDF 90th %	Frequency-Based Percentiles[2] 10th	25th	50th	75th	90th
# Taxa per grab	16	0 - 83	4	11	32	4	6	12	23	37
Density (#/m^2)	3525	0 - 103350	180	1610	6638	225	650	1825	4250	8400
H′ per grab	2.60	0 – 5.32	1.17	2.60	3.86	1.09	1.91	2.65	3.44	3.99

[1] Value of response variable corresponding to the designated cumulative % area point along the y-axis of the CDF graph.
[2] Corresponding lower 10th percentile, lower quartile, median, upper quartile, and upper 10th percentile of all values for each of the 3 benthic variables.

Table 3.4.4. Fifty most abundant benthic taxa in the SAB coastal ocean survey. Mean density per m^2 and % frequency of occurrence based on 50 grabs. Classification: Native=native species, Indeter=Indeterminate.

Taxa Name	Taxon	Classification	Mean Density	% Frequency of Occurrence
Ampelisca abdita	Amphipod	Native	356.5	2
Tubificidae	Oligochaete	Indeter	123.5	62
Branchiostoma spp.	Chordate	Indeter	103.5	48
Spiophanes bombyx	Polychaete	Native	102	62
Protohaustorius wigleyi	Amphipod	Native	79.5	18
Nemertea	Nemertean	Indeter	57	66
Protodorvillea kefersteini	Polychaete	Native	54	44
Mediomastus spp.	Polychaete	Indeter	51.5	18
Synelmis ewingi	Polychaete	Native	51	26
Exogone lourei	Polychaete	Native	42.5	20
Solen viridis	Bivalve	Native	38	20
Prionospio spp.	Polychaete	Indeter	37.5	42
Cnidaria	Cnidarian	Indeter	36.5	10
Pisione remota	Polychaete	Native	36.5	30
Goniadides carolinae	Polychaete	Native	35.5	30
Chone spp.	Polychaete	Indeter	31	28
Glyceridae	Polychaete	Indeter	31	42
Lumbrineris verrilli	Polychaete	Native	30.5	6
Metharpinia floridana	Amphipod	Native	30.5	32
Apseudes sp. A	Tanaid	Native	30	10
Caecum johnsoni	Gastropod	Native	29.5	20
Maldanidae	Polychaete	Indeter	29	26
Polygordius spp.	Polychaete	Indeter	28.5	32
Ophiuroidea	Ophiuroid	Indeter	27.5	32
Unciola irrorata	Amphipod	Native	26	20
Caecum pulchellum	Gastropod	Native	25	12
Bathyporeia parkeri	Amphipod	Native	24.5	16
Apseudes olympiae	Tanaid	Native	23	26
Lumbrinerides dayi	Polychaete	Native	22	14
Bhawania goodei	Polychaete	Native	21.5	32
Nephtyidae	Polychaete	Indeter	21.5	46
Dentatisyllis carolinae	Polychaete	Native	20.5	30
Branchiomma nigromaculata	Polychaete	Native	19.5	4
Spionidae Genus F	Spionid	Indeter	19	14
Armandia maculata	Polychaete	Native	17.5	26
Bhawania heteroseta	Polychaete	Native	17.5	10
Cirrophorus lyra	Polychaete	Native	17.5	24
Euchone spp.	Polychaete	Indeter	17.5	16
Spionidae	Spionid	Indeter	17.5	36

Taxa Name	Taxon	Classification	Mean Density	% Frequency of Occurrence
Goniadella sp. A	Polychaete	Native	17	14
Terebellidae	Polychaete	Indeter	17	20
Cirratulidae	Polychaete	Indeter	15.5	34
Actiniaria	Cnidarian	Indeter	15	16
Notomastus latericeus	Polychaete	Native	15	10
Oxyurostylis smithi	Cumacean	Native	15	12
Phtisica marina	Amphipod	Native	15	16
Laevicardium spp.	Bivalve	Indeter	14.5	14
Scoloplos capensis	Polychaete	Native	14.5	8
Sphaerosyllis glandulata	Polychaete	Native	14.5	18
Acanthohaustorius millsi	Amphipod	Native	14	20

Table 3.4.5 Fifty most abundant benthic taxa in the SAB estuarine survey. Mean density per m^2 and % frequency of occurrence based on 1039 grabs. Classification: Native=native species, Indeter=Indeterminate, Non-Ind =non-indigenous.

Taxa Name	Taxon	Classification	Mean Density	% Frequency of Occurrence
Streblospio benedicti	Polychaete	Native	432.1	52
Mediomastus spp.	Polychaete	Indeter	193.5	49
Tubificidae	Oligochaete	Indeter	167.1	41
Lumbrineris tenuis	Polychaete	Native	153.5	35
Tubificoides wasselli	Oligochaete	Native	126.4	15
Ampelisca abdita	Amphipod	Native	124.8	19
Caulleriella spp.	Polychaete	Indeter	114.1	12
Ampelisca vadorum	Amphipod	Native	96.8	6
Tharyx acutus	Polychaete	Native	90.0	29
Exogone spp.	Polychaete	Indeter	81.4	17
Sabellaria vulgaris	Polychaete	Native	65.5	13
Parapionosyllis spp.	Polychaete	Indeter	57.8	7
Scoloplos rubra	Polychaete	Native	57.7	26
Polydora cornuta	Polychaete	Native	50.7	19
Actiniaria	Actiniarian	Indeter	50.2	13
Tubificoides brownae	Oligochaete	Native	49.9	19
Paraprionospio pinnata	Polychaete	Native	46.9	28
Mediomastus ambiseta	Polychaete	Native	45.9	21
Nemertea	Nemertean	Indeter	45.9	46
Cirratulidae	Polychaete	Indeter	45.8	23
Aphelochaeta spp.	Polychaete	Indeter	44.9	11
Ampelisca spp.	Amphipod	Indeter	37.5	7
Mulinia lateralis	Bivalve	Native	36.0	12
Heteromastus filiformis	Polychaete	Native	35.1	31
Acteocina canaliculata	Gastropod	Native	34.4	14
Tharyx spp.	Polychaete	Indeter	32.9	9
Protohaustorius deichmannae	Amphipod	Native	31.9	4
Neanthes succinea	Polychaete	Native	30.2	24
Batea catharinensis	Amphipod	Native	29.8	12
Aricidea wassi	Polychaete	Native	29.6	10
Streptosyllis spp.	Polychaete	Indeter	27.1	11
Spiochaetopterus costarum oculatus	Polychaete	Native	26.7	13
Mediomastus californiensis	Polychaete	Native	26.1	10
Marenzelleria viridis	Polychaete	Native	26.0	7
Polydora socialis	Polychaete	Native	23.8	12
Polycirrus spp.	Polychaete	Indeter	23.0	4
Clymenella torquata	Polychaete	Native	22.0	10
Cirrophorus spp.	Polychaete	Indeter	21.5	11
Bivalvia	Bivalve	Indeter	21.3	23

Taxa Name	Taxon	Classification	Mean Density	% Frequency of Occurrence
Tellina agilis	Bivalve	Native	21.1	13
Carinomella lactea	Nemertean	Native	20.4	17
Thyone pawsoni	Holothuroid	Native	19.9	0
Unciola serrata	Amphipod	Native	18.2	4
Leptocheirus plumulosus	Amphipod	Native	17.6	3
Melita nitida	Amphipod	Native	17.2	10
Cyathura burbancki	Isopod	Native	17.0	9
Veneroida	Bivalve	Indeter	15.3	8
Rangia cuneata	Bivalve	Non-Ind	15.0	6
Paracaprella tenuis	Amphipod	Native	14.8	10
Ampelisca verrilli	Amphipod	Native	14.7	8

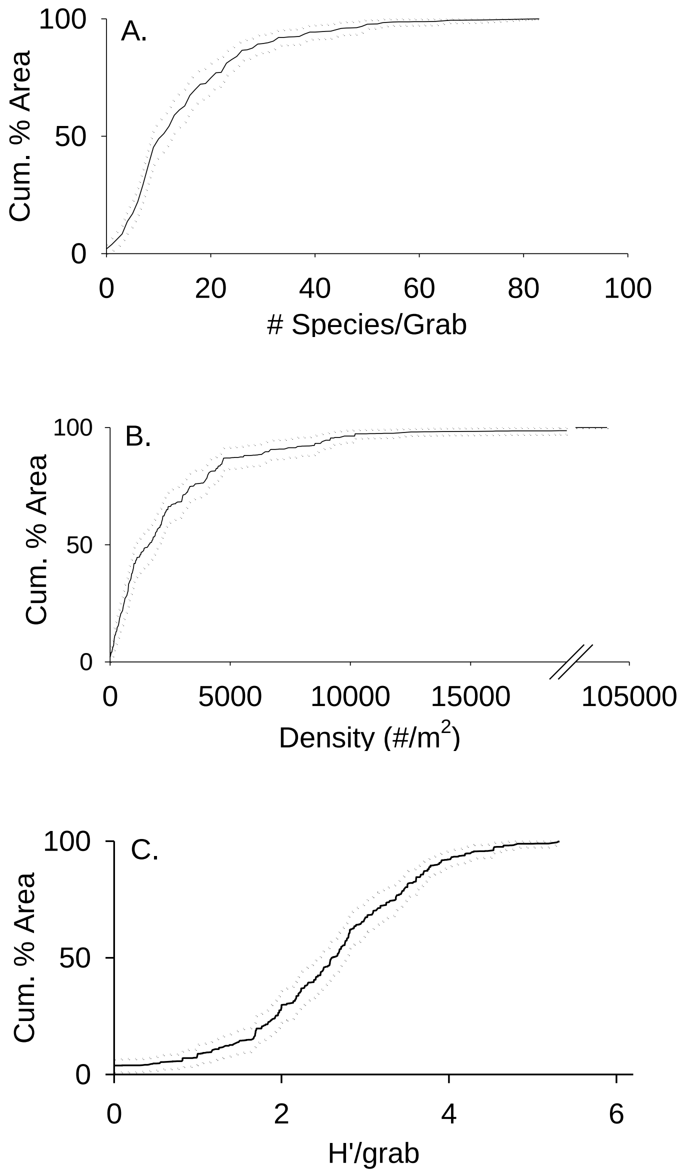

Figure 3.4.3. Percent area (solid lines) and 95% Confidence Intervals (dotted lines) of SAB estuarine benthic infaunal species richness (A), density (B), and H′ diversity (C).

3.4.3 Diversity

Coastal Ocean

Species richness, expressed as the number of taxa present in a 0.04 m^2 grab, was relatively high in the coastal-ocean assemblages. A total of 462 taxa were identified region-wide from the 50 benthic grabs. Species richness ranged from 10 to 114 taxa/grab and averaged 38 taxa $grab^{-1}$ (Table 3.4.3, Figure 3.4.2, Appendix E). Approximately 50% of the offshore survey area had ≥ 34 taxa $grab^{-1}$ and 10% of the area had ≥ 64 taxa $grab^{-1}$.

The high species richness, plus an even distribution of species abundance within stations, resulted in high values of the diversity index H′ (log base 2) for the coastal ocean portion of the SAB. Diversity values ranged from 1.98 to 6.13 $grab^{-1}$ and averaged 4.17 $grab^{-1}$ (Table 3.4.3, Figure 3.4.2, Appendix E). Approximately 50% of the offshore survey area had H′ ≥ 4.07 $grab^{-1}$ and 10% of the area had H′ ≥ 5.43 $grab^{-1}$.

Estuaries

Species richness values for estuarine waters, expressed as the number of taxa present in a 0.04 m^2 grab, were consistent with previous reports of southeastern estuarine benthic assemblages (Hyland et al. 1996, Hyland et al. 1998). A total of 948 taxa were identified region-wide from the 1,039 benthic grabs. Species richness ranged from 0 to 83 taxa $grab^{-1}$ and averaged 16 taxa $grab^{-1}$ (Table 3.4.3, Figure 3.4.3). Approximately 50% of the estuarine survey area had ≥ 11 taxa $grab^{-1}$ and 10% of the area had ≥ 32 taxa $grab^{-1}$.

Values for the diversity index H′ (log base 2) ranged from 0 to 5.32 $grab^{-1}$ and averaged 2.60 $grab^{-1}$ (Table 3.4.3, Figure 3.4.3). Approximately 50% of the estuarine survey area had H′ ≥ 2.60 $grab^{-1}$ and 10% had H′ ≥ 3.86 $grab^{-1}$. These values are very similar to results for estuaries sampled in this same region in the mid-1990s (Hyland et al. 1996; Hyland et al. 1998).

SAB Region-Wide

Diversity of benthic macroinfauna, as measured by species richness and the diversity index H′, was higher in the offshore than in estuarine portions of the region. As an example, species richness averaged 38 taxa $grab^{-1}$ in offshore waters and was less than half that number (16 taxa $grab^{-1}$) in estuaries. Only three of the 50 offshore stations, representing about 10% of the offshore survey area, had ≤ 16 taxa $grab^{-1}$ (the estuarine mean). A more detailed examination of species richness, using quartile ranges, across the SAB shows a general pattern of decreasing species richness with increasing latitude for the coastal ocean portion of the sampling area, though no such pattern was apparent for the estuarine portion of the region (Figure 3.4.4). Also, within the offshore environment, the highest species richness values tend to occur more in the outer shelf areas. When species richness is examined with the offshore and estuarine data combined, it is clear that the highest values occur primarily offshore while the lowest values occur inshore (Figure 3.4.5).

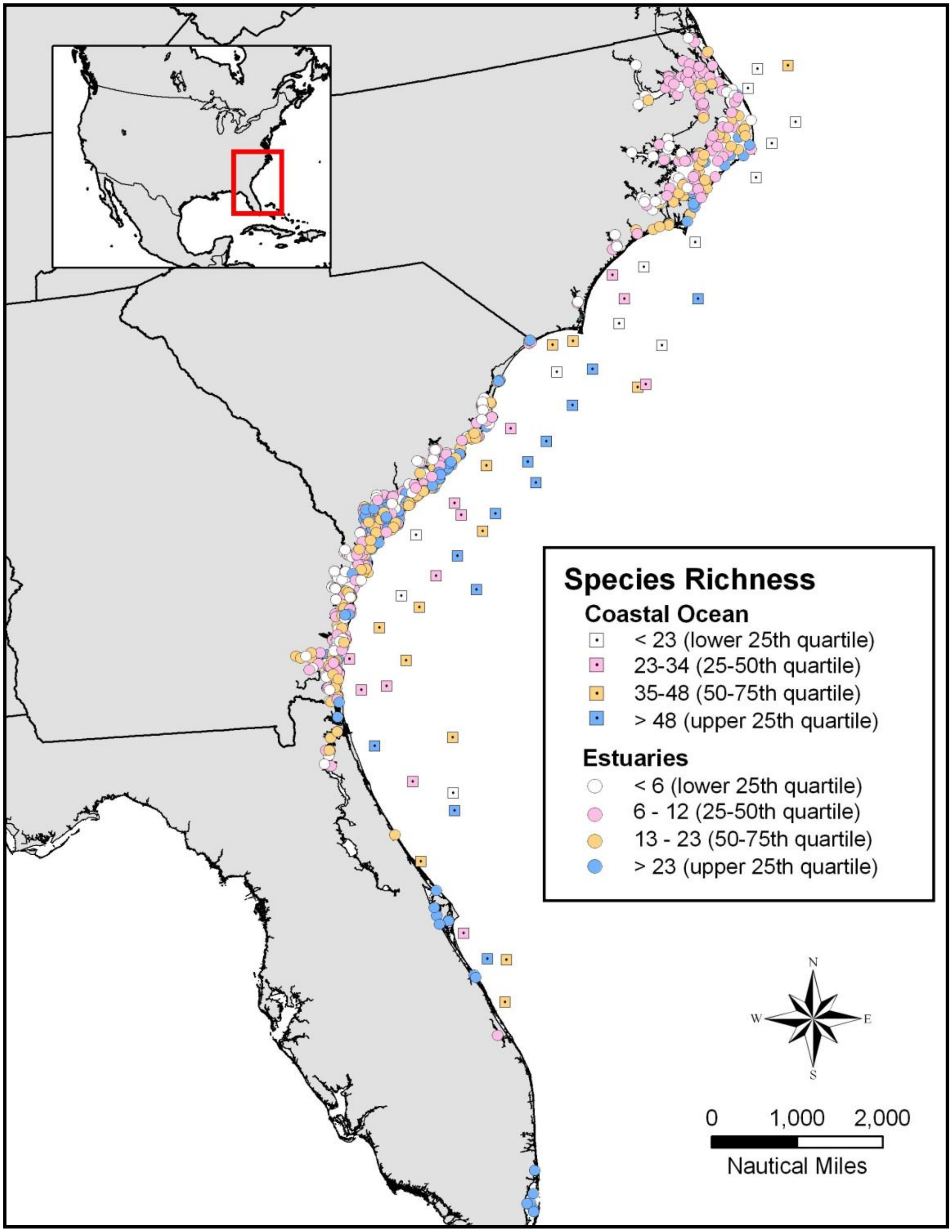

Figure 3.4.4. Spatial distribution of benthic species richness in coastal ocean and estuarine sediments.

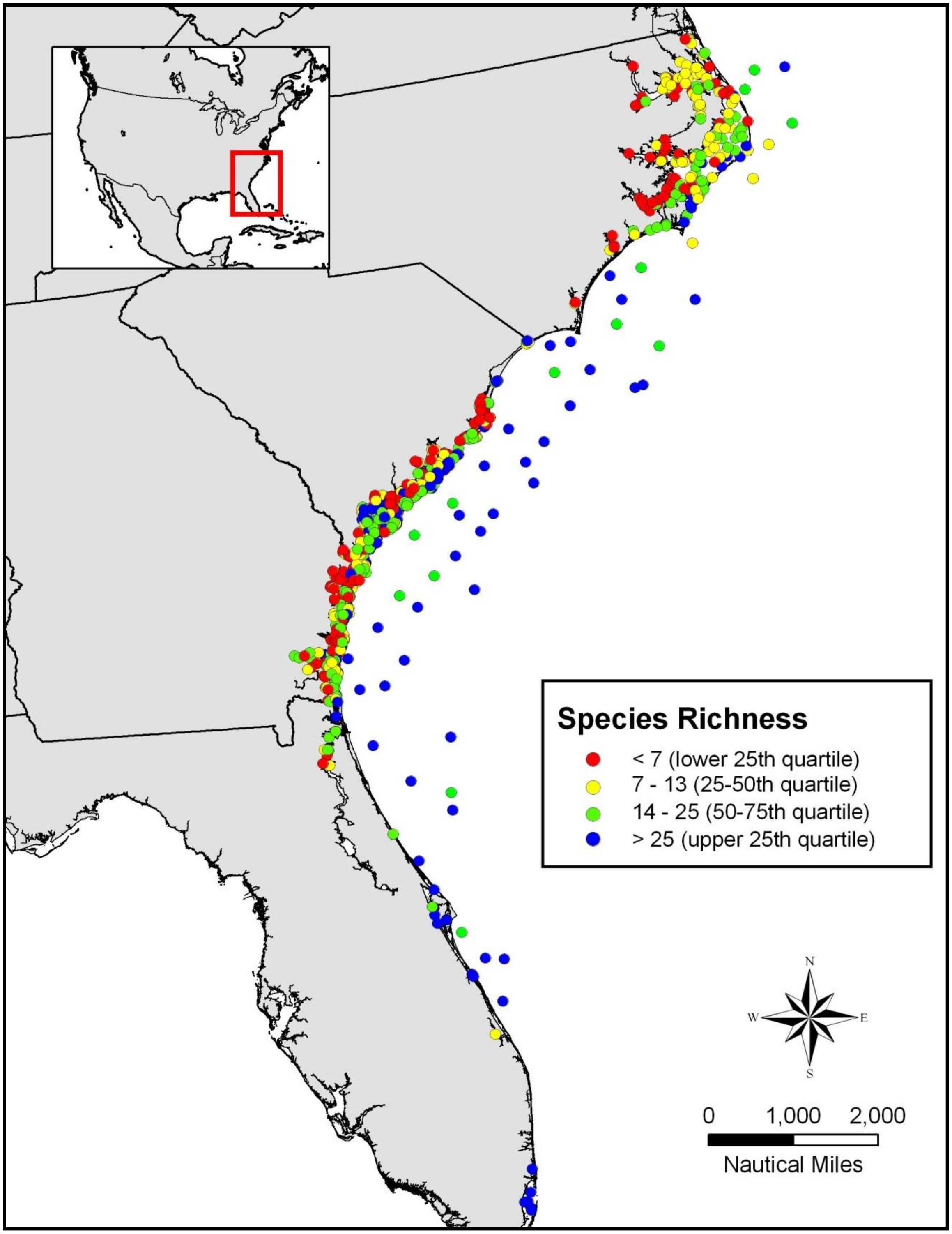

Figure 3.4.5. Spatial distribution of benthic species richness in SAB sediments.

3.4.4 Non-Indigenous Species

The region-wide scale of the current survey, from estuaries seaward to the continental shelf break, provides a unique opportunity to examine the benthic macroinfauna data for the occurrence of non-indigenous species throughout the SAB region. Overall, based on coastal-ocean and estuarine data combined, there were a total of 1,168 taxa identified from 1,139 grabs. Of those 1,168 taxa, 721 were identified to the species level. Of the 721, three species were identified as non-indigenous based on a comparison with the USGS Non-indigenous Aquatic Species database (nas.er.usgs.gov). These were *Corbicula fluminea* (Asian clam), *Petrolisthes armatus* (green porcelain crab), and *Rangia cuneata* (Atlantic rangia). All three non-indigenous species were collected from estuarine stations; none were from coastal-ocean waters. These three non-indigenous species account for < 0.01% of the total species identified in the SAB database. The SAB benthos appears to be less invaded than some other coastal regions such as the Pacific Coast benthos, where non-indigenous species are common in estuaries and occur offshore as well though in more limited numbers (e.g., 1.2% of the identified species in a survey of the western U.S. continental shelf by Nelson et al. 2008).

3.5 Potential Linkage of Biological Condition to Stressor Impacts

Multi-metric benthic indices are an important tool for detecting signals of degraded sediment quality and have been developed for a variety of estuarine applications (Engle et al. 1994, Weisberg et al. 1997, Van Dolah et al. 1999, Llanso et al. 2002a, 2002b). An important feature of a multi-metric benthic index is the ability to combine multiple benthic community attributes (e.g., numbers of species, diversity, abundance, relative proportions of groups of species) into a single measure that maximizes the ability to distinguish between degraded versus non-degraded benthic condition while taking into account biological variability associated with natural controlling factors (e.g. latitude, salinity, sediment particle size). Van Dolah et al. (1999) developed a Benthic-Index of Biological Integrity (B-IBI) for southeastern estuaries, which provides a sensitive tool for assessing adverse effects of degraded habitat quality on benthic communities. Of the estuarine area represented in the present SAB study, 7% was rated poor (≤ 1.5), 9% was rated fair (1.5 – 3.0), and 84% was rated good (≥ 3.0) based on the B-IBI.

No such multi-metric benthic index exists for the coastal-ocean portion of the SAB. In the absence of a benthic index, potential stressor impacts in offshore waters were assessed by looking for obvious linkages between reduced values of key benthic characteristics (diversity, richness, density) and synoptically measured indicators of poor sediment or water quality. To be consistent with related offshore studies where multi-metric benthic indices have been lacking (Nelson et al. 2008, Balthis et al. 2009), low values of benthic attributes were defined as the lower 10^{th} percentile of observed values and evidence of poor sediment or water quality was defined as: ≥ 1 chemical in excess of ERMs, TOC > 50 mg/g, or DO in near-bottom water < 2 mg/L. Because none of the offshore stations were rated as having poor sediment or water quality based on these latter guidelines, there was little evidence to suggest linkages between impaired benthic condition and measured stressors (Appendix E). One site, Station 41 on the outer shelf off North Carolina, had low values of species richness and abundance that co-occurred with a moderate level of sediment TOC (39.9 mg/g). This was the only site that came close to exceeding the above guidelines. The lack of such an association suggests that lower-end values of biological attributes represent parts of a normal reference range controlled by natural factors.

Results of this study show that conditions throughout the SAB are predominantly fair to good with respect to many of the measured ecological indicators (Figure 3.5.1). However, this assessment also indicates that there are portions, particularly in estuaries compared to the offshore environment, which are under some chemical or physical stress. It would be prudent to use such information as an early warning signal and justification for implementing effective coastal management practices in order to prevent potential growth of future environmental risks from increasing human activities in the region. In addition, the SAB region provides many important ecosystem goods and services across a variety of categories: supporting (e.g., nutrient cycling, reservoirs of biodiversity, habitat for protected species and other natural populations), provisional (e.g., mineral extraction, alternative energy, food, corridors for maritime trade), regulating (e.g., pollutant sequestering, hurricane buffering), and cultural (e.g., swimmable and fishable waters for recreation; protected areas for research, education, and nature conservation). As coastal development continues throughout the southeastern region, the component estuarine and coastal-ocean environments should be treated as a connected ecosystem if we are to better understand and manage these important resources and the functions they provide.

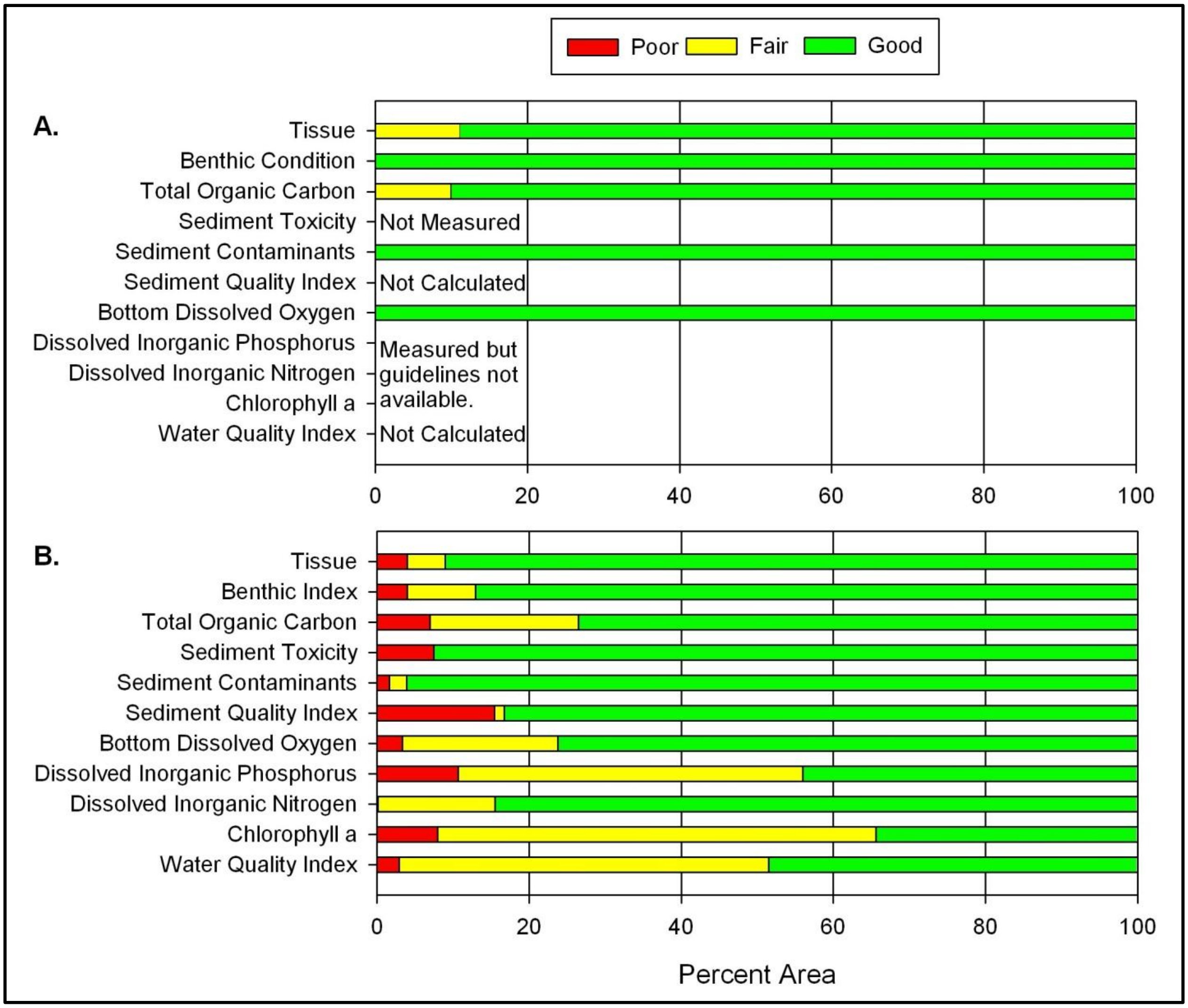

Figure 3.5.1. Summarized assessment of multiple indicators of ecosystem health for SAB coastal ocean region (A = Coastal Ocean, B = Estuarine). Refer to Table 2.7.1 for indicator threshold values. Note: There is no benthic index for offshore waters, thus the evaluation of benthic condition in this case was based on whether there were any co-occurrences of reduced values of key benthic attributes (i.e. diversity, richness, or density within lower 10th percentile of all observed values) and evidence of poor sediment or water quality (≥ 1 chemical in excess of ERMs, TOC > 50 mg/g, and DO in near-bottom water < 2 mg/L); there were no such co-occurrences.

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The estuarine portion of this study involved the participation of numerous representatives from a variety of federal and state agencies including EPA, NOAA, Florida, Georgia, South Carolina and North Carolina. Additional contributions were made by the following organizations:

- Arthur D. Little, Inc. (Boston, MA) - Sediment and Tissue Contaminants
- Barry A. Vittor & Associates, Inc (Mobile, AL) - Benthic Taxonomy
- CRG Environmental Laboratories Inc (Torrance, CA) - Sediment and Tissue Contaminants
- Environmental Research Institute (Storrs, CT) - Sediment and Tissue Contaminants, Nutrients, Total Suspended Solids, Sediment Grain Size, and Sediment Total Organic Carbon
- GPL Laboratories (Frederick, MD) - Sediment and Tissue Contaminants
- TAI Scientist - Division of Strand and Associates, Inc (Mobile, AL) -Benthic Taxonomy
- TDI-Brooks Laboratories (College Station, TX) - Nutrients, Total Suspended Solids, Sediment Grain Size, and Sediment Total Organic Carbon
- TRAC Laboratories (Pensacola, FL) - Amphipod Sediment Toxicity Assay

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Appendix A. Locations (latitude, longitude), depths, sampling frame areas, and sediment characteristics of SAB coastal ocean sampling stations.

Station	Latitude (DD)	Longitude (DD)	Depth (m)	Sampling Frame Area (km^2)	TOC (mg/g)	% Coarse (sand/gravel)	% silt-clay
SE04001	31.36625	-80.87812	20	57.26	0.78	98.75	1.25
SE04002	32.27212	-79.34330	41	110883.70	0.50	99.06	0.94
SE04003	33.06317	-78.99763	14	110883.70	0.30	99.51	0.49
SE04004	27.95232	-80.07897	40	110883.70	2.65	93.46	6.54
SE04005	31.63705	-80.57387	20	110883.70	0.13	99.10	0.90
SE04006	30.23263	-81.14682	21	110883.70	0.09	99.29	0.71
SE04007	31.57760	-79.71103	60	110883.70	0.39	98.38	1.62
SE04008	27.54257	-80.17257	18	110883.70	29.56	98.74	1.26
SE04009	33.52407	-78.34247	23	110883.70	0.37	98.90	1.10
SE04010	31.00938	-80.64163	25	110883.70	0.01	99.43	0.57
SE04011	32.19853	-80.29453	16	110883.70	0.30	99.16	0.84
SE04012	31.50058	-80.38985	29	110883.70	0.20	98.91	1.09
SE04013	33.87035	-77.51060	28	110883.70	0.20	99.13	0.87
SE04014	31.92925	-79.86140	35	110883.70	0.05	99.20	0.80
SE04015	32.12618	-79.52537	41	110883.70	0.09	99.07	0.93
SE04016	34.49895	-76.43633	13	110883.70	0.17	99.24	0.76
SE04017	29.04322	-80.83685	21	110883.70	3.00	92.33	7.67
SE04018	36.01737	-75.26730	33	110883.70	0.01	99.17	0.83
SE04019	29.82830	-80.78468	27	110883.70	0.49	99.17	0.83
SE04020	30.19302	-80.25955	53	110883.70	1.86	99.16	0.84
SE04021	33.95535	-76.53930	42	110883.70	0.88	99.24	0.76
SE04022	29.65300	-80.36010	43	110883.70	2.98	98.91	1.09
SE04023	33.22947	-77.44340	45	110883.70	0.54	98.97	1.03
SE04024	34.09792	-77.39780	26	110883.70	0.80	99.56	0.44
SE04025	33.78810	-78.08550	15	110883.70	3.98	90.97	9.03
SE04026	30.79113	-80.90655	25	110883.70	0.27	99.23	0.77
SE04027	34.36198	-77.09250	23	110883.70	0.76	98.72	1.28
SE04028	34.34528	-77.47862	16	110883.70	0.58	99.16	0.84
SE04029	28.27788	-80.49652	16	110883.70	3.31	88.53	11.47
SE04030	32.87658	-78.61013	43	110883.70	1.08	97.77	2.23
SE04031	30.79103	-81.19778	15	110883.70	0.20	99.16	0.84
SE04032	32.74693	-79.35072	19	110883.70	0.28	99.27	0.73
SE04033	31.77548	-80.14060	30	110883.70	0.24	98.93	1.07
SE04034	33.17650	-78.23268	33	110883.70	1.32	99.05	0.95
SE04035	35.85053	-75.42660	24	110883.70	0.30	98.73	1.27
SE04036	33.23763	-77.34313	47	110883.70	0.34	99.27	0.73
SE04037	35.98105	-74.89810	83	110883.70	4.74	99.09	0.91
SE04038	32.44360	-79.79097	16	110883.70	0.32	99.28	0.72
SE04039	34.98853	-75.56278	37	110883.70	0.18	92.04	7.96
SE04040	35.43008	-74.95900	41	110883.70	1.10	98.14	1.86
SE04041	33.58008	-77.06697	40	110883.70	39.94	99.01	0.99
SE04042	32.49767	-78.81927	50	110883.70	16.40	96.24	3.76
SE04043	33.78847	-78.33452	16	110883.70	2.16	94.28	5.72
SE04044	32.71425	-78.86517	33	110883.70	1.07	98.79	1.21
SE04045	29.48200	-80.37595	40	110883.70	26.48	98.56	1.44
SE04046	32.31815	-79.73765	25	110883.70	0.34	99.09	0.91
SE04047	31.10745	-81.27568	10	110883.70	0.37	98.91	1.09
SE04048	35.27827	-75.29312	23	110883.70	0.04	98.71	1.29
SE04050	33.48602	-77.92563	28	110883.70	0.75	98.53	1.47
SE04A11	27.99100	-80.28477	22	110883.70	17.28	98.48	1.52

Appendix B. Near-bottom water characteristics by SAB coastal ocean station.

Station	Temp. (°C)	Salinity (psu)	DO (mg/L)	pH	DIN (mg/L)	Nitrite (mg/L)	Nitrate (mg/L)	Ammonia (mg/L)	DIP (mg/L)	N/P	Silicate (mg/L)	Chlorophyll *a* (µg/L)	TSS (mg/L)
SE04001	16.9	34.4	7.9	8.5	0.013	0.003	0.01	0	0.02	2.5	0.28	0.37	4.90
SE04002	18.6	36.4	7.5	8.4	0.032	0.012	0.01	0.01	0.02	3.2	0.39	0.30	2.20
SE04003	13.9	34.7	8.3	8.2	0.012	0.002	0.01	0	0.02	2.8	0.5	0.49	3.47
SE04004	20.2	36.4	7.3	8.4	0.226	0.016	0.2	0.01	0.05	8.5	0.88	0.35	1.54
SE04005	16.6	35.1	7.9	8.5	0.032	0.002	0.02	0.01	0.02	3.9	0.66	0.20	1.77
SE04006	18.2	35.2	7.6	8.5	0.033	0.003	0.02	0.01	0.02	5.6	0.53	0.64	2.87
SE04007	18.5	36.0	7.5	8.4	0.046	0.006	0.03	0.01	0.03	5.0	0.91	0.22	1.89
SE04008	23.7	36.4	6.9	8.5	0.043	0.013	0.02	0.01	0.02	4.9	1.12	0.15	0.86
SE04009	14.3	35.9	8.2	8.3	0.022	0.002	0.02	0	0.01	3.4	1.23	0.59	5.60
SE04010	19.5	36.0	7.4	8.5	0.04	0.02	0.01	0.01	0.02	4.2	0.23	0.24	1.81
SE04011	15.7	35.5	8.0	8.4	0.025	0.005	0.02	0	0.02	3.3	0.85	0.23	1.87
SE04012	16.9	35.2	7.8	8.5	0.022	0.002	0.02	0	0.02	2.1	0.26	0.31	2.03
SE04013	16.2	36.4	7.9	8.3	0.012	0.002	0.01	0	0.03	1.1	0.27	0.50	5.31
SE04014	18.2	36.3	7.6	8.4	0.032	0.002	0.02	0.01	0.02	3.2	0.36	0.28	2.58
SE04015	19.3	36.4	7.4	8.4	0.034	0.004	0.02	0.01	0.02	3.0	0.56	0.27	1.51
SE04016	13.4	33.4	8.5	8.3	0.012	0.002	0.01	0	0.02	2.5	0.58	1.81	7.37
SE04017	19.8	35.8	7.4	8.4	0.034	0.004	0.02	0.01	0.03	2.9	0.55	1.37	4.46
SE04018	7.2	33.6	9.7	8.2	0.032	0.002	0.01	0.02	0.04	3.1	0.35	0.57	1.85
SE04019	20.0	36.2	7.3	8.5	0.032	0.002	0.02	0.01	0.02	4.0	0.32	0.36	1.89
SE04020	20.8	36.4	7.2	8.4	0.162	0.012	0.14	0.01	0.04	7.2	0.91	0.77	0.93
SE04021	22.8	36.3	7.0	8.4	0.034	0.004	0.02	0.01	0.02	4.4	0.54	0.37	1.85
SE04022	21.0	36.3	7.2	8.5	0.099	0.019	0.07	0.01	0.03	5.4	0.73	0.67	2.10
SE04023	20.7	36.4	7.2	8.4	0.035	0.005	0.03	0	0.02	3.5	0.48	0.45	2.40
SE04024	15.4	36.1	8.0	8.3	0.021	0.001	0.02	0	0.02	3.4	0.27	0.30	1.50
SE04025	13.9	35.0	8.3	8.2	0.033	0.003	0.02	0.01	0.02	6.2	0.51	2.41	7.50
SE04026	18.7	35.4	7.5	8.5	0.022	0.002	0.02	0	0.02	2.9	0.14	0.31	1.20
SE04027	14.6	35.4	8.2	8.3	0.021	0.001	0.01	0.01	0.02	3.4	0.3	0.84	4.90
SE04028	13.2	34.7	8.4	8.2	0.02	0	0.02	0	0.02	3.8	0.13	0.33	2.30
SE04029	21.4	36.5	7.1	8.5	0.029	0.009	0.01	0.01	0.02	3.2	1.05	1.09	4.30
SE04030	19.4	36.5	7.4	8.4	0.024	0.004	0.02	0	0.02	3.2	0.46	0.44	1.73
SE04031	17.6	34.8	7.7	8.5	0.032	0.002	0.02	0.01	0.02	3.9	0.34	0.63	6.83
SE04032	17.2	36.1	7.7	8.3	0.02	0	0.02	0	0.02	2.9	0.2	0.31	4.00
SE04033	17.4	36.2	7.7	8.6	0.035	0.005	0.02	0.01	0.02	4.1	0.27	0.38	1.23
SE04034	19.0	36.5	7.5	8.4	0.032	0.002	0.02	0.01	0.02	3.1	0.43	0.35	3.29
SE04035	7.4	33.0	9.7	8.2	0.033	0.003	0.02	0.01	0.03	1.6	0.43	1.26	25.00

Station	Temp. (°C)	Salinity (psu)	DO (mg/L)	pH	DIN (mg/L)	Nitrite (mg/L)	Nitrate (mg/L)	Ammonia (mg/L)	DIP (mg/L)	N/P	Silicate (mg/L)	Chlorophyll *a* (µg/L)	TSS (mg/L)
SE04036	20.5	36.4	7.3	8.3	0.099	0.009	0.08	0.01	0.03	6.1	0.52	0.24	1.43
SE04037	6.4	33.7	9.9	8.2	0.269	0.009	0.25	0.01	0.08	6.0	0.48	0.40	1.90
SE04038	16.7	36.2	7.8	8.4	0.032	0.002	0.02	0.01	0.02	4.0	0.45	0.19	0.27
SE04039	18.6	35.4	7.6	8.3	0.034	0.004	0.02	0.01	0.02	3.8	0.46	0.64	2.80
SE04040	7.7	33.7	9.6	8.3	0.05	0.03	0	0.02	0.04	3.8	0.24	0.85	1.20
SE04041	21.6	36.4	7.1	8.3	0.051	0.021	0.02	0.01	0.02	4.8	0.21	0.39	1.60
SE04042	20.0	36.4	7.3	8.4	0.036	0.016	0.01	0.01	0.02	5.0	0.25	0.48	1.43
SE04043	13.5	35.2	8.4	8.2	0.03	0.01	0.01	0.01	0.01	5.7	0.15	0.98	3.07
SE04044	19.3	36.5	7.4	8.4	0.031	0.001	0.02	0.01	0.02	5.2	0.23	0.28	3.18
SE04045	21.3	36.4	7.1	8.5	0.061	0.021	0.03	0.01	0.02	6.1	0.33	1.06	2.36
SE04046	17.6	36.3	7.7	8.4	0.03	0	0.02	0.01	0.01	5.4	0.18	0.25	1.91
SE04047	17.6	33.3	7.8	8.4	0.028	0.008	0.01	0.01	0.03	3.3	0.55	1.68	4.00
SE04048	7.8	32.9	9.6	8.2	0.041	0.001	0.02	0.02	0.03	3.9	0.51	2.83	6.20
SE04050	14.0	35.9	8.2	8.3	0.03	0	0.02	0.01	0.03	2.9	0.31	0.76	3.90
SE04A11	22.6	36.4	7.0	8.5	0.033	0.003	0.02	0.01	0.02	3.2	1.17	2.39	2.90

Appendix C. Near-surface water characteristics by SAB coastal ocean station.

Station	Temp. (°C)	Salinity (psu)	DO (mg/L)	pH	DIN (mg/L)	Nitrite (mg/L)	Nitrate (mg/L)	Ammonia (mg/L)	DIP (mg/L)	N/P	Silicate (mg/L)	Chlorophyll *a* (µg/L)	TSS (mg/L)
SE04001	18.3	33.7	7.7	8.5	0.027	0.007	0.02	0	0.02	3.0	0.78	0.20	3.00
SE04002	19.0	36.3	7.5	8.4	0.031	0.011	0.01	0.01	0.04	1.7	0.37	0.22	1.35
SE04003	14.0	34.6	8.3	6.7	0.033	0.003	0.02	0.01	0.02	5.2	0.42	0.28	3.93
SE04004	23.3	36.4	6.9	8.5	0.033	0.013	0.01	0.01	0.02	4.3	0.59	0.23	2.50
SE04005	17.3	35.3	7.8	8.6	0.032	0.002	0.02	0.01	0.02	4.4	0.89	0.14	2.14
SE04006	19.5	34.8	7.5	8.5	0.033	0.003	0.02	0.01	0.02	3.9	1.23	0.39	3.20
SE04007	24.3	36.3	6.8	8.4	0.039	0.009	0.02	0.01	0.03	4.0	0.68	0.09	2.13
SE04008	23.7	36.3	6.9	8.2	0.039	0.019	0.01	0.01	0.02	4.9	0.99	0.14	1.25
SE04009	14.4	35.8	8.2	7.4	0.052	0.002	0.03	0.02	0.02	9.0	1.12	0.22	3.53
SE04010	19.3	35.8	7.4	8.5	0.037	0.007	0.02	0.01	0.02	3.7	0.41	0.17	2.12
SE04011	15.9	35.5	8.0	8.4	0.036	0.006	0.02	0.01	0.03	3.5	1	0.26	3.16
SE04012	17.3	35.1	7.8	8.5	0.012	0.002	0.01	0	0.01	2.9	0.76	0.25	3.61
SE04013	18.6	36.3	7.5	8.2	0.023	0.003	0.02	0	0.03	2.2	0.5	0.15	1.75
SE04014	18.4	36.5	7.5	8.4	0.026	0.006	0.02	0	0.03	2.8	0.53	0.16	2.17
SE04015	19.5	36.4	7.4	8.4	0.038	0.008	0.02	0.01	0.04	1.9	0.64	0.26	4.35
SE04016	13.4	33.3	8.5	7.2	0.033	0.003	0.02	0.01	0.03	2.4	0.49	1.58	4.78
SE04017	20.0	35.8	7.4	8.4	0.033	0.003	0.02	0.01	0.02	3.1	1.06	1.07	5.04
SE04018	7.7	33.3	9.6	8.0	0.036	0.006	0.02	0.01	0.04	2.1	0.32	0.41	2.35
SE04019	20.7	36.0	7.2	8.4	0.034	0.004	0.02	0.01	0.02	4.8	0.84	0.23	1.38
SE04020	22.7	36.3	7.0	8.4	0.044	0.004	0.03	0.01	0.03	3.8	0.36	0.25	1.40
SE04021	23.6	35.8	6.9	8.3	0.033	0.003	0.03	0	0.02	3.1	0.48	0.19	1.50
SE04022	23.7	36.3	6.9	8.5	0.023	0.003	0.02	0	0.02	2.6	0.6	0.17	4.14
SE04023	20.8	35.8	7.2	8.0	0.044	0.004	0.03	0.01	0.02	3.6	0.71	0.48	4.08
SE04024	16.0	36.3	7.9	8.2	0.022	0.002	0.02	0	0.02	2.1	0.94	0.19	3.75
SE04025	14.0	33.6	8.4	7.8	0.032	0.002	0.02	0.01	0.02	4.3	0.32	1.44	9.20
SE04026	19.0	35.2	7.5	8.5	0.031	0.001	0.02	0.01	0.02	5.1	0.17	0.17	1.42
SE04027	14.9	35.5	8.1	8.3	0.032	0.002	0.02	0.01	0.02	4.2	0.28	0.20	3.15
SE04028	13.6	34.5	8.4	8.2	0.032	0.002	0.02	0.01	0.02	2.9	0.62	0.14	1.43
SE04029	21.6	36.5	7.1	8.4	0.033	0.003	0.02	0.01	0.02	4.3	0.73	0.60	6.20
SE04030	19.4	36.4	7.4	8.3	0.023	0.003	0.02	0	0.1	0.6	0.79	0.24	3.10
SE04031	18.8	34.2	7.6	8.5	0.024	0.004	0.02	0	0.02	3.8	0.52	0.41	2.95
SE04032	17.2	36.1	7.7	7.3	0.032	0.002	0.02	0.01	0.02	4.0	0.33	0.30	15.93
SE04033	18.6	36.2	7.5	8.6	0.04	0.01	0.02	0.01	0.02	4.9	0.26	0.23	2.54
SE04034	19.4	36.4	7.4	8.3	0.046	0.006	0.03	0.01	0.02	4.8	0.71	0.26	1.77
SE04035	8.5	31.4	9.6	8.2	0.047	0.007	0.03	0.01	0.03	3.9	0.64	1.36	6.46

Station	Temp. (°C)	Salinity (psu)	DO (mg/L)	pH	DIN (mg/L)	Nitrite (mg/L)	Nitrate (mg/L)	Ammonia (mg/L)	DIP (mg/L)	N/P	Silicate (mg/L)	Chlorophyll *a* (µg/L)	TSS (mg/L)
SE04036	21.5	35.7	7.2	8.1	0.045	0.005	0.03	0.01	0.02	3.9	0.64	0.29	5.68
SE04037	6.7	33.7	9.8	8.1	0.232	0.012	0.21	0.01	0.07	5.4	0.42	0.65	3.95
SE04038	16.6	36.1	7.8	8.4	0.063	0.003	0.04	0.02	0.03	5.6	0.39	0.17	4.83
SE04039	18.6	35.3	7.6	8.2	0.036	0.006	0.02	0.01	0.02	4.6	0.45	0.53	2.80
SE04040	8.0	32.8	9.6	7.5	0.036	0.006	0.02	0.01	0.03	2.5	0.21	0.62	4.35
SE04041	22.0	36.1	7.1	8.4	0.043	0.023	0.01	0.01	0.02	4.8	0.24	0.36	4.35
SE04042	20.4	36.4	7.3	8.3	0.026	0.016	0	0.01	0.06	1.4	0.19	0.55	1.77
SE04043	13.6	34.9	8.4	7.8	0.022	0.012	0	0.01	0.02	3.3	0.33	0.50	3.80
SE04044	19.3	36.4	7.4	8.4	0.03	0	0.02	0.01	0.11	0.5	0.44	0.32	5.17
SE04045	21.7	36.6	7.1	8.2	0.032	0.002	0.02	0.01	0.02	3.0	0.41	0.21	2.55
SE04046	17.5	36.3	7.7	8.4	0.011	0.001	0.01	0	0.02	2.6	0.43	0.23	0.97
SE04047	18.1	33.2	7.7	8.4	0.038	0.008	0.02	0.01	0.02	3.8	0.58	1.36	3.85
SE04048	8.7	31.2	9.5	5.8	0.041	0.001	0.03	0.01	0.02	5.1	0.38	2.02	7.00
SE04050	14.1	35.5	8.3	7.7	0.031	0.001	0.02	0.01	0.02	5.5	0.53	0.36	6.95
SE04A11	23.3	36.4	6.9	8.5	0.04	0.01	0.02	0.01	0.02	5.4	1.37	0.76	1.40

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. 1995) for coastal ocean stations.

Station	# of ERLs Exceeded	# of ERMs Exceeded	Mean ERM-Q
SE04001	0	0	0.006
SE04002	0	0	0.006
SE04003	0	0	0.004
SE04004	0	0	0.007
SE04005	0	0	0.004
SE04006	0	0	0.003
SE04007	0	0	0.005
SE04008	1	0	0.007
SE04009	0	0	0.004
SE04010	0	0	0.003
SE04011	0	0	0.004
SE04012	0	0	0.004
SE04013	0	0	0.008
SE04014	0	0	0.003
SE04015	0	0	0.004
SE04016	1	0	0.013
SE04017	0	0	0.007
SE04018	0	0	0.004
SE04019	0	0	0.003
SE04020	0	0	0.006
SE04021	0	0	0.008
SE04022	0	0	0.006
SE04023	1	0	0.028
SE04024	1	0	0.012
SE04025	0	0	0.012
SE04026	0	0	0.007
SE04027	0	0	0.007
SE04028	0	0	0.008
SE04029	0	0	0.012
SE04030	1	0	0.011
SE04031	0	0	0.003
SE04032	0	0	0.007
SE04033	0	0	0.005
SE04034	0	0	0.006
SE04035	0	0	0.006
SE04036	0	0	0.008
SE04037	0	0	0.019
SE04038	0	0	0.005
SE04039	0	0	0.008
SE04040	0	0	0.010
SE04041	1	0	0.014
SE04042	0	0	0.008
SE04043	0	0	0.010
SE04044	0	0	0.007
SE04045	0	0	0.006
SE04046	0	0	0.004
SE04047	0	0	0.007
SE04048	1	0	0.019
SE04050	1	0	0.012
SE04A11	1	0	0.015

Appendix E. Summary by station of benthic macroinfaunal (> 0.5 mm) characteristics for coastal-ocean stations. One replicate benthic grab (0.04 m^2) processed from each station. H′ derived using base 2 logs. * Values within lower 25th percentile of all values of a specific benthic variable; **values within lower 10th percentile. Also included are selected abiotic variables for assessing potential benthic-stressor linkages. Table shows that no stations with at least one benthic variable in lower 10th percentile coincided with indicators of poor sediment or water quality: ≥ 1 chemical in excess of ERMs, TOC > 50 mg/g, or DO in near-bottom water < 2 mg/L.

Station	# Taxa per Grab	Density (#/m^2)	H′ per Grab	TOC (mg/g)	DO (mg/L)	# ERMs exceeded
SE04001	35	1700	4.56	0.78	7.9	0
SE04002	64	3725	5.26	0.50	7.5	0
SE04003	32	3100	4.07	0.30	8.3	0
SE04004	41	5150	3.80	2.65	7.3	0
SE04005	19*	1475	2.88**	0.13	7.9	0
SE04006	63	5700	5.10	0.09	7.6	0
SE04007	52	2575	5.22	0.39	7.5	0
SE04008	40	3225	4.58	29.56	6.9	0
SE04009	20*	1150*	3.34*	0.37	8.2	0
SE04010	39	2850	4.69	0.01	7.4	0
SE04011	18*	625**	4.00	0.30	8.0	0
SE04012	39	2325	4.60	0.20	7.8	0
SE04013	22*	650**	4.39	0.20	7.9	0
SE04014	73	4925	5.57	0.05	7.6	0
SE04015	38	1775	4.84	0.09	7.4	0
SE04016	10**	275**	3.28*	0.17	8.5	0
SE04017	35	3175	3.84	3.00	7.4	0
SE04018	18*	1425	3.46*	0.01	9.7	0
SE04019	32	1175*	4.79	0.49	7.3	0
SE04020	37	2400	3.88	1.86	7.2	0
SE04021	59	3800	4.86	0.88	7.0	0
SE04022	20*	1250*	3.29*	2.98	7.2	0
SE04023	44	1875	5.18	0.54	7.2	0
SE04024	29	1325*	4.52	0.80	8.0	0
SE04025	37	3450	3.97	3.98	8.3	0
SE04026	31	3075	2.96*	0.27	7.5	0
SE04027	15**	500**	3.72	0.76	8.2	0
SE04028	26	2325	3.70	0.58	8.4	0
SE04029	25	1150*	4.47	3.31	7.1	0
SE04030	114	8400	6.13	1.08	7.4	0
SE04031	27	1400*	4.39	0.20	7.7	0
SE04032	43	4250	3.29*	0.28	7.7	0
SE04033	24	1625	3.97	0.24	7.7	0
SE04034	91	7900	5.64	1.32	7.5	0
SE04035	19*	2525	2.55**	0.30	9.7	0
SE04036	31	1775	4.21	0.34	7.3	0
SE04037	48	23650	1.99**	4.74	9.9	0
SE04038	23	2250	3.50*	0.32	7.8	0
SE04039	11**	650**	3.14*	0.18	7.6	0
SE04040	17*	1900	2.59**	1.10	9.6	0
SE04041	14**	375**	3.77	39.94	7.1	0
SE04042	75	4450	5.69	16.40	7.3	0
SE04043	35	3000	3.97	2.16	8.4	0

Station	# Taxa per Grab	Density (#/m^2)	H′ per Grab	TOC (mg/g)	DO (mg/L)	# ERMs exceeded
SE04044	70	3850	5.63	1.07	7.4	0
SE04045	52	2525	5.43	26.48	7.1	0
SE04046	27	1150*	4.16	0.34	7.7	0
SE04047	34	3150	3.72	0.37	7.8	0
SE04048	12**	1700	2.21**	0.04	9.6	0
SE04050	62	6450	5.07	0.75	8.2	0
SE04A11	50	4775	4.65	17.28	7.0	0

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