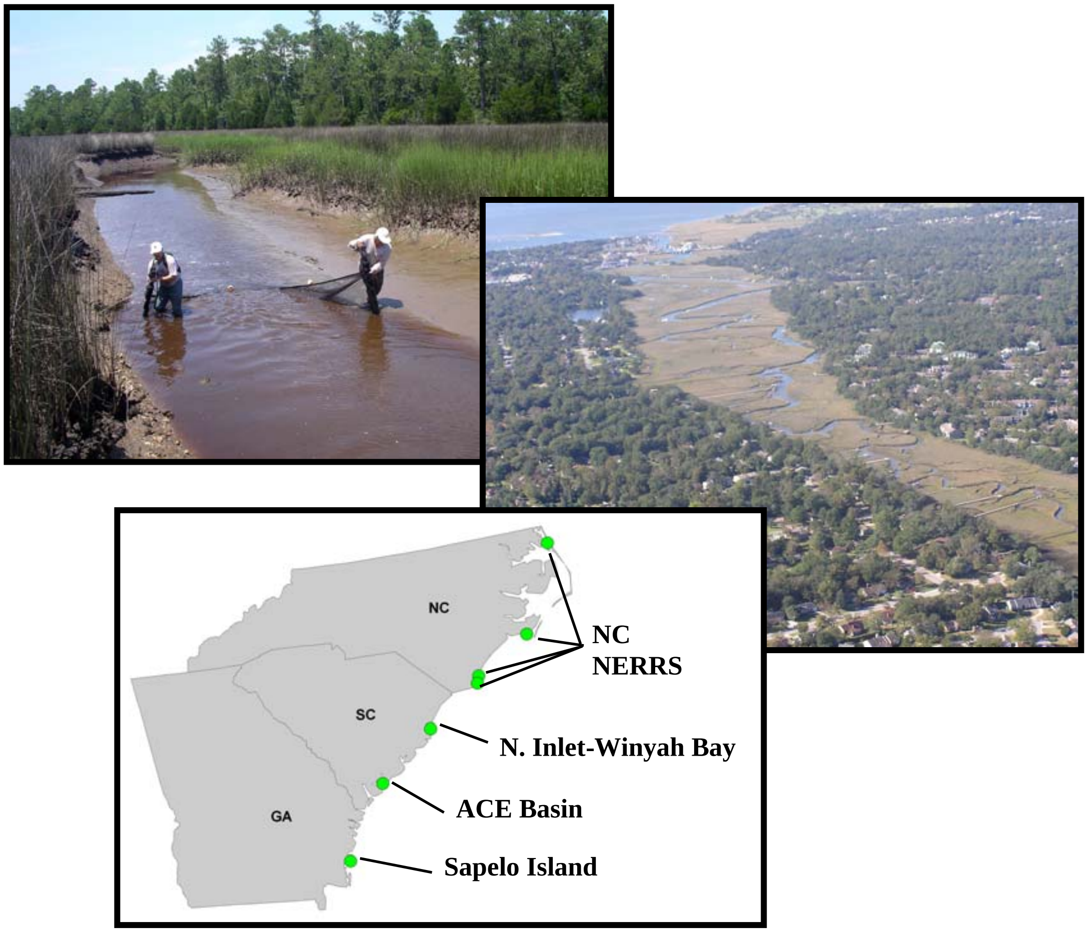
Support for Integrated Ecosystem Assessments of NOAA's National Estuarine Research Reserves System (NERRS), Volume II:

Assessment of Ecological Condition and Stressor Impacts in Subtidal Waters of the North Carolina NERRS



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Support for Integrated Ecosystem Assessments of NOAA's National Estuarine Research Reserves System (NERRS), Volume II:

Assessment of Ecological Condition and Stressor Impacts in Subtidal Waters of the North Carolina NERRS

Cynthia Cooksey[a], Jeff Hyland[a], Ed Wirth[a], W. Leonard Balthis[a], Mike Fulton[a], David Whitall[b], and Susan White[c]

[a]NOAA, Center for Coastal Environmental Health and Biomolecular Research, 219 Fort Johnson Road, Charleston, S C, 29412-9110, USA

[b]NOAA, Center for Coastal Monitoring and Assessment, 1305 East-West Highway, Silver Spring, MD, 20910, USA

[c]NOAA, Center for Human Health Risk, Hollings Marine Laboratory, 219 Fort Johnson Road, Charleston, SC, 29412-9110, USA

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Carlos M. Gutierrez Secretary	Conrad C. Lautenbacher, Jr. Administrator	John (Jack) H. Dunnigan Assistant

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Abstract

A study was conducted to assess the status of ecological condition and potential human-health risks in subtidal estuarine waters throughout the North Carolina National Estuarine Research Reserve System (NERRS) (Currituck Sound, Rachel Carson, Masonboro Island, and Zeke's Island). Field work was conducted in September 2006 and incorporated multiple indicators of ecosystem condition including measures of water quality (dissolved oxygen, salinity, temperature, pH, nutrients and chlorophyll, suspended solids), sediment quality (granulometry, organic matter content, chemical contaminant concentrations), biological condition (diversity and abundances of benthic fauna, fish contaminant levels and pathologies), and human dimensions (fish-tissue contaminant levels relative to human-health consumption limits, various aesthetic properties). A probabilistic sampling design permitted statistical estimation of the spatial extent of degraded versus non-degraded condition across these estuaries relative to specified threshold levels of the various indicators (where possible). With some exceptions, the status of these reserves appeared to be in relatively good to fair ecological condition overall, with the majority of the area (about 54%) having various water quality, sediment quality, and biological (benthic) condition indicators rated in the healthy to intermediate range of corresponding guideline thresholds. Only three stations, representing 10.5% of the area, had one or more of these indicators rated as poor/degraded in all three categories. While such a conclusion is encouraging from a coastal management perspective, it should be viewed with some caution. For example, although co-occurrences of adverse biological and abiotic environmental conditions were limited, at least one indicator of ecological condition rated in the poor/degraded range was observed over a broader area (35.5%) represented by 11 of the 30 stations sampled. In addition, the fish-tissue contaminant data were not included in these overall spatial estimates; however, the majority of samples (77% of fish that were analyzed, from 79%, of stations where fish were caught) contained inorganic arsenic above the consumption limits for human cancer risks, though most likely derived from natural sources. Similarly, aesthetic indicators are not reflected in these spatial estimates of ecological condition, though there was evidence of noxious odors in sediments at many of the stations. Such symptoms reflect a growing realization that North Carolina estuaries are under multiple pressures from a variety of natural and human influences. These data also suggest that, while the current status of overall ecological condition appears to be good to fair, long-term monitoring is warranted to track potential changes in the future. This study establishes an important baseline of overall ecological condition within NC NERRS that can be used to evaluate any such future changes and to trigger appropriate management actions in this rapidly evolving coastal environment.

Key Words: North Carolina NERRS, southeastern estuaries, ecological condition, benthic communities, sediment and tissue contaminants, Integrated Ecosystem Assessments

1. Introduction

Under the FY05-09 Strategic Plan of NOAA's National Centers for Coastal Ocean Science (NCCOS 2004), NCCOS is prompted to produce baseline assessments of ecological resources and to quantify impacts of ecosystem stressors in various NOAA protected areas, including National Estuarine Research Reserve System (NERRS) locations. The NERRS is an especially important network of NOAA protected areas characterized by diverse habitats and living resources, multiple human uses, and resultant high ecological and societal value. An integrated system-wide approach for monitoring and assessing ecological condition of NERRS resources and potential threats from multiple stressors currently does not exist (except for some water-quality parameters). The purpose of the present effort was to work in partnership with the NERRS program to assess current status of ecological condition and human-health risks throughout NERRS, beginning with GA and NC reserves, and to provide this information as a framework for forecasting future changes due to natural or human-induced disturbances. This work also is intended to complement system-wide water-quality monitoring (SWMP) and other site-specific research activities currently underway in the NERRS program.

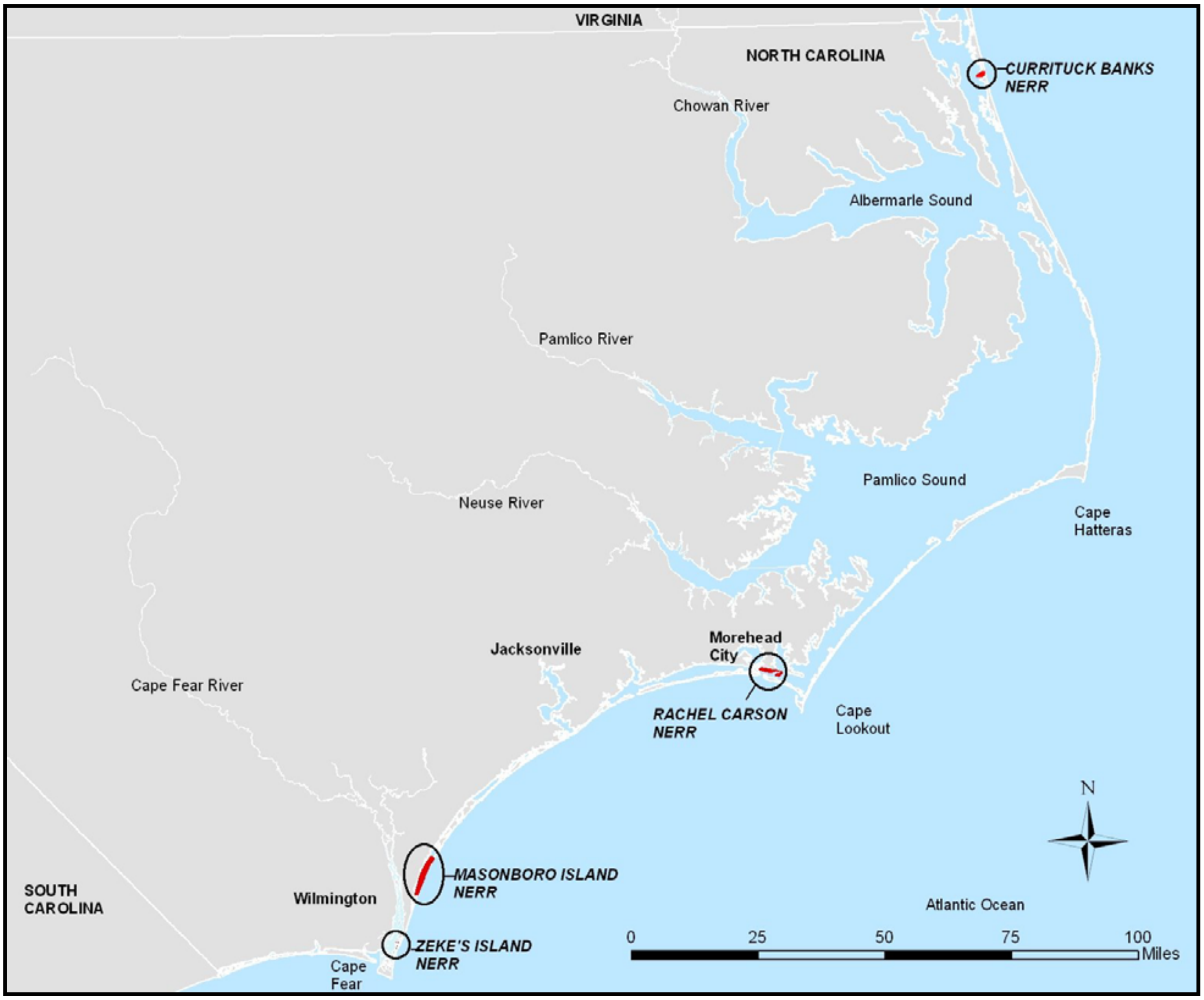

Figure 1. Map of study area, NC NERRS station locations**.**

This NERRS-NCCOS partnership resulted in solid contributions by NERRS staff in planning, field support and logistics, and data interpretation. In addition, local information helped in the identification of sampling sites and provided insight into nearby watershed influences on water quality (i.e. land use change and development), improving interpretation of watershed and historical data. NC NERRS staff also facilitated access to sampling locations.

There are two complementary components of this project: (1) a tidal-creek, sentinel habitat study to develop a framework for evaluating impacts of land-use and associated stressors on tidal creeks; and (2) a probabilistic monitoring component to assess the spatial extent of ecological condition throughout sub-tidal estuarine waters, based on the status of various measured ecological indicators relative to specific management thresholds. Field work for both components was conducted in summer 2006 and incorporated multiple indicators of ecological condition including basic habitat characteristics (dissolved oxygen, salinity, temperature, pH, depth, sediment granulometry and organic matter content, levels of nutrients and chlorophyll in the water column), chemical contaminants in sediments and biota (metals, PAHs, PCBs, pesticides, and PBDEs), and diversity and abundances of benthic fauna. The tidal-creek component focused on NERRS at Sapelo Island, GA and Masonboro Island, NC and is being integrated with results of prior/ongoing tidal-creek work in SC. Results of the tidal-creek component are discussed in the companion Volume I of this report. The present Volume II focuses on results of the sub-tidal probabilistic component conducted throughout all four NERRS locations in NC: Currituck Sound, Rachel Carson, Masonboro Island, and Zeke's Island (Figure 1).

Together, the two project components are intended to provide a demonstration of the utility of the complementary assessment tools, one serving as a sentinel of environmental signals in areas of estuaries where signals are likely to occur, and the other providing a means for assessing the spatial extent of condition throughout a targeted resource category (i.e., sub-tidal estuarine waters of a reserve) and how the relative proportions of healthy vs. degraded areas may be changing with time. This pilot project is providing new information on the status of ecological condition and human-health risks in the NC and GA NERRS. The results may also serve as a useful framework of assessment strategies that could be applied systematically across other reserves to support national comparisons.

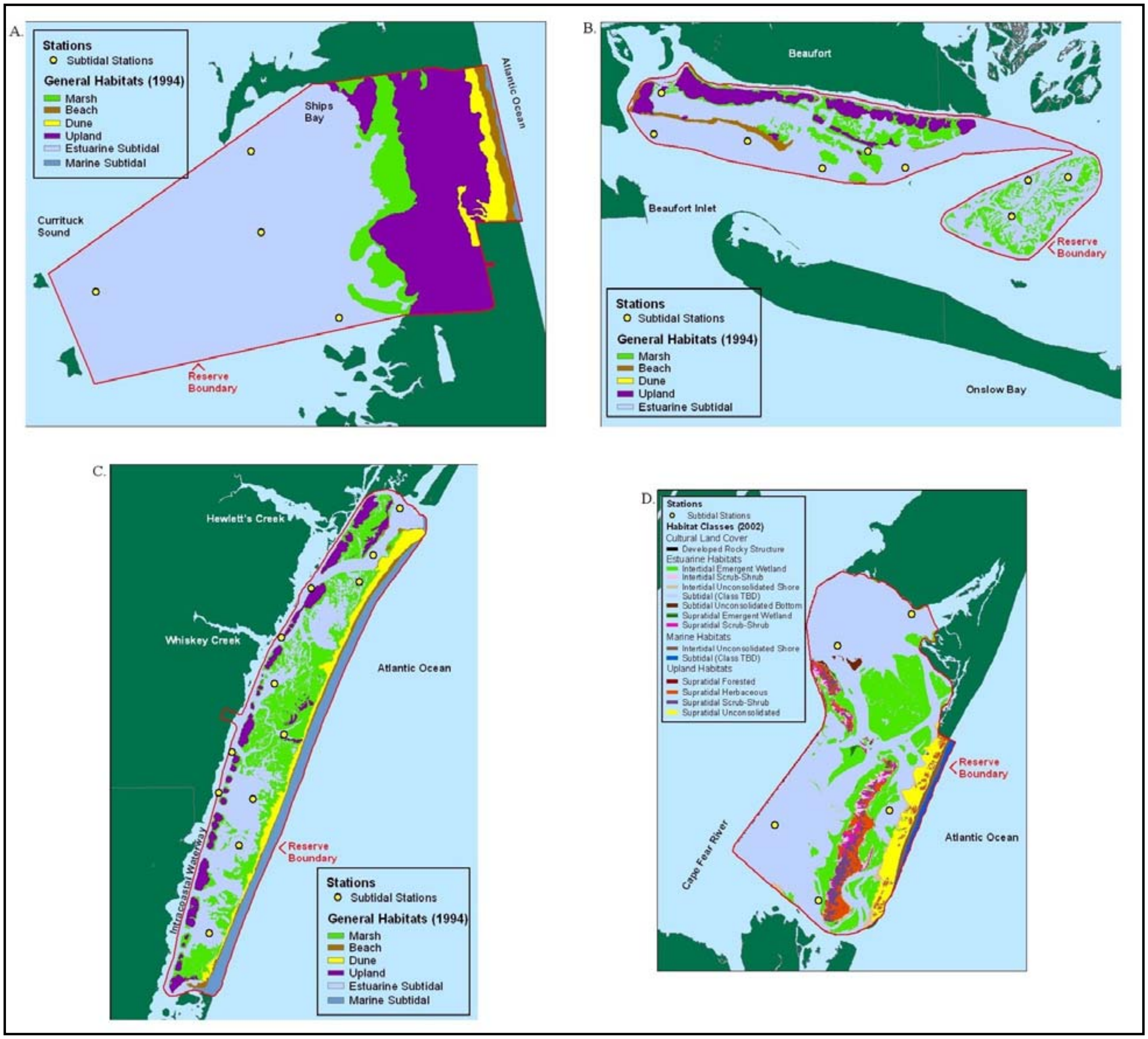

Figure 2. Station locations within each of the NC NERRS: Currituck Banks (A), Rachel Carson (B), Masonboro Island (C), and Zeke's Island (D). Sampling stations are indicated by yellow circles and labeled with the site names.

2. Methods

2.1 Sampling Design and Field Collection

A total of 30 stations were sampled in the North Carolina National Estuarine Research Reserve System (NC NERRS). The four component NC NERRS reserves (Currituck Sound, Rachel Carson, Masonboro Island, and Zeke's Island) are located across a wide latitudinal range and encompass a variety of physical environments. Therefore, stations were distributed proportionally among the subtidal areas of the component NC NERRS sites, as follows, using a stratified random design (Figures 1 and 2):

Currituck Banks (4 stations)
Rachel Carson (9 stations)
Masonboro Island (12 stations)
Zeke's Island (5 stations)

Geographic delineations of these areas were derived from GIS shapefiles provided by the NC NERRS office, based on a habitat classification scheme which was recently adopted to consistently describe ecosystems throughout the Reserve System and at various levels of detail (Kutcher et al. 2005). The NERRS Habitat Classification scheme is a modified combination of classification schemes established for the U.S. Geological Survey (Anderson et al. 1976), U.S. Fish and Wildlife Service (Cowardin et al. 1979), and NOAA Coastal Change Analysis Program (C-CAP 2004). The NERRS Habitat Classification scheme uses a nested hierarchical structure to describe habitat and land cover conditions at 5 levels of detail: System, Subsystem, Class, Subclass, and Descriptors. Each habitat category is assigned a unique text label and numerical code for each hierarchical level. This allows the classified data to be analyzed efficiently and summarized at any of the 5 levels.

The NC NERRS office conducted a pilot project at the Zeke's Island component to evaluate the NERRS Habitat Classification scheme and develop standardized methods for consistent application of the scheme for the four NC NERRS components. Habitat analyses and area calculations were conducted using ESRI GIS software. Products resulting from the NC NERRS habitat classification effort include geo-referenced digital shapefiles with polygons that delineate habitat subclasses for each of the four NC NERRS components. Attribute tables of the shapefiles include a text label and numerical code for the four highest levels of the classification scheme. Attribute data for Descriptors (level 5) will be added as time and priorities allow. Areal coverage in acres was calculated and summarized for each habitat sub-class for each of the four NC NERRS components.

For this study, the sub-tidal portions of each NC NERRS reserve, the survey area, were extracted as polygons. Each of the four NC NERRS is considered an individual stratum. Within each stratum, a set of random locations was generated using the Random Point Generator extension to ArcView (Jenness 2003). Points were generated with a minimum separation distance of 2 km within each component NC NERRS. The number of sites in each reserve was proportional to the total subtidal area of the four reserves combined (i.e., selection weighted by size).

All field work was conducted in September 2006 from small trailerable boats. Sampling dates for the 30 stations were as follows: four stations at Currituck Banks on September 7, nine stations at Rachel Carson from 9 – 11 September, 12 stations at Masonboro Island from 12 – 14 September, and five stations at Zeke's Island on September 15. Coordinates for each station are given in Appendix A.

At each station, synoptic sampling of a variety of ecological indicators was conducted — including general habitat characteristics, multiple stressor levels, toxicity, and biological responses — to support "weight-of-evidence" assessments of condition and examination of potential associations between presence of stressors and potential bioeffects. Salinity (ppt), pH, temperature (^{o}C), dissolved oxygen (mg L^{-1}), and water depth (m) were measured at approximately 1 m off the bottom using a Hydrolab, Minisonde 4, water-quality data logger. Discrete samples (1 L) of near-surface water (~ 0.5 m below surface) also were collected at each station for the analysis of nutrients, total suspended solids (TSS), and chlorophyll *a*.

Sediment samples for analysis of chemical contaminants, total organic carbon (TOC), grain-size, sublethal toxicity (Microtox assay), and benthic community characteristics were collected at each station using a 0.04-m^2 Young grab sampler. Grabs were collected to a maximum depth of 10 cm and rejected if < 5 cm or if there was other evidence of sampling disturbance (e.g., major slumping, debris caught in jaws). Surficial sediments (upper 2-3 cm) were collected and composited from multiple grabs to provide sufficient material (~ 8 L) for the TOC, grain-size, Microtox, and contaminant analyses. Subsamples of the composited material were removed and placed into appropriate sample containers. As part of the QA/QC process, steps were taken to minimize spurious contamination such as between-station rinses of the grab and sampling utensils with acetone and site water. Sediments collected for contaminant analyses were maintained on ice throughout sampling and shipment, stored frozen (- 40 °C) once transferred to the laboratory, and analyzed within 12 months of receipt. Sediments collected for toxicity testing were maintained on ice throughout sampling and shipment, kept under refrigeration (~ 4 °C) once in the laboratory, and analyzed within 30 days of receipt. Three separate Young grabs also were collected at each station and processed as individual replicate samples for the analysis of benthic macroinfauna. Contents of the grabs were sieved in the field with a 0.5-mm mesh screen. Material remaining on the screen was fixed in 10% buffered formalin with rose bengal and transferred to the laboratory for further processing.

Sampling of fish for chemical contaminant analysis was attempted at each station using a baited hook and line. A total of 22 fish collected among four species, from 14 of the 30 stations, were selected for analysis as follows:

- 3 white perch (*Morone americanus*) from two stations at Currituck Banks;
- 11 Atlantic croaker (*Micropogonias undulatus*): one fish from Currituck Banks, two fish from one station at Rachel Carson, one fish each from three stations at Masonboro Island, and five fish from one station at Zeke's Island;
- 2 spot (*Leiostomus xanthurus*): one fish each from Currituck Bank and Zeke's Island; and
- 6 pigfish (*Orthopristis chrysoptera*): one fish each from five stations at Rachel Carson and one station at Masonboro Island.

Fish samples were maintained on ice throughout sampling and shipment, stored frozen (- 40 °C) once transferred to the laboratory, and analyzed within 12 months of receipt. Fish muscle was used for tissue chemical contaminant analysis.

2.2 Water Quality Analysis

Preliminary processing of water samples for nutrients, chlorophyll, and TSS was conducted onshore at the end of each sampling day. A portion of the water (~0.5 L) from each station was vacuum-filtered using Filterware microfiltration glassware and a Whatman GF/F 47mm filter.

The filtered water sample was then transferred to a 120 mL 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* (CHLa) and phaeopigments (PHAEO). Whole water samples were frozen in 60 mL polypropylene bottles and later analyzed for total nitrogen (TN) and total phosphorus (TP). Remaining water was used to measure TSS within 7 days of collection.

Water chemistry was measured at the Chesapeake Biological Laboratory (Solomons, Maryland) using established laboratory methods for the analysis of NH_4^+ (method 804-86T, Technicon 1986a), $NO_{2/3}$ (method 158-71, Technicon 1977), PO_4^{3-} (method 155-71W, Technicon 1973), and Si (method 811-86T, Technicon 1986b). TN, TP, TDN, and TDP concentrations were determined by a persulfate digestion method (Valderrama 1981). The Welschmeyer method (Welschmeyer 1994) was used to determine both CHL and PHAEO. TSS was analyzed using a photometric method on a HACH DR/2500 TSS analyzer (method 8006, Hach 2003).

2.3 Chemical Contaminant Analysis

2.3.1 Laboratory Sample Preparation

Sediment samples were kept frozen at approximately - 40 ºC until analysis could proceed. To thaw, samples were left in closed containers in a + 4 ºC cooler for approximately 24 hours. Samples were thoroughly homogenized by hand prior to any sample extraction. Fish tissue samples were frozen upon receipt in the laboratory and stored at - 40 ºC until analysis. Fish were removed from the freezer and stored overnight at 4 ºC and allowed to partially thaw. The fish were filleted (skin on) and well homogenized using a ProScientific homogenizer in 500 mL Teflon containers. The homogenized tissue sample was split into an organic (pre-cleaned glass container) and inorganic (pre-cleaned polypropylene container) and stored at - 40 ºC until extraction or digestion.

A percent dry-weight determination was made gravimetrically on an aliquot of the wet sediment and tissues.

2.3.2 Inorganic Sample Digestion and Analysis

Dried sediment was ground with a mortar and pestle and transferred to a 20 mL plastic screw-top container. A 0.25 g sub-sample of the ground material was transferred to a Teflon-lined digestion vessel and digested in 5 mL of concentrated nitric acid using microwave digestion. The sample was brought to a fixed volume of 50 mL in a volumetric flask with deionized water and stored in a 50 mL polypropylene centrifuge tube until instrumental analysis of Li, Be, Al, Fe, Mg, Ni, Cu, Zn, Cd, and Ag. A second 0.25 g sub-sample was transferred to a Teflon-lined digestion vessel and digested in 5 mL of concentrated nitric acid and 1 mL of concentrated hydrofluoric acid in a microwave digestion unit. The sample was then evaporated on a hotplate at 225 °C to near dryness and 1 mL of nitric acid was added. The sample was brought to a fixed volume of 50 mL in a volumetric flask with deionized water and stored in a 50 mL polypropylene centrifuge tube until instrumental analysis for V, Cr, Co, As, Sn, Sb, Ba, Tl, Pb, and U. Selenium was analyzed by hotplate digestion using a 0.25 g sub-sample and 5 mL of concentrated nitric acid. Each sample was brought to a fixed volume of 50 mL in a volumetric flask with deionized water and stored in a 50 mL polypropylene centrifuge tube until instrumental analysis. Additionally, two to three grams wet tissue were microwave digested in Teflon-lined digestion vessels using 10 mL of concentrated nitric acid along with 2 mL of hydrogen peroxide. Digested samples were brought to a fixed volume with deionized water in graduated polypropylene centrifuge tubes and stored until analysis. Finally, a separate inorganic aliquot was used for mercury analysis. Approximately 0.5 g of wet sediment or tissue was analyzed on a Milestone DMA-80 Direct Mercury Analyzer.

All remaining elemental analysis was performed using an Inductively Coupled Plasma Mass Spectrometry (ICP-MS) except for silver, which was determined using Graphite Furnace Atomic Absorption (GFAA) spectroscopy. Data quality was controlled by using a series of blanks, spiked solutions, and standard reference materials including NRC MESS-3 (Marine Sediments) and NIST 1566b (freeze dried mussel tissue).

2.3.3 Organic Extraction and Analysis

An aliquot (10 g sediment or 5 g tissue wet weight) was extracted with anhydrous sodium sulfate using Accelerated Solvent Extraction (ASE) in either 1:1 methylene chloride:acetone (for sediments) or 100% dichlormethane (for tissues) (Schantz 1997). Following extraction, samples were dried and cleaned using Gel Permeation Chromatography and Solid Phase Extraction to remove lipids and then solvent-exchanged into hexane for analysis. Samples were analyzed for PAHs, PBDEs, PCBs (by congener), and a suite of chlorinated pesticides using appropriate GC/MS technology. Data quality was ensured by using a series of spiked blanks, reagent blanks, and appropriate standard reference materials including NIST 1944 (sediments) and NIST 1566b (muscle tissue).

2.4 Sediment toxicity testing

Microtox assays were conducted using the standardized solid-phase test protocols (Microbics Corporation 1992) and a Microtox Model 500 analyzer (Strategic Diagnostics Inc., CA). In this assay, sediment was homogenized and a 7.0 – 7.1 g sediment sample was used to make a series of sediment dilutions with 3.5% NaCl diluent, which were incubated for 10 minutes at 15 ºC. Luminescent bacteria (*Vibrio fisheri*) were then added to the test concentrations. The liquid phase was filtered from the sediment phase and bacterial post-exposure light output was then measured using Microtox Omni Software. An EC50 value (the sediment concentration that reduces light output by 50% relative to the controls) was calculated for each sample. Triplicate samples were analyzed simultaneously. Sediment samples were classified as either toxic or non-toxic using criteria developed by Ringwood and Keppler (1998).

2.5 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 quality steps included: (1) tests of ongoing sorting proficiency on 10% of samples by independent sorters to assure that $\geq 95\%$ of animals in each sample were removed by original sorter; (2) use of skilled taxonomists with updated standard taxonomic keys and reference collections to perform species identifications; (3) checks for potential misidentifications on minimum of 10% of samples by independent qualified taxonomists; and (4) appropriate corrective actions to resolve any potential sorting or species identification errors. 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 (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 1.

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

Indicator	Threshold	Reference
Water Quality		
Salinity (ppt)	< 5 = Oligohaline 5 – 18 = Mesohaline >18 – 30 = Polyhaline > 30 = Euhaline	Carriker 1967
DO (mg/L)	< 2 = Low (Poor) 2 – 5 = Moderate (Fair) > 5 = High (Good)	USEPA 2004; Diaz and Rosenberg 1995
DIN (mg/L)	> 0.5 = High (Poor) 0.1 – 0.5 = Moderate (Fair) < 0.1 = Low (Good)	USEPA 2004
DIP (mg/L)	> 0.05 = High (Poor) 0.01 – 0.05 = Moderate (Fair) < 0.01 = Low (Good)	USEPA 2004
CHLa (µg/L)	> 20 = High (Poor) 5 – 20 = Moderate (Fair) < 5 = Low (Good)	USEPA 2004
Sediment Quality		
Silt-Clay Content (%)	> 80 = Mud 20 – 80 = Muddy Sand < 20 = Sand	USEPA 2004
TOC Content (mg/g)	> 50 = High (Poor) 20 – 50 = Moderate (Fair) < 20 = Low (Good)	USEPA 2004
	> 35 = High (Poor)	Hyland et al. 2005

Table 1 continued.

Indicator	Threshold	Reference
Chemical Contamination	mERM-Q > 0.058 or ≥ 1 ERM value exceeded = High (Poor); mERM-Q > 0.02 – 0.058 or ≥ 5 ERL values exceeded = Moderate (Fair); mERM-Q ≤ 0.02 or No ERMs exceeded or < 5 ERLs exceeded = Low (Good)	Hyland et al. 1999; USEPA 2004
Individual chemical contaminant concentrations	> ERM Bioeffects likely < ERL = Bioeffects not likely	Long et al. 1995
Sediment Toxicity: Microtox	Silt-Clay ≥ 20%: Toxic if EC50 ≤ 0.2% Silt-Clay < 20%: Toxic if EC50 ≤ 0.5%	Ringwood et al. 1997; Ringwood and Keppler 1998
<u>Biological Condition</u>		
B-IBI	≤ 1.5 = Degraded Benthos 1.5 – 3 = Some Stress ≥ 3 = Healthy Benthos	Van Dolah et al. 1999
Chemical Contaminants in Fish Tissues	≥ 1 chemical exceeded Human Health upper limit = High (Poor) ≥ 1 chemical within Human Health risk range = Moderate (Fair) All chemicals below Human Health lower risk limit = Low (Good)	USEPA 2000

2.6 Data Analysis

A probabilistic, stratified-random, sampling design was used in this study in order to provide a basis for making unbiased statistical estimates of the spatial extent of degraded versus non-degraded condition within the NC NERRS, based on the status of various measured ecological indicators and corresponding thresholds of interest at component sampling sites (Table 1). A similar approach has been applied throughout EPA's EMAP and related National Coastal Assessment (NCA) programs (e.g., USEPA 2001a, 2001b, 2002). Methods for estimating the proportion of area of NC NERRS corresponding to specified values of an indicator, and its associated variance, are based on published formulae for stratified random sampling designs (Cochran 1977, Fulton et al. 2007, Llanso et al. 2005). For every site i in stratum h, y_{hi} takes the value 1 when a criterion is met, and 0 otherwise. The estimated proportion and its associated variance for stratum h is calculated as

$$\hat{p}_h = \bar{y}_h = \sum_{i=1}^{n_h} \frac{y_{hi}}{n_h} \qquad (1)$$

and

$$\mathrm{var}(p_h) = s_h^2 = \sum_{i=1}^{n_h} \frac{(y_{hi} - \bar{y}_h)^2}{n_h - 1}\,. \tag{2}$$

The estimated proportion for a given system (combined across L strata) is given as

$$\hat{P} = \sum_{i=1}^{L} W_h \bar{y}_h\,, \tag{3}$$

where the weighting factor $W_h = A_h/A$; A_h is the area of stratum h, and A is the combined area of all strata. The variance of (3) is calculated as

$$\mathrm{var}(\hat{P}) = \sum_{h=1}^{L} W_h^2 S_h^2 / n_h\,. \tag{4}$$

Results of the above type of spatial estimates are presented throughout this report as the percent area (± 95% confidence interval) of NC NERRS within specified ranges of a particular indicator. Thresholds defining such ranges (see Table 1) include, where possible, those having known biological significance (e.g.; dissolved oxygen < 2 mg/L) or that represent other basic environmental delineations (e.g.; breakpoints depicting various salinity zones). Additional data summaries include box-whisker plots of key distributional properties (e.g., where boxes are interquartile ranges, horizontal lines within boxes are medians, and wisker endpoints are 10th and 90th percentile points) and other basic data tabulations.

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. 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 ≤ 0.02 and > 0.058 have been associated with a low and high incidence of stress, respectively, in benthic communities of southeastern estuaries (Hyland et al 1999).

The biological significance of fish-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 USEPA (2000) for a variety of organic and inorganic contaminants (Table 3). Concentrations of contaminants measured in fish tissues (filets with skin on) 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 nor were they included in the final estimate of ecological condition of NC NERRS (see Table 14).

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

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

[a] without Perylene

[b] Total DDTs = 2,4′-DDD + 4,4′-DDD + 2,4′-DDE + 4,4′-DDE + 2,4′-DDT + 4,4′-DDT

[c] Total PCBs: ((Sum of 18 PCB congeners) * 2.19) + 2.19

Table 3. Risk-based EPA advisory guidelines for recreational fishers (US EPA, 2004).

	Health Endpoint (non-cancer)	**Health Endpoint (cancer)**
Metals µg/g	**Concentration Range**[a]	**Concentration Range**[b]
Arsenic (inorganic)[c]	0.35-0.70	0.008–0.016
Cadmium	0.35-0.70	
Mercury (methelmercury)[d]	0.12-0.23	
Selenium	5.9-12.0	
Organics ng/g		
Chlordane	590-1200	0.03–0.07
DDT (total)	59-120	0.035–0.069
Dieldrin	59-120	0.00073–0.0015
Endosulfan	7000-14000	
Endrin	350-700	
Heptachlor Epoxide	15-31	0.0013–0.0026
Hexachlorobenzene	940-1900	0.0073–0.015
Lindane	350-700	0.009–0.018
Mirex	230-470	
Toxaphene	290-590	0.011–0.021
PCB (total)	23-47	0.0059–0.012

a. Range of concentrations associated with non-cancer health endpoint risk for consumption of four 8-oz meals per month.

b. Range of concentrations associated with cancer health endpoint risk for consumption of four 8-ounce meals per month.

c. Inorganic arsenic, the form considered toxic, estimated as 2% of total arsenic (USEPA 2000).

d. Because most mercury in fish is present as methyl mercury, USEPA 2000 recommends total mercury be analyzed for with the conservative assumption that all mercury is present as methylmercury.

3. Results and Discussion

3.1 Water Quality

3.1.1 General Water Characteristics

Key bottom-water characteristics, as measured during this survey, throughout the four reserves (Figure 3, Table 4, Appendix A) can be summarized as follows: (1) relatively shallow water depths ranging from 0.7 – 4.3 m and averaging 1.5 m (water depths were not corrected to Mean Low Low Water); (2) widely variable salinities ranging from oligohaline to euhaline values of 2.6 – 36.2 ppt (overall mean of 25.6 ppt); (3) moderate to high DO levels ranging from 4.6 – 9.0 mg/L and averaging 5.9 mg/L; (4) typical late-summer, southern-temperate temperatures ranging from 22.5 – 25.6 °C and averaging 24.3 °C; and (5) slightly basic pH levels ranging from 7.3 – 8.7 and averaging 7.8. Mean water-quality variables at each of the individual reserves ranged from 1.0 m (Currituck Banks) to 1.8 m (Masonboro Island) for depth, 2.7 ppt (Currituck Banks) to 35.0 ppt (Rachel Carson) for salinity, 5.6 mg/L (Masonboro Island) to 7.5 mg/L (Currituck Banks) for DO, 24.0 °C (Masonboro Island) to 24.6 °C (Rachel Carson) for temperature, and 7.6 (Zeke's Island) to 7.9 (Currituck Banks) for pH. Currituck Banks was characterized by the lowest salinities and highest DO levels of the four reserves.

DO levels in bottom waters at all stations were well above a reported benthic hypoxic-effect-threshold of about 1.4 mg/L (Diaz and Rosenberg 1995). Only one station at Masonboro Island, representing 3.5% (± 6.9%) of the NC NERRS survey area, had a moderate DO concentration (4.6 mg/L) below the 5 mg/L upper threshold (Figure 4, Table 5). The majority of the area (96.5 ± 6.9%), represented by 29 of the 30 stations, had DO in the high range (> 5.0 mg/L) considered safe for marine life. In contrast, Hyland et al. (2000) reported low-DO conditions over larger portions of North Carolina estuaries state-wide, with DO < 2 mg/L in 4% of the area and DO < 5 mg/L in another 14% of the area. USEPA (2004) also reported a lower incidence of high-DO water throughout southeastern estuaries region-wide, with DO > 2 mg/L in 74% of the area, 2-5 mg/L in 24% of the area, and < 2 mg/L in 2% of the area.

The amount of total suspended solids (TSS) in the water column has a direct effect on turbidity (a measure of water clarity) by causing the attenuation or scattering of light. 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 in surface waters throughout the NC NERRS stations ranged from 6.0 to 24.0 mg/L and averaged 12.0 mg/L (Table 4, Appendix A). Mean TSS at each of the four individual reserves ranged from a low of 8.5 mg/L at Masonboro Island to 17.6 mg/L at Currituck Banks. Fifteen of the 30 stations, representing an estimated 50% of the survey area, had TSS concentrations < 10.5 mg/L and 27 stations, representing about 90% of the area, had concentrations < 18.7 mg/L. These values appear to be within a normal range for North Carolina estuaries. For example, unpublished data on TSS collected from surface waters of North Carolina estuaries as part of the EPA EMAP program (1997/98 data from 40 sites, www.epa.gov/emap/nca/) show a range of 0 to 54.5 mg/L and mean of 8.7 mg/L. Though we are not aware of any TSS guideline for estuarine receiving waters, only one station at Rachel Carson had a TSS concentration (24.0 mg/L) above the State of North Carolina's effluent discharge limit of 20 mg/L for Outstanding Resource Waters (NCDENR 2007).

The State of North Carolina has a turbidity standard for saltwater measured in Nephelometric Turbidity Units (i.e., 25 NTU, NCDENR 2007) which is a measure of the amount of light scattered due to the presence of suspended particles. NTU levels, usually obtained through use of a nephelometric sensor, were not measured in the present study. While there is no simple conversion factor to use for relating TSS to NTU, a general rule of thumb reported by Michaud (1994) is that 1 mg TSS/L ≈ 1.0 to 1.5 NTUs. If this latter approximation range is applied to the TSS concentrations in Appendix A, then it can be estimated that at best case (using the lower conversion factor) none of the 30 NC NERRS stations had NTU levels above 25 and that at worse case (higher conversion factor) six of the stations, representing 18.6% of the total reserve area, had values above 25. Half of these stations were in the Currituck Banks reserve.

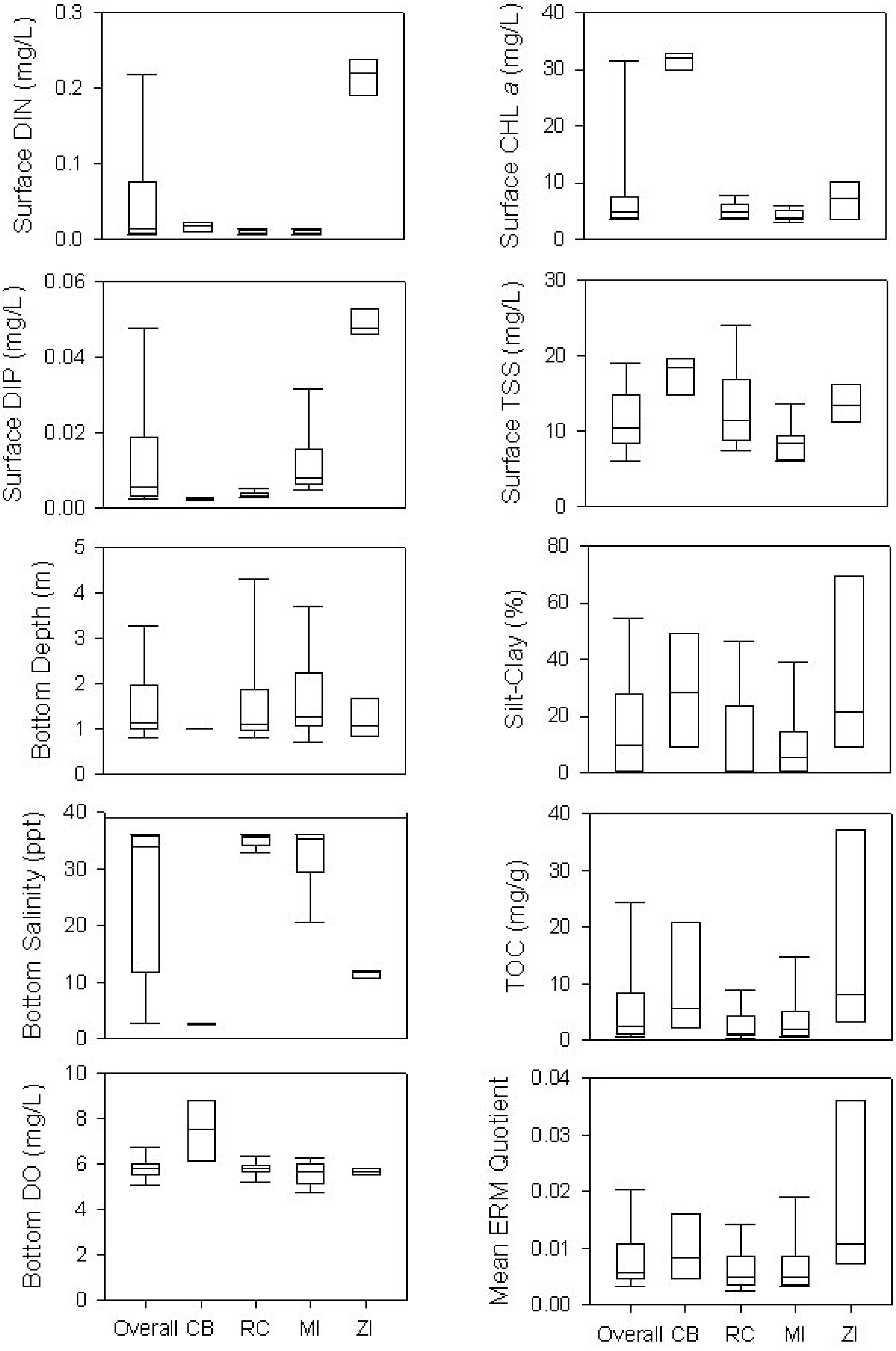

Figure 3. Box and whisker plots of selected water and sediment characteristics among the four NC NERRS. Boxes=interquartile range, horizontal lines=median, whisker endpoints=10th and 90th percentile. CB=Currituck Banks (n=4), RC=Rachel Carson (n=9), MI=Masonboro Island (n=12), and ZI=Zeke's Island (n=5).

Table 4. Comparison of selected water and sediment characteristics among the four NC NERRS.

	Overall		Currituck Banks		Rachel Carson		Masonboro Island		Zeke's Island	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Water:										
Depth (m)	1.5	0.7 – 4.3	1.0	1.0 - 1.0	1.6	0.8 - 4.3	1.8	0.7 - 3.8	1.2	0.7 - 2.0
DO (mg/L)	5.9	4.6 – 9.0	7.5	5.9 - 9.0	5.8	5.2 - 6.3	5.6	4.6 - 6.3	5.8	5.4 - 5.9
Salinity	25.6	2.6 – 36.2	2.7	2.6 - 2.7	35.0	32.8 - 36.1	32.2	19.9 - 36.2	11.4	9.9 - 12.1
Temperature (ºC)	24.2	22.5 – 25.6	24.1	23.2 - 25.2	24.6	23.3 - 25.6	24	22.5 - 25.3	24.2	23.7 - 24.8
pH	7.8	7.3 – 8.7	7.9	7.3 - 8.7	7.8	7.4 - 8.0	7.8	7.6 - 8.0	7.6	7.5 - 7.8
DIN (mg/L)	0.055	0.007 - 0.238	0.018	0.010 - 0.023	0.010	0.007 - 0.015	0.035	0.007 - 0.115	0.216	0.186 - 0.238
DIP (mg/L)	0.015	0.002 - 0.053	0.002	0.002 - 0.003	0.004	0.003 - 0.005	0.012	0.005 - 0.034	0.049	0.046 - 0.053
CHL *a* (µg/L)	8.57	2.70 - 33.07	31.72	29.45 - 33.07	5.02	3.54 - 7.76	4.2	2.70 - 6.15	6.96	3.18 - 11.44
TSS	12.0	6.0 - 24.0	17.6	13.5 – 20.0	13.1	7.5 – 24.0	8.5	6.0 - 15.5	13.7	11.0 - 18.0
Sediments:										
TOC (mg/g)	6.6	0.5 - 37.8	9.6	2.0 - 25.1	2.6	0.5 – 9.0	4	0.5 - 16.7	17.9	2.7 - 37.8
Silt-Clay (%)	17.4	0.1 - 72.9	29.0	3.2 - 55.7	11.6	0.1 - 46.4	10.4	0.2 - 44.3	35.7	4.5 - 72.9
mean ERM-Q	0.0093	0.0024 - 0.0369	0.0096	0.0036 - 0.0184	0.0062	0.0024 - 0.0143	0.0073	0.0032 - 0.0207	0.0196	0.0056 - 0.0369

Table 5. Number of stations (by reserve) and percent area of overall NC NERRS exhibiting designated ranges in selected environmental variables. CB=Currituck Banks (n=4), RC=Rachel Carson (n=9), MI=Masonboro Island (n=12), and ZI=Zeke's Island (n=5).

	Number of Stations				% Area Overall
Indicator*	CB	RC	MI	ZI	(± 95% C.I.)
Water:					
Salinity Classification					
Oligohaline (< 5 ppt)	4	0	0	0	11.6 (0)
Mesohaline (5 – 18 ppt)	0	0	0	5	17.6 (0)
Polyhaline (>18 – 30 ppt)	0	0	4	0	14.0 (11.7)
Euhaline (> 30 ppt)	0	9	8	0	56.8 (11.7)
DO (mg/L)					
< 2 (Poor)	0	0	0	0	0
2 – 5 (Fair)	0	0	1	0	3.5 (6.9)
> 5 (Good)	4	9	11	5	96.5 (6.9)
DIN (mg/L)					
> 0.5 (Poor)	0	0	0	0	0
0.1 – 0.5 (Fair)	0	0	2	5	24.6 (9.2)
< 0.1 (Good)	4	9	10	0	75.4 (9.2)
DIP (mg/L)					
> 0.05 (Poor)	0	0	0	2	7.0 (8.4)
0.01 – 0.05 (Fair)	0	0	5	3	28.1 (14.9)
< 0.01 (Good)	4	9	7	0	64.9 (12.2)
CHL a (μg/L)					
> 20 (Poor)	4	0	0	0	11.5 (0)
5 – 20 (Fair)	0	4	3	3	33.9 (16.9)
< 5 (Good)	0	5	9	2	54.6 (16.9)
Sediments:					
Silt-Clay:					
> 80% (Mud)	0	0	0	0	0
20 – 80% (Muddy Sands)	3	2	2	3	11.6 (16.1)
< 20% (Sand)	1	7	10	2	88.4 (16.1)
TOC (mg/g)					
> 50 (Poor)	0	0	0	0	0
20 – 50 (Fair)	1	0	0	2	9.9 (10.2)
< 20 (Good)	3	9	12	3	90.1 (10.2)
> 35 (Poor)	0	0	0	2	7.0 (8.4)

Table 5 continued.

	Number of Stations				% Area Overall
Indicator*	CB	RC	MI	ZI	(± 95% C.I.)
Significant Microtox Toxicity	0	2	4	3	31.0 (16.6)
Chemical Contamination					
High (Poor)	0	0	0	0	0
Moderate (Fair)	0	0	1	2	10.5 (10.9)
Low (Good)	4	9	11	3	89.5 (10.9)
<u>Benthic Condition:</u>					
B-IBI					
≤ 1.5 (Degraded Benthos)	0	0	1	2	10.5 (10.9)
1.5 – 3 (Some Stress)	1	0	3	0	13.4 (12..2)
≥ 3 (Healthy Benthos)	3	9	8	3	76.1 (15.5)
Marine Debris (and other aesthetic indicators) present:	0	0	0	0	0

* See Table 1 for complete descriptions of threshold values for all indicators.

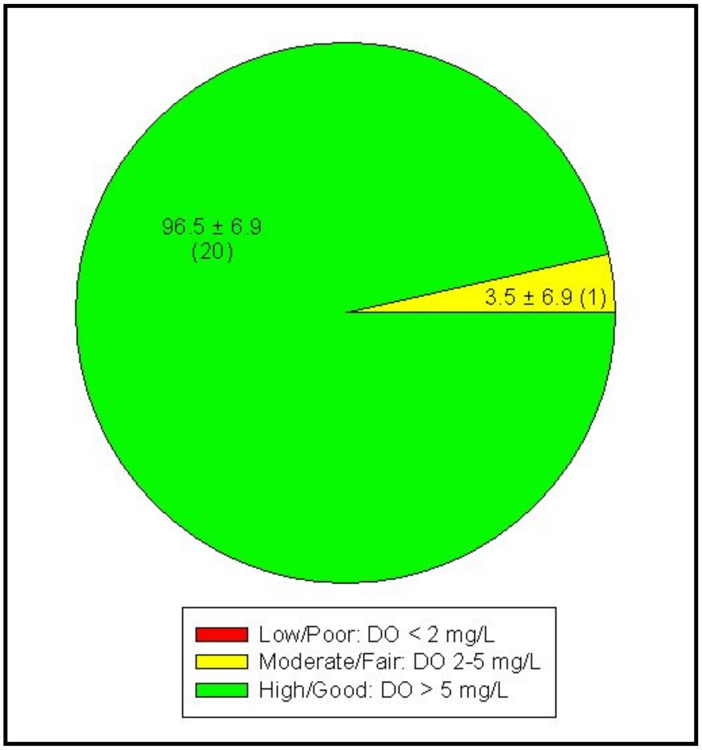

Figure 4. Percent area (± 95% Confidence Interval) of NC NERRS within specified ranges of dissolved oxygen (DO, mg/L) in bottom waters.

3.1.2 Nutrients and Chlorophyll

Dissolved inorganic nitrogen (DIN) levels in surface waters ranged from 0.0068 – 0.2385 mg/L and averaged 0.0552 mg/L (Figure 3, Table 4, Appendix B). Mean DIN at each of the four individual reserves ranged from a low of 0.0098 mg/L at Rachel Carson to a high of 0.2156 mg/L at Zeke's Island. No part of NC NERRS had high DIN levels (> 0.5 mg/L) indicative of high eutrophic potential, while 75.4 ± 9.2% of the area had low "good" levels of DIN (< 0.1 mg/L) (Figure 5, Table 5). USEPA (2004) reported similarly low levels of DIN during the late summer time-frame for southeastern estuaries region-wide, with DIN < 0.1 mg/L in 79% of the area, 0.1 – 0.5 mg/L in 21% of the area, and > 0.5 mg/L in < 1% of the area.

Dissolved inorganic phosphorus (DIP) levels in surface waters ranged from 0.0020 – 0.0532 mg/L and averaged 0.0146 mg/L (Figure 3, Table 4, Appendix B). Mean DIP at each of the four individual reserves ranged from a low of 0.0024 mg/L at Currituck Banks to 0.0492 mg/L at Zeke's Island. An estimated 64.9 ± 12.2% of the overall survey area had low levels of DIP < 0.01 mg/L; 28.1 ± 14.9% had moderate levels from 0.01 – 0.05 mg/L; and 7.0 ± 8.4% of the area, represented by two stations at Zeke's Island, had DIP in the upper range (> 0.05 mg/L) indicative of high eutrophic potential (Figure 5, Table 5). USEPA (2004) reported similar levels of DIP during the late summer time-frame for southeastern estuaries region-wide, with DIP < 0.01 mg/L in 64% of the area, 0.1 – 0.5 mg/L in 24% of the area, and > 0.5 mg/L in 12% of the area.

Chlorophyll *a* (CHLa) levels in surface waters ranged from 2.70 – 33.07 µg/L and averaged 8.58 µg/L (Figure 3, Table 4, Appendix B). Mean CHLa at each of the four individual reserves ranged from a low of 4.20 µg/L at Masonboro Island to a high of 31.72 µg/L at Currituck Banks. An estimated 54.6 ± 16.9% of the overall survey area had low levels of CHLa < 5 µg/L; 33.9 ± 16.9% had moderate levels from 5 – 20 µg/L; and 11.6 ± 0% of the area, represented by all four of the stations at Currituck Banks, had CHLa in excess of the upper 20 µg/L threshold, indicative of high eutrophic potential (Figure 5, Table 5). The co-occurrence of relatively low levels of DIN and DIP and moderate to high levels of CHLa, as observed here over a sizeable portion of the NERRS survey area (Appendix B), reflects a natural process of nutrient reduction due to uptake by phytoplankton and resultant chlorophyll production, which is typical of southeastern estuaries during the spring to summer period (USEPA 2004). USEPA (2004), however, reported CHLa at moderate to high levels over a much broader portion of southeastern estuaries region-wide, with only 18% of the area having values < 5 µg/L, 80% having values from 5 – 20 µg/L, and 3% having values > 20 µg/L.

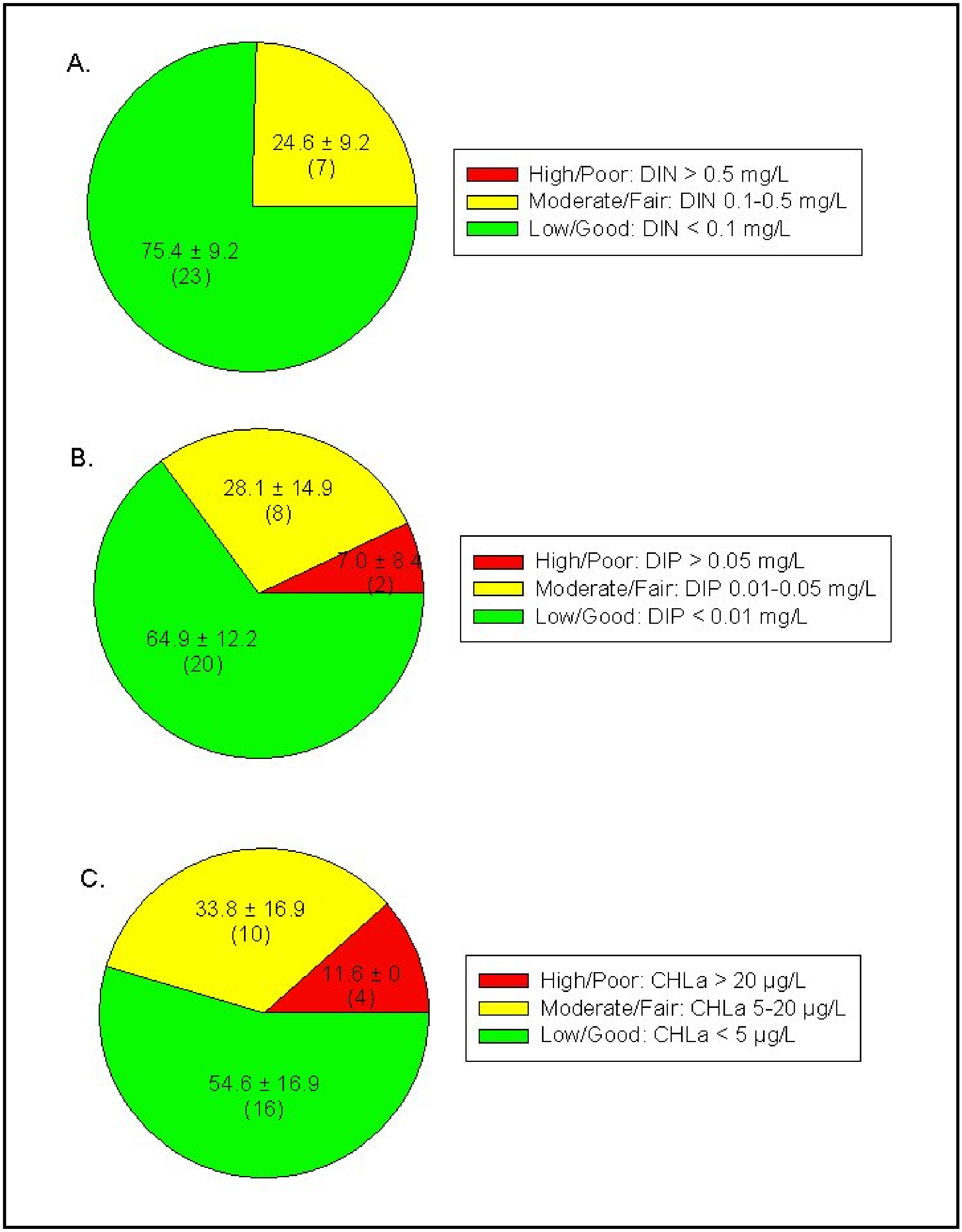

Figure 5. Percent area (± 95% Confidence Interval) of NC NERRS within specified ranges of (A) dissolved inorganic nitrogen (DIN, mg/L), (B) dissolved inorganic phosphorus (DIP, mg/L), and (C) chlorophyll a (CHLa, µg/L) in surface waters.

3.2 Sediment Quality

3.2.1 Grain Size and TOC

The percentage of silt-clay in sediments ranged from 0.1% to 72.9% and averaged 17.4% throughout the four reserves (Table 4, Fig. 3, Appendix A). Mean percent silt-clay at each of the individual reserves ranged from a low of 10.4% at Masonboro Island to 35.7% at Zeke's Island, depicting a predominance of sands to intermediate muddy sands throughout much of the area. Approximately 88% of the overall survey area had sediments composed of sands (< 20% silt-clay) and 12% was composed of intermediate muddy sands (20-80% silt-clay). None of the stations were composed of muds (> 80% silt-clay) (Table 5).

Total organic carbon (TOC) in sediments ranged from 0.5 to 37.8 mg/g and averaged 6.6 mg/g throughout the four reserves (Table 4, Fig. 3, Appendix A). Mean TOC at each of the individual reserves ranged from a low of 2.6 mg/g at Rachel Carson to 17.9 mg/g at Zeke's Island. The majority of the survey area (90.1%) had relatively low TOC levels of < 20 mg/g, while the remaining portion (9.9%) had moderate TOC levels (20 – 50 mg/g; Table 5). None of the survey area had high levels of TOC in a range (> 50 mg/g) potentially harmful to benthic fauna (Figure 6). In comparison, Hyland et al. (2000) reported a much larger range of TOC values (0.2 – 117.8 mg/g) and a lower percentage of area (73%) in the low (< 20 mg/g) range for North Carolina estuaries statewide. The upper and lower thresholds of 20 mg/g and 50 mg/g 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). Hyland et al. (2005) also identified TOC concentrations > 35 mg/g 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 survey area with TOC in excess of this slightly more conservative threshold also was small (7.0 %) and limited to two sites at Zeke's Island (Table 5). The cause of the elevated TOC at these sites is unknown at this time.

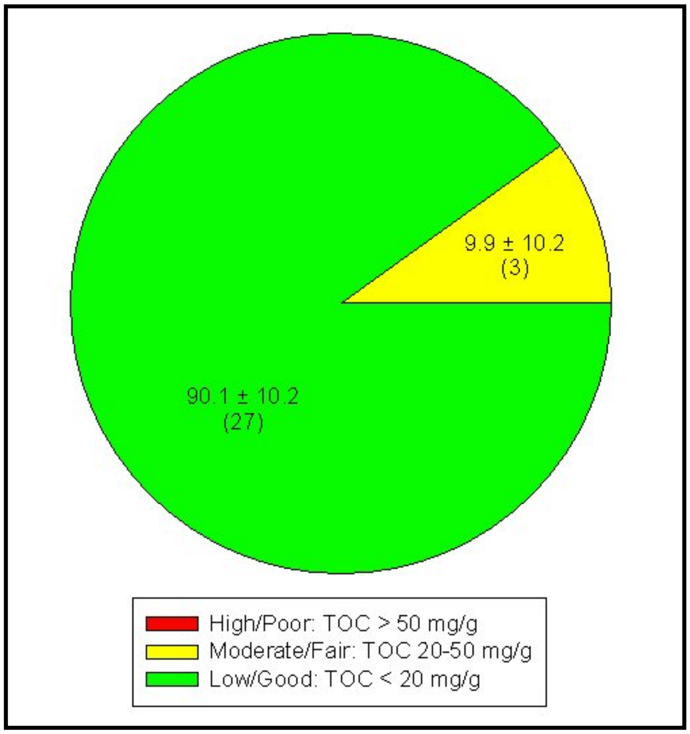

Figure 6. Percent area (± 95% Confidence Interval) of NC NERRS within specified ranges of total organic carbon (TOC, mg/g) in sediments.

3.2.2 Chemical Contaminants in Sediments

In general, concentrations of most chemical contaminants were at low background levels (Appendix C). None of the NC NERRS sampling sites had detectable concentrations of pesticides (e.g.; DDT and its metabolites) or PBDEs (brominated flame retardants). Mean total PCB concentrations for each of the four reserves ranged from 0.120 ng/g dry weight (dw) at Rachel Carson to 0.599 ng/g dw at Zeke's Island. PCB concentrations among the 30 individual stations ranged from < method detections limits (MDL) – 1.24 ng/g dw. Total PCB concentrations at all stations were well below the ERL for total PCBs of 22.7 ng/g dw (Long et al. 1995). Concentrations of PAHs (Appendix C) in sediments were also generally quite low throughout the four reserve locations. Only three of the 25 individual PAHs analyzed were present at detectable concentrations (naphthalene, perylene and benzo (b) fluoranthene) at any of the stations. No PAHs were detected at any of the Masonboro Sound stations and the highest concentration for any individual PAH was 80 ng/g dw (perylene) in a sample from Zeke's Island. Perylene is a natural, plant-derived PAH that is produced through the process of diagenesis under anoxic or reduced conditions (Sanders et al. 2002). There are no ERL or ERM values for perylene or benzo (b) fluoranthene; however the maximum naphthalene concentration, 11.3 ng/g dw in a sample from Zeke's Island, was well below the corresponding ERL value of 160 ng/g dw (Long et al. 1995). Mean total PAH concentrations for each of the four reserves ranged from 9.71 ng/g dw at Currituck Banks to 68.6 ng/g dw at Zeke's Island. The maximum total PAH concentration among the 30 stations, 154 ng/g dw, was well below the corresponding ERL value of 4022 ng/g dw (Long et al. 1995).

Inorganic contaminant concentrations also were at low background concentrations for most analytes (Appendix C). Arsenic was the only inorganic analyte that was measured at elevated concentrations, above sediment quality guideline values, at any of the NERRS sampling stations (Table 6). Mean arsenic concentrations for each of the four reserves ranged from 1.87 μg/g dw at Currituck Banks to 7.99 μg/g dw at Zeke's Island. Concentrations at individual sampling stations ranged from 0.69 – 15.1 μg/g dw. Arsenic concentrations exceeded the ERL (8.2 μg/g dw, Long et al. 1995) at two stations from Zeke's Island and one station from Masonboro Sound. Hyland et al. (2000) also reported arsenic concentrations as high as 17.2 μg/g dw in estuarine sediments throughout NC. Arsenic concentrations are naturally elevated in soils along the southeastern coast (Shacklette and Boerngen 1984, Scott et al. 1994, Sanger et al. 1999, Van Dolah et al. 2004, 2006). Thus, it is likely that the moderately elevated levels of arsenic observed at a few of the NC NERRS stations (three of 30) were due to natural geological conditions rather than anthropogenic sources (also see Kimbrough et al. 2008, Riedel and Valette-Silver 2002).

Mean ERM-Qs are listed by station in Appendix D. Stations with mean ERM-Qs > 0.058 were recorded as having poor sediment quality in a range associated with a high likelihood of impaired benthic condition (Hyland et al. 1999). Values ranging from > 0.02 to 0.058 were classified as moderately degraded and values ≤ 0.02 were considered to have "good" sediment quality previously associated with a high incidence of unimpaired benthic condition (Hyland et al. 1999). None of the NC NERRS stations had mean ERM-Q values above 0.058. Three stations (one from Masonboro Island and two from Zeke's Island) had mean ERM-Qs between 0.02 and 0.058 indicating slightly contaminated habitats with moderate risks of adverse conditions for benthic fauna. These three stations are the same ones with arsenic concentrations in excess of the lower-threshold ERL value and this single contaminant, probably derived from natural sources, was largely responsible for the moderately elevated mean ERM-Q values.

Overall chemical contamination of a sediment sample was classified as high (i.e., poor sediment quality) if the mean ERM-Q was > 0.058, or if ≥ 1 contaminant exceeded its corresponding ERM value; moderate if the mean ERM-Q was > 0.02 to 0.058, or if ≥ 5 contaminants exceeded corresponding ERL values and none were above the ERM values; and low (i.e., good quality) if the mean ERM-Q was ≤ 0.02 and there were < 5 contaminants below ERL values and no contaminants above ERM values (Table 1). Based on these criteria, 89.5 ± 10.9% of the overall NC NERRS survey area had sediment contaminants in the low range and the remaining 10.5 ± 10.9% had contaminants in the moderate range (Table 5, Figure 7). None of the stations were classified as having high sediment contamination. For comparison, Hyland et al. (2000), using the above mean ERM-Q thresholds, reported low sediment contamination in 57% of NC estuaries state-wide, moderate contamination in 27% of the area, and high contamination in 16% of the area. USEPA (2004), using the above numbers of ERL and ERM values that were exceeded as thresholds, reported low contamination in 99% and moderate contamination in the remaining 1% of southeastern estuaries region-wide. If the latter thresholds (based only on numbers of ERL/ERM values exceeded) were used in the present analysis, then 100% of the NC NERRS survey area would be classified as having low sediment contamination (Appendix D).

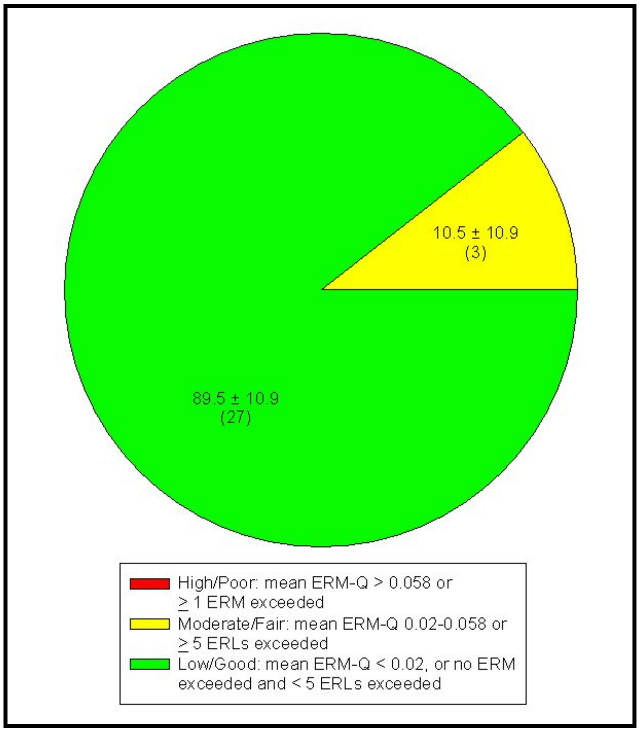

Figure 7. Percent area (± 95% Confidence Interval) of NC NERRS within specified ranges of chemical contamination in sediments.

Table 6. Number of stations by reserve and percent area within each reserve with contaminants in sediment that exceeded corresponding ERL and ERM Sediment Quality Guidelines (SQG) values (µg/g dry mass; Long et al. 1995). CB=Currituck Banks (n=4), RC=Rachel Carson (n=9), MI=Masonboro Island (n=12), and ZI=Zeke's Island (n=5).

			# stations > SQG			% Area > SQG
Analyte	SQG	CB	RC	MS	ZI	(± 95% C.I.)
Arsenic	ERL: 8.2	0	0	1	2	10.5 (10.9)
Arsenic	ERM: 70	0	0	0	0	0

3.2.3 Sediment Toxicity: Microtox

Sediments from nine of the 30 stations, representing 31 ± 16.6% of the survey area, were classified as toxic based on the Microtox assay (Table 5, Appendix E). This measure of sublethal toxicity (reduction in microbial bioluminescence) was observed in sediments from two of seven stations at Rachel Carson, four of eight stations at Masonboro Island, and three of five stations at Zeke's Island. None of the sediments from Currituck Banks caused toxicity. Three of the stations with significant toxicity (NC06MI08, NC06ZI02, and NC06ZI05) were the same ones described as having moderately degraded sediment quality, based on the mean ERM-Q, and which also had arsenic in excess of its corresponding ERL value. The remaining six stations that exhibited a significant Microtox response, were classified as having good sediment quality based on low levels of chemical contamination. This lack of concordance could be due to a number of factors including toxicity from unmeasured contaminants, or those without sediment quality guidelines, or oversensitivity of the Microtox assay relative to the influence of other physicochemical variables. Other authors (e.g., Van Dolah et al. 2006) have noted that this assay is very sensitive to sediment-associated contamination, but also has a tendency for false positives (i.e., toxicity without evidence of chemical contamination). Hyland et al. (2000 and references therein), in comparing results of Microtox tests conducted on sediments throughout NC estuaries to those documented from other coastal systems, reported toxicity in about 14% of the NC estuaries, 39% for the Hudson-Raritan estuary, 43% for Charleston Harbor, 45% for Boston Harbor, 57% for Savannah River, 68% Long Island Sound, 70% for Winyah Bay, and 96% for Biscayne Bay. Thus, aside from the potential oversensitivity of the Microtox assay, the estimated spatial extent of sediment toxicity throughout the present NC NERRS survey area, including all nine sites that tested positive in the Microtox assay, was within the lower end of the above range of spatial estimates for other coastal systems.

3.3 Biological Condition

3.3.1 Benthic Communities

Macrobenthic infauna (> 0.5 mm) were sampled at a total of 30 stations throughout the four NC NERRS reserves. Three replicate grabs (0.04 m^2 each) were collected at all stations resulting in a total of 90 benthic grabs. A total of 310 taxa were identified from the 90 samples, including 184 to the species level. Polychaetes were the dominant taxa, both by percent abundance (67%; Figure 8) and percent taxa (43%; Figure 8, Table 7). Crustaceans and bivalves were the second and third most dominant taxa respectively, both by % abundance (11% bivalves, 9% crustaceans) and % species (23% crustaceans, 16% bivalves). Collectively, these three groups represented 86% of the total faunal abundance and 83% of the species throughout the four reserves. Crustaceans were represented mostly by amphipods (40 identifiable taxa, 13% of the total number of taxa) followed by hexapoda (13 larval insect taxa, 4.2% of total taxa) and decapoda (12 taxa, 3.9% of total taxa) (Table 7).

Species richness, expressed as the number of taxa present in a 0.04-m^2 grab, ranged from 2 – 47 taxa per grab with a mean of 20 taxa per grab (Table 8, Appendix F). Mean richness was highest at Rachel Carson (27 taxa per grab) and lowest at Zeke's Island (9 taxa per grab) (Table 8, Figure 9). H′ diversity (log base 2 derived) ranged from 0.3 – 4.9 with a mean of 2.9. Mean H′

for each of the four individual reserves followed an identical pattern to species richness, with mean values being highest at Rachel Carson (4.5) and lowest at Zeke's Island (1.8). A total of 8,908 individual specimens were collected across the 30 stations (90, 0.04-m^2 grab samples). Densities ranged from 375 – 7,842 m^{-2} and averaged 2474 m^{-2}. Mean density was highest at Rachel Carson NERR (2,725 m^{-2}) and lowest at Zeke's Island NERR (2,207 m^{-2}).

There was a great deal of variability in the composition of dominant taxa among the four reserve locations, possibly reflecting observed differences in salinity, percent silt-clay, and TOC content of sediment. The polychaete *Streblospio benedicti* was the most abundant species overall, though it displayed a wide range in density (means of 6.2 – 733/m^2) and frequency of occurrence (means of 16.6 – 93.3%) among the four reserves (Table 9). *S. benedicti* was particularly abundant at Masonboro Island and Zeke's Island and relatively sparse at Currituck Banks. *S. benedicti* is a well known inhabitant of organically enriched sediments (Pearson and Rosenberg 1978), which is consistent with its high abundance at Zeke's Island where the highest percentages of TOC and fine-grained sediments were observed. Currituck Banks, which had the lowest salinity (oligohaline range) among the four reserves, stood out as having the highest densities of tubificid oligochaetes, larval insects of the genus *Chironomus*, and the polychaete *Amphicteis floridus*. The latter two dominant species at Currituck Banks in fact were not present in samples from the other three reserves. None of the species on the list of the 50 most abundant taxa (Table 9) are known non-indigenous species for the region of collection.

The B-IBI is a multi-metric index providing a quantitative unbiased basis for coding a sample as degraded vs. non-degraded biologically. Typically, B-IBI values ≤ 1.5 are indicative of a highly degraded benthos, values ≥ 3 are indicative of a healthy benthos, and transitional values between 1.5 and 3 reflect partial symptoms of stress (Van Dolah et al. 1999). The B-IBI for the four reserves ranged from 1 – 5 and averaged 3.6 (Table 8, Figure 9, Appendix F). Mean B-IBI was highest at Rachel Carson (4.5) and lowest at Masonboro Island and Zeke's Island (3.2). Two of the five stations at Zeke's Island and one of the 12 stations at Masonboro Island, together representing 10.5 ± 10.9% of the total survey area, had values ≤ 1.5 indicative of an impaired benthos (Table 5, Figure 10). Four other stations (one at Currituck Banks and three at Masonboro Island), together representing 13.4 ± 12.4% of the area, had values in the intermediate range. However, the majority (76.1 ± 15.5%) of the NC NERRS survey area had mean B-IBI values in the upper (≥ 3) range indicative of a healthy benthos (Table 5, Figure 10). Notably, all nine of the stations sampled at the Rachel Carson reserve had values in the upper range (Table 8, Appendix F). Hyland et al. (2000) reported a similar profile of benthic condition for estuaries state-wide, with B-IBI values ≥ 3 in 70% of the area, values from 1.5 – 3 in 15% of the area, and values ≤ 1.5 in 15% of the area. Similar estimates also have been reported for estuaries throughout the southeastern region, e.g., 79% with healthy benthic condition, 10% in the intermediate range, and 11% with degraded benthic condition (USEPA 2004).

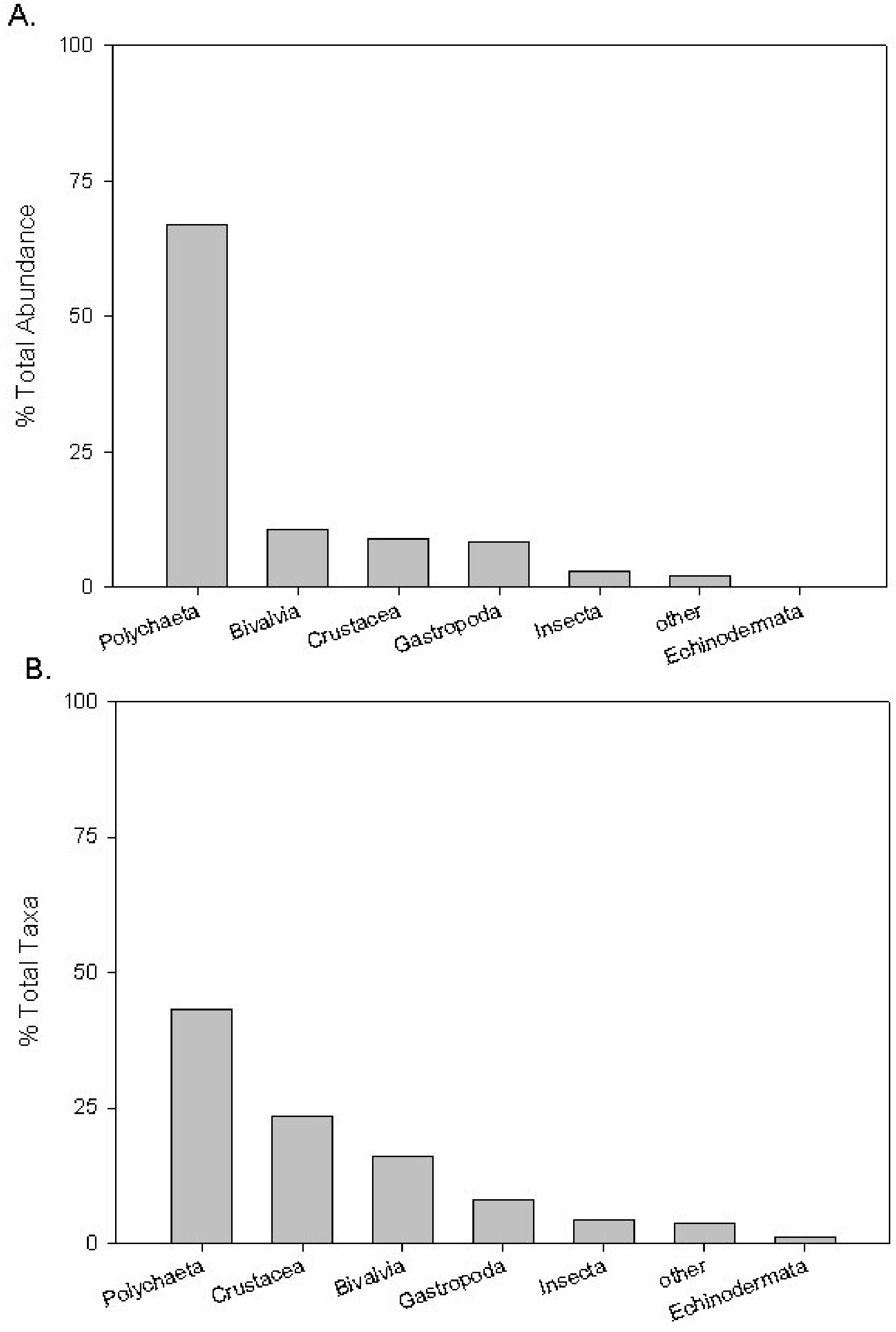

Figure 8. Relative compositions of major benthic taxonomic groups at NC NERRS. Data based on 3 replicate grabs (0.04m2) at each of 30 stations (Currituck Banks=4, Rachel Carson=9, Masonboro Island=12, Zeke's Island=5). (A) % composition by abundance (total # individuals=8908), (B) % composition by taxa (total # taxa=310).

Table 7. Summary of major taxonomic groups of benthic infauna and corresponding numbers of identifiable taxa in samples from NC NERRS.

Taxonomic Group	Number identifiable taxa	% Total identifiable taxa
Phylum Cnidaria		
Class Hydrozoa	1	0.3
Class Anthozoa	1	0.3
Phylum Platyhelminthes	1	0.3
Phylum Nemertea	3	1.0
Phylum Nemata	2	0.6
Phylum Sipuncula	1	0.3
Phylum Mollusca		
Class Gastropoda	25	8.1
Class Bivalvia	50	16.1
Class Polyplacophora	1	0.3
Phylum Annelida		
Class Polychaeta	128	41.3
Class Clitellata	7	2.3
Phylum Arthropoda		
Subphylum Crustacea		
Class Malacostraca		
Order Decapoda	12	3.9
Order Mysida	2	0.6
Order Cumacea	2	0.6
Order Tanaidacea	4	1.3
Order Isopoda	5	1.6
Order Amphipoda	40	12.9
Class Branchiopoda	1	0.3
Class Ostracoda	6	1.9
Subphylum Hexapoda	13	4.2
Phylum Phoronida	1	0.3
Phylum Brachiopoda	1	0.3
Phylum Echinodermata		
Class Ophiuroidea	1	0.3
Class Echinoidea	1	0.3
Class Holothuroidea	1	0.3
Phylum Chordata	1	0.3
Total	*310*	*100*

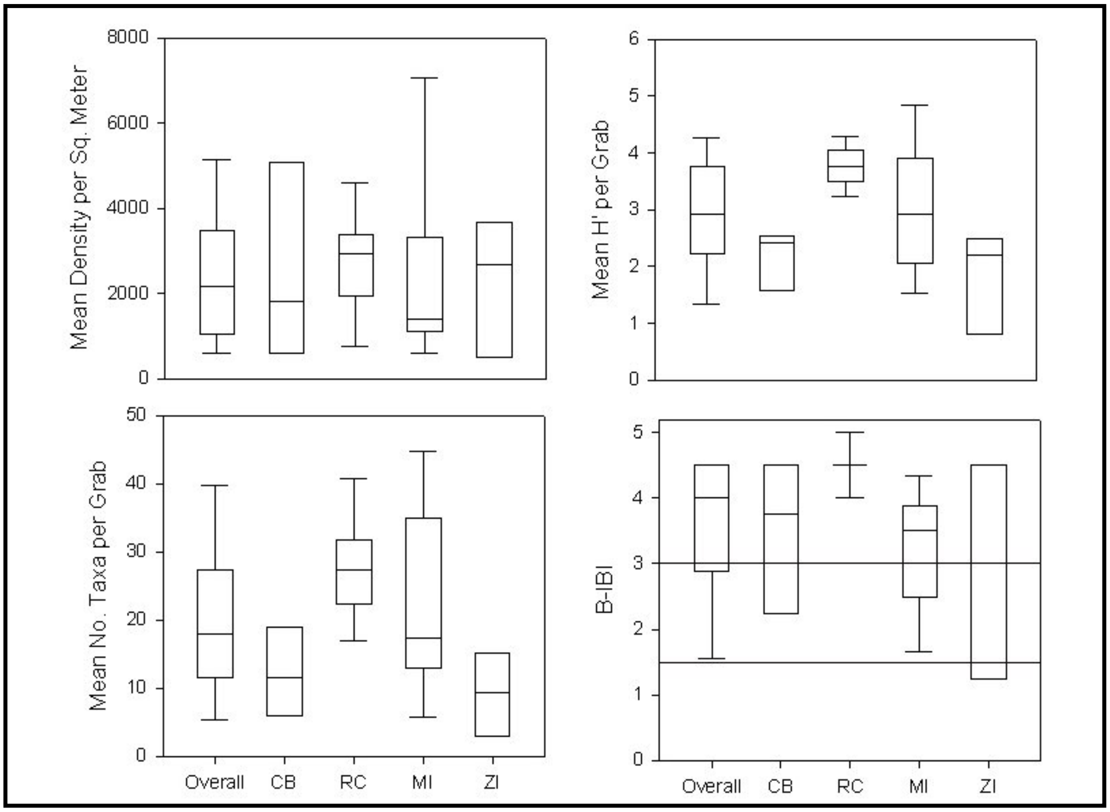

Figure 9. Box and wisker plots of benthic variables (mean abundance, mean H′, mean number of taxa, benthic index of biotic integrity [B-IBI]) among the four NC NERRS. Boxes=interquartile range, horizontal lines=median, whisker endpoints=10th and 90th percentile.

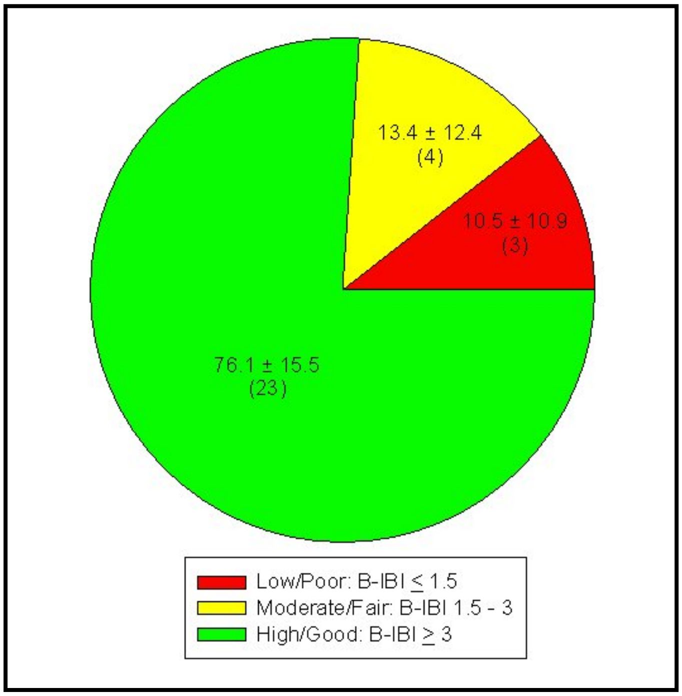

Figure 10. Percent area (± 95% Confidence Interval) of NC NERRS within specified ranges of benthic condition based on benthic index scores (B-IBI).

Table 8. Comparison of selected benthic characteristics among the NC NERRS.

NERRS Site	Mean # Taxa per grab		Total # Taxa per station		Mean Density (#/m^2)		Mean H′ per grab		B-IBI Score	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Overall	20	2 - 47	38	3 - 85	2474	375 - 7842	2.9	0.3 - 4.9	3.6	1 - 5
Currituck Banks	12	5 - 20	20	11 - 30	2508	583 - 5792	2.2	1.3 - 2.6	3.5	2 - 4.5
Rachel Carson	27	17 - 41	53	33 - 73	2725	750 - 4583	3.8	3.2 - 4.3	4.5	4 - 5
Masonboro Island	21	6 - 47	41	9 - 85	2387	417 - 7842	3.1	1.4 - 4.9	3.2	1.5 - 4.5
Zeke's Island	9	2 - 18	15	3 - 30	2207	375 - 3808	1.8	0.3 - 2.7	3.2	1 - 4.5

Table 9. Fifty most abundant benthic taxa at NC NERRS (listed in decreasing order of abundance among all samples combined). Mean density (m^{-2}) and frequency of occurrence (% of samples from corresponding NERRS reserves) are listed for each of the four NERRS and all four combined. CB=Currituck Banks (12 grabs), RC=Rachel Carson (27 grabs), MI=Masonboro Island (36 grabs), and ZI=Zeke's Island (15 grabs). Letters in parentheses refer to major taxonomic group: P = Polychaeta, O = Oligochaeta, B = Bivalva, G = Gastropoda, C = Crustacea, In = Insecta, and N = Nemertea.

Taxon	Density (#/m^2)					Frequency (% of Samples)				
	Overall	CB	RC	MI	ZI	Overall	CB	RC	MI	ZI
Streblospio benedicti (P)	480.2	6.2	251.8	733	663.3	65.5	16.6	66.6	69	93.3
Tubificidae (O)	191.6	952	72.2	79	68.3	55.5	91.6	37	64	40
Mediomastus spp. (P)	185		151.8	163	445	58.8		66.6	67	73.3
Nassarius obsoletus (G)	126.3			101	515	26.6			28	93.3
Tellina spp. (B)	97.7		195.3	97	1.6	52.2		88.8	61	6.6
Chironomus spp.(In)	56.1	420.8				8.8	66.6			
Acteocina canaliculata (G)	55.8		179.6	4.8		25.5		66.6	14	
Maldanidae (P)	50.5		97.2	53		27.7		48.1	33	
Lumbrineris tenuis (P)	41.1		136.1	0.6		11.1		33.3	2.7	
Amphicteis floridus (P)	37.2	279.1				5.5	41.6			
Gemma gemma (B)	36.9		53.7	43	21.6	27.7		25.9	33	40
Spiochaetopterus oculatus (P)	35.5		3.7	13	176.6	13.3		14.8	11	26.6
Brania wellfleetensis (P)	33.6		5.5	80		13.3		14.8	22	
Haplocytheridea setipunctata (C)	33.6		103.7	4.8	3.3	22.2		48.1	17	6.6
Laeonereis culveri (P)	33	162.5	25.9	0.6	20	15.5	58.3	11.1	2.7	20
Rhepoxynius hudsoni (C)	33		41.6	51		11.1		11.1	19	
Nemertea (N)	27.7		37.9	20	50	54.4		77.7	53	60
Prionospio spp. (P)	26.9		58.3	24		26.6		55.5	25	
Mediomastus ambiseta (P)	25.8		78.7	5.5		6.6		11.1	8.3	
Caulleriella sp. J (P)	25.5		75.9	6.9		12.2		18.5	17	
Aricidea taylori (P)	23.3		76.8	0.6		8.8		25.9	2.7	
Parapionosyllis longicirrata (P)	22.7		2.7	55		13.3		3.7	31	
Hargeria rapax (C)	22.7	156.2	5.5	0.6		8.8	50	3.7	2.7	
Capitella capitata (P)	22.5		2.7	33	50	14.4		11.1	14	33.3
Bivalvia (B)	22.5	4.1	26.8	34	1.6	34.4	16.6	51.8	39	6.6

Table 9 continued.

Taxon	Density (#/m^2)					Frequency (% of Samples)				
	Overall	CB	RC	MI	ZI	Overall	CB	RC	MI	ZI
Acanthohaustorius millsi (C)	21.6		70.3	1.3		3.3		7.4	2.7	
Cirratulidae (P)	18.8		17.5	25	21.6	30		29.6	33	46.6
Tharyx acutus (P)	18.8		13.8	31	13.3	24.4		33.3	25	26.6
Spionidae (P)	16.9	4.1	29.6	19		27.7	16.6	51.8	25	
Axiothella mucosa (P)	15.8		37.9	11		18.8		44.4	14	
Paraonis fulgens (P)	14.7		49			5.5		18.5		
Polydora cornuta (P)	14.7	6.2	1.8	33	1.6	12.2	16.6	3.7	19	6.6
Cirrophorus spp. (P)	14.4		15.7	24		20		14.8	39	
Tellina iris (B)	13.3		35.1	6.9		15.5		33.3	14	
Parandalia tricuspis (P)	13			12	50	13.3			14	46.6
Aricidea suecica (P)	12.7		14.8	21		20		22.2	33	
Scoloplos rubra (P)	11.3		25.9	3.4	13.3	20		40.7	11	20
Leitoscoloplos spp. (P)	10.8		19.4	9.7	6.6	23.3		33.3	22	26.6
Listriella barnardi (C)	10.8		20.3	12		22.2		40.7	25	
Nereididae (P)	10.2		3.7	21	5	15.5		14.8	22	13.3
Nephtys picta (P)	9.7		7.4	19		22.2		22.2	39	
Streptosyllis arenae (P)	9.7		11.1	16		10		14.8	14	
Ampelisca verrilli (C)	9.7		29.6	2		16.6		44.4	8.3	
Armandia maculata (P)	9.1		6.4	18		10		14.8	14	
Diplodonta spp. (B)	9.1		9.2	15	3.3	17.7		29.6	17	13.3
Tagelus divisus (B)	9.1		20.3	6.9	1.6	11.1		22.2	8.3	6.6
Tubulanus (N)	8.8		22.2	5.5		17.7		37	17	
Prionospio heterobranchia (P)	8.6		28.7			10		33.3		
Cyathura polita (C)	8.6	62.5	0.9			7.7	50	3.7		
Corophiidae (C)	8	41.6	7.4	0.6		8.8	33.3	11.1	2.7	

3.3.2 Chemical Contaminants in Fish Tissues

Analysis of chemical contaminants in fish tissues (wet-weight concentrations of metals, PAHs, PBDEs, PCBs, and pesticides) was performed on homogenized filets (including skin) from 22 samples of four species — white perch (*Morone americanus*), Atlantic croaker (*Micropogonias undulatus*), spot (*Leiostomus xanthurus*), and pigfish (*Orthopristis chrysoptera*). Many of the measured contaminants in these samples were below corresponding MDLs (Appendix G). However, twelve of the 22 inorganic elements that were measured (Al, As, Ba, Cr, Cu, Fe, Mn, Ni, Hg, Se, V, and Zn) were present at detectable levels consistently across all four fish species. Additionally, there were several organic contaminants that were present at detectable levels including total PCBs (all four fish species), 4,4'-DDD (croaker), 4,4'-DDE (white perch, croaker, and spot), dieldrin (croaker and spot), and mirex (croaker).

USEPA (2000) developed human-health consumption limits for cancer and non-cancer (chronic systemic) health endpoints for a variety of contaminants (Table 3). The values listed in Table 3, against which measured concentrations were compared, represent risk-based limits associated with the consumption of four 8-ounce meals of fish per month for the general adult population (similar to the approach used by most state advisory programs, USEPA 2004). Cancer endpoints were based on a 1 in 100,000 risk level. Measured contaminant concentrations (Appendix G) fell well below both the cancer and non-cancer consumption limits for most chemicals. However, one white perch from Currituck Banks, of the 22 fish analyzed in this study, had mercury levels (0.14 ug/g wet) that exceeded the lower threshold for non-cancer effects (0.12 ug/g wet). Also, inorganic arsenic (estimated as 2% of total arsenic (USEPA 2000)) exceeded both the lower and upper cancer thresholds in 16 of the 22 fish samples that were analyzed (all six pigfish and 10 of the 11 croaker) and the lower cancer threshold in one of two samples of spot (Table 10). In contrast, all three samples of white perch had levels of inorganic arsenic below the human-health consumption limits. None of the fish samples from the Currituck Banks reserve had inorganic arsenic above the consumption limits, though the remaining three reserves all contained fish with inorganic arsenic in the cancer-risk range.

Greene and Crecelius (2006) assessed total and inorganic arsenic in samples of summer flounder, croaker, bass, and hard clams collected from Delaware estuaries. Roughly 18% of fish samples contained inorganic arsenic, though it was detectable in croaker in only one of five samples at a relatively low concentration (0.00057 µg/g wet). Croaker in the present study typically had higher levels of inorganic arsenic (ranging from 0.003 to 0.313 µg/g wet). This difference may be due to the relatively elevated levels of natural arsenic found in sediments along the NC coast (see above Section 3.2.2). We evaluated unpublished arsenic data from fish collected as part of the EPA EMAP Program (1995/97 data for 17 fish- nine croaker and eight spot, www.epa.gov/emap/nca/. Inorganic arsenic (estimated as 2% of total arsenic) exceeded both the upper and lower cancer thresholds in five of the 17 fish samples (two of nine croaker and three of eight spot) and the lower cancer threshold in three other samples (one croaker and two spot). While the proportion of these samples with arsenic levels above the cancer thresholds was lower than in the present study, this comparison does demonstrate that these levels are often exceeded in fish from other North Carolina locations. Additionally, other data for wild caught red drum from the southeastern and gulf coasts of the U.S. further demonstrate that US EPA cancer risk limits are regularly exceeded (11 of 13 samples), though the ranges (0.0044 – 0.057 µg/g wet) again appear to be lower than those observed in the present study (C. Browdy, personal communication, S.C. Department of Natural Resources, Charleston S.C.). Conversely, USEPA (2004) reported low levels of inorganic arsenic in fish tissues, below the cancer or non-cancer consumption limits, in all samples collected from estuaries throughout the southeastern U.S. Measured arsenic levels in the tissues of fish from these various studies may have been influenced by the size and age of the fish sampled.

Table 10. Comparison of measured concentrations of inorganic arsenic in fish tissues (µg/g wet weight) to corresponding cancer and noncancer health endpoints, based on consumption of four 8-ounce meals per months (US EPA 2000). CB=Currituck Banks, RC=Rachel Carson, MI=Masonboro Island, ZI=Zeke's Island.

Sample #	Species	NERRS	Concentration[a] (µg/g wet weight)	> Noncancer Endpoints[b]	> Cancer Endpoints[c]
NC06CB01-a	white perch	CB	0.0024		
NC06CB01-b	white perch	CB	0.0031		
NC06CB03-b	croaker	CB	0.0032		
NC06CB04-a	spot	CB	0.0029		
NC06CB04-b	white perch	CB	0.0030		
NC06RC01-a	pigfish	RC	0.1185		**
NC06RC01-b	croaker	RC	0.3127		**
NC06RC01-c	croaker	RC	0.1292		**
NC06RC03-a	pigfish	RC	0.0724		**
NC06RC05-a	pigfish	RC	0.0386		**
NC06RC06-a	pigfish	RC	0.0781		**
NC06RC08-a	pigfish	RC	0.0536		**
NC06MI05-a	croaker	MI	0.1403		**
NC06MI09-a	croaker	MI	0.0879		**
NC06MI10-a	croaker	MI	0.0863		**
NC06MI12-a	pigfish	MI	0.1208		**
NC06ZI03-a	croaker	ZI	0.0993		**
NC06ZI03-b	croaker	ZI	0.0660		**
NC06ZI03-c	croaker	ZI	0.0558		**
NC06ZI03-d	croaker	ZI	0.0785		**
NC06ZI03-e	croaker	ZI	0.1298		**
NC06ZI05-a	spot	ZI	0.0137		*

a. Inorganic arsenic concentration estimated as 2% of total arsenic.

b. Tissue concentrations > 0.35 – 0.70 µg/g (wet weight) representing risks of human chronic systemic effects. *Measured concentration exceeds lower endpoint; **measured concentration exceeds upper endpoint.

c. Tissue concentrations > 0.0078 – 0.016 µg/g (wet weight) representing human cancer risks at a 1 in 100,000 risk level. *Measured concentration exceeds lower endpoint; **measured concentration exceed upper endpoint.

3.3.3 Potential Linkages of Biological Condition to Ecosystem Stressors

Multi-metric benthic indices are often used as indicators of pollution-induced degradation of the benthos (see review by Diaz et al. 2004) and have been developed for a variety of estuarine applications (Engle et al. 1994, Weisberg et al. 1997, Van Dolah et al. 1999, Llannso 2002, Llannso et al. 2003). A desired feature of these indices is the ability to differentiate impaired vs. unimpaired benthic condition, based on a number of key biological attributes (e.g., numbers of species, abundance, dominance, percent sensitive taxa), while attempting to take into account variations associated with natural controlling factors. In the present study, we utilized the benthic index of biotic integrity (B-IBI) for southeastern estuaries, developed by Van Dolah et al. (1999), to provide a quantitative unbiased basis for coding each sample as degraded vs. non-degraded biologically. An additional approach used here was to evaluate benthic condition (expressed as B-IBI scores) in relation to sediment contamination and toxicity, the combination of which is often referred to as the Sediment Quality Triad (SQT). The SQT has been shown to be very effective as a "weight-of-evidence" approach to assessing pollution-induced degradation of the benthos (Long and Chapman 1985, Chapman 1990).

Overall, about 66% of the survey area (20 stations) had a healthy benthos with low levels of sediment contamination and no toxicity (Table 11). No part of the NC NERRS had a degraded benthos with both high contamination and toxicity (i.e., positive hits in all three legs of the SQT). Twenty-one percent of the survey area (six stations) had a degraded benthos co-occurring with significant sediment toxicity, but without elevated levels of measured chemical contaminants, possibly suggesting toxicity/bioeffects from other unmeasured stressors. The remaining 13% of the survey area, represented by four stations, showed some symptoms of stress, but no connection between adverse biological and exposure conditions. These cases included one station with a degraded benthos accompanied by low levels of contaminants and no toxicity, and three stations that had significant Microtox toxicity but no evidence of degraded benthic condition or sediment contamination. Possible explanations include: contaminants were present but were not bioavailable; contaminants were present in toxic bioavaliable forms, but there was no adverse benthic effects due to biological avoidance or resistance mechanisms; or benthic impacts were caused by other natural stressors (e.g., biological interactions, physical disturbances of sediment). It is noteworthy that none of the stations in the Rachel Carson reserve had a degraded benthos.

A closer look at the co-occurrences of degraded benthic condition and various stressor indicators further highlights the relatively close agreement between low B-IBI scores (<3) and significant Microtox toxicity, as well as the possible influence of stressors other than the measured chemical contaminants as sources of the observed bioeffects (Table 12). Six of the seven stations with degraded benthic condition also had significant Microtox toxicity. Two of these stations, both in the Zeke's Island reserve, also contained high levels of TOC, in a reported range (> 35 mg/g) associated with a high risk of disturbance from organic over-enrichment (Hyland et al. 2005). Interestingly, none of the stations with a degraded benthos and significant toxicity co-occurred with high levels of measured sediment contamination. As noted above, this may be due to toxicity from other unmeasured sediment contaminants. None of the stations with a degraded benthos also had low DO in a range (< 2.0 mg/L) potentially harmful to benthic fauna.

There was little concordance between the observed incidence of fish-tissue and sediment contamination (Table 13). Inorganic arsenic in excess of cancer-risk consumption limits was the only contaminant that exceeded human-health guidelines for cancer or non-cancer systemic effects. All but one station where such an exceedance occurred had sediments with very low mean ERM-Qs and no contaminants in excess of corresponding ERL or ERM values. Generally, with the exception of arsenic (or estimated inorganic arsenic), most chemical contaminants were below detection limits or present at low background levels in both sediments and fish tissues.

Table 11. Summary of sediment quality based on combined measures of sediment contamination, sediment toxicity, and condition of benthic communities.

Type Effect			No. Stations	% Area (± 95% C.I.)	Possible Conclusion
Sediment Cont.[a]	Toxicity[b]	Degraded Benthos[c]			
+	+	+	0	0	Degraded benthos with high contamination and toxicity: strong evidence of contaminant induced degradation of benthos.
+	-	+	0	0	Degraded benthos with high contamination or toxicity, but not both: under-sensitivity of assays or field and lab bioeffects caused by unmeasured stressors.
-	+	+	6	21.1 (14.4)	
-	-	+	1	2.9 (5.7)	Some stress, but no connection between adverse biological and exposure conditions: contaminants not bioavailable; or contaminants present in toxic bioavailable forms, but no clear benthic response due to avoidance or resistance; or benthic impacts caused by other natural stressors (e.g., biological interactions, physical disturbances of sediment).
+	+	-	0	0	
+	-	-	0	0	
-	+	-	3	9.9 (10.8)	
-	-	-	20	66.1 (17.6)	Healthy benthos with low levels of sediment contamination and toxicity.

a. Mean ERM-m > 0.058 or ≥ 1 ERM value exceeded.

b. Significant Microtox toxicity.

c. B-IBI < 3.

Table 12. Evaluation of benthic condition in relation to various possible stressors.

A.

NERRS Site	Stations with Degraded Benthos (B-IBI < 3)	B-IBI Score	Stressor Indicator[a]					
			mERM-Q	# Contaminants > ERM	# Contaminants > ERL	DO (mg/L)	TOC (mg/g)	Sig. Microtox Toxicity (Y/N)
Currituck Banks	CB01	2	0.003612	0	0	8.3	1.98	N
Masonboro Island	MI03	2.5	0.008107	0	0	5.34	4.71	**Y**
	MI04	2	0.008873	0	0	5.08	5.29	**Y**
	MI08	1.5	0.020689	0	1	5.06	16.7	**Y**
	MI09	2.5	0.015499	0	0	6.19	10.27	**Y**
Zeke's Island	ZI02	1.5	0.036887	0	1	5.9	**37.75**	**Y**
	ZI05	1	0.035535	0	1	5.44	**36.79**	**Y**

a. Bold values exceed corresponding probable effect threshold levels.

B.

Type Effect	No. of Stations	% Area (± 95% C.I.)
Healthy benthos with low stressor levels	20	66.1 (17.6)
Healthy benthos with ≥ 1 stressor at high risk level	3	9.9 (10.8)
Degraded benthos with low stressor levels	1	2.9 (5.7)
Degraded benthos with ≥ 1 stressor at high risk level	6	21.1 (14.4)

Table 13. Comparison of fish tissues contaminant levels to corresponding sediment contaminants at station with tissue contaminant values above human health endpoints.

Station	Fish Type	Contaminants	Sediment Mean ERM-Q	# of contaminants in sediment > ERL	# of contaminants in sediment > ERM
NC06CB04	White Perch	Mercury	0.009096	0	0
NC06MI05	Atlantic Croaker	Arsenic	0.003244	0	0
NC06MI09	Atlantic Croaker	Arsenic	0.015499	0	0
NC06MI10	Atlantic Croaker	Arsenic	0.00422	0	0
NC06MI12	Pigfish	Arsenic	0.003187	0	0
NC06RC01	Pigfish, Atlantic Croaker	Arsenic	0.00458	0	0
NC06RC03	Pigfish	Arsenic	0.004996	0	0
NC06RC05	Pigfish	Arsenic	0.014272	0	0
NC06RC06	Pigfish	Arsenic	0.004908	0	0
NC06RC08	Pigfish	Arsenic	0.011519	0	0
NC06ZI03	Atlantic Croaker	Arsenic	0.009127	0	0
NC06ZI05	Spot	Arsenic	0.035535	1	0

3.4 Overall Ecological Condition and Human Factors

As noted above, the majority (about 66%) of the NC NERRS had a healthy benthos without signs of significant sediment contamination or toxicity (Figure 11, Table 11). Moreover, no part of the survey area was found to have degraded benthic condition accompanied by both high sediment contamination and toxicity (positive hits in all three legs of the SQT). Ecological condition within the NC NERRS, based on such a SQT approach, appears to be slightly healthier compared to an earlier assessment of conditions conducted throughout North Carolina estuaries state-wide (Hyland et al. 2000). The latter authors, who used similar methods and indicators, reported 54% of estuarine habitat being in good condition and 7% having degraded benthic condition with high sediment contamination and toxicity. Another 12% of the area showed evidence of a degraded benthos coupled to significant pollutant exposure (high sediment contamination or toxicity though not both). The adverse environmental conditions in the earlier state-wide assessment tended to be concentrated spatially in the Neuse and Pamlico Rivers and their tributaries. Hyland et al. (2000, Figs. 6 and 7 therein) also pointed out that, while detectable in some locations, the spatial extent of sediment contamination and toxicity observed for these North Carolina estuaries is much less in comparison to other U.S. coastal regions where similar studies have been performed.

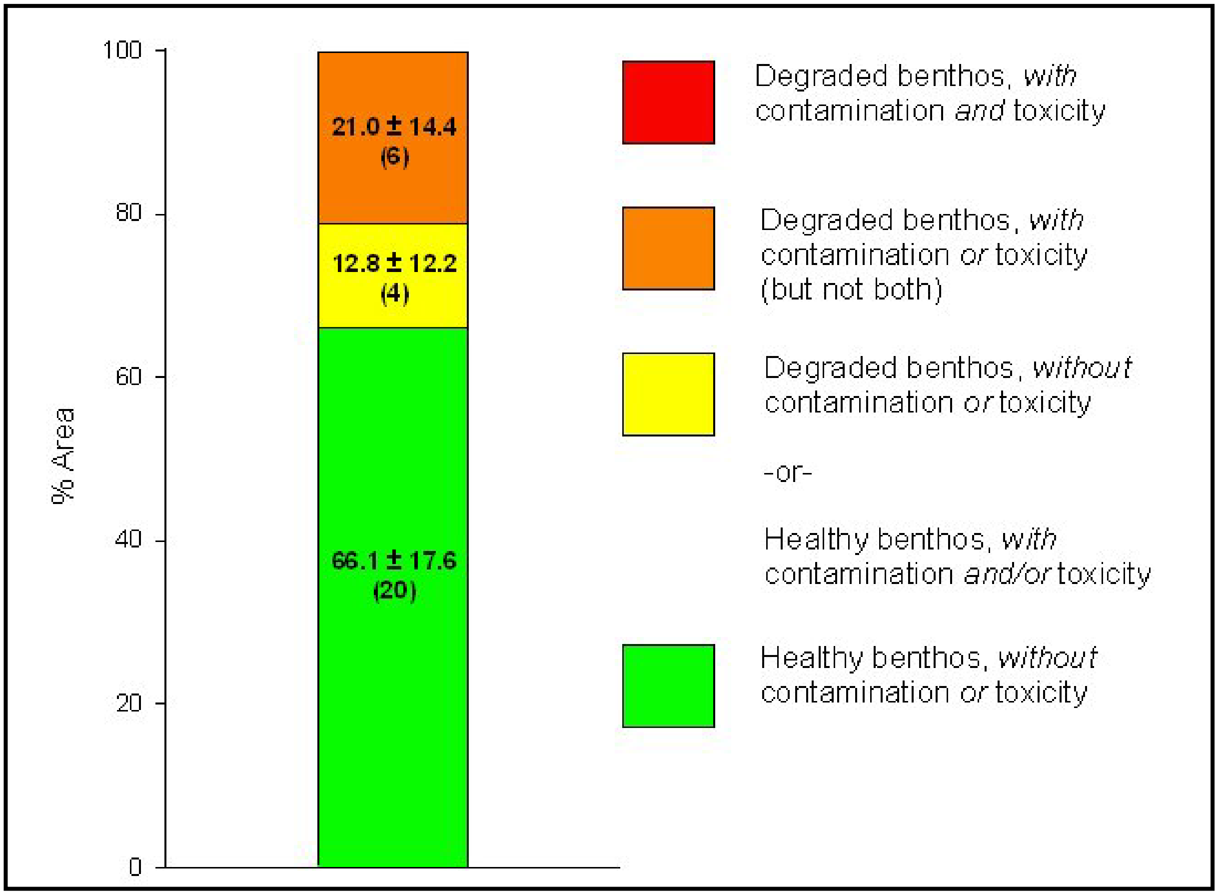

Figure 11. Summary of sediment quality based on combined measures of benthic condition (degraded = B-IBI < 3), sediment toxicity (significant Microtox toxicity), and sediment contamination (mean ERM-Q > 0.058 or ≥ 1 ERM value exceeded).

Water quality measurements across the NC NERRS exhibited some signs of elevated nutrient levels, including DIN (25% of area classified as fair), DIP (7% of area classified as poor and 28% as fair), and chlorophyll a (11 % of area classified as poor and 34% as fair). DO levels, however, were in the high range (> 5 mg/L) across most of the survey area (96%). These results are very similar to those published in the National Coastal Condition Report (USEPA 2004) for estuaries throughout the southeastern U.S., with the exception of DO. In this latter case, the percent area with high DO ("good" category) was observed over a much smaller portion of area region-wide (74%) in comparison to the present NC NERRS. Although there were symptoms of eutrophic conditions in the NC NERRS, as evidenced by the poor to fair levels of chlorophyll a levels across a large area (45%), the majority of NC NERRS had all water quality measurements in the good to fair condition. Our evaluation of water quality of the NC NERRS is in general agreement with results from the National Estuarine Eutrophication Assessment Program for the southeast region, which used very different assessment techniques, but found 2 of the 3 studied North Carolina estuarine systems having low to moderate symptoms of eutrophication based on chlorophyll and DO (Bricker et al. 2007).

There has been an evolving interest recently in the U.S. and other parts of the world to adopt an ecosystem approach to the management (EAM) of coastal resources (Murawski 2007, Marine Ecosystems and Management 2007). Integrated ecosystem assessments (IEAs) have been identified as an important component of an EAM strategy (Levin et al. 2008, Murawski and Menashes 2007). An IEA is a synthesis and quantitative analysis of information on relevant natural and socio-economic factors in relation to specified ecosystem management goals. Key steps in the IEA process include the assessment of baseline conditions defining the status of the system as well as the assessment of stressor impacts and their links to source drivers and pressures. Another underlying tenet in this process is the role of humans as both a source and receptor of ecosystem effects. While the focus of the present study has been on indicators of ecological condition and its potential linkage to humans as sources of stress, some of the indicators that we have included can be used to help evaluate how key human uses of these resources are being affected as a result of the current status of ecosystem condition. These include indicators of potential human-health risks (fish contaminant levels) and aesthetic value (e.g., water clarity, marine debris, noxious odors).

As an indicator of potential human-health risks, concentrations of chemical contaminants (metals, PAHs, PBDEs, PCBs, pesticides) were measured in whole fillets of 22 fish samples from 14 stations and compared to EPA consumption limits for cancer and non-cancer (chronic systemic health) risks. While most contaminants were below MDLs or the consumption limits, one fish of the 22 (4%) contained levels of mercury that exceeded the lower threshold for non-cancer effects, but there was no clear pattern evident of widespread consumption concerns due to Hg. More importantly, 17 of the fish samples (77%) from 11 of the 14 stations where fish were caught (79%) contained inorganic arsenic above the limits for cancer risks. In comparison, USEPA (2004) reported contaminants in whole fish tissues at concentrations above these same risk-based guidelines at a much lower percentage of stations (20%) for southeastern estuaries region-wide. Moreover, inorganic arsenic was not one of the contaminants that exceeded the guidelines; contaminants found at such elevated levels in this latter case were total PAHs and PCBs. Related data, focused on the Albemarle-Pamlico Estuarine System portion of the region

(USEPA 2006), indicate a higher percentage (30%) of stations where the human-health guidelines were exceeded. The elevated levels of arsenic that were observed consistently among the majority of fish tissues in the present study most likely originate from the naturally elevated concentrations of arsenic in crustal rocks of the area and therefore probably are not indicative of human impacts. None of the fish with elevated inorganic arsenic levels showed obvious pathological disorders (e.g., tumors, lesions, fin rot).

Aesthetic indicators included measures of water clarity (TSS), presence of debris ("trash") in surface and bottom waters, visual evidence of oil sheens in surface waters or bottom sediments, and noxious odors. As noted previously, TSS concentrations in surface waters ranged from 6.0 to 24.0 mg/L and averaged 12.0 mg/L, which appear to be within a normal range for such naturally turbid waters characteristic of southeastern estuaries. There was no evidence of marine debris, either floating or collected in bottom grabs, at any of the reserve sites. Similarly, we observed no signs of surface oil slicks or oil sheens in bottom sediments. The only positive evidence of an aesthetic effect was the occurrence of noxious odors in bottom sediments at a number of the stations. A total of 16 stations, representing 53.0% of the overall survey area, had sediments with noxious (hydrogen sulfide) odors. By reserve, this condition was observed at four of the five stations at Currituck Banks, two of the nine stations at Rachel Carson, six of the 12 stations at Masonboro Island, and four of the five stations at Zeke's Island. The most probable source of the sulfide smell is the natural decomposition of detrital organic matter across these near-coastal estuarine sites.

With some exceptions, as discussed above, the status of subtidal estuarine habitats throughout the NC NERRS appears to be in relatively good to fair ecological condition overall, with the majority of the area (about 54%) having various water quality, sediment quality, and biological (benthic) condition indicators rated in the healthy to moderate/intermediate range (Table 14). This is consistent with an overall rating of good to fair condition for southeastern estuaries region-wide (USEPA 2004). Only three stations in the present study, representing 10.5% of the area, had one or more indicators of water quality, sediment quality, and biological condition rated as poor/degraded in all three categories. While such a conclusion is encouraging from a coastal management perspective, it should be viewed with some caution. For example, although co-occurrences of adverse biological and abiotic environmental conditions were limited spatially, at least one indicator of adverse condition (rated in the poor/degraded range) was observed over a broader area (35.5%) represented by 11 of the 30 stations sampled. In addition, the fish-tissue contaminant data were not included in these overall spatial estimates (see Table 14); however, as noted above, there is evidence that fish in the area have elevated levels of inorganic arsenic, above consumption limits for human cancer risks, though most likely derived from natural sources. Similarly, aesthetic indicators are not reflected in these spatial estimates of ecological condition, though as noted above there was evidence of noxious odors at many of the stations.

Such symptoms reflect a growing realization that North Carolina estuaries are under multiple pressures from a variety of natural influences as well as anthropogenic factors, including rapidly increasing human populations and coastal development, nutrient enrichment and sedimentation from agriculture, and industrialized point sources of pollution (Mallin et al. 2000). These data also suggest that, while current status of overall ecological condition appears to be good to fair, long-term monitoring is warranted to track any potential changes in the future. This study establishes an important baseline of overall ecological condition within the NC NERRS that can be used to evaluate such changes and to trigger appropriate management actions in this rapidly evolving coastal environment.

Table 14. Estimates of overall ecological condition at NC NERRS based on combined indicators of water quality, sediment quality, and biological condition (note: fish tissue contaminant data are not included in these calculation of % area, since they represent only a portion of the total stations).

Condition	No. of Stations	% Area (± 95% C.I.)
[a]All water quality, sediment quality, and biological condition indicators rated as "good/healthy"	8	27.1 (15.4)
[b]One or more water quality, sediment quality, or biological condition indicators rated "Moderate/Fair" (but none as 'Poor/Degraded")	8	26.9 (16.4)
[c]One or more water quality, sediment quality, <u>or</u> biological condition indicators rated as "Poor/Degraded"	11	35.5 (16.0)
[d]One or more water quality, sediment quality, <u>and</u> biological condition indicators rated as "Poor/Degraded"	3	10.5 (10.9)

a. DO > 5 mg/L, DIN < 0.1 mg/L, DIP < 0.01 mg/L, CHL*a* < 5 mg/L, TOC < 20 mg/g, mean ERM-q ≤ 0.02 or < 5 ERL values exceeded and no ERM value exceeded, no Microtox toxicity, and B-IBI ≥ 3.

b. DO 2-5 mg/L, DIN 0.1-0.5 mg/L, DIP 0.01-0.05 mg/L, CHL*a* -5-20 mg/L, TOC 20-50 mg/g, mean ERM-q 0.02-0.058 or ≥ 5 ERL values exceeded and no ERM value exceeded, no Microtox toxicity, and B-IBI 1.5-3.

c. DO < 2 mg/L, DIN > 0.5 mg/L, DIP > 0.05 mg/L, CHL*a* > 20 mg/L, TOC > 50 mg/g, mean ERM-q ≥ 0.058 or ≥ 1 ERM value exceeded, significant Microtox toxicity, and B-IBI ≤ 1.5.

d. See "c" thresholds.

4.0 Overall Project Summary and Conclusions

The present report is part of a two-volume set summarizing results of a collaborative NCCOS-NERRS effort to assess the status of ecosystem conditions and potential stressor impacts at NERRS sites in the southeastern U.S., and to provide this information as a basis for monitoring future conditions in these same areas or in other NERRS locations. There are two complementary components of this overall initial effort: (1) a sentinel habitats study designed to evaluate the impacts of development on tidal creek ecosystems, including potential impacts to human health and well-being; and (2) a probabilistic monitoring component to assess the spatial extent of ecological condition throughout sub-tidal estuarine waters, based on the status of various measured ecological indicators relative to specific management thresholds. The tidal creek component, discussed in Volume I (Sanger et al. 2008), focused on NERRS sites at Sapelo Island, Georgia and Masonboro Island, North Carolina and was coordinated with results of related tidal creek work in South Carolina. The sub-tidal probabilistic component, discussed in the present Volume II, was conducted throughout all four North Carolina NERR locations (Currituck Sound, Rachel Carson, Masonboro Island, and Zeke's Island). Together, the two project components are intended to provide a demonstration of the utility of the complementary assessment tools, one serving as a sentinel of environmental signals in areas of estuaries where signals are likely to occur (i.e., tidal creeks close to pollutant sources), and the other providing a quantitative basis for assessing the relative proportions of degraded vs. non-degraded conditions throughout a targeted resource category (i.e., sub-tidal estuarine waters of a reserve) relative to the various measured indicators and associated management thresholds. While providing new information on the status of ecological condition and human health risks in several southeastern U.S. NERRS locations, the results also are intended to serve as a useful framework of assessment strategies that could be applied systematically across other reserves to support broader regional and national comparisons.

4.1 Summary Points from Volume I: Assessing Impacts of Coastal Development on the Ecology and Human Well-Being of Tidal Creek Ecosystems (from Sanger et al. 2008).

Southeastern tidal creeks and associated watersheds are sensitive to coastal development and provide an early warning of potential degradation from upland land uses well before adverse conditions would be detected in larger coastal waters (e.g., tidal rivers, bays). Accounting for the spatial variability in hydrological and other watershed attributes among individual tidal creek systems is an important factor to consider in assessing the environmental quality of these habitats. Thus, the application of an appropriate tidal creek classification scheme in the sampling design process to accommodate such variability was a critical aspect of the research described in Volume I. One important finding of this research was that the sensitivity of tidal creeks to changes in the environmental quality of the surrounding watersheds diminishes downstream toward the mouths of the creeks. Smaller intertidal creeks generally had higher concentrations of non-point source pollutants (e.g., water quality, nutrients, and pathogen indicators), which likely reflect both the greater upland runoff component and estuarine dilution influence (i.e., tidal flushing) associated with larger creeks. Additionally, indicators of deteriorating environmental quality were found to vary directly with increasing levels of impervious cover, the latter allowing greater inputs of runoff and associated pollutants from the surrounding watershed into tidal creeks, particularly in headwater regions. The integrity and productivity of headwater portions of tidal creek environments are often impaired by land use changes and associated non-point source pollution, suggesting that these habitats serve as valuable early-warning sentinels of ensuing stress including ecological and potential public health threats (e.g., seafood consumption advisories, swimming advisories). A conceptual model of these linkages was validated and expanded for the southeastern US. Lastly, the tidal creek study and its associated conceptual model provide a useful framework for forecasting potential changes in ecological and human health indicators within these systems in relation to varying watershed attributes and land use patterns.

4.2 Summary Points from Volume II: Assessing Ecological Condition and Stressor Impacts in Subtidal Waters of the North Carolina NERRS (Present Volume)

This component of the project was aimed at assessing the status of ecological condition and stressor impacts in subtidal estuarine waters throughout the four North Carolina NERR locations (Currituck Sound, Rachel Carson, Masonboro Island, and Zeke's Island). Sampling incorporated multiple indicators of ecosystem condition including measures of water quality, sediment quality, biological condition, and potential threats to human health and well-being (e.g., fish-tissue contaminant levels relative to human health consumption limits, various aesthetic properties). A probabilistic sampling design permitted statistical estimation of the spatial extent of degraded versus non-degraded condition across these estuaries relative to specified threshold levels of the various indicators (where possible). With some exceptions, the status of this reserve appeared to be in relatively good to fair condition overall, with the majority of the area (about 54%) having various water quality, sediment quality, and biological (benthic) condition indicators rated in the healthy to intermediate range of corresponding guideline thresholds. Only three of the 30 stations sampled, representing 10.5% of the area, had one or more of these indicators rated as poor/degraded in all three categories. However, although co-occurrences of adverse biological and abiotic environmental conditions were limited spatially, at least one indicator of ecological condition rated in the poor/degraded range was observed over a broader area (35.5% represented by 11 stations). In addition, fish-tissue contaminant data were not included in these overall spatial estimates; however, the majority of samples (77% of fish that were analyzed, from 79%, of stations where fish were caught) contained inorganic arsenic above the consumption limits for human cancer risks, though most likely derived from natural sources. Such symptoms reflect a growing realization that North Carolina estuaries are under multiple pressures from a variety of natural and human influences. These data also suggest that, while the current status of overall ecological condition appears to be good to fair, long-term monitoring is warranted to track potential changes in the future. This study establishes an important baseline of overall ecological condition within the NC NERR that can be used to evaluate any such future changes and to trigger appropriate management actions in this rapidly evolving coastal environment.

4.3 Concluding Remarks on Coastal Management Applications and Opportunities

NCCOS's mission, as defined in its FY05-09 Strategic Plan (NCCOS 2004), is to provide coastal managers with scientific information and tools needed to balance society's environmental, social, and economic goals. The NCCOS Strategic Plan also calls for baseline assessments of ecological resources and potential stressor impacts in NERRS and other NOAA protected areas. The NERRS' mission is to practice and promote coastal and estuarine stewardship through innovative research and education activities focused on the NERRS (NERRS 2005). The present collaborative studies sought to address common research and management goals supportive of both program missions. The two studies provide new information on the current status of the ecological condition and human health risks at NERRS sites and neighboring waters in Georgia, South Carolina, and North Carolina as well as a set of complementary assessment tools for monitoring future conditions in these same areas or in other NERRS locations. The tidal creek study and its associated conceptual model (Volume I) provide a framework for forecasting potential changes from coastal development on the ecological and human health and well-being within these systems. The tidal creek study also exemplifies the utility of these habitats as a sentinel of environmental signals in areas of estuaries (e.g., in upper reaches close to pollutant sources) where signals are most likely to occur. The probabilistic sampling approach used in the subtidal assessment (Volume II) provides an additional unbiased statistical basis for quantifying the spatial extent of condition relative to the various measured indicators and desired management thresholds, throughout a targeted resource category, and thus a quantitative baseline for monitoring how the relative proportions of healthy vs. degraded areas may be changing with time. Thus, in addition to providing new information on the status of ecosystem conditions in specific southeastern U.S. NERRS locations, the results also are intended to serve as a framework of assessment strategies that could be applied systematically across other reserves to support national comparisons. Such ecological assessment tools would also complement system-wide, water-quality monitoring program (SWMP) and other site-specific research activities currently underway in the NERRS program.

Such baseline assessments of the status of ecosystem conditions and stressor impacts also provide the first steps in the implementation of Integrated Ecosystem Assessments (IEAs) of NERRS sites. An IEA is a synthesis and quantitative analysis of information on relevant natural and socio-economic factors in relation to specified ecosystem management goals (Murawski and Menashes 2007, Levin et al. 2008). The NERRS, as a system of protected areas, offers an ideal series of place-based sites for an IEA, which includes the assessment of baseline conditions defining current ecosystem status as well as potential stressor impacts and their links to source drivers and pressures (as was the focus here). NOAA has placed an emphasis on conducting IEAs to support improved ecosystem approaches to management (EAM) within its protected coastal resources in order to offer coastal managers a more comprehensive framework to their coastal decision making. Such an approach requires increased understanding of these complex systems and improved integration and collaboration in their management.

Related to the above point, as a NOAA protected resource, the NERRS offers an ideal opportunity to become a suite of place-based reference sites across the nation for documenting status and trends in coastal ecosystem conditions among reserves and in comparison to other non-protected areas. Results of the present two studies have provided new information on the status of conditions at NERRS sites in the southeastern U.S. These areas were found to be reasonable regional references, with the caveat that some symptoms of stress were detectable and thus the realization that such areas and surrounding watersheds are under multiple pressures from a variety of natural and human influences. Long-term monitoring is warranted to track potential changes in the future. The data and assessment strategies provided here can be applied in any such efforts for these same areas, as well as in any future surveys in other NERRS sites to support broader-scale regional and national comparisons.

Another underlying project goal is to make the present information and assessment tools readily available for meeting NERRS research and management needs. There is a tremendous opportunity to achieve this goal through the educational and outreach resources of NERRS, including their strong education programs, Coastal Training Programs (CTP), and stewardship coordinators. Any related efforts to inform the public and coastal management community through targeted presentations and products derived from these studies should help to expand their utility toward addressing important coastal management and human health concerns.

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Appendix A. Locations, depths, and water and sediment characteristics of 30 stations sampled in NC NERRS in September 2006.

NERRS Site	Station	Latitude (DD)	Longitude (DD)	Near-Bottom Water					TSS[ab] (mg/L)	TOC (mg/g)	% Coarse (sand/gravel)	% Silt-Clay	Median phi
				Depth (m)	Temp. (ºC)	Salinity (ppt)	DO (mg/L)	pH					
Currituck Bank	1	36.38929	-75.8413	1	24.25	2.7	8.3	8.01	20 (30)	1.98	96.76	3.24	2.305
	2	36.39447	-75.8468	1	23.69	2.74	6.81	7.64	18.5 (27.75)	25.11	44.3	55.7	4.163
	3	36.39127	-75.8590	1	25.21	2.59	8.97	8.7	18.5 (27.75)	2.68	72.46	27.54	3.418
	4	36.39926	-75.8474	1	23.19	2.71	5.92	7.28	13.5 (20.25)	8.63	70.31	29.69	3.684
Masonboro Island	1	34.12385	-77.8679	2.02	24.39	35.23	5.8	7.82	6 (9)	1.9	89.31	10.69	2.367
	2	34.18657	-77.8185	3.83	25.03	36.14	6.29	8.02	8.5 (12.75)	0.53	98.21	1.79	1.13
	3	34.12228	-77.8588	1.05	23.61	21.91	5.34	7.59	8 (12)	4.71	86.97	13.03	2.623
	4	34.11205	-77.8627	0.66	23.3	19.95	5.08	7.69	8.5 (12.75)	5.29	85.35	14.65	2.825
	5	34.15813	-77.8507	1.2	22.87	33.86	5.34	7.74	9.5 (14.25)	0.91	97.24	2.76	2.502
	6	34.17625	-77.8258	3.4	25.06	36.2	5.84	8.03	9.5 (14.25)	0.81	99.69	0.31	1.549
	7	34.16906	-77.8425	1.24	23.23	35.53	5.67	7.86	6 (9)	1.32	99.45	0.55	2.186
	8	34.13656	-77.8503	1.15	23.65	29.62	5.06	7.63	15.5 (23.25)	16.7	55.7	44.3	3.584
	9	34.09257	-77.8709	1.3	24.89	35.79	6.19	7.83	8.5 (12.75)	10.27	72.91	27.09	3.343
	10	34.14796	-77.8526	0.85	22.48	29.49	4.61	7.65	9.5 (14.25)	1.8	99.08	0.92	2.504
	11	34.13828	-77.8643	2.26	25.26	36.22	5.72	7.94	6 (9)	2.54	91.45	8.55	2.231
	12	34.17035	-77.8296	2.15	24.76	36.09	6.07	8.03	7 (10.5)	1.11	99.83	0.17	2.221
Rachel Carson	1	34.70448	-76.6583	4.3	25.3	36.05	5.77	8.02	10 (15)	0.86	99.41	0.59	2.237
	2	34.70024	-76.6453	0.8	25.07	35.69	5.81	7.94	19 (28.5)	1.07	99.66	0.34	2.321
	3	34.69266	-76.6123	1.03	23.31	34.71	5.56	7.75	14 (21)	2.26	91.58	8.42	2.686
	4	34.70261	-76.6372	1.37	23.94	33.89	5.78	7.57	24 (36)	0.82	99.42	0.58	1.066
	5	34.69811	-76.6022	0.95	23.91	34.76	6.01	7.78	14.5 (21.75)	8.99	53.65	46.35	3.764
	6	34.71168	-76.6732	1.1	23.74	32.78	5.23	7.43	11.5 (17.25)	2.21	88.53	11.47	2.595
	7	34.70574	-76.6747	2.27	25.39	35.9	5.89	8.04	7.5 (11.25)	0.48	99.92	0.08	2.015
	8	34.69778	-76.6093	1.05	25.26	35.96	5.88	7.92	7.5 (11.25)	6.24	64.48	35.52	3.642
	9	34.70010	-76.6307	1.51	25.6	35.65	6.32	7.9	10 (15)	0.7	99.2	0.8	2.346
Zeke's Island	1	33.92343	-77.9484	1.07	24.14	11.42	5.66	7.61	14.5 (21.75)	4.06	86.61	13.39	2.711
	2	33.95100	-77.9457	0.69	23.67	12.13	5.9	7.7	18 (27)	37.75	27.09	72.91	6.152
	3	33.93167	-77.9541	1.97	23.8	9.89	5.7	7.56	13.5 (20.25)	2.69	95.48	4.52	3.214
	4	33.93312	-77.9391	1.01	24.72	11.83	5.68	7.76	11 (16.5)	8.13	78.5	21.5	2.696
	5	33.95433	-77.9360	1.41	24.84	11.73	5.44	7.53	11.5 (17.25)	36.79	33.93	66.07	5.039

a. Surface water.
b. Value in parentheses is TSS converted to NTU (reference).

Appendix B. Summary by station of nutrient and chlorophyll concentrations in surface waters at 30 stations sampled in NC NERRS in September 2006.

NERRS Site	Station	DIN (mg/L)	NH_4^+ (mg/L)	TDN (mg/L)	TN (mg/L)	DIP (mg/L)	TDP (mg/L)	TP (mg/L)	Si (mg/L)	CHL *a* (µg/L)	Phaeophytin (µg/L)
Currituck Banks	1	0.023	0.020	0.54	1.53	0.0029	0.0072	0.0474	1.50	31.75	3.38
	2	0.010	0.007	0.47	1.40	0.0020	0.0049	0.0363	1.31	32.6	5.14
	3	0.014	0.011	0.46	1.30	0.0024	0.0043	0.0350	1.36	29.45	4.23
	4	0.023	0.020	0.53	1.36	0.0024	0.0056	0.0397	1.29	33.07	5.01
Masonboro Island	1	0.007	0.003	0.20	0.31	0.0086	0.0191	0.0418	0.25	5.25	1.83
	2	0.008	0.003	0.18	0.29	0.0046	0.0151	0.0358	0.11	3.66	1.56
	3	0.104	0.055	0.51	0.59	0.0271	0.0443	0.0627	0.84	3.43	1.91
	4	0.115	0.056	0.56	0.64	0.0338	0.0501	0.0680	0.98	2.70	1.56
	5	0.014	0.006	0.28	0.39	0.0131	0.0225	0.0433	0.32	5.24	4.05
	6	0.008	0.003	0.18	0.27	0.0051	0.0152	0.0340	0.12	3.89	1.61
	7	0.008	0.003	0.27	0.37	0.0062	0.0190	0.0376	0.23	3.70	1.59
	8	0.054	0.035	0.34	0.48	0.0133	0.0270	0.0626	0.50	6.15	2.96
	9	0.018	0.008	0.22	0.31	0.0075	0.0203	0.0432	0.22	3.59	1.27
	10	0.068	0.042	0.38	0.49	0.0163	0.0347	0.0585	0.57	4.97	2.59
	11	0.008	0.003	0.19	0.28	0.0068	0.0138	0.0326	0.16	4.16	1.44
	12	0.007	0.003	0.18	0.28	0.0079	0.0161	0.0358	0.15	3.66	1.56
Rachel Carson	1	0.007	0.003	0.16	0.28	0.0036	0.0127	0.0470	0.11	6.2	2.63
	2	0.009	0.003	0.18	0.38	0.0034	0.0124	0.0556	0.13	7.76	3.54
	3	0.011	0.003	0.23	0.34	0.0043	0.0141	0.0345	0.26	3.54	1.64
	4	0.008	0.003	0.23	0.43	0.0028	0.0134	0.0543	0.31	6.21	3.68
	5	0.011	0.004	0.20	0.32	0.0029	0.0120	0.0417	0.24	3.7	1.62
	6	0.015	0.007	0.25	0.39	0.0054	0.0213	0.0396	0.35	5.26	2.41
	7	0.007	0.003	0.16	0.23	0.0032	0.0117	0.0319	0.13	4.90	1.80
	8	0.013	0.008	0.18	0.26	0.0042	0.0126	0.0302	0.12	3.74	1.48
	9	0.007	0.003	0.18	0.24	0.0031	0.0122	0.0285	0.15	3.88	1.29
Zeke's Island	1	0.221	0.123	0.80	0.94	0.0532	0.0675	0.1011	1.41	8.90	3.00
	2	0.237	0.141	0.78	0.91	0.0479	0.0627	0.1019	1.31	11.44	3.54
	3	0.186	0.074	0.81	0.85	0.0463	0.0624	0.0855	1.34	3.18	1.62
	4	0.239	0.150	0.78	0.89	0.0524	0.0697	0.1004	1.53	7.33	2.83
	5	0.195	0.089	0.77	0.87	0.0463	0.0653	0.0870	1.36	3.95	1.58

Appendix C. Summary of sediment contaminant concentrations (dry mass) by analyte at 30 NC NERRS stations. Concentrations that were reported below method detection limits (<MDL) were assigned a value of zero for data analysis purposes.

Analyte	Currituck Banks			Rachel Carson			Masonboro Sound			Zeke's Island		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Metals (% dry)												
Aluminum	1.62	0.560	2.86	0.728	0.222	1.86	1.37	0	8.57	2.67	0.656	5.64
Iron	1.11	0.595	2.03	0.599	0	1.67	0.477	0	1.59	2.06	0.587	3.98
Trace Metals (µg/g dry mass)												
Arsenic	1.87	0.690	3.66	2.41	1.34	5.13	2.89	1.45	8.20	7.99	2.55	15.1
Barium	167	90.0	205	166	89.0	260	120	84.7	177	163	108	296
Beryllium	0.272	01	0.559	0.206	0	0.644	0.202	0	0.71	0.804	0.251	1.54
Cadmium	0.069	0.021	0.151	0.027	0.011	0.051	0.065	0.044	0.120	0.104	0.050	0.182
Chromium	23.6	15.9	35.0	16.0	6.96	28.10	17.2	9.18	32.4	29.5	16.9	46.0
Cobalt	3.39	1.41	5.74	1.70	0.671	3.67	1.24	0.512	2.85	4.63	1.58	8.97
Copper	1.96	0	5.87	0	0	0	2.57	0	12.8	7.19	0	18.4
Lead	11.9	6.30	19.7	7.45	3.17	13.2	7.32	4.26	14.0	15.2	8.24	25.5
Lithium	12.6	4.02	26.2	7.59	2.52	23.5	7.47	1.79	24.8	28.2	5.84	57.4
Manganese	108	72.3	152	67.9	36.9	106	45.9	27.4	74.2	216	70.8	465
Mercury	0.014	0.002	0.037	0.005	0.001	0.017	0.0	0.000	0.0	0.031	0.006	0.066
Nickel	5.52	1.42	11.3	2.57	0	7.880	2.25	0	7.47	8.94	2.47	18.0
Selenium	0.185	0	0.509	0.073	0	0.369	0.197	0	0.549	0.487	0.193	0.930
Silver	0	0	0	0	0	0	0	0	0	0	0	0
Thallium	0.238	0.106	0.357	0.171	0.061	0.302	0.180	0.107	0.295	0.256	0.148	0.406
Tin	1.03	0.551	1.51	0.584	0.198	1.08	0.550	0.245	1.06	1.20	0.566	2.18
Uranium	1.24	0.746	1.64	0.737	0.451	1.18	1.21	0.925	1.56	1.61	1.00	2.28
Vanadium	31.2	17.3	49.5	18.5	7.59	36.2	18.8	10.4	37.6	37.6	18.8	62.3
Zinc	21.2	0	44.9	8.63	0	34.6	9.77	0	43.7	44.5	0	90.4
PAHs (ng/g dry)												
Napthalene	0	0	0	0	0	0	0	0	0	4.25	0	11.3
2-MethylNapthalene	0	0	0	0	0	0	0	0	0	0	0	0
1-MethylNapthalene	0	0	0	0	0	0	0	0	0	0	0	0
biphenyl	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethylnaphthalene	0	0	0	0	0	0	0	0	0	0	0	0
acenaphthylene	0	0	0	0	0	0	0	0	0	0	0	0
acenaphthene	0	0	0	0	0	0	0	0	0	0	0	0
1,6,7-trimethylnaphthalene	0	0	0	0	0	0	0	0	0	0	0	0
flourene	0	0	0	0	0	0	0	0	0	0	0	0
dibenzothiophene	0	0	0	0	0	0	0	0	0	0	0	0
phenanthrene	0	0	0	0	0	0	0	0	0	0	0	0
anthracene	0	0	0	0	0	0	0	0	0	0	0	0

Appendix C continued.

Analyte	Currituck Banks			Rachel Carson			Masonboro Sound			Zeke's Island		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
1-methylphenanthrene	0	0	0	0	0	0	0	0	0	0	0	0
flouranthene	0	0	0	0	0	0	0	0	0	0	0	0
pyrene	0	0	0	0	0	0	0	0	0	0	0	0
benz(a)anthracene	0	0	0	0	0	0	0	0	0	0	0	0
chrysene+triphenylene	0	0	0	0	0	0	0	0	0	0	0	0
benzo(b)flouranthene	3.14	0	8.91	3.98	0	12.8	0	0	0	12.9	3.76	23.5
benzo(j+k)flouranthene	0	0	0	0	0	0	0	0	0	0	0	0
benzo(e)pyrene	0	0	0	0	0	0	0	0	0	0	0	0
benzo(a)pyrene	0	0	0	0	0	0	0	0	0	0	0	0
perylene	6.57	0	16.3	0	0	0	0	0	0	36.1	9.25	80.0
indeno(1,2,3-cd)pyrene	0	0	0	0	0	0	0	0	0	0	0	0
dibenz(a,h)anthracene	0	0	0	0	0	0	0	0	0	0	0	0
benzo(g,h,i)perylene	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL PAHs	9.71	0.00	25.2	16.6	0.00	67.1	14.9	0.00	106	68.6	13.0	154
PBDEs (ng/g dry)												
PBDE 17	0	0	0	0	0	0	0	0	0	0	0	0
PBDE 28	0	0	0	0	0	0	0	0	0	0	0	0
PBDE 71	0	0	0	0	0	0	0	0	0	0	0	0
PBDE 47	0	0	0	0	0	0	0	0	0	0	0	0
PBDE 66	0	0	0	0	0	0	0	0	0	0	0	0
PBDE 100	0	0	0	0	0	0	0	0	0	0	0	0
PBDE 99	0	0	0	0	0	0	0	0	0	0	0	0
PBDE 85	0	0	0	0	0	0	0	0	0	0	0	0
PBDE 154	0	0	0	0	0	0	0	0	0	0	0	0
PBDE 153	0	0	0	0	0	0	0	0	0	0	0	0
PBDE 138	0	0	0	0	0	0	0	0	0	0	0	0
PBDE 183	0	0	0	0	0	0	0	0	0	0	0	0
PBDE 190	0	0	0	0	0	0	0	0	0	0	0	0
PCBs (ng/g dry)												
PCB 103	0	0	0	0	0	0	0	0	0	0	0	0
PCB 104	0	0	0	0	0	0	0	0	0	0	0	0
PCB 105	0	0	0	0	0	0	0	0	0	0	0	0
PCB 106/118	0	0	0	0	0	0	0	0	0	0	0	0
PCB 107/108	0	0	0	0	0	0	0	0	0	0	0	0
PCB 110	0	0	0	0	0	0	0	0	0	0	0	0
PCB 114	0	0	0	0	0	0	0	0	0	0	0	0
PCB 119	0	0	0	0	0	0	0	0	0	0	0	0

Analyte	Currituck Banks			Rachel Carson			Masonboro Sound			Zeke's Island		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
PCB 12	0	0	0	0	0	0	0	0	0	0	0	0
PCB 123	0	0	0	0	0	0	0	0	0	0	0	0
PCB 126	0	0	0	0	0	0	0	0	0	0	0	0
PCB 128/167	0	0	0	0	0	0	0	0	0	0	0	0
PCB 130	0	0	0	0	0	0	0	0	0	0	0	0
PCB 132/168	0	0	0	0	0	0	0	0	0	0	0	0
PCB 138/163/164	0.20	0	0.44	0.10	0	0.23	0.11	0	0.29	0.34	0.17	0.55
PCB 141	0	0	0	0	0	0	0	0	0	0	0	0
PCB 146	0	0	0	0	0	0	0	0	0	0	0	0
PCB 149	0	0	0	0	0	0	0	0	0	0	0	0
PCB 15	0	0	0	0	0	0	0	0	0	0	0	0
PCB 151	0	0	0	0	0	0	0	0	0	0	0	0
PCB 153	0	0	0	0	0	0	0	0	0	0	0	0
PCB 154	0	0	0	0	0	0	0	0	0	0	0	0
PCB 156	0	0	0	0	0	0	0	0	0	0	0	0
PCB 157	0	0	0	0	0	0	0	0	0	0	0	0
PCB 158	0	0	0	0	0	0	0	0	0	0	0	0
PCB 159	0	0	0	0	0	0	0	0	0	0	0	0
PCB 169	0	0	0	0	0	0	0	0	0	0	0	0
PCB 170/190	0	0	0	0	0	0	0	0	0	0	0	0
PCB 172	0	0	0	0	0	0	0	0	0	0	0	0
PCB 174	0	0	0	0	0	0	0	0	0	0	0	0
PCB 177	0	0	0	0	0	0	0	0	0	0	0	0
PCB 18	0	0	0	0	0	0	0	0	0	0	0	0
PCB 180	0	0	0	0	0	0	0	0	0	0	0	0
PCB 183	0	0	0	0	0	0	0	0	0	0	0	0
PCB 184	0	0	0	0	0	0	0	0	0	0	0	0
PCB 187	0	0	0	0	0	0	0	0	0	0	0	0
PCB 188	0	0	0	0	0	0	0	0	0	0	0	0
PCB 189	0	0	0	0	0	0	0	0	0	0	0	0
PCB 193	0	0	0	0	0	0	0	0	0	0	0	0
PCB 194	0	0	0	0	0	0	0	0	0	0	0	0
PCB 195	0	0	0	0	0	0	0	0	0	0	0	0
PCB 198	0	0	0	0	0	0	0	0	0	0	0	0
PCB 2	0	0	0	0	0	0	0	0	0	0	0	0
PCB 20	0	0	0	0	0	0	0	0	0	0	0	0
PCB 200/201	0	0	0	0	0	0	0	0	0	0	0	0
PCB 202	0	0	0	0	0	0	0	0	0	0	0	0
PCB 206	0	0	0	0.02	0	0.16	0.03	0	0.18	0.26	0	0.70
PCB 207	0	0	0	0	0	0	0	0	0	0	0	0

Analyte	Currituck Banks			Rachel Carson			Masonboro Sound			Zeke's Island		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
PCB 209	0	0	0	0	0	0	0	0	0	0	0	0
PCB 26	0	0	0	0	0	0	0	0	0	0	0	0
PCB 28	0	0	0	0	0	0	0	0	0	0	0	0
PCB 29	0	0	0	0	0	0	0	0	0	0	0	0
PCB 3	0	0	0	0	0	0	0	0	0	0	0	0
PCB 31	0	0	0	0	0	0	0	0	0	0	0	0
PCB 37	0.20	0	0.78	0	0	0	0	0	0	0	0	0
PCB 44	0	0	0	0	0	0	0	0	0	0	0	0
PCB 45	0	0	0	0	0	0	0	0	0	0	0	0
PCB 48	0	0	0	0	0	0	0	0	0	0	0	0
PCB 5/8	0	0	0	0	0	0	0	0	0	0	0	0
PCB 50	0	0	0	0	0	0	0	0	0	0	0	0
PCB 52	0	0	0	0	0	0	0	0	0	0	0	0
PCB 56/60	0	0	0	0	0	0	0	0	0	0	0	0
PCB 61/74	0	0	0	0	0	0	0	0	0	0	0	0
PCB 63	0	0	0	0	0	0	0	0	0	0	0	0
PCB 66	0	0	0	0	0	0	0	0	0	0	0	0
PCB 69	0	0	0	0	0	0	0	0	0	0	0	0
PCB 70	0	0	0	0	0	0	0	0	0	0	0	0
PCB 76	0	0	0	0	0	0	0	0	0	0	0	0
PCB 77	0	0	0	0	0	0	0	0	0	0	0	0
PCB 81	0	0	0	0	0	0	0	0	0	0	0	0
PCB 82	0	0	0	0	0	0	0	0	0	0	0	0
PCB 84	0	0	0	0	0	0	0	0	0	0	0	0
PCB 87/115	0	0	0	0	0	0	0	0	0	0	0	0
PCB 88	0	0	0	0	0	0	0	0	0	0	0	0
PCB 89/90/101	0	0	0	0	0	0	0	0	0	0	0	0
PCB 9	0	0	0	0	0	0	0	0	0	0	0	0
PCB 92	0	0	0	0	0	0	0	0	0	0	0	0
PCB 95	0	0	0	0	0	0	0	0	0	0	0	0
PCB 99	0	0	0	0	0	0	0	0	0	0	0	0
Pesticides (ng/g dry)												
2,4'-DDD	0	0	0	0	0	0	0	0	0	0	0	0
2,4'-DDE	0	0	0	0	0	0	0	0	0	0	0	0
2,4'-DDT	0	0	0	0	0	0	0	0	0	0	0	0
4,4'-DDD	0	0	0	0	0	0	0	0	0	0	0	0
4,4'-DDE	0	0	0	0	0	0	0	0	0	0	0	0
4,4'-DDT	0	0	0	0	0	0	0	0	0	0	0	0
Aldrin	0	0	0	0	0	0	0	0	0	0	0	0
Chlorpyrifos	0	0	0	0	0	0	0	0	0	0	0	0

Analyte	Currituck Banks			Rachel Carson			Masonboro Sound			Zeke's Island		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Cis-chlordane (alpha-chlordane)	0	0	0	0	0	0	0	0	0	0	0	0
Dieldrin	0	0	0	0	0	0	0	0	0	0	0	0
Endosulfan I	0	0	0	0	0	0	0	0	0	0	0	0
Endosulfan II	0	0	0	0	0	0	0	0	0	0	0	0
Endosulfan Sulfate	0	0	0	0	0	0	0	0	0	0	0	0
Gamma-HCH (g-BHC, lindane)	0	0	0	0	0	0	0	0	0	0	0	0
Heptachlor	0	0	0	0	0	0	0	0	0	0	0	0
Heptachlor epoxide	0	0	0	0	0	0	0	0	0	0	0	0
Hexachlorobenzene	0	0	0	0	0	0	0	0	0	0	0	0
Mirex	0	0	0	0	0	0	0	0	0	0	0	0
Trans-nonachlor	0	0	0	0	0	0	0	0	0	0	0	0

Appendix D. Summary by station of mean ERM quotients and the number of contaminants that exceeded the corresponding ERL or ERM values (from Long et al., 1995) at 30 NC NERRS stations.

Station	NERRS Site	Mean ERM-Q	# of ERLs exceeded	# of ERMs exceeded	Sediment Quality Assessment based on ERL/ERM exceedances[a]	Sediment Quality Assessment based on ERM-Q Threshold[b]
NC06CB01	Currituck Banks	0.003612	0	0	good	good
NC06CB02	Currituck Banks	0.018458	0	0	good	good
NC06CB03	Currituck Banks	0.007425	0	0	good	good
NC06CB04	Currituck Banks	0.009096	0	0	good	good
NC06RC01	Rachel Carson	0.00458	0	0	good	good
NC06RC02	Rachel Carson	0.002653	0	0	good	good
NC06RC03	Rachel Carson	0.004996	0	0	good	good
NC06RC04	Rachel Carson	0.005539	0	0	good	good
NC06RC05	Rachel Carson	0.014272	0	0	good	good
NC06RC06	Rachel Carson	0.004908	0	0	good	good
NO06RC07	Rachel Carson	0.002355	0	0	good	good
NO06RC08	Rachel Carson	0.011519	0	0	good	good
NC06RC09	Rachel Carson	0.004782	0	0	good	good
NC06MI01	Masonboro Sound	0.004966	0	0	good	good
NC06MI02	Masonboro Sound	0.004727	0	0	good	good
NC06MI03	Masonboro Sound	0.008107	0	0	good	good
NC06MI04	Masonboro Sound	0.008873	0	0	good	good
NC06MI05	Masonboro Sound	0.003244	0	0	good	good
NC06MI06	Masonboro Sound	0.00337	0	0	good	good
NC06MI07	Masonboro Sound	0.005015	0	0	good	good
NC06MI08	Masonboro Sound	0.020689	1	0	good	moderate
NC06MI09	Masonboro Sound	0.015499	0	0	good	good
NC06MI10	Masonboro Sound	0.00422	0	0	good	good
NC06MI11	Masonboro Sound	0.006027	0	0	good	good
NC06MI12	Masonboro Sound	0.003187	0	0	good	good
NC06ZI01	Zeke's Island	0.00563	0	0	good	good
NC06ZI02	Zeke's Island	0.036887	1	0	good	moderate
NC06ZI03	Zeke's Island	0.009127	0	0	good	good
NC06ZI04	Zeke's Island	0.010628	0	0	good	good
NC06ZI05	Zeke's Island	0.035535	1	0	good	moderate

a. Good (low contamination) = < 5 ERLS exceeded and no ERM exceeded; Moderate = ≥ 5 ERLs exceeded and no ERMs exceeded; Poor (high contamination) = ≥ 1 ERM exceeded (sensu USEPA 2004).

b. Good (low contamination) = mean ERM-Q < 0.02; Moderate = mean ERM-Q > 0.02 to 0.058; Poor (high contamination) = mean ERM-Q > 0.058 (sensu Hyland et al. 1999).

Appendix E. Summary by station of Microtox toxicity tests conducted in sediments from 30 NC NERRS stations. Stations were determined to be toxic if %EC50 was <0.5 and the silt-clay content was <20%, or if the %EC50 was <0.2 and the silt-clay content was >20%.

Station	NC NERRs Site	Silt-Clay Content (%)	Microtox EC50	Toxic Response (y/n)
NC06CB01	Currituck Banks	3.24	4.4832	n
NC06CB02	Currituck Banks	55.7	0.6316	n
NC06CB03	Currituck Banks	27.54	3.4598	n
NC06CB04	Currituck Banks	29.69	2.6036	n
NC06RC01	Rachel Carson	0.59	>16.0950	n
NC06RC02	Rachel Carson	0.34	>16.6338	n
NC06RC03	Rachel Carson	8.42	5.3420	n
NC06RC04	Rachel Carson	0.58	6.5340	n
NC06RC05	Rachel Carson	46.35	0.1112	**y**
NC06RC06	Rachel Carson	11.47	0.8575	n
NO06RC07	Rachel Carson	0.08	>.16.7856	n
NO06RC08	Rachel Carson	35.52	0.1729	**y**
NC06RC09	Rachel Carson	0.8	11.3830	n
NC06MI01	Masonboro Sound	10.69	2.3986	n
NC06MI02	Masonboro Sound	1.79	>16.9245	n
NC06MI03	Masonboro Sound	13.03	0.2857	**y**
NC06MI04	Masonboro Sound	14.65	0.2440	**y**
NC06MI05	Masonboro Sound	2.76	>15.3524	n
NC06MI06	Masonboro Sound	0.31	5.7567	n
NC06MI07	Masonboro Sound	0.55	3.6188	n
NC06MI08	Masonboro Sound	44.3	0.1709	**y**
NC06MI09	Masonboro Sound	27.09	0.0617	**y**
NC06MI10	Masonboro Sound	0.92	13.5398	n
NC06MI11	Masonboro Sound	8.55	2.3017	n
NC06MI12	Masonboro Sound	0.17	10.7327	n
NC06ZI01	Zeke's Island	13.39	2.5966	n
NC06ZI02	Zeke's Island	72.91	0.0401	**y**
NC06ZI03	Zeke's Island	4.52	1.9629	n
NC06ZI04	Zeke's Island	21.5	0.0889	**y**
NC06ZI05	Zeke's Island	66.07	0.0284	**y**

Appendix F. Summary by station of benthic macroinfaunal (> 0.5mm) characteristics at 30 stations sampled in NC NERRS in September 2006. Three replicate benthic grabs (0.04m^2 each) were taken at each station.

NERRS Site	Station	Mean # Taxa per Grab	Total # Taxa per Station	Mean Density (#/m^2)	Mean H′ per Grab	B-IBI Score
Currituck Banks	1	5	11	667	1.3	2
	2	8	16	583	2.3	3
	3	20	30	5792	2.4	4.5
	4	15	23	2992	2.5	4.5
Rachel Carson	1	26	56	2317	3.4	4.5
	2	21	46	2942	3.2	5
	3	34	67	3308	4.1	4.5
	4	27	50	3267	3.4	4.5
	5	24	50	1992	3.6	4
	6	29	49	3467	3.7	4.5
	7	17	33	750	3.7	4.5
	8	41	73	4583	4.2	4.5
	9	27	54	1900	3.9	4.5
Masonboro Island	1	18	38	1417	2.9	3
	2	39	73	2500	4.7	4.5
	3	13	27	1342	2.8	2.5
	4	6	14	417	1.8	2
	5	13	22	1058	2.5	3.5
	6	21	46	1008	4	3.5
	7	47	85	3608	4.8	4
	8	6	9	1225	1.4	1.5
	9	14	29	5200	1.7	2.5
	10	17	33	1617	2.8	3.5
	11	40	70	7842	3.4	4
	12	20	43	1408	3.5	3.5
Zeke's Island	1	12	22	2683	2.1	4.5
	2	4	8	658	1.3	1.5
	3	18	30	3508	2.7	4.5
	4	9	14	3808	2.2	4.5
	5	2	3	375	0.2	1

Appendix G. Summary of fish tissue contaminant concentrations (wet mass) by analyte and fish species at NC NERRS. Concentrations that were reported below detection limits (<MDL) were assigned a value of zero for data analysis purposes.

Analyte	White Perch			Croaker			Spot			Pigfish		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Metals (µg/g wet weight)												
Aluminum	0.969	0.462	1.818	1.42	0.73	2.30	1.89	1.75	2.03	1.01	0.674	1.734
Arsenic	0.140	0.118	0.153	4.97	0.16	15.63	0.415	0.144	0.686	4.02	1.93	6.04
Inorganic Arsenic[a]	0.0028	0.0024	0.0031	0.099	0.003	0.313	0.008	0.003	0.014	0.080	0.039	0.121
Barium	0.0460	0.0387	0.0579	0.071	0.032	0.236	0.097	0.097	0.097	0.064	0.031	0.115
Beryllium	0	0	0	0	0	0	0	0	0	0	0	0
Cadmium	0	0	0.001	0	0	0.002	0	0	0.001	0.001	0	0.002
Chromium	0.459	0.431	0.495	0.434	0.300	0.560	0.508	0.486	0.529	0.519	0.323	0.858
Cobalt	0	0	0	0.002	0	0.010	0.009	0	0.018	0	0	0
Copper	0.288	0.251	0.317	0.343	0.274	0.556	0.331	0.323	0.340	0.448	0.313	0.586
Iron	10.6	9.4	11.3	11.5	10.2	13.0	25.7	16.2	35.1	12.2	10.8	14.4
Lead	0.008	0	0.017	0.004	0	0.013	0.007	0.005	0.009	0.086	0.003	0.399
Lithium	0	0	0	0.007	0	0.019	0	0	0	0.020	0	0.028
Manganese	0.250	0.202	0.282	0.331	0.243	0.849	0.538	0.288	0.788	0.212	0.138	0.271
Mercury	0.108	0.090	0.140	0.020	0.009	0.035	0.018	0.012	0.023	0.031	0.019	0.040
Nickel	0.018	0.013	0.022	0.049	0.010	0.240	0.030	0.027	0.032	0.033	0.024	0.043
Selenium	0.671	0.603	0.731	0.726	0.527	1.25	0.523	0.502	0.545	0.701	0.518	0.842
Silver	0	0	0	0	0	0	0	0	0	0	0	0
Thallium	0	0	0	0	0	0	0	0	0	0	0	0
Tin	0	0	0	0	0	0	0.009	0	0.018	0	0	0
Uranium	0	0	0	0	0	0	0	0	0	0	0	0
Vanadium	0.078	0.067	0.085	0.111	0.060	0.168	0.096	0.064	0.129	0.156	0.124	0.175
Zinc	11.9	9.2	15.8	4.93	4.22	5.48	7.94	7.68	8.19	5.81	4.99	7.01
PAHs (ng/g wet weight)												
Napthalene	0	0	0	0	0	0	0	0	0	0	0	0
2-MethylNapthalene	0	0	0	0	0	0	0	0	0	0	0	0
1-MethylNapthalene	0	0	0	0	0	0	0	0	0	0	0	0
biphenyl	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethylnaphthalene	0	0	0	0	0	0	0	0	0	0	0	0
acenaphthylene	0	0	0	0	0	0	0	0	0	0	0	0
acenaphthene	0	0	0	0	0	0	0	0	0	0	0	0
1,6,7-trimethylnaphthalene	0	0	0	0	0	0	0	0	0	0	0	0
flourene	0	0	0	0	0	0	0	0	0	0	0	0
dibenzothiophene	0	0	0	0	0	0	0	0	0	0	0	0
phenanthrene	0	0	0	0	0	0	0	0	0	0	0	0
anthracene	0	0	0	0	0	0	0	0	0	0	0	0
1-methylphenanthrene	0	0	0	0	0	0	0	0	0	0	0	0
flouranthene	0	0	0	0	0	0	0	0	0	0	0	0
pyrene	0	0	0	0	0	0	0	0	0	0	0	0
benz(a)anthracene	0	0	0	0	0	0	0	0	0	0	0	0
chrysene+ triphenylene	0	0	0	0	0	0	0	0	0	0	0	0
benzo(b)flouranthene	0	0	0	0	0	0	0	0	0	0	0	0
benzo(j+k) flouranthene	0	0	0	0	0	0	0	0	0	0	0	0
benzo(e)pyrene	0	0	0	0	0	0	0	0	0	0	0	0
benzo(a)pyrene	0	0	0	0	0	0	0	0	0	0	0	0

Appendix G continued.

Analyte	White Perch			Croaker			Spot			Pigfish		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
perylene	0	0	0	0	0	0	0	0	0	0	0	0
indeno(1,2,3-cd) pyrene	0	0	0	0	0	0	0	0	0	0	0	0
dibenz(a,h)anthracene	0	0	0	0	0	0	0	0	0	0	0	0
benzo(g,h,i)perylene	0	0	0	0	0	0	0	0	0	0	0	0
PBDEs (ng.g wet weight)												
PBDE 17	0	0	0	0	0	0	0	0	0	0	0	0
PBDE 28	0	0	0	0	0	0	0	0	0	0	0	0
PBDE 71	0	0	0	0	0	0	0	0	0	0	0	0
PBDE 47	0	0	0	0	0	0	0	0	0	0	0	0
PBDE 66	0	0	0	0	0	0	0	0	0	0	0	0
PBDE 100	0	0	0	0	0	0	0	0	0	0	0	0
PBDE 99	0	0	0	0	0	0	0	0	0	0	0	0
PBDE 85	0	0	0	0	0	0	0	0	0	0	0	0
PBDE 154	0	0	0	0	0	0	0	0	0	0	0	0
PBDE 153	0	0	0	0	0	0	0	0	0	0	0	0
PBDE 138	0	0	0	0	0	0	0	0	0	0	0	0
PBDE 183	0	0	0	0	0	0	0	0	0	0	0	0
PBDE 190	0	0	0	0	0	0	0	0	0	0	0	0
PCBs (ng/g wet weight)												
Total PCBs	0.359	0.300	0.399	1.98	0.415	4.030	0.990	0.288	1.91	0.555	0.293	0.818
Pesticides (ng/g wet weight)												
2,4'-DDD	0	0	0	0	0	0	0	0	0	0	0	0
2,4'-DDE	0	0	0	0	0	0	0	0	0	0	0	0
2,4'-DDT	0	0	0	0	0	0	0	0	0	0	0	0
4,4'-DDD	0	0	0	0.096	0	0.675	0	0	0	0	0	0
4,4'-DDE	0.460	0	0.854	0.902	0	2.605	0	0	0.868	0	0	0
4,4'-DDT	0	0	0	0	0	0	0	0	0	0	0	0
Aldrin	0	0	0	0	0	0	0	0	0	0	0	0
Chlorpyrifos	0	0	0	0	0	0	0	0	0	0	0	0
Cis-chlordane (alpha-chlordane)	0	0	0	0	0	0	0	0	0	0	0	0
Dieldrin	0	0	0	0.297	0	0.625	0	0	0.625	0	0	0
Endosulfan I	0	0	0	0	0	0	0	0	0	0	0	0
Endosulfan II	0	0	0	0	0	0	0	0	0	0	0	0
Endosulfan Sulfate	0	0	0	0	0	0	0	0	0	0	0	0
Gamma-HCH (g-BHC, lindane)	0	0	0	0	0	0	0	0	0	0	0	0
Heptachlor	0	0	0	0	0	0	0	0	0	0	0	0
Heptachlor epoxide	0	0	0	0	0	0	0	0	0	0	0	0
Hexachlorobenzene	0	0	0	0	0	0	0	0	0	0	0	0
Mirex	0	0	0	0.088	0	1.061	0	0	0	0	0	0
Trans-nonachlor	0	0	0	0	0	0	0	0	0	0	0	0

[a]. Inorganic arsenic estimated at 2% of total arsenic (USEPA 2000).

United States Department of Commerce

Carlos M. Gutierrez
Secretary

National Oceanic and Atmospheric Administration

Vice Admiral Conrad C. Lautenbacher, Jr. USN (Ret.)
Under Secretary of Commerce for Oceans and Atmospheres

National Ocean Service

John (Jack) H. Dunnigan
Assistant Administrator for Ocean Service and Coastal Zone Management