Support for Integrated Ecosystem Assessments of NOAA's National Estuarine Research Reserve System (NERRS):

Assessment of Ecological Condition and Stressor Impacts in Subtidal Waters of the Sapelo Island National Estuarine Research Reserve

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Support for Integrated Ecosystem Assessments of NOAA's National Estuarine Research Reserve System (NERRS):

Assessment of Ecological Condition and Stressor Impacts in Subtidal Waters of the Sapelo Island National Estuarine Research Reserve

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Abstract

A study was conducted in June 2009 to assess the current status of ecological condition and potential human-health risks throughout subtidal estuarine waters of the Sapelo Island National Estuarine Research Reserve (SINERR) along the coast of Georgia. Samples were collected for multiple indicators of ecosystem condition, including water quality (dissolved oxygen, salinity, temperature, pH, nutrients and chlorophyll, suspended solids, fecal coliform bacteria and coliphages), sediment quality (granulometry, organic matter content, chemical contaminant concentrations), biological condition (diversity and abundance of benthic fauna, fish tissue contaminant levels and pathologies), and human dimensions (fish-tissue contaminant levels relative to human-health consumption limits, various aesthetic properties). Use of a probabilistic sampling design facilitated the calculation of statistics to estimate the spatial extent of the Reserve classified according to various categories (i.e., Good, Fair, Poor) of ecological condition relative to established thresholds of these indicators, where available.

Overall, the majority of subtidal habitat in the SINERR appeared to be healthy, with over half (56.7 %) of the Reserve area having water quality, sediment quality, and benthic biological condition indicators rated in the healthy to intermediate range of corresponding guideline thresholds. None of the stations sampled had one or more indicators in all three categories rated as poor/degraded. While these results are encouraging, it should be noted that one or more indicators were rated as poor/degraded in at least one of the three categories over 40 % of the Reserve study area, represented by 12 of the 30 stations sampled. Although measures of fish tissue chemical contamination were not included in any of the above estimates, a number of trace metals, pesticides, polybrominated diphenyl ethers (PBDEs), and polychlorinated biphenyls (PCBs) were found at low yet detectable levels in some fish at stations where fish were caught. Levels of mercury and total PCBs in some fish specimens fell within EPA guideline values considered safe, given a consumption rate of no more than four fish meals per month. Moreover, PCB congener profiles in sediments and fish in the SINERR exhibit a relative abundance of higher-chlorinated homologs which are uniquely characteristic of Aroclor 1268. It has been well-documented that sediments and fish in the creeks and marshes near the LCP Chemicals Superfund site, near Brunswick, Georgia, also display this congener pattern associated with Aroclor 1268, a highly chlorinated mixture of PCBs used extensively at a chlor-alkali plant that was in operation at the LCP site from 1955-1994. This report provides results suggesting that the protected habitats lying within the boundaries of the SINERR may be experiencing the effects of a legacy of chemical contamination at a site over 40km away. These effects, as well as other potential stressors associated with increased development of nearby coastal areas, underscore the importance of establishing baseline ecological conditions that can be used to track potential changes in the future and to guide management and stewardship of the otherwise relatively unspoiled ecosystems of the SINERR.

1. Introduction

To accomplish its goal of effective and sustainable spatial management of coastal and marine resources, a primary objective of NOAA's National Centers for Coastal Ocean Science (NCCOS) is to produce baseline assessments of coastal ecosystem conditions for decision-makers to evaluate their coastal management efforts and policies (NCCOS 2010). Key to accomplishing this objective is to obtain spatial and temporal data on ecologically important habitats, species, and processes in biologically important marine and coastal areas, including National Estuarine Research Reserve System (NERRS) locations. In 2006, NCCOS began working in partnership with the NERRS program to assess current status of ecological condition and human-health risks throughout NERRS, beginning with reserves in NC and GA, and to provide this information as a framework for forecasting future changes due to natural or human-induced disturbances. The work is intended to complement system-wide water-quality monitoring (SWMP) and other site-specific research activities currently underway in the NERRS program.

In 2006, NCCOS conducted studies in NERRs in GA and NC (Sanger et al. 2008, Cooksey et al. 2008). The efforts had two components: (1) a sentinel habitat component conducted in tidal creeks at the Sapelo Island, GA NERR site (SINERR) and at Masonboro Island, NC (one of four NCNERR sites); and (2) a subtidal, probabilistic sampling component carried out at all four NCNERR sites (Currituck Banks, Rachel Carson, Masonboro Island, Zeke's Island). Together, the two project components were intended to provide a demonstration of the utility of complementary assessment tools, one serving as a sentinel of environmental markers 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. The 2006 pilot project was intended to provide 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 (Cooksey et al. 2008).

The current study continues the NCCOS/NERRS partnership described above by conducting a subtidal, probabilistic assessment of ecological condition in the Sapelo Island, GA NERR site (SINERR). This survey is part of a Long Term Agreement between NCCOS and NOAA's Office of Ocean and Coastal Resource Management's (OCRM) Estuarine Reserves Division (ERD), signed in April 2008, with the purpose of establishing a formal partnership between the NERRS and NCCOS to address common research and management goals. The study was designed to assess the status of condition throughout subtidal portions of the reserve using multiple ecological indicators and a probabilistic sampling design consisting of 30 random stations. The effort was led by NCCOS personnel, with significant planning, field support and logistics, and data interpretation contributed by SINERR staff. A similar, probabilistic-based, companion study was conducted by SINERR staff to assess status of ecological condition throughout salt marsh wetland portions of the reserve. Results of the latter wetland effort will be published subsequently in the literature.

The NERRS was created as part of the Coastal Zone Management Act, passed by Congress in 1972. Under the system, healthy estuarine ecosystems which typify different regions of the U.S. are designated and managed as sites for long-term research and used as a base for estuarine education and interpretive programs. The SINERR was created in 1976 as the second such site in the NERRS. The Reserve System provides a mechanism for addressing scientific and technical aspects of coastal management problems through a comprehensive, interdisciplinary, and coordinated approach. Research and monitoring programs, including the development of baseline information, form the basis of this approach (SINERR 2008).

Located in the Duplin River estuary, the SINERR encompasses 4,000 acres of tidal salt marsh and 2,110 acres of upland maritime forest and hammock land. For the present study, a total of 30 sampling sites were selected randomly throughout the subtidal portion of the SINERR. Multiple indicators of potential stressor levels, biological condition, and basic habitat characteristics were sampled at each of these sites. By incorporating a random probabilistic sampling design, the resulting data can be used to make unbiased statistical estimates of the spatial extent of the sanctuary's health with respect to the various measured indicators and corresponding management thresholds and to provide this information as a baseline for determining how environmental conditions may be changing in the future.

2. Methods

2.1 Sampling Design and Field Collections

The overall SINERR sampling area was delineated in a Geographic Information System (GIS) using a boundary shapefile obtained from the NERRS Centralized Data Management Office (CDMO). Subtidal and emergent marsh habitats were distinguished based on classifications in the U.S. Fish and Wildlife Service National Wetlands Inventory (Cowardin et al. 1979). The base GIS layer used to identify subtidal estuarine habitat was derived from a shapefile defining wetlands and deepwater habitats of the United States (U.S. Fish and Wildlife Service 2011). For the subtidal habitat type, sampling sites were generated using the Generalized Random Tessellation Stratified (GRTS) functions for R statistical software (R Development Core Team 2008) in the package *spsurvey* (Kincaid 2008). An unstratified, equal probability survey design consisting of 30 sampling sites was generated with 100% oversample (30 replacement/alternate sites) for the subtidal habitat. Additionally, another set of sampling sites was created for the marsh habitat (30 sites plus 30 alternate). These marsh sites served as the basis for a separate companion study undertaken by the SINERR office.

Field samples were collected at 30 subtidal stations using small, trailerable boats from June 8 – 12, 2009 (Figure 1, Appendix A). At each station, samples were collected for the following core indicators:

- community structure and composition of benthic macroinfauna (> 0.5 mm)
- concentrations of chemical contaminants in sediments (metals, pesticides, polychorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and polybrominated diphenyl ethers (PBDEs))
- sediment toxicity (Microtox® assay)
- sediment grain size classification (sand, silt, clay fraction)
- sediment organic carbon content
- microbial contamination of the water column
- water-column depth, temperature, salinity, dissolved oxygen, pH, turbidity, chlorophyll *a*, total suspended solids (TSS), nutrients.

In-situ point measurements of temperature, salinity, dissolved oxygen, pH, and depth were acquired using a YSI 6-series multi-parameter sonde. For station depths > 1 m, separate readings were taken for surface and bottom water. Discrete samples (1 L) of near-surface water (~ 0.5 m below surface) were also collected at each station for the analysis of nutrients, TSS, turbidity, chlorophyll *a*, and microbial contamination.

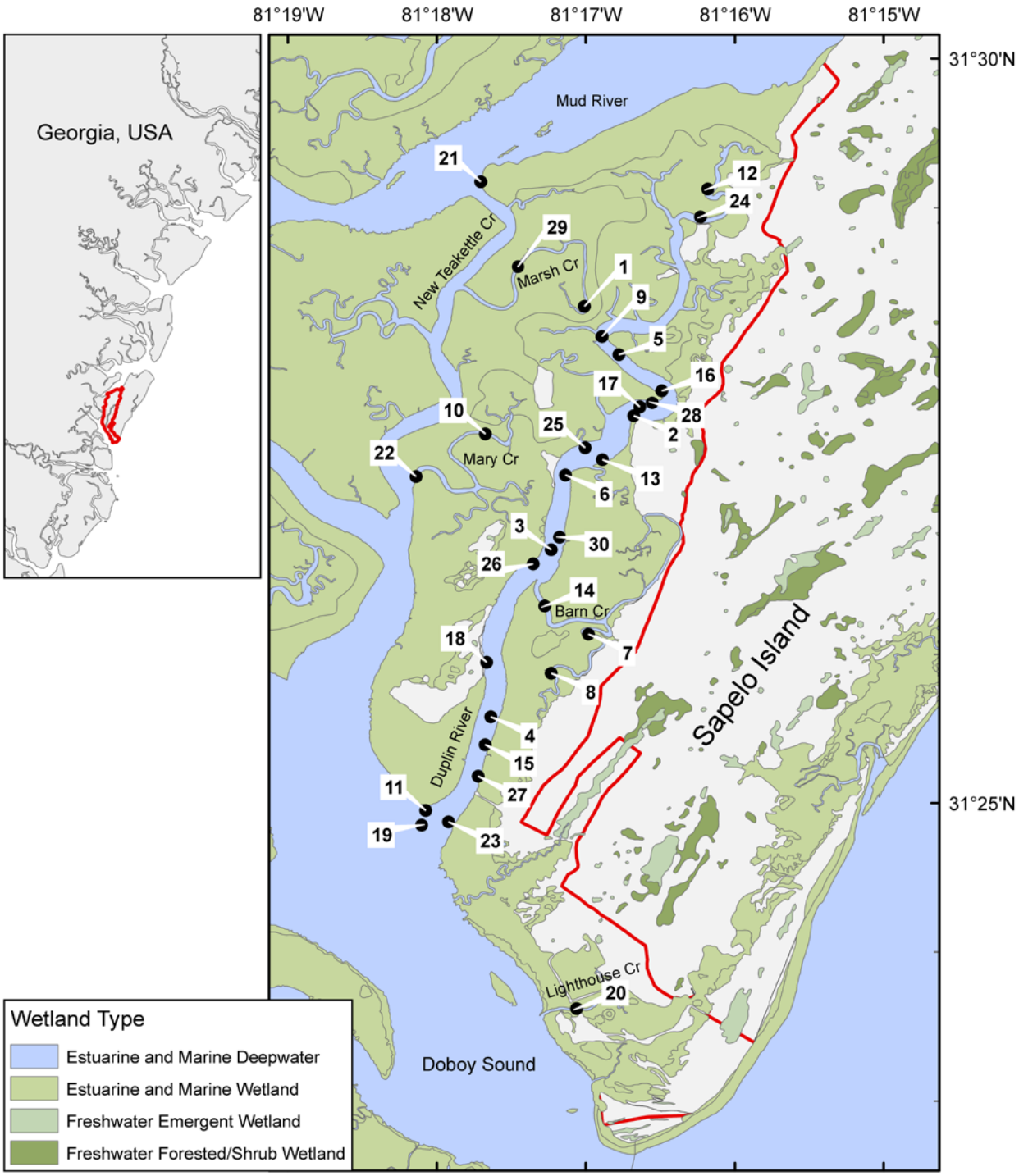

Figure 1. Map of Sapelo Island National Estuarine Research Reserve sampling sites. Subtidal and emergent marsh habitat classifications are from Classification of Wetlands and Deepwater Habitats of the United States (U.S. Fish and Wildlife Service 2011).

Sediment samples were collected at each station for analysis of chemical contaminants, total organic carbon (TOC), grain-size, sublethal toxicity (Microtox® assay), and benthic community characteristics using a 0.04-m^2 Young grab sampler. Grabs were collected to a maximum depth of 10cm and rejected if < 5 cm or if there was other evidence of sample disturbance (e.g., major slumping of sediment surface, debris caught in jaws). Two discrete grab samples for the analysis of benthic macroinfauna were collected at each station and processed as individual replicates. The contents of each grab 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. Surficial sediments (upper 2 – 3 cm) were collected and composited from additional multiple grabs to provide a quantity sufficient for the TOC, grain-size, Microtox®, and contaminant analyses. Subsamples of the composited sediment were removed and placed into appropriate sample containers. To minimize potential cross-contamination between stations, the grab sampler and utensils were rinsed with acetone and ambient water before commencement of sampling at each site. Sediments collected for contaminant analyses were maintained on ice throughout sampling and shipment and stored frozen (at -40 °C) once transferred to the laboratory. Sediment samples were analyzed for contaminants within 12 months of receipt. Sediments collected for toxicity testing were maintained on ice throughout sampling and shipment, kept under refrigeration (~ 4 °C) in the laboratory, and analyzed within 30 days of receipt.

Fishing was attempted at each station, either by hook and line or cast net, to obtain samples for tissue contaminant analysis. A total of 29 fish representing seven distinct taxa were successfully captured at nine of the 30 stations. No more than 3 individuals of any one species at a site were retained for tissue analysis, resulting in 22 fish being kept for analysis. In support of a separate study to measure contaminant levels in bottlenose dolphins and fish conducted by researchers from NOAA's Center for Human Health Risk at the Hollings Marine Lab in Charleston, S.C., an additional 21 fish were collected at four supplemental stations in the Brunswick, Georgia area south of Sapelo Island. Twelve of the 21 fish collected were retained for analysis. Tissue contaminant concentrations in these latter specimens were compared to those observed in specimens from SINERR.

2.2 Analysis of Water-Column Nutrients, Chlorophyll and Phaeopigments, TSS, and Turbidity

Initial sample preparations were performed by the field crew within a day of collection. Approximately 0.5 L of water from each station was vacuum-filtered using Filterware microfiltration glassware and a Whatman GF/F 47-mm 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). Each filter was folded and wrapped in a foil pouch, frozen, and analyzed within 30 days for chlorophyll *a* (CHLa) and phaeopigments (PHAEO). Whole (unfiltered) water samples were also obtained from each station, portions of which were placed in 60-mL polypropylene bottles and kept frozen until later analyzed for total nitrogen (TN) and total phosphorus (TP). A 25 mL aliquot of the unfiltered water was also removed and measured on site for turbidity using a Hach 2100P turbidity meter; resulting measurements were expressed in standard Nephelometric

Turbidity Units (NTU). The remaining unfiltered water from each station was used to measure TSS within seven days of collection.

Subsequent instrumental analyses were performed at the Chesapeake Biological Laboratory (Solomons, Maryland) using established analytical methods. Dissolved nutrients were measured as follows: NH4+ (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). Concentrations of TN, TP, TDN, and TDP were determined by a persulfate digestion method (Valderrama 1981). The Welschmeyer method (Welschmeyer 1994) was used to determine both CHLa and PHAEO. Concentrations of TSS were measured on a HACH DR/2500 TSS analyzer using a photometric method (method 8006, Hach 2003).

2.3 Fecal Coliform Analysis

The level of fecal coliform bacteria in water may indicate the presence of sewage pollution and is routinely monitored by states as an indicator of possible health risk to people who may be swimming in or harvesting shellfish from contaminated water. When sewage is present in the waters, elevated counts of fecal coliform bacteria occur. However, the source of the high bacteria counts may not originate with human sewage. Wildlife and domestic/farm animals can also contribute this type of bacteria to the water.

Fecal coliform densities were determined using the membrane filter technique (APHA 1998). Briefly, different volumes of each surface water sample were filtered through a 0.45 µm nitrocellulose filter, using sterile filter funnels on a vacuum manifold, and placed onto mFC Agar plates (60 x 12 mm). The plates were placed in Whirlpack bags, sealed, and incubated in a circulating waterbath for 24 hours ± 2 hours at 44.5 °C ± 0.5 °C. Typical fecal coliform colonies were counted and bacterial numbers calculated as CFU/100 ml water.

2.4 Coliphages

The F+RNA (Family Leviviridae) coliphages have been advocated for use as an indicator of enteric virus contamination (Havelaar 1993). These viruses are morphologically similar to Enteroviruses, and would be expected to exhibit similar persistence and survivability in the environment and following treatment processes. There is evidence that coliphages are a better indicator of enteric virus presence than the present fecal indicator microorganisms.
Two methods were used for the detection of coliphages. The single agar layer method (U.S. EPA method 1602) is enumerative and was used to enumerate somatic and male-specific coliphages for all samples. The enrichment method (U.S. EPA method 1601) provided presence/absence results. Water samples which were negative for male-specific coliphages by the single agar layer method were further analyzed by the enrichment presence/absence method to detect very low numbers of coliphages.

2.5 Chemical Contaminant Analysis

2.5.1 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 organic and inorganic subsamples, placed in pre-cleaned glass and polypropylene containers, respectively, 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.

2.5.2 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 for subsequent analysis of Li, Be, Al, Fe, Mg, Ni, Cu, Zn, Cd, and Ag. A second 0.25-g sub-sample of dried sediment was transferred to a Teflon-lined vessel and digested with 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 1mL 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 for subsequent analysis of V, Cr, Co, As, Sn, Sb, Ba, Tl, Pb, and U. Samples for selenium analysis were prepared by hotplate digestion using a 0.25-g sub-sample of dried sediment 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 for subsequent analysis. To prepare fish-tissue samples for analysis, 2 – 3 grams of 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. The analysis of mercury, for both sediments and tissue samples, was performed on separate aliquots of wet sediment or tissue material.

Mercury was analyzed on a Milestone DMA-80 Direct Mercury Analyzer. All remaining elemental analyses were performed using Inductively Coupled Plasma Mass Spectrometry (ICP-MS). 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).

2.5.3 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 1947 (fish muscle tissue).

2.6 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 fischeri*) were then added to the test concentrations. The liquid phase was filtered from the sediment phase and bacterial post-exposure light output was measured using Microtox® Omni Software. An EC50 value (the sediment concentration that reduced 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 nontoxic using criteria developed by Ringwood and Keppler (1998).

2.7 Benthic Community Analysis

Samples were transferred from formalin to 70 % ethanol in the laboratory. Each of the two infaunal replicates from each station was analyzed separately by independent laboratories. The first replicate was analyzed by Barry A. Vittor & Associates, Inc., Mobile, Alabama. The second replicate was analyzed in-house by the Coastal Ecology Program at the NOAA Center for Coastal Environmental Health and Biomolecular Research (CCEHBR), Charleston, South Carolina. Macroinfaunal invertebrates were sorted from the sample debris under a dissecting microscope and identified to the lowest practical taxon (usually to 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 the 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 a 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 taxa combined), densities of numerically dominant taxa (m^{-2}), number of taxa, H′ diversity (Shannon 1948, Hayek and Buzas 2010) derived with base-2 logarithms, and estimates of condition based on a benthic index of biotic integrity developed for southeastern U.S. estuaries (B-IBI, Van Dolah et al. 1999). Computation of the B-IBI followed the procedures and habitat designations of Van Dolah et al. (1999).

2.8 Data Analysis

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

Measured parameters were compared to established thresholds of concern, where available (Table 1 – Table 3), and the corresponding percentiles of the estimated CDFs were reported.

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

The 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 U.S. EPA (2000) for specific organic and inorganic contaminants (Table 3). Concentrations of contaminants measured in fish tissues (fillets 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; hence, tissue contaminant data were neither evaluated on a percent area basis nor included in the final estimate of ecological condition of SINERR (see Table 14).

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

Indicator	Threshold	Reference
Water Quality		
Salinity (psu)	< 5 = Oligohaline 5 – 18 = Mesohaline >18 – 30 = Polyhaline > 30 = Euhaline	Carriker 1967
DO (mg/L)	< 2 = Low (Poor) 2 – 5 = Moderate (Fair) > 5 = High (Good)	U.S. EPA 2008; Diaz and Rosenberg 1995
DIN (mg/L)	> 0.5 = High (Poor) 0.1 – 0.5 = Moderate (Fair) < 0.1 = Low (Good)	U.S. EPA 2008
DIP (mg/L)	> 0.05 = High (Poor) 0.01 – 0.05 = Moderate (Fair) < 0.01 = Low (Good)	U.S. EPA 2008
CHLa (µg/L)	> 20 = High (Poor) 5 – 20 = Moderate (Fair) < 5 = Low (Good)	U.S. EPA 2008
Sediment Quality		
Silt-Clay Content (%)	> 80 = Mud 20 – 80 = Muddy Sand < 20 = Sand	U.S. EPA 2008
TOC Content (mg/g)	> 50 = High (Poor) 20 – 50 = Moderate (Fair) < 20 = Low (Good)	U.S. EPA 2008
	> 35 = High (Poor)	Hyland et al. 2005
Overall chemical contamination	≥ 1 ERM value exceeded *OR* mERM-Q > 0.058 = High (Poor); ≥ 5 ERL values exceeded *OR* 0.02 < mERM-Q ≤ 0.058 = Moderate (Fair); No ERMs exceeded *AND* < 5 ERLs exceeded *AND* mERM-Q ≤ 0.02 = Low (Good)	U.S. EPA 2008; Hyland et al. 1999

Table 1. (continued).

Indicator	Threshold	Reference
Individual chemical contaminant concentrations	> ERM = High probability of bioeffects < ERL = Low probability of bioeffects	Long et al. 1995; Table 2 herein
Toxicity (Microtox®)	Silt-clay < 20 %: Toxic if EC50 < 0.5 % Silt-clay ≥ 20 %: Toxic if EC50 < 0.2 %	Ringwood et al. 1997
Biological Condition		
B-IBI	< 1.5 = Degraded benthos 2 – 2.5 = 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[a] = Moderate (Fair) All chemicals below Human Health lower risk limit = Low (Good)	U.S. EPA 2008
Individual chemical contaminants in fish tissues	Non-cancer (chronic systemic effects) endpoints based on consumption of four 8-ounce meals per month (general adult population). Cancer risk endpoints (1 in 100,000 risk level) based on consumption of four 8-ounce meals per month (general adult population).	U.S. EPA 2000; Table 3 herein

[a] Range of concentrations of a given chemical contaminant considered safe at a consumption rate of four 8-oz fish meals/month.

Table 2. Sediment Effects Range-Low (ERL) and Effects Range-Median (ERM) guideline values (Long et al. 1995).

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

Table 3. Risk-based EPA advisory guidelines for recreational fishers (U.S. EPA 2000).

	Non-cancer Health Endpoint[a]			Cancer Health Endpoint[b]		
Metals (μg/g)						
Arsenic (inorganic)[c]	>0.35	–	0.70	>0.0078	–	0.016
Cadmium	>0.35	–	0.70			
Mercury (methylmercury)[d]	>0.12	–	0.23			
Selenium	>5.90	–	12.00			
Organics (ng/g)						
Chlordane	>590	–	1200	>34	–	67
Chlorpyriphos	>350	–	700			
DDT (total)	>59	–	120	>35	–	69
Dieldrin	>59	–	120	>0.73	–	1.5
Endosulfan	>7000	–	14000			
Heptachlor epoxide	>15	–	31	>1.3	–	2.6
Hexachlorobenzene	>940	–	1900	>7.3	–	15.0
Lindane	>350	–	700	>9.0	–	18
Mirex	>230	–	470			
Toxaphene	>290	–	590	>11.0	–	21
PAHs (benzo[a]pyrene)				>1.6	–	3.2[e]
PCB (total)	>23	–	47	>5.9	–	12.0

[a] Range of concentrations for non-cancer health endpoints are based on the assumption that consumption over a lifetime of four 8-oz meals per month would not generate a chronic, systemic health risk.

[b] Range of concentrations for cancer health endpoints are based on the assumption that consumption over a lifetime of four 8-oz meals per month would yield a lifetime cancer risk no greater than an acceptable risk of 1 in 100,000.

[c] Inorganic arsenic, the form considered toxic, estimated as 2% of total arsenic.

[d] Because most mercury present in fish and shellfish tissue is present primarily as methylmercury and because of the relatively high cost of analyzing for methylmercury, the conservative assumption was made that all mercury is present as methylmercury (U.S. EPA, 2000).

[e] A non-cancer concentration range for PAHs does not exist.

3. Results and Discussion

Of the 30 stations sampled, the majority (24 sites) were located in the Duplin River (Figure 1), which represents essentially the core of the SINERR, or its largest tributary, Barn Creek/Post Office Creek. The remaining six stations were located in the western (New Teakettle Creek at Mud River, Marsh Creek, Mary Creek) and southern part of the Reserve (Lighthouse Creek near the mouth of Doboy Sound).

Station depths at the time of sampling, not corrected to Mean Lower Low Water (MLLW), ranged from 1.0 – 9.7 m (mean of 4.0 m). Depths corrected to MLLW (referenced to estimated tidal heights relative to MLLW at Daymark 173, Old Teakettle Creek) ranged from 0.1 – 7.9 m (mean of 2.7 m).

3.1 Water Quality

3.1.1 General Water Characteristics

Salinities throughout the Reserve ranged from 18.7 – 28.2 ppt, with a mean bottom salinity of 21.4 ppt (Table 4). Surface salinities were less variable (range of 18.7 – 22.3 ppt), with a mean of 20.3 ppt. Bottom salinities were highest near the mouth of the Duplin River and in Lighthouse Creek near the entrance to Doboy Sound. In the Duplin River, bottom salinities generally decreased upriver with distance from Doboy Sound (R^2=0.70, p<0.001, $d.f.$=19; Figure 2). This longitudinal salinity gradient is well-documented in the Duplin River (Kjerve 1973, Mackay 2008) and is believed to be due mainly to fresh groundwater discharge in the upper and middle Duplin.

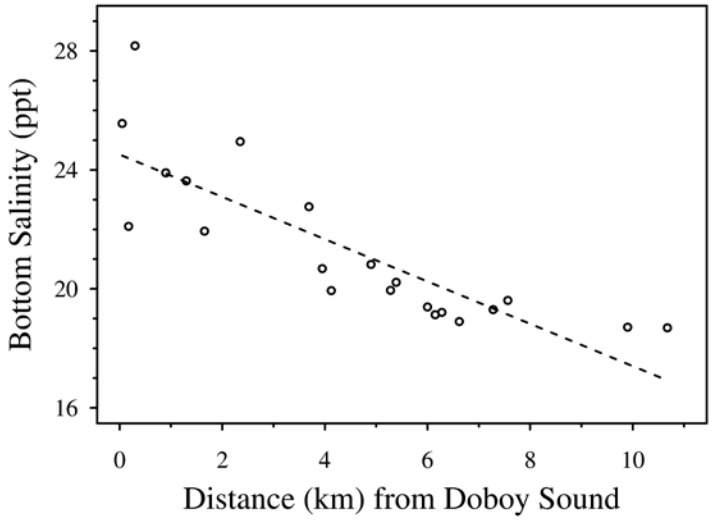

Figure 2. Longitudinal salinity gradient in the Duplin River.

Water temperatures were relatively uniform and typical for early June in southeastern U.S. estuaries. Bottom-water temperatures ranged from 25.9 – 28.2 °C (mean of 27.2 °C) and surface temperatures were slightly higher (29.2 °C max, 27.7 °C mean). Lowest temperatures were observed near the mouth of the Duplin River at Doboy Sound or at the deepest sites in the Duplin River.

Measured dissolved oxygen (DO) concentrations in bottom waters ranged from 2.3 – 5.1 mg/L (mean of 3.7 mg/L) and were slightly higher in surface waters (mean = 4.1 mg/L, max=6.0 mg/L). Most bottom DO concentrations were between 3.0 and 4.0 mg/L (Figure 3).

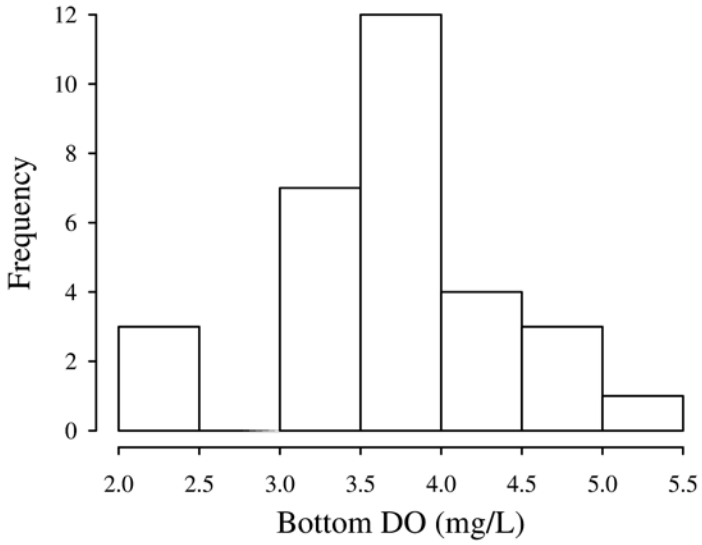

Figure 3. Frequency distribution of bottom dissolved oxygen (DO) values throughout Sapelo Island National Estuarine Research Reserve.

Bottom DO concentrations decreased along the length of the Duplin River from the mouth at Doboy Sound to the head (R^2=0.88, p<0.001, $d.f.$=19; Figure 4). This pattern has been noted by other authors (Frankenberg 1976) and is likely due to the higher oxygen demand (Pomeroy and Cai 2006) resulting from higher concentrations of particulate and dissolved organic carbon (POC and DOC) in the upper Duplin (Chalmers 1997).

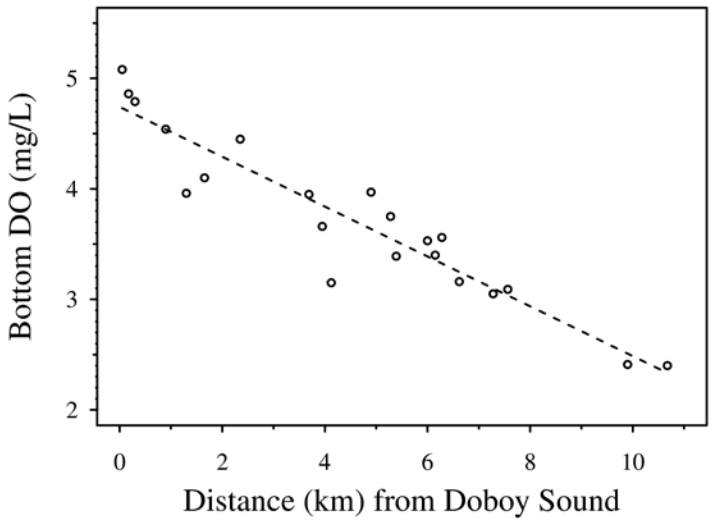

Figure 4. Longitudinal dissolved oxygen gradient in the Duplin River.

Bottom DO concentrations measured throughout the Reserve were in close agreement with real-time water quality measurements taken at the Marsh Landing Dock in the lower Duplin River (NERR fixed monitoring station sapldwq, latitude = 31.4177, longitude = -81.2961) approximately 0.5 m from the bottom. Figure 5 shows the range of DO measurements recorded

at the lower Duplin monitoring site (spldwq) during the same time period, with DO concentrations measured at the 30 stations sampled in this study superimposed. Points corresponding to stations on either side of the Marsh Landing Dock (downstream station 23 and upstream station 27) are labeled in the plot. Sites located farther upstream in the Duplin River or tidal creeks tended to have lower DO levels, as discussed above.

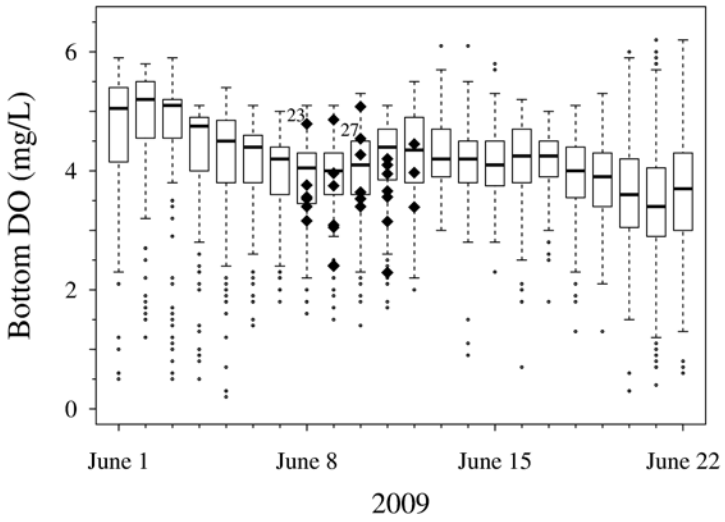

Figure 5. Real-time water quality measurements of dissolved oxygen recorded at the lower Duplin River monitoring site (box and whisker plots) compared with instantaneous dissolved oxygen levels measured at the 30 sites sampled in this study (solid diamonds).

DO levels at the time of sampling were above the commonly-cited criterion for hypoxia of 2 mg/L (U.S. EPA 2008) at all 30 stations. Using the criteria in Table 1, 96.7 % of the Reserve subtidal area would be classified as in "Fair" condition (2 – 5 mg/L) with respect to DO (Table 5, Figure 8). Only one station (station 19, mouth of Duplin River at Doboy Sound), representing 3.3 % of the area, had DO concentrations classified as "Good" (> 5 mg/L). By comparison, the most recent Georgia Coastal Assessment (Guadagnoli et al. 2005) found 63 % of the area of Georgia estuaries in "Fair" condition, while 37 % was rated as "Good".

A number of reports have used the criterion for defining "Poor" DO conditions of < 2 mg/L (U.S. EPA 2004, 2008; Bricker et al. 1999, 2007). However, Sheldon and Alber (2010) noted that earlier studies defining hypoxia as < 2 ml O_2/L (e.g., Diaz and Rosenberg 1995) have sometimes been cited incorrectly as using < 2 mg O_2/L (U.S. EPA 2004, 2008). They point out that, at standard temperature and pressure, the conversion factor from mL to mg O_2 is 1.4276, so 2 ml O_2/L is equivalent to approximately 2.85 mg O_2/L. Therefore, they recommend using 3 mg/L as a lower criterion for DO for Georgia waters. In our sampling, three stations, representing 10 % of the subtidal area of the SINERR, had DO concentrations < 3 mg/L.

The range of pH values was nearly the same in surface and bottom waters (7.0 – 7.6 in surface waters, 7.1 – 7.6 in bottom waters), with pH averaging 7.3 in both surface and bottom waters throughout the Reserve. Due to the increased buffering capacity of higher salinity seawater, pH is expected to increase with salinity. Not surprisingly, pH exhibited a longitudinal gradient in

the Duplin River, with higher pH values closest to the mouth at Doboy Sound and decreasing with distance upriver toward the headwaters (R^2=0.83, p<0.001, $d.f.$=19; Figure 6).

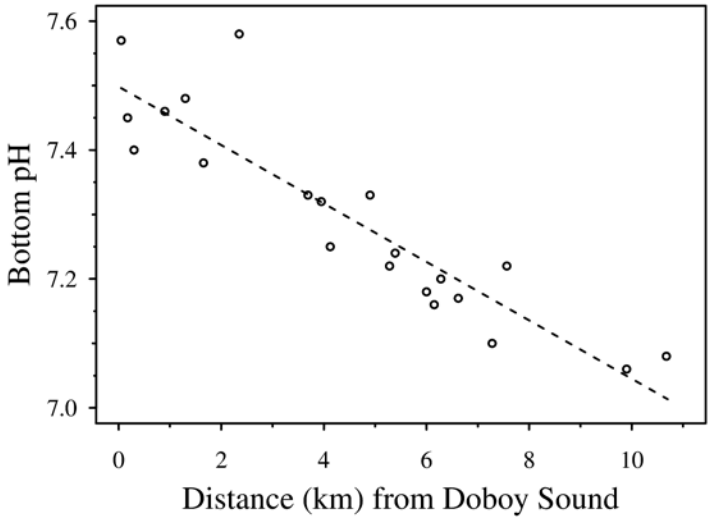

Figure 6. Longitudinal gradient of pH in the Duplin River.

Measurements of water clarity were made using a number of different approaches. The simplest is Secchi depth, which provides an integrated measure of transparency throughout the water column as the depth at which a 20 cm black and white Secchi disk is no longer visible. Additionally, turbidity was measured using a nephelometer, which provides a measure of light scattering by suspended matter in the water column. Total suspended solids (TSS) also was measured as milligrams of suspended material retained on a standard glass filter pad per liter of water.

Secchi depths ranged from 0.5 – 1.5 m, with a mean depth of 0.8 m (Table 4). For naturally turbid southeastern estuaries such as those in coastal Georgia, a criterion for "good" water clarity has been suggested as >10 % light transmission at 1 m depth (U.S. EPA 2008, Sheldon and Alber 2010), which is roughly equivalent to a Secchi depth of 0.5 m (U.S. EPA 2001). Hence, water clarity at nearly all stations in the SINERR would be classified as "good", with Secchi depth at only one site (station 29, Mary Creek) being exactly equal to the cutpoint of 0.5 m, but not exceeding it.

Turbidity ranged from 4.0 – 19.9 NTU in surface waters (mean of 9.0 NTU) and 8.7 – 48.5 NTU in bottom waters (mean = 20.9 NTU). These bottom turbidities often exceeded the median of turbidities recorded at the SINERR real-time monitoring site (spldwq) at Marsh Landing Dock, lower Duplin River during the same time period, but fell within the range of measured extremes (Figure 7). While no turbidity standard exists for Georgia coastal waters, South Carolina has adopted a maximum state standard of 25 NTU for saltwater, not to be exceeded in near-surface water samples (Van Dolah et al. 2004). Surface turbidities at all stations sampled in SINERR fell well below this value.

Total suspended solids (TSS) ranged from 46 – 106 mg/L, averaging 65.4 mg/L across the 30 sampled sites. These values appear to be typical of the region, as TSS measured throughout Georgia estuaries during four years of sampling between 2000 and 2004 (not measured in 2001) ranged from 6 – 227 mg/L, with a mean of 57 mg/L (NCA 2010). Water quality measurements from each of the 30 stations sampled in SINERR are included as Appendix A.

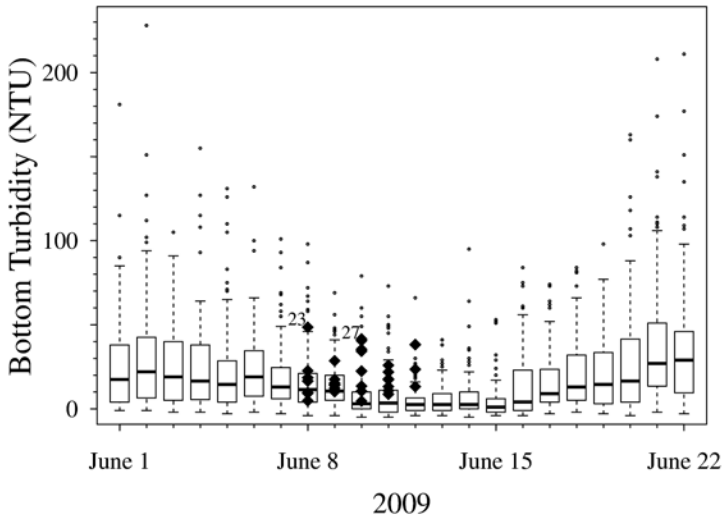

Figure 7. Real-time water quality measurements of bottom turbidity recorded at the lower Duplin River monitoring site (box and whisker plots) compared with turbidity levels measured at the 30 sites sampled in this study (solid diamonds).

3.1.2 Nutrients and Chlorophyll

Concentrations of dissolved inorganic nitrogen (DIN) ranged from 0.05 – 0.11 mg/L and averaged 0.08 mg/L (Table 4). Using criteria established by the U.S. EPA (2008), 96.7 % of the study area would be classified as "Good", with the remaining 3.3 % having "Fair" water quality with respect to DIN (Table 5, Figure 8). This is in contrast to Georgia estuaries overall, of which 54 % were classified as "Good", 37 % "Fair", and 4 % "Poor" (Guadagnoli et al. 2005).

Dissolved organic phosphorus (DIP) averaged 0.03 mg/L, ranging from 0.02 – 0.06 mg/L (Table 4). Based on the EPA nutrient criteria, 86.7 % of the subtidal area of the Reserve would be classified as "Fair" and 10 % as "Poor" (Table 5, Figure 8). No DIP measurement was available for one of the sites (station 9, representing 3.3 % of the study area). In comparison, Georgia estuarine waters in general were rated 7 % "Good", 68 % "Fair", and 20 % "Poor" (Guadagnoli et al. 2005).

Surface-water concentrations of chlorophyll *a*, an indicator of phytoplankton biomass and abundance, ranged from 3.57 – 13.22 µg/L and averaged 7.07 µg/L (Table 4). Using the criteria for chlorophyll *a* in Table 1, 23.3 % of the study area would be classified as "Good", with the remaining 76.7 % classified as "Fair" (Table 5, Figure 8). These chlorophyll *a* concentrations are lower than those measured previously in Georgia estuaries as a whole, of which only 6 % were rated "Good", 82 % "Fair", and 9 % "Poor" (Guadagnoli et al. 2005).

Water-column nutrients measured at each of the 30 stations sampled in SINERR are included as Appendix B.

3.1.3 Fecal Coliforms

The U.S. EPA has developed recommended criteria for shellfish growing waters and to protect human health associated with primary contact recreation, such as swimming or other activities that potentially involve total body immersion and/or incidental water exposure (U.S. EPA 1986). The criteria for shellfish harvesting waters requires a geometric mean count based on five consecutive samples over a 30-day period that does not exceed 14 colony-forming units (CFU)/100 ml and no more than 10 % of the samples can be greater than 43 CFU/100 ml. The criteria to protect contact recreation requires a geometric mean count that does not exceed 200 CFU/100 ml and more than 10% of the samples can exceed 400 CFU/100 ml. Since only a single sample was collected at each site during this study, we can't assess absolute compliance with the criteria; however, the data do provide some indication as to whether the sampling location is likely to meet standards.

Fecal coliform counts ranged from 1 CFU/100 ml to 37 CFU/100 ml for the 30 water samples (Appendix C). Water samples from 12 of 30 sites exceeded the lower criteria of 14 CFU/100 ml criteria for shellfish growing waters, but no sample exceeded the upper limit of 43 CFU/100 ml. None of the samples exceeded the lower criteria for contact recreation (200 CFU/100 ml). In the long running South Carolina Coastal and Estuarine Assessment Program (SCECAP), Van Dolah et al. (2006) consider any sample with $\leq$ 43 CFU/100 ml to be representative of good bacterial water quality. Based on this approach, all the Sapelo water samples would be indicative of good bacterial water quality.

3.1.4 Coliphages

No F+ coliphage were detected in any of the samples (see Appendix C). These findings suggest that the measured fecal coliforms were likely associated with wildlife rather than human sources of fecal pollution.

Table 4. Selected water and sediment characteristics measured throughout the Sapelo Island National Estuarine Research Reserve.

Parameter	Mean	Range	Std. Dev.	CDF 10th Percentile	CDF 50th Percentile	CDF 90th Percentile
Water						
Depth (m)	4.0	1.0 – 9.7	2.1	1.4	3.5	6.8
Depth (m, corr. to MLLW)	2.7	0.1 – 7.9	2.0	0.5	2.5	5.4
Surface						
Salinity (ppt)	20.3	18.7 – 22.3	1.1	18.8	20.1	21.8
Temperature (°C)	27.7	25.9 – 29.2	0.7	26.9	27.7	28.3
DO (mg/L)	4.1	2.3 – 6.0	1.0	2.5	3.8	5.3
pH	7.3	7.0 – 7.6	0.2	7.1	7.2	7.4
Turbidity (NTU)	9.0	4.0 – 19.9	4.1	4.8	7.7	14.9
Secchi Depth (m)	0.8	0.5 – 1.5	0.2	0.5	0.7	1.0
TSS (mg/L)	65.4	46 - 106	18.3	47.9	57.7	93.1
DIN (mg/L)	0.08	0.05 – 0.11	0.02	0.05	0.08	0.09
DIP (mg/L)	0.03	0.02 – 0.06	0.01	0.02	0.03	0.05
Chl *a* (µg/L)	7.07	3.57 – 13.22	2.56	3.88	6.80	10.41
Bottom						
Salinity (ppt)	21.4	18.7 – 28.2	2.5	18.9	20.4	25.0
Temperature (°C)	27.2	25.9 – 28.2	0.5	26.5	27.1	27.8
DO (mg/L)	3.7	2.3 – 5.1	0.7	2.4	3.6	4.5
pH	7.3	7.1 – 7.6	0.1	7.1	7.2	7.5
Turbidity (NTU)	20.9	8.7 – 48.5	11.0	9.7	16.9	38.4
Sediment						
TOC (mg/g)	12.7	1.0 – 33.7	10.1	2.6	9.3	28.4
Silt-clay (%)	41.0	1.7 – 99.6	33.3	5.9	31.1	90.0
Mean ERM quotient	0.014	0.003 – 0.028	0.009	0.005	0.011	0.027

Table 5. Status of water, sediment, and biological indicators throughout Sapelo Island National Estuarine Research Reserve.

Indicator	Number of sites	Estimated Percent Area	95% Confidence Limits Lower	95% Confidence Limits Upper
DO (mg/L)				
>5 (Good)	1	3.3	0.0	9.0
2 – 5 (Fair)	29	96.7	91.0	100.0
<2 (Poor)	0	0.0	0.0	0.0
DIN (mg/L)				
<0.1 (Good)	29	96.7	91.3	100.0
0.1 – 0.5 (Fair)	1	3.3	0.0	8.7
>0.5 (Poor)	0	0.0	0.0	0.0
DIP (mg/L)				
<0.01 (Good)	0	0.0	0.0	0.0
0.01 – 0.05 (Fair)	26	86.7	75.5	97.8
>0.05 (Poor)	3	10.0	0.0	20.0
Missing*	1	3.3	0.0	9.3
Chl *a* (µg/L)				
<5 (Good)	7	23.3	12.3	34.4
5 – 20 (Fair)	23	76.7	65.6	87.7
>20 (Poor)	0	0.0	0.0	0.0
Silt-clay				
<20% (Sand)	11	36.7	25.2	48.2
20 – 80% (Muddy sand)	13	43.3	27.6	59.1
>80% (Mud)	6	20.0	7.2	32.8
TOC				
<20 mg/g (Good)	23	76.7	64.3	89.0
20 – 50 mg/g (Fair)	7	23.3	11.0	35.7
>50 mg/g (Poor)	0	0.0	0.0	0.0
Significant Microtox® Toxicity	9	30.0	16.1	43.9
Chemical Contamination				
Low (Good)	22	73.3	59.9	86.7
Moderate (Fair)	8	26.7	13.3	40.1
High (Poor)	0	0.0	0.0	0.0
B-IBI				
≥3 (Healthy benthos)	24	80.0	69.7	90.3
2 – 2.5 (Some stress)	6	20.0	9.7	30.3
≤1.5 (Degraded benthos)	0	0.0	0.0	0.0

* DIP analysis results for one site (Station 09) unacceptable.

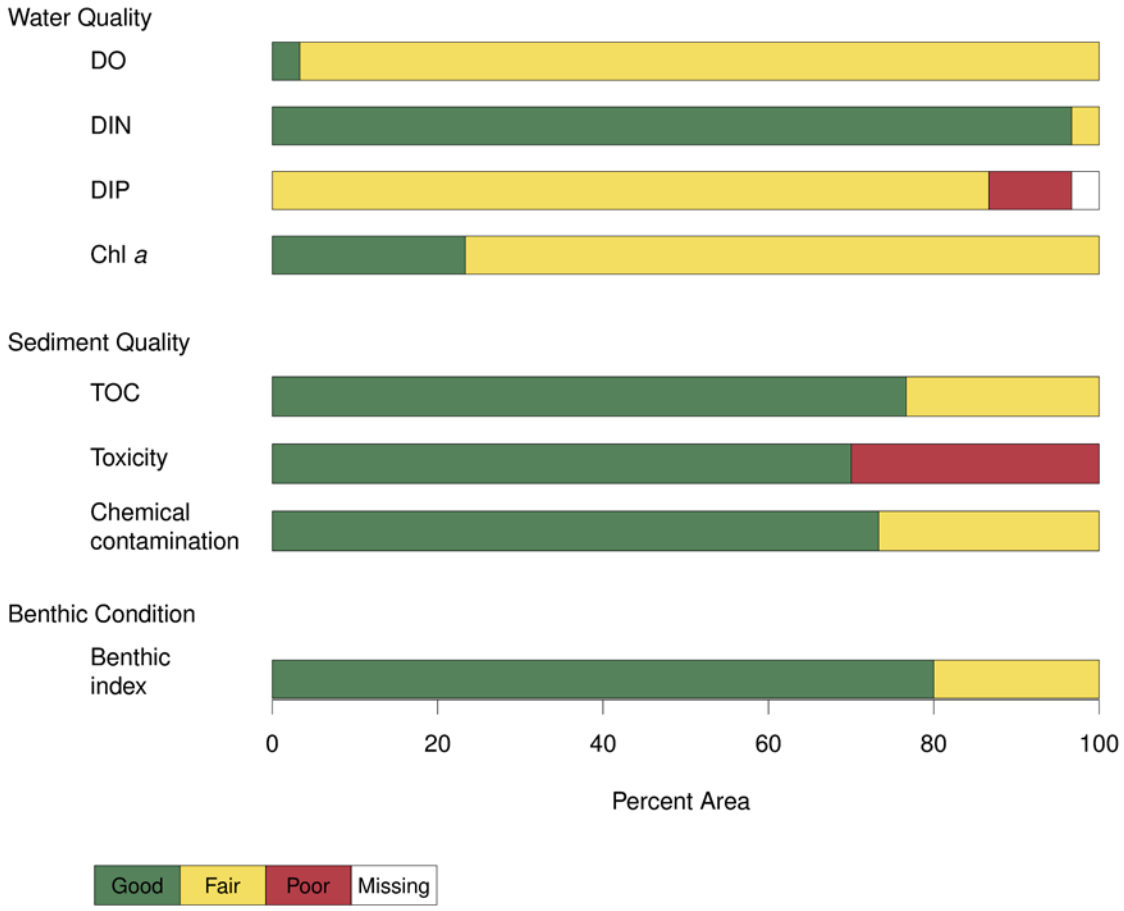

Figure 8. Graphical representation of the percent area of Sapelo Island National Estuarine Research Reserve classified according to the criteria listed in Table 1.

3.2 Sediment Quality

3.2.1 Grain Size and TOC

Sediments collected throughout the Reserve spanned a spectrum from sand (1.7 % silt-clay content) to mud (99.6 % silt-clay). The mean silt-clay content of sediments was 41.0 %. The total organic carbon (TOC) content of sediments was highly correlated with percent fines (R^2=0.74, p<0.001, d.f.=28; Figure 9). TOC ranged from 1.0 – 33.7 mg/g, with a mean of 12.7 mg/g. With respect to sediment criteria for TOC (Table 1, U.S. EPA 2008), 76.7 % of the study area would be classified as "Low/Good" and 23.3 % "Moderate/Fair" (Table 5, Figure 8). There were no stations rated in the "poor" range (TOC > 50 mg/g). All samples were also below a more conservative upper threshold of 35 mg/g proposed by Hyland et al. (2005). In contrast to some of the measured water quality parameters, which appeared to follow a gradient along the length of the Duplin River, no spatial pattern in the distribution of sediment grain size and/or TOC was found.

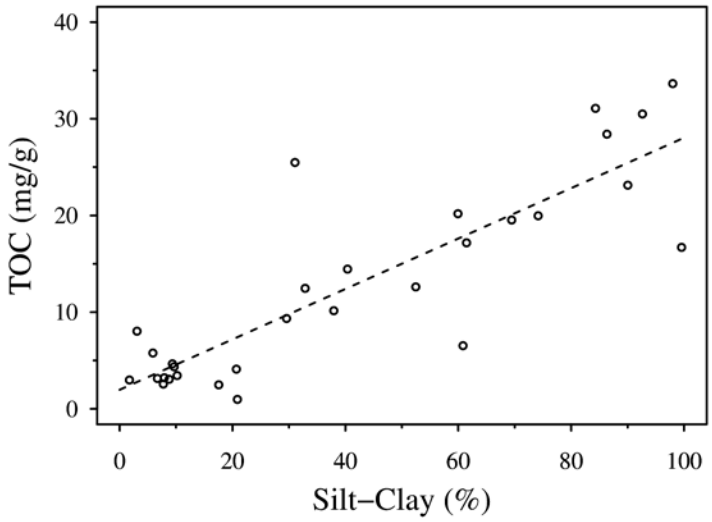

Figure 9. Relationship between sediment total organic carbon (TOC) and percent silt-clay content.

3.2.2 Chemical Contaminants in Sediments

Hyland et al. (1999) found a high incidence (> 75 %) of degraded benthic infaunal assemblages at mean ERM-Q values > 0.058 and moderate impacts (~ 50 % incidence) associated with mean ERM-Qs > 0.02 – 0.058. None of the mERM-Q values calculated for the 30 stations sampled in this study exceeded the upper risk level of 0.058 (Figure 10A). Furthermore, no ERM for any of the chemical analytes listed in Table 2was exceeded in sediments. ERL values were exceeded for only a single chemical (arsenic) and this occurred at 11 of the 30 stations. Arsenic concentrations varied from 0.3 – 14.7 µg/g (mean = 6.6 µg/g), which is within the usual range (5 – 15 µg/g) for uncontaminated nearshore and estuarine sediments (Neff 1997). Valette-Silver et al. (1999) have noted that high levels of arsenic in sediments coincide spatially with phosphate deposits in the southeast, suggesting that phosphorite deposits are involved in the process of arsenic enrichment. Hence, the observed levels of arsenic in SINERR sediments may result from natural processes, though anthropogenic point and non-point source inputs such as arsenic-containing pesticides or copper-chromium-arsenic (CCA) wood preservatives may also contribute.

Mean ERM-Qs at a number of sites did fall within the range (> 0.02 – 0.058) associated with a moderate risk of impacts on benthic infauna. To illustrate which chemicals contributed the most to the mean ERM-Q at each site, we partitioned the summed ERM quotient (before dividing by the number of chemical analytes to obtain the mean ERM-Q) into chemical classes (i.e., metals, PAHs, pesticides, PCBs; Figure 10B). It is apparent that the main contributors to overall mean ERM-Qs are the trace metals. We can also plot the individual ERMs for metals as shown in Figure 10C to illustrate which trace metals predominate. As would be expected given the ERL exceedances described above, arsenic was a significant contributor to the summed ERM quotient for metals. However, a number of other trace metal including chromium, lead, zinc, copper, and mercury also were detected.

The majority of sites sampled in this study (73.3 % area) had low levels of sediment contamination, based on the criteria listed in Table 1 (U.S. EPA 2008, Hyland et al. 1999). Although only one SQG guideline was exeeded (the ERL for arsenic), mERM-Qs at eight stations (26.7 %) were in the moderate risk range (> 0.02 – 0.058; Hyland et al. 1999). None of the sites were found to have high levels of chemical contamination expected to cause a high incidence of degraded benthic condition (Table 5, Figure 8). These results are very similar to those found for Georgia state-wide. In assessing the condition of Georgia estuaries based on 50 sites each in 2000 and 2001 (Guadagnoli et al. 2005) reported that 72 % of the area had low levels of sediment contamination, based on the mERM-Q, and 24 % were in the moderate risk range. In contrast to our findings, however, a small percentage (4 %) was found to have levels of sediment contamination in excess of the upper mERM-Q risk level of 0.058.

It is possible that much of the sediment trace metal content observed in this study is derived from natural, rather than anthropogenic, processes. A number of authors (Windom et al. 1989, Schropp et al. 1990, Summers et al. 1996) have shown that normalizing metals concentrations to a reference metal (i.e., Al) can help to identify sediments that are unnaturally enriched with metals *vs*. those with metals derived from natural sources. Aluminum is a good candidate for normalization since it has high natural abundance and is not commonly associated with anthropogenic inputs (Windom et al. 1989). In the present study, concentrations of Al were highly correlated with concentrations of As, Cr, Cu, Pb, and Zn ($0.80 < r^2 < 0.94$, all significant at α=0.05). Correlations of Cd and Hg with Al were less pronounced (r^2 of 0.50 and 0.77, respectively), but significant. For each of the above metals, all of the measured concentrations were within upper 95 % prediction limits derived from linear regression of individual metal concentrations on Al concentrations. Because trace metal concentrations co-vary strongly with Al, it is likely that they are derived mainly from natural sources.

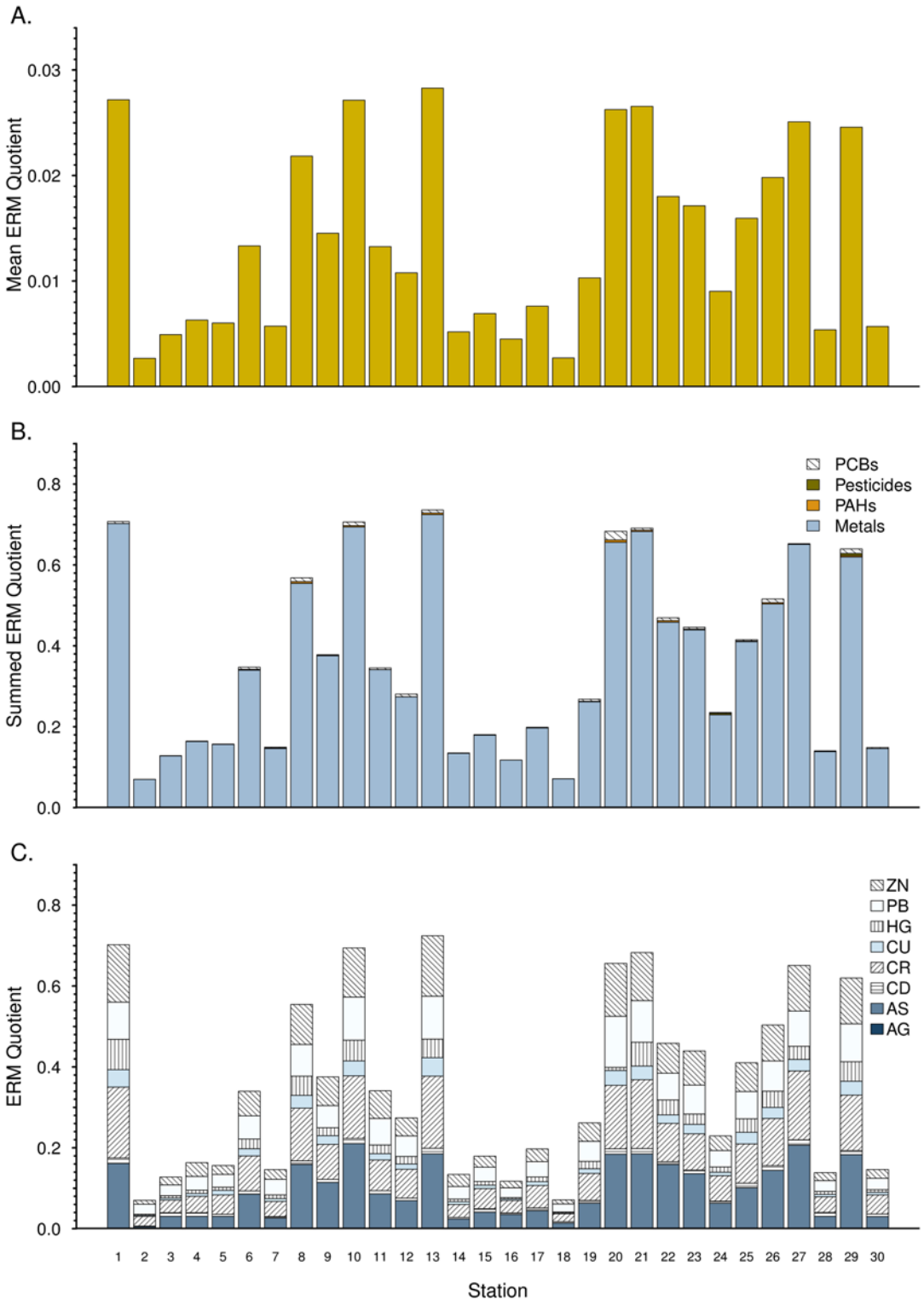

Figure 10. Effects range-mean (ERM) quotients calculated for each of 30 stations at Sapelo Island National Estuarine Research Reserve. (A) Mean ERM quotient; (B) Summed ERM quotient; (C) ERM quotient for metals only.

Though many organic contaminants were not present in sediments at detectable concentrations and none exceeded their corresponding SQGs or contributed significantly to overall mean ERM-Qs, a number of analytes were found at low yet detectable levels at some or all of the sampling sites. Total PAHs were detected at 14 of 30 sites, with concentrations ranging from 3.77 – 17.65 ng/g. Total PCBs were detected at all sites, with concentrations from 0.02 – 3.84 ng/g. The distribution of individual PCB congeners that were found at detectable concentrations, averaged across all 30 sites, is shown in Figure 11. Congeners are listed according to the numbering system proposed by Ballschmiter and Zell (1980) which has been adopted by the International Union of Pure and Applied Chemists (IUPAC). Total DDTs were detectable in sediments at two sites (0.17 – 0.26 ng/g), while total PBDEs were detected at only one site (0.02 ng/g). Concentrations of all chemical analytes measured are summarized in Appendix C.

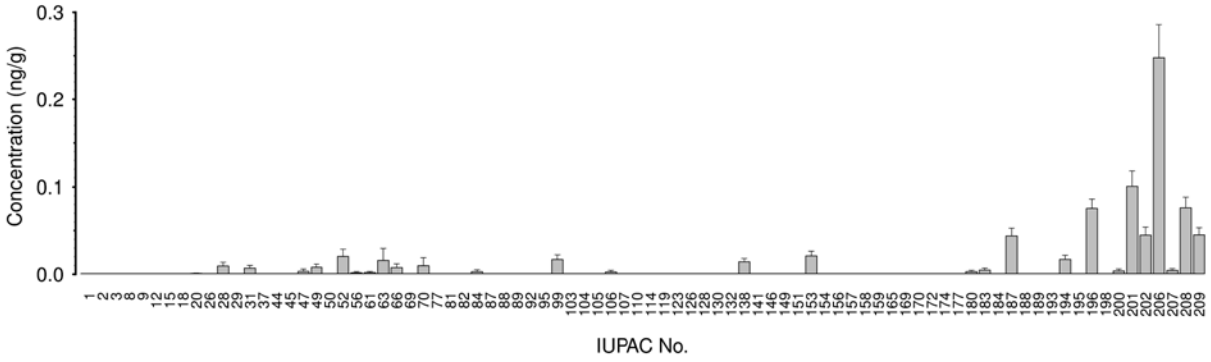

Figure 11. Polychlorinated biphenyl (PCB) congener profile of sediments collected at Sapelo Island National Estuarine Research Reserve. Congeners are listed according to the International Union of Pure and Applied Chemists (IUPAC) numbering system. Bar height represents mean congener concentration across all 30 sites. Whiskers represent the standard error of the mean.

In all cases where chemical analytes were detected, higher contaminant concentrations were associated with fine-grained sediments. There was a near perfect correlation between mean ERM-Q and percent silt-clay ($R^2 = 0.98$, $p < 0.001$, $d.f. = 28$; Figure 12).

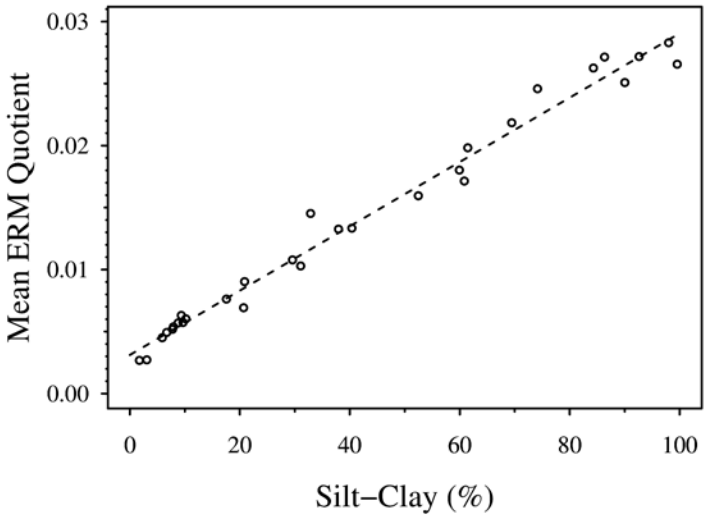

Figure 12. Relationship between sediment mean Effects Range-Median (ERM) quotient and percent silt-clay.

3.2.3 Sediment Toxicity

A luminescent bacteria toxicity test, the Microtox® acute toxicity solid-phase test, was used to assess toxicity of sediments. In this assay, the EC_{50} is the sediment concentration that reduces light production by 50 % relative to controls. Bacteria are exposed to the sediments, a column filter is used to separate the liquid phase containing the bacteria from the sediment, and then light output is measured with the bacteria in the liquid phase.

Nine of the 30 stations sampled were identified as toxic according to the test, representing 30 % of the study area (Table 5, Figure 8). Six of these nine sites also were a subset of the eleven sites where the ERL for arsenic was exceeded; however, sediments at the other five sites where the arsenic ERL was exceeded were not toxic, according to the Microtox® assay. Of the eight stations having mean ERM-Q values > 0.02 – 0.058 (found previously to be associated with moderate impacts on benthic infaunal assemblages; Hyland et al. 1999), four were deemed toxic.

Statewide, 97 % of Georgia coastal waters showed no signs of sediment toxicity, including 2 sites in the Duplin River (Guadagnoli et al. 2005). However, those results were obtained using a different toxicity test, the standard 10-day sediment bioassay based on survival of the marine amphipod *Ampelisca abdita*. Only two sites were found to have significant toxicity (out of 100 sites sampled over the two-year period): one in Sapelo Sound and another in the Savannah River.

Some authors have noted that the Microtox® assay may be affected by the silt-clay content of sediments. If the bacteria adsorb onto clay particles and do not remain in the liquid phase, then light output would be reduced due to physical effects rather than toxicity (Ringwood et al. 1997). Benton et al. (1995) found that Microtox® toxicity of clean sediments was significantly correlated with percent silt-clay content. Ringwood et al. (1997) also demonstrated the relationship between Microtox® EC_{50} and sediment silt-clay content using artificially prepared

sediment mixtures composed of varying concentrations of sand and clay as well as natural sediments from uncontaminated reference sites. They recommended two different EC_{50} criteria be used for sediments containing $\geq$ 20 % or < 20 % silt-clay (EC_{50} < 0.2 or EC_{50} < 0.5, respectively).

Scheiwe et al. (1985) demonstrated a significant relation between Microtox® EC_{50} and the concentrations of classes of organic chemicals. In comparative studies, the Microtox® assay gave a larger proportion of positive responses than lethality tests with *Rhepoxynius abronius* (Williams et al. 1986) or the freshwater cladoceran, *Daphnia magna* (Geisy et al. 1988). Because of uncertainty about the bioavailability of extracted chemicals and the irrelevance of bacterial bioluminescence to benthic ecosystems, the greater sensitivity of the Microtox® test may reflect chemical contamination rather than a potential for ecological degradation (Swartz 1989).

In most instances, significant Microtox® toxicity of sediments collected at SINERR was associated with higher sediment contaminant concentrations, expressed as mean ERM-Q (Figure 13). Given the high degree of correlation between mean ERM-Q and grain size noted previously (Figure 12), most of these positive (toxic) responses also were associated with fine-grained sediments. Nearly half of all stations within the same range of mean ERM-Q (or % silt-clay) were classified as non-toxic by the Microtox® assay. Nonetheless, at some sites, the relatively low levels of sediment contaminants found at SINERR may be sufficient to elicit a positive response in the Microtox® assay, perhaps in combination with other measured (e.g., % silt-clay) or unmeasured factors.

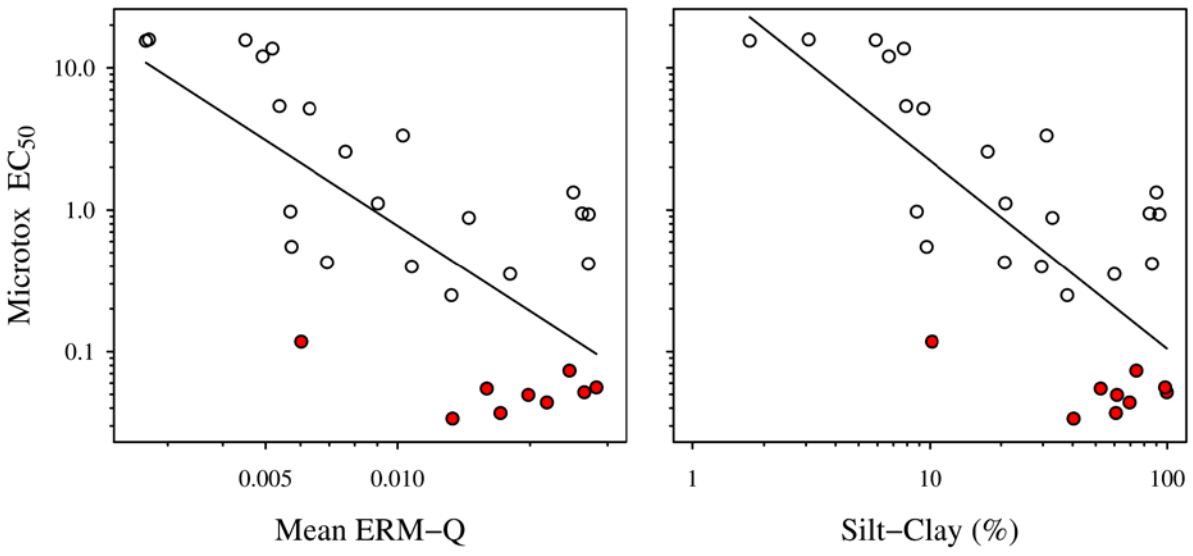

Figure 13. Relationship of Microtox® EC_{50} to mean Effects Range-Median Quotient and percent silt-clay in sediments collected at Sapelo Island National Estuarine Research Reserve. Filled circles indicate samples registered as positive (toxic) responses by the Microtox® assay.

3.3 Biological Condition

3.3.1 Benthic Communities

A total of 200 taxa were identified in 60 grabs from the 30 stations, 116 of which were identified to species level. Polychaetes and crustaceans were the dominant taxa, both by abundance and number of taxa (Figure 14, Table 6). Polychaete taxa were much more numerous in terms of density (#/m^2) than crustaceans (46.5 % of total density, compared to 26.4 %), while the number of crustacean taxa was only slightly higher (36 % of all taxa vs. 33.5 % for polychaetes). The majority of crustacean taxa were represented by amphipods (17.5 % of all taxa) and decapods (9.5 %). Polychaete and crustacean taxa together accounted for 69.5 % of the total number of taxa, while these two groups combined with bivalves and gastropods made up 94.5 %. Similarly, polychaetes and crustaceans made up 72.8 % of total infaunal density, but bivalves and gastropods together contributed only an additional 6 %. The third most abundant taxonomic group, accounting for 20.4 % of total density, was the 'Other' group, which was dominated by oligochaetes and nemerteans (14.6 % and 5.2 % of total density, respectively).

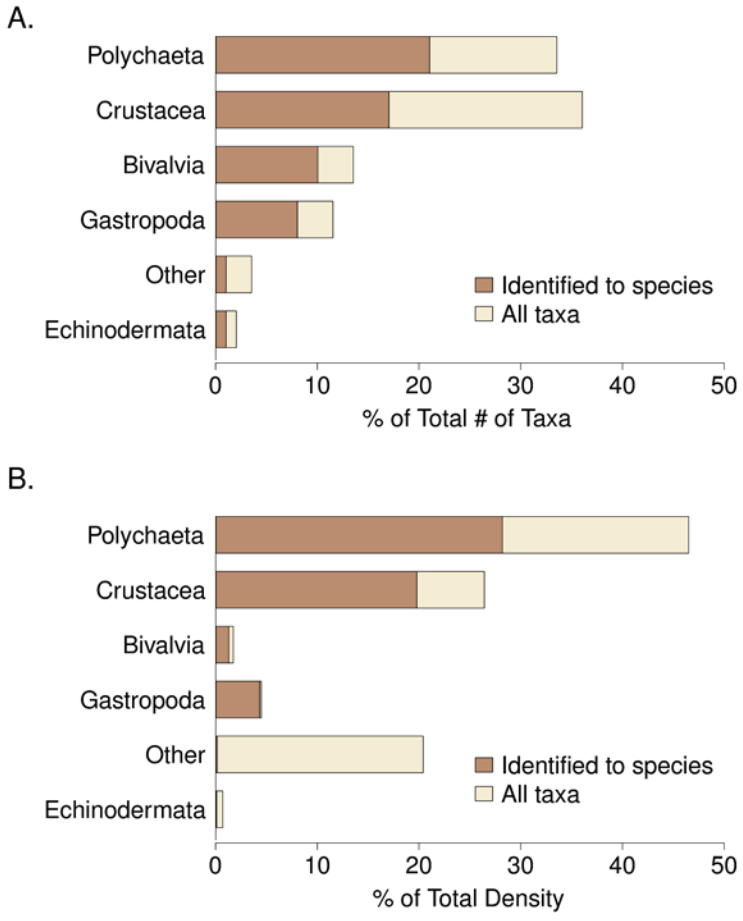

Figure 14. Taxonomic composition of benthic infauna as (A) percent of total number of taxa and (B) percent of total density.

Table 6. Number and percent of total identifiable taxa by taxonomic group.

Taxonomic Group	Number identifiable taxa	% Total identifiable taxa
Phylum Cnidaria		
Class Anthozoa*	2	1.0
Phylum Nemertea*	1	0.5
Phylum Sipuncula*	1	0.5
Phylum Mollusca		
Class Bivalvia	27	13.5
Class Gastropoda	23	11.5
Phylum Annelida		
Class Clitellata		
Subclass Oligochaeta*	1	0.5
Class Polychaeta	67	33.5
Phylum Arthropoda		
Subphylum Chelicerata*	1	0.5
Subphylum Crustacea		
Class Malacostraca		
Order Amphipoda	35	17.5
Order Cumacea	4	2.0
Order Decapoda	19	9.5
Order Isopoda	6	3.0
Order Mysida	2	1.0
Order Tanaidacea	4	2.0
Class Ostracoda	2	1.0
Phylum Phoronida*	1	0.5
Phylum Echinodermata		
Class Holothuroidea	2	1.0
Class Ophiuroidea	2	1.0
Total	*200*	*100*

* Taxonomic groups followed by an asterisk were assigned to the group ‘Other’ in Figure 14.

Mean species richness, expressed as the mean number of taxa in two 0.04 m^2 grabs at a station, ranged from 4.5 – 30 taxa per grab, with a grand mean of 13.8 taxa per grab (Table 7, Figure 15). Total species richness, the number of taxa in the two grabs at a station combined, ranged from 7 – 50 taxa, averaging 21.6 taxa per station. Mean Shannon diversity (H′, calculated using $\log_2$) ranged from 1.4 – 4.2 per grab, with a grand mean of 2.7 per grab.

A total of 6,669 specimens were collected across the 30 sites (60, 0.04 m^2 grabs). Total density of infaunal taxa at each station ranged from 325 – 11,500 ind./m^2 (Table 7, Figure 15), with a mean density over the 30 sites equal to 2,779 ind./m^2. A dense assemblage of gammarid amphipods (>10,000 ind./m^2) was found at one site (station 15). Most of these amphipods (7,800 ind./m^2) were represented by the corophiid amphipod, *Apocorophium lacustre*, and occurred in only one of the two grabs at the station.

Table 7. Summary of benthic metrics.

Parameter	Mean	Min	Max	Std. Dev.	CDF 10th Percentile	CDF 50th Percentile	CDF 90th Percentile
Total richness	21.6	7	50	12.2	8.0	16.0	35.0
Mean richness	13.8	4.5	30	7.5	5.7	11.0	24.5
Mean H'	2.7	1.4	4.2	0.7	1.6	2.5	3.5
Total Density	2,778.75	325	11,500	2,430.3	462.5	1,925.0	5,437.5
B-IBI	3.3	2	4	0.6	2.2	3.1	3.8

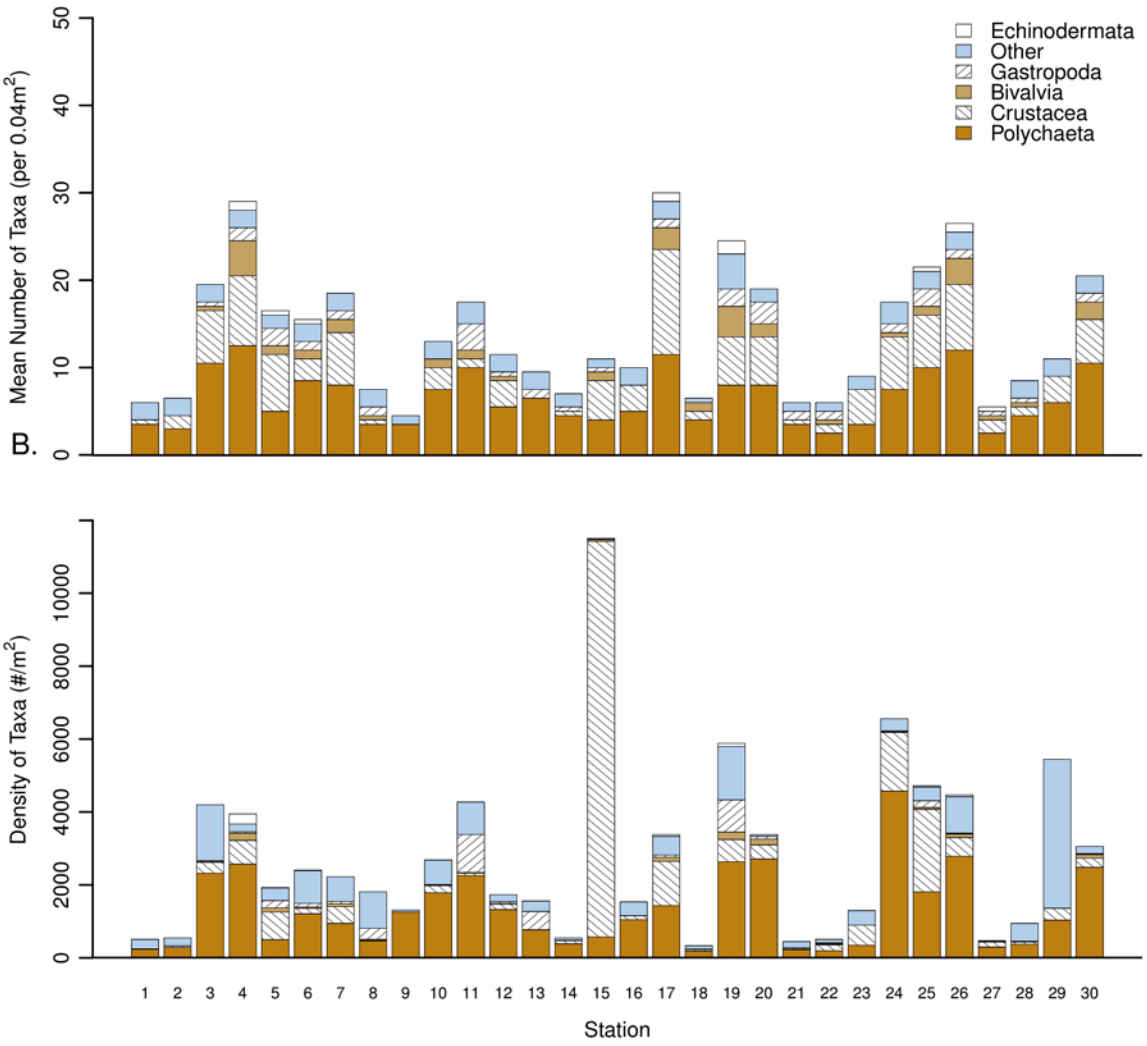

Figure 15. Taxonomic composition of benthic infauna at 30 stations in Sapelo Island National Estuarine Research Reserve.

The five most abundant taxa across all 30 sites, in descending order, included unidentified oligochaetes (subclass Oligochaeta), the capitellid polychaete *Mediomastus* spp., the corophiid amphipod *Apocorophium lacustre*, the spionid polychaete *Streblospio benedicti*, and proboscis worms (identified either as genus *Tubulanus* or phylum Nemertea). Four of the five dominants occurred in more than half of the samples collected (63 – 83 % of samples, Table 8). *Apocorophium lacustre* was found in only 3 samples and, as described above, most of these occurred in a single grab at station 15. Oligochaetes typically are identified to species only in low-salinity (< 5 ppt) habitats and hence are reported as the higher taxonomic level (i.e., subclass). Oligochaetes were assigned to the taxon group 'Other' in Figure 14 and make up 71.5 % of the density of that group shown in Figure 14B. Nemerteans were identified either to genus (*Tubulanus*) or left simply as phylum Nemertea and accounted for 25.6 % of the 'Other' group. The remaining 2.9 % was made up of Anthozoans (Actiniaria), Sipunculids, a Phoronid, and a Xiphosuran.

Table 8. Fifty dominant benthic taxa found at Sapelo Island National Estuarine Research Reserve.

Taxon	Group	Density	Frequency (% of samples)
Oligochaeta	Oligochaeta	12138	81.7
Mediomastus spp.	Polychaeta	11775	70.0
Apocorophium lacustre	Crustacea	7850	5.0
Streblospio benedicti	Polychaeta	7813	63.3
Nemertea	Nemertea	4350	83.3
Neanthes succinea	Polychaeta	2913	45.0
Corophiidae	Crustacea	2738	11.7
Paraprionospio pinnata	Polychaeta	2713	43.3
Leucon americanus	Crustacea	2450	25.0
Lumbrineris tenuis	Polychaeta	2400	35.0
Acteocina canaliculata	Gastropoda	1938	10.0
Tharyx acutus	Polychaeta	1713	43.3
Glycinde solitaria	Polychaeta	1225	35.0
Nassarius obsoletus	Gastropoda	1175	21.7
Edotia triloba	Crustacea	1100	40.0
Ampelisca spp.	Crustacea	1050	38.3
Ampelisca abdita	Crustacea	1025	21.7
Cirratulidae	Polychaeta	938	26.7
Melita nitida	Crustacea	900	21.7
Tharyx spp.	Polychaeta	875	16.7
Polydora cornuta	Polychaeta	813	25.0
Apocorophium simile	Crustacea	788	20.0
Paracaprella tenuis	Crustacea	738	10.0
Exogone rolani	Polychaeta	650	15.0
Scoloplos rubra	Polychaeta	500	25.0
Ophiuroidea	Echinodermata	488	18.3
Caulleriella spp.	Polychaeta	475	6.7
Podarkeopsis levifuscina	Polychaeta	475	23.3
Spiochaetopterus oculatus	Polychaeta	450	13.3
Ampelisca vadorum	Crustacea	413	20.0
Lumbrineris spp.	Polychaeta	350	16.7
Scoloplos robustus	Polychaeta	313	21.7
Actiniaria	Anthozoa	300	5.0
Hiatella arctica	Bivalvia	288	20.0
Melita spp.	Crustacea	213	5.0
Oedicerotidae	Crustacea	213	13.3
Nereididae	Polychaeta	188	10.0
Nucula aegeensis	Bivalvia	188	8.3
Hypereteone fauchaldi	Polychaeta	175	8.3
Glycera americana	Polychaeta	163	13.3
Diopatra cuprea	Polychaeta	150	10.0
Tellinidae	Bivalvia	150	10.0
Cerapus spp.	Crustacea	150	6.7
Heteromastus filiformis	Polychaeta	138	13.3
Melitidae	Crustacea	138	8.3
Ogyrides alphaerostris	Crustacea	138	8.3
Hypereteone heteropoda	Polychaeta	125	15.0
Bivalvia	Bivalvia	125	10.0
Fargoa gibbosa	Gastropoda	113	5.0
Batea catharinensis	Crustacea	112.5	3.3

A benthic index (B-IBI, Van Dolah et al. 1999) was used as an overall indicator of infaunal condition. The B-IBI is a multi-metric index formed by averaging the individual scores (either 1, 3, or 5 based on 10^{th} and 50^{th} percentiles of values) of four benthic metrics: mean abundance, mean number of taxa, percent abundance of all but the top two numerical dominants, and percent abundance of pollution-sensitive taxa (families Ampeliscidae, Haustoriidae, Tellinidae, Lucinidae, Hesionidae, Cirratulidae; isopods *Cyathura burbancki* and *Cyathura polita*). Since the B-IBI is an average of four metrics, each equal to 1, 3, or 5, values of the index range from 1 to 5 in increments of 0.5. B-IBI values < 3 suggest the presence of a degraded benthic assemblage (some apparent level of stress to very unhealthy) since the average metrics deviate from conditions typical of the 'best' (upper 50^{th} percentile) reference sites (Van Dolah et al. 1999). Index values < 2 represent the clearest evidence of a degraded benthos.

Benthic index values ranged from 2 – 4 and averaged 3.3 (Table 7). Six stations had B-IBI values in the transitional range of 2 – 2.5, indicating possible stress. One of these sites (station 9) had a B-IBI = 2, but otherwise there were few indications of stress at this site: mERM-Q < 0.02, negative Microtox® assay, TOC < 20 mg/g, and DO = 3.1 mg/L. Four of the five sites with B-IBI = 2.5 had ERL exeedances for arsenic, mERM-Qs ranging from 0.018 – 0.027, silt-clay from 59.9 – 99.6 %, and TOC from 16.7 – 30.5 mg/g. Two of these four sites had significant Microtox® toxicity. One of the six sites with transitional index values (station 15) had a B-IBI of 2.5, but all other indicators were suggestive of healthy benthic conditions: DO = 3.96 mg/g, TOC = 4.1 mg/g, silt-clay = 20.7 %, negative Microtox® assay, and mERM-Q = 0.007. This site had a very large assemblage (> 10,000 ind./m^2) of gammarid amphipods (*Apocorophium lacustre*, family Corophiidae) that were numerically dominant. Since the B-IBI includes percent abundance of all but the top two dominants as one of the four component metrics, this may explain the low index score at this site.

Aside from the six sites discussed above, the remaining 24 stations (80 % of the study area) had B-IBI values indicative of a healthy benthos (Table 5, Figure 8). None of the 30 sites had benthic biological condition that would be considered clearly degraded (i.e., B-IBI < 2). Guadagnoli et al. (2005) obtained similar results for Georgia estuaries state-wide, despite using a different benthic index (Engle et al. 1994; Engle and Summers 1999). They rated 81 % of Georgia estuaries as having good benthic condition, 12 % fair, and 7% poor, using the benthic index cited above which was developed for northern Gulf of Mexico estuaries.

3.3.2 Chemical Contaminants in Fish Tissues

A total of 29 fish representing seven finfish species were collected at nine of the 30 SINERR sampling stations. At most three specimens of any given species from each station were retained, resulting in 22 individual specimens analyzed for tissue chemical contamination (Table 9).

Table 9. Summary of fish specimens collected in Sapelo Island National Estuarine Research Reserve.

Station	Species	Common Name	No. of specimens
25	*Bairdiella chrysoura*	Silver perch	3
11	*Cynoscion nebulosus*	Spotted seatrout	1
14	*Cynoscion nebulosus*	Spotted seatrout	1
17	*Cynoscion nebulosus*	Spotted seatrout	1
18	*Menticirrhus* spp.	Whiting	1
11	*Micropogonias undulatus*	Atlantic croaker	1
17	*Micropogonias undulatus*	Atlantic croaker	1
22	*Micropogonias undulatus*	Atlantic croaker	1
5	*Mugil cephalus*	Striped mullet	2
9	*Mugil cephalus*	Striped mullet	1
17	*Mugil cephalus*	Striped mullet	3
25	*Mugil cephalus*	Striped mullet	3
12	*Paralichthys lethostigma*	Southern flounder	1
14	*Sciaenops ocellatus*	Red drum	1
25	*Sciaenops ocellatus*	Red drum	1

In addition to fish collected in SINERR, another 21 specimens representing four of the above species were collected at four stations in the Brunswick, Georgia area (Figure 16) in support of a separate study of contaminant concentrations in bottlenose dolphins and fish in the Turtle/Brunswick River Estuary. As above, no more than three specimens of each species at a station were retained for analysis, leaving a total of 12 fish specimens analyzed (Table 10). The LCP Superfund site near Brunswick has been host to several industrial ventures between 1919 and 1994, resulting in contamination of sediments at the site and in the adjacent marshes of Purvis Creek, a tributary of the Turtle River, with mercury and PCBs, mostly as Aroclor 1268 (Maruya et al. 1997). Fish collection sites in the present study included two stations in Purvis Creek (BR09_001 and BR09_002), one station in another tributary of the Turtle River, Burnett Creek (BR09_004), and one station in a tributary of the lower Brunswick River, Plantation Creek (BR09_003). Figure 16 shows the locations of the Brunswick sites in relation to SINERR stations.

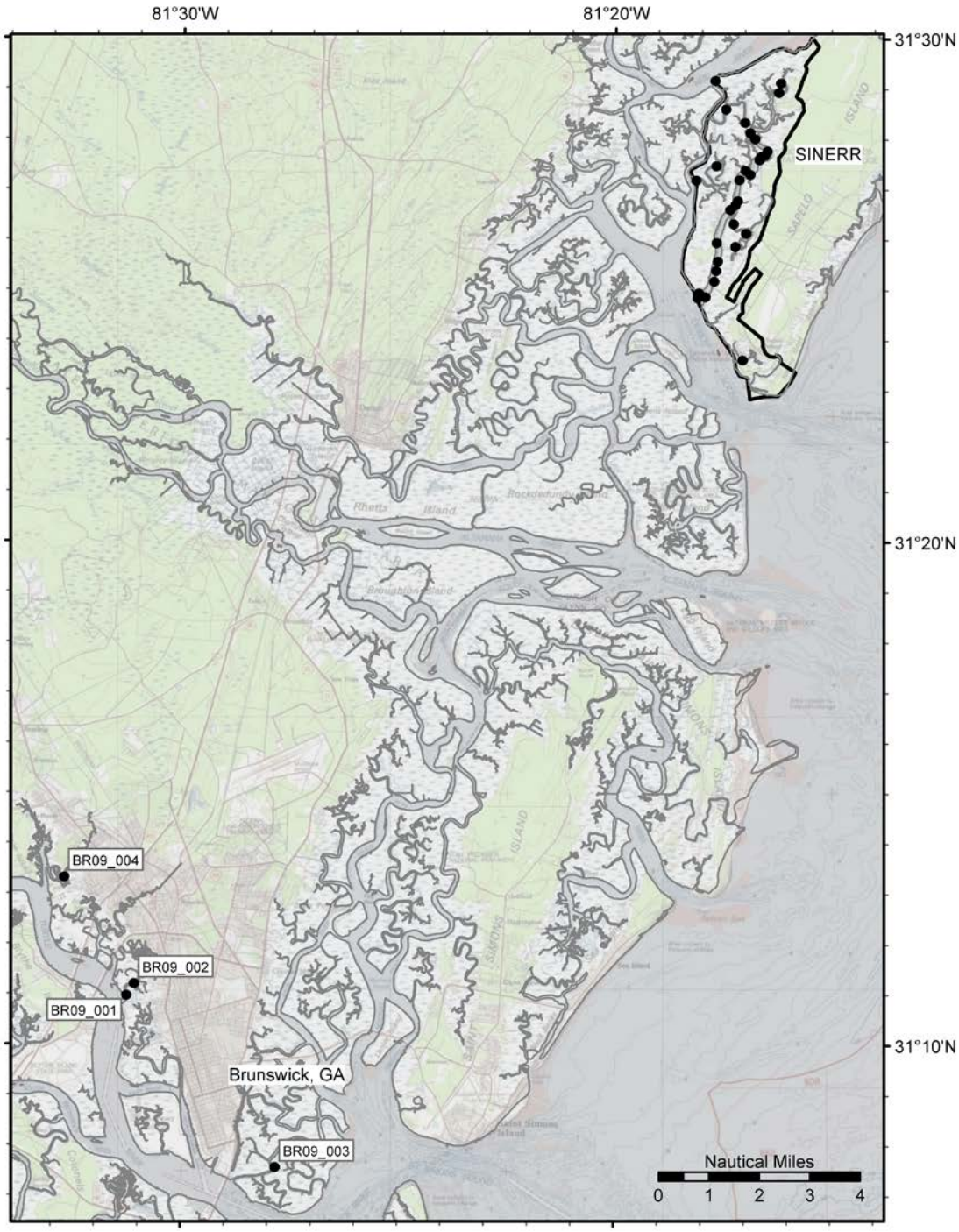

Figure 16. Map showing the location of Brunswick, GA fish collection sites in relation to Sapelo Island National Estuarine Research Reserve (SINERR).

Table 10. Summary of fish specimens collected near Brunswick, Georgia.

Station	Species		No. of specimens
BR09_004	*Bairdiella chrysoura*	Silver perch	1
BR09_001	*Menticirrhus* spp.	Whiting	1
BR09_001	*Micropogonias undulatus*	Atlantic croaker	1
BR09_001	*Mugil cephalus*	Striped mullet	3
BR09_002	*Mugil cephalus*	Striped mullet	3
BR09_003	*Mugil cephalus*	Striped mullet	1
BR09_004	*Mugil cephalus*	Striped mullet	2

Of the 22 trace metals for which analyses were performed, most (with the exception of Be and Tl) were found at detectable levels in edible tissues of at least one of the fish specimens collected at SINERR. Eleven trace elements (Al, As, Ba, Cr, Cu, Fe, Hg, Mn, Ni, Se, and Zn) were detected consistently in all seven species of fish analyzed (Figure 17). Inorganic arsenic (estimated as 2 % of total As) exceeded the lower cancer health endpoint in all but one fish specimen collected in SINERR (21 of 22 specimens). The upper cancer health endpoint for inorganic arsenic was exceeded in 16 of the 22 specimens (see Table 13).

Mercury was detected in all three specimens of silver perch collected at station 25 at SINERR (Figure 17). Tissue concentrations in one individual (Table 13) exceeded the lower non-cancer health endpoint for methylmercury (under the assumption that measured concentrations of total mercury are all methylmercury). Similar levels were measured in whiting (1 specimen) collected at station 18, which also exceeded the lower non-cancer health endpoint for methylmercury. In comparison, individual specimens of whiting (*Menticirrhus* spp.) and silver perch (*Bairdiella chrysoura*) collected near Brunswick, GA had tissue mercury levels in excess of the upper (non-cancer) health endpoint for methylmercury.

Though analyzed, PAHs were not present in fish tissues at concentrations above the analytical method detection limits (Appendix G – I).

Polybrominated diphenyl ethers (PBDEs) were detected in 13 of the 22 fish specimens collected at SINERR, representing five species (Figure 18). Of the 13 PBDEs measured, three congeners (BDE-47, -100, and -154) were found at detectable levels. Only the tetrabromo congener BDE-47 was present at detectable levels in all 13 fish samples from five species and is one of three congeners (BDE-47, -153, and -154) known to accumulate to the highest degree in fish (Hites 2004, Søfteland et al. 2011, Xia et al. 2011). PBDEs belong to a class of persistent organic pollutants (POPs) that are structurally akin to PCBs and other halogenated compounds. One of a number of contaminants of emerging concern (CECs), PBDEs have been used in a wide array of products, including building materials, electronics, plastics, polyurethane foam, and textiles. While not systematically monitored in the past, EPA's upcoming National Coastal Condition Assessment (NCCA) will include sampling for PBDEs and other CECs in fish tissue collected from the Great Lakes (U.S. EPA 2012).

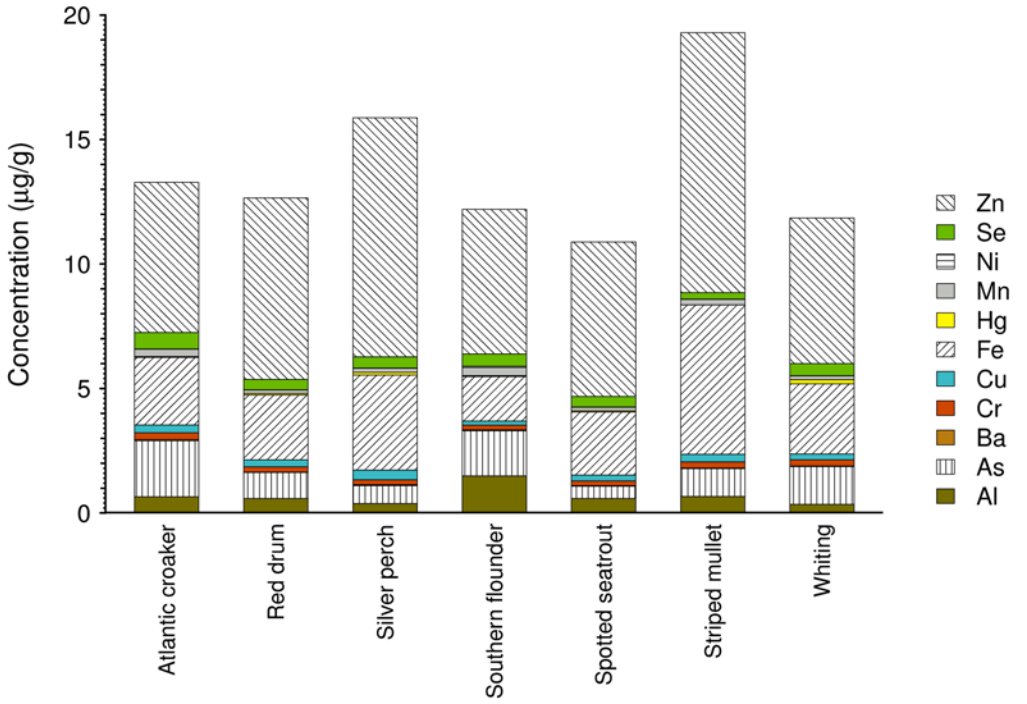

Figure 17. Relative concentrations of trace metals in edible tissues of fish collected in Sapelo Island National Estuarine Research Reserve.

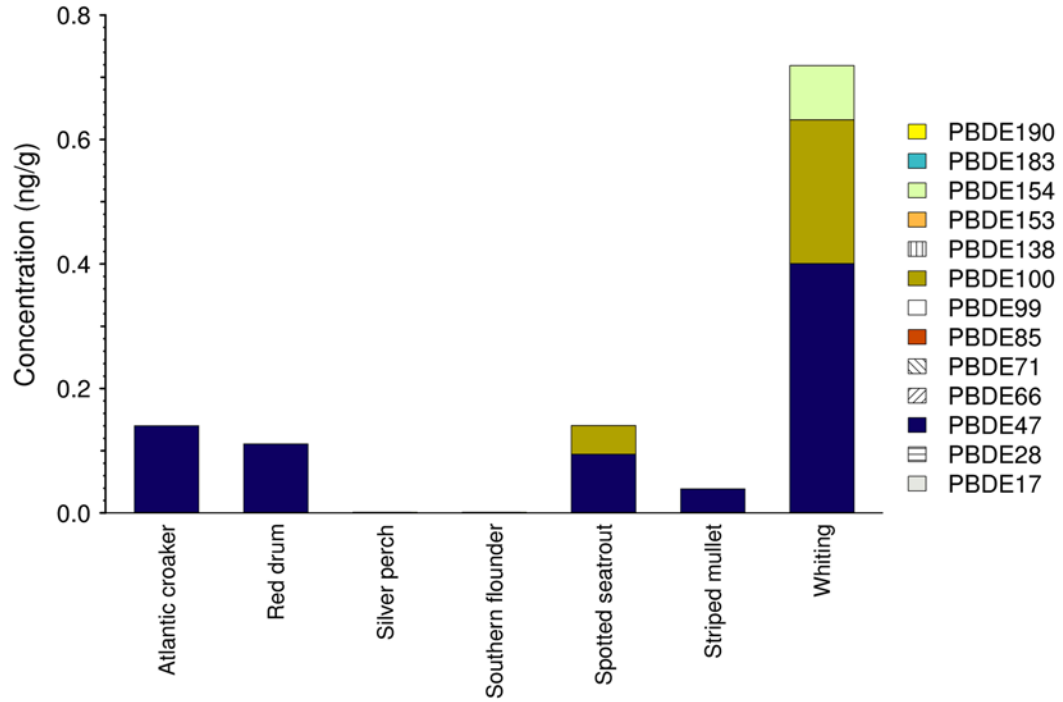

Figure 18. Relative concentrations of PBDEs in edible tissues of fish collected in Sapelo Island National Estuarine Research Reserve.

Twelve of 19 measured pesticides were present in fish tissues at detectable concentrations in SINERR. These were detected in six of the seven fish species collected (all but southern flounder, *P. lethostigma*). Highest tissue pesticide concentrations were observed for 4,4′-DDE (maximum of 3 ng/g in Atlantic croaker). The distribution of pesticide concentrations by fish species is shown in Figure 19. Although pesticides were found in fish tissues at levels above the analytical detection limit, total DDT levels were well below the lower U.S. EPA (2000) guideline values for both non-cancer and cancer health endpoints (59 and 35 ng/g, respectively).

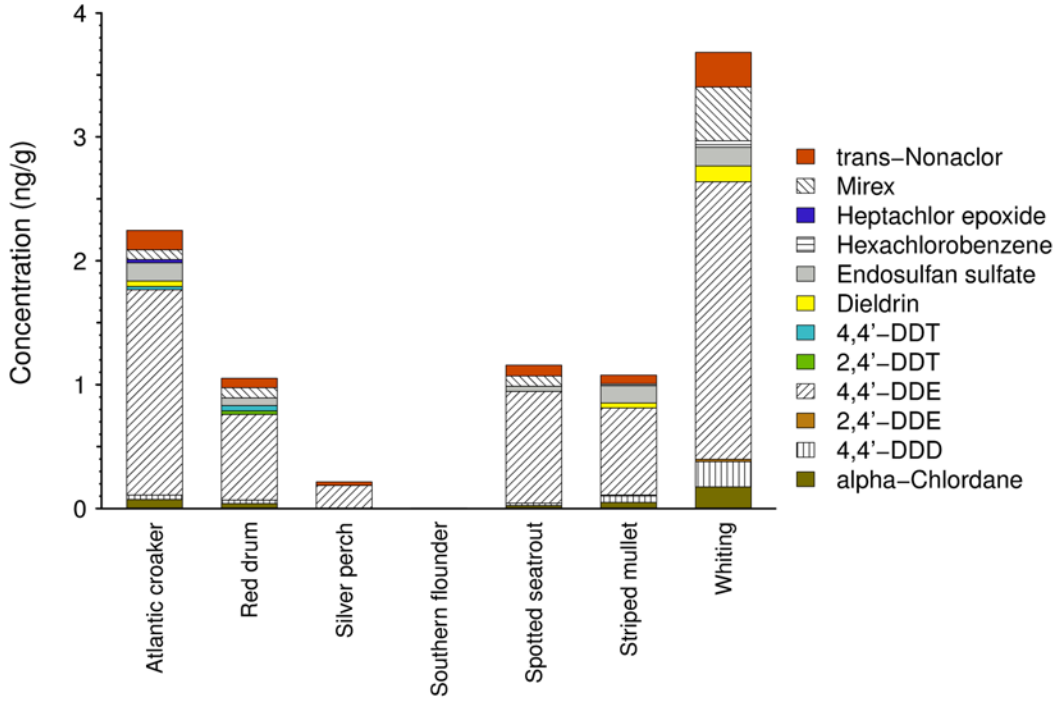

Figure 19. Relative concentrations of pesticides in edible tissues of fish collected in Sapelo Island National Estuarine Research Reserve.

Of the 81 PCB congeners measured, 62 were found in detectable quantities in edible tissue of fish collected in SINERR (Figure 20). Total PCBs in the seven fish species from seven stations where fish were collected (averaged over multiple specimens of the same species caught at a station) ranged from 0.790 – 40.590 ng/g, with a mean of 8.795 ng/g. The highest levels of total PCBs were observed in one specimen of whiting (*Menticirrhus* spp.) at station 18 (Table 13), exceeding EPA's recommended lower non-cancer health endpoint of 23 ng/g. Total PCBs in exceedance of the upper cancer health endpoint of 12 ng/g were observed at stations 11, 14, and 25 in spotted seatrout (*Cynoscion nebulosus*), red drum (*Sciaenops ocellatus*), and silver perch (*Bairdiella chysoura*). The lower cancer health endpoint of 5.9 ng/g was exceeded at stations 9, 11, 22, and 25 in striped mullet (*Mugil cephalus*) and Atlantic croaker (*Micropogonias undulatus*).

The distribution of PCB congeners (as a proportion of total PCBs) is shown in Figure 20. Though relative abundances are notable for penta- and hexa-chlorobiphenyls, relative abundances are highest for highly chlorinated homologs hepta- to nona-chlorobiphenyls (PCB congeners composed of 7 – 10 chlorine atoms). Previous studies in the area adjacent to the LCP Chemicals Superfund site near Brunswick, GA have documented particularly high levels of Cl_7 – Cl_{10} PCBs in sediments and biota (Kannan et al. 1997, Maruya and Lee 1998a, Maruya and Lee 1998b). The congener pattern associated with the LCP site is characteristic of Aroclor 1268, a highly chlorinated mixture of PCBs used extensively at a chlor-alkali plant that was in operation there from 1955-1994. Recent studies have documented PCB congener patterns in bottlenose dolphins and fish from the Brunswick and Sapelo Island areas that match closely the congener profile of Aroclor 1268 (Pulster et al. 2005, Pulster and Maruya 2008, Ballmer et al. 2011, Kucklick et al. 2011), suggesting that contaminants associated with the LCP Chemicals Superfund site are being transported to the Sapelo Island NERR over 40km northeast of the Brunswick area. Ballmer et al. (2011) speculated that contaminated prey or sediments were the most likely routes leading to dolphin exposure as the Aroclor 1268 mixture is extremely hydrophobic (Maruya and Lee 1998a).

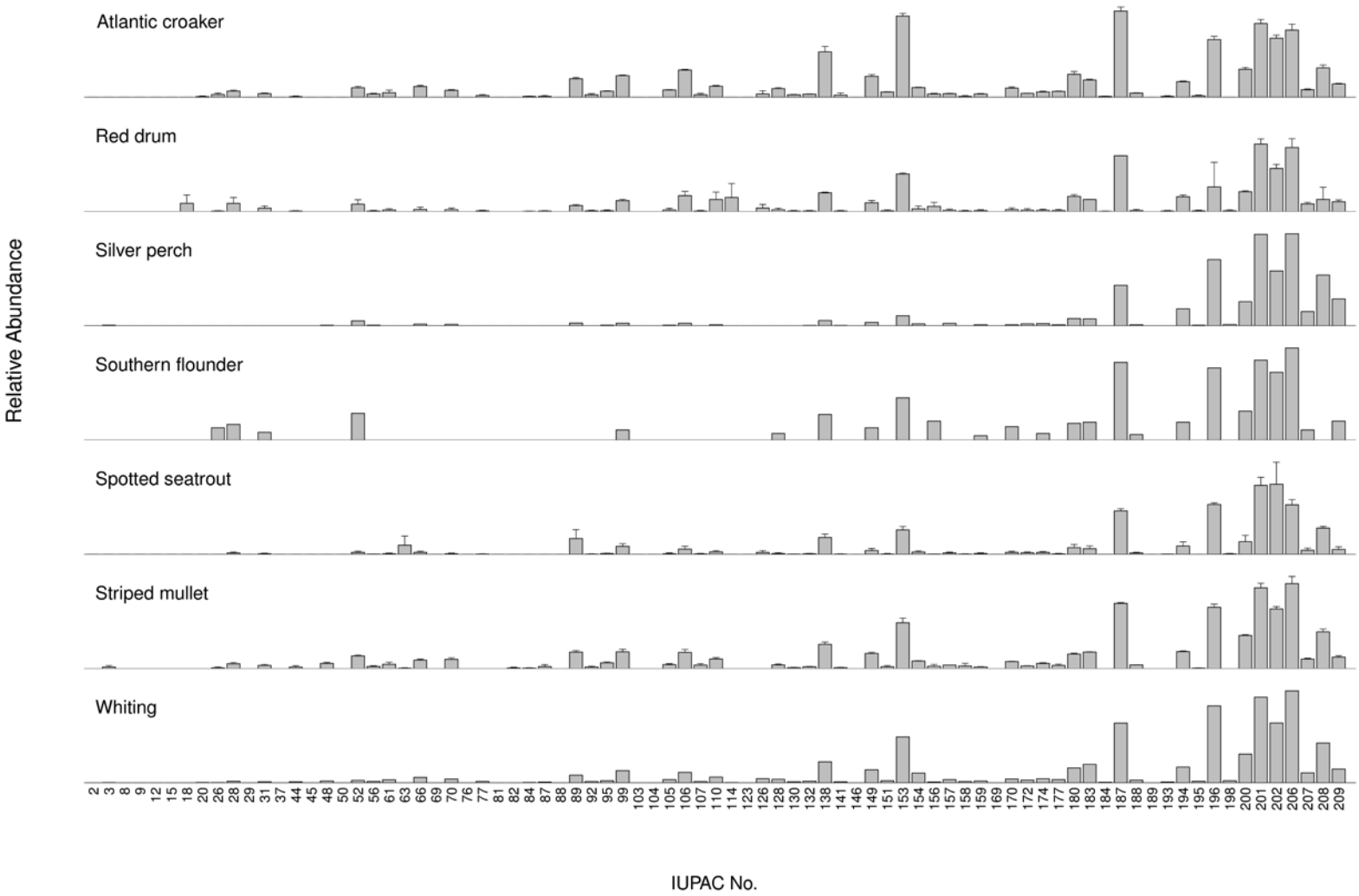

Figure 20. Relative abundance of PCB congeners in edible tissues of fish collected in SINERR. Bar height represents congener relative abundance (as % of total PCBs) averaged across stations (when species were collected at multiple stations). Whiskers represent one standard error of mean % total PCBs.

Figure 21 – Figure 24 provide a comparison of congener profiles of four species of fish collected both from the Brunswick, GA area and SINERR. Particularly for some species (e.g., silver perch), the congener pattern is strikingly similar to and characteristic of Aroclor 1268. Note, however, that PCB concentrations in Brunswick fish are roughly one to two orders of magnitude higher than SINERR fish. Although PCB profiles in fish collected at SINERR include other globally-distributed congeners (e.g., PCB 138, 153) that are generally indicative of non-Aroclor 1268 formulations (Kucklick et al. 2011), the notable pattern of highly-chlorinated PCBs (>7 chlorine atoms) suggests that PCB contaminants similar to the LCP Chemicals source have apparently reached SINERR, though at much lower concentrations than in Brunswick. A similar pattern of highly-chlorinated PCB congeners also was observed in SINERR sediments (Figure 11).

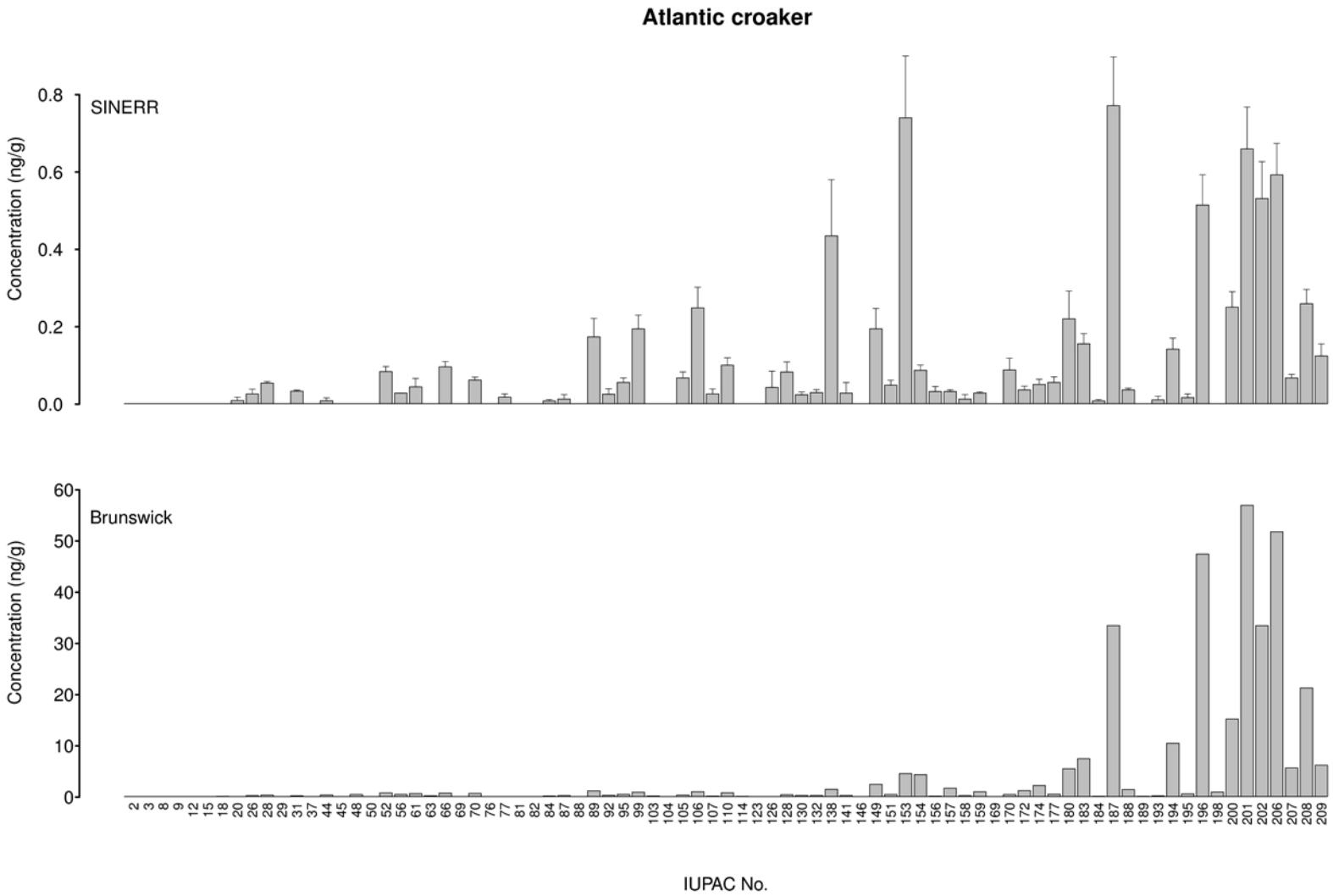

Figure 21. Comparison of PCB congener profiles in edible tissues of Atlantic croaker (*Micropogonias undulatus*) collected in SINERR and Brunswick GA. Bar heights represent mean congener concentration averaged across stations (when species were collected at multiple stations). Whiskers represent the standard error of the mean. Note different scales for concentration.

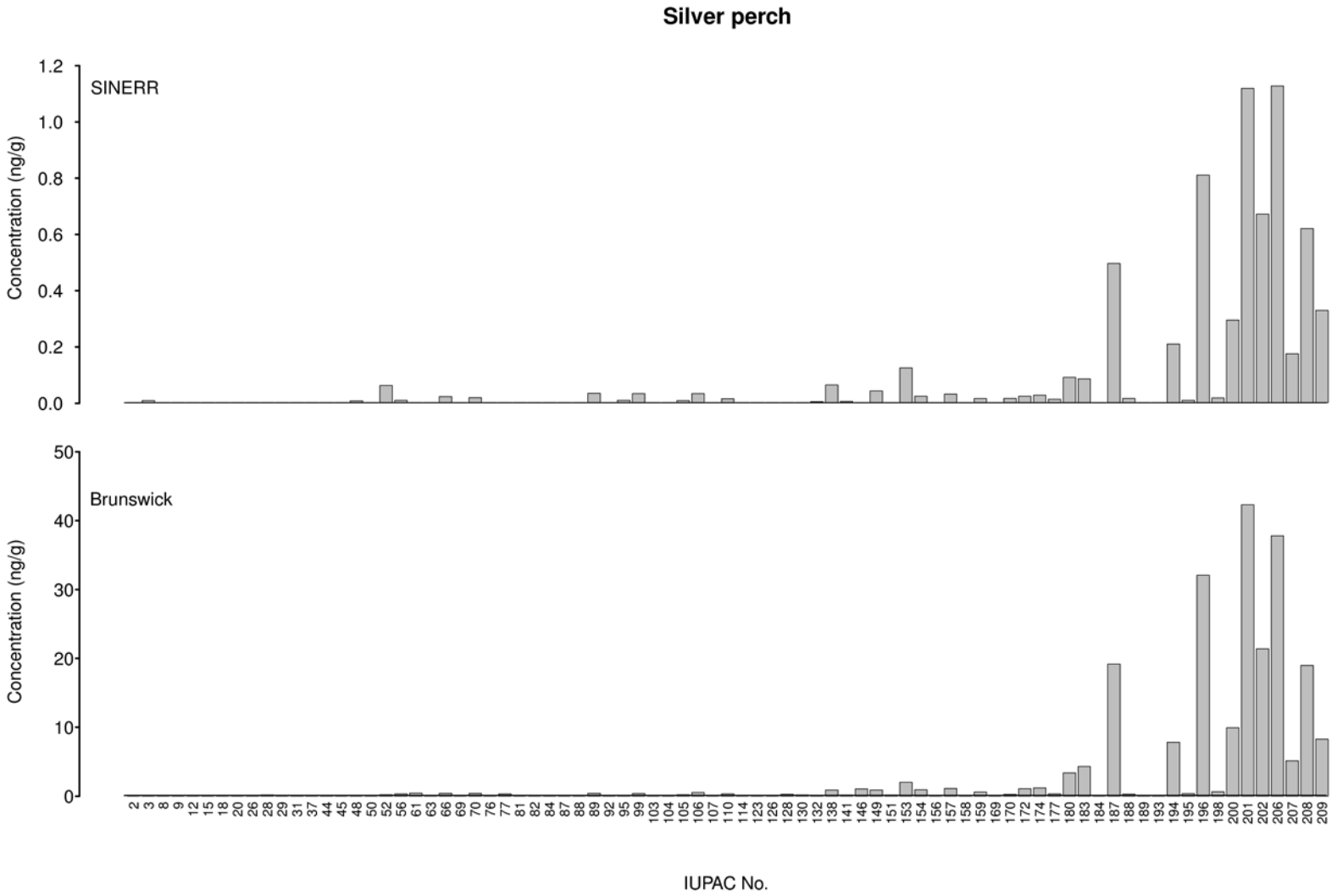

Figure 22. Comparison of PCB congener profiles in edible tissues of silver perch (*Bairdiella chrysoura*) collected in SINERR and Brunswick GA. Bar heights represent mean congener concentration averaged across stations (when species were collected at multiple stations). Note different scales for concentration.

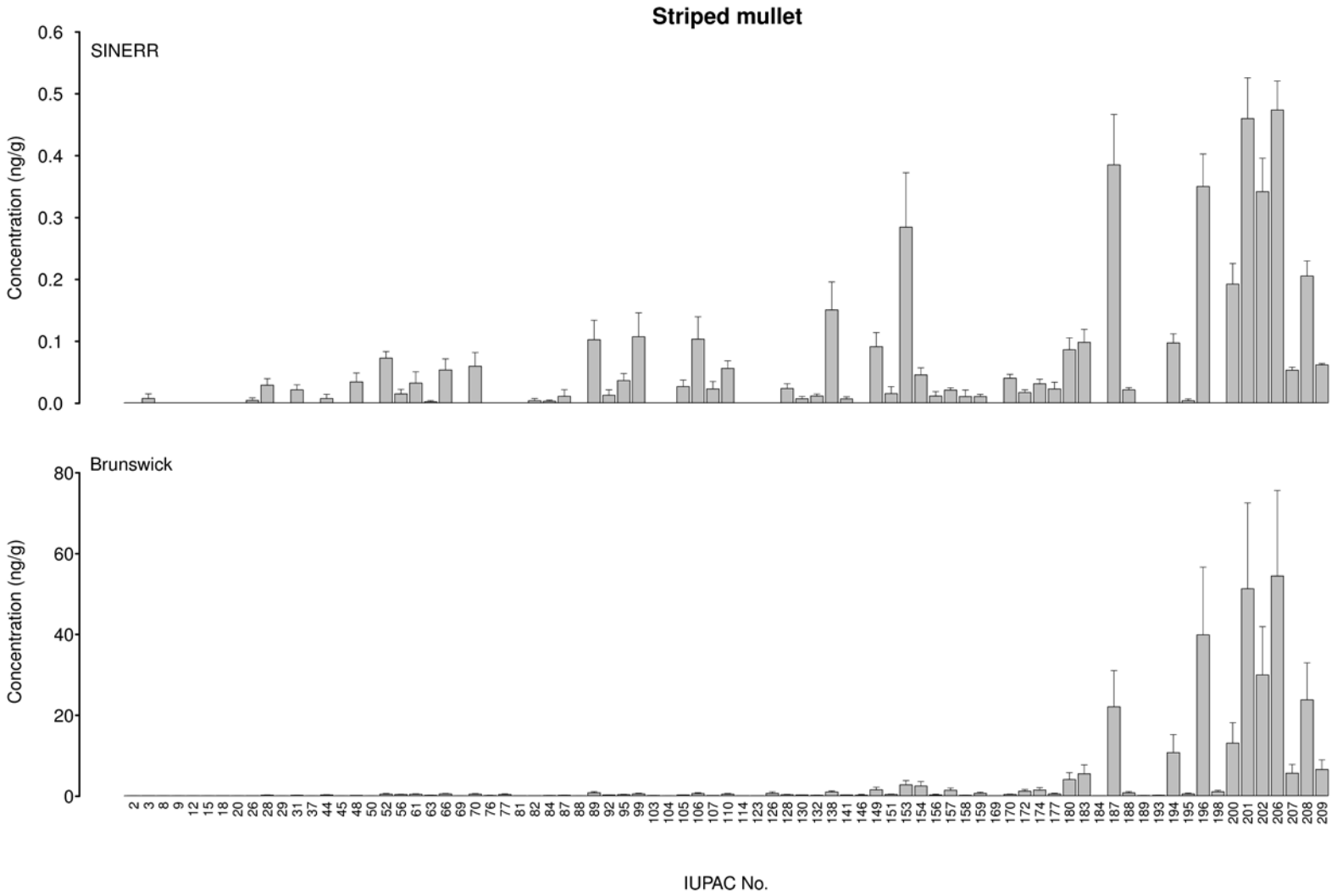

Figure 23. Comparison of PCB congener profiles in edible tissues of Striped mullet (*Mugil cephalus*) collected in SINERR and Brunswick GA. Bar heights represent mean congener concentration averaged across stations (when species were collected at multiple stations). Whiskers represent the standard error of the mean. Note different scales for concentration.

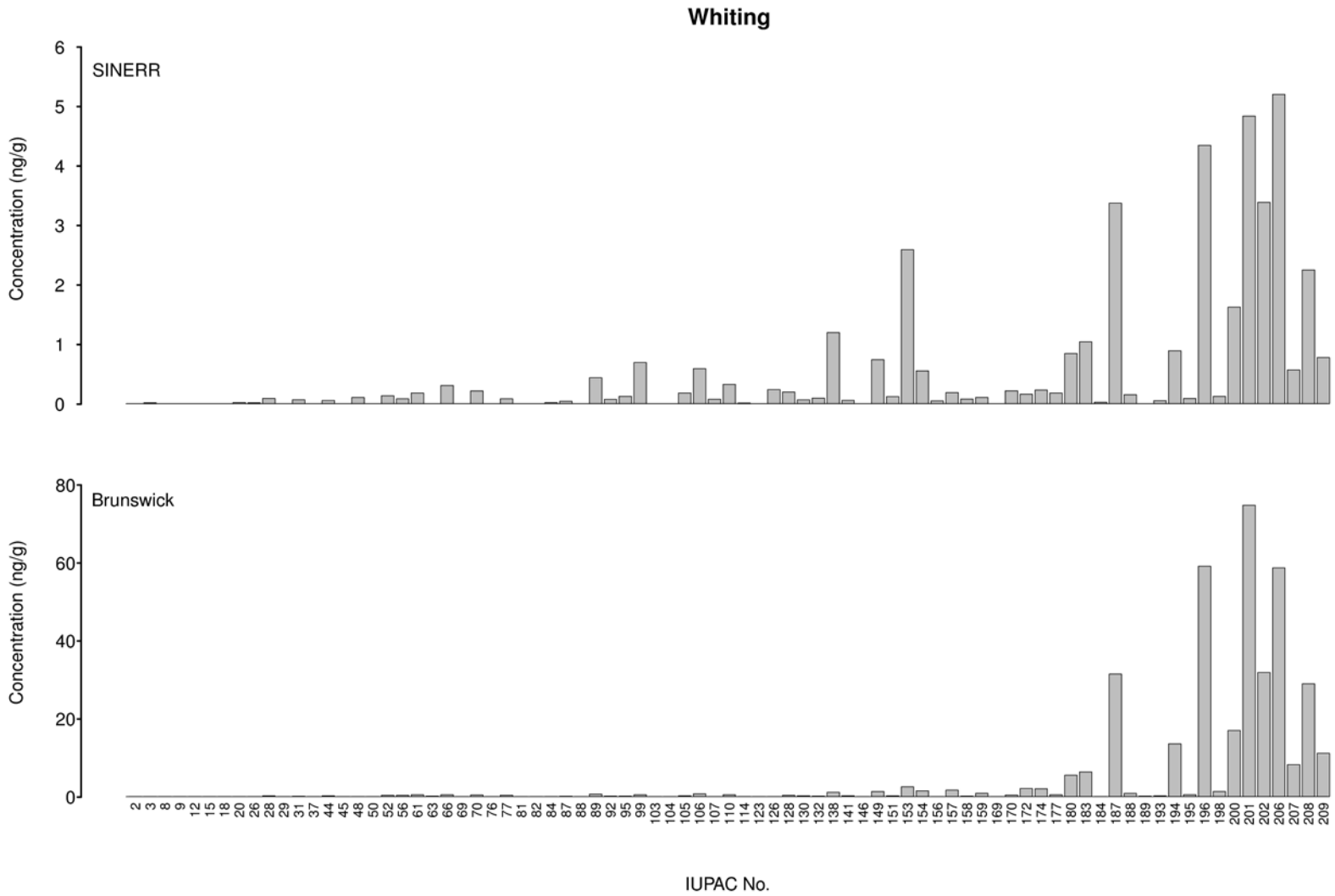

Figure 24. Comparison of PCB congener profiles in edible tissues of whiting (*Menticirrhus* spp.) collected in SINERR and Brunswick GA. Bar heights represent mean congener concentration averaged across stations (when species were collected at multiple stations). Note different scales for concentration.

As a further illustration of the characteristic distribution of PCB congeners in fish tissues collected in the vicinity of SINERR and Brunswick, GA, profiles from these sites were compared to other coastal regions of the southeastern U.S. using data collected as part of the joint EPA/NOAA Environmental Monitoring and Assessment Program (EMAP) in 1995 and 1997 (Figure 25). These data (Hyland et al. 1998, NCA 2010) represent PCB concentrations in edible tissues (fillets) of Atlantic croaker (*Micropogonias undulatus*) collected from estuaries in NC, SC, GA, and FL. PCB congener distributions in fish from NC, SC, and FL reflect the dominance of globally persistent congeners not found (or not abundant) in Aroclor 1268 (i.e., 138, 153, 170; Pulster et al. 2005), while GA fish show clearly the influence of higher-chlorinated homologs, particularly PCB 206, the most abundant congener in Aroclor 1268 (Kannan et al. 1997). Note that some of the more prevalent Aroclor 1268 congeners (e.g., 201, 202, 208) are not included in the inter-site comparison because historically they have not been measured.

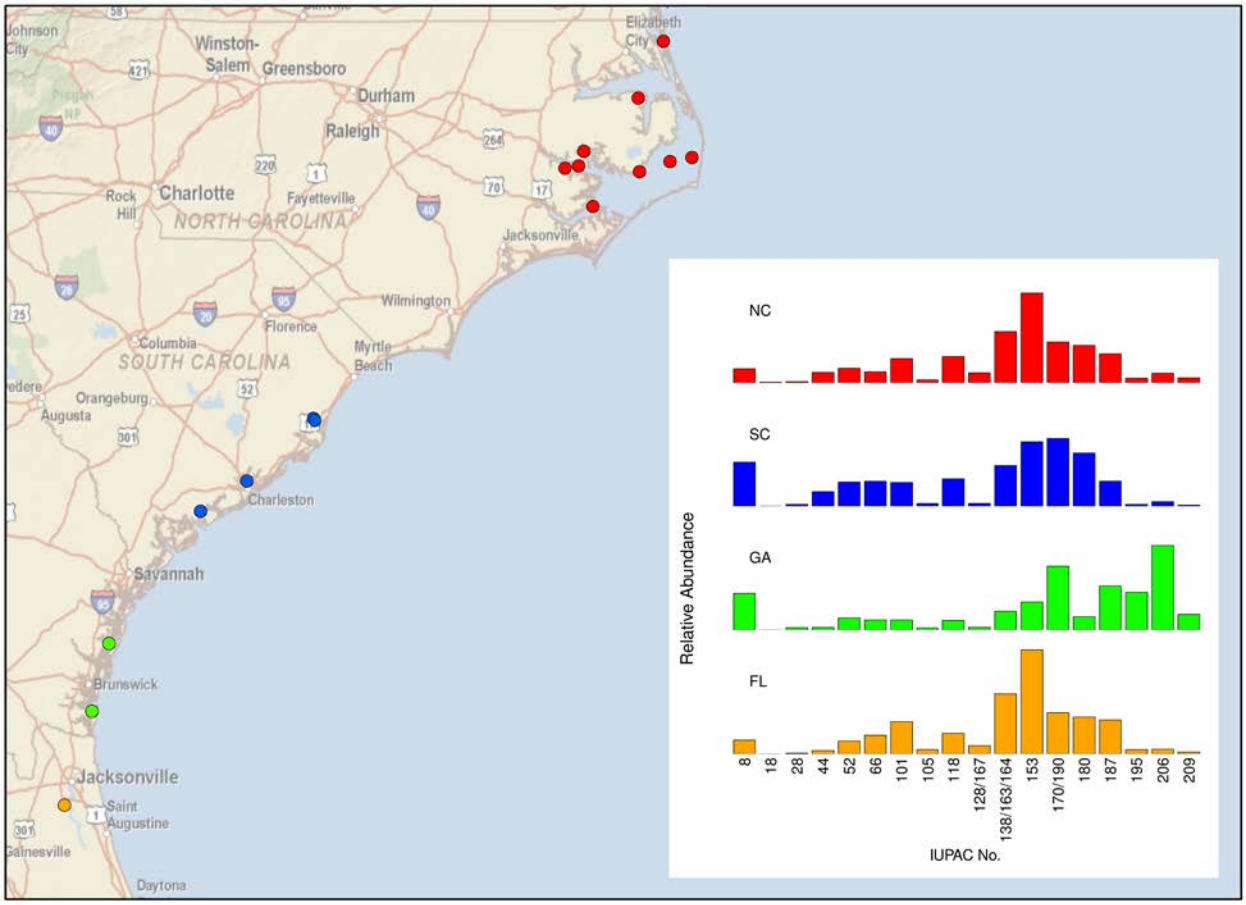

Figure 25. Comparison of congener profiles for polychlorinated biphenyls (PCBs) measured in edible tissues of Atlantic croaker (*Micropogonias undulatus*) in different regions of the southeastern coastal United States.

3.3.3 Potential Linkages of Biological Condition to Ecosystem Stressors

In order to assess the relationship between benthic biological condition and potential environmental stressors, a sediment quality triad (SQT) approach was employed using the B-IBI (Van Dolah et al. 1999) as a measure of overall benthic health, in combination with SQGs (i.e., ERL and ERM; Long et al. 1995) and Microtox® toxicity test results as indicators of chemical contamination and overall sediment toxicity, respectively. The SQT has been demonstrated as an effective "weight-of-evidence" approach to assessing pollution-induced degradation of the benthos (Long and Chapman 1985, Chapman 1990).

Of the 30 stations sampled, 17 (56.7 % of the study area) had a healthy benthic assemblage with low levels of sediment contamination and no toxicity (Table 11). No part of the SINERR had a degraded benthos with both high contamination and toxicity (i.e., positive concordances of all three components of the SQT). Two sites (6.7 % of the area) had a degraded benthos accompanied by significant sediment toxicity but low levels of sediment contamination. The remaining 11 stations, representing about 37% of the study area, showed some signs of stress but no connection between adverse biological and exposure conditions. For example, four of these eleven stations (13.3 % of the study area, showed evidence of a degraded benthos (B-IBI < 3), but with no accompanying signs of sediment contamination or toxicity (thus possibly due to unmeasured stressors or natural factors). Seven of the eleven stations (23.3 % area) had a healthy benthic assemblage and low levels of sediment contamination, but significant Microtox® toxicity (possibly due to other unmeasured contaminants or over-sensitivity of the assay).

Table 12 summarizes values of relevant parameters for stations where benthic assemblages exhibited signs of impairment (i.e., B-IBI < 3). As noted above, sediments at two of these sites also had significant Microtox® toxicity. The level of sediment chemical contamination at these two sites was relatively low, but within the range ($0.02 < \text{mERM-Q} \leq 0.058$) found to be associated with moderate (~ 50 % incidence) impacts to benthic infaunal assemblages in southeastern U.S. estuaries (Hyland et al. 1999). As Figure 10 illustrates, the main contaminants driving mERM-Q values were trace metals, including As, which exceeded the corresponding ERL at these sites. Two of the remaining four sites in Table 12 also had mERM-Qs between 0.02 and 0.058 and exceedances of the ERL for As. Other potential stressors, namely DO and TOC (as an indicator of organic over-enrichment), were within levels considered low to moderate. Concentrations of DO were above commonly-cited criterion levels for hypoxia of 2 mg/L (U.S. EPA 2008) as well as the recommended lower guideline value for Georgia coastal waters of 3 mg/L (Sheldon and Alber 2010). Total organic carbon at two of the six stations with B-IBI < 3 was within the range associated with moderate levels of organic enrichment (20 – 50 mg/g TOC; U.S. EPA 2008), but below levels associated with a high risk of disturbance (> 50 mg/g as reported by U.S. EPA 2008, or > 35 mg/g as reported by Hyland et al. 2005).

It should be noted that while the six stations discussed above had B-IBI values < 3, all of these were within the transitional range of 2 – 2.5, indicating possible stress, but still above values (B-IBI $\leq$ 1.5) considered to represent the clearest evidence of degraded benthos (Van Dolah et al. 1999).

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

Effect Type			No. Stations	% Area (± 95% C.I.)	Possible Conclusion
Sediment Contam.[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 other stressors.
-	+	+	2	6.67 (5.64)	
-	-	+	4	13.33 (10.92)	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	
-	+	-	7	23.33 (12.95)	
-	-	-	17	56.67 (14.69)	Healthy benthos with low levels of sediment contamination and toxicity.

a. One or more Effects Range-Median (ERM) values exceeded or mean ERM quotient (mERM-Q) > 0.058.
b. Significant Microtox toxicity.
c. Benthic index (B-IBI) < 3.

Table 12. Comparison of potential stressor sources at stations that showed some indications of an impaired benthos based on benthic index (B-IBI) scores (though all values were only in the intermediate/partial-stress range).

Station	B-IBI	Mean ERM-Q	No. Contaminants > ERM	No. Contaminants > ERL	DO (mg/L)	TOC (mg/g)	Significant Microtox® Toxicity
1	2.5	0.0272	0	1	3.40	30.50	—
9	2.0	0.0145	0	0	3.09	12.46	—
15	2.5	0.0069	0	0	3.96	4.10	—
21	2.5	0.0266	0	1	3.64	16.70	Yes
22	2.5	0.0180	0	1	4.27	20.18	—
29	2.5	0.0246	0	1	3.53	19.97	Yes

There was a low degree of concordance between fish tissue contaminant concentrations and sediment contaminant levels (Table 13). Establishing an association between sediment and tissue concentrations would be difficult, however, since fish of any given species were collected at no more than four of the 30 stations. Moreover, the SINERR study area was relatively small and some of the species collected would be expected to move in and out of the area. At all stations where tissue contaminants exceeded human-health endpoints, m-ERMQs were in the reported range (< 0.020) associated with a low risk of impacts to benthic infauna in southeastern U.S. estuaries (Hyland et al. 1999). Only one site (Station 22) had a corresponding exceedance of the ERL for As.

Table 13. Summary measures of sediment quality at stations where human health guidelines were exceeded in edible tissues of fish collected in Sapelo Island National Estuarine Research Reserve.

Station Code	Species (no. of specimens)	Analyte	Cancer Health Endpoint Exceeded	Non-Cancer Health Endpoint Exceeded	Sediment mERM-Q	No. of Sed. Contaminants > ERL	No. of Sed. Contaminants > ERM
SI09_005	Striped mullet (2)	As	Upper		0.0060	0	0
SI09_009	Striped mullet (1)	As	Upper		0.0145	0	0
SI09_009	Striped mullet (1)	Total PCBs	Lower			0	0
SI09_011	Atlantic croaker (1)	As	Upper		0.0133	0	0
SI09_011	Atlantic croaker (1)	Total PCBs	Lower				
SI09_011	Spotted seatrout (1)	Total PCBs	Upper			0	0
SI09_012	Southern flounder (1)	As	Upper		0.0108	0	0
SI09_014	Spotted seatrout (1)	As	Lower		0.0052	0	0
SI09_014	Red drum (1)	As	Lower			0	0
SI09_014	Red drum (1)	Total PCBs	Upper			0	0
SI09_017	Spotted seatrout (1)	As	Lower		0.0076	0	0
SI09_017	Atlantic croaker (1)	As	Upper			0	0
SI09_017	Striped mullet (3)	As	Upper			0	0
SI09_018	Whiting (1)	As	Upper		0.0027	0	0
SI09_018	Whiting (1)	Hg		Lower		0	0
SI09_018	Whiting (1)	Total PCBs	Upper	Lower		0	0
SI09_022	Atlantic croaker (1)	As	Upper		0.0180	1	0
SI09_022	Atlantic croaker (1)	Total PCBs	Lower			0	0
SI09_025	Silver perch (3)	As	Lower*		0.0160	0	0
SI09_025	Striped mullet (3)	As	Upper			0	0
SI09_025	Red drum (1)	As	Upper			0	0
SI09_025	Silver perch (1)	Hg		Lower		0	0
SI09_025	Silver perch (1)	Total PCBs	Upper			0	0
SI09_025	Striped mullet (1)	Total PCBs	Lower			0	0

* One of three specimens exceed the upper cancer health endpoint for inorganic As.

3.4 Overall Ecological Condition and Human Factors

As discussed in Section 3.3.3, more than half of SINERR stations (56.7 % area) had healthy benthic assemblages without any accompanying indications of significant sediment contamination or toxicity. Furthermore, no stations had hits in all three legs of the SQT (i.e., degraded benthic condition accompanied by significant sediment contamination and toxicity). In fact, only six stations showed signs of possible benthic impairment ($2 \leq$ B-IBI ≤ 2.5) and of those, only two (6.7 % of the survey area) were connected to any evidence of adverse exposure conditions (i.e., Microtox® toxicity hits but no significant chemical contamination).

Figure 26 compares sediment quality triad (SQT) results – based on combined measures of sediment contamination, toxicity, and benthic condition – for the present SINERR study *vs*. other similar studies of southeastern U.S. estuaries. The first bar summarizes results from the Environmental Monitoring and Assessment Program (EMAP) in the Carolinian Province (CP) from 1994 and 1995 for SC and GA estuaries only (n=41). The second bar is also from EMAP-CP 1994-1995, but includes all CP estuaries (NC, SC, GA, FL; n=168). The third bar is based on data from a recent study in the NC NERR (Cooksey et al. 2008).

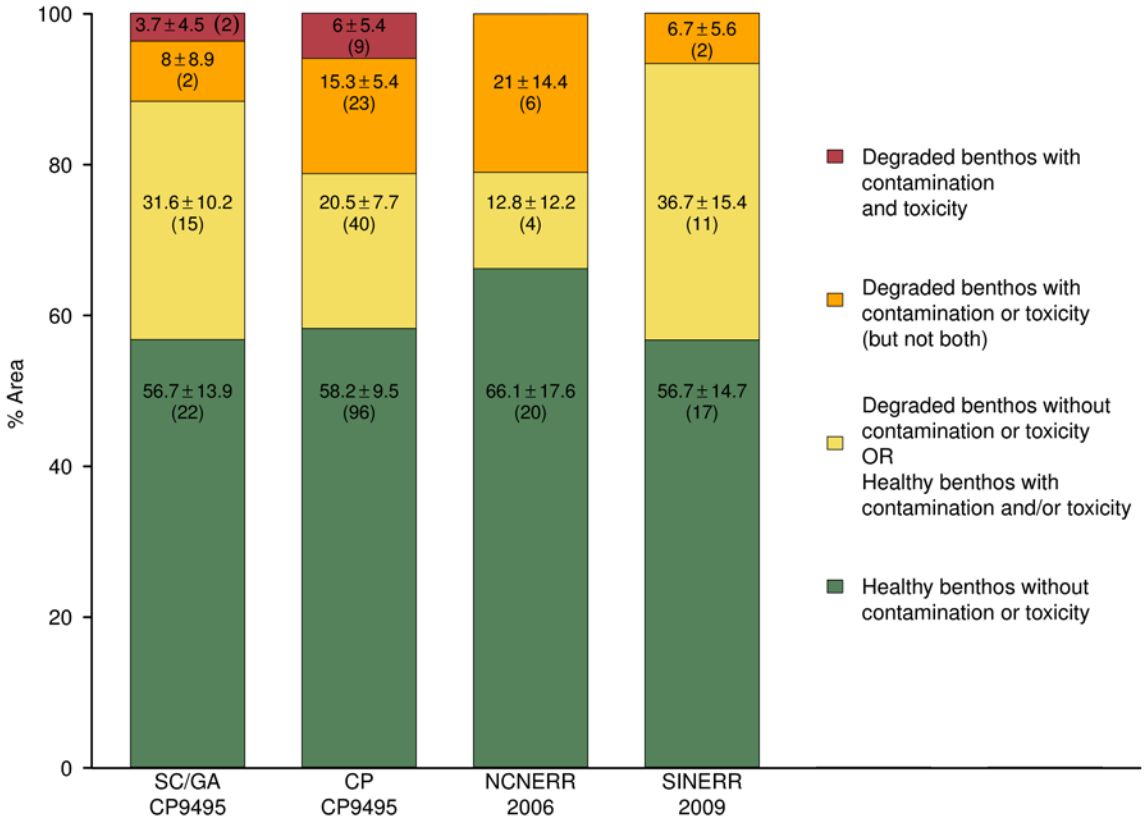

Figure 26. Comparison of SQT results for Sapelo Island National Estuarine Research Reserve *vs*. other related studies of southeastern U.S. estuaries.

In the studies that included GA estuaries, there were no co-occurrences of a degraded benthos, high sediment contamination, and toxicity (i.e., within the red zone of the bar graphs) at any of the corresponding GA sites. The two stations in the red zone of the first bar graph were in SC and the nine stations in the second bar graph were in NC, SC, and FL. The lowest incidence of degraded benthos accompanied by either sediment contamination or toxicity was found in SINERR (i.e., 6.7 % as noted above). Moreover, although a relatively large proportion of the area of SINERR (~37 %) showed some signs of stress, there was no obvious connection between adverse biological and exposure conditions at any of the 11 corresponding sites; in fact, seven of these sites, representing 23.3 % of the study area, actually had healthy benthic assemblages though accompanied by significant sediment Microtox® toxicity. Thus, overall, healthy benthic assemblages were observed in about 80% of the SINERR study area. In comparison, healthy benthic condition (whether or not accompanied by sediment contamination or toxicity) occurred in about 76 % of the NCNERR study area; 66.9 % of the EMAP-CP area (province-wide); and 78.9 % of the SC/GA portion of the EMAP-CP area.

Water quality measurements across SINERR showed elevated levels of some nutrients, primarily DIP (86.7 % classified as "Fair", 10 % as "Poor"), but with low levels of DIN over most of the study area (96.7 % classified as "Good", 3.3 % "Fair"). Chlorophyll *a* concentrations were somewhat elevated (76.7 % in the "Fair" range, 23.3 % "Good"). DIN levels were lower than Georgia estuaries as a whole (37 % "Fair", 4 % "Poor"; Guadagnoli et al. 2005) or estuaries in the southeastern U.S. overall (9 % "Fair", 1 % "Poor"; U.S. EPA 2008). Levels of DIP and chlorophyll *a* were slightly higher than southeastern U.S. estuaries overall, but lower compared to all Georgia estuaries combined. Dissolved oxygen concentrations in SINERR would be classified as "Fair" (96.7 % of the study area), with only one station, representing 3.3 % of the study area, having DO concentrations > 5 mg/L. However, no stations had DO conditions that would be considered "Poor", and lower DO levels were associated with sites near the headwaters of the Duplin River or small tidal creeks having low tidal exchange, higher particulate and dissolved organic carbon (POC and DOC), and higher biological oxygen demand (BOD). Comparatively, nutrient and DO levels are in close agreement with results of the National Estuarine Eutrophication Assessment Program (Bricker et al. 2007), which used different assessment techniques but found low to moderate eutrophic conditions throughout Georgia estuaries.

In an attempt to assess human-health risks, concentrations of chemical contaminants (metals, PAHs, PCBs, PBDEs, and pesticides) were measured in skin-on fillets of 22 fish specimens collected at nine stations in SINERR. The measured concentrations were compared (where available) to fish consumption guidelines developed by U.S. EPA (2000), which provide monthly consumption limits for different concentration ranges of chemical contaminants that define acceptable levels of risk. For non-cancer (chronic, systemic) effects, the monthly consumption limits define a range of concentrations that would not generate a health risk over a lifetime; the cancer limits define ranges that would yield a lifetime cancer risk no greater than an acceptable risk of 1 in 100,000. Hence, in cases where the upper limit of the defined range is exceeded, there may be assumed to exist an increased risk of health effects at the corresponding monthly consumption rate over a lifetime. Sixteen of the 22 fish specimens collected in this study (six out of seven species from eight of the nine stations where fish were caught) had inorganic arsenic levels (estimated as 2 % of total As) that exceeded the corresponding upper

cancer health endpoint. Four of 22 fish specimens (18 %) from four stations (44 %) exceeded the upper cancer health endpoint for total PCBs. However, with respect to non-cancer health endpoints, Hg (assumed to be all methylmercury) and total PCBs fell within the EPA guidance limits (i.e., between the lower and upper endpoints) in two of 22 fish specimens (9 %) at two of the nine stations (22 %) where fish were collected. In assessing the status of southeastern U.S. estuaries with respect to fish tissue contamination, EPA (U.S. EPA 2008) uses only non-cancer limits for the contaminants discussed above. They found 10 % of all sites sampled where fish were caught exceeded the upper endpoint of the guidance range for at least one chemical contaminant (i.e., "Poor" condition), 11 % fell within the guidance range for at least one contaminant ("Fair"), and 79 % were below the guidance range for all chemicals ("Good"). Hence, using these criteria, 78 % of sites sampled in this study would be classified as "Good", 22 % as "Fair", and none classified as "Poor" with respect to fish tissue contamination. Compared to the EPA assessment, which found tissue contaminant exceedances for total PAHs and total PCBs, the "Fair" rating for SINERR fish tissues resulted from guideline exceedances for Hg and total PCBs.

As discussed previously, PCB congener profiles in fish tissues collected in SINERR were strikingly similar to those in fish collected near Brunswick, GA and reflect the pattern of PCB homologs characteristic of Aroclor 1268, which is associated with extensive contamination of marsh sediments around the LCP Chemicals Superfund site near Brunswick. Of the 12 fish collected at four stations near Brunswick, GA during this sampling as part of a related study (dolphin health assessment), 11 exceeded the upper non-cancer health endpoint for total PCBs and one exceeded the lower non-cancer health endpoint. Two of the 12 fish specimens exceeded the upper non-cancer health endpoint for Hg. These results suggest further that the exceedances in SINERR fish discussed above, particularly PCBs but also possibly Hg, may be linked to the well-documented source of contamination at the LCP Chemicals Superfund site southwest of the Reserve. Incidentally, none of the fish collected during this study showed any obvious signs of pathology (i.e., lumps due to internal growths, external growths, ulcers, or fin rot).

Aesthetic indicators also were sampled at each SINERR station and included measures of water clarity (turbidity and 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 discussed previously, TSS ranged from 46 – 106 mg/L, averaging 65.4 mg/L across the 30 sampled sites, which appear to be within a normal range given the naturally high turbidity of southeastern U.S. estuaries. Turbidity ranged from 4.0 – 19.9 NTU in surface waters (mean of 9.0 NTU) and 8.7 – 48.5 NTU in bottom waters (mean = 20.9 NTU). None of the surface turbidities exceeded the upper-limit threshold of 25 NTU adopted by the state of South Carolina as a standard for near-surface saltwater (no saltwater turbidity guideline exists for GA). There were no signs 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 specific evidence of an aesthetic effect was the occurrence of noxious odors in bottom sediments at six of the stations (20 % of the study area). These sites had sediments with noxious (hydrogen sulfide) odors, likely resulting from the natural decomposition of detrital organic matter.

The status of ecological condition for subtidal aquatic habitats at SINERR, based on combined indicators of water quality, sediment quality, and benthic biological condition, appears to be in

fair condition overall, with the majority of the reserve (56.7 %) having one or more indicator scores in the "Moderate/Fair" category (Table 14). While 12 stations (40 % of the study area) had one or more water quality, sediment quality, or benthic biological condition indicators rated as "Poor/Degraded," this resulted from three stations having high DIP values and nine stations having significant Microtox® toxicity (see Table 5). There were no clear linkages of degraded benthic biological condition with poor water or sediment quality other than co-occurrences of a partially degraded benthos (intermediate B-IBI scores) and significant sediment toxicity (without evidence of high sediment contamination) at two of the 30 sites.

Table 14. Estimates of overall ecological condition at Sapelo Island National Estuarine Research Reserve based on combined indicators of water quality, sediment quality, and biological condition (note: fish tissue contaminant data are not included in these calculations 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* benthic biological condition indicators rated as "Good/Healthy"	0	0
[b] One or more water quality, sediment quality, *or* benthic biological condition indicators rated "Moderate/Fair" (but none as 'Poor/Degraded")	17	56.7 (14.9)
[c] One or more water quality, sediment quality, *or* benthic biological condition indicators rated as "Poor/Degraded"	12	40.0 (15.1)
One or more water quality, sediment quality, *and* benthic biological condition indicators rated as "Poor/Degraded"	0	0
One or more water quality, sediment quality, *or* benthic biological condition indicators "Missing"	1	3.3 (5.9)

[a] DO > 5 mg/L, DIN < 0.1 mg/L, DIP < 0.01 mg/L, CHLa < 5 mg/L, TOC < 20 mg/g; mean ERM-q ≤ 0.02 AND < 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, CHLa 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 2 - 2.5.

[c] DO < 2 mg/L, DIN > 0.5 mg/L, DIP > 0.05 mg/L, CHLa > 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.

These results suggest that the Reserve is in fair condition overall but under multiple pressures from a variety of natural and/or anthropogenic factors. The lack of evidence of extensive biological impacts linked to poor water or sediment quality suggests that current stressor levels may not be of sufficient magnitude to be expressed clearly as bioeffects. However, the types and concentrations of chemical contaminants in sediments and biota (fish), significant Microtox® sediment toxicity, and transitional benthic index scores observed at some sites serve as early-warning signals of ensuing environmental pressures that present management challenges. A major programmatic goal of SINERR is to protect and, where necessary, restore the productivity and integrity of the Reserve's resources. Together with other research components of the SINERR such as the System Wide Monitoring Program (SWMP) and the Georgia Coastal Ecosystems Long Term Monitoring Program (GCE-LTER), this study establishes an important baseline of overall ecological condition within the Reserve that can be used to evaluate potential changes in the future and to trigger appropriate management actions to maintain the integrity of this relatively unspoiled resource.

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5. Appendices

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

				Near-Bottom Water					Bottom Sediments		
Station	Latitude (DD)	Longitude (DD)	Depth (m)	Temp. (°C)	Salinity (ppt)	DO (mg/L)	pH	Turbidity (NTU)	TOC (mg/g)	Sand (%)	SiltClay (%)
1	31.47230	-81.28348	1.7	27.10	20.08	3.40	7.18	22.4	30.50	7.37	92.63
2	31.46001	-81.27798	8.4	26.61	19.39	3.53	7.18	16.5	2.98	98.26	1.74
3	31.44505	-81.28719	5.3	27.52	20.68	3.66	7.32	17.3	3.14	93.30	6.70
4	31.42636	-81.29398	5.1	27.70	21.94	4.10	7.38	25.9	4.65	90.64	9.36
5	31.46691	-81.27962	5.1	27.17	19.30	3.05	7.10	28.5	3.44	89.81	10.19
6	31.45338	-81.28561	6.8	27.86	20.82	3.97	7.33	13.2	14.45	59.62	40.38
7	31.43559	-81.28304	2.8	27.81	20.63	3.56	7.20	10.8	4.35	90.34	9.66
8	31.43123	-81.28718	4.4	27.99	19.67	2.29	7.07	8.7	19.53	30.54	69.46
9	31.46893	-81.28152	9.7	26.96	19.61	3.09	7.22	10.2	12.46	67.13	32.87
10	31.45799	-81.29460	2.2	27.18	20.54	3.53	7.19	10.5	28.41	13.67	86.34
11	31.41582	-81.30126	1.0	27.76	22.10	4.86	7.45	17.5	10.15	62.05	37.95
12	31.48542	-81.26971	2.2	27.16	18.69	2.40	7.08	12.2	9.34	70.42	29.58
13	31.45511	-81.28146	1.2	28.21	20.22	3.39	7.24	23.5	33.64	1.99	98.00
14	31.43875	-81.28790	4.4	27.17	23.33	4.20	7.42	13.2	2.56	92.26	7.75
15	31.42325	-81.29463	5.7	26.58	23.63	3.96	7.48	14.0	4.10	79.31	20.69
16	31.46286	-81.27483	3.7	27.12	18.90	3.16	7.17	9.2	5.77	94.11	5.90
17	31.46102	-81.27729	3.4	27.03	19.13	3.40	7.16	18.5	2.48	82.44	17.56
18	31.43246	-81.29445	7.1	27.40	24.95	4.45	7.58	38.2	8.03	96.92	3.08
19	31.41419	-81.30173	2.4	26.84	25.56	5.08	7.57	34.3	25.48	68.94	31.07
20	31.39268	-81.28336	3.5	25.88	25.96	3.76	7.24	22.6	31.08	15.69	84.31
21	31.48623	-81.29512	1.4	27.04	20.33	3.64	7.22	13.5	16.70	0.44	99.56
22	31.45321	-81.30234	4.3	26.71	23.62	4.27	7.42	41.6	20.18	40.07	59.94
23	31.41455	-81.29872	4.0	25.99	28.17	4.79	7.40	48.5	6.53	39.16	60.84
24	31.48230	-81.27052	2.4	27.09	18.71	2.41	7.06	15.3	0.97	79.13	20.87
25	31.45643	-81.28340	2.5	27.37	19.95	3.75	7.22	14.4	12.61	47.53	52.47
26	31.44346	-81.28921	3.3	27.25	22.76	3.95	7.33	21.9	17.17	38.54	61.46
27	31.41972	-81.29540	4.2	26.83	23.90	4.54	7.46	40.5	23.13	9.97	90.03
28	31.46148	-81.27592	4.4	27.11	19.21	3.56	7.20	9.7	3.21	92.08	7.92
29	31.47673	-81.29091	2.8	27.10	20.44	3.53	7.21	35.4	19.97	25.85	74.15
30	31.44643	-81.28625	3.4	27.70	19.94	3.15	7.25	17.7	3.05	91.22	8.78

Appendix B. Water-column nutrients and total suspended solids (TSS) in near-surface waters.

Station	DIN (mg/L)	NH_4^+ (mg/L)	TDN (mg/L)	TN (mg/L)	DIP (mg/L)	TDP (mg/L)	TP (mg/L)	Si (mgL)	Chloro-phyll *a* (µg/L)	Phaeo-phytin (µg/L)	TSS (mg/L)
1	0.0802	0.053	0.52	0.69	0.0507	0.0873	0.1172	1.68	8.28	3.37	84
2	0.0991	0.065	0.53	0.62	0.0511	0.0645	0.0845	1.30	3.91	2.47	58
3	0.0908	0.057	0.50	0.61	0.0300	0.0580	0.0799	1.21	3.92	2.23	89
4	0.0624	0.027	0.48	0.61	0.0251	0.0729	0.0779	1.29	11.36	4.22	76
5	0.0620	0.039	0.47	0.59	0.0266	0.0584	0.0771	1.27	4.33	2.42	53
6	0.0611	0.022	0.45	0.61	0.0241	0.0622	0.0723	1.17	10.41	3.80	74
7	0.0748	0.045	0.50	0.59	0.0297	0.0589	0.0784	1.95	6.20	2.67	56
8	0.0621	0.045	0.52	0.67	0.0493	0.0880	0.1098	2.81	7.09	2.79	103
9	0.0811	0.049	0.49	0.56	—	0.0572	0.0666	2.52	3.82	1.96	50
10	0.0661	0.036	0.48	0.58	0.0300	0.0660	0.0762	2.35	6.82	2.61	58
11	0.0781	0.041	0.70	0.60	0.0387	0.0483	0.0697	1.84	7.12	4.00	64
12	0.0498	0.034	0.47	0.57	0.0233	0.0529	0.0673	1.52	3.88	1.93	72
13	0.0750	0.049	0.51	0.61	0.0328	0.0654	0.0820	2.36	5.90	2.53	92
14	0.0571	0.021	0.46	0.60	0.0201	0.0635	0.0783	1.44	13.22	3.99	50
15	0.0947	0.060	0.48	0.60	0.0604	0.0528	0.0693	1.25	7.52	2.72	46
16	0.0616	0.043	0.47	0.58	0.0360	0.0563	0.0712	1.32	7.74	2.94	49
17	0.0894	0.062	0.54	0.63	0.0318	0.0559	0.0712	1.01	4.42	2.61	48
18	0.0455	0.015	0.41	0.57	0.0201	0.0545	0.0731	1.62	11.74	3.89	60
19	0.0488	0.015	0.41	0.55	0.0189	0.0554	0.0781	1.30	9.97	4.06	63
20	0.1061	0.063	0.47	0.59	0.0300	0.0602	0.0793	1.31	5.39	3.18	52
21	0.0934	0.056	0.48	0.58	0.0396	0.0670	0.0867	2.48	5.65	2.75	106
22	0.0697	0.026	0.50	0.60	0.0218	0.0572	0.0743	2.05	7.74	2.88	104
23	0.0782	0.038	0.46	0.56	0.0244	0.0538	0.0713	1.27	6.11	2.59	53
24	0.0472	0.031	0.51	0.57	0.0317	0.0514	0.0668	1.35	3.57	2.02	50
25	0.0919	0.062	0.55	0.63	0.0282	0.0611	0.0743	1.25	8.19	3.07	48
26	0.0718	0.037	0.47	0.62	0.0276	0.0641	0.0880	1.63	8.57	3.93	65
27	0.0942	0.058	0.50	0.61	0.0241	0.0529	0.0857	1.42	10.03	5.40	—
28	0.0955	0.064	0.54	0.59	0.0372	0.0550	0.0733	1.21	6.10	2.52	51
29	0.0865	0.056	0.56	0.63	0.0366	0.0678	0.0960	1.55	6.80	2.99	64
30	0.0818	0.056	0.55	0.63	0.0319	0.0650	0.0787	1.58	6.18	2.68	58

Appendix C. Fecal coliform and F+ coliphage counts from SINERR water samples.

Station Number	Date Collected	Fecal coliforms (CFU/100mL)	F+ coliphage (PFU/100mL)
1	6/10/2009	37	0
2	6/08/2009	14	0
3	6/11/2009	26	0
4	6/11/2009	9	0
5	6/09/2009	20	0
6	6/12/2009	10	0
7	6/11/2009	18	0
8	6/11/2009	25	0
9	6/09/2009	20	0
10	6/10/2009	6	0
11	6/09/2009	9	0
12	6/09/2009	6	0
13	6/12/2009	25	0
14	6/11/2009	7	0
15	6/09/2009	18	0
16	6/08/2009	5	0
17	6/08/2009	15	0
18	6/12/2009	1	0
19	6/10/2009	5	0
20	6/08/2009	4	0
21	6/10/2009	2	0
22	6/10/2009	5	0
23	6/08/2009	2	0
24	6/09/2009	8	0
25	6/09/2009	16	0
26	6/11/2009	16	0
27	6/10/2009	11	0
28	6/08/2009	20	0
29	6/10/2009	3	0
30	6/11/2009	23	0

Appendix D. Summary of sediment contaminant concentrations (dry mass) by analyte at 30 SINERR stations. Concentrations below method detection limits (<MDL) were assigned a value of zero for data analysis purposes. None of the chemicals exceeded corresponding upper-threshold ERM bioeffect guideline values; there was only one chemical (arsenic) that exceeded its corresponding lower-threshold ERL bioeffect guideline value and these exceedances occurred at 11 of 30 stations (see Appendix E).

Analyte	Mean	Minimum	Maximum	Std. Dev.
Trace Metals (% dry mass)				
Aluminum	3.374	0.616	7.790	2.489
Iron	1.887	0.191	4.253	1.318
Trace Metals (µg/g dry mass)				
Antimony	0.030	0.000	0.887	0.162
Arsenic	6.584	0.334	14.700	4.717
Barium	79.207	21.452	198.266	31.703
Beryllium	0.959	0.000	2.278	0.717
Cadmium	0.081	0.012	0.131	0.033
Chromium	31.736	7.072	66.087	19.039
Cobalt	4.392	0.502	9.829	3.099
Copper	4.977	0.605	12.313	3.544
Lead	12.704	4.341	27.527	6.517
Lithium	30.402	2.880	74.300	24.875
Manganese	191.325	32.358	582.876	168.035
Mercury	0.017	0.002	0.053	0.014
Nickel	5.739	0.725	12.593	3.421
Selenium	0.456	0.000	0.976	0.288
Silver	0.000	0.000	0.000	0.000
Thallium	0.240	0.086	0.432	0.113
Tin	0.992	0.209	2.073	0.644
Uranium	1.787	0.781	2.738	0.431
Vanadium	47.888	9.917	103.911	30.510
Zinc	25.968	3.850	61.344	17.817
PAHs (ng/g dry mass)				
1-Methylnaphthalene	0.000	0.000	0.000	0.000
1-Methylphenanthrene	0.000	0.000	0.000	0.000
1,6,7-Trimethylnaphthalene	0.000	0.000	0.000	0.000
2-Methylnaphthalene	0.000	0.000	0.000	0.000
2,6-Dimethylnaphthalene	0.000	0.000	0.000	0.000
Acenaphthene	0.000	0.000	0.000	0.000
Acenaphthylene	0.000	0.000	0.000	0.000
Anthracene	0.000	0.000	0.000	0.000
Benz[a]anthracene	0.000	0.000	0.000	0.000
Benzo[a]pyrene	0.000	0.000	0.000	0.000
Benzo[b]fluoranthene	0.000	0.000	0.000	0.000
Benzo[e]pyrene	0.000	0.000	0.000	0.000
Benzo[g,h,i]perylene	0.000	0.000	0.000	0.000
Benzo[j+k]fluoranthene	0.000	0.000	0.000	0.000
Biphenyl	0.000	0.000	0.000	0.000
Chrysene+Triphenylene	0.000	0.000	0.000	0.000
Dibenz[a,h]anthracene	0.000	0.000	0.000	0.000
Dibenzothiophene	0.000	0.000	0.000	0.000

Appendix D (continued).

Analyte	Mean	Minimum	Maximum	Std. Dev.
Fluoranthene	4.128	0.000	17.648	5.159
Fluorene	0.000	0.000	0.000	0.000
Indeno[1,2,3-c,d]pyrene	0.000	0.000	0.000	0.000
Naphthalene	0.000	0.000	0.000	0.000
Perylene	21.412	0.000	90.452	21.986
Phenanthrene	0.000	0.000	0.000	0.000
Pyrene	0.000	0.000	0.000	0.000
Low Molecular Weight PAHs	0.000	0.000	0.000	0.000
High Molecular Weight PAHs	4.128	0.000	17.648	5.159
Total PAHs	4.128	0.000	17.648	5.159
PBDEs (ng/g dry mass)				
PBDE 100 (2,2',4,4',6-pentabromodiphenyl ether)	0.000	0.000	0.000	0.000
PBDE 138	0.000	0.000	0.000	0.000
PBDE 153 (2,2',4,4',5,5'-hexabromodiphenyl ether)	0.000	0.000	0.000	0.000
PBDE 154 (2,2',4,4',5,6'-hexabromodiphenyl ether)	0.000	0.000	0.000	0.000
PBDE 17	0.000	0.000	0.000	0.000
PBDE 183 (2,2',3,4,4',5',6-heptabromodiphenyl ether)	0.000	0.000	0.000	0.000
PBDE 190	0.000	0.000	0.000	0.000
PBDE 28 (2,4,4'-tribromodiphenyl ether)	0.000	0.000	0.000	0.000
PBDE 47 (2,2',4,4'-tetrabromodiphenyl ether)	0.000	0.000	0.000	0.000
PBDE 66	0.000	0.000	0.000	0.000
PBDE 71	0.000	0.000	0.000	0.000
PBDE 85 (2,2',3,4,4'-pentabromodiphenyl ether)	0.000	0.000	0.000	0.000
PBDE 99 (2,2',4,4',5-pentabromodiphenyl ether)	0.001	0.000	0.023	0.004
PCBs (ng/g dry mass)				
PCB 1 (2-Chlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 103 (2,2',4,5',6-Pentachlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 104 (2,2',4,6,6'-Pentachlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 105 (2,3,3',4,4'-Pentachlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 106/118 Mixture	0.002	0.000	0.060	0.011
PCB 107/108 Mixture	0.000	0.000	0.000	0.000
PCB 110 (2,3,3',4',6-Pentachlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 114 (2,3,4,4',5-Pentachlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 119 (2,3',4,4',6-Pentachlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 12 (3,4-Dichlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 123 (2,3',4,4',5'-Pentachlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 126 (3,3',4,4',5-Pentachlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 128/167 Mixture	0.000	0.000	0.000	0.000
PCB 130 (2,2',3,3',4,5'-Hexachlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 132/168 Mixture	0.000	0.000	0.000	0.000
PCB 138/163/164 Mixture	0.014	0.000	0.075	0.021
PCB 141 (2,2',3,4,5,5'-Hexachlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 146 (2,2',3,4',5,5'-Hexachlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 149 (2,2',3,4',5',6-Hexachlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 15 (4,4'-Dichlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 151 (2,2',3,5,5',6-Hexachlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 153 (2,2',4,4',5,5'-Hexachlorobiphenyl)	0.020	0.000	0.089	0.031

Appendix D (continued).

Analyte	Mean	Minimum	Maximum	Std. Dev.
PCB 154 (2,2',4,4',5,6'-Hexachlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 156 (2,3,3',4,4',5-Hexachlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 157 (2,3,3',4,4',5'-Hexachlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 158 (2,3,3',4,4',6-Hexachlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 159 (2,3,3',4,5,5'-Hexachlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 165 (2,3,3',5,5',6-Hexachlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 169 (3,3',4,4',5,5'-Hexachlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 170/190 Mixture	0.000	0.000	0.000	0.000
PCB 172 (2,2',3,3',4,5,5'-Heptachlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 174 (2,2',3,3',4,5,6'-Heptachlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 177 (2,2',3,3',4,5',6'-Heptachlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 18 (2,2',5-Trichlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 180 (2,2',3,4,4',5,5'-Heptachlorobiphenyl)	0.002	0.000	0.042	0.009
PCB 183 (2,2',3,4,4',5',6-Heptachlorobiphenyl)	0.004	0.000	0.049	0.012
PCB 184 (2,2',3,4,4',6,6'-Heptachlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 187 (2,2',3,4',5,5',6-Heptachlorobiphenyl)	0.043	0.000	0.165	0.049
PCB 188 (2,2',3,4',5,6,6'-Heptachlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 189 (2,3,3',4,4',5,5'-Heptachlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 193 (2,3,3',4',5,5',6-Heptachlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 194 (2,2',3,3',4,4',5,5'-Octachlorobiphenyl)	0.016	0.000	0.093	0.025
PCB 195 (2,2',3,3',4,4',5,6-Octachlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 196/203 Mixture	0.075	0.000	0.240	0.058
PCB 198 (2,2',3,3',4,5,5',6-Octachlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 2 (3-Chlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 20 (2,3,3'-Trichlorobiphenyl)	0.0003	0.000	0.010	0.002
PCB 200 (2,2',3,3',4,5,6,6'-Octachlorobiphenyl)	0.003	0.000	0.049	0.012
PCB 201 (2,2',3,3',4,5',6,6'-Octachlorobiphenyl)	0.100	0.000	0.403	0.093
PCB 202 (2,2',3,3',5,5',6,6'-Octachlorobiphenyl)	0.044	0.000	0.177	0.051
PCB 206 (2,2',3,3',4,4',5,5',6-Nonachlorobiphenyl)	0.247	0.000	0.871	0.208
PCB 207 (2,2',3,3',4,4',5,6,6'-Nonachlorobiphenyl)	0.004	0.000	0.051	0.012
PCB 208 (2,2',3,3',4,5,5',6,6'-Nonachlorobiphenyl)	0.076	0.000	0.297	0.067
PCB 209 (2,2',3,3',4,4',5,5',6,6'-Decachlorobiphenyl)	0.045	0.000	0.192	0.045
PCB 26 (2,3',5-Trichlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 28 (2,4,4'-Trichlorobiphenyl)	0.009	0.000	0.102	0.024
PCB 29 (2,4,5-Trichlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 3 (4-Chlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 31 (2,4',5-Trichlorobiphenyl)	0.006	0.000	0.072	0.018
PCB 37 (3,4,4'-Trichlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 44 (2,2',3,5'-Tetrachlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 45 (2,2',3,6-Tetrachlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 47/48 Mixture	0.003	0.000	0.081	0.015
PCB 49 (2,2',4,5'-Tetrachlorobiphenyl)	0.008	0.000	0.084	0.019
PCB 50 (2,2',4,6-Tetrachlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 52 (2,2',5,5'-Tetrachlorobiphenyl)	0.020	0.000	0.204	0.046
PCB 56/60 Mixture	0.001	0.000	0.036	0.007

Appendix D (continued).

Analyte	Mean	Minimum	Maximum	Std. Dev.
PCB 61/74 Mixture	0.001	0.000	0.039	0.007
PCB 63 (2,3,4',5-Tetrachlorobiphenyl)	0.015	0.000	0.409	0.075
PCB 66 (2,3',4,4'-Tetrachlorobiphenyl)	0.007	0.000	0.096	0.023
PCB 69 (2,3',4,6-Tetrachlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 70/76 Mixture	0.009	0.000	0.276	0.050
PCB 77 (3,3',4,4'-Tetrachlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 8/5 Mixture	0.000	0.000	0.000	0.000
PCB 81 (3,4,4',5-Tetrachlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 82 (2,2',3,3',4-Pentachlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 84 (2,2',3,3',6-Pentachlorobiphenyl)	0.002	0.000	0.069	0.013
PCB 87/115 Mixture	0.000	0.000	0.000	0.000
PCB 88 (2,2',3,4,6-Pentachlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 89/90/101 Mixture	0.000	0.000	0.000	0.000
PCB 9 (2,5-Dichlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 92 (2,2',3,5,5'-Pentachlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 95 (2,2',3,5',6-Pentachlorobiphenyl)	0.000	0.000	0.000	0.000
PCB 99 (2,2',4,4',5-Pentachlorobiphenyl)	0.016	0.000	0.099	0.029
Total PCBs	0.795	0.015	3.841	0.809
Pesticides (ng/g dry mass)				
2,4'-DDD (o,p'-DDD)	0.000	0.000	0.000	0.000
2,4'-DDE (o,p'-DDE)	0.000	0.000	0.000	0.000
2,4'-DDT (o,p'-DDT)	0.000	0.000	0.000	0.000
4,4'-DDD (p,p'-DDD)	0.000	0.000	0.000	0.000
4,4'-DDE (p,p'-DDE)	0.000	0.000	0.000	0.000
4,4'-DDT (p,p'-DDT)	0.014	0.000	0.258	0.056
Total DDTs	0.014	0.000	0.258	0.056
Aldrin	0.000	0.000	0.000	0.000
alpha-Chlordane	0.000	0.000	0.000	0.000
alpha-Hexachlorocyclohexane (alpha-BHC)	0.000	0.000	0.000	0.000
beta-Hexachlorocyclohexane (beta-BHC)	0.000	0.000	0.000	0.000
Chlorpyrifos	0.000	0.000	0.000	0.000
cis-Nonachlor	0.001	0.000	0.022	0.004
Dieldrin	0.000	0.000	0.000	0.000
Endosulfan I	0.000	0.000	0.000	0.000
Endosulfan II (Beta-Endosulfan)	0.000	0.000	0.000	0.000
Endosulfan sulfate	0.000	0.000	0.000	0.000
gamma-Chlordane	0.013	0.000	0.100	0.027
gamma-Hexachlorocyclohexane (gamma-BHC = Lindane)	0.000	0.000	0.000	0.000
Heptachlor	0.000	0.000	0.000	0.000
Heptachlor epoxide	0.000	0.000	0.000	0.000
Hexachlorobenzene (HCB)	0.006	0.000	0.028	0.008
Mirex	0.000	0.000	0.000	0.000
Oxychlordane	0.000	0.000	0.000	0.000
trans-Nonachlor	0.000	0.000	0.000	0.000

Appendix E. Summary by station of mean ERM quotients and the number of contaminants that exceeded corresponding ERL or ERM values (from Long et al. 1995). Note: For each station where an ERL was exceeded, the corresponding chemical was consistently arsenic.

Station	Mean ERM-Q	# of ERLs Exceeded	# of ERMs Exceeded
1	0.0272	1	0
2	0.0027	0	0
3	0.0049	0	0
4	0.0063	0	0
5	0.0060	0	0
6	0.0133	0	0
7	0.0057	0	0
8	0.0218	1	0
9	0.0145	0	0
10	0.0271	1	0
11	0.0133	0	0
12	0.0108	0	0
13	0.0283	1	0
14	0.0052	0	0
15	0.0069	0	0
16	0.0045	0	0
17	0.0076	0	0
18	0.0027	0	0
19	0.0103	0	0
20	0.0263	1	0
21	0.0266	1	0
22	0.0180	1	0
23	0.0171	1	0
24	0.0090	0	0
25	0.0160	0	0
26	0.0198	1	0
27	0.0251	1	0
28	0.0054	0	0
29	0.0246	1	0
30	0.0057	0	0

Appendix F. Summary of Microtox® sediment toxicity results.

Station	Silt-Clay (%)	EC_{50} (%)	Toxic†
1	92.63	0.9324	—
2	1.74	>15.5124	—
3	6.70	12.0516	—
4	9.36	5.1706	—
5	10.19	0.1176	Yes
6	40.38	0.0338	Yes
7	9.66	0.5503	—
8	69.46	0.0439	Yes
9	32.87	0.8798	—
10	86.34	0.4171	—
11	37.95	0.2496	—
12	29.58	0.3985	—
13	98.00	0.0560	Yes
14	7.75	13.6671	—
15	20.69	0.4259	—
16	5.90	>15.6735	—
17	17.56	2.5745	—
18	3.08	>15.8391	—
19	31.07	3.3406	—
20	84.31	0.9463	—
21	99.56	0.0518	Yes
22	59.94	0.3532	—
23	60.84	0.0370	Yes
24	20.87	1.1116	—
25	52.47	0.0550	Yes
26	61.46	0.0496	Yes
27	90.03	1.3303	—
28	7.92	5.3907	—
29	74.15	0.0735	Yes
30	8.78	0.9747	—

† For silt-clay < 20 %, toxic if EC50 < 0.5 %; for silt-clay $\geq$ 20 %, toxic if EC50 < 0.2 %.

Appendix G. Summary by station of benthic macroinfaunal (>0.5mm) characteristics. Two replicate benthic grabs (0.04m^2 each) were processed from each station. H′ derived using base 2 logarithms.

Station	Total # of Taxa	Mean # of Taxa per Grab	Mean Density (# of ind./m^2)	Mean H′ per Grab	B-IBI
1	9	6.0	500.0	2.2	2.5
2	9	6.5	537.5	2.2	3.5
3	30	19.5	4187.5	2.9	3.5
4	50	29.0	3937.5	4.0	4.0
5	31	16.5	1925.0	3.2	3.5
6	21	15.5	2400.0	3.1	3.0
7	29	18.5	2212.5	3.4	3.5
8	11	7.5	1800.0	2.2	3.0
9	7	4.5	1300.0	1.4	2.0
10	19	13.0	2675.0	2.9	3.5
11	25	17.5	4262.5	3.0	3.5
12	15	11.5	1725.0	2.8	3.0
13	12	9.5	1550.0	2.5	3.0
14	11	7.0	537.5	2.5	3.5
15	21	11.0	11500.0	1.6	2.5
16	16	10.0	1525.0	2.5	4.0
17	48	30.0	3375.0	4.2	4.0
18	12	6.5	325.0	2.2	3.0
19	35	24.5	5875.0	3.5	4.0
20	30	19.0	3375.0	2.8	3.5
21	9	6.0	437.5	2.2	2.5
22	9	6.0	500.0	2.1	2.5
23	14	9.0	1287.5	2.5	3.5
24	31	17.5	6550.0	2.5	3.5
25	34	21.5	4712.5	3.2	3.5
26	39	26.5	4462.5	3.5	4.0
27	10	5.5	462.5	1.9	3.0
28	12	8.5	937.5	2.3	3.0
29	16	11.0	5437.5	1.5	2.5
30	32	20.5	3050.0	3.3	4.0

Appendix H. Summary of fish tissue contaminant concentrations (wet mass) by analyte and fish species (Atlantic croaker, red drum, silver perch) at SINERR. Concentrations below the limit of detection (<MDL) were assigned a value of zero for data analysis purposes.

	Atlantic Croaker			Red Drum			Silver Perch		
Analyte	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Metals (µg/g wet mass)									
Aluminum	0.609	0.512	0.746	0.537	0.426	0.648	0.339	0.287	0.395
Arsenic	2.255	1.312	2.854	1.049	0.678	1.420	0.723	0.414	1.231
Inorganic Arsenic	0.045	0.026	0.057	0.021	0.014	0.028	0.014	0.008	0.025
Barium	0.038	0.020	0.073	0.010	0.006	0.015	0.034	0.023	0.054
Beryllium	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.004
Cadmium	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Chromium	0.279	0.242	0.308	0.218	0.217	0.220	0.195	0.182	0.211
Cobalt	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.010
Copper	0.314	0.277	0.359	0.278	0.264	0.292	0.388	0.317	0.502
Iron	2.712	2.503	2.833	2.607	2.485	2.728	3.821	3.454	4.381
Lead	0.006	0.000	0.013	0.003	0.000	0.006	0.007	0.000	0.020
Lithium	0.005	0.000	0.015	0.000	0.000	0.000	0.006	0.000	0.017
Manganese	0.299	0.268	0.329	0.144	0.083	0.204	0.174	0.154	0.212
Mercury	0.031	0.019	0.048	0.060	0.017	0.104	0.101	0.060	0.136
Nickel	0.015	0.011	0.019	0.003	0.000	0.006	0.010	0.000	0.022
Selenium	0.659	0.593	0.768	0.416	0.415	0.416	0.447	0.376	0.562
Silver	0.000	0.000	0.000	0.000	0.000	0.000	0.021	0.000	0.064
Thallium	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.004
Tin	0.003	0.000	0.008	0.000	0.000	0.000	0.004	0.000	0.012
Uranium	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.006
Vanadium	0.068	0.000	0.124	0.008	0.000	0.015	0.044	0.020	0.090
Zinc	6.026	4.816	7.528	7.287	7.002	7.571	9.597	9.545	9.642
PAHs (ng/g wet mass)									
1,6,7-Trimethylnaphthalene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2,6-Dimethylnaphthalene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Benzo[g,h,i]perylene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Dibenz[a,h]anthracene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Indeno[1,2,3-c,d]pyrene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1-Methylnaphthalene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1-Methylphenanthrene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2-Methylnaphthalene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Acenaphthene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Acenaphthylene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Anthracene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Benz[a]anthracene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Benzo[a]pyrene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Benzo[b]fluoranthene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Benzo[e]pyrene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Benzo[j+k]fluoranthene	0.000	0.000	0.000	17.475	17.475	17.475	0.000	0.000	0.000
Biphenyl	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Chrysene+Triphenylene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Dibenzothiophene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fluoranthene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix H (continued).

	Atlantic Croaker			Red Drum			Silver Perch		
Analyte	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Fluorene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Naphthalene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Perylene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Phenanthrene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pyrene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PBDEs (ng/g wet mass)									
PBDE 100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PBDE 153	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PBDE 154	0.000	0.000	0.000	0.073	0.071	0.075	0.000	0.000	0.000
PBDE 183	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PBDE 28	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PBDE 47	0.139	0.107	0.199	0.110	0.053	0.167	0.000	0.000	0.000
PBDE 85	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PBDE 99	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PBDE 138	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PBDE 17	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PBDE 190	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PBDE 66	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PBDE 71	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total PBDEs	0.139	0.107	0.199	0.183	0.125	0.242	0.000	0.000	0.000
PCBs (ng/g wet mass)									
Total PCBs	7.760	5.840	11.005	7.007	0.790	13.224	6.691	0.604	18.797
PCB homologs with ≥7 Cl atoms	4.584	3.719	6.216	4.985	0.481	9.490	6.132	0.352	17.559
Aroclor1268[a]	4.331	3.570	5.808	4.818	0.481	9.155	6.058	0.352	17.338
Pesticides (ng/g wet mass)									
2,4'-DDD (o,p'-DDD)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2,4'-DDE (o,p'-DDE)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2,4'-DDT (o,p'-DDT)	0.000	0.000	0.000	0.028	0.000	0.056	0.000	0.000	0.000
4,4'-DDD (p,p'-DDD)	0.036	0.000	0.108	0.029	0.000	0.058	0.000	0.000	0.000
4,4'-DDE (p,p'-DDE)	1.658	0.913	2.989	0.691	0.173	1.208	0.182	0.000	0.546
4,4'-DDT (p,p'-DDT)	0.026	0.000	0.078	0.044	0.000	0.089	0.000	0.000	0.000
Total DDTs	1.720	0.913	3.175	0.792	0.262	1.322	0.182	0.000	0.546
Aldrin	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
α-Chlordane	0.067	0.058	0.078	0.035	0.000	0.070	0.000	0.000	0.000
Chlorpyrifos	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Dieldrin	0.045	0.000	0.135	0.000	0.000	0.000	0.000	0.000	0.000
Endosulfan I	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Endosulfan II (β-Endosulfan)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Endosulfan sulfate	0.146	0.085	0.213	0.061	0.000	0.123	0.000	0.000	0.000
γ-BHC (Lindane)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Heptachlor	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Heptachlor epoxide	0.025	0.000	0.076	0.000	0.000	0.000	0.000	0.000	0.000
Hexachlorobenzene (HCB)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mirex	0.080	0.000	0.137	0.082	0.000	0.165	0.000	0.000	0.000
trans-Nonachlor	0.156	0.117	0.220	0.076	0.000	0.152	0.027	0.000	0.082

[a] Sum of PCB congeners identified by Maruya and Lee (1998a) as indicative of Aroclor 1268 (Ballmer et al. 2011).

Appendix I. Summary of fish tissue contaminant concentrations (wet mass) by analyte and fish species (flounder, spotted seatrout, mullet) at SINERR. Concentrations below the limit of detection (<MDL) were assigned a value of zero for data analysis purposes.

	Flounder			Spotted Seatrout			Mullet		
Analyte	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Metals (µg/g wet mass)									
Aluminum	1.448	1.448	1.448	0.546	0.357	0.910	0.634	0.325	1.544
Arsenic	1.814	1.814	1.814	0.495	0.394	0.584	1.140	0.963	1.480
Inorganic Arsenic	0.036	0.036	0.036	0.010	0.008	0.012	0.023	0.019	0.030
Barium	0.032	0.032	0.032	0.014	0.012	0.016	0.027	0.012	0.080
Beryllium	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cadmium	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.001
Chromium	0.193	0.193	0.193	0.195	0.171	0.213	0.241	0.193	0.312
Cobalt	0.000	0.000	0.000	0.004	0.000	0.013	0.008	0.000	0.015
Copper	0.165	0.165	0.165	0.238	0.187	0.264	0.295	0.245	0.358
Iron	1.788	1.788	1.788	2.528	2.092	2.749	6.114	3.957	8.721
Lead	0.000	0.000	0.000	0.001	0.000	0.003	0.011	0.003	0.021
Lithium	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.000	0.017
Manganese	0.336	0.336	0.336	0.144	0.115	0.170	0.221	0.117	0.560
Mercury	0.030	0.030	0.030	0.047	0.023	0.084	0.006	0.003	0.008
Nickel	0.047	0.047	0.047	0.005	0.000	0.009	0.017	0.000	0.068
Selenium	0.499	0.499	0.499	0.422	0.390	0.451	0.247	0.190	0.295
Silver	0.000	0.000	0.000	0.000	0.000	0.000	0.015	0.000	0.067
Thallium	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tin	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Uranium	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Vanadium	0.012	0.012	0.012	0.043	0.000	0.102	0.034	0.000	0.081
Zinc	5.799	5.799	5.799	6.210	5.238	7.592	10.780	7.660	15.598
PAHs (ng/g wet mass)									
1,6,7-Trimethylnaphthalene	0.000	0.000	0.000	4.820	0.000	14.459	0.000	0.000	0.000
2,6-Dimethylnaphthalene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Benzo[g,h,i]perylene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Dibenz[a,h]anthracene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Indeno[1,2,3-c,d]pyrene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1-Methylnaphthalene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1-Methylphenanthrene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2-Methylnaphthalene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Acenaphthene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Acenaphthylene	0.000	0.000	0.000	0.000	0.000	0.000	0.917	0.000	8.254
Anthracene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Benz[a]anthracene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Benzo[a]pyrene	0.000	0.000	0.000	7.297	0.000	21.892	0.000	0.000	0.000
Benzo[b]fluoranthene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Benzo[e]pyrene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Benzo[j+k]fluoranthene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Biphenyl	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Chrysene+Triphenylene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Dibenzothiophene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fluoranthene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix I (continued).

	Flounder			Seatrout			Mullet		
Analyte	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Fluorene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Naphthalene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Perylene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Phenanthrene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pyrene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PBDEs (ng/g wet mass)									
PBDE 100	0.000	0.000	0.000	0.046	0.000	0.139	0.000	0.000	0.000
PBDE 153	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PBDE 154	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PBDE 183	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PBDE 28	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PBDE 47	0.000	0.000	0.000	0.093	0.000	0.183	0.036	0.000	0.072
PBDE 85	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PBDE 99	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PBDE 138	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PBDE 17	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PBDE 190	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PBDE 66	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PBDE 71	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total PBDEs	0.000	0.000	0.000	0.140	0.000	0.321	0.036	0.000	0.072
PCBs (ng/g wet mass)									
Total PCBs	1.249	1.249	1.249	9.480	4.437	18.548	4.020	1.607	7.076
PCB homologs with ≥7 Cl atoms	0.928	0.928	0.928	7.158	3.446	13.687	2.723	1.089	4.257
Aroclor1268	0.894	0.894	0.894	7.006	3.446	13.323	2.631	1.041	4.074
Pesticides (ng/g wet mass)									
2,4'-DDD (o,p'-DDD)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2,4'-DDE (o,p'-DDE)	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.000	0.024
2,4'-DDT (o,p'-DDT)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4,4'-DDD (p,p'-DDD)	0.000	0.000	0.000	0.017	0.000	0.052	0.042	0.000	0.126
4,4'-DDE (p,p'-DDE)	0.000	0.000	0.000	0.903	0.662	1.319	0.607	0.244	1.303
4,4'-DDT (p,p'-DDT)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total DDTs	0.000	0.000	0.000	0.920	0.662	1.372	0.656	0.267	1.452
Aldrin	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
α-Chlordane	0.000	0.000	0.000	0.019	0.000	0.058	0.034	0.000	0.110
Chlorpyrifos	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Dieldrin	0.000	0.000	0.000	0.000	0.000	0.000	0.018	0.000	0.161
Endosulfan I	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Endosulfan II (β-Endosulfan)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Endosulfan sulfate	0.000	0.000	0.000	0.043	0.000	0.069	0.120	0.000	0.287
γ-BHC (Lindane)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Heptachlor	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Heptachlor epoxide	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Hexachlorobenzene (HCB)	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.056
Mirex	0.000	0.000	0.000	0.084	0.000	0.251	0.000	0.000	0.000
trans-Nonachlor	0.000	0.000	0.000	0.086	0.053	0.145	0.054	0.000	0.161

Appendix J. Summary of fish tissue contaminant concentrations (wet mass) by analyte and fish species (whiting) at SINERR. Concentrations below the limit of detection (<MDL) were assigned a value of zero for data analysis purposes.

	Whiting		
Analyte	Mean	Min	Max
Metals (ug/g wet mass)			
Aluminum	0.308	0.308	0.308
Arsenic	1.517	1.517	1.517
Inorganic Arsenic	0.030	0.030	0.030
Barium	0.022	0.022	0.022
Beryllium	0.000	0.000	0.000
Cadmium	0.000	0.000	0.000
Chromium	0.242	0.242	0.242
Cobalt	0.000	0.000	0.000
Copper	0.241	0.241	0.241
Iron	2.816	2.816	2.816
Lead	0.000	0.000	0.000
Lithium	0.000	0.000	0.000
Manganese	0.151	0.151	0.151
Mercury	0.167	0.167	0.167
Nickel	0.008	0.008	0.008
Selenium	0.484	0.484	0.484
Silver	0.000	0.000	0.000
Thallium	0.000	0.000	0.000
Tin	0.000	0.000	0.000
Uranium	0.000	0.000	0.000
Vanadium	0.000	0.000	0.000
Zinc	5.846	5.846	5.846
PAHs (ng/g wet mass)			
1,6,7-Trimethylnaphthalene	0.000	0.000	0.000
2,6-Dimethylnaphthalene	0.000	0.000	0.000
Benzo[g,h,i]perylene	0.000	0.000	0.000
Dibenz[a,h]anthracene	0.000	0.000	0.000
Indeno[1,2,3-c,d]pyrene	0.000	0.000	0.000
1-Methylnaphthalene	0.000	0.000	0.000
1-Methylphenanthrene	0.000	0.000	0.000
2-Methylnaphthalene	0.000	0.000	0.000
Acenaphthene	0.000	0.000	0.000
Acenaphthylene	0.000	0.000	0.000
Anthracene	0.000	0.000	0.000
Benz[a]anthracene	0.000	0.000	0.000
Benzo[a]pyrene	0.000	0.000	0.000
Benzo[b]fluoranthene	0.000	0.000	0.000
Benzo[e]pyrene	0.000	0.000	0.000
Benzo[j+k]fluoranthene	0.000	0.000	0.000
Biphenyl	0.000	0.000	0.000
Chrysene+Triphenylene	0.000	0.000	0.000
Dibenzothiophene	0.000	0.000	0.000
Fluoranthene	0.000	0.000	0.000

Appendix J (continued).

	Whiting		
Analyte	Mean	Min	Max
Fluorene	0.000	0.000	0.000
Naphthalene	0.000	0.000	0.000
Perylene	0.000	0.000	0.000
Phenanthrene	0.000	0.000	0.000
Pyrene	0.000	0.000	0.000
PBDEs (ng/g wet mass)			
PBDE 100	0.231	0.231	0.231
PBDE 153	0.000	0.000	0.000
PBDE 154	0.087	0.087	0.087
PBDE 183	0.000	0.000	0.000
PBDE 28	0.000	0.000	0.000
PBDE 47	0.400	0.400	0.400
PBDE 85	0.000	0.000	0.000
PBDE 99	0.000	0.000	0.000
PBDE 138	0.000	0.000	0.000
PBDE 17	0.000	0.000	0.000
PBDE 190	0.000	0.000	0.000
PBDE 66	0.000	0.000	0.000
PBDE 71	0.000	0.000	0.000
Total PBDEs	0.718	0.718	0.718
PCBs (ng/g wet mass)			
Total PCBs	40.604	40.604	40.604
PCB homologs with ≥7 Cl atoms	30.369	30.369	30.369
Aroclor1268	29.487	29.487	29.487
Pesticides (ng/g wet mass)			
2,4'-DDD (o,p'-DDD)	0.000	0.000	0.000
2,4'-DDE (o,p'-DDE)	0.019	0.019	0.019
2,4'-DDT (o,p'-DDT)	0.000	0.000	0.000
4,4'-DDD (p,p'-DDD)	0.204	0.204	0.204
4,4'-DDE (p,p'-DDE)	2.240	2.240	2.240
4,4'-DDT (p,p'-DDT)	0.000	0.000	0.000
Total DDTs	2.463	2.463	2.463
Aldrin	0.000	0.000	0.000
α-Chlordane	0.169	0.169	0.169
Chlorpyrifos	0.000	0.000	0.000
Dieldrin	0.128	0.128	0.128
Endosulfan I	0.000	0.000	0.000
Endosulfan II (β-Endosulfan)	0.000	0.000	0.000
Endosulfan sulfate	0.150	0.150	0.150
γ-BHC (Lindane)	0.000	0.000	0.000
Heptachlor	0.000	0.000	0.000
Heptachlor epoxide	0.000	0.000	0.000
Hexachlorobenzene (HCB)	0.054	0.054	0.054
Mirex	0.433	0.433	0.433
trans-Nonachlor	0.280	0.280	0.280

United States Department of Commerce

John E. Bryson
Secretary

National Oceanic and Atmospheric Administration

Jane Lubchenco
Administrator

National Ocean Service

David Kennedy
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