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Soft-Bottom Benthic Assemblages and Levels of Contaminants in Sediments and Biota at Gray's Reef National Marine Sanctuary and Nearby Shelf Waters off the Coast of Georgia (2000 and 2001)

NOAA Technical Memorandum NOS NCCOS 6

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Soft-Bottom Benthic Assemblages and Levels of Contaminants in Sediments and Biota at Gray's Reef National Marine Sanctuary and Nearby Shelf Waters off the Coast of Georgia (2000 and 2001)

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United States Department of Commerce	National Oceanic and Atmospheric Administration	National Ocean Service
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Executive Summary

A series of studies was initiated to assess the condition of benthic macroinfauna and chemical contaminant levels in sediments and biota of the Gray's Reef National Marine Sanctuary (GRNMS) and nearby shelf waters off the coast of Georgia. Four key objectives of the research are (1) to document existing environmental conditions within the sanctuary in order to provide a quantitative benchmark for tracking any future changes due to either natural or human disturbances; (2) to examine broader cross-shelf spatial patterns in benthic fauna and sediment contaminant concentrations and to identify potential controlling factors associated with the observed patterns; (3) to assess any between-year temporal variability in benthic fauna; and (4) to evaluate the importance of benthic fauna as prey for higher trophic levels. Such questions are being addressed to help fulfill long-term science and management goals of the GRNMS. However, it is anticipated that the information will be of additional value in broadening our understanding of the surrounding South Atlantic Bight (SAB) ecosystem and in bringing the knowledge to bear on related resource-management issues of the region.

We have begun to address the first three of these objectives with data from samples collected in spring 2000 at stations within GRNMS, and in spring 2001 at stations within the sanctuary and along three cross-shelf transects extending from the mouths of Sapelo, Doboy, and Altamaha Sounds out to sanctuary depths (about 17-20 m). This report provides a description of baseline conditions within the sanctuary, based on results of the spring 2000 survey (Section II), and uses data from both 2000 and 2001 to examine overall spatial and temporal patterns in biological and chemical variables within the sanctuary and surrounding inner-shelf environment (Section III).

Highlights of conclusions reported in Section II:

- Results of the initial spring 2000 survey indicated that, in general, chemical contaminants in sediments throughout GRNMS are at background levels, below probable bioeffect guidelines. The low sediment contamination is most likely attributable to the remote location of this offshore environment and the sandy nature of the substrate (e.g., absence of a silt-clay fraction).
- Contaminants in tissues of target benthic species within the Sanctuary are below human-health guidelines (where available) based on a limited sample population (10 fillets of black sea bass and 9 arc-shell composites).
- Both sediments and tissues contained trace concentrations of chemical contaminants associated with human sources (pesticides, PCBs, PAHs), demonstrating that such materials are making their way to the offshore sanctuary environment, either by air or underwater cross-shelf transport from land.
- The vast stretches of sands throughout the sanctuary support a highly diverse infaunal community, a finding which should change a frequent misconception that these "featureless" substrates surrounding live-bottom rocky outcrops are "biological deserts."
- The probabilistic sampling design applied in spring 2000 provides a powerful quantitative tool for assessing current status in conditions of the sanctuary and for using this information as a baseline for tracking any future changes due to natural or anthropogenic influences. At the time of sampling, zero % of the sanctuary area showed any significant evidence of impaired benthic condition coupled to adverse levels of chemical contaminants in sediments. However, the presence of trace concentrations of pesticides, PCBs, and PAHs in both sediments and biota

demonstrate that chemical substances originating from human activities are capable of reaching the offshore sanctuary environment and thus should be monitored to ensure that future problems do not develop.

- Results of this study provide information on current environmental conditions and future monitoring strategies to use in the development of revised sanctuary management plans.

Highlights of conclusions reported in Section III:

- Percent silt-clay content of sediment in samples from spring 2001 displayed a distinct pattern along all three cross-shelf transects, with appreciable amounts appearing at the mouths of the three sounds. These finer-grained particles represent a potential source for sorption of chemical contaminants in the run-off entering these systems. Cross-shelf differences in salinity and temperature provided additional evidence of the influence of river flow on the immediately adjacent shelf environment. Warmer and less saline condition of water for stations nearest to land was especially pronounced at Station 30 at the mouth of Altamaha Sound, which is presumably attributable to the larger river flow coming out of the Altamaha River relative to the other two sounds.
- In general, chemical contaminants in sediments sampled in spring 2001 throughout the surrounding inner-shelf sampling area appeared to be at low background levels, similar to conditions observed within the sanctuary during the previous year. Importantly, there was a general pattern of decreasing concentrations with increasing distance from shore, thus suggesting possible outwelling of these materials from inland sources through the coastal sounds.
- There were distinct cross-shelf patterns in the structure and composition of benthic fauna sampled in spring 2001. Variations in the fauna appeared to be associated with sediment granulometric characteristics (% silt-clay and median particle size) and other factors related to distance to shore (e.g., depth). Additional unmeasured controlling factors also related to distance from shore may be contributing to these patterns. These include physical factors (e.g., erosional effects near the mouths of the three sounds) and biological factors (e.g., closer proximity of nearshore sites to sources of recruitment by estuarine species).
- There also were notable cross-shelf differences in species diversity. Stations furthest offshore had the greatest numbers of species. This result is consistent with the high level of diversity found throughout most GRNMS sites during the initial spring 2000 survey and supports the view that the sanctuary, and probably much of the offshore South Atlantic Bight region, is an important reservoir of marine biodiversity.
- Additional finer-scale spatial variations in benthic fauna were detected among stations within the sanctuary boundaries and may be related to differences in the proximity to live-bottom habitat. However, any such spatial variability in benthic fauna within the sanctuary is less pronounced than the broader spatial patterns observed across the shelf.
- Minor differences in benthic community structure were detected between sampling periods (spring 2000 vs. spring 2001) at sites within GRNMS. As with the interpretation of small-scale spatial variability, it is important to recognize that such variability is much less pronounced than the broader spatial patterns observed across the shelf. Albeit small, such temporal variability will need to be taken into account in any future efforts to monitor potential long-term environmental changes due to human or natural disturbances.

Section I

General Approach

1. Introduction and Objectives

A series of studies was initiated to assess the condition of benthic macroinfauna and chemical contaminant levels in sediments and biota of the Gray's Reef National Marine Sanctuary (GRNMS) and nearby shelf waters off the coast of Georgia. Benthic research in the sanctuary by previous investigators has focused largely on live-bottom assemblages associated with rocky outcrops (Fig. I-1). In contrast, there has been limited work on the ecology of unconsolidated sandy substrates, which characterize the majority of the seafloor within the sanctuary and surrounding continental shelf. The soft-bottom benthos is a key component of coastal ecosystems, playing vital roles in detrital decomposition, nutrient cycling, and energy flow to higher trophic levels. Moreover, because of their relatively stationary existence within the sediments, benthic infauna (Fig. I-2) can serve as reliable indicators of potential environmental disturbances to the seafloor.

Four key objectives of this research are (1) to document existing environmental conditions within the sanctuary in order to provide a quantitative benchmark for tracking any future changes due to either natural or human disturbances; (2) to examine broader cross-shelf spatial patterns in benthic fauna and sediment contaminant concentrations and to identify potential controlling factors associated with the observed patterns; (3) to assess any between-year temporal variability in benthic fauna; and (4) to evaluate the importance of benthic fauna as prey for higher trophic levels. Such questions are being addressed to help fulfill long-term science and management goals of the GRNMS. However, it is anticipated that the information will be of additional value in broadening our understanding of the surrounding South Atlantic Bight (SAB) ecosystem and in bringing the knowledge to bear on related resource-management issues of the region. We have begun to address the first three of

Figure I-1. Live bottom habitat at GRNMS.

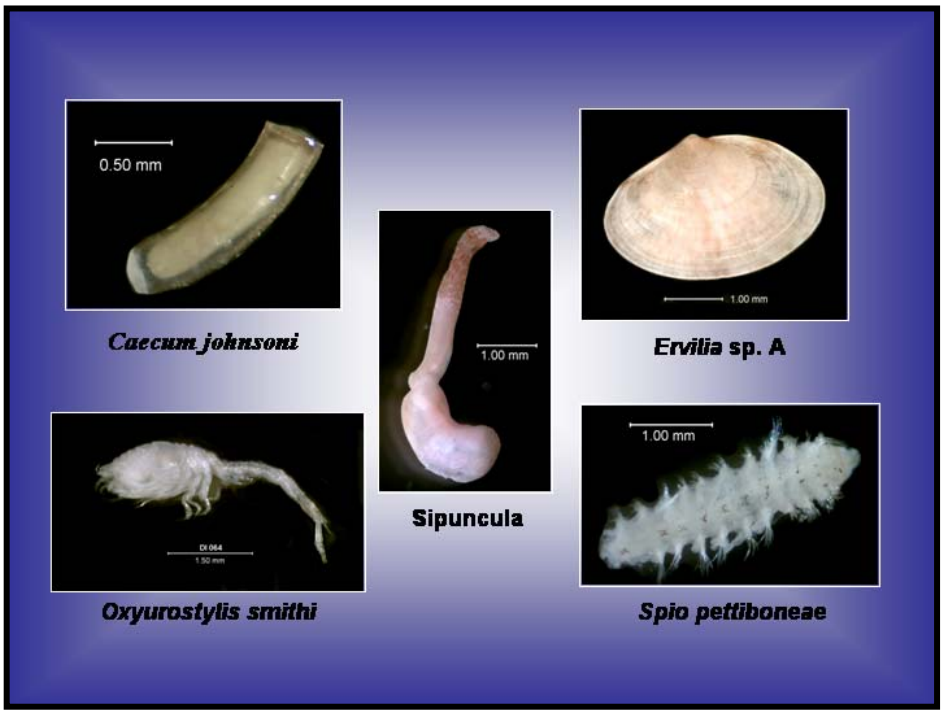


Figure I-2. Examples of dominant macroinfaunal species at GRNMS.

these objectives with data from samples collected in spring 2000 at stations within GRNMS, and in 2001 at stations within the sanctuary and along three cross-shelf transects extending from the mouths of Sapelo, Doboy, and Altamaha Sounds out to sanctuary depths (about 17-20 m).

This report provides a description of existing conditions within the sanctuary, based on results of the spring 2000 survey (Section II), and uses data from both 2000 and 2001 to examine overall spatial and temporal patterns in biological and chemical variables within the sanctuary and surrounding inner-shelf environment (Section III). Additional follow-up studies are currently underway to address the fourth objective on trophic importance of the benthos, and to expand the sampling over longer periods and into deeper areas out to the edge of the continental shelf. Results of this latter work will be reported elsewhere in the literature once available.

2. Methods

The study was designed around a two-year field effort with one sampling event in each year. The first cruise was conducted April 3-7, 2000 (NOAA Ship FERREL Cruise FE-00-06-GR) and the second was conducted April 29-May 5, 2001 (NOAA Ship FERREL Cruise FE-01-08-MA: Leg 1).

There were two primary objectives for the first year of sampling (spring 2000): (1) assess baseline condition of macroinfauna (> 0.5 mm), concentrations of chemical contaminants in sediments, and contaminant body-burdens in target benthic species within the sanctuary boundaries; and (2) provide a quantitative basis for tracking potential changes in these properties with time due to either natural or human events. To address Year-1 objectives, 20 stations were established all within the sanctuary boundaries (Figs. I-3 and I-4). A random sampling design was applied to support probability-based estimates of the percentage of area with degraded versus non-degraded condition relative to various measured environmental indicators. The resulting sampling framework is a 58-km^2 grid of 20 individual cells, each of which is 2.9 km^2, and which together are representative of the total area of the sanctuary (Fig. I-4). One station was randomly located within each cell.

The second year of sampling (spring 2001) included additional sites outside the sanctuary in nearby inner-shelf areas (Fig. I-3). Sampling was conducted at a total of 20

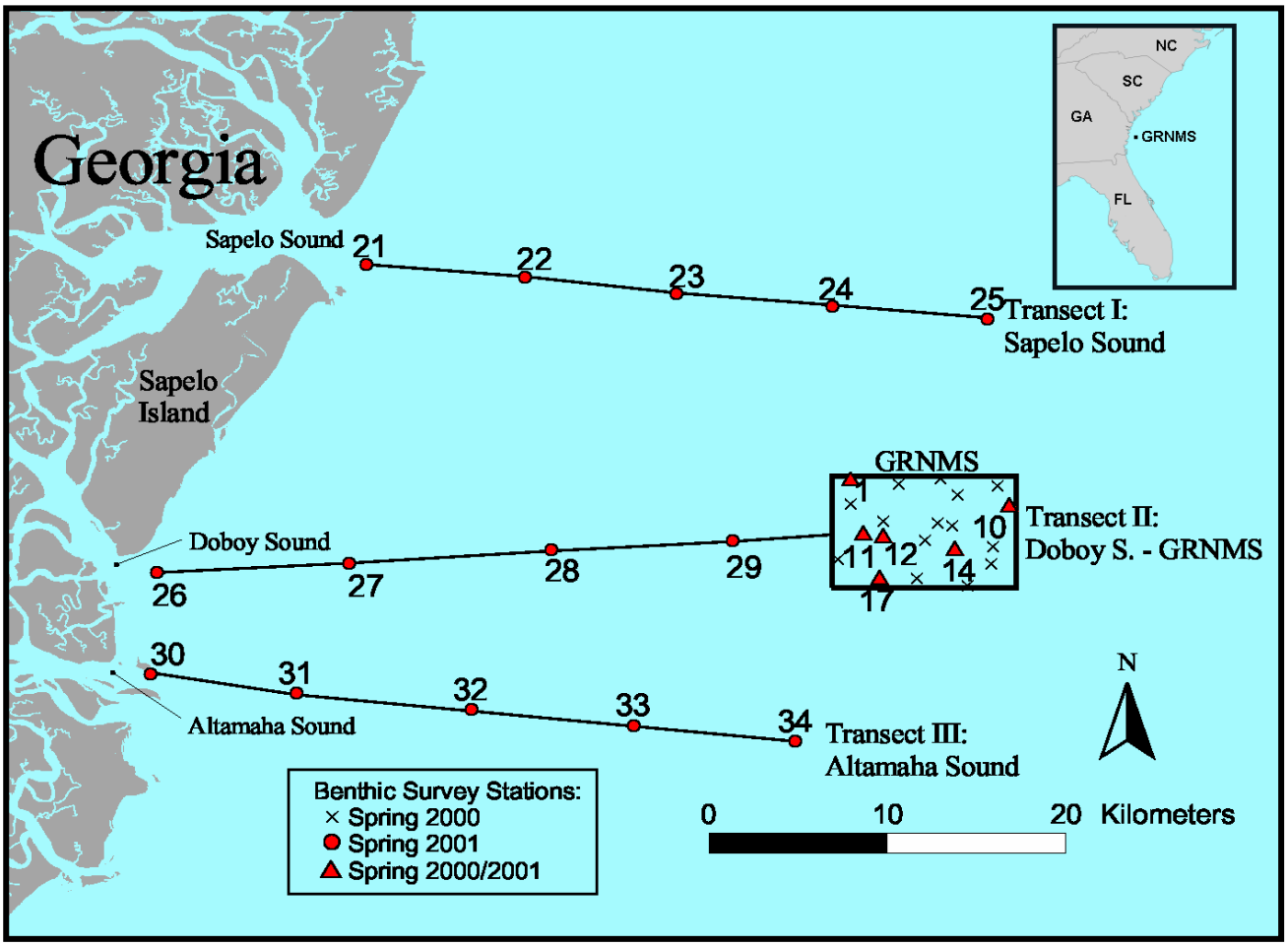


Figure I-3. Sampling design. Station numbers are shown for sites sampled in spring 2001. Station numbers for sites sampled in spring 2000 are identified in Figure 4.

stations: three cross-shelf transects of five stations each, including one of the previous Yr-1 stations within the sanctuary (Station 12) serving as the seaward end of the middle transect; and five additional Yr-1 stations within the sanctuary boundaries (Stations 1, 10, 11, 14, and 17). The objective of the three cross-shelf transects was to provide the means to examine spatial patterns in benthic assemblages and sediment contaminant levels in relation to both natural factors (e.g., depth, sediment characteristics) and potential anthropogenic factors (e.g., proximity to land-based sources of contaminants). An important aspect of this first objective was to determine the extent to which land-based sources of pollutants and other materials are transported through river systems to the offshore shelf environment, inclusive of GRNMS, and the potential effects that these materials may have on biological resources along the way. A second objective of the spring 2001 survey was to examine potential between-year temporal variability. This objective was addressed by re-sampling the six Year-1 stations within the sanctuary boundaries, including the outermost station along the middle transect.

During both years, samples were collected at each station for characterization of general habitat conditions (depth, temperature, salinity, pH, dissolved oxygen, total organic carbon, grain size), concentrations of sediment contaminants (metals, pesticides, PCBs, PAHs), diversity and abundance of

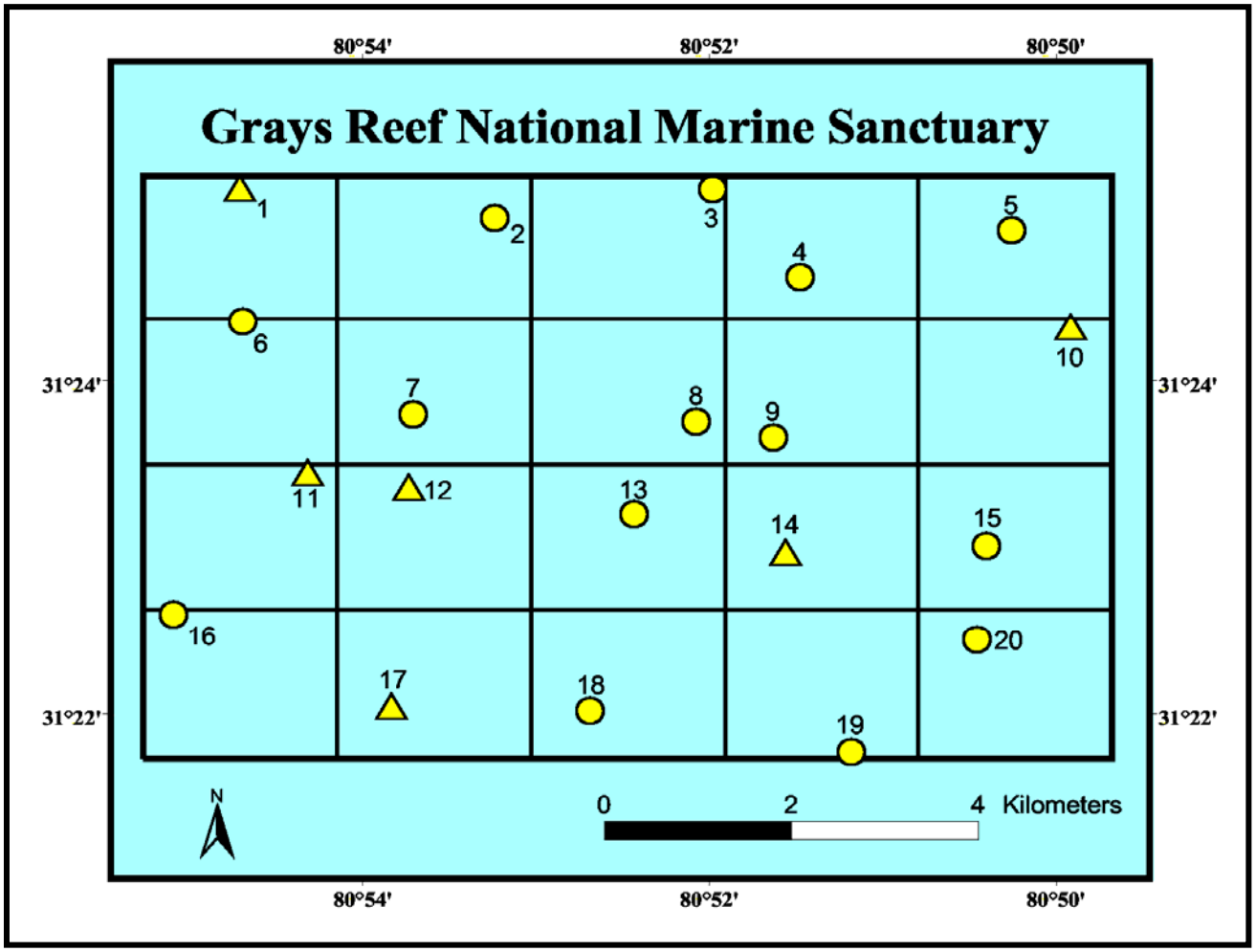


Figure I-4. Station locations within GRNMS. Stations were randomly selected within each of the 20 cells (2.9 km^2 each). All stations were sampled in spring 2000 and stations marked with triangles were resampled in spring 2001.

macroinfauna (> 0.5 mm), and aesthetic quality of water and sediment (presence of anthropogenic debris, visible oil, noxious sediment odor, and water clarity based on secchi depths). During spring 2000, samples of benthic and demersal fauna (*Arca zebra* and *Centropristis striata*) also were collected in selected areas and analyzed for concentrations of chemical contaminants in tissues. The turkey wing ark shells, *A. zebra*, were collected by divers and the black seabass, *C. striata*, were collected using fish traps.

Physical properties of water (salinity, conductivity, dissolved oxygen, pH, and temperature) were measured with a Hydrolab (DS3) multiprobe data logger. Measurements were obtained at the surface, near-bottom, and, where possible, at mid-depth within the water column.

Sediment samples for macroinfaunal analysis were collected at each station in triplicate using a 0.04 m^2 Young grab sampler (Fig. I-5). Each replicate was sieved in the field through a 0.5-mm mesh screen and preserved in 10% buffered formalin with rose bengal. All infaunal samples were transferred to 70% ethanol once in the laboratory. Animals were sorted from sample debris under a dissecting microscope and identified to the lowest practical taxon (usually to species).

The upper 2 – 3 centimeters of sediment from additional grabs were taken at each station, combined into a single station composite, and then subsampled for analysis of metals, organic contaminants (PCBs, pesticides, PAHs), total organic carbon (TOC), and grain size. TOC and grain size were analyzed using protocols modified from Plumb (1981). TOC content of sediment was measured on a CHN elemental analyzer (at 950˚ C combustion temperature). Methods for analysis of chemical contaminants followed those of Sanders (1995), Fortner et al. (1996), Kucklick et al. (1997), and Clum et al. (2002). Metal analyses were performed using inductively coupled plasma mass spectrometry (ICP/MS) for the following suite of metals: Al, Cr, Cu, Fe, Mn, Ni, Sn, As, Cd, Pb and Zn. Ag and Se were analyzed using graphite furnace atomic absorption (GFAA). Cold vapor atomic absorption (CVAA) was used for analysis of Hg. The organic PCBs and pesticides were analyzed by dual-column gas chromatography with electron capture detection (GC-ECD). A gas chromatograph equipped with an ion-trap mass spectrometer (GC/MS-IT) was used for analysis of PAHs. See Appendix A for a list of the typical method detections limits for all measured contaminants. Method detection limits for PAHs were determined as three times the standard deviation of repeated matrix spike determinations; for organochlorines and other pesticides as three times the standard deviation of repeated measures; and for metals as the mean blank plus three standard deviations (CFR 1991, Long et al. 1998).

Sediment quality guidelines (SQG) for each corresponding chemical were used (where available) to help in interpreting the biological significance of the observed contaminant levels. Two types of SQGs were used: (1) Effects Range-Low (ERL) and Effects Range-Median (ERM) values of Long et al. (1995, updated from Long and Morgan 1990); and (2) Threshold Effects Level (TEL) and Probable Effects Level (PEL) values of MacDonald et al. (1996). ERL and TEL values are both lower-threshold bioeffect limits, below which adverse effects of the contaminants on sediment-dwelling organisms are not expected to occur. In contrast, ERM and PEL values both represent mid-range concentrations of chemicals above which adverse effects are more likely to occur. Concentration-to-SQG comparisons were based on the ERL and ERM values for most chemicals; in some cases, however (e.g., where updated ERL and ERM values were not available), the alternative TEL and PEL values were used.

Results of these various analyses are presented in the following two sections and

Figure I-5. Sediment sample collection aboard the NOAA Ship FERREL.

corresponding appendices. Section II provides a description of existing "baseline" conditions of biological and environmental indicators based on results of the spring 2000 survey. Section III uses data from both the 2000 and 2001 surveys to examine broader spatial and temporal patterns in these variables within the sanctuary and surrounding shelf environment.

Section II

Assessment of Ecological Condition within Gray's Reef National Marine Sanctuary

1. Results

Key habitat characteristics within the sanctuary based on the spring 2000 survey (Fig. II-1) consisted of (1) inner-shelf depths, typically between 17-20 m (full range was 14.5-21.1 m); (2) euhaline (oceanic) salinities around 34 ppt; (3) very high DO levels around 8 mg/L, which are well above a reported benthic hypoxic effect threshold of about 1.4 mg/L (Diaz and Rosenberg 1995) as well as most State standards of 5 mg/L or lower; (4) low levels of organic carbon in sediments, typically between 1-2 mg/g; and, (5) coarse sediments consisting mostly of sand with some shell hash and gravel-size particles. There was no fine (silt-clay) fraction of sediment apparent in these samples. The coarse (> 62 micron) fraction comprised 99-100% of the sediment at all stations. A more detailed record of these variables by station is presented in Appendix B.

Appendix C lists means and ranges in concentrations of various chemical contaminants measured in this study (i.e., pesticides, PAHs, PCBs, and metals) and, where available, corresponding sediment quality guidelines (SQG) for interpreting the biological significance of the observed contaminant levels (as defined in Section I). Sediments were fairly clean with respect to the presence of such contaminants. Ninety-five percent of the area of the sanctuary had sediments with all measured contaminants below corresponding, lower-threshold ERL/TEL guidelines (Fig. II-2). There were no stations with "high" levels of contamination — defined here as one or more contaminants present at concentrations above upper-threshold ERM/PEL guideline values, or multiple (three or more) contaminants present at moderate concentrations between these lower and upper bioeffect thresholds. One station, representing just 5% of the

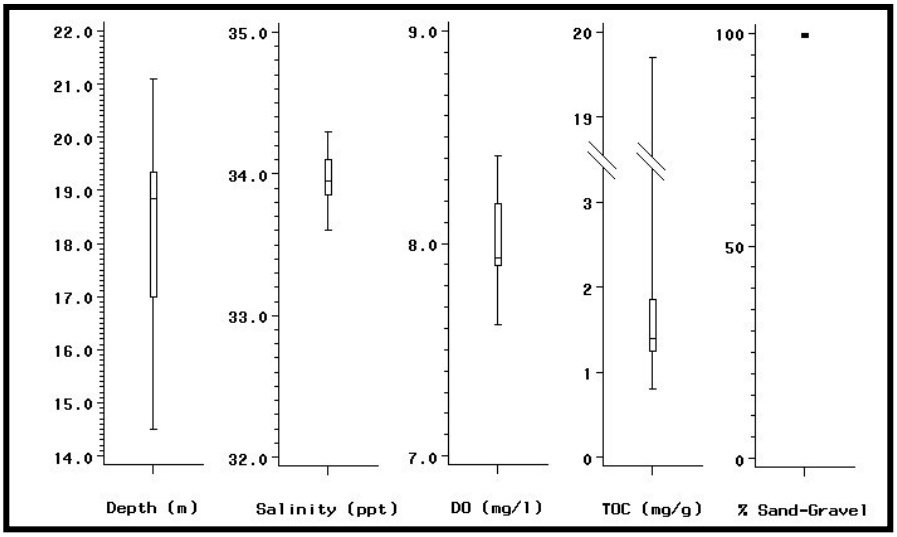


Figure II-1. Key habitat characteristics at GRNMS in April 2000 (n = 20 sites). Boxes are interquartile ranges, horizontal lines within boxes are medians and wisker endpoints are high/low extremes. Note in the last plot that values of % sand-gravel fall within a very narrow range of 99-100%.

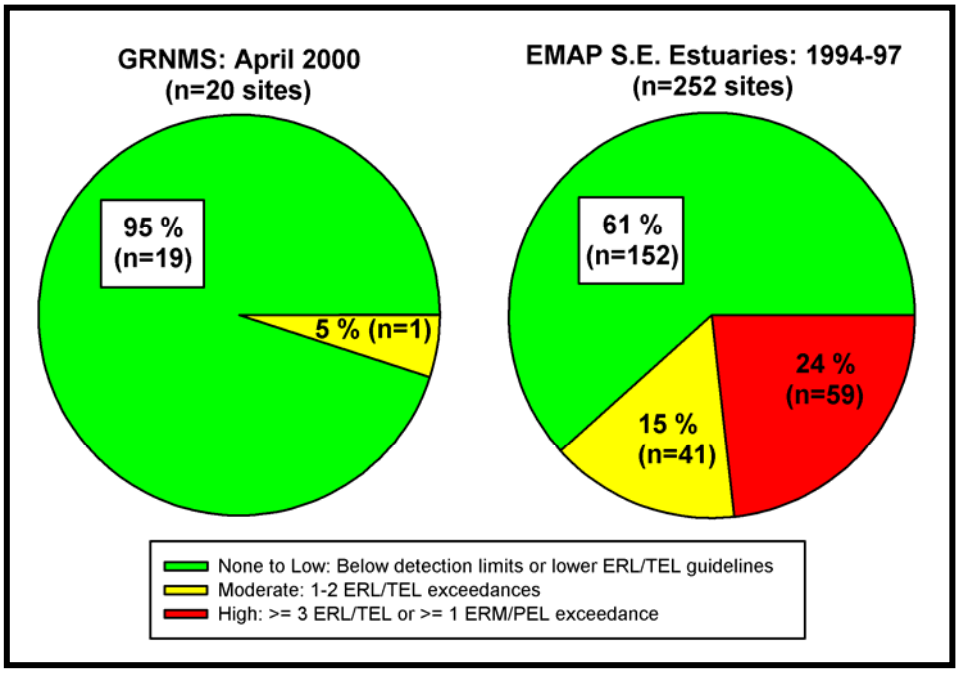


Figure II-2. Comparison of sediment contamination (% area) at GRNMS during the present study vs. southeastern estuaries sampled during EMAP (unpublished data from J. Hyland).

sanctuary's area, had a moderate concentration of copper (103 µg/g) that was above the lower-threshold ERL guideline value of 34 µg/g, but still below the higher ERM value of 270 µg/g. Though the source could be natural or anthropogenic, the concentration of copper at this station was higher than the concentrations typically observed in other southeastern coastal areas remote from contaminant sources (Windom et al. 1989).

In comparison to conditions at Gray's Reef, sediment contamination in neighboring estuaries is much higher (Fig. II-2). For example, based on data from 252 sites sampled throughout southeastern estuaries from 1994-97, as part of the Environmental Monitoring and Assessment Program (EMAP), it can be estimated that 24% of the area of this region has high sediment contamination (J. Hyland, unpublished data). This percentage is obviously higher than the zero % incidence observed presently within the sanctuary. Another 15% of southeastern estuaries had moderate levels of contamination.

The generally low level of sediment contamination throughout the sanctuary is a satisfying result from a resource-management perspective. Yet it is important to recognize that man-made pesticides (DDT, chlorpyrifos) and other chemical substances directly associated with human activities (PCBs, PAHs) were detectable in these sediments, though not at concentrations likely to cause significant bioeffects (see Appendix C). Their presence even at trace concentrations provides direct evidence that such materials are capable of reaching the offshore sanctuary environment, either by atmospheric fallout or cross-shelf transport from land. It is especially interesting that this list includes a relatively non-persistent pesticide like chlorpyrifos.

Appendix D lists means and ranges in contaminant concentrations measured in the tissues of two bottom-dwelling organisms, black sea bass *Centropristis striata* and the turkey wing ark shell *Arca zebra* (Fig. II-3). FDA human-health guidelines (either action levels or levels of concern) are included where available for comparison. There were no exceedances of the FDA guideline values in any of these 19 samples (10 individual fish fillets and 9 arc-shell composites). Moderate concentrations of lead, however, just below the Level of Concern value of 3 µg/g dry weight, were found in one fish sample (2.6 µg/g) and one arc-shell sample (2.9 µg/g).

Similar to results for sediments, tissues of both species contained trace concentrations of additional man-made pesticides (DDT, chlorpyrifos, dieldrin, lindane, heptachlor epoxide) and other chemical substances associated with human sources (PCBs, PAHs). The fact that immobile organisms like the arks are picking up these contaminants, albeit at low concentrations, is further evidence that such materials are making their way to the offshore sanctuary environment.

The benthic infauna inhabiting sandy substrates within the sanctuary are comprised mostly of polychaete worms, molluscs, and arthropods (Fig. II-4). These three major taxonomic groups represent 90% or more of the fauna, both by percentage of species and abundance. The dominant (10 most abundant) taxa were the bivalves *Ervilia* sp. A and *Crassinella lunata*; gastropod *Caecum johnsoni*; chordate *Branchiostoma* spp. (lancelets); sipunculid *Aspidosiphon muelleri*; polychaetes *Spiophanes bombyx* and *Spio pettiboneae*; unidentified ophiuroids; and unidentified actiniarian anthozoans (Table II-1). The abundance of each of these 10 taxa was at least 1% of the total faunal abundance and their cumulative abundance accounted for 75.6% of total abundance. All 10 taxa also exhibited a very high frequency of occurrence, each being present in at least 75% of the samples.

Centropristis striata

Arca zebra

Figure II-3. Images of black sea bass *Centropristis striata* and the turkey wing ark shell *Arca zebra* collected for tissue analysis.

The top dominant taxon at Gray's Reef was *Ervilia* sp. A, which represented 55.9% of the total abundance and occurred in 75% of the samples (Table II-1). Its presence is important in that the specimens may represent a new subspecies of *Ervilia concentrica*. In addition, *Ervilia* is very important from a trophic perspective. Sedberry (1985), for example, reported that the largest percentage by number (38%) of prey consumed by tomtate, *Haemulon aurolineatum*, in the South Atlantic Bight consisted of *Ervilia*. Another dominant infaunal species occurring at Gray's Reef, the lancelet *Branchiostoma* spp., was reported by Sedberry as representing the largest volume (41.6%) of prey consumed by tomtate.

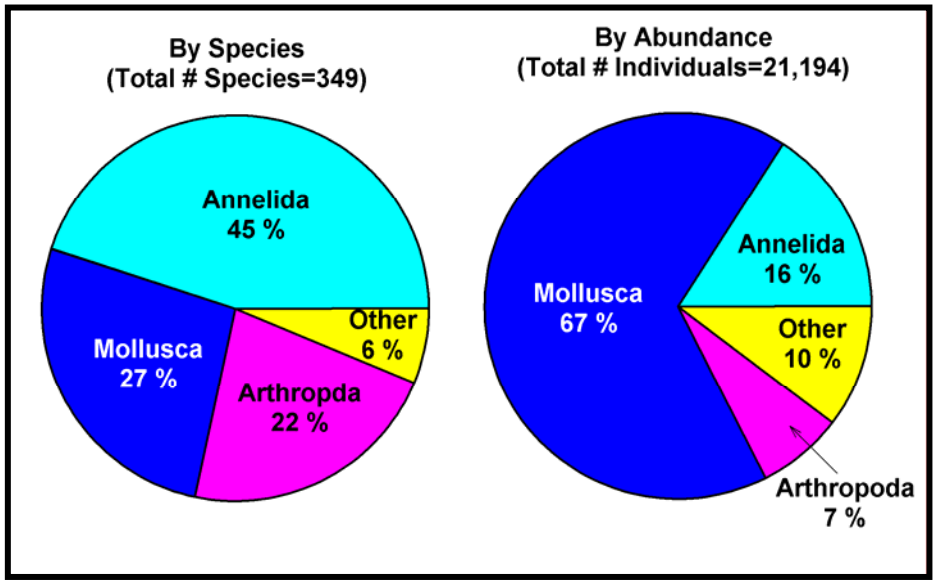


Figure II-4. Relative composition of major taxonomic groups of macroinfauna at GRNMS. Data based on 3 replicate grabs (0.04 m^2) at each of 20 stations.

The dominant species in Table II-1 are very different from the list of dominant (10 most abundant) invertebrate species collected at Gray's Reef during an earlier (1980-81) MMS-sponsored survey of living marine resources of the south Atlantic OCS (MRRI 1982). Eight of the 10 dominant species found during the MMS survey were crustaceans (*Luconacia incerta*, *Elasmopus* sp. A, *Erichthonius brasiliensis*, *Lembos smithi*, *Caprella equilibra*, *Podocerus* sp., *Photis* sp., and *Leptochelia* sp.) and the remaining two were polychaetes (*Lumbrieris inflata* and *Polycirrus carolinensis*). None of these species were among the list of dominants collected in the present study (though some occurred at lower densities as subdominants). Also, the abundant and trophically important *Ervilia* sp. A and *Branchiostoma* spp. noted above were absent in the MMS study. This contrast in faunal composition between studies is due largely to differences in sampling approaches. During the MMS study, for example, divers used suction samplers to collect macroinvertebrates from veneers of sand closely associated with live-bottom outcrops and avoided large open patches of sand that were the focus of the present study. In addition, sampling at Gray's Reef during

Table II-1. Dominant macroinfaunal species at GRNMS contributing to >= 1% of total species abundance individually and to 75% of cumulative % abundance collectively.

Taxon	Group	Average Density (#/m^2)	% of Total Abundance	Cum % Abundance	% Station Occurrence
Ervilia sp. A*	Bivalve	4938	55.9	55.9	75
Caecum johnsoni	Gastropod	301	3.4	59.3	95
Crassinella lunulata	Bivalve	268	3.0	62.4	100
Branchiostoma spp.	Chordate	251	2.8	65.2	95
Aspidosiphon muelleri	Sipunculid	218	2.5	67.7	95
Spiophanes bombyx	Polychaete	164	1.9	69.5	100
Spio pettiboneae	Polychaete	158	1.8	71.3	100
Oxyurostylis smithi	Cumacean	155	1.7	73.0	100
Ophiuroidea	Ophiuroid	125	1.4	74.5	90
Actiniaria	Anthozoan	102	1.2	75.6	80

* Possible new subspecies of *Ervilia concentrica*.

the MMS study was conducted over a limited area at a single station (IS02), while the present study was conducted at multiple stations intended to be more representative of the total area of the sanctuary.

The macroinfaunal assemblages of Gray's Reef are highly diverse. From just this one sampling occasion (60 individual, 0.04 m^2 grab samples) a total of 349 different species were identified (Table II-2). The total number of species found at each station (based on three replicate grabs) ranged from 53 to 117. Mean number of species per replicate sample ranged from 27 to 64 and mean H' diversity ranged from 0.71 to 5.61. Van Dolah et al. (1997) reported a similarly high diversity of macroinfauna, with mean numbers of species ranging from 34 to 70 species/0.04m^2, in a study conducted with comparable methods in inner-shelf sands off the coast of South Carolina. Although a difference in methods precludes direct comparisons, the earlier MMS sampling at Gray's Reef also showed a high diversity of macroinvertebrates in sandy substrates interspersed among live-bottom (MRRI 1982).

The high diversity of benthic fauna at Gray's Reef is further illustrated in Fig. II-5, which compares mean number of species, H', and abundance per grab at sanctuary sites to these same attributes at sites of similar salinity sampled throughout southeastern estuaries as part of EMAP (J. Hyland, unpublished data). Typically, the two measures of diversity (number of species and H') were about twice as high as those associated with the neighboring estuaries. Inter-quartile ranges for both measures were much higher and did not overlap with the estuarine sites. Abundances were about the same.

These results serve as a basis to put aside a frequent misconception that the wide expanses of "featureless" sandy bottom surrounding live-bottom outcrops within the sanctuary are a "biological desert" and that diverse and abundant marine life occur only where hard bottom is emergent. Such a pattern may be true for assemblages of larger and more

Table II-2. Characteristics of benthic macroinfaunal (> 0.5mm) at stations sampled in GRNMS, April 2000. Three replicate grabs (0.04m^2 each) were taken at each station.

Station	Mean No. Taxa (per grab)	Total No. Taxa[a]	Mean Density (No./m^2)	H´ Diversity[b]
1	32	66	2542	4.96
2	58	113	5775	5.11
3	53	102	5217	5.25
4	52	96	4492	5.29
5	57	98	4083	5.61
6	31	62	2617	4.39
7	32	57	2233	4.86
8	59	117	9850	4.28
9	41	84	3125	5.16
10	64	115	7967	4.82
11	34	71	6650	2.37
12	49	96	5933	4.52
13	40	81	40642	0.82
14	45	89	50258	0.71
15	46	94	4300	4.78
16	27	53	1642	4.88
17	42	80	3608	3.59
18	41	85	5900	3.64
19	47	91	1858	4.91
20	45	86	423	5.32

a. Grand total from all 20 stations = 349 taxa.
b. Calculated using base 2 logarithms.

visible epifaunal species that require hard substrates for attachment. However, there are highly diverse and abundant assemblages of infaunal organisms inhabiting the unconsolidated sands that characterize much of the surrounding seafloor. These fauna are important as major prey to higher trophic levels and serve other vital roles in the ecology of the Gray's Reef ecosystem.

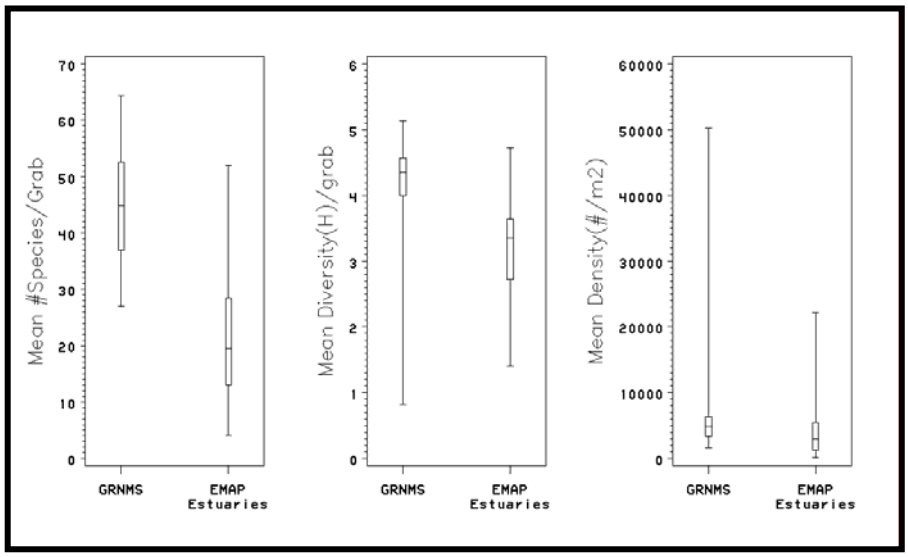


Figure II-5. Comparison of benthic species richness, diversity and abundance at GRNMS sites (n = 20) vs. estuarine sites of similar salinity (> 30 ppt) in EMAP Carolinian Province (n = 38). Boxes are interquartile ranges, horizontal lines within boxes are medians and wisker endpoints are high/low extremes. Base 2 logarithms were used to calculate H´.

2. Implications for Coastal Management

Data from the initial April 2000 survey suggest that contaminants in sediments and biota generally are at background levels, below probable-effect sediment quality and human health guidelines. Moreover, highly diverse and abundant macroinfaunal assemblages were observed at most stations throughout the sanctuary. These results, together with the absence of historical development of this portion of the OCS, provide reasonable evidence for suggesting that the sanctuary is currently in "good health" with respect to sediment quality and biotic integrity of the benthos and that present conditions can be used as a baseline for tracking any future changes. The presence of trace concentrations of pesticides, PCBs, and PAHs in both sediments and biota demonstrates that chemical substances from human sources are capable of reaching the offshore sanctuary environment and thus should be monitored to ensure that future problems do not develop.

The ability to monitor potential changes relative to present baseline conditions is greatly facilitated by the probabilistic sampling design used in this study. As noted earlier, the sampling framework consisted of a population of 20 cells, each of which contained a randomly selected station, and which together are representative of the total area of the sanctuary. Under this design, each sampling point (station) is a statistically valid probability sample. Thus, percentages of the sanctuary with degraded vs. non-degraded environmental condition relative to selected indicators can be estimated based on conditions observed at individual sampling points. The percentage of overall degraded area, for example, can be computed by dividing the summed areas of individual cells in which impacts were observed by the total area of the sanctuary. Statistical confidence intervals around these estimates can be calculated as well.

Figure II-6 further illustrates how one might use these data to monitor potential changes in sediment quality with time. In this example, a combination of benthic species richness and sediment contamination is selected as an indicator of sediment quality. Criteria for

evaluating high vs. low sediment contamination follows those defined earlier in Fig. II-2. In addition, a threshold value of < 30 species/grab is suggested here as a criterion for evaluating potentially "degraded" vs. "non-degraded" condition with respect to species richness. Note that this specific value was derived by selecting a number just below the lower 10th percentile point from the cumulative frequency distribution of species richness values measured presently at Gray's Reef sites. Because we are assuming these data to be representative of baseline reference conditions, this value can be regarded as a lower reference-range limit. Lower reference-range limits derived in the same fashion for H' and density, although not included in Fig. II-6, were < 0.80/grab and < 2000/m^2, respectively.

Having defined evaluation criteria for both sets of variables, one can now estimate the percentage of area within the sanctuary that showed co-occurring evidence of an impaired benthos and contaminated sediments. Combining measures in such a "weight-of-evidence" approach has been shown to be a very effective tool for assessing pollution-induced degradation of the benthos (Chapman 1990). Figure II-6 shows that in spring 2000, zero % of the sanctuary area had low species richness (indicative of a potentially impaired benthos) accompanied by high sediment contamination.

With the baseline established, one can then address the final question of how the condition of the sanctuary with respect to these variables is changing with time. The size of the change relative to some pre-determined set of management action criteria (such as the ones chosen arbitrarily in Fig. II-6) provides a basis for deciding whether or not to apply specific

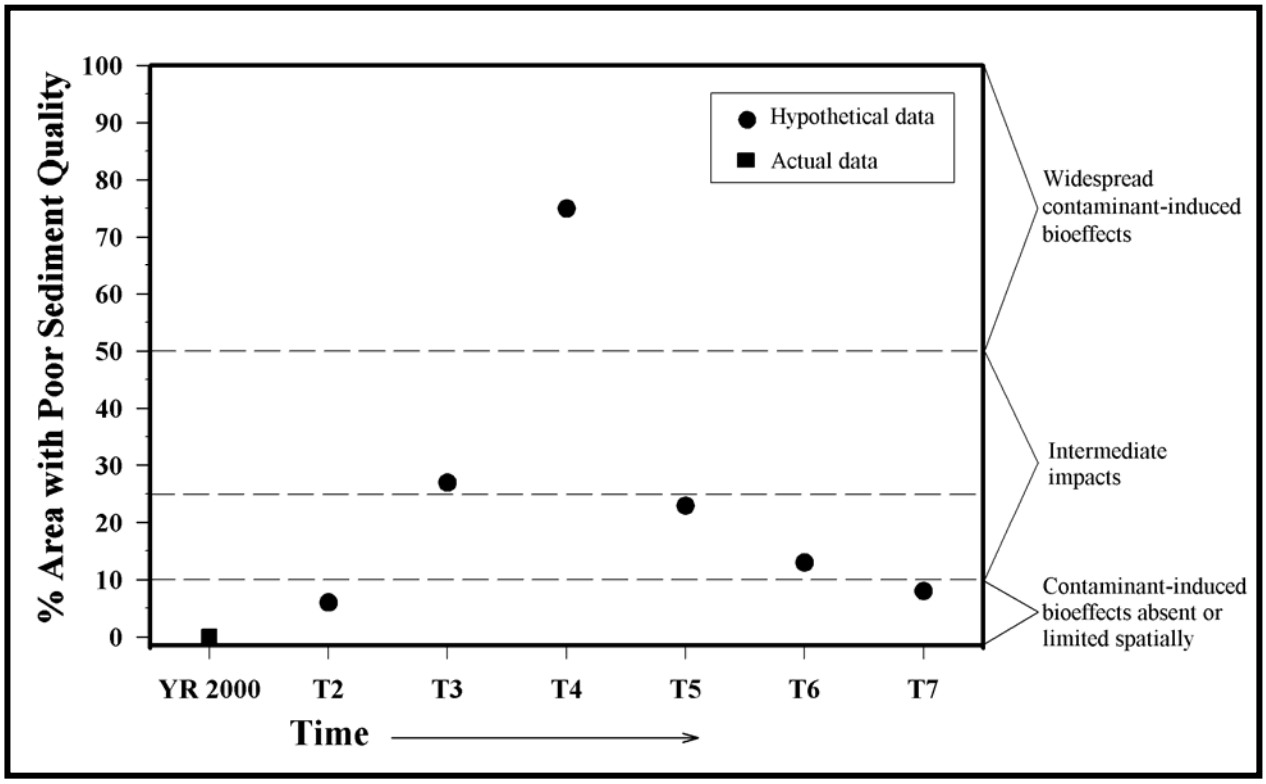


Figure II-6. Examples of how probability-based sampling data could be used to monitor potential changes in sediment quality with time at GRNMS. Y-axis is % area exhibiting poor sediment quality, as indicated by combined evidence of low benthic species richness (e.g., < 30 species/grab) accompanied by high sediment contamination (e.g., 1 ERM or ≥ 3 ERL exceedances).

mitigation measures. Selection of specific management action criteria should be based on a consensus of agreement among managers, science advisors, and stakeholders. However, regardless of what criteria are selected, the goal is to use this information as a basis for identifying the onset of a potential problem and whether the size of the affected area is growing so that corrective actions can be taken before the problem becomes too severe. Similarly, this information can be used to track recovery of potentially impacted areas to background conditions. As human activities in coastal regions continue to grow, it would be prudent to incorporate such approaches to help in identifying and managing potential environmental pressures that could follow.

3. Conclusions

- In general, chemical contaminants in sediments throughout the sanctuary in spring 2000 were at background levels, below probable bioeffect guidelines. A low-level spike of copper, between corresponding lower- and upper-threshold ERL and ERM sediment quality guideline values, was observed at one station. Also, trace concentrations of man-made pesticides (DDT, chlorpyrifos) and other chemical substances from human sources (PCBs, PAHs) were detected in these sediments, though not at concentrations likely to cause significant bioeffects. The low sediment contamination is most likely attributable to the remote location of this offshore environment and the sandy nature of the substrate (e.g., absence of a silt-clay fraction).
- Contaminants in tissues of target benthic species were below human-health guidelines (where available) based on a limited sample population (10 fillets of black sea bass and 9 arc-shell composites). Moderate concentrations of lead, however, just below the FDA Level of Concern value of 3 μg/g dry weight, were found in one fish sample (2.6 μg/g) and one arc-shell sample (2.9 μg/g). Similar to results for sediments, tissues of both species contained trace concentrations of additional chemical contaminants associated with human sources (pesticides, PCBs, PAHs), further demonstrating that such materials are making their way to the offshore sanctuary environment, either by air or underwater cross-shelf transport from land.
- The vast stretches of sands throughout the sanctuary appeared to support a highly diverse infaunal community, a finding which should change a frequent misconception that these "featureless" substrates surrounding live-bottom rocky outcrops are "biological deserts." Measures of diversity (number of species and H'), for example, are about twice as high as those observed for the benthos in neighboring estuaries of comparable high salinity.
- The probabilistic sampling design applied in this study provides a powerful quantitative tool for assessing current status in conditions of the sanctuary and for using this information as a baseline for tracking any future changes due to natural or anthropogenic influences. At the time of sampling, zero % of the sanctuary area showed any significant evidence of impaired benthic condition coupled to adverse levels of chemical contaminants in sediments. However, the presence of trace concentrations of pesticides, PCBs, and PAHs in both sediments and biota demonstrate that chemical substances originating from human activities are capable of reaching the offshore sanctuary environment and thus should be monitored to ensure that future problems do not develop.

- Results of this study provide information on environmental conditions as of spring 2000 and future monitoring strategies to use in the development of revised sanctuary management plans.

4. Acknowledgments

FY2000 work was sponsored by the NOAA National Marine Sanctuaries (NMS) Program. Special recognition is extended to Reed Bohne (NOAA/GRNMS Office), Charlie Alexander (NOAA/NMS Headquarters), Nathalie Valette-Silver (NOAA/NCCOS Headquarters), and Jon Hare (NOAA/NCCOS/CCFHR) for program coordination; to Barry Vittor & Associates (Mobile, AL) for analysis of macroinfaunal samples, TOC, and particle-size; to Peter Jenkins, Aaron Dias, Erich Strozier, Scott Sivertsen, and Brian Shaddrix (NOAA/NCCOS/CCEHBR) for analysis of contaminants in sediments and tissues; and to Cathy Sakas, Greg McFall, and Ralph Rogers (NOAA/GRNMS Office), as well as the crew of the NOAA Ship FERREL, for assistance with sample collections.

Section III

Spatial Patterns and Temporal Trends in Benthic Fauna and Sediment Contaminants

1. Results and Discussion

1.1 Review of Major Findings of the Initial Spring 2000 Survey Conducted Within the Sanctuary

Summarized here are several major conclusions about environmental conditions within the sanctuary, based on the initial spring 2000 survey. This information is presented as a basis of comparison with results of the follow-up spring 2001 survey and to help in understanding patterns emerging from the combined data sets.

Key habitat characteristics within the sanctuary (Fig. III-1) consisted of (1) inner-shelf depths, typically between 17-20 m (full range was 14.5-21.1 m); (2) euhaline (oceanic) salinities around 34 ppt; (3) very high DO levels around 8 mg/L; (4) low levels of organic carbon in sediments, typically between 1-2 mg/g; and (6) coarse sediments consisting mostly of sand with some shell hash and gravel-size particles. There was no fine (silt-clay) fraction of sediment apparent in these samples taken within the sanctuary boundaries.

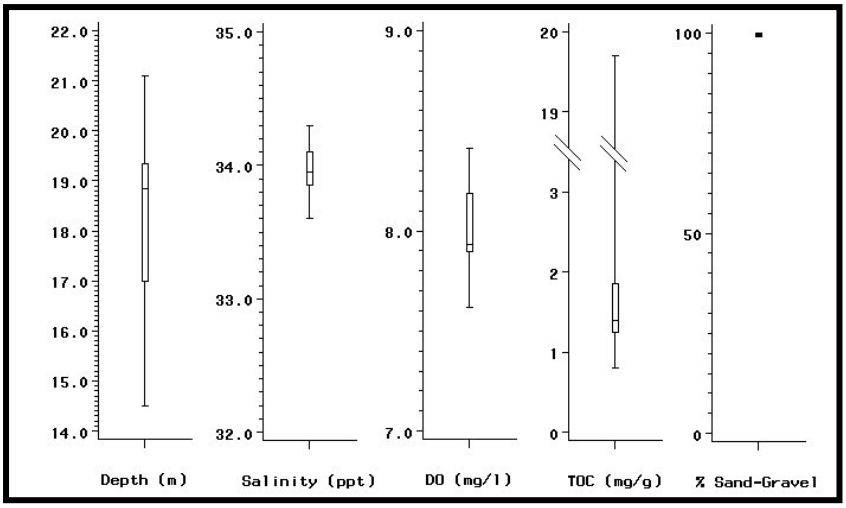


Figure III-1. Key habitat characteristics at GRNMS in April 2000 (n = 20 sites). Boxes are interquartile ranges, horizontal lines within boxes are medians and wisker endpoints are high/low extremes. Note in the last plot that values of % sand-gravel fall within a very narrow range of 99-100%.

In general, chemical contaminants in sediments throughout the sanctuary appeared to be at background levels, below probable bioeffect guidelines and are much lower in comparison to neighboring estuaries (Fig. III-2). A slightly elevated concentration of Cu (103 µg/g), between corresponding lower- and upper-threshold ERL and ERM sediment quality guideline values (34 µg/g and 270 µg/g, respectively), was observed at one station. Also, trace concentrations of pesticides (DDT, chlorpyrifos) and other chemical substances from human sources (PCBs, PAHs) were detected in these sediments, though not at concentrations likely to cause significant bioeffects. The low sediment contamination is most likely attributable to the remote location of this offshore environment and the sandy nature of the substrate

(e.g., absence of a silt-clay fraction).

Contaminants measured in tissues of target benthic species were also below human-health guidelines (where available) based on a limited sample population (10 fillets of black sea bass and 9 arc-shell composites). Moderate concentrations of lead, however, just below the FDA Level of Concern value of 3 µg/g dry weight, were found in one fish sample (2.6 µg/g) and one arc-shell sample (2.9 µg/g). Similar to results for sediments, tissues of both species contained trace concentrations of additional chemical contaminants associated with human sources (pesticides, PCBs, PAHs), further demonstrating that such materials are making their way to the offshore sanctuary environment, either by air or underwater cross-shelf transport from land. Water masses in this region are known to undergo periodic cross-shelf movement.

The vast stretches of sands throughout the sanctuary support highly diverse macroinfaunal assemblages. Species richness (number of species), for example, are about twice as high as those observed for the benthos in neighboring estuaries of comparable high salinity (Fig. III-3).

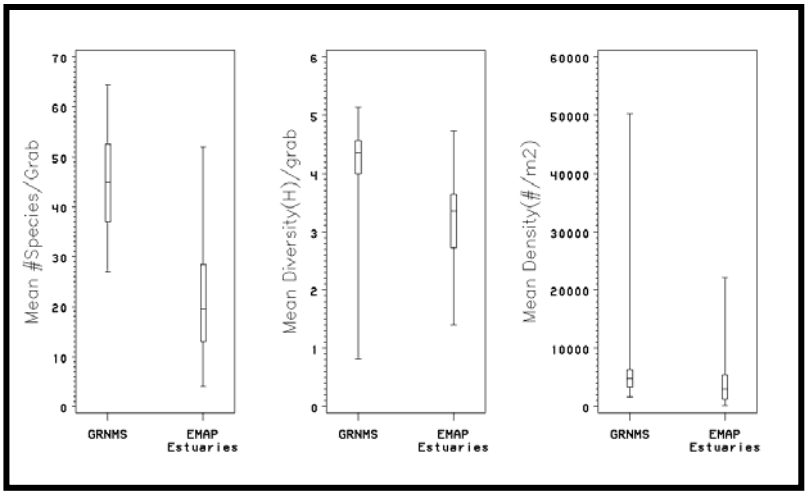


Figure III-3. Comparison of benthic species richness, diversity and abundance at spring 2000 GRNMS sites (n = 20) vs. estuarine sites of similar salinity (> 30 ppt) in EMAP Carolinian Province (n = 38). Boxes are interquartile ranges, horizontal lines within boxes are medians and wisker endpoints are high/low extremes. Base 2 logarithms were used to calculate H′.

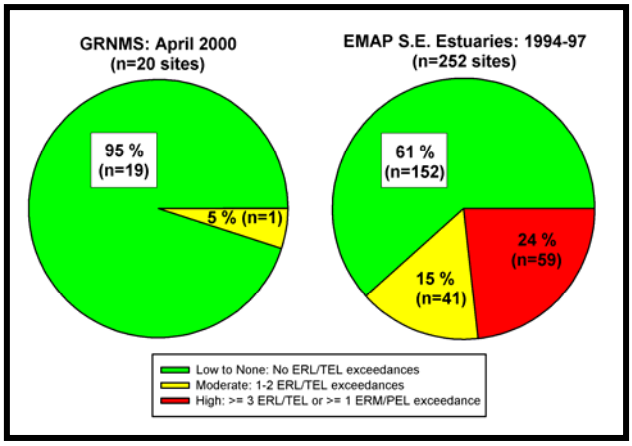


Figure III-2. Comparison of sediment contamination (% area) at GRNMS during the present study (April 2000) vs. southeastern estuaries sampled during EMAP (unpublished data from J. Hyland, NOAA).

1.2 Results of the Spring 2001 Survey: General Habitat Characteristics of the Surrounding Shelf Environment

A detailed listing by station of key habitat characteristics (site location, distance from land, depth, temperature, salinity, DO, pH, TOC, grain size variables) for each of the stations sampled in spring 2001 is presented in Appendix E. Characteristics of sites within the sanctuary (Stations 1, 10, 11, 12, 14, and 17) were similar to those observed in the previous year: typical oceanic salinities (35.6-36.1 ppt); very high DO levels (all ≥ 7.2 mg/L), which are well above a reported benthic hypoxic effect threshold of about 1.4 mg/L (Diaz and Rosenberg 1995) as well as most State standards of 5 mg/L or lower; low levels of TOC in sediments (0.5-1.7 mg/g); and coarse sediments consisting almost entirely of sand (98.9-99.8 %).

Table III-1. Comparison of habitat characteristics at nearest-shore stations (21, 26, 30) and furtherest offshore stations (25, 12, 34) along the three cross-shelf transects, spring 2001. Mean (and range) are listed for each variable.

	Nearshore Sites	Offshore Sites
Distance from Land (km)	2	32
Depth (m)	8.1 (4.1 – 10.1)	15.3 (14.8 – 15.7)
Temperature (°C)	21.8 (21.5 – 22.4)	19.0 (18.2 – 19.6)
Salinity (ppt)	29.9 (22.8 – 33.7)	35.7 (35.5 – 35.9)
Dissolved Oxygen (mg/L)	7.3 (6.9 – 7.9)	7.3 (7.2 – 7.3)
pH	7.9 (7.9 – 7.9)	7.9 (7.9 – 8.0)
% Silt-Clay	24.2 (21.5 – 28.9)	0.97 (0.26 – 0.42)
TOC (mg/g)	4.6 (2.8 – 5.7)	2.9 (1.7 – 5.1)

Cross-shelf variations were evident in some of these variables, notably depth, temperature, salinity, % silt/clay, and TOC (Table III-1). Stations nearest to land (21, 26, and 30) compared to those furthest offshore (25, 12, and 34) were characterized by shallower depths (mean of 8.1 vs. 15.3 m), slightly warmer water (mean near-bottom water temperature of 21.8 vs. 19.0 °C), lower salinity (mean of 29.9 vs. 35.7 ppt), higher silt/clay content of sediments (mean silt/clay content of 24.2 vs. 0.9%), and higher TOC content of sediments (mean of 4.6 vs. 2.9 mg/g). Percent silt/clay displayed a distinct pattern across all three transects (Fig. III-4) with appreciable amounts (22 – 29%) appearing at the mouths of the three sounds. These finer-grained particles represent a potential source for sorption of any chemical contaminants in the run-off entering these systems.

The warmer and less saline condition of water for stations nearest to land was especially pronounced at Station 30 near the entrance of Altamaha Sound, which is presumably attributable to the larger river flow coming out of the Altamaha River relative to the other two sounds (Amft et al. 2002, Chunyan and Blanton 2002). Altamaha Sound is at the mouth of the Altamaha River, the largest river in Georgia. Doboy Sound, adjacent to our middle transect, has no major upland sources of freshwater, but receives some low-salinity water from the Altamaha River via the IntraCoastal Waterway, connecting marsh channels, and tidal exchange with Altamaha's near-coastal plume. Sapelo Sound with no direct connection to Altamaha or other rivers has the least amount of net outward water transport among the three sounds. The TOC content of sediments at stations along Transect I off Sapelo Sound in the present study was much lower in comparison to the other two transects and may be related to this lower outward flux and greater distance from potential Altamaha River sources. There were no distinct cross-shelf patterns in DO or pH along any of the transects. The relative influence of these various abiotic environmental variables on patterns of benthic fauna is examined below.

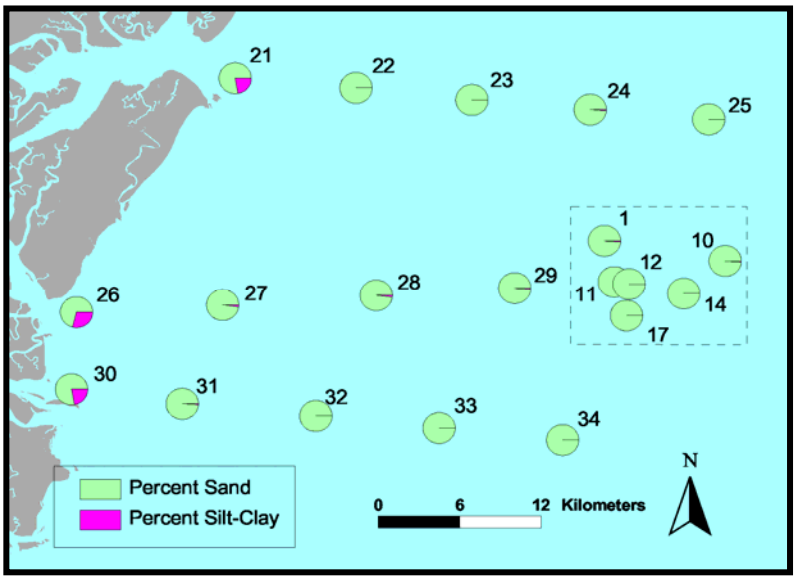


Figure III-4. Cross-shelf patterns in % silt-clay vs. sand content of sediment, based on spring 2001 data. Numbers refer to station number.

1.3 Results of the Spring 2001 Survey: Cross-Shelf Patterns of Chemical Contaminants in Sediments

In general, chemical contaminants in sediments of the surrounding inner-shelf sampling area appeared to be at low background levels, similar to conditions observed within the sanctuary during the previous year. Most stations (19 of the 20 sampled) had sediments with all measured contaminants below corresponding ERL/TEL sediment quality guidelines (Fig. III-5). There were no stations with "high" levels of contamination — defined here as one or more contaminants present at concentrations above upper ERM/PEL guideline values, or multiple (three or more) contaminants present at moderate concentrations between these lower and upper bioeffect critical points. One station (28) had a slightly elevated Cd concentration of 1.25 µg/g, which was just above the lower-threshold ERL guideline value of 1.2 µg/g, but still below the higher ERM value of 9.6 µg/g.

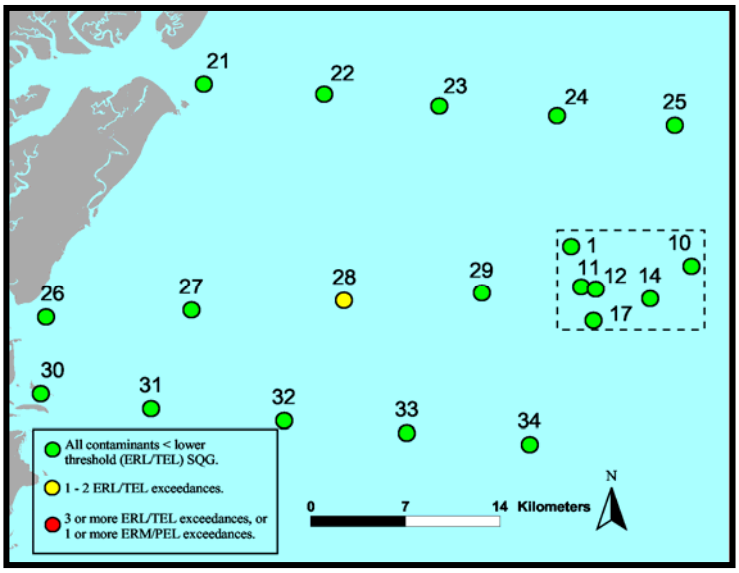
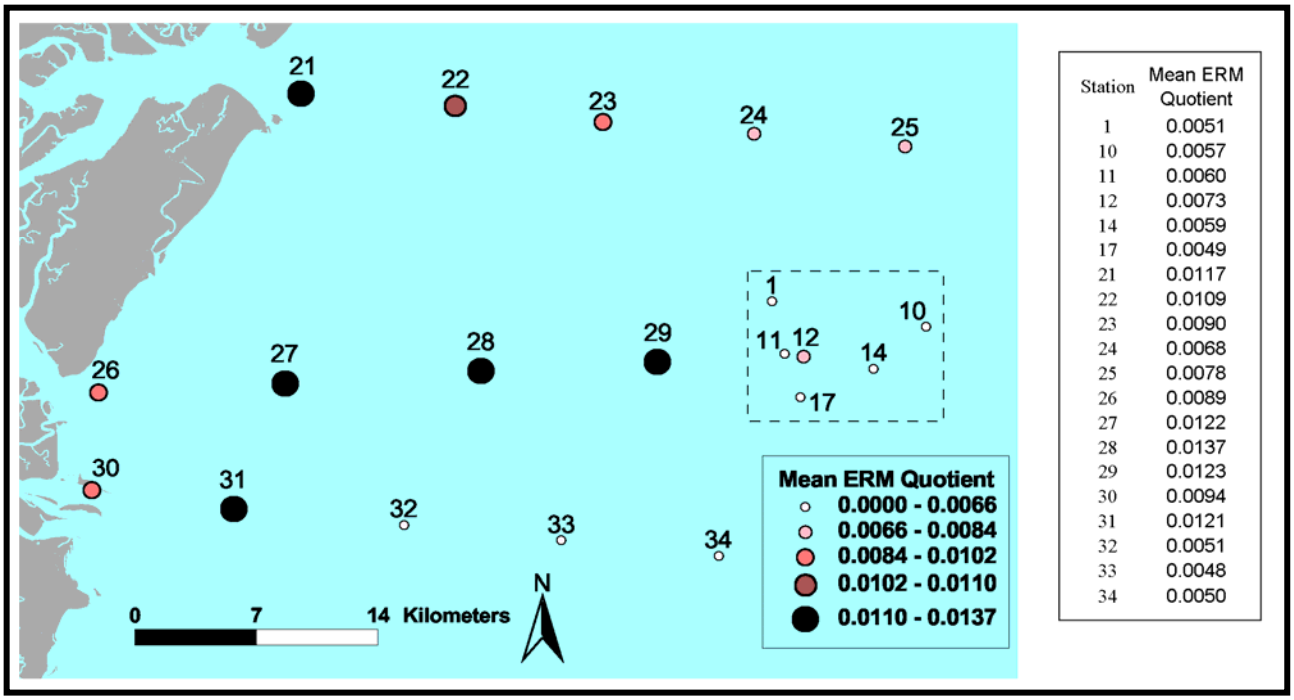


Figure III-5. Summary of chemical contaminants concentrations in sediments relative to sediment quality guidelines (SQG). Data are from spring 2001.

Though the source could be natural or anthropogenic, the concentration of cadmium at this station was higher than the concentrations typically observed in other southeastern coastal areas remote from contaminant sources (typically < about 0.4 µg/g, Windom et al. 1989).



Station	Mean ERM Quotient
1	0.0051
10	0.0057
11	0.0060
12	0.0073
14	0.0059
17	0.0049
21	0.0117
22	0.0109
23	0.0090
24	0.0068
25	0.0078
26	0.0089
27	0.0122
28	0.0137
29	0.0123
30	0.0094
31	0.0121
32	0.0051
33	0.0048
34	0.0050

Figure III-6. Cross-shelf patterns in chemical contaminant levels expressed as mean ERM quotients. Data are from spring 2001.

It is also important to recognize that other chemical substances in addition to Cd were detectable in sediments throughout the study area, though not at high concentrations likely to cause adverse biological effects (Appendix F). These materials included mostly metals (arsenic, chromium, copper, lead, manganese, mercury, nickel, selenium, and zinc) and some PAHs (biphenyl and perylene). Importantly, there was a general pattern of decreasing concentrations with increasing distance from shore, thus suggesting possible outwelling of these materials from inland sources through the coastal sounds. Such a pattern is illustrated in Fig. III-6, in which the level of contamination at a station is expressed as a mean ERM quotient (*sensu* Long et al. 1998, 2000; Long and MacDonald 1998; Hyland et al. 1999). The mean ERM quotient is the mean of the ratios of individual chemical concentrations in a sample relative to corresponding published ERM sediment quality guideline values. 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).

There is an indication of decreasing sediment contamination (at low levels) with increasing distance from land based on these quotients, suggesting that contaminants originating from inland sources are being transported to the shelf environment through the sounds. Additional evidence of this process was provided by a companion study of the pesticide atrazine (measured as total triazines) in water samples collected at cross-shelf stations in conjunction with our spring 2001 survey. Concentrations were below detection limits at most stations, but a trace concentration of 8 ng/L was detected, although still below the published minimum detection limit of 25 ng/L for the test kit (Strategic Diagnostics Inc., 1998), at Station 30 nearest to the entrance of Altamaha Sound (unpublished data, Paul Pennington, NOAA, Charleston, S.C.). The detection of triazines, even at a trace concentration, is noteworthy given the open-ocean conditions and the non-persistent nature of these materials (e.g., a half life of about 30 days for atrazine).

None of the stations in this study appeared to have mean ERM quotients high enough to suggest significant risks of adverse effects on benthic fauna. Hyland et al. (1999) reported a high incidence of impaired benthic assemblages in southeastern estuaries at mean ERM quotients above a critical point of about 0.06 (78% of samples in that range) and a low incidence of effects (5% of samples) at mean ERM quotients below 0.02. Although in the present study we are dealing with offshore benthic fauna, none of the stations had mean ERM quotients in this upper bioeffect range. The highest value was 0.0137, well within the reported low-risk range. Also, all PCBs, all pesticides, most PAHs (except biphenyl, and

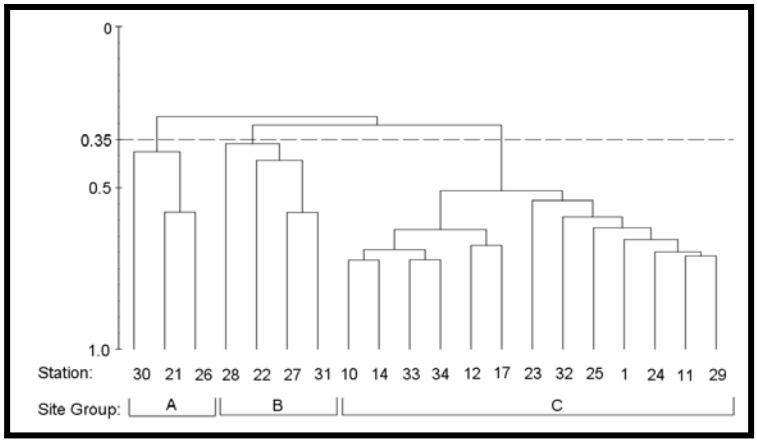


Figure III-7. Dendrogram resulting from clustering of stations sampled in spring 2001, using group-average sorting and Bray-Curtis similarity. Samples within each station are combined over all 3 replicates. A similarity level of 0.35 (dotted line) was used to define the major site groups.

perylene), and some metals (silver and tin) were below analytical detection limits across all stations sampled in spring 2001. This further suggests that potential environmental contaminants in this region of the continental shelf are currently at fairly low levels reflecting general background conditions.

1.4 Spatial Patterns in Benthic Fauna

1.4.1 Cross-Shelf Patterns

Differences in the distribution of benthic infauna among stations sampled in spring 2001 were examined using normal (Q mode) cluster analysis (Boesch 1977). Group-average sorting (= unweighted pair-group method; Sneath and Sokal 1973) was used as the clustering method and Bray-Curtis similarity (Bray and Curtis 1957) was used as the resemblance measure. The analysis was run on double-square-root transformed abundances (combined over replicates within a station) using the PRIMER software package (Clarke and Gorley 2001). Rare species (i.e., those representing <1% of the total abundance of a sample) were excluded from the analysis. Results were expressed as a dendrogram (Fig. III-7) in which samples were ordered into groups of increasingly greater similarity based on resemblances of component-species abundances. Using a Bray-Curtis similarity value of 0.35 as a separation rule yielded three major site groups, denoted as A, B, and C. There is a distinct cross-shelf pattern in the distribution of these site groups (Fig. III-8).

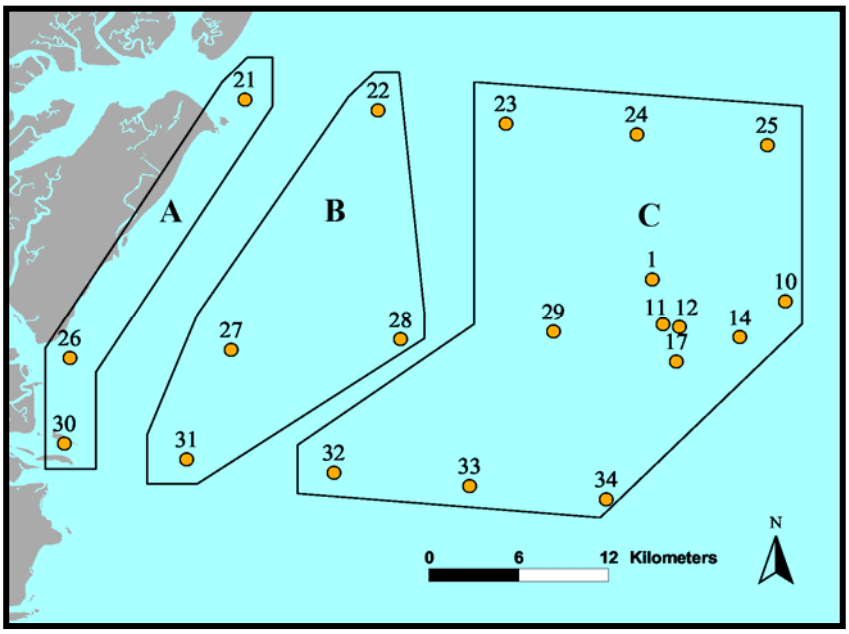


Figure III-8. Cross-shelf distribution of site groups resulting from cluster analysis of benthic macroinfaunal data collected in spring 2001.

Table III-2. Summary of abiotic environmental variables by site group, spring 2001. Included are the site group means and univariate test statistics for significance of among-group differences (df = 2, 17 for F statistics).

Variable	Site Group Means:			F Statistics	
	A	B	C	F Value	Pr > F
Depth (m)	8.1	9.2	14.7	13.81	0.0003
Temperature (°C)	21.8	20.3	19.4	38.38	< 0.0001
DO (mg/L)	7.3	7.3	7.2	0.16	0.8538
pH	7.9	7.9	7.9	3.05	0.0738
% Silt-Clay	24.2	1.6	0.4	320.39	< 0.0001
Mean ERM Quotient	0.010	0.012	0.006	14.47	0.0002
phi (Median Particle Size)	1.95	2.08	1.03	9.20	0.0020
TOC (mg/g)	4.6	3.7	2.3	8.52	0.0570
Salinity (‰)	29.9	34.5	35.6	3.41	0.0027
Distance from Shore (km)	2	11	28	39.43	< 0.0001

Group A consists of the three stations closest to land (21, 26, and 30), Group C consists of stations within GRNMS and surrounding area near the seaward ends of the three offshore transects, and Group B consists of transitional stations in-between.

Canonical discriminant analysis was used to determine whether the separation of the cluster groups could be explained by other measured abiotic environmental factors (*sensu*

Green and Vascotto 1978, Hyland et al. 1991). Abiotic variables that displayed significant mean differences across the three groups (at $\alpha = 0.05$) were included in the analysis (all except DO and pH, Table III-2). The analysis sought to derive a reduced set of discriminant (canonical) functions that best described the separation of the pre-declared station groups based on data represented by the different abiotic environmental variables. Total Structure Coefficients (TSC), which are the correlations between the original variables and the discriminant scores on each function, provided a measure of the relative contribution of each variable to group separation.

Results showed that the first two canonical functions were significant (CAN 1: $p<0.0001$, $df = 16, 20$; CAN 2: $p=0.0062$, $df = 7, 11$) and together accounted for 100% of the among-group variation in abiotic variables (98% and 2% respectively). A plot of the discriminant scores on each of these two functions showed a clear separation of site groups (Fig. III-9). TSCs (Table III-3) reveal that the first canonical function (CAN 1) is most highly correlated with % silt-clay, thus explaining the separation of siltier, nearshore Group A stations from the sandier, more offshore stations in Groups B and C. TSCs for salinity and temperature also indicate relatively high correlations with discriminant scores on CAN 1, and thus their possible influence on the separation of Group A stations from Groups B and C. In addition to having sediments with higher silt-clay content, Group A stations were slightly warmer and less saline, revealing characteristics that are probably all due to the closer proximity of Group A stations to land and the influence of the coastal sounds. The first canonical function also had a fairly high correlation with "distance from shore" as a variable (Table III-3). Additional unmeasured controlling factors related to distance from shore also could be contributing to these patterns. These include physical factors (e.g., erosional effects near the mouths of the three sounds) and biological factors (e.g., closer proximity of Group A sites to sources of recruitment by estuarine species).

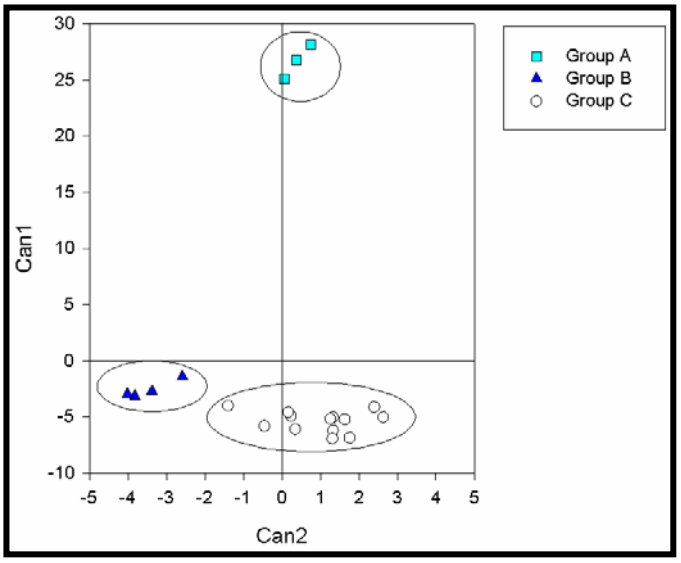


Figure III-9. Separation of site groups on the first and second canonical function derived from canonical discriminant analysis performed on abiotic environmental variables, spring 2001. Can 1 = first canonical function (98% of variability). Can 2 = second canonical function (2% of variability).

Table III-3. Total structure coefficients (TSC) of abiotic environmental variables on the first two canonical functions associated with variations among site groups, spring 2001. Coefficients considered important in each function are underlined.

Variable	TSC	
	Can1	Can2
Depth	-0.580	<u>0.605</u>
Temperature	0.861	-0.324
Salinity	-0.705	0.091
TOC	0.453	0.325
% silt-clay	<u>0.990</u>	0.050
Mean ERM Quotient	0.328	-0.819
Phi	0.426	<u>-0.660</u>
Distance from Shore	-0.735	0.570

The canonical plot (Fig. III-9) reveals that the second canonical function explains most of the variation between Groups B and C. TSCs for CAN 2 indicate that the strongest

Table III-4. Comparison of benthic characteristics by site group, spring 2001. P = polychaete, G = gastropod, B = bivalve, C = crustacean, O = oligochaete, E = echinoderm and Ch = Chordate.

Site Group	Taxa	Ind. m^{-2}	Dominant Fauna Cumulative %	Dominant Fauna Frequency[a]	Mean Abundance (m^{-2})[b]	Mean No. taxa/grab	Mean H′/grab[c]	Total No. Taxa
A	*Mediomastus* spp. (P)	15875	31	67	17192	41	3.28	149
	Polycirrus eximius (P)	9958	50	67				
	Tharyx acutus (P)	5650	61	67				
	Streblospio benedicti (P)	2833	67	100				
	Mediomastus ambiseta (P)	2092	71	67				
	Spiophanes bombyx (P)	1825	74	100				
	Tubificidae (O)	1458	77	100				
	Exogone rolani (P)	1158	79	67				
	Eumida sanguinea (P)	1125	81	67				
	Mediomastus californiensis (P)	1017	83	100				
B	*Mediomastus* spp. (P)	4513	26	60	5860	31	2.75	143
	Spiophanes bombyx (P)	1856	36	100				
	Owenia fusiformis (P)	1600	45	60				
	Oxyurostylis smithi (C)	1594	54	100				
	Mediomastus ambiseta (P)	900	60	60				
	Tellina spp. (B)	500	62	80				
	Asteroidea (E)	450	65	80				
	Phoxocephalidae (C)	331	67	60				
	Protohaustorius wigleyi (C)	306	69	60				
	Rhynchocoela	288	70	100				
C	*Caecum johnsoni* (G)	1735	8	100	7382	54	3.60	382
	Fabricinuda trilobata (P)	1421	14	23				
	Protodorvillea kefersteini (P)	1175	20	92				
	Tubificidae (O)	1129	25	100				
	Branchiostoma spp. (Ch)	1083	30	92				
	Spiophanes bombyx (P)	975	34	100				
	Crassinella dupliniana (B)	717	37	92				
	Parapionosyllis longicirrata (P)	587	40	92				
	Sphaerosyllis piriferopsis (P)	577	42	54				
	Erichthonius brasiliensis (C)	525	45	62				

a. Percentage of samples in which taxa occurred.
b. All taxa combined.
b. Calculated using base 2 logarithms.

correlations on this function are with mean ERM quotients, median sediment particle size (phi), and depth (Table III-3). Though mean ERM quotients vary distinctly across site groups (Table III-2), values are not in the range associated with a high risk of adverse effects on benthic fauna (as discussed above) and are not likely to be the cause of the observed faunal patterns. Thus, the remaining two abiotic variables, depth and median sediment particle size (phi), associated with the separation of Group B from C on CAN 2 (Fig. III-9) could be contributing to the corresponding biological differences between these two groups. A comparison of Group B and C stations (Table III-2) reveals a transition from medium to coarse sands (i.e., higher to lower phi values) and into slightly deeper water depths.

These results suggest that granulometric characteristics of sediment (% silt-clay, median particle size) and depth are important controlling factors contributing to the observed cross-shelf patterns in benthic fauna. Depth was secondary to sediment effects, but would probably show a much stronger influence if data from middle and outer-shelf sites were available to include in the analysis. Future work will include an analysis of spatial variations across the entire width of the shelf in the GRNMS region.

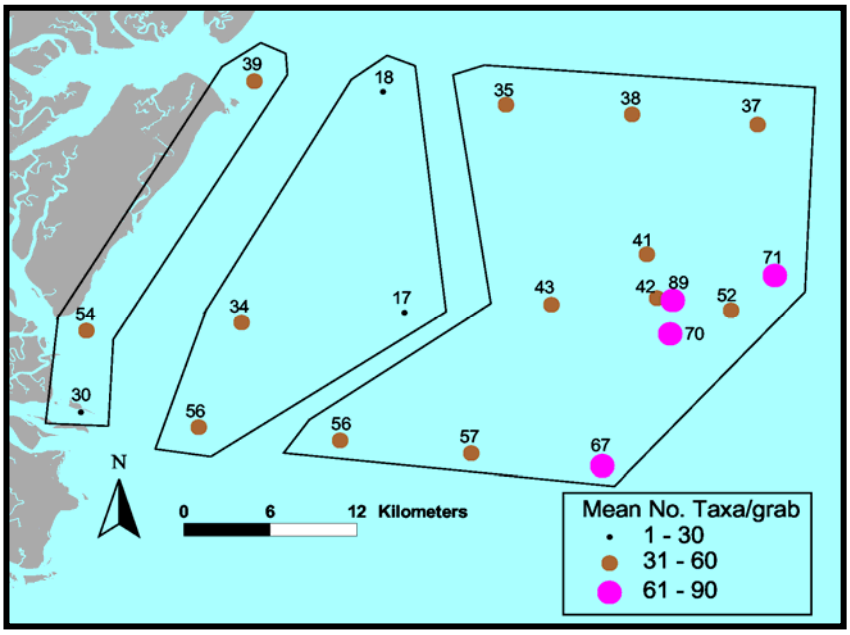


Figure III-10. Comparison of species richness among the three site groups, spring 2001. Values are the mean no. taxa/grab at each station.

Table III-4 provides a comparison of the characteristics of benthic fauna across the three site groups. There are distinct cross-shelf differences in species composition. Dominant fauna of Group A included common estuarine species (e.g., Fig. III-11), which reflects the close proximity of these sites to land and to potential sources of estuarine larvae. Many of the Group A dominants (e.g., the polychaetes *Streblospio benedicti*, *Tharyx acutus*, *Mediomastus* spp., *M. ambiseta*, *Eumida sanguinea*, *Polycirrus eximius*) were absent or rare at stations furthest offshore (Table III-4, Appendix G). In contrast, dominant fauna of Group C included many species that were absent or rare at the nearshore Group A sites (e.g., the gastropod *Caecum johnsoni*; the bivalve *Crassinella dupliniana*; the crustacean *Erichthonius brasiliensis*; the chordate *Branchiostoma* spp; and the polychaetes *Fabricinuda trilobata, Protodorvillea kefersteini, Pararpionosyllis longicirrata,* and *Sphaerosyllis piriferopsis*). Site Group B included

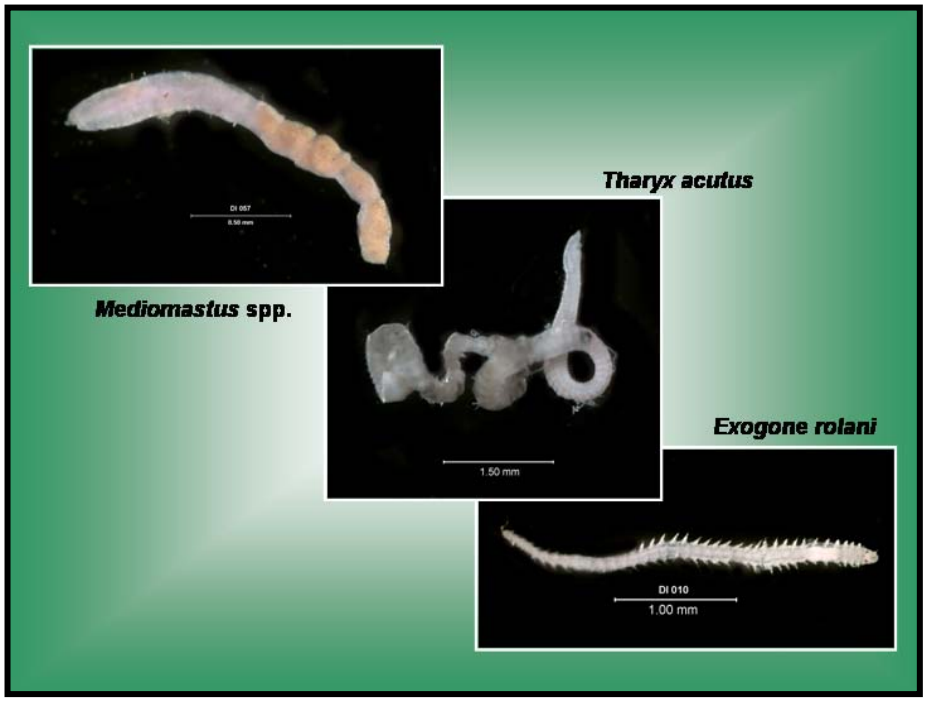


Figure III-11. Examples of polychaetes present in Cluster Group A.

dominants common to both other groups, but which overlapped to a greater extent with the more seaward Site Group C. A more detailed list of species and corresponding abundances by site group is provided in Appendix G.

There also were notable cross-shelf differences in species diversity (Table III-4, Fig. III-10). Stations furthest offshore in Group C, especially those in GRNMS, had the greatest numbers of species (Fig. III-10). The mean number of species per grab at one of these sites (Station 12) within GRNMS was 89, which is a very sizable number for the relatively small sampling area of the 0.04 m^2 grab. Blake and Grassle (1994) also found a high diversity of macroinfauna at deeper continental slope and rise sites off the Carolinas (600 – 3500m), with the highest occurring at an 800-m site seaward of Charleston. Similar to the cross-shelf pattern observed here, diversity of macrofauna has been shown to increase with depth across the continental shelf off New England (Neff et al. 1989), in the middle Atlantic Bight (Boesch 1979), and in the South Atlantic Bight off Cape Lookout (Day et al. 1971). In contrast to these patterns, MRRI (1982) found that the diversity of benthic fauna in close association with live-bottom areas off the North Carolina, South Carolina, and Georgia coasts was higher at mid-shelf sites in comparison to inner-shelf and outer-shelf sites, and that changes in diversity were more related to varying degrees of topographic complexity and habitat heterogeneity than to depth or distance from shore.

Further details on the characteristics of these fauna at each of the individual stations sampled in spring 2001 are provided in Appendix H.

1.4.2 Finer-Scale Spatial Variability at Sites within the Sanctuary

Stations within the GRNMS boundaries all fell within Site Group C (Fig. III-7) revealing that any spatial variability in benthic fauna within the sanctuary is less pronounced than the broader spatial patterns observed across the shelf. Yet, finer-scale spatial variations can be seen within the sanctuary as well. For example, normal (Q mode) cluster analysis of benthic data collected from the 20 stations within the sanctuary boundaries during the previous spring 2000 survey shows that stations separate into two major groups, denoted A and B, at a Bray-Curtis similarity of 0.55 (Fig. III-12). Note that this division point is at a fairly high level of similarity compared to the value of 0.35 used above to define broader cross-shelf groupings. The same methods were used for both cluster analyses.

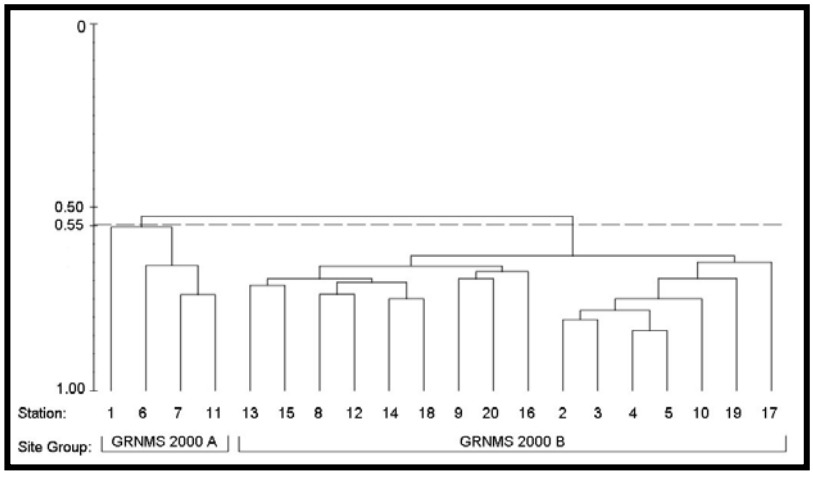


Figure III-12. Dendrogram resulting from clustering of stations sampled within GRNMS in spring 2000, using group-average sorting and Bray-Curtis similarity. Samples within each station are combined over all 3 replicates. A similarity level of 0.55 (dotted line) was used to define the two major site groups.

The sanctuary Site Group A consists of Stations 1, 6, 7, and 11 co-located in the northwest sector of the sanctuary (Fig. I-4). Group B consists of the remaining 16 stations. There are no obvious differences in the physical

characteristics of these stations, based on measured environmental variables, with the exception that Group A stations are further from known locations of live-bottom habitat, which tend to be more concentrated in the central portion of the sanctuary (GRNMS Office, unpublished data). Thus, proximity to live-bottom habitat could be a factor contributing to such finer-scale spatial variations. This interpretation would be consistent with the above diversity patterns noted by MRRI (1982) for benthic fauna in close association with live-bottom habitat. In general, the benthic fauna at Group A stations appear to be less diverse and abundant in comparison to the other sanctuary sites (Fig. III-13). Otherwise, most of the dominant species are common to both sanctuary site groups.

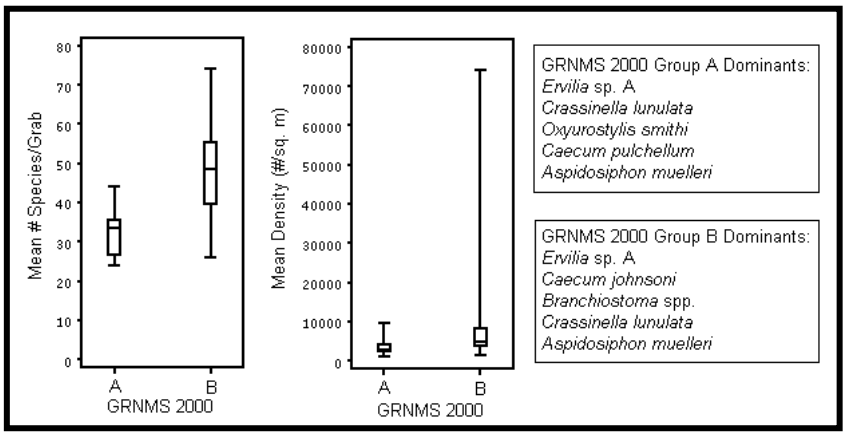


Figure III-13. Comparison of benthic species richness (# species/grab), abundances (#/m^2), and dominants at spring 2000 site groups A vs. B. For the # species and abundances: boxes are interquartile ranges, horizontal lines within boxes are medians, and wisker endpoints are high/low extremes.

1.5 Temporal Variability of Benthic Fauna

As described above in the methods section, six stations within GRNMS (1, 10, 11, 12, 14, and 17) were sampled in both spring 2000 and 2001. Differences in benthic community structure at these sites between the two sampling periods were assessed using non-metric multidimensional scaling ordination (MDS) (Kruskal and Wish 1978) on the Bray-Curtis similarity matrix of double-square-root transformed species abundance data. The analysis was performed using the PRIMER software package (Clarke and Gorley 2001). As with the cluster analyses, rare species (i.e., those representing <1% of the total abundance of a sample) were excluded from the analysis.

A two-dimensional plot of the MDS results (Fig. III-14) shows a distinct difference between sampling periods (solid vs. open symbols) and that the difference is especially pronounced for Stations 1 and 11. Contour lines are superimposed on groups of samples that have similar benthic composition at a Bray-Curtis similarity level of 0.6 or greater. At this level of similarity, we see that sampling periods form separate groups and that Stations 1 and 11 separate from the other stations in both years. Distances between sampling points in the two-dimensional plot are a representation of the relative ranks of their similarities (i.e., the closer together two points are, then the more similar they are). Thus, samples from Stations 1 and 11 were less similar to other sanctuary stations in spring 2000 than in spring 2001. The separation of Stations 1 and 11 from the other sanctuary stations by MDS (in either year) is consistent with the above small-scale spatial variations detected with cluster analysis of data from the 20 spring 2000 stations.

As for the interpretation of small-scale spatial variability, it is important to recognize that the level of temporal variability that we are seeing here is much less pronounced than the broader spatial patterns observed across the shelf. The Bray-Curtis similarity value of 0.60 used to group sampling points in the MDS plot (Fig. III-14) is at a fairly high level of similarity

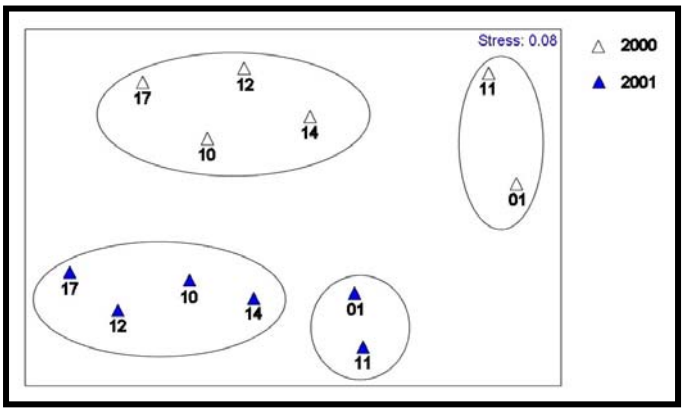


Figure III-14. Results of non-metric, two-dimensional MDS ordination on the Bray-Curtis similarity matrix of double square-root transformed species abundance data from six GRNMS stations sampled in spring 2000 and 2001. Sampling points similar at Bray-Curtis similarity of ≥ 0.6 are encircled. Note that the stress value of 0.08 suggests that a higher-dimensional ordination is not necessary to improve interpretations (Clarke and Gorley 2001).

compared to the value of 0.35 used above to define broader cross-shelf groupings. In fact, when samples collected in spring 2000 from the six GRNMS stations that were sampled again in spring 2001 are included in a cluster analysis of all spring 2001 stations, we find that they all cluster together within the offshore Site Group C along with corresponding samples collected at these same sites in 2001. This indicates that any temporal variability seen in the MDS analysis is secondary to the broader cross-shelf spatial patterns. Albeit small, such temporal variability will need to be taken into account in any future efforts to monitor potential long-term environmental changes due to human or natural disturbances.

2. Conclusions

- Percent silt/clay content of sediment displayed a distinct pattern across all three transects, with appreciable amounts appearing at the mouths of the three sounds. These finer-grained particles represent a potential source for sorption of any chemical contaminants in the run-off entering these systems. Cross-shelf differences in salinity and temperature provided additional evidence of the influence of river flow on the immediately adjacent shelf environment. Warmer and less saline condition of water for stations nearest to land was especially pronounced at Station 30 located at the mouth of Altamaha Sound, which is presumably attributable to the larger river flow coming out of the Altamaha River relative to the other two sounds.
- In general, chemical contaminants in sediments of the surrounding inner-shelf sampling area appeared to be at low background levels, similar to conditions observed within the sanctuary during the previous year. Most stations (19 of the 20 sampled) had sediments with all measured contaminants below corresponding, lower-threshold, sediment quality guidelines. One station had a slightly elevated cadmium concentration of 1.25 µg/g, which was just above the lower-threshold ERL guideline value of 1.2 µg/g, yet still below the higher median-effect ERM value of 9.6 µg/g. Other chemical substances in addition to Cd were detectable in sediments throughout the study area, though not at high concentrations likely to cause adverse biological effects. These materials included mostly metals (arsenic, chromium, copper, lead, manganese, mercury, nickel, selenium, and zinc) and some PAHs (biphenyl, perylene). Importantly, there was a general pattern of decreasing concentrations with increasing distance from shore, suggesting possible outwelling of these materials from inland sources through the coastal sounds. Total triazines in water samples also were detectable at Station 30 near the mouth of Altamaha Sound.
- There were distinct cross-shelf patterns in the structure and composition of benthic

fauna. Variations in the fauna appeared to be associated with sediment granulometric characteristics (% silt-clay and median particle size) and other factors related to distance to shore (e.g., depth). Additional unmeasured controlling factors also related to distance from shore may be contributing to these patterns. These include physical factors (e.g., erosional effects near the mouths of the three sounds) and biological factors (e.g., closer proximity of nearshore sites to sources of recruitment by estuarine species). Dominant fauna of Site Group A, consisting of stations closest to the mouths of the three sounds, included common estuarine species (e.g., the polychaetes *Streblospio benedicti*, *Tharyx acutus*, *Mediomastus ambiseta*, *Eumida sanguinea*, *Polycirrus eximius*). Many of these nearshore dominants were absent or rare at stations further offshore. In contrast, dominant fauna of Site Group C, consisting of GRNMS stations and other sites near the seaward ends of the three cross-shelf transects, included many species that were absent or rare at Group A sites (e.g., the gastropod *Caecum johnsoni*; the bivalve *Crassinella dupliniana*; the crustacean *Erichthonius brasiliensis*; the chordate *Branchiostoma* spp; and the polychaetes *Fabricinuda trilobata* and *Protodorvillea kefersteini*). A third Group B, consisting of transitional sites, included dominants common to both other groups, but which overlapped to a greater extent with the more seaward Site Group C.

- There also were notable cross-shelf differences in species diversity. Stations furthest offshore in Group C had the greatest numbers of species. This result is consistent with the high level of diversity found throughout most GRNMS sites during the initial spring 2000 survey and supports the view that the sanctuary, and probably much of the offshore South Atlantic Bight region, is an important reservoir of marine biodiversity.
- Additional finer-scale spatial variations in benthic fauna were detected among stations within the sanctuary boundaries and may be related to differences in the proximity to live-bottom habitat. However, any such spatial variability in benthic fauna within the sanctuary is less pronounced than the broader spatial patterns observed across the shelf.
- Minor differences in benthic community structure were detected between sampling periods (spring 2000 vs. spring 2001) at sites within GRNMS. As with the interpretation of small-scale spatial variability, it is important to recognize that such variability is much less pronounced than the broader spatial patterns observed across the shelf. Albeit small, such temporal variability will need to be taken into account in any future efforts to monitor potential long-term environmental changes due to human or natural disturbances.
- The probabilistic sampling design applied in the first year of this study provides a quantitative framework for assessing current status in conditions of the sanctuary and for using this information as a benchmark for tracking any future changes due to natural or anthropogenic influences. The spring 2000 sampling showed no significant evidence of impaired benthic condition coupled to adverse levels of chemical contaminants in sediments. However, the presence of trace concentrations of pesticides, PCBs, and PAHs in both sediments and biota demonstrate that chemical substances originating from human activities are capable of reaching the offshore sanctuary environment and thus should be monitored to ensure that future problems do not develop. This point is reinforced by

results of the follow-up spring 2001 survey, which showed a general pattern of decreasing trace concentrations of sediment-associated contaminants with increasing distance from shore along the three cross-shelf transects, thus suggesting possible inputs from inland sources through the coastal sounds. Atmospheric deposition is another possible source of these materials.

3. Acknowledgments

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Appendices

Appendix A. Typical Method Detection Limits (MDL) for the sediment and tissue contaminant samples.

Analyte	Sediment MDL	Tissue MDL
Metals (µg/g dry wt., unless otherwise indicated)		
Aluminum (%)	0.0001	0.364
Arsenic	0.0030	0.006
Cadmium	0.0005	0.001
Chromium	0.0268	0.047
Copper	0.0115	0.020
Iron (%)	0.0001	0.929
Lead	0.0021	0.004
Manganese	0.0124	0.100
Mercury	0.0189	0.019
Nickel	0.0021	0.004
Selenium	0.0330	0.010
Silver	0.0200	0.035
Tin	0.0045	0.008
Zinc	0.2955	0.517
PAHs (ng/g dry wt.)		
Acenaphthene	42.2	42.2
Acenaphthylene	11	11
Anthracene	22.6	22.6
Benzo(a)anthracene	49.8	49.8
Benzo(a)pyrene	63.2	63.2
Benzo(b)fluoranthene	38.6	38.6
Benzo(e)pyrene	29.2	29.2
Benzo(g,h,i)perylene	39.6	39.6
Benzo(j+k)fluoranthene	33	33
Biphenyl	41.2	41.2
Chrysene+Triphenylene	14.2	14.2
Dibenz(a,h+a,c)anthracene	10.6	10.6
2,6 Dimethylnaphthalene	24.4	24.4
Fluoranthene	27.8	27.8
Fluorene	18.2	18.2
Indeno(1,2,3-cd)pyrene	61.4	61.4
1-Methylnaphthalene	26.2	26.2
2-Methylnaphthalene	36	36
1-Methylphenanthrene	24.2	24.2
Naphthalene	65.6	65.6
Perylene	36.8	36.8
Phenanthrene	21.8	21.8
Pyrene	20.4	20.4
1,6,7 Trimethylnaphthalene	12.2	12.2
PCBs (ng/g dry wt.)		
PCB 8	0.13	0.13
PCB 18	0.15	0.15
PCB 29	0.10	0.10
PCB 28	0.20	0.20
PCB 50	0.10	0.10
PCB 52	0.07	0.07
PCB 104	0.10	0.10
PCB 44	0.05	0.05
PCB 66	0.06	0.06
PCB 101	0.10	0.10
PCB 87	0.10	0.10
PCB 77	1.50	1.50
PCB 118	0.07	0.07
PCB 188	0.10	0.10
PCB 153	0.10	0.10
PCB 105	0.12	0.12
PCB 138	0.18	0.18
PCB 126	0.13	0.13
PCB 187	0.05	0.05
PCB 128	0.07	0.07
PCB 201	0.10	0.10
PCB 180	0.11	0.11
PCB 170	0.16	0.16
PCB 195	0.12	0.12
PCB 206	0.10	0.10
PCB 209	0.10	0.10
PCB 154	0.10	0.10
Pesticides (ng/g dry wt.)		
Aldrin	0.01	0.01
Alpha-chlordane	0.08	0.08
Chlorpyrifos	0.10	0.10
Dieldrin	0.18	0.18
Endosulfan ether	0.10	0.10
Endosulfan I	0.10	0.10
Endosulfan II	0.10	0.10
Endosulfan lactone	0.10	0.10
Endosulfan sulfate	0.10	0.10
Heptachlor	0.04	0.04
Heptachlor epoxide	0.10	0.10
Hexachlorobenzene	0.06	0.06
Lindane[d]	0.08	0.08
Mirex	0.16	0.16
Trans-nonachlor	0.09	0.09
2,4'-DDD	0.06	0.06
4,4'-DDD	0.24	0.24
2,4'-DDE	0.06	0.06
4,4'-DDE	0.03	0.03
2,4'-DDT	0.14	0.14
4,4'-DDT	0.02	0.02

Appendix B. Summary of station location, water quality and sediment data for stations sampled within GRNMS in April 2000. Modification of table from Barry A. Vittor & Associates, Inc. (2001).

Station	Latitude	Longitude	Depth (m)	Bottom Water				TOC (mg/g)	% Gravel	% Sand	% Silt/Clay	USACE Description
				Temp (˚C)	Salinity (ppt)	D.O. (mg/L)	pH					
1	31.4199˚	80.9099˚	17.5	17.8	33.6	8.4	7.9	1.1	0.00	99.87	0.00	Sand
2	31.4160˚	80.8876˚	19.3	17.9	33.7	8.2	7.9	1.1	3.36	96.14	0.00	Sand
3	31.4192˚	80.8670˚	19.4	17.9	33.8	8.3	7.9	1.5	0.00	99.45	0.00	Sand
4	31.4107˚	80.8586˚	20.8	17.9	33.8	8.2	7.9	1.2	0.00	99.74	0.00	Sand
5	31.4154˚	80.8381˚	21.1	17.6	34.1	8.2	7.9	0.8	0.00	99.82	0.00	Sand
6	31.4061˚	80.9123˚	18.0	17.9	34.0	7.9	7.9	1.3	0.00	99.79	0.00	Sand
7	31.3968˚	80.8965˚	16.0	17.9	34.0	7.9	7.9	1.3	0.00	99.53	0.00	Sand
8	31.3948˚	80.8686˚	14.5	18.2	33.9	8.1	7.6	4.9	9.41	90.04	0.00	Sand
9	31.3949˚	80.8619˚	19.7	18.2	33.9	8.2	7.9	1.2	0.00	99.56	0.00	Sand
10	31.4058˚	80.8328˚	19.0	17.7	34.1	8.2	7.9	1.4	4.39	94.73	0.00	Sand
11	31.3912˚	80.9058˚	16.7	17.9	34.0	7.9	8.0	1.9	0.00	99.69	0.00	Sand
12	31.3898˚	80.8962˚	17.0	17.9	34.1	7.9	8.0	4.2	0.00	99.37	0.00	Sand
13	31.3869˚	80.8748˚	18.7	17.9	34.2	7.9	8.0	1.8	0.00	99.46	0.00	Sand
14	31.3829˚	80.8595˚	19.3	18.0	33.7	7.7	8.0	1.4	3.57	96.19	0.00	Sand
15	31.3834˚	80.8402˚	18.1	18.0	33.9	7.7	8.0	1.5	0.00	99.76	0.00	Sand
16	31.3768˚	80.9184˚	15.2	18.0	34.1	8.0	8.0	1.3	3.55	96.18	0.00	Sand
17	31.3671˚	80.8978˚	19.6	17.9	34.3	7.9	8.0	19.7	15.53	83.79	0.00	Sand
18	31.3830˚	80.8784˚	17.0	17.9	34.3	7.9	8.0	2.7	6.25	93.38	0.00	Sand
19	31.3628˚	80.8537˚	19.0	18.0	33.9	7.6	8.1	1.6	0.00	99.29	0.00	Sand
20	31.3735˚	80.8413˚	19.2	18.0	33.9	7.7	8.0	1.3	2.23	97.51	0.00	Sand

Appendix C. Summary of contaminant concentrations and sediment quality guideline (SQG) exceedances at GRNMS sites in April 2000 (n = 20 sites). Concentrations of analytes below method detection limits are reported as < MDL; in such cases, a value of zero was used for data computations (e.g., averaging across all stations).

Analyte	Average	Range		SQG		# Sites > SQG	
		Min	Max	ERL/TEL[a]	ERM/PEL[a]	ERL/TEL	ERM/PEL
Metals (µg/g dry wt., unless otherwise indicated)							
Aluminum (%)	0.04	0.01	0.07	--	--	--	--
Arsenic	0.98	0.12	3.15	8.2	70	0	0
Cadmium	0.03	< MDL	0.23	1.2	9.6	0	0
Chromium	0.02	< MDL	0.26	81	370	0	0
Copper	5.30	< MDL	103.00	34	270	1	0
Iron (%)	0.16	0.04	0.39	--	--	--	--
Lead	0.52	0.01	2.19	46.7	218	0	0
Manganese	17.15	7.36	35.60	--	--	--	--
Mercury	< MDL	< MDL	< MDL	0.15	0.71	0	0
Nickel	2.38	0.91	5.00	20.9	51.6	0	0
Selenium	0.03	< MDL	0.21	--	--	--	--
Silver	0.05	< MDL	0.93	1.0	3.7	0	0
Tin	< MDL	< MDL	< MDL	--	--	--	--
Zinc	9.43	< MDL	40.80	150	410	0	0
PAHs (ng/g dry wt.)							
Acenaphthene	< MDL	< MDL	< MDL	16	500	0	0
Acenaphthylene	< MDL	< MDL	< MDL	44	640	0	0
Anthracene	< MDL	< MDL	< MDL	85.3	1100	0	0
Benzo(a)anthracene	< MDL	< MDL	< MDL	261	1600	0	0
Benzo(a)pyrene	< MDL	< MDL	< MDL	430	1600	0	0
Benzo(b)fluoranthene	< MDL	< MDL	< MDL	--	--	--	--
Benzo(e)pyrene	< MDL	< MDL	< MDL	--	--	--	--

Appendix C (Continued).

Analyte	Average	Range		SQG		# Sites > SQG	
		Min	Max	ERL/TEL[a]	ERM/PEL[a]	ERL/TEL	ERM/PEL
Benzo(g,h,i)perylene	< MDL	< MDL	< MDL	--	--	--	--
Benzo(j+k)fluoranthene	< MDL	< MDL	< MDL	--	--	--	--
Biphenyl	< MDL	< MDL	< MDL	--	--	--	--
Chrysene+Triphenylene	< MDL	< MDL	< MDL	--	--	--	--
Dibenz(a,h+a,c)anthracene	< MDL	< MDL	< MDL	63.4	260	0	0
Dibenzothiophene	< MDL	< MDL	< MDL	--	--	--	--
2,6 Dimethylnaphthalene	< MDL	< MDL	< MDL	--	--	--	--
Fluoranthene	< MDL	< MDL	< MDL	600	5100	0	0
Fluorene	< MDL	< MDL	< MDL	19	540	0	0
Indeno(1,2,3-cd)pyrene	< MDL	< MDL	< MDL	--	--	--	--
1-Methylnaphthalene	2.08	< MDL	9.12	--	--	--	--
2-Methylnaphthalene	4.05	< MDL	16.30	70	670	0	0
1-Methylphenanthrene	< MDL	< MDL	< MDL	--	--	--	--
Naphthalene	8.11	< MDL	32.50	160	2100	0	0
Perylene	< MDL	< MDL	< MDL	240	1500	0	0
Phenanthrene	< MDL	< MDL	< MDL	--	--	--	--
Pyrene	< MDL	< MDL	< MDL	665	2600	0	0
1,6,7 Trimethylnaphthalene	< MDL	< MDL	< MDL	--	--	--	--
Total PAHs[b]	14.24	< MDL	57.82	4022	44792	0	0
PCBs (ng/g dry wt.)							
Total PCBs	1.12	0.12	1.77	22.7	180	0	0
Pesticides (ng/g dry wt.)							
Aldrin	< MDL	< MDL	< MDL	--	--	--	--
Alpha-chlordane	< MDL	< MDL	< MDL	--	--	--	--
Chlorpyrifos	0.02	< MDL	0.13	--	--	--	--
Dieldrin	< MDL	< MDL	< MDL	15.2[c]	0.715[c]	0	0
Endosulfan ether	< MDL	< MDL	< MDL	--	--	--	--

Appendix C (Continued).

Analyte	Average	Range		SQG		# Sites > SQG	
		Min	Max	ERL/TEL[a]	ERM/PEL[a]	ERL/TEL	ERM/PEL
Endosulfan I	< MDL	< MDL	< MDL	--	--	--	--
Endosulfan II	< MDL	< MDL	< MDL	--	--	--	--
Endosulfan lactone	< MDL	< MDL	< MDL	--	--	--	--
Endosulfan sulfate	< MDL	< MDL	< MDL	--	--	--	--
Heptachlor	< MDL	< MDL	< MDL	--	--	--	--
Heptachlor epoxide	< MDL	< MDL	< MDL	--	--	--	--
Hexachlorobenzene	< MDL	< MDL	< MDL	--	--	--	--
Lindane[d]	< MDL	< MDL	< MDL	0.32 [c]	0.99 [c]	0	0
Mirex	< MDL	< MDL	< MDL	--	--	--	--
Trans-nonachlor	< MDL	< MDL	< MDL	--	--	--	--
DDD[e]	< MDL	< MDL	< MDL	--	--	--	--
DDE[e]	< MDL	< MDL	< MDL	--	--	--	--
DDT[e]	0.00	< MDL	0.09	--	--	--	--
Total DDT[f]	0.00	< MDL	0.09	1.58 [c]	46.1 [c]	0	0

[a] SQGs are the ERL and ERM values from Long et al. (1995), unless noted otherwise.
[b] Without Perylene.
[c] SQGs are the TEL and PEL values from MacDonald et al. (1996).
[d] Gamma BHC.
[e] DDD = 2′4′-DDD + 4′4′-DDD; DDE = 2′4′-DDE + 4′4′-DDE; DDT = 2′4′-DDT + 4′4′-DDT.
[f] Total DDTs = 2′4′-DDD + 4′4′-DDD + 2′4′-DDE + 4′4′-DDE + 2′4′-DDT + 4′4′-DDT.

Appendix D. Summary of contaminant concentration ranges observed in edible tissues of black sea bass and arc shells at GRNMS sites in April 2000. All concentrations are reported on a dry-weight basis. FDA guideline values are included (where available) and have been converted to dry weight by multiplying published wet-weight values by a factor of 5. Concentrations of analytes below method detection limits are reported as < MDL; in such cases, a value of zero was used for data computations (e.g., averaging across all stations).

Analyte	Black Sea Bass (n=10)			Arc Shell (n=9)			FDA Guideline	# Sites > Guideline
	Average	Range		Average	Range			
Metals (µg/g dry wt.)								
Aluminum	48.72	40.40	61.80	89.86	59.30	182.00	--	--
Arsenic	58.52	6.76	89.30	63.57	< MDL	93.00	215.0[a]	0
Cadmium	< MDL	< MDL	< MDL	4.01	< MDL	7.79	15.0[a]	0
Chromium	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	55.0[a]	0
Copper	0.41	0.19	1.17	5.96	< MDL	8.02	--	--
Iron	1.90	< MDL	16.90	147.89	60.70	294.00	--	--
Lead	0.30	< MDL	2.64	0.40	< MDL	2.92	3.0[a]	0
Manganese	0.13	< MDL	0.55	17.11	< MDL	26.70	--	--
Mercury	0.23	0.11	0.59	0.05	< MDL	0.12	5.0[b]	0
Nickel	2.20	< MDL	21.70	1.37	< MDL	3.80	350.0[a]	0
Selenium	2.83	2.43	3.35	6.79	5.13	10.30	--	--
Silver	0.05	< MDL	0.18	3.24	1.60	4.66	--	--
Tin	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--
Zinc	24.33	< MDL	47.30	114.11	< MDL	211.00	--	--
PAHs (ng/g dry wt.)								
Acenaphthene	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--
Acenaphthylene	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--
Anthracene	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--
Benzo(a)anthracene	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--
Benzo(a)pyrene	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--
Benzo(e)pyrene	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--
Benzo(b)fluoranthene	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--
Benzo(g,h,i)perylene	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--
Benzo(j+k)fluoranthene	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--
Biphenyl	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--
Chrysene+Triphenylene	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--

Appendix D. (continued)

Analyte	Black Sea Bass (n=10)			Arc Shell (n=9)			FDA Guideline	# Sites > Guideline
	Average	Range		Average	Range			
Dibenz(a,h+a,c)anthracene	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--
Dibenzothiophene	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--
2,6 Dimethylnaphthalene	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--
Fluoranthene	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--
Fluorene	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--
Indeno(1,2,3-cd)pyrene	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--
1-Methylnaphthalene	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--
2-Methylnaphthalene	2.62	< MDL	26.20	16.07	< MDL	48.50	--	--
1-Methylphenanthrene	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--
Naphthalene	< MDL	< MDL	< MDL	6.87	< MDL	61.80	--	--
Perylene	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--
Phenanthrene	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--
Pyrene	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--
1,6,7 Trimethylnaphthalene	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--
Total PAHs w/o Perylene	2.62	< MDL	26.20	22.93	< MDL	110.30	--	--
PCBs (ng/g dry wt.)								
Total PCBs	10.52	5.23	19.90	2.11	1.25	2.68	10000.0[c]	0
Pesticides (ng/g dry wt.)								
Aldrin	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	1500.0[b]	0
Alpha-chlordane	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--
Chlorpyrifos	0.10	< MDL	0.60	0.14	< MDL	0.84	--	--
DDD[d]	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	25000.0[b]	0
DDE[d]	0.73	0.35	1.93	0.26	< MDL	0.41	25000.0[b]	0
DDT[d]	0.09	< MDL	0.26	< MDL	< MDL	< MDL	25000.0[b]	0
Total DDTs[e]	0.82	0.35	2.19	0.26	< MDL	0.41	25000.0[b]	0
Dieldrin	0.10	< MDL	0.41	0.04	< MDL	0.35	1500.0[b]	0
Endosulfan ether	0.02	< MDL	0.24	< MDL	< MDL	< MDL	--	--
Endosulfan I	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--
Endosulfan II	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--
Endosulfan lactone	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--
Endosulfan sulfate	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--
Heptachlor	0.03	< MDL	0.10	< MDL	< MDL	< MDL	1500.0[b]	0

Appendix D. (continued)

Analyte	Black Sea Bass (n=10)			Arc Shell (n=9)			FDA Guideline	# Sites > Guideline
	Average	Range		Average	Range			
Heptachlor epoxide	0.27	< MDL	2.69	2.87	2.18	3.59	1500.0 [b]	0
Hexachlorobenzene	0.07	< MDL	0.13	0.01	< MDL	0.06	--	--
Lindane	0.79	0.15	1.34	0.94	0.73	1.13	--	--
Mirex	0.22	< MDL	0.86	< MDL	< MDL	< MDL	500.0 [b]	0
Trans-nonachlor	0.17	< MDL	0.39	< MDL	< MDL	< MDL	--	--
Lipids (% dry wt.)	1.53	0.85	3.00	6.20	4.73	7.18	--	--

[a] FDA Level of Concern for contaminants in shellfish. Value is lowest of multiple values reported by FDA for humans of various ages consuming either crustaceans or molluscs at the 90th percentile consumption rate. Values (converted from wet weight to dry weight) are from: FDA 1993a for As, FDA 1993b for CD, FDA 1993c for CR, FDA 1993d for Pb, FDA 1993e for Ni.
[b] FDA Action Level for poisonous or deleterious substances in human food and animal feed (level for edible portion of fish is given). FDA 1994.
[c] FDA Tolerance for unavoidable residues of PCBs in fish and shellfish. FDA 1984.
[d] DDD = 2′4′-DDD + 4′4′-DDD; DDE = 2′4′-DDE + 4′4′-DDE; DDT = 2′4′-DDT + 4′4′-DDT.
[e] Total DDTs = 2′4′-DDD + 4′4′-DDD + 2′4′-DDE + 4′4′-DDE + 2′4′-DDT + 4′4′-DDT.

Appendix E. Station location, water quality, and sediment data for stations sampled in April-May 2001. Modification of table from Barry A. Vittor & Associates, Inc. (2002).

Station	Distance from Land (km)	Location	Latitude	Longitude	Near – Bottom Water					TOC (mg/g)	% Sand	% Silt/Clay	Median phi	USACE Description
					Depth (m)	Temp. (˚C)	Salinity (ppt)	D.O. (mg/l)	pH					
1	31.5	GRNMS	31.4194	-80.9127	15.5	19.2	35.6	7.2	8.0	0.5	99.47	0.53	0.587	sand
10	38.9	GRNMS	31.4055	-80.8320	18.0	19.2	36.0	7.2	8.0	0.8	98.93	1.07	0.979	sand
11	31.5	GRNMS	31.3913	-80.9056	12.0	19.3	35.9	7.2	7.9	1.0	99.16	0.88	1.546	sand
14	35.2	GRNMS	31.3832	-80.8588	18.1	19.3	36.1	7.2	8.0	1.0	99.75	0.25	1.047	sand
17	31.5	GRNMS	31.3677	-80.8973	17.0	19.3	35.9	7.2	7.9	1.7	99.72	0.28	0.331	sand
21	1.9	Transect I	31.5316	-81.1574	10.1	21.6	33.7	7.1	7.9	2.8	77.87	22.14	0.957	silty sand
22	9.3	Transect I	31.5252	-81.0765	7.0	20.4	34.5	7.3	7.9	2.0	99.57	0.43	2.495	sand
23	16.7	Transect I	31.5162	-81.0001	13.5	19.4	34.9	7.3	7.9	2.5	99.98	0.02	1.672	sand
24	24.1	Transect I	31.5100	-80.9218	15.0	19.1	35.1	7.2	7.9	1.6	99.19	0.81	1.271	sand
25	31.5	Transect I	31.5036	-80.8433	14.8	18.2	35.5	7.3	7.9	1.9	99.71	0.29	1.118	sand
26	1.9	Transect II	31.3700	-81.2622	10.1	21.5	33.2	6.9	7.9	5.7	71.06	28.94	2.236	silty sand
27	9.3	Transect II	31.3754	-81.1642	9.3	20.4	34.6	7.3	7.9	4.2	98.00	2.00	2.483	sand
28	16.7	Transect II	31.3815	-81.0632	12.2	19.8	34.6	7.3	7.8	3.1	97.50	2.50	1.593	sand
29	24.1	Transect II	31.3867	-80.9719	14.2	19.5	35.5	7.2	7.9	3.0	99.44	0.56	0.940	sand
12	31.5	Transect II/ GRNMS	31.3894	-80.8963	15.7	19.3	35.9	7.2	7.9	1.7	99.74	0.26	1.276	sand
30	1.9	Transect III	31.3168	-81.2653	4.1	22.4	22.8	7.9	7.9	5.4	78.49	21.52	2.674	silty sand
31	9.3	Transect III	31.3072	-81.1910	8.5	20.5	34.3	7.2	7.9	5.6	98.61	1.39	1.752	sand
32	16.7	Transect III	31.2986	-81.1028	10.4	20.2	34.8	7.3	7.9	3.9	99.61	0.39	1.338	sand
33	24.1	Transect III	31.2901	-81.0210	12.2	20.0	35.3	7.3	8.0	5.1	99.85	0.15	0.510	sand
34	31.5	Transect III	31.2822	-80.9398	15.3	19.6	35.8	7.3	8.0	5.1	99.58	0.42	0.786	sand

Appendix F. Summary of contaminant concentrations and sediment quality guideline (SQG) exceedances at GRNMS sites in April-May 2001 (n = 20 sites). Concentrations of analytes below method detection limits are reported as < MDL; in such cases, a value of zero was used for data computations (e.g., averaging across all stations).

Analyte	Average	Range		SQG		#sites > SQG	
		Min	Max	ERL/TEL[a]	ERM/PEL[a]	ERL/TEL	ERM/PEL
Metals *(ug/g dry wt., unless otherwise indicated)*							
Aluminum (%)	0.26	0.02	1.50	--	--	--	--
Arsenic	2.48	0.95	4.62	8.2	70	0	0
Cadmium	0.38	0.10	1.25	1.2	9.6	1	0
Chromium	9.47	3.66	21.10	81	370	0	0
Copper	2.10	1.29	3.43	34	270	0	0
Iron (%)	0.23	0.03	0.91	--	--	--	--
Lead	1.54	0.56	3.25	46.7	218	0	0
Manganese	53.78	10.20	143.00	--	--	--	--
Mercury	0.002	<MDL	0.015	0.15	0.71	0	0
Nickel	2.72	1.04	6.67	20.9	51.6	0	0
Selenium	0.03	<MDL	0.47	--	--	--	--
Silver	<MDL	<MDL	<MDL	1	3.7	0	0
Tin	<MDL	<MDL	<MDL	--	--	--	--
Zinc	23.93	18.20	36.90	150	410	0	0
PAHs *(ng/g dry wt.)*							
Acenaphthene	<MDL	<MDL	<MDL	16	500	0	0
Acenaphthylene	<MDL	<MDL	<MDL	44	640	0	0
Anthracene	<MDL	<MDL	<MDL	85.3	1100	0	0
Benzo(a)anthracene	<MDL	<MDL	<MDL	261	1600	0	0
Benzo(a)pyrene	<MDL	<MDL	<MDL	430	1600	0	0
Benzo(b)fluoranthene	<MDL	<MDL	<MDL	--	--	--	--
Benzo(e)pyrene	<MDL	<MDL	<MDL	--	--	--	--
Benzo(g,h,i)perylene	<MDL	<MDL	<MDL	--	--	--	--
Benzo(j+k)fluoranthene	<MDL	<MDL	<MDL	--	--	--	--
Biphenyl	2.28	<MDL	9.04	--	--	--	--
Chrysene+Triphenylene	<MDL	<MDL	<MDL	--	--	--	--
Dibenz(a,h+a,c)anthracene	<MDL	<MDL	<MDL	63.4	260	0	0
Dibenzothiophene	<MDL	<MDL	<MDL	--	--	--	--
2,6 Dimethylnaphthalene	<MDL	<MDL	<MDL	--	--	--	--
Fluoranthene	<MDL	<MDL	<MDL	600	5100	0	0
Fluorene	<MDL	<MDL	<MDL	19	540	0	0
Indeno(1,2,3-cd)pyrene	<MDL	<MDL	<MDL	--	--	--	--
1-Methylnaphthalene	<MDL	<MDL	<MDL	--	--	--	--
2-Methylnaphthalene	<MDL	<MDL	<MDL	70	670	0	0
1-Methylphenanthrene	<MDL	<MDL	<MDL	--	--	--	--
Naphthalene	<MDL	<MDL	<MDL	160	2100	0	0
Perylene	0.43	<MDL	8.58	--	--	--	--
Phenanthrene	<MDL	<MDL	<MDL	240	1500	0	0
Pyrene	<MDL	<MDL	<MDL	665	2600	0	0
1,6,7 Trimethylnaphthalene	<MDL	<MDL	<MDL	--	--	--	--
Total PAHs[b]	2.71	<MDL	17.62	4022	44792	0	0

Appendix F. Continued.

Analyte	Average	Range		SQG		#sites > SQG	
		Min	Max	ERL/TEL[a]	ERM/PEL[a]	ERL/TEL	ERM/PEL
PCBs *(ng/g dry wt.)*							
Total PCBs	<MDL	<MDL	<MDL	22.7	180	0	0
Pesticides *(ng/g dry wt.)*							
Aldrin	<MDL	<MDL	<MDL	--	--	--	--
Alpha-chlordane	<MDL	<MDL	<MDL	--	--	--	--
Chlorpyrifos	<MDL	<MDL	<MDL	--	--	--	--
Dieldrin	<MDL	<MDL	<MDL	0.715[c]	4.3[c]	0	0
Endosulfan ether	<MDL	<MDL	<MDL	--	--	--	--
Endosulfan I	<MDL	<MDL	<MDL	--	--	--	--
Endosulfan II	<MDL	<MDL	<MDL	--	--	--	--
Endosulfan lactone	<MDL	<MDL	<MDL	--	--	--	--
Endosulfan sulfate	<MDL	<MDL	<MDL	--	--	--	--
Heptachlor	<MDL	<MDL	<MDL	--	--	--	--
Heptachlor epoxide	<MDL	<MDL	<MDL	--	--	--	--
Hexachlorobenzene	<MDL	<MDL	<MDL	--	--	--	--
Lindane[d]	<MDL	<MDL	<MDL	0.32[c]	0.99[c]	0	0
Mirex	<MDL	<MDL	<MDL	--	--	--	--
Trans-nonachlor	<MDL	<MDL	<MDL	--	--	--	--
DDD[e]	<MDL	<MDL	<MDL	--	--	--	--
DDE[e]	<MDL	<MDL	<MDL	--	--	--	--
DDT[e]	<MDL	<MDL	<MDL	--	--	--	--
Total DDT[f]	<MDL	<MDL	<MDL	3.89[c]	51.7[c]	0	0

[a] SQGs are the ERL and ERM values from Long et al. (1995), unless noted otherwise.
[b] Without Perylene.
[c] SQGs are the TEL and PEL values from MacDonald et al. (1996).
[d] Gamma BHC.
[e] DDD = 2′4′-DDD + 4′4′-DDD; DDE = 2′4′-DDE + 4′4′-DDE; DDT = 2′4′-DDT + 4′4′-DDT.
[f] Total DDTs = 2′4′-DDD + 4′4′-DDD + 2′4′-DDE + 4′4′-DDE + 2′4′-DDT + 4′4′-DDT.

Appendix G. Mean abundance (per m^2) by cluster group for taxa representing ≥ 1% of total abundance at a station. Cluster groups are based on spring 2001 data. Group A stations are closest to mouths of coastal sounds; Group C stations are furthest offshore; Group B stations are in-between.

Taxa	Mean Abundance (no./m2)		
	A	B	C
Acanthohaustorius intermedius	0	0	31
Acanthohaustorius millsi	0	0	98
Acteocina candei	0	0	13
Acteocina recta	0	0	31
Actiniaria	200	6	98
Americhelidium americanum	8	81	27
Ampelisca bicarinata	0	0	23
Apocorophium simile	208	0	0
Apoprionospio dayi	0	169	0
Armandia maculata	17	6	179
Aspidosiphon spp.	0	6	169
Aspidosiphon albus	0	0	23
Aspidosiphon muelleri	0	0	112
Asteroidea	25	450	6
Axiothella mucosa	8	0	162
Batea catharinensis	358	50	0
Bathyporeia spp.	0	0	8
Bathyporeia parkeri	0	19	31
Bathyporeia quoddyensis	0	75	29
Bhawania goodei	0	0	315
Bhawania heteroseta	8	0	150
Bivalvia	33	125	123
Brachiopoda	0	19	29
Branchiostoma spp.	8	6	1083
Brania wellfleetensis	0	0	94
Caecum cooperi	0	0	48
Caecum floridanum	0	0	48
Caecum johnsoni	33	19	1735
Caecum pulchellum	0	19	96
Caprella sp. C	0	0	117
Cirratulidae	192	31	62
Cirrophorus ilvana	0	0	31
Crassinella dupliniana	0	0	717
Crassinella lunulata	0	0	246
Cyclaspis sp. O	0	81	13

Taxa	Mean Abundance (no./m2)		
	A	B	C
Dentatisyllis carolinae	0	0	150
Diplodonta	0	44	81
Echinoidea	0	19	242
Enchytraeidae	8	0	119
Ensis minor	8	13	42
Erichthonius brasiliensis	50	19	525
Eudevenopus honduranus	0	250	83
Eumida sanguinea	1125	181	10
Exogone lourei	0	0	162
Exogone rolani	1158	6	310
Fabricinuda trilobata	0	0	1421
Filogranula sp. A	0	0	296
Galathowenia oculata	0	106	52
Gastropoda	0	6	31
Glycera spp.	17	0	44
Glycera robusta	17	6	50
Glyceridae	8	31	52
Goniada littorea	0	194	4
Goniadides carolinae	0	0	346
Grubeosyllis rugulosa	0	0	110
Haustoriidae	0	0	40
Heteropodarke lyonsi	0	0	58
Laevicardium laevigatum	0	0	56
Lepidonotus sp. A	275	6	0
Lucina spp.	0	63	21
Lucina radians	0	19	0
Lucinidae	0	0	29
Magelona sp. H	0	200	0
Maldanidae	100	0	94
Mediomastus spp.	15875	4513	10
Mediomastus ambiseta	2092	900	0
Mediomastus californiensis	1017	81	29
Metatiron tropakis	0	31	6
Metharpinia floridana	0	100	154
Mitrella lunata	175	0	4

Appendix G. Continued.

Taxa	Mean Abundance (no./m2)		
	A	B	C
Nephtys spp.	33	94	127
Nephtys picta	8	119	67
Nucula aegeenis	792	0	2
Onuphidae	17	44	323
Ophelina acuminata	0	69	0
Ophiuroidea	42	19	110
Owenia fusiformis	0	1600	33
Oxyurostylis smithi	300	1594	173
Paracaprella pusilla	267	0	0
Paracerceis caudata	0	0	40
Paraonis fulgens	0	0	37
Paraonis pygoenigmatica	0	0	81
Parapionosyllis longicirrata	67	0	587
Pholoe minuta	0	0	154
Phoronis (LPIL)	0	113	0
Photis pugnator	33	6	290
Phoxocephalidae	0	331	138
Pionosyllis gesae	0	0	154
Plakosyllis quadrioculata	0	0	87
Podocerus kleidus	0	0	62
Polycirrus spp.	0	0	81
Polycirrus eximius	9958	25	33
Prionospio spp.	8	19	138
Protodorvillea kefersteini	0	0	1175
Protohaustorius wigleyi	0	306	52
Rhepoxynius hudsoni	0	150	60
Rhynchocoela	375	288	412
Rictaxis punctostriatus	8	150	265
Rissoina sp. C	0	0	17
Semele nuculoides	0	56	188
Serpulidae	0	0	50
Sipuncula	33	131	360
Sphaerosyllis aciculata	8	0	90
Sphaerosyllis piriferopsis	0	0	577
Sphaerosyllis taylori	0	0	50
Spio spp.	0	0	31
Spio pettiboneae	8	6	496
Spionidae	33	31	62
Spiophanes bombyx	1825	1856	975
Streblospio benedicti	2833	0	0
Strigilla mirabilis	0	119	2
Synelmis ewingi	0	25	21
Tanaissus psammophilus	0	0	196
Tectonatica pusilla	17	156	23
Tellina spp.	67	500	85
Tellinidae	0	44	102
Tharyx acutus	5650	163	0
Tubificidae	1458	13	1129
Unciola serrata	292	13	0

Appendix H. Characteristics of benthic macroinfauna (> 0.5 mm) at stations sampled in spring 2001. Three replicate grabs (0.04 m^2 each) were taken at each station.

Station	Location	Mean No. of Taxa (per grab)	Total No. of Taxa[a]	Mean Abundance (No./m2)	H' Diversity[b]
1	GRNMS	41.3	77	3091.7	5.21
10	GRNMS	71.3	125	9841.7	5.62
11	GRNMS	42.0	79	3125.0	5.53
14	GRNMS	51.7	91	4375.0	5.38
17	GRNMS	70.3	122	15758.3	4.39
21	Transect I	38.7	71	9033.3	3.91
22	Transect I	17.7	31	1941.7	3.59
23	Transect I	35.0	81	3050.0	5.31
24	Transect I	37.7	79	3583.3	5.21
25	Transect I	37.0	65	3033.3	4.86
26	Transect II	54.7	91	28591.7	3.50
27	Transect II	34.3	69	5500.0	4.21
28	Transect II	17.0	39	2025.0	4.14
29	Transect II	43.0	86	2758.3	5.50
12	Transect II/ GRNMS	89.0	170	16883.3	5.55
30	Transect III	29.7	56	13950.0	2.44
31	Transect III	56.3	93	13975.0	3.91
32	Transect III	56.3	107	4725.0	5.39
33	Transect III	57.0	94	17491.7	4.26
34	Transect III	67.0	118	8250.0	5.39

a. Grand total from all 20 stations = 474 taxa.
b. Calculated using base 2 logarithms.