Benthic Macroinfaunal Communities and Levels of Chemical Contaminants in Sediments and Biota at Gray's Reef National Marine Sanctuary and Nearby Shelf Waters off the coast of Georgia

(FY02 Annual Report for the 2000-2002 Site Characterization Study of Gray's Reef National Marine Sanctuary)

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Submitted by

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1. Introduction

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. 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. 2) can serve as reliable indicators of potential environmental disturbances to the seafloor.

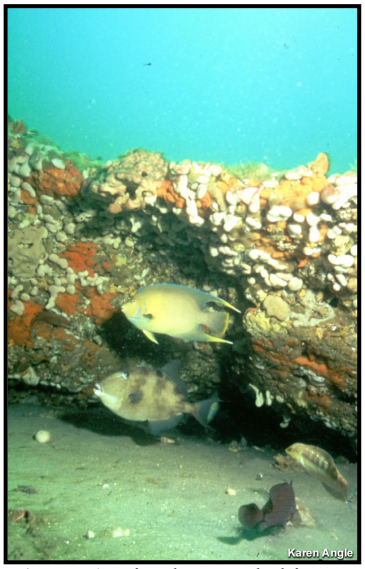

Figure 1. Live bottom habitat at GRNMS. Photo courtesy of Karen Angle.

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.

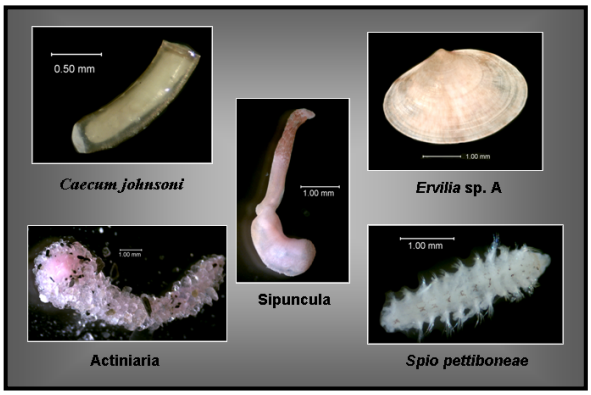

Figure 2. Examples of dominant macroinfaunal species at GRNMS.

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 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). A description of existing conditions within the sanctuary, based on results of the spring 2000 survey, was provided in an earlier report (Hyland et al. 2001). In the following report, we present new results of the spring 2001 survey and use data from both years to examine overall

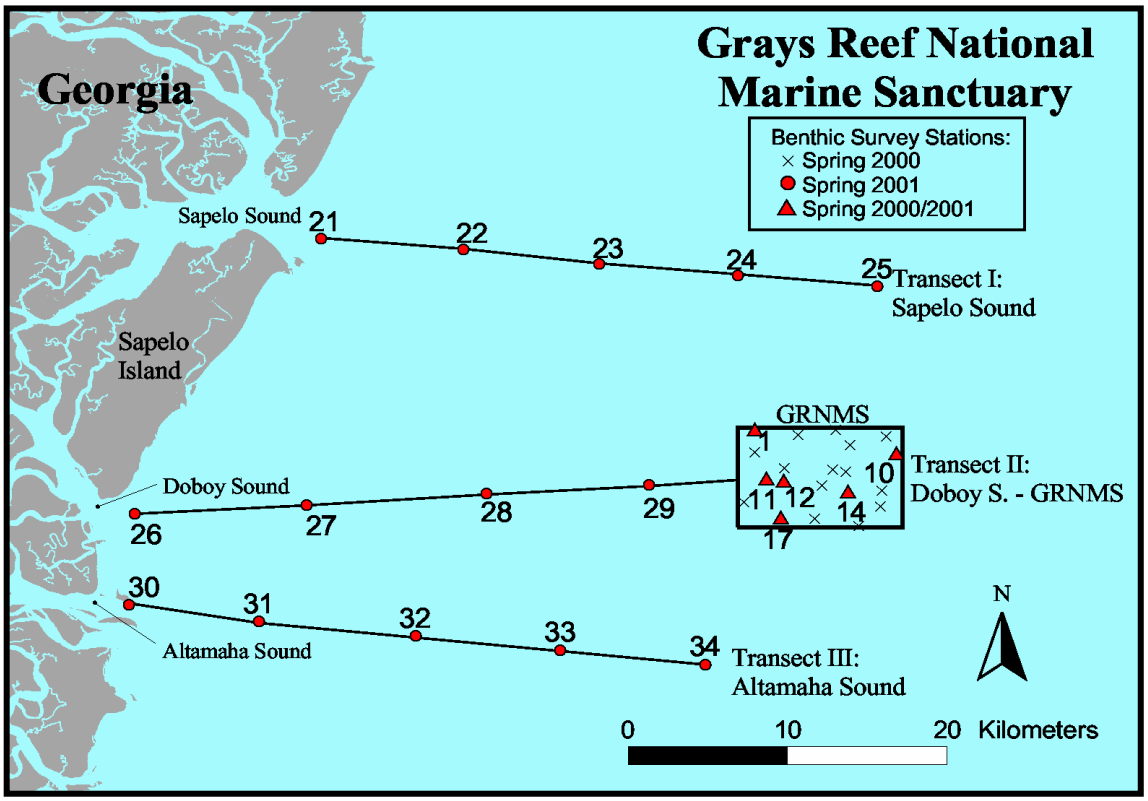

Figure 3. Sampling design. Station numbers are shown for sites sampled in spring 2001. Station numbers for sites sampled in spring 2000 are identified in Figure 4.

spatial and temporal patterns in biological and chemical variables within the sanctuary and surrounding inner-shelf environment. 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).

Objectives of the first year of sampling (spring 2000) were: (1) to 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) to 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. 3 and 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

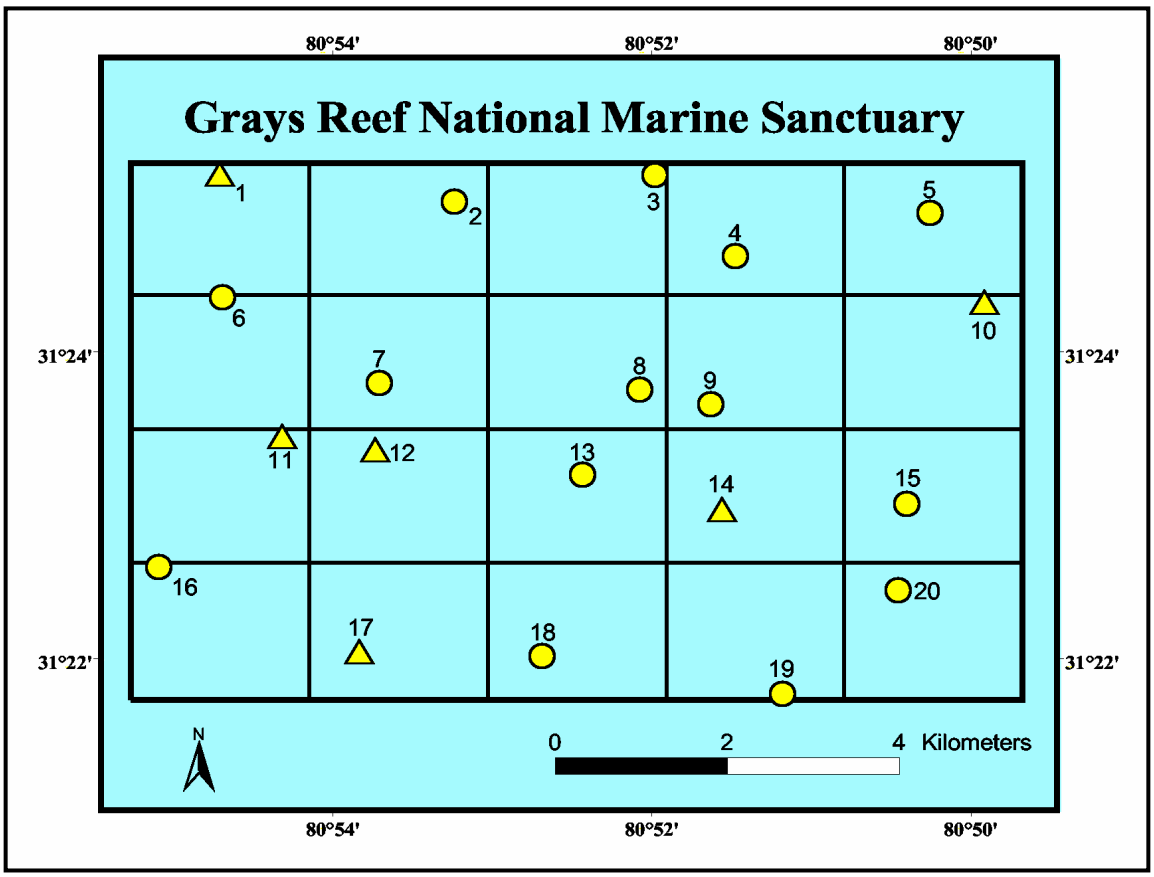

Figure 4. Station locations within GRNMS. Stations were randomly selected within each of the 20 cells (2.9 km^2 each). All stations were sampled in spring 2000 and ones with triangles were resampled in spring 2001.

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. 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. 3). Sampling was conducted at a total of 20 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 macroinfauna (> 0.5 mm), and aesthetic quality (presence of anthropogenic debris, visible oil, noxious sediment odor, and water clarity based on secchi depths). During the first year, samples of benthic and demersal fauna (the turkey wing arc shell *Arca zebra* and black sea bass *Centropristis striata*) also were collected in selected areas (by divers for the molluscs and by fish traps for the fish) and analyzed for concentrations of chemical contaminants in tissues.

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. 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 multiple 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). An ion-trap mass spectrometer equipped with a gas chromatograph (GC/MS-IT) was used for analysis of PAHs.

Sediment quality guidelines (SQG) for each corresponding chemical were used (where available) to help in interpreting the biological significance of the observed contaminant levels (Appendix B). 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 (see appendix B); in some cases, however (e.g., where updated ERL and ERM values were not available), the alternative TEL and PEL values were used.

3. Results and Discussion

3.1 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 (Hyland et al. 2001). 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. 5) 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.

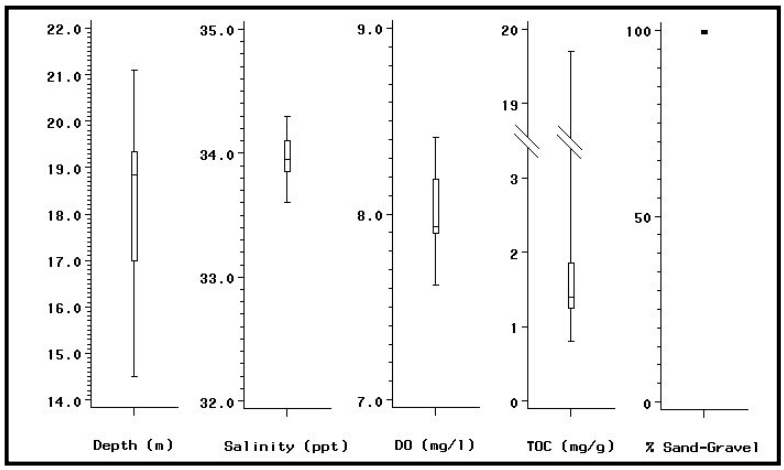

Figure 5. Key habitat characteristics at GRNMS in April 2000 (n = 20 sites). Boxes are interquartile ranges, horizontal lines within boxes are medians and wisker endpoints are high/low extremes. Note in the last plot that values of % sand-gravel fall within a very narrow range of 99-100%.

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. 6). A slightly elevated concentration of Cu (103 µg/g), between corresponding lower- and upper-threshold ER-L and ER-M sediment quality guideline values (34 µg/g and 270 µg/g, respectively), 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).

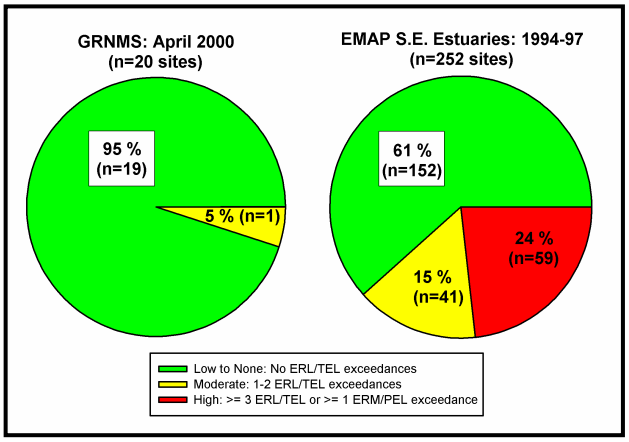

Figure 6. Comparison of sediment contamination (% area) at GRNMS during the present study (April 2000) vs. southeastern estuaries sampled during EMAP (unpublished data from J. Hyland, NOAA).

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 10 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.

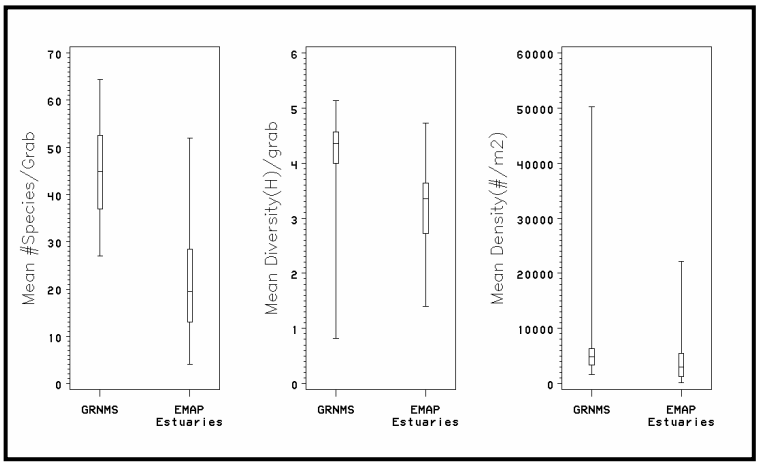

Figure 7. Comparison of benthic species richness, diversity and abundance at GRNMS sites (n = 20) vs. estuarine sites of similar salinity (> 30 ppt) in EMAP Carolinian Province (n = 38). Boxes are interquartile ranges, horizontal lines within boxes are medians and wisker endpoints are high/low extremes. Base 2 logarithms were used to calculate H′.

The vast stretches of sands throughout the sanctuary support highly diverse macroinfaunal assemblages. 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 (Fig. 7).

3.2 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 A. 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 %).

Cross-shelf variations were evident in some of these variables, notably depth, temperature, salinity, % silt/clay, and TOC (Table 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. 8) 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.

Table 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. 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)

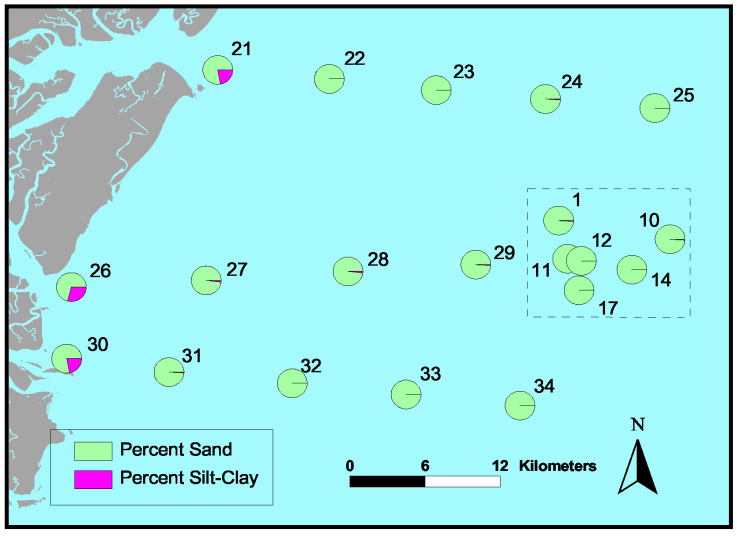

Figure 8. Cross-shelf patterns in % silt-clay vs. sand content of sediment, based on spring 2001 data.

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.

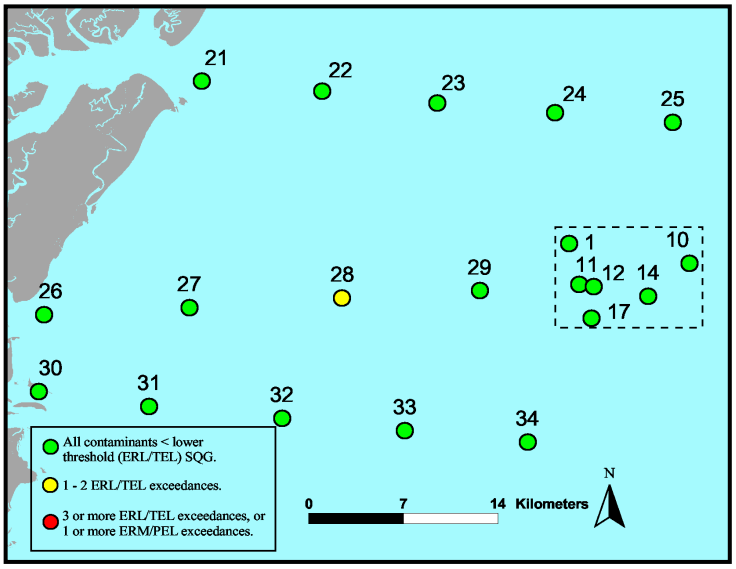

Figure 9. Summary of chemical contaminants concentrations in sediments relative to sediment quality guidelines (SQG). Data are from spring 2001.

3.3 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. 9). 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. 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).

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 B). 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. 10, 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).

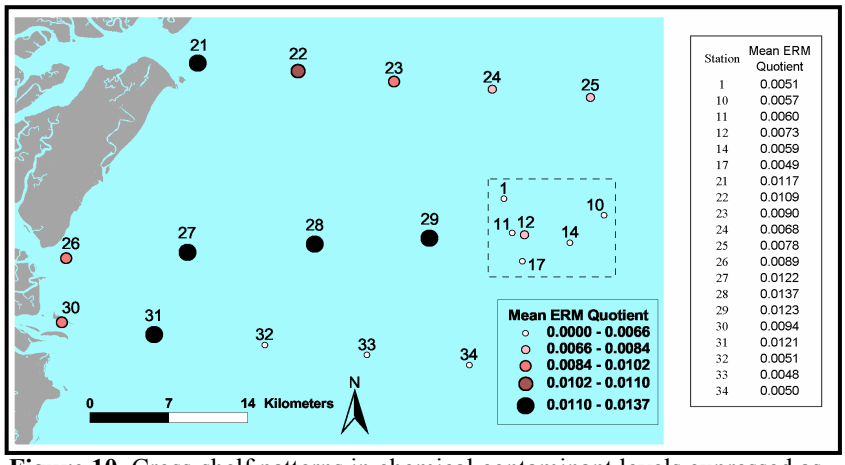

Figure 10. Cross-shelf patterns in chemical contaminant levels expressed as mean ERM quotients. Data are from spring 2001.

So 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 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).

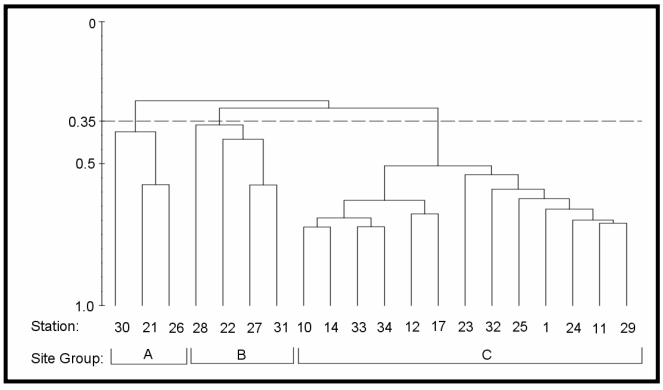

Figure 11. Dendogram resulting from clustering of stations sampled in spring 2001, using group-average sorting and Bray-Curtis similarity. Samples within each station are combined over all 3 replicates. A similarity level of 0.35 (dotted line) was used to define the major site groups.

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 (which are the most applicable data known to us for comparison). The highest value was 0.0137, well within the reported low-risk range. Also, all PCBs, all pesticides, most PAHs (except biphenyl, and perylene), and some metals (silver and tin) were below analytical detection limits across all stations sampled in spring 2001, thus further suggesting that potential environmental contaminants in this region of the continental shelf are currently at fairly low levels reflecting general background conditions.

3.4 Spatial Patterns in Benthic Fauna

3.4.1 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. 11) 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

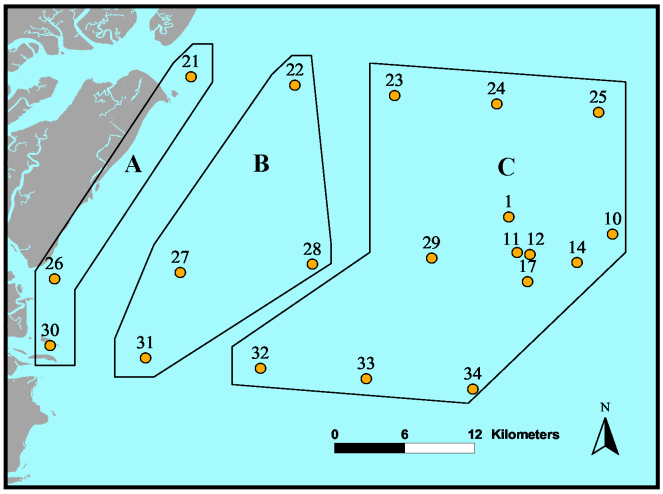

Figure 12. Cross-shelf distribution of site groups resulting from cluster analysis of benthic macroinfaunal data collected in spring 2001.

Table 2. Summary of abiotic environmental variables by site group. 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

the distribution of these site groups (Fig. 12). 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.

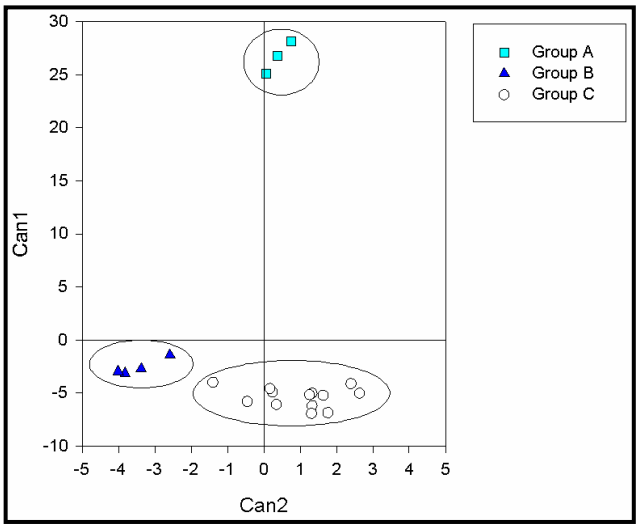

Figure 13. Separation of site groups on the first and second canonical function derived from canonical discriminant analysis performed on abiotic environmental variables. Can 1 = first canonical function (98% of variability). Can 2 = second canonical function (2% of variability).

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 Viscoto 1978, Hyland et al. 1991). Abiotic variables that displayed significant mean differences across the three groups (at $\alpha = 0.05$ or near) were included in the analysis (all except DO and pH, Table 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. 13). TSCs (Table 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

Table 3. Total structure coefficients (TSC) of abiotic environmental variables on the first two canonical functions associated with variations among site groups. 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

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

Site Group	Taxa	Dominant Fauna			Mean Abundance (m^{-2})[b]	Mean No. taxa/grab	Mean H'/grab[c]	Total No. Taxa
		Ind. m^{-2}	Cumulative %	Frequency[a]				
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.

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 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).

The canonical plot (Fig. 13) reveals that the second canonical function explains most of the variation between Groups B and C. TSCs for CAN 2 indicate that the strongest correlations on this function are with mean ERM quotients, median sediment particle size

(phi), and depth (Table 3). Though mean ERM quotients vary distinctly across the three site groups (Table 2), the values are not in the range associated with a high risk of adverse effects on benthic fauna (as discussed above) and thus are not likely to be the cause of the observed faunal patterns. Thus, the remaining two abiotic variables associated with the separation of Group B from C on CAN 2 (Fig. 13) and that could be contributing to the corresponding biological differences between these two groups are depth and median sediment particle size (phi). A comparison of Group B and C stations (Table 2) reveals a transition from medium to coarse sands (i.e., higher to lower phi values) and to 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.

Table 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, 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 4, Appendix C). 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 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 C.

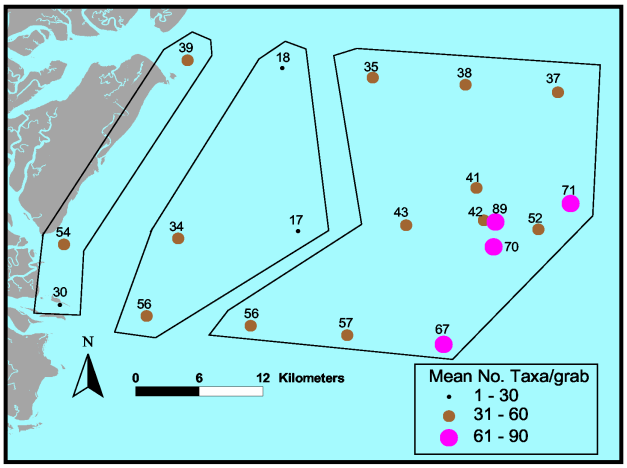

Figure 14. Comparison of species richness among the three site groups (Spring 2001). Values are the mean no. taxa/grab at each station.

There also were notable cross-shelf differences in species diversity (Table 4, Fig. 14). Stations furthest offshore in Group C, especially those in GRNMS, had the greatest numbers of species (Fig. 14). 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 D.

3.4.2 Finer-Scale Spatial Variability at Sites Within the Sanctuary

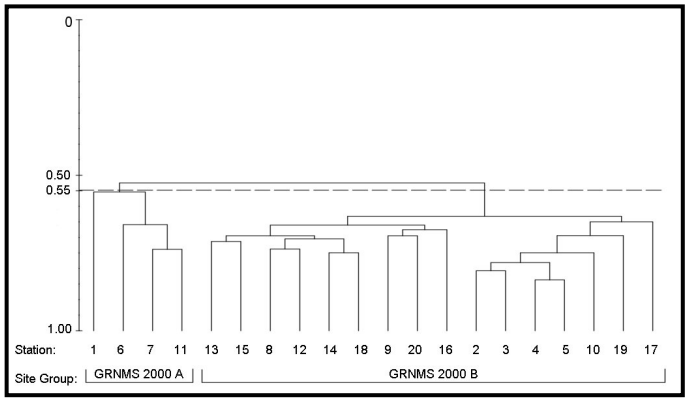

Figure 15. Dendogram resulting from clustering of stations sampled within GRNMS in spring 2000, using group-average sorting and Bray-Curtis similarity. Samples within each station are combined over all 3 replicates. A similarity level of 0.55 (dotted line) was used to define the two major site groups.

Stations within the GRNMS boundaries all fell within Site Group C (Fig. 11) 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. 15). 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.

The sanctuary Site Group A consists of Stations 1, 6, 7, and 11 co-located in the northwest sector of the sanctuary (Fig. 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. 16). Otherwise, most of the dominant species are common to both sanctuary site groups.

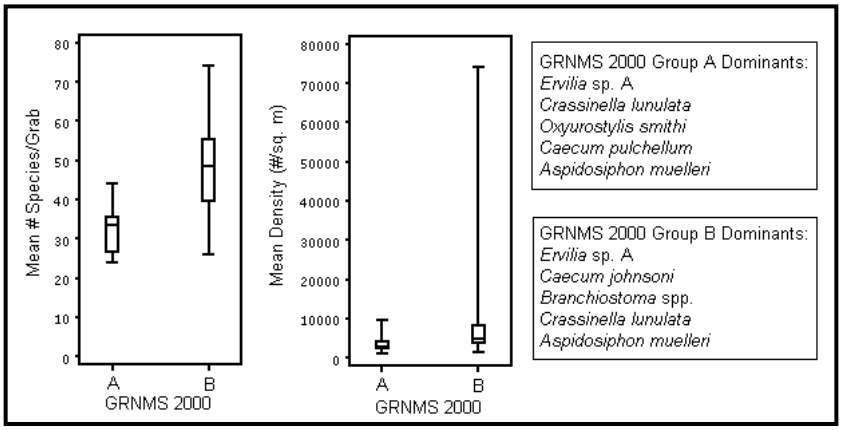

Figure 16. Comparison of benthic species richness (# species/grab), abundances (#/m^2), and dominants at GRNMS 2000 site groups A vs. B. For the # species and abundances: boxes are interquartile ranges, horizontal lines within boxes are medians, and wisker endpoints are high/low extremes.

3.5 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. 17) 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

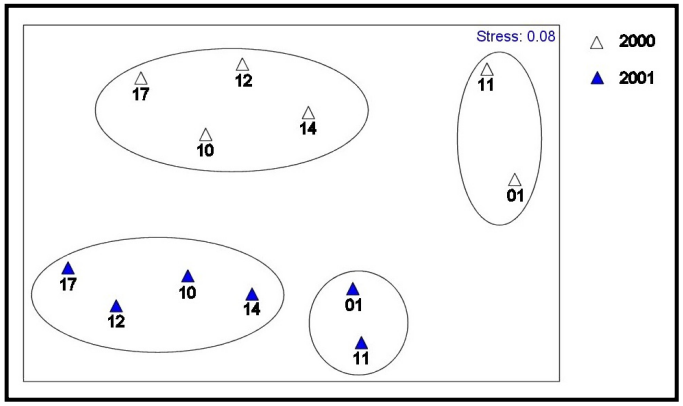

Figure 17. Results of non-metric, two-dimensional MDS ordination on the Bray-Curtis similarity matrix of double square-root transformed species abundance data from six GRNMS stations sampled in spring 2000 and 2001. Sampling points similar at Bray-Curtis similarity of ≥ 0.6 are encircled. Note that the stress value of 0.08 suggests that a higher-dimensional ordination is not necessary to improve interpretations (Clarke and Gorley 2001).

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. 17) is at a fairly high level of similarity 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 discussed above, along with corresponding samples collected at these same sites in 2001, thus indicating 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.

4. 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 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, thus 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 in-between, 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 for 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.

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Appendix A

Appendix A. 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	USAE 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 B

Appendix B. 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	ER-L/TEL[a]	ER-M/PEL[a]	ER-L/TEL	ER-M/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 B. Continued.

Analyte	Average	Range		SQG		#sites > SQG	
		Min	Max	ER-L/TEL[a]	ER-M/PEL[a]	ER-L/TEL	ER-M/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] SQG value is from Long et al. (1995), unless noted otherwise.
[b] Without Perylene.
[c] SQG is 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 C

Appendix C. 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

Taxa	Mean Abundance (no./m2)		
	A	B	C
Crassinella lunulata	0	0	246
Cyclaspis sp. O	0	81	13
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

Appendix C. Continued.

Taxa	Mean Abundance (no./m2)		
	A	B	C
Mediomastus californiensis	1017	81	29
Metatiron tropakis	0	31	6
Metharpinia floridana	0	100	154
Mitrella lunata	175	0	4
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

Taxa	Mean Abundance (no./m2)		
	A	B	C
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 D

Appendix D. 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.