Survey of Benthic Macroinfauna and Levels of Chemical Contaminants in Sediments and Biota at Gray's Reef National Marine Sanctuary

(FY01 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 study is being conducted to assess the condition of benthic macroinfauna and contaminant levels in sediments and biota of the Gray's Reef National Marine Sanctuary (GRNMS) and nearby inner-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 surround the rocky-reef structures and characterize much of the inner-shelf area in the general vicinity of Gray's Reef. The present study is providing a first-ever quantitative baseline on levels of potential environmental contaminants and condition of the infaunal organisms living within these substrates. 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. Such information is of direct importance to the development of management plans for the Sanctuary, as a contribution to our understanding of the overall ecology of this system and as a baseline for monitoring any future changes due to either natural or anthropogenic influences. The present benthic survey is a component of a larger, ongoing coordinated site characterization of the sanctuary by the GRNMS Office and three NCCOS Centers (CCMA, CCFHR, and CCEHBR).

Figure 1. Live bottom habitat at Grays Reef National Marine Sanctuary. Photo courtesy of Karen Angle.

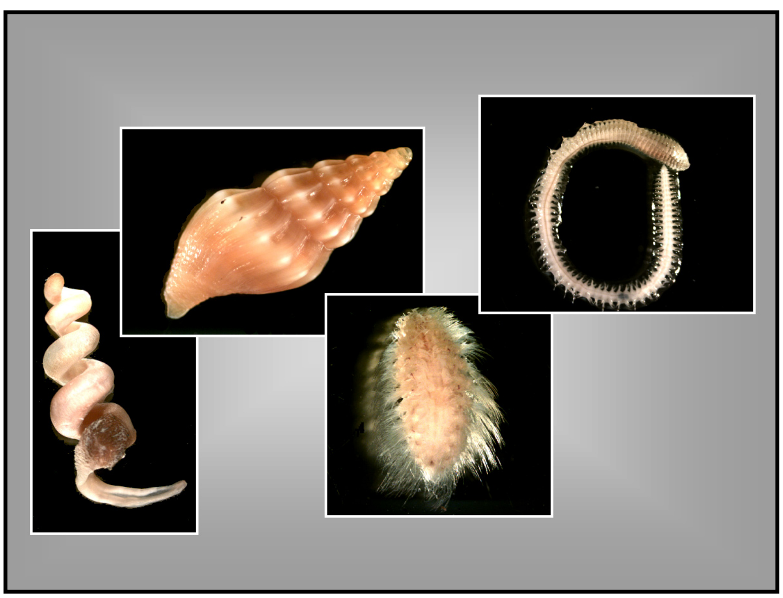

Figure 2. Examples of benthic macroinfaunal at GRNMS.

2. Objectives and Scope

The study is 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). Cruise reports are available upon request (email <jeff.hyland@noaa.gov>).

Objectives of the first year of sampling were to: (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. 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 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.

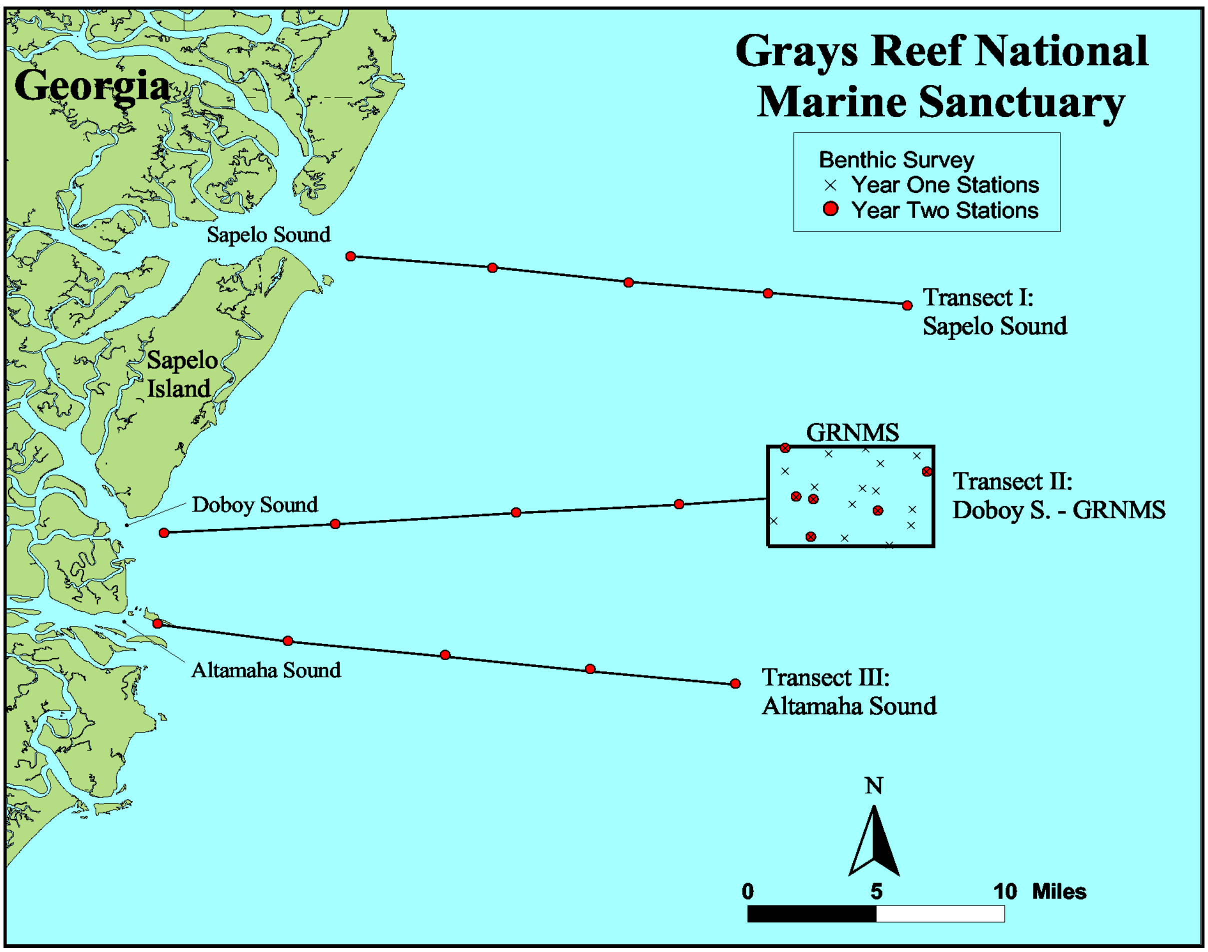

Figure 3. Sampling design for benthic survey.

At each of the 20 Year-1 stations, samples were collected for characterization of general habitat conditions (depth, temperature, salinity, pH, DO, TOC, 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). Target benthic species (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 bass) and analyzed for contaminant levels in tissues.

The second year of sampling 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 station in Grays Reef serving as the seaward end of the middle transect, and an additional five stations within the sanctuary boundaries. The three cross-shelf transects provide the means to examine spatial patterns in benthic communities and sediment contaminant levels in relation to both natural factors (e.g., depth) and potential anthropogenic factors (e.g., proximity to land-based sources of contaminants). An important goal here is 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. Near-field versus far-field comparisons at similar offshore depths as the sanctuary (focusing on outermost stations along the three transects) are being used as well to test for additional patterns in biological resources in relation to reef proximity (including, for example, potential biological interactions such as predation effects from foraging by reef species). Sampling also was conducted at six of the previous Year-1 stations within the sanctuary boundaries, including the outermost station along the middle transect, to provide a basis for examining potential between-year temporal variability.

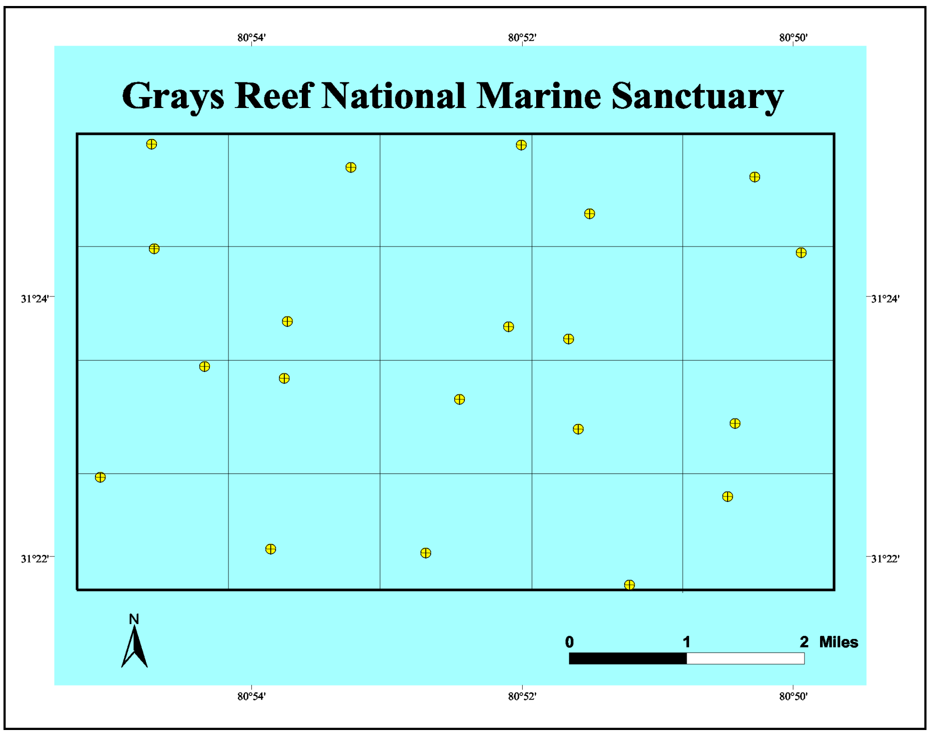

Figure 4. Site locations within GRNMS. The random sampling framework allows unbiased statistical estimation of the percentage of area with degraded vs. non-degraded condition relative to various measured environmental variables. Each cell = 2.9 km^2.

At each of the 20 Year-2 stations, as before, samples were collected for characterization of diversity and abundance of benthic fauna, concentration of sediment contaminants, general habitat parameters (depth, temperature, salinity, TOC, grain size), and aesthetic quality (presence of debris, oil slicks, noxious sediment odor, and water clarity based on secchi depths). Bottom trawls for demersal fishes and macroinvertebrates and bongo nets for ichthyoplankton also were taken opportunistically at each of the cross-shelf transect sites as part of a companion survey conducted by the NOAA CCFHR. The two synoptic data sets will be compared to examine predator-prey relationships and other potential benthic-pelagic interactions.

3. Current Progress and Preliminary Findings

All field sampling for this project has been completed. Samples from the recent Year-2 survey (April 29-May 5, 2001) are still being processed and resulting data will be presented in an overall final report in fall 2002. The following description of conditions within the sanctuary is based on data from the analysis of Year-1 samples collected April 3-7, 2000.

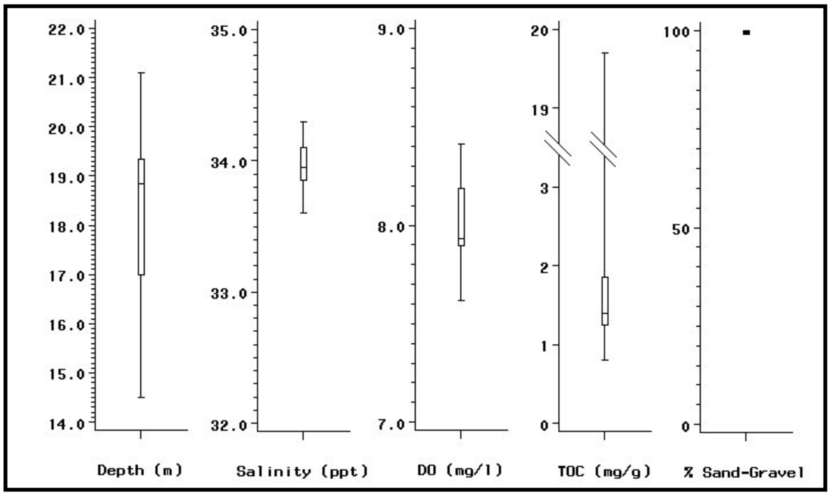

Figure 5. Key habitat characteristics at GRNMS in April 2000 (n = 20 sites). Boxes are interquartile ranges, horizontal lines within boxes are medians and wisker endpoints are high/low extremes. Note in the last plot that values of % sand-gravel fall within a very narrow range of 99-100%.

Key habitat characteristics within the sanctuary (Fig. 5) consist 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 A.

Appendix B 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. Two types of SQGs are included: (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 midrange concentrations of chemicals above which adverse effects are more likely to occur. Concentration-to-SQG comparisons were based on the lower ERL and upper ERM values for most chemicals (see appendix); in some cases, however (e.g., where updated ERL and ERM values were not available), the alternative TEL and PEL values were used.

Sediments were fairly clean with respect to presence of chemical contaminants. Ninety-five % of the area of the sanctuary had sediments with all measured contaminants below corresponding, lower-threshold ERL/TEL guidelines (Fig. 6). 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 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. 6). 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.

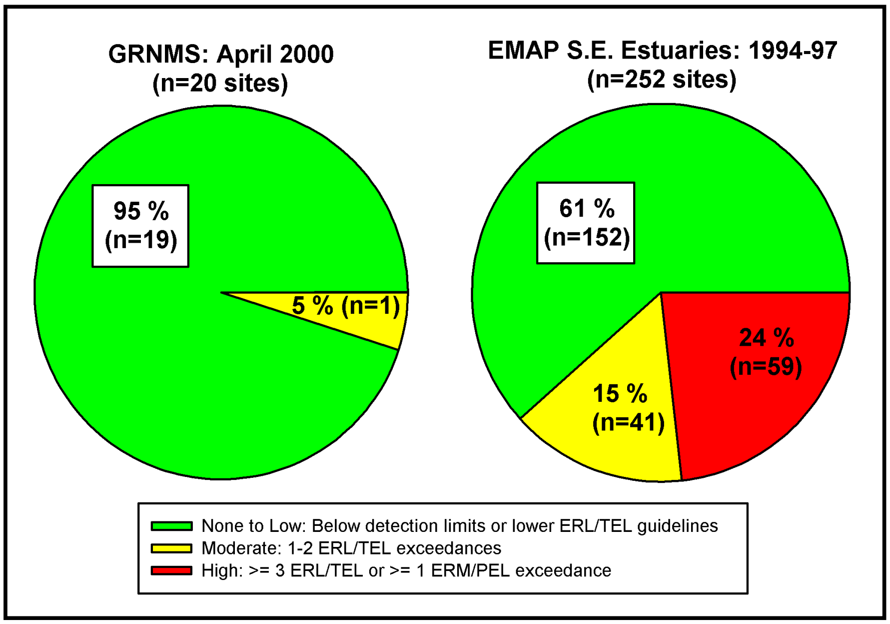

Figure 6. Comparison of sediment contamination (% area) at GRNMS during the present study vs. southeastern estuaries sampled during EMAP (unpublished data from senior author).

The generally low levels 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 B). 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 C 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

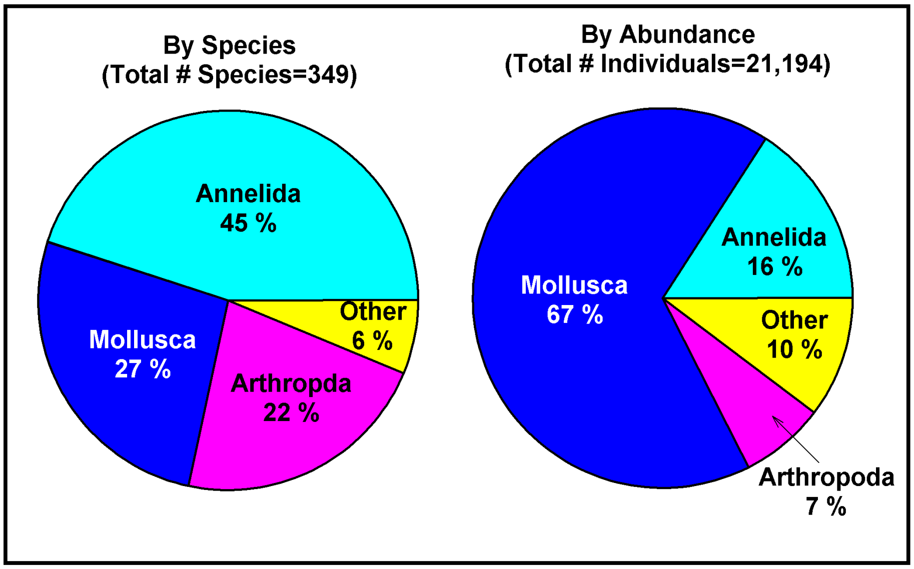

Figure 7. Relative composition of major taxonomic groups of macroinfauna at GRNMS. Data based on 3 replicate grabs (0.04 m^2) at each of 20 stations.

Arca zebra. 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, either by air or underwater cross-shelf transport.

The benthic infauna inhabiting sandy substrates within the sanctuary are comprised mostly of polychaete worms, molluscs, and arthropods (Fig. 7). These three major taxonomic groups

Table 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*.

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 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.

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 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.

The dominant species in Table 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

Table 2. Characteristics of benthic macroinfaunal (> 0.5mm) at stations sampled in GRNMS, April 2000. Three replicate grabs ($0.04 m^2$ 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.

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 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 2). The total number of species found at each station (based on three grabs per station) 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. 8, 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.

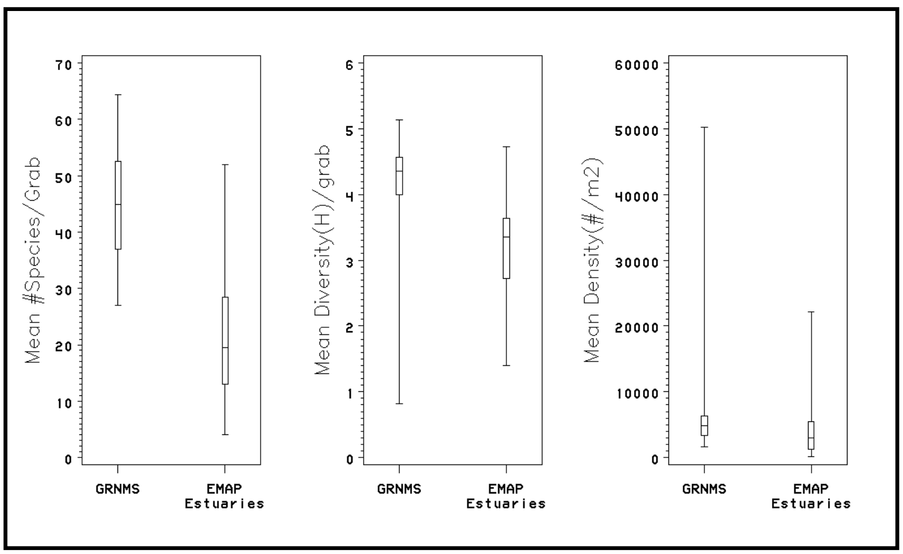

Figure 8. Comparison of benthic species richness, diversity and abundance at GRNMS sites (n = 20) vs. estuarine sites of similar salinity (> 30 ppt) in EMAP Carolinian Province (n = 38). Boxes are interquartile ranges, horizontal lines within boxes are medians and wisker endpoints are high/low extremes. Base 2 logarithms were used to calculate H′.

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 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.

4. Implications for Coastal Management

Data from the initial April 2000 survey suggest that contaminants in sediments and biota generally are at background reference 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 9 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. 6. 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 10^{th} 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. 9, 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 9 shows that in the Year 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. 9) provides a basis for deciding whether or not to apply specific mitigation measures. Selection of specific management action criteria should be based on a consensus of agreement among cognizant 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.

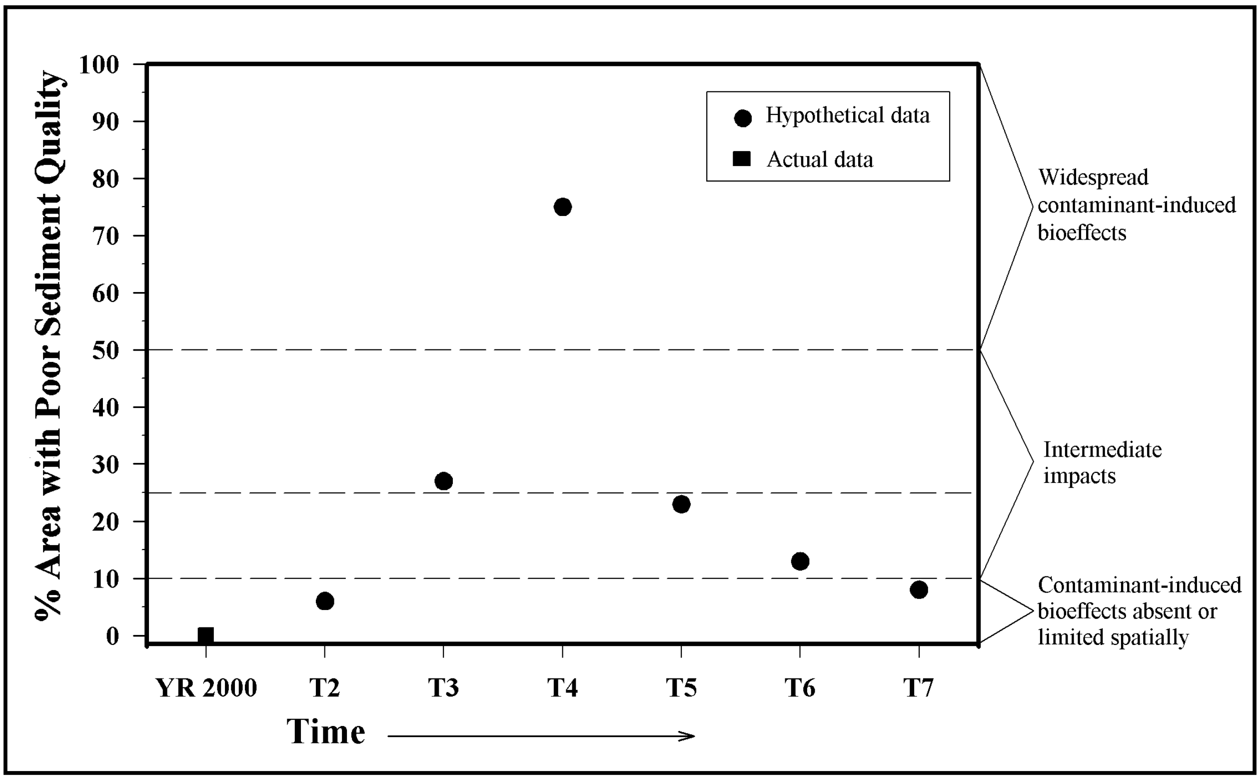

Figure 9. Examples of how probability-based sampling data could be used to monitor potential changes in sediment quality with time at GRNMS. Y-axis is % area exhibiting poor sediment quality, as indicated by combined evidence of low benthic species richness (e.g., < 30 species/grab) accompanied by high sediment contamination (e.g., 1 ERM or ≥ 3 ERL exceedances).

5. Conclusions

- In general, chemical contaminants in sediments throughout the sanctuary are at background levels, below probable bioeffect guidelines. A low-level spike of copper, between corresponding lower- and upper-threshold ER-L and ER-M 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 are 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 support a highly diverse and abundant infaunal community, a finding which should change a frequent misconception that these "featureless" substrates surrounding live-bottom rocky outcrops are "biological desserts." 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 present, zero % of the sanctuary area shows 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.

6. Acknowledgments

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

Appendix B (Continued).

Analyte	Average	Range		SQG		# Sites > SQG	
		Min	Max	ER-L/TEL[a]	ER-M/PEL[b]	ER-L/TEL	ER-M/PEL
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	< 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[c]	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	--	--	--	--

Appendix B. (contiued)

Analyte	Average	Range		SQG		# Sites > SQG	
		Min	Max	ER-L/TEL[a]	ER-M/PEL[b]	ER-L/TEL	ER-M/PEL
Alpha-chlordane	< MDL	< MDL	< MDL	--	--	--	--
Chlorpyrifos	0.02	< MDL	0.13	--	--	--	--
Dieldrin	< MDL	< MDL	< MDL	15.2[d]	0.715[e]	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[f]	< MDL	< MDL	< MDL	0.32[d]	0.99[e]	0	0
Mirex	< MDL	< MDL	< MDL	--	--	--	--
Trans-nonachlor	< MDL	< MDL	< MDL	--	--	--	--
DDD[g]	< MDL	< MDL	< MDL	--	--	--	--
DDE[g]	< MDL	< MDL	< MDL	--	--	--	--
DDT[g]	0.00	< MDL	0.09	--	--	--	--
Total DDT[h]	0.00	< MDL	0.09	1.58[d]	46.1[e]	0	0

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

Appendix C. 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	--	--

Appendix C. (continued)

Analyte	Black Sea Bass (n=10)			Arc Shell (n=9)			FDA Guideline	# Sites > Guideline
	Average	Range		Average	Range			
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	--	--
Dibenz(a,h+a,c)anthracene	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--
Dibenzothiophene	< MDL	< MDL	< MDL	0.15	< MDL	1.32	--	--
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	--	--

Appendix C. (continued)

Analyte	Black Sea Bass (n=10)			Arc Shell (n=9)			FDA Guideline	# Sites > Guideline
	Average	Range		Average	Range			
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
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 contaminant in shellfish. Value is lowest of multiple values reported by FDA for humans of various ages consuming either crustaceans or mollusks 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. Classification used by FDA 1994.

[e] Total DDTs = 2′4′-DDD + 4′4′-DDD + 2′4′-DDE + 4′4′-DDE + 2′4′-DDT + 4′4′-DDT.