Annual Report – FY2001

Support of monitoring activities and site characterization at Gray's Reef National Marine Sanctuary

26 October 2001

Submitted to:

Reed Bohne
Sanctuary Manager, Gray's Reef National Marine Sanctuary
NOAA, National Ocean Service
Office of Ocean and Coastal Resource Management
Marine Sanctuaries Division

Submitted by:

Jon Hare, Harvey Walsh and Katey Marancik
Center for Coastal Fisheries and Habitat Research
Beaufort, North Carolina

Cheryl Woodley and John Bemiss
Center for Coastal Environmental Health
and Biomolecular Research
Charleston, South Carolina

Jeff Hyland
Center for Coastal Monitoring & Assessment
Charleston, South Carolina

NOAA ~ National Ocean Service ~ National Centers for Coastal Ocean Science

Introduction

In April 2000, the National Centers for Coastal Ocean Science (NCCOS) initiated a new project in cooperation with the National Marine Sanctuary Program: Support of Monitoring Activities and Site Characterization at Gray's Reef National Marine Sanctuary (GRNMS). Three NCCOS Centers are involved in the work: the Center for Coastal Fisheries and Habitat Research (CCFHR), the Center for Coastal Environmental Health and Biomolecular Research (CCEHBR) and the Center for Coastal Monitoring and Assessment (CCMA).

Nine objectives were defined in the original, three year proposal. A status of work related to each objective is provided below. An opportunity to conduct coral biomarker research arose and as a result, status of work related to a 10th objective is included.

1. Participate in Gray's Reef National Marine Sanctuary fish monitoring activities including work in adjacent deeper areas

2. Analyze fish monitoring data for changes in abundance and species composition over time (1995-1999)

Staff of CCFHR have been involved in fish monitoring efforts since initial baseline work in the 1980's. CCFHR staff continued to participate in the semi-annual fish monitoring efforts in the 1990's. Two fish monitoring surveys were attempted by NCCOS during FY01: October 2000 from the NOAA Ship FERREL and June 2001 from the RV CAPE FEAR. Dive operations were not possible on either occasion owing to poor weather. GRNMS staff, however, were able to conduct visual censuses from a smaller vessel during the summer. The data have not yet been transferred to CCFHR. Since 1995, 11 visual censuses have been completed (Table 1).

Table 1. Summary of adult censuses completed by year and by season at GRNMS.

Year	Spring	Summer	Fall
1995			X
1996	X	X	X
1997	X		X
1998		X	
1999	X	X	
2000	X		
2001		X	

The opportunity to work in deeper water on adult fish was not realized in FY01. However, sampling for juvenile fish was conducted in the Savannah Scarp region in cooperation with GRNMS during a Sustainable Seas Expedition cruise (see below).

Analysis of the visual census data shows both seasonal and interannual changes in the reef fish community at GRNMS. Analysis of the data is part of Dave Score's Masters project at Georgia Southern University and CCFHR has been providing technical assistance. Multi-dimensional scaling analysis (MDS), a non-parametric multivariate technique, has been used to examine the reef fish community at GRNMS based on the visual census data. Different seasons were sampled in different years (Table 1) and thus, each year with multiple samplings was analyzed separately. MDS demonstrates clear differences in the reef fish community among seasons (Figure 1). Comparing species richness among seasons within years shows that species diversity is lower in the spring compared to the summer and fall (Figure 2), which explains in part the differences between seasons detected in the MDS

analysis. However, there is no difference in species diversity between summer and fall. Therefore, the community differences identified in the MDS analysis is due to other factors (abundance of fish, species replacement).

Owing to the differences observed among seasons, interannual differences in the fish community need to be compared within seasons (Table 1). MDS analysis illustrated differences among years for all three seasons (Figure 3).

The fish community at GRNMS is variable. Community structure changes seasonally and interannually. These data raise the scientific issue regarding the increase in diversity and changes in fish community structure between seasons. Are these differences caused by settlement of reef fish from the plankton or are they due to migration of adult fish to and from GRNMS?

3. Assess adequacy of fish monitoring sampling design for detecting changes in abundance and composition of fishes over time

One goal of our collaborative effort with GRNMS has been to improve the methods used for the visual census monitoring. A practical use of the community analyses described above is the finding that to address interannual questions, censuses need to be conducted in the same season. Thus, GRNMS

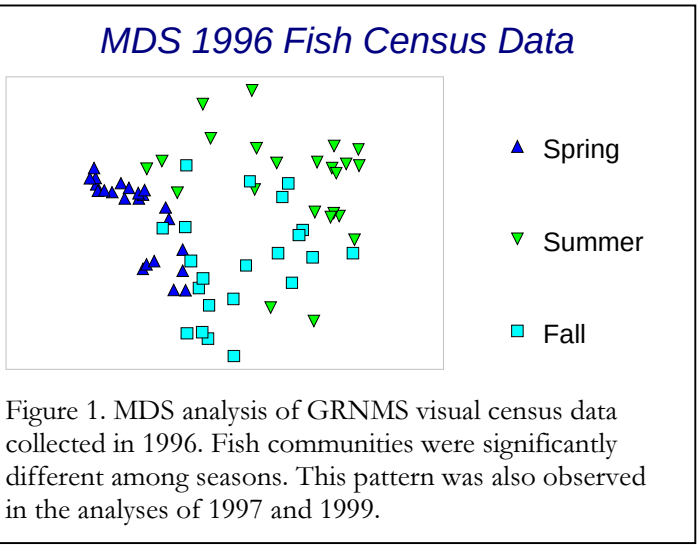


Figure 1. MDS analysis of GRNMS visual census data collected in 1996. Fish communities were significantly different among seasons. This pattern was also observed in the analyses of 1997 and 1999.

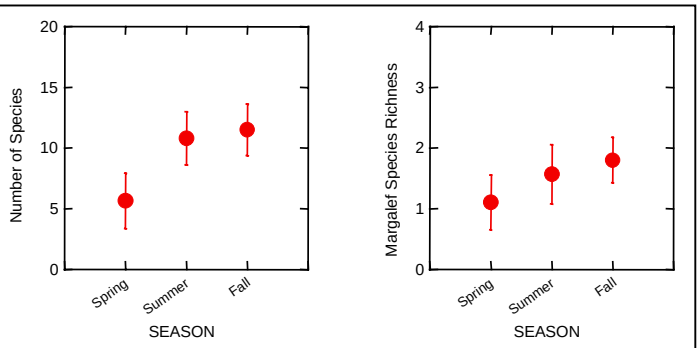


Figure 2. Number of species and a measure of species richness for the 1996 spring, summer and fall visual census data.

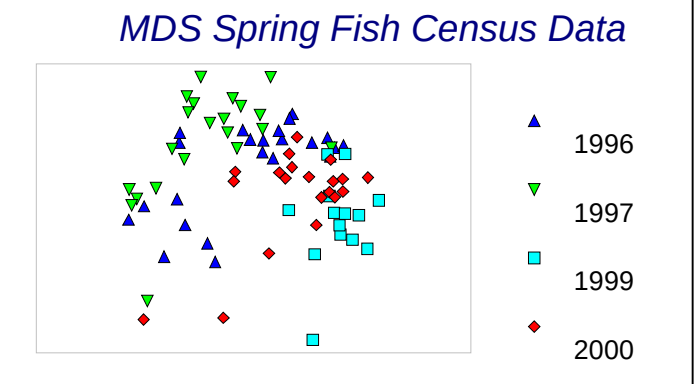


Figure 3. MDS analysis of GRNMS visual census data collected during the spring in 1996, 1997, 1999 and 2000. Fish communities were significantly different among years. This pattern was also observed in the interannual comparisons made using summer and fall data.

should focus their censusing efforts in the same season(s) every year.

The data collected thus far can also be used to address the scale of interannual change that can be reliably detected. Current efforts can detect a annual change of 40-80% in fish abundance depending on species (Figure 4). With this information, CCFHR and GRNMS plan to address the specific goals of the monitoring effort and then re-assess the sampling methodology.

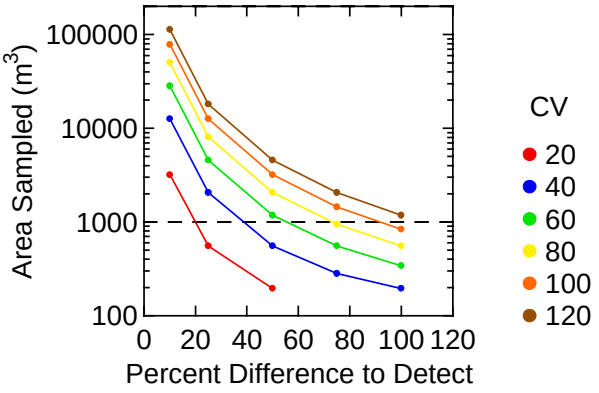


Figure 4. Calculation of sample sizes needed to detect an annual change in reef fish abundance using GRNMS visual census methods. Current sampling effort (twenty 50 m² cylinders per census) is indicated by dotted line. Gag abundance has a CV of 41.4% and is represented by the blue line. Current sampling can reliably detect a 40% difference between years. Belted sandfish, bank sea bass and slipperly dick have CV's in the 54-60% range (green line). Black sea bass has a CV of near 80% (yellow line).

4. Determine the importance of non-reef habitats to juvenile stages of reef fishes and evaluate the linkages between non-reef and reef habitats

Two field components were designed to address this objective: ROV characterization of benthic habitats and beam trawl sampling of juvenile fish in different benthic habitats. Characterization of the video tapes taken during FY00 was completed this year. All the tapes were viewed twice and habitat descriptions recorded at 5 second intervals. Most of the sites sampled consisted of sand substrate with varying degrees of shell hash. In addition, fish were enumerated from each tape. These data will be coupled with the beam trawl data following the last cruise in January 2002.

Table 2. Summary of cruises conducted as part of the GRNMS project and status of beam trawl collections.

Year	Month	Dates	Vessel	Sorted	Pre-ID	Final ID
2000	April	17-21	NOAA Ship FERREL	X	X	X
	April	24-27	NOAA Ship FERREL	X	X	X
	June	19-22	NOAA Ship JANE YARN	X	X	X
	August	15-17	NOAA Ship JANE YARN	X	X	X
	October	03-07	NOAA Ship FERREL	X	X	X
2001	Jan/Feb	30-01	NOAA Ship OREGON II	X	X	X
	March	21-23	NOAA Ship FERREL	X	X	X
	Apr/May	30-04	NOAA Ship FERREL	X	X	X
	June	04-09	RV CAPE FEAR	X	X	X
	August	03-06	NOAA Ship FERREL	X	X	X
	September	07-11	RV SEAWARD JOHNSON II	X	X	
	October	11-13	NOAA Ship FERREL			
2002	January	planned	NOAA Ship OREGON II			

Beam trawl sampling was conducted on seven research cruises during FY01 (Table 2). Sampling was conducted along the standard cross-shelf transect (Figure 5) during 6 cruises: October 2000, January 2001. March 2001, April 2001, June 2001 and August 2001. Preliminary results from this sampling demonstrate that a number of reef fish species settle to non-reef habitats including serranines (black sea bass, bank sea bass, rock sea bass and sand perch; Figure 6). In addition, distinct cross-shelf zonation exists for the serranines. Black sea bass settle inshore, bank and rock sea bass settle offshore and sand perch settle across the shelf. Similar cross-shelf patterns are found in other species. The results demonstrate that reef fish use a variety of habitats during their life history and for many species protection of a single habitat will not protect the species from anthropogenc perturbations.

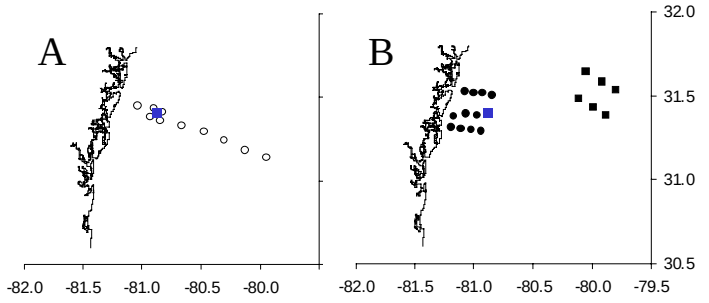


Figure 5. A) Station locations for standard beam trawl collections. At each location, three replicate 5 minute tows are made. GRNMS is represented by the blue square. B) Station locations for concurrent sampling with contamination and meiobenthos during April 2001 (inshore set of stations) and for Sustainable Seas Expedition sampling in the vicinity of Savannah Scarp (offshore set of stations).

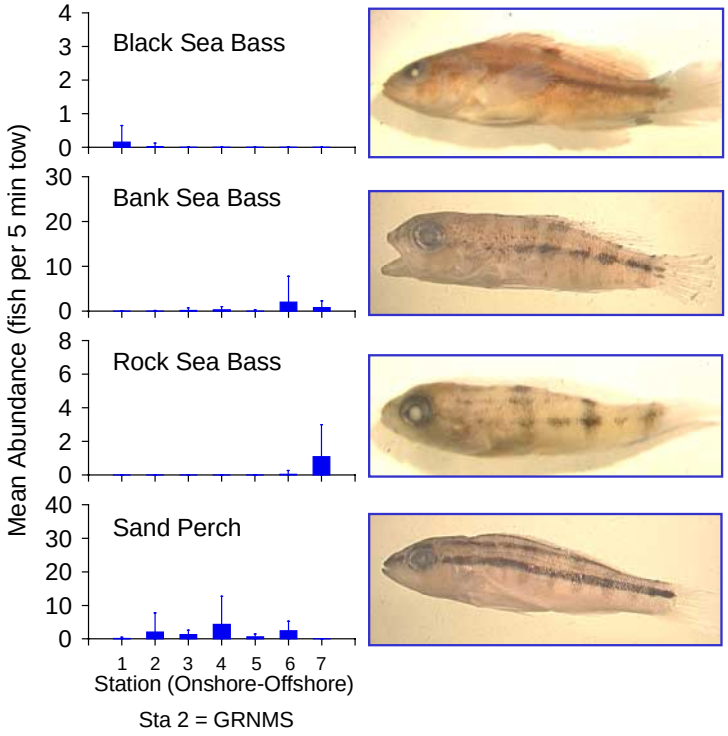


Figure 6. Average cross-shelf distribution and photographs of juvenile serranines on the Georgia shelf. Station locations are shown in Figure 5A.

Examinations of juvenile fish habitat utilization were extended beyond the initial scope of the project during FY01. Beam trawl sampling was conducted in combination with CCMA's examinations of benthic contamination and meiofauna on the inner Georgia Bight shelf (Figure 5B). These data will allow examination of the link between juvenile fishes and a variety of biotic and abiotic habitat components. In addition sampling was conducted during a Sustainable Sea Expedition cruise aboard the Seaward Johnson II (Figure 5B). Sampling occurred further

offshore than our previous work. Several interesting juvenile fish were collected including snowy grouper (tentative), rock sea bass and anglefish. Knowledge of juvenile habitat of snowy grouper is lacking and these collections will assist the ongoing Marine Protected Area planning by the South Atlantic Fishery Management Council.

Overall, this work is leading to a regional understanding of juvenile fish habitat utilization. Coupling these data with previous data on estuarine and reef use by juvenile fish, a complete picture of juvenile fish habitat utilization is emerging for the southeastern United States. The importance and role of GRNMS can then be evaluated within the framework of this regional understanding.

5. Provide customized satellite-derived sea surface temperature products to assist research and management activities within Gray's Reef National Marine Sanctuary

An operational GRNMS specific Sea Surface Temperature (SST) imagery product was developed, whereby the most recent CoastWatch SST image is posted on our website (http://www.bea.nmfs.gov/grnms/) (Figure 7). Improvements need to be made in the layout, but the operational provision of the imagery is ongoing.

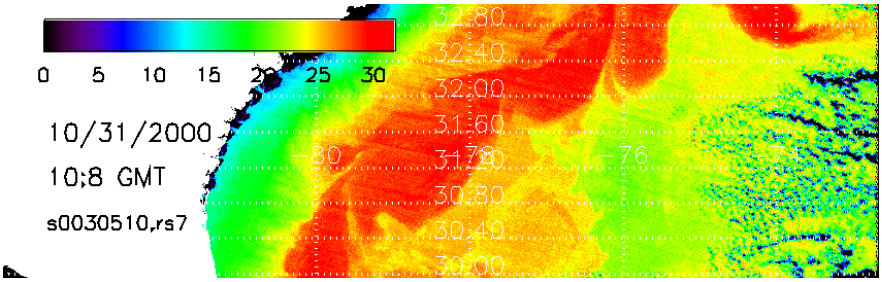


Figure 7. Example of operational SST product. The large-scale product is shown, but a small-scale product is also provided. The imagery is received from NESDIS converted to a gif and posted on the web page. The imagery posted is ~6 hours old.

Primary efforts with remotely sensed data has focused on improving the operational navigation of SST imagery. This is necessary as the area of GRNMS is small (~17 nm^2) and the current navigational error in the imagery is relatively large (average root mean squared error = 2.5 nm). The scale of GRNMS requires that SST data be well navigated. An automated procedure has been developed that corrects ~99% of the navigational error. This process is being refined and a manuscript describing the automated rectification is in preparation. The process will then be inserted in the standard operational procedures to provide an improved SST product for GRNMS.

The rectification procedure is also being used in the development of SST climatologies for GRNMS. All images from 1995 through 2000 will be passed through the procedure to improve the navigation. These improved images will then be used to develop the SST climatology and the production of an anomaly product.

6. Determine the species of fish that spawn in the vicinity of Gray's Reef National Marine Sanctuary

7. Evaluate larval transport to and dispersal from Gray's Reef National Marine Sanctuary to surrounding areas

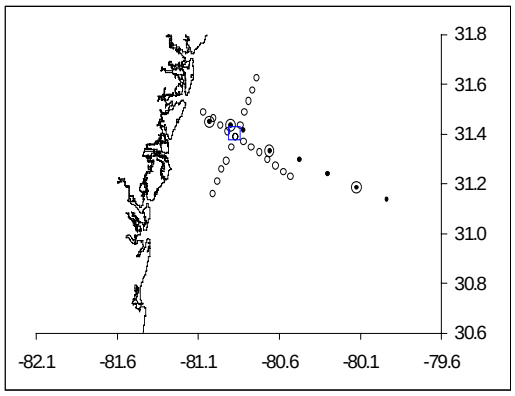


Figure 8. Location of ichthyoplankton stations. Filled and large circles are beam trawl stations, open closely spaced circles are the smaller-scale along and across-shelf sampling location and the blue box is the boundaries of GRNMS.

Ichthyoplankton collections and drifter releases are used to identify fish species that spawn in the vicinity of GRNMS and to elucidate transport of larvae to and from GRNMS. Nine cruises have been completed in support of these objectives and five sets of drifter releases have been made. Three categories of ichthyoplankton sampling have been completed: 1) in conjunction with cross-shelf beam trawl stations (see Figure 5A and 8); 2) smaller-scale along-shelf and cross-shelf sampling (Figure 8); and 3) a vertical distribution study conducted 3 nm to the east of GRNMS. These various datasets are discussed in more detail below in the context of the scientific questions addressed as part of these research objectives.

One goal of the ichthyoplankton component is to identify which species of fish are spawning in the vicinity of GRNMS. Preliminary examination of the data from stations immediately adjacent to GRNMS indicates that a number of species spawn in the vicinity of GRNMS including several reef fish taxa. Of particular interest are larvae of *Diplectrum* (sand perch), serranines (black sea bass, bank sea bass, rock seabass and sand perch) and

Table 3. Summary of ichthyoplankton data processing. Identification will continually be revisited to make improvements when new information becomes available. Sampling category refers to: BT - in conjunction with the cross-shelf beam trawl stations; SS - smaller-scale (3 nm station spacing) along-shelf and cross-shelf sampling; VD -vertical distribution study.

Date	Total	Gear	Sorted	pre-ID	final ID	Computerized	Sampling Category
Apr-00	50	Bongo	50	50	50	50	BT/SS
Aug-00	8	Sled	8	8	8	8	BT
Oct-00	33	Bongo	13	13	12	12	BT/SS
Jan-01	31	Bongo					BT/SS
Mar-01	22	Bongo					BT/SS
Apr-01	7	Bongo					BT
Jun-01	30	Bongo					BT/SS
Aug-01	138	TT/Bongo					BT/VD
Oct-01	9	Bongo					BT
Jan-02	planned						BT/SS

Sparidae (porgies). The inclusion of additional samples and larval length and age estimates will provide a better representation of recently spawned larvae.

A second goal of the ichthyoplankton component is to evaluate the relation between larval fish assemblages and water mass distribution in the vicinity of GRNMS. Larval fish assemblages are groups of fish larvae that coexist in time and space. By comparing larval distributions among and within assemblages, with concomitant measures of the physical environment, insights can be gained into the processes that affect larval distributions, transport and ultimately, recruitment to juvenile habitats.

A preliminary analysis has been completed using the April 2000 cross-shelf and along-shelf ichthyoplankton data. Across-shelf stations fell within two water masses, Georgia Bight Water and Georgia Bight/Gulf Stream Water mix (Fig. 9A). Georgia Bight Water is cooler, less saline, and more stratified than Georgia Bight/Gulf Stream mixed water (Fig. 10). Along-shelf stations were all located in Georgia Bight water, however, there were differences in temperature and salinity within the water mass (Figure 9B).

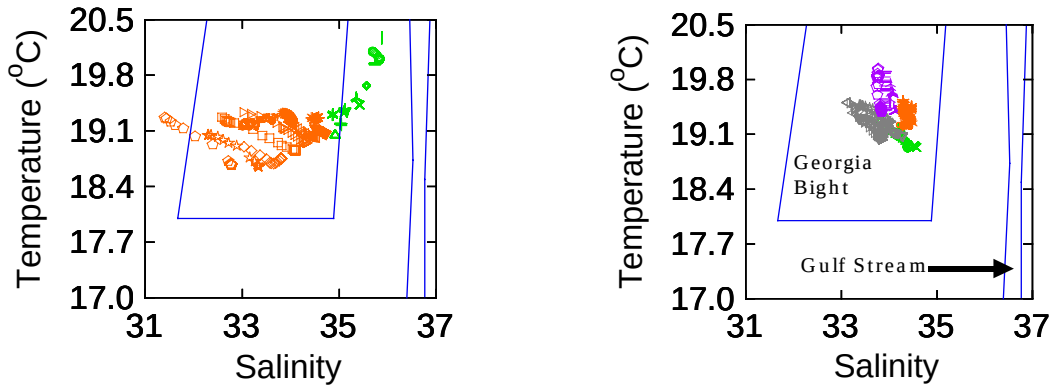


Figure 9. Three water masses were defined using temperature and salinity: Georgia Bight, Georgia Bight/Gulf Stream Mix, and Gulf Stream water. A) Across-shelf stations were located in Georgia Bight (red) and Georgia Bight/Gulf Stream Mix water (green). B) Along-shelf stations were all located in Georgia Bight water; however, four subgroups were defined (different colors).

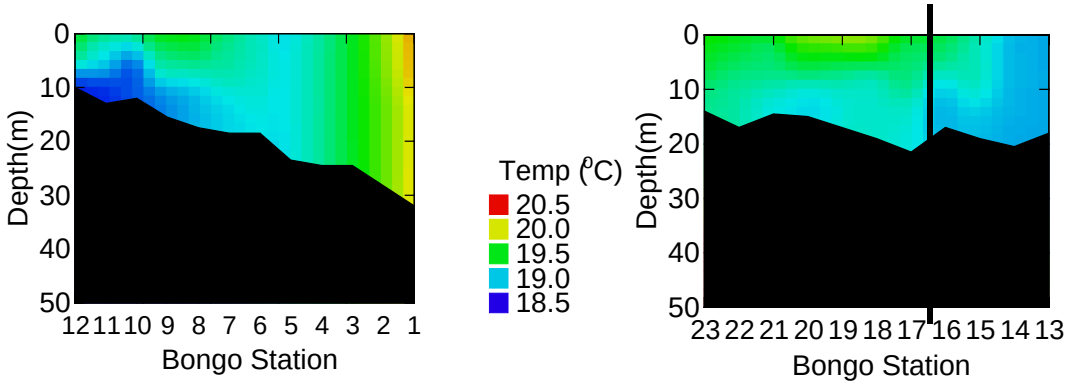


Figure 10. Temperature sections across-shelf (left) and along-shelf (right) from April 2000. Georgia Bight water is cooler, less saline, and stratified. Georgia Bight/Gulf Stream mixed water is warmer, more saline, and vertically homogeneous.

Larval fish communities from within the Georgia Bight Water were significantly different from those of the Georgia Bight/Gulf Stream Water mix (Fig. 11). Few differences were seen in the communities of the along-shelf sub groups (Fig. 11). Similar differences were found in August between the larval fish assemblages between Georgia Bight and Georgia Bight/Gulf Stream mixed water.

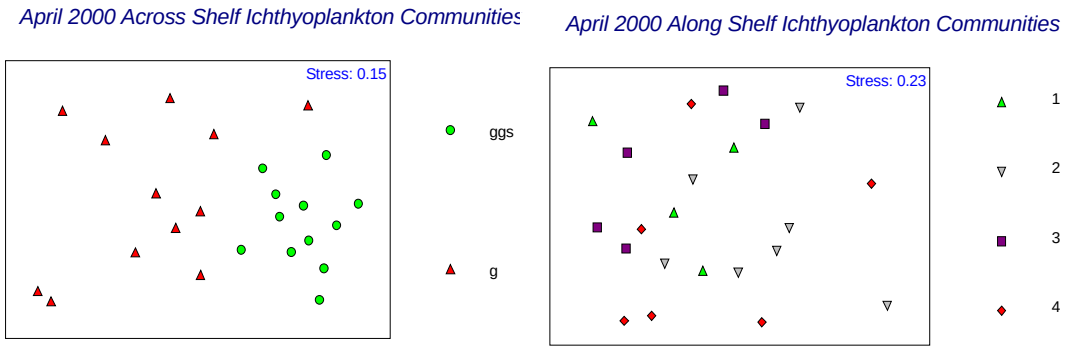


Figure 11. MDS plots of April 2000 across-shelf and along-shelf transects. A) Larval fish communities found in the Georgia Bight/Gulf Stream Water mix (ggs) differed significantly from those found in Georgia Bight Water (g). Larval Gobiidae, Serranidae, and Paralichthyidae made up 50% of the Georgia Bight/Gulf Stream Water mix ichthyoplankton. Georgia Bight Water was dominated by larvae of the families Triglidae and Gobiidae. B) All stations were within Georgia Bight Water (g). Subgroups 2 and 4 contained communities that differed, while all others were not significantly different.

These preliminary analyses illustrate a relationship between larval fish assemblages and water mass characteristics. Hydrographic information may therefore be useful in predicting the location of assemblages. More importantly, the location and strength of the front between Georgia Bight shelf water and mixed Georgia Bight/Gulf Stream water may control where specific larval fish are found, and thereby influence the supply of larvae to juvenile nursery habitat. Specifically with regard to GRNMS, the supply of larvae to the Sanctuary from offshore may be greatly influenced by the supply of Georgia Bight/Gulf Stream mixed water.

In addition to the ichthyoplankton work, satellite tracked drifters have been released to examine the potential transport of fish larvae spawned in the vicinity of GRNMS. Five sets of releases have been made: April 2000, June 2000, October 2000, January 2001 and March 2001. The drifters indicate that circulation in the Georgia Bight is largely wind-driven. An example comes from a drifter released in April 2000; the drifter initially moved offshore, then exhibited large along-shelf movements (Figure 12). These movements appear to be related to wind forcing (Figure 13), but additional analyses are required. Wind data from 2000 have been low-passed filtered; wind data from 2001 needs to be similarly processed. In addition, the angles of motion need to be rotated to along-shelf and cross-shelf components rather than the north/south and east/west components. The angle of rotation changes as the angle of the coastline changes (Figure 12). A spatial model of angles of rotation has been completed and the drifter data need to be re-processed accordingly.

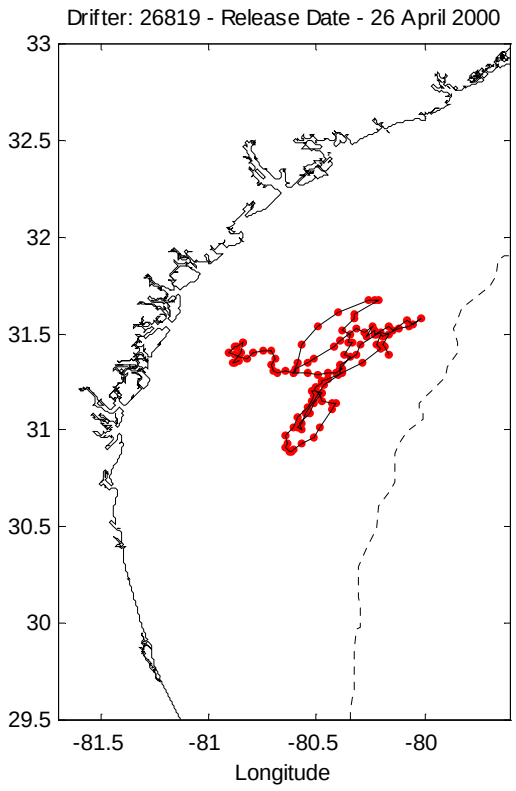


Figure 12. Track of a drifter released in April 2000. Shoreline and 50 m isobath are shown. Drifter was released within GRNMS.

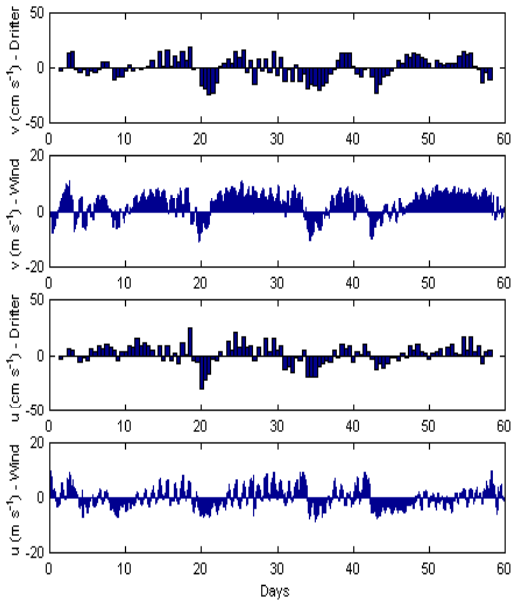


Figure 13. Comparison of north/south and east/west components of drifter 26819 movement with north/south and east/west component of the wind from NOAA buoy located in GRNMS.

Prelimary contacts have been made to integrate the drifter work with an ongoing circulation modeling and observational effort headed by Cisco Werner (UNC-Chapel Hill) (http://www.skio.peachnet.edu/projects/sabsoon.html).

To assist with the potential modelling effort, a larval vertical distribution study was conducted during August 2001. Vertically-discrete ichthyoplankton sampling was conducted every three hours for 96 hours. These samples will provide data for the development of vertical distribution models of larval fish that can then be coupled with 3-D numerical models of circulation to model larval transport.

Identification of Larval and Juvenile Fishes Using 12S Mitochondrial DNA

In addition to the work described above, CCFHR and CCEHBR are collaborating to use genetic techniques to identify the larval and juvenile stages of fish that are important to GRNMS and other hard-bottom areas in the southeast. In particular, understanding black sea bass (*Centropristis striata*) spawning and larval transport is a top priority owing to its commercial and recreational importance. However, *Centropristis* larvae cannot be identified to species. Additionally, our juvenile identifications are tentative (see Figure 6).

Our goal with this element of the project is to establish a genetic species identity database for the snapper grouper complex. Such a database would greatly facilitate the

identification of larval and juvenile specimens. To accomplish this goal, within and between species genetic differences must be defined. In addition, due to the broad geographic range of species in this group, genetic samples need to be collected from different regions. Once a database has been established using adults as known material, molecular probes can be designed for the identification of egg, larval and juvenile stages that cannot be distinguished using traditional identification techniques. The current application of this methodology is to better define the species that spawn in GRNMS and enable a clearer evaluation of larval transport to and from GRNMS.

A comprehensive genetic species identification database is being compiled for southeastern snapper and serranine species. The serranines are of particular interest because of the abundance of five species within GRNMS (*Centropristis straita*, *C. ocyurus*, *Diplectrum formosum*, *Serranniculus pumilio* and *Serranus subligarius*). Snappers are of some importance to GRNMS but are of great importance to FKNMS. We are using the conserved 12S region of the mitochondria as the informative target region. We have concentrated on adult voucher specimens for the initial genetic characterization and database construction. To date we have a complete database for the more common snappers occurring in the Florida Keys and the common serranines along the southeast coast (Table 4). However, one of the major impediments has

Table 4 Summary of samples collected to date to support development of genetic database for identifying eggs, larvae, juveniles of snappers and serranines.

Scientific Name	Common Name	Abbrev	Samples	
Gulf of Mexico Samples			**Total**	**Seq**
Diplectrum formosum	Sand perch	Dfor	9	0
Ocyurus chrysurus	Yellowtail	Ochr	8	0
Lutjanus buccanella	Blackfin snapper	Lbuc	5	0
Acanthocybium Solandri	Wahoo	Asol	1	0
Sphyraena barracuda	Barracuda	Sbar	1	0
Haemulon plamieri	White grunt	Hpla	1	0
Lachnolamus maximus	Hogfish	Lmax	10	0
Lutjanus analis	Mutton snapper	Lana	11	0
Lutjanus vivanus	Silk snapper	Lviv	8	0
Lutjanus joci	Dog snapper	Ljoc	1	0
Lutjanus cyanopterus	Cubera snapper	Lcya	3	0
Etelis oculatus	Queen snapper	Eocu	6	0
Southeastern US Samples				
Centropristis striata	Sea bass	Cstr	9	9
Centropristis ocyurus	Sea bass	Cocy	7	7
Diplectrum formosum	Sand perch	Dfor	9	0
Centropristis philadelphica	Sea bass	Cphi	2	0
Florida Keys Samples				
Lutjanus vivanus	Silk snapper	Lviv	20	9
Lutjanus mahogoni	Mahogany snapper	Lmah	18	3
Lutjanus joci	Dog snapper	Ljoc	17	7
Lutjanus analis	Mutton snapper	Lana	16	9
Lutjanus griseus	Grey snapper	Lgri	13	10
Ocyurus chrysurus	Yellowtail snapper	Ochr	12	12
Rhomboplites aurorubens	Vermilion snapper	Raur	12	12
Lutjanus apodus	Schoolmaster	Lapo	10	8
Lutjanus synagris	snapper	Lsyn	11	9
Lutjanus sp.	Lane snapper	-----	2	0
Lutjanus cyanopterus	----------	Lcya	2	2
Lutjanus campechanus	Cubera snapper	Lcam	4	3
	Red snapper			

been the inability to obtain rare species and samples from two of the regions desired (Gulf and North Carolina to northern Florida). Obtaining these samples from different sites is imperative to determine potential population structure, verification and validation of species level identification markers.

Preliminary analysis of 12S mitochondrial DNA sequences has been conducted for 84 individuals representing 11 species found in the Florida Keys. Phylogenetic trees have been created with neighbor-joining analysis using p distances. The results indicate that all major species groups were monophyletic (Fig. 14). Moreover, the results support the use of the 12S region of mtDNA to identify unknown individuals to species.

Similar analyses have been conducted on two *Centropristis* species: *C. striata* and *C. ocyurus.* Again, using the 12S mitochondrial DNA, sequences have been generated from 16 individuals. Phylogenetic trees have been constructed from the sequence data (Figure 15). The two species were differentiated by 36 fixed differences out of 38 polymorphic sites. This number of fixed sites will support an inexpensive adaptation to RFLP (restriction fragment length polymorphism) analysis for quick screening of individuals to species. Two individuals of a third species have, *Centropristis philadelphica*, and samples of *Diplectrum formosum* have recently been obtained. These individuals will be sequenced and compared with *C. striata* and *C. ocyurus* to determine the number of fixed differences between the four

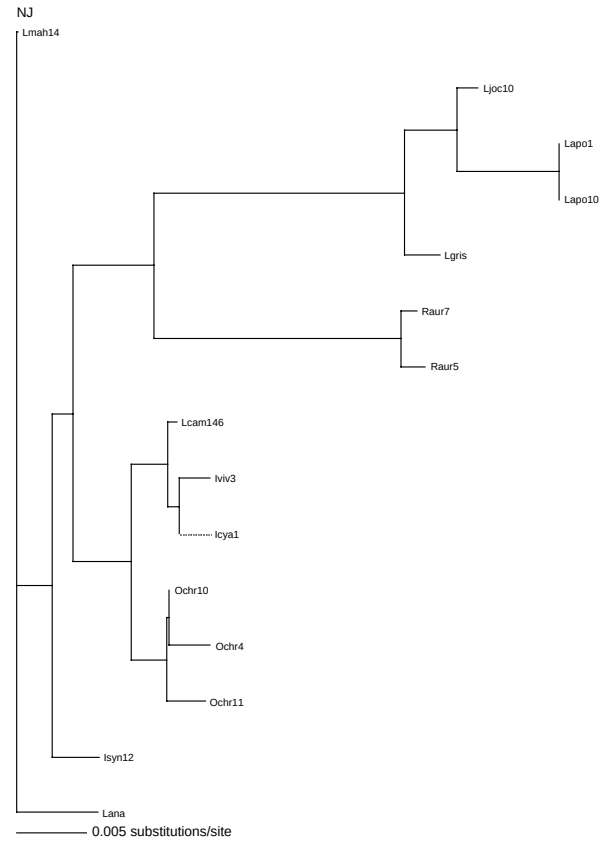


Figure 14. Neighbor joining analysis of common snapper species from the Florida Keys. All major species were monophyletic. Tree construction was based on consensus sequences of multiple individuals within each species. Abbreviations for species are provided in Table 4.

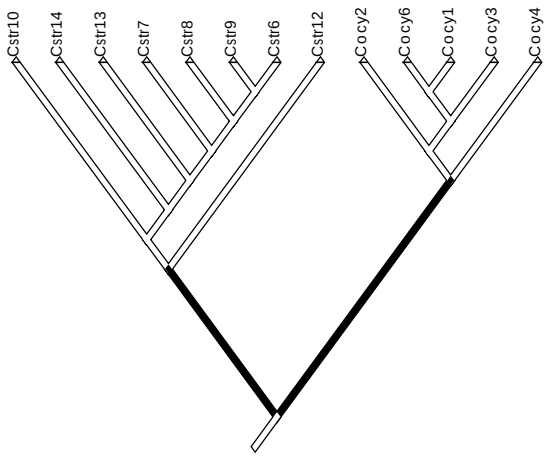


Figure 15. Differentiation of two species of sea bass, *Centropristis striata* and *C. ocyurus* (see Table 4 for abbreviations). Tree construction was by neighbor joining analysis using p distances.

species. The approach of using genetics as a tool in fish identification is extremely powerful and will lead to previously unattainable information regarding the larval and juvenile ecology of *Centropristis* species.

8. Provide an assessment of the efficacy of Gray's Reef National Marine Sanctuary to act as a source of fish recruits for other hard bottom areas in the region

A document was prepared for GRNMS for submission to the South Atlantic Fishery Management Council (SAFMC) (included as Appendix 1). This document used best available scientific data to assess GRNMS as a MPA using the criteria established by the SAFMC. In summary, GRNMS is representative of inner-shelf hard-bottom areas found along the southeastern US continental shelf. The area in GRNMS consists of extensive, but patchy, hard bottom of moderate relief, interspersed with sand and shell hash bottom. GRNMS can be considered a heritage site protecting a small area of important habitat. In the context of the SAFMC MPA process, which proposes to use MPA's as a fishery management tool, the area of GRNMS is very small. As part of a network of MPA's, however, GRNMS could play an important role. Drifter data discussed above demonstrates that GRNMS could act as a source for larvae to a number of locations throughout the region (Figure 16). The SAFMC, however, chose not to consider GRNMS as a potential MPA.

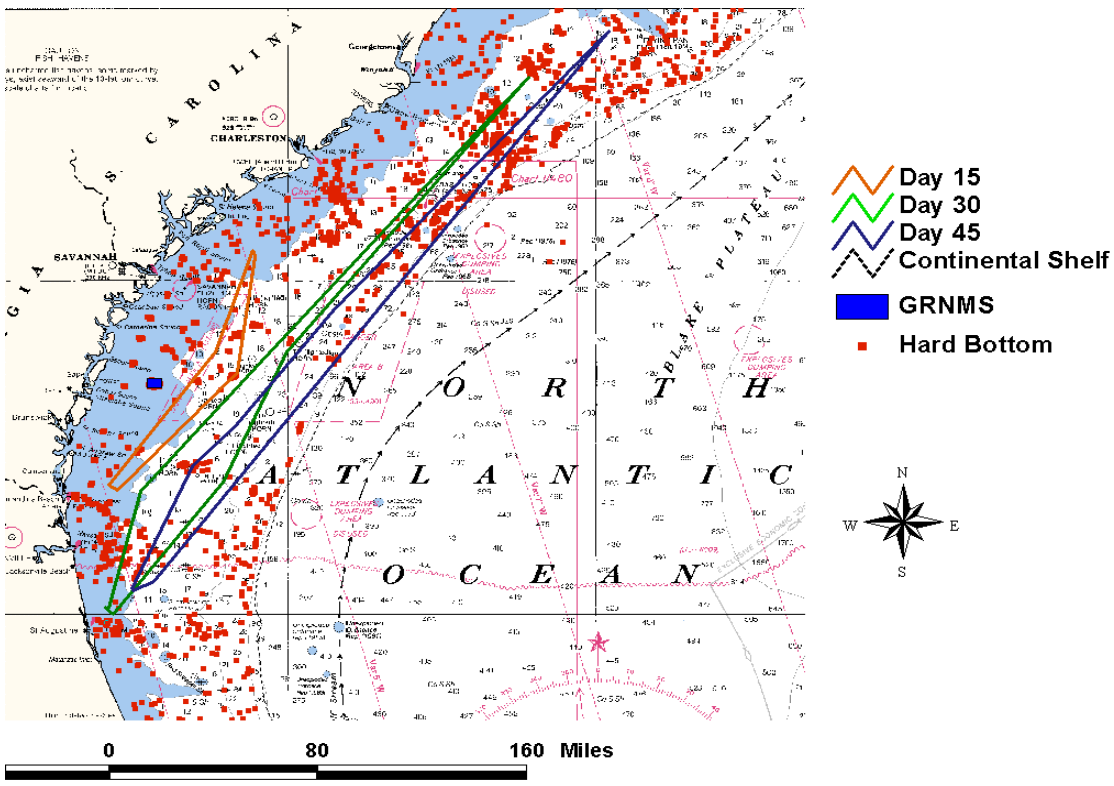


Figure 16. Envelopes of 12 drifters released within Gray's Reef National Marine Sanctuary. Drifters were released in April, June, October, 2000 and January 2001. Envelopes show the outline of the area encompassed by the drifters 15, 30 and 45 days following release. These data indicate that larval fish spawned within GRNMS could be in contact with a number of other hard bottom areas at the end of the larval stage. Larval duration of most of the snapper grouper species range from 15 to 45 days.

9. Provide an assessment of the condition of macroinfaunal assemblages, concentrations of chemical contaminants in sediments, and contaminant body-burdens in target benthic species of the Gray's Reef National Marine Sanctuary

A separate report, which was an identified project deliverable, describing this the results of this component was submitted on 1 October 2001. This report is included as Appendix 2.

10. Biomarkers of Corals in GRNMS (preliminary objective title)

Oculina varicosa coral samples collected in July 2000 have been maintained in aquaria and used for a variety of preliminary tests. The initial goal was to develop protocols for maintenance and growth of this coral species. We have shown that we can maintain this species long-term in culture. We have also used subsamples of the *Oculina* as standards material for a number of different experimental protocols. These include:

1. Heat stressing coral fragments to prepare protein standards for western blots,

2. Lipid analysis to determine the fatty acid composition of corals, a novel fatty acid was detected. We are continuing lipid analyses and have proposed a time course experiment to evaluate the change in the coral's lipid composition when the corals are moved from a natural diet to an artificial one when the organism is in culture. This will help us determine if there are possible artifacts due to diet change when we use cultured corals in laboratory exposure experiments.

3. Cell culture - We used fragments of Oculina to attempt to establish invitro cell cultures. We were able to maintain dispersed coral cells for two weeks in cell culture. We have since met with Dr. Gary Ostrander of John Hopkins Medical University, who has primary coral cell cultures and discussed culture techniques. If successful, invitro studies can provide a basis for coral research that does not require sacraficing wild corals.

4. DNA extraction - Fragments of the Oculina have been used to extract DNA and RNA to develop genomic and cDNA libraries that will be used to identify stress-related genes, determine gene regulation and provide genetic markers to evaluate allele distribution in corals sensitive or resistant to various stressors.

5. cDNA library construction – Oculina mRNA has been extracted and cDNA libraries have been constructed during the fourth quarater of FY01. We have selected over 300 ESTs (expressed sequence tags), converted the viral vectors to plasmids and purified plasmid DNA in preparation for sequencing. Sequences from these clones will be used as part of a marine genomics project to evaluate the mRNAs and subsequently genes related to the bioindicators we are using to assess coral health and disease.

Professional Presentations

Walsh HJ, Hare JA, Degan BP, Bath Martin G. Use of non-reef habitats in the vicinity of Gray's Reef National Marine Sanctuary by juvenile reef fishes. Larval Fish Conference - August 2001

Marancik KE, Hare JA, Clough L, Walsh HJ. Distribution of larval fish surrounding Gray's Reef National Marine Sanctuary. Larval Fish Conference - August 2001

Walsh HJ, Hare JA, Degan BP, Bath Martin G. Fish community structure on the Georgia shelf. Larval Fish Conference - August 2001

Other Activities

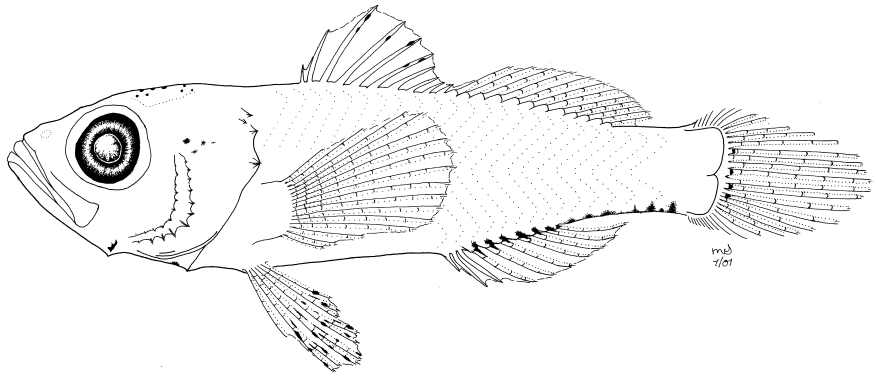
Jon Hare and Cheryl Woodley participated in the National Marine Sanctuary Research Workshop - February 2001.

Gretchen Bath Martin participated in a GRNMS Species Conservation Workshop - December 2000

Mike Burton presented the MPA Assessment to the Marine Protected Areas Advisory Panel to the South Atlantic Fishery Management Council - May 2001.

Jon Hare, Harvey Walsh, Pete Parker, Mike Burton, Roger Mays and Cynthia Cooksey participated in the GRNMS Research Monitoring Workshop - June 2001

Jon Hare presented the MPA Assessment to the Habitat Advisory Panel to the South Atlantic Fishery Management Council - August 2001.



For more information please contact

Jon Hare
NOAA NOS CCFHR
101 Pivers Island Road
Beaufort, NC 28516
Jon.Hare@noaa.gov
(252) 728-8732
(252) 728-8784

APPENDIX 1

Assessment of Gray's Reef National Marine Sanctuary relative to the criteria established by the South Atlantic Fishery Management Council for Marine Protected Areas in the South Atlantic

Assessment of Gray's Reef National Marine Sanctuary relative to the criteria established by the South Atlantic Fishery Management Council for Marine Protected Areas in the South Atlantic

Submitted to the South Atlantic Fishery Management Council on 21 May 2001

Prepared for Gray's Reef National Marine Sanctuary by:

Jonathan Hare [1‡], Michael Burton [1], Ervan Garrison [2], Jeffrey Hyland [3], Richard Parker [1] & George Sedberry [4].

[1] – NOAA NOS/NMFS, Center for Coastal Fisheries and Habitat Research, 101 Pivers Island Road, Beaufort, North Carolina 28516

[2] - Department of Geology, Geography-Geology Building, University of Georgia, Athens, Georgia 30602

[3] - NOAA NOS, Center for Coastal Monitoring and Assessment, Carolinian Province Office, 219 Fort Johnson Road, Charleston, South Carolina 29422

[4] - Marine Resources Research Institute, South Carolina Department of Natural Resources, 217 Ft. Johnson Road, Charleston, South Carolina 29422

[‡] - corresponding author:
252-728-8732 (phone)
252-728-8784 (FAX)
Jon.Hare@noaa.gov (email)

Introduction

Marine Protected Areas (MPAs) have increasingly been considered as a strategy to conserve the sustainability of marine fish and shellfish fisheries either as an alternative to or in combination with traditional fisheries management methods. Three general categories of MPAs have been recognized based on different management objectives (Yoklavich 1998, Parrish 1999). 1) MPAs can provide research or heritage (e.g. parks) sites and these MPAs are generally small in size, < 5% of total habitat. 2) MPAs can serve as insurance against overfishing and these MPAs have been considered at scales of 5-20% of available habitat. 3) MPAs can act as an alternative to traditional management strategies with few restrictions on fisheries outside of MPAs but with no-take or very-limited-take within large MPAs (20-50% of habitat).

The South Atlantic Fishery Management Council (SAFMC) is currently considering MPAs with the '*primary purpose of aiding in the recovery of overfished stocks and to insure the persistence of healthy fish stocks, fisheries and habitats*' (SAFMC 2001a). In light of the general categories of MPAs described above, the SAFMC is considering MPAs analogous to category 2 and 3: as insurance against overfishing and as an alternative strategy for sustainable fisheries. The SAFMC is further limiting its consideration to MPAs '… *primarily aimed at protecting deepwater snapper grouper species and taking into consideration criteria the Council has identified*'. These criteria take the form of specific questions that need to be addressed for each proposed area. The SAFMC has requested '… *specific input on possible areas that the Council should examine in their consideration of marine protected areas*' (SAFMC 2001a). At this time, the Council is primarily considering permanent closures for specific elements of marine communities with exceptions for permitted scientific and educational activities. The Council does not intend to prohibit take of pelagic species. In short, the Council is primarily interested in MPAs that can supplement fishery management practices to protect deepwater snapper grouper species, while allowing fishing for pelagic species.

The South Atlantic Fishery Management Council has also presented its goals for MPAs generally (SAFMC 2001a). MPAs in the SAFMC jurisdiction would be used to: 1) supplement fisheries management practices for all species under SAFMC jurisdiction; 2) manage ecosystems as a whole; 3) protect, restore and improve Essential Fish Habitat (EFH) and EFH - Habitat Area of Particular Concern; and 4) provide scientific research areas to improve understanding of species under management.

Our purpose here is to provide an assessment of Gray's Reef National Marine Sanctuary (GRNMS) relative to the SAFMC proposed MPAs along the southeastern US shelf. We focus on the specific criteria for the intent presented by the SAFMC (protect deepwater snapper grouper species, SAFMC 2001a), but we also address the general SAFMC MPAs goals identified above. We first provide general comments regarding GRNMS as an MPA as defined by the SAFMC. We then specifically address the Council's stated criteria with the best available data. We leave the endorsement or non-endorsement of GRNMS as an MPA to GRNMS managers and the SAFMC.

General Consideration of GRNMS as an MPA

The target of current MPA consideration is the snapper grouper management unit. This unit is ecologically and taxonomically complex, containing 73 species from nine families. Species in this management unit utilize pelagic and benthic habitats from inside estuaries to the continental slope. For most species, adults are generally associated with hard bottom habitats throughout the SAFMC jurisdiction (examples of exceptions include tilefish use mud bottoms and amberjacks are pelagic). In the southern portion of SAFMC jurisdiction (south of Cape Canaveral), hard bottom habitat is typically in the form of coral reefs. In the northern portion of SAFMC jurisdiction (north of Cape Canaveral) hard bottom habitat is typically in the form of rocky pavement and outcroppings.

In the northern portion of SAFMC jurisdiction, members of the snapper grouper management unit form discrete communities, which are believed to be structured by temperature, depth and latitudinal gradients (Table 1, Grimes et al. 1982, Chester et al. 1984). Most research, however, has focussed on North Carolina and South Carolina shelves. Snapper grouper fish communities are not static; Parker and Dixon (1998) found an increase in species diversity on reefs off of North Carolina over 15 years. Community structure and distribution within the snapper grouper management unit **must** be considered in the MPA process. Similarly, the MPA process **must** recognize that these communities and distributions are dynamic.

Table 1. Communities of species in the snapper grouper management unit. Principal species representing each community are listed as are the general depth and latitudinal range of the community. Minor components of communities are indicated in parentheses. Based on Chester et al. (1984). Deepwater grouper species are indicated by *.

Community	Principal Species	Depth Range/ Latitude Range
I	Red porgy Vermilion snapper Red snapper Gag White grunt Gray triggerfish (Scamp)	40-70 m (mid-shelf)/ NC/SC shelves
II	Snowy grouper* Warsaw grouper* Yellowedge grouper* Blueline tilefish*	> 100 m (deep shelf)/ NC/SC shelves
III	Red grouper Rock hind Red hind Scamp (White grunt)	40-70 m (mid-shelf)/ Cape Fear, NC and south
IV	Knobbed porgy Speckled hind Amberjacks (Gray triggerfish) (Red porgy)	50-100 m (outer shelf)/ Cape Fear, NC and south
V, VI, VII	Sheepshead porgy Longspine porgy Tomtate Pigfish Whitebone porgy Spottail porgy Black sea bass (White grunt)	<30 m (iner-shelf)/ NC/SC shelves

GRNMS is managed by the Office of National Marine Sanctuaries of the National Oceanic and Atmospheric Administration and encompasses nearly 17 NM^2 of bottom on the inner continental shelf of Georgia (Figure 1). The Sanctuary consists of extensive, but patchy, hard bottom of moderate relief, interspersed with sand and shell hash bottom (Hunt 1974, Henry and van Sant 1982). Although the fauna is less diverse than coral reefs, the hard bottom found within GRNMS has coral reef-like characteristics. The rock outcrops and immediate adjacent sand bottom form a complex of habitats that supports a diverse assemblage of algae and epifaunal invertebrates including bryozoans, sponges, barnacles, sea fans, corals, sea stars, lobsters, shrimp, crabs and mollusks (Wenner et al. 1983). Some of the larger forms of invertebrates contribute to the diversity of habitats by providing habitat and prey for other species (Hendler 1984, Sedberry 1989).

The diverse abiotic and biotic habitats within GRNMS are utilized by a number of demersal and pelagic fish species (listed in Appendix 1). The fish fauna is typical of the inner shelf (Community V, VI and VII in Table 1), and none of the deep water snapper grouper fishery species (speckled hind, snowy grouper, warsaw grouper, yellowedge grouper, misty grouper, tilefish, blueline tilefish, sand tilefish) have been observed at GRNMS. Owing to their absence, GRNMS as a SAFMC MPA would have little impact on deep water snapper grouper species. However, approximately a third of the species in the snapper grouper management unit have been observed at GRNMS (Appendix 1). **Thus, GRNMS could be considered as an MPA under the general goals presented by the SAFMC (SAFMC 2001a).**

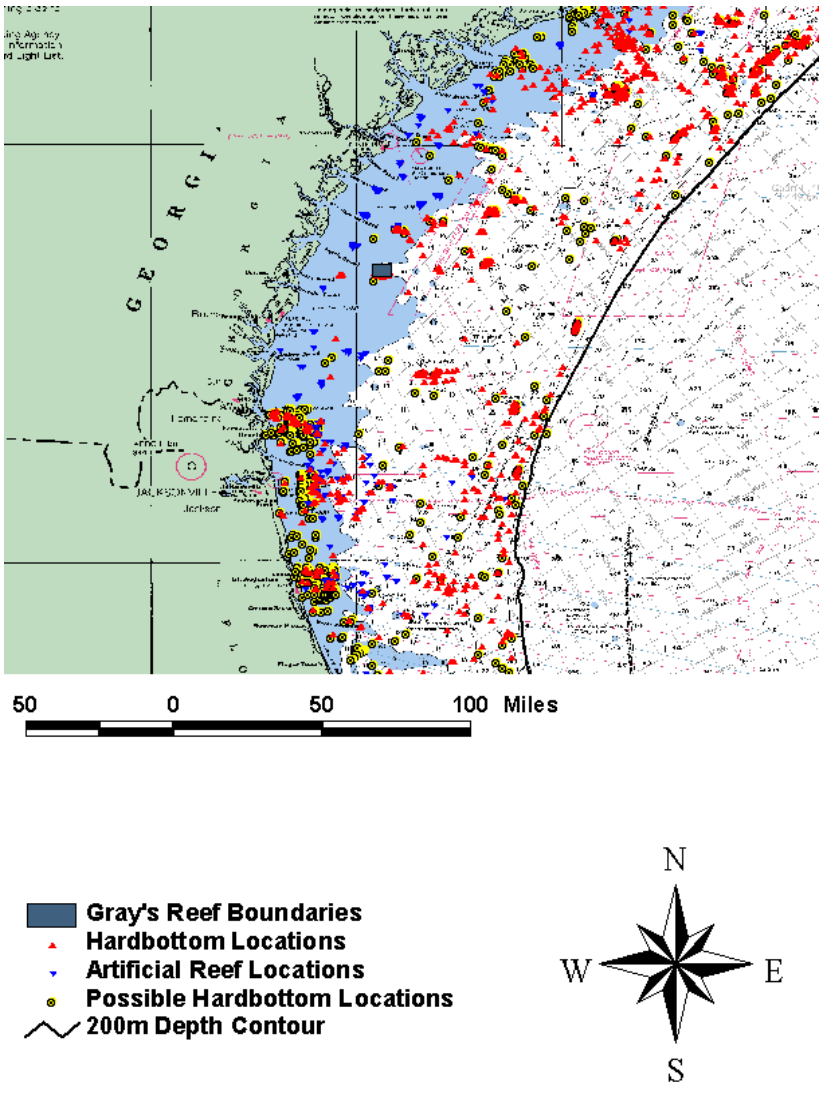


Figure 1. Map showing Gray's Reef National Marine Sanctuary and other hard bottom areas of the Georgia Bight.

Specific Criteria

Regionally representative?

GRNMS is generally representative of inner shelf, hard bottom habitats from North Carolina to northern Florida. Hard bottom habitats throughout the southeast US continental shelf are inhabited by a number of demersal reef fish species and frequented by a number of pelagic fish species. Reef fish communities along the southeastern US, however, exhibit both along-shelf and cross-shelf patterns (Chester et al. 1984, Sedberry and van Dolah 1984, Parker et al. 1994). The fauna at GRNMS is more similar to hard bottom areas at similar depths off of South Carolina than North Carolina (Parker et al. 1994). Similarly, the fauna at GRNMS is likely more similar to hard bottom habitats at 20 m off of South Carolina compared to hard bottom habitats at 50 m off of South Carolina (Sedberry and Van Dolah, 1994). **In light of the SAFMC general MPA goals, GRNMS could serve as an MPA representing the inner shelf ecosystem and the Essential Fish Habitats associated with inner shelf hard bottom areas.**

Not conserved elsewhere?

To our knowledge, no areas of hard bottom north of Cape Canaveral are currently classified as MPAs as defined by the SAFMC. There is approximately 9500 km^2 of hard bottom habitat between Cape Canaveral and Cape Hatteras at depths from 27 to 101 m (Parker et al. 1983). The total area of hard bottom is larger as sites within the 27 m isobath have not been quantified[1].

High habitat diversity?

Most of the habitats present on the inner southeastern US shelf are represented within GRNMS. Two general habitat types can be distinguished on the inner shelf: ~75% of the bottom consists of unconsolidated sand and shell hash and the remaining 25% of bottom consists of hard bottom (Parker et al. 1983). There are misconceptions that sand bottom is sparsely inhabited by marine life. A highly abundant and diverse assemblage of benthic infauna inhabits unconsolidated sediments. Preliminary data from ongoing work at GRNMS show the presence of highly diverse assemblages of macroinfauna characterized by measures of diversity that are generally over twice the values found in nearby estuaries (Jeff Hyland, NOAA, unpublished data). Similarly, a diverse assemblage of fishes also inhabits sand habitat on the shelf (Wenner and Sedberry 1989, Harvey Walsh unpublished data) and some reef fish species feed on benthic infauna from sand habitats (Sedberry, 1985, 1988, 1989, Sedberry and Cuellar, 1993). Although hard bottom habitat covers less area than sand bottom, fish diversity and abundance are greater in the vicinity of hard bottom (Wenner 1983, Sedberry and Van Dolah 1984). Hard bottom habitats are structurally more complex and provide a greater number of microhabitats. Parker et al. (1994) identified four distinct habitats within GRNMS based on fish assemblages: ledge and dense live-bottom, moderate live bottom, sparse live-bottom, and sand.

[1] These estimates are for Cape Hatteras to Cape Canaveral from 27-101 m. Data on bottom habitat distribution (SEAMAP 1998) indicates that the proportion of sand bottom to hard bottom inshore of 27 m is roughly similar, with the exception that there is more artificial hard bottom inshore than offshore of 27 m.

Unique habitat?
GRNMS is not unique, rather it is representative of hard bottom habitats scattered across the inner southeastern US shelf.

General chemical contaminants in the sediments of GRNMS are at background levels, below probable bioeffect thresholds, throughout GRNMS (Jeff Hyland, unpublished data). Contaminants in tissues of target benthic species also appear to be below human health guidelines (based on a limited sample population of 20 fish and mollusks collected in April 2000, Jeff Hyland, unpublished data). These observations, coupled with additional preliminary evidence of a healthy and diverse benthic fauna, support the idea that Gray's Reef is currently in good ecological condition. It is unknown if this is representative of the region or unique to GRNMS.

Includes fragile habitat(s)?
Many of the sponge and coral species found on hard bottom are fragile (Van Dolah et al., 1987) and this is discussed in more detail below.

Includes vulnerable species?
Many of the dominant epifanual sponge and coral species common to hard bottom areas grow very slowly. Larger forms may be 30-50 years old (Van Dolah et al., 1987). If correct, then these species would recover very slowly from anthropogenic disturbances (e.g. trawling, anchoring). In addition, none of the dominant macroinfauna species inhabiting sand bottom within GRNMS are classified as opportunistic, pollution-tolerant species indicating that sediments within GRNMS are not polluted (Jeff Hyland, NOAA, unpublished data). This conclusion agrees with preliminary chemical analyses of sediments and macrofauna (Jeff Hyland, NOAA, unpublished data). These data suggest that the sand macroinfauna may be susceptible to anthropogenic disturbances.

Twenty-three species of the snapper grouper management unit have been found within GRNMS as juveniles or adults (Appendix 1)[2]. Six of these species are currently considered overfished (SAFMC 2001b): gag, red snapper, vermilion snapper, yellowtail snapper, sheepshead and red porgy. Of these six, only gag and sheepshead are common within GRNMS. The status of an additional nine species is presently unknown: Atlantic spadefish, whitebone porgy, scup, longspine porgy, almaco jack, crevalle jack, bar jack, yellow jack, and bank sea bass. Eight of the 23 snapper grouper management unit species occurring within GRNMS are not currently considered overfished: black sea bass, scamp, greater amberjack, mutton snapper, gray snapper, tomtate, white grunt, and gray triggerfish. **In light of the SAFMC general MPA goals, GRNMS could serve as an MPA to supplement management practices for the snapper grouper species that use GRNMS and to act as insurance for species whose current population status is unknown**.

[2] In all likelihood this number will increase by several species as additional research is conducted.

Includes vulnerable or rare stages?

From the perspective of fishes, four stages can be defined: egg, larval, early-juvenile (<1 year old) and late-juvenile/adult (> 1 year old). Late juveniles/adults are vulnerable to directed fisheries and as by-catch. Early juveniles are vulnerable as by-catch. The late juvenile/adults that occur within GRNMS are discussed above. There is little information on the occurrence of egg, larval and early-juvenile fish within GRNMS, but research is underway and more information will be available within 6-12 months (Jon Hare, NOAA, unpublished data).

Supports exploited species?

As discussed above, 23 members of the snapper grouper management unit have been found within GRNMS. In addition, a number of other recreationally or commercially exploited pelagic species occur in GRNMS including several sharks, Atlantic menhaden, Spanish mackerel and king mackerel (Appendix 1).

Supplies adjacent areas?

The utility of an MPA for insurance against overfishing or as a strategy to sustain fisheries is largely a function of the motility of species relative to the size of the MPA (Parrish 1999). The less time a fish spends in an MPA, the less efficient the MPA is in protecting the fish from fishing. Clearly many of the pelagic species move over scales much larger than GRNMS, and thus we are addressing this question only for members of the snapper grouper management unit that are benthic as adults.

The abundance and diversity of fishes in areas closed to fishing increases; the evidence is overwhelming (see review by Mosquera et al., 2000). This increased abundance of fish, however, must result in more fish outside of the MPA to be a benefit to fisheries. This export can occur during any of the four stages defined above: late-juvenile/adult (> 1 year old), early juvenile (< 1 year old), larval and egg. Information on late-juvenile/adult movements is limited. There may be seasonal patterns in movement (Dave Score, NOAA, unpublished data) or ontogenetic patterns in movement (Jon Hare, NOAA, unpublished data) that would result in fish moving to and from GRNMS. Sedberry et al. (1998) found a emigration rate of 6-15% for black sea bass tagged within GRNMS and at liberty for > 1 month. At these emigration rates, GRNMS would provide protection from fishing for black sea bass and as an MPA, GRNMS **might** result in greater numbers of black sea bass on adjacent non-MPA hard bottom. Emigration rates of other species to and from GRNMS are unknown.

There is almost no specific information on movements of early juveniles. In a recent review, Lindeman et al. (2000) concluded that many members of the snapper grouper management unit utilize early-juvenile habitats that are spatially distinct from late juvenile/adult habitats. For example, late juvenile/adult gag have been observed at GRNMS. Larvae are pelagic on the shelf and early juveniles utilize estuarine habitats (Keener et al. 1988, Ross and Moser 1994, Jon Hare, NOAA, unpublished data). Juvenile gag move from estuaries onto the shelf in the fall of their first year but the exact nature of these movements is unclear. Although juveniles are rarely the target of directed fisheries, they can be caught as by-catch. Juveniles of many other snapper-grouper species move

between habitats, and the exact nature of these movements will have implications on the success of an MPA. However, not enough is known to quantify its importance for each species in the snapper grouper management unit.

MPAs are often viewed as protecting spawning stock, which supplies non-protected areas with settling larvae, thereby contributing individuals to fished areas. Recent work conducted at GRNMS indicates that larvae spawned within GRNMS could be transported to other hard bottom habitats on time scales consistent with larval durations (Figure 1). It is likely that GRNMS would act as a source of larvae to other hard bottom areas and that GRNMS would receive larvae from other hard bottom sites in the area.

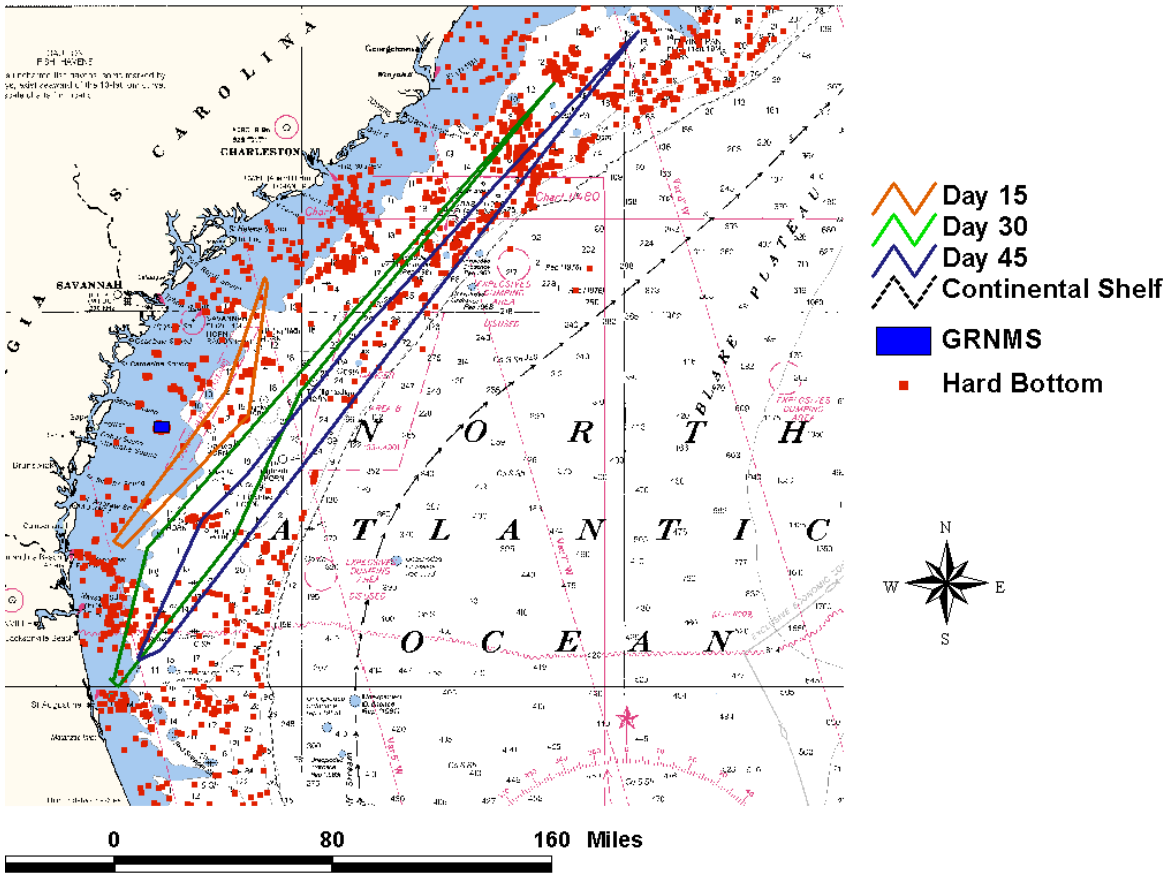


Figure 2. Envelopes of 12 drifters released within Gray's Reef National Marine Sanctuary. Drifters were released in April, June, October, 2000 and January 2001. Envelopes show the outline of the area encompassed by the drifters 15, 30 and 45 days following release. These data indicate that larval fish spawned within GRNMS could be in contact with a number of other hard bottom areas at the end of the larval stage. Larval duration of most of the snapper grouper species range from 15 to 45 days (Lindeman et al. 2000)

Is the area large enough?
GRNMS is not large enough by itself to act as insurance against overfishing or to promote the sustainability of reef fisheries along the southeast US shelf. GRNMS represents at most 0.6% of the hard bottom habitat between Cape Hatteras and Cape Canaveral[3]. **In light of the SAFMC general MPA goals, GRNMS by itself could serve as a scientific research area to improve understanding of species under management.**

To meet the SAFMC goals of using MPAs as a fishery management tool, previous studies suggest that MPAs on scales much larger than GRNMS are required. MPAs on the scale of 5-20% of habitat are needed to act as insurance against overfishing and MPAs on the scale of 20-50% are needed to promote the sustainability of fisheries without other regulations (Yoklavich 1998, Parrish 1999). At the scale of Cape Canaveral to Cape Hatteras, an MPA at GRNMS would have no effect on fisheries. However, at a more local scale (central Georgia coast), within the range of adult movement and larval transport, GRNMS **may** enhance local fish populations.

The SAFMC goal of using MPAs as a fishery management tool could be met by using an MPA at GRNMS as part of a larger network of MPAs. It is beyond the scope of this document to deal with this possibility. However, we would consider addressing this topic at the request of either the SAFMC or GRNMS.

Are adjacent coastal areas supportive?
Not in a position to answer this question.

Is it aesthetically appealing?
Aesthetics are personal, but we find the rocky ledges and open sand of GRNMS aesthetically pleasing.

Is it accessible to user groups?
GRNMS is 32 km off the coast of Sapelo Island, Georgia and is accessible by boat.

Can enforcement provide support?
GRNMS meets many of the enforcement recommendations outlined in SAFMC (2001a). GRNMS is rectangular, but is reasonably small. The boundaries are delineated by surface buoys, which are on NOAA nautical charts and are visible on radar under most sea conditions.

The Council's stated intent is to not '… *prohibit fishing for and/or the harvesting/ possession of pelagic species*' within MPAs developed as part of this process (SAFMC 2001a). However, the Joint Law Enforcement Committee and Advisory Panel on Enforcement Criteria for Establishing Marine Protected Areas stated, '*if any fishing activity or gear is allowed, enforcement becomes very difficult*'. If fishing for pelagic

[3] This estimate is based on the total reef area calculated by Parker et al. (1983), which is from 27-101 m. If areas <27 m were included, the amount of total reef habitat would be larger, thereby decreasing the relative amount of reef habitat within GRNMS.

species within GRNMS as a SAFMC MPA is allowed, then it is likely that enforcement cannot provide support.

Is there effective management?
GRNMS currently has some restrictions on use (Appendix 2) and has a small staff dedicated to research, management, education and outreach at the Sanctuary. A management plan has been in place since 1983. It is currently being revised by GRNMS staff and the GRNMS Advisory Council.

Does it satisfy socio-cultural needs?
Not in a position to answer this question.

Does it preserve historical site(s)?
GRNMS is a historical fishing location. Gray's Reef has been known to local fishermen for hundreds of years and in the 18th and 19th century it was identified as the Sapelo Ground (Terrell, 1996).

GRNMS also represents a unique location of paleontologically and archaeologically interesting finds. Under the inclusive definition used by the Marine Sanctuary Act, "historical" resources include those of both an archaeological and paleontological nature. At GRNMS the discovery of several fossil species-Pleistocene horse, mammoth and bison-in a relatively restricted geographic locale is unparalleled. That these fossil finds were discovered and identified by a concerted scientific program of research beginning in 1994 is also important. The finds have been located, mapped and carefully recovered for laboratory study. This work has resulted in a greater understanding of past sea level, climate and their impact on coastal biological communities. GRNMS plays a unique preservation role for these resources by limiting bottom disturbance as well as monitoring studies of them.

Acknowledgements

Reed Bohne (GRNMS), Brian Degan (CCFHR), Katey Marancik (CCFHR), Harvey Walsh (CCFHR) provided useful comments during preparation of this document. Alex Score (GRNMS) provided Figure 1. Marlene Patterson (CCFHR) put together Figure 2. Harvey Walsh and Brian Degan provided Appendix 1. Becky Shortland (GRNMS) provided Appendix 2 and several references. Figures used on the cover were provided by GRNMS.

Literature Cited

Chester, AJ; Huntsman, GR; Tester, PA; Manooch, CS. 1984. South Atlantic Bight reef fish communities as presented in hook-and-line catches. Bull. Mar. Sci. 34:267-279.

Gilligan, MR. 1989. An illustrated field guide to the fishes of Gray's Reef National Marine Sanctuary. NOAA Tech. Memo. NOS MEMD 25:1-77.

Grimes, CB; Manooch, CS; Huntsman, GR. 1982. Reef and rock outcropping fishes of the outer continental shelf of North Carolina and South Carolina and ecological notes on the red porgy and vermilion snapper. Bull. Mar. Sci. 32: 277-289.

Hendler, G. 1984. The association of *Ophiothrix lineata* and *Callyspongia vaginalis*: A brittlestar sponge cleaning symbiosis? P.S.Z.N. I: Mar. Ecol. 5: 9-27.

Henry, VJ; Van Sant, SB. 1982. Results of reconnaissance mapping of the Gray's Reef National Marine Sanctuary. A report prepared for the Georgia Department of Natural Resources, Coastal Resources Division, Brunswick, GA, under cooperative agreement with Sanctuary Programs Division of the National Oceanic and Atmospheric Administration

Hunt, JL. 1974. The geology and origin of Gray's Reef, Georgia continental shelf. M.Sc.Thesis, University of Georgia, Athens

Keener, P; Johnson, GD; Stender, BW; Brothers, EB; Beatty, HR. 1988. Ingress of postlarval gag, *Mycteroperca microlepis* (Pisces: Serranidae), through a South Carolina barrier island inlet. Bull. Mar. Sci. 42:376-396.

Lindeman, KC; Pugliese, R; Waugh, GT; Ault, JS. 2000. Developmental patterns within a multispecies reef fishery: Management applications for essential fish habitats and protected areas. Bull. Mar. Sci. 66:929-956.

Mosquera, I; Cote, IM; Jennings, S; Reynolds, JD. 2000. Conservation benefits of marine reserves for fish populations. Anim. Conserv. 3:321-332.

Parker, RO; Chester, AJ; Nelson, RS. 1994. A video transect method for estimating reef fish abundance, composition and habitat utilization at Gray's Reef National Marine Sanctuary, Georgia. Fish. Bull., U.S. 92:787-799.

Parker, RO; Colby, DR; Willis, TD. 1983. Estimated amount of reef habitat on a portion of the U. S. South Atlantic and Gulf of Mexico Continental Shelf. Bull. Mar. Sci. 33:935-940.

Parker, RO; Dixon, RL. 1998. Changes in a North Carolina reef fish community after 15 years of intense fishing-global warming implications. Trans. Amer. Fish. Soc. 127: 909-920.

Parrish, R. 1999. Marine reserves for fisheries management: why not? Cal. Coop. Ocean. Fish. Invest. 40:77-86.

Ross, SW; Moser, ML. 1995. Life history of juvenile gag, *Mycteroperca microlepis*, in North Carolina estuaries. Bull. Mar. Sci. 56:222-237.

Sedberry , GR. 1985. Food and feeding of the tomtate, *Haemulon aurolineatum* (Pisces, Haemulidae), in the South Atlantic Bight. Fish. Bull., U.S. 83: 461-466.

Sedberry, GR. 1988. Food and feeding of black sea bass, *Centropristis striata*, in live bottom habitats in the South Atlantic Bight. J. Elisha Mitchell Sci. Soc. 104: 35-50.

Sedberry, GR. 1989. Feeding habits of whitebone porgy, *Calamus leucosteus* (Teleostei: Sparidae), associated with hard bottom reefs off the southeastern United States. Fish. Bull., U.S. 87: 935-944.

Sedberry, GR, Cuellar, N. 1993. Planktonic and benthic feeding by the reef-associated vermilion snapper, *Rhomboplites aurorubens* (Teleostei: Lutjanidae). Fish. Bull. U.S. 91: 699-709.

Sedberry, GR; Van Dolah, RF. 1984. Demersal fish assemblages associated with hard bottoms habitat in the South Atlantic Bight of the U.S.A. Env. Biol. Fishes 11:241-258.

South Atlantic Fishery Management Council. 2001a. Magnuson-Stevens ACT/NEPA scoping document: using marine protected areas in the South Atlantic. Charleston, South Carolina.

South Atlantic Fishery Management Council. 2001b. Briefing document for snapper grouper assessment group meeting February 20-21 in Jacksonville Florida. Charleston, South Carolina.

Southeast Area Monitoring and Assessment Program. 1998. Bottom mapping workgroup, South Atlantic Bight, CD-ROM deliverables.

Terrell, BG. 1996. Fathoming our past – historical contexts of the National Marine Sanctuaries. The Mariners' Museum, Newport News, VA

Van Dolah, RF; Wendt, PH; Nicholson, N. 1987. Effects of a research trawl on a hard-bottom assemblage of sponges and corals. Fish. Res. 5:39-54.

Wenner, EL; Knott, DM; Dolah, RF; Burrell, VG. 1983. Invertebrate communities associated with hard bottom habitats in the South Atlantic Bight. Estuar. Coast. Shelf Sci. 17:143-158.

Wenner, CA; Sedberry, GR. 1989. Species composition, distribution, and relative abundance of fishes in the coastal habitat off the southeastern United States. NOAA Tech. Rep. 79:1-58.

Yoklavich, M. (ed.) 1998. Marine harvest refugia for West Coast rockfish: a workshop. NOAA-TM-NMFS-SWFSC-255.

Appendix 1. Fish Fauna within Gray's Reef National Marine Sanctuary. Data is derived from five sources indicated in the Fish Censuses column: A) Gilligan (1989), B) Parker et al. (1994), C) Sedberry et al. (1999), D) Walsh et al., (unpublished data, NOAA, NOS, NCCOS, CCFHR), E) Score et al. (unpublished data, NOAA, NOS, NMS, GRNMS).Members of the snapper grouper management unit were from Appendix C in SAFMC (2001a) and status of snapper grouper stocks was from SAFMC (2001b).

			Fish Census					Snapper/Grouper FMP	
Family	**Species**	**Common Name**	**A**	**B**	**C**	**D**	**E**	**Member**	**Overfished**
Odontaspididae	*Odontaspis taurus*	sand tiger	x						
Carcharhinidae	*Carcharhinus falciformis*	silky shark	x						
	Carcharhinus leucas	bull shark	x						
	Carcharhinus obscurus	dusky shark	x						
	Carcharhinus plumbeus	sandbar shark	x						
	Galeocerdo cuvieri	tiger shark	x						
	Negaprion brevirostris	lemon shark	x						
	Rhizoprioltodon terraenovae	Atlantic sharpnose shark	x						
Sphyrnidae	*Splhlryna lewini*	scalloped hammerhead	x						
	Splhlryna mokarran	great hammerhead	x						
	Splhlryna zygaena	smooth hammerhead	x						
Squalidae	*Squalus acanhtias*	spiny dogfish	x						
Orectolobidae	*Ginglymostoma cirratum*	nurse shark	x	x			x		
Dasyatidae	*Dasyatis sayi*	bluntnose stingray				x			
	Dasyatis americana	southern stingray	x	x			x		
	Dasyatis centroura	roughtail stingray	x						
Congridae	*Ariosoma balearicum*	bandtooth conger				x			
	Conger oceanicus	conger eel	x						
Ophichthidae	*Letharchus velifer*	sailfin eel	x			x			
	Ophichthus ocellatus	palespotted snake eel	x			x			
	Ophichthus sp.	snake eel				x			
	Myrophis punctatus	speckled worm eel	x	x					
	Ahlia egmontis	key worm eel	x						
Muraenidae	Muranenidae	unidentified moray		x					
	Muraena retifera	reticulate moray	x						
	Gymnothorax saxicola	ocellated moray	x						
	Gymnothorax moriger						x		
Clupeidae	*Brevoortia tyrannus*	Atlantic menhaden	x	x		x			
	Etrumeus teres	round herring				x			
	Sardinella aurita	Spanish sardine	x	x		x			
	Ophisthonema oglinum	Atlantic thread herring	x						
Engraulidae	*Anchoa hepsetus*	striped anchovy				x			
	Anchoa lamprotaena	bigeye anchovy				x			

Family	Species	Common Name	A	B	C	D	E	Member	Overfished
Synodontidae	*Synodus foetens*	inshore lizardfish	x	x		x	x		
	Synodus intermedius	sand diver	x				x		
	Trachinocephalus myops	snakefish	x	x		x			
Batrachoididae	*Porichtys plectrodon*	Atlantic midshipman	x						
	Opsanus pardus	leopard toadfish	x		x		x		
	Opsanus sp.	unidentified toadfish		x					
	Opsanus tau	oyster toadfish	x				x		
Antennariidae	*Antennarius radiosus*	singlespot frogfish	x						
	Antennarius scaber	splitlure frogfish	x						
	Histrio histrio	sargassumfish	x						
	Antennarius ocellatus	ocellated frogfish	x						
Ogcocephalidae	*Ogocephalus nasutus*	shortnose batfish				x			
	Ogcocephalus spp.	batfish	x						
	Halieutichthys spp.	batfish	x						
Gadidae	*Urophycis floridana*	southern hake				x			
	Urophycis regia	spotted hake	x			x			
	Urophycis earlli	Carolina hake	x						
Bythitidae	*Obilbia sp.*	brotula	x						
Ophidiidae	*Lepophidium sp*	cusk-eel	x						
	Ophidion holbrooki	bank cusk-eel	x			x			
	Ophidion grayi	blotched cusk-eel				x			
	Ophidion marginatum	striped cusk-eel				x			
	Ophidion selenops	mooneye cusk-eel				x			
	Ophidion welshi	crested cusk-eel				x			
	Ophidion spp.	cusk eel	x						
Carapidae	*Carapus bremudensis*	pearlfish				x			
	Eciodon dawsoni	pearlfish				x			
Exocoetidae	*Hirundichthys affinis*	fourwing flyingfish				x			
Atherinidae	*Menidia menidia*	Atlantic silverside				x			
Syngnathidae	*Hipocampus erectus*	lined seahorse	x	x		x			
	Syngnathus springeri	bull pipefish				x			
	Syngnathus louisianae	chain pipefish	x	x					
	Micrognathus crinitus	banded pipefish	x	x					
Holocentridae	*Holocentrus ascencionis*	squirrelfish	x	x			x		
Serranidae	*Centropristis ocyurus*	bank sea bass	x	x	x		x	yes	unknown
	Centropristis striata	black sea bass	x	x	x	x	x	yes	no
	Centropristis philadelphica	rock sea bass	x	x					
	Diplectrum formosum	sand perch	x	x		x	x		
	Serraniculus pumilio	pygmy sea bass				x			
	Serranus subligarius	belted sandfish	x	x		x	x		
	Serranus phoebe	tattler	x						
	Mycteroperca phenax	scamp	x	x			x	yes	no
	Mycteroperca microlepis	gag	x	x			x	yes	yes
Grammistidae	*Rypticus maculatus*	whitespotted soapfish	x	x			x		

Family	Species	Common Name	A	B	C	D	E	Member	Overfished
Priacanthidae	*Priacanthus arenatus*	bigeye	x	x					
	Pristigenys alta	short bigeye	x	x		x			
Apogonidae	*Apogon pseudomaculatus*	twospot cardinalfish	x	x			x		
	Phaeoptyx pigmentaria	dusky cardinalfish	x	x					
	Apogon maculatus	flamefish	x						
Pomatomidae	*Pomatomus saltatrix*	bluefish	x						
Rachycentridae	*Rachycentron canadum*	cobia	x				x		
Echeneidae	*Echeneis naucrates*	sharksucker	x						
Carangidae	*Decapterus macarellus*	mackerel scad	x				x		
	Decapterus sp.	scad				x			
	Selene vomer	lookdown				x			
	Caranx bartholomaei	yellow jack	x	x			x	yes	unknown
	Caranx ruber	bar jack	x	x			x	yes	unkown
	Caranx sp.	unidentified jack		x					
	Decapterus punctatus	round scad	x	x			x		
	Seriola dumerili	greater amberjack	x	x			x	yes	no
	Seriola rivoliana	almaco jack		x				yes	unknown
	Caranx hippos	crevalle jack	x					yes	unknown
	Trachurus lathami	rough scad	x						
	Trachinotus falcatus	permit	x						
	Naucrates ductor	pilotfish	x						
Coryphaenidae	*Corypltaena hippurus*	dolphin	x						
Lutjanidae	*Lutjanus analis*	mutton snapper				x		yes	no
	Lutjanus campechanus	red snapper	x	x			x	yes	yes
	Lutjanus sp.	juvenile snapper		x					
	Rhomboplites aurorubens	vermilion snapper	x				x	yes	yes
	Lutjanus griseus	gray snapper	x				x	yes	no
	Ocyurus chrysurus	yellowtail snapper	x				x	yes	yes
Haemulidae	*Haemulon sp.*	grunt		x		x			
	Haemulon aurolineatum	tomtate	x		x		x	yes	no
	Orthopristis chrysoptera	pigfish	x	x					
	Haemulon plumieri	white grunt	x				x	yes	no
Sparidae	*Lagodon rhomboides*	pinfish	x		x	x	x		
	Sparidae	porgy				x			
	Stenotomus sp.	porgy ?				x			
	Stenotomus aculeatus	porgy ?			x				
	Stenotomus caprinus	longspine porgy	x	x				yes	unknown
	Stenotomus chrysops	scup	x		x		x	yes	unknown
	Diplodus holbrooki	spotfin pinfish	x	x	x		x		
	Calamus leucosteus	whitebone porgy	x	x	x		x	yes	unknown
	Archosargus probatocephalus	sheepshead	x	x			x	yes	yes
	Pagrus pagrus	red porgy	x	x			x	yes	yes
Labride	*Xyrichtys novacula*	pearly razorfish	x	x		x	x		
	Halichoeres caudalis	painted wrasse	x		x		x		
	Halichoeres bivittatus	slippery dick	x	x			x		
	Tautoga onitis	tautog	x	x			x		

Family	Species	Common Name	A	B	C	D	E	Member	Overfished
Scaridae	*Sparisoma sp.*	unidentified parrotfish		x			x		
Sciaenidae	*Cynosion nothus*	silver seatrout				x			
	Leiostomus xanthurus	spot				x			
	Micropogonias undulatus	Atlantic croaker				x			
	Equetes umbrosus	cubbyu		x	x	x	x		
	Equetus acuminatus	high-hat		x	x		x		
	Equetus lanceolatus	jacknife-fish		x	x				
Mullidae	*Pseudupeneus maculatus*	spotted goatfish		x		x			
	Mullus auratus	red goatfish		x	x				
	Upeneus parvus	dwarf goatfish		x			x		
Ephippidae	*Chaetodipterus faber*	Atlantic spadefish		x	x		x	yes	unknown
Chaetodontidae	*Chaetodon ocellatus*	spotfin butterflyfish		x	x		x		
	Chaetodon sedentarius	reef butterflyfish		x	x		x		
	Chaetodon striatus	banded butterflyfish		x	x				
	Chaetodon aya	bank butterflyfish		x					
Pomacanthidae	*Holocanthus bermudensis*	blue angelfish		x	x		x		
Pomacentridae	*Pomacentrius partitus*	bicolor damselfish		x	x		x		
	Pomacentrius variabilis	cocoa damselfish		x	x		x		
	Chromis enchrysurus	yellowtail reeffish		x					
	Abudefduf saxatilis	sargeant major		x			x		
Mugilidae	*Mugil curema*	white mullet				x			
	Mugil cephalus	striped mullet				x			
Opistognathidae	*Opistognathus sp.*	jawfish			x				
Dactyloscopidae	*Dactyloscopus moorei*	sand stargazer				x			
Clinidae	*Starksia ocellata*	checkered blenny		x			x		
Blenniidae	*Hypleurochilus geminatus*	crested blenny		x			x	x	
	Ophioblennius atlanticus	redlip blenny		x	x		x		
	Parablennius marmoreus	seaweed bleeny		x	x		x		
	Blenniidae	unidentified blenny			x				
Callionymidae	*Diplogrammus pauciradiatus*	spotted dragonet				x			
Gobiidae	*Ioglossus calliurus*	blue goby			x				
	Ioglossus helenae	hovering ggy		x					
	Microgobius sp.	goby				x			
	Microgobius carri	Seminole goby		x	x				
	Pslotris celsus	highspine goby		x					
	Coryphopterus punctipectophorus	spotted goby		x					
	Coryphopterus dicrus	colon goby		x					
	Coryphopterus glaucofraneum					x			
	Lythrypnus phorellus	convict goby	x						
	Lythrypnus spilus	bluegold goby	x						

Family	Species	Common Name	AB	C	D	E	Member	Overfished
Acanthuridae	*Acanthurus bahianus*	ocean surgeon	x	x		x		
	Acanthurus chirurgus	doctorfish	x	x		x		
Scombridae	*Euthynnus alleteratus*	little tunny	x	x				
	Scomberomorus maculatus	Spanish makerel	x	x				
	Scomberomorus cavalla	king mackerel	x			x		
Sphyraenidae	*Sphyraena barracuda*	great barracuda	x	x		x		
	Sphyraena guachancho	guaguanche	x					
	Sphyraena borealis	northern sennet	x					
	Sphyraena picudilla	southern sennet	x					
	Sphyraena sp.							
Stromateidae	*Peprilus triacanthus*	butterfish			x			
	Psenes maculatus	silver driftfish		x				
Scorpaenidae	*Scorpaena dispar*	hunchback scorpionfish	x		x			
	Scorpaena plumieri	spotted scorpionfish	x		x			
	Scorpaena sp.	scorpionfish			x			
	Scorpaena brasiliensis	barbfish	x					
	Scorpaena calcarata	smoothhead scorpionfish	x					
	Scorpaena agassizi	longfin scorpionfish	x					
Triglidae	*Prionotus carolinus*	northern searobin	x		x			
	Prionotus evolans	striped searobin	x					
	Prionotus ophryas	bandtail searobin	x					
	Prionotus sp.	searobin		x	x			
	Prionotus roseus	bluespotted searobin	x					
	Prionotus scitulus	leopard searobin	x					
Bothidae	*Ancylcopsetta quadrocellata*	three-eye flounder			x			
	Bothus sp.	flounder			x			
	Citharichthys macrops	spotted whiff			x			
	Citharichthys sp	flounder			x			
	Cyclopsetta fimbriata	spotfin flounder			x			
	Etropus sp.	flounder			x			
	Paralichthys lethostigma	southern flounder			x	x		
	Scophthalamus aquosus	windowpane			x			
	Syacium papillosum	dusky flounder	x		x			
	Bothidae	flounder		x				
Soleidae	*Gymnachirus melas*	naked sole			x			
Cynoglossidae	*Symphurus diomedeanus*	spottedfin tonguefish			x			
	Symphurus minor	largescale tonguefish			x			
	Symphurus plagiusa	blackcheek tonguefish			x			
	Symphurus urospilus	spottail tonguefish			x			
Balistidae	*Aluterus schoepfi*	orange filefish	x	x		x	x	
	Aluterus heudoloti	dotterel filefish	x	x				
	Monocanthus hispidus	planehead filefish	x	x		x		
	Monocanthus setifer	pygmy filefish	x					
	Balistes capriscus	gray triggerfish	x	x	x	x	yes	no
	Cantherhines pullus	orangespotted filefish	x			x		

Family	Species	Common Name	A	B	C	D	E	Member	Overfished
Tetraodontidae	*Sphoeroides sp.*	puffer					x		
	Sphoeroides maculatus	northern puffer	x		x				
	Sphoeroides nephelus	Florida puffer	x						
	Sphoeroides spengleri	bandtail puffer	x				x		
	Sphoeroides testudineus	checkered puffer	x						
	Sphoeroides dorsalis	marbled puffer	x				x		
	Lagocephalus laevigatus	smooth puffer	x						
Diodontidae	*Chilomycterus schoepfi*	stripped burrfish	x						
	Diodon hystrix	porcupinefish		x					
Ostraciidae	*Lactophyrs quadricornis*	scrawled cowfish	x	x			x		
	Lactophyrs triqueter	smooth trunkfish	x	x					

Appendix 2

GRAY'S REEF NATIONAL MARINE SANCTUARY
List of Prohibited Activities

(a) Except as may be necessary for national defense (subject to the terms and conditions of Article 5, Section 2 of the Designation Document) or to respond to an emergency threatening life, property, or the environment, or except as may be permitted by the Director in accordance with § 922.48 and § 922.92, the following activities are prohibited and thus are unlawful for any person to conduct or to cause to be conducted within the Sanctuary:

(1) Dredging, drilling, or otherwise altering the seabed in any way nor constructing any structure other than a navigation aid.

(2) Discharging or depositing any material or other matter except:

(i) Fish or parts, bait, and chumming materials;

(ii) Effluent from marine sanitation devices; and

(iii) Vessel cooling waters.

(3) Operating a watercraft other than in accordance with the Federal rules and regulations that would apply if there were no Sanctuary.

(4) Using, placing, or possessing wire fish traps.

(5) Using a bottom trawl, specimen dredge, or similar vessel-towed bottom sampling device.

(6) (i) (A) Breaking, cutting, or similarly damaging, taking, or removing any bottom formation, marine invertebrate, or marine plant.

(B) Taking any tropical fish.

(C) Using poisons, electric charges explosives, or similar methods to take any marine animal not otherwise prohibited to be taken.

(ii) There shall be a rebuttable presumption that any bottom formation, marine invertebrate, tropical fish, marine plant, or marine animal found in the possession of a person within the Sanctuary have been collected within or removed from the Sanctuary.

(7) Tampering with, damaging, or removing any historic or cultural resources.

(b) All activities currently carried out by the Department of Defense within the Sanctuary are essential for the national defense and, therefore, not subject to the prohibitions in this section. The exemption of additional activities having significant impacts shall be determined in consultation between the Director and the Department of Defense.

APPENDIX 2

Survey of benthic macroinfauna and levels of chemical contaminants in sediments and biota at Gray's Reef National Marine Sanctuary

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)

September 2001

Submitted by

Jeffrey Hyland, Cynthia Cooksey, Leonard Balthis, Geoff Scott, and Daniel Bearden

NOAA National Ocean Service, National Centers for Coastal Ocean Science, 219 Fort Johnson Road, Charleston, SC 29412-9110

Submitted to

Gray's Reef National Marine Sanctuary Office
NOAA National Ocean Service
Office of National Marine Sanctuaries
10 Ocean Science Circle
Savannah, GA 31411

NOAA ■ National Ocean Service ■ National Centers for Coastal Ocean Science

1. Introduction

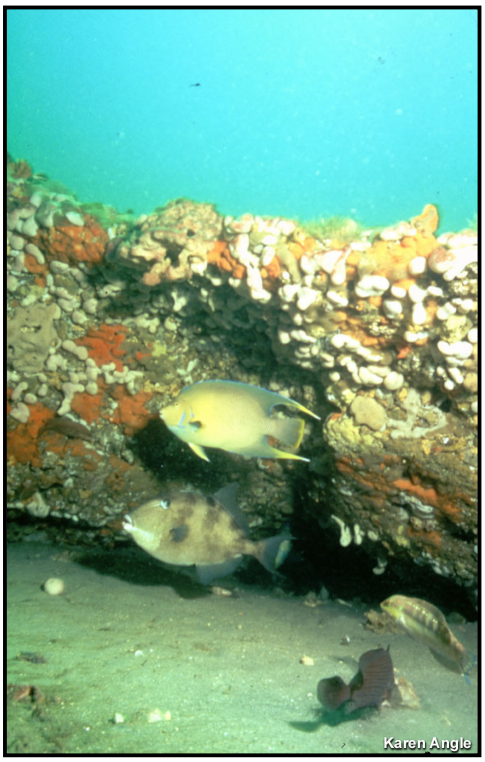


Figure 1. Live bottom habitat at Grays Reef National Marine Sanctuary. Photo courtesy of Karen Angle.

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.

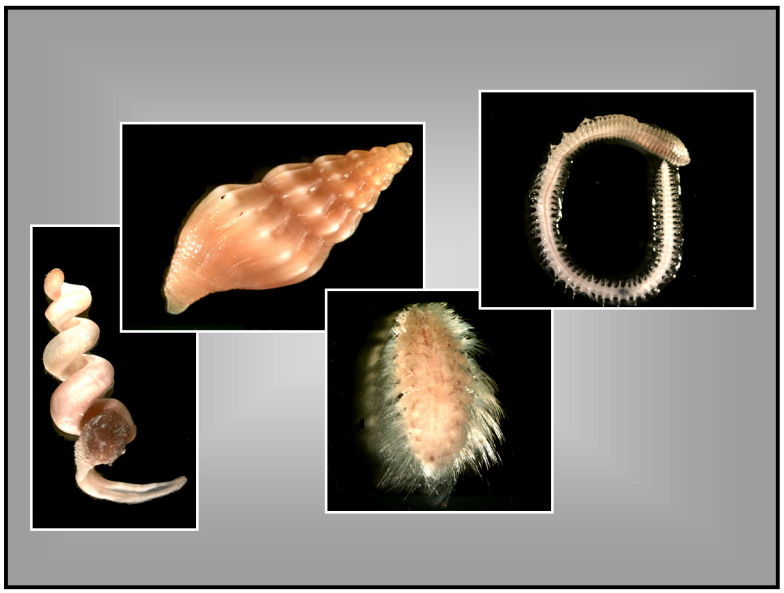


Figure 2. Examples of benthic macroinfaunal at GRNMS.

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).

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.

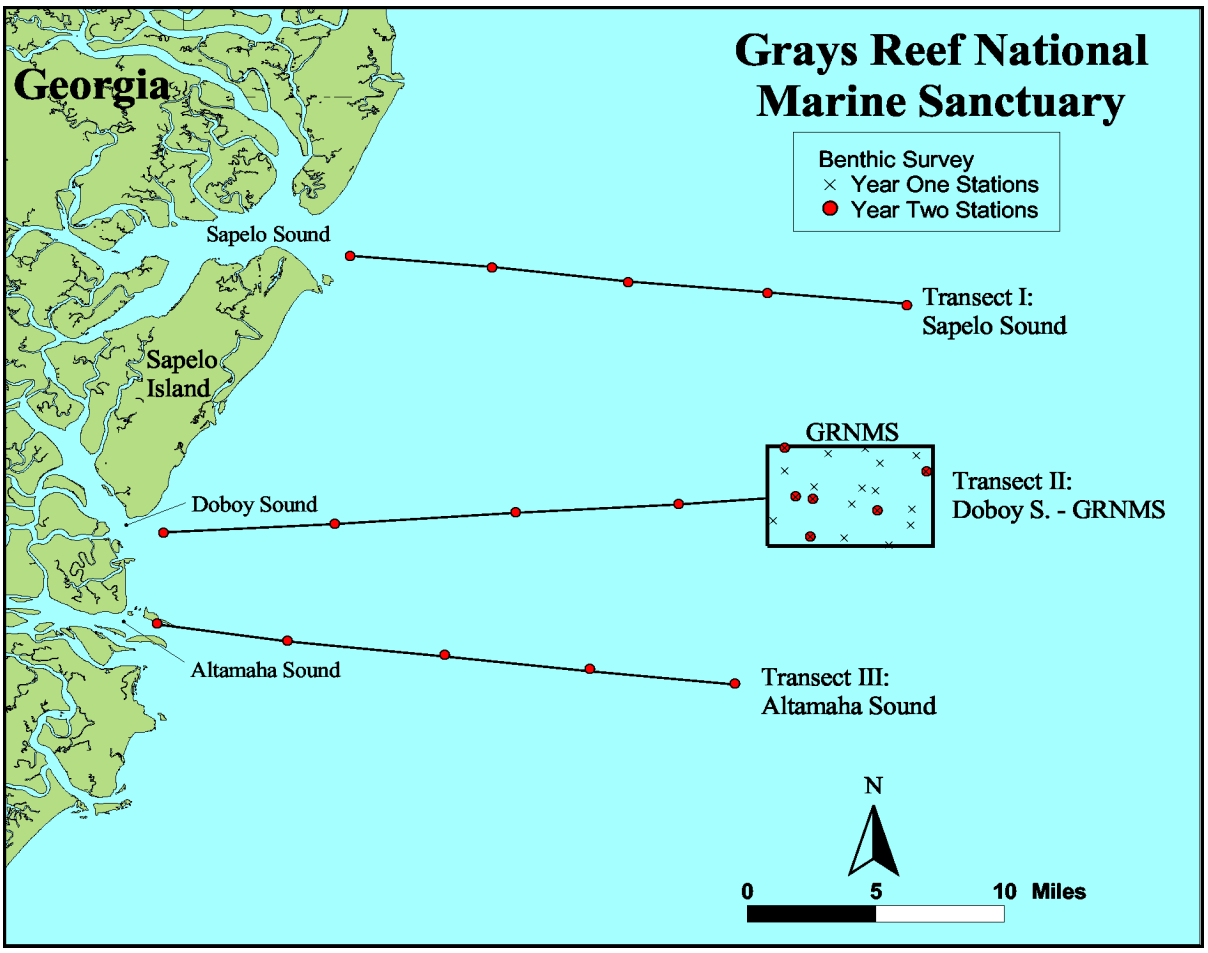


Figure 3. Sampling design for benthic survey.

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.

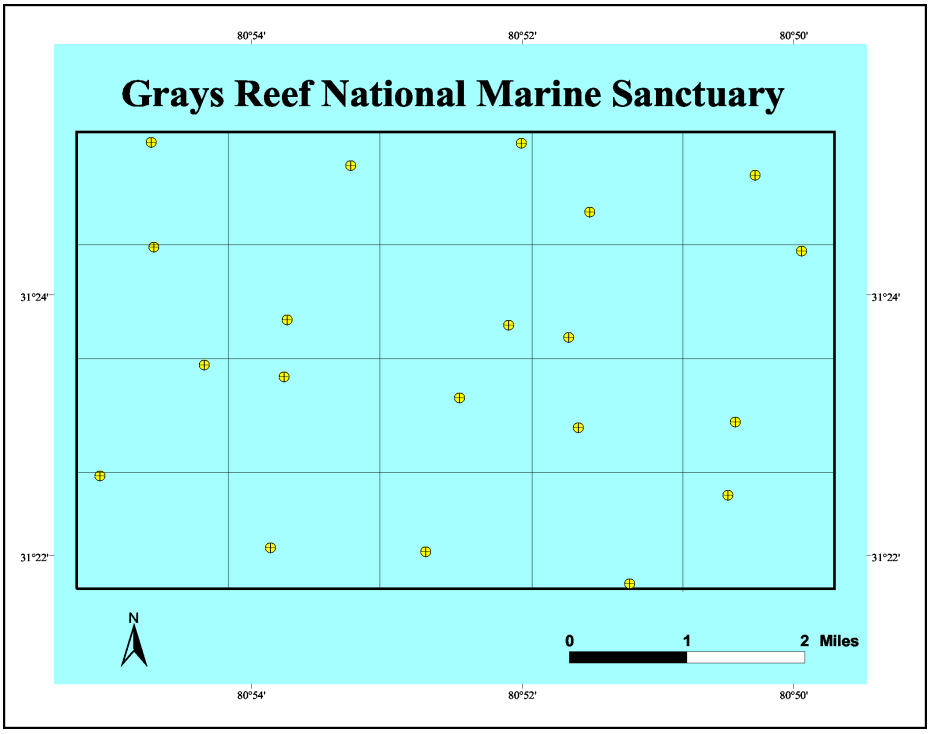


Figure 4. Site locations within GRNMS. The random sampling framework allows unbiased statistical estimation of the percentage of area with degraded vs. non-degraded condition relative to various measured environmental variables. Each cell = 2.9 km^2.

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.

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.

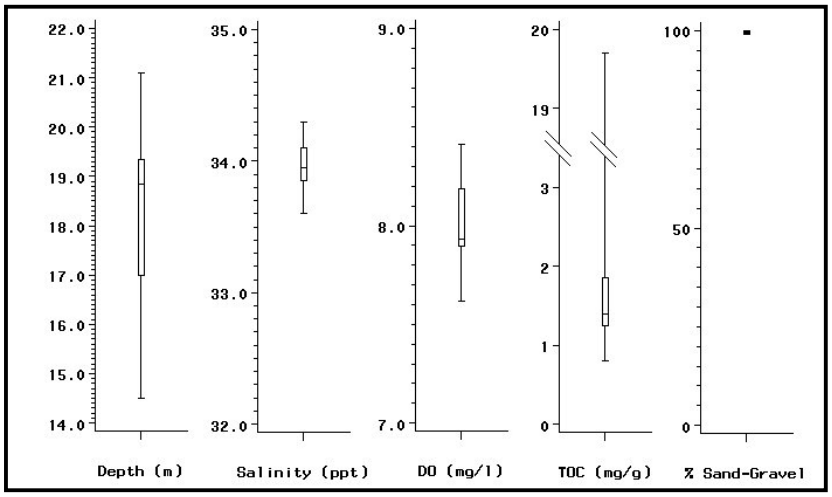


Figure 5. Key habitat characteristics at GRNMS in April 2000 (n = 20 sites). Boxes are interquartile ranges, horizontal lines within boxes are medians and wisker endpoints are high/low extremes. Note in the last plot that values of % sand-gravel fall within a very narrow range of 99-100%.

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.

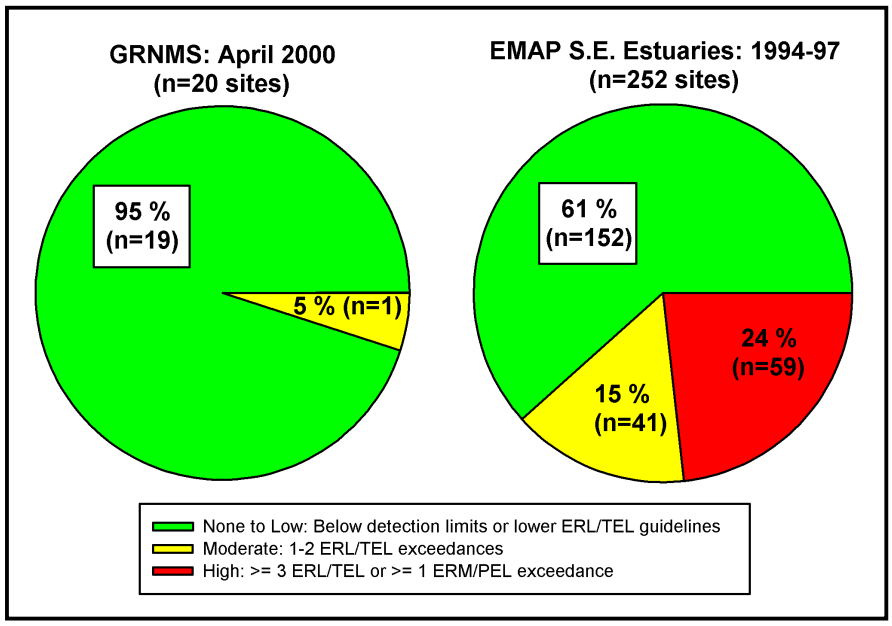


Figure 6. Comparison of sediment contamination (% area) at GRNMS during the present study vs. southeastern estuaries sampled during EMAP (unpublished data from senior author).

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

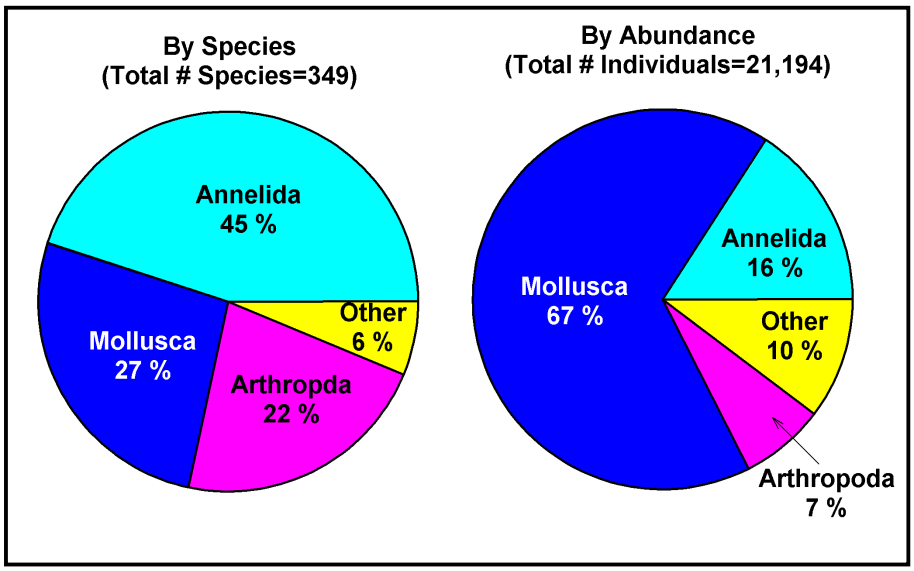


Figure 7. Relative composition of major taxonomic groups of macroinfauna at GRNMS. Data based on 3 replicate grabs (0.04 m^2) at each of 20 stations.

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	Ophiuroid	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 (0.04m^2 each) were taken at each station.

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

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

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.

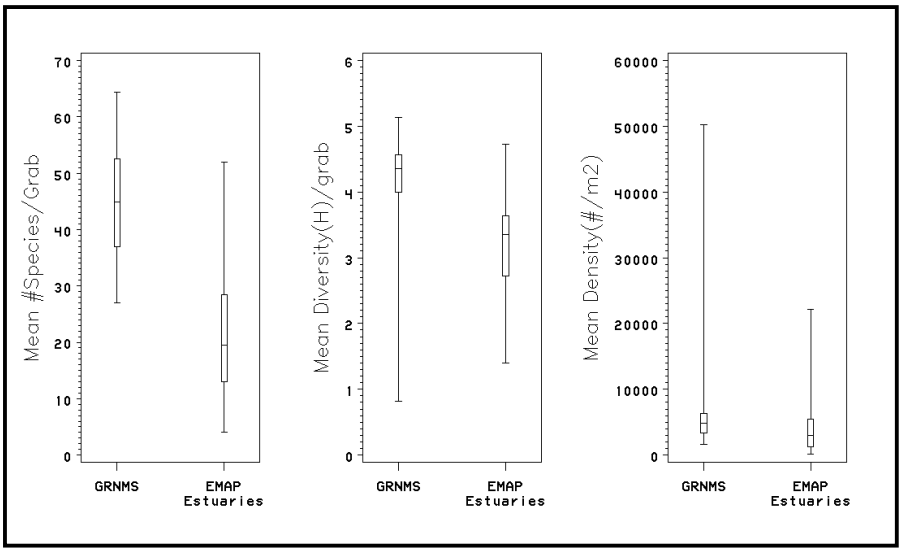


Figure 8. Comparison of benthic species richness, diversity and abundance at GRNMS sites (n = 20) vs. estuarine sites of similar salinity (> 30 ppt) in EMAP Carolinian Province (n = 38). Boxes are interquartile ranges, horizontal lines within boxes are medians and wisker endpoints are high/low extremes.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

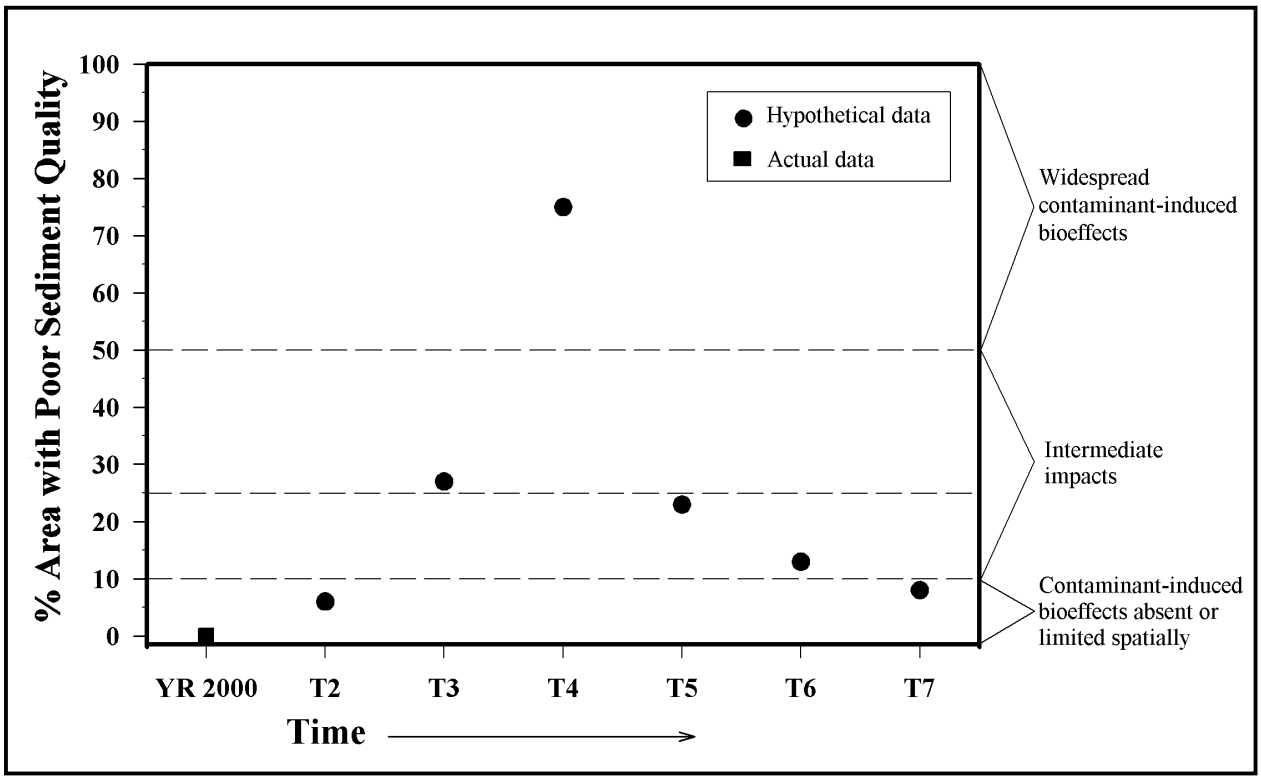


Figure 9. Examples of how probability-based sampling data could be used to monitor potential changes in sediment quality with time at GRNMS. Y-axis is % area exhibiting poor sediment quality, as indicated by combined evidence of low benthic species richness (e.g., < 30 species/grab) accompanied by high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

This work was sponsored by the NOAA National Marine Sanctuaries (NMS) Program. Special recognition is extended to Reed Bohne (NOAA/GRNMS Office), Charlie Alexander (NOAA/NMS Headquarters), Nathalie Valette-Silver (NOAA/NCCOS Headquarters), and Jon Hare (NOAA/NCCOS/CCFHR) for program coordination; to Barry Vittor & Associates (Mobile, AL) for analysis of macroinfaunal samples, TOC, and particle-size; to Peter Jenkins,

Aaron Dias, Eric Strozier, Scott Sivertsen, and Brian Shaddrix (NOAA/NCCOS/CCEHBR) for analysis of contaminants in sediments and tissues; and to Cathy Sakas, Greg McFall, and Ralph Rogers (NOAA/GRNMS Office), as well as the crew of the NOAA Ship FERREL, for assistance with sample collections.

7. References

Barry A. Vittor & Associates, Inc. 2001. Gray's Reef benthic macroinvertebrate community assessment, April 2000. Final Report to NOAA under contract No. 50-DGNC-0-90024, NOAA NOS, Charleston, SC.

Chapman, P.M. 1990. The sediment quality triad approach to determining pollution-induced degradation. *Science Total Environment*, 97(98): 815-825.

Diaz, R.J., & R. Rosenberg. 1995. Marine benthic hypoxia: A review of its ecological effects and the behavioral responses of benthic macrofauna. *Oceanography & Marine Biology: an Annual Review*, 1995, 33: 245-303.

FDA. 1984. Polychlorinated biphenyls (PCBs) in fish and shellfish; Reduction of Tolerances; Final Decision. Federal Register, Vol. 49, No. 100. 21 CFR Part 109.

FDA. 1993a. Guidance document for arsenic in shellfish. Center for Food Safety and Applied Nutrition. U.S. Food and Drug Administration, Washington, DC.

FDA. 1993b. Guidance document for cadmium in shell-fish. Center for Food Safety and Applied Nutrition. U.S. Food and Drug Administration, Washington, DC.

FDA. 1993c. Guidance document for chromium in shell-fish. Center for Food Safety and Applied Nutrition. U.S. Food and Drug Administration, Washington, DC.

FDA. 1993d. Guidance document for lead in shellfish. Center for Food Safety and Applied Nutrition. U.S. Food and Drug Administration, Washington, DC.

FDA. 1993e. Guidance document for nickel in shellfish. Center for Food Safety and Applied Nutrition. U.S. Food and Drug Administration. Washington, DC.

FDA. 1994. Action levels for poisonous or deleterious substances in human food and animal feed. Department of Health and Human Services, Public Health Service, Food and Drug Administration. Washington, DC.

Long, E.R., D.D. MacDonald, S.L. Smith, & F.D. Calder. 1995. Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. *Environmental Management*, 19: 81–97.

Long, E.R. & L.G. Morgan. 1990. The potential for biological effects of sediment-sorbed contaminants tested in the National Status and Trends Program. NOAA Tech. Memo. NOS OMA 52, NOAA, Silver Spring, MD.

MacDonald, D.D, R.S. Carr, F.D. Calder, E.R. Long, & C.G. Ingersoll. 1996. Development and evaluation of sediment quality guidelines for FL coastal waters. *Ecotoxicology*, 5: 253-278.

Marine Resources Research Institute (MRRI). 1982. South Atlantic OCS Area Living Marine Resources Study, Year II. Vols. I-III. Final Report submitted by MRRI (S.C. Wildlife and Marine Resources Department) under Contract AA551-CT1-18 to Minerals Management Service, Washington, D.C.

Sedberry, G.R. 1985. Food and feeding of the tomtate, *Haemulon aurolineatum* (Pisces, Haemulidae), the South Atlantic Bight. *Fishery Bulletin*, 83(3): 461-466.

Van Dolah, R.F., P.H. Wendt, D.A. Goldman, A.B. Wrona, R.A. Pardieck, & M.V. Levisen. 1997. An Assessment of Benthic Infaunal Assemblages and Sediments in the Vicinity of the Charleston Ocean Dredged Material Disposal Area. Final Report submitted by Marine Resources Research Institute (S.C. Department of Natural Resources) to U.S. Army Corps of Engineers Charleston District. 59 p and 3 appendices.

Windom, H.L., S.J. Schropp, F.D. Calder, J.D. Ryan, R.G. Smith Jr., L.C. Burney, F.G. Lewis, and C.H. Rawlinson. Natural trace metal concentrations in estuarine and coastal marine sediments of the southeastern United States. Environmental Science and Technology, 23: 314-320.

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. (contiuned)

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	< MDL	< MDL	< MDL	--	--
2,6 Dimethylnaphthalene	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--
Fluoranthene	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--
Fluorene	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--
Indeno(1,2,3-cd)pyrene	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--
1-Methylnaphthalene	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--
2-Methylnaphthalene	2.62	< MDL	26.20	16.07	< MDL	48.50	--	--
1-Methylphenanthrene	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--
Naphthalene	< MDL	< MDL	< MDL	6.87	< MDL	61.80	--	--
Perylene	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--
Phenanthrene	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--
Pyrene	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--
1,6,7 Trimethylnaphthalene	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--
Total PAHs w/o Perylene	2.62	< MDL	26.20	22.93	< MDL	110.30	--	--
PCBs (ng/g dry wt.)								
Total PCBs	10.52	5.23	19.90	2.11	1.25	2.68	10000.0[c]	0
Pesticides (ng/g dry wt.)								
Aldrin	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	1500.0[b]	0
Alpha-chlordane	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	--	--
Chlorpyrifos	0.10	< MDL	0.60	0.14	< MDL	0.84	--	--

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.