Annual Report – FY2002

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

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Submitted to:

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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 were 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. Some of the products identified in the original three year proposal are not yet completed. These are identified in Appendix 1 and will be completed during FY03. These items are also identified specifically in the description of the status of work related to each objective.

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. Since 1995, 15 visual censuses were attempted and 12 were completed (Table 1). One fish monitoring survey was completed in August 2002. Divers from GRNMS, the National Undersea Research Center in Wilmington, and volunteers participated. The data from this survey were incorporated into the Gray’s Reef Fish Monitoring Dataset version 6. The file and associated documentation were transferred to Greg McFall at GRNMS and a copy kept at CCFHR.

Table 1. Summary of adult censuses completed by year and by season at GRNMS. X indicates survey completed. * indicates survey attempted but not completed. Number ([14]) indicates numerical census code used in the Gray’s Reef Fish Monitoring Dataset version 6.

Year	Spring	Summer	Fall
1995			X[1]
1996	X[2]	X[3]	X[4]
1997	X[5]		X[6]
1998		X[7]	
1999	X[8]	X[9]	
2000	X[10]	*[11],X[12]	*
2001	*[13]		
2002		X[14]	

Analysis of the fish monitoring data is part of Dave Score's Masters project at Georgia Southern University and CCFHR will continue to provide technical assistance (Appendix 1 – Task 1). No further analyses of these data were completed by CCFHR in FY02, but a summary of the analyses conducted to date follows. Analysis of the visual census data shows both seasonal and interannual changes in the reef fish community at GRNMS. Multi-dimensional scaling analysis (MDS), a non-parametric multivariate technique, was 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 partly 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. MDS analysis illustrated differences among years for all three seasons (Figure 3).

To summarize, the fish community at GRNMS is variable. Community structure changes seasonally and interannually. These data raise the scientific issue regarding the cause of 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 was to improve the methods used for the visual census monitoring. The community analyses described above indicate that to compare between years, censuses need to

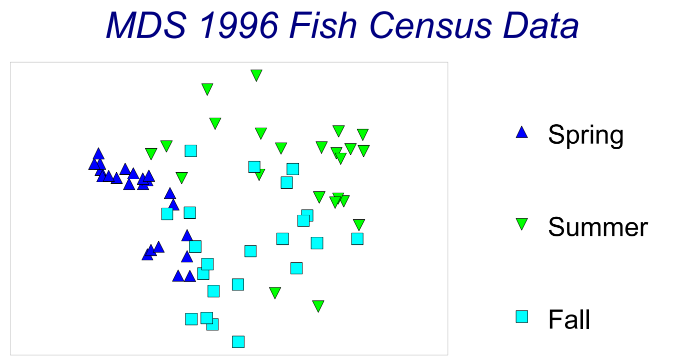

Figure 1. MDS analysis of GRNMS visual census data collected in 1996. Fish communities were significantly different among seasons. This pattern was also observed in the analyses of 1997 and 1999.

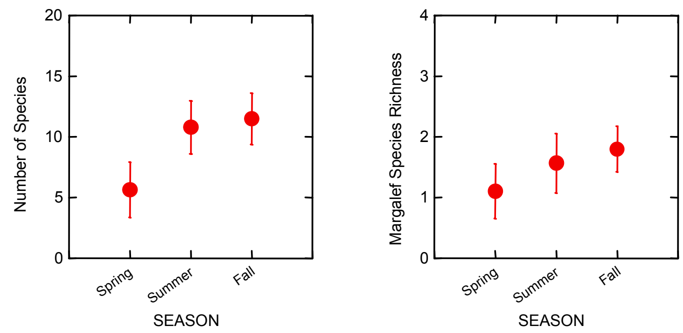

Figure 2. Number of species and a measure of species richness for the 1996 spring, summer and fall visual census data.

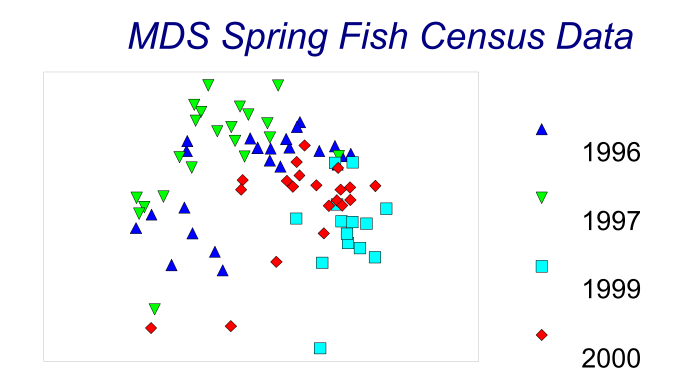

Figure 3. MDS analysis of GRNMS visual census data collected during the spring in 1996, 1997, 1999 and 2000. Fish communities were significantly different among years. This pattern was also observed in the interannual comparisons made using summer and fall data.

be conducted in the same season. Thus, GRNMS 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.

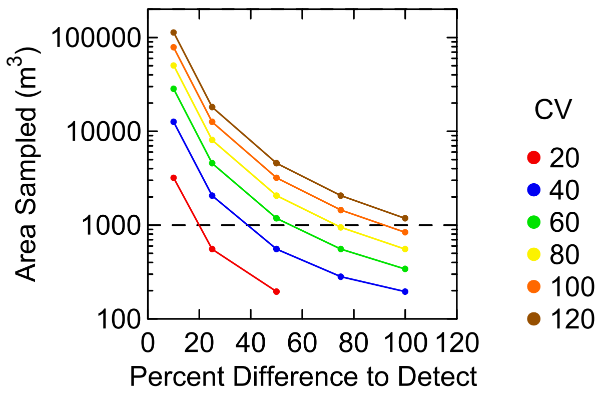

Figure 4. Calculation of sample sizes needed to detect an annual change in reef fish abundance using GRNMS visual census methods. Current sampling effort (twenty 50 m^2 cylinders per census) is indicated by dotted line. Gag abundance has a CV of 41.4% and is represented by the blue line. Current sampling can reliably detect a 40% difference between years. Belted sandfish, bank sea bass and slippery dick have CV's in the 54-60% range (green line). Black sea bass has a CV of near 80% (yellow line).

A workshop was planned during FY02 to use the fish monitoring data collected to date to assess whether the fish monitoring efforts are addressing the objectives of GRNMS. Initial plans were to address the adequacy of the fish monitoring program at a research workshop, which was held in June 2001. As planning for the research workshop developed, the amount of time committed to reviewing the fish monitoring effort decreased, to the point that it was decided to convene a separate fish monitoring workshop at a later time. Time was not found during FY02 for the fish monitoring workshop, but CCFHR will participate in this workshop when it is held (Appendix 1; Task 2).

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 during FY01. 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 were included in the analysis of the beam trawl samples (see below).

Video observations were also made within GRNMS during April 2002 to better characterize the spatial distribution of benthic habitats within GRNMS. A report describing this work was submitted to GRNMS and NMS and is attached here as Appendix 2. Subsequent to these observations, benthic habitats within GRNMS were mapped more thoroughly by CCMA staff in cooperation with CCFHR. Data from our mapping (Appendix 2) were provided to CCMA researchers prior to their mapping efforts, however, the CCMA effort was independent of the research reported here.

Table 2. List of all cruises completed during this project during which beam trawl sampling was done. Several different sets of stations have been sampled and the number of stations per station set are shown. The location of stations in each set are shown in Figure 5.

				Transects				
				Gray's Reef	Sustainable Seas	GA shelf		
Cruise	Year	Month	Dates	cross-shelf	offshore	inshore	offshore	cross-shelf
FE-00-06-GR-Leg5	2000	April	24-27	9				
JY-06-00		June	19-22	9				
JY-08-00		August	15-17	9				
FE-00-12 LL		October	03-07	10				
OII-01-01 Leg3	2001	Jan/Feb	30-01	10				
FE-01-07 BL Leg 1		March	21-23	10				
FE-01-08-MA Leg1		Apr/May	30-04	10		11		
CF-06-01		June	04-09	10				
FE-01-11BL		August	03-06	10				
SJII-09-01		Sept	07-09		6			
FE-02-03 BL		October	11-13	10				
OII-02-01 Leg3	2002	February	08-13	10	6	10	4	
FE-02-09-MA		April	05-06					5
FE-02-10-BL-Leg1		April	08-13	4				26
FE-03-02 BL		October	12-13	4				

Beam trawl sampling was conducted on five research cruises during FY02 for of total of 15 cruises to date for the project (Table 2). Sampling was conducted along the Gray's Reef cross-shelf transect, the Sustainable Seas offshore stations, and at stations on the Georgia shelf (Figure 5). The Georgia shelf stations were sampled in collaboration with CCMA researchers to

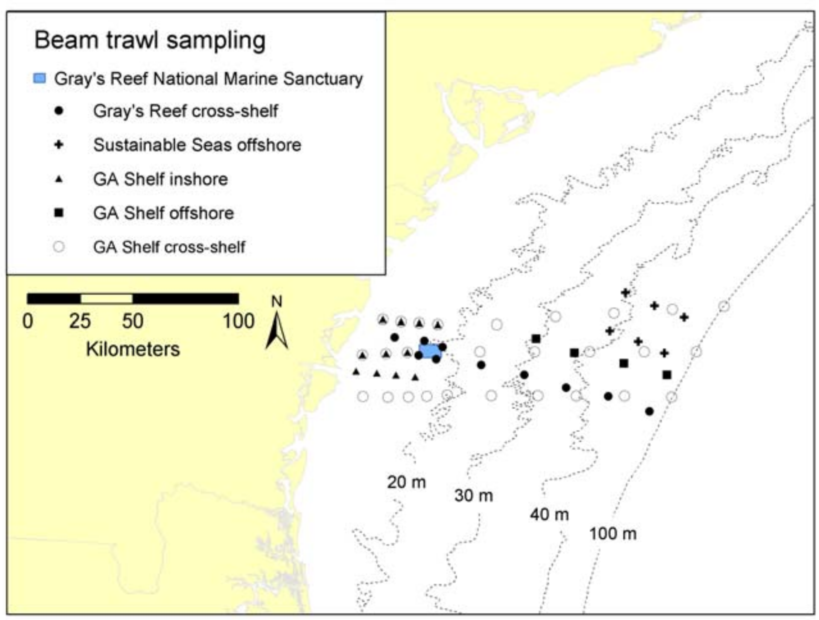

Figure 5. Map showing location of beam trawl stations sampled during the 15 cruises conducted on the Georgia shelf.

provide material for linking juvenile fish diet with benthic infauna abundance. A total of 183 stations were sampled with 563 beam trawl tows. More than 80 taxa were collected in the vicinity of GRNMS (Table 3).

Table 3. Summary of number of beam trawl stations sampled, net tows made, number of taxa and number of fish collected.

Cruise	Year	Month	Dates	Number of Stations	Tows	Taxa	Fish
FE-00-06-GR-Leg5	2000	April	24-27	9	28	59	1595
JY-06-00		June	19-22	9	28	50	542
JY-08-00		August	15-17	9	27	33	307
FE-00-12 LL		October	03-07	10	42	44	1722
OII-01-01 Leg3	2001	Jan/Feb	30-01	10	30	48	1269
FE-01-07 BL Leg 1		March	21-23	10	28	37	699
FE-01-08-MA Leg1		Apr/May	30-04	21	63	57	1279
CF-06-01		June	04-09	10	29	64	482
FE-01-11BL		August	03-06	10	30	57	491
SJII-09-01		Sept	07-09	6	17	48	439
FE-02-03 BL		October	11-13	10	30	49	1529
OII-02-01 Leg3	2002	February	08-13	30	90	88	6316
FE-02-09-MA		April	05-06	5	15		
FE-02-10-BL-Leg1		April	08-13	10	82	50	982
FE-03-02 BL		October	12-13	4	24		

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. These results will be submitted as papers for peer-review publication (Appendix 1 – Tasks 3 & 4). One manuscript will describe juvenile fish habitat utilization on open sand habitats in the vicinity of GRNMS. A second manuscript will examine the settlement ecology of serranines in the vicinity of GRNMS.

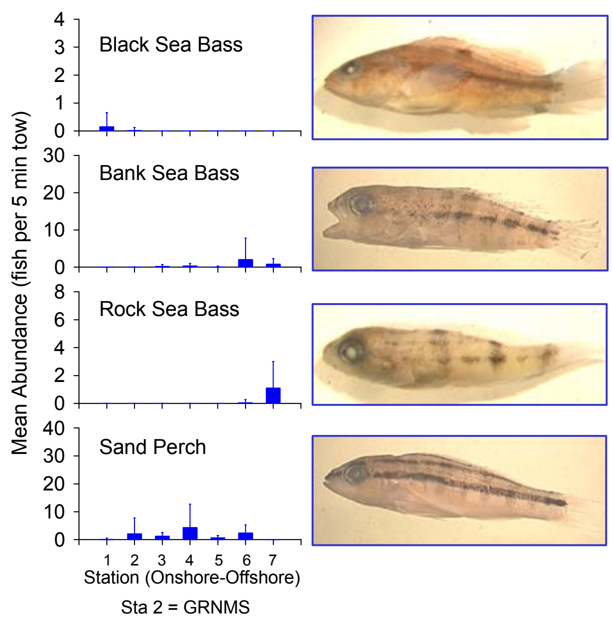

Figure 6. Average cross-shelf distribution and photographs of juvenile serranines on the Georgia shelf. Station locations are on the Gray's Reef cross-shelf transect and are shown as solid dots in Figure 5

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 5). These data will allow examination of the link between juvenile fishes and a variety of biotic and abiotic habitat components. Coordinated work between CCFHR and CCMA was continued during FY02 during a cruise in April 2002 (Figure 5). Beam trawl samples were collected with the expressed objective of examining gut contents of juvenile fishes.

Further, CCFHR researchers worked with Renaldo Smith, an undergraduate from Savannah State University. CCFHR staff and Renaldo conducted beam trawl sampling in the vicinity of GRNMS during October 2002. Samples were collected from the 4 stations surrounding GRNMS (Figure 5) during day and night. The stations vary in depth and bottom type. The samples will be used to compare/contrast juvenile fish assemblages at the 4 stations and to document day and night differences in juvenile fish availability.

The beam trawl samples have also lead to a more detailed list of species that occur in the vicinity of GRNMS. Appendix 3 presents the list of species that occur in the vicinity of GRNMS specifically during the adult, juvenile and larval stage. This list is described in more detail below. A large number of open sand species are now documented in the vicinity of GRNMS. Future effort must examine the ecological relationships between reef and sand habitats and this is part of NCCOS's FY03 work.

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

Efforts with remotely sensed data have focused on improving the operational navigation of CoastWatch SST imagery. This is necessary as the area of GRNMS is small (~17 nm^2) and the current navigational error in NESDIS CoastWatch data 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 was developed that corrects ~99% of the navigational error. This process is being refined and a manuscript describing the automated rectification is in preparation (Appendix 1 – Task 5). 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 1996 through 1999 were passed through the procedure to improve the navigation. These corrected images can be used to develop climatologies of SST (Figure 7). However, we now question the accuracies of the temperatures in the CoastWatch SST data products, which could compromise the quality of the climatologies. We plan to compare SST data with buoy data to evaluate the accuracy of the CoastWatch SSTs. If we find that the SSTs are not accurate, we will use a different dataset to produce the climatologies. If we find that SSTs are accurate or can be easily corrected, then we will use the data in the production of climatologies. Once climatologies are available, an operational SST anomaly product will be produced (Appendix 1 – Task 6).

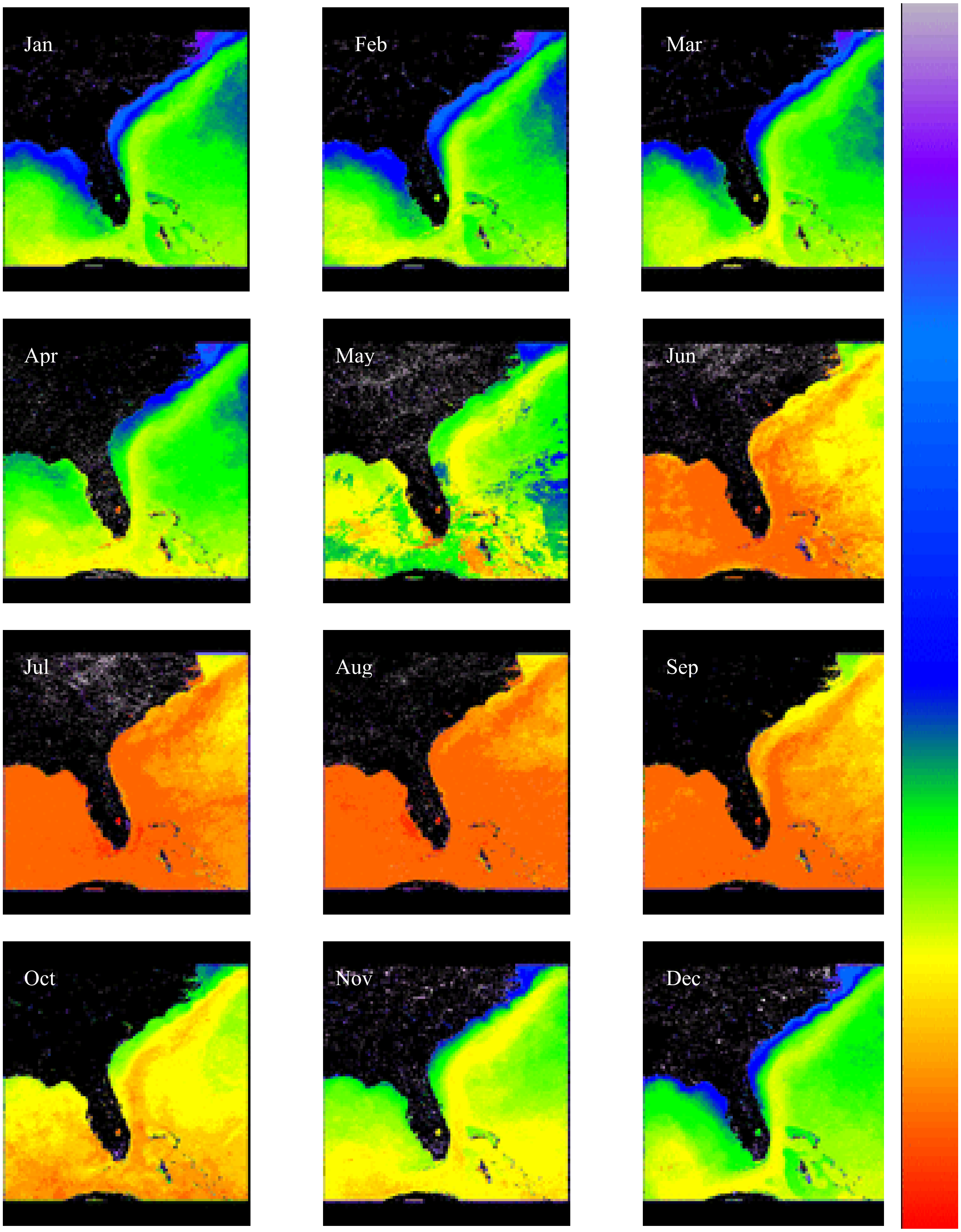

Figure 7. Monthly average sea surface temperature based on data from 1995 to 1999. Data were passed through automated rectification routine. Within a year, the month maximum value was chosen and then these monthly maximums were averaged. These data are illustrative. There is still the question of the accuracies of CoastWatch SSTs, which is currently under investigation.

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

Ichthyoplankton collections and drifter releases were used to identify fish species that spawn in the vicinity of GRNMS and to elucidate transport of larvae to and from GRNMS. Twelve cruises were completed in support of these objectives; two in FY03 (Table 4). Three categories of ichthyoplankton sampling were completed: 1) in conjunction with cross-shelf beam trawl stations (Gray's Reef cross-shelf transect, see Figure 8); 2) smaller-scale along-shelf and cross-shelf transects (Figure 8); and 3) a vertical distribution study conducted 3 nm to the east of GRNMS (Tucker sled station, Figure 8). These various datasets are discussed in more detail below in the context of the scientific questions addressed as part of these research objectives.

A total of 78 ichthyoplankton stations were sampled along the Gray's Reef cross-shelf transect (Table 5, Figure 8). More than 150 taxa were collected and ~75% of the individuals

Table 4. List of all cruises completed during this project during which cross-shelf ichthyoplankton sampling was conducted. Several different sets of stations have been sampled and the number of stations per station set are shown. The location of stations in each set are shown in Figure 8.

				Transects		
				Gray's Reef	GA shelf	
Cruise	Year	Month	Dates	cross-shelf	cross-shelf	along-shelf
FE-00-06-GR-Leg4	2000	April	17-21		24	22
FE-00-06-GR-Leg5		April	24-27	4		
JY-06-00		June	19-22			
JY-08-00		August	15-17	8		
FE-00-12 LL		October	03-07	7	12	11
OII-01-01 Leg3	2001	Jan/Feb	30-01	8	12	11
FE-01-07 BL Leg 1		March	21-23	8	3	11
FE-01-08-MA Leg1		Apr/May	30-04	7		
CF-06-01		June	04-09	7	12	11
FE-01-01BL		August	03-06	10		
FE-02-03 BL		October	11-13	8		
OII-02-01 Leg3	2002	February	08-13	10	24	22

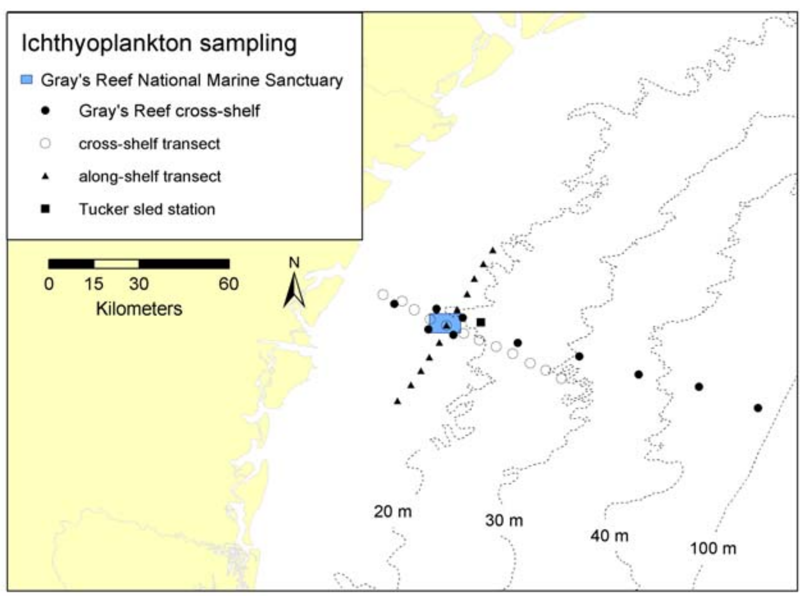

Figure 8. Map showing location of beam trawl stations sampled during the 15 cruises conducted on the Georgia shelf.

collected were identified to the genus or species level. The taxonomic resolution obtained is unprecedented for ichthyoplankton samples on the southeast coast of the United States.

Table 5. Summary of number of ichthyoplankton stations sampled on the Gray's Reef cross-shelf transect. Number of net tows made, number of taxa and number of fish collected are also provided.

				Number of		
Cruise	Year	Month	Dates	Stations	Taxa	Fish
FE-00-06-GR-Leg5	2000	April	24-27	4	24	284
JY-08-00		August	15-17	8	76	3726
FE-00-12 LL		October	03-07	7	70	1097
OII-01-01 Leg3	2001	Jan/Feb	30-01	8	33	310
FE-01-07 BL Leg 1		March	21-23	8	39	119
FE-01-08-MA Leg1		Apr/May	30-04	8	83	1426
CF-06-01		June	04-09	7	90	2905
FE-01-11BL		August	03-06	10	78	10178
FE-02-03 BL		October	11-13	8	58	1074
OII-02-01 Leg3	2002	February	08-13	10	44	423

A preliminary list of fish species spawning in the vicinity of GRNMS was developed based on ichthyoplankton samples (Appendix 3). This list will provide managers with an understanding of the species that utilize GRNMS as spawning habitat. The spawning list was combined with the species list developed from the beam trawl sampling, from the adult fish monitoring, and from other sources. Visual surveys by divers found 89 species in GRNMS (Parker et al. 1994; Gray's Reef Fish Monitoring Dataset version 6). Beam trawl and ichthyoplankton sampling added 64 species for a total of 153 fish species reported from the vicinity of GRNMS. Ichthyoplankton collections indicated that 33 of these species are spawning in the vicinity of GRNMS and approximately a third of these are reef fish species.

Work is ongoing 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. This research is the basis of a Masters thesis which will be completed during spring of 2003 and the resulting manuscript will be submitted as a paper for peer-review publication (Appendix 1 – Task 7).

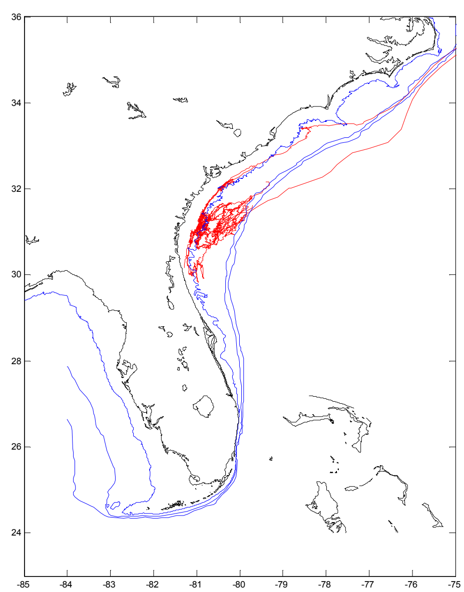

Figure 9. Summary plot of all 15 drifter tracks. Most drifters remained on the Georgia shelf. The few that left the Georgia shelf were rapidly past Cape Hatteras in association with the Gulf Stream.

In addition to larval fish and hydrographic sampling, 15 satellite tracked drifters were released to examine the potential transport of fish larvae spawned in the vicinity of GRNMS. Five sets of releases were made: April 2000, June 2000, October 2000, January 2001 and March 2001. The drifters were tracked for ~ 60 days. The combination of drifter tracks indicate that retention is high on the Georgia shelf (Figure 9), which implies that some reef fish populations on the Georgia shelf may be relatively isolated. Coupled with the list of species spawning in the vicinity of GRNMS, these data indicate that reef fish populations of many species at GRNMS may be recruitment limited. The physical description of the drifter tracks is currently ongoing and will form the basis for a peer-review journal article (Appendix 1 – Task 8).

During FY02, a student was identified to use 3-D numerical modeling as a tool for examining larval transport to and from GRNMS. The modeling will build on the SABSOON and SEACOOS efforts, which are headed by Harvey Seim and Cisco Werner at UNC-Chapel Hill (http://www.skio.peachnet.edu/projects/sabsoon_web/index.html). The drifter tracks collected as part of this study (Figure 9) will be used to validate the flow fields predicted by the circulation model. Further, a larval vertical distribution study, which was conducted during August 2001 (Figure 8) 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. The vertical distribution samples are currently being processed; additional vertical distribution sampling may be conducted during FY03. The overall goal of this modeling work is to quantify the sources of larvae that settle to GRNMS and the fate of larvae that are spawned at GRNMS.

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). 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 southeast 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. The SAFMC, however, chose not to consider GRNMS as a potential MPA.

To further this objective, drifter tracks from this study are being combined with the tracks of drifters released in the Tortugas South Ecological Reserve and the Experimental Oculina Research Reserve. This combination of drifter tracks reinforces the conclusion that the reef fish populations on the Georgia shelf and GRNMS are isolated from reef fish populations to the south. These results will be presented at the Southeast Coastal Ocean Science Conference and Workshop. Participation in this meeting is at the request of GRNMS staff. The work described in this presentation will be included in a manuscript that overviews issues that should be included in the designation of MPAs along the southeast US coast.

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

The two years of benthic sampling have been completed. A draft summary report was submitted in December 2002 and a summary report will be submitted during the 2nd quarter of FY03.

Professional Presentations

Marancik, K.E., J.A. Hare and H.J. Walsh. Linking larval distributions with juvenile settlement patterns of flatfish on the Georgia shelf. Fifth International Symposium on Flatfish Ecology, 3-7th November 2002, Port Erin Marine Laboratory, Isle of Man (Appendix 4)

Other Activities

Jon Hare and Jeff Hyland participated in the 2nd Annual Research Coordinators Meeting, 28 January – 1 February 2002, Charleston, South Carolina

Seven posters were prepared for the 2nd Annual Research Coordinators Meeting that described the joint NCCOS-GRNMS study. (Appendix 5)

Jon Hare gave a presentation to the GRNMS Science Advisory Committee, 4 March 2002, Savannah, Georgia.

Jon Hare gave a presentation to South Atlantic Fishery Management Council, 6 March 2002, Savannah, Georgia (copy is available upon request)

Jon Hare provided video to Cathy Sakas for a Georgia Public Television project

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APPENDIX 1

List of tasks that remain to be completed as part of FY00-02 funding

1. Assist Dave Score in finishing analyses of reef fish monitoring data

2. Participate in reef fish monitoring workshop

3. Submit manuscript describing juvenile fish habitat utilization in open sand habitats in the vicinity of GRNMS

4. Submit manuscript describing settlement of serranines to open sand habitats in the vicinity of GRNMS

5. Submit manuscript describing automated procedure for navigating CoastWatch SST imagery.

6. Provide customized SST products including an anomaly product to GRNMS.

7. Submit manuscript describing larval fish assemblages and link to hydrography on the Georgia Shelf

8. Submit manuscript describing circulation on the Georgia shelf based on drifter observations

9. Submit manuscript examining issues related to MPAs along the southeast US coast

APPENDIX 2

Preliminary investigation of habitat distribution in Gray's Reef National Marine Sanctuary: Results of NOAA Ship FERREL Cruise FE-02-10-Leg 1.

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Introduction

Gray's Reef National Marine Sanctuary (GRNMS) encompasses one of the most extensive areas of hard-bottom on the inner continental shelf of the southeastern United States. Rock deposited during the Pliocene (two-three million years before the present) underlies unconsolidated sediment on the Georgia continental shelf (Hunt 1974). In certain areas, the layer of unconsolidated sediments is shallow or absent, resulting in exposed or nearly exposed hard substrate. A number of sessile invertebrates are attached to the hard substrate forming a complex habitat.

Hard-bottom and its associated attached invertebrates support a rich fauna of mobile invertebrates and fish. Most of the species in the South Atlantic Fishery Management Council's Snapper Group Fishery Management Plan utilize live/hard bottom habitats during their adult stages. Thus, the distribution, ecology, and health of hard-bottom habitat is a fundamental factor influencing fisheries on the southeast US continental shelf.

Several studies have attempted to quantify the amount of live-bottom on the southeast US continental shelf. Using a random stratified sampling design, Parker et al. (1983) made an initial evaluation of the abundance of different benthic habitats (Table 1) and concluded that live-bottom covered ~30% of shelf (27-101 m) from Cape Fear to Cape Canaveral. A recent Southeast Area Monitoring and Assessment Program document (SEAMAP-SA 2001) indicates that hard-bottom may cover 50% of the bottom from North Carolina to east coast of Florida. This SEAMAP-SA document states, however, that the actual proportion of hard-bottom is overestimated since much of the sampling effort reported targeted hard-bottom areas. This said, the estimates from Parker et al. (1983) and SEAMAP-SA (2001) are reasonably close and provide an general estimate of the amount of hard-bottom on the southeast US shelf.

Table 1. Estimates of proportion of bottom habitat type on the southeast US continental shelf. Habitat types are as reported in the source document.

Parker et al. (1983)		SEAMAP-SA (2001)	
Habitat Type	Percentage	Habitat Type	Percentage
Sand/Shell	57.9	No Hard-Bottom	41.8
Vegetation	12.3	Probable Hard-bottom	17.5
Reef	30.0	Hard-bottom	39.2
		Artificial Reef	1.5
Overall Hard-Bottom Habitat [1]	42.3	Overall Hard-Bottom Habitat [2]	56.7

[1] - Overall hard-bottom habitat estimated as combination of vegetation and reef
[2] - Overall hard-bottom habitat estimated as combination of hard-bottom and probable hard-bottom

In April 2000, the National Centers for Coastal Ocean Science (NCCOS) initiated a new project funded by the National Marine Sanctuary Program: Support of Monitoring Activities and Site Characterization at Grays 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). The overall goal of the project is to better characterize the ecology of GRNMS as a whole, and to understand the function of GRNMS within the context of the larger southeast US continental shelf ecosystem. As part of this overall project, the objective of this study was to provide a preliminary estimation of habitat distribution in GRNMS. The efforts described here were not meant to be exhaustive. Rather, the purpose was to develop a preliminary map of habitats that could be used by GRNMS now and to provide preliminary information to support the design and completion of a more thorough mapping of habitats.

Methods

Camera Sled - *A Seaview camera attached to a stainless steel frame was used to view the sea floor (Figure 1). The video signal was transmitted to the surface via a non-load bearing umbilical. The camera sled was deployed through the NOAA Ship FERREL's starboard A-frame with the hydro-winch. The umbilical fed to a video display and an observer watched the display and recorded habitat types.*

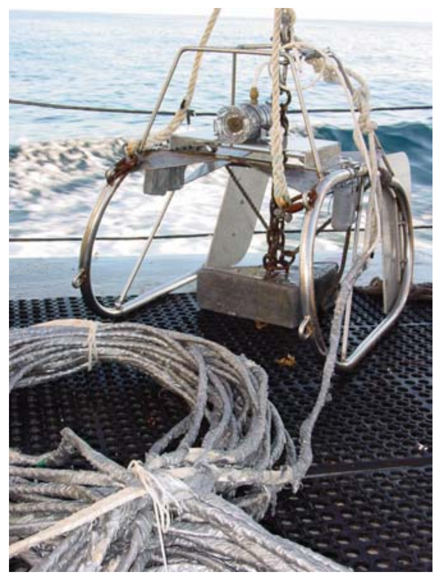

Figure 1. Camera and sled used to map benthic habitats within the vicinity of Gray's Reef National Marine Sanctuary. Photograph by Greg McFall.

Several different camera deployment techniques were used (Table 2). Initially, the ship drifted with the camera sled off the starboard side, but very little distance was covered. Second, the camera sled was towed off the starboard side with the port engine engaging and then disengaging to maintain speed around 1.5 knots. With this approach, the vertical position of the camera was difficult to maintain. Finally, the camera sled was towed with the port engine ahead slow. Speed was maintained at ~3.5 knots and the vertical position of the camera was more easily maintained at 1-3 m above the bottom. A 60 lb. weight was attached under the camera to keep the wire angle ~45^{o} during towing.

Habitat Definition - Defining habitats is difficult without general knowledge of organism's habitat utilization. Our definitions were based on Parker et al. (1994) and the insights gained during our past research in and around Gray's Reef National Marine Sanctuary.

Table 2. Summary of methods of camera sled deployment. Several summary statistics for the different deployment methods are provided: average speed maintained by ship, average wire angle, estimate of the distance from the sled to the GPS antennae, and average spatial resolution. Calculations of average speed and average spatial resolution are described in data processing section. Distance from GPS was calculated as D_{GPS-B} + WD•tan(ϕ). The distance from the GPS antennae to the block on the A-frame (D_{GPS-B}) was estimated to be 13 m. Water depth (WD) was assumed to be 18 m, an approximate average for Gray's Reef National Marine Sanctuary; actual values typically vary from 15-22 m. Wire angle (ϕ) was estimated multiple times during each camera sled deployment and was averaged for each deployment type.

Camera Sled Deployment Type	Average [SD] Speed (knots)	Wire Angle (ϕ)	Sled Distance from GPS (m)	Average Spatial Resolution (m)
Drift	0.66 [±0.12]	0	13	20.45
Slow Tow	1.52 [±0.24]	45	31	46.78
Tow – unweighted	2.27 [±0.73]	65	51	70.22
Tow – weighted	3.30 [±0.21]	45	31	102.01

Seven habitat types were defined (Table 3). Classifications were subjective, but only two habitat pairs were difficult to distinguish. First, sand waves were sometime difficult to distinguish from sand when waves were smaller and less organized. Sand waves were defined if a continuous parallel structure was observed despite height. Sand was defined if bottom was textured but continuos parallel structure was not obvious.

Table 2. Summary of habitat classifications. Percent occurrence is based on number of observations of one type of habitat / total number of observations.

Habitat Classification	Description	Percent Occurrence
Sand Waves	Parallel and continuos waves in sand	52.1%
Sand	Other sand areas	10.1%
Very sparse Live Bottom	1-10% cover of live bottom	15.5%
Sparse Live Bottom	10-50% cover of live bottom	17.6%
Moderate Live Bottom	50-80% cover of live bottom typically with exposed hard bottom	4.4%
Total Live Bottom	80-100% cover of live bottom typically with exposed hard bottom	0.3%
Ledge	Exposed hard bottom with relief	0.0%

Second, the boundary between very sparse and sparse live bottom was ambiguous. Although precise definitions were created, the streaming video made determination of 8% live bottom versus 12% live bottom arbitrary. Future efforts need to record video and quantify percent cover (see Discussion). One observer made 95% of the habitat classifications and thus, differences in subjective decisions among observes were minimized.

Habitat observations were made every minute (e.g., 15:30:00) as indicated by the ship's Trimble DSM12 GPS. In addition to observations every minute, all instances of moderate live bottom, total live bottom, and ledge were noted. These additional observations were assigned times at the mid-point between minute observation (e.g., 15:30:30).

Data Processing - Habitat observations were georeferenced by matching the time of observation with the ship's location at the time of observation. The ship's Scientific Computer Systems recorded GPS position and time data approximately every 10 s. The ship's location for the both types of habitat observations (minutely - 15:30:00; additional - 15:30:30) was linearly interpolated from the series of GPS time, latitude and longitude. Interpolated locations were then paired with their corresponding habitat classifications.

In addition, to georefercing the habitat observations, the interpolated location series was used to estimate ship speed and spatial resolution of the habitat classification. Ship speed in knots (ship v) was estimated for each minutely habitat observation as:

$$\text{Ship v} = \sqrt{(lat_i - lat_{i-1})^2 + ((long_i - long_{i-1})^2 \bullet 0.854^o long/^o lat_{31.4oN})} \bullet 60\ nm/^o lat \bullet 60\ min/hr\ .$$

Average ship velocity for each camera sled deployment method was then calculated. Spatial resolution in meters (SR) is the distance traveled between observations; in other words a velocity expressed in meters / minute.

$$SR = \text{ship v (nm/hr)} \bullet 1.853\ km/nm \bullet 1000\ m/km \bullet 1\ hr/60min$$

where i represents an record from the interpolation of latitude and longitude at 1 minute intervals. Spatial resolution was then averaged for each camera sled deployment type.

Results

Eight hundred and seventy one minutely observations were made over three days. Sand waves (Figure 2) and sand habitat predominated, but very sparse and sparse live bottom covered about 30% of the bottom surveyed (Table 3). Fifty-one additional observations were made, a majority of which were of moderate live bottom, total live bottom and ledge. Ledges were observed 12 times but not during the minute observations.

Figure 2. Photograph of the image on the video monitor showing sand waves.

Live bottom habitats were found predominantly in the southern half of the Sanctuary (Figure 3). The most continuous live bottom was found in the central portion, which is where the fish monitoring has been conducted since 1994. Well-defined ledges were found in this central area, but ledges of smaller relief were found in the south central and east central portion of the Sanctuary.

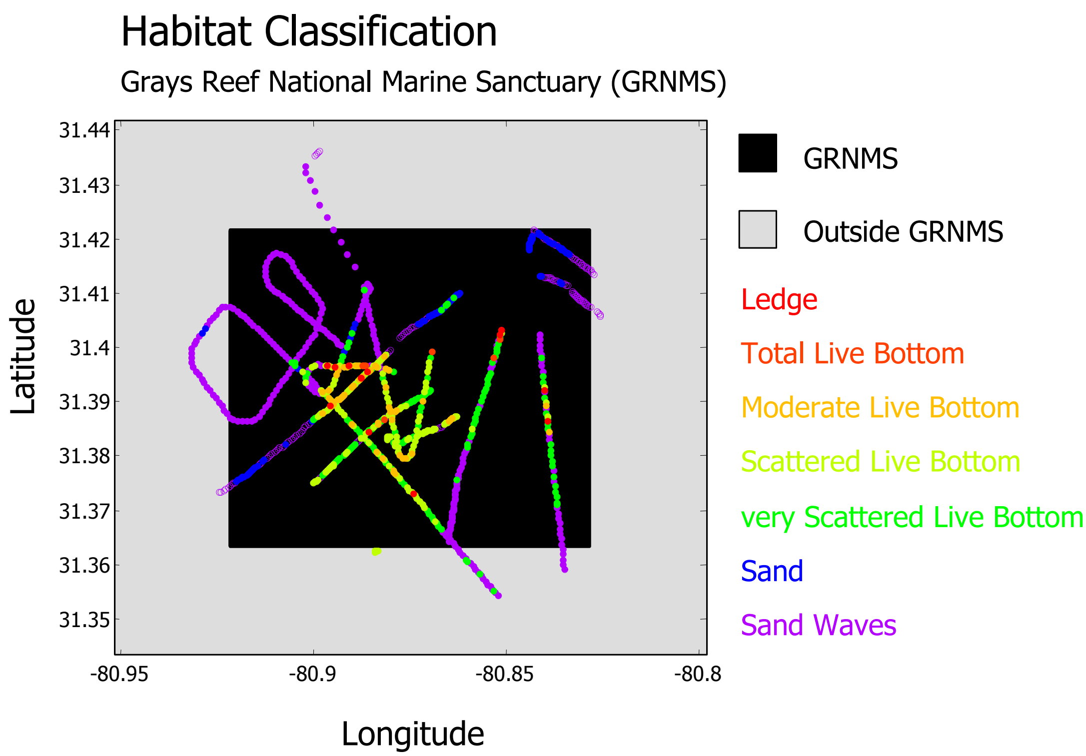

Figure 3. Map of habitat distribution in Gray's Reef National Marine Sanctuary. Key to color coding of habitat type is presented on the left. The Sanctuary is represented as the black box and gray denotes areas outside of the Sanctuary boundary.

Discussion

Gray's Reef National Marine Sanctuary encompasses the range of benthic habitats found on the southeast US continental shelf. Parker et al. (1994) demonstrated that different species utilize different habitat types in the vicinity of GRNMS and thus, GRNMS can be viewed as a sanctuary for multiple habitat types supporting multiple species assemblages. Further, most benthic habitats on the southeast US shelf are represented in GRNMS, but a number of studies have documented latitudinal and cross-shelf patterns in the use of hard bottom habitats by fish (Chester et al., 1984) and invertebrates (Tenore 1985). Based on these studies, GRNMS can be thought of as a representation of benthic habitats on the Georgia inner shelf.

The estimates of bottom habitat abundance are similar to those of earlier studies (Table 1 and 2). While conducting this study, it was clear that habitat heterogeneity is on a finer scale than evaluated even here. During the one minute observation interval, habitat type would change several times. Future efforts should plan for a sampling resolution of less than 10 m to better resolve habitat heterogeneity. Further, there are distinctions within the habitat classifications made here. Some hard bottom was largely covered with grogonian corals, whereas other areas were dominated by sponges. Similarly, some unconsolidated sediment was composed primarily of sand, where other areas were a mixture of sand and shell. The role of micro-habitat in structuring invertebrate and fish assemblages is largely unknown but potentially important.

A random sampling design was not used here and thus, the observations of habitat type cannot be extended beyond the area sampled. Certain areas in GRNMS were not examined and should be targeted in future work. However, a large number of observations were made in a small area (871 observations in 58 km^2) contributing significantly to our understanding of habitat distribution and abundance in GRNMS. These data will support ongoing efforts to better characterize the ecology of GRNMS as a whole, and to understand the function of GRNMS within the context of the larger southeast US continental shelf ecosystem.

Acknowledgements

We thank Don Field and Mark Fonseca of the Applied Spatial Ecology and Habitat Characterization Team at the Center for Coastal Fisheries and Habitat Research for the loan of the equipment that made this work possible. We also thank the officers and crew of the NOAA Ship FERREL whose ideas and hard work improved the work conducted.

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APPENDIX 3

List of fish species occurring in and around Gray's Reef National Marine Sanctuary

Appendix 3. List of fish species occurring in and around Gray's Reef National Marine Sanctuary. List includes species from censuses made at the GRNMS as part of monitoring program (Score et al.). Data are also from beam trawl work (Walsh et al.) and ichthyoplankton work that is reported here. Finally data from Parker et al. (1994) are provided.

Order	Family	Taxa	Common Name	Parker et al.	Score et al.	GRNMS - Walsh et al.	GRNMS - Marancik et al.	Spawning at GRNMS
Lamniformes	Orectolobidae	*Ginglymostoma cirratum*	nurse shark	x	x			
Rajiformes	Dasyatidae	*Dasyatis americana*	southern stingray	x	x			
Rajiformes	Dasyatidae	*Dasyatis sayi*	bluntnose stingray			x		
Anguilliformes	Muraenidae	Muranenidae	unidentified moray	x		x		
Anguilliformes	Muraenidae	*Gymnothorax moringa*	spotted moray		x			
Anguilliformes	Ophichthidae	*Ophichthus sp.*	unidentified snake eel				x	S
Anguilliformes	Ophichthidae	*Letharchus velifer*	sailfin eel			x		
Anguilliformes	Ophichthidae	*Myrophis punctatus*	speckled worm eel	x			x	S
Anguilliformes	Ophichthidae	*Ophichthus ocellatus*	palespotted snake eel			x		
Anguilliformes	Congridae	*Ariosoma balearicum*	bandtooth conger			x		
Clupeiformes	Clupeidae	Clupeidae	unidentified herring				x	
Clupeiformes	Clupeidae	*Brevoortia tyrannus*	Atlantic menhaden	x		x	x	S
Clupeiformes	Clupeidae	*Etrumeus teres*	round herring			x		
Clupeiformes	Clupeidae	*Opisthonema oglinum*	Atlantic thread herring				x	S
Clupeiformes	Clupeidae	*Sardinella aurita*	Spanish sardine	x		x		
Clupeiformes	Engraulididae	Engraulidae	unidentified anchovy				x	S
Clupeiformes	Engraulididae	*Anchoa sp.*	unidentified anchovy			x	x	S
Clupeiformes	Engraulididae	*Anchoa hepsetus*	striped anchovy			x	x	S
Clupeiformes	Engraulididae	*Anchoa lamprotaena*	bigeye anchovy			x		
Clupeiformes	Engraulididae	*Anchoa mitchilli*	bay anchovy				x	S
Aulopiformes	Synodontidae	Synodontidae	unidentified lizardfish				x	S
Aulopiformes	Synodontidae	*Synodus foetens*	inshore lizardfish	x	x	x		
Aulopiformes	Synodontidae	*Synodus intermedius*	sand diver		x			
Aulopiformes	Synodontidae	*Trachinocephalus myops*	snakefish	x		x		
Gadiformes	Gadidae	Gadidae	unidentified hake			x		
Gadiformes	Gadidae	*Urophycis sp.*	unidentified hake				x	S
Gadiformes	Gadidae	*Urophycis floridana*	southern hake			x		
Gadiformes	Gadidae	*Urophycis regia*	spotted hake			x		
Ophidiiformes	Ophidiidae	*Ophidion marginatum/holbrooki*	cusk-eel			x		

Order	Family	Taxa	Common Name	Parker et al.	Score et al.	GRNMS - Walsh et al.	GRNMS - Marancik et al.	Spawning at GRNMS
Ophidiiformes	Ophidiidae	*Ophidion marginatum/welshi*	cusk-eel			x		
Ophidiiformes	Ophidiidae	*Ophidion sp.*	unidentified cusk-eel			x	x	S
Ophidiiformes	Ophidiidae	*Ophidion Type 8*	cusk-eel				x	S
Ophidiiformes	Ophidiidae	*Ophidion grayi*	blotched cusk-eel			x		
Ophidiiformes	Ophidiidae	*Ophidion holbrooki*	bank cusk-eel			x		
Ophidiiformes	Ophidiidae	*Ophidion marginatum*	striped cusk-eel			x	x	S
Ophidiiformes	Ophidiidae	*Ophidion selenops*	mooneye cusk-eel			x	x	S
Ophidiiformes	Ophidiidae	*Ophidion welshi*	crested cusk-eel			x		
Batrachoidiformes	Batrachoididae	*Opsanus sp.*	unidentified toadfish	x				
Batrachoidiformes	Batrachoididae	*Opsanus pardus*	leopard toadfish		x			
Batrachoidiformes	Batrachoididae	*Opsanus tau*	oyster toadfish		x			
Lophiiformes	Ogcocephalidae	*Ogcocephalus nasutus*	shortnose batfish			x		
Lophiiformes	Ogcocephalidae	*Ogcocephalus parvus*	roughback batfish			x		
Gobiesociformes	Gobiescoidae	Gobiescoidae	unidentified clingfish				x	
Cyprinodontiformes	Exocoetidae	*Hirundichthys affinis*	fourwing flyingfish			x		
Cyprinodontiformes	Belonidae	Beloniform	unidentified needlefish				x	S
Atheriniformes	Atherinidae	*Menidia menidia*	Atlantic silverside			x		
Beryciformes	Holocentridae	*Holocentrus ascencionis*	squirrelfish	x	x			
Syngnathiformes	Syngnathidae	*Hippocampus sp.*	unidentified seahorse				x	
Syngnathiformes	Syngnathidae	*Hippocampus erectus*	lined seahorse	x		x		
Syngnathiformes	Syngnathidae	*Micrognathus crinitus*	banded pipefish	x				
Syngnathiformes	Syngnathidae	*Syngnathus louisianae*	chain pipefish	x				
Syngnathiformes	Syngnathidae	*Syngnathus springeri*	bull pipefish			x		
Scorpaeniformes	Scorpaenidae	Scorpaenidae	unidentified scorpionfish				x	S
Scorpaeniformes	Scorpaenidae	*Scorpaena dispar*	hunchback scorpionfish			x		
Scorpaeniformes	Scorpaenidae	*Scorpaena plumieri*	spotted scorpionfish			x		
Scorpaeniformes	Triglidae	*Prionotus sp.*	unidentified searobin	x		x	x	S
Scorpaeniformes	Triglidae	*Prionotus carolinus*	northern searobin			x		
Scorpaeniformes	Triglidae	*Prionotus scitulus*	leopard searobin			x		
Perciformes		Perciformes	unidentified Perciform				x	S
Perciformes	Serranidae	Serraninae	unidentified serraninae				x	S
Perciformes	Serranidae	*Centropristis sp.*	unidentified sea bass				x	S
Perciformes	Serranidae	*Diplectrum spp.*	unidentified sand perch				x	S
Perciformes	Serranidae	*Centropristis ocyurus*	bank sea bass	x	x	x		
Perciformes	Serranidae	*Centropristis philadelphica*	rock sea bass	x				
Perciformes	Serranidae	*Centropristis striata*	black sea bass	x	x	x		
Perciformes	Serranidae	*Diplectrum formosum*	sand perch	x	x	x		
Perciformes	Serranidae	*Mycteroperca microlepis*	gag	x	x			
Perciformes	Serranidae	*Mycteroperca phenax*	scamp	x	x			
Perciformes	Serranidae	*Serraniculus pumilio*	pygmy sea bass			x	x	S

Order	Family	Taxa	Common Name	Parker et al.	Score et al.	GRNMS - Walsh et al.	GRNMS - Marancik et al.	Spawning at GRNMS
Perciformes	Serranidae	*Serranus subligarius*	belted sandfish	x	x	x		
Perciformes	Grammistidae	*Rypticus sp.*	unidentified soapfish				x	
Perciformes	Grammistidae	*Rypticus maculatus*	whitespotted soapfish	x	x			
Perciformes	Priacanthidae	*Priacanthus arenatus*	bigeye	x				
Perciformes	Priacanthidae	*Pristigenys alta*	short bigeye	x		x		
Perciformes	Apogonidae	*Apogon sp.*	unidentified cardinalfish			x		
Perciformes	Apogonidae	*Apogon pseudomaculatus*	twospot cardinalfish	x	x	x		
Perciformes	Apogonidae	*Phaeoptyx pigmentaria*	dusky cardinalfish	x				
Perciformes	Rachycentridae	*Rachycentron canadum*	cobia		x			
Perciformes	Carangidae	Carangidae	unidentified jack			x		
Perciformes	Carangidae	*Caranx/Chloroscombrus*	unidentified jack				x	S
Perciformes	Carangidae	*Caranx sp.*	unidentified jack	x				
Perciformes	Carangidae	*Decapterus sp.*	unidentified scad			x	x	S
Perciformes	Carangidae	*Caranx bartholomaei*	yellow jack	x	x			
Perciformes	Carangidae	*Caranx ruber*	bar jack	x	x			
Perciformes	Carangidae	*Chloroscombrus chrysurus*	Atlantic bumper			x		
Perciformes	Carangidae	*Decapterus macarellus*	mackerel scad		x			
Perciformes	Carangidae	*Decapterus punctatus*	round scad	x	x	x	x	S
Perciformes	Carangidae	*Selene vomer*	lookdown			x		
Perciformes	Carangidae	*Seriola dumerili*	greater amberjack	x	x			
Perciformes	Carangidae	*Seriola rivoliana*	almaco jack	x				
Perciformes	Coryphaenidae	*Coryphaena hippurus*	dolphin				x	S
Perciformes	Lutjanidae	*Lutjanus sp.*	unidentified snapper	x				
Perciformes	Lutjanidae	*Lutjanus analis*	mutton snapper			x		
Perciformes	Lutjanidae	*Lutjanus campechanus*	red snapper	x	x			
Perciformes	Lutjanidae	*Lutjanus griseus*	gray snapper		x			
Perciformes	Lutjanidae	*Ocyurus chrysurus*	yellowtail snapper		x			
Perciformes	Lutjanidae	*Rhomboplites aurorubens*	vermilion snapper		x			
Perciformes	Gerreidae	Gerreidae	unidentified mojarra				x	
Perciformes	Haemulidae	*Haemulon sp.*	unidentified grunt	x				
Perciformes	Haemulidae	*Haemulon aurolineatum*	tomtate		x	x		
Perciformes	Haemulidae	*Haemulon plumieri*	white grunt		x			
Perciformes	Haemulidae	*Orthopristis chrysoptera*	pigfish	x			x	S
Perciformes	Sparidae	Sparidae	unidentified porgy				x	S
Perciformes	Sparidae	*Stenotomus sp.*	unidentified porgy			x		
Perciformes	Sparidae	*Archosargus probatocephalus*	sheepshead	x	x			
Perciformes	Sparidae	*Calamus leucosteus*	whitebone porgy	x	x			
Perciformes	Sparidae	*Diplodus holbrooki*	spotfin pinfish	x	x			
Perciformes	Sparidae	*Lagodon rhomboides*	pinfish		x	x	x	S
Perciformes	Sparidae	*Pagrus pagrus*	red porgy	x	x			

Order	Family	Taxa	Common Name	Parker et al.	Score et al.	GRNMS - Walsh et al.	GRNMS - Marancik et al.	Spawning at GRNMS
Perciformes	Sparidae	*Stenotomus caprinus*	longspine porgy	x				
Perciformes	Sparidae	*Stenotomus chrysops*	scup		x			
Perciformes	Sciaenidae	Sciaenidae	unidentified drum				x	S
Perciformes	Sciaenidae	*Cynosion nothus*	silver seatrout			x	x	S
Perciformes	Sciaenidae	*Cynosion regalis*	weakfish			x	x	S
Perciformes	Sciaenidae	*Equetes umbrosus*	cubbyu	x	x			
Perciformes	Sciaenidae	*Equetus lanceolatus*	jackknife-fish	x				
Perciformes	Sciaenidae	*Larimus fasciatus*	banded drum				x	S
Perciformes	Sciaenidae	*Leiostomus xanthurus*	spot			x	x	S
Perciformes	Sciaenidae	*Menticirrhus americanus*	southern kingfish				x	S
Perciformes	Sciaenidae	*Menticirrhus littoralis*	gulf kingfish				x	S
Perciformes	Sciaenidae	*Menticirrhus saxatilis*	northern kingfish				x	S
Perciformes	Sciaenidae	*Micropogonias undulatus*	Atlantic croaker			x	x	S
Perciformes	Sciaenidae	*Pareques acuminatus*	high-hat	x	x			
Perciformes	Sciaenidae	*Pogonias cromis*	black drum				x	S
Perciformes	Sciaenidae	*Sciaenops ocellatus*	red drum				x	S
Perciformes	Mullidae	*Mullus auratus*	red goatfish	x				
Perciformes	Mullidae	*Upeneus parvus*	dwarf goatfish		x			
Perciformes	Ephippidae	*Chaetodipterus faber*	Atlantic spadefish	x	x			
Perciformes	Chaetodontidae	*Chaetodon ocellatus*	spotfin butterflyfish	x	x			
Perciformes	Chaetodontidae	*Chaetodon sedentarius*	reef butterflyfish	x	x			
Perciformes	Chaetodontidae	*Chaetodon striatus*	banded butterflyfish	x				
Perciformes	Pomacanthidae	*Holocanthus bermudensis*	blue angelfish	x	x			
Perciformes	Pomacentridae	*Abudefduf saxatilis*	sargeant major		x			
Perciformes	Pomacentridae	*Pomacentrus partitus*	bicolor damselfish	x	x			
Perciformes	Pomacentridae	*Pomacentrus variabilis*	cocoa damselfish	x	x			
Perciformes	Mugilidae	*Mugil cephalus*	striped mullet			x		
Perciformes	Mugilidae	*Mugil curema*	white mullet			x	x	
Perciformes	Sphyraenidae	*Sphyraena barracuda*	great barracuda	x	x			
Perciformes	Labridae	*Halichoeres sp.*	unidentified wrasse				x	S
Perciformes	Labridae	*Xyrichthys spp.*	unidentified razorfish				x	S
Perciformes	Labridae	*Halichoeres bivittatus*	slippery dick	x	x			
Perciformes	Labridae	*Halichoeres caudalis*	painted wrasse		x	x		
Perciformes	Labridae	*Tautoga onitis*	tautog	x	x			
Perciformes	Labridae	*Xyrichtys novacula*	pearly razorfish	x	x	x		
Perciformes	Scaridae	*Sparisoma sp.*	unidentified parrotfish	x	x			
Perciformes		Ophisthognathid/Lutjanidae	unidentified jawfish/snapper				x	S
Perciformes	Uranoscopidae	Uranoscopidae	unidentified stargazer				x	S
Perciformes	Uranoscopidae	*Astroscopus sp.*	unidentified stargazer			x		
Perciformes	Dactyloscopidae	Dactyloscopidae Type 1 (*D. moorei*)	unidentified sand stargazer				x	S

Order	Family	Taxa	Common Name	Parker et al.	Score et al.	GRNMS - Walsh et al.	GRNMS - Marancik et al.	Spawning at GRNMS
Perciformes	Dactyloscopidae	*Dactyloscopus moorei*	sand stargazer			x		
Perciformes	Clinidae	*Starksia ocellata*	checkered blenny		x			
Perciformes	Blenniidae	Blenniidae	unidentified blenny	x		x	x	S
Perciformes	Blenniidae	*Chasmodes/Parablennius marmoreus*	unidentified blenny			x		
Perciformes	Blenniidae	*Hypleurochilus geminatus*	crested blenny		x	x		
Perciformes	Blenniidae	*Ophioblennius atlanticus*	redlip blenny	x	x			
Perciformes	Blenniidae	*Parablennius marmoreus*	seaweed blenny	x	x	x		
Perciformes	Callionymidae	*Diplogrammus pauciradiatus*	spotted dragonet			x	x	S
Perciformes	Gobiidae	Gobiidae	unidentified goby				x	S
Perciformes	Gobiidae	*Microgobius sp.*	unidentified goby			x		
Perciformes	Gobiidae	*Coryphopterus glaucofraenum*	bridled goby		x			
Perciformes	Gobiidae	*Ioglossus calliurus*	blue goby	x				
Perciformes	Gobiidae	*Microgobius carri*	Seminole goby	x				
Perciformes	Acanthuridae	*Acanthurus bahianus*	ocean surgeon	x	x			
Perciformes	Acanthuridae	*Acanthurus chirurgus*	doctorfish	x	x			
Perciformes	Scombridae	Scombridae	unidentified mackerel			x		
Perciformes	Scombridae	*Euthynnus alleteratus*	little tunny	x			x	S
Perciformes	Scombridae	*Scomberomorus cavalla*	king mackerel		x		x	S
Perciformes	Scombridae	*Scomberomorus maculatus*	Spanish mackerel	x			x	S
Perciformes	Stromateidae	*Psenes sp.*	unidentified driftfish				x	
Perciformes	Stromateidae	*Peprilus burti*	gulf butterfish				x	S
Perciformes	Stromateidae	*Peprilus paru*	butterfish				x	S
Perciformes	Stromateidae	*Peprilus triacanthus*	butterfish			x	x	S
Perciformes	Stromateidae	*Psenes maculatus*	silver driftfish	x				
Pleuronectiformes	Bothidae	Bothidae	unidentified flounder	x				
Pleuronectiformes	Bothidae	*Bothus ocellatus/robinsi*	eyed/spottail flounder			x		
Pleuronectiformes	Bothidae	*Bothus sp.*	unidentified flounder			x		
Pleuronectiformes	Bothidae	*Bothus ocellatus*	eyed flounder			x		
Pleuronectiformes	Bothidae	*Bothus robinsi*	spottail flounder			x		
Pleuronectiformes	Paralichthyidae	*Citharichthys sp*	unidentified flounder			x		
Pleuronectiformes	Paralichthyidae	*Etropus sp.*	unidentified *Etropus*			x	x	S
Pleuronectiformes	Paralichthyidae	*Syacium sp.*	unidentified flounder			x	x	S
Pleuronectiformes	Paralichthyidae	*Ancylcopsetta quadrocellata*	ocellated flounder			x		
Pleuronectiformes	Paralichthyidae	*Citharichthys macrops*	spotted whiff			x		
Pleuronectiformes	Paralichthyidae	*Citharichthys spilopterus*	bay whiff				x	S
Pleuronectiformes	Paralichthyidae	*Cyclopsetta fimbriata*	spotfin flounder			x	x	
Pleuronectiformes	Paralichthyidae	*Etropus crossotus*	fringed flounder				x	S
Pleuronectiformes	Paralichthyidae	*Hippoglossina oblongatta*	flounder				x	S
Pleuronectiformes	Paralichthyidae	*Paralichthys lethostigma*	southern flounder			x		
Pleuronectiformes	Paralichthyidae	*Syacium papillosum*	dusky flounder			x		

Order	Family	Taxa	Common Name	Parker et al.	Score et al.	GRNMS - Walsh et al.	GRNMS - Marancik et al.	Spawning at GRNMS
Pleuronectiformes	Scopthalmidae	*Scopthalmus aquosus*	windowpane			x		
Pleuronectiformes	Soleidae	*Gymnachirus melas*	naked sole			x		
Pleuronectiformes	Soleidae	*Trinectes maculatus*	hogchoker				x	S
Pleuronectiformes	Cynoglossidae	*Symphurus diomedeanus*	spottedfin tonguefish			x		
Pleuronectiformes	Cynoglossidae	*Symphurus minor*	largescale tonguefish			x		
Pleuronectiformes	Cynoglossidae	*Symphurus plagiusa*	blackcheek tonguefish			x		
Pleuronectiformes	Cynoglossidae	*Symphurus urospilus*	spottail tonguefish			x		
Tetraodontiformes	Balistidae	*Aluterus heudoloti*	dotterel filefish	x				
Tetraodontiformes	Balistidae	*Aluterus schoepfi*	orange filefish	x	x			
Tetraodontiformes	Balistidae	*Balistes capriscus*	gray triggerfish	x	x			
Tetraodontiformes	Balistidae	*Cantherhines pullus*	orangespotted filefish		x			
Tetraodontiformes	Balistidae	*Monocanthus hispidus*	planehead filefish	x		x		
Tetraodontiformes	Ostraciidae	*Lactophyrs sp.*	unidentified trunkfish			x	x	S
Tetraodontiformes	Ostraciidae	*Lactophyrs quadricornis*	scrawled cowfish	x	x			
Tetraodontiformes	Ostraciidae	*Lactophyrs triqueter*	smooth trunkfish	x				
Tetraodontiformes	Tetraodontidae	*Sphoeroides sp.*	unidentified puffer				x	S
Tetraodontiformes	Tetraodontidae	*Sphoeroides dorsalis*	marbled puffer		x			
Tetraodontiformes	Tetraodontidae	*Sphoeroides spengleri*	bandtail puffer		x			
Tetraodontiformes	Diodontidae	*Diodon hystrix*	porcupinefish	x				

APPENDIX 4

Marancik, K.E., J.A. Hare and H.J. Walsh. Linking larval distributions with juvenile settlement patterns of flatfish on the Georgia shelf. Fifth International Symposium on Flatfish Ecology, 3-7th November 2002, Port Erin Marine Laboratory, Isle of Man

Linking larval distributions with juvenile settlement patterns of flatfish on the Georgia shelf, USA

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INTRODUCTION

Transport mechanisms influencing supply of larvae to nursery habitats are an important element in the population and community dynamics of flatfish. In the western central Atlantic, most flatfish produce pelagic larvae. Flatfish larvae can settle either near or far from their spawning location, and transport pathways are influenced by many factors including wind, currents, and biological interactions (Champalbert and Koutsikopoulos 1995). Inferring which of these pathways are utilized requires knowledge of where fish are spawned, how they are distributed as larvae, and where they settle. Although flatfish make up a large percentage of fish caught in ichthyoplankton and juvenile sample collections, little is known about the distribution and settlement patterns on the southeast United States continental shelf. Our objectives were to generate a list of flatfish spawning in the area, to determine larval and juvenile flatfish distributions, and use this information to begin to describe larval transport pathways.

MATERIAL AND METHODS

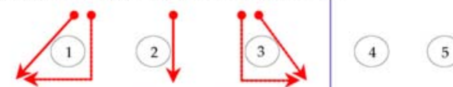
Larval and juvenile fish were collected on the Georgia Shelf, USA. Samples were taken from April 2000 – February 2002 at 10 stations using oblique tows of a 60 cm bongo net and a 2 m beam trawl. Temperature, salinity, and depth measurements were taken at each station and used to define seasons.

Sampling			Stations Sampled	
Year	Month	Season	Juveniles	Larvae
2000	April	*Spring*	9	4
	June	*Summer*	9	0
	August	*Summer*	9	8
	October	*Fall*	10	7
2001	January	*Winter*	10	8
	March	*Winter*	10	8
	May	*Spring*	10	7
	June	*Summer*	10	7
	August	*Summer*	10	10
	October	*Fall*	10	8
2002	February	*Winter*	10	10

36 larval and juvenile taxa were collected; ranked abundances are shown in the table below. Citations are given for the juvenile habitat (estuarine, inner shelf, or outer shelf) used by each taxa.

		Collected as:		Juvenile Habitat		
Family	Species	Juvenile	Larval	Estuarine	Inner Shelf	Outer Shelf
Scopthalmidae	*Scopthalmus aquosus*	26		Able and Fahay 1998 ——————————→		
Paralichthyidae	*Ancylopsetta quadrocellata*	12			Topp and Hoff 1972	
	Citharichthys arctifrons		15			Sullivan et al. 2000
	Citharichthys arctifrons/cornutus		9			X
	Citharichthys cornutus		11			Tucker 1982
	Citharichthys gymnorhinus	20	8			Tucker 1982
	Citharichthys macrops	11			Tucker 1982	
	Citharichthys spp.	7				
	Citharichthys spilopterus		7	Walsh et al. 1999		
	Cyclopsetta fimbriata	15	13		Topp and Hoff 1972? ——————→	
	Cyclopsetta spp.		20			
	Etropus crossotus	17	3	Reichert and Van der Veer 1991		
	Etropus spp.	1	5			
	Gastropsetta frontalis	25				Topp and Hoff 1972
	Hippoglossina oblonga		10		Sullivan et al. 2000	
	Paralichthys albigutta/lethostigma		14	X		
	Paralichthys albigutta	22		Walsh et al. 1999		
	Paralichthys dentatus	24	19	Walsh et al. 1999		
	Paralichthys lethostigma	9	17	Walsh et al. 1999		
	Paralichthys squamilentus?	27			?	
	Syacium papillosum	14			Topp and Hoff 1972 ——————→	
	Syacium spp.	13	4			
Bothidae	*Bothus ocellatus*	8				Gutherz 1967
	Bothus ocellatus/robinsi	4	2			Gutherz 1967
	Bothus robinsi	3				Gutherz 1967
	Engyophrys senta		18			Robins et al. 1986
	Monolene sessilicauda	21				Robins et al. 1986
	Monolene spp.		16			
Soleidae	*Gymnachirus melas*	18	12		Topp and Hoff 1972 ——————→	
	Trinectes maculatus		6			
Cynoglossidae	*Symphurus spp.*	6	1			
	Symphurus diomedianus	23				Monroe 1998
	Symphurus minor	2				Monroe 1998
	Symphurus parvus	19				Monroe 1998
	Symphurus plagiusa	10		Walsh et al. 1999		
	Symphurus urospilus	5				Monroe 1998

Five Transport/Settlement Patterns were observed. Pattern 1 is inshore movement, pattern 2 is no cross-shelf movement, pattern 3 is offshore movement, pattern 4 is shifting settlement habitat, and pattern 5 is examples of taxonomic issues. Each pattern was observed in each season. Specific examples of each pattern follow.



	1	2	3	4	5
Spring	*E. crossotus* *G. melas* *T. maculatus*	*Syacium spp.?* *B. robinsi* *C. gymnorhinus*	*B. ocellatus*	*S. urospilus* *S. minor* *G. melas*	*Etropus spp.* *Bothus spp.* *Symphurus spp.* *Citharichthys spp.* *Cyclopsetta spp.* *Syacium spp.* *Monolene spp.*
Summer	*E. crossotus* *G. melas* *T. maculatus* *C. cornutus*	*Syacium spp.* *B. robinsi* *C. gymnorhinus*	*B. ocellatus*		
Fall	*E. crossotus*	*Syacium spp.* *B. robinsi*	*B. ocellatus*		
Winter	*P. albiguta* *P. lethostigma* *P. dentatus*	*B. robinsi* *C. arctifrons* *C. spilopterus*	*B. ocellatus*		

FOR EACH GRAPH

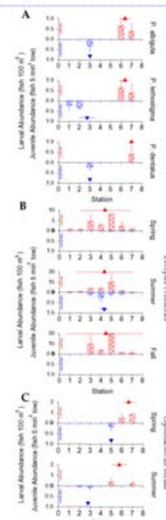
Cross-shelf distribution data are presented for larvae (top, red portion of graph) and settlement sized juveniles (bottom, blue portion). Bars represent mean CPUE at a station within a season (with standard error bars). Weighted mean cross-shelf position is indicated by the triangle (with standard deviation bars).

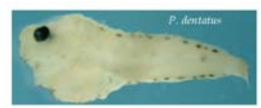
PATTERN 1: Inshore Movement

Inshore movement of larvae to settlement habitat was demonstrated in all four seasons and in 7 taxa.

Paralichthys (A) and *Etropus crossotus* (B) juveniles settle in estuaries, but these data suggest that juveniles can settle directly in the estuary from the shelf (hence no juveniles collected), or may settle to the benthos and then move inshore to the estuaries.

Juvenile *G. melas* (C) also appeared to shift settlement habitat with season. This apparent shift is described further in Pattern 4.

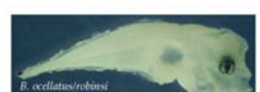


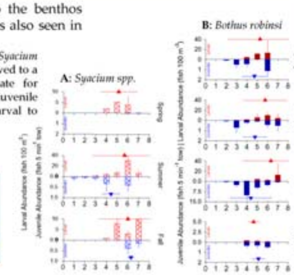


PATTERN 2: No Cross-shelf Movement

In 5 taxa, juveniles appeared to settle to the benthos directly below the larvae. This pattern was also seen in all seasons and across the shelf.

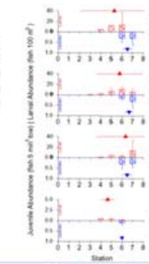
Unfortunately, larval and juvenile descriptions of *Syacium* spp. and the genus *Bothus* (larvae can only be narrowed to a complex of *Bothus ocellatus/robinsi*) are inadequate for specific identifications, but, comparing larval and juvenile data suggest little change in distribution from larval to juvenile stages.





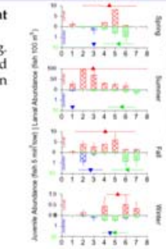
PATTERN 3: Offshore Movement

Bothus ocellatus may show a third pattern, offshore movement to settlement habitat. Offshore movement was indicated in all four seasons.



PATTERN 4: Shifting settlement habitat

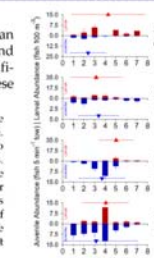
At least three species, *G. melas* (Fig. 3), *Symphurus urospilus* (blue), and *S. minor* (green), showed shifts in settlement habitat with season.



PATTERN 5: Taxonomic Issues

Many larval and juvenile fish can not be identified to species, and unfortunately, genus level identifications make analyses such as these difficult/impossible.

For example, four species of *Etropus* are commonly found off the coast of Georgia. Three of these species are difficult to distinguish at larval and juvenile stages. The larval and juvenile *Etropus spp.* were distributed across the shelf in similar numbers. The lack of pattern in this taxa is likely caused by the combining of transport patterns for more than one species that occur and settle on different areas of the shelf.



CONCLUSIONS

Larvae from the same part of the shelf are being transported in at least three different directions (inshore, offshore, and no cross-shelf movement) at the same time. A simple passive horizontal transport model cannot explain the patterns observed (Patterns 1 through 4). Other factors that may be influential include passive or behavioral vertical migrations or horizontal swimming behavior. Hare and Govoni (*in prep*) suggest there are vertical differences in the distribution of several flatfish species during winter and that these differences are associated with larval transport. The data presented here add that depth distribution may be influential in all seasons.

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APPENDIX 5

Seven posters were prepared for the 2nd Annual Research Coordinators Meeting that described the joint NCCOS-GRNMS study. (Appendix 5)

An Overview of the Collaboration between the National Centers for Coastal Ocean Science and Gray's Reef National Marine Sanctuary

Gray's Reef National Marine Sanctuary

NCCOS Principal Investigators

Jon Hare - Center for Coastal Fisheries and Habitat Research, Beaufort
Jeff Hyland - Center for Coastal Monitoring and Assessment, Charleston
Cheryl Woodley - Center for Coastal Environmental Health and Biomolecular Research, Charleston

Grays Reef National Marine Sanctuary

Reed Bohne - Sanctuary Manager
Greg McFall - Research Coordinator

Background

In April 2000, the National Centers for Coastal Ocean Science (NCCOS) and the National Marine Sanctuaries (NMS) embarked on a collaborative research project. One of these collaborative projects centers on Gray's Reef National Marine Sanctuary (GRNMS) off the coast of Georgia. The overall purpose of the project is for NCCOS scientists to participate in monitoring and site characterization activities relevant to GRNMS. The scientific activities, however, are broad and attempt to establish how GRNMS functions within the larger ecosystem of the southeast United States continental shelf. The larger-scale focus of the research will assist in the management of GRNMS by providing information about the Sanctuary, as well as defining the linkages between components of the Sanctuary and areas outside of the Sanctuary. Further, using GRNMS as a model, the research is assessing the utility of GRNMS to act as a Marine Protected Area with the purpose of promoting the sustainability of commercially and recreationally important fisheries.

The collaborative research project has nine specific objectives and this series of posters presents the results to date. In this panel (**Panel 1**) and the second panel (**Panel 2**), each objective is stated and a brief overview is given. In **Panel 3**, a summary of sampling is provided and a stage-specific fish species list is developed for GRNMS. **Panel 4 and 5** present results from our examination of juvenile fishes. **Panel 6** summarizes the spawning and larval fish distribution research and **Panel 7** uses some of our work in the Tortugas South Ecological Reserve (Florida Keys National Marine Sanctuary) to illustrate our examination of the fate of larvae spawned within Sanctuaries using satellite-tracked drifters.

This work is funded through FY02, and the information presented here represents an overview and status report. The final product for much of this work will be peer-reviewed publications. The continued development of a close-knit relationship between the research and management missions of NCCOS and NMS is also an important product of this project. At the end of Panel 2, we show where NCCOS scientists have participated in the GRNMS management process to illustrate how science and management can work hand-in-hand. We are very interested in continuing our collaborative research with GRNMS and with the larger NMS system and hope that this display will help convince you that our research is relevant to the mission of NMS.

Specific Research Objectives

1. ***Participate in Gray's Reef National Marine Sanctuary fish monitoring activities including work in adjacent deeper areas.*** CCFHR have been involved in fish monitoring efforts since initial baseline work in the 1980's (Parker et al. 1994). CCFHR staff continued to participate in the semi-annual fish monitoring efforts in the 1990's. During the course of this project, two successful visual censuses have been made, one by a joint team of divers and one by GRNMS divers (Table 1). Three additional attempts were made, but poor visibility prevented completion of the visual censuses.

   No adult fish work has been completed in deeper areas, but CCFHR staff did participate in Sustainable Seas Expedition cruise in September 2001 to extend the juvenile fish work into deeper waters (see Objective 4).

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

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

2. ***Analyze fish monitoring data for changes in abundance and species composition over time (1995-1999).*** Analysis of the visual census data is part of Dave Score's Masters Thesis (Georgia Southern University) and CCFHR staff have been providing technical assistance. The adult census data has been analyzed using multi-dimensional scaling analysis (MDS), a non-parametric multivariate technique, to examine changes in the reef fish community at GRNMS. MDS demonstrates clear differences in the reef fish community among seasons (Figure 1). Comparing years within seasons, inter-annual differences in the reef fish community were found among years (Figure 2). These analyses raise the question, what causes the intra and inter-annual variability in reef fish community structure? Two hypotheses can be proposed: the seasonal and interannual differences in reef fish community structure are caused by H1) differences in settlement of reef fish from the plankton and H2) differences in migration patterns of juvenile and adult reef fish. Future research could address these questions.

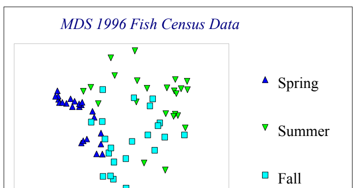


Figure 1. MDS analysis of GRNMS visual census data collected in 1996. Fish communities were significantly different among seasons. This pattern was also observed in the analyses of 1997 and 1999

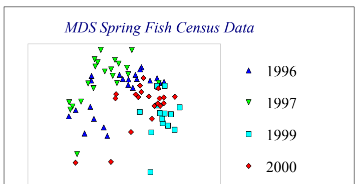


Figure 2. MDS analysis of GRNMS visual census data collected during the spring in 1996, '97, '99 and '00. Fish communities were significantly different among years This pattern was also observed in the interannual comparisons made using summer and fall data.

3. ***Assess adequacy of fish monitoring sampling design for detecting changes in abundance and composition of fishes over time.*** The adult census data collected and analyzed to date demonstrates that interannual comparisons must be made within seasons. In other words, data collected in the fall of 2000 is not comparable to data collected in spring 2001. NCCOS and GRNMS need to decide the season in which monitoring efforts will be made and then expend the necessary resources to accomplish this task. Similarly, analysis of the data (not shown) indicates that there is a trade-off between expending effort to quantify diversity of fishes and expending effort to quantify the number of specific species of fishes. These two issues will be discussed by GRNMS and CCFHR staff and whatever changes are decided for the monitoring sampling design will be implemented in FY03 if the project is continued.

4. ***Determine the importance of non-reef habitats to juvenile stages of reef fishes and evaluate the linkages between non-reef and reef habitats.*** Reef fish population dynamics are controlled by processes that act during the larval and early juvenile stages (Sale 1991). Specifically, for the juvenile stage, there is almost a complete lack of information regarding settlement habitats on the southeast United States continental shelf. Defining settlement habitat becomes a necessary first step in habitat-based management to conserve fisheries species as well as ecological studies of reef fish populations dynamics on the southeast United States shelf. Additionally, settlement to non-reef habitats implies a link between reef and non-reef habitats that must be considered in habitat based management. As a first step in this study, we are examining the importance of non-reef habitats to juvenile stages of reef fish and this research is described more fully in Panel 4 and Panel 5. We are concentrating our efforts around GRNMS and along a cross-shelf corridor (see Figure 9B in Panel 3). In addition, we have conducted some work in deeper water offshore of GRNMS as part of the Sustainable Seas Expedition in 2001 and coupled benthic infaunal sampling (Objective 9) with juvenile fish collections over an area extending from GRNMS shoreward to the coast during the spring of 2001 (see Figure 9B in Panel 3).

Figure 3. A *Xyrichtys novacula* (pearly razorfish) juvenile.

5. ***Provide customized satellite-derived sea surface temperature products to assist research and management activities within Grays Reef National Marine Sanctuary.*** Our primary efforts with remotely sensed data have focused on improving the operational navigation of NOAA 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) (Figure 4A). 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. This process can also be extended to other regions of the United States and thus other Sanctuaries but would require cooperation with local CoastWatch Nodes. NOAA NESDIS CoastWatch Program provide partial support for this work.

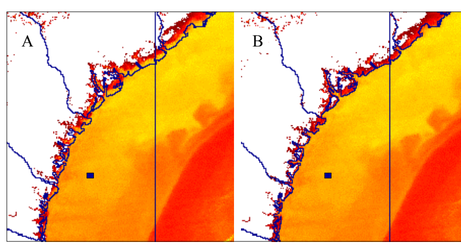


Figure 4A. CoastWatch sea surface temperature (SST) image prior to georectification. Notice that the image data is offset from the map. **B.** Same CoastWatch SST image after automated georectification. The derived offset was 5 pixels vertical and 2 pixels horizontal. GRNMS is shown as a blue box.

6. ***Determine the species of fish that spawn in the vicinity of Grays Reef National Marine Sanctuary &***
7. ***Evaluate larval transport to and dispersal from Grays Reef National Marine Sanctuary to surrounding areas.*** Spawning and larval transport are relevant to both the population dynamics of marine fish and to the development of Marine Protected Areas. As stated above, larval and early juvenile survival are likely critical factors in determining the dynamics of marine fish populations and need to be considered in any type of management that touches upon the sustainability of living marine resources. Further, one cornerstone of the MPA concept is that adult populations will increase in the protected area and subsequently produce more offspring, which will increase the number of recruits to non-protected areas. An assessment of a potential MPA must include information on what species spawn within the proposed MPA and where larvae spawned within the MPA go. The source of larvae to an MPA also must be investigated to determine if an MPA is dependent on larval supply from other areas. Our work has two related components. First we are determining the species that spawn in the vicinity of GRNMS through larval surveys. This work is described in more detail in Panel 6. Second, we are examining larval transport processes in the vicinity of GRNMS. One aspect of this work is described in more detail in Panel 6 and a second aspect is described in Panel 7 through an example from our work in the Tortugas Ecological Reserve (Florida Keys Marine Sanctuary).

Identification of Larval and Juvenile Fishes Using 12S Mitochondrial DNA

An important element of the larval and juvenile fish work described here is identification. To study fish, you first must be able to identify fish. Further, identifications need to be at the species level, as identification at the family and even genus level may blur important ecological and life history differences. The settlement habitat of species in the genus *Centropristis* described in Panel 5 is a case in point. At the genus level, *Centropristis* settles across the entire shelf, but at the species-level, a distinct cross-shelf zonation in settlement habitat is apparent.

Our goal with this component of the project is to establish a genetic species identity database for the snapper- grouper complex in the western Atlantic Ocean. 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 juvenile habitat utilization, determine the species that spawn in GRNMS, and enable a clearer evaluation of larval transport to and from GRNMS. In particular, understanding black sea bass (*Centropristis striata*) and bank sea bass (*Centropristis ocyurus*) spawning and larval transport is a top priority owing to their commercial and recreational importance. However, *Centropristis* larvae and juveniles cannot be identified to 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.

Preliminary analysis of 12S mitochondrial DNA sequences has been conducted on two *Centropristis* species: *C. striata* and *C. ocyurus*. Sequences have been generated from 16 individuals and phylogenetic trees have been constructed from the sequence data (Figure 5). 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, *Centropristis philadelphica*, and individuals of *Diplectrum formosum (*as an outgroup*)* have been obtained and the 12S region is being sequenced. The sequences will be compared with sequences from *C. striata* and *C. ocyurus* to determine the number of fixed differences between the four species. The 12S region from juveniles is currently being sequenced to verify our identifications. Plans are underway to start the analysis of *Centropristis* larvae.

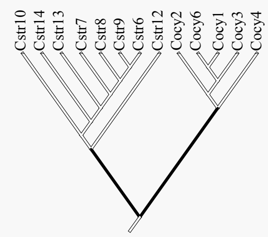
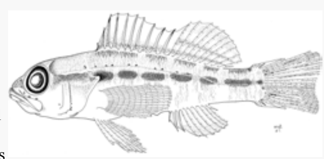


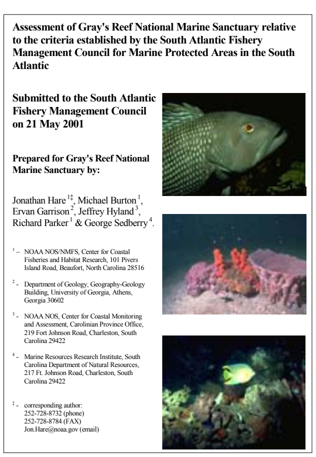
Figure 5. Differentiation of two species of sea bass, Centropristis striata (Cstr) and C. ocyurus (Cocy) based on sequences of the 12S region of the mtDNA genome. Tree construction was by neighbor joining analysis using p distances

Figure 6. A technical illustration of a juvenile *Centropristis ocyurus* to be used in a peer-reviewed publication describing the identification of juvenile Serraninines on the southeastern United State s shelf. A key based on traditional characters will be presented, but the initial positive identifications will be based on 12S mtDNA sequences. This approach brings together the expertise of two NCCOS Centers to solve a problem which is fundamental to stewardship, conservation and understanding.



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.*** In an ideal world, an assessment of GRNMS as a MPA would follow the research conducted during this project. However, the South Atlantic Fishery Management Council (SAFMC) is proceeding with the implementation of MPAs as a fisheries management tool. GRNMS asked NCCOS to respond to a specific request from the SAFMC. Scientists from NCCOS, National Marine Fisheries Service, South Carolina Department of Natural Resources and University of Georgia worked together to answer the specific questions posed by the SAFMC relative to GRNMS and also addressed the larger theme that the SAFMC needs to take an ecosystem and whole life history view in their design of MPAs.

The release of satellite-tracked drifters as part of objective 7 has provided a first order determination of the areas that would receive larvae from spawning within GRNMS (Figure 7). The envelops of the drifter locations at 15, 30 and 45 days indicate that larval fish spawned within GRNMS could be supplied to a number of other hard bottom areas on the southeast United States continental shelf. Larval duration of most of the snapper grouper species range from 15 to 45 days (Lindeman et al. 2000). Definition of settlement habitats, determination of the species that spawn within the vicinity of GRNMS, and further examination of larval transport will refine our ideas regarding the potential of GRNMS to act as a source of recruits. This project will also contribute to evaluating MPA siting on the southeast United States continental shelf as a whole, thereby supporting management at GRNMS and throughout the region.



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:

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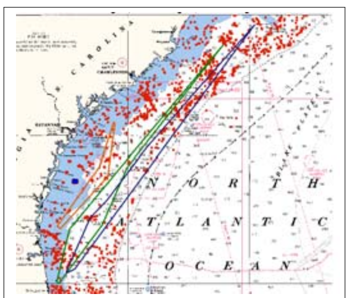

Figure 7. Envelopes of 12 drifters released within GRNMS in April, June, October, 2000 and January 2001. Envelopes show the outline of the area encompassed by the drifters 15 (red), 30 (green) and 45 (blue) days following release. GRNMS is shown as a blue rectangle (■) and known reef areas are shown as red squares (■).

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*** - This objective address the current environmental conditions within the GRNMS and documents the benthic invertebrates that inhabit open sand habitats. In general, chemical contamination in sediments throughout GRNMS are at background levels. A low-level spike of copper was observed at one station. Trace concentrations of man-made pesticides (DDT, chlorpyrifos) and other human produced chemical substances (PCBs, PAHs) were detected at low concentrations. Likewise, contaminants in tissues of target benthic species are below human health guidelines, but chemicals associated with human sources were found (PCBs, PAHs). At present, 0% of GRNMS shows significant evidence of impaired benthic condition, however some, very limited contamination was found. Monitoring efforts should continue to provide early warning to GRNMS managers and other coastal managers should contamination become more prevalent.

Coupled with the benthic contamination work, surveys of benthic invertebrates have been conducted. GRNMS was designated to conserve natural reef on the southeast United States continental shelf, but the Sanctuary also contains large areas of open sand. These vast stretches of open sand support a highly diverse and abundant infaunal community, which should change a frequent misconception that these featureless substrates surrounding reefs are "biological deserts". The juvenile fish work described in Panel 4 also supports the view that the open sand habitats are utilized by a diversity of organisms. Results from this objective provide a more complete understanding of GRNMS as a Sanctuary for a variety of continental shelf habitats. Further coupling of the benthic infauna work with the juvenile fish work will better describe the links between reef and non-reef habitats on the southeast United States continental shelf.

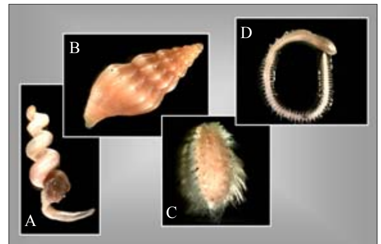

Figure 8. Examples of benthic macroinfauna from GRNMS. A. *Aspidosiphon mulleri*. B. *Kurtziella rubella*. C. *Chloeia viridis*. D. *Nephtys picta*.

Outreach and Cooperation

An important element of Sanctuary activities is vesting the public in the National Marine Sanctuaries system. One way to achieve this is to involve people in the collaborative research described here. We have taken this element to heart and have involved 15 students, volunteers, and teachers in the research to date.

- Katie Barker - University of Wisconson - Field work volunteer
- Brian Degan - North Carolina State University - Oak Ridge Institute for Science and Education Student Research Participation Program
- Anna DuRant - Cape Fear Community College - Field work volunteer
- Amelia Jugovich - Smith College Internship Program
- Siya Lem - University of North Carolina Wilmington - Oak Ridge Institute for Science and Education Student Research Participation Program
- Jamie Levis - Cape Fear Community College - Field work volunteer
- Katrin Marancik - East Carolina University - Oak Ridge Institute for Science and Education Student Research Participation Program
- Gretchen Bath Martin - Old Dominion University - Student Career Experience Program
- Regan McNatt - North Carolina State University - Field work volunteer
- Jessi O'Leary - East Carolina University - Laboratory work volunteer
- Jeanne Packheiser - Teacher-at-Sea Program
- Sam Patel - East Carolina University - Laboratory work volunteer
- Drew Shoaf - East Carolina University - Laboratory work volunteer
- Chad Smith - East Carolina University - Laboratory work volunteer
- Ben Walthers - MIT-WHOI Joint Program - Field work volunteer

Another important aspect of the NCCOS - NMS collaboration is cooperation. At the request of GRNMS staff, we have participated in many management activities and some of these are listed below.

- State of the Reef Planning Meeting - March 2000
- South Atlantic Fishery Management Council Habitat Advisory Panel Meeting - August, 2000
- GRNMS Species Conservation Workshop - December 2000
- National Marine Sanctuary Research Workshop - February 2001
- South Atlantic Fishery Management Council Marine Protected Area Advisory Panel Meeting - May, 2001
- GRNMS Research Monitoring Workshop - June 2001
- South Atlantic Fishery Management Council Habitat Advisory Panel Meeting - August, 2001

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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. Fishery Bulletin 92:787-799.

Sale PF (ed). 1991. The ecology of fishes on coral reefs. Academic Press.

Lindeman KC. 2000. Developmental patterns within a multispecies reef fishery. Management applications for essential fish habitats and protected areas. Bulletin of Marine Science 66:929-956.

Introduction of Lionfish to Southeast United States Continental Shelf

During the summer of 2001, scientists at CCFHR documented the presence of lionfish (*Pterois volitans*) off the coast of North Carolina. Discussions with other researchers turned up other documented cases of lionfish along the east coast. In one instance, juvenile fish were captured indicating that lionfish are reproducing. A manuscript has been submitted describing the observations to date (Whitfield et al. in review. Marine Ecology Progress Series). This is a significant finding of an introduced marine fish and the potential consequences for natural reef systems is unknown. No lionfish have been observed within GRNMS but one was collected approximately 20 nm to the southeast.

Overview of Sampling Conducted as Part of NCCOS-GRNMS Collaborative Research Project and Fish Species List for GRNMS for Larval, Juvenile and Adult Life History Stages

Table 2. Summary of cruises conducted in support of the juvenile and larval fish components of the NCCOS-GRNMS Project. Eleven cruises have been completed to date and one is planned for February of this year. The Gray's Reef cross-shelf cruises represent the standard juvenile and larval fish sampling discussed in panels 4, 5, and 6. Two sampling designs were included. One was a large-scale cross-shelf array of stations where both larval and juvenile fish were collected (●); the other was a smaller-scale along- and cross-shelf array where only larval fish were collected (○). The Sustainable Seas offshore cruise (■) was conducted with various partners and juvenile sampling offshore of GRNMS was completed. Finally, the Georgia Shelf Inshore cruise (▲) was joint between CCMA and CCFHR and coupled the juvenile fish collections with benthic macroinfauna collections. The number of stations sampled during each cruise are provided. Two ichthyoplankton samples and three beam trawl samples were taken at each station.

			Transects		
			Gray's Reef	Sustainable Seas	GA shelf
Year	Month	Dates	cross-shelf	offshore	inshore
2000	April	24-27	9		
	June	19-22	9		
	August	15-17	9		
	October	03-07	10		
2001	Jan/Feb	30-01	10		
	March	21-23	10		
	Apr/May	30-04	10		11
	June	04-09	10		
	August	03-06	10		
	Sept	07-09		6	
	October	11-13	10		
2002	February	08-13	10	6	11

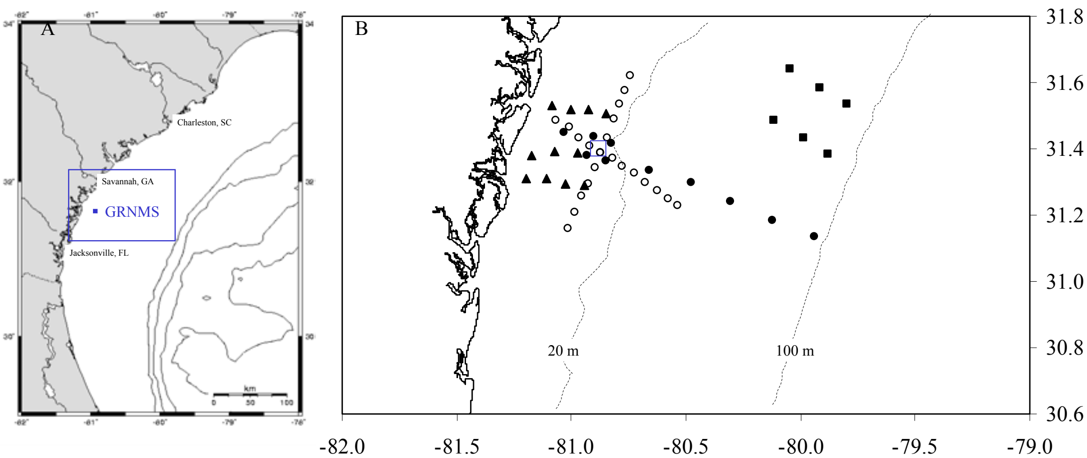


Figure 9A. Map of southeast United States continental shelf showing study region of the coast of Georgia. **9B**. Map of specific study region showing different sampling locations. Symbols for sample locations are provided below and descriptions are given in Table 2.

● Gray's Reef large scale cross-shelf juvenile and ichthyoplankton stations

○ Gray's Reef small scale cross-shelf and along-shelf ichthyoplankton stations

■ Sustainable Seas Expedition juvenile stations

▲ GA shelf inshore juvenile stations

Table 3. Fish fauna within Gray's Reef National Marine Sanctuary (GRNMS). Data are derived from on going NCCOS projects. Adult data comes from the visual censuses. Larval data comes from ichthyoplankton collections, and juvenile data comes from beam trawl collections. Reef fish are identified in red text, possible reef fish are identified in blue text, and non-reef fish are identified in black text.

Family	*Species*	Common Name	Adult	Larval	Juvenile
Orectolobidae	*Ginglymostoma cirratum*	nurse shark	A		
Dasyatidae	*Dasyatis americana*	southern stingray	A		
	Dasyatis sayi	bluntnose stingray			J
Congridae	*Ariosoma balearicum*	bandtooth conger			J
Ophichthidae	Ophichthidae	snake eel		L	
	Letharchus velifer	sailfin eel			J
	Ophichthus ocellatus	palespotted snake eel			J
Muraenidae	*Gymnothorax moringa*	spotted moray	A		
Clupeidae	Clupeidae	herring		L	
	Brevoortia tyrannus	Atlantic menhaden			J
	Etrumeus teres	round herring			J
	Sardinella aurita	Spanish sardine			J
Engraulidae	Engraulidae	anchovy		L	
	Anchoa hepsetus	striped anchovy		L	J
	Anchoa lamprotaena	bigeye anchovy			J
	Anchoa sp.	anchovy		L	
Synodontidae	Synodontidae	lizardfish		L	
	Synodus foetens	inshore lizardfish	A		J
	Synodus intermedius	sand diver	A		
	Synodus sp.	lizardfish		L	
	Trachinocephalus myops	snakefish			J
Batrachoididae	*Opsanus pardus*	leopard toadfish	A		
	Opsanus tau	oyster toadfish	A		
Ogcocephalidae	*Ogcocephalus nasutus*	shortnose batfish			J
Bregmacerotidae	*Bregmaceros houdei*	codlet		L	
Gadidae	Gadidae	hake		L	
	Urophycis floridana	southern hake			J
	Urophycis regia	spotted hake			J
Ophidiidae	Ophidiidae	cusk-eel		L	
	Ophidion grayi	blotched cusk-eel			J
	Ophidion holbrooki	bank cusk-eel			J
	Ophidion marginatum	striped cusk-eel		L	J
	Ophidion selenops	mooneye cusk-eel		L	
	Ophidion welshi	crested cusk-eel			J
	Otophidium omostigmum	polka-dot cusk-eel		L	
	Ophidion Type 8	cusk-eel		L	
	Ophidion sp.	cusk-eel		L	
Exocoetidae	Exocoetidae	flyingfish		L	
	Hirundichthys affinis	fourwing flyingfish			J
Atherinidae	*Menidia menidia*	Atlantic silverside			J
Syngnathidae	Syngnathidae	pipefish		L	
	Hipocampus erectus	lined seahorse			J
	Hipocampus sp.	seahorse		L	
	Syngnathus springeri	bull pipefish			J
Holocentridae	*Holocentrus ascencionis*	squirrelfish	A		
Serranidae	*Centropristis ocyurus*	bank sea bass	A		J
	Centropristis striata	black sea bass	A		J
	Diplectrum formosum	sand perch	A	L	J
	Mycteroperca microlepis	gag	A		
	Mycteroperca phenax	scamp	A		
	Serraniculus pumilio	pygmy sea bass		L	J
	Serranus subligarius	belted sandfish	A		J
	Serraninae			L	
Grammistidae	*Rypticus maculatus*	whitespotted soapfish	A		

Reef fish taxa **Possible reef fish taxa** **Non-reef fish taxa**

Family	*Species*	Common Name	Adult	Larval	Juvenile
Priacanthidae	*Pristigenys alta*	short bigeye			J
Apogonidae	*Apogon pseudomaculatus*	twospot cardinalfish	A		
Rachycentridae	*Rachycentron canadum*	cobia	A		
Carangidae	Carangidae	jack		L	
	Caranx bartholomaei	yellow jack	A		
	Caranx crysos	blue runner		L	
	Caranx ruber	bar jack	A		
	Decapterus macarellus	mackerel scad	A		
	Decapterus punctatus	round scad	A		
	Decapterus sp.	scad		L	
	Selene vomer	lookdown			J
	Seriola dumerili	greater amberjack	A		
	Seriola sp.	jack		L	
Lutjanidae	*Lutjanus analis*	mutton snapper			J
	Lutjanus campechanus	red snapper	A		
	Lutjanus griseus	gray snapper	A		
	Ocyurus chrysurus	yellowtail snapper	A		
	Rhomboplites aurorubens	vermilion snapper	A		
Gerreidae	Gerreidae	mojarra		L	
Haemulidae	*Haemulon aurolineatum*	tomtate	A		
	Haemulon plumieri	white grunt	A		
	Haemulon sp.	grunt			J
	Orthopristis chrysoptera	pigfish		L	
Sparidae	Sparidae	porgy		L	
	Archosargus probatocephalus	sheepshead	A		
	Calamus leucosteus	whitebone porgy	A		
	Diplodus holbrooki	spotfin pinfish	A		
	Lagodon rhomboides	pinfish	A	L	J
	Pagrus pagrus	red porgy	A		
	Stenotomus chrysops	scup	A		
	Stenotomus sp.	porgy			J
Sciaenidae	Sciaenidae	drum		L	
	Cynosion nothus	silver seatrout		L	J
	Cynosion nothus/arenarius	seatrout		L	
	Cynoscion sp.	seatrout		L	
	Equetes umbrosus	cubbyu	A		
	Larimus sp.	drum		L	
	Leiostomus xanthurus	spot		L	J
	Sciaenops ocellata/Pogonias	drum		L	
	Menticirrhus americanus	southern kingfish		L	
	Menticirrhus littoralis	gulf kingfish		L	
	Menticirrhus saxatilis	northern kingfish		L	
	Menticirrhus sp.	kingfish		L	
	Micropogonias undulatus	Atlantic croaker		L	J
	Pareques acuminatus	high-hat	A		
	Sciaenidae Type 1	drum		L	
Mullidae	*Upeneus parvus*	dwarf goatfish	A		
Ephippidae	*Chaetodipterus faber*	Atlantic spadefish	A		
Chaetodontidae	*Chaetodon ocellatus*	spotfin butterflyfish	A		
	Chaetodon sedentarius	reef butterflyfish	A		
Pomacanthidae	*Holocanthus bermudensis*	blue angelfish	A		
Pomacentridae	*Abudefduf saxatilis*	sargeant major	A		
	Pomacentrus partitus	bicolor damselfish	A		
	Pomacentrus variabilis	cocoa damselfish	A		
Mugilidae	*Mugil cephalus*	striped mullet			J
	Mugil curema	white mullet			J
Sphyraenidae	*Sphyraena barracuda*	great barracuda	A		

Family	*Species*	Common Name	Adult	Larval	Juvenile
Labridae	Labridae	wrasse		L	
	Halichoeres bivittatus	slippery dick	A		
	Halichoeres caudalis	painted wrasse	A		
	Halichoeres sp.	wrasse		L	
	Tautoga onitis	tautog	A		
	Xyrichtys novacula	pearly razorfish	A		J
	Sparisoma sp.	unidentified parrotfish	A		
Dactyloscopidae	*Dactyloscopus moorei*	sand stargazer		L	J
Clinidae	*Starksia ocellata*	checkered blenny	A		
Blenniidae	Blenniidae	unidentified blenny		L	
	Hypleurochilus geminatus	crested blenny	A		J
	Ophioblennius atlanticus	redlip blenny	A		
	Parablennius marmoreus	seaweed blenny	A		
Callionymidae	*Diplogrammus pauciradiatus*	spotted dragonet			J
Gobiidae	Gobiidae	unidentified goby		L	
	Coryphopterus glaucofraenum	bridled goby	A		
	Microgobius sp.	goby			J
Acanthuridae	*Acanthurus bahianus*	ocean surgeon	A		
	Acanthurus chirurgus	doctorfish	A		
Scoberidae	*Euthynnus sp.*	mackerel		L	
	Scomberomorus cavalla	king mackerel	A		
Stromateidae	*Peprilus triacanthus*	butterfish			J
	Peprilus sp.	butterfish		L	
Scorpaenidae	*Scorpaena dispar*	hunchback scorpionfish			J
	Scorpaena plumieri	spotted scorpionfish			J
	Scorpaena sp.	scorpionfish			J
Triglidae	Triglidae	searobin		L	
	Prionotus carolinus	northern searobin			J
	Prionotus sp.	searobin		L	J
Paralichthyidae	*Ancylcopsetta quadrocellata*	ocellated flounder			J
	Citharichthys gymnorhinus	angelfin whiff		L	
	Citharichthys macrops	spotted whiff			J
	Citharichthys sp	flounder		L	J
	Cyclopsetta fimbriata	spotfin flounder		L	J
	Etropus crossotus	fringed flounder		L	
	Etropus sp.	flounder		L	J
	Paralichthys lethostigma	southern flounder			J
	Hippoglossina oblongatta	flounder		L	
	Syacium papillosum	dusky flounder			J
	Syacium sp.	flounder		L	
Scopthalmidae	*Scopthalmus aquosus*	windowpane			J
Bothidae	*Bothus sp.*	flounder			J
Soleidae	*Gymnachirus melas*	naked sole			J
Cynoglossidae	*Symphurus diomedeanus*	spottedfin tonguefish			J
	Symphurus minor	largescale tonguefish			J
	Symphurus plagiusa	blackcheek tonguefish			J
	Symphurus urospilus	spottail tonguefish			J
	Symphurus sp.	tonguefish		L	
Balistidae	*Aluterus schoepfi*	orange filefish	A		
	Balistes capriscus	gray triggerfish	A		
	Cantherhines pullus	orangespotted filefish	A		
	Monacanthus hispidus	planehead filefish			J
	Monacanthus sp.	filefish		L	
Tetraodontidae	*Sphoeroides dorsalis*	marbled puffer	A		
	Sphoeroides sp.	puffer		L	
	Sphoeroides spengleri	bandtail puffer	A		
Ostraciidae	*Lactophrys quadricornis*	scrawled cowfish	A		

Juvenile and small adult fish community structure on the Georgia shelf

Harvey Walsh, Jon Hare, Brian Degan, and Gretchen Bath Martin
NOAA Beaufort Laboratory, Center for Coastal Fisheries and Habitat Research

2 m Beam trawl

CTD Cast

ROV video

Introduction

Gray's Reef National Marine Sanctuary (GRNMS) contains one of many live-bottom reefs that are scattered along the continental shelf from North Carolina to north-central Florida. These reefs support many fish species that are targets of both commercial and recreational fisheries (e.g., gag and black sea bass). Management plans currently exist for both GRNMS and reef fish species found in the Sanctuary, but overfishing remains a problem. Fisheries management is moving towards habitat-based approaches (e.g., Marine Protected Areas, MPAs), which brings sanctuary management and fisheries management closer together. Habitat-based management protects species by excluding human activities from areas of known habitat and in the case of reef fish management, typically involves forming Marine Protected Areas that encompass reef habitat and exclude some human activities. The approach of protecting adult habitat ignores the fact that juveniles stages can also be adversely affected by human activities. For example, bycatch directly impacts juvenile survival and habitat loss may lead to lower juvenile production. Further, if juvenile habitat is distinct from adult habitat, individuals are susceptible to fishing while moving from juvenile to adult habitat.

For many reef fishes along the southeast United States, we have limited knowledge regarding juvenile habitat and thus cannot begin to consider habitat-based management approaches to limit adverse human effects on juvenile stages (Lindeman et al. 2000). Four general juvenile habitats can be defined: estuarine, open sand, reef and pelagic. We have a good understanding of juvenile reef fish utilization of estuarine habitats; both gag and black sea bass juveniles use estuaries. We have little information about the use of the other three habitats. Further, we don't know if open sand, reef and pelagic habitats on the southeast United States continental shelf are subdivided along some spatial or temporal gradients, as has been found in other systems (Steves et al. 1999, Sullivan et al. 2000). An objective of the present NCCOS-GRNMS project is to examine utilization of open sand habitats by juvenile reef fish. Our focus is the area around GRNMS, but we are working across the shelf and throughout the year to document cross-shelf and seasonal patterns in habitat utilization. The cross-shelf information will assist with our goal of understanding GRNMS within the context of the larger southeast United States continental shelf ecosystem.

Materials and Methods

Juvenile and small adult fish were sampled at 10 stations along a cross-shelf transect (see Figure 9 in Panel 3). The stations, including 4 around the perimeter of GRNMS, range in depth from 11 to 47m. Sampling at each station occurs only at night and consists of 3, 5-minute, 2 m beam trawl tows (3 mm mesh). Concurrent CTD casts provide measurements of water temperature and salinity. To date, 10 cruises have been completed, and 7 are included in the current analysis (see Table 2 in Panel 3). During April 2000, remotely operated vehicle (ROV) operations were conducted to determine benthic habitat characteristics. Data from ROV drifts made at each station are currently being analyzed.

Principle component analysis (PCA) was used to describe the spatial and temporal characteristics of environmental variables. Non-metric multi-dimensional scaling (MDS) analysis of the abundance (fish•5 minute tow^{-1}) for all the taxa collected were used to describe patterns in the fish community structure. Significant differences between seasons and cross-shelf groups were determined using analysis of similarity (ANOSIM).

Results

Juvenile and small adults of 111 taxa from 48 families were identified from the beam trawl collections (see Table 3 in Panel 3). Identification of several juvenile stages of fish to species is difficult. Therefore, some of the most abundant taxa are currently only identified to genus (Table 4). PCA of the environmental variables resulted in 3 principle components (Table 5) that explained 85% of the cumulative variation (Table 6) and described both seasonal and cross-shelf (depth) components of the data (Figure 10). Sample months grouped into seasons based on water temperature (spring- April and May, summer- June and August, fall- October, and winter- January and March) and were represented mainly by PC 2. Cross-shelf station groups were explained primarily by PC 1 and PC 3 and grouped stations into 4 depth strata. Inshore stations were less saline and stratification was important. Therefore, season and depth were used as factors to group stations in the MDS analysis.

Fish community analysis using MDS revealed seasonal and cross-shelf trends (Figure 11). Significant differences in the community structure were found between seasons (Table 7) and depth strata (Table 8). Nine taxa were most abundant during the four seasons (Table 9). Within each season, 3 to 4 abundant taxa contributed to at least 50% of the responsibility of seasonal groupings. Six of these taxa were also most abundant at the different depth strata (Table 10). GRNMS is in the 18-20m depth strata with flounder (*Etropus* sp.), sand stargazer, and mooneye cusk-eel dominating the catches.

Discussion

The fish community in the vicinity of GRNMS was dominated by small, cryptic, sand species and relatively few reef species were collected. The most abundant reef fish were serranines, which include 3 species of sea bass (*Centropristis philadelphica, C. ocyurus,* and *C. striata*). Improving the taxonomic resolution for juvenile fish identification (e.g., Sparidae, *Etropus* and *Bothus*) will provide a better understanding of juvenile fish habitat utilization. Coupling beam trawl survey results with concurrent ichthyoplankton data will help delineate spawning periods and larval duration (see Panel 6). Analysis of larval and juvenile distributions on the shelf also will help define settlement patterns for a number of reef and non-reef species (see Panel 5 for an example). Further, fish size distribution data from beam trawl surveys will reveal settlement habitat, and movement patterns of the abundant species.

We have defined fish habitat use of open sand on the continental shelf. From previous studies, we also have a good understanding of which species use nearshore (Wernner and Sedberry 1989) and estuarine habitats as juvenile nurseries (Reichert and van der Veer 1991, Walsh et al. 1999). To gain a complete understanding of juvenile habitat utilization, we now need to sample both reef and pelagic habitats. Such research would allow management decisions regarding protected areas to be made within the context of all habitats that a given species uses during its life history.

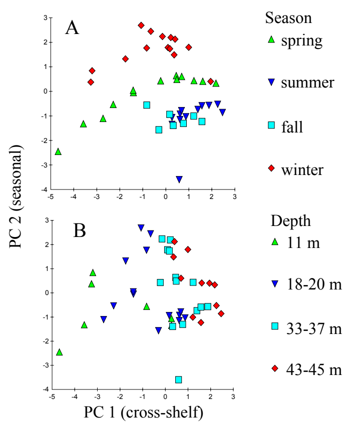


Figure 10. PCA of environmental data showing (A) seasonal and (B) cross-shelf groupings.

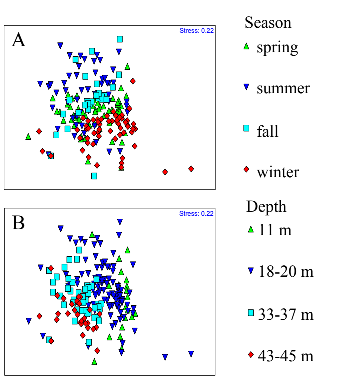
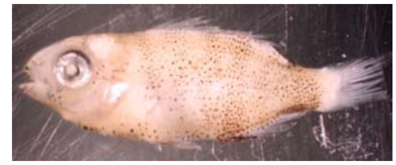
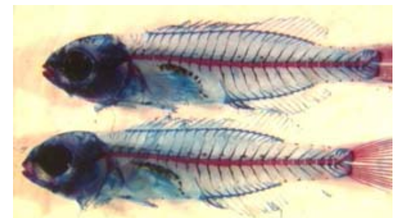


Figure 11. MDS of fish abundance data showing (A) seasonal and (B) cross-shelf groupings.



Stenotomus sp. collected with a 2 m beam trawl.



Cleared and stained juvenile pinfish

Table 4. The 20 most abundant taxa collected during beam trawl sampling. Reef fish are shown in red

Taxa	Common name	CPUE Mean	CPUE Sum
Etropus sp.	flounder	7.58	1614
Prionotus sp.	searobin	3.03	645
Symphurus minor	largescale tonguefish	2.73	582
Ophidion selenops	mooneye cusk-eel	2.52	536
Bothus sp.	flounder	2.04	435
Dactyloscopus moorei	sand stargazer	1.83	390
Diplectrum formosum	sand perch	1.69	359
Prionotus carolinus	northern searobin	1.21	257
Leiostomus xanthurus	spot	0.96	204
Microgobius sp.	goby	0.76	162
Synodus foetens	inshore lizardfish	0.75	159
Urophycis regia	spotted hake	0.48	102
Diplogrammus pauciradiatus	spotted dragonet	0.42	90
Otophidium omostigmum	polka-dot cusk-eel	0.41	88
Monocanthus hispidus	planehead filefish	0.33	70
Symphurus urospilus	spottail tonguefish	0.32	69
Centropristis ocyurus	bank sea bass	0.29	62
Serraniculus pumilio	pygmy sea bass	0.29	62
Anchoa hepsetus	striped anchovy	0.29	61
Citharichthys sp.	whiff	0.23	49

Table 5. Station environmental variables used for PCA, and coefficients of the principle components.

Environmental Variable	Principle Component 1	2	3
surface temperature (st)	0.353	-0.549	0.242
surface salinity (ss)	0.444	0.409	0.308
bottom temperature (bt)	0.292	-0.553	0.355
bottom salinity (bs)	0.493	0.268	0.008
depth	0.456	0.150	-0.369
st-bt	0.375	-0.108	-0.488
ss-bs	0.036	0.346	0.589

Table 6. Eigenvalues and variation explained by each principle component from PCA of environmental data.

Principle Component	Variation Eigenvalue	%	cumulative %
1	2.66	37.9	37.9
2	1.95	27.9	65.8
3	1.36	19.5	85.3

Table 7. ANOSIM of seasons averaged across all depth strata. Global R=0.343 and p<0.001.

Season	R	p
Spring, Summer	0.339	0.001
Spring, Fall	0.409	0.001
Spring, Winter	0.221	0.001
Summer, Fall	0.158	0.006
Summer, Winter	0.489	0.001
Fall, Winter	0.503	0.001

Table 8. ANOSIM of depth strata averaged across all seasons. Global R=0.343 and p<0.001.

Depth (m)	R	p
11, 18-20	0.230	0.004
11, 33-37	0.694	0.001
11, 43-45	0.653	0.001
18-20, 33-37	0.330	0.001
18-20, 43-45	0.455	0.001
33-37, 43-45	0.240	0.001

Table 9. Average abundance and contributions of abundant taxa collected during each season.

Season	Taxa	Common name	Average CPUE	Contribution %	cumulative %
Spring	Etropus sp.	flounder	9.69	25	25
	Ophidion selenops	mooneye cusk-eel	3.9	12	36
	Symphurus minor	largescale tonguefish	5.52	10	47
	Dactyloscopus moorei	sand stargazer	3.58	10	57
Summer	Diplectrum formosum	sand perch	4.32	26	26
	Etropus sp.	flounder	2.68	14	40
	Ophidion selenops	mooneye cusk-eel	0.71	11	51
Fall	Prionotus sp.	searobin	17.75	26	26
	Bothus sp.	flounder	7.56	17	43
	Ophidion selenops	mooneye cusk-eel	5.46	12	56
Winter	Etropus sp.	flounder	14.04	38	38
	Urophycis regia	spotted hake	1.59	10	48
	Leiostomus xanthurus	spot	3.58	9	57

Table 10. Average abundance and contributions of abundant taxa collected at each depth strata.

Depth	Taxa	Common name	Average CPUE	Contribution %	cumulative %
11 m	Etropus sp.	flounder	14.6	48	48
	Prionotus sp.	searobin	1.98	18	66
18-20 m	Etropus sp.	flounder	7.06	24	24
	Dactyloscopus moorei	sand stargazer	3.38	18	42
	Ophidion selenops	mooneye cusk-eel	2.64	15	57
33-37 m	Symphurus minor	largescale tongufish	6.77	25	25
	Bothus sp.	flounder	4.47	17	43
	Etropus sp.	flounder	9.71	13	55
43-45 m	Bothus sp.	flounder	4.22	27	27
	Symphurus minor	largescale tonguefish	6.9	26	54

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Use of non-reef habitat in the vicinity of Gray's Reef National Marine Sanctuary by juvenile reef fishes

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Introduction

Definition of juvenile habitat is an important element of habitat-based management and fisheries-based management. The population dynamics of many marine fishes may be driven by survival during the late-larval and early juvenile stage (Doherty and Fowler 1994, Quinlan and Crowder 1999). Human activities that effect the entry of larvae into juvenile habitats or that effect juvenile habitats directly may have adverse effects on juvenile survival and consequently, adult populations. Four general juvenile habitats can be defined on the southeast United States continental shelf: reef, open sand, pelagic and estuarine. Use of estuarine and pelagic (e.g., Sargassum) habitats by juvenile reef fish have been documented for several species (Lindeman et al. 2000), but other habitats have largely been ignored. Our current work with GRNMS focuses on juvenile habitat utilization of open sand habitats (Panel 4). This research has revealed that several species of serranines use open sand habitats during the juvenile stage.

The serranines include the genera *Serranus*, *Serraniculus*, *Diplectrum* and *Centropristis* and are important mid-level predators on southeast US reefs. They feed on invertebrates and small fish. They also serve as food for larger predators and both *Centropristsis striata* and *Centropristis ocyurus* are important members of the reef fish fishery. Owing to the importance of this group to the ecology of reefs, including those in GRNMS, we are defining the settlement habitat for these species and defining the age- and size-at-settlement. Further, the age-at-settlement information will be used in the studies of larval transport (panel 6 and 7) to establish the length of the dispersive larval stage. We are identifying fish using traditional methods and using genetic techniques to verify identifications. A description of the juvenile stages of this important group will also be produced to facilitate future studies (see Identification Box in panel 2).

Centropristis

philadelphica
-rare/common

ocyurus
-common

striata
-rare

Diplectrum

formosum
-abundant

Serraniculus

pumilio
-common

Figure 12. Pictures of the 5 most common juvenile serraninae collected on the Georgia shelf.

Table 11. Abundance (fish•5 min tow^{-1}) of juvenile serraninaes collected on the Georgia shelf during the first 7 cruises.

		Centropristis						*Diplectrum*		*Serraniculus*	
		philadelphica		*ocyurus*		*striata*		*formosum*		*pumlio*	
Year	Month	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
2000	April			1.32	4.79	0.14	0.45	1.23	1.97	0.41	0.87
	June			0.07	0.27			4.74	8.85	0.19	0.40
	August							3.89	7.55	0.35	1.13
	October							1.70	2.79	0.82	2.34
2001	Jan/Feb			0.13	0.43			0.33	1.15	0.10	0.31
	March			0.30	0.67			0.14	0.44	0.14	0.45
	Apr/May	0.43	1.17	0.39	0.95			0.90	1.39	0.04	0.19

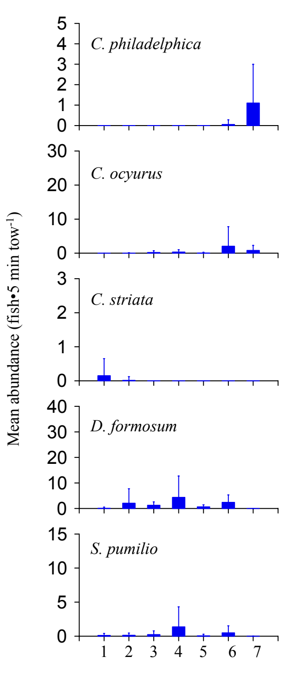


Figure 13. Abundance (fish•5 min tow^{-1}) across the Georgia shelf. Station 2 represents the 4 sites around the perimeter of GRNMS.

Methods

Beam trawl surveys were conduced at 10 stations on a cross-shelf transect bisecting GRNMS (see Panel 4). Species have been identified from 7 cruises. All fish were identified, counted, and measured to the nearest tenth of a millimeter standard length (SL). Juvenile serranines were identified to species. These identifications are being verified using genetic techniques. Abundance and size were plotted to determine cross-shelf distributions and to define settlement patterns. Otolith aging is now underway to determine settlement ages.

Results

Relatively few juvenile reef fish were collected during beam trawl sampling on the Georgia shelf. The most abundant group was the Serraninae. Six serranine species were collected (Figure 12, Table 11) including *Centropristis philadelphica, C. ocyurus, C. striata, Diplectrum formosum, Serraniculus pumilio, and Serranus subligarius* (one specimen).

Seasonal Abundance - *Centropristis ocyurus* was the most abundant species in the genus, and abundance peaked in the spring (Table 11). *C. striata* and *C. philadelphica* were also collected during the spring, but only during one cruise (Table 11). *Diplectrum formosum* was the most abundant serranine collected, with highest abundance in the summer (Table 11). *Serraniculus pumilio* was commonly collected and most abundant in the fall (Table 11).

Distribution - *Centropristis philadelphica* was collected at the outer most stations (Figure 13). *C. ocyurus* was collected across most of the shelf, but with peak abundances on the outer shelf (Figure 13). *C. striata* was collected only at the inshore-most station (Figure 13). Both *Diplectrum formosum* and *Serraniculus pumilio* were collected at all but the most offshore station (Figure 13).

Size - *Centropristis philadelphica* sizes ranged from 12-29 mm SL and the smallest juveniles were collected at the outermost stations (Figure 14). Juvenile *C. ocyurus* SL ranged from 9-52 mm with the small juveniles collected across the shelf but most abundant offshore (Figure 14). *C. ocyurus* size increased with increasing station depth suggesting either movement from inshore to offshore or higher post-settlement mortality inshore. *Diplectrum formosum* sizes ranged from 9-199 mm and small fish were caught across most of the shelf (Figure 14). *D. formosum* SL increased with decreasing depth suggesting either movement inshore or higher post-settlement mortality offshore. *Serraniculus pumilio* ranged from 8-53 mm and the smallest juveniles were collected on the mid-shelf (Figure 14).

Settlement - The three species of *Centropristis* have separate settlement habitats (Table 12). *C. striata* settles inshore and in the estuary (Able and Fahay 1998), *C. ocyurus* settles on the shelf out to at least 50 m, and *C. philadelphica* settles on the deeper shelf (> 40 m). Both *Diplectrum formosum* and *Serraniculus pumilio* settle on the mid-shelf.

Discussion

Few reef species use open sand habitats as settlement areas (~10%). However, the sea basses and sand perch do use open sand shelf habitat as settlement and nursery areas. Although the three species of *Centropristis* settle during the same season, they settle into different cross-shelf zones of open sand habitat. This implies that the use of GRNMS by adult Centropristis is dependent on the use of habitats outside of GRNMS (*C. striata* - estuaries; *C. ocyurus* and *C. philadelphica* outer shelf). We do not know if these differences result from different spawning areas, different larval transport pathways or different settlement behaviors. Coupling the juvenile and larval fish data will aid in determining the proximate cause for differing settlement habitats. Otolith aging now underway will further elucidate larval transport pathways by defining the length of the larval stage.

We estimate that there are approximately 50 species of reef fish that inhabit GRNMS as adults. Juvenile habitats on the southeast United States continental shelf have been defined for approximately 20% of the species. Detailed information on settlement (size, timing, age) has been described for approximately 10%. To form a more complete understanding of juvenile habitat utilization on the southeast shelf, we must now sample reef and pelagic habitats, both seasonally and across-shelf. With this information, we could address managers specific questions regarding what habitats need to be protected to support the conservation of a given species.

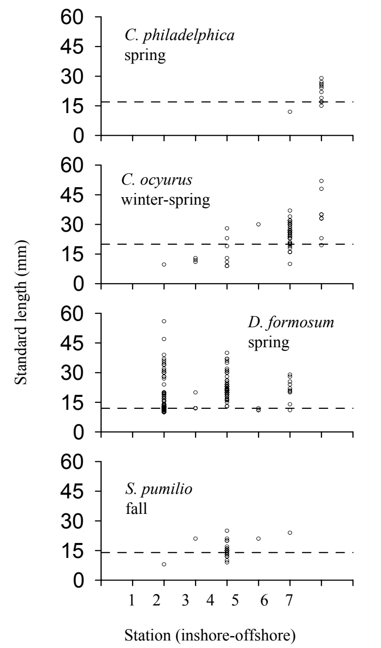
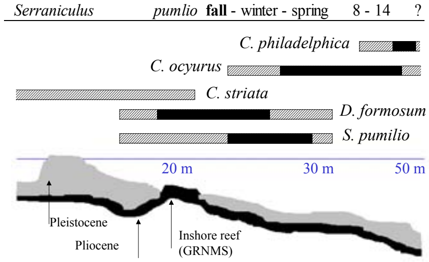


Figure 14. Standard length (mm) of serraninae across the Georgia shelf. Station 2 represents the 4 sites around the perimeter of GRNMS. Only cruises for the primary settlement period of a species are plotted. The dotted line on each graph shows estimated maximum size at settlement for each species.

Table 12. Settlement characteristics of serraninaes on the Georgia shelf. Settlement season and size are based on the number of small juveniles collected. Season is the time of year (cruise) when the smallest fish were abundant and the primary season is in bold text.

		Season	Size	Age
Centropristis	*philadelphica*	spring	12 - 17	?
	ocyurus	**winter** - spring	9 - 20	?
	striata	spring	16	?
Diplectrum	*formosum*	spring - **summer** - fall	9 - 12	?
Serraniculus	*pumlio*	**fall** - winter - spring	8 - 14	?



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Distribution of larval fish surrounding Gray's Reef National Marine Sanctuary

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Introduction

An important consideration for siting marine protected areas (MPAs) is knowing where a species of interest spawns. Visual observation of spawning is the most direct method, but is largely impractical in most field situations. The reproductive stage of gonads is frequently used to assess spawning time and location, but requires taking a large number of adults. The time and location of spawning can also be determined relatively easily by tracking seasonal patterns in the size and abundance of larval fish. We are using the last method to determine which fish species spawn in and around GRNMS.

Larval fish assemblages, groups of larval fish species co-occurring in both space and time, provide an indirect means to examine both spawning and transport issues. Variation in larval fish assemblages has been linked to seasonal and event scale changes in hydrography (Cowen et al. 1993, Doyle et al. 1993). Larval distribution and assemblages have been analyzed in combination with water mass information (temperature and salinity) to further infer larval transport processes. Larval fish assemblages have been identified and studied along the United States east coast from Cape Hatteras north to the Scotian Shelf (Cowen et al. 1993, Doyle et al. 1993), but have not been examined along the southeastern US. The lack of investigation is largely owing to the greater species diversity found in the southeastern US and the difficulty in identifying larvae to species (see Identification box in Panel 2).

The objectives of this study are to develop a list of fish spawning in the vicinity of GRNMS and to indirectly examine larval transport processes on the Georgia continental shelf. These objectives will be addressed through an analysis of larval fish assemblages and their relation with water mass distribution.

Materials and Methods

Ichthyoplankton sampling was conducted about every other month in the vicinity of GRNMS (Fig. 9B in Panel 3). Three transects were sampled comprising two scales, small scale 61km along-shelf and cross-shelf transects (stations spaced 5.5km apart) and a large scale 93km cross-shelf transect (stations spaced 18.5km apart; Table 13). Data from the April 2000 cruise have been analyzed further and will serve here as an example of the type of questions we will address with the complete data set. All larval fish from the April 2000 cruises were sorted and identified to family. Temperature and salinity data were used to define water mass as described by Pietrafesa et al. (1994). Similarities in ichthyoplankton community data within and between water masses were compared using non-metric multi-dimensional scaling (MDS) and analysis of similarities (ANOSIM).

Spawning in the Vicinity of GRNMS

We have identified larvae for April 2000 through March 2001 (see Table 3 in Panel 3). Sixty-one larval taxa were identified, which included four types of reef fish (serraninae, *Halichoeres* sp., blenniidae, and *Diplectrum formosum*) and one possible type of reef fish (sparidae). Many reef fish (e.g., gag and black sea bass) migrate offshore to spawn. As a result, few would be seen as larvae within GRNMS, accounting for the lack of larval reef fish encountered. Further analysis of offshore stations, the transport data, and coupling the larval data with the juvenile data will help determine the validity of this hypothesis.

Larval Assemblages and Water Masses

The April cross-shelf stations fell within two water masses, Georgia Bight Water and Georgia Bight/Gulf Stream Water mix (Fig. 16A). Georgia Bight Water is cooler, less saline, and more stratified than Georgia Bight/Gulf Stream mixed water (Fig. 17A). The along-shelf stations were all located in Georgia Bight water (Fig. 16B); however, there were differences in temperature and salinity within the water mass (Figs. 16B, 17B). Larval fish communities from within the Georgia Bight Water were significantly different from those of the Georgia Bight/Gulf Stream Water mix (Fig. 18) in the cross-shelf stations. Few differences were seen in the larval fish communities among the sub groups of the Georgia Bight shelf water sampled in the along-shelf transects (Fig. 18).

These data illustrate a relationship between larval fish assemblages and water mass characteristics. Hydrographic information may, therefore, be useful in predicting the location of assemblages. Also, the location and strength of fronts between water masses may control where specific larval fish are found, and thereby influence the supply of larvae to juvenile habitat. These data will be used to track seasonal variations in water masses and assemblage structure and to describe in more detail the characteristic spawning assemblages in the vicinity of GRNMS. Based on the results from family level analyses, we predict hydrography will also effect assemblage structure when fish identifications are at a finer taxonomic resolution. This work will provide important information for management of the sanctuary.

Future Directions

A variety of topics still need to be investigated in order to make sound decisions concerning the location and size of MPAs. Among our top priorities is improving larval identification. We are currently developing larval keys (e.g., sciaenidae and serranidae) as well as investigating genetic markers (e.g., serranidae and lutjanidae, see identification box in Panel 2) to separate species within hard to distinguish families. Three dimensional physical models are being developed for the southeast United States continental shelf. Coupling these models to larval fish vertical distribution will help describe transport mechanisms. Since many reef fish are known to migrate offshore to spawn, information on offshore distribution and abundance will also be needed.

Table 13: Sampling cruises completed from April 2000 through October 2001.
In June 2000 we were unable to collect any ichthyoplankton samples due to boat constraints.
*time and weather restricted us from collecting more than a partial transect.

			Number of Transects		
Year	Month	Dates	along-shelf small scale	cross-shelf small scale	cross-shelf large scale
2000	April	24-27	2	2	1
	June	19-22			
	August	15-17			1
	October	03-07	1	1	1
2001	Jan/Feb	30-01	1	1	1
	March	21-23	1	1*	1
	Apr/May	30-04	1	1	1
	June	04-09	1	1	1
	August	03-06			1

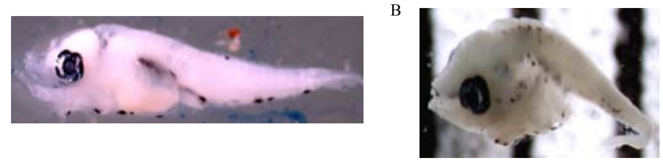

Figure 15: Larval fish seen around GRNMS. A) *Centropristis* sp. B)*Menticirrhus americanus*

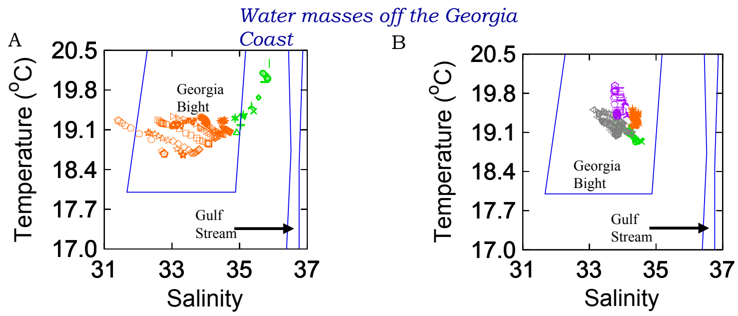

Figure 16: Two water masses were defined using temperature and salinity (Pietrafesa et al. 1994): Georgia Bight Water and Georgia Bight/Gulf Stream Mix Water. **A)** April 2000 cross-shelf bongo stations were located in Georgia Bight (red) and Georgia Bight/Gulf Stream Water mix (green). **B)** April 2000 along-shelf bongo stations were all located in Georgia Bight Water; however, four subgroups can be defined (different colors).

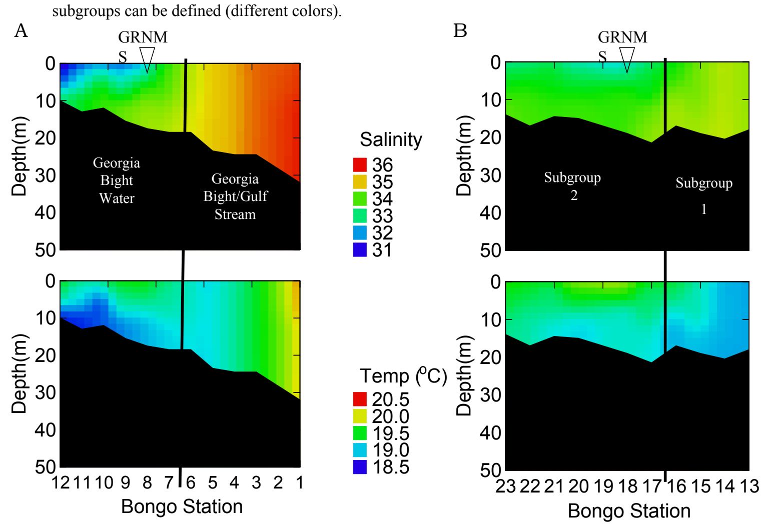

Figure 17: Salinity and temperature section for **A)** a 61km cross-shelf section and **B)** a 61km along-shelf section. In the cross-shelf section, Georgia Bight water is evident inshore as cooler, less saline, and stratified. Georgia Bight/Gulf Stream mixed water is warmer, more saline, and vertically homogeneous. In the along-shelf section two of the four subgroups defined in Fig. 2B are illustrated, but in general water properties are similar.

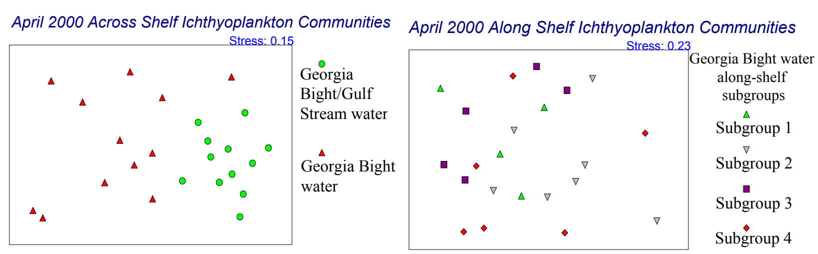

Figure 18: **A)** Results of the MDS analysis of larval fish communities of the cross-shelf transect in April 2000. Larval fish communities found in the Georgia Bight/Gulf Stream Water mix differed significantly from those found in Georgia Bight Water (R=0.603, p=0.001). Larval Gobiidae, Serranidae, and Paralichthyidae made up 50% of the Georgia Bight/Gulf Stream Water mix. Georgia Bight Water was dominated by larvae of the families Triglidae and Gobiidae. **B)** Results of the MDS analysis of larval fish communities of the along shelf transect in April 2000. All stations were within Georgia Bight Water. Subgroups 2 and 4 contained communities that differed (R=0.341, p=0.009) while all others were not significantly different.

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Potential Fate of Larvae Spawned in the Tortugas South Ecological Reserve

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Introduction

Marine Protected Areas (MPA) are gaining interest as a tool for fisheries managers. A number of studies have found that adult fish abundance and age structure increase in areas where fishing is prohibited (Mosquera et al. 2000). Although these changes help restore an MPA to more natural conditions, they do not by themselves help rebuild or sustain fish populations outside of the MPA. For MPAs to be effective in fisheries management, fish must move from the MPA to non-protected areas.

Most marine fish have pelagic larvae, which typically disperse in the plankton for 15 to 60 days, then settle to juvenile habitats. One way for MPAs to supply fish to non-protected areas is for larvae spawned in the MPA to settle to areas outside of the MPA. The increases in adult abundance and age structure in an MPA results in greater larval production which hypothetically refuels stock rebuilding in non-protected areas. Therefore, an important element of MPA design is knowledge of the fate of larvae spawned in an MPA.

The Tortugas South Ecological Reserve is located southwest of the Dry Tortugas and includes a topographical rise, Riley's Hump. Riley's is one of the few reported mutton snapper spawning aggregation sites, and there is currently concern over the status of mutton snapper stocks (Burton 1998). Spawning aggregations of other species of snapper and grouper have also been reported at Riley's Hump (Lindeman et al. 2000). The Tortugas South Ecological Reserve is closed to all fishing and there is hope that this will lead to rebuilding of mutton snapper abundance both within and outside of the Reserve.

As part of a larger National Marine Sanctuaries project, we are examining the potential fate of larvae spawned at Riley's Hump. Lee et al. (1992, 1994) proposed several larval transport pathways for larvae spawned in the Florida Keys region (Figure 19). These proposed transport pathways indicate the potential for local retention, as well as transport up the west Florida shelf. However, the Loop Current, which is part of the western boundary current system in the western Atlantic, flows west to east along the Florida Keys. This strong current may entrain larvae and rapidly advect them downstream (Florida Current, Gulf Stream).

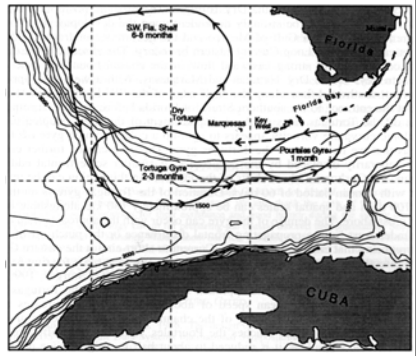


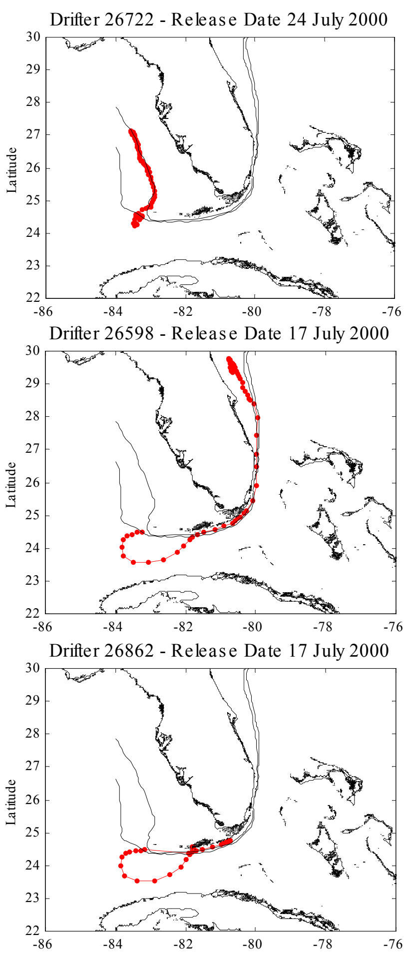
Figure 19. Proposed larval transport pathways for the Florida Keys region (from Lee et al. 1992)

Lutjanus synagris juvenile

Ocyurus chrysurus

Figure 20. Satellite-tracked drifters consist of two components: a transmitter (gray and blue ball) and a drogue (orange tube). Location is determined by Service ARGOS satellites. Water temperature is also measured. The drogue allows the drifter to move with the water at depth. In this study, drogues were centered at 15 m.

Figure 21. Examples of different categories of drifter tracks. (A) Movement of drifter up the west Florida shelf. (B) Movement of drifter to the east coast of Florida. (C) Retention of drifter in the vicinity of the Florida Keys.



Materials and Methods

Satellite tracked drifters (Figure 20) were released over Riley's Hump during the summers of 2000 and 2001 as part of a larger project (Table 14). Location data were received from Service ARGOS, filtered for spurious locations, and then smoothed using a cubic spline. Analyses of the data are underway, but initial results and conclusions are reported here.

Table 14. Summary of drifter releases made over Riley's Hump in the Tortugas South Ecological Reserve. Releases were made from the NOAA Ship WHITING and NOAA Ship FERREL.

Release Date	Number of Drifters Released
24 June 2000	3
17 July 2000	4
24 July 2000	3
31 July 2000	4
26 June 2001	1
8 July 2001	3
16 July 2001	4
20 July 2001	3

Results

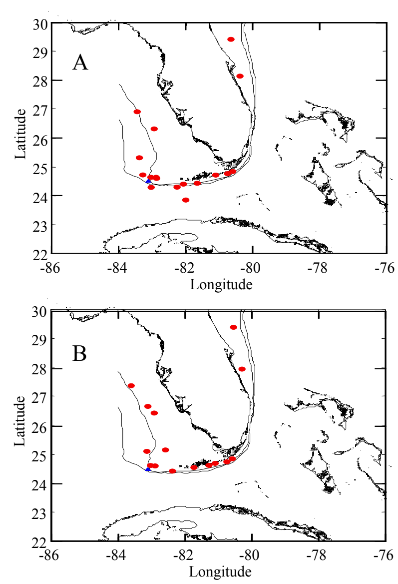
The fate of drifters could be classified into five categories (Table 15, examples of three categories are shown in Figure 21). Nearly a third of the drifters stayed in the Tortugas area and over half remained in the area of the Tortugas and Florida Keys, supporting the assertion of Lee et al. (1992, 1994) that larvae spawned at Riley's Hump would be retained. Two drifters moved up the west Florida shelf again supporting the hypothesis of Lee (1992, 1994), but the pathway was different (compare Figure 21A with Figure 19). Six drifters moved eastward and were apparently incorporated into the Florida Current, but four were detrained from the current and moved onto the east Florida shelf.

Table 15. Classification of the fate of satellite tracked drifters released over Riley's Hump in the Tortugas South Ecological Reserve

Fate of Drifter	Number of Drifters
East Coast of Florida	4
West Florida Shelf	2
Tortugas Area	8
Florida Keys	5
Southeast US shelf	2
Transmissions Cut Short	4

Although the tracks of drifters illustrate larval transport pathways, larval stages are of finite time. The question becomes where were drifters at a time equivalent with larval durations. Most snapper and grouper species have a 30-45 d larval duration (Lindeman et al. 2000). Examination of the location of drifters 30 and 45 days from release indicate that larvae spawned at Riley's Hump could be supplied to deep reefs along the west Florida shelf, reefs along the Tortugas and Florida Keys tract and reefs along the east coast of Florida (Figure 22).

Figure 22. Location of drifters at (A) 30 days after release and (B) 45 days after release. Red symbols show locations of individual drifters. Blue triangle shows release location.



Discussion

Preliminary analysis of drifter tracks strongly support the larval transport pathways proposed by Lee et al. (1992, 1994). The data also indicate that larvae may be supplied to the east Florida shelf. The siting of the Tortugas South Ecological Reserve appears to be excellent from the point of view of supplying larvae to other reef areas. Additionally, spawning aggregations are known from within the Reserve, and as part of a larger project we are monitoring adult snapper and grouper populations in the Tortugas South Ecological Reserve to determine if adult biomass increases over time. We are also sampling larval fish to determine which species are moving along the described transport pathways. A similar study is underway at Gray's Reef National Marine Sanctuary and the Oculina Research Reserve along the east coast of Florida. Together these studies will help frame the question of larval sources and larval supply on the scale of the ecosystem.

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