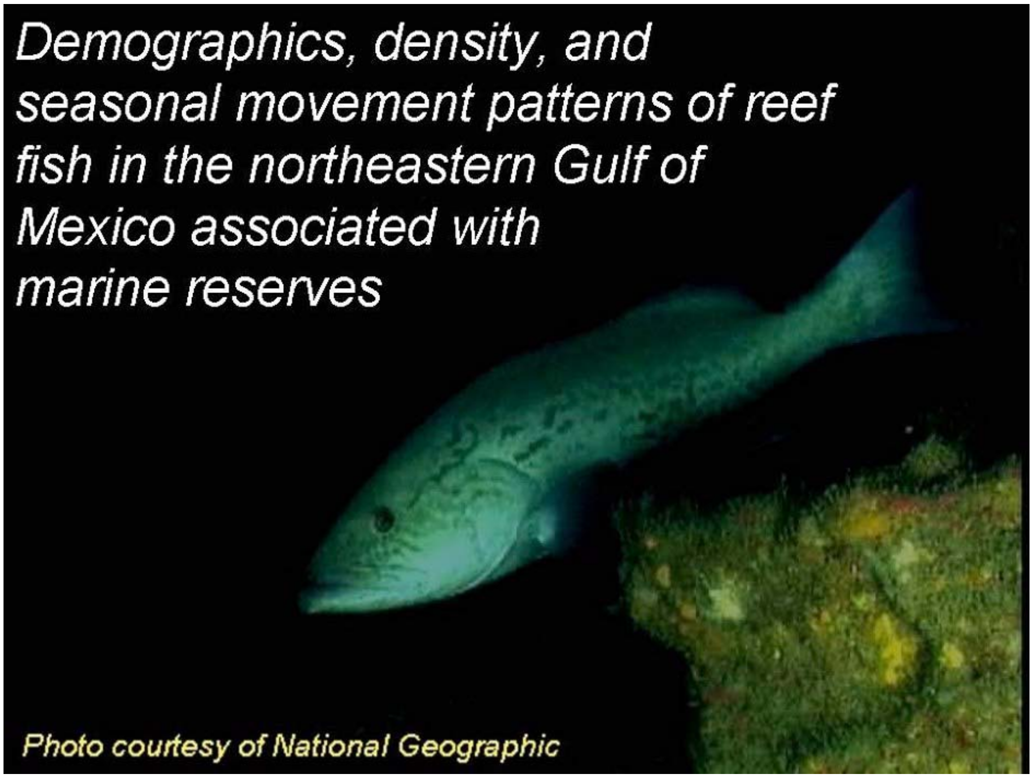

Demographics, density, and seasonal movement patterns of reef fish in the northeastern Gulf of Mexico associated with marine reserves

Photo courtesy of National Geographic

MARFIN Project FINAL Report

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by

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Overview

The overall goal of the MARFIN research project, *Demographics, density, and seasonal movement patterns of reef fish in the northeastern Gulf of Mexico associated with marine reserves,* was to determine the movement and demographic patterns of economically important reef fish species in the Madison Swanson and Steamboat Lumps Marine Reserves (each about 100 nm^2) in the northeastern Gulf of Mexico on the West Florida Shelf (WFS) (Figure 1), reserves established by the Gulf of Mexico Fishery Management Council in June 2000 to help evaluate the effects of fishing on reef fish populations. The species of interest in this study included the dominant fisheries species gag (*Mycteroperca microlepis*) scamp (*M. phenax)*, red grouper (*Epinephelus morio)*, red snapper (*Lutjanus campechanus)*, vermilion snapper (*Rhomoplites aurorubens)*, and amberjack (*Seriola dumerelli)*. The results of this study are intended to inform fishery management by increasing our understanding of the nature and distribution of reef fish species over their habitat and by evaluating the effectiveness of marine reserves in protecting dominant reef fish populations and spawning groups.

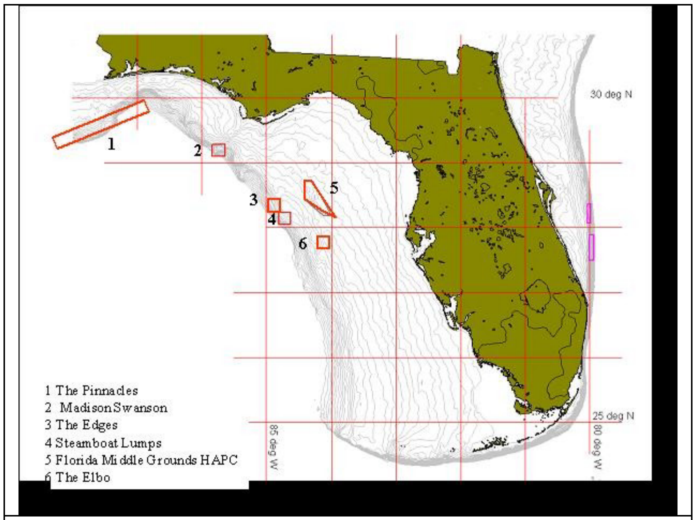

Figure 1. Sites visited during Sustainable Seas Expedition, Summer 2001. (1) Pinnacles (2) Madison Swanson Marine Reserve (3) Steamboat Lumps Marine Reserve (4) The Edges (5) The Florida Middle Grounds (6) The Elbow

We compared reef fish movement and demographic patterns within and outside of the reserves over the period of the study (2003-2005), addressing two general questions: (1) what is the associated community structure of reef fish on the shelf edge? and (2) will shelf-edge reserves protect the demographics of reef fish spawning aggregations?

The objectives of the study included the following.

(1) Locating historical fishing sites within and outside the Madison-Swanson and Steamboat Lumps Marine Reserves with the aid of commercial fishers.
(2) Determining the age structure, movement patterns and rates, and sex ratios of all economically important species sampled from study sites using conventional dart and internal anchor tags and non-injurious biopsy methods, with additional information provided by the use of ultrasonic tags.
(3) Censusing fish populations with remotely operated vehicles (ROV) on the selected sites within and outside of marine reserves to determine density (mark-resight methods), size structure (laser systems), and sex ratio of sexually dimorphic species.
(4) Evaluating interannual variation in demographic, census, and movement patterns of economically important reef fish between years
(5) Evaluating the significance of the seasonal winter closure of the grouper fishery.

Two opportunities significantly influenced our ability to accomplish these objectives. The first was an invitation to participate in a U. S. Geological Survey Cruise (Chief Scientist Kathryn Scanlon, USGS) in 2000 onboard the NOAA ship Oregon II to conduct sidescan-sonar mapping of the Madison-Swanson and Steamboat Lumps regions of the West Florida Shelf (WFS). This cruise allowed us to ground truth the reserve sites before they went into effect. The second opportunity was being asked to participate and lead (Chief Scientist Felicia Coleman) the National Geographic's Sustainable Seas Expedition (SSE) in 2001 across the northern section of the WFS onboard the NOAA Ship R/V Gordon Gunther, using manned submersibles provided by NUYTCO (Vancouver, British Columbia). This invitation arose after we submitted a proposal (unsolicited) to the SSE outlining methods for conducting quantitative habitat sampling (Appendix A). These cruises provided us with unique opportunities to lay the groundwork for objective, systematic classifications of shelf-edge habitats throughout the region.

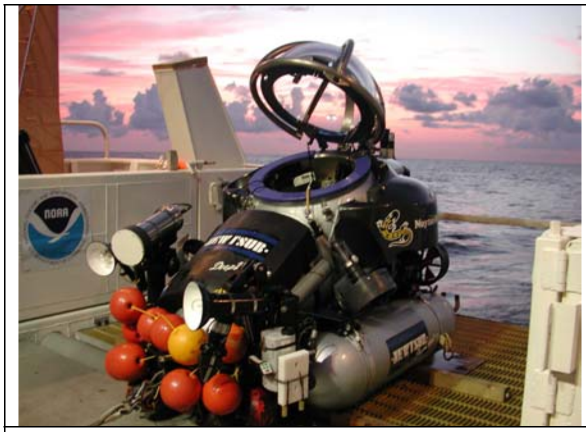

Figure 2. Deepworker submarine, Nuytco.

We developed habitat descriptions throughout the study area (Figure 1) based on sediment characterizations and a combination of exploratory dives and relatively simple transect studies using the 'Deep Worker' manned submersible (Figure 2) to obtain quantitative bottom video and still images. This project involved the participation of the principal investigators, as well as K. Scanlon (USGS, Woods Hole), M. Miller (NOAA Fisheries, Miami); and G. P. Schmahl, E. Hickerson, D. Weaver (Flower Garden Banks National Marine Sanctuary). By combining the habitat information obtained through these ancillary studies with the knowledge of commercial fishers operating in the region, we were able to identify a series of study sites (gag spawning sites) in high quality reef fish habitat, relating reef fish presence and activity patterns.

Our general goal was to take advantage of the limited closed period (the "sunset period" of four years, from 2000-2004) for the two shelf-edge marine reserves) to evaluate the effects of fishing on reef fish populations. The Gulf of Mexico Fishery Management Council recently extended the closures for an additional six years largely based on the combined results of this and our other associated studies, but also because of supportive comments from commercial and recreational fishermen operating in the area. Data from this study clearly will inform management. As a consequence, it will have a direct effect on both the commercial and recreational reef fish fisheries of the southeastern United States. These fisheries are extremely important to this region as indicated by combined 1996 snapper-grouper landings in the Gulf of Mexico of 16 million pounds with an ex-vessel value near $36 million (Waters 1997, Potts *et al.* 1998). Valuation of the recreational fishery is much higher than this, in the billions of dollars per year (Bell *et al.* 1993, Gentner *et al.* 2001) when considering both direct and indirect expenditures. Also affected are non-consumptive users, including divers and conservationists, both of whom consider existence value an important factor in fisheries management. Valuation of tourist-related activities (e.g., diving visits) are unknown at this time.

Part I: Habitat Characterization

Introduction

When the Magnuson Act was re-authorized in 1996, it included a mandate to evaluate essential fish habitat (EFH), including (1) its description and identification, (2) potential threats, and (3) development of conservation and enhancement methods. This is an enormous task in the Gulf of Mexico, which has an area of 1.5 million km^2. However, most of the production of interest to fisheries occurs on the continental shelf. While continental shelves typically represent only a small part of the ocean (7.6% globally), the continental shelf of the Gulf of Mexico represents 30% of its total area. The area is largely (90%) mud, except along the west coast of Florida (Rabalais *et al.* 1999) and in distinct areas, such as the Flower Garden Banks off Texas. In the northeastern Gulf of Mexico, the continental shelf edge supports an extremely rich and diverse biota and represents critical essential fish habitat for many ecologically and economically important species

Virtually all of the historical (pre-EFH mandate) habitat work conducted in the eastern Gulf of Mexico was conducted under the auspices of the Mineral Management Service for oil and gas exploration. These studies divided the eastern Gulf into two regions based on historical events related to Pleistocene sea-level fluctuations and sediment deposition: (1) a northeastern region extending from the Mississippi River to the Florida Panhandle up to a feature known as the Desoto Canyon; and (2) the West Florida Shelf (WFS). The northeastern region is characterized by relatively high relief and sediments rich in quartz whereas the WFS is characterized by low-relief drowned patch reefs from mid-shelf to the shelf edge that run parallel to the Pleistocene shoreline and are covered with a biogenic veneer of carbonate sediments. The WFS expands north to south, widening from 25-125 km across to ~290 km off south Florida. Sediments along the shelf shift from carbonate ooze at the shelf-edge (~100-m) to quartz sand inshore, with intervening stretches of carbonate sand derived from coralline algae in deeper areas and molluscan shell in shallower areas (Hine 1983). These sediments cover hardbottom habitat that is exposed along its length as live bottom reefs (e.g., coral, rock, and sponge) that occurs throughout the WFS out to the 200 m depth contour (Parker Jr. *et al.* 1983).

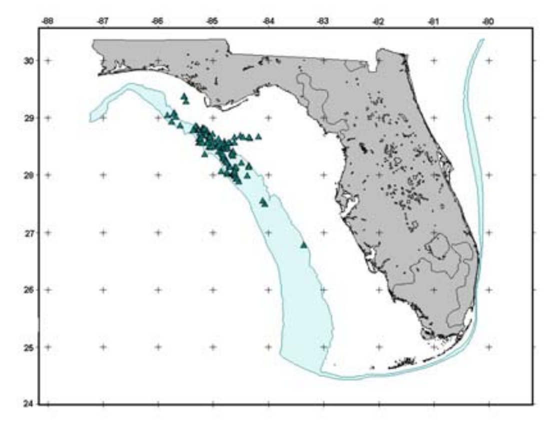

Figure 3. Primary gag fishing sites on the WFS.

Despite the fact that the live bottom areas of the WFS have been fished for over 100 years (Camber 1955) and remain of major importance to reef fish fishery production (Koenig et al. 2000) (Figure 3), the relationship of habitat and fishery production has been little studied until recently and there are no estimates of direct or indirect effects of shelf-edge fishing on habitat or on benthic communities. Direct effects include such things as habitat damage from trawling or anchoring while indirect effects could include ecosystem-level disruptions of trophic relationships resulting either from the removal of top fish predators (e.g., sharks) or the removal of important forage species (e.g., menhaden, shrimp). An example of the potentially destructive effects of shelf-edge fishing are apparent in the Experimental Oculina Research Reserve off the central east coast of Florida where we observed extensive fishing-induced destruction of Oculina varicosa coral habitat and removal of spawning aggregations (Koenig et al. 2000, Reed et al. 2004, Koenig et al. 2005).

Further, these areas are likely to experience more intense fishing pressure as shallower areas become depleted and fishery regulations (including increased size limits and gear restrictions) push commercial and recreational fishers further offshore. They are also likely to experience greater impact from increased oil and gas exploration in the eastern Gulf. Threats from pipeline construction through these areas and the expansion of oil and gas exploitation to the eastern Gulf make such habitat characterization and mapping of great importance (see Appendix B, our comments on a gas pipeline proposal).

Objective, systematic, and intuitively-understandable habitat maps are fundamental to the study and management of living natural resources (Mumby and Harborne 1999). Yet these are woefully undeveloped in offshore areas of greatest fishery production, such as shelf-edge reefs (50 – 120 m deep) (although increasingly available for shallow water). Most of the shelf-edge areas in the Gulf of Mexico not only lack habitat maps, but also lack adequate descriptions of the benthic geomorphology and surficial geology, the basis on which habitat maps should be developed.

Clearly, attempts are being made to rectify this situation, with more mapping of areas such as the Twin Ridges, the Madison-Swanson and Steamboat Lumps Marine Reserves, the Florida Middle Grounds, Pulleys Ridge and The Tortugas Ecological Reserve. Recent acoustic surveys over a relatively small portion of our study area coupled with submersible and ROV transects and stationary videos derived from USGS, NMFS, and FSU reef fish studies such as this one are providing essential clues to the structure and function of these habitats and their associated communities. These areas were mapped with side-scan sonar in 1997 and 2000 (Scanlon *et al.* 1999, Scanlon *et al.* 2003). By 2002, portions of the DeSoto Canyon and Madison Swanson Fishery Reserve were mapped using multibeam bathymetry methods.

We include here our characterization of the benthic community structure of west Florida shelf-edge reefs and relate the distribution of biota to the underlying geologic character of the seafloor. This lays the basis for a BACI (Before-After-Control-Impact) impact assessment study (Schmitt and Osenberg (editors) 1996) for the effects of the WFS no-take reserves on benthic communities. The logistical constraints of working below SCUBA depths required that we keep this study simple. However, because so little is known about this benthic community and its importance in fishery production, and because of the inevitable political clambering for results from controversial no-take zoning, the results of this study are of great importance.

Materials and methods

Acoustic mapping

Optical remote sensing techniques such as sidescan-sonar provide acoustic backscatter information that enable researchers to distinguish acoustic facies corresponding to different bottom types (rock, sand, mud substrates) that are important in delineating fish habitat. Multibeam bathymetric data provide seafloor bathymetry at extremely high resolution in the vertical and horizontal. Combining side-scan and bathymetric data provides an excellent means of characterizing the seabed and mapping the extent of various habitats.

Sidescan-sonar data (100 kHz) for the northeastern Gulf of Mexico was acquired along parallel adjacent transects by the U. S. Geological Survey using an EdgeTech DF1000[1] sidescan-sonar system, and Isis topside acquisition system (Triton Elics, Inc.). Images were made at a rate of 7.5 pings/second, yielding a 200-meter (100 meters to each side) swath width. The data were decimated to a 0.4-m pixel size using a median filtering routine. They were then processed with corrections to the slant range (to remove the water column artifact and convert slant-range distance to true ground distance), destriping (to correct minor striping noise or dropouts), and beam angle (to correct variations in beam intensity). Further processing was performed to remove additional noise and to orient each sidescan line in space. Digital mosaicking was accomplished using the PCI Remote Sensing software package. This dataset was mapped at a resolution of 1m/pixel in a UTM zone 16 projection with the WGS84 ellipsoid. Darker tones on the sidescan-sonar images represent areas of relatively low acoustic-backscatter intensity and lighter tones, areas of high backscatter. Mosaics were interpreted to produce acoustic facies maps indicating benthic habitat and substrate type. We obtained bathymetry data (300kHz) from multibeam acoustic images at extremely high vertical and horizontal resolution from the U. S. Geological Survey (Gardner et al. 2002).

Classification scheme

Our approach to mapping shelf-edge habitat follows closely that used by Mumby and Harborne (1999) for shallow coral reefs in the Caribbean. However, unlike Mumby and Harbourne—who used optical remote sensing by satellite and/or aircraft to produce broad-scale geomorphology maps--we relied on remote optical techniques (described above) to obtain information at shelf-edge depths. The maps so produced, even if applied only in the areas surveyed, provide a benchmark for monitoring temporal and spatial changes in the habitat and its associated community. Each location polygon on a habitat map includes the following in a GIS database: (1) a geomorphologic descriptor, (2) a benthic sessile community descriptor, and (3) a benthic motile community descriptor. This work is ongoing at this time.

Geomorphology.-- Sediment samples are important for the interpretation of surficial geology and acoustic backscatter characteristics of the side-scan sonar. Together with the sidescan sonar data, they are used to distinguish acoustic reflectivities corresponding to different bottom types (e.g., rock, sand, mud substrates), which are important in the delineation of fish habitat. We collected sediment samples using a modified Van Veen grab. Samples were typically taken at night to avoid time conflicts with ROV and or submersible use, and stored at room temperature in 710 ml plastic freezer containers. Data recorded included sample position (latitude and longitude, plus direction and angle of the winch cable supporting the Van Veen for correcting sample positions), date, visual description, and relative current strength.

Benthic community characterization.--To characterize the benthic habitat, we made quantitative strip (belt) transects within defined geomorphologic features using digital and hi-8 videography and visual observations (recorded on a tape recorder and written) made from the submersible. We chose strip transects over square or round quadrat transects because they cut across many variations or patches (habitat heterogeneity) in the habitat and thus increase precision. For short transects, only a compass heading was necessary to achieve a straight line, following pre-selected transect locations (see below). It was preferable to take multiple short transects than few long ones. Multiple random transects were used for density (number per unit area) determination and many other community measures (Krebs 1999). Following Aronson et al (1994), we determined that five (5) transects within each defined feature provided an adequate sample size. Transect lengths were at least 25 m, with longer transects being made in depauperate habitats. To the extent possible, transect locations were chosen ahead of time (selecting start positions with a random numbers table) and drawn out on an expanded side-scan image of the feature of interest. This allowed the topside sub tracker to orient the sub pilot to transect positions, especially in conditions of low visibility. Sub pilots working closely with the sub tracker could alter transect position if necessary based on bottom conditions.

In the absence of acoustic imagery, sea floor features were located by repeated passes of the supporting vessel's echosounder over the bottom. Features identified in this manner were then plotted, producing a very rough acoustic map that was used to orient subsequent ROV or submersible transects. Rough transect positions were drawn across the plotted feature as a reference. The submersible was used primarily for "live bottom" characterization. All survey positions were tracked so that observational/video information could be referred to the acoustic image.

The flat featureless bottom of Madison Swanson and Steamboat Lumps was surveyed throughout by video on a camera sled ("Rosebud") in 2003 (Scanlon, unpublished data). Video transects made with the camera at an oblique angle provided a description of the sand, mud, or shelly habitat and associated species.

Videography

Video imagery on statistically random belt transects was recorded with both downward- and forward-looking (oblique) video cameras. The downward-looking camera (Sony Hi-8 with Amphibico Housing) had two parallel laser beams, 20 cm apart, in the field of view, which provided scale for standardizing quadrat sizes and for measuring coral colonies and other features on the bottom. For individual features of interest, 14-18 individual non-overlapping frames (e.g., from red grouper hole and reference areas) were grabbed and an array of fifty random dots was superimposed on each frame. The number of dots overlying particular substrate types was used to estimate percent cover of discernable substrate types. The forward-looking camera had three lasers arranged in a single plane at 10 cm intervals. It was used in determining fish densities. The lasers were aimed so that laser dots were visible at about 5 m in the lower half of the camera's field of view. Two adjacent parallel beams provided scale, and the third beam, which converged on the two parallel beams and crosses each at 5 and 10 m, gave an estimate of distance. Estimates of distance allowed us to determine the width of the field of view (i.e., transect width) at a selected distance from the camera. Also, fish measurements were made from random specimens by projecting the parallel beams onto the sides of fish in the field of view.

Fish densities (numbers per hectare) were determined in each habitat type by estimating the area of view of the video camera during belt transects made by the submersible. Quantifying fish populations with belt transects is preferable to the non-quantitative methods because belt transects provide a statistical basis for spatial and temporal comparisons. Such methods measure relative rather than absolute abundance, thereby requiring that inter-annual comparisons occur during similar seasons and time of day to account for changes in faunal activity patterns. Small species or early life stages of larger species are often cryptic. Therefore, density estimates of small fish are highly variable and probably much lower than actual values, especially in structurally complex habitats.

The submersible maintained an elevation of approximately 0.5 to 1.0 meters off the bottom and a speed of 0.1 to 0.2 m/s (= 0.36 to 0.72 km/hr) or less to avoid making blurred images with the down-looking video. Each transect took about 4 minutes to complete.

Estimating belt transect area from submersible videos required several values: the selected distance from the camera within which fish would be counted (D), the camera's horizontal angle of view (A), and the length of the transect (L). The effective distance (D) may not be the limits of visibility, but instead the limit at which fish can be identified with a high degree of certainty. All fish appearing beyond this distance were excluded from counts. The geographic positions (DGPS) of the submersible at the beginning and end points of each transect were recorded by the ship's baseline tracking system and transect length (L) was measured using ArcView software.

The width of the field of view (W) at distance (D) was calculated by:

$W = 2 (\tan (\frac{1}{2}A)) (D)$,

Then the area of the transect (TA) was calculated by:

$$TA = (L \times W) - \frac{1}{2} (W \times D)$$

Estimating transect area allowed calculation of the average density and standard error of observed fish species. Species that tended to follow or circle the submersible, such as amberjack, were not repeatedly counted as they passed through the video field, but rather their total abundance was estimated and audio-recorded directly onto the video tape.

In addition to the video transect data we recorded other observations while in the submersible such as fish behavior and the presence of fishing gear on the bottom. Some important behaviors that may affect density estimates include fish following and circling the submersible (e.g., amberjack, scamp), remaining stationary (e.g., bigeyes), cryptic behaviors (e.g., cardinal fish) and variable cryptic and above-bottom schooling behaviors (e.g., anthiines). We also took notes on color changes and presumed courtship behavior.

Our limited ROV observations (NMFS Phantom S4 ROV) were made without the use of the laser system described above because they were made prior to our development of the laser technique. All fish in those dives were recorded as the ROV made linear transects of constant speed through the selected habitat. The fish were then quantified as number observed per minute of transect time.

Data records and analysis

Data records included verbal records, written records, and videography. Records kept included the date, time, dive number, pilot, position, depth, and mission, transect number and position (Appendix A). Emphasis was placed on collection of high quality video imagery to record behavior and diagnostic characteristics of animals and plants. Frames were grabbed from video records to use for organism identification. Videotapes and sub-operator notes (written notes and audio tapes) from the various transects were duplicated and archived.

Community characteristics were analyzed using a tape deck and high-resolution monitor. From videos, we obtained percent cover, density of dominant sessile species, species composition, species richness and other species diversity measures, and spatial pattern of dominant species (i.e., random, regular, or clumped). A fixed number of non-overlapping images from each transect were quantified by overlaying random dot patterns (50 random dots per pattern) and identifying the organism (e.g., octocoral, sponges, tunicates) or substrate (e.g., sand, bare rock) type lying under each dot to estimate percent cover. We followed procedures outlined in Krebs (1999) and Aronson et al. (1994).

For the purposes of the habitat characterization and classification, habitat-structuring organisms were evaluated as major taxa, for example, gorgonians or sponges, or were further subdivided on the basis of morphology and color. Similarity of benthic communities was analyzed using Morisita's index of similarity. Krebs (1999) recommends this measure from over 20 such measures (including the Bray-Curtis measure, which is strongly affected by sample size and therefore not useful here) because it is not affected by sample size as other measures are. For cluster analysis, we used the UPGMA (unweighted pair-group method using arithmetic averages) method, as recommended by Krebs (1999). These benthic community categories are classified using standard multivariate hierarchical classification techniques. Measures of similarity of the communities are calculated first, then a clustering algorithm is used to classify community types. The choice of both similarity index and clustering method is important to the resulting classification pattern and thus was chosen on the basis of ecological understanding (Krebs 1999). The communities of fishes and motile invertebrates associated with the various habitats were classified using the same similarity and clustering techniques. Habitats of special significance, such as the grouper spawning habitat were described in fine detail, whereas other shelf-edge habitats of lesser immediate importance were described in less detail.

Percent cover (and other measures such as density of dominant taxa) data must be collected optically *in situ*. Quadrat methods (e.g., strip transects) using a down-looking video camera with a laser metric are most efficient for this purpose at shelf-edge depths. A forward-looking video system should be used to record the abundance, size, and species composition of fishes and motile invertebrates and to observe growth forms of habitat components.

Results

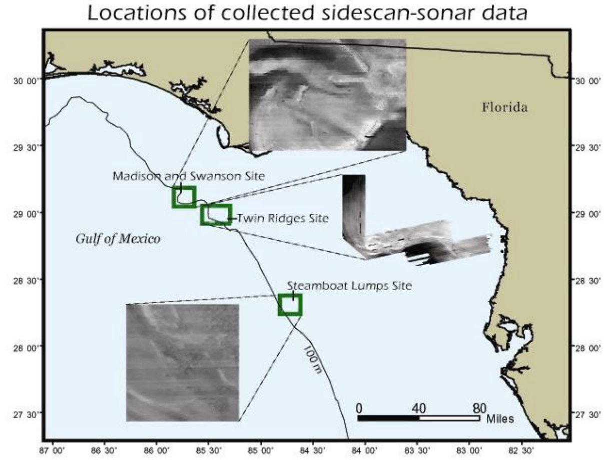

Figure 4. West Florida Shelf northeastern section showing side scan images used to identify bottom features in both fishery reserves and in a control site. Map courtesy of K. Scanlon, U. S. G. S.

Developing acoustic images of the marine protected areas on the West Florida Shelf was not constrained by season the way that demographic studies of spawning are. Thus, offshore cruises could be timed to periods with the highest probability of benign weather conditions—typically the late spring and summer prior to hurricane season. In addition, the work could be carried out before we outlined the specific spawning sites for study. Indeed, this was a prerequisite for finding those sites and ensuring that we were not sampling over sand or mud bottom.

We developed a geomorphologic base map of the Madison-Swanson and Steamboat Lumps Marine Reserves with colleagues in the U. S. Geological Survey in 2000 (Figure 4) (see http://kai.er.usgs.gov/regional/contusa/index.html). Digital mosaics were available onboard within 24 h and could be used immediately for fish sampling and citing of video observations for specific habitat type station work. Preliminary work was also conducted in an area known as *Twin Ridges*, but we did not investigate this area as part of the study. The interpretation of the sediment composition follows from the sidescan image and ground truthing of features through systematic sediment sampling that occurred in 2000 and 2001. Knowing the surficial geology of the sea floor provides information about the kinds of organisms inhabiting it and the strength of currents that typically sweep through the area. For instance, fish tend to burrow in silty clay, which will hold a higher angle when excavated than will pure sand, which collapses.

We developed benthic cover maps on the NOAA-National Geographic SSE cruise. Visibility on the dives tended to be poor due to tropical storm, Allison. We made at least eight successful submersible dives in the reserve on both low and high relief sites. We evaluated the benthic cover at known grouper spawning sites (low relief) and known snapper spawning sites (higher relief) from the videos, as well as several other sites that appeared to be of some interest, based on sidescan-sonar images.

Habitat characterization

Madison Swanson

Madison Swanson is the northernmost of the two WFS reserves. It contains rocky bottom covered with a thin veneer of carbonate-derived sediments (Figure 5). Two primary features are found: Stu's Ridge, crossing the northern boundary, and a set of low-relief patch reefs across the southern extent known to be grouper spawning habitat. The intervening area is mostly sand and gravel, with finer sediment accumulating off the edge of the platform to the south. The area of sand and gravel has many large (10s meters high) sand waves in association. Moving into deeper waters to the south are much finer grained sediments and mud with some clay (see appendix B).

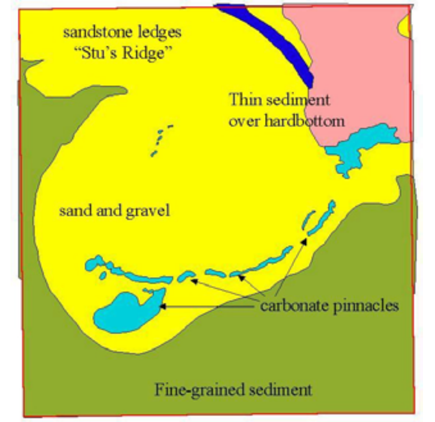

Figure 5. Madison Swanson Fishery Reserve overlay of sediment types after ground-truthing side scan with sediment sampling. Courtesy of K. Scanlon, USGS.

Stu's Ridge.--(Depth ~70 m) Stu's Ridge (named after Kimberly "Stu" Davis, a geographer currently with the World Wildlife Fund) is a relatively high-relief (~10-15 m) ridge that runs through the northeastern part of the Madison Swanson Reserve, continuing to the northwest outside of the reserve. It is composed of tabular slabs of sandstone that we interpret to be lithified remains of paleobeaches (Pleistocene shoreline), called beachrock (Scanlon *et al.* 2003). The sandstone slabs contain widely spaced cracks and crevices. The rock surface is covered with octocoral and sponges (Figure 6). The benthic cover on the site is sponges, octocorals and antipatherians or black corals.

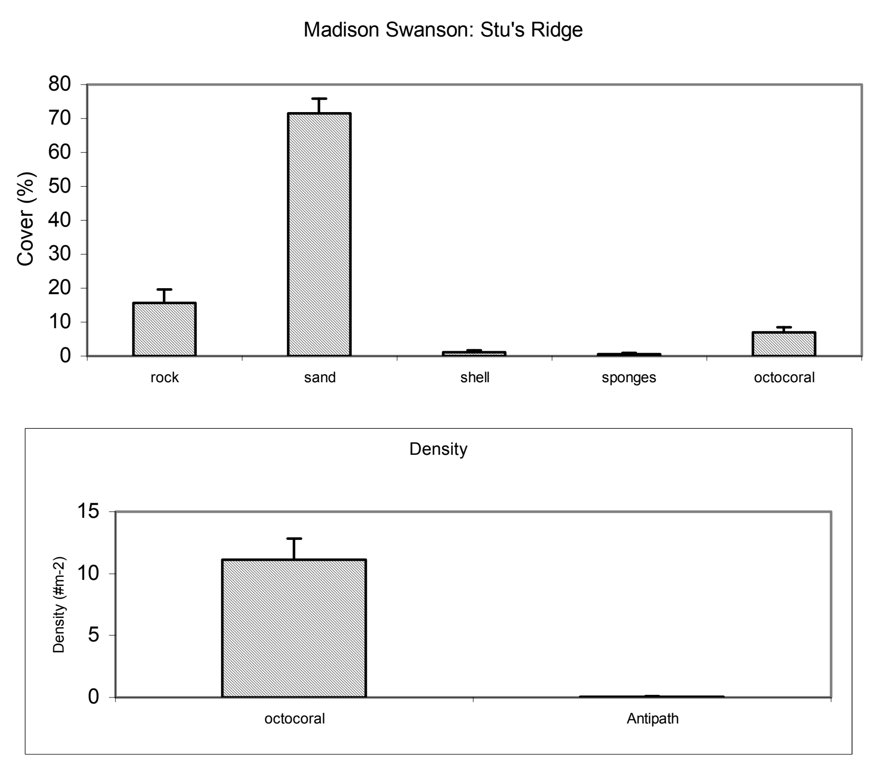

Figure 6. Benthic cover on carbonate ridges of Stu's Ridge in the northeastern sector of Madison Swanson Fishery Reserve.

Drowned Patch Reef Aggregation Sites (Depths ~ 90 m.)--The habitat here in the southern part of the Madison Swanson Reserve consists primarily of scattered, low (0.6-1.0 m) and somewhat higher-relief (2.0-3.0 m) rocky outcrops embedded in sand with a veneer of silt. Much of the silt in the area likely results from the tropical storm, Allison. These pinnacles are quite distinct from the sandstone ridge (Figure 5). They are limestone derived and may be built on drowned patch reefs. The limestone appears to be composed of numerous species of coral and algae and the remains of many sessile and encrusting benthic organisms. The limestone has been dissolved and bored by clams and other organisms, leaving many holes and crannies of various sizes. The area appears to have been actively fished, based on the presence of lost longline gear. Fish on the reefs include amberjack, scamp, snowy grouper, red snapper, and many small reef fish, known as rough-tongued bass, which serve as forage species for the larger predators. Rocks were covered with crustose coralline algae and sessile invertebrates, including encrusting sponges, sea fans, corkscrew sea whips, and scattered clusters of *Oculina* coral. Mobile invertebrates include arrow crabs, crinoids, hermit crabs, and basket stars.

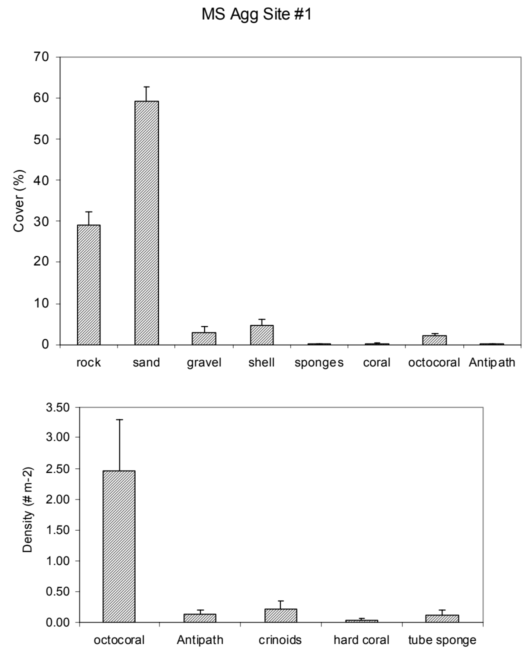

Figure 7. Benthic cover of southeastern drowned patch reefs in Madison Swanson aggregation site

Three different spawning sites were examined. General features of the entire area of the southeastern drowned patch reefs were large areas of sand interrupted by carbonate reefs that were surrounded by shell and gravel and covered with sponges, coral, octocorals, and antipatherians (7-9). These features differed from Stu's ridge in their overall height and to some extent in the type of cover.

*Mad Swan Cones.--(*Depths ~70-80 m) The Mad Swan Cones consist of a series of pinnacles, each roughly 10 m in height off the bottom. The most abundant fish in the area were small basses, including red barbier and rough-tongued bass. Reef butterflyfish and bank butterflyfish were less abundant, but consistently present, in the area. All of the reef fish of any economic importance, such as red snapper, gag, and scamp, were very small, as determined using laser metrics.

Alien Spaceship Landing Strip.--(Depth ~100 m.) This area, so named because of the paired series of parallel, evenly spaced features over an area of several hundred meters, is primarily sand with an overlay of silt. The "lights" of the "landing strip" are, in fact, very small, low-profile rocky outcrops. Associated with the outcrops were small basses, such as rough-tongued bass and tattler, and short bigeyes. Over the sandy areas were squid, large hermit crabs, and batfish.

Geologic distinctions.—The beachrock slabs to the north and limestone pinnacles to the south are distinctive features associated with changes in sea level and should be widespread near the shelf edge throughout the eastern Gulf of Mexico. They also are expected to support distinct benthic communities. We found no gag along the northern ridge, although scamp, a closely-related species, was plentiful.

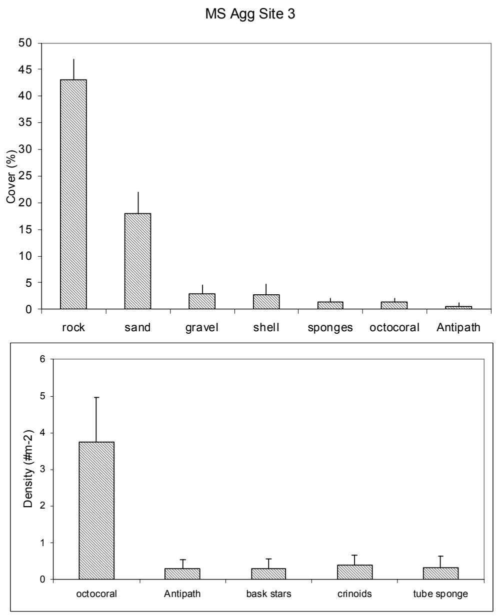

Figure 8. Benthic cover of southeastern drowned patch reefs in Madison Swanson aggregation site 3

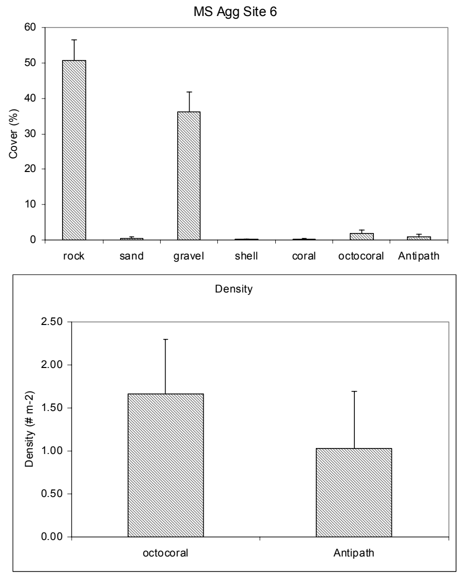

Figure 9. Benthic cover of southeastern drowned patch reefs in Madison Swanson aggregation site 6

Steamboat Lumps

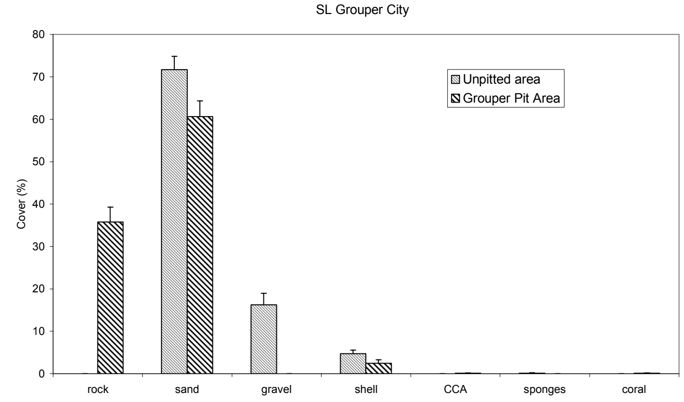

Figure 10. Benthic cover in the Steamboat Lumps Marine Reserve in red grouper habitat.

Steamboat Lumps has large expanses of fine-grained sediments pitted with many presumed tilefish burrows. There were also conical pits inhabited by red grouper *Epinephelus morio* (see Part III, below). The pits exhibited relatively high rock coverage and had the only biogenic structure in the area (Figure 10). At Steamboat Lumps, the grouper pits contained a rocky outcrop at the center with a mean diameter of 2.54 m (s.d. = 1.23, n=3). However, these rocky outcrop areas were in large depressions (sandy slopes with scattered boulders) that reached 6.8 m in diameter and over 2 m deep. These depressions were comprised of 35.7 (3.5 SE) % cover of exposed hard substrate (boulders and rocky outcrops) encrusted with invertebrates and crustose coralline algae compared with 0(0)% in the reference areas. Unfortunately, taxal richness for this encrusting community was not determinable from the video due to inadequate lighting and the sub did not have capability to collect samples. Certain organisms were observed only in the holes (e.g. urchins) while others were observed only in the sandy reference areas (arborescent bryozoans and a red fleshy alga). Hence, within the limitations of remote observation, there was no clear difference in richness of the sessile benthic organisms at this site. Fish assemblage was very different between holes and reference areas.

Part II: Demographics of Reef Fish Populations

Introduction

Many of the most important reef fish fisheries in the Gulf of Mexico are either already overexploited or in danger of being so (Coleman et al. 2000, NMFS 2005). Included among overfished populations are red snapper, red grouper, vermilion snapper, and greater amberjack. Unknown are the statuses of such major stocks as black grouper Mycteroperca bonaci, scamp M. phenax, and snowy grouper E. niveatus, and minor stocks like speckled hind E. drummondhayi and Warsaw grouper E. nigritus. Minor stocks, such as Nassau grouper E. striatus and goliath grouper E. itajara have been protected since the early 1990s due to overexploitation. Species such as gag show serious negative trends that include declines in the proportion of males in the population, loss of spawning aggregations, severely truncated age and size distributions, and a downward trend in the recruitment of juveniles to seagrass habitat (Coleman et al. 1996, Koenig et al. 1996, Domeier and Colin 1997, Koenig and Coleman 1998, Schirripa et al. 1999).

Stock assessments, by their nature, evaluate species in the context of annual catches in both commercial and recreational fisheries. Key features of fish life cycles, life histories, and behaviors are often either unknown or poorly understood. However, many of these species share life history characteristics and behaviors that allow making generalizations about their susceptibility to exploitation (Coleman *et al.* 2000) or their risk of extinction (Musick *et al.* 2000)—including their slow growth, slow maturing, and longevity.   While these characteristics might be offset by their large reproductive capacities, the loss of older age classes and larger size classes can have a profound effect on overall reproductive output (Berkeley *et al.* 2004a, Berkeley *et al.* 2004b).   Further, the vicissitudes of the larval environment must be considered as a forcing factor when reproductive output is diminished. Clearly, exploitation of spawning populations and loss of males provide such factors.

Two characteristics of many reef fishes make them especially vulnerable to fishing. First, is their tendency to spawn in aggregations, and second, is the reproductive style of sex change. Fishermen targeting spawning aggregations may inadvertently threaten the reproductive capacity (Coleman 1996) and genetic diversity (Chapman *et al.* 1999) of these fishes. Scientific reports of fishing effects on demographics and spawning aggregations indicate serious causes for concern (Olsen and Laplace 1979, Carter 1989, Sadovy 1993, Coleman *et al.* 1996, Beets and Friedlander 1998, McGovern *et al.* 1998, Johannes *et al.* 1999, Harris and Collins 2000, Alonzo and Mangel 2004). Gag and scamp, grouper species that spawn in aggregations on shelf-edge reefs of east and west Florida and the South Atlantic Bight, have undergone significant skewing of the sex ratio, with a female bias, and severely truncated size and age structures over the past 20 years coincident with increased fishing pressure on spawning aggregations (Coleman et al. 1996, McGovern et al. 1998, Harris and Collins 2000). A similar shift in sex ratio was observed for snowy grouper *Epinephelus niveatus* in the Atlantic (McGovern pers. comm.).

All protogynous reef species examined to date show some social component to the sex change mechanism (Warner 1988). That is, exogenous cues from the social environment of the fish (e.g., sex ratio, size ratio) trigger sex change. However, social mechanisms do not preclude the possibility that some components of the sex-change mechanism are endogenous (size- or age-related). Theoretically, a female changes to a male at a size (age) when being male increases reproductive success. Female reproductive success is limited by the number of eggs she can produce in a season, but a male's reproductive success relates to the number of females whose mating he can monopolize. Because size is a factor in the ability to monopolize mating, males are typically large.

Red grouper: Red grouper appear occur on the shelf edge in hard bottom areas characterized by the presence of solution holes; such areas are often overlain with a veneer of sand. Red grouper appear to excavate the solution holes, clearing away the sand, and thus creating settlement sites for an array of sessile invertebrates. We are currently evaluating this behavior at shallower depths, and its consequences on regional biodiversity. But it is our intent to examine this behavior in the Steamboat Lumps Fishery Reserve, an area that has extensive low-relief habitat supporting red grouper populations. These excavations give a distinct signal on the side-scan sonar images allowing quantification of the extent of red grouper occurrence over a broad area.

Red snapper: Red snapper stocks, while overfished, have recently increased in the eastern Gulf of Mexico. They are relatively abundant within the proposed study region, based on our recent surveys. Fishing records and anecdotal information (Schirripa and Legault 1999) suggest that large reproductive "sows" are caught in deeper waters including shelf-edge areas by the longline fishery. It is possible that the experimental MPAs will protect such reproductive individuals and the location of their preferred habitat.

Greater Amberjack. Amberjack are included in the reef fish management plan largely because they are so tightly connected to bottom structure. We include them here because of their prevalence in the water column above grouper spawning habitat. The majority of fish landed in the Gulf of Mexico are caught off the West Coast of Florida. Catches in both recreational and commercial fisheries have declined in recent years (Cummings and McClellan 2000). The NMFS recently declared the Greater Amberjack to be overfished.

The intent of this study was to evaluate fishing effects on the demographics of grouper spawning aggregations. Because marine protected areas provide significant experimental units for evaluating the effects of fishing, we focused on three key questions that we felt were answerable within a relatively short period of time: (1) do male gag remain in the spawning habitat year round (thus justifying year round protection rather than seasonal); (2) if so, then does protecting spawning habitat recover males in the populations; and (3) does the absence of males lead to missed spawning opportunities for females.

Materials and Methods

Locating grouper spawning aggregations

Reef fish in the northeastern Gulf are associated with specific sites such as drowned reef habitat, paleoshorelines, or pinnacle structures. Although not conversant in these terms, commercial grouper fishermen are perhaps the most knowledgeable individuals about the location of these sites for the species they pursue. Thus, we sought their help in locating reef fish spawning sites within and around the Madison-Swanson and Steamboat Lumps Marine Reserves during the first year of the study. Fishermen agreeing to work with us provided vessels in charter and their expertise throughout this study[1]. We overlaid the commercial fishermen's knowledge on the habitat maps we developed or obtained from colleagues at the U. S. Geological Survey (see last section) to define study sites.

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[1] Funds for the participation of commercial fishermen were obtained from the National Fish and Wildlife Federation and from the NOAA Cooperative Research Program.

Collecting biological information

We know of no tagging studies of reef fish that have been carried out on the shelf edge because the high rates of mortality experienced by fish brought up from depths of 50 to 100 m results in little return for the enormous effort expended conducting such studies. The physiological problems associated with swimbladder embolism when fish are hauled to the surface from such depths results in expansion of gas up to 10 times the volume on the bottom and very low survival (< 5%).

As part of another MARFIN study in which we participated (NA87FF0421: “Evaluation of multiple factors involved in release mortality of undersized red grouper, gag, red snapper, and vermilion snapper.”), we developed trapping methods for retrieving fish from depths with greatly reduced mortality rates.


Figure 11. (A) Landing reef fish in traps. (B) Tags used (from top down) are dart tags, internal anchor tags, and acoustic tags.

We trapped fish with chevron fish traps (2m x 1.5 m x 0.7 m; mesh = 2.5 x 5 cm; modeled after those used in the MARMAP sampling program) built by RMS Marine Supply, Medart, FL. Traps were set on spawning sites at depths of 50-120 m (Figure 11a). Baited traps were left on sites for 4 to 6 hours, and subsequently raised to a depth (roughly 40% depth of capture) that allowed the swim-bladder to increase up to 2.5 times its volume on the bottom, equivalent to bringing a fish to the surface from about a 15 m capture depth. For example, fish caught in 100 meters of water were raised to 35 meters and held there while a diver descended to vent the swim bladder with a specially designed pole spear with a 1 cm diam point that would not penetrate more than 3 cm into the fish. Then the trapped fish were then raised to the surface slowly, brought onboard the vessel, and released into a large (500 l) tank with constantly running fresh seawater. This method ensured that fish were not subjected to the often-lethal effects of swimbladder expansion, rupture and hemorrhage. All biological sampling occurred onboard the vessel. Using non-lethal methods, we obtained biopsies of gonads to determine sex and reproductive condition, and tissues to determine genetic relatedness[2]; we also removed dorsal fin spines and rays for determining ages, and took body measurements (cm TL).

Movement patterns.

After capture and sampling, all fish were tagged in the dorsal aspect with dart tags. Some subset of these fish were also tagged with ultrasonic transmitter tags (Vemco Company, four-year or two-year battery life, 69 kHz) with individually coded transmitters (Figure 11b). Ultrasonic tags were surgically implanted intraperitoneally in selected fish, typically males and large females of gag, but also large individuals of red snapper, scamp, red grouper, and Warsaw grouper. Fish receiving ultrasonic transmitters were also tagged with internal anchor tags so that they could be easily identified if resighted or recaptured. After tagging and sampling (measured, genetic, gonad and dorsal fin samples taken), fish were immediately released at the capture site.

Fish movements were followed using a portable receiver from the vessel while on site, and in situ data-logging VR-2 receivers (Vemco Company, one year battery life) that archive the presence of tagged fish within a radius of 0.25 nm (ground-truthed on site). VR2s were attached by divers at a depth of 30 m to mooring lines anchored on 8 selected gag spawning sites along the carbonate pinnacles ridge in Madison Swanson Reserve (see Figure 22b). A receiver records the coded signal (identifies individual fish) of the untrasonic tag whenever the fish is within 0.25 nm of the receiver. Signals are emitted at

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[2] Analysis of genetic samples was subsequently funded by the NOAA Cooperative Research Program (NA04NMF4540213), “Investigating Gag Recruitment Processes Using Otolith Chemical and Genetic Markers”

either 5 minute or 2 minute intervals, depending on the tag type. A single VR2 can monitor up to 30 tags simultaneously if they emit coded signals at two-minute intervals, more if the interval is longer. VR2s were retrieved by divers and downloaded every 3 to 6 months, depending on offshore weather conditions. VR2 batteries were changed annually.

Because of the potential value of the shelf-edge MPAs to grouper and snapper reproduction, fish were selected for ultrasonic tagging on the basis of sex, size, and reproductive state. Specifically, we wanted to know if the large spawners remained within the MPAs year-round or returned to the MPAs during the spawning season. The value of MPAs is increased dramatically if large spawners show high site fidelity (Bohnsack 1996, Roberts *et al.* 2001, Berkeley *et al.* 2004a, Berkeley *et al.* 2004b).

Census

Remotely operating vehicle (ROV) video censuses conducted on sampling sites allowed us to estimate densities and sizes of economically-important species. We used a triple laser metric system mounted to the ROV digital video or still cameras. The triple laser metric system--allowing direct measurements of individual fish and habitat features--consists of two lasers set 10 cm apart that project beams parallel to one another, and a third laser set in line with the others at another 10 cm interval from the adjacent laser that projects a converging beam. That is, the third laser is adjusted so that the beam converges with that projecting from the adjacent laser at a distance of 5 m. The laser beams are projected on features and appear as red dots on digitally-produced images, thus allowing us to use the three-pronged laser system to determine sizes of fish and habitat features. It also allows us to determine distance (D), which is extremely important for determining levels of water clarity (visibility) and the area (length x width) of belt transects run using the ROV. This system can be adapted to the Bohnsack-Bannerot survey method to estimate radius of the survey cylinder.

Estimates of transect area require determining several values: (1) the effective distance for identifying fish species, (2) the camera's horizontal angle of view, and (3) the length of the transect. The effective distance (D) may not be limited by visibility, but instead by the distance at which the fish can be identified with a high degree of certainty. The horizontal angle of view (A) depends on the capabilities of the camera used and the position of the zoom. The lengths of transects (L) can be estimated from the speed of the ROV and the time (number of seconds or minutes) of transit, allowing calculation of the average density (number per hectare) and standard error of observed fish species. To estimate transect area, we first calculate the width of the field of view (W) at distance (D) by:

$$W = 2 (\tan (\tfrac{1}{2}A)) (D),$$

Then we calculate the area of the transect (TA) as:

$$TA = (L \times W) - \tfrac{1}{2} (W \times D)$$

Fish measurements require only measuring the distance between the beams projected from the parallel lasers in the series. Recall that the parallel lasers are set 10 cm apart. When the beams are projected onto the fish (a straight-on perpendicular projection on the lateral side), they appear on the image as red dots on the fish's side and serve as a 10 cm reference. Sex ratios of local populations on a given site will be estimated visually from video and still images for sexually dimorphic species.

Aging

We aged fish using spines and rays. Although otoliths are typically used for aging, otolith removal is lethal and therefore not acceptable for tag-release studies. Spines and rays are like otoliths in laying down annuli. Unlike otoliths, in which the opaque zone is considered an annulus, in rays and spines, the translucent zones are counted (Chilton and Beamish 1982) (Figure 12 and 13). We validated spine and ray ages (1) by comparison with otolith ages (validated in other studies) and (2) by comparison with spine and ray ages of recaptured fish.

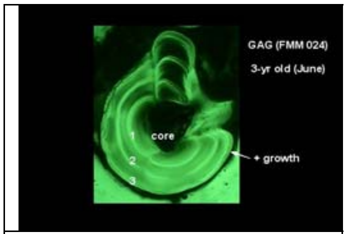

Figure 12. Cross-section gag dorsal fin ray showing annuli and peripheral growth. Photo by Murie (UF).

Our method of preparing and scoring spines and rays closely followed that of Debicelli (2005). Two spines and two rays were snipped from the bases of the anterior portions of the first and second dorsal fins of gag, red grouper, scamp, and red snapper using diagonal wire cutters. Samples were put into labeled envelopes and kept on ice until returning to the laboratory. In the laboratory the samples were dried in a 60^{o} C drying oven overnight and stored dry in Ziploc bags until further processing. Processing involved cleaning tissue off the spines and rays, imbedding the bases of the spines and rays in epoxy resin, and sectioning bases into 0.5 to 0.7 mm thick cross sections and mounting multiple sections on a microscope slide. To clean the samples we placed then in 10 ml pyrex test tubes in water, and immersed the tube in a boiling water bath for 1 to 3 minutes. We then removed the loose tissue with forceps and a soft brush and allowed the samples to dry at room temperature over night. The samples were then imbedded in epoxy resin (Clear Cote Corp., St. Petersburg, FL) in labeled 1.8 ml polypropylene microcentrofuge tubes and allowed to cure overnight.

Figure 13. Cross-section red snapper dorsal fin spine showing annuli. Photo by J. Nelson (FSU).

We modified a Graves lapidary trim saw to obtain 0.05-0.07 mm sections, using two parallel diamond blades (@9 cm diam). To make cross-sections, a chuck, designed to hold the epoxy-filled microcentrofuge tubes firmly, was slid along a plastic guide bolted to the saw parallel to and 5 cm away from the blades, allowing the blades to cut through the epoxy and all but a small piece of the polypropylene tube. After each completed section, a 2.2 mm spacer was inserted between the guide and the chuck, advancing the chuck closer to the blade allowing an additional cut which produced two additional sections. Three cuts yielded five sections, which were removed with forceps and placed on a labeled microscope slide after a quick rinse in distilled water. Sections were allowed to dry then were covered with Flotex clear mounting medium. Mounted sections were viewed under a compound microscope at 40x power.

Ray and spine ages were validated by comparison with otolith ages in a regression model. If the slope is close to 1 and the intercept close to zero, we considered ray aging a reasonable method for this study. A disparity was found in ray aging relative to otolith aging in red grouper; we are working to correct this problem, which apparently resulted from counting false annuli in younger fish. Scamp aging is incomplete at the time of this writing, but we expect to finish by June 2006. Statistical comparisons of age and size of reef fish inside vs. outside of Madison Swanson over the three years of study were made by two-way ANOVA. Validation of fin ray ages was done by comparison with otolith ages in a linear regression model.

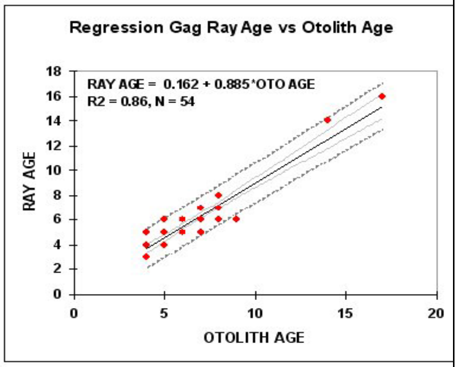

Figure 13. Regression of gag ray ages on otolith ages.

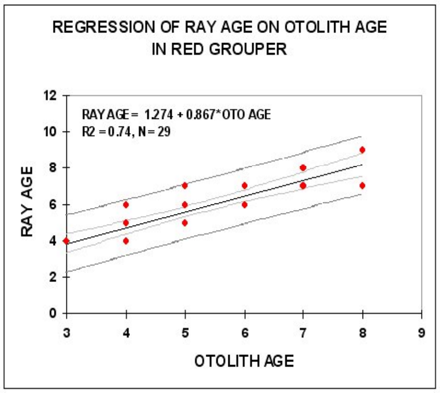

Figure 14. Regression of red grouper ray age on otolith age

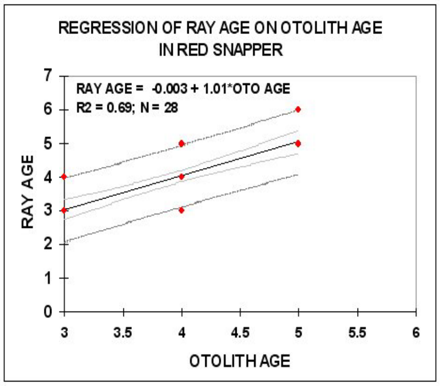

Figure 15. Regression of red snapper age on otolith age.

RESULTS

Size and age

Validation.--Because all of our samples were collected on deep-water sites, we captured no fish younger than 3 years old. Ray age agreed well with otolith age for gag (Figure 13; $R^2 = 0.86$), although ray ages were more variable. Variation resulted from false checks (marks that look like annuli) and from the earliest annuli being obscured by blood vessels in the central core of the rays. We could accurately read rays up to 17 years, the oldest gag in our sample.

Red grouper ray ages overestimated otolith age by about a year in younger (< 5 year old) fish (Figure 14). We are examining this error and will correct it, but it should not seriously affect the comparison of ages inside versus outside of the reserve.

Red snapper ray ages coincided closely with otolith ages in fish up to 5 years old, the oldest fish from which we obtained otoliths (Figure 15).

Size and age comparisons

In comparing gag age and size structure inside vs. outside of Madison Swanson Reserve, we found no significant difference ($P > 0.05$) (Figure 16; Table 1). Also, there were no significant differences between any years ($P > 0.05$).

Red grouper were significantly older ($P < 0.0001$) and larger ($P < 0.0001$) inside Madison Swanson Reserve relative to outside (Figure 17). However, there was no significant interaction between inside and outside ($P > 0.05$), meaning that the trend in size and age inside paralleled the outside. Thus, even though age and size were significantly greater inside relative to outside, over the course of this study there was no significant relative change.

Red snapper were significantly older ($P < 0.0001$) and larger ($P < 0.0001$) inside the reserve than outside (Figure 18). There was also a significant interaction ($P < 0.0001$) (Table 1), indicating that the size and age structure inside was significantly increasing ($P < 0.001$) relative to outside.

Scamp were significantly larger ($P < 0.0001$) inside than outside (Figure 19). There was also a significant interaction ($P < 0.01$ (Table 1), indicating that the size and age structure inside was significantly increasing ($P < 0.05$) relative to the outside.

Greater amberjack were not significantly larger inside than outside ($P > 0.05$) overall, but they were in 2005 ($P < 0.05$). There was also a significant interaction ($P < 0.05$) indicating the change in size inside is different from outside.

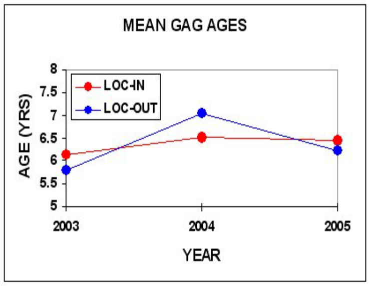

Figure 16a. Mean gag age from fish inside and outside Madison Swanson Reserve over three years. Age inside not significantly different than outside (P>0.05). N = 467

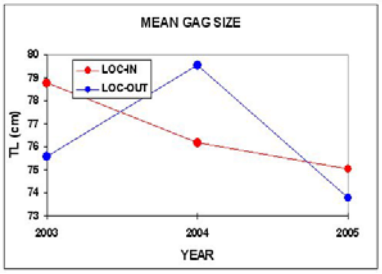

Figure 16b. Mean gag size from fish captured in vs out of Madison Swanson Reserve over three years. Size inside not significantly different than outside (P>0.05). N = 614

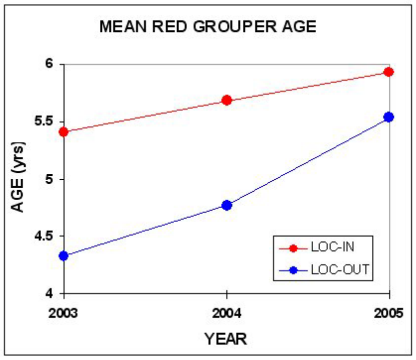

Figure 17a. Mean red grouper age from fish captured inside vs. outside of Madison Swanson Reserve. Age inside significantly older than outside (P<0.0001). N = 311

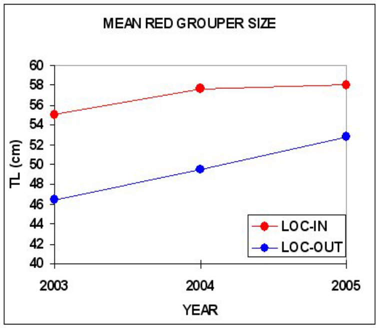

Figure 17b. Mean red grouper age from fish captured inside vs. outside of Madison Swanson Reserve. Size inside significantly larger than outside (P<0.0001). N = 477

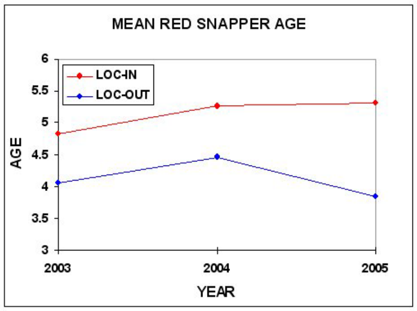

Figure 18a. Mean red snapper age comparing fish inside and outside Madison Swanson Reserve. Inside significantly older than outside (P<0.0001). N = 399

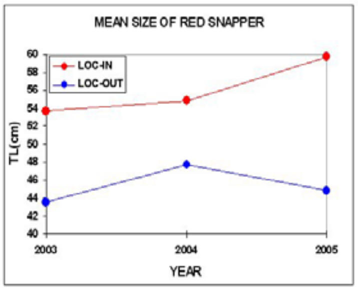

Figure 18b. Mean red snapper size from fish captured in and outside Madison Swanson Reserve. Size inside significantly larger than outside (P<0.0001). N = 658

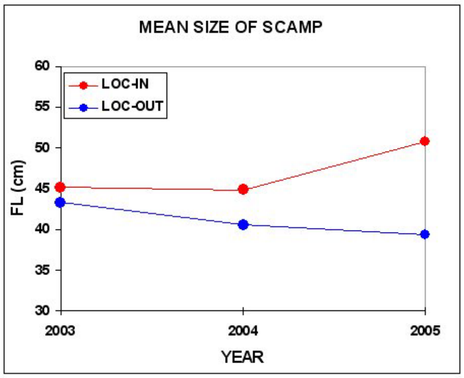

Figure 19. Mean scamp size inside vs. outside of Madison Swanson Reserve. Size inside significantly larger than outside (P<0.0001). N = 401

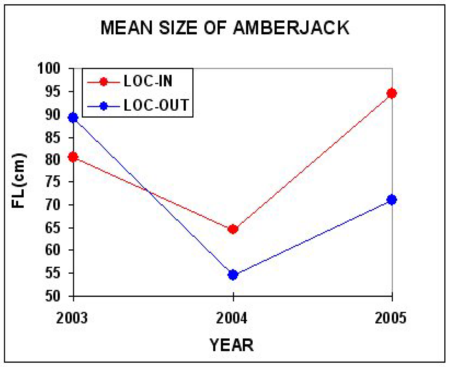

Figure 20. Mean amberjack size inside vs. outside of Madison Swanson Reserve. Size inside is only significantly greater than outside in 2005 (P<0.05)

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Table 1. Two-way ANOVA tables of gag, red snapper, and red grouper age and size, and size only for scamp and amberjack, inside and outside of Madison Swanson Reserve over three years of study.

Species	FACTOR	Source	DF	SS	Mean square	Fisher's F	Pr > F
Gag							
	Age	YEAR	2	23.959	11.979	4.121	0.017
		LOC	1	0.283	0.283	0.097	0.755
		YEAR*LOC	2	9.823	4.911	1.690	0.186
	Size	YEAR	2	1323.748	661.874	4.576	0.011
		LOC	1	3.225	3.225	0.022	0.881
		YEAR*LOC	2	696.310	348.155	2.407	0.091
Red Snapper	Age						
		YEAR	2	19.506	9.753	9.270	0.001
		LOC	1	81.609	81.609	77.565	< 0.0001
		YEAR*LOC	2	6.857	3.428	3.258	0.039
	Size	YEAR	2	1429.384	714.692	9.691	< 0.0001
		LOC	1	16793.481	16793.481	227.725	< 0.0001
		YEAR*LOC	2	1667.887	833.943	11.309	< 0.0001
Red Grouper	Age						
		YEAR	2	21.023	10.511	5.034	0.007
		LOC	1	32.722	32.722	15.673	< 0.0001
		YEAR*LOC	2	4.187	2.093	1.003	0.368
	Size	YEAR	2	353.782	176.891	2.371	0.095
		LOC	1	5060.813	5060.813	67.825	< 0.0001
		YEAR*LOC	2	262.766	131.383	1.761	0.173
Scamp	Size	YEAR	2	156.745	78.372	1.673	0.189
		LOC	1	1385.810	1385.810	29.578	< 0.0001
		YEAR*LOC	2	518.095	259.048	5.529	0.004
Amberjack	Size	YEAR	2	8428.620	4214.310	12.300	< 0.0001
		LOC	1	1530.168	1530.168	4.466	0.038
		YEAR*LOC	2	2839.671	1419.835	4.144	0.020

Sex Ratio in Gag

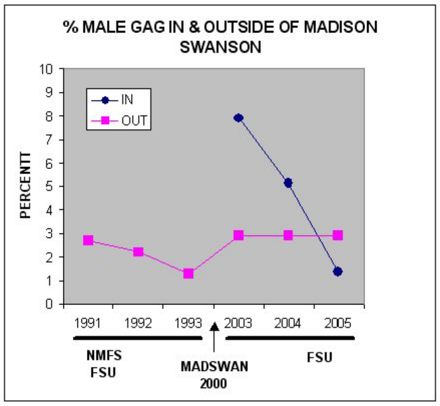

Figure 21. Percent male gag in NE Gulf of Mexico; historical and recent percentages inside and outside Madison Swanson Reserve.

The percent male gag inside the reserve in 2003 was nearly half that recorded in the 1970s (17%) when fishing pressure in the northeastern Gulf of Mexico was relatively low, and three to four times higher than that recorded by NMFS and FSU researchers in the early 1990s (2 to 3%) when fishing pressure was heavy (Figure 21). However the 2003 percent males declined almost linearly over the three years of this study to its present level, which is indistinguishable from that outside the reserve (2 to 3%). The percentage of males inside the reserve in 2003 was significantly greater than in 2005 (P < 0.01).

Movement Patterns

Gag -- Several species of reef fish (gag, scamp, red grouper, red snapper, and others) were tagged with transmitters on the carbonate ridge in the southern part of Madison Swanson Reserve (Figure 22). Moorings were set up at eight of the spawning sites (1, 15, 14, 13, 5, 12, 10, and 3) along the ridge. VR2s were attached to the moorings so that each of those spawning sites could be monitored. Fish were first tagged with transmitters in the spring of 2003 and the observation period was ended in the summer of 2005. We continued to tag with transmitters throughout this period. Figures 23 through 36 show movement patterns of individual fish (y-axis = detections per day; the x-axis = dates). Transmitters emit a

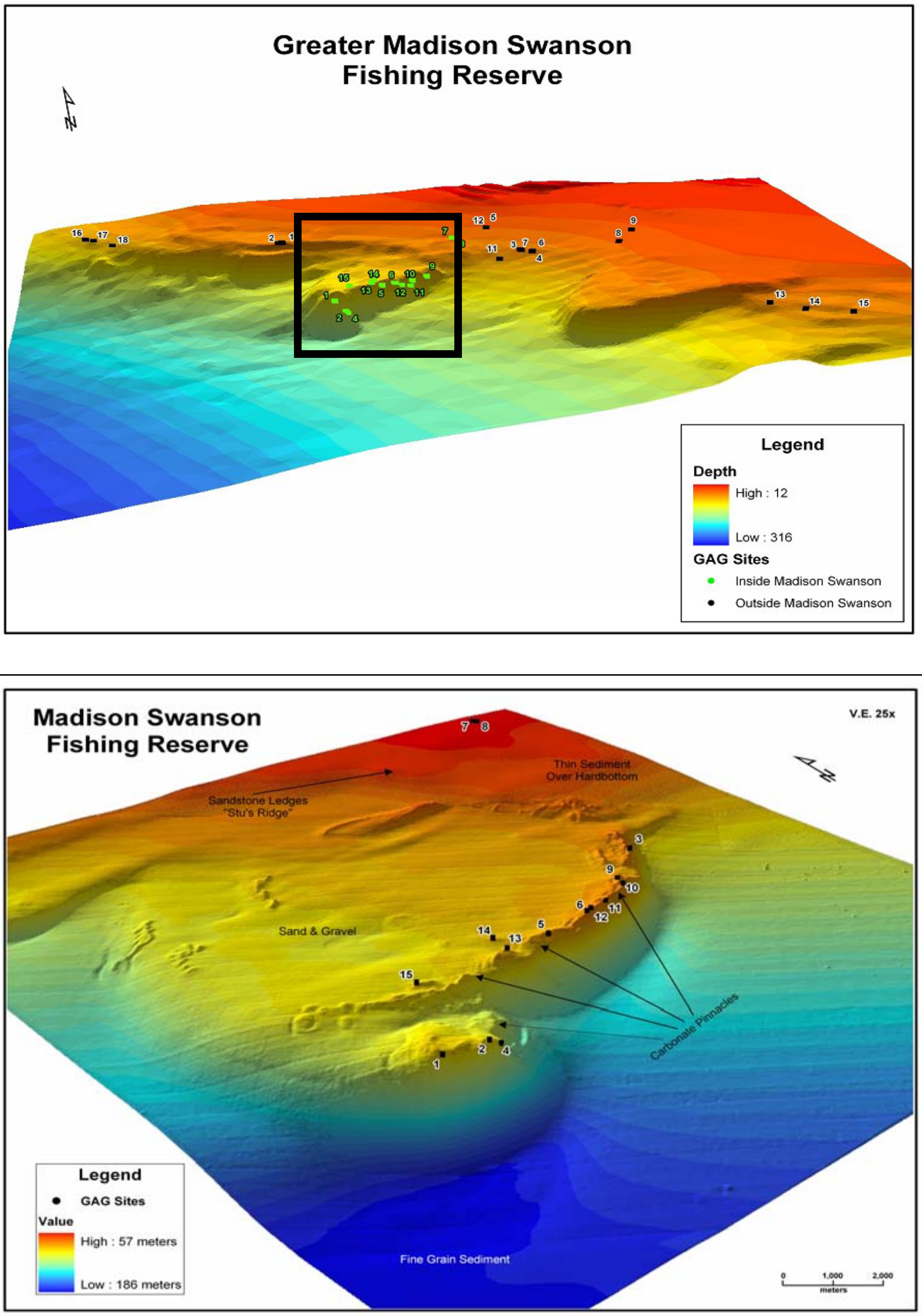

Figure 22. Multibeam images in Madison Swanson Reserve showing primary spawning sites of gag *Mycteroperca microlepis* on the southern carbonate pinnacle ridge next to a sharp drop-off. Eight moorings on sites 1, 15, 14, 13, 5, 12, 10, and 3 support VR2 monitoring sites to investigate movements of individual fish tagged with transmitters. A. Sites within (green) and outside (black) the marine reserve (box indicates reserve boundaries). B. Madison Swanson Marine Reserve. Image courtesy of J. Gardener, USGS, modified by J. Ueland, FSU

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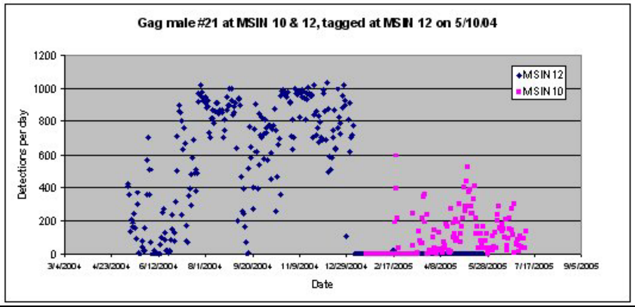
<td>
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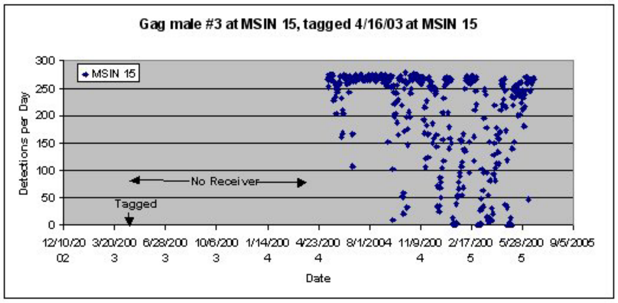
<td>
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<td>Figure 23. Male gag movement patterns between spawning sites MSIN 12 and MSIN 10 (locations in Figure 22). Tag date = 5/10/04 at MISIN 12; remained there until 1/5/05, then switched to MSIN 10, ~ 1.0 nm away and remained there until the end of the observation period on 7/8/05.</td>
<td>Figure 24. Male gag movement patterns around spawning site MSIN 15 (locations in Figure 22). Tag date = 4/16/03 and not observed on any other sites for the entire observation period (ended 6/19/05).</td>
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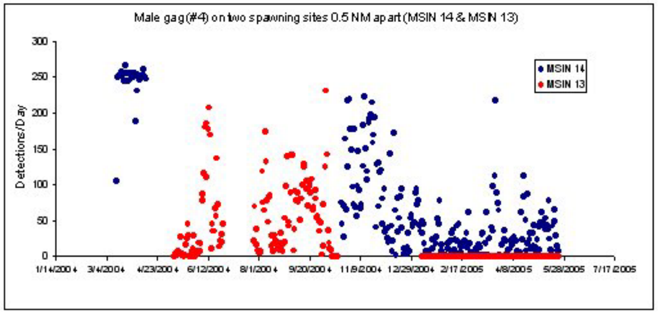
<td>
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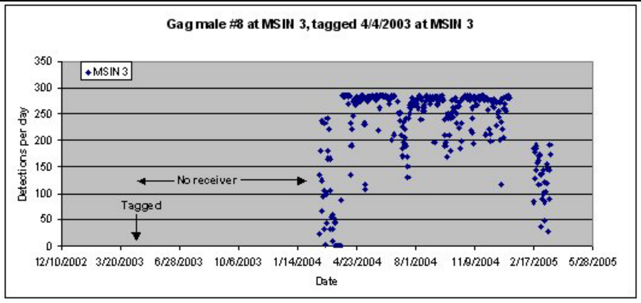
<td>
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<tr>
<td>Figure 25. Male gag movement patterns between spawning sites MSIN 14 and MSIN 13 (locations in Figure 22). Tag date = 4/17/03 at MSIN 14; moved to another site 0.5 nm away briefly. Returned to original site and remained there until the end of the study (5/28/05).</td>
<td>Figure 26. Male gag movement patterns around spawning site MSIN 3 (location in Figure 22). Tag date = 4/4/03 and remained on the same site for the duration of the observation period to 3/17/05.</td>
</tr>
</table>

consistent number of coded signals per day—if the fish remains within 0.25 nm of the receiver, the maximum number of detections will be recorded (see “control transmitter” - Figure 36). Several factors can mask the signals so that the receiver does not record; these include echosounders (fathometers) on fishing vessels or intense meteorological events, like hurricanes.

For a transmitter in a released fish, if there is a high number of detections per day, the tagged fish remained within range of the receiver for most or all of the day. A low number of detections per day means that the fish was out of range most of the day.

We found sexually-distinct movement patterns among gag. Males clearly remain within the vicinity of the receivers on one or two spawning sites for extended periods of time (Figures 23-26). We’ve tracked these four individuals for many months and found that they occur within range of the receivers most of the time. Some fish would switch to a site close to the original capture site; they then showed strong site fidelity to the alternate site. The greatest range of movement observed was one nautical mile (nm) (Figure 23) over a 14-month period. Other males were tracked for about 2 years and rarely left the spawning site (Figures 24 and 26). Another male moved from the spawning site on which it was captured to another spawning site 0.5 nm away, stayed there for 5 months, then returned to the original spawning site for the remainder of the observation period (Figure 25).

Female gag show a very different pattern from that of the males (Figures 27 to 31). They tend to move much more frequently, stopping on one site for only a relatively short period of time, up to a couple of months, then moving on. In some cases, they appear to be just passing through (Figure 31) because the VR2 receiver records only a few detections.

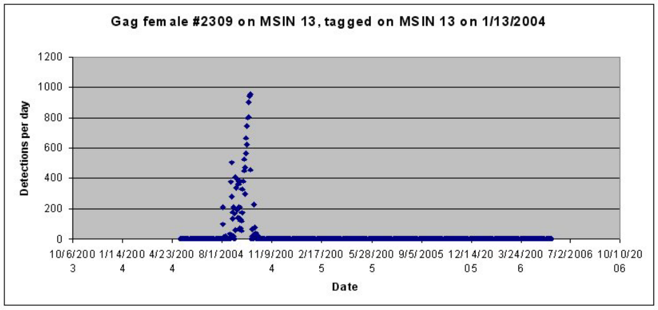

Figure 27. Female gag movement patterns on MSIN 13. Tag date = 1/13/04 on this site; last heard on 10/11/04.

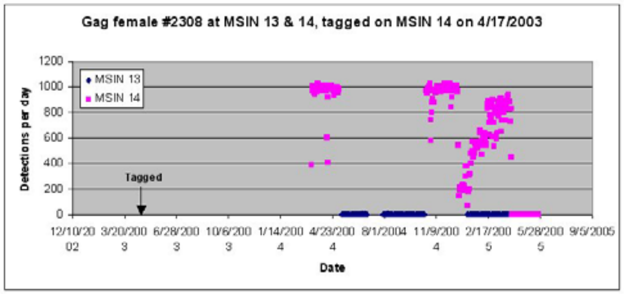

Figure 28. Female gag movement patterns between MSIN 13 and MSIN 14. Tag date = 4/17/03 on MSIN 14; last heard at 14 on 4/2/05. Detected intermittently on 13, 0.5 nm away. Sites 13 and 14 were monitored until 5/28/05.

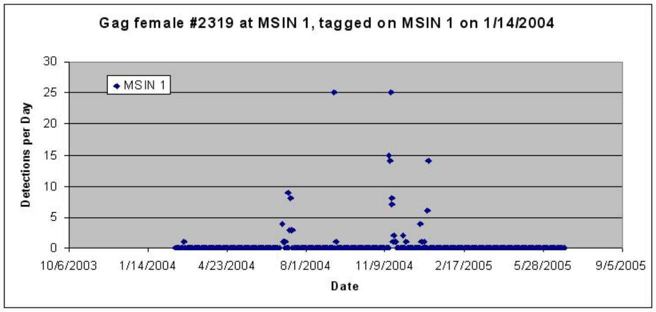

Figure 29. Female gag tagged at spawning site 1 on 1/14/04 showed up intermittently on site 1 until 1/3/05, when last heard (site monitored until 6/24/05).

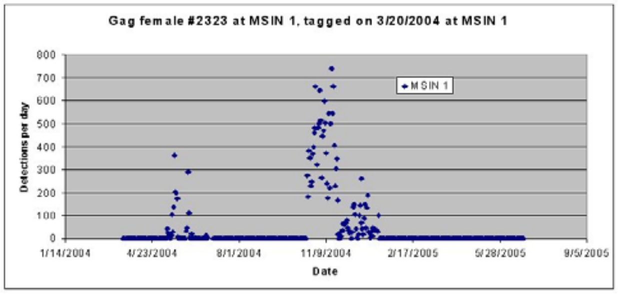

Figure 30. Female gag tagged on 3/20/04 at spawning site 1 and visited intermittently until 1/8/05, when last heard (site monitored until 6/24/05).

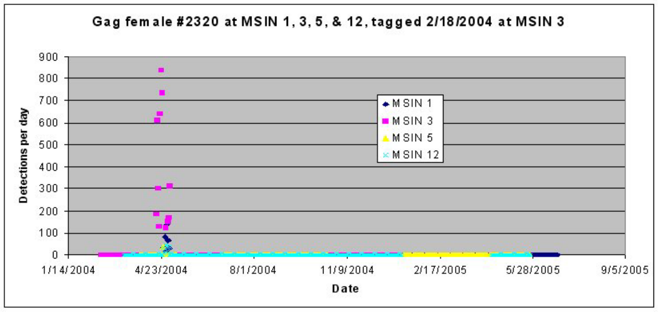

Figure 31. Female gag tagged on site 3 on 2/18/04 and observed on sites 1, 3, 5, and 12. The total range of this observed movement was 6 nm.

The complete record of ultrasonically tagged gag is shown in Table 2. Some tagged fish disappeared from spawning sites during the observation period. It is not know whether poaching was a major factor in the disappearance of these fish, but poaching was intense at times on the spawning sites where the moorings and VR2s were monitoring telemetered fish. Undoubtedly some of the experimental fish were lost to poaching.

Table 2. Telemetered gag, red snapper, and scamp within the Madison Swanson reserve. Gag spawning sites indicated on this table are depicted in Figure 22.

						Sites					
						2003		**2004**		**2005**	
Sp.	**Code**	**TL (cm)**	**Sex**	**Tag date**	**Tag Site**	**Jan - Jun**	**July - Dec**	**Jan - Jun**	**Jul - Dec**	**Jan - Jun**	**Max dist. (nm)**
GA	3	95	M	4/16/2003	15	15	LR	15	15	15	0
GA	4	99	M	4/17/2003	14	14	LR	13,14	13	14	0.5
GA	7	109	M	3/24/2003	5	ND	LR	ND	ND	ND	N/A
GA	8	107	M	4/4/2003	3	3	LR	3	3	3	0
GA	9	117	M	4/4/2003	3	ND	LR	ND	ND	ND	N/A
GA	21	126	M	5/10/2004	12			12	12	12,10	1
GA	23	122	M	4/16/2003	12	12	LR	3	3	3	0
GA	24	122	M	5/4/2003	14	ND	LR	5,13,14	5,13,14	ND	0.7
GA	2310	85	M	4/17/2003	13	13	LR	13	13	13	0
GA	2313	121	M	6/29/2004	13			13	13	ND	0
GA	2330	98	M	5/26/2005	15					15	0
GA	2305	90	F	4/17/2003	14	ND	LR	ND	ND	ND	N/A
GA	2306	91	F	5/4/2003	1	1	LR	1	1	1	0
GA	2308	89	F	4/17/2003	14	14	LR	13,14	13,14	14	0.5
GA	2309	94	F	1/13/2004	13			13	13	ND	0
GA	2315	91	F	5/10/2004	3			3	ND	ND	0
GA	2316	89	F	1/14/2004	2			ND	ND	ND	N/A
GA	2319	92	F	1/14/2004	1			1	1	1	0
GA	2320	106	F	4/18/2004	3			1,3,5,10,2	ND	ND	6
GA	2323	91	F	3/20/2004	1			1	1	1	0
GA	2332	98	F	10/20/2004	5				ND	ND	N/A
GA	47	86	F	1/9/2005	12					12,10	1
RS	2307	56	?	7/26/2003	6		LR	12	12, 15	12, 15	2.8
RS	2322	70	?	1/13/2004	15			15	15	15	0
RS	2325	78	F	3/13/2004	1			1	1	1	0
RS	2321	73	?	4/18/2004	16			12, 1	12	12	4
RS	2324	68	F	5/10/2004	5			13, 5	13, 5	ND	0.7
RS	2312	63	M	6/29/2004	12			12	ND	ND	N/A
SC	5	54	M	4/15/2003	3		LR	3	3	3	0

ND = not detected; N/A = not applicable; LR = lost receiver.

Note: Gag spawning sites indicated in this table are depicted in Figure 22B

Red snapper -- Large red snapper (including females) displayed strong spawning site fidelity similar to that of male gag (Figures 32 and 34). Like male gag they remained on gag spawning sites for many months of observation. During the summer months they spawned on these same sites, as indicated by hydrated eggs in summer females. Some would move to nearby spawning sites, similar to male gag behavior, and remain at those alternate sites for extended periods (Figure 33).

Red grouper – Red grouper showed exceedingly strong site fidelity. This is apparently related to their habitat-structuring behavior (see later discussion in Part III) and their haremic mating behavior, unlike the aggregating behavior of the other three species. When we tagged them with ultrasonic receivers it was difficult to distinguish tagged fish from dead fish. Because of their behavior of remaining on or in the bottom even depth-indicating transmitters would not provide a distinction between dead and alive fish. So we relied on recaptures to evaluate their degree of movement (see later in this section).

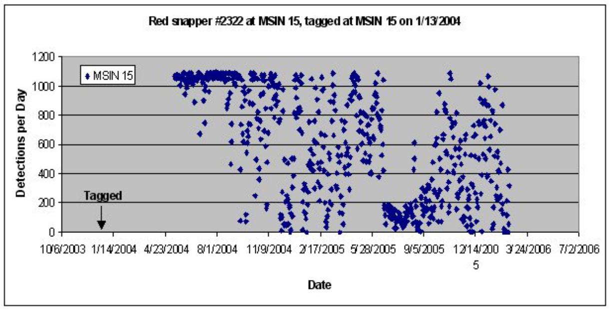

Figure 32. Red snapper (sex unknown) tagged at site 15 on 1/13/04 and heard on that site until the end of the observation period on 2/17/06.

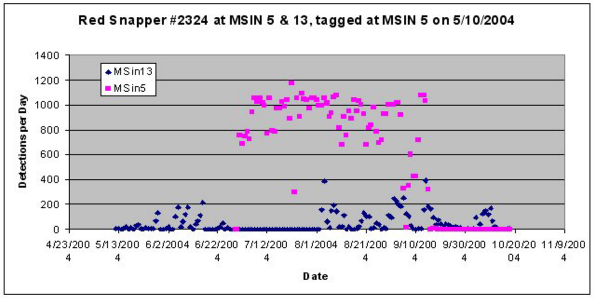

Figure 33. Female red snapper tagged at site 13 on 5/10/04 and moved between sites 13 and 5 (0.6 nm apart). Fish last heard on site 13 on 10/18/04; the stations were monitored until 6/1/05.

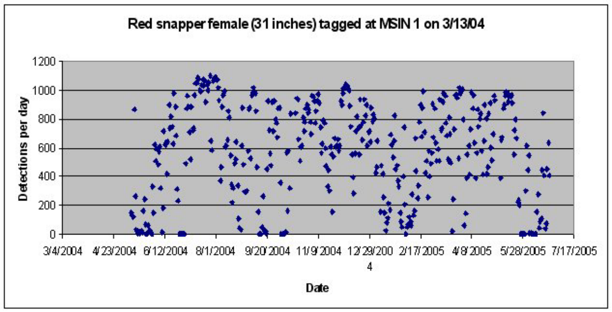

Figure 34. Female red snapper tagged at MSIN 1 on 3/13/04 and last heard at the end of the observation period on 6/23/05. This fish appears to have about a four-month period of movement to and from this site

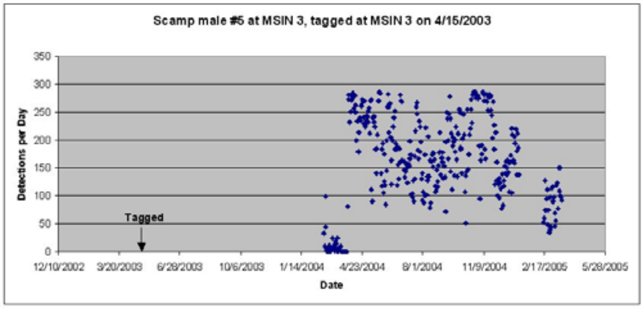

Figure 35. Scamp male tagged at site 3 and on 4/15/03 and remained on the same site until the end of the observation period on 3/18/05.

Scamp -- Only a single scamp (male) was tagged with a transmitter. This fish displayed movement patterns similar to that of male gag and remained around the tagging site until the end of the observation period (23 months).

Control -- A "control" transmitter (Figure 36) was deployed at station 5 to archive data from a "dead" fish (i.e., transmitter not moving) by the VR2. We placed a transmitter on the bottom (i.e., not in a fish) at one of the spawning sites (site 5) and monitored it along with fish tagged on that and other sites. We experimentally determined that the echosounder (fathometer) on our boat masks detection of the signal by the VR2 receiver. That is, the receiver does not record the presence of the transmitter, i.e., the fathometer completely obliterates the signal from the tag. Hurricane Ivan (19 September 2004), which produced 40 ft waves in the area, forced a similar detection loss.

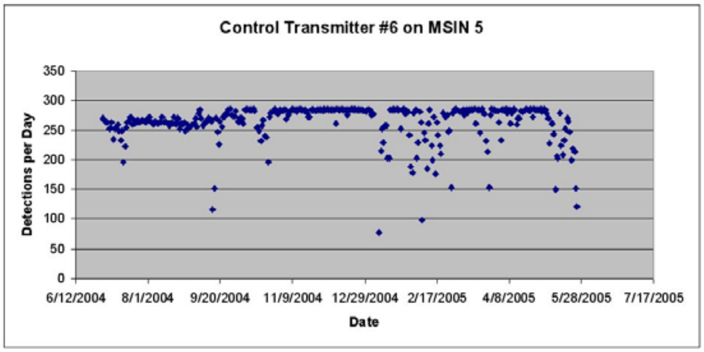

Figure 36. Control transmitter deployed at spawning site 5 to provide data as a dead fish. Severe storms and echosounders disrupt detection by receivers.

Direct abundance estimates: ROV and Manned submersible

We estimated abundance of economically important fish species on seven gag spawning sites inside and seven gag spawning sites outside of the Madison Swanson Fishery Reserve during the gag spawning season (March) in 2005 (Figure 37).

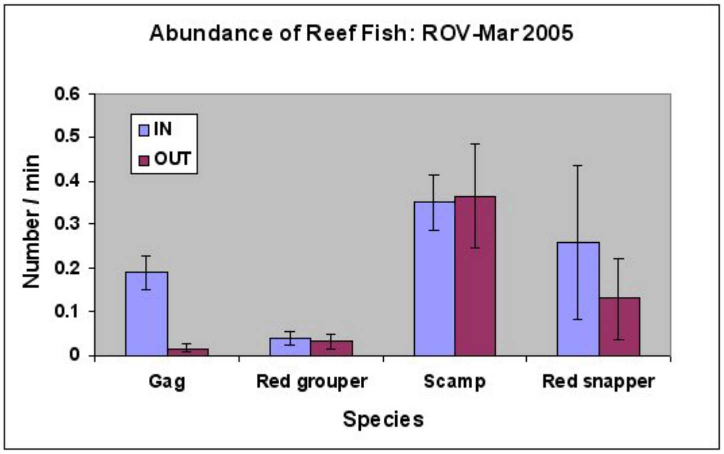

Figure 37. Number of reeffish observed per minute of ROV transect time on spawning sites inside (N=7) and outside (N=7) Madison Swanson Reserve (March 2005). Range transect time: 15-120 minutes.). Number of gag per minute is significantly greater ($P<0.05$) inside than outside; others are not significantly different. Error bars are SE.

We found that the abundance of gag during the spawning season on spawning aggregations inside the reserve was significantly higher ($P<0.05$) than outside (Figure 37). The abundance of the other three dominant reef fish were not significantly different inside vs. outside ($P>0.05$).

Gag behavior is a significant factor in getting good information on abundance. We noted in 2001 on the SSE (Sustainable Seas Expedition) cruise that gag would run from the manned submersible and remain just on the periphery of visibility. Apparently the lights would frighten them because they would gather closer to the vehicle when the lights were off for a while, then turned back on. We observed the same phenomenon with the NURP ROV dives in 2005. This avoidance behavior made it impossible to do quantitative transects using the triple laser as an estimate or transect area. So we used traditional methods of recording abundance in terms of number observed per minute of transect time. Because of the avoidance behavior, abundance of gag is likely underestimated with ROV and manned submersibles. Comparisons between inside and outside the reserve probably show valid relative abundance estimates, but should not be interpreted as absolute abundance. We did not observe this same avoidance behavior in the other species.

Tagging Studies

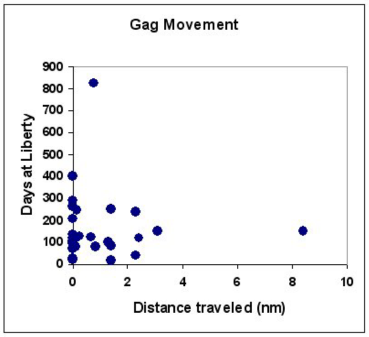

Figure 38a. Relationship between days at liberty and distance traveled in recaptured gag. No significant correlation ($P>0.05$).

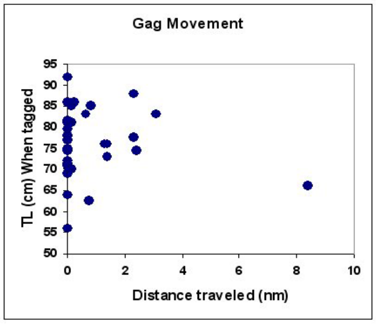

Figure 38b. Relationship between size of fish and distance traveled in recaptured gag. No significant correlation ($P>0.05$).

Tag returns by fishermen wereor during 2003 and 2004, even though many told us they captured tagged fish. Some said that they thought we only tagged fish inside the reserve and didn't want to be accused of poaching if they returned the tag. There were many other excuses for not reporting the tags, but in 2005 when we offered a drawing reward for every tag turned in we got a much better response. A monetary incentive is clearly necessary.

Gag recaptured in the fishery (Table 3) showed a greater mean distance traveled (6.6 nm) and a lower time at liberty (122 d) than did the gag recaptured during our sampling program (Table 4). We sampled permanent sites inside and outside Madison Swanson Reserve (Figure 22a), but the fishermen reporting recaptures fish a much wider geographical area. Even though, there were no fish reported to have traveled distances greater than 15 nm. Recapture data from our study (Table 4) show that gag show strong site fidelity on the shelf-edge environment. The mean distance moved was 0.8 nm and the mean days at liberty was 157. This low movement rate corroborates our telemetry data. We did not find a correlation between days at liberty and distance moved (Figure 38a), nor did we find a correlation between size and distance moved (Figure 38b). Although the fish that moved the farthest (8.4 nm) was a small fish (66 cm TL), the fish that was at liberty the longest (825 d) was also a small fish (62.5 cm), and moved only 0.75 nm.

Table 3. Gag *Mycteroperca microlepis* caught by fishermen

TL (cm) When tagged	Date Tagged	Location tagged	Recapture lat/lon	Recapture Date	Days at Liberty	Distance moved (nm)	Direction	External tag no.
63	10/18/2004	MSOUT18A	N29 17.9 / W85 50.8	2/9/2005	114	10.7	SE	1850
68	3/18/2005	MSIN 17.1	N29 17.4 / W85 37.7	6/22/2005	96	1.2	NE	2197
69	4/15/2003	MSIN3	ND	7/13/2003	89	n/a	n/a	184
69.8	1/7/2005	MSOUT 2.1	ND	3/22/2005	74	n/a	n/a	1556
73	4/15/2003	MSIN20	N29 16.5 / W85 27.1	5/17/2003	32	14.5	NE	160
76	4/14/2003	MSIN10	N29 13.8 / W85 35.6	8/11/2003	119	6.7	NE	176
76	5/5/2003	MSIN 15	N29 16.5 / W85 37.5	10/8/2003	156	10.9	NNE	491
78	3/24/2003	MSIN10	ND	7/13/2003	111	n/a	n/a	277
78.5	3/18/2005	MSIN 17.1	N29 16.7 / W85 38.8	6/9/2005	83	0.06	N	2072
79.5	1/10/2005	MSOUT 8	N29 14.0 / W85 25.8	6/4/2005	145	1.8	SW	1995
81	1/7/2005	MSIN 17	N29 19.4 / W85 37.7	6/17/2005	161	2.9	NNE	618
87	1/7/2005	MSIN 17.1	N29 17.2 / W85 27.7	6/17/2005	161	9.7	NE	1577
92	10/19/2004	MSIN 9	N29 13.0 / W85 36.1	8/5/2005	290	5.7	NE	849
94	4/3/2003	MSIN6	N29 14.0 / W25 34.7	6/17/2003	75	8.6	NE	143

Table 4. Gag *Mycteroperca microlepis* recaptured by us during demographic study inside and outside Madison Swanson Reserve.

TL (cm) when tagged	DATE tagged	TAG SITE	RECAPTURE SITE	DATE recaptured	Days at Liberty	Distance traveled (nm)	Direction moved	External tag no.
56	6/30/2004	MSOUT 7	MSOUT 7	7/25/2004	25	0	N/A	994
62.5	3/23/2003	MSIN 17.4	MSIN 17.1	6/25/2005	825	0.75	NE	201
64	1/9/2005	MSIN 5	MSIN 5	5/26/2005	137	0	N/A	1404
66	10/20/2004	MSIN 10	MSOUT 23	3/19/2005	150	8.4	NNE	864
69	10/20/2004	MSIN 9.1	MSIN 9.1	2/16/2005	119	0	N/A	1542
70	10/19/2004	MSIN 9.1	MSIN 10	2/16/2005	120	0.13	NNE	828
71	4/14/2003	MSIN 5	MSIN 5	7/27/2003	104	0	N/A	285
71.5	1/9/2005	MSIN 12	MSIN 12	4/14/2005	95	0	N/A	1412
72	7/27/2003	MSIN 14	MSIN 14	2/19/2004	207	0	N/A	470
73	4/17/2003	MSIN 13	MSIN 6	5/5/2003	18	1.4	WSW	503
73	5/5/2003	MSIN 13	MSIN 13	7/27/2003	83	1.4	ENE	503
74.5	10/20/2004	MSIN 6	MSIN 3	2/16/2005	119	2.4	NE	856
74.5	1/9/2005	MSIN 12	MSIN 12	4/14/2005	95	0	N/A	1426
75	4/18/2004	MSIN 10	MSIN 10	5/26/2005	403	0	N/A	863
76	5/5/2003	MSIN 6	MSIN 6	1/13/2004	253	1.4	ENE	499
76	4/17/2003	MSIN 14	MSIN 12	7/28/2003	102	1.3	SE	171
77	6/29/2004	MSIN 13	MSIN 13	3/19/2005	263	0	N/A	1006
77.5	1/9/2005	MSIN 12	MSIN 3	2/16/2005	38	2.3	NE	1447
78	6/29/2004	MSIN 13	MSIN 13	7/24/2004	25	0	N/A	1001
79.5	1/10/2005	MSOUT 8	MSOUT 8	5/27/2005	137	0	N/A	1360
79.5	1/10/2005	MSOUT 8	MSOUT 8	5/27/2005	137	0	N/A	1360
81	5/7/2004	MSIN 17.1	MSIN 17	1/7/2005	245	0.13	NE	618
81	6/29/2004	MSIN 13	MSIN 13	4/14/2005	289	0	N/A	1006
81.5	1/9/2005	MSIN 15	MSIN 15	3/19/2005	69	0	N/A	1487
83	10/19/2004	MSIN 3	MSIN 5	3/19/2005	151	3.1	SE	830
83	3/24/2003	MSIN 5	MSIN 13	7/27/2003	125	0.65	W	203
85	10/20/2004	MSIN 5	MSIN 12	1/9/2005	81	0.83	SE	1514
85	10/20/2004	MSIN 6	MSIN 12	1/9/2005	81	0.12	NE	868
86	3/24/2003	MSIN 10	MSIN 10	4/14/2003	21	0	N/A	295
86	3/24/2003	MSIN 10	MSIN 9	7/28/2003	126	0.24	N/A	295
88	2/16/2005	MSIN 3	MSIN 12	10/14/2005	240	2.3	SE	2074
92	1/10/2005	MSOUT 8	MSOUT 8	5/27/2005	137	0	N/A	1333

Recaptured red snapper (Table 5) also showed a high degree of site fidelity with no fish moving more than 10 nm and most moving far less than that. This result corroborates our telemetry data which indicates a strong affinity of large individuals for the spawning sites.

Table 5. Red snapper *Lutjanus campechanus* recaptured inside and outside of Madison Swanson Reserve.

SP.	TL (cm) when tagged	Date Tagged	Site tagged	Recapture lat/long	Recapture Date	Days at Liberty	Distance moved (nm)	Direction	External tag no.
RS	36.5	1/10/2005	MSOUT 9.1	N29 14.0 / W85 26.0	3/7/2005	56	0	N/A	1336
RS	40	1/10/2005	MSOUT 9.1	N9 14.0 / W85 26.0	3/7/2005	56	0	N/A	1379
RS	40	1/10/2005	MSOUT 9	N9 14.0 / W85 26.0	3/7/2005	56	0	N/A	1386
RS	48	4/4/2003	MSIN 6	N29 09.8 / W85 42.2	4/4/2003	0	0	N/A	133
RS	64	3/24/2003	MSIN 13	N29 09.8 / W85 44.8	7/27/2003	125	0	N/A	213
RS	42	5/3/2003	MSOUT 4	N29 12.9 / W85 33.1	8/13/2005	833	0.4	S	374
RS	40	3/22/2003	MSIN 8	N29 16.5 / W85 37.5	10/9/2003	201	0.7	SE	262
RS	40.5	5/3/2003	MSOUT 4	N29 13.9 / W85 33.5	3/31/2004	333	0.8	N/A	369
RS	48	5/2/2003	MSOUT14	N28 55.0 / W85 17.3	7/6/2003	65	2.3	SE	544
RS	46.5	5/3/2003	MSOUT4	N29 13.0 / W85 32.9	7/25/2003	83	5.8	SE	361
RS	62	3/19/05	MSIN 10	N29 17.8 / W85 49.1	4/9/2005	21	9.8	NW	2108
RS	40	4/19/2004	MSOUT4	N28 58.4 / W85 09.4	2/5/2005	292	9.9	SE	698
RS	63	1/10/2005	MSOUT 9.1	N29 14.0 / W85 25.8	8/11/2005	213	ND	N/A	1346
RS	41	5/3/2003	MSOUT8	ND	6/9/2003	37	ND	N/A	322
RS	50	3/22/2003	MSIN7	ND	10/9/2003	201	ND	N/A	268
RS	52	3/12/2003	MSIN17.2	ND	10/4/2004	572	ND	N/A	86
RS	41	5/3/2003	MSOUT 4	ND	5/17/2004	380	ND	N/A	368
RS	50	5/7/2004	MSIN 17.6	ND	5/17/2004	10	ND	N/A	1263
RS	42	1/10/2005	MSOUT 9.1	ND	5/16/2005	126	ND	N/A	1397
RS	45.5	1/10/2005	MSOUT 8	ND	6/3/2005	144	ND	N/A	1351
RS	45	5/7/2004	MSIN 17.4	ND	5/21/2005	379	ND	N/A	1217

Table 6. Red grouper recaptured inside and outside of Madison Swanson Reserve.

SP.	TL (cm) when tagged	Date Tagged	Site tagged	Recapture lat/long	Recapture Date	Days at Liberty	Distance moved (nm)	Direction	External tag no.
RG	41	7/25/2004	MSOUT7	MSOUT 7	5/31/2005	310	0	N/A	686
RG	63	1/10/2005	MSOUT 7	MSOUT 7	6/7/2005	148	0	N/A	1303
RG	52	2/16/2005	MSIN 10	MSIN 10	5/26/2005	99	0	N/A	2186
RG	45.5	7/25/2004	MSOUT 3	MSOUT 3	5/27/2005	306	0	N/A	1855
RG	59.5	1/10/2005	MSOUT 7	MSOUT 7	5/27/2005	137	0	N/A	1324
RG	55.5	1/10/2005	MSOUT 3	MSOUT 3	5/27/2005	137	0	N/A	1311
RG	49	7/25/2004	MSOUT 7	MSOUT 7	1/10/2005	169	0	N/A	686
RG	51	3/20/2004	MSIN 12	MSIN 12	7/25/2004	127	0	N/A	587
RG	68	3/18/2005	MSIN 17.1	N29 17.4 / W85 37.7	6/22/2005	96	1.2	NE	2171
RG	45	5/3/2003	MSOUT4	ND	7/30/2003	88	ND	ND	549
RG	51	4/7/2004	MSOUT 2.2	ND	9/2/2004	148	ND	ND	974
RG	67	7/26/2004	MSOUT2.1	ND	10/25/2004	91	ND	ND	1887
RG	49	4/7/2004	MSOUT 2.2	ND	10/25/2004	201	ND	ND	955
RG	56	5/27/2005	MSOUT 8	ND	6/7/2005	11	ND	ND	1981
RG	49	3/19/2005	MSOUT 10	ND	5/27/2005	69	ND	ND	2109
RG	56	5/27/2005	MSOUT 11	ND	7/12/2005	46	ND	ND	1915

Recaptured red grouper (Table 6) showed the highest degree of site fidelity with no fish moving more than 1.2 nm. This result corroborates our limited telemetry data on red grouper which indicates a strong affinity for home sites. Red grouper appear to invest a large amount of energy in establishing a home site (= excavation) (see description elsewhere in this report), so movement from that site is unlikely.

Scamp (Table 7) also exhibited low movement for the few recaptures observed. These data corroborate the telemetry data that show a male remaining around the spawning site year round.

Table 7. Scamp recaptured inside and outside of Madison Swanson Reserve.

SP.	FL (cm) when tagged	Date Tagged	Site tagged	Recapture lat/long	Recapture Date	Days at Liberty	Distance moved (nm)	Direction	External tag no.
Scamp	54	4/15/2003	MSIN 3	MSIN 3	2/20/2004	311	0	N/A	192
Scamp	52	3/13/2003	MSIN 9	MSIN 9.1	6/29/2004	474	0.1	NW	254
Scamp	47	5/2/2003	MSOUT 15	N28 54.9 W 85 15.4	6/23/2003	52	1.2	SE	527
Scamp	41.5	5/2/2003	MSOUT 14	N28 58.0 W85 21.0	2/16/2005	656	2	NW	536

Discussion

A primary consideration in the establishment of a marine fishery reserve is whether or not the managed species remain in the reserve or readily move through. We used several methods to estimate degree of movement in the Madison Swanson Fishery Reserve, including comparison of size and age inside and out, tag and recapture, and ultrasonic tag monitoring in large individuals. If the size and age increased inside, but not outside, it would be an indication that fish were remaining inside for extended periods of time, enough time to increase in size and age. Tag and recapture would provide estimates of movement rates outside of the reserve, especially if fishermen were diligent about returning tags. Also, we would recapture fish during our regular sampling program both inside and outside the reserve. Telemetry would provide continuous information on individual fish movements over time, something that tag-recapture cannot provide. With tag-recapture data, one is never certain of the range of movements of a fish in the interval between tagging and recapturing.

Because the Madison Swanson and Steamboat Lumps Reserves were established primarily to examine the sex ratio and potential reproductive problems of gag, we focused most of our attention on that species. Our first step in this work (after our mapping work) was to locate gag spawning aggregation sites inside and outside of the reserve. We focused our attention on Madison Swanson Reserve because it was closer to land (50 nm from Panama City) and because it had a greater diversity of habitat types and a greater number of gag aggregation sites than Steamboat Lumps Reserve. Commercial fishermen, many of whom had been in the business for over 25 years, were extremely helpful in pointing out at least 15 spawning sites inside and 15 outside. They were aware of the biological characteristics of spawning sites (e.g., copperbelly males, gravid females, high abundance during the spawning months) because they targeted them during the spawning season; such targeting increased catch per effort dramatically (Koenig et al. 1996).

Our first methodological problem was to develop a method to maximize survival of fish caught in deep water (50 to 120 m depth) as the reserves are in this depth range. In past studies (MARFIN NA87FF0421: “Evaluation of multiple factors involved in release mortality of undersized red grouper, gag, red snapper, and vermilion snapper), we found that at 40 m capture depth released fish (gag and red snapper) suffered 50% mortality from swimbladder embolism. At 80-m depth, mortality increased to 95%. Our first attempt at solving this problem was to bring the traps up slowly to the surface or to stage them at several depths prior to bringing them to the surface. These attempts failed, so we tried venting the fish at a depth equivalent to a capture depth of 10 to 15 m, a capture depth that most reef fish can tolerate without serious embolism problems. This worked out, and although survival varied between species (scamp were most sensitive) gag, red snapper and red grouper had survival rates near 90%, even at 100 m depth of capture. We used a modified pole spear that only allowed the point to penetrate the side of the fish about 3 cm. This effectively allowed the gas to escape before the damaging effects of the embolism would be experienced by the fish. With the help of some topical antibiotic, vented fish apparently healed very quickly, as judged from healed wounds on recaptured fish.

We know of no other studies that have examined movement of reef fish at these shelf-edge depths because of the problems of capture-release mortality. All other studies of fish movement have been done in shallow depths. But movement patterns of reef fish from shallower depths cannot be validly assumed the same for these deeper depths. In the deeper depths of the shelf edge the habitat is generally higher relief (more structure for reef fish) and the environment is more physically stable because storm surge intensity is dampened dramatically as depth increases. Clearly such studies of movement patterns at shelf-edge depths is of the highest significance because, (1) many reef fish species, including the four focused on in this study, spawn in those depths (2) the reef fish fishery of the southeastern US (commercial and for-hire vessels) is centered in those depths.

Movement Patterns

In general reef fish on the shelf edge exhibit limited movement, and in the case of male gag and scamp and large red snapper, remain in close association with spawning sites year round. Red grouper do not form spawning aggregations, but remain on home sites (excavations) and apparently spawn there. We are presently investigating their reproductive behavior, which appears to be a lek-type mating system where the male defends his territory from other males and mates with females who enter it. We have not confirmed this yet, but there nevertheless is a considerable investment of red grouper in their home sites, so it seems unlikely that they would readily move about.

Telemetry – We observed a clear distinction between male and female gag patterns of movement relative to the spawning sites. Males show extreme spawning site fidelity, whereas females are looser with their site connection, but many do not range far from the spawning area.

Male spawning site association suggests a mechanism for fishing-induced loss of males. Fishermen continue to fish spawning sites after the spawning season, even though the catch per effort has decreased (Koenig, personal observation). Since males remain on those sites and females move about (and back to shallower depths) then males would be a dominant post-spawning component of the sites and the rate of capture of males would increase. Fisherman logs and NMFS data suggest that this is a likely mechanism.

Although a single male scamp was tagged with an ultrasonic transmitter and observed, it exhibited strong spawning site fidelity just as male gag. Because there was a suggestion of fishing-induced loss of scamp males, just as with gag males (Coleman *et al.* 1996), it appears likely that a similar mechanism of male loss is occurring; and a similar solution of closed areas would rectify the problem.

Interesting results of the telemetry work not only includes the tight association large red snapper exhibit with their spawning sites, but also the fact that they use the same spawning sites as gag, only in different seasons. Gag spawn in the winter-early spring, whereas red snapper are summer spawners. In various studies of reef fish reproductive behavior it has been noted that there are spawning “hotspots” where many species use the same sites, but at different times (Colin 1992). Such appears to be the case with red snapper and gag spawning. It has been noted in stock assessments of red snapper that the large “sows” are typically caught on long lines in shelf-edge depths, and it has been suggested that these are important spawning sites. Our work confirms those suggestions, but adds an important observation—that the association of the “sows” (males as well as females) to the specific spawning sites is extremely tight. Thus, it is clear that protection of red snapper size and age structure as well as spawning “sows” may be accomplished with no-take fishing reserves. As the red snapper fishery, especially the long-line fishery, increases fishing pressure in the shelf-edge habitat, the chances of removing all of these large old breeders increases. It is not certain what this would mean to the regenerative potential of the population as a whole, but such a loss of these breeders could be averted with the establishment of more shelf-edge fishery reserves.

Recaptures – Basically the recapture data, both from our studies and from fisherman tag returns supports our position that movement of economically important reef fish in the shelf-edge environment is limited. This limited movement is extreme in red grouper, but further work must be done on this species to confirm movement patterns. Vemco Inc., who manufacture the ultrasonic transmitters, are developing a transmitter that would emit a different signal if the telemetered fish were dead or if the transmitter was not in a fish. This is the technology that is necessary to detect movement patterns in a sedentary fish like red grouper. With other types of transmitters, such as the ones used in this study, the researcher is never sure with extremely sedentary species whether or not the transmitter is in a live fish or not.

Size and Age

We examined the dominant fishery species of reef fish (gag, red snapper, red grouper, and scamp) for size and age comparisons. In all species but gag the size and age was significantly greater inside than outside of the reserve. And in red snapper and scamp, there was a significant increase in size and age in fish inside relative outside. This suggests that movement is low enough in these species to protect their spawning populations to the point where older and larger breeders would provide a greater reproductive capacity--more and higher quality eggs; (Berkeley *et al.* 2004a, Berkeley *et al.* 2004b).

There was no significant difference between inside and outside size and age for gag, but other data collected in this study shows that movement rates in this species are very low. We also demonstrate that males are tightly associated with specific spawning sites for extended periods of time, and many females remain within the reserve. Also, the recapture data show that movement is quite restricted in general. What then could account for this discrepancy? Why didn't the age and size of gag increase in the reserve if fish remained within its boundaries? We believe that poaching is the answer. Poachers target gag because they produce the best return for the effort, and they try to minimize their time within the reserve. We have observed poachers in the reserve, a number of commercial and for-hire fishermen have observed poachers in the reserve, and the US Coast Guard has observed poachers in the reserve fishing in the area where we monitor the gag spawning aggregations (Figure 22b). The poaching issue is discussed in greater detail later in this report.

Sex Ratio in Gag

The gag population of the SE US suffered a decline in the percentage of males between the 1970s and the 1990s (Coleman *et al.* 1996, McGovern *et al.* 1998) from a historical level of 17 – 20% males to a recent level of 1 to 5% males. These percentages were derived from hook and line catches. But the study reported here employs traps. So we used the outside trapping rates of male capture to compare with the inside rates. We found that the percentage of males caught outside was similar to and not significantly different from the percentages determined from hook and line in the early 1990s. The inside percent males declined from a significantly higher than outside percentage of about 8% in 2003 to a low of about 2% in 2005, which was not significantly different from the outside percentage. Again, we believe that poaching is responsible for these changes in sex ratio over the course of this study.

To compare temporally the sex ratios of any species it is important to realize that it is the relative sex ratio (that observed after selection by capture gear) and not the absolute sex ratio (the actual sex ratio) that is being compared. In the case of gag, both the fishery characteristics and fish behavior must be considered. Valid comparisons can only be made between the same geographical locations, vessels (commercial), gears (hook and line), and fishing patterns (fishing depth). Also, seasonal movement and segregation of the sexes must be considered. All these considerations were addressed in the Gulf of Mexico (Hood and Schlieder 1992, Coleman *et al.* 1996) and the Atlantic (Collins *et al.* 1987, McGovern *et al.* 1998) for gag. The seasonal behavior of gag can be divided into three four-month periods: aggregation, which includes pre-spawning (observed in December in shallow-water locations along the east coast of Florida and in some locations in the eastern Gulf of Mexico) and spawning aggregations; post-aggregation, which is the time after spawning when aggregations disperse and transitional gag are relatively abundant, and pre-aggregation, which is characterized by feeding prior to the spawning season.

Knowledge of the mechanism of sex change is important for implementation of effective management. If sex change were strictly a function of size or age (endogenous control), then a loss of large females would mean an automatic lowering of the proportion of males. However, if sex change is the result of social interactions (exogenous control) then disruption of the social process could partially incapacitate the sex-change mechanism. In the former situation, management for size and age structure might recover the proportion of males, regardless of whether or not fishing on aggregations is prohibited. In the latter situation, spawning aggregations would have to be protected to protect the social structure responsible for sex ratio compensation. However, shelf-edge fishing could also remove males outside of the spawning season regardless of the sex change mechanism, as females disperse after aggregation and males remain on the shelf-edge where commercial fishing continues throughout the year (Coleman et al. 1996, Alan Collins unpublished data). With the data we present in this report (Figures 24 to 26) it is evident that male gag remain tightly associated with their spawning sites year round. We know that the catch of males increases after the spawning season from fisherman logs and from sampling done by NMFS. So, it appears likely that that the protection of males requires a closed area rather than a closed season. To evaluate this issue fishing-induced loss of males, we have developed a heuristic model of population response under seven different management scenarios (Appendix D). The model supports our findings that marine reserves can protect males and, assuming an increase in reproductive capacity by this, would help maintain populations.

Challenges to MPA Implementation.

Construction of natural gas pipeline across the west Florida shelf. At the beginning of this project, we were informed about two natural gas pipelines that were proposed to come from Mobile Bay to Tampa Bay, crossing the west Florida shelf. The proposed route would have cut through both of the marine protected areas we intended to study in this grant (Figure 39). We were particularly concerned about the effects of construction on essential fish habitat both within and outside of the reserves. The pipeline contractors must accurately show the degree of impact from construction activities. We suggest that the ecological impact study provided by one of the pipeline construction companies did not adequately provide this. Further, we found that in both cases, pipeline construction would destroy critical habitat, compromise the ecological structure and function of resident biotic communities, and undermine an otherwise unique opportunity to evaluate fishing effects on shelf-edge reef fish populations.

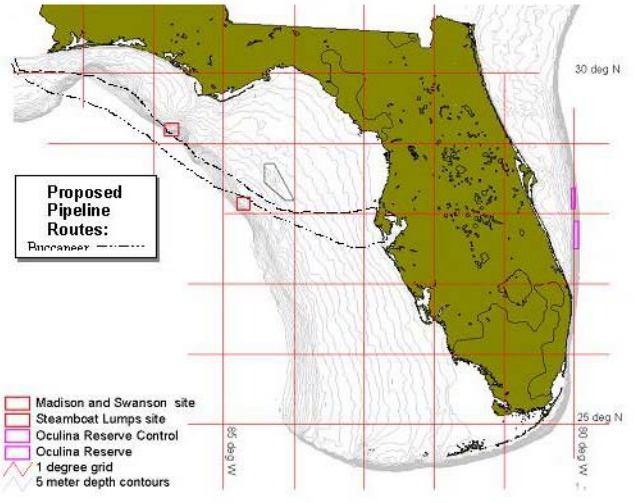

Figure 39 _Proposed pipelines routes for natural gas across the west Florida Shelf.

We reviewed the environmental impact statements of both companies, wrote a white paper on the topic (Appendix E) and recommended that the pipelines be rerouted to areas outside of the reserves, paying particular attention to avoid live bottom and high relief habitat to the extent possible. We recommended that new environmental impact studies be required that provided more realistic profiles of habitat. Further, we suggested that a team of scientists develop for the Federal Energy Regulatory Commission and the Mineral Management Service a standardized format for conducting such studies so that valid comparisons can be made among different projects and different areas. The outcome of our involvement in this was that the pipelines were rerouted to avoid the marine protected areas and to the extent practicable other areas of high relief along the WFS.

Compliance and enforcement of MPA boundaries.

The primary challenge to obtaining information on the efficacy of marine reserves is that compliance with reserve boundaries continues to be a problem and enforcement presence is not sufficient to keep fishers out of the reserve. During every trip we or our colleagues at the National Marine Fisheries Service have made out to the reserves, there have been multiple commercial and recreational fishing vessels fishing for reef fish within reserve boundaries. The Coast Guard has apparently stepped up their surveillance of the area, resulting in several recent busts, including the one noted in the box to the right. We recently participated in discussions with law enforcement on how to best increase their presence and strongly urged that all reef fish vessels—commercial and recreational for-hire—be equipped with vessel monitoring devices to ensure higher compliance. We have presented multiple talks to US Coast Guard personnel in Panama City and at the Mobile Air Training Center to ensure that they understand the rationale and issues surrounding marine protected areas. We also present results of our work and the evidence that poaching is not being effectively controlled. The Coast Guard, in response is stepping up their efforts in recent times (2005 and 2006) and using more effective methods of enforcement.

It is important to also recognize that along with increased enforcement there should be more effective penalties imposed on repeat offenders and the legal system should recognize the limitations of the Coast Guard and other enforcement agencies in catching offenders. Now in the electronic age, poachers can see approaching Coast Guard Cutters on radar from many miles away. Air plane surveillance is a more effective approach primarily because of speed. The Coast Guard flies over the reserves regularly, but clearly, the flight crew cannot personally interview the captain of the offending vessel. So the legal system must recognize the difficulties in catching offenders operating 50 to 100 nm offshore and make appropriate allowances.

Press Release: Gulf of Mexico Fishery Management Council

COAST GUARD SEIZES MORE THAN 1,300 POUNDS OF ILLEGALLY-CAUGHT FISH OFF FLORIDA

December 20, 2002 (USCG 8th Dist. Rel. 173-02) - NEW ORLEANS - The U.S. Coast Guard seized more than 1,300 pounds of fish caught illegally aboard a 44-foot long liner 35 miles southwest of Cape San Blas, Florida, at about 6 a.m. on Tuesday. The crew of the Coast Guard Cutter Stingray patrolled the closed fishing area known as Madison and Swanson sites, when they noticed the fishing vessel, The Shadow, home-ported in Panama City, Florida, on radar within the closed area. The fishing vessel's crew quickly changed course and began to increase their speed. The crew of the Stingray established radio communication with the master of The Shadow and boarded the fishing vessel. During the boarding, the team discovered a mixed catch of yellowedge grouper, orange roughy, tilefish, brown grouper, and hake. The boarding team directed the crew of The Shadow to haul back their eight miles of bottom longline gear, which placed them 2.5 miles within the closed area.

The catch was seized and sold on behalf of the U.S. Department of Commerce at fair market value to a local fish house. The crew of the Stingray escorted The Shadow into City Marina in Panama City, that afternoon. The Coast Guard cited the master of The Shadow with one fisheries violation, and two commercial fishing vessel safety regulation violations. The master will appear before an Administrative Law Judge to determine the fine. The Stingray is an 87-foot patrol boat stationed out of Mobile, Alabama.

Ocean dumping

Commercial fishers recently made us aware that the U. S. Environmental Protection Agency and the Florida Department of Environmental Protection had granted a permit for the dumping of 500 million gallons of phosphate mining waste over the west Florida shelf (Figure 40a; dump area indicated to crossing and to the southwest of the shelf-edge reserves). We immediately contacted both these

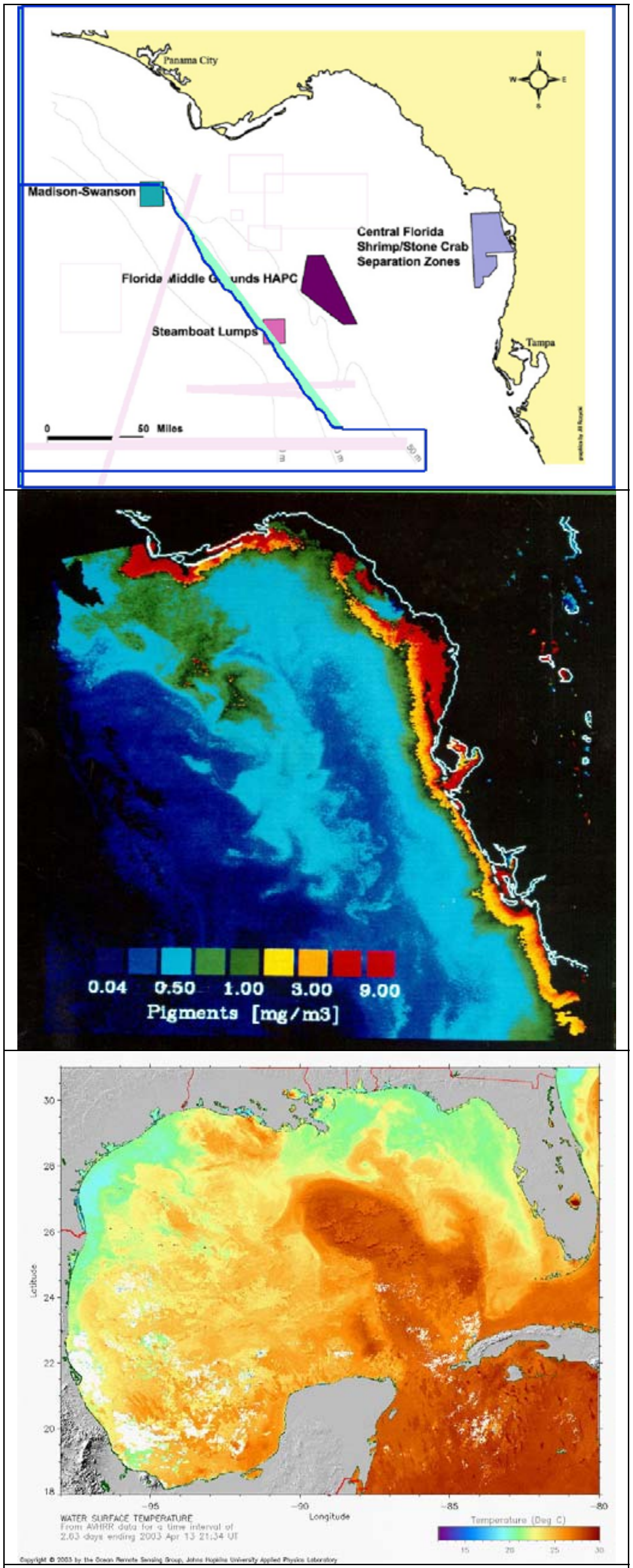

Figure 40. Converging events on the west Florida Shelf: (A) Proposed dump site for 500 million gallons of phosphate mining waste (B) Presence of seasonal phytoplankton bloom . (C) Presence of the Loop Current (red).

agencies to express our concern that they were ignoring their own mandates to not interfere with scientific research, with important commercial or recreational fishing efforts. In addition, they had not contacted the right people and were completely unaware that there were two marine protected areas lying within the proposed dumping zone. Further, they had relied on a 30 year old paper about toxic algal blooms that said that few such blooms occurred closer to shore than 40 nautical miles. They used this as their rationale for dumping beyond that distance, thus shifting the point source from land to the continental shelf edge. Further, they were not aware of either the presence of the Loop Current (Figure 40c) in the region of dumping or the fact that a significant phytoplankton plume occurs seasonally in the area (Figure 40b). The convergence of four events in this region--the Loop Current presence high in the northern Gulf, the seasonal phytoplankton plume, the spawning of many of the important reef fish of the area, and the dumping of nutrient waste could cause a significant and perhaps toxic algal bloom that could decimate larval and possibly adult populations and be transported both to the western Gulf through spin-off eddies and to the eastern seaboard via connection with the Gulf Stream. We interacted with physical oceanographers and the commercial fishing industry to make alternative recommendations to these agencies.

Recreational Fishing Lobby Efforts

A significant impediment to the retention of the west Florida shelf-edge reserves and the implementation of marine reserves throughout the United States is the effort of recreational fishing groups. The development of the marine reserves in the northeastern Gulf of Mexico led these groups to try to implement legislation (The Freedom to Fish Act) that would essentially allow them to continue fishing in any marine protected area in the country. In response to this, we have developed with other colleagues and the support of the Pew Charitable Trust, a study to evaluate the spatial and temporal changes in catch of commercial and recreational fishers throughout the southeast (including the Gulf of Mexico and southeast Atlantic coast), the Northeast, Pacific coasts. Preliminary results suggest that for many economically important species, recreational fishers have just as significant effect on populations as do commercial fishers.

Also, in response to a law suit filed by the Coastal Conservation Association, a recreational fishing lobby group, to allow trolling for highly migratory species in the Madison Swanson and Steamboat Lumps Marine Reserves, we designed an experiment that was subsequently carried out by researchers at the National Marine Fisheries Service to evaluate whether fishers trolling at the surface could be distinguished from those trolling at the bottom and thus able to catch grouper within reserve boundaries. Preliminary results suggest that these two trolling techniques are indistinguishable by a top-side observer (including Coast Guard and Florida Marine Patrol personnel) meaning that allowing trolling created a significant enforcement problem and would require that trolling not be allowed within reserve boundaries.

Part III. Reef fish Behavioral Studies

Introduction

All reef fish species are known to associate with structure, whether natural or artificial, and the red grouper, *Epinephelus morio,* is no exception. Like other groupers, they make ontogenetic habitat shifts, moving from a pelagic open-water larval stage lasting 35-50 days (Colin *et al.* 1996) to an inshore hardbottom-associated juvenile stage lasting up to 5 years (Moe 1969). They then egress to offshore reefs across the continental shelf and to the shelf edge where they spend the remainder of their lives (up to 35 years) (Moe 1969). As juveniles and as adults, they exhibit a high degree of site fidelity (personal observation and see Part II of this document).

In these habitats, red grouper function ecologically as top-level predators (Goeden 1982, Parrish 1987), feeding primarily on crustaceans (Moe 1969, Parrish 1987). However, they may have an additional functional role as habitat engineers (Coleman and Williams 2002). Species can engineer habitat either passively, modifying it with their shape (e.g., hermatypic corals, oysters, sea grasses, marine algae) or actively, modifying it through their behavioral activity (e.g., burrowing shrimp, worms, clams). In so doing, they can profoundly influence the diversity and structure of ecosystems they inhabit if the spatial scale of their activities is large (Jones *et al.* 1994). Whether this is the case or not for red grouper is unknown. What we report here is the first step in an ongoing study of the role red grouper play in the creation and maintenance of habitat. The objectives are threefold: (1) to describe the habitat used by red grouper over the course of their life time, from nearshore hardbottom areas to the continental shelf edge, (2) to demonstrate whether red grouper are capable of habitat manipulation, and if they are, (3) test whether resident red grouper act alone to manipulate habitat in their environment.

Methods

Study sites

These observations were made in the eastern Gulf of Mexico, for juveniles in nearshore waters of the Florida Keys (Figure 41), and for adults in the Steamboat Lumps Marine Reserve (Figure 42).

*Juvenile habitat.--*Study sites in the nearshore waters of the Florida Keys--Hawks Cay and Burnt Point—were established during the summer of 2000. They were found by towing divers in parallel transects. Each site was marked temporarily with an anchored buoy, measured for area and depth (cm), and the coordinates entered into a Geographic Positioning System (GPS).

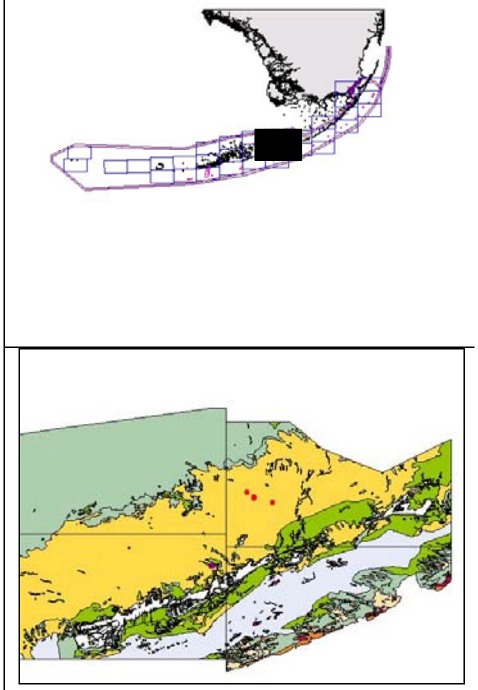

Figure 41. Sites for study of red grouper in the Florida Keys National Marine Sanctuary.

Reinforcement-bar stakes were drilled into the northeast and southwest corner of each site. The stakes served as anchors for attachment of underwater markers used to relocate sites during the study, and they served to stabilize 8,100 cm^2 quadrats (36 frames, each 225 cm^2) for repeated measures. Reference sites were haphazardly chosen 50-100 m down-current of each grouper site. Quadrats in grouper and reference sites were photographed using a digital still underwater camera (Olympus C-2020 Zoom, 3.2 mega-pixel; Olympus C3030 with a tetra 30-30 underwater housing). Photographs were then analyzed to determine the position and percent cover of all sessile invertebrates and algae associated with the solution hole by superimposing an array of fifty random dots on each frame and using the number of dots in each substrate type to estimate the percent cover.

Adult habitat.--Offshore study sites were chosen from sidescan imagery of the Steamboat Lumps Marine Reserve obtained in 2000 during a U. S. Geological Survey cruise. Ground-truthing with a remotely operated vehicle (ROV) revealed that bright spots appearing on side-scan images were actually pits with clusters of rocks at the center and an adult red grouper in association. In 2001, these sites were revisited while onboard the NOAA vessel Gordon Gunter to conduct habitat characterizations. The red grouper habitat was described from digital video images taken from the manned submersible R/V Deepworker (Nuytco Inc., Vancouver British Columbia). The Deepworker was mounted with two digital video cameras, a forward-viewing camera (VX 1000 Sony 3-chip digital camera in underwater housing) and a downward viewing camera (Sony Hi-8 Handi-Cam in Amphibico underwater housing). Each camera was mounted with a laser system: a three-laser system on the forward camera, with two parallel beams set 10 cm apart, one set to have its beam converge at 5 m, and two lasers et 20 cm apart on the downward camera. Footage from the forward camera was used to identify and measure (using the laser reference) individual fish and to determine the density of species in the fish assemblages surrounding grouper pits and reference areas located 100 m from sites. Footage from the downward camera was used to estimate the size of grouper pits (using the laser reference) and to describe habitat (substrate composition and the sessile invertebrate fauna). To characterize habitat, 14-18 individual non-overlapping frames were grabbed from grouper pits and reference areas. We superimposed an array of fifty random dots on each frame and used the number of dots in each discernable substrate type to estimate the percent cover.

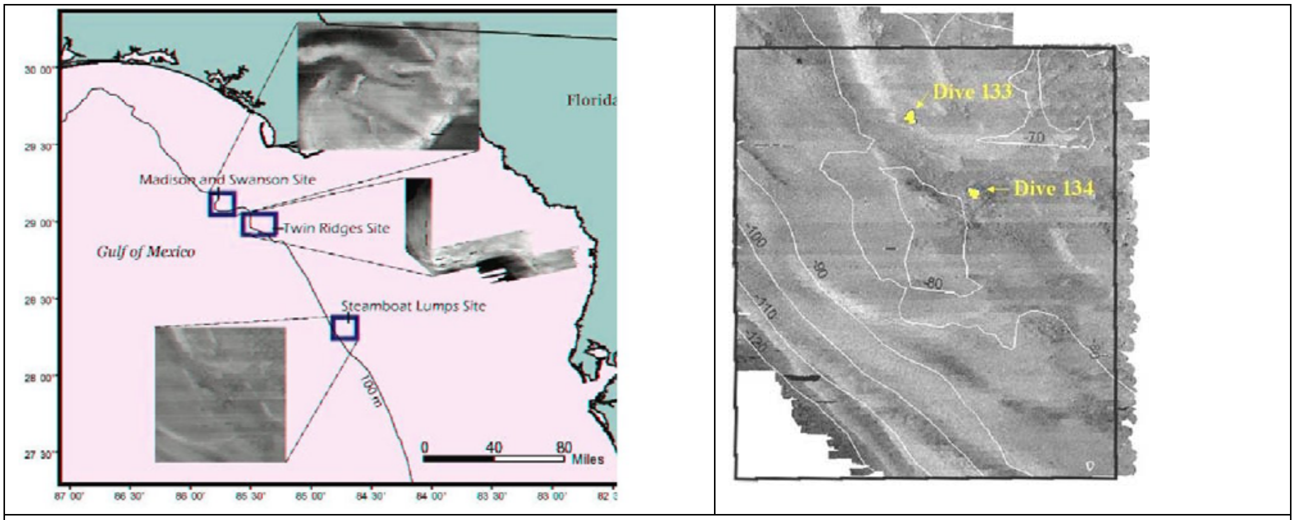

Figure 42. Sites for study of red grouper *Epinephelus morio* in Steamboat Lumps Fishery Reserve in the northeastern Gulf of Mexico. Area = 115 square nautical miles.

Identification of resident habitat engineers in juvenile habitat

To determine whether red grouper excavate sediment from solution holes, two fish were captured and placed in individual cages (1.0 m wide x 1.0 m long x 0.5 m high; mesh = 3 cm) that were open to the bottom (summer 2000). Appropriate caging sites were found by prodding the substrate with a 1.0 m fiberglass rod . Cages were placed over sites having sediment depths of at least 0.3 m over a 0.09 m^2 area, roughly the size of grouper-inhabited solution holes, but appearing on the surface like a flat continuous area of sand. Fish remained in cages for a 48-hour period and then were released.

To determine whether solution holes were routinely cleared of sediments by resident fauna, we introduced 4-5 liters of charcoal particles (high purity activated carbon, charred bone, density > water; particle size 1.6 – 3.2 mm) into 13 grouper-occupied sites (7 at Hawk's Cay and 6 at Burnt Point) at approximately 0900 EST and checked for charcoal removal at two-hour intervals. (Aquarium charcoal was used because it is non-toxic and easily distinguished from the shell-sand substrate surrounding the holes.) At all sites where charcoal removal occurred, the distance and bearing of charcoal particles from the site were measured.

In sites where charcoal removal occurred, grouper removal experiments were conducted. Twelve sites were selected, 6 in Hawks Cay and 6 in Burnt Point. At each location, three sites were randomly selected to serve as grouper removal sites (3 at Hawks Cay and 3 at Burnt Point) and the remaining three served as controls. Grouper were caught using circle hooks baited with squid, transported in a live well approximately 10 miles from the site and held separately in cages until termination of the experiment, and then tagged with individually numbered internal anchor tags and released at their capture sites.

RESULTS

Habitat descriptions

Juvenile habitat.—The area examined for juvenile red grouper in nearshore waters consisted of a rugose, perforated limestone-base with numerous solution holes covered with a thin veneer of poorly sorted biogenic carbonate sand and gravel composed predominantly (95% in 6 sediment samples) of coral, calcareous *Halemeda* sp. algae, and mollusks. Red grouper were always found in association with exposed solution holes in this hardbottom area that were similar in depth (2 to 4 meters), geomorphology, and sessile organism coverage. The sites ranged in size from about 1 m^2 to 3 m^2 in area and extended about a meter below the surface. The dominant organisms were basket sponges and coralline algae.

Adult grouper communities. –The area examined for adult red grouper offshore occurred at depths of 80 m. Red grouper were always found in association with large sandy cone-shaped pits that were roughly 6.8 m in diameter and 2 m deep (Figure 43 and 44). The pits were arranged in clusters and differed somewhat in geomorphology. The northern sites had a thick wedge of sediment and patchily distributed rocky outcrops whereas the southern site had a more continuous hardbottom layer that was exposed in some places and buried by thin sediment in others. The slopes of the pit depression contained scattered boulders, and at the center of each depression was an exposed rocky outcrop having a mean diameter of 2.5 m (s.d. = 1.23, n = 3). The rocky outcrop associated with pits covered roughly 36 % (3.5 SE) of the pit area.

Most of the hard substrate was encrusted with invertebrates and crustose coralline algae compared with 0(0)% in the reference areas. Taxal richness for this encrusting community could not be determined because the camera had inadequate lighting and the sub was not equipped with a manipulator arm for collecting samples. Certain organisms were clearly associated only with grouper holes (e.g. urchins) while others were observed only in the sandy reference areas (e.g., arborescent bryozoans and a red fleshy alga). Hence, within the limitations of remote observation, there was no clear difference in richness of the sessile benthic organisms at this site.

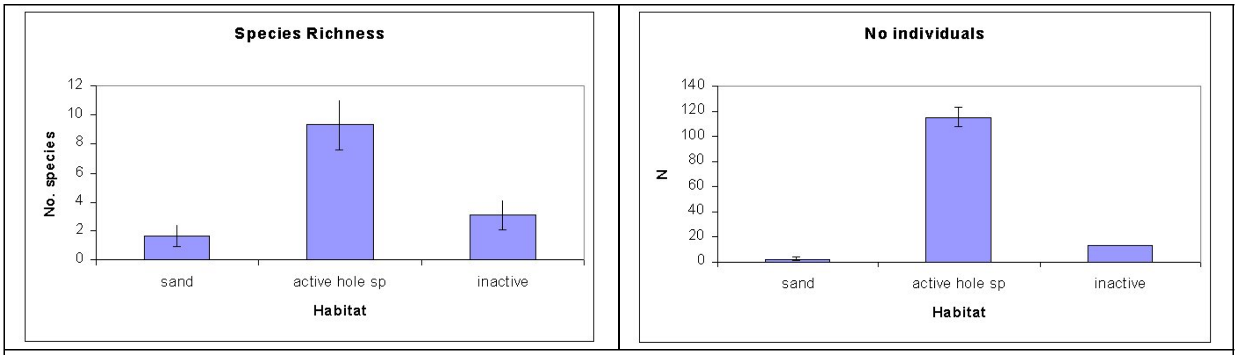

Figure 43. (A) Species richness and (B) abundance over the different habitat types in Steamboat Lumps Fishery Reserve. Active pits are those having a red grouper *Epinephelus morio* in residence. Inactive pits are those appearing to have once been active.

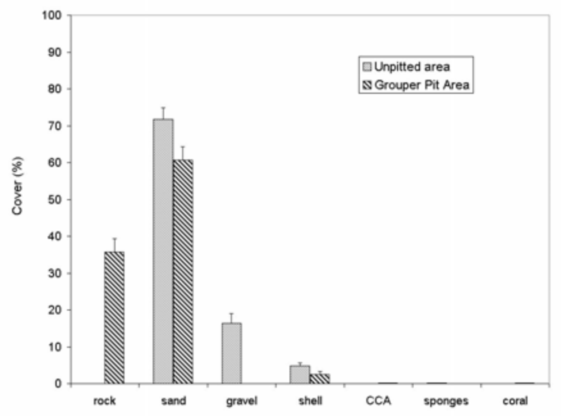

Figure 44. Percent cover of different types of substrate in Steamboat Lumps Fishery Reserve within and outside of active red grouper pits.

Habitat engineering

Resident habitat engineers in solution holes— In both instances of caging red grouper juveniles, the fish excavated sufficient sediment to produce a subsurface pit that they could be completely contained within, at least 0.5 m in depth. Sediment was piled up around the inside periphery of the cages and in one case, the fish escaped by digging under the side of the cage.

Removal experiments indicated that red groupers operate as habitat engineers. Fish actively dispersed charcoal from the excavations within two hours of charcoal introduction by taking it up in their mouths, swimming out of the solution hole up to 3 m away from home sites, and depositing the charcoal. In every case where a red grouper was known to inhabit an excavation, charcoal was distributed from the hole within 24-hours post charcoal introduction. Furthermore, red groupers appear to be the dominant (or more likely the only) habitat engineers in these solution holes, based on the observation that only very localized movement of charcoal occurred in their absence. Spiny lobster, *Panulirus argus*, while abundant in solution holes, did not exhibit excavating activities, although they did appear to push sediment around in a limited fashion.

	
Figure 45. Active red grouper solution hole	*Figure 46.* Sediment-filled solution hole

DISCUSSION

The shallow water solution holes inshore as well as the deepwater pits offshore, based on physical processes alone, should serve as sediment sinks. Certainly, the daily movement of fine particulates by tidal currents and periodic movement of coarse sediments either in sand waves or by major storm systems is a normal feature of these environments. However, our data indicate that there are patchily distributed sites within each area that remain open and are not filled with sediment. Further, we find that at least in the nearshore environment, that red grouper are primarily responsible for excavating and maintaining exposed solution holes (Figures 45 and 46). They remove the carbonate sediment veneer to expose a hard limestone surface beneath and in so doing transform an otherwise two-dimensional area into a three-dimensional structure, thus providing refuge for themselves and perhaps for other organisms, as well. That is, grouper may facilitate the use of exposed substrate as settlement surfaces for sessile organisms, including sponges, corals, and anemones. Sluka and colleagues (2001)proposed that the increased structural complexity provided by corals and algae on inshore patch reefs of the Florida Keys resulted in increased fish abundance or richness. It is at least plausible that the octocoral and algal cover occur on the patch reefs because of the excavating activities of red grouper. The observation of octocorals bordering the excavations but not occurring elsewhere on the limestone flats suggests a causal relationship.

Although we did not observe excavating activities at offshore sites, we suspect that this behavior is maintained throughout an individual’s lifetime as it makes ontogenetic habitat shifts from nearshore to offshore sites with maturity. Indeed, it was our initial observations of red grouper in Steamboat Lumps that suggested that such a relationship existed. Habitat with red grouper in residence appeared as small oases in an otherwise featureless seafloor. One of us (Koenig) observed early juvenile red grouper reared during studies by (Colin *et al.* 1996) digging into aquarium substrate at the base of a shell immediately after metamorphosis.

How long a single fish retains residence in an excavation is unknown. One of the juveniles we identified in a solution hole during the summer of 2000 retained residence in the same hole a year later. A spear fisherman took another individual tagged in 2002 within weeks of tagging (S. Heppell, personal communication). It may be that the solution holes represent a limiting factor for these juveniles. During our studies, new red grouper took up residence in solution holes almost immediately following removal of the previous resident. Some sites had a sequence of four tenants in rapid succession following our initial removal.

We suspect that individual sites are maintained over generations. Certainly, our experience in Florida Bay suggests that solution holes are long-lived. Sites in Florida Bay with substantial coral growth, for instance, would have to have been maintained consistently over long periods of time—longer than the juvenile stage of an individual fish--for coral heads 0.3 m in diameter to grow (see Figure 45).

Finally, the question remains as to the advantages conferred to red grouper by excavating solution holes. Potential benefits of living in burrows or holes produced by habitat engineers like tilefish and red grouper include protection from roving predators, increased availability of prey, or as occurs in yellowedge grouper burrow, close proximity to cleaning stations (ref). We have observed a large number of cleaner organisms (shrimp and fish) associated with these holes that were not observed in reference habitat sites. Thus, the establishment of these holes may confer a health benefit through increased access to parasite removal in addition to foraging and safety benefits thereby providing a positive feedback loop for the excavating activity. There is a need to demonstrate the interaction strengths between the engineer and the other species associated with the restructured habitat. This would reveal the level of interdependence between the system and the engineer.

While the juvenile red grouper populations inshore around the Florida Keys are protected from exploitation to some extent by size limits of 26 inches (66 cm), incidental catch and subsequent release of these fish may disrupt maintenance of habitat. Further, the impact of the recreational lobster fishery in the Keys during August causes a significant amount of disturbance, resulting in increased movement among juvenile red grouper displaced from solution holes by divers after lobster. Red grouper have been harvested in the United States since the 1880s and are currently the most common grouper species landed in both commercial and recreational fisheries of the Gulf of Mexico. They are now considered overfished (Schirripa *et al.* 1999, NMFS 2004)). Red grouper likely have a disproportionately large per capita influence on the system within which it lives. We suggest that this applies equally to the apex predators and to ecosystem engineers. Indeed, the problem is probably exacerbated for fish species like tilefish and red grouper that likely have multiple ecological roles that may have synergistic influences on biodiversity over broad spatial scales.

Part IV. Partnerships, Outreach, and Follow-on Projects

Partnerships.--Partners in this project include the U. S. Geological Survey (USGS), the National Oceanic and Atmospheric Administration's and the National Geographic's Sustainable Seas Project (SSE), National Marine Fisheries Service (NMFS), the Pew Marine Conservation Program, the National Fish and Wildlife Foundation, the National Sea Grant, the U. S. Coast Guard, and commercial fishers. Each of these partners contributed significantly to our success in this project.

Kathryn Scanlon and James Gardner, USGS, produced the acoustic side-scan and multibeam images that served as the geomorphologic basis for the habitat maps. The SSE provided access to oceanographic and submersible vessels for habitat and faunal characterizations. Margaret Miller and John Brusher, NMFS, participated in viewing and analysis of videotapes. National Sea Grant and MARFIN provided the base funding for the entire project. The Pew Fellows Program offset these funding needs and provided support for the development of spatially explicit models of grouper populations to be used in the site choice and design of marine protected areas.

After witnessing several incidences of poaching inside the marine reserves, we started contacting the U. S. Coast Guard directly both when we were on site and when returning to shore. These observations also prompted us to directly solicit increased aerial surveillance from the Coast Guard, which included several presentations to Coast Guard Air Training Center in Mobile, AL. The U. S. Coast Guard has shown significant support for our research by conducting randomly timed surveillance missions over these marine reserves.

Critical to the project was the development of strong positive relationships with commercial fishermen. This was aided in no small part by funding acquired from National Fish and Wildlife Foundation to cover expenses associated with participation of the commercial fishermen. As a result of this significant opportunity, we have established strong working relationships with many commercial fishers in Florida who have come to see the benefits to their fisheries of marine protected areas.

*Outreach.—*As part of the information transfer capabilities for this project, the Environmental Defense, a well-known and respected conservation organization, has aided us considerably. This organization has developed both a powerpoint presentation and a tabletop display that discuss the potential for improving fishery management through use of no-fishing zones in the Gulf of Mexico. These highlight gag populations and West Florida Shelf habitats. These outreach materials have been presented at fishery and coastal issues symposiums, earth day events, and citizen meetings throughout the Gulf region. The organization has developed fact sheets describing the goals and findings of the study which are posted in a dedicated content area within the Environmental Defense website which reaches thousands of citizens annually (http://www.environmentaldefense.org/system/templates/page/subissue.cfm?subissue=6.

Follow-on projects.—As a result of the combined partnerships, we have been able to develop a number of follow-on projects that relate directly to the research we conducted through the auspices of the NOAA Marfin Program

(1) *Study of Fisher Behavior Relative to Marine Protected Areas in the Southeastern United States.* Conducted with Dr. Martin Smith, an economist at Duke, to develop a bioeconomic model of fisher behavior relative to spatially explicit management scenarios. This project was funded by the NOAA Saltonstall-Kennedy Program to conduct this study and part of it appeared in the Canadian Journal of Fisheries and Aquatic Sciences this year (Smith *et al.* 2006)

(2) Heuristic Population Model of gag in the northeastern Gulf of Mexico. Developed with Selina Heppell and Scott Heppell, Oregon State University (Heppell *et al.* 2006).

(3) *Potential Areas for Marine Protection on the West Florida Shelf.*—We received funding from NOAA's Coral Reef Conservation Grant Program through the Gulf of Mexico Fishery Management Council to evaluate two sites on the west Florida Shelf: Pulley's Ridge and the Florida Middle Grounds. Pulley's Ridge is a north-south trending paleoshoreline (b/w ~24°20' and 26°40' N lat) along the 60-80 meter isobath. It has a significant coral formation at the southern extent west of the Dry Tortugas that is dominated by the agraicid coral, *Leptoseris cucullata,* and by the green alga, *Anadyomene spp.* It also contains stony corals, including *Montastraea cavernosa* and *Porites sp.,* both of which assume a flattened growth form to enhance exposure to the limited light available at those depths, and fairly abundant coralline red algae and sponges. These unique features draw the Gulf Council's attention to possibly designating it as a Habitat Area of Particular Concern (HAPC), thus providing coral protection from the damaging effects of fishing and boating activity (e.g., trawling, longlining, anchoring), and perhaps extend the protection to that of a marine reserve, prohibiting any extractive use in the area.

    The Florida Middle Grounds in the northeastern Gulf off central Florida is of interest because it contains a relatively high relief community of stony coral and octocorals, representing the northernmost extent of coral reef communities in the U.S. In the 1970s, the Mineral Management Service sponsored work on the Florida Middle Grounds that included sampling transects (wet diving) of the area to describe the benthic cover. Since that time, fishing in the Middle Grounds has increased significantly. Yet no studies have evaluated the impact of this intensive activity on either the reef fish populations or on the habitat. Using the coordinates from those historic stations, we returned to those stations to map and characterize the benthic habitat so that we can conduct 25-year contrast. The Middle Grounds is already an HAPC. The Gulf Council is interested in determining whether it should be designated as a marine reserve.

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APPENDIX A

Unsolicited Proposal Sent to the NOAA- National Geographic Society's Sustainable Seas Program

Sustainable Seas Expedition – Field Season 2001
Islands in the Stream
Assessing Critical Habitat and Connections

Proposed Research Plan

Concept

In the year 2001, the Sustainable Seas Expedition (SSE), a joint project between the National Geographic Society (NGS) and the National Oceanic and Atmospheric Administration (NOAA), proposes to conduct a comprehensive expedition, integrating many different scientific disciplines to paint a picture of the coral reef and hard bottom communities throughout the Gulf of Mexico and the western Atlantic along the coast of Florida and Georgia -- including the Flower Garden Banks, Florida Keys, and Gray's Reef National Marine Sanctuaries, and the Madison-Swanson and Steamboat Lumps Marine Protected Areas. Specifically, the intent is to develop habitat characterizations of these areas that are nationally and internationally consistent and objective.

The expeditions intends to explore both protected an unprotected coral and hard bottom communities – the "islands" – of Belize, Mexico, and the United States, as well as the currents – the "stream" – that connects them. Community characteristics to be evaluated include the underlying geology, biology, and ecology, and the current patterns that function as dispersal pathways of invertebrate and vertebrate larvae, and the migratory routes of marine mammals, fish species, and sea turtles.

The proposed expedition presents a unique opportunity to explore and research these unique habitats, and obtain valuable imagery – digital video and still photography, water quality information, oceanographic and atmospheric data, and habitat characterizations. Such data are critical for improving our collective understanding of coral reefs and hard bottom communities, the stress to which they are subjected, and the effectiveness of management measures designed to protect them. Specifically, the data can be applied to existing efforts with Mexico to establish a coral reef initiative similar to that already developing in the United States (e.g., the Coral Reef Task Force).

Introduction and Background

Because habitat lies at the foundation of both fishery production and biodiversity, inventories of its spatial and temporal extent are essential to effective management and conservation. Further, these inventories need to fit into a classification framework that is nationally and internationally consistent and objective.

Advantages of a standardized marine habitat classification system include the identification of diversity 'hotspots' and environmentally sensitive areas, and the location and monitoring of productive source areas such as spawning aggregation sites. Such a system would provide the basis for scientific investigations involving species associations, habitat types, and ecosystem function. They could also be used for boundary demarcation of marine protected areas or multiple-use zones, and would allow the detection of changes in habitat features, based on natural or anthropogenic causes.

Obvious targets for these kinds of inventories are the biologically diverse but poorly studied coral reef and hard bottom areas throughout the Gulf of Mexico and western Atlantic. The rationale for doing so is twofold: (1) because they are highly productive, contributing overwhelmingly to the ecological and economic health of the regions in which they occur; and (2) because they are vulnerable to intense anthropogenic pressure and thus to rapid decline.

Clearly, coral reef and hard bottom areas contribute to productivity by serving as critical spawning sites for many economically important reef fish, including groupers and snappers (Coleman et al. 1996, Coleman et al. 2000). Because some of these habitats have been fished for over one hundred years

(Camber 1955, Moe 1963, Schirripa and Legault 1997), it is possible that indirect as well as direct fishing impacts have affected the benthic communities (and thus the habitat values) of these reefs. Direct effects include anchor, long-line, and trawl impacts. Indirect effects may include trophic cascade effects resulting from the removal of top-level predators (e.g., sharks, groupers, snappers) from the system or declines in biodiversity due to the loss of habitat engineers. Yet, these reef communities have been studied very little and virtually no inventories exist for them anywhere in the western hemisphere. Missing includes information ion benthic community structure, composition, processes, and habitat functions of these reefs.

To date most of the marine habitat classification schemes that do exist are established on an ad hoc basis with little consistency in terminology. In addition, the vast majority of schemes (98%) lack quantitative descriptors (Green et al. 1996). Thus, there is a strong need for a system of marine habitat classification that combines the geomorphologic and biological components of the habitat in a systematic and standardized way. Mumby and Harborne (1999) recently proposed such a system of marine habitat mapping and classification that combines functional geomorphology with benthic cover and composition in a systematic and hierarchical fashion to produce objective categories at any desired level of descriptive resolution. Although they were classifying shallow-water coral reefs with the use of aerial and satellite imagery to characterize geomorphology, their system is easily adapted to the use of acoustic imagery combined with optical imagery in classifying the deep-water coral reefs of the shelf-edge.

Goal and Specific Objectives

The overall goal of the Sustainable Seas Expedition 2001 Field season is to classify habitat throughout the Gulf of Mexico, as well as the western Atlantic along the coasts of Florida and Georgia, at selected sites that include marine protected areas as well as unprotected areas. The best classification schemes will be developed in areas where mapping is already available from aerial imagery, satellite imagery, or side-scan sonar imagery and surficial geology. Reference habitat sites will be designated within the protected areas.

Specific objectives are:

To compare the efficiency and accuracy of several methods (SEABOSS = Seabed observation and sampling system, manned submersible, and ROV digital video) in evaluating habitat cover and benthic species composition.

To combine the geomorphologic, habitat cover, and species composition data into a systematic classification scheme using hierarchical multivariate techniques.

To select reference habitat sites and indicators of biological condition within each of the marine protected areas based on the classification criteria developed during the study.

Approach

The overall approach will be to use the information from aerial imagery, satellite imagery, or side-scan sonar mosaics and surficial geology, including sub-seafloor characteristics (the sonar system can detect rock meters below the seafloor sediment), to select sites for habitat class designation. Clearly, it is not practical, nor possible within reasonable time frames, to visually cover the entire area covered by the expedition. Therefore, we will first classify visual and/or acoustic information into geomorphologic features, then conduct visual surveys to determine the habitat characteristics of each feature. This process will be randomly replicated on like geomorphologic features to determine the extent of habitat variability associated with each feature. Such an approach will allow probabilistic statements about the nature of the regional benthic community based solely on the geomorphology.

Objective 1: Comparison of methods.

Several bottom-viewing devices will be compared to determine efficiency and accuracy of habitat designation among the various habitats. The habitats surveyed will likely incorporate both high relief (up to 20 m above the seafloor) features and low relief (less than 1 m above seafloor) features. It is also likely that high-relief structures require a different approach than do low relief structures. For comparisons, the same geomorphologic features will be sampled in replicate with each device (SEABOSS, ROV, and manned submersible).

The SEABOSS is a seabed-sampling device developed by USGS, Woods Hole. It consists of a downward-looking video and still camera and a forward-looking video camera with lights, a strobe, a sediment grab sampler, and lasers for scale measurement. The device is suspended above the bottom as the ship moves slowly over the bottom. The videos provide real-time video in a forward and downward direction. Operators adjust the distance off the bottom mechanically as a change in depth is detected. High-resolution video images are collected in a continuous fashion and the 35 mm photos and geological samples are collected at the will of the video viewer. The SEABOSS is used routinely by USGS to verify side-scan imagery. Photographs will be taken at random points along replicate transects in each geomorphologic feature.

There are several ROVs available to this project already. They will require an adaptable real-time surface-viewed digital video system to obtain higher resolution and to allow selection of single high-resolution frames from a continuous digital video-taped transects. A laser system will be used with the digital video for scale measurement.

The submersible, which can be deployed from the R/V Gordon Gunter, will also be used for video and visual transects in both low and high-relief areas. Again, a laser system will be used for scale measurement.

All three optical imaging systems will be used to determine the composition and density of the same sets of benthic assemblages. For comparison we will first set out a transect course (a weighted line on the bottom is the most direct way to do this). Each device will then make replicate passes over the transect course. Video transect and still photo data will then be analyzed by several independent ‘readers’ and estimates of cover, composition and density will be compared statistically. Precision and accuracy will be evaluated for all three devices and for the submersible visual sampling. All methods used will be standard and adapted for deep water coral habitat (Aronson 1994).

Two of the systems (submersible and ROV) will also be used to estimate fish species composition and relative abundance. A transect course will be set out as with the benthic sampling, but unlike the benthic sampling of sessile organisms, observers must be mindful that motile organisms such as fish may be differentially attracted or repelled by the bottom-viewing devices and likely have temporal activity patterns that would change apparent densities and compositions from time to time. Therefore, it is essential to record trial number, time of day, and any other factors that might produce different relative abundances for the same locality. Several different types of transect methods will be employed, using both visual observations from the submersible and video observations from the submersible and ROV. For selected species on the video records, a modified variable-area transect method will be used (Krebs 1999, p. 181) to estimate density from the submersible and ROV video records (standardized with an on-film laser scale.) We will also use the line transect method (Krebs 1999, p.158) for visual estimations from the submersible. Replicate visual and video estimations will then be compared statistically for estimation of precision and accuracy.

Objective 2: Habitat classification.

The classification of geomorphologic features is relatively straightforward because remote acoustic imagery is unequivocal, produces relatively sharp boundaries, and can be classed into convenient categories. By contrast, assemblages of benthic organisms and associated substrata are more difficult to classify because they often exhibit considerable variation, tend to grade gradually from one assemblage to another, and require direct visualization for identification and estimation of cover.

Dominant macroalgae and hard and soft corals, sponges and other large sessile invertebrates will be identified to the lowest practicable taxon and recorded in units of density (no./m^2). After collection of the benthic species density data from a number of geomorphologically distinct sites, estimates will be made of the similarity in the benthic assemblages among sites using a Morisita’s similarity index. Others have used the Bray-Curtis measure but this measure is strongly affected by sample size, and is only recommended for low species diversity and small sample sizes (Krebs 1999, p. 383). Morisita’s index of similarity, on the other hand, is nearly independent of sample size and is considered the best for ecological purposes (Krebs 1999, p. 405). Krebs (1999) also recommends the cluster analysis technique called the UPGMA (unweighted pair-group method using arithmetic averages) method as being relatively simple and widely used. Choice of similarity metric and cluster analysis and whether the data are transformed, standardized or used in unaltered form will affect the way the benthic assemblages are classified. As Krebs (1999, p. 395) points out, “there is no single kind of classification that is the ‘best’ system of grouping samples. We must rely on our ecological knowledge to evaluate the end results of any classification.” Characteristic and discriminating species or substrate of each class will be determined as using Similarity Percentage Analysis, and geomorphologic and benthic classes will be merged into a single habitat classification scheme. All data will be incorporated into a GIS (Geographic Information System) format so that the information can be easily examined on large and small scales. P-codes will be obtained for exact positioning with differential GPS (Global Positioning System).

Measurements of basic water quality characteristics such as salinity and temperature (and other measures) will be made at each site, because recent survey data from the Steamboat Lumps Marine Protected Area suggests that freshwater discharge is associated with certain geomorphologic features of the area.

Objective 3: Reference sites and indicator species.

Dayton and others (Dayton et al. 1998) point out the importance of establishing reference sites in marine ecosystems. They state that the detection of trends in ecosystems depends on a good description of the foundation or benchmark against which changes are measured and a distinction between natural and anthropogenic change. They also point out that several difficulties arise in attempting to establish benchmarks or reference conditions. One difficulty in marine systems is the lack of knowledge of the system before changes—such as intense fishing pressure-- took place. Many marine habitats have been fished for so many years that there is little information on how an untouched system might behave. Certain types of fishing, such as the trawling that occurred in the Oculina Banks of the South Atlantic, are clearly implicated as causative agents in the extensive loss of coral habitat and general biodiversity.

It is not always clear what changes result from the loss of apex predators (e.g., groupers and snappers) from the benthic communities in which they were once abundant. But the changes can be examined in several of the sites proposed for habitat classification. This is particularly true in areas that are closed to fishing and are relatively large. In these areas, the anthropogenic impacts on habitat would likely result predominantly from fishing, particularly in shelf-edge areas that are relatively deep and distant from terrestrial point and non-point sources of pollution. However, chemical and physical pollution would likely arise on local scales from oil and gas exploration and eventual exploitation, or from the transit of the areas with pipelines associated with that industry. Therefore representative habitats will be selected and categorized from sites within the marine protected areas. As a benchmark of temporal change we will establish permanently marked replicate plots of several different scales (e.g., 1, 10, 100, 1000 m2) within and outside of the reserves. The species composition, density, and distribution patterns of sessile benthic organisms will be determined within each plot using standard ecological methods (Aronson 1994, Krebs 1999).

Selection of representative habitats will be made after development of a classification scheme. Distinctive habitats with obvious value to the production of economically important species (e.g., juvenile habitat, spawning habitat) or to the support of biodiversity will be given special emphasis. For example, some species appear to act as ecosystem engineers, augmenting habitat complexity for their own use. Where hard bottom areas are swept clean of sediment by these species, they appear as “oases” in videos, supporting a wide array of fish and sessile invertebrate species (including sponges and soft corals) on the localized patches. It is unknown whether the availability of these oases expands and contracts with the population size of the ecosystem engineer, but temporal comparisons of both acoustic and visual observations in the protected areas will shed light on this question. If such a relationship exists between an ecosystem engineer and habitat, then these engineers serve as clear examples of keystone species, in a structural rather than trophic sense.

Because of the very limited information on shelf-edge ecosystems, it would be merely guessing to select a priori indicator species. A better approach would be to use species composition as an indicator of environmental condition (Philippi et al. 1998). The rationale for this is that environmental factors differentially affect species so that changes in environmental factors would be reflected in species composition. However, as stated before, the shelf-edge areas have been fished for many years and there are clear effects of such activities on the fish community (e.g., loss of large predators). How this change in the fish community affects the sessile benthic species composition is unknown. It is also unknown how the benthic species composition will change in the absence of fishing. Nevertheless, coral reef and hard bottom areas will provide the best benchmark species composition in both the fish community and in the sessile benthic community, and thus will provide the best indicators of environmental effects.

Expected Results

The proposed work is designed to provide an objective, systematic, and hierarchical classification of coral reef and hard bottom habitats. The method couples geomorphologic features derived from acoustic surveys with determinations of benthic cover and species composition derived from direct and remote optical imaging. The habitat maps and other information derived from this work will be incorporated into a GIS framework. All future site-specific information will also be archived within this database.

The benefits from this work will accrue to ecologists and environmental and fishery scientists, as well as natural resource managers. The Sustainable Fisheries Act of 1996 mandated the regional fisheries management councils to prepare management plans for essential fish habitat. The coral reef and hard bottom habitats throughout the Gulf of Mexico and South Atlantic are most essential as spawning habitat for many reef fish species of high economic importance (Coleman et al. 1999, Coleman et al. 2000, and Koenig et al. 2000).

The classification scheme developed and the information gained from these investigations will form the basis for a BACI (Before-After-Control-Impact) impact assessment work (Underwood 1994) (Schmitt and Osenberg (editors) 1996), and should provide new insights into this little studied coral habitat ecosystem. In particular, it provides the opportunity to gain exceptional information on shelf-edge coral habitats, which have received little attention because they are remote, difficult to sample (they occur below SCUBA depths, 50 – 120 m deep), and require large ships and remote acoustic and visual imaging.

Most of the techniques and equipment required to map these important habitats are specialized and expensive. But the work is essential, given the vulnerability of these areas to damage. Only in the last decade have the techniques and electronics become available that make this project feasible (e.g., exact positioning equipment, differential GPS, GIS mapping software, high-resolution side-scan sonar, digital video and portable computer systems to support it). Such mapping is the basic step to the understanding of these ecosystems and the Sustainable Seas Expedition provides the unique opportunity to develop baseline information over an extremely large area. Expansion of mapping to include both protected and unprotected habitat will form the basis for establishing a network of marine protected areas, as recently proposed by the American Fisheries Society in their policy statement (Coleman et al. 2000) and called to action through the recent Executive Order on establishing marine protected areas.

APPENDIX B

Side scan images and pictorial glossary of sediment structure and geomorphologic features of marine protected areas in the northeastern Gulf of Mexico. (see separate pdf file).

APPENDIX C

Reef fish resources and gas pipelines on the West Florida Shelf: potential conflicts

Christopher C. Koenig, Felicia C. Coleman, and Kathryn M. Scanlon

ABSTRACT

Marine protected areas (MPAs) placed appropriately provide promising options for the management of exploited populations by protecting critical habitat, community structure and function, and spawning populations. They also provide the unique opportunity to experimentally evaluate the effects of anthropogenic impacts (particularly fishing) on the biotic and physical components of ecosystems. Recently (19 June 2000), the Gulf of Mexico Fishery Management Council established two MPAs in the northeastern Gulf of Mexico. The impetus for establishing these reserves was strong evidence of fishing-induced changes in the demographics (especially changes in sex ratio) of several economically important reef fish species. Herein, we discuss proposed construction of two gas pipelines that would run through both MPAs. We are particularly concerned about the effects of construction on essential fish habitat both within and outside of the reserves. The pipeline contractors must accurately show the degree of impact from construction activities. We suggest that the ecological impact study provided by one of the pipeline construction companies has not adequately provided this. Further, we find that in both cases, pipeline construction would destroy critical habitat, compromise the ecological structure and function of resident biotic communities, and undermine an otherwise unique opportunity to evaluate fishing effects on shelf-edge reef fish populations.

We recommend that the pipelines be rerouted to areas outside of the reserves, paying particular attention to avoid live bottom and high relief habitat to the extent possible. We recommend that new environmental impact studies are required that provide more realistic profiles of habitat. Further, we suggest that a team of scientists develop for the Federal Energy Regulatory Commission and the Mineral Management Service a standardized format for conducting such studies so that valid comparisons can be made among different projects and different areas.

INTRODUCTION

Concern over extreme demographic changes in gag (*Mycteroperca microlepis*) populations of the southeastern United States—including declines in the proportion of males, declines in the size and age structure of spawning groups (Coleman et al. 1996, McGovern et al. 1998), and the apparent occurrence of inbreeding (Chapman et al. 1999)--prompted the Gulf of Mexico Fishery Management Council to recommend closing portions of the west Florida shelf edge (50-120 m depths) to fishing. On June 19, 2000, the National Marine Fisheries Service officially established two marine protected areas (MPAs) in gag spawning habitat, known as the Madison-Swanson MPA and the Steamboat Lumps MPA (Figure 14). The two areas combined cover over 200 nm^2 and will remain closed for a period of four years.

Studies within the newly-formed Madison-Swanson and Steamboat Lumps MPAs and associated control sites are already underway by scientists at a number of different state, federal, and academic institutions. These studies include side-scan sonar and multibeam mapping, ROV (remotely operated vehicle) video transect work, and studies of the community and behavioral ecology of resident populations. Because the whole intent of MPAs is to exclude as many confounding anthropogenic effects as possible, the reserve and control sites are being monitored to evaluate recovery from fishing effects.

Gas pipelines proposed to transit the northeastern Gulf of Mexico from Mobile Bay, Alabama, to near Tarpon Springs, Florida, could cross both MPAs. We reviewed the draft environmental impact statements that describe the potential effects of construction on outer continental shelf habitat. We were particularly interested in the extent to which construction could disrupt the integrity of critical shelf-edge habitat and the evaluation of fishing effects in these regions. We first describe the pipeline construction process, as outlined by the construction companies--Buccaneer Gas Pipeline Company and Gulfstream Natural Gas System--and then critique those portions of the Draft Environmental Impact Statements (DEIS) provided by each company's subcontracting firm, Continental Shelf Associates (CSA) for Buccaneer, and Sea Byte, Inc., for Gulfstream. The intent of this paper is to provide recommendations to these companies and to future oil and gas construction projects on the outer continental shelf.

Shelf-edge Reef Fish Populations: A brief review

Most of the economically-important reef fish species of the southeastern United States are overfished (Coleman et al. 2000). Many of them are protogynous hermaphrodites—fish that change sex from female to male—and a great many of them co-occur in shelf-edge habitat (Koenig et al. 2000). Among the factors hindering effective management of these species are poor catch records, poor collective memories of the historical state of fished populations, essentially no records at all of the unfished condition (Jackson 1997), and a lack of political will to implement appropriate management practices.

The reductionist approach of single-species management compounds this problem because it typically limits inquiry to the population dynamics of one stage in the life cycle of an exploited species (the adults). It rarely considers other stages (larvae, juveniles, subadults) that are equally important to population persistence, and ignores the fact that exploited species form part of a complex interacting ecosystem.

The Magnuson-Stevens Fishery Management and Conservation Act of 1996 (NMFS, 1996) provided for substantive changes to this approach by suggesting that essential fish habitat and ecosystem-level processes are important components of effective fisheries management. Admittedly, the definition of essential fish habitat is broad—defined in the act as "those waters and substrate necessary to fishes for spawning, breeding, feeding, or growth to maturity" (NMFS, 1996). But the mandate is clear, that EFH *must* be protected and that potentially adverse effects on EFH from fishing and non-fishing activities (which would include pipeline construction or other oil and gas-related activities*)* *must* give way to actions that encourage habitat conservation.

One important step toward management in the framework of ecological realities is the use of MPAs (NMFS 1999, NRC 2000, Bulletin of Marine Science 2000). MPAs not only provide the opportunity to observe reef fish population parameters and community structure in an unfished state, but they also provide opportunities to experimentally evaluate the effects of fishing on specific behaviors, demographics, ecological interactions, and habitat. For example, an MPA allows evaluating the extent to which fishing that targets gag spawning aggregations selects for males and disrupts the sex change process.

Of particular interest in the Gulf of Mexico are the shelf-edge (50 – 120 m depth) reefs of west Florida, reefs that have been fished for over 100 years (Camber 1955). As important as these areas are, neither the direct nor the indirect effects of fishing on habitat or the associated reef communities have been evaluated. Direct effects of fishing, in addition to removal of targeted species, include mechanical damage to habitat due to mobile fishing gear, trapping, and anchoring. Indirect effects include trophic cascades resulting from the removal of top-level predators (Hughes 1984, Hughes et al. 1987) and potential habitat loss resulting from removal of species that act as geologic agents (Scanlon et al. in review, Coleman and Williams in review). One need look no further than the EORR (Experimental Oculina Research Reserve) MPA off central east Florida for an example of extensive fishing-induced habitat destruction and the effects on benthic communities (Koenig et al. 2000).

Gag spawning aggregations occur in these shelf-edge regions from the eastern Gulf of Mexico to North Carolina (Koenig et al. 1996, McGovern et al. 1998, Koenig et al. 2000). Yet, the area in the northeastern Gulf between latitudes 28^0 and 29^0 30'N at depths ranging from 50 to 120 m, is considered both the gag population center of abundance and the heart of the commercial fishery (Schirripa et al. 1999). Many other economically important reef fish species also spawn in this region, including scamp (*Mycteroperca phenax*), red grouper (*Epinephelus morio*), gray snapper (*Lutjanus griseus*), red *snapper*

(Lutjanus campechanus), vermilion snapper (*Lutjanus rhomboplites*), red porgy (*Pagrus pagrus*), and others (Coleman et al. 1996, Koenig et al. 2000). Thus locating MPAs in this region is particularly important.

Proposed pipelines on the west Florida Shelf

Buccaneer's proposed pipeline is approximately 411 miles long. It passes through roughly 200 miles of critical shelf-edge habitat (but see comments below), including some 12 miles in the southwest portion of the Madison-Swanson MPA. Gulfstream's proposed pipeline is approximately 420 miles long, crosses roughly 59 miles of shelf-edge habitat (~53 miles on the west Florida shelf edge and ~6 miles on the Alabama shelf-edge), 3.5 miles of which are in the northeast corner of the Steamboat Lumps MPA (Figure 14). The Buccaneer pipeline is in somewhat shallower water than the one proposed by Gulfstream.

Pipeline occurring at depths less than about 61 m must be buried in the substrate. This is an expensive and destructive process, in terms of its impact on habitat. Pipeline occurring at depths greater than 61 m is neither buried nor anchored to the bottom. However, this does not mean that construction is a low impact process at those depths. In order for the 1.0 m diameter pipeline to maintain a smooth sigmoidal shape as it is laid from the barge to the seafloor, the barge must be secured in place by twelve anchors, 8 forward of the barge and 4 aft. Each anchor measures about 5 x 6 m and weighs at least 13 tons. The anchors are distributed radially from the barge by cables 7.6 cm in diameter; the anchors and cables together cover a swath approximately one nautical mile wide. The barge progresses along the pipeline route by drawing in the fore anchor cables, letting out the aft anchor cables, and subsequently repositioning the anchors for another round. This action is repeated twice within each mile, such that there are 24 anchor strikes per mile.

The extent of the habitat damage caused by this process is related to the compounded effects of anchor-cable sweep (the extent to which anchor cables contact the bottom), anchor drag, and sea-state. The anchor-cable sweep is greatest near the anchors as the barge is drawn forward due to the considerable catenary in the cable line. When cables sweep the bottom, they act like trawls or dredges, but with far greater force, literally raking away all habitat structure. Anchor strikes affect less area than cable sweep, but an increased sea state will likely increase the damaging effects of both. Neither company considered the effects of sea state.

Each company was responsible for conducting photo-video surveys along portions of the proposed route and then comparing those videos to geophysical data (side-scan sonar imagery and seismic reflection profiles) to determine the degree of relationship between the two. The Minerals Management Service required that the photo documentation surveys be conducted at depths shallower than 100 meters, even though the proposed pipelines would cross habitat at greater depths. In the side-scan sonar data, dark, medium, and light areas correspond to the acoustic properties of the seafloor. For example, a hard rocky bottom would produce a dark image, and a soft-grained, sediment-covered bottom would produce a light image. However, other factors (e.g., small-scale roughness of the seafloor, angle of slope, and state of compaction of sediments) also affect the acoustic properties of the seafloor, and hence complicate the interpretation of the acoustic image produced.

CRITIQUE OF ESTIMATED IMPACTS TO SHELF-EDGE HABITAT.

Because we are most interested in the effects of construction on habitat important to reef fish, we confine our comments to estimates of hard bottom (carbonate rock either exposed or covered by a thin veneer of sediment), and specifically "live bottom" (hard bottom with sessile epifauna) coverage made by Sea Byte, Inc., (for Gulfstream) and CSA (for Buccaneer).

The ground-truthing exercises conducted by Sea Byte at both shelf (15 – 50 m) and shelf-edge (50 – 100 m, the greatest depth required by MMS for habitat delineation) depths revealed:

(1) that areas with light acoustic reflectivity had 15 % live bottom coverage, (2) that areas with moderate reflectivity had 21 % live bottom coverage, and (3) that areas with dark reflectivity had 53 % live bottom coverage. Although the percentage of live bottom increased with the degree of reflectivity—that is, the lower the reflectivity, the lower the percentage of live bottom--the relationship was a poor indicator of the presence of live bottom. For instance, when similar studies were conducted inshore by Seabyte (1999), they found a high degree of correlation between dark reflectivity and the presence of live bottom. This was not the case on the OCS. Based on that finding, Sea Byte decided that the geophysical data did not adequately represent the extent of live bottom in the OCS. Thus, they relied upon a series of parallel photo-video transects made along the entire pipeline route (to 100 m depths), interpolating the extent of live bottom between the transects. This approach provided nearly 100 % coverage of the proposed impact area and gave more realistic estimates of live-bottom coverage.

The proposed route of the pipeline relative to shelf-edge habitat is ambiguous in the documents prepared for Buccaneer by CSA. In fact, they provide three different proposed pipeline paths relative to depth: one in which the pipeline appears to be shallower than the 100 meter isobath over all of its length (CSA 1999, 2000a), one in which it deeper than 100 m in several places (CSA 2000b), and yet a third in which the 300 ft. (91 m) isobath and the 100 m (328 ft.) isobath are indistinguishable (CSA 2000c). If the first route is correct then the pipeline route covers about 200 miles in shelf-edge depths. If the second route is correct then it covers about 100 miles. For purposes of discussion, we used the first map presented in the series for evaluation. This choice was completely arbitrary because the maps are so confusing.

Continental Shelf Associates, Inc., (Buccaneer) performed photo-video documentation surveys over 75 miles of the shallower pipeline route across the west Florida shelf (from shore to about 50 m depths). However, they only surveyed about 8 % (15 of the nearly 200 miles) of the route through the more critical shelf-edge habitat, sampling only six sites, four of which were clustered in a 20 mile segment midway along that line and none of which were deeper than 100 m. Unlike Sea Byte, CSA found, as stated in their summary, an “exceptionally high degree of correlation” between the geophysical data and their photo-documentation of live bottom (CSA 1999) and that the geophysical data, if anything, overestimated the amount of live bottom (CSA 2000a).

This interpretation by CSA is in part due to their assumption that live bottom only occurred in geophysically-determined hard bottom habitat. However, closer examination of their maps shows that the correlation—much like that found by Sea Byte-- is not particularly good for predicting how much live bottom exists in an area. Live bottom exists to some extent in all geophysically-determined zones. For instance, in one segment (plot 4 of segment 2 on shelf edge habitat in CSA 1999), live bottom was found in video transects in “light” areas (not identified in the map legend, but presumably sediments ranging in texture from silty to fine or medium grained sand, based on the text), while very little live bottom is found in “dark” areas,

We found interpreting CSA’s maps difficult because the terminology in the text and the maps was unclear. For instance, the self-contradictory phrase "carbonate (limestone) sediment" is used repeatedly. Limestone, by definition, is a rock, not a sediment. One can only guess what this term is meant to describe, because it is not defined in the map legend or in the text. Furthermore, the map legend contains a number of units (e.g., "exposed carbonate (limestone) sediment", "sediment veneer over carbonate (limestone) sediment", "sand covering carbonate (limestone) sediment with scattered outcrops", "exposed carbonate (limestone) sediment with areas of outcrops and sand pockets", and "scattered outcrops") which appear to have considerable overlap, are ambiguous or contradictory, are contrary to common geological usage, and are never defined. As a result, these maps are of little use either for delineating or for quantifying benthic habitats.

Considering CSA’s inadequate photo coverage of the shelf-edge habitat and the apparently low concurrence between the geophysical patterns and their photo-documentation data, we consider that their report grossly underestimates the extent of shelf-edge live bottom coverage. Although it is not unreasonable to quantify biotal coverage and sessile invertebrates potentially impacted, it is more important to determine construction impacts to the actual habitat, regardless of the density (or biotal coverage) of the individual benthic species. For example, in CSA's (2000c) quantitative survey, they state that about 8 % of the construction route is live bottom habitat, but that only 12.5 % of that is covered by sessile invertebrates. They have interpreted this to mean that 1 % (.08 x .125) of the live bottom habitat would be destroyed. We caution that the emphasis should be placed on the areal coverage of the habitat, and not on the areal coverage of the individual organisms. To do so leads to an erroneous perception, vastly underestimating the impact on habitat of pipeline construction.

Discussion and Recommendations

There is considerable concern among scientists and conservationists about the rate of habitat loss worldwide. In fact habitat loss is considered the primary reason for declines in biodiversity (Wilcove and Wilson 2000). The litany of agents responsible for the declines include water diversion projects, hydropower dams, agricultural practices, and urbanization. To these can be added habitat destruction caused by mobile fishing gears—trawls and dredges—which have devastated many low-relief live bottom habitats (Dayton et al 1995, Auster et al. 1996, Watling and Norse 1998). There is strong interest in monitoring these effects and limiting them to the extent possible. Pipeline construction is just one more effect that should be closely evaluated. Such construction is not constrained in the same way that mobile fishing gear is because (1) it can affect areas typically inaccessible to trawls; and (2) it has the potential through shear force of impact to cause far more damage to habitat, reducing high relief structure to rubble.

We are very concerned by the methods used to delimit habitat in the reports of proposed pipeline construction in the northeastern Gulf of Mexico. The reason that accurate estimates of different habitat types are so critical is that these numbers are used to evaluate the extent of damage caused by pipeline construction. For purposes of these studies, the Mineral Management Service applied the "low-relief live bottom stipulation" which is that those applying for oil and gas leases conduct photo-documentation surveys of the sea floor within the project area only at depths of 100 m or less (Gulfstream 2000). Live bottom is considered by MMS to be "seagrass communities or those areas which contain biological assemblages consisting of sessile invertebrates (such) as sea fans, sea whips, hydroids, anemones, ascidians, sponges, bryozoans, or corals living upon and attached to naturally-occurring hard or rocky formations with rough, broken, or smooth topography; or areas whose lithotope favors the accumulation of turtles, fishes, and other fauna." No surveys are required in areas of greater depth.

We find the depth restriction of 100 m not only arbitrary, but exclusive of a number of important types of marine habitat. Of particular concern are exclusions of deep-water reef fish habitat and coral and sponge communities. For instance, important reef fish habitat exists at depths greater than 100 m, including essential habitat for tilefish *Lopholatilus chamaeleonticeps*, blueline tilefish *Caulolatilus microps*, Warsaw grouper *Epinephelus nigritus*, snowy grouper *E. niveatus*, speckled hind *E. drummondhayi*, and yellowedge grouper *E. flavolimbatus* (Parker and Mays 1998). All four of the groupers are considered at risk of extinction by the American Fisheries Society (Musick et al. 2000), and two of them--Warsaw grouper and speckled hind--are now considered threatened (Coleman et al. 2000), thus requiring special management attention. Extensive live bottom (65 % coverage) exists at depths of 120 to 160 m off the southwest Florida shelf (Phillips et al. 1990). Further, beds of the deep-water coral *Lophelia pertusa (= L. prolifera)* occur in water depths of 439 to 512 m some 40 miles east of the Mississippi delta. Similar banks off Norway and the Faeroe Islands, which support enormously diverse biota, have suffered tremendous losses (Roberts 1997). Although little is known of these habitats—or perhaps *because* so little is known--they should be quantified in estimates of habitat impacts from oil and gas construction projects. Thus, we recommend that photo-documentation surveys include all depths at which any oil and gas activities are to occur.

The most significant source of habitat damage during pipeline construction is due to anchor cable sweep. Buccaneer (2000) estimated the damage to range from one to one-and-a-half acres per anchor strike, or about 24 to 36 acres per construction mile. Gulfstream (2000), on the other hand, estimated that habitat damage would be on the order of 114 acres per construction mile at depths ranging from 61 m (200 ft) to 100 m (328 ft). It would be much greater at shallower depths because the lower angle of the anchor cable causes more of it to touch the bottom. Thus, the two estimates of habitat damage due to cable sweep differ 3- to 9-fold, depending on the construction depth. The estimated area of damage provided by Gulfstream is more realistic because it is based on engineering considerations (e.g., sweep features of each anchor cable and relationship to depth) and historical observations.

How could these companies, running parallel analyses along parallel routes, come to such disparate conclusions about the relationship between the geophysical data and photo ground truthing, in estimating anchor-cable sweep damage, and in estimating habitat coverage? Further, why did both companies choose routes that went specifically through marine protected areas?

We found it difficult to make comparisons between the habitat quantification documents provided by the two pipeline construction companies because the methodologies used were not standardized. In fact, CSA did not even follow standard survey or statistical methodologies, making comparisons impossible in most cases. To avoid problems of interpretation, we recommend that standard methods and terminology be developed by a team of scientists for use by the Federal Energy Regulatory Commission (FERC) and the Mineral Management Service (MMS). Subcontractors should also be required to provide statistically-sound error values in their estimates of areal habitat coverage.

It is unclear why both Buccaneer and Gulfstream chose pipeline routes that transit MPAs. They either were wholly unaware of the Gulf Council's July 1999 recommendation that these sites be set aside as MPAs or they categorically chose to ignore these boundaries. Regardless which of these scenarios is true, there is little doubt that significant damage in critical habitat would occur and experimental studies of reef fish reproductive behavior and the effects of fishing on habitat and ecosystem function would be compromised. If the boundaries of these MPAs are not respected a rare opportunity to evaluate fishing effects might be lost. Thus, we recommend that oil and gas construction projects hold MPAs as sacrosanct and avoid all anthropogenic disruption.

MPAs likely will form an important component of future fisheries management plans. To wit, on May 26, 2000, President Clinton signed an Executive Order calling for the expansion of the system of MPAs throughout the United States (Federal Register vol. 65, no. 105, pp. 34909-34911). The intent is to "(a) strengthen the management, protection, and conservation of existing marine protected areas and establish new or expanded MPAs; (b) develop a scientifically based, comprehensive national system of MPAs representing diverse U.S. marine ecosystems, and the nation's natural and cultural resources; (c) *avoid causing harm to MPAs through federally conducted, approved, or funded activities*" (our italics). This Executive Order sets the tone for future conservation of living marine resources. Our respect for these resources and the MPAs that contribute to their sustainability translates into a respect for future generations.

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