A Stepwise Approach to Investigating the Movement Patterns and Habitat Utilization of Goliath Grouper, *Epinephelus itajara*, Using Conventional Tagging, Acoustic Telemetry and Satellite Tracking

Anne-Marie Eklund and Jennifer Schull
NOAA-Fisheries, Southeast Fisheries Science Center, Division of Protected Resources and Biodiversity, 75 Virginia Beach Drive, Miami, FL 33149; 305-361-4271; anne.marie.eklund@noaa.gov; jennifer.schull@noaa.gov

Key words: goliath grouper, jewfish, *Epinephelus itajara*, acoustic tagging, mark-recapture

Abstract: Goliath grouper,[1] *Epinephelus itajara*, the largest grouper in the western North Atlantic, has been protected from all harvest in U.S. waters since 1990, after years of overexploitation at its spawning aggregations. We are currently assessing this species' recovery by using a variety of tagging methods, including conventional tagging and acoustic telemetry. We have been monitoring the adult populations at offshore spawning aggregations and the juveniles at their nursery areas along mangrove shorelines. Conventional mark/recapture studies enabled us to predict juvenile goliath grouper population densities, growth rates and survival rates. Conventional tagging and recaptures of both adults and juveniles have given information on habitat use and movement patterns, while manually tracking acoustically tagged fish provided fine-scale habitat use and seasonal movements. Continuous data-logging hydrophones provided long-term data on site residency of both juveniles and adults. Future studies will include the use of satellite tracking to define large scale ontogenetic and spawning migrations to previously undescribed habitats. Each method of tagging has provided answers to key questions regarding goliath grouper population biology, but every method also has had its limitations. By starting with the most economical and simplest methods, we have built upon each study by adding complexity as it is warranted.

[1] Name change from jewfish to goliath grouper, May 2001.

J.R. Sibert and J.L. Nielsen (eds.), Electronic Tagging and Tracking in Marine Fisheries, 189–216.

1. INTRODUCTION

Tagging of marine fishes has been an important aspect of fishery biology and management for many years (Nielson, 1992; Laird and Stott, 1978; Boreman, 1996). Fish can be tagged with a variety of visual marks, as well as with tags that emit acoustic or radio transmissions. Through conventional mark-recapture studies, it is possible to estimate population abundance (Krebs, 1999; Koenig and Coleman, 1998), growth rates (Cruz-Escalona et al., 2000; Turner et al., 1990) and movement patterns (Xiao, 1996; Laird and Stott, 1978) of many different species of fish. However, getting the information from fish marked with visual tags is dependent upon their recapture. In many studies fewer than 10% of the marked fish are ever recaptured. Nevertheless, recaptures of even a few marked fish have yielded important information on stock structure and range of movements (e.g., Mather et al., 1995; Schaefer and Fable, 1994). Even in these cases, however, the information gained is only the start and endpoints of the migration, with no data on where the fish had been while at large.

In terrestrial and freshwater systems, biologists are able to tag animals with radio transmitters. Shore-based and aerial radio receivers can easily pick up the signal of individual fish and other animals, within a large range of up to 1500 m (de Morais and Raffray, 1999). While radio waves do not transmit in marine systems, there have been many advances in marine biotelemetry, including the use of acoustics in tracking marine fishes. Acoustic signals can only be heard from 100-500 m, depending on ambient noise (Arendt, in press; Priede et al., 1990, Eklund, pers. obs.), but directional hydrophones can precisely locate the position of an animal in water. Manual tracking is a labor-intensive method of tracking marine fish and invertebrates (Commiskey, 1999; Gunn et al., 1999; Wetherbee and Rechisky, 1999; Yano, 1999; Yano et al., 1999; Block et al., 1992), which has yielded much information on animals' movements and behaviors. Recent advances in biotelemetry have resulted in data-log ging capabilities on hydrophones, which can be left on site for weeks or months, collecting data on the presence/absence or exact position of fish marked with acoustic transmitters (Bolden, this volume; Arendt, in press).

New technologies have made tracking fish over large distances possible by enabling the tags to transmit their location to satellites, if the animal is on the surface or if the tag has disengaged from the animal (Lutcavage et al., 1999; Welch and Eveson, 1999). In addition, continuous data on depth, temperature and geolocation can be archived on these tags, giving the researcher a continuous log of where the animal has been (Davis and Gunn, 1992; Block et al., 1998). The archival tags have been mainly used on fish that may make transoceanic migrations, such as whale sharks (Gunn et al.,

1999) and bluefin tuna (*Thunnus thynnus*) (Block et al., 1998; Davis and Gunn, 1992).

With the advent of these new technologies comes much confusion about what tagging method is best for each animal. To the uninitiated, the terminology of biotelemetry can be daunting, as it encompasses fields of engineering, oceanography and physical science, in addition to basic biology and ecology. Often, researchers are eager to use the latest and most expensive technology, without totally understanding the advantages and disadvantages of each method. It is our purpose to describe our experiences in using a few different tagging and tracking techniques and the successes and limitations that each method provided. The particular tagging method chosen depends on the question asked and in some cases, even the most current and sophisticated biotelemetry techniques cannot provide answers that the most basic mark-recapture study can provide. Each tagging method that we describe has or will provide answers that the other methods cannot, owing to their inherent limitations.

Case Study: Tagging and Tracking Goliath Grouper

The goliath grouper, *Epinephelus itajara*, is one of the largest groupers in the world, growing to at least 210 cm TL and living at least 37 years. Prior to our research, there was remarkably little information on the species, with only one study investigating its life history (Bullock et al., 1992). Its population status in recent years has prompted much interest in investigating the goliath grouper's life history and population dynamics.

Although once common along both the Gulf of Mexico and Atlantic coasts of Florida, goliath grouper populations declined rapidly through the 1980s, shortly after spawning aggregations in the eastern Gulf of Mexico were discovered (Sadovy and Eklund, 1999). In 1990, the fishery was closed by emergency rule and all harvest of this species was, and still is, prohibited in U.S. waters (GMFMC, 1990; SAFMC, 1990). The fish is now a candidate for the U.S. Threatened and Endangered Species List, is currently on the IUCN Red List of Threatened Animals (Hudson and Mace, 1996), and is considered by the American Fisheries Society to be at risk of extinction in North America (Musick et al., 2000).

Our research objectives were to assess the recovery of this species, by describing its critical habitat during different life history stages and producing recruitment forecasting by estimating the abundance of juveniles and spawning adults over time. We determined that the goliath grouper's large size, longevity and overall hardiness made it an ideal subject for telemetry studies. There were several different tagging and tracking methods we could employ successfully to answer our research questions.

This paper will focus on the aspects of our study that make use of biotelemetry methods, coupled with conventional mark/recapture studies. We have used a step-by-step approach to our tagging work, beginning with conventional tagging experiments that were later augmented by acoustic telemetry. We have gained valuable information from both conventional and acoustic tagging, with each method providing results that facilitate and map our plans for future satellite tracking. We discuss the key findings and limitations to each methodology as they relate to our overall objectives of investigating goliath grouper life history and distribution.

We have tagged juvenile goliath grouper in their nursery habitat in order to estimate absolute abundance of the juveniles as a predictor of year class strength. Our conventional and acoustic tagging studies have yielded important information on critical nursery habitat, site fidelity, movement patterns and growth and survival rates of juveniles. We have also censused adult goliath grouper on selected spawning aggregations and have marked some of these fish with visual tags and sonic transmitters in order to describe their seasonal migration patterns and their habitat use during the spawning period.

2. STUDY AREA

2.1 Juvenile Habitat

We studied juvenile populations at four sites in the Ten Thousand Islands off southwest Florida in the Gulf of Mexico: Rabbit Key Pass, Russell Pass, Fakahatchee, and Faka Union Channel (Figure 1). This region, considered the historical center of abundance for juvenile goliath grouper in Florida (Bullock and Smith, 1991), is an essentially undeveloped maze of mangrove forest islands and tidal passes, protected by the Everglades National Park and the Rookery Bay National Estuarine Research Reserve. Local environmental characteristics include water temperatures ranging from 18 to 33°C, water depths of 2 to 10 m, salinity ranges from 30 to 33 ppt, and tidal amplitudes up to 2 m. Strong tidal currents over time have eroded undercuts along many of the mangrove islands. Our observations (using SCUBA) of these undercuts revealed them to be highly complex habitat, with many goliath grouper, gray snapper (*Lutjanus griseus*), snook (*Centropomis undecimalis*), spadefish (*Chaetodipterus faber*) and several species of portunid and xanthid crabs utilizing the same areas.

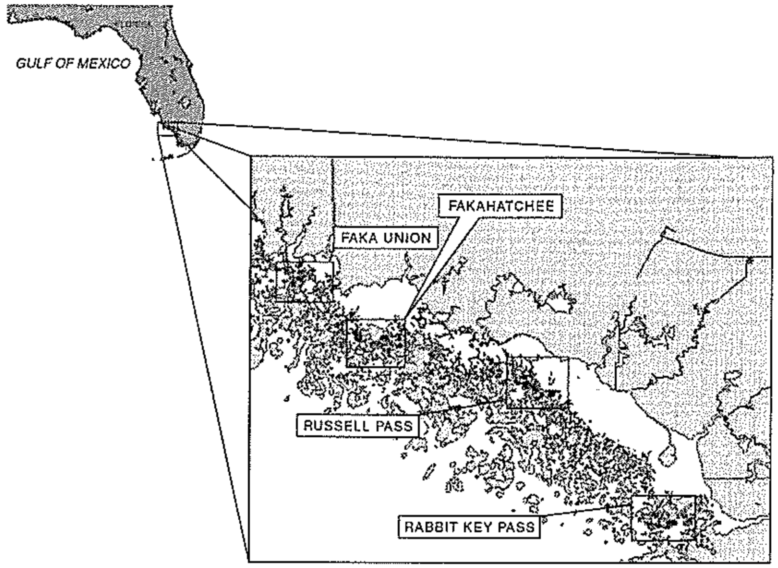

Figure 1. Four sampling areas for juvenile goliath grouper within the Ten Thousand Islands of southwest Florida, U.S.A.

2.2 Adult Habitat

Adult goliath grouper inhabit coral reefs and wrecks at depths ranging from 5 to 50 m (Sadovy and Eklund, 1999). They were once commonly found close to shore under bridges and jetties (DeMaria, 1996), but are now more often observed several kilometers offshore in the Gulf of Mexico, associated with isolated wrecks and U. S. Navy Navigation Towers at depths ranging from 30 to 50 m (Figure 2). These sites provide habitat for many reef fishes, such as grunts (haemulids), snappers (lutjanids), jacks (carangids), groupers (serranids), and wrasses (labrids), as well as for many reef invertebrates including decapod crustaceans. We concentrated our efforts thus far on these offshore wrecks and towers, because they are thought to be spawning aggregation sites and because we have been unable to locate any goliath grouper spawning aggregations on natural reef habitats.

In addition to the offshore wrecks, goliath grouper have also been observed frequently at a fishing pier at the southern end of Boca Grande, Florida (Figure 2). The pier is a popular diving and fishing location because of the concentration of tarpon (*Megalops atlanticus*), snook and snappers (*Lutjanus sp.*), as well as goliath grouper. Located at the mouth of Charlotte Harbor, a large estuary, the pier provides habitat structure in a productive area of intense tidal flow and shallow water (0-10 m).

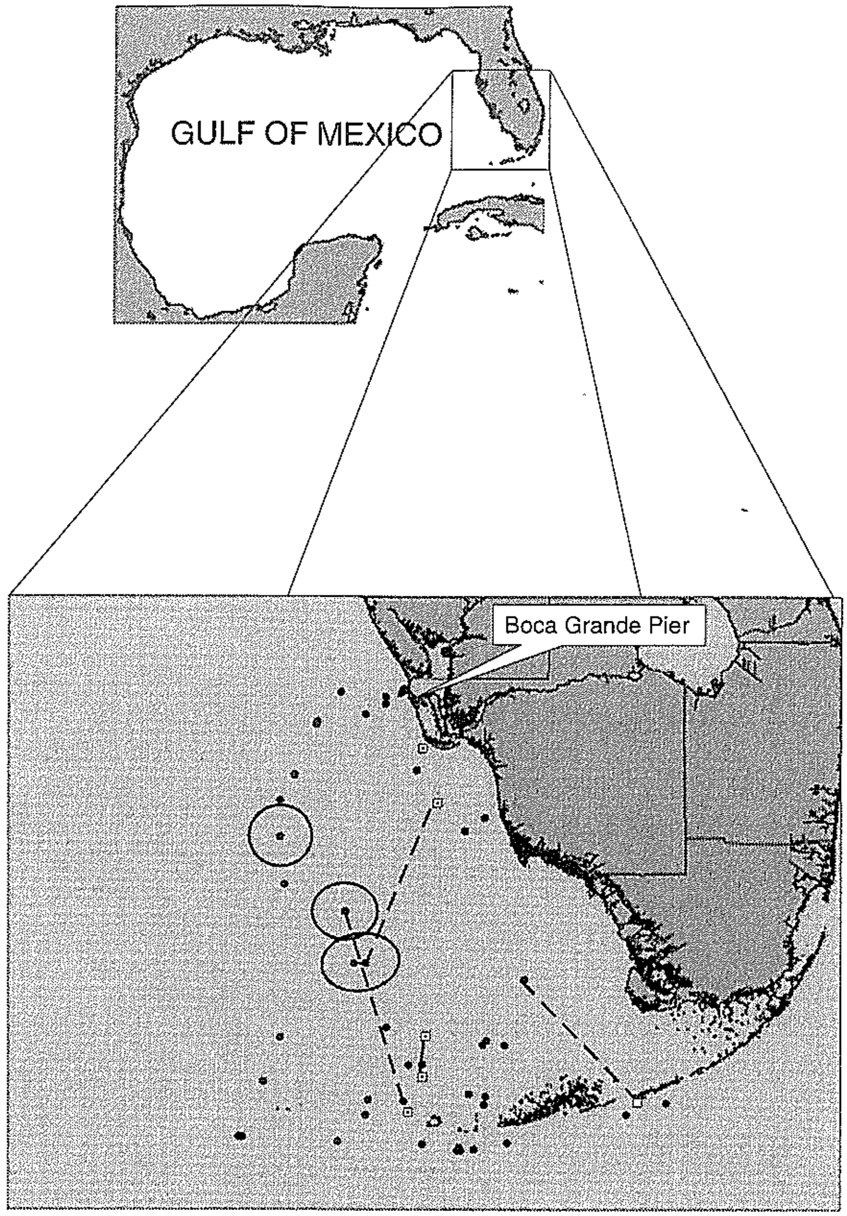

Figure 2. Locations off the coast of Florida, U.S.A. where adult goliath grouper were tagged (filled circles) and where adult goliath grouper have been observed or caught, other than at their original tagging locations (open squares). The dashed lines represent movement of goliath grouper from a tagging site to another site. The large circles depict the areas where goliath grouper are known to aggregate during the spawning season.

3. CONVENTIONAL TAGGING STUDIES

3.1 Objectives and Methodology

3.1.1 Juveniles

The primary objective of our conventional mark/recapture study was to estimate juvenile goliath grouper abundance, growth rates and survival rates. Recaptures of previously tagged individuals also allowed us to describe their preferred habitat and to document their movements, including patterns of seasonal activity and ontogenetic migrations. Together this information can be used to forecast recruitment and to promote protection of critical nursery habitat.

We initiated the juvenile mark/recapture study in June 1997. Juveniles were caught using circle hooks set on lines (20-30 lines per area) in deep undercuts along mangrove islands in four discrete areas of the Ten Thousand Islands (Figure 1). Each hook was baited with a live catfish (*Arius felis*) from which the spines had been removed, and allowed to fish for four to eight hours with the hook resting on the bottom. Captured juveniles were weighed to the nearest gram (g) and measured to the nearest mm—standard length (SL) and total length (TL). Scales and dorsal fin rays and spines were collected to age fish. Before release at the site of capture, each fish was tagged with a stainless-steel-core internal anchor tag secured on the ventral side of the body. We included on each tag, in addition to a unique tag number for identification of individual fish, the Florida Marine Research Institute's (FMRI) toll-free tagging hotline number (800-367-4461) in case anglers captured any of our tagged fish. To facilitate reporting, we distributed posters to area bait shops and marinas to inform people of the pertinent information we needed and how to get in touch with us. We recorded the tag number, location, and the length and weight of all recaptured fish. For any fish at large longer than six months, we resampled scales and dorsal fin rays and spines. All mark and recapture locations were recorded with a Global Positioning System unit (GPS) and entered into a geographical information system (GIS) mapping database (Arcview, ESRI, 380 New York St., Redlands, CA 92373) to allow characterization of juvenile habitat use, movement patterns and site fidelity.

3.1.2 Adults

We initiated tagging of adult goliath grouper in 1996 at four to five offshore aggregation sites to determine the degree of site fidelity and inter-aggregation movements. In the fall of 1998, we started tagging fish at inshore wrecks, reefs, and the Boca Grande pier to study their annual migrations to and from the spawning sites. Knowledge of the utilization of critical spawning habitat, movements, and the extent of seasonal migrations will help us describe the stock structure of this protected species.

Adult goliath grouper were tagged externally just below the dorsal fin using dart tags with large disks at the proximal end embossed with discrete tag numbers. Tagging occurred *in situ* and remotely (at distances of 3 to 4 m) by a diver using a modified spear gun. *In situ* tagging ensured that fish experienced minimal physiological stress, far less than they would have with typical onboard tagging. A disk at the proximal end of the tag contained a large number, along with the toll free Tagging Hotline number. Observations of tagged fish were made by us on our annual dives (using SCUBA), by our associate Captain Don DeMaria, by recreational divers or by commercial or recreational fishers.

3.2 Successes

3.2.1 Juveniles

The conventional tagging method proved a cost-effective means of tagging a large number of fish with a high recapture rate. We were able to estimate population abundance and growth and survival rates. We were also able to describe juvenile habitat use and their movement patterns. We tagged 148 juvenile goliath grouper (size range 205-1005 mm TL, mean = 684) in four discrete areas from June 1997 to October 1999. Our recapture rate was very high, at 37%. Twenty percent of the tagged fish were recaptured twice and several were recaptured multiple times (Figure 3). Some fish were caught 4-8 times within 35 m of their original tagging location, and 25 individuals were recaptured in the same location in which they were tagged, indicating a high degree of site fidelity. Only a few fish exhibited movements greater than 300 m: one fish in Rabbit Key Pass, one fish in Russell Pass and two fish in Faka Union (Figures 4-7).

Through the FMRI tagging hotline, we documented two fish that emigrated from the study area to offshore reefs/wrecks. One of the fish moved 31.7 km within a two-month period (Figure 8). This fish was one of the largest we had caught in the nursery habitat, at close to one meter in length. The second fish was recaptured 22.3 km and two years after it was tagged. At the time of recapture, the second fish was just over one meter in length. Since goliath grouper become reproductively mature between 1100 and 1350 mm, we suspect that this movement represents an ontogenetic migration to adult habitat. Future work using satellite telemetry may reveal more such movements (see satellite tracking section below).

3.2.2 Adults

From July 1996 through January 2000, we tagged 856 adult goliath grouper on offshore aggregation sites and inshore wrecks (Figure 2). Fifty of those fish have been re-sighted. Twelve of those tagged on offshore aggregations were re-sighted on their original tagging sites: four were re-sighted within the same spawning season (11-43 days post tagging), six were re-sighted during the subsequent spawning season, one was re-sighted in each of the following two spawning seasons, and one was observed at the same location three years after tagging. We believed that these fish might move seasonally on and off the aggregations, but we did not know the degree of site fidelity these fish might have within and among the spawning seasons. Based on the fish re-sighted at their original tagging locations, we suspected that at least some of the aggregating fish return to the same aggregation sites year after year, assuming that they leave the sites at all.

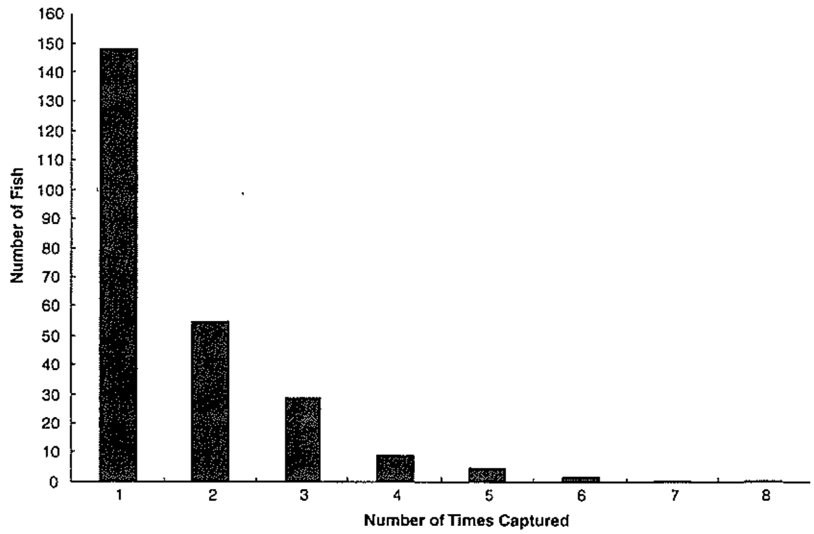

Figure 3. Number of juvenile goliath grouper tagged and recaptured in the Ten Thousand Islands of southwest Florida, U.S.A. from June 1997- October 1999.

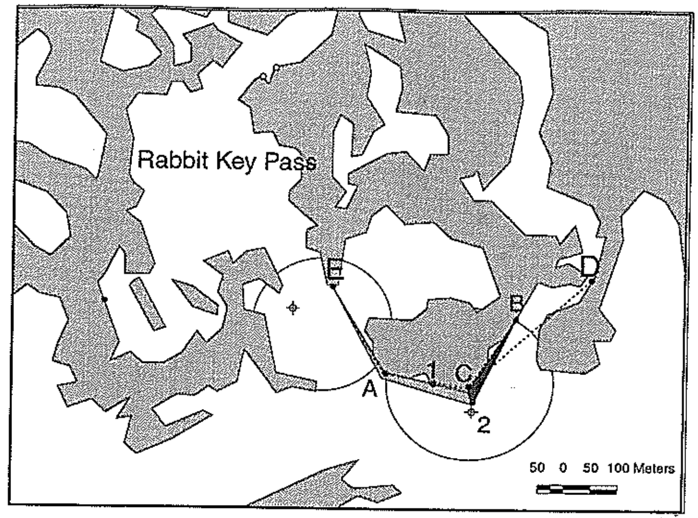

Figure 4. The Rabbit Key Pass study area for juvenile goliath grouper within the Ten Thousand Islands of southwest Florida, U.S.A. Letters represent areas where juvenile goliath grouper were tagged and recaptured and in some cases also detected acoustically. Numbers represent areas where the fish were detected acoustically, but no lines were set there to catch the fish. Letters and numbers represent areas where fish exhibited some movement to and from those sites. Dotted lines connect areas where fish were tagged to areas where they were subsequently recaptured. The two polygons describe the observed activity space of two acoustically tagged fish. The polygons were created by drawing the minimum distance along the shoreline that connects all locations where the fish were either recaptured or detected acoustically. The filled circle that does not have any letter or number designation is an area where goliath grouper were caught and subsequently recaptured, but no movement was detected to or from that area. Hollow circles are sites where goliath grouper were caught but never recaptured. The large circles represent the approximate range of the VR1 receivers, which are designated by the small circle-enclosed crosses. All fish were caught with baited circle hooks attached to set lines along mangrove shorelines.

Four fish tagged at offshore aggregation sites were re-sighted after 9-12 months, inshore either near the southwest coast of Florida or near the Florida Keys, demonstrating spawning migrations of 87-153 km (Figure 2). Two fish exhibited shorter movements among aggregation sites, one moving 16 km within 20 days and the other fish moving 22 km within four months. These small movements between offshore sites might indicate that the aggregations are not static and that individuals move among sites during the spawning season.

The remaining 32 re-sightings were of fish tagged inshore, outside the spawning period, and observed at the same site within two weeks to two months post-tagging. One fish tagged at a popular dive spot was observed at that same wreck repeatedly for 8 months.

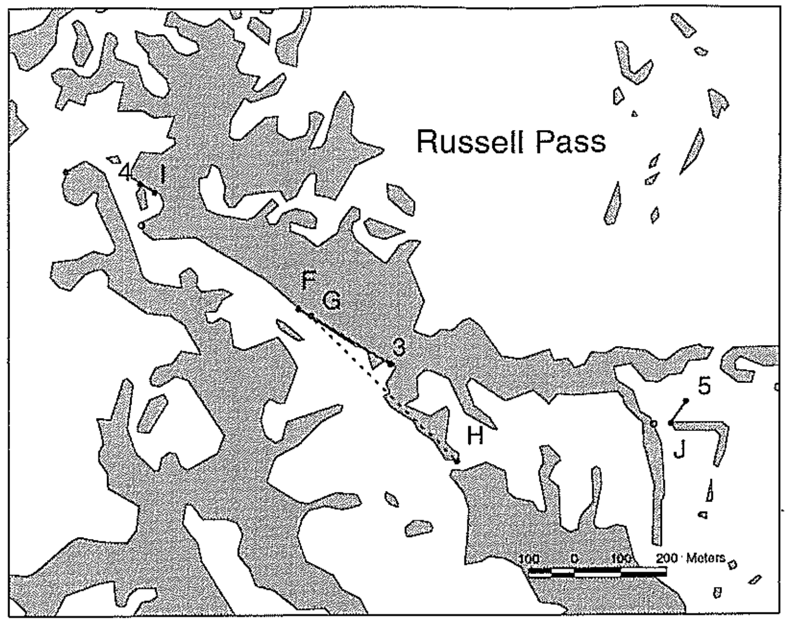

Figure 5. The Russell Pass study area for juvenile goliath grouper within the Ten Thousand Islands of southwest Florida, U.S.A. Letters represent areas where juvenile goliath grouper were tagged and recaptured, and in some cases also detected acoustically. Numbers represent areas where the fish were detected acoustically, but no lines were set there to catch the fish. Letters and numbers represent areas where fish exhibited some movement to and from those sites. The dotted line connects a site where fish were tagged to another site where the fish were subsequently recaptured. The solid lines connect sites where fish were tagged with acoustic transmitters to sites where they were later detected. The filled circle without any letter or number designation is an area where goliath grouper were caught and subsequently recaptured, but no movement was detected to or from that area. Hollow circles are sites where goliath grouper were caught but never recaptured. All fish were caught with baited circle hooks attached to set lines along mangrove shorelines.

Prior to our tagging efforts, we believed that goliath grouper might be somewhat solitary outside their summer spawning season. However, in early spring of 1999, we discovered an aggregation of goliath grouper in 5 m of water under an extended pier at Boca Grande, Florida. Since we have tagged over 200 fish in that location, we now know that these fish are much more gregarious than we had originally thought. Our misconception of goliath grouper being a solitary species (outside spawning aggregations) may be an artifact of low population numbers. Indeed, anecdotal information from historical references demonstrated that the species used to be abundant along bridges and docks all along the keys (DeMaria, 1996).

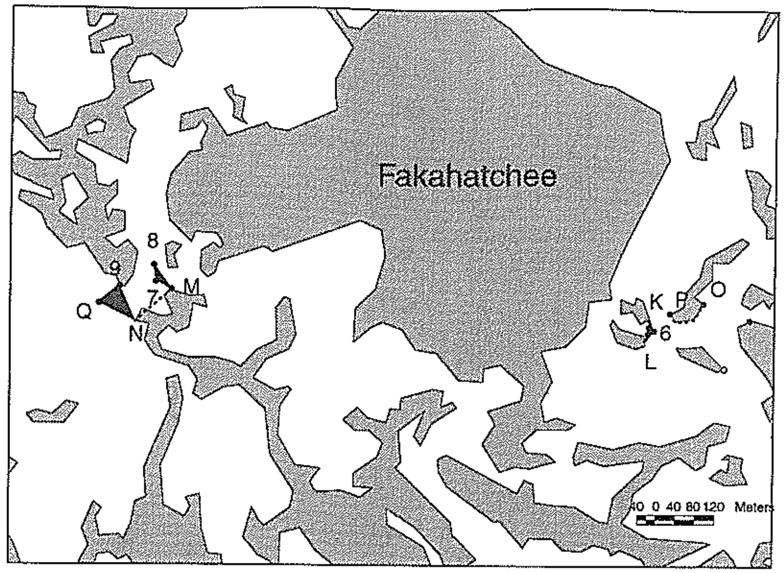

Figure 6. The Fakahatchee Island study area for juvenile goliath grouper within the Ten Thousand Islands of southwest Florida, U.S.A. Letters represent areas where juvenile goliath grouper were tagged and recaptured, and in some cases also detected acoustically. Numbers represent areas where the fish were detected acoustically, but no lines were set there to catch the fish. Letters and numbers represent areas where fish exhibited some movement to and from those sites. Dotted lines connect areas where fish were tagged to areas where they were subsequently recaptured. The three polygons describe the observed activity space of three acoustically tagged fish in the area. The polygons were created by drawing the minimum distance along the shoreline that connects all locations where the fish were either recaptured or detected acoustically. The filled circle that does not have any letter or number designation is an area where goliath grouper were caught and subsequently recaptured, but no movement was detected to or from that area. The hollow circle represents a site where goliath grouper were caught but never recaptured. All fish were caught with baited circle hooks attached to set lines along mangrove shorelines.

3.3 Limitations

There were several limitations to the mark/recapture work. First, any information on habitat and movement was limited to the tagging and recapture or re-sighting locations, with no data on the points in between capture locations. Marked fish (juveniles and adults) could only be recovered where we (or others) fished or dove, inherently biasing the descriptions of habitat. This bias is particularly true for the juvenile work, since they were captured and recaptured using baited hooks, which may attract an animal to the area. Because attraction to bait modifies typical behavior patterns, it could compromise, to some degree, descriptions of essential fish habitat. Second, we were not able to catch many juvenile fish in the winter months (Figure 9).

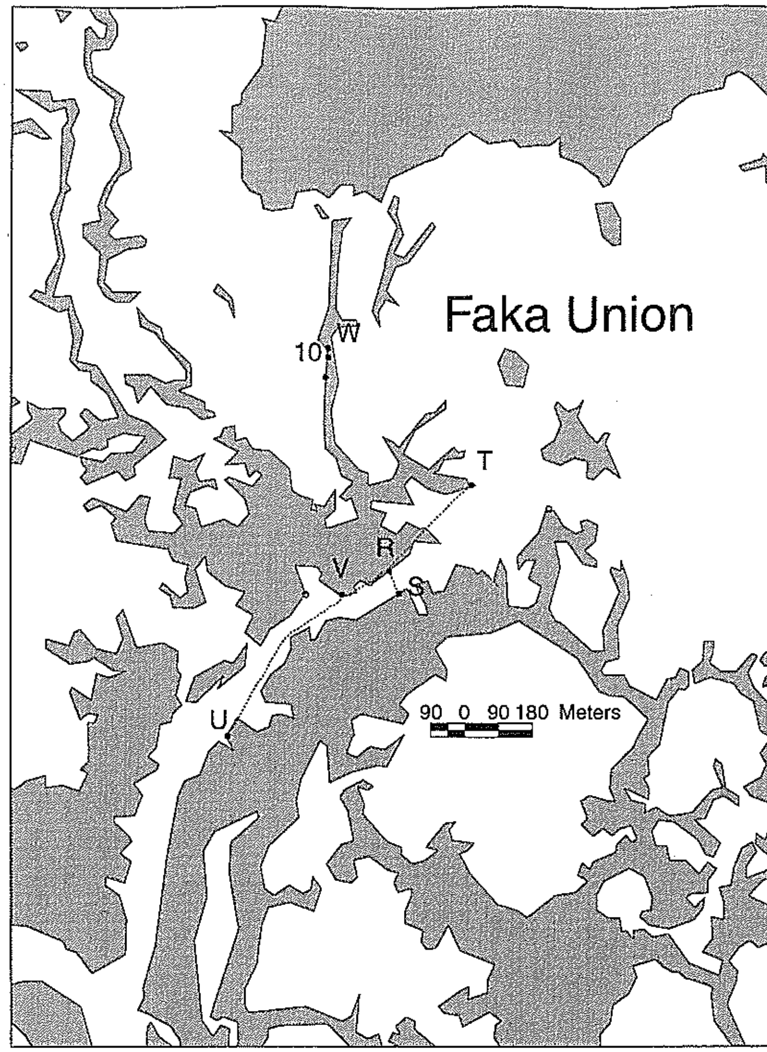

Figure 7. The Faka Union study area for juvenile goliath grouper within the Ten Thousand Islands of southwest Florida, U.S.A. Letters represent areas where juvenile goliath grouper were tagged and recaptured, and in some cases also detected acoustically. Numbers represent areas where the fish were detected acoustically, but no lines were set there to catch the fish. Letters and numbers represent areas where fish exhibited some movement to and from those sites. The dotted line connects sites where fish were tagged to other sites where the fish were subsequently recaptured. The solid line between W and 10 connects the site where a fish was tagged with an acoustic transmitter to a site where it was later detected. The filled circle without any letter or number designation is an area where goliath grouper were caught and subsequently recaptured, but no movement was detected to or from that area. Hollow circles are sites where goliath grouper were caught but never recaptured. All fish were caught with baited circle hooks attached to set lines along mangrove shorelines.

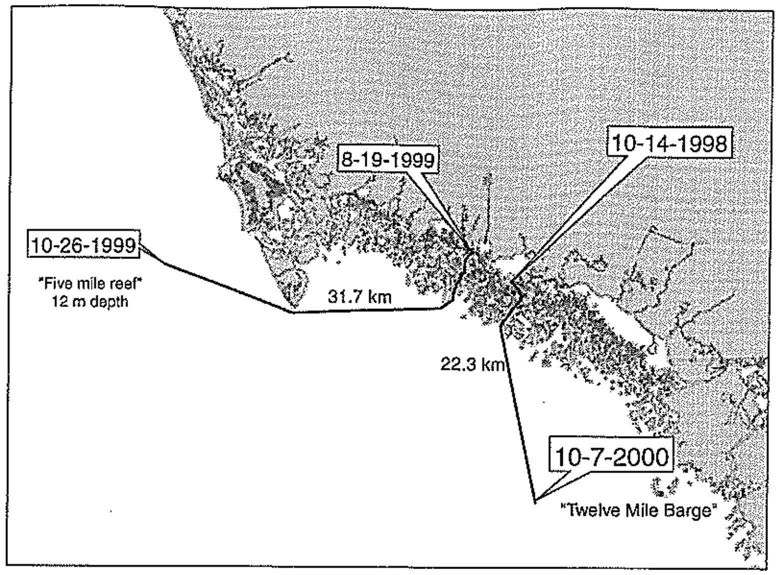

Figure 8. The movement of two goliath grouper that were tagged in the Ten Thousand Islands of southwest Florida and later recaptured on offshore artificial reefs.

Conventional tagging and recapturing could not discern whether the low catch rates were due to seasonal migrations from shallow mangrove areas to greater depths with less variable water temperature or due to reduced feeding and movement caused by reduced metabolic rates associated with cold temperatures.

We had further limitations in our tagging study of adult goliath grouper, since we were relying on visual observations of marked animals underwater or on an extremely limited catch-and-release fishery. To date, fewer than 6% of our tagged adults have been observed or caught. Even though we've been through several improvements in tag design to increase readability, the tag numbers are still difficult to read under water. Biofouling covered our early tags, and anti-fouling paint has decreased, but not eliminated, the amount of fouling on tags deployed from 1997 to the present. We also have questions about tag retention on adult goliath grouper, since we have had a few reports of tags observed on the bottom, adjacent to the Boca Grande site. The ability to detect tagged fish via acoustic telemetry can greatly enhance our work on goliath grouper movements.

4. ACOUSTIC TELEMETRY—PHASE I: DISCRETE SAMPLING

4.1 Objectives and Methodology

4.1.1 Juveniles

We were encouraged to try acoustic telemetry, based upon the results of our conventional tagging studies. The mark/recapture work revealed little to no movement of juvenile goliath grouper over two years time, suggesting that we would be able to track the fish using acoustic tags. Acoustic tagging also looked promising as a means of addressing two primary limitations we encountered during conventional tagging: (1) problems related to characterizing habitat use; and (2) problems related to seasonal migration patterns. Using hydrophones to detect tagged fish should not interfere with normal fish behavior. In addition, this method allows tracking fish year round, even during periods when catch rates using conventional methods are typically low.

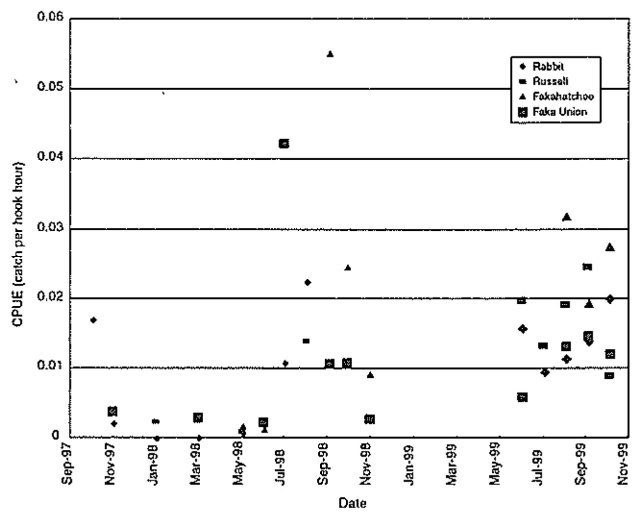

Figure 9. Seasonal catch per hook-hours of juvenile goliath grouper caught on baited circle hooks in four locations within the Ten Thousand Islands of southwest Florida, U.S.A.

We used Sonotronics' (1130 E. Pennsylvania St., Tucson, AZ 85714) transmitters that had a life expectancy of 48 months and a theoretical range through open water of one kilometer. We implanted the transmitters in the fish's peritoneal cavity through a small incision, inserted the transmitter and two internal anchor tags, then closed the incision with several surgical stitches. Using multiple anchor tags on acoustically tagged fish allowed us to immediately recognize them during conventional tagging work.

Approximately once a month, we attempted to located the acoustically tagged fish, using a portable, directional hydrophone. Each acoustic tag transmits a unique string of pulses that identifies each fish. In most cases, we could use our information on movement patterns gleaned from the conventional tagging study to give us a general idea of where to listen for the fish, if they were not near the area of last encounter. Once a fish was detected, we recorded the position with GPS. When a fish was located at the same site over several months, we confirmed that the fish was still alive by prodding the shoreline with push-poles or oars or by diving in the vicinity. This activity usually prompted the animal to move, which we could detect acoustically.

4.1.2 Adults

Because so few of the conventionally tagged adult goliath grouper were resighted and because of the problems with tag biofouling, we also tagged twelve adults with Sonotronics' ultrasonic tags. Using this method, we could detect the presence of an acoustically tagged fish without having to dive on the wrecks and observe a tagged animal. The transmitters were externally placed below the dorsal fin, in much the same way the visual tags were placed on adults. We listened for the fish with a directional hydrophone during our annual cruises to census the spawning aggregations.

4.2 Successes

4.2.1 Juveniles

Of the 14 juvenile fish tagged in the mangrove habitat, we were able to follow 9 fish successfully. Throughout the year, the majority of the fish were detected at the original tagging sites, although not all fish were detected during each sampling event. Most acoustically tagged fish remained close to the mangrove undercuts where they were originally tagged, demonstrating small activity areas of 330-6350 m^2 (Figures 4-7). Acoustic tracking revealed a second type of habitat: deep depressions of shell and rock in tidal passes, away from the shoreline (e.g., site 2 in Figure 4, site 5 in figure 5, sites 6-8 in Figure 6, site 10 in Figure 7). This habitat may be used as tidal and/or thermal refugia, although we have detected fish acoustically in the depressions year round at both high and low tide.

Fish that remained undetected for several months would sometimes reappear in the same location in which they were tagged. However, we found no seasonal pattern to their presence or absence. In fact, the majority of the fish were detected at the same sites throughout the year, giving us no evidence of seasonal migration. Although our catch rates were much lower in the colder months (Figure 9), the acoustic study provided evidence that the fish do not migrate from the area seasonally. A more likely explanation for our lower catch rates is that the colder water temperatures depress the goliath grouper metabolism and lower their movement and consumption rates. Goliath grouper are known to be susceptible to cold weather and have been reported in historical fish kills (Sadovy and Eklund, 1999).

Another aspect of goliath grouper behavior that we have learned through both our visual and acoustic tracking is that these fish are gregarious or social in nature. Several of the recaptured fish exhibited overlapping movements, and both of our acoustically tagged fish in Rabbit Key Pass have been found together at the same site for several months. Using SCUBA, we've seen as many as three goliath grouper close enough to be almost touching.

4.2.2 Adults

Since the adult goliath grouper exhibit seasonal migrations and much greater movements than the juveniles, we were less likely to detect clear patterns, especially considering our small sample size (12 fish). It does not necessarily require a large sample size, however, to gain insightful information. One fish that we tagged with a transmitter at one wreck was heard the next day on another aggregation site 6.6 km away. That information may be indicative of the dynamics of these aggregation sites. We have not detected any of our other acoustically tagged adult fish.

4.3 Limitations

We were unable to detect five (36%) of the 14 juvenile fish that were tagged acoustically. Of those five undetected fish, one died, two experienced transmitter failure, and we were unable to explain the remaining two absences. We confirmed the mortality when the transmitter, *sans* carcass, was found at the high tide mark during a spring low tide. The transmitter failures were due to problems with the magnetic switch for the battery (Sonotronics, pers. comm.). Subsequent orders of transmitters arrived without the magnetic switch, in an attempt to avoid this particular problem. Unfortunately, battery life was wasted without some means for leaving the transmitter off until time of tag placement.

We have been unable to detect four of five fish in Russell Pass since August 1999. Since all of the acoustically tagged fish in Rabbit Key and in Fakahatchee were heard throughout the fall and winter, we do not attribute their absence in Russell Pass to seasonal migration. More likely, they have moved deep in the mangrove undercuts where the mud and mangrove roots could block the signal. Another plausible explanation for the missing fish is that they move periodically between tidal refugia and their original tagging sites. These disappearances underscore one of the more problematic limitations of acoustic tracking. Namely, that non-detection of a fish does not give us enough information. Non-detection may not necessarily mean that the fish is not there, since the signal can easily be blocked in the dense undergrowth. Continuous tracking could help elucidate what had happened to these fish and to provide better information on movement and site residency patterns.

Since the adult fish were tagged on offshore wrecks that we only visit once or twice per year, our effort to detect them was limited. We learned from conventional tagging studies that at least some adults, unlike juveniles, undertake large migrations and exhibit short-term movements among aggregation sites, several kilometers apart. Our visual tagging work on the adults did not give us as much information on micro-scale movements. Fish could remain static on a small wreck site or might move off the wreck in an unknown direction. Thus, our ability to track the adults with a directional hydrophone was limited. We have only detected one of the twelve acoustically tagged fish.

Through both the visual and acoustic tagging, we have evidence of site fidelity and also of inter-aggregation movements. Using these methods, however, we could not determine whether most of the fish remain on the same site throughout the spawning period or to what extent they exhibit inter-aggregation movements. Both re-sighting of visual tags and the detection of the acoustic tags that we have used thus far merely give us a single point in time. A continuous recording of acoustic-tagged fish at each of the known aggregation sites would more adequately assess site fidelity and inter-aggregation movements of adult goliath grouper during the spawning season.

5. ACOUSTIC TELEMETRY—PHASE II: CONTINUOUS DATA LOGGING

5.1 Objectives and Methodology

Diel movements, habitat utilization and site residence times can be better described through continuous acoustic tracking either manually or with continuously recording data loggers. A hydrophone equipped with a data recorder can log presence/absence of a fish. We have much greater odds of detecting the acoustic signal through data loggers than we do with discrete monthly or annual searches using a manually operated hydrophone. Discrete sampling only gives us information about fish presence or absence at that one moment in time, but it does not provide us with any data on whether the fish was present yesterday or will be there tomorrow.

5.1.1 Juveniles

Our visual and acoustic tagging results have given us a good indication of the area of activity that the juvenile goliath grouper utilize. In Rabbit Key and Fakahatchee, we have been able to construct minimum convex polygons to describe several fish's activity space (Figures 4 and 6). In October 2000, we set up two data-logging acoustic receivers in Rabbit Key Pass at areas within those polygons (Figure 4). We used Vemco (100 Osprey Drive, Shad Bay, Nova Scotia, Canada, B3T 2C1) VR1 receivers, because they can be easily transported and can be moored on the bottom. Since they cannot be seen from the surface, we were unconcerned about theft or vandalism.

Four juvenile fish (ranging in size from 410 to 840 mm TL) were tagged internally with 16-mm acoustic transmitters that emit unique pulses every two minutes at 69 MHz, the frequency that the VR1's receive. Two fish were tagged at point E, one at point C, and one inside the creek at point D (Figure 4). One VR1 receiver was placed across from point E, moored at the bottom of a channel marker. Another receiver was placed 2 m away from point C, slightly in the channel and at the mouth of the small creek (Figure 4). We conducted range tests for each receiver and found that the ranges for the two receivers overlapped slightly. If any tagged fish were to move along the shoreline (within the already defined activity space in Figure 4), then they would be detected by one of the two receivers. Two of the tagged fish were recaptures from our conventional tagging experiment. One of the recaptures had been caught three times previously, either at point C or point D (Figure 4), and the other was originally tagged at point D. Thus, we already had some information on their activity patterns and expected them to remain in the area of the receivers' ranges. The receivers can stay submerged, collecting data for up to six months, limited by memory capacity and/or battery life.

5.1.2 Adults

Similar to the juvenile work, we set up VR1 receivers to record the presence of adult goliath grouper on three offshore spawning aggregation sites and at one inshore site (the Boca Grande pier). Since our visual and acoustic work demonstrated that some fish return to the same areas each year and that there is also some movement among the aggregation sites, continuous data loggers allowed us to monitor the dynamics of these spawning aggregations. The receivers can document the onset and extent of inshore/offshore migrations and the movement among the offshore sites. Similar work using VR1 receivers has been highly successful in describing habitat and movement patterns of tautog in Chesapeake Bay (Arendt, in press) and sharks in Sarasota Bay (Heupel and Hueter, this volume).

We used 16-mm acoustic tags in 10 adult goliath grouper at the Boca Grande Pier in June 2000 and in 20 adults on three offshore aggregations during spawning periods in August and September 2000 (Figure 2). Fish were caught on line and brought to the surface for internal tag placement. While on the surface, we measured each fish and took samples of dorsal fin rays for age and growth analysis.

5.2 Successes

5.2.1 Juveniles

After two months of data logging in the mangrove habitat, we downloaded the receivers in December, 2000. The receiver at point C (Figure 4) repeatedly (and almost daily) detected the fish tagged at that location, but it never detected either of the two fish that were tagged at point E or the fish that was tagged in the creek at point D (Figure 4). The receiver across from point E recorded the presence of both fish tagged in that area every day, but it did not detect the other fish that were tagged at points D and C. In both cases, the receiver recorded the presence of the fish intermittently, throughout each day. There were hours of time when the fish were not recorded, presumably due to the fish withdrawing farther into the mangrove undercuts, where reception of the transmitters would be limited. Further analysis will provide us with information on diel and tidal activity patterns. Over the two months of study, we found no evidence of the fish moving in our predicted activity space along the shoreline or any tagged fish moving in or out of the creek area. Perhaps, over a longer time series we will observe such movements. We predict that activity patterns will increase in the summer, when the water temperature increases.

Even with such a short time series, however, it is already apparent that we can collect data more efficiently using the data loggers than we can through our monthly checks using the manually operated hydrophone. For example, during one field day of data downloading, we collected two months of continually recorded data on three fish. On that same day, we attempted our manual tracking of nine fish previously tagged with the Sonotronics transmitters (see previous section) and found only three of them.

The information gained per man-hour of tracking was minimal compared to that gained from the data logger. The manual tracking gave us a single position for each of three fish on one single day, but the data loggers gave us presence/absence of three fish for every two minutes from October 5 to December 12.

5.2.2 Adults

Figure 10 describes the presence or absence of the ten fish that were tagged at Boca Grande Pier, from June 24, 2000 through January 23, 2001, when the data were downloaded. Overall, each fish appeared to behave independently of the others, with three fish remaining in the area almost constantly and others disappearing for days or weeks at a time, particularly during the spawning period of July-September. All of the fish disappeared in December, possibly owing to cold water temperatures. Not one of the ten fish was detected at the three aggregation sites where we had other VR1 receivers stationed.

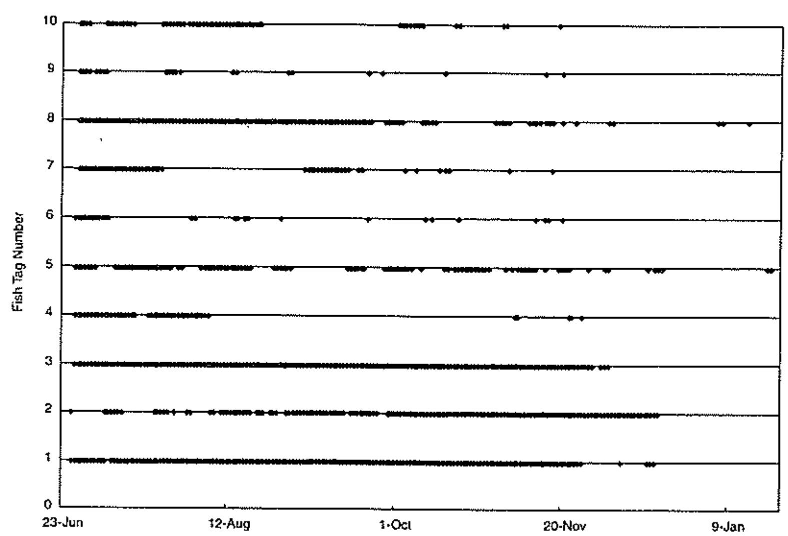

Figure 10. Detection of acoustically tagged fish by a VEMCO VR1 receiver moored at the Boca Grande Pier at the mouth of Charlotte Harbor, Florida, USA, from June 2000 through January 2001. Black diamonds indicate when each tagged fish was detected. A space with no black diamonds indicate when a fish remained undetected for more than 24 hours.

Most of the twenty adults that were tagged offshore during the spawning season remained site-faithful for much longer than we had anticipated, since we had perceived the aggregations as seasonal spawning sites. Out of 17 fish tagged on the Californian wreck in August and September, 12 were still detected on the wreck in November or early December, when receiver's memory became full (Figure 11). Four others had left the wreck in September or early October and one fish (#33) was detected only sporadically after September. Both fish tagged on a shrimp boat wreck had disappeared by the end of September, but the one fish tagged at a navigation tower remained on the tower through January 2001. The receiver at the tower also detected two of the Californian tagged fish, who visited the tower for less than a day; the Californian and the tower are 6.6 km apart. Prior to this data collection, we had anecdotal data suggesting that these aggregations were seasonal in nature. These data revealed that the majority of the fish observed during the spawning season were residents of the sites, not seasonal visitors.

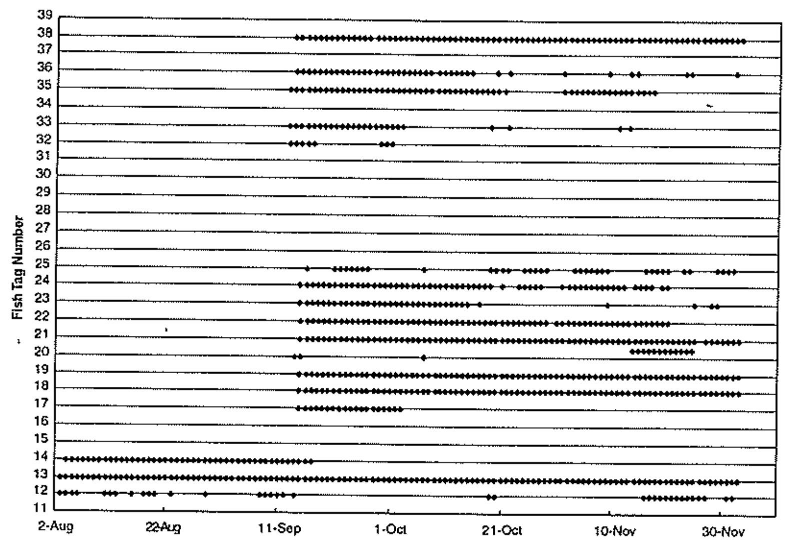

Figure 11. Detection of acoustically tagged fish by a VEMCO VR1 receiver moored at the Californian, a ship wreck in 30-40 m water depth in the eastern Gulf of Mexico, from August through December 2000. Black diamonds indicate when each tagged fish was detected. A space with no black diamonds indicate when a fish remained undetected for more than 24 hours.

5.3 Limitations

Although the data-log ging capabilities of the VR1s are extensive, they can provide no information on fish location when fish move away from receivers. We know that we lose detection capabilities for juvenile fish, when they withdraw farther into the mangrove overhangs. This loss is indistinguishable from that associated with fish leaving the area altogether. Presumably, when the juveniles grow to the adult stage they may undertake ontogenetic migrations to the reefs, where the adults reside. Acoustic tracking, either manually or with data loggers, will not give us information on any large scale and unidirectional movements of these fish.

In the adult study, finding any of the 10 fish tagged inshore on one of the three offshore sites, where receivers are moored, would be extremely good fortune. Likewise, it would be serendipitous if some of the 20 fish tagged at the summer spawning aggregations were to migrate to Boca Grande to be detected by the receiver moored on the pier. We know that these migrations are possible, based on our conventional tagging study (Figure 2); however, it is also very possible that these fish remain at the tagging sites throughout the year. If the fish do move to other unknown places both inshore and offshore, the route that they may take during these migrations is also unknown, making manual tracking difficult at best. Continuous manual tracking of these fish would be extremely labor intensive, since we do not as yet know when the onset of migration occurs, and since the migrations may well be over 50 km in length.

6. SATELLITE TRACKING

6.1 Future Objectives and Methodology

Our next phase of telemetry work involves the use of satellite "pop-off" tags. This method likely can provide answers to three key questions that thus far have alluded us using other tagging methods: (1) What is the ontogenetic migration route from the juvenile mangrove habitat to the adult offshore reef habitat? (2) What is the spatial extent of spawning migrations? (catchment area of aggregations) and (3) Where do the spawning aggregations occur on natural reef sites?

6.1.1 Juveniles

Divers have observed few young adult goliath grouper on reefs. The largest juveniles observed in mangrove habitats are about 1000 mm TL. Since there is no directed fishery for this protected species, we do not expect to receive much more information on migrations through mark/recapture. Satellite tracking with pop-off, archival tags could give us useful information on ontogenetic migrations. Although archival tags are expensive, we will only need returns from a few fish of the largest juvenile size class found in mangroves to make this project possible. Large juveniles will be equipped with archival tags, externally placed below the dorsal fin. These temperature and pressure-sensitive tags will record depth at 2% of the programmed depth range (e.g., for programmed depths ranging from 0 to 30 m, it will record depths to 0.6 m precision). The tags will be programmed to disengage from the animal one year post tagging, increasing the probability that large fish will have left the mangrove area. Once the tag reaches the surface, it will communicate with the Argos satellites, which will record its position. The tag will then be retrieved and the data downloaded, providing information on depth and temperature changes during migration and/or any temperature induced cues to migration. The depth sensor will also confirm when the tag was on the fish.

6.1.2 Adults

If fish are tagged on spawning aggregations with satellite transmitters programmed to disengage several months post-spawning, then we can discover the extent of movement after spawning. For example, it appears that some gag (*Mycteroperca microlepis*) aggregating to spawn in the northeast Gulf of Mexico may have migrated from as far away as the South Carolina coast (Coleman et al., 1999). Inferences of stock structure can be drawn from such information and would be instrumental in developing management strategies, including the design of marine protected areas.

If fish are tagged on resident sites outside the spawning season and the tags are programmed to disengage during peak spawning, we might be able to locate previously undiscovered spawning aggregation sites, perhaps including some yet unknown natural reef areas. Fish from inshore Gulf of Mexico waters, as well as those from the Florida Keys and points north along the Atlantic coast will be targeted for these satellite transmitters. By retrieving the archival tags after the satellite transmission, we will also gain data on depth changes during the spawning migration and possible temperature cues to the initiation of the migration.

6.2 Limitations

There are limits to the Argos system, particularly at the low latitude of our study area. The four Argos satellites are polar orbiters that only pass five times per day at 25 degrees North latitude, with each pass low on horizon. The position of the tag may only be resolved within several kilometers. However, the resolution of the satellite tracked positions should still be enough for us to understand the general area of ontogenetic and spawning migrations, and the archived data on the tag will give us information on the dates and depths of migration. Unlike studies conducted on transoceanic migrators, such as bluefin tuna (Block et al., 1998), we will not attempt to calculate geoposition through archived data on these tags. Block et al. (1998), among others, have been able to use data generated from light meters on the tags to calculate latitude and longitude. Since the geoposition data can only be resolved within one degree of latitude, there is no reason to collect light data for goliath grouper, which may only migrate a couple hundred kilometers at the most.

7. SUMMARY

We have presented here the evolution of our tagging studies of goliath grouper populations in southern Florida. We have used a step-wise approach in our conventional tagging and biotelemetry studies to elucidate goliath grouper life history, behavior and population dynamics. Each phase of our tagging work has led to the next phase, in ever increasing technological complexity. It is worth noting that increases in technological complexity are not necessarily accompanied by increases in information quality. For instance, some of our most important results have come from our conventional tagging studies of juvenile goliath grouper. Acoustic and satellite telemetry, however, have provided, or will provide, answers to questions that cannot be addressed adequately with visual tags.

Using conventional tags, we have learned where adult and juvenile fish are found and the extent of their movements over time. We are also able to estimate juvenile abundance, growth rates and survival rates by recapturing individuals. The acoustic work has given us a much better description of seasonal activity patterns, habitat utilization, fine-scale movements of the juveniles, and inter-aggregation movements of the adults.

Using the acoustic data to assess habitat use, we are currently testing hypotheses relating to the effects of habitat limitation, by comparing goliath grouper densities in areas with different amounts of shoreline undercuts and bathymetric heterogeneity. Without our acoustic tagging work, we would not have had enough information on habitat use to proceed. The acoustic tracking has given us a better estimation of juvenile goliath grouper home ranges, so that we could convert our abundance estimates from the mark/recapture study into density estimates.

Continuous tracking of acoustically tagged animals has facilitated our description of home ranges, daily activity patterns, and site fidelity. It is only through our acoustic data-log ging methods that we have determined the residency patterns of our adult goliath grouper, both inshore and offshore. Satellite telemetry should provide insights into ontogenetic and spawning migrations.

Each sampling method has certain limitations. Assessment of abundance and growth rates required larger sample sizes that were only economically feasible with conventional tagging methods. Smaller sample sizes, however, are sufficient to elucidate ontogenetic or spawning migrations. Therefore, the more expensive satellite tracking can be done on a smaller number of individuals, whereas the lower cost visual tags are best used for larger sample sizes.

Our stepwise approach allowed us to use the experience and information gained from each tagging method to plan subsequent experiments. We learned from our conventional tagging studies that the goliath grouper are hardy, have a high tag retention rate, and have a high degree of site fidelity. Armed with that information, we knew that an acoustic tracking experiment could be successful. The visual and acoustic tagging results were used to plan placement of the data-log ging equipment for the more intensive, continuous acoustic tracking. Discrete acoustic sampling demonstrated that juvenile goliath grouper are often, but not always in a localized area. Continuous acoustic tracking with data loggers revealed how long they remain at their home sites. Both visual and acoustic tagging helped us realize that the adults may move among aggregation sites, but continuous tracking has shown that such movements are uncommon. The data loggers also revealed that the majority of the fish at the offshore sites are residents, not seasonal visitors. Finally, results from both conventional and acoustic tagging have given us some indications of longer range ontogenetic and spawning migrations, so that satellite telemetry can be used on a small number of individuals to determine the long range movements which acoustic sampling cannot describe.

ACKNOWLEDGEMENTS

We are extremely thankful for the help and expertise of our colleagues, Christopher Koenig and Felicia Coleman, who have been an integral part of this project and without whom this research would not have been possible. We would also like to thank the many individuals that assisted us in the field, especially Don DeMaria who has single-handedly tagged all of the adult goliath grouper in our study, Larry Demere who showed us where and how to catch the juveniles, and Dr. Matt Finn who caught so many of them for us. Todd Bevis has been an important part of this project and we thank him immensely for his dedication to various aspects of the research. We would also like to thank Dave McClellan, Peter Fischel, Joe Contillo and countless others who have braved mosquitoes and lightening all in the name of science. Jim Tobias was instrumental in plotting our data onto GIS maps. NOAA-Fisheries' Office of Protected Resources, Everglades National Park, and the Curtis and Edith Munson Foundation provided funds to make this research possible.

REFERENCES

Arendt, M. (2001) Diel and seasonal activity patterns of adult tautog (*Tautoga onitis*) in lower Chesapeake Bay, inferred from ultrasonic telemetry. *Env. Biol. Fish* (in press).

Block, B.A., Dewar, H., Williams, T., Prince, E., Farwell, C., Fudge D. (1998) Archival tagging of Atlantic bluefin tuna (*Thunnus thynnus thynnus*). *Mar. Tech. Soc. J.* **32**, 37-46.

Block, B.A., Booth, D.T, and Carey, F.G. (1992) Depth and temperature of the blue marlin, *Makaira nigricans*, observed by acoustic telemetry. *Mar. Biol.* **114**, 175-183.

Boreman, J. (1996) Why tag fish? *Underwat. Nat.* **23**(2), 15-17.

Bullock, L.H., and Smith, G.B. (1991) Seabasses (Pisces: Serranidae). Memoirs of the Hour Glass Cruises, 8 (2), 243 pp.

Bullock, L.H., Murphy, M.D., Godcharles, M.F., and Mitchell, M.E. (1992) Age, growth, and reproduction of jewfish *Epinephelus itajara* in the eastern Gulf of Mexico. *Fish. Bull. U.S.*, **90**, 243-249.

Coleman, F.C., Koenig, C.C., Eklund, A.M., and Grimes, C.B. (1999) Management and conservation of temperate reef fishes in the grouper-snapper complex of the southeastern United States. *In* Musick, J.A. (ed.) Life in the Slow Lane: Ecology and Conservation of Long-Lived Marine Animals, American Fisheries Society Symposium 23, Bethesda, Maryland. pp. 233-242.

Commiskey, P.A. (1999) The use of ultrasonic tags for life history studies of red king crab in Womens Bay, Kodiak, Alaska. (*Abstract*) *Fifteenth International Symposium on Biotelemetry*, Juneau, Alaska, May 9-14, 1999.

Cruz-Escalona, V.H., Abitia-Cardenas, L.A., Campos-Davila, L., and Galvan-Magana, F. (2000) Trophic interrelations of the three most abundant fish species from Laguna San Ignacio, Baja California Sur, Mexico. *Bull. Mar. Sci.* **66**, 361-373.

Davis, T., and Gunn, J. (1992) Archival tagging provides detailed data. *Aust. Fish.* **51**, 31.

DeMaria, K. (1996) Changes in the Florida Keys marine ecosystem based upon interviews with experienced residents. The Nature Conservancy and Center for Marine Conservation Special Report, The Nature Conservancy, Key West, FL.

de Morais, L.T., and Raffray, J. (1999) Movements of *Hoplias aimara* during the filling phase of the Petit-Saut dam, French Guyana. *J. Fish Biol.* **54**, 627-635.

Gulf of Mexico Fishery Management Council (GMFMC) (1990) Amendment number 2 to the fishery management plan for the reef fish fishery of the Gulf of Mexico, 31pp.

Gunn, J.S., Stevens, J.D., Davis, L.O., and Norman, B.M. (1999) Observations on the short-term movements and behaviour of whale sharks (*Rhincodon typus*) at Ningaloo Reef, Western Australia. *Mar. Biol.* **135**, 553-559.

Hudson, E., and Mace, G. (1996) Marine fish and the IUCN red list of threatened animals. Report of the workshop held in collaboration with WWF and IUCN at the Zoological Society of London from April 29th-May 1st, 1996, Institute of Zoology, Zoological Society of London, London.

Koenig, C. C., and Coleman, F. C. (1998) Absolute abundance and survival of juvenile gag, *Mycteroperca microlepis* in seagrass beds of the northeastern Gulf of Mexico. *Trans. Am. Fish. Soc.* **127**, 44-55.

Krebs, C.J. (1999) *Ecological Methodology*. Addison-Welsey Educational Publishers, Inc., Menlo Park, California, 620 pp.

Laird, L.M., and Stott, B. (1978) Marking and tagging. *In* Bagenal, T. (ed.) *Methods for Assessment of Fish Production in Fresh Waters*, Blackwell Scientific Publications, Oxford, England, pp. 84-100.

Lutcavage, M.E., Brill, R.W., Skomal, G.B., Chase, B.C., and Howey, P.W. (1999) Results of pop-up satellite tagging of spawning size class fish in the Gulf of Maine: Do North Atlantic bluefin tuna spawn in the mid-Atlantic? *Can. J. Fish Aquat. Sci.* **56**, 173-177.

Mather, F.J., Mason, J.M., and Jones, A.C. (1995) Historical document: life history and fisheries of Atlantic bluefin tuna. NOAA Technical Memorandum, NMFS-SEFSC-370, 165 pp.

Musick, J.A., Harbin, M.M., Berkeley, S.A., Burgess, G.H., Eklund, A.M., Findley, L., Gilmore, R.G., Golden, J.T., Ha, D.S., Huntsman, G.R., McGovern, J.C., Parker, S.J., Poss, S.G., Sala, E., Schmidt, T.W., Sedberry, G.R., Weeks, H., and Wright, S.G. (2000) Marine, estuarine, and diadromous fish stocks at risk of extinction in North America (exclusive of Pacific salmonids). *Fisheries* **25**, 6-30.

Nielson, L.A. (1992) Methods of Marking Fish and Shellfish. American Fisheries Society, Special Publication 23, Bethesda, Maryland, 208 pp.

Priede, I.G., Smith, K.L., Jr., and Armstrong, J.D. (1990) Foraging behavior of abyssal grenadier fish: inferences from acoustic tagging and tracking in the North Pacific Ocean. *Deep Sea Res.* **37**, 81-101.

Sadovy, Y., and Eklund, A. (1999) Synopsis of biological data on the Nassau grouper, *Epinephelus striatus* (Bloch 1792), and the jewfish, *E. itajara* (Lichtenstein 1822). U.S. Dep. Commer., NOAA Tech. Rep. NMFS 146, and FAO Fisheries Synopsis 157, 65 pp.

Schaefer, H.C., and Fable, W.A., Jr. (1994) King mackerel, *Scomberomorus cavella,* mark-recapture studies off Florida's east coast. *Mar. Fish. Rev.* **56**, 13-23.

South Atlantic Fishery Management Council (SAFMC) 1990. Amendment Number 2. Regulatory impact review. Regulatory flexibility analysis and environmental assessment for fishery management plan for the snapper-grouper fishery of the South Atlantic region, 47 pp.

Turner, S.C., Restrepo, V.R., and Eklund, A.M. (1990) A review of the growth of Atlantic bluefin tuna, *Thunnus thynnus.* ICCAT Working Document, SCRS/90/78.

Welch, D.W., and Eveson, J.P. (1999) An assessment of light-based geoposition estimates from archival tags. *Can. J. Fish. Aquat. Sci.* **56**, 1217-1227.

Wetherbee, B.M., and Rechisky, E. (1999) Movement patterns of juvenile sandbar sharks on their nursery grounds in Delaware Bay. (Abstract) Fifteenth International Symposium on Biotelemetry, Juneau, Alaska, May 9-14, 1999.

Xiao, Y. (1996) A framework for evaluating experimental designs for estimating rates of fish movement from tag recoveries. *Can. J. Fish. Aquat. Sci.* **53**, 1272-1280.

Yano, K. (1999) Telemetry studies on the movements of the zebra shark and tawny nurse shark at the Yaeyama Islands, Okinawa, Japan. (Abstract) Fifteenth International Symposium on Biotelemetry, Juneau, Alaska, May 9-14, 1999.

Yano, K., Ochi, Y., Shimizu, H., and Kosuge, T. (1999) Diurnal swimming patterns of the diamondback squid as observed by ultrasonic telemetry. (Abstract) Fifteenth International Symposium on Biotelemetry, Juneau, Alaska, May 9-14, 1999.