Report from the Scientists

Follow-On to the 12 March 2013 Gulf of Mexico Fishery Management Council Science Workshop on Goliath Grouper

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Other attendees involved in the research: Robert Ellis (FSU), Geoffrey Shideler (UMiami), Orian Tzadik (USF)

BACKGROUND.— The intent of this document is to provide an overview of the status of goliath grouper and to update the SEDAR 23 (2009) Research Recommendations. The update to SEDAR 2009 is provided in an annotated format to show where progress has been made, what studies are currently underway, and to provide additional recommendations for research, as agreed upon by the scientists contributing to this document. Included as an appendix is a short treatise written by Koenig and Coleman on the vulnerability of goliath grouper populations, comparing the science with non-science based opinions on their status, per the GMFMC's request. A summary of the workshop itself will be provided by the Gulf of Mexico Fishery Management Council staff.

Components of the Report include the following:

Basic Information about Goliath Grouper

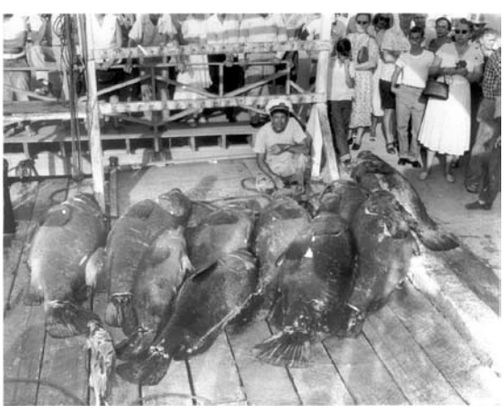
Goliath grouper is the largest of the western north Atlantic groupers. It can reach about 455 kg (800 lbs) and over 2-m total length. The following features can easily distinguish goliath grouper: broad head, round tail, small eyes, and short dorsal spines. They tend to have a brownish-yellow or greenish-gray mottled pattern and small black spots on their fins. Fish mature at 5 or 6 years of age at about one meter in length. They are relatively long lived, with individuals at least 37 years old found in exploited populations. However, it is possible that older fish occurred in unfished populations.

Goliath grouper occur in tropical and subtropical waters of the Atlantic Ocean, on both coasts of Florida, and from the Gulf of Mexico down to the coasts of Brazil and the Caribbean. Most adults occur on shallow reefs, the deepest being about 260 ft (80 m) (NMFS 2006). They form spawning aggregations of about 100 individuals at consistent sites from July through September. Fish may move up to 200 km from inshore reefs to these spawning sites, which typically occur offshore on rock ledges, isolated patch reefs, and shipwrecks[1].

After spawning, the fertilized eggs hatch into a small larva that spend about 6 weeks in open water before settling in shallow mangrove habitat along the coast, first in mangrove leaf litter, and then along mangrove shorelines. Juveniles remain in the mangroves for 5 or 6 years, by which time they start to mature and egress to shallow reefs, eventually joining adult populations offshore. Their distribution in mangroves depends on local water quality, particularly dissolved oxygen content (> 4 ppm) and mid-range salinities (> 10 ppt).

Global Threats to Goliath Grouper

Goliath groupers are vulnerable to cold temperatures and to red tides, but clearly the greater threats are overfishing and habitat loss, which can lead to local extinction. In the United States, fishing pressure was so intense during the 1970s and 1980s that many aggregations disappeared and the population declined dramatically, leading both the Gulf of Mexico Fishery Management Council and the South Atlantic Fishery Management Council to close the fishery throughout the federal waters of the southeastern U. S. entirely in 1990 and throughout the Caribbean in 1993[2]. The U. S. then listed the goliath grouper as a candidate species to the Endangered Species List (ESL) in 1991 throughout its geographic range in U. S. waters--an area extending from North Carolina southward through the Gulf of Mexico. National Marine Fisheries Service, under the authority of the Magnuson-Stevens Fisheries Conservation and Management Act, continues to list the goliath grouper as overfished in Reports to Congress on the Status of Fisheries, but no longer lists it as a candidate for the ESL. The World Conservation Union (IUCN), however, classifies this species as critically endangered throughout most of its range.



Overfishing. -- Goliath Grouper have been overexploited to the point of economic extinction. It was in large part due to public testimony of commercial fishers on the status of the fishery that resulted in protection for this species by the Gulf of Mexico and South Atlantic Fishery Management Councils. Goliath grouper's susceptibility to overexploitation is in part due to their slow growth, longevity, and large size at sexual maturity. In addition, because they aggregate to spawn and are

[1] Collins et al telemetry work indicates that at least 1 individual travelled 175 km to reach the Stoney wreck during spawning season

[2] This may only be for US territories. There is likely legal fishing on other islands in the Caribbean, but we need confirmation. Anyone?

also predictably associated with high relief habitat throughout the rest of the year, they are easy targets for exploitation. This is true for any species in which large numbers of otherwise widely-dispersed fish become concentrated in predictable areas and times. Fishing on spawning aggregations reduces spawning potential and increases catch-per-unit-effort to the point of population collapse, while also removing reproductive individuals that are usually the largest fish in the population. Indeed, intense recreational and commercial fishing pressure contributed to the population decline of goliath grouper in the 1980s. Similar fishing-induced declines have occurred on spawning aggregations of Nassau grouper *Epinephelus striatus*, gag *Mycteroperca microlepis*, and other grouper species throughout the world.

Mangrove Habitat Loss. -- Juvenile goliath grouper recruit to mangrove habitat throughout their geographic range. This habitat in Florida has declined since the early 1900s due to channelization to redirect freshwater flow from the Everglades, mosquito-abatement, and development for agricultural, industrial, and residential purposes. Most of the existing mangrove habitat in the entire United States occurs along the west Florida coast. Very little mangrove habitat remains on the southeast coast. Because mangroves serve as important juvenile habitat for these fish, their loss could restrict goliath population recovery even if reproductive levels of adult fish are high.

2009_SEDAR23 Section IV. 1. DATA WORKSHOP RESEARCH RECOMMENDATIONS

Note –The black text below is the 2009 Sedar Report. Blue text indicates updates since the 2009 SEDAR report provided by contributors to the March 2013 workshop report.

1.1 LIFE HISTORY WORKING GROUP

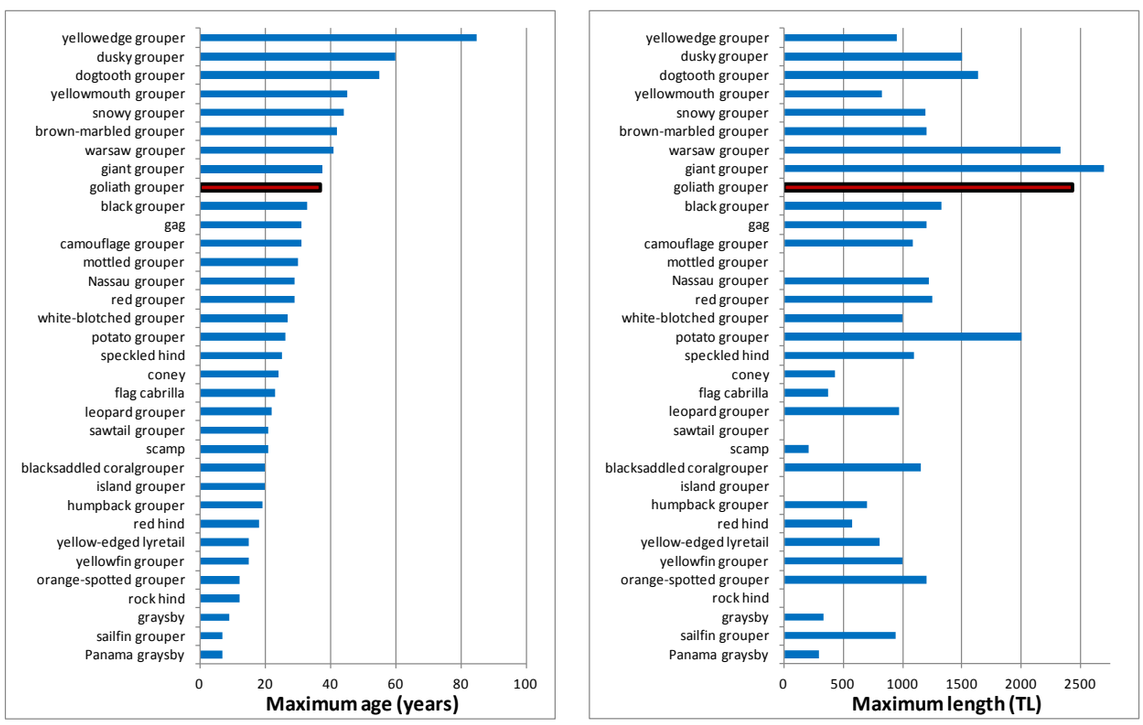
Stock Definition:

- D. Jones has new MARFIN funding to use otolith microchemistry (laser ablation) to determine if there are distinct subpopulations based on geographic differences in chemical signatures. Juvenile habitat would be represented at the origin of otolith, adult habitat at the margins (SA and/or Gulf) ***goliath grouper were not originally considered in this MARFIN proposal, but could easily be added with availability of otoliths and moderate time resources.*
- Koenig referenced the availability of goliath grouper eggs from the SA and GOM which could be used for genetic population structure analysis. Eggs will be sampled for Dr Matthew Craig (U Puerto Rico) who has done the most extensive work on goliath grouper population genetics (Craig et al. 2009)
- Description of larval stages of goliath grouper is part of an ongoing MARFIN project by Koenig and Coleman (= Koenig and Coleman 2010).
- Collins contributed genetic samples from opportunistic mortality events that potentially identified a genetic bottleneck of goliath grouper in Florida (Seyoum et al., 2013). Recent research in the GoM (Collins) and in the Atlantic (Koenig and Coleman) has resulted in a broader sampling area and an increased number of genetic samples. Collaboration between Collins, Koenig and the FWRI genetics lab (Seyoum et al.) is ongoing. The results of these analyses should contribute important information regarding the genetic structure of the adult population in Florida waters.
- Limited recent drifter studies along the US South Atlantic coast have shown the potential for wide distribution patterns along the coast from Cape Hatteras to the Florida Keys (Lesher and Sedberry, SEDAR 10-DW-06). With location and timing of spawning now known, it would be a good opportunity to initiate additional drifter studies in the SA and GOM.
- Ongoing research (Koenig and Coleman 2010) will verify known SPAGS and suspected SPAGS. It will also determine the size structure of spawning fish, their residency time on the SPAGS, and size-related fecundity. With more known SPAGS, there is the potential to assess the abundance of reproductive adults based on numbers present at SPAGS and knowing the geographical range of the participating spawners.
- Koenig, Coleman, Murie, and Stallings (= Koenig et al 2012) started a NOAA-funded project in 2012 to evaluate the regional age structure, reproductive biology, and trophic patterns of adult goliath grouper in Florida. The primary goal of the work is to provide demographic data on goliath grouper that can be used by stock assessment scientists to assess population recovery.
- Benchmarks – given the tremendous uncertainty associated with using standing stock biomass (ssb) as a benchmark for data poor fish populations (see McClenachan 2009), it seems more reasonable to consider using alternate approaches. This could include the following: (1) examining regional density patterns to see when the population stops spreading, one that is relevant to current conditions and one that considers that the current carrying capacity may be different than it was in 1950 (e.g. more artificial bottom now; potentially different prey abundance now); develop a new baseline population by which we benchmark future management, and (2) including a juvenile index of abundance to account for potential future lags in population change.
- Collins and Barbieri completed a NOAA funded project in 2010 that identified habitat associations and size distributions of goliath grouper in the central eastern Gulf of Mexico. These data identify habitat preference and average numbers of individuals at

various habitats and depths. These data are currently only available as a final report (Collins and Barbieri, 2010); peer reviewed manuscripts are in progress.

Age and Growth:

- A directed effort to collect hard parts from large, old fish to validate these methods for old individuals.
- FWC/FWRI (Collins and Barbieri; also the FWRI Fish Health research program) has made a directed effort to sample all goliath grouper reported during sporadic mortality events (red tide, cold kills, illegal harvest). Data collection is ongoing, but between 2006 -2013, 73 individuals have been sampled for hard parts for ageing. Otoliths are processed and aged by FWRI; fin rays are sent to Deb Murie (UF) for ageing; fin spines are also kept at FWRI for assessment of ageing potential.
- More detailed information on maximum age and size is needed. There are no new data available for maximum age or maximum size since Bullock et al. 1992. There is reason to suspect that maximum age is a low estimate due to the small number of large, old fish sampled. Additionally, there is concern over whether or not the asymptote is fully represented due to the low number of samples represented at the oldest ages (Fig.1). However, this maximum age does fall within the values observed for other epinephelines [i.e., brown-marbled grouper[3] *E. fuscoguttatus* (42 y for females and 40y for males; Pears, 2006), red grouper *E. morio* (29 y; Lombardi-Carlson et al., 2006), *E.*), warsaw grouper *H. nigitus* (41 y; Manooch, 1987), Nassau grouper *E. striatus* (29 y; Sadovy and Eklund 1999)]. Among the best species for comparison (due to similar size, tropical/subtropical distribution and ecological role) are the Indo-Pacific Giant grouper *E. lanceolatus* (37 y; NSW Dept of Primary Industries 2008) and the potato grouper *E. tukula* (26 y; Grandcourt 2005). In general, the observed maximum ages of most grouper species are based on relatively few individuals and are poorly known. Where these species are heavily fished, it may be less likely to find individuals that reach their maximum ages.



- An estimate of the maximum age of goliath groupers is used for estimating the rate of natural mortality for this species – an important component for modeling populations. In all natural populations, there are a lot of younger individuals and fewer older individuals. The ages of fish observed in a population typically follows an exponential decline, and the odds of finding older individuals is much less than younger ones. When

[3] Common names and age and length tables provided by O'Hop for the 2013 report

species are fished, there is usually a lower probability of finding older fish in a population compared to that of unfished conditions.

- The current estimate for maximum age of goliaths is 37 years and is based on 382 specimens (Bullock et al. 1992) after over a century of fishing (sometimes heavy) in this country, but it is possible that goliaths can reach older ages. A method of estimating total mortality rate (Z) based on maximum age is provided by Hoenig (1982), and under lightly fished or unfished conditions Z is also a reasonable estimate for natural mortality rate (M). For a maximum age of 37 years, Z (≈M for unfished populations) is estimated to be 0.12 per year, and a typical approach in stock assessments is to use this estimate as an approximation for M. If goliath grouper can live to older ages, the assumed rate of natural mortality would be lower. For example, for a maximum age of 50 years, M would be approximately 0.09 per year.

- In data poor situations where there is uncertainty in the levels of historical catches and life history parameters (such as maximum age, growth, etc.), there is advice for setting the upper bound on the annual rate of removals by fishing (fishing mortality at the maximum sustainable yield, F_{MSY}) equal to either M or 0.6-0.8 of M (MacCall 2009). Applying this advice to goliath groupers using M≈0.12, annual F should be no higher than 0.072-0.096. [Dulvy et al. 2004 discuss other possible metrics that also could be applied in data poor situations for setting other types of population benchmarks.]

- The release mortality rate (one component of total fishing mortality) for goliath groupers based on tag-recapture studies in the Florida Everglades is thought to be low (e.g., Brusher and Schull 2009). The most recent assessment (SEDAR, 2011) used a 5% release mortality rate. At these low levels of F for the estimated release mortality rate and if F_{MSY} is set to 0.072-0.096 using data-poor fishery standards, a fishery (commercial or recreational) on goliath grouper populations would be greatly limited.
- FWC/FWRI (Collins and Barbieri) have been performing underwater visual surveys within the central eastern Gulf of Mexico (n = 700+ surveys) since 2007. Surveys are performed during all months of the year at designated sites, and goliath grouper are measured via underwater video. These surveys are providing information regarding the size structure (which can be used as a proxy for age structure) of the population within the study area. Manuscripts are in progress but some of this information is available via a final report to NOAA (Collins and Barbieri, 2010).
- As suggested during the last SEDAR (SEDAR6, 2004): "The panel recommended continued work on ageing. Ages should be standardized to a calendar year, so that information on a year class is treated consistently throughout the year."
- Murie (as part of Koenig et al. 2012) is evaluating the regional age structure of goliath populations in Florida. Most samples are obtained using non-lethal methods by fishers in each region whom we have trained; others (including otoliths and finrays) are collected opportunistically from FWC staff from dead fish reported to the FWC Fish Kill hotline to validate age.

Reproduction

- Ongoing research (Koenig and Coleman, MARFIN) continues to evaluate fecundity, sexual pattern, SPAG distribution, size structure and sex ratio within SPAGS, and mating system using non-lethal methods.

Habitat and Movement:

- See Koenig et al (2011) for data on state-wide habitat preferences and movement patterns.

- Koenig and Coleman (2010, current) continue to evaluate movement patterns of recaptured goliath grouper based on tag returns

- We need spatially-explicit models. Due to microhabitat preferences and site attachment in both juvenile and adult goliath groupers, density values (as number of individuals per unit area or length of coastline) should be used with caution in population estimates and modeling; it is essential to contrast densities in high quality habitats versus low quality habitats, and not use a single density value which could results in over-estimates of total population levels. Future modeling efforts should also account for the known (or unknown) statewide spatial distribution of both juveniles and adults.

- Collins and Barbieri (2010) surveyed a range of habitat types (artificial and natural reefs to 50 m) distributed throughout the central eastern Gulf of Mexico. Goliath grouper abundance was compared to habitat type, size and season.

- We need a state-wide evaluation of habitat quality integrating habitat structure and water quality. Including this knowledge in our goliath grouper assessments will allow us to expand population models into ecosystem-based management.
- What is the extent of high quality mangrove habitat, and where is it located in Florida? There is a need for a state-wide assessment of mangroves as fish habitat, to evaluate potential high quality sites that are the nurseries, not only for juvenile goliath grouper but also for juveniles of a diverse group of other fish and invertebrate species.
- When evaluating high quality habitat (both in mangroves and reefs), in addition to evaluating the structural characteristics, what is the water quality of each habitat? There is a need to quantify, state-wide in real time and 24/7 the water quality (salinity, temperature, dissolved oxygen) of mangroves, and coastal reefs. This research question applies not only to goliath grouper but also to all estuarine and coastal species that use mangroves and reefs (coral reefs, reef ledges) during their life history.
- What are the biological corridors used during the ontogenetic migrations from juvenile mangrove habitat to reef adult habitat and the spawning migrations from resident habitat to spawning aggregation sites (SPAGS)? We don't know if goliath grouper use a specific path or network (=biological corridor) during their two major migratory events (ontogenetic and reproductive).
- What are the maximum distances that can be covered by juveniles in ontogenetic migrations towards the adult habitat, and by adults in their spawning migrations? These data are needed to understand the ontogenetic and spawning connectivity within the goliath grouper population.

- Collins (NOAA MARFIN grant in progress) and Koenig and Coleman (2010, NOAA MARFIN grant in progress), Koenig et al. (2009) have data from tagging studies indicating that juveniles move up to 400 km from nursery to adult habitat and adults move up to 500 km to reach SPAGS from home sites.

- Ellis and Koenig (Koenig and Coleman 2010) are determining movement patterns of goliath grouper associated with spawning aggregations located off the east coast of Florida. They are conducting ongoing monitoring of goliath groupers tagged with VEMCO 69-KHz acoustic tags ("pingers") as part of the Florida Atlantic Coastal Telemetry (FACT) array group. Study objectives include: determine interannual spawning site fidelity, determine annual movement patterns related to spawning activity, determine daily movement patterns related to environmental factors such as upwelling events, and estimate natural mortality using Kaplan-Meyer survival estimation.

- Collins (NOAA MARFIN grant in progress) is utilizing acoustic telemetry to identify residence times and long-term behavioral patterns of goliath grouper at designated

artificial reefs in the central eastern Gulf of Mexico. All monitored goliath grouper are fitted with pressure sensitive acoustic tags, which give a depth data point every 1 – 3 minutes. These tracking data allow for a fine scale assessment of position within the water column throughout the day (and throughout the year), providing information regarding diel behavior as well as longer term movement patterns. This project also identifies the behavior of goliath grouper after catch and release angling, and was designed to sample fish throughout the depth range at which they are most susceptible to fishing pressure (to 40 m in the Gulf of Mexico.)

- Tzadik and Stallings (Koenig et al 2012) are evaluating connectivity between nursery and adult habitats using the fin-ray samples obtained for aging. They are analyzing the microchemical constituents of individual goliath grouper to test spatial and temporal variability in the contribution of different juvenile habitats to adult populations. Using trace element signatures in different mangrove habitats across south Florida known to be juvenile nursery habitat, they will be able to define spatial and temporal variability in goliath grouper habitat. They will also reconstruct juvenile habitat use in adult samples by backtracking across annuli to known nursery ages. This effectively augments the data obtained from tagging studies.

Diet and Trophic Analysis

- Koenig et al (2012) are conducting trophic studies of goliath grouper through targeted stomach content and stable isotope analyses to evaluate dietary shifts in trophic level ($\delta^{15}N$) and basal resource use ($\delta^{13}C$) over time.

1.2 COMMERCIAL AND RECREATIONAL STATISTICS WORKING GROUP

The prohibition on any harvest of goliath grouper precludes any fishery dependent research other than that conducted by on-board observers or recorded in fishermen's logbooks. Continued collection of size, frequency in the catches by gear, and observed release condition is important for obtaining release mortality estimates and possibly an estimate of numbers caught by gear, fishing area, and depth. It is expected that as the abundance of this species increases, so too will the frequency of encounter with fishing gears. Brusher and Schull's (2009) study that goliath grouper have a reasonably good chance of surviving the encounter with fishing gear at least in shallower waters. Capture-recapture studies could be designed to examine the effects of releases from the recreational fishery. With the apparent increase in numbers of goliath grouper reported by anglers, it is inevitable that more encounters with fishing gear will occur and this seems to be borne out by reports from angler surveys such as the ENP Angler Creel Survey and the MRFSS. Surveys of spawning aggregations are needed to extend the usefulness of Don DeMaria's earlier surveys and to monitor population trends of adults.

- Collins (NOAA MARFIN grant in progress) is utilizing acoustic telemetry to identify residence times and long-term behavioral patterns of goliath grouper at designated artificial reefs in the central eastern Gulf of Mexico. All monitored goliath grouper are fitted with pressure sensitive acoustic tags, which give a depth data point every 1 – 3 minutes. These tracking data allow for a fine scale assessment of position within the water column throughout the day (and throughout the year), providing information regarding diel behavior as well as longer term movement patterns. This project also identifies the behavior of goliath grouper after catch and release angling, and was designed to sample fish throughout the depth range at which they are most susceptible to fishing pressure (to 40 m in the Gulf of Mexico.)

1.3 INDICES OF ABUNDANCE WORKING GROUP

No research recommendations were provided by the Working Group.

2. ASSESSMENT WORKSHOP RESEARCH RECOMMENDATIONS

Recommendations on future research and data collection were provided at the DW. An additional recommendation for a "research fishery" was briefly discussed at the Assessment Workshop (AW), but was never formalized.

3. REVIEW PANEL RESEARCH RECOMMENDATIONS

Although results were unsatisfactory for this stock assessment, they did serve to clarify additional research necessary for future assessment efforts. The next benchmark assessment cannot be successfully completed without data from the research recommended by the Data, Assessment, and Review Panels.

Stock Definition:

- Goliath grouper should be genetically sampled from as many areas in the South Atlantic and Gulf of Mexico as possible to allow for a more thorough examination of the current single stock definition.

- FWC/FWRI and FSU are collaborating and have collected over 400 DNA samples from both coasts of Florida. It is the aim of this collaboration to produce a more complete genetic structure of the stock in Florida.

- Examination of spawning aggregations over the entire distribution range should include seasonality, sex ratios, and individual fidelity.

Long-term monitoring:

- Basic reproductive data are lacking throughout the species distribution, including: size and age at maturity for each sex, sexual sequence with size and age for each sex, and fecundity.

- As described in the above research recommendations by the Life History Working Group, research on age structure, and locations of suitable juvenile and adult habitat, discard and discard mortality rates should be accomplished throughout the species distribution

- Economic impact:

Because of the relatively small size of a potentially reopened consumptive fishery for goliath grouper, a socio-economic evaluation of the relative benefits of consumptive versus non-consumptive uses would be beneficial. There may be greater long-term economic benefit to development of sustainable non-consumptive eco-tourism venues than would be possible from a consumptive fishery.

Goliath grouper is a valuable member of the shelf reef community of Florida. It feeds at a relatively low trophic level and excavates sediment-smothered reefs thereby increasing habitat complexity and biodiversity (Coleman and Koenig 2011). High adult densities are also associated with high abundance of economically important reef fish (Koenig et al. 2011). In addition, because of the great size of adults and their tendency to aggregate, they provide a unique spectacle for the eco-tourist dive industry. Nowhere in the world can such large fish be observed and photographed up close but in south Florida, making both coasts of this state world-renown dive destinations. The dive-tourist industry is building in south Florida, and economic benefits from this industry depend on a healthy population of goliath grouper.

- See the report submitted to the Florida Fish and Wildlife Conservation Commission. (Harrington et al 2009).
- Study underway by graduate student Geoffrey Shideler , University of Miami – survey of recreational anglers.
- Study underway by Kai Lorenzen, University of Florida – Goliath grouper management stakeholder process. http://www.aquaticresources.org/goliath.html

_____END SEDAR REPORT_____

Goliath Grouper Management: Thinking Outside the Box

CC Koenig, FC Coleman, RD Ellis (2013, manuscript in prep)

The goliath grouper is a unique reef fish species that requires innovative methods of stock assessment. First, because the species is protected, there are no catch data; second, because the catch history is sketchy at best, there is a poor understanding of the population in an unfished state. Thus, to establish reference points such as MSY and SPR50, stock assessment biologists must make guesses and unwarranted assumptions to support their selection of reference points—this is an unacceptable basis for managing fish stocks. Other complicating factors include changes in habitat conditions for juveniles and adults. Juvenile habitat, which is exclusively mangrove forests (Koenig et al. 2007), has suffered severe losses in both coverage and quality in South Florida (Ogden et al. 2005, and many other studies) thus limiting the productive capacity for the species. Conversely, adult habitat has increased as the state of Florida continues to deploy high-relief artificial structures, which is preferred habitat for adults (Koenig et al. 2011). Clearly, this species cannot be managed effectively by traditional stock assessment methods but there are other options (Johannes 1998).

The behavioral characteristics of goliath grouper provide the management opportunity to assess stocks directly. For example, mark-recapture methods provide a means of estimating absolute abundance of juveniles during their 5-year sojourn in mangrove forests, a time when their home-range movements are highly restricted (Koenig et al. 2007). Similarly, mark-resight methods provide a means of estimating absolute site density of adults, which also have strong site fidelity (Collins 2009, Koenig et al. 2011). In ongoing studies by Koenig, Coleman, Collins, and others, it is clear that adults migrate great distances (e.g., as much as 300 mi) to join the spawning aggregations in SE and SW Florida, then they move back to their home sites in October and November. Thus, spawning biomass would be best estimated in August and September on spawning aggregations because stock-size estimates at spawning places and times are representative of broad geographical regions. Also, fin spines and rays can be used for non-destructive aging (Brusher and Schull 2009, Murie et al. 2009), and lasers can be used to measure adults *in situ*. Thus, direct measures of juvenile and adult abundance, size and age structure may be obtained efficiently and effectively.

But how do we establish reference points for goliath grouper that allow some removal of individuals but that maintains the population near carrying capacity? Limiting reference points, i.e., point indicating a population level at which fishing should be halted, could be established in a manner similar to those developed for marine mammals (Wade 1998) as proposed by Sainsbury (2008) for threatened, endangered or protected species. Because of the high vulnerability of goliath grouper combined with its high ecological and live-economic value, it is necessary to use extreme precautionary measures. Wade used the concept of Potential Biological Removal (PBR) to establish limiting reference points. PBR is the maximum number of animals that may be removed from the population while still achieving recovery of the depleted population (i.e., from 30% depletion to the natural carrying capacity in no more than 100 years) or subsequent maintenance of the population at its carrying capacity (for at least 20 years). Wade (1998) found through extensive simulations that a very robust estimate of this limiting reference point is:

$$PBR = N_{min} \cdot \frac{1}{2} R_{max} \cdot F_r$$

where *N min* is the minimum population estimate of the stock, ½ *R max* is one half the maximum net productivity (recruitment) rate, and *Fr* is a recovery factor between 0.1 and 1. A value of 1 for *Fr* allows no extra margin for error. A low value of *Fr* is precautionary (Wade 1998). Wade showed that an *Fr* of 0.5 would allow marine mammal populations to reach or maintain their carrying capacity with high probability. A mortality that is consistently greater than the PBR has a 5% chance of depleting a population. PBR is therefore a relatively conservative measure. It has not been simulation tested for fish populations but might well prove to be an effective precautionary catch limit for groups other than marine mammals,

especially in 'data poor' situations (Sainsbury 2008). However, because of the high vulnerability of goliath grouper to fishing, the dependence on limited (and declining) mangrove habitat, and the generally poor water quality of that habitat (Koenig et al. 2007), they may be closer to low fecundity marine mammals than they are to highly fecund marine fish.

Sainsbury (2008) explains that the best target reference points (mortality or catch levels that would not jeopardize recovery or maintenance of the goliath grouper population) should approach zero fishing mortality. Levels of catch that are acceptable could be changed over time depending on the response of the juvenile and adult population, i.e., no significant population declines. Of course, the success of this approach is dependent upon accurate measure of mortality (legal catch, illegal catch, incidental catch mortality, and natural mortality), monitoring of the juvenile and adult populations and effective management intervention if limiting reference points are exceeded. The Reef Environmental Education Foundation (REEF) provides an automatic measure of goliath grouper population status in various regions and could be used as a backup to direct measurements on spawning sites. Regional carrying capacities could be estimated from equilibrium conditions in REEF data, similar to what we observed off southwest Florida from 1998 through 2008 (Koenig et al. 2011).

Direct measures of juvenile abundance will detect population declines due to events such as red tide and cold events. A dramatic example of cold-event mortality occurred in January 2010 when there was a juvenile mortality that exceeded 90% (based on 'catch-per-unit-effort' in Everglades National Park (ENP) creel surveys). Such a pervasive impact on a species that requires 5 years in the shallow mangrove nursery translates to near-zero recruitment to the adult population until 2015. If this event had gone unnoticed, i.e., no monitoring of the mangrove abundance, recruitment would have been vastly underestimated and allowable fishing mortality vastly overestimated. Thus, it is important to estimate juvenile abundance and size and age structure through periodic mangrove habitat surveys in south Florida. The creel survey of the ENP is less than ideal because: (1) the measure is indirect, that is, the relationship between juvenile abundance and catch-per-unit-effort of the recreational fishery depends on the behavior of the fishermen (if fishermen *target* goliath grouper for catch-release sport rather than just catch them incidentally, then catch-per-effort (and presumed abundance) will be overestimated; and (2) the ENP creel survey does not determine size or age structure (although it did identify the results of dramatic events such as the cold snap of 2010).

Direct measures of adult absolute site abundance may also be made through mark-resight methods used on spawning aggregations during spawning months of August and September. Because spawning fish represent adults from a broad geographical region, direct measures may be made of the abundance of the spawning population. We have shown that some percentage of the goliath grouper associated with reef sites are not directly on the site, but probably out foraging over the sand (crabs in the family Callapidae, which spend their adult lives under the sand, are a main dietary item). Thus, many direct counts of adults on reefs are underestimates of the actual abundance; therefore we successfully used a speargun-based mark-resight method to obtain accurate and statistically comparable measures of site density (Koenig et al. 2011). Such *in situ* site density measures would be used on spawning fish to check on the abundance of the spawning population in this proposed adaptive management approach.

Overview of the management considerations for goliath grouper:

1. Monitor juvenile abundance and age structure.
    - Use fish traps and set lines for capture-release to determine absolute density per linear shoreline and size and age structure in mangroves.
    - Start in the Ten Thousand Islands (TTI), a mangrove habitat known to be of high quality for goliath grouper juveniles (Koenig et al. 2007). Explore other South Florida mangrove areas with water quality suitable to support juveniles. Augment direct mark-recapture field monitoring with ENP creel surveys.
    - Age captured juveniles using fin rays (Brusher and Schull 2009) and estimate net productivity, or recruitment to the adult population from the TTI and other mangrove

areas of southwest and southeast Florida.

2. Monitor adult site density on SPAGS during spawning season (August and September).
   - Spawning sites (restricted to areas off Palm Beach and Martin Counties on the east coast and Lee and Collier Counties off the west coast of Florida) represent fish from the entire regions of the east coast and west coast (evidence from Collins and ongoing research by Koenig, Coleman and Ellis). Goliath grouper site density estimates may be made using mark-resight estimates on spawning sites during August and September (Koenig et al. 2011). Spawning sites may be verified through the use of nocturnal acoustic activity (Mann et al. 2009, ongoing research by Koenig and Coleman).
   - REEF data should be used to evaluate regional population equilibrium. Koenig et al. (2011) validated REEF data and showed that the adult goliath grouper population reached equilibrium off southwest Florida in the late 1990s, but continued to increase in other parts of the state. A similar equilibrium probably exists now off southeast Florida, but recovery in other parts of the state should be evaluated.

3. Fishing allowances.
   - Catch of goliath grouper is unsustainable under normal fishing conditions. Commercial fishing should not be allowed at all. Recreational fishing, if allowed post-recovery, should be extremely limited, carefully regulated and verified—for example, through the use of a stamp system (fisher buys a stamp for a single fish and only a limited number of stamps are issued each year, depending on feedback from PBR estimation).

4. Time-area closures and gear restrictions:
   - The known spawning areas of southeast and southwest Florida (i.e., off Palm Beach and Martin Counties on the east coast, and off Lee and Collier Counties on the west coast) should be closed to fishing for goliath grouper year-round because many spawners remain on spawning sites in these areas, and these sites are economically valuable to the dive-tourist industry.
   - Gears, such as bottom long lines, that inadvertently catch goliath grouper and may produce significant incidental mortality, should be excluded year round in the spawning areas .

5. Slot limits:
   The greatest migrations to spawning sites were made by the largest individuals (ongoing research, Koenig, Coleman, Ellis). These individuals are also the most fecund and likely have the highest quality eggs (Berkley et al. 2004, Berkland and Dayton 2005). Therefore, we suggest that the fishery catch be limited to a slot size for adults only, (e.g., > 1.2 m & < 1.7 m) and only at depths shallower than 30 m.[4]

6. Reference points (limit and target):
   - Limit reference points should be calculated from PBR where the recovery factor *Fr* is 0.5. This reference point limit (i.e., point at which fishing should be halted) can be adjusted as more information becomes available (e.g., if no significant effect on the spawning population can be shown, the allowable catch may be raised). The value can lie between 0.1 and 1.0. The lower the value of *Fr*, the higher the precaution. A limit reference point of 0.5 provides significant precaution for other protected species (Wade 1998).

   - A target reference point is one in which a constant removal can be maintained without significant loss of population recovery or maintenance at carrying-capacity. The target

[4] While the proposed slot limit may be appropriate based upon size at maturity, there are other considerations. Goliath grouper specimens of 900 mm TL or greater may exceed the current EPA methyl mercury consumption limits of 0.3 mg/kg (Tremain and Adams, 2012) based on recent sampling, so recommending such a slot or size limit may be inadvisable from a human consumption standpoint .

limit should be modest initially, but then, depending upon the juvenile and adult population response (determined from direct mark-return measures), this limit could be raised.

7. Mangrove habitat protection and recovery of water quality:
    - Mangrove habitat and water quality of that habitat should be recovered and protected in south Florida. Significant mangrove habitat loss has occurred over the last 50 years (Koenig et al. 2007), but more importantly, there has been significant degradation in mangrove water quality from pollutants and from eutrophication (Ogden et al. 2005). Because of the long juvenile sojourn in the mangroves, goliath grouper require long-term stability of dissolved oxygen, salinity, and temperature. Dramatic changes in water quality, even for short periods to time, will reduce survival. So, juvenile goliath grouper are important indicator species for water quality in the mangrove habitat.

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[5] Correct spelling for New South Wales "groupers"

APPENDIX I. Vulnerability of the Goliath Grouper Population in Florida: A Summary of the Science and Opinion

by Christopher Koenig and Felicia Coleman

Despite the vulnerability of goliath grouper to environmental conditions and habitat loss, the restrictions on fishing have put this species on the track to recovery in the southeastern U. S. waters. Full recovery is indicated when the age structure, size structure, and geographic range are reestablished. Until then, some level of protection will likely always be required. While not clear that the population has fully recovered, the positive trend has brought calls to reopen the fishery. Evaluation of the dynamics of spawning aggregations by visual and acoustic methods could provide a basis for monitoring recovery. That is, if goliath grouper abundance in spawning aggregations is a correlate of stock size, then these fishery-independent methods can be used efficiently to monitor recovery. The benefits of recovery may well extend into additional commercial enterprises, particularly ecotourism as opportunities to view these magnificent fish in their natural habitat increases.

Figure 1. Goliath grouper off the Atlantic coast of Florida. Photo by Jim Abernathy.

Figure 2. An aggregation. Photo by Walt Stearns.

The question is: should managers in Florida ignore the global status of this species as critically endangered when making management decisions over such a restricted geographic range?

We say no. We base this answer on the scientific evidence we have compiled over the last 15 plus years of studying this species and on our review of the literature and reports of colleagues and other scientists throughout the world. Among these are Bullock *et al.* 1992, Sadovy and Eklund 1999, Frias- Torres 2006, Koenig *et al*. 2007, Felix-Hackradt and Hackradt 2008, Brusher and Schull 2 009, Craig et al. 2009, Gerhardinger et al. 2009, Mann et al. 2009, McLeanachan 2009, Murie et al. 2009, Graham et al. 2009, Evers et al. 2009, Cass-Calay and Schmidt 2009. The science-free perceptions and very vocal pronouncements of various groups about the biology, behavior, and population status of this species, while loud and strong, should not trump the best available scientific evidence in making management decisions. Our objective in this brief document is to juxtapose the scientific evidence following from this body of research with the most pervasive opinions voiced in the southeastern United States.

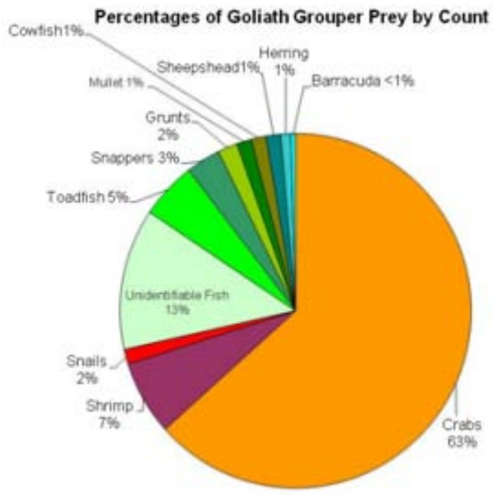

FIGURE 3. Main prey items in the diet of goliath grouper sampled from south Florida.

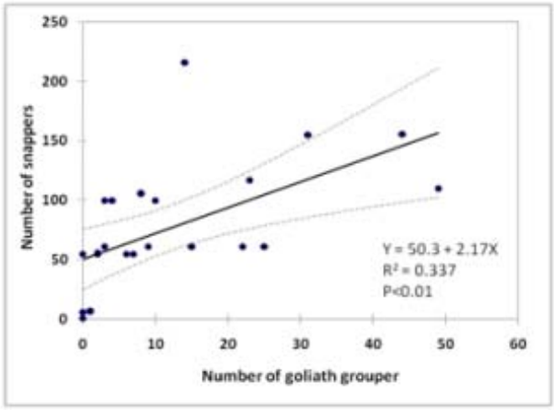

FIGURE 4. Regression of number of snapper individuals (all species) on goliath grouper density (number per reef site) off southwest Florida on high-relief sites. Dashed lines denote 95% Confidence Limits.

The Opinion: Goliath groupers compete directly with recreational reef fish fishermen for and substantially reduce the populations of groupers and snappers on reefs in south Florida.

The Science: There are two lines of evidence against this view provided by dietary and trophic studies of goliath grouper and videographic surveys of the distribution and abundance of reef fish on reefs off southwest Florida, the center of goliath grouper abundance. In the stomach contents of over 200 goliath groupers sampled from South Florida we found no groupers and very few snappers. Only three percent of the prey items were snappers, and these were all gray snappers occurring in the mangroves in close proximity to the juvenile goliath grouper.

Stomach contents represent prey eaten just prior to capture, or a short-term view of diet (Figures 3 and 7). However, for an understanding of diet over the long term, and goliath grouper's position in the food web (i.e., trophic level) we used stable isotope analysis (Koenig and Coleman 2009). Results showed a relatively low position in the food web, similar to that of South Florida pinfish (*Lagodon rhomboides*; Chasar et al. 2005). Thus, goliath grouper must typically feed on lower trophic level species, not on those species occupying higher trophic levels, such as groupers and snappers.

In our reef surveys of southwest Florida, we found a significant positive relationship between the number of snapper (all species combined) and the number of goliath groupers present on surveyed sites; that is, the higher the number of goliath grouper occupying a reef, the higher the number of snappers on that reef (Figure 4). We found no significant relationship between the number of adult goliath grouper and the number of individuals of other groupers on the same sites. These data support the diet studies showing that few if any snappers and groupers are eaten by adult goliath grouper. Further, we found that most of the snappers and groupers on sites with goliath groupers were smaller than the minimum-fishery-size limit which suggests either that goliath grouper, if they do eat these fish, concentrate only on those exceeding the minimum size limit, or alternatively, that the fishery itself is responsible for removal of economically important species.

The Opinion: Goliath grouper compete directly with lobster fishermen by eating many lobsters in South Florida.

The Science: Our stomach content data, sampled from goliath grouper in areas of high lobster abundance, provide strong evidence against this view. Using the same stomach content data, we found only one lobster (less than 1% of the dietary items). The diet consisted mostly of crabs and slow-moving bottom-dwelling fishes such as toadfish.

The fact is that lobsters are preferred prey for many species, including sharks, rays, triggerfish, and grouper (including goliath grouper). When

determining the impact of a predator on a particular prey population, however, the question is not what can the predator eat, or even, what prey does the predator prefer? The appropriate question is: what does the predator eat within an ecological context?

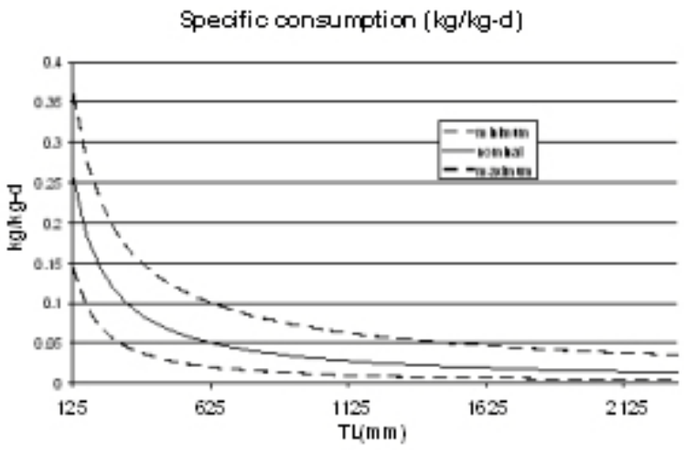

FIGURE 5. Modeled consumption rates of goliath grouper relative to total length (TL). Graph shows that as the fish grows, their weight-specific consumption rates decline. Thus, a large individual eats much less per body mass than a small individual.

The supposition that lobster form an important component of the goliath grouper diet follows from a report written by Jack Randall (Hawaii Biological Survey) about reef species sampled from the West Indies in the 1960s (Randall 1967). In this report, Randall indicated that a high percentage of the goliath grouper diet consisted of spiny lobsters. At that time (1959 - 1961) and in that place (St. John, VI), lobsters were abundant (Randall, personal communication), so the observation of goliath grouper feeding on them is not surprising. But between 1960 and about 1998, lobster landings tripled throughout the region, including Florida (FAO 2001). Today, in many areas of the Caribbean, lobster populations are severely overexploited while there are limited data about population health, abundance, and fisheries to help inform fishery management practices (FAO 2009). In the Florida Keys, where the fishery for lobsters is intense, it is doubtful that goliath grouper can affect the fishery catch significantly, and our data support this view.

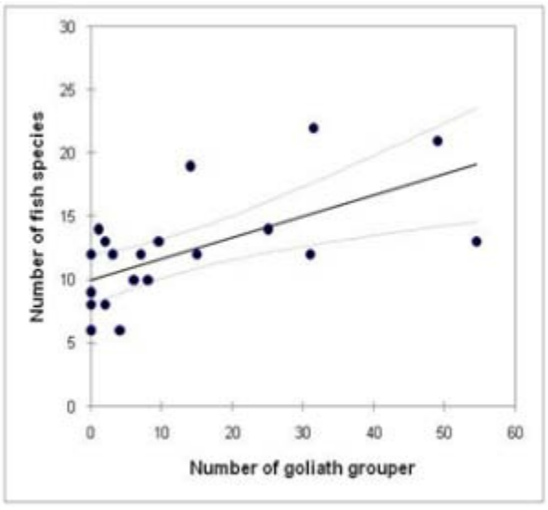

FIGURE 6. Regression of species richness (all reeffish) on goliath grouper density (No. per reef site) off southwest Florida on high-relief sites (R^2 = 0.38; $P<0.01$). Dashed lines denote 95% Confidence Limit.

The Opinion: Goliath grouper, because of their large size, require huge amounts of food to survive and eat indiscriminately, reducing biodiversity on reefs.

The Science: While it is true that adult goliath grouper are large, they are also extremely sedentary, rarely leaving home sites except to migrate to spawning sites. Their method of predation is to sit and wait for prey, and then use a suction method, common to all groupers and many other reef fish, to draw prey into their mouths.

To estimate the food consumption rate of goliath grouper, we developed a bioenergetics model. While the model is preliminary, it shows that adult goliath grouper require only small amounts of food for maintenance (Figure 5) because of their low metabolic rates and slow growth rates, which become progressively slower as the fish increase in size.

If goliath grouper ate everything on the reef, we would expect to see lower biodiversity with higher goliath grouper abundance. However, the exact opposite is true. Our data indicate that biodiversity is higher overall in areas with greater numbers of goliath grouper; that is, the relationship between the number of fish species and the abundance of goliath grouper is a positive one (Figure 6).

The Opinion: Our reefs are "out of balance"; goliath grouper have to be "thinned out" to regain that balance.

The Science: Many Florida reefs are out of ecological balance. Indeed, this is a world-wide phenomenon that is related to the combined effects of overfishing, coastal development, pollution, and climate change, not to the presence of goliath grouper. Altered ecological balance will not be regained by reducing the abundance of goliath grouper, a native species that is recovering from intense overfishing, but by allowing other overfished species to recover while attempting to reduce a variety of human-induced impacts. Those fishers with decades of experience on Florida reefs know this to be true. It is the newcomers with less experience who perceive overfished reefs as "normal". Scientists call this phenomenon "shifting baselines" because the perception of "normal" changes with each successive generation.

Figure 7. Dr. James Locascio getting stomach samples from patient grouper.

The Opinion: Goliath grouper are dangerous to divers.

The Science: Our observations suggest that the frequency of goliath grouper bites is vanishingly small (Fig. 7). We have interacted directly with over 5000 adult goliath grouper in the water, and have tagged over 2100 large individuals with spear guns. During all these interactions, we have experienced only a single harmless nip on the hand by one individual that we cornered under a ledge in an attempt to make it produce sounds (booms) that we could record.

Some divers have reported being bitten by goliath grouper. In most cases, the diver had a stringer of speared fish that were the likely target of the grouper, rather than the diver. However, considering that goliath grouper have very small teeth and a very weak bite (they feed by sucking prey into their mouths, not by biting it, like a shark), the worst wound that could be inflicted by a goliath grouper would amount to scratches, not serious injuries.

The Opinion: There must be a periodic kill of hundreds of adult goliath grouper to obtain data on size, age, and reproductive condition necessary for stock assessment.

The Science: None of these data require the destruction of the fish. All can be obtained through careful sampling of individuals.

Size is a simple measure to obtain non-destructively. We do this underwater with a video camera mounted with a double laser system. The laser system produces beams that are adjusted to be parallel. With the camera and lasers on, the beams are projected onto the sides of a fish oriented perpendicular to the beams (Figure 8). Later, in the lab, the fish can be measured because the distance between the laser dots projected onto the fish is known.

Age is most often determined from fishery catches by removing otoliths (concretions similar to limestone in the ear chambers of fish; otoliths function in equilibrium and hearing) from

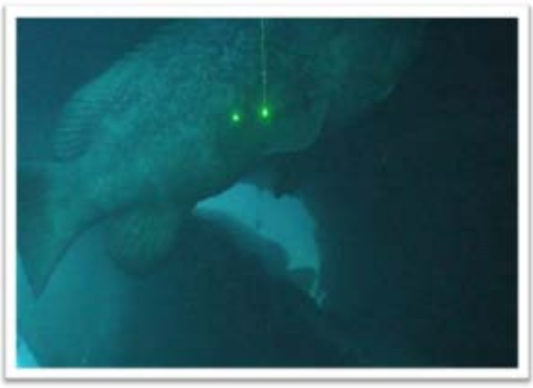

FIGURE 8. Laser dots on the side of an adult goliath grouper are used to obtain size information. These dots are 10 cm apart.

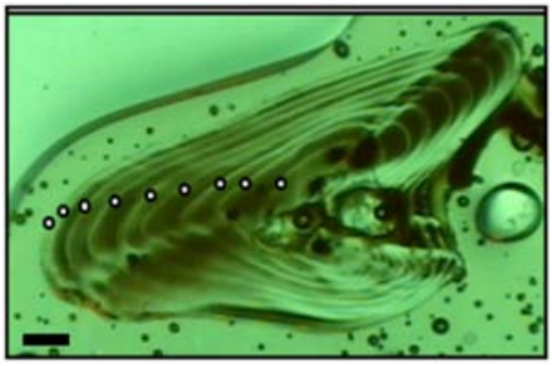

FIGURE 9. Fin ray from goliath grouper used for aging purposes. *Photo by Debra Murie.*

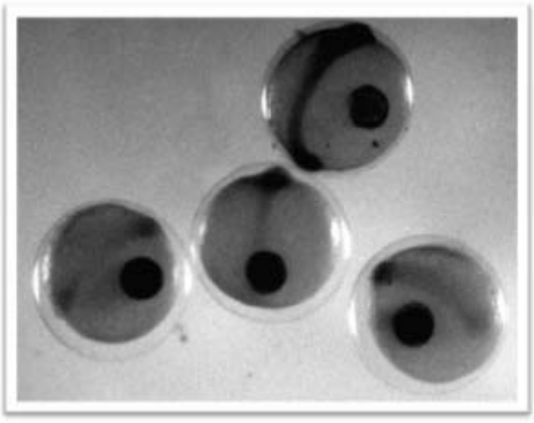

FIGURE 10. Goliath grouper eggs, September 2009. *Photo by Chris Koenig.*

individual landed fish. However, age can also be determined non-lethally from dorsal fin rays (Figure 9). These cartilaginous rays can be cut from the fish after it is captured; the fish can then be tagged and released unharmed, and the removed fin rays grow back in several months. Like otoliths, fin rays lay down annual rings, similar to the rings of a tree, and these can be used to age the fish. Murie *et al*. (2009) have published on the use of dorsal fin rays for goliath grouper aging.

We have received considerable support from recreational and commercial fishermen interested in participating in non-consumptive research projects that involve use of non-destructive sampling of goliath grouper. This type of project would provide a considerable amount of data on regional age and size structure, data on regional and seasonal diet, and movement data because captured fish could be tagged before releasing them. As an added bonus, this volunteer program would provide an opportunity for researchers to educate the fishermen on the recent scientific research on goliath grouper and further dispel the myths circulating within the fishing community.

While the goliath grouper population is in recovery, the current status is unknown, as is the potential impact of removals of hundreds of adult fish. Certainly the opportunity to educate fishermen in general marine ecology and goliath grouper biology and conservation practices should far outweigh the completely unnecessary destruction of individuals.

Reproductive data can also be collected from goliath grouper non-lethally, and economically to provide stock assessment biologists with the necessary information to assess recovery of the stock. To determine reproductive state, sex, and sexual pattern (e.g., gonochorist or hermaphrodite), we take gonad biopsies by inserting a small tube into the genital opening and vacuuming out a small piece of the gonad tissue. This tissue is then prepared for viewing under the microscope to determine reproductive condition. It is also possible to estimate the mass of the ovary in females in spawning condition and, coupled with spawning frequency, estimate fecundity. Spawning frequency is estimated non-destructively on the aggregations by using methods discussed in Mann et al. (2009). In brief, fish were externally tagged with a short-interval depth-sensing tag and monitored for several weeks. Because spawning fish ascend above the reef, the spawning frequency of an individual can be determined directly by the frequency of female ascents.

We also can estimate directly the reproductive output and timing of spawning by collecting eggs (Figure 10) using an array of nets deployed downstream from spawning sites, as we have done off the Atlantic and Gulf coasts of Florida (see Koenig and Coleman 2009). See details of

the spawning behavior and timing of goliath grouper in Mann *et al.* (2009).

Photo by Walt Stearns.

Discussion:

Goliath grouper is a native species that evolved on reefs on both sides of the Atlantic over millions of years. It is a natural and integral component of Florida's reef ecology and thus is not disruptive to the reef community. Truly disruptive species include such non-native species as the Indo-Pacific lionfish (*Pterois volitans*), a species introduced to western Atlantic in the early 1990s. Lionfish are active predators of newly recruiting fish to native reefs, wreaking havoc on reef populations (Albins and Hixon 2008). Part of the problem is the absence of checks and balances on lionfish population expansion through control by predators or other factors. Yet there are few eradication plans for this species because the economic impact has not been determined.

All the scientists who have studied the behavior and ecology of goliath grouper acknowledge their optimism over the ongoing recovery of this species in Florida. Other fish species similarly fished to economic extinction have not fared so well. For example, the giant sea bass (*Stereolepis gigas*) population of the Eastern Pacific has not recovered despite nearly 30 years of limited protection. (http://www.arkive.org/black-sea-bass/stereolepis-gigas/info.html). This species is similar to goliath grouper in that it is large and feeds primarily on crabs and slow-moving fishes.

Still, the optimism is guarded because the level of goliath grouper recovery remains unknown and the time trajectory for complete recovery uncertain. A key element in recovery of goliath grouper populations in Florida is the availability of high-quality mangrove habitat in southwest Florida (Koenig et al. 2007, Koenig and Coleman 2009). Juveniles spend their first 5 to 6 years of life in this habitat and it was here in the juvenile population that the first signs of recovery appeared (Cass-Calay and Schmidt 2009).

Optimism is also dampened by the fact that the south Florida ecosystem has been altered to such a high degree over the last 100 years (Ogden et al. 2005), that suitable mangrove nursery in all probability presents a bottleneck to the production of this species (Koenig et al. 2007). Also, losses due to release mortality and illegal harvest result in continued overfishing (Porch et al. 2006). Because of these issues and the inherent vulnerability of goliath grouper to fishing pressure, caution should be the hallmark of any management decision. The fact that a number of very vocal people consider goliath grouper a nuisance species speaks worlds about the poor

job we have done collectively as scientists and managers to educate the public about marine systems. The fact that managers would seriously consider destructive sampling of a species known to be critically endangered elsewhere in their range suggests adherence to political rather than ecological or conservation principles.

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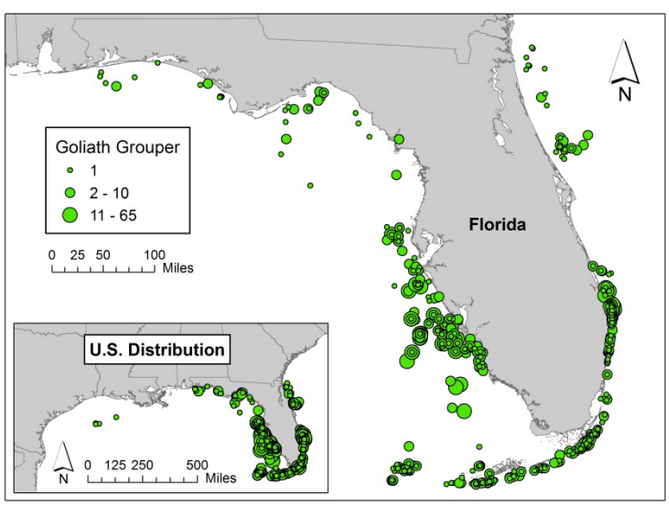
Additional Resources:

1. Marine, Estuarine, and Diadromous Fish Stocks at Risk of Extinction in North America (Exclusive of Pacific Salmonids). (pdf file on the American Fisheries Society website) For the first time AFS scientists review the risk of extinction in marine fishes in North American waters. Populations within 82 species or subspecies are found to be vulnerable to extirpation, and 22 may be vulnerable to global extinction.

2. The IUCN Red List of Threatened Species (IUCN website). Gland, Switzerland and Cambridge, UK. xviii + 61pp.

Distribution Map of Goliath Grouper



Research conducted by scientists at Florida State University Coastal and Marine Laboratory in collaboration with the National Marine Fisheries Service is intended to define the behavior, demographics, and movement patterns of goliath grouper *Epinephelus itajara* in the eastern Gulf of Mexico. The research involves dedicated individuals in the fishing industry of South Florida who have

helped us identify spawning aggregation sites and have participated in all components of the field research. Such fishery-independent information will lead to estimates of stock recovery and elucidation of the mating system of this important grouper species.

With the help of the Florida Fish and Wildlife Conservation Commission, we have been developing a catalogue of goliath grouper sightings throughout the southeastern United States. These efforts so far have concentrated in Florida, but we are slowly obtaining information from other sites.