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PATTERN OF RECOVERY OF THE GOLIATH GROUPER *EPINEPHELUS ITAJARA* POPULATION IN THE SOUTHEASTERN US

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ABSTRACT

In the present study, we evaluate the past and current distribution and abundance of the Atlantic goliath grouper, *Epinephelus itajara* (Lichtenstein, 1822), in coastal waters of the southeastern United States. The study is based on quantitative surveys conducted by us (n = 190) and the Florida Fish and Wildlife Conservation Commission's Artificial Reef Program (n = 505), coupled with semi-quantitative data submitted by volunteer divers to the Reef Environmental Education Foundation (n = 27,542) over the past 15+ yrs. The vast majority of the goliath grouper population is restricted to Florida waters. We found that the population of goliath grouper, after dramatic fishery-induced declines in the 1970s and 1980s, and eventual fishery closure in the 1990s, increased off southwest Florida in the mid-1990s, directly offshore of the high-quality mangrove nursery of the Ten Thousand Islands. It then expanded north and south, eventually increasing off Florida's central east coast. Tagged fish, regardless of life stage, showed strong site fidelity to home sites: juveniles (2963 tagged, 32.6% recaptured) to mangrove nursery sites and adults (2110 tagged, 7.6% recaptured) to offshore reefs. All long-distance movements appeared to be in response to approaching maturity, with juveniles emigrating from mangroves to take up residence on offshore reefs, to seasonal spawning activity, with adults moving from home sites to aggregation sites, or to apparent feeding sites in inlets. Understanding these patterns of population recovery and movement is fundamental to devising appropriate management policies.

Human activities threaten the sustainability of reef fish populations either directly by intense exploitation, or indirectly by affecting habitat quantity and quality. The synergy of these activities has had a pronounced impact on the Atlantic goliath grouper, *Epinephelus itajara* (Lichtenstein, 1822), causing economic extinction in the United States (Koenig et al. 2007), endangerment throughout the rest of its range in the western Atlantic (IUCN 2010), and probable biological extinction in west Africa (Craig et al. 2009). Despite significant declines on a large spatial scale, anecdotal information suggests goliath grouper populations in Florida are increasing after 20 yrs of protection afforded by the South Atlantic and Gulf of Mexico Fishery Management Councils and Florida Fish and Wildlife Conservation Commission (FFWCC) when they closed the fishery in 1990 (Porch et al. 2006, Cass-Calay and Schmidt 2009). This is encouraging when one considers that intense exploitation in the United States up to and including the 1980s led to the fishery closure (Sadovy and Eklund 1999), and subsequent candidate species listing of goliath grouper on the Endangered Species List in 1991. But the reality is that there have been no real data to back this up because since the fishery closure, no fishery-dependent data have been collected and fishery-independent monitoring has been largely lacking (Koenig et al. 2007), thus hindering the ability of the National Marine Fisheries Service (NMFS) to conduct stock assessments or make informed policy decisions about management.

The anecdotal evidence for regional recovery, especially in southwest Florida, elicited a largely science-free response from various fishing sectors that encouraged management to reopen the goliath grouper fishery at some level. This has occurred despite accumulating evidence of this species' high vulnerability to exploitation (e.g., Bullock et al. 1992, Sadovy and Eklund 1999, Frias-Torres 2006, Gerhardinger et al. 2006, Koenig et al. 2007, Felix-Hackradt and Hackradt 2008, Brusher and Schull 2009, Cass-Calay and Schmidt 2009, Craig et al. 2009, Evers et al. 2009, Gerhardinger et al. 2009, Graham et al. 2009, Mann et al. 2009, McClenachan 2009, Murie et al. 2009). Our primary objective in the present study is to describe the distribution and abundance of the goliath grouper population of the southeastern US with a focus on Florida, the center of US abundance for this species, the center for the historical fishery, and now the center of much controversy. A secondary, but quite important objective is to demonstrate the utility of using existing databases, such as that of the Reef Environmental Education Foundation (www.reef.org) to provide what often amounts to the best scientific data available for informing management decisions, particularly in areas and for species for which there is no traditional fishery-dependent data collection.

Methods

Data Sets

We used three data sets to determine the distribution and abundance of goliath grouper: two quantitative data sets describing surveys conducted by expert divers [our data from this study, n = 190 surveys, 2005–2008[1] and data obtained through the Florida Fish and Wildlife Conservation Commission (FFWCC) Artificial Reef Program, n = 505 surveys, 1999–2008], and one semi-quantitative dataset, containing surveys conducted by both expert and novice divers from the Reef Environmental Education Foundation (REEF, http://www.reef.org; n = 27,542). We confined our evaluation to Florida based on reports we obtained from natural resource departments throughout the southeastern coastal states (from North Carolina to Texas), and on a preliminary examination of the REEF datasets (Table 1), both of which revealed that the vast majority of the goliath grouper population occurs in Florida waters.

Study Sites

All study sites are within the eight zones of Florida coastal and marine waters designated by REEF (Fig. 1). Zone 1 covers the western panhandle from the Florida-Alabama state line to Cape San Blas; zone 2 from Cape San Blas to the Pasco-Pinellas county line; zone 3 extends to the Sarasota-Charlotte county line; zone 4 covers the rest of peninsular southwest Florida; zone 5 covers the Florida Keys and Florida Bay; zone 6 from Key Biscayne National Park to Jupiter Inlet; zone 7 from Jupiter Inlet to Cape Canaveral; and zone 8 from Cape Canaveral to the St. Mary's River (the Florida-Georgia state line). Using REEF zone designations allowed us to make regional comparisons of distribution and abundance of goliath grouper as determined by quantitative data from FSU and FFWCC surveys and semi-quantitative data from REEF surveys. A high degree of concordance between the two datasets would indicate that REEF data provide reliable regional and temporal patterns of abundance suitable for use in stock assessments.

We evaluated habitat within each zone using REEF's habitat classification: (1) mixed or multiple habitat types; (2) high profile natural structure with relief > 1.22 m; (3) low profile natural structure with relief < 1.22 m; (4) sloping drop-offs in which the bottom slopes to deeper water; (5) walls with shear drop-offs > 7.62 m; (6) ledges with single or few sharp drops in bottom topography > 1.22 m; (7) seagrass; (8) sand; (9) rubble of broken coral, rock, boul-

1 Archived at the Florida State University Coastal and Marine Laboratory, FSUCML

Table 1. Relative abundance of Atlantic goliath grouper, *Epinephelus itajara*, reported to REEF (Reef Environmental Education Foundation) for the period 2004–2008 for coastal states in the southeastern United States.

State	Total # surveys	Total # sites surveyed	# surveys with goliath grouper	# sites with goliath grouper	% surveys with goliath grouper	% sites with goliath grouper
Florida	9,488	1,000	912	236	9.61	23.60
Texas	639	24	3	3	0.47	12.50
Georgia	196	59	5	2	2.55	3.39
South Carolina	115	18	1	1	0.87	5.56
North Carolina	69	21	0	0	0.00	0.00
Louisiana	2	1	0	0	0.00	0.00
Alabama	0	0	0	0	0.00	0.00
Mississippi	0	0	0	0	0.00	0.00

ders, and/or gravel; (10) artificial reefs, including ship wrecks, platforms, dumped debris, or other artificially created habitats; and (11) open deep water in which the bottom is not visible.

We obtained natural reef sites from our own database and from fishers with significant local knowledge, and obtained artificial reef sites from the FFWCC artificial reef database (http://myfwc.com/docs/Conservation/REEFS.pdf). We recorded reef depth, size, and the presence of holes, caves, and/or crevasses large enough to accommodate adult goliath grouper (minimum opening dimension, ~50 cm diam), identifying as many positions as possible before sampling occurred.

We stratified our (FSU's) sampling by region and by habitat type (high or low relief, natural or artificial reefs), sampling artificial and natural reefs randomly; that is, without prior detailed knowledge of the reef characteristics or the presence of goliath grouper). We then used the site-specific abundance to estimate "preferred" goliath grouper habitat. We restricted our evaluation of this to the 5-yr period, 2004–2008, based on the assumption that highest densities in a recovering population would appear in the most recent times.

Goliath Grouper Distribution, Abundance, Habitat Preference

All divers (FSU, FFWCC, REEF) conducted surveys using the Roving Diver Technique (RDT). We augmented that approach only on reefs where goliath groupers were abundant (> 10 individuals). In that case, when possible, we used two quantitative methods, Petersen Mark-Resight (mark-recapture) and tag effort (catch effort) methods (Krebs 1999). The RDT survey consisted of two divers swimming independently over a given reef, surveying as much of the reef as practicable in a single dive, and recording the number of goliath grouper present. We recorded associated species with a video camera and measured goliath grouper with parallel lasers at the same time as the RDT surveys. Dive time was always > 30 min and was typically sufficient for both divers to survey the entire site. At the end of the survey, divers compared notes and came to a consensus on the total number of goliath grouper seen. Our preliminary sampling suggested that visual surveys, while accurate for small populations, underestimated larger ones. Both the tag-effort and Petersen mark-resight methods (modified for goliath grouper) involved tagging fish in situ with a modified spear point (Fig. 2 and described below) and recording the time-to-tag for each tagged fish (effort taken as the time interval between tagging). These methods required (1) that the tagger was sufficiently skilled to apply effort evenly throughout the tagging period, and (2) that the tagger could tag a large portion of the population.

Tagger-divers implanted tags (FLOY, http://www.floytag.com/; 15.2 cm long BFIM-96 tags with plastic tubing surrounding a 0.051 cm diam double stainless-steel wire core) in the muscular region just below the soft dorsal fin of each goliath grouper. Each tag had a unique number imbedded on a 3.2 cm diam white plastic laminate disc and was secured with an applicator tip to the end of a 122 cm single-band AB Biller speargun with a 152 cm spear shaft and

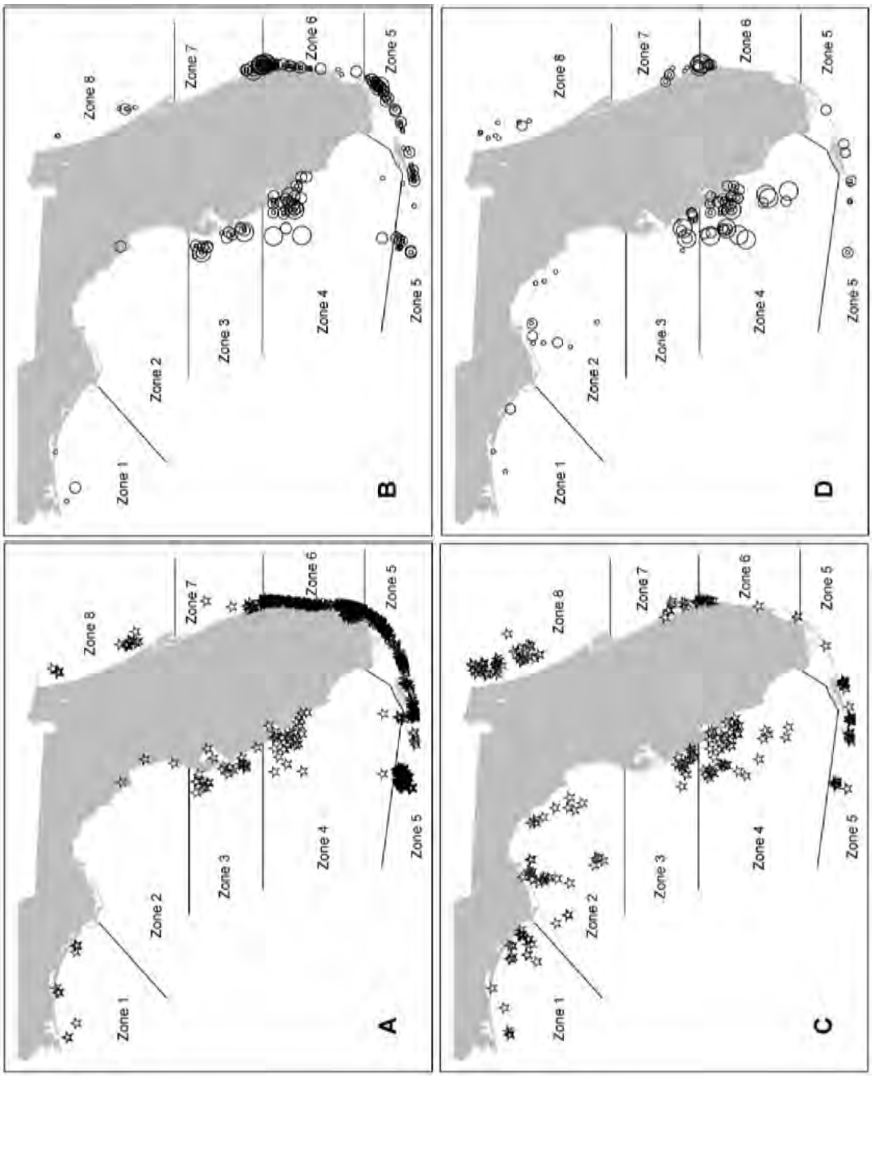

Figure 1. Distribution of goliath grouper, *Epinephelus itajara*, sampling sites (panels A and C) and site densities (panels B and D) across eight geographic zones in Florida, from 2004 to 2008. (A) Survey sites for semi-quantitative data, (B) goliath grouper site density based on semi-quantitative data, (C) survey sites for quantitative data, (D) goliath grouper densities based on quantitative data.

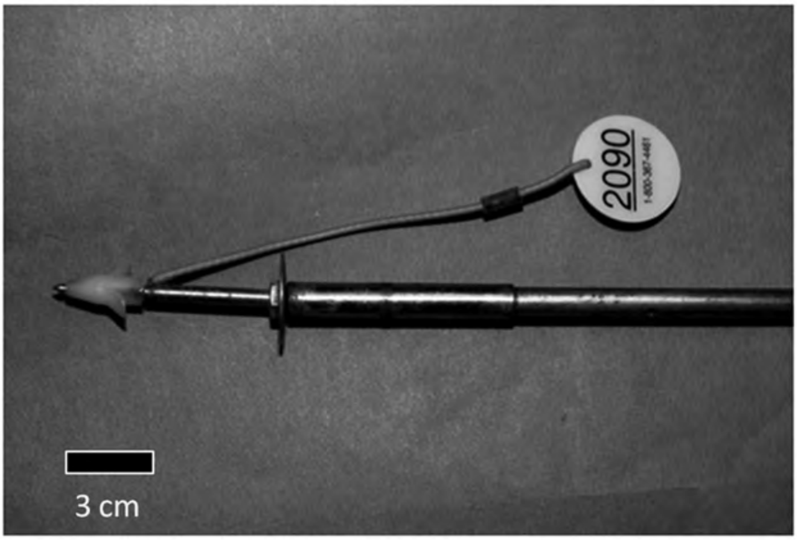

Figure 2. Applicator tip with tag attached at the end of a spear shaft used for tagging adult goliath grouper underwater with a spear gun.

86 cm line (Fig. 2). A 2-cm diam stainless steel washer placed 5 cm down the shaft limited the penetration depth of the applicator in the dorsal musculature. The short line allowed the tagger to shoot with greater precision while swimming above and behind the fish, and to quickly pull the shaft free before the fish could swim away and bend the applicator tip.

Tag-effort data provided a relationship between tags-per-unit effort (TPUE) and accumulated tagged fish. A linear relationship (as estimated from regression methods) denotes equal catchability (equal tag-ability, Ricker 1975). The Petersen method is somewhat more involved. After initial tagging, we found that tagged fish and untagged fish formed separate groups, thus violating the assumption of equal sightability (random assortment). However, tagged and untagged fish were interspersed by the following day, so we made re-sighting dives 1 d after tagging dives. On re-sighting dives, three divers swam random transects over the fish to estimate the relative proportion of tagged and untagged fish. Swimming above the fish allowed divers to see tags on either side of the fish body, regardless of which side of the fish they had tagged, and kept the fish from becoming alarmed by diver presence. Resighting fish multiple times by this method is equivalent to sampling with replacement.

We estimated population size (N) using the following equation:

$$N = T(C + 1)/(R + 1),$$

where T = total number tagged, C = total number observed, marked and unmarked, on the day after initial tagging, and R = total number of tagged fish observed on the day after initial tagging. If the N derived from the two methods is not significantly different, then the assumptions of a closed population and random assortment of the sampled population hold.

REEF surveys use semi-quantitative categories to describe fish abundances: zero (no fish seen), single (one fish seen), few (2–10), many (11–100), and abundant (> 100). To compare REEF data on goliath grouper abundance with our data, we modified the REEF categories to fit our data, and then converted all REEF data to fit these modified categories. Category modifications included the following (except for categories zero and single, which remained unchanged): (1) we eliminated the "abundant" category (> 100) because we never encountered goliath grouper abundances that high in any data set, (2) we truncated the upper limit of the "many" category from 100 to 65, which represented the greatest number of goliath grouper we encountered at any site; and (3) we used the median number from the remaining categories, which changed "few" to 6, and many to 38, assuming that half of the abundance estimates would be above and half below the median value. Applying these categories to the REEF's diver surveys for goliath grouper, we estimated mean goliath grouper densities (numbers of individuals per site) for each zone, habitat type, and year, and grouped REEF data into three 5-yr intervals: 1994–1998, 1999–2003, and 2004–2008 to provide a sufficient number of observations within all zones for comparison. All expert ("quantitative") surveys involved experienced science divers whereas those conducted by REEF ("semi-quantitative") included divers with varying levels of experience, from expert to novice. We tested the assumption that REEF divers, regardless of experience, identified adult goliath grouper correctly by comparing our quantitative surveys with REEF's semi-quantitative surveys.

To evaluate habitat preferences we compared site-specific densities (number of goliath grouper per site, regardless of size of the site or site characteristics) of goliath grouper for each reef type within each zone. We assumed that reef types with the highest abundances represented preferred sites. We then compared differences in goliath grouper densities in preferred habitats among zones using quantitative and semi-quantitative data (2004–2008).

Movement Patterns

We studied movement patterns of adult goliath grouper from 1996 to 2008 by tagging adults either in situ (n = 2089) or while we had them onboard research vessels (n = 21). We also studied movement patterns of juvenile goliath grouper, tagged in the Ten Thousand Islands (n = 2763) from 1999 to 2006 (methods reported in Koenig et al. 2007) and in the Florida Keys (n = 200) from 2007 to 2008. Juveniles captured in the Florida Keys received dart tags (Floy FT-1-97SS) below the first dorsal fin. All tags included a toll-free reporting number (provided by FFWCC) and instructions for types of data to report (i.e., tag number, sighting position in latitude and longitude, depth of capture or sighting, size of fish, and contact information of the responder). To encourage reporting, we distributed informational posters describing the study to dive shops and marinas throughout the state. We entered all verified data from responders into an ArcGIS (ESRI ArcMap 9.2) database with relevant movement profile plotted using HawthsTools (www.spatialecology.com).

Regional Size Estimates

On all FSU surveys (n = 190), we attempted to obtain size estimates of adult goliath grouper. We used three types of data for these estimates: (1) direct measurement of captured fish, (2) direct measurements of fish taken in situ with a parallel beam laser-equipped video camera, and (3) estimates of fish sizes taken by expert divers or spearfishermen who targeted goliath grouper many years prior to the fishery closure. Most measurements were made using the video-laser method, which involved projecting parallel laser beams a known distance apart (10 or 20 cm) onto the sides of the fish while it was perpendicular to the beams. In the laboratory, we used distance between laser dots on the sides of the fish as a known length, then used dividers to estimate total length. FFWCC and REEF data contained no goliath grouper size estimates.

Species Associations

We used both quantitative and semi-quantitative surveys in high-relief offshore habitat of zone 4 to evaluate characteristics of associated fish communities in relation to site abundance of goliath grouper. Video surveys conducted in concert with our quantitative goliath grouper surveys provided associated community characteristics. Semi-quantitative REEF surveys provided species names and rough estimates of abundance (1, 2–10, 10–100, and > 100) from which we selected the median value of each range. For those species with abundances > 100, we used 101. Most fishes in this category were schooling species with large population sizes that were not possible to estimate accurately, so we chose 101 as a standard estimate of their abundance. These data provided a means of estimating the relationship between abundance of goliath grouper and both species richness and the abundance of other fishes in the associated reef community. We used rarefaction methods (Krebs 1999) to standardize fish species richness of each survey prior to regression analyses, because sample size strongly affects richness. Because valid richness comparisons must be made between similar habitats (Simberloff 1978), we analyzed only high relief habitat from offshore in zone 4. We did not standardize fish abundance data prior to regression analysis because abundance is typically concentrated in the few dominant species recorded early in the survey; rare species contribute little to abundance estimates.

Statistical Comparisons

We made statistical comparisons of site density and habitat preference data using nonparametric statistics, Mann-Whitney for paired tests and Kruskall-Wallace for multiple comparisons with Dunn's test for multiple pair-wise comparisons at the 0.05 significance level. We then used linear regression to evaluate the relationship between the density of goliath grouper and the associated fish community.

Results

Study Sites

Of the eleven habitat types identified in the REEF database, only six (i.e., high profile reef, low profile reef, wall with shear drop off, ledge, rubble, and artificial) were used by goliath grouper in Florida. We condensed these into four habitat types based on reef height (low relief < 1.2 m; high relief > 1.2 m) and composition (natural or artificial reefs). Artificial reefs are virtually all high relief; low relief sites occurred in only two of the 589 sites (0.3%) in the expert (FSU/FFWCC) data, and only 55 of the 1836 sites (3%) in the semi-quantitative (REEF) data.

We modified our reef site pre-selection strategy for regional goliath grouper surveys because of unanticipated problems encountered in the field. These were: (1) relief of reefs differed significantly from expectations (many reefs had far less relief than that recorded in fishers log books, apparently due to silting); and (2) fishers' willingness to provide reef locations varied widely, with some opening their logbooks while others only provided published artificial reefs. The result is that the number of natural reefs surveyed differed among zones. Ultimately, we selected reefs blind, using anglers' knowledge when it was forthcoming. We also chose not to stratify sites by depth because within depths sampled (10–50 m), there were no apparent depth-related trends in site densities within zones. It was clear from our pre-survey work that goliath grouper did not avoid shallow depths; we consistently observed 30–40 adults in water depths < 10 m in Boca Grande, Florida. They also appeared to decline in abundance precipitously at depths > 50 m, as observed by technical divers (M Barnette, NOAA, St. Petersburg, FL, pers comm).

Goliath Grouper Distribution, Abundance, Habitat Preference

Analysis of the REEF database confirmed anecdotal evidence that goliath grouper abundance was far greater in Florida than in neighboring states in the southeastern US (Table 1). In Florida during the 5-yr interval evaluated (2004–2008), 9.6% of the surveys and 23.6% of the surveyed sites reported goliath grouper. Goliath grouper occurred rarely in other states where REEF surveys were reported (Texas, Georgia, and South Carolina), as well as in those states lacking REEF surveys (Mississippi and Alabama) as confirmed by their respective Departments of Natural Resources (DNRs).

An examination of habitat types within all zones for the period 2004–2008 revealed that goliath grouper preferred high-relief artificial and natural reefs over

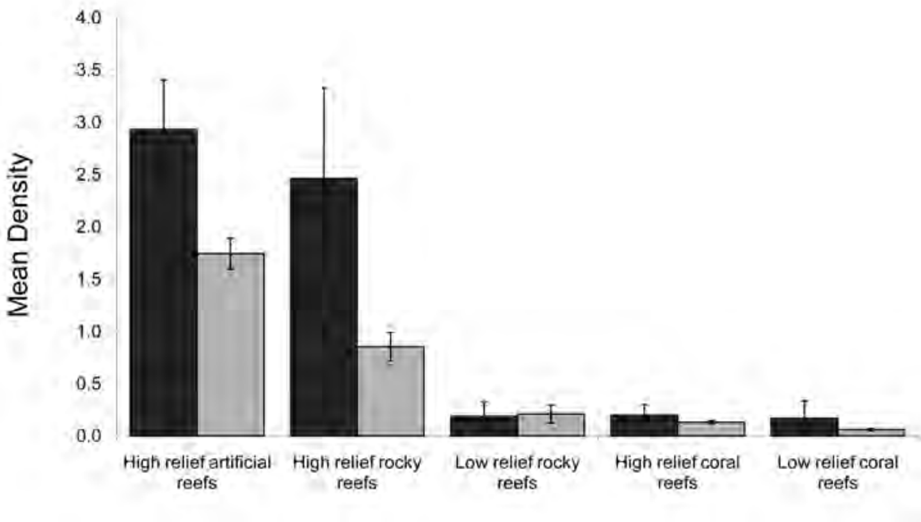

Figure 3. Mean number of goliath grouper, *Epinephelus itajara*, per habitat type in Florida. Data pooled across eight geographic zones and 5 yrs (2004–2008) using quantitative FSU and FFWCC data (dark bars, n = 374) and semi-quantitative REEF data (light bars, n = 7071), comparing high and low relief habitat types, including artificial reefs (all considered high relief, ≥ 1.2 m), high-relief rocky reefs (rocky ledges and walls ≥ 1.2 m), low-relief rocky reefs (rubble and low-relief rocky outcrops and ledges < 1.2 m), high-relief coral reefs (≥ 0.9 m), and low-relief coral reefs (< 0.9 m). Error bars are standard errors.

high-relief coral reefs and all low-relief reefs (Kruskall-Wallace and Dunn's test: $P < 0.05$), but showed no preference between the high-relief artificial reefs and high-relief natural reefs (Mann-Whitney: $P > 0.05$, Fig. 3).

Although density estimates of goliath grouper associated with high-relief artificial and natural reefs were significantly higher using quantitative rather than semi-quantitative methods (Mann-Whitney: $P < 0.05$), both data sets showed a similar preference of goliath grouper for high-relief natural and artificial reefs (Fig. 3; Kruskall-Wallace and Dunn's test: $P < 0.05$). The data also revealed a similar distribution pattern of higher densities in preferred habitat in southwest Florida in zone 4, and in southeast Florida in the northern part of zone 6 and zone 7 (Kruskall-Wallace and Dunn's test: $P < 0.05$; Figs. 1, 4). The only areas in which we found significant density differences based on methodology were in zones 3 and 6 (Mann-Whitney: $P < 0.05$; Fig. 4, Table 2). Closer examination revealed that within these two zones, densities varied greatly with latitude, and biased site selection occurred. In each zone, quantitative estimates occurred in high-density areas (the southern part of zone 3 and northern part of zone 6) and the semi-quantitative measures occurred in low-density areas (the northern part of zone 3 and southern part of zone 6, which is mostly coral reef habitat, see Fig. 1). Bias in quantitative data resulted from the overwhelming number of artificial reef sites in the FFWCC data. Bias in semi-quantitative data relates to the following attributes of recreational divers: (1) they typically prefer coral reef sites for diving and so visit these sites more often (explaining the bias in zone 6); and (2) they tend not to travel far from home to dive. Given that the northern part of zone 3 is in close proximity to the metropolitan Tampa–St. Petersburg area where

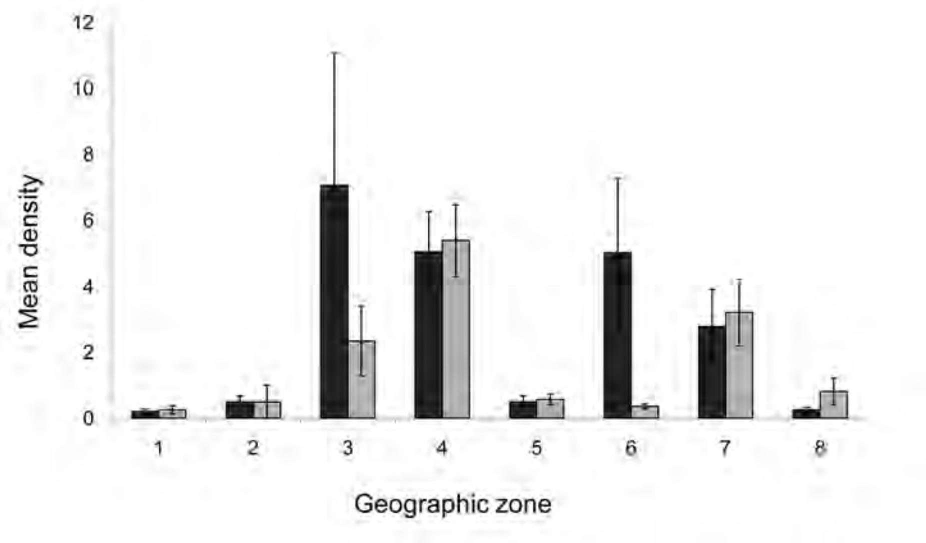

Figure 4. Mean site density of goliath grouper, *Epinephelus itajara*, on high-relief structure (artificial, rocky, and coral reefs) across eight geographic zones in Florida from 2004 to 2008, comparing quantitative data (black bars) with semi-quantitative data (gray bars). Error bars are standard errors.

human population size (and therefore diver population size) is large, the bias in zone 3 is readily explained.

Initial expansion of the adult goliath grouper population occurred off southwest Florida in zone 4, an area of high-quality mangrove habitat (Koenig et al. 2007) during the mid 1990s (Fig. 5). Population densities in that area remained relatively stable through to the present, as densities in all other zones combined continue significant increase (linear regression: $P < 0.05$; Figs. 5, 6)

Table 2. Regional sample sizes of surveys conducted in each of eight geographic zones in Florida for the period 2004–2008. The areal extent of each zone and semi-quantitative data are from Reef Environmental Education Foundation (REEF) database. Quantitative data from Florida State University and Florida Fish and Wildlife Conservation Commission expert surveys. For zones, see Figure 1.

Florida zones	1	2	3	4	5	6	7	8
Quantitative data								
# sites surveyed	36	36	17	76	43	11	18	43
# surveys	38	44	17	161	45	11	19	43
Semi-quantitative data								
# sites surveyed	18	8	39	57	383	436	38	21
# surveys	52	12	160	182	4,989	3,418	617	58

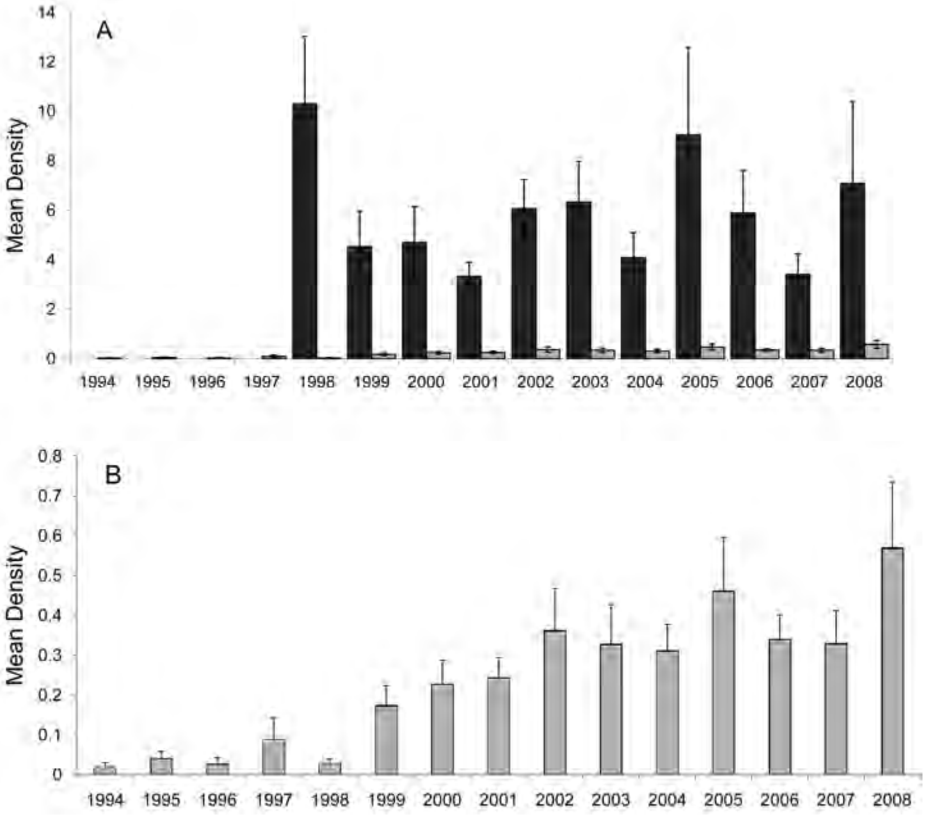

Figure 5. Mean densities (REEF's semi-quantitative data) of goliath grouper, *Epinephelus itajara*, in high-relief artificial and rocky habitat of Florida from 1994 to 2008. (A) Zone 4 (black bars) and all other zones (gray bars). (B) Expanded view of all other zones (excluding zone 4). Error bars are standard error.

The size structure of goliath grouper from offshore reefs was similar among the eight zones (Kruskall-Wallace: $P > 0.05$; Fig. 7). Mean total length varied from ~130 to 150 cm per region.

Movement Patterns

Eighty-two percent of 165 recaptured or resighted adult goliath groupers moved < 1 km (Fig. 8a). Time at liberty varied from 1 to 2835 d with a mean of 167 d and a median of 25 d. The mean distance moved was 10.7 km. The maximum distance traveled by an adult was 175 km. The maximum time an adult was at liberty was almost 8 yrs; that fish moved 25 km and was 232 cm TL when recaptured (Fig. 8b). Movements > 1 km typically occurred during the spawning season and appeared to represent migrations between home sites and aggregation sites, although some may represent seasonal feeding excursions (Fig. 9). Recaptured goliath grouper that were tagged as juveniles in mangrove habitat in another study (Koenig et al. 2007) moved primarily west or south of their nursery grounds. The most extreme movements occurred in

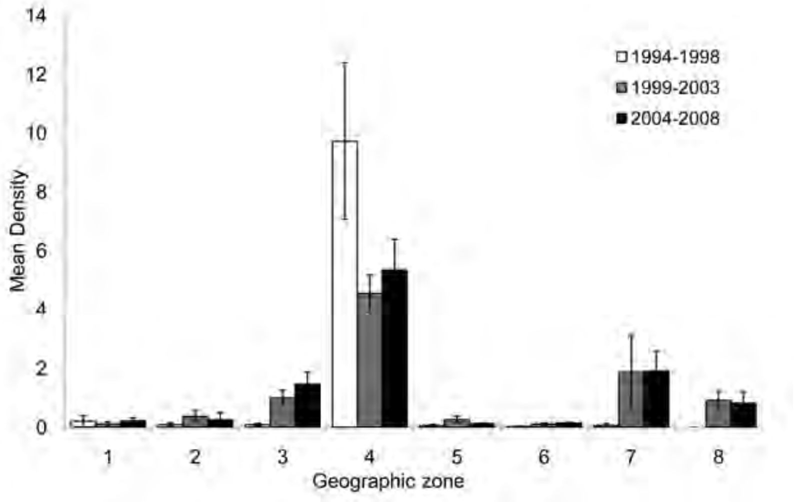

Figure 6. Mean site density of goliath grouper, *Epinephelus itajara*, in high relief artificial and rocky habitat over eight geographic zones and three 5-yr time intervals in Florida. Data from REEF surveys.

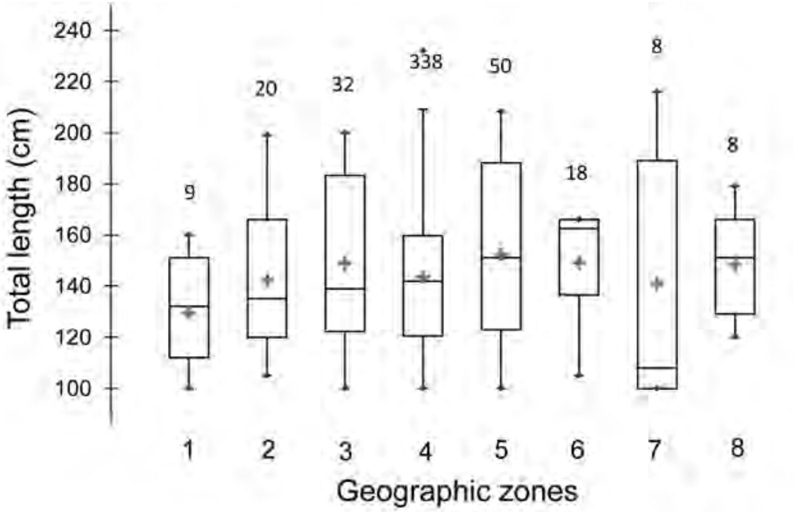

Figure 7. Size distribution of goliath grouper, *Epinephelus itajara*, in eight geographic zones in Florida. Range = vertical lines, mean = +, median = horizontal line in box, area below line = first quartile, area above line = third quartile. Numbers above box plots = sample size. Data from FSU surveys 2004–2008.

two juveniles; one moved 200 km northwest (resighted off Tampa, but not measured by the fisher who recaptured it), and the other, 52.2 cm TL on recapture, moved over 400 km to the east coast off Indian River (Fig. 10).

Species Associations

Our evaluation of the composition and abundance of fish species associated with goliath grouper obtained from semi-quantitative REEF survey data (Fig. 11a) and from quantitative video surveys (Fig. 11b) revealed a weak positive relationship (linear regression of rarified data: $P < 0.07$) between species richness and density of goli-

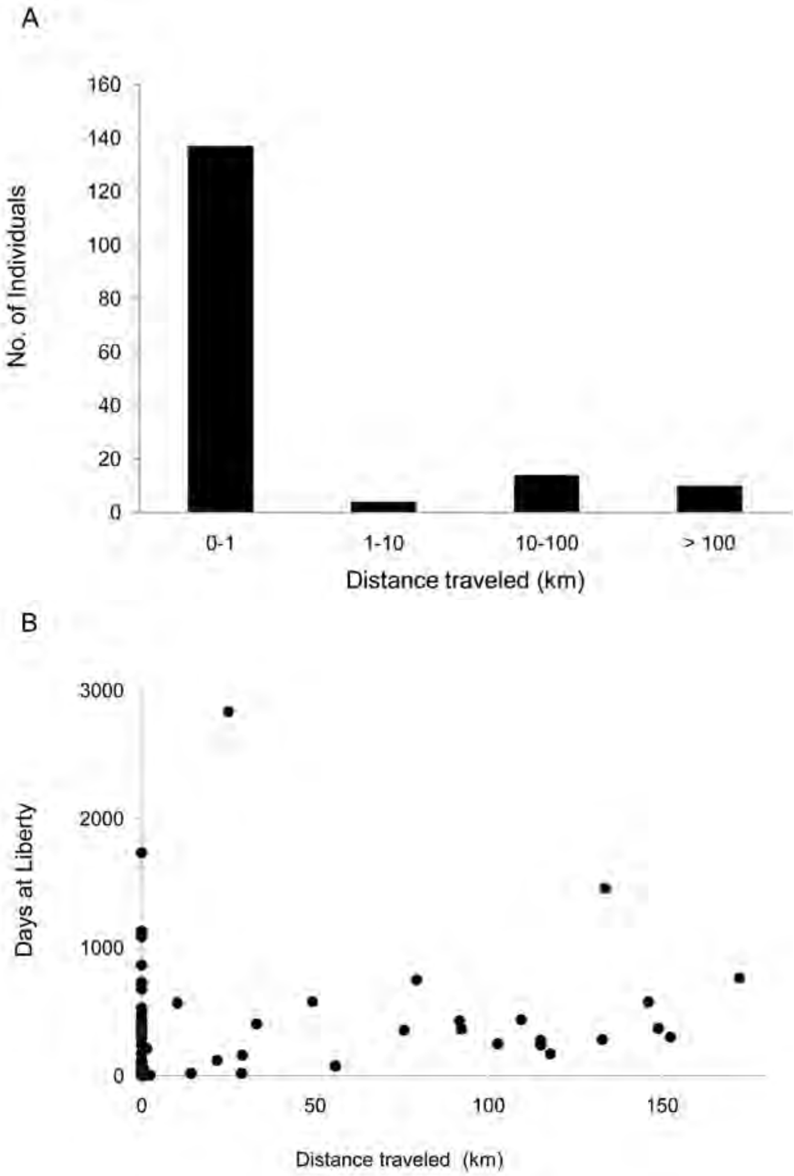

Figure 8. Distance travelled in Florida by adult goliath grouper, *Epinephelus itajara* (n = 165), from original offshore tagging site. (A) Overall, and (B) relative to time at liberty. Data from FSU tagging study, 1996–2009.

ath grouper on high-relief sites in zone 4 (zone of highest goliath grouper densities). The relationship between site-specific density of goliath grouper and overall abundance of other reef fish was highly significant using both semi-quantitative (Fig. 12a, $P < 0.001$) and quantitative (Fig. 12b, $P < 0.0001$) surveys.

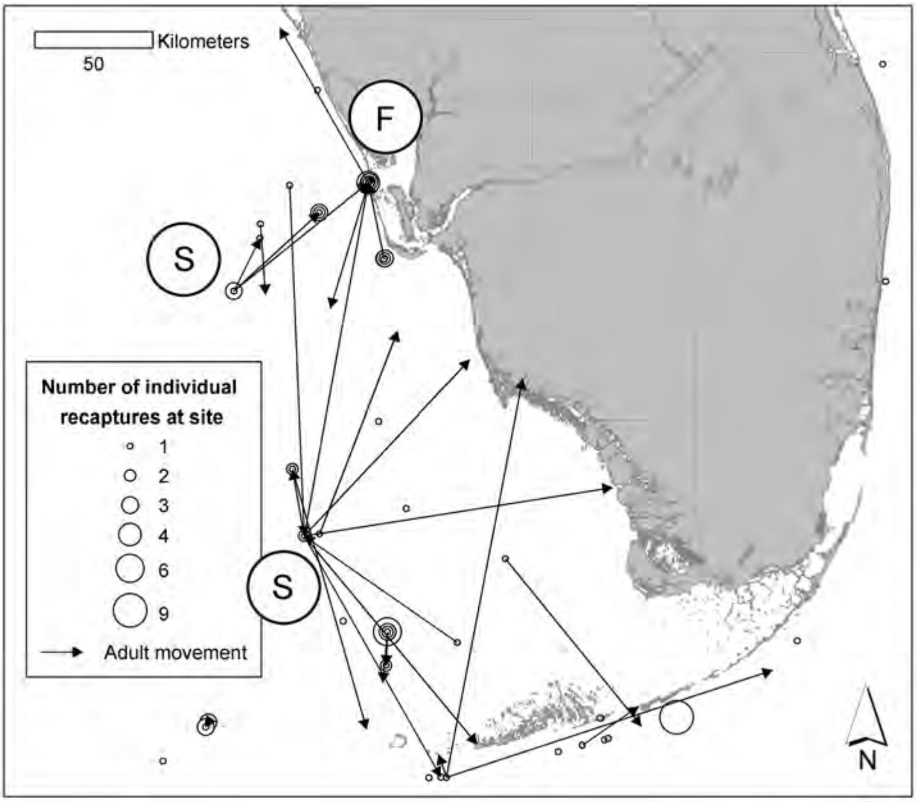

Figure 9. Movement of tagged adult goliath grouper, *Epinephelus itajara,* in Florida. F = presumed feeding site; S = spawning sites. Data from FSU tagging study, 1994–2009.

Discussion

One of our primary objectives in this study was to determine whether the REEF fishery-independent database provided an effective means of tracking recovery patterns of the goliath grouper population in the southeastern US. Stallings (2009) used a similar approach to great effect in his evaluation of predator declines throughout the Caribbean, a region with similarly poor fisheries-dependent data. What we found was that semi-quantitative data collected by REEF provide a convenient means of determining regional density of adult goliath grouper in Florida for future stock assessments. We found no reason to suspect the quality of the REEF data related to goliath grouper for several reasons. First, whether someone is an expert or inexperienced diver, the probability of misidentifying an adult goliath grouper is very low. Second, we compared density estimates we made using REEF data to those we obtained ourselves—data that were carefully and systematically collected by a single team of professionally trained divers using statistically sound and standardized methods—and found a high degree of agreement between the two datasets. The two datasets are concordant in all regions except in zones where both low and high densities exist (zones 3 and 6), but the differences in those zones can be explained by differences in geographical sampling effort.

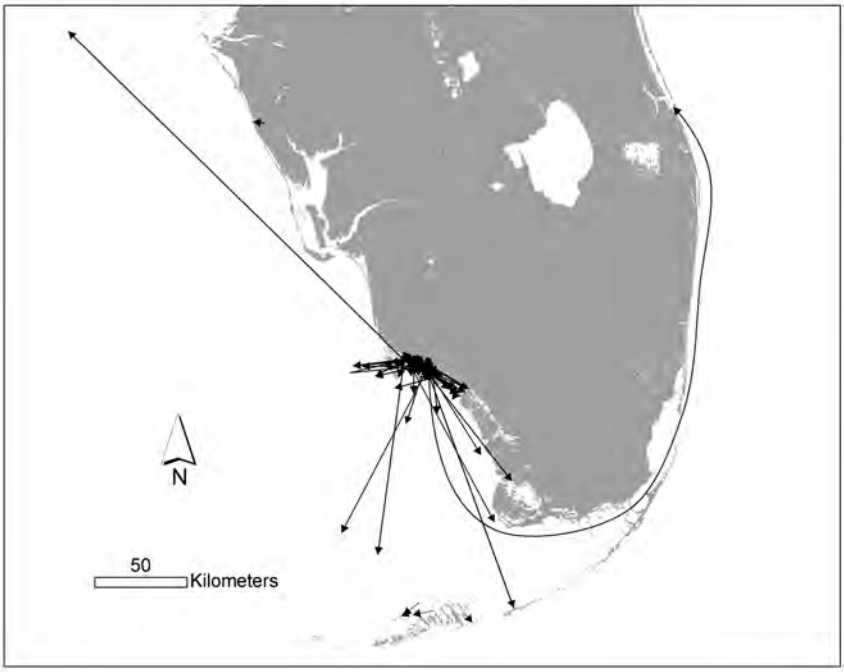

Figure 10. Movement of tagged juvenile goliath grouper, *Epinephelus itajara*, in Florida from nursery habitat in the Ten Thousand Island area offshore to shallow water reefs. Data from FSU tagging study, 1999–2009 (n = 2963).

Data from this study confirm historical observations (Smith 1971, Sadovy and Eklund 1999) that goliath grouper prefer high-relief habitat that provides shelter. These data also demonstrate that this preference does not extend to coral reef habitat in Florida. We assume that low densities of goliath grouper on coral reefs relates to low availability of food resources. For example, it is possible that the primary food of goliath grouper (crabs and other crustaceans, Koenig and Coleman 2009), are low in abundance in coral reef habitat and/or inaccessible because of the extreme rugosity of coral reef habitat.

Our data show that goliath grouper are sedentary and have a high degree of site fidelity. Corroborative findings have been reported by Pina-Amargos and Gonzalez-Sanson (2009). Indeed, 82% of our adult recaptures moved < 1 km, regardless of time spent at liberty. As juveniles, goliath grouper show similar site fidelity, occupying the same 160 m of mangrove island shoreline for several years (Koenig et al. 2007). The only significant long-range movement patterns we observed were (1) movements of juveniles from their nursery habitat to offshore adult habitat after reaching 5–6 yrs of age, (2) movement of adults to and from apparent feeding locations in inlets, and (3) movement of adults to and from spawning sites.

We found that the REEF data were useful in reconstructing the pattern of population increase following the fishery closure in 1990. Goliath grouper apparently respond to density-dependent factors, moving from their center of abundance in the high-density areas of southwest Florida adjacent to high-quality juvenile mangrove habitat, to lower density areas elsewhere. Our tagging data suggest that this occurs in the late-juvenile stage. Thus, the general pattern of adult goliath grouper recovery

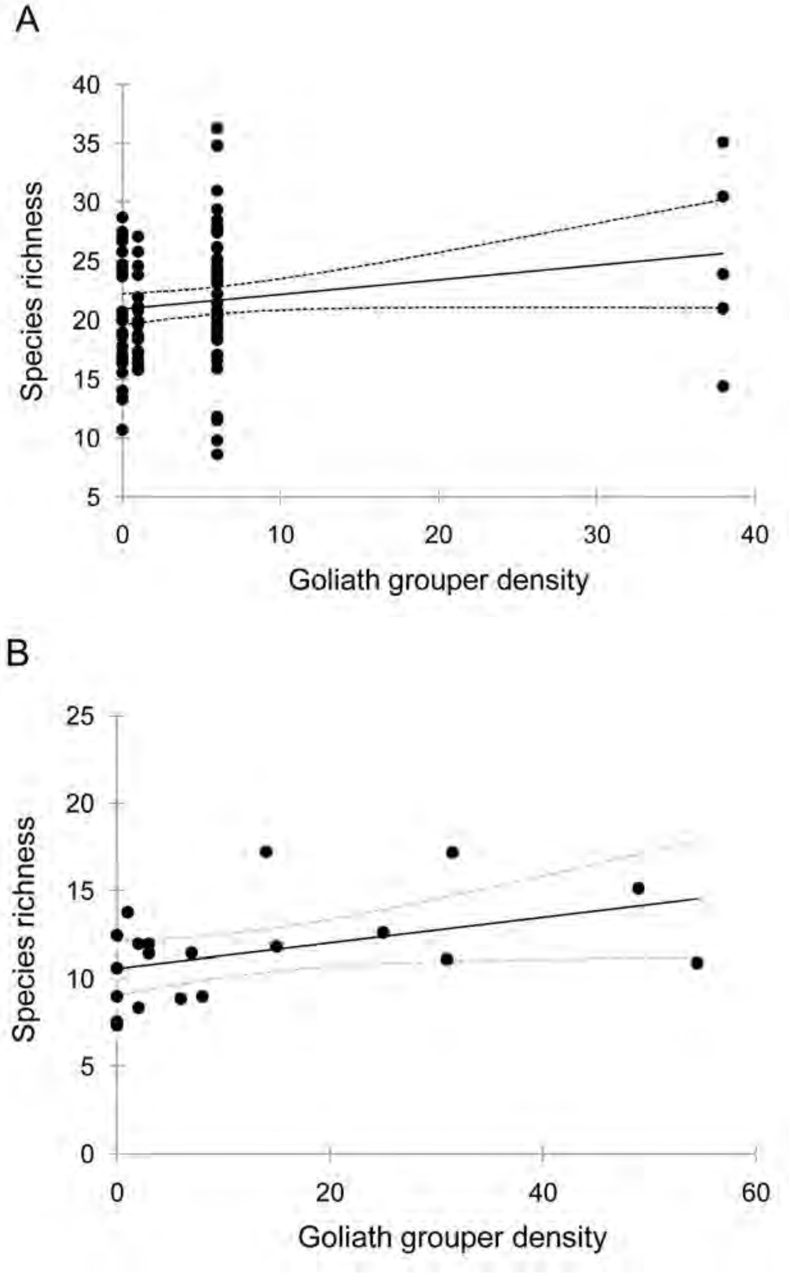

Figure 11. Regression of fish species richness on goliath grouper, *Epinephelus itajara*, site density on high-relief reefs surveyed in 2006–2008 in southwest Florida (zone 4). (A) Semi-quantitative REEF data, $Y = 20.9 + 0.12*X$ ($R^2 = 0.036$, P = 0.07). (B) Quantitative data, $Y = 10.57 + 0.007*X$ ($R^2 = 0.19$, P = 0.06). Dashed lines, 95% confidence limits.

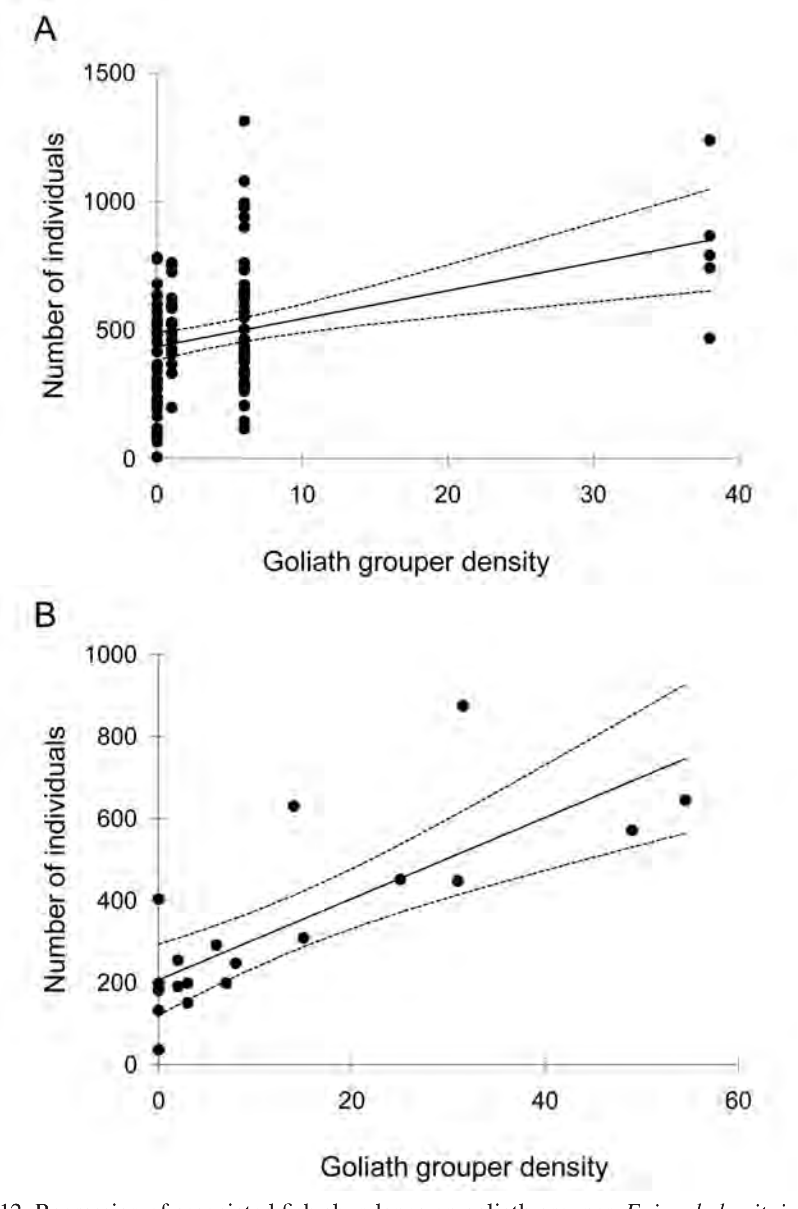

Figure 12. Regression of associated fish abundance on goliath grouper, *Epinephelus itajara*, site density on high-relief reefs surveyed in 2006–2008 in southwest Florida (zone 4). (A) Semi-quantitative REEF data, $Y = 436.2 + 10.87*X$ ($R^2 = 0.12$, $P < 0.001$). (B) Quantitative data, $Y = 206.8 + 9.88*X$ ($R^2 = 0.6$, $P < 0.0001$). Dashed lines, 95% confidence limits.

since the 1990 fishery closure is one of apparent rapid recovery off the Ten Thousand Islands area—the dominant juvenile habitat in the southeastern United States and the likely source of most adult fish (Koenig et al. 2007)—followed by relatively slow recovery in other areas of the state. This is strongly correlated with data from a study conducted by Cass-Calay and Schmidt (2009) on incidental recreational catch of goliath grouper in the Everglades National Park. Their data indicated a distinct increase

Figure 13. Photograph of goliath grouper, *Epinephelus itajara,* surrounded by scad, *Decapterus* sp., and barjacks, *Caranx ruber*. Photo credit: W Stearns (www.waltstearns.com).

during the mid 1990s, especially in western portions of the Park. The vast majority of juveniles recorded in that study exceeded 400 mm TL, representing fish that would migrate from mangrove to offshore reef sites within 2 yrs (Koenig et al. 2007). This supports Koenig et al.'s (2007) contention that presence of high-quality juvenile habitat plays a key role in population recovery for this species.

To what extent does emigration from regions of productive nurseries to regions where goliath grouper populations are sparse affect recovery? The answer to this question depends to some extent on historical records of population abundance in the northern regions of their range. Currently, population densities in north Florida on both Gulf and Atlantic coasts are low, as are populations in other states. Only unreliable catch records exist in these areas and none prior to the onset of intense fishing, so the answer is uncertain. This species cannot tolerate temperatures < ~15 °C (Sadovy and Eklund 1999), so their expansion to more northern latitudes is somewhat limited. However, they do appear in relatively shallow water off the Florida Panhandle, but there they apparently move offshore during the fall and winter when cold fronts move through the area. They apparently take refuge in deeper waters where temperatures remain relatively stable and typically above 15 °C (http://www.coastalclimate.org/marine/bst.php). Thus, it is doubtful that northern populations will ever achieve densities as high as southern populations except in response to climate change.

Species Associations

Because goliath grouper adults are indigenous to Florida reefs and may dominate the biomass on reefs where they reside, they likely play an important role in shaping reef communities within their range. Indeed, we found a positive relationship between the density of goliath grouper and biological diversity of other fish species

(Fig. 11). It is likely that habitat heterogeneity plays an important role in this pattern, as heterogeneous habitats tend to be more speciose. Although goliath grouper are clearly attracted to heterogeneous habitat, it is possible that they also play an active role in its creation through their excavating behavior (Coleman and Koenig 2010), resulting in a positive influence on species richness at a local scale, as occurs in red grouper, *Epinephelus morio* (Valenciennes, 1828) (Coleman et al. 2010). It is possible, in fact, that these two congeneric sympatric species potentiate each other's performance by exposing high relief reefs buried by storms, thereby making them available for myriad other species.

We also found a significant relationship between population density of goliath grouper and overall abundance of other reef fishes that the mere presence of high relief habitat does not explain. That is, fish abundance was higher on high relief sites that harbored goliath grouper than it was on similar sites in the absence of goliath grouper. For example, we observed several species of small schooling fishes, including round herring, *Etrumeus teres* (DeKay, 1842) and round scad, *Decapterus punctatus* (Cuvier, 1829), tightly associated with goliath grouper, apparently using the large fish as a refuge from pelagic predators such as jacks and tunas (Fig. 13).

Despite strident assertions of some fishers to the contrary, fishes the size of goliath grouper are not voracious and indiscriminant predators within the reef fish community. Clearly, if this were true, then an increase in their abundance would result in a decline of fish species richness and abundance on reefs in which they occur, and stomach content analysis would corroborate this finding. We have demonstrated here that the former is not true, and elsewhere (Koenig and Coleman 2009) that the latter is not true. Indeed, where diet is concerned, crabs and other crustaceans comprise 70% of the goliath grouper diet. We suggest instead that the indigenous goliath grouper has a positive effect on the biodiversity and abundance of associated reef fishes, a result expected from principles of evolutionary ecology.

While we are optimistic about ongoing recovery of this species in Florida, we curb our enthusiasm with a number of nagging facts. First, the level of goliath grouper recovery remains unknown and the time trajectory for complete recovery is uncertain. Second, the south Florida ecosystem that serves as the center for goliath grouper abundance has been altered to such a high degree over the last 100 yrs (Ogden et al. 2005) that suitable mangrove habitat, the primary nursery for goliath grouper, is probably limiting recovery (Koenig et al. 2007). Third, the population is likely subjected to high levels of release mortality and illegal catch, which contribute to continued overfishing (Porch et al. 2006). Fourth, similar fish species also fished to economic extinction have not fared well. For instance, the giant sea bass, *Stereolepis gigas* Ayres, 1859**,** population of the Eastern Pacific, which shares many characteristics with goliath grouper, has not recovered despite nearly 30 yrs of limited protection (http://www.arkive.org/black-sea-bass/stereolepis-gigas/info.html).

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 widespread perception remains that goliath grouper is a nuisance species points to 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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