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ASSESSING FISHING EXPERTS' KNOWLEDGE TO IMPROVE CONSERVATION STRATEGIES FOR AN ENDANGERED GROUPER IN THE SOUTHWESTERN ATLANTIC

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*The Atlantic goliath grouper (*Epinephelus itajara*) is a critically endangered reef fish that has suffered from overfishing. In Brazil, the species has been under a fishing ban since 2002; however, there are no evidences of population recovery. In this context, data to help improve management programs are sorely needed. We assessed fisheries landings and interviewed key informants to investigate fishing, habitat use, and occurrence of goliath grouper in Abrolhos Bank, eastern Brazil. In mangroves, longline was the main fishing gear used to catch the species. Informants reported higher abundances of goliath grouper in red mangroves (*Rizophora mangle*) within shallow and complex channels. In marine reefs, the species was caught mainly through spearfishing. Goliath grouper occurrence was associated with coral and rocky reefs and was described as an aggregation site of up to 20 individuals. Informants also reported a decline in goliath grouper abundance across all habitats, primarily due to overfishing. Aggregation and nursery sites were mapped and described as essential for goliath grouper conservation. In Brazil, a scarcely enforced fishing moratorium alone is insufficient to guarantee the recovery of goliath grouper populations. Besides increasing the moratorium enforcement, we suggest implementing no-take zones, which encompass both nursery habitats and seasonal aggregation sites described in this study.*

Keywords: *small-scale fishing*, Epinephelus itajara, *fisheries management*, *spawning aggregation*, *Abrolhos Bank*

Introduction

The development of survey strategies aimed at the conservation of highly endangered and widely distributed species can be challenging, expensive, and requires long and enduring research programs (Wiley and Simpfendorfer 2010). To work around this issue, alternative approaches that require a short time to generate results have been used to obtain critical data to support species conservation. These approaches use non-conventional data sources to infer long-

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time abundance trends for targeted species, for example, analyzing historical data (e.g., old books, photographs, and reports [Luiz and Edwards 2011; McClenachan 2009; Pitcher and Lam 2010]) and fishers' knowledge (Leeney and Poncelet 2015; Sáenz-Arroyo et al. 2005) to investigate historical abundance and distribution of endangered sharks, groupers, and sawfish.

Fishers' knowledge has been widely used to assess aspects of natural resources, mainly in developing countries, where data gaps are common (Ruddle and Hickey 2008). Fishers have detailed ecological knowledge of resources at a local geographic scale (Johannes 1998). For instance, they might remember particularly good catches from a productive day (Daw 2010) and can provide reliable data about occurrence sites (Reis-Filho et al. 2016) and reproduction (Silvano et al. 2006). When elicited though detailed questionnaires, fishers' knowledge can provide accurate catch data, even after decades have elapsed (e.g., Saénz-Arroyo and Revollo-Fernández 2016; Thurstan et al. 2016). Such historical baseline data can be used to manage current declines in fish populations (Bender et al. 2014), and be encompassed in conservation strategies of spawning aggregations (Hamilton et al. 2005; Johannes 1998). Such detailed ecological knowledge from fishers could also play an important role in developing measures to conserve vulnerable life history stages (Herbst and Hanazaki 2014).

The Atlantic goliath grouper, *Epinephelus itajara,* a large fish of the tropical and subtropical coastal areas of the western Atlantic, has been experiencing severe population declines throughout its geographic range (Craig et al. 2008; McClenachan 2009). The life history traits of goliath groupers—in particular its longevity, late gonadal maturation, and the formation of seasonal spawning aggregations—make it particularly vulnerable to overfishing (Sadovy and Eklund 1999). As a result, goliath grouper is listed as Critically Endangered by the International Union for Conservation of Nature (Craig 2011).

In Brazil, continuous declines in goliath grouper captures led the Brazilian Environmental Agency (Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis - IBAMA) to establish a precautionary fishing moratorium in 2002. The critical conservation status of the goliath grouper and the lack of data and financial resources in Brazil have also encouraged researchers to use non-conventional approaches such as fishers' knowledge to obtain data on basic ecology (e.g., Ferreira et al. 2014; Gerhardinger et al. 2006, 2009; Giglio et al. 2015, 2017). Data on goliath grouper catches, distribution, and occurrence of nursery habitats and spawning aggregations are essential to develop conservation strategies, but these data are poorly assessed. In this study, we interview experienced fishers of eastern Brazil to assess local ecological knowledge about goliath groupers. Our interviews provides information on: 1) fishing and changes in abundance; 2) distribution, habitat use, and abundance patterns; and 3) the occurrence and socioeconomic context of illegal fishing. Based on these data, we evaluated already existing conservation strategies and proposed new ones for the goliath grouper population recovery in Brazil.

Materials and Methods

Study Site

Abrolhos Bank, located in the state of Bahia in eastern Brazil, comprises the largest and richest reef complex of the South Atlantic (Leão et al. 2003) and encompasses a mosaic of habitats, including beaches, rocky and coralline reefs, mangrove swamps, and vegetated sandbanks (Moura et al. 2013). The Bank itself consists of an expansion of the continental shelf (42,000 km^2) with depths rarely exceeding 30 m.

There are nearly 20,000 small-scale fishers in Abrolhos Bank who rely on fishing for their food and livelihood. Groupers (e.g., *Epinephelus morio* and *Mycteroperca bonaci*), snappers (e.g., *Ocyurus chrysurus* and *Lutjanus jocu*), and parrotfishes (*Scarus* spp.) make up the bulk of their catch (Francini-Filho and Moura 2008a; Freitas et al. 2011). In the mangrove, the main fish resources are snooks (*Centropomus* spp.), catfishes (*Bagre marinus*), croakers (*Micropogonias furnieri*), snappers, and mojarras (*Diapterus* spp.) (Santos and Brannstrom 2015). This study was conducted in the Caravelas–Nova Viçosa estuarine complex, located in the Abrolhos Bank. In this region, fishing is a traditional and secular activity, and fishers have detailed knowledge about fish resources (Giglio and Bornatowski 2016; Giglio et al. 2015).

Informant Selection

Fishers were interviewed at fishing markets, their homes, and harbors between April 2006 and March 2009. A local fisher accompanied interviewers to provide introductions to informants. During structured interviews, informants were asked to identify those who were especially knowledgeable about the goliath grouper. We used these recommendations to select "key informants" (Davis and Wagner 2003); those who had been identified by at least 15 of their peers.

Interviews with Key Informants

Key informants were interviewed individually using semi-structured questionnaires that were audio-recorded and later transcribed. Questions were adapted from Gerhardinger et al. (2006) and addressed fisher profile, aspects of goliath grouper fishery (characteristics of fishing gear, best catches, and commercialization), and ecological aspects (habitat use, occurrence, and abundance; Table S1). These key informants were asked to share their perceptions regarding changes in the abundance of goliath grouper since they commenced fishing, assigning a percentage value to the perceived increase, decrease, or stability of the stocks. The frequencies and proportions of the fishers who provided similar responses were calculated as a measure of the reliability of the responses (cf. Silvano and Begossi 2005). Furthermore, using a method adapted from Friedman et al. (1986), we assessed reliability of the qualitative answers with the following equation:

$$LF = (NC/NT) \times 100$$

where LF is the level of fidelity; NC is the number of key informants who gave the consensual response (i.e., the most frequently cited response); and NT is the total number of key informants who answered the specific question.

Mapping of Fishers' Knowledge

We recorded fishers' knowledge of goliath grouper occurrence sites on a satellite map (50 × 65 cm) of the Caravelas–Nova Viçosa estuarine complex that displays the estuarine and mangrove areas and a nautical chart (50 × 65 cm) that shows the reef areas of Abrolhos Bank (for details on method, see Gerhardinger et al. 2009). Key informants were further asked to mark sites where they caught goliath grouper. The resultant maps were overlaid and analyzed using ArcGIS® (v. 10.2.2; ESRI 2014).

Catch Data

To assess the extent of goliath grouper poaching, a local fisher collected data on the landings from Caravelas municipality between September 2007 and February 2009. The fishing port was monitored for five days per week between 09:00 and 17:00 hours, the period in which catches are brought to port. Fishers generally agreed to provide information on goliath grouper poaching, although they did not show individuals caught. They agreed to participate in the survey because the data collector is a reliable fisher known by most of the subjects and was able to explain the survey aims. The data collector asked fishers about the weight of the specimen caught, total length, the fishing gear used, and the catch location. We used body size (weight) to discriminate life stages between juvenile (< 17 kg) and adult individuals (≥ 17 kg; Freitas et al. 2015).

Results

Key Informants' Profile

A total of 241 fishers were interviewed from 16 fishing villages. Fishers assigned 465 peer recommendations of goliath grouper experts to 55 different fishers, at an average of 1.9 peer recommendations by each interviewed fisher. Of these, we selected the 22 most cited fishers as the key informants. The age of key informants ranged from 30 to 72 years old (average = 53 years) and their fishing experience ranged from 20 to 60 years (average = 42 years). Eleven key informants fished only in the reef (average experience = 42 years), seven fished in the mangrove (average experience = 41 years), and four of them fished in both environments (average experience = 39 years).

Goliath Grouper Fisheries

Longline was the most commonly used fishing gear to catch goliath grouper in mangroves (67%). The species was a secondary target of snapper (Lutjanidae) and weakfish (Sciaenidae) fisheries. Deciding where to fish is complex and was based on several parameters, such as the lunar cycle, water salinity, and the presence of mangrove trees, rocks, and estuarine channels. Reef informants used

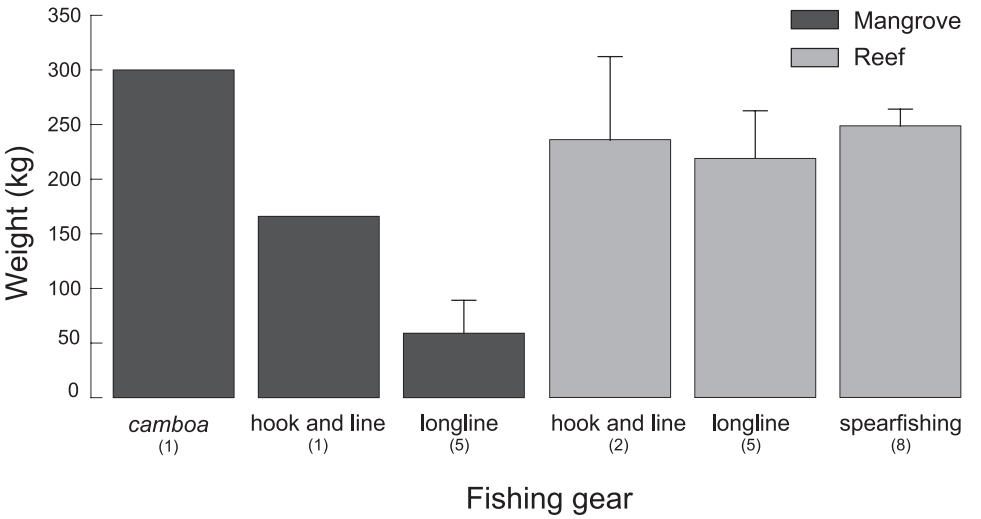

Figure 1. Largest goliath grouper (by weight) ever caught according to fishers' knowledge. Data were categorized based on habitat and fishing gear. The number of responses per category is in parentheses. Bar and whisker represent average and standard error, respectively. *Camboa* is a type of gillnet with small mesh size (40 mm).

mainly spearfishing (64%) to catch goliath grouper. Three fishers used longline as well as hook and line in mangroves and reef areas.

The largest goliath groupers were captured in the reefs through spearfishing (average weight = 248 kg), hook and line (236 kg), and longline (219 kg). The weight of the largest individuals caught did not vary substantially among types of fishing gear (Figure 1). In mangroves, the largest individuals were caught with *camboa* net—a gillnet with small mesh size, 40 mm (300 kg)—hook and line (166 kg), and longline (59 kg; Figure 1). Longline was the main fishing gear used to catch the species, but it catches smaller individuals than with the other two gear types.

Over two-thirds (78%) of the reef key informants believe that the flavor of goliath grouper does not vary according to the individual size. On the other hand, 56% of the mangrove key informants believe the meat of juveniles between 8 and 10 kg has better flavor (Table 1). Fishers argue that despite the fishing moratorium, goliath grouper can be easily sold in the fish markets. This is especially true for small juveniles due to their preferred flavor. Large individuals are filleted and commercialized, as are other grouper species, but because their flavor is not preferred, they receive a lower price per kilogram than the smaller fish. Nevertheless, reef fishers mentioned that selling one large individual provides one week's worth of income.

Temporal and Spatial Distribution and Habitat Use

Informants reported that juvenile goliath groupers inhabit only mangroves, whereas adults are commonly found in the biogenic and rocky reefs (Table 1). Two-thirds of key informants (n = 13) reported that species can be encountered year-round, while a third of reef fishers (n = 4) reported a seasonal occurrence

Table 1. Summary of fishers' knowledge regarding goliath grouper in Abrolhos Bank, Brazil.

	Mangrove fishers				Reef fishers			
Biological aspects	Response	NC	NT	LF	Response	NC	NT	LF
Habitat use								
Juveniles	mangroves	10	10	100	mangroves	12	13	92
Adults	associated with rocks and wooden branches	8	9	89	associated with rocky and coral reefs	12	13	92
Seasonality	year-round	5	6	83	year-round	8	12	67
	austral summer	1	6	17	austral summer	4	12	33
Spawning aggregation	did not witness	10	10	100	has witnessed	5	15	33
					did not witness	10	15	67
Individuals with mature gonads	has witnessed	3	11	27	has witnessed	8	15	53
	did not witness	8	11	73	did not witness	7	15	47
Size of mature individuals	20 and 100 kg	2	3	66	10–250 kg (mean = 92 ±27)	8	8	100
Preferred size for consumption								
Meat flavor	*"Both small and large have good meat."*	4	9	44	*"Any size is the same taste."*	7	9	78
	"The better have 8 kg to 10 kg."	5	9	56	*"From 50 kg down the taste is better."*	1	9	11
Socioeconomic aspects								
Economic importance	had no economic importance	7	11	64	had no economic importance	8	14	57
	had economic importance	4	11	36	had economic importance	6	14	43
Distribution / marketing	*"Sale was easy."*	5	10	50	*"Sale was easy."*	5	14	36
					"The smaller is easier to sell. . .."	4	14	29

NC: number of key informants who gave the consensual response (i.e., the most frequently cited response); NT: total number of key informants who answered the specific question; LF: level of fidelity, with higher numbers representing more consensus among fishers.

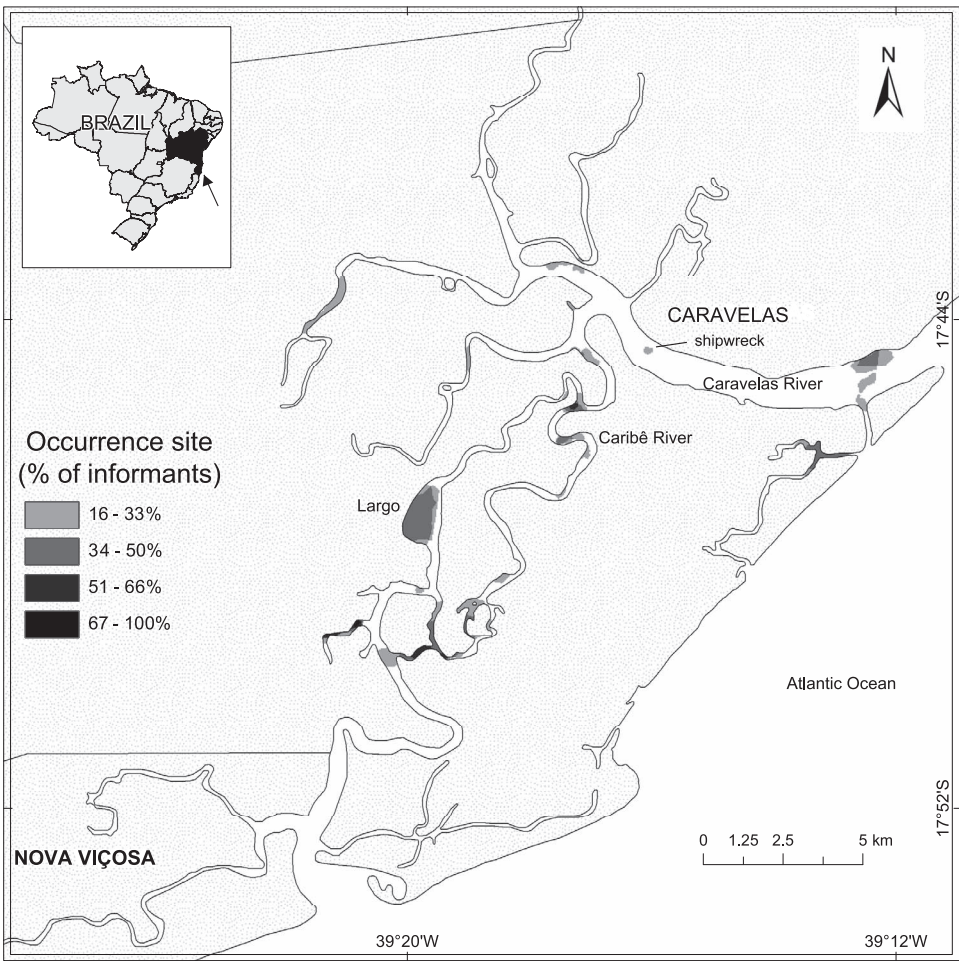

Figure 2. Occurrences of goliath grouper in mangrove according to fishers' knowledge. Indications refer to the percentage of fishers that mentioned a goliath grouper occurrence in a site.

during the austral summer (Table 1). Reef informants described an aggregation with 8–20 adult individuals during the austral summer (see below). Over half (53%) of key informants captured individuals with mature gonads and body sizes varying between 10 and 250 kg (average = 92) during the austral summer. On the other hand, mangrove fishers did not report any catches of adult individuals or sightings of individuals with mature gonads at any time of the year.

Mapping Goliath Grouper Occurrences

Informants described 21 goliath grouper occurrence sites in mangroves (Figure 2). They noted that, in some sites, there are concentrations of juveniles (< 5 kg) using the shallow areas of the Caribê and Largo Rivers to avoid predators, as well as to feed. Two elder informants reported that small juveniles

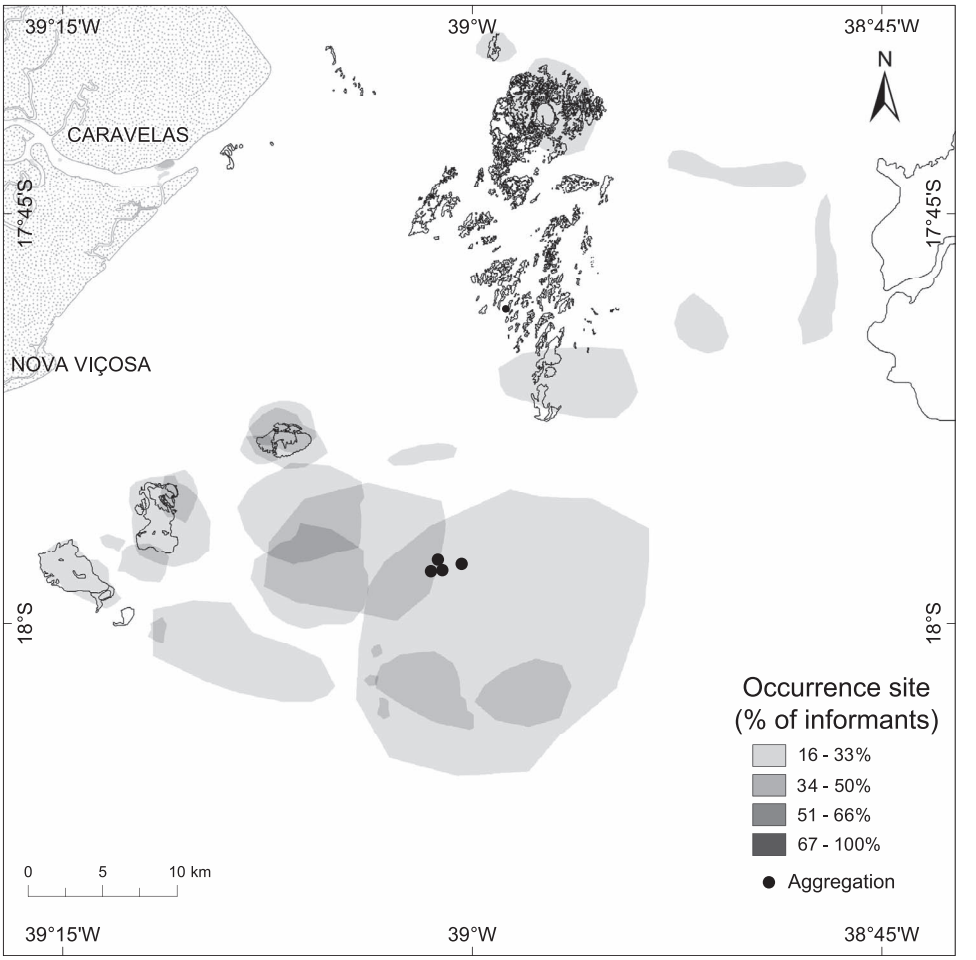

Figure 3. Occurrences of goliath grouper in reefs according to fishers' knowledge. Indications refer to the percentage of fishers that mentioned a goliath grouper occurrence in a site.

feed on crabs in the mud and mangrove roots during high tides. Larger juveniles (> 10 kg) were noted in the wider and deeper channels of the Caravelas River (Figure 2) associated with rocky bottoms or submerged in red mangrove trees (*Rizophora mangle*).

The goliath grouper occurrence sites in reefs identified by reef key informants were not as specific as those noted by the informants for mangroves. Most of the reported occurrences in reefs were associated with the Frias reefs, a site characterized by large rock boulders (2–6 m height and 10–30 m diameter) at 20–27 m depth (Figure 3). Fishers indicated spawning aggregation sites of goliath grouper on Abrolhos Bank. Four large rocks on the Frias reefs were mapped as aggregation sites. Two informants reported catches of more than 20 large individuals per year in these rocks during the austral summer months of the 1990s (see Supplementary Figure 1).

Catch Data

A total of 57 individuals were caught in mangroves using *camboa* nets (n = 26), longline (n = 14), hook and line (n = 8), gillnet (n = 4), trawl (n = 3), and spearfishing (n = 2). Significant differences were noted in the weight of individuals caught in the mangroves using these different kinds of gear (Kruskal-Wallis test $x^2 = 27.9$, $p < 0.001$; Figure 4a). Longline and spearfishing had the highest averages, while gillnet and trawl had the smallest. The average weight was 7 kg and only 3.4% of the individuals weighed greater than that at the first gonadal maturation (L50 = 25 kg; Freitas et al. 2015).

On reefs, 47 individuals were caught through spearfishing (n = 25), hook and line (n = 19), longline (n = 2), and trawl (n = 1). Significant differences were noticed in the weight of goliath grouper individuals caught with different types of fishing gear ($x^2 = 13.5$; $p = 0.003$). The heaviest fish were caught by spearfishing (Figure 4b), while those caught with longlines weighed the least. Sixty-six percent of the catches were above the L_{50} weight.

Abundance Trends

A decline of more than 40% in goliath grouper abundance was recognized by two thirds of the reef key informants and for 54% of the mangrove key informants (Figure 5). Two experienced reef informants reported an increase in the abundance of goliath grouper and one less-experienced informant quoted no change. Among the experienced mangrove informants, two referred to an increase in abundance, while two cited no change. Reef informants who mentioned decreases in abundance cited overfishing as the main cause. Among mangrove informants, the causes of decreasing abundance were overfishing (5 of 7), boat noise (1 of 7), and changes in the environment (1 of 7).

Discussion

Goliath Grouper Occurrence and Habitat Use

Our results revealed that fishers have detailed knowledge of goliath grouper occurrences and movement patterns in the mangroves. The close association of small juveniles to secondary rivers containing well-developed red mangrove shorelines at shallow depths (< 2 m) can be a strategy for more effective foraging and lower exposure to predators, such as sharks, snappers, and snooks (Koenig et al. 2007; Sadovy and Eklund 1999). In addition, juveniles can perform short-term migrations according to tidal cycles (Frias-Torres et al. 2007) or to a feeding strategy (Odum et al. 1982). In fact, during a *camboa* net fisheries assessment, the authors observed small juveniles regurgitating blue crabs (*Callinectes* spp.).

Reef informants reported areas with high goliath grouper abundance, but not specific sites, such as commonly reported (Félix-Hackradt and Hackradt 2008; Sadovy and Eklund 1999). Abrolhos Bank is characterized by large, sparse, and complex reefs (Leão et al. 2003), providing more habitats to the species. Sites with the largest goliath grouper abundances were described by fishers as spawning aggregations. In addition to fishers' knowledge, indirect evidence suggests the

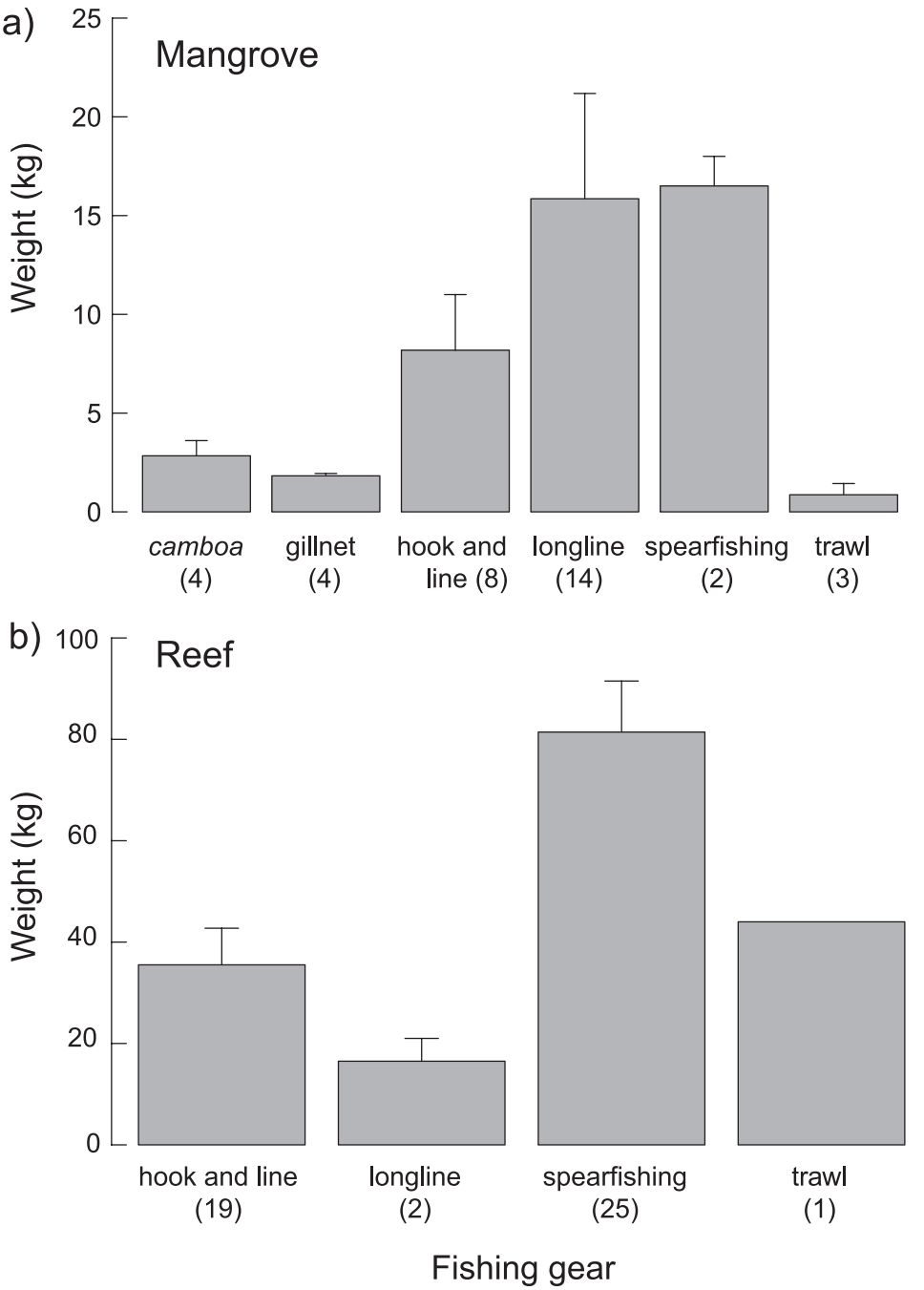

Figure 4. a) Weight of goliath groupers caught in a) mangroves (n = 57) and b) reefs (n = 47), according to fishing gear. Bars and whisker represent average and standard errors, respectively. The number of responses per category is in parentheses.

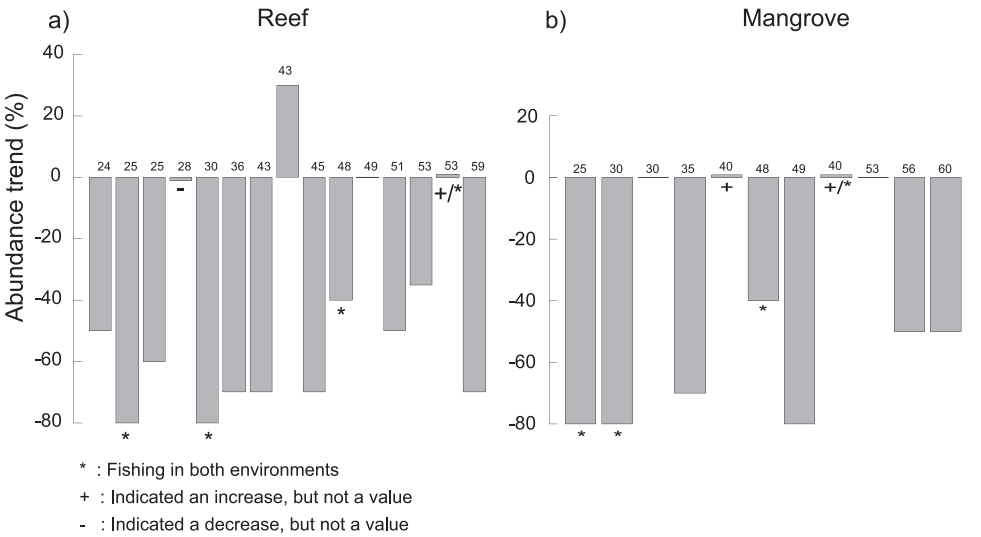

Figure 5. Fishers' perceptions of goliath grouper abundance trends in reef (a) and mangrove (b). Trend values are described as percentages. Each bar represents a key informant. Numbers above bars indicate years of fishing experience.

occurrence of spawning aggregations at Frias rocky reefs, such as observations of individuals with large gonads and distinctive behavior among males and females. However, fishers reported high fishing pressure in Frias reefs through scuba spearfishing by recreational practitioners. Clearly, an effective surveillance is needed to reduce poaching in Frias reefs, given its importance as the only known goliath grouper aggregation site on Abrolhos Bank.

Our data on occurrence adds to the knowledge that goliath grouper numbers are declining in the Abrolhos Bank and are part of a dramatically shifting baseline in goliath grouper abundance over the last four decades in the larger region. Furthermore, anecdotal data from Abrolhos Bank revealed a decline in body size and abundance of goliath grouper (Giglio et al. 2015), as well as illegal catches in aggregation sites (Giglio et al. 2016). This is part of a larger trend in Brazil, where goliath grouper continues to be poached and commercialized (Giglio et al. 2014). This decline in abundance may have affected the ecological role of the species in the ecosystem as a top predator, as well as influenced the community structure (Britten et al. 2014). All these factors hinder population recovery.

Overall, the perceptions of mangrove and reef fishers regarding habitat use by goliath grouper juveniles and adults are in accordance with conventional scientific data. In particular, juveniles inhabit shallow mangrove waters, while adults are found in marine environments offshore (Sadovy and Eklund 1999). Goliath grouper migrate to various habitats from nursery mangroves to deeper reefs as adults (approximately 30 kg; Koenig et al. 2007). However, key informants reported occasionally catching large adults of up to 300 kg in mangroves at shallow depths (2–4 m). In fact, adult individuals are reported to also occur in estuaries and mangroves (Koenig et al. 2007), but the reasons for

these movements are poorly understood. The eldest informant associates the occurrence of large individuals on shallow mangrove waters to a feeding strategy targeting mud crabs in the river margin. In the mangroves of Abrolhos Bank, crabs of the genus *Callinectes* are the main food item of juvenile goliath groupers (Freitas et al. 2015). At present, no data are available on the stomach contents of adult individuals inhabiting mangroves. Based on the high abundance of crustaceans in Abrolhos Bank mangroves (CEPENE 1999), adult individuals can be performing feeding incursions to predate on an abundant, "low cost" prey.

Goliath Grouper Fishing

The fishery landings assessment revealed that goliath grouper was regularly poached with various types of fishing gear during all life phases. All informants reported that they have poached goliath grouper more than once during the fishing ban. The goliath grouper is considered a scarce but desirable species, which was encountered and harvested when targeting more common species. Goliath grouper has been under a fishing moratorium since 2002; however, they are still caught illegally in Abrolhos Bank due to inefficient government surveillance and the fishers' need for meat as a result of poor socioeconomic conditions. Today, there is no evidence of a decrease in goliath grouper poaching.

Spearfishing is widely described as the main threat to goliath grouper because the species is docile and does not fear spearfishers (Ferreira et al. 2014; Sadovy and Eklund 1999). In Abrolhos Bank, this fishing practice is popular and was mentioned as the main contributor to the goliath grouper decline. This was especially true for reef fishers who caught goliath grouper when spearfishing. One of the more experienced reef informants note (Personal communication, August 8, 2006):

> The greatest harm to the goliath grouper was diving [spearfishing], which killed many of them in the bottom. I even dived with a guy here...we killed a whole lot...divers here killed a lot of goliath groupers.

Although providing general trends in goliath grouper catches, the results of the fishery landings assessment may be misrepresented because, after the capture, fishers may mischaracterize and mislabel the species as other grouper species. Furthermore, some fishers may not have disclosed whether they caught goliath grouper individuals, fearing punitive measures. The number of individuals poached is, therefore, expected to be higher than the 105 verified in this study.

Goliath Grouper Conservation

In Abrolhos Bank, goliath grouper and other commercially important reef fish, such as snappers, groupers, and parrotfishes, have been considered to be overexploited (Francini-Filho and Moura 2008a; Freitas et al. 2011). No-take marine protected areas (MPA) can have positive effects on fish abundance both inside and outside their limits (Francini-Filho and Moura 2008b). However, poaching and the lack of surveillance have reversed these positive effects (Francini-Filho, personal communication, January 2014). These are some of the main challenges in implementing the effective no-take zones in Abrolhos Bank.

Considering the ineffectiveness of the goliath grouper fishing moratorium in Brazil, populations in Abrolhos Bank could gain protection through no-take areas that encompass nursery habitats and seasonal aggregation sites described in this study. In 2012, a proposal for the expansion and creation of new MPAs in Abrolhos Bank failed mainly because fishing stakeholders were not adequately involved in the process (Freitas et al. 2014). Therefore, large areas of the Abrolhos Bank remain unprotected. An alternative approach to circumvent the resistance to the establishment of MPAs is the active participation of fishers. There are many successful examples of community-based no-take zones that increased the abundance of fish in adjacent areas (Bonaldo et al. 2017; Hamilton et al. 2011). Therefore, the inclusion of fishers in all stages of the MPA design, creation, and management can minimize conflicts, reduce costs in surveillance, and indicate new conservation areas (Lopes et al. 2013). Fishers can be allies to conservation if there is an opportunity to incorporate their knowledge into practical actions.

Acknowledgments

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