

Collaborative Research on Dusky Grouper (*Epinephelus marginatus*): Catches from the Small-Scale Fishery of Copacabana Beach, Rio De Janeiro, Brazil

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Abstract

The dusky grouper (*Epinephelus marginatus*) is a reef fish with high market, cultural and ecological values. Therefore, it is an important species to the food security of small-scale fishers in Brazil and in other coastal regions. Nevertheless, groupers can be susceptible to overfishing because they are large, sedentary and with delayed maturity. The lack of data on fishery catches and on the biology of dusky grouper can be an obstacle for the success of management measures. The main goal of this study was to collect information on dusky grouper catches, morphometry (length and weight) and spawning period (observations of its gonads), through a collaboration with local fishers in the Copacabana Beach ("Posto 6"), southeastern Brazilian coast. Two fishers were trained to measure the total length (TL, in cm), weight (kg), and to observe the gonads (whether mature or not, and with or without visible eggs) of all individuals of dusky grouper caught at Copacabana, from September 2013 to June 2015. During the 21 months of data collection, 800 individuals of dusky grouper were examined by the trained fishers, yielding 793 individuals with both length and weight data. The mean length of dusky grouper caught by fishers (N = 796) was 52.4 cm (standard deviation of 12.4 cm, range from 17-130 cm). Most of the individuals caught ranged between 45 and 65 cm, being thus above both the minimum allowed size in Brazil (47 cm) and above the size at first maturity for this fish according to the literature (range of 35-60 cm for females). Although many individuals were adults, only a few individuals (18 of 800) of dusky grouper had mature gonads. This indicates that large spawning fish may be located at deeper sites or at distant spots, out of the reach of these small-scale fishers. Most dusky groupers were caught by spear fishing, in a single island. The collaboration with local fishers greatly improved the amount of data collected; so, we suggest that this approach should be adopted in future studies. These results show a valuable opportunity to properly manage the dusky grouper population at the southeastern Brazilian coast.

Keywords: Brazilian small-scale fisheries; Reef fish; Fish reproduction; Fisheries management; *Epinephelus marginatus*; Dusky grouper

Introduction

Epinephelid groupers include about 160 species, which are ecologically and economically important, being distributed along subtropical and tropical seas [1]. The dusky grouper is one of the most common fishes in the Adriatic [2] and in the Mediterranean [3], being important economically and recreationally. A protogynous hermaphrodite fish, the dusky grouper reaches female sexual maturity at 3 kg of weight, showing a mean length at first maturity (L_{50}) of 43.8 cm (L_s); its sex reversal to the male occurs at 10 kg with a L_{50} of 81.3 cm (L_s) [2,3]. The largest specimens of this fish were caught in Tunisia (35 kg) and in Brazil (60 kg) [2]. The dusky grouper has been described in the literature as a solitary and territorial fish with a maximum length of 150 cm, maximum observed age of 50 years and with its distribution in the Atlantic Ocean [4-7]. This fish is very important and high-valued in the Mediterranean Sea, where there are many aquaculture initiatives to raise dusky grouper [8,9]. Nevertheless, groupers can be susceptible to overfishing because they are large, sedentary and with delayed maturity [10]. Declines in the fish stocks of dusky grouper and other grouper species have been observed in many regions, including the Brazilian coast, Mediterranean and Gulf of California, usually through studies using historical information or fishers' knowledge due to the lack of data on catches [11-14].

Reef fishes, such as the dusky grouper, are of great importance for artisanal fisheries off the coast of Brazil, according to previous studies

on small-scale fishers, which include 1,761 data on fish landings [15]. In Brazilian small-scale fisheries, the dusky grouper is a particularly important food source, as this fish is considered as tasty, having a high market value, besides being recommended to be eaten by unhealthy persons during convalescence [16,17]. This importance and multiple uses indicate that dusky grouper has a high market, cultural and ecological value. Therefore, this fish can be considered as an important species concerning the food security of small-scale fisheries in Brazil [15,17,18]. Data on dusky grouper reproduction are very scarce in the Brazilian coast [19]. Individuals of this species, regularly caught by fishers, frequently include immature females with an absence of sexually mature individuals [18,20]. Therefore, it is very important to sample larger numbers of individuals of the dusky grouper to acquire more data on its reproduction in Brazil. An earlier study at the small-scale fishery of Copacabana, in the southeastern Brazilian coast, shows how difficult it is to obtain data on the spawning period of this fish

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Received April 04, 2016; Accepted May 25, 2016; Published May 31, 2016

Citation: Begossi A, Salivonchyk S, Renato Silvano AM (2016) Collaborative Research on Dusky Grouper (*Epinephelus Marginatus*): Catches from the Small-Scale Fishery of Copacabana Beach, Rio De Janeiro, Brazil. J Coast Zone Manag 19: 428. doi:10.4172/2473-3350.1000428

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[18]. Previous studies have also emphasized the importance of the local knowledge of fishers, in order to improve biological knowledge, on the reproduction of the dusky grouper and of the other target fishes [18,21-23].

The objective of this study was to collect information on dusky grouper catches, morphometry (length and weight) and spawning period (observations of its gonads) in the small-scale fishery of Copacabana Beach (“Posto 6”), southeastern Brazilian coast. We compared the sizes of individuals of dusky grouper caught by diving (spear fishing) with those caught by using other, less selective fishing gear (line and gillnet). We also compared the sizes of groupers caught at distinct fishing spots. These results should contribute to filling existing knowledge gaps about the biology of this important fish, thus helping to improve its conservation and management.

Methods

Study site

Copacabana Beach includes a small-scale fishing community (“Colonia do Posto 6”) created in 1923, where groupers have been a target fish and a “noble fish”, which means a high-priced commercial fish [24]. Fishing at Copacabana Beach (Figure 1) is performed with small-scale motor canoes or boats using nets, hooks and lines and by spear fishing [25]. Recently, spear fishing through diving has become important, especially among young fishers.

Sampling procedures

One of the authors (AB) undertook fieldwork from September 25, 2013 to June 11, 2015 at the landing point of the Colonia de Pescadores Z-13 (“Posto 6”), at Copacabana. Data collection methods included collaborating with two fishers after training them following a protocol conducted by AB. The protocol included measuring the TL (total length in cm) and weight (kg) of the fish, in addition to open the fish to be able to observe its gonads (whether mature or not, and with or without visible eggs). This procedure of macroscopically observing the mature gonads of the fish was previously used in other studies with snook (*Centropomus undecimalis*) [22], bluefish (*Pomatomus saltatrix*) [23] and dusky grouper [15,17,18,26]. “Macroscopical observation” means that the gonads are observed through a naked eye.

Two fishermen known from previous studies at Copacabana Beach [18,25] were selected to participate in this study. In addition to being fishers, these collaborators are also fish cleaners who clean and cut fish fillets. In this fishery, fish catches are placed at stands and sold by

fishers. The sold groupers are sent to the fish cleaners, who clean the fish for the consumers. Once or twice a month, AB collected these data from the collaborators, along with other relevant information. These two fishers were paid by AB through a grant.

The size frequencies of the groupers caught were compared between two kinds of fishing gear: diving (spear) and others (line and gillnets), through a Kolmogorov-Smirnov test of two distributions. The median sizes of groupers caught were compared among fishing spots through a non-parametric Kruskal-Wallis test (data did not show a normal distribution, even after transformations).

Results

During the 21 months of sampling, 800 individuals of dusky grouper (*Epinephelus marginatus*) were caught, measured and examined by the trained fishers. The lengths of four and the weights of three groupers could not be measured, resulting in a sample of 793 individuals with both length and weight measured. The mean length of the groupers was 52.38 cm (N = 796) with a standard deviation of 12.35 cm, and the length range was 17-130 cm. Most of the individuals caught had lengths between 45 and 65 cm (Figure 2).

The mean weight of the groupers collected was 3.05 kg (N = 797),

Month	Length, cm		St dev of Length		Weight, kg		St dev of Weight		Number of fish	
	2013/2014	2014/2015	2013/2014	2014/2015	2013/2014	2014/2015	2013/2014	2014/2015	2013/2014	2014/2015
Sep	44.86	51.20	6.07	11.61	2.00	2.76	0.50	3.25	7	66
Oct	50.71	51.41	11.50	9.72	2.93	2.60	2.47	1.87	24	76
Nov	47.57	53.74	9.51	10.75	2.21	3.24	1.56	2.58	23	87
Dec	72.00	56.61		11.08	5.48	3.37		2.35	1	24
Jan	65.74	54.35	18.46	11.85	7.06	3.27	8.01	2.93	10	68
Feb	55.10	53.67	18.25	8.02	4.55	2.65	4.59	1.20	20	33
Mar	46.21	53.79	7.44	10.78	2.19	3.10	1.10	2.32	28	29
Apr	45.16	56.39	16.86	16.49	2.76	4.71	2.27	6.22	31	28
May	50.69	62.60	12.64	14.78	2.86	5.03	3.64	3.45	75	15
Jun	45.67	57.00	5.73	11.38	1.65	3.81	0.59	2.65	24	31

Table 1: Mean and Standard Deviation of Length and Weight of *E. marginatus* (N = 700) catches by month at Copacabana beach (Rio de Janeiro, Brazil), from September 2013 to June 2015.



Figure 1: Map of the study area (Copacabana beach, Rio de Janeiro, Brazil) with importante fishing spots used in the small-scale fishery to obtain catches, including the dusky grouper *E. marginatus*.

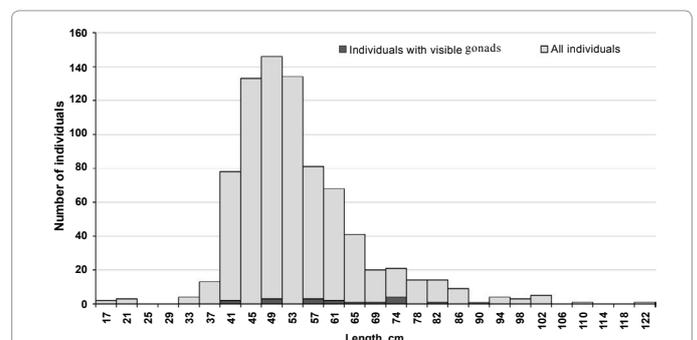
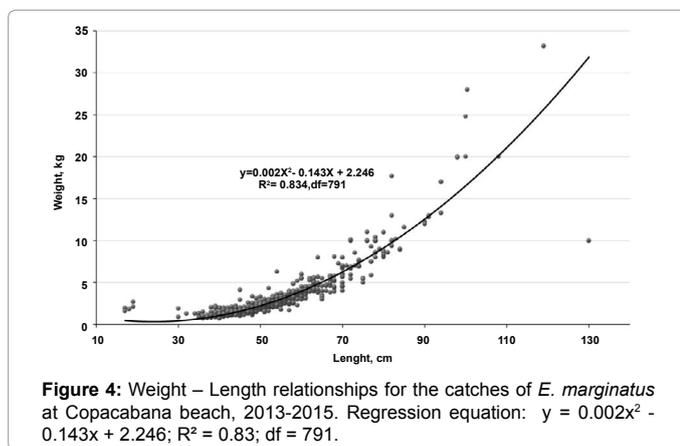
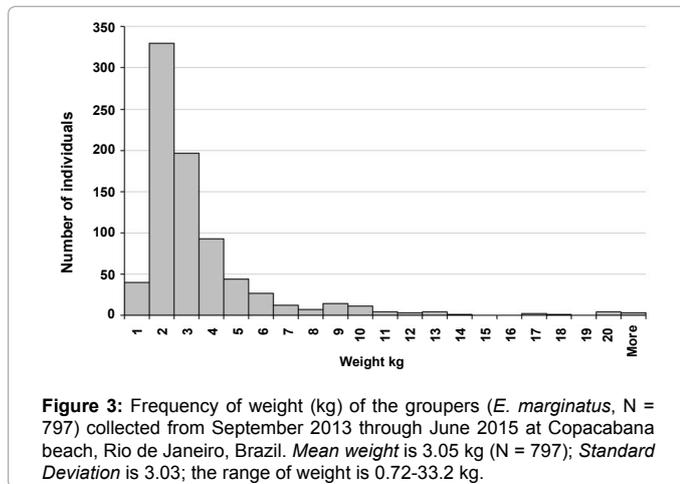


Figure 2: Frequencies of length and presence of visible gonads of the groupers (*E. marginatus*, n = 796) collected from September 2013 through June 2015, Copacabana beach, Brazil. Mean length is 52.38 cm (N = 796); Standard Deviation 12.35 cm; the length range is 17-130 cm. Y = number of individuals.



with a standard deviation of 3.03; the weight range was 0.72-33.2 kg, and most individuals had weights between 2 and 4 kg (Figure 3).

Table 1 shows the catches of dusky grouper at Copacabana during 2013-2015, which were obtained after 42 fieldwork visits by one of the authors (AB) and 205 days of fish observations by the two collaborative fishers. Large individuals of dusky grouper were caught in the summer (January and February) and autumn (May). In May 2014 many individuals were caught (similar to the spring of 2015) (Table 1). The weight-length relationship of dusky grouper (n = 793) is shown in Figure 4.

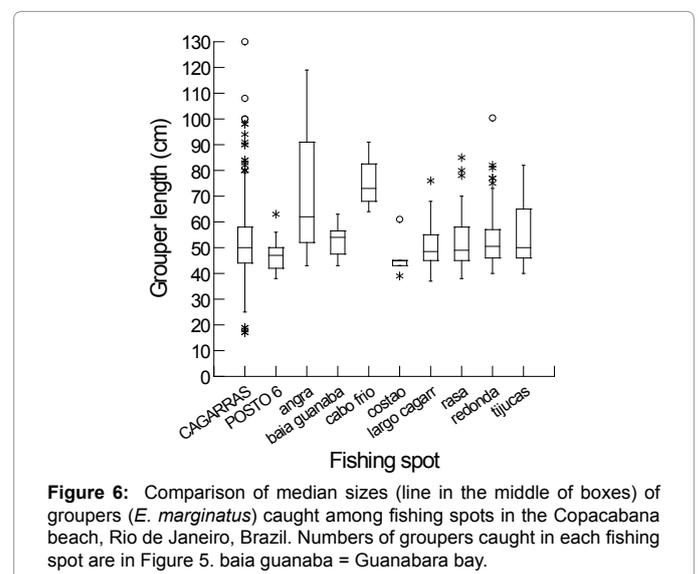
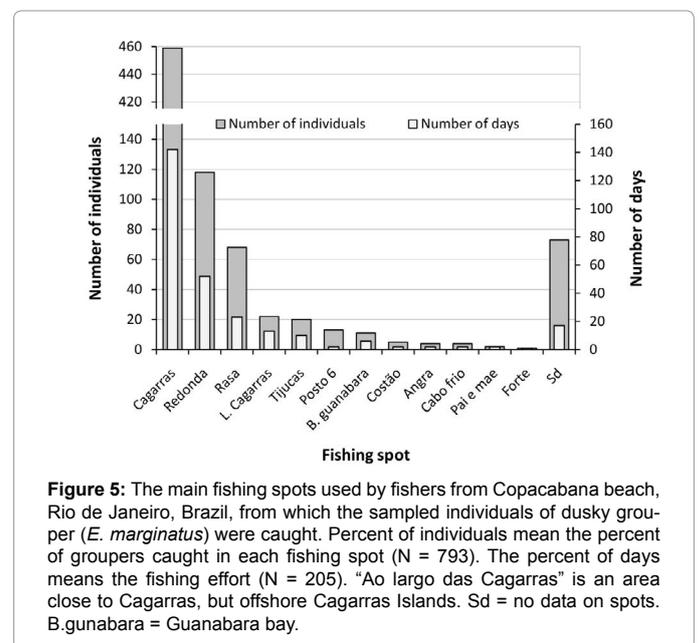
Of the 800 dusky groupers examined, only 18 had mature gonads, 15 of which were collected, ranging from 15-48 ml (Table 2). These mature fish were mostly caught at Cagarras Island in the summer, especially in November (Figure 5). The weights of the mature dusky groupers ranged from 1.95-8.6 kg, and the lengths ranged from 40-81 cm.

Most dusky groupers (57%) were caught at the Cagarras Islands (Figure 5). The median size of groupers caught differed among fishing spots ($H = 19.2$, $d.f. = 9$, $p < 0.05$). Just a few large groupers were caught at two distant fishing areas, located about 460 km (Angra dos Reis) and 640 km (Cabo Frio) from the city of Rio de Janeiro (Figure 5). If we excluded these two distant spots from the analysis, the size of groupers caught did not differ among the other fishing spots ($H = 8.2$, $d.f. = 7$, $p = 0.32$). The median size of groupers caught at all these fishing spots was around 50 cm length (Figure 6).

Considering the 299 dusky groupers to which data were available regarding fishing methods, 91% were caught through spear fishing during snorkeling (one of the fishers who collaborate in this study uses this method). Notwithstanding that much more groupers were caught by spear fishing (n = 271), compared to other fishing techniques (line and gillnets, N = 28), the frequency of size classes of groupers caught did not differ between spear fishing and the other gears ($p > 0.05$, Figure 7).

Discussion

The support and collaboration of the two fishers from Copacabana beach increased our sampling effort and hence the efficiency of the research. When comparing these results with an earlier study on dusky grouper at Copacabana Beach performed in 2006-2007 during 19 months with 36 days of fieldwork [18], we observe that the collaborative process with the fishers allowed us to almost double our sampling effort (42 days of fieldwork, 205 examination days and 800 fish examined)



Date	Length (cm)	Weight (kg)	Gonad volume (ml)	Fishing spot
10/09/13	40	1.95	15	Cagarras Islands
11/12/13	42	1.38	48	Cagarras Islands
11/14/13	48	1.92	22	Cagarras Islands
11/03/13	56	3.46	38	Cagarras Islands
11/03/13	59	3.42	40	Cagarras Islands
11/14/13	63	5.15	45	Cagarras Islands
11/14/13	49	2.30	25	Cagarras Islands
12/09/13	72	5.48	30	Cagarras Islands
11/25/14	70	6.00	20	Cagarras Islands
11/25/14	81	8.60	20	Redonda Island
01/07/15	64	5.70	30	Cagarras Islands
01/07/15	62	4.30	29	Cagarras Islands
02/04/15	48	1.79	30	Rasa Island
02/04/15	59	2.97	25	Redonda Island
04/15/15	72	6.67	25	Cabo Frio

Table 2: Macroscopically visible gonads of *E. marginatus*, with visible eggs (oocytes) from dusky groupers examined from catches from Copacabana beach (Rio de Janeiro, Brazil), from September 2013 through June 2015. Three dusky groupers observed in April had mature gonads, but they were not collected.

Month	2014	2006-2007
Feb	20	5
Mar	28	5
Apr	31	9
May	75	2
Jun	24	0
Jul	66	2
Aug	34	2
Sep	66	2
Oct	76	NS
Nov	87	9
Total	507	36

Table 3: Comparisons of results (number of fish sampled) from research on dusky grouper (*Epinephelus marginatus*) sampled in 2006, 2007 (just the researcher) and in 2014 (with fishers' collaboration) in Copacabana beach, Rio de Janeiro, Brazil.

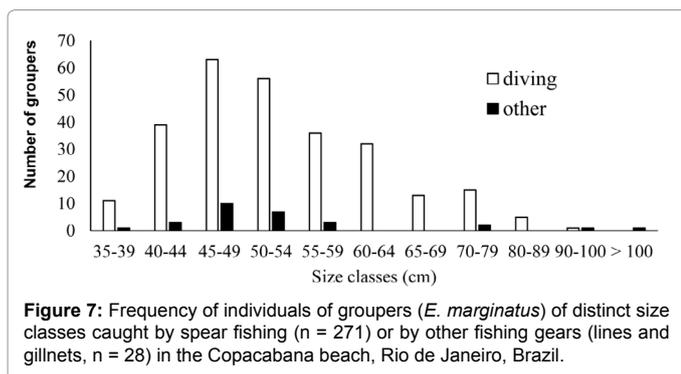


Figure 7: Frequency of individuals of groupers (*E. marginatus*) of distinct size classes caught by spear fishing (n = 271) or by other fishing gears (lines and gillnets, n = 28) in the Copacabana beach, Rio de Janeiro, Brazil.

(Table 3). We examined 507 dusky groupers in 2014 in a monthly basis, compared to 24 in 2006 and 12 in 2007 [18]. Compared to other studies [20], we obtained a relatively large sample of 800 groupers in this study, 18 of which had mature gonads in which oocytes were macroscopically visible. Earlier preliminary results of research with dusky groupers have indicated that the research protocol including collaborative processes with fishers was valuable enough in order to proceed with this kind of methodology [26].

Since the pioneering work of Johannes [27], Ruddle [28] and Berkes [29], many other researchers have successfully collaborated

with fishers. Some of these collaborative studies have been conducted in the Brazilian coast [18,21,22,30], in the small-scale Amazonian fisheries, in Australian rivers and with Mayan lobster fishers [31-33]. Furthermore, an important set of small-scale fishery researchers have performed collaborative research with small-scale fishers in Latin America, as exemplified in a recent FAO technical paper [34]. Research can be improved if biologists and ecologists would have, first, a better understanding of the empirically based fishers' knowledge; second, a perception on their interest in participating in research connected with their fishery; and finally, a comprehension on the importance of an interactive dialogue with fishers for successful fishery management.

Fishermen caught most of the groupers shown here by spear fishing during snorkeling. Glamuzina and Skaramuca [2] observed that this species is especially exposed to spear fishing due to its way of life and attitude towards divers. In the south of Brazil, line fishing is the most important method for catching the dusky grouper [35]. Our previous studies of other small-scale reef fisheries show that hook and line is an important method to catch dusky grouper [25,36,37]. However, at the Copacabana Beach, young fishers have been moving toward snorkeling and spear fishing, which is currently an important fishing method. Fishing through diving may represent either an opportunity or a challenge to the management of dusky grouper fisheries. Diving is usually a highly selective fishing method, which allows fishers to direct effort to catch the largest individuals in a population. Such size selectiveness may remove large fish with important ecological functions (for example, predators), besides having great reproductive and survival potential [38,39]. We observed that overall size frequencies of groupers caught did not differ between diving and other, less selective fishing gears (the number of fishing trips using other fishing gears was lower compared to diving). Moreover, although not statistically significant, we observed a possible trend of large groupers (from 60 to 89 cm) being more often caught by diving (Figure 7). Therefore, the potential impacts of diving should be properly assessed in comparison with the impacts of other fishing techniques. The popularity of diving among fishers in the studied region may require future management measures aimed to avoid capture of larger fish, such as zoning with no-take areas [7]. On the other hand, diving fishers have often a good knowledge about fish, such as about its behavior and habitat. Such knowledge could help to develop co-management measures aimed to groupers [40,41].

Mature gonads were found in the catches at Copacabana in groupers with lengths from 40-81 cm (Table 2). According to Marino et al. [3], the first sexual maturity of dusky groupers occurs at lengths of 36.7 cm in females and 68.5 cm in males, corresponding to ages of 5 and 12 years, respectively. Froese and Pauly [7] show the length at first maturity (L_{50}) of females to be 47 cm. In Brazil, the L_{50} of the females of dusky grouper is considered to be 47 cm with a range of 35-60 cm [19]. The minimum length we obtained in our study was a 40 cm female with mature gonads. This is within the range observed by Andrade et al. [19] and Marino et al. [3]. The minimum legal size in Brazil is 47 cm for *E. marginatus* (garoupa) [42]. However, considering that this information is very important in the management of a fishery, it is reasonable to suggest that the minimum legal size for catching grouper should be reduced to 40 cm. Fishers should be consulted about this management measure, which might be well accepted, as most of the dusky grouper caught were larger than 40 cm (Figure 2).

Mature groupers were observed in Copacabana Beach, especially in the summer and specifically in November. These results agree with earlier studies on reproduction of this fish from other areas in Brazil [19,20].

As in our earlier studies [15,17,18], the number of immature individuals was relatively high, because only 18 individuals out of 800 were found with mature gonads. Other studies also found a high proportion of young individuals [20,35]. We agree with Condini et al. [20] that spawning groupers should be located at deeper ranges; however, we also suggest that the hypothesis that spawning groupers could be located in rocky areas far from the shoreline can be very plausible [43]. Areas far from the shore or at greater depth ranges are sites that small-scale fishers usually cannot reach with their technologies (see fishing spots for groupers used by small-scale fisheries of Copacabana in [18]. Based on information from SCUBA divers, Bodilis et al. [44] observed that small dusky groupers (≤ 25 cm TL) are frequently observed in shallow waters; groupers from 20-25 cm are found at depths of ≥ 30 m, and the largest individuals (over 40 cm) at depths from 15-60 m (but groups of all sizes are present in shallow waters). Thus, mature and larger females may be more out of reach for most small-scale fishers in the studied region (Copacabana, Rio de Janeiro).

The fishing spots used at Copacabana include coastline islands, such as the Cagarras Islands and others, such as Rasa and Redonda. We mapped the fishing spots used for groupers, including those in the Cagarras Islands in previous studies [25,45]. This study confirms the importance of the Cagarras Islands as sites for dusky grouper fishing. Moreover, most mature groupers came from this area. Even though we consider the importance of that area, it is important to note that most groupers caught by fishers are over 40 cm in length. Larger groupers were caught at more distant fishing spots. Cagarras Island showed the largest variation in the sizes of groupers caught, including the largest individual caught by fishers (Figure 6).

The fact that a few individuals caught were mature helps explaining why such an important target fish does not seem overexploited yet. Scarcities of spawning fishes in landings could be an indicator of both recruitment and growth overfishing, as juveniles are caught before reaching reproductive size [46]. Indeed, a previous study suggests that the lack of knowledge of fishers about the reproduction of large pelagic fish may be an indicator of overfishing [21]. In this study we observed that most of the non-spawning fish were large individuals, beyond the size at first maturity. This may indicate that fishers are not targeting large reproductive fish, for example in spawning aggregations [41]. A previous genetic study of *E. marginatus* using microsatellite markers in the Paraty bay (southern coast of Rio de Janeiro State) suggested panmixia and a single stock with an N_E (effective population size) estimated at 663 individuals. This number could represent the threshold of the population capacity for avoiding genetic loss, due to genetic drift [47].

Conclusions

This study provided useful information to fisheries management of the dusky grouper, an important reef fish with high commercial value and targeted by many small-scale fisheries, including those in the Brazilian coast. The collaboration with local fishers greatly improved the amount of data collected and the overall consistency of the research. We thus recommend that this approach should be more broadly adopted in future studies. Fishing of dusky grouper is concentrated especially in a single archipelago (Cagarras), mostly done through spear fishing, which represents opportunities and challenges to management. Our results indicate that catches consist mostly of large adults, indicating a possibly non-overexploited stock of dusky grouper. Nevertheless, very few individuals were observed with mature gonads. We suggest that reproductive fish may be in deeper sites, out of reach of these small-scale fishers, or far from shore. Although important for management,

these ecological patterns remain as hypotheses to be checked in future studies.

Acknowledgements

We are grateful to FAPESP - Fundação de Amparo à Pesquisa do Estado de São Paulo for visiting researcher scholarship to SS (Processo FAPESP N° 14/24994-8 and 14/16939-7), and to CNPq - Conselho Nacional de Desenvolvimento Científico e Tecnológico for productivity scholarships to AB (Processo CNPq N° 302762/2013-0) and to RAMS (Processo CNPq N°309014/2013-1). In particular, the grant from CNPq to AB supported the fieldwork.

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