

Mapping goliath grouper aggregations in the southwestern Atlantic

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The Atlantic goliath grouper, *Epinephelus itajara* (Lichtenstein, 1822), is the largest reef fish in the western Atlantic Ocean, reaching up to 2.5 meters long and > 400 kg (BULLOCK et al., 1992). The species matures at 5-8 years with a maximum age of 37 years (BULLOCK et al., 1992). Some characteristics of goliath grouper that make them particularly vulnerable to overfishing include their large body size, slow growth, high longevity, late maturity, and the formation of predictable seasonal spawning aggregations (SADOVY; EKLUND, 1999). Consequently, the species has suffered sharp population declines across its entire distribution range (CRAIG et al., 2009; McCLENACHAN, 2009; GIGLIO et al., 2015) and currently is classified as Critically Endangered by the International Union for the Conservation of Nature (CRAIG, 2011). In Brazil, the species have been fully protected by a federal law since 2002, however, illegal fisheries threaten the population's recovery (GIGLIO et al., 2014a).

During the reproductive season, goliath grouper form relatively small (10 to 100 individuals) spawning aggregations (SADOVY; EKLUND, 1999) with individuals migrating distances up to 300 km to specific spawning areas (PINA-AMARGÓS; GONZÁLEZ-SANSÓN, 2009). Data on the spatial and temporal distributions of spawning aggregations are mostly available for the northern hemisphere (SADOVY; EKLUND, 1999; MANN et al., 2009; KOENIG et al., 2011; 2016). In Brazil, anecdotal reports of aggregation sites have been described using fishers' knowledge (GERHARDINGER et al., 2009; FERREIRA et al., 2014) and *in situ* surveys (FÉLIX-HACKRADT; HACKRADT, 2008; BUENO et al., 2016). Identification and management of aggregation sites continues to be a critical component of conservation (SADOVY DE MITCHESON et al., 2012), as spawning aggregations

are often exploited at unsustainable levels before fishery managers learn of their existence (ERISMAN et al., 2015).

Here, we describe the occurrence of goliath grouper aggregations along the Brazilian coast, using data compiled from literature, fishermen catches and divers' sightings. Identifying aggregation sites and the timing of aggregation formation is essential to implementing strategies to combat poaching and recover the population of the species in Brazil.

To collect reports of goliath grouper aggregations in literature, we conducted a search through Scopus and Scielo databases using the words "goliath grouper + aggregation + Brazil" and the Portuguese equivalents "mero + agregação + Brasil". During surveys seeking fishers' and divers' knowledge (e.g. GIGLIO et al., 2014b; 2015) we interviewed approximately 520 fishers and 100 divers in eight states along the Brazilian coast. We asked respondents if they had witnessed goliath grouper aggregations or knew some colleague who had reported an aggregation. We also conducted a search on aggregation videos on Youtube and Vimeo using the keywords: "agregação + mero", "mero" and "mergulho + meros" and contacted the videos' authors to obtain data. Participants were questioned to provide data on location (coordinates), date of sighting or catch, depth, habitat type, number of individuals observed, and images to confirm the aggregations' occurrence. We considered an aggregation to consist of five or more fish sighted or fished at the same site.

A total of 98 reports of goliath grouper aggregations were described at eleven sites, dating between 1993 and 2015 (Figures 1 and 2, Table 1). The overall abundance was 15.6 ± 3.3 (SE) individuals per report. Five aggregations were associated with natural reefs (rocky reefs) and six with artificial reefs (three in shipwrecks,

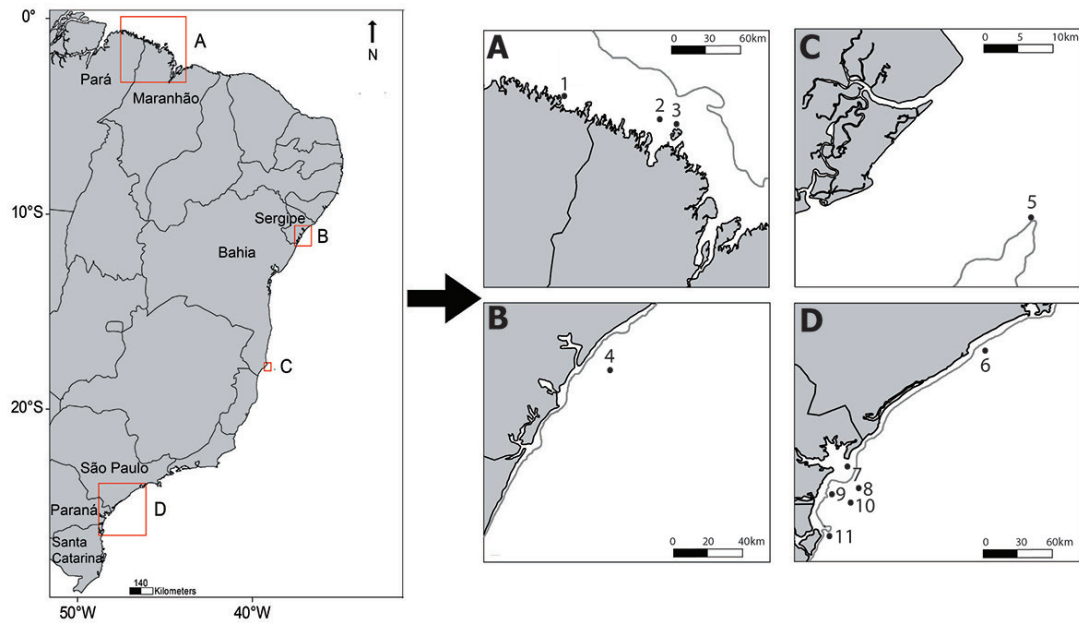


Figure 1. Aggregation sites of goliath grouper along Brazilian coast. Gray lines represent isobaths of a) 30 m. depth and b, c, d) 10 m. depth.

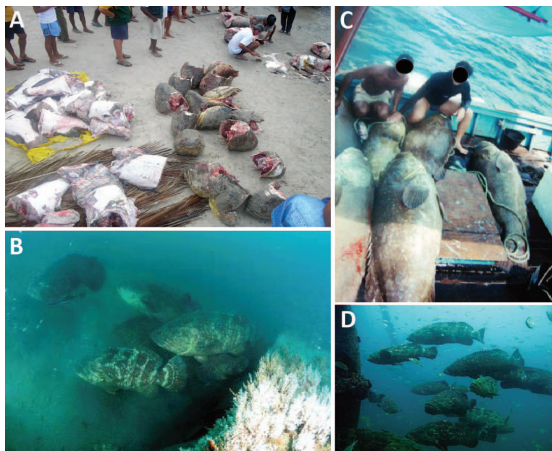


Figure 2. Aggregations of goliath grouper in Brazilian coast: a) Poaching apprehension in Cururupu at February 2009; b) Parque dos Meros at February 2009; c) Abrolhos Bank at March 2000; and d) Monobóia at January 2010. Credits: a) Gerex IBAMA; b) M. Krause; c) Rivelino Nova Viçosa and d) J. Leite.

two in oil-gas structures and one on a concrete reef). Large goliath grouper aggregations (> 40 individuals) were recorded in Bragança (state of Pará) and at a mooring buoy located 8 km offshore, named Monobóia (state of Santa Catarina). Most of aggregation sites ($n = 5$) were in the southern region. All the aggregations occurred on the continental shelf in shallow waters (6 to 28.8 m depth) and relatively near the coast (< 42 km; Table 1). Aggregations on artificial and natural reefs occurred within similar depth ranges (20.3 ± 2.14 m and 20 ± 1.6

m, respectively). Despite non-significant differences, abundance on natural reefs was higher than on artificial ones (20 ± 4.3 and 13.1 ± 2.6 individuals, respectively; Kruskal-Wallis test $\chi^2 = 2.14$; $p = 0.14$). Aggregations occurred during the austral summer (December to March), with peaks in January and February. In southern Brazil, a systematic monitoring verified that abundances on artificial reefs increased in spring and peaked during the austral summer (see BUENO et al., 2016).

Our study revealed the first broad-scale spatial and temporal patterns of goliath grouper aggregations in the southwestern Atlantic. Aggregations were observed in shallow areas (< 30 m depth) on structurally complex reefs. Goliath grouper are one of the few large groupers that form aggregations on shallow reefs, typically less than 50 m deep (KOENIG; COLEMAN, 2009). Aggregations are known to occur on high-relief reefs, especially on artificial structures that provide shelter and food (SADOVY; EKLUND, 1999; MANN et al., 2009). In Brazil, artificial reefs generally attract higher abundances of goliath grouper than do the natural ones (SIMON et al., 2011; GIGLIO et al., 2014b). Sites were related to coastal areas relatively close to large estuaries and mangrove areas, which are essential settlement sites for goliath grouper larvae and as nursery habitats for juveniles (SADOVY; EKLUND, 1999; KOENIG et al., 2007).

Female individuals had developed ovaries in austral summer in southern Brazil (BUENO et al., 2016) and

Table 1. Occurrences of goliath grouper aggregations along the Brazilian Coast. States: PA = Pará; MA = Maranhão; SE = Sergipe; BA = Bahia; SP = São Paulo; PR = Paraná, and SC = Santa Catarina. The exact date and geographical coordinates of aggregations are not given in this table so as not to divulge the exact location. Distance from the coast was estimated along a straight line from the nearest point on the coast.

Site	Name/state	Geographical coordinates	No. of reports	Date (month/year)	No. of Individuals	Depth (m)	Distance from the coast (km)	Habitat	Source
1	Bragança/PA	39°17' S 46°27' W	2	02/2009 and 02/2011	16 and 44	15-22	3	rocky reef	ICMBio (apprehension)
2	Cururupu/ MA	1°34' S 44°23' W	1	3/2009	17	17	10	rocky reef	IBAMA (apprehension)
3	Lençóis de Cururupu/ MA	1°25' S 44°34' W	1	2/2005	30	17	1.5	rocky reef	ICMBio and IBAMA (apprehension)
4	Plataforma Sergipe/SE	10°56' S 36°50' W	1	2/2008	11	20	15	oil-gas structure	professional diver
5	Frias rocky reefs/BA	17°58' S 38°59' W	4	2 and 3/1993, 1/1995 and 3/2000	6, 11, 8 and 18	23	35	rocky reef	fisher
6	Queimadi- nha/SP	24°22' S 46°47' W	1	1/2011	6	13	18	shipwreck	recreational diver
7	Castilho/PR	25°16' S 47°57' W	2	3/2010, 02/2011	17 and 8	21	10	rocky reef	recreational diver
8	Parque dos Meros/PR	25°49' S 48°22' W	26	spring and summer (2006-2015)	17, 9, 7, 32*	17	32	concrete reef	FELIX- HACKRADT; HACKADT (2008), BUENO et al. (2016), recreational diver
9	Dianka/PR	25°53' S	2	2 and 6/2009	8 and 7	28	39	shipwreck	recreational diver
10	Balsa Norte/ PR*	25°47' S 48°06' W	25	spring and summer (2006-2015)	30*	27	42	shipwreck	BUENO et al. (2016), recreational diver
11	Monobóia/ SC*	26°13' S 48°24' W	33	spring and summer (2006-2015)	54*	23	8	oil-gas structure	BUENO et al. (2016)

* maximum number of individuals sighted, extracted from BUENO et al. (2016). In this reference, the mean abundance per site was not given, thus, to calculate abundance per site we used half of the maximum value. Ex: for the Monoboia, maximum abundance was 54, so we used 27 as the mean value.

northeastern Brazil (FREITAS et al., 2015) showing that spawning occurs in this season. Our results also ascertained that aggregations occur during the austral summer in shallow waters (< 30 m depth), similarly to the spawning season for populations in the northern hemisphere (KOENIG et al., 2011). The mapped sites need to be surveyed to verify the occurrence of active spawning aggregations. Sadly, goliath grouper aggregations have been heavily poached, mainly in Northern Brazil (GIGLIO et al., 2014a). A better surveillance of known sites during the spawning season (the austral summer) is urgently needed to curb poaching and aid in the recovery and conservation of this critically endangered species.

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