Knowledge connections for conservation of the Atlantic Goliath Grouper, *Epinephelus itajara*: records of tropical Brazilian coast

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The Atlantic Goliath Grouper (AGG), *Epinephelus itajara*, the largest Epinephelidae in the Atlantic Ocean, it is classified as critically endangered in Brazil. In the Brazilian northeast, studies focusing on the species are still incipient. Here we study the occurrence, habitat use, and spatial distribution of AGG in Alagoas (Brazil) by combining participatory methods, such as Citizen Science and Local Ecological Knowledge. Living individuals represented 64% (n = 85) of the records, while dead individuals were 36% (n = 47), with 14 records from illegal captures. Juveniles are common in estuaries and shallow natural coastal reefs, while adults are distributed in deeper areas on natural and artificial reefs. The occurrence was significantly higher on Alagoas' southern coast. The São Francisco River (SFR) estuary stood out with 52 occurrences. We mapped 37 occurrence sites for AGG distributed along the coast, emphasising an artificial reef near SFR that received 12 reports about aggregations. The influence area of the SFR was indicated as a priority for species conservation due to the identification of a nursery and possible aggregations close to its mouth. We highlight the urgency of implementing short and long-term management actions along Alagoas' coast.

Keywords: Conservation, Epinephelidae, Fishing, Habitat, Social Participation.

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O mero, *Epinephelus itajara*, o maior Epinephelidae do Oceano Atlântico, está classificado como criticamente ameaçado no Brasil. No Nordeste brasileiro, os estudos voltados à esta espécie ainda são incipientes. Aqui estudamos a ocorrência, uso do habitat e distribuição espacial do mero em Alagoas (Brasil) combinando métodos participativos, como Ciência Cidadã e Conhecimento Ecológico Local. No total, os indivíduos vivos representaram 64% (n = 85) e os mortos 36% (n = 47), com 14 registros de capturas ilegais. Juvenis foram observados em estuários e em recifes naturais costeiros rasos, enquanto adultos grandes distribuíram-se em recifes naturais e artificiais em áreas mais profundas. A ocorrência foi significativamente maior no litoral sul de Alagoas. O estuário Rio São Francisco (RSF) se destacou com 52 ocorrências. Mapeamos 37 locais onde o mero ocorre, distribuídos ao longo do litoral, com destaque para um recife artificial localizado próximo ao RSF, que obteve 12 citações sobre agregações. Indicamos que a área de influência do RSF é prioritária para a conservação, em razão da identificação de um berçário e de possíveis agregações próximas a sua foz. Destacamos a urgência na aplicação de ações de gestão de curto e longo prazo em Alagoas.

Palavras-chave: Conservação, Epinephelidae, Habitat, Participação Social, Pesca.

INTRODUCTION

The Atlantic Goliath Grouper, *Epinephelus itajara* (Lichtenstein, 1822), is the largest Epinephelidae species in the Atlantic Ocean, being able to exceed 200 cm in total length (TL) and weigh over 400 kg (Sadovy, Eklund, 1999). Its life cycle is associated with several coastal ecosystems (Koenig *et al.*, 2017) depending on the ecological connectivity of their habitats (Bertoncini *et al.*, 2018). Juveniles live in estuaries close to mangroves and migrate to the continental shelf, natural reefs and artificial structures when they reach adulthood (>120 cm TL) (Bueno *et al.*, 2016; Collins, Motta, 2017). The species is described as sedentary fish with great fidelity to their habitat (Koenig *et al.*, 2011). However, telemetry studies have shown that large movements are done for reproductive reasons (Eklund, Schull, 2001; Pina-Amargós, González-Sansón, 2009; Ellis *et al.*, 2013).

Intrinsic characteristics such as late maturation, predictable occurrence, no fear of human presence, and formation of spawning aggregation make this species sensitive to fishing pressure, besides degradation of its habitat (Sadovy, Eklund 1999; Ferreira *et al.*, 2014; Bertoncini *et al.*, 2018). The Atlantic Goliath Grouper is classified as vulnerable by the International Union for Conservation of Nature; IUCN Red List (Bertoncini *et al.*, 2018). However, in Brazil, the species remains critically endangered (Hostim-Silva *et al.*, 2005; Ferreira *et al.*, 2018). Overfishing and habitat degradation are indicated reasons for their populations' decline and local disappearances throughout their distribution range and specifically in some sites of the Brazilian coast (Gerhardinger *et al.*, 2009; Bertoncini *et al.*, 2018; Ferreira *et al.*, 2018).

In Northeastern Brazil, mainly in the state of Alagoas, *E. itajara* is widely recognised by recreational (SCUBA) divers and fisher in all its habitats (Reuss-Strenzel, Assunção,

2008; Giglio *et al.*, 2014a,b,c; Ferreira *et al.*, 2014). Illegal fishing and marketing practices indicate a deficiency in environmental information and enforcement in this region, directly hampering species' recovery and reducing the opportunities to understand its biology (Giglio *et al.*, 2014c; Sampaio *et al.*, 2015). The Brazilian researchers, managers, and the "Meros do Brasil" Project put extensive efforts into socio-environmental research initiatives to protect *E. itajara* and the coastal and marine environments. However, the knowledge about its ecology and the implementation of mitigation measures needs to be expanded, particularly in the Brazilian Northeast, where studies focused on the Atlantic goliath grouper are incipient (Bertoncini *et al.*, 2018).

Due to limited scientific information, social participation emerges as a practical tool for obtaining knowledge (Ferreira *et al.*, 2014; Zapelini *et al.*, 2017; Castellanos-Galindo *et al.*, 2018), especially because resources for research and fisheries management are scarce. Participatory approaches can provide quali-quantitative data and safer and more satisfactory results when associated with conventional methods (Bueno *et al.*, 2016; Jiménez-Alvarado *et al.*, 2019; Reis-Filho, 2020; Reis-Filho *et al.*, 2021). Furthermore, they are important to achieve the conservation program's goals, as they bring society closer to decision-making (Herbst, Hanazaki 2014; Sampaio *et al.*, 2015).

Citizen Science and Local Ecological Knowledge (LEK) have been widely used as viable low-cost alternatives for obtaining data (Cerutti-Pereyra *et al.*, 2018; Reis-Filho, 2020). The knowledge of artisanal and amateur fisher and recreational divers can contribute to ecological studies, time-series understanding, changes in baseline, species conservation status, and building up management plans (Reis-Filho *et al.*, 2016; Zapelini *et al.*, 2017; Pittman, Heyman, 2020). Thus, they provide precious information to be considered when applying these methods (Batista *et al.*, 2014; Michailidis *et al.*, 2020; Pita *et al.*, 2020).

The present study investigated ecological aspects of the Atlantic goliath grouper along the Brazilian tropical coast, such as occurrences, relationships with fishing, spatial distributions, and habitat use. We also identified priority areas for conservation (nursery and aggregations), recognized historical changes, and evaluated a conservation policy for *E. itajara*. It was hypothesized that the habitat used by the juvenile Atlantic goliath groupers (TL <120 cm) is not restricted to estuaries, being these animals widely distributed on coastal reefs throughout the Alagoas coast (NE Brazil).

MATERIAL AND METHODS

Sampling sites. The coast of Alagoas is approximately 230 km long, sheltering estuaries with large mangrove areas, such as the São Francisco River and the Jequiá, Roteiro, Mundaú, and Manguaba lagoons (Correia, Sovierzoski, 2008). It also presents numerous and extensive coral and sandstone reefs, in addition to historical shipwrecks (Correia, 2011; Sampaio, Pinto, 2019). All these environments are used by Atlantic goliath groupers (AGG) and play fundamental roles in the productivity and maintenance of fisheries resources, making artisanal fishing and tourism important economic activities (Correia, Sovierzoski, 2008; Sampaio *et al.*, 2015). Our study focused on the coast of Alagoas and its Federal Marine Protected Areas (MPA) (Fig. 1).
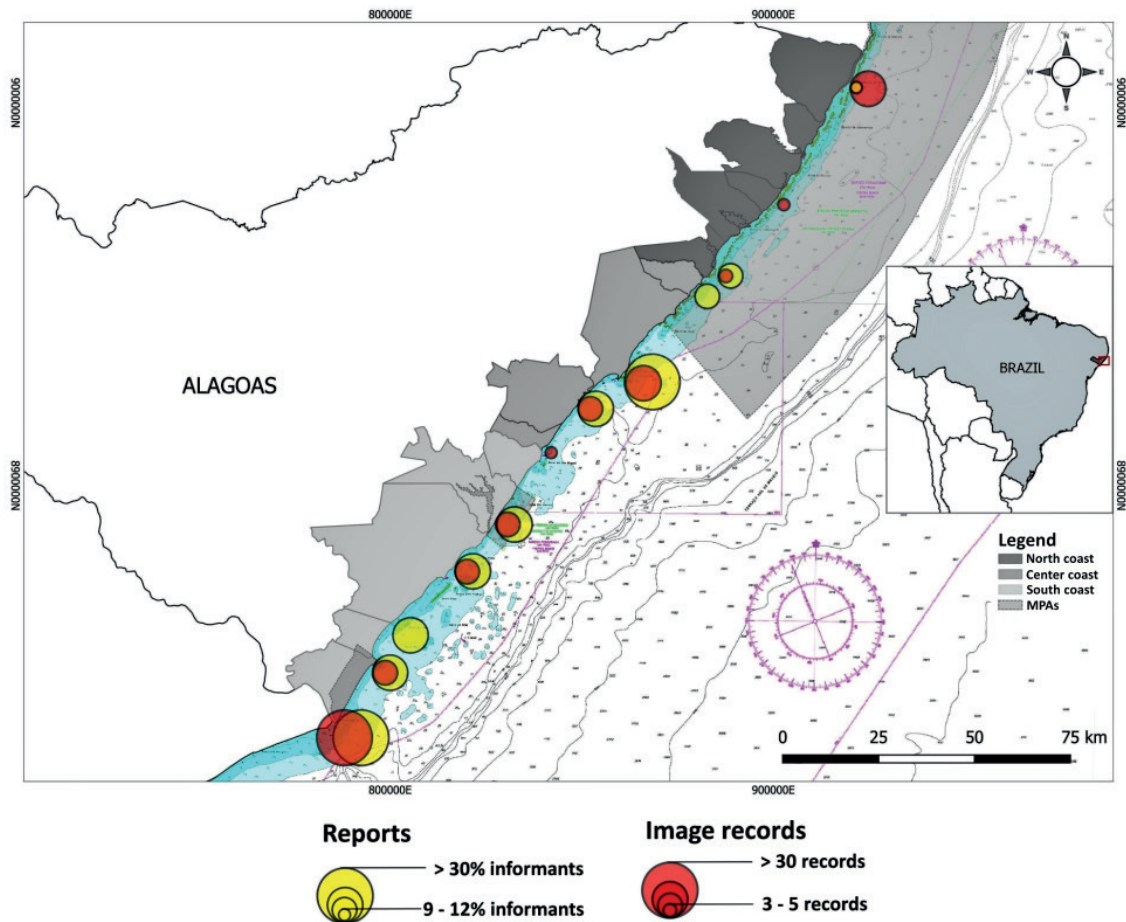
FIGURE 1 | Distribution of Atlantic Goliath Grouper (AGG) *Epinephelus itajara* from the coast of Alagoas. Sites with the occurrence of the AGG validated through photographic or scientific records (Image records); places cited by informants for the occurrence of the species (Reports). Alagoas State, Brazil. The Alagoas coast was separated into north, central and south sectors. The figure highlighted Federal Marine Protected Areas (MPA), on the north coast is the MPA "Costa dos Corais". To the south is located the Marine Extractive Reserve of Lagoa do Jequiá and Environmental Protection Area of Piaçabuçu in the extreme south of the coast.

Data collection. Data were collected between 2017 and 2021 through the combined use of participatory methods. Its purpose is to complement different sources for the knowledge about AGG in the Alagoas coast. The Citizen Science (CS) approach was used to obtain photo or video records of AGG through voluntary participation of amateur fisher (spearfishing and sport), professional fisher (artisanal), and recreational divers, distributed along the coast of Alagoas (Giglio *et al.*, 2014b; Jiménez-Alvarado *et al.*, 2019). Records from any time (decade, year and month) in the sample period and past were shared by volunteers. From this, historical photographs were accessed, from the 1970s, 1980s, and 1990s. CS volunteers were invited by the researchers to participate, and the objectives of the study were explained. As they passed the information, they accessed old records or those of colleagues, shared with the researchers and encouraged others to share.

Data were carefully investigated and validated through the relationship established with the informants, nature, and image characteristics. Investigations were also

performed using photographs on social media networks: Instagram, Facebook, and WhatsApp (Retka *et al.*, 2019; Roos, Longo, 2021). The searches on Instagram were carried out with the aid of hashtags containing the scientific name of AGG or popular in Brazil, study area and names of activities that interact with the species, such as diving and fishing. Combinations were also made with the words. The hashtags were: #itajara, #itajaraalagoas, #epinephelus #epinephelusitajara, #mero, #meroalagoas, #meroal, #mergulhoalagoas, #pescamero #pescaesportivaalagoas #pescasubalagoas, #mergulhoal, #pescaesportivaal, #pescasubal. For Facebook, it was chosen to search with a combination of the words "mero", "itajara", "Alagoas ", "pesca", "mergulho" (Roos, Longo, 2021). Images published since the beginning of the prospected social networks were sought, being from 2004 for Facebook and 2010 for Instagram (Roos, Longo, 2021). On WhatsApp, the records were obtained through sharing by CS volunteers.

The collection of images from social networks was only performed when contact was established with the authors of the records. Ethical guidelines were followed, without recording personal information of the authors or performing any harassment (Monkman *et al.*, 2018). When the author of the record did not agree to provide information, the image was not collected for the purposes of this research. Through contact with the authors of the records, information was sought such as site and date, geographic coordinates, depth, number of individuals and animals' size. The sizes of AGG individuals were estimated by recreational diver volunteers, spearfishing, professional fisher and scientific diving. Amateur fishers (sport) shared more accurate information as they usually measure fish after the catch with metric rulers. Animals recorded in strandings were also measured properly using tape measure.

Trust and discretion relationships were established with professional fisher (artisanal), amateur fisher (spearfishing), and recreational divers from the coast of Alagoas to assess local ecological knowledge (LEK). The interviews were performed haphazardly to cover informants with different experience levels (Reis-Filho, 2020) through the semi-structured face-to-face and remote forms applications (Reis-Filho *et al.*, 2016; Sampaio, Oliveira, 2016; **S1**).

The snowball sampling was used as a facilitator in the search for interviewees (Bravo-Calderon *et al.*, 2021). The informant, at the end of his interview, indicated another one to be interviewed, and so on, until the desired number of informants was reached (Sampaio, Oliveira, 2016). The researcher responsible for the interviews (MLJ) lives in a fishing community and conservation unit on the coast of Alagoas, which allowed for better access to the informants, as well as the building of relationships of trust through coexistence. Past fisheries research and monitoring work also contributed to the success of the interviews, in the communities accessed (Reis-Filho *et al.*, 2015). Local agents from the communities also contributed as facilitators, reducing the mistrust of the interviewees (Zapelini *et al.*, 2017). As this is a protected species, there was fear on the part of some interviewees in sharing information, however, technical recommendations were followed for respectful interviewing and low disturbance (Bunce *et al.*, 2000).

We opted for reports from fishing professionals whose modalities had more significant interaction with the AGG, how coastal gillnet, "hook and line", spearfishing (Zapelini *et al.*, 2017). Questions about catches and observations sites were added on nautical charts (Ferreira *et al.*, 2014). Sites with more than three citations (n ≥3) were used to build the maps through the QGIS software (Version 3.10). The points mapped through LEK

were only validated from the confirmation of image records obtained from the sites, collected by CS, social networks or through scientific diving records.

Over 100 hours of scientific diving for prospecting the AGG happened in natural shallow reefs (~90h), up to 20 m in depth, and artificial reefs in deeper waters (~ 10h), over 20 m deep, distributed in eight cities from Alagoas State. The dives were conducted between the summers of 2017 and 2021, due to oceanographic conditions. Sites were assessed according to the sampling potential (turbidity, depth <40 m, logistics, species occurrence through photographic records, and citations), following the ReBentos protocol (Leão *et al.*, 2015).

On scientific dives visual censuses were carried out by means of the band transect and intensive search for the recording of AGG (Bueno *et al.*, 2016; Pereira *et al.*, 2021). The visual census technique consists of delimiting a distance of 20 m with the aid of a tape measure for each transect; this extension is covered linearly, and the species, number of individuals and their lengths are recorded within a radius of one meter from the diver's visual field (Brock, 1954; Leão *et al.*, 2015).

The intensive search was based on the recording of all the species observed and on the search for pre-defined species, size of individuals and if necessary, the number, in a determined sampling effort (time), giving priority to environments that cannot be sampled by transect, such as burrows and places with depths greater than 20 m (Leão *et al.*, 2015; Pereira *et al.*, 2021).

Body size classes were analyzed through the following categories: juvenile (total length: TL <50 cm), subadult (TL = 50–100 cm), adult (TL = 101–150 cm), and large adult (TL > 151 cm). Habitats were categorised as "estuaries" (mangroves), "reefs" (coral and sandstone), or "artificial reef" (shipwrecks) (Giglio *et al.*, 2014b). The shore of Alagoas was classified in north, central, and south coast for the records and based on oceanographic and socioeconomic aspects, similarities between the cities, and geographical aspects, following Correia, Sovierzoski (2008). The north coast includes cities from Maragogi to Barra de Santo Antônio; the central coast includes cities from Paripueira to Barra de São Miguel, and the south coast cities from Roteiro to Piaçabuçu.

The northern coast has countless coral reef formations, exposed at low tides near the beach line and others in submerged areas, with irregular patches aspects (Correia, Sovierzoski 2008; Correia, 2011). This portion of the Alagoas coast houses a large part of the Marine Protect Area (MPA) "Costa dos Corais", and all the cities on the northern coast are inserted in it. It constitutes the largest Brazilian coastal MPA, created to protect the reef environments of this region and its biodiversity.

The central portion represents the most urbanized and populated region of the coast, also housing the port area of the state. It has countless beaches, sandstone and coral reefs, well exploited by fishing and tourism activities, as well as the best-known and most visited shipwrecks in the state of Alagoas. The Mundaú-Manguaba Estuarine Lagoon Complex suffers from degradation, but has great socio-economic importance for artisanal fishing (Santos, Sampaio, 2013).

In the southern coast area are located the cities suffering from the influence of the São Francisco River, the largest national river (Sampaio, Pinto, 2019). There are two main areas of coral reefs along the beach line, but the majority of the reefs are formed by sandstone strands, with several submerged formations far from the coast. Estuarine-lagoon ecosystems are also found in the cities of Roteiro and Jequiá da Praia. In Jequiá

da Praia, these ecosystems are protected by the RESEX Marinha da Lagoa do Jequiá. The mangrove ecosystems occupy very significant areas, mainly along this region.

"Codes" were created to guarantee the secrecy of the mapped sites. Each code has two letters related to the nature of the place and a number. The first letter corresponds to the habitat: estuary (E), natural reef (N), and artificial reef (A); the second letter represents the coast: north coast (N), central coast (C), and the south coast (S); and the number is used to distinguish and order.

Statistical analyses. We compared the individuals' sizes through Permutational Analyses of Variance (PERMANOVA) with the Bray-Curtis similarity index using Primer 6 software. The species spatial distribution was compared through the X^2 test ($p = > 0.05$), performed in R software (Version 3.6.3; Stats Package, R Development Core Team, 2021).

RESULTS

We recorded 227 photographs of 132 individuals obtained through records of sport fishing (n = 49), spearfishing (n = 23), and by professional fisher (n = 13), besides recreational (n = 30) and scientific diving (n = 3), and stranding (n = 14) (Fig. 2). There were 93 individuals recorded through citizen science, 21 for social media, and 18 by researchers through strandings, dives, or fishing observations. The three records made through scientific diving that went into visual censuses were only on the central coast, representing the low local density of 0.001 fish/m² for the region. Our results indicated a significant difference between record types in the AGG length (Pseudo-F = 13.73; p = 0.001), most occurring during the development of this research, between 2017 and 2021 (64%; n = 84). An increasing number of records was observed during this period (Fig. 3A). AGG were recorded for estuaries (n = 55), natural reefs (n = 34), artificial reefs (n = 29), and strandings (n = 14) (Fig. 3B).
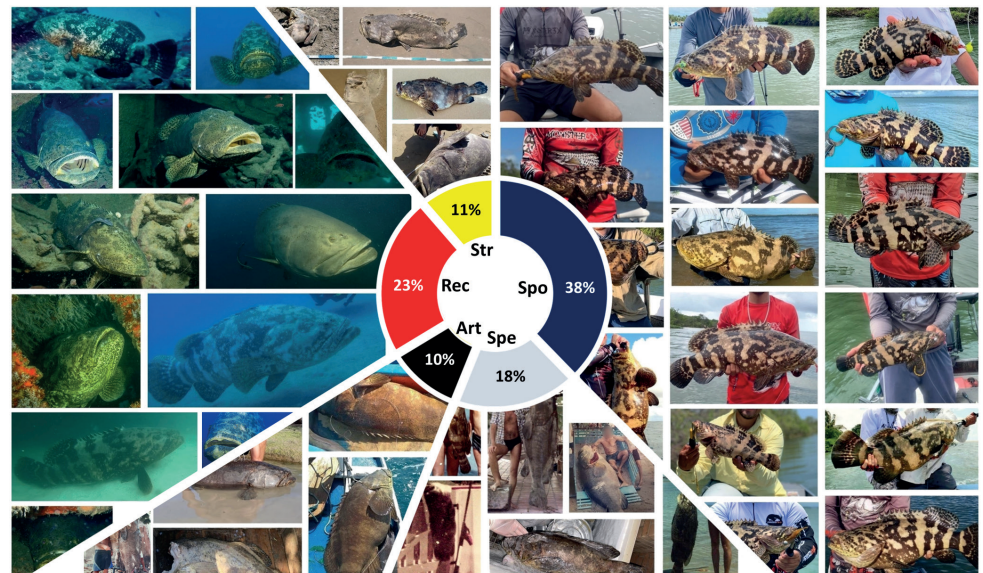

FIGURE 2 | Percentage of Atlantic Goliath Grouper records for Sport fishing (Spo), Spearfishing (Spe), Professional fisher (Art), Recreational diving (Rec), and Stranding (Str).
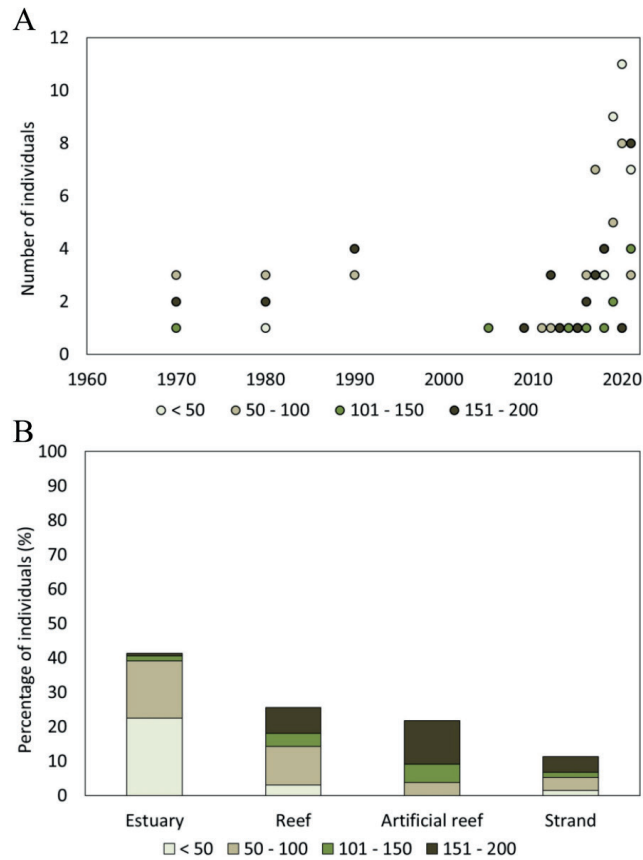
FIGURE 3 | **A.** Number of sightings of Atlantic Goliath Grouper (AGG) *Epinephelus itajara* in Alagoas (between 1960 and 2021) by length category. **B.** Percentage of required AGG recorded by habitats arranged in length category. Color-differentiated total length (TL) categories: juvenile (<50); subadult (50–100 cm); adult (101–150 cm); large adult (151–200 cm).

Concerning the pre–moratorium period (2002), we recorded 19 (14%) photographs from the 1970s, 1980s, and 1990s. Two showed juvenile individuals, eight showed subadults, one showed adult, and eight showed large adults caught by spearfishing in coastal natural reefs, at depths between 5 and 20 m. Individuals were distributed along the north (n = 7), central (n = 7), and south (n = 5) coast (Fig. 4).

Live AGG observed while diving or sport fished totalled 64% (n = 85), with one individual found by sport fishers in an abandoned gill net, ghost fishing, in the São Francisco River estuary. Among the dead individuals recorded (n = 47; 36%), 14 were stranded, and 14 were illegal catches. A total of 28 (21%) dead individuals were recorded in the post–moratorium period. Illegal catches of juvenile individuals (n = 5), subadults (n = 3), adults (n = 3), and large adults (n = 3) were done by professional artisanal fisher with line and hook (n = 8), gillnets (n = 4), and spearfishing (n = 2).

Juveniles totalled 25% (n = 34) and subadults 31% (n = 41) observed or captured in estuaries and natural reefs. Adults accounted for 11% (n = 14) in estuaries, natural reefs, and artificial reefs. Large adults totalled 22% (n = 29) in natural and artificial reefs (Figs. 5A,B). Strandings (11%; n = 14) were also recorded for all length classes. There

1970s   1980s   1990s

FIGURE 4 | Photographic records from the pre-moratorium period, from the 1970s, 1980s, and 1990s. All images are of captures made through spearfishing in shallow coastal reefs off the Alagoas coast.

was a significant difference in the AGG total length comparing types of environments (Pseudo–F = 36.77; p = 0.001). The PERMANOVA pairwise test showed differences for all comparisons between environments (Tab. **S2**).

Regarding the relationship between their size and vertical disposition in the marine environment, juveniles and subadults were concentrated to 14 m in depth. At the same time, adults and large adults were predominantly distributed between 15 and 40 m.

The records were distributed over 13 of the 15 cities along the coast of Alagoas. However, the occurrences were significantly higher (X^2 = 19.342; p < 0.001) in the south coast (Fig. 4). The Piaçabuçu city stood out with 60 (46%) records, with 52 occurrences of juvenile and subadult individuals for the São Francisco River estuary (ES2), followed by Maceió (17%; n = 22) and Maragogi (12%; n = 16). When comparing the coast by sectors, there was a difference in the length of the AGG (PERMANOVA, Pseudo-F = 30.99; p = 0.001). However, there was no difference between the central and north coast (Pairwise PERMANOVA, t = 0.33; p = 0.84). The AGG sizes were different comparing central and south sectors (Pairwise PERMANOVA, t = 6.79; p = 0.001) and north and south (Pairwise PERMANOVA, t = 4.99; p = 0.001) (Fig. 6).

Thirty-two interviews were performed with professional fisher (n = 12), amateur spearfisher (n = 10), and recreational divers (n = 10), distributed along the coast. Professional artisanal fisher has as main activities spearfishing (n = 9), "line and hook" fishing (n = 2), and gillnet (n = 1). However, they are also experts on other fishing gears. Respondents were aged between 18 and 69 years old (mean = 40; SD = 13.5), with different experience levels for professional fisher (mean = 24 years; SD = 14), amateur spearfishing (mean = 18 years; SD = 13.6), and recreational divers (mean = 19 years; SD = 10.9).
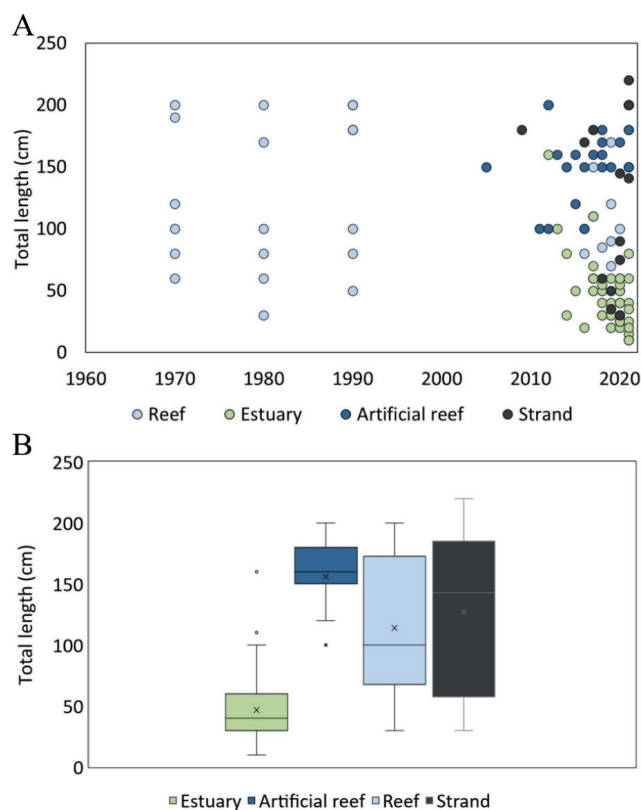
FIGURE 5 | A. Sightings of individuals of Atlantic Goliath Grouper (AGG) *Epinephelus itajara* in Alagoas, between 1960 and 2021, arranged by habitat and; **B.** Distribution of AGG with estimated Total Length arranged by habitat. Stranded animals also make up the boxplot. Habitats are separated by color, boxplots presents the maximum and minimum limits (upper and lower rush). In the interquartile range are the third and first quartiles at the ends, median and mean (x) of the AGG total length.

All interviewees claimed to know the AGG, describing characteristics of the species such as colour, behaviour, body size, and head shape. Interviewees (78%; n = 25) claimed that the species is still the target of fisheries, being sold uncharacterized, as black grouper, *Mycteroperca bonaci* (Poey, 1860), in fillet or slices. Seven fishers (six professional; one amateur) assumed intentional captures and these illegal practices. Professional fisher also provided detailed information on illegal catches of 24 AGG individuals (two juveniles; 22 adults), landed and sold in important fishing ports in Maceió, Coruripe, and Piaçabuçu. Fourteen of these catches were reported by spearfishing (professional and amateur), with the others being accidentally caught by shrimp trawling (n = 2), line and hook (n = 6), and gillnets (n = 2).

The professional fisher (n = 9) described that juvenile and subadult AGG are found in mangroves and shallow natural reefs (<10 m), usually near "river mouths", and that adults can also be found in these places. However, deeper water sites (>20 m), especially artificial reefs, are indicated as the AGG adults preferred habitats. Of these interviewees, 56%, with a mean experience of 30 years (SD = 14.5), stated that AGG is no longer abundant on the Alagoas coast, but they still observe or catch large individuals. Younger
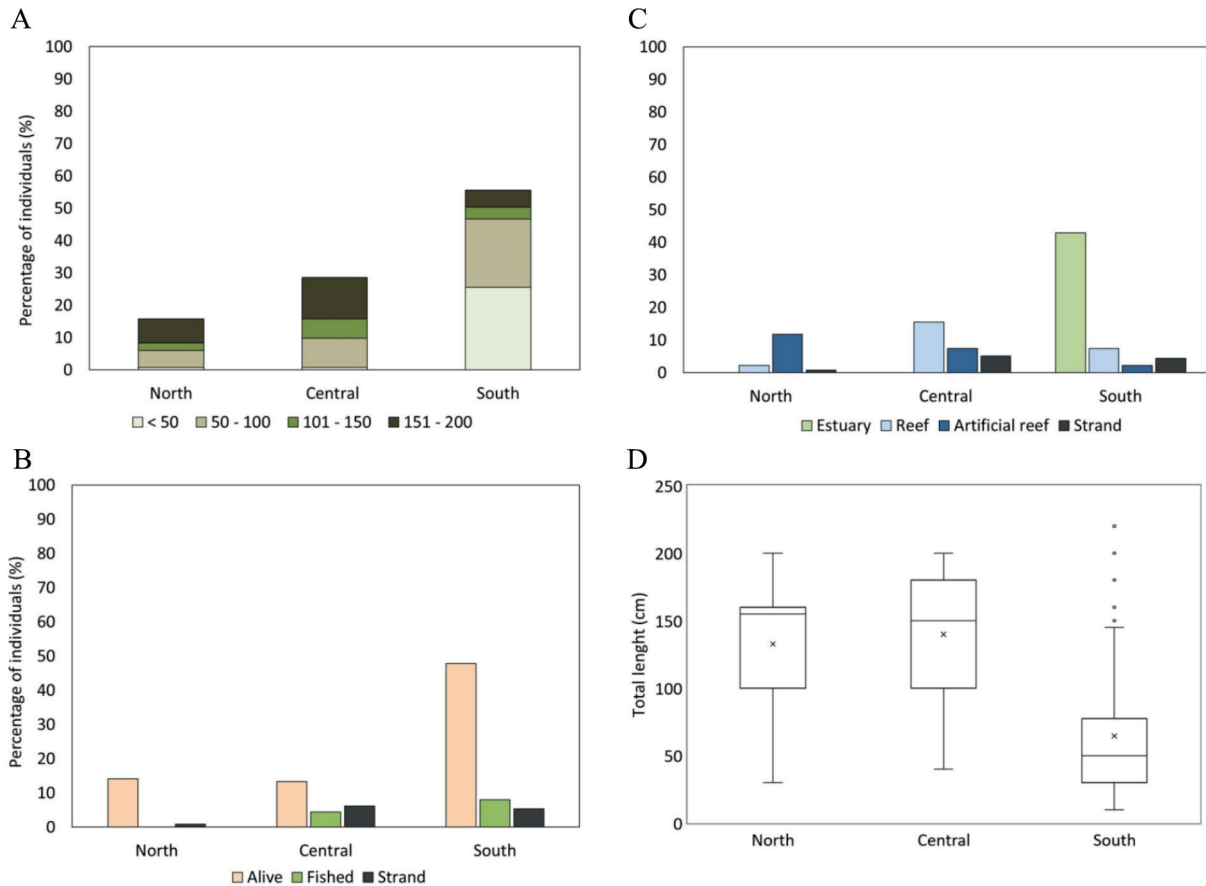
FIGURE 6 | A. Percentage of Atlantic Goliath Grouper (AGG) *Epinephelus itajara* registered along the coast of Alagoas, arranged in length category and; **B.** Percentage of individuals registered alive and dead (fished and stranded), along the division of the coast of Alagoas. **C.** Percentage of AGG recorded along the coast of Alagoas, distributed by habitats. Stranded animals also make up the graph. **D.** Distribution of AGG with estimated TL, arranged along the coast of Alagoas. Boxplots present the maximum and minimum limits (upper and lower rush). In the interquartile range are the third and first quartiles at the ends, median and mean (x) of the total length of the subjects. Color-differentiated total length (TL) categories and separated by habitats.

fishers (31%), with a mean of 15 years (SD = 4.5), indicated that they did not observe changes in the abundance of the species. Experient professional fisher with more than 40 years of experience (n = 3) report that *E. itajara* were abundant until the 1990s, mainly in shallow natural reefs, where they occur as young and adults. They indicated overfishing, primarily through "shrimp trawling" and "spearfishing", associated with the nurseries' degradation (mangroves and shallow reefs), as the leading causes for this change.

The AGG can still be spotted in 58 places, as indicated by respondents. We considered 37 for mapping due to the number of citations (n ≥ 3) and validation through image records or by scientific dive (Tab. 1). These sites are distributed among estuaries, and natural and artificial reefs, with 65% (n = 24) on the south, 30% (n = 11) on the central, and 5% (n = 2) on the north coast (Tab. 1).

TABLE 1 | Mapped sites for the occurrence and possible aggregation of Atlantic Goliath Grouper (AGG) *Epinephelus itajara* indicated by professional fisher, spearfishers and recreational divers. Number of citations (N. reports): Number of AGG registered by photographers at different times (Image records); Activity: professional fisherman (Art); spearfishing (Spe); recreational diver (Rec).

Habitat	Site	N. reports		Coast	Image records	Class
		Ocurrence	Aggregation			
Artificial	AS1	12	12	South	2	Spe/Art/Rec
Artificial	AC2	11		Central	7	Spe/Art/Rec
Artificial	AC3	10		Central	3	Spe/Art/Rec
Artificial	AC4	10		Central	1	Spe/Art/Rec
Reef	RC1	7		Central	3	Spe/Art/Rec
Reef	RS2	7		South		Art
Reef	RS3	7		South	2	Art
Artificial	AS5	6		South	1	Spe/Art/Rec
Reef	RC4	6		Central	2	Spe/Art/Rec
Reef	RS5	6		South		Art
Reef	RS6	6		South		Art
Estuary	ES1	6		South	2	Art
Estuary	ES2	6		South	33	Art
Reef	RS7	5	4	South		Spe/Art
Artificial	AS7	5	3	South		Spe/Art
Estuary	ES3	5		South		Art
Artificial	AC8	5		Central		Spe/Rec
Reef	RC8	4		Central	2	Spe/Rec
Reef	RN9	4		North	3	Spe/Rec
Reef	RS10	4		South	2	Art/Rec
Reef	RS11	4		South	1	Spe/Art
Reef	RS12	4		South	1	Art
Reef	RC13	3		Central	3	Rec
Artificial	AN9	2		North	6	Rec

Three places of possible aggregation distributed on the south coast were indicated. An artificial structure (AS1) located near the mouth of São Francisco River obtained notoriety with 12 citations. In the summer (between December and March), annual aggregations were extirpated in syzygy tides. According to divers, up to 20 individuals of up to 200 cm (TL) and weighing over 300 kg were observed in this location. Professional fisher (9%; n = 3) reported that aggregations of large and dark AGG move from the bottom to close to the surface, producing sound and welcoming them. At the same time, individuals with standard colors with bulky bellies remain in the background.

Respondents from the south coast (34%; n = 11) stated that the AGG are frequent throughout the fishing and diving area, not restricted to the points mentioned. They also noted that AGG are generally not found in the last places they were seen, as they move between mud and natural or artificial reefs in search of food, including octopuses (Octopodidae), crustaceans (Palinuridae, Penaeidae, Portunidae, and Scyllaridae), and fish (Ariidae, Carangidae, Dasyatidae, and Holocentridae). They also explained that *E. itajara* indicates the presence of economically important and threatened species, such as Carangidae, Centropomidae, Lutjanidae, and Sphyraenidae.

When asked about what could be done to conserve the AGG, respondents indicated surveillance (69%; n = 22) and awareness of fisher (38%; n = 12) as measures to combat illegal catches and trade. They also stated the need for fisheries management (31%; n = 10), nurseries and aggregation sites protection (13%; n = 4), and observation tourism focused on the AGG (6%; n = 2).

DISCUSSION

Using a repertoire of methods to assess the AGG population on the coast of Alagoas, we found several records from sport fishing, illegal fishing, making it possible to understand the current situation of the species. We identify nursery and aggregation sites and priority areas for conservation. AGG observations and catches of all size classes have been occurring throughout the coast of Alagoas (Giglio *et al.*, 2014b,c; Sampaio *et al.*, 2015). The abundance of records can lead to the false perception that the species is not rare on the coast of Alagoas and that its population is thriving. Despite that, the populations suffer from fishing pressure and degradation of their habitats, being highly threatened.

No aggregations were observed through the images, but up to two adults were photographed on artificial reefs in three records of recreational divers. It is possible to see pictures with up to four individuals captured in the same fishery in historical records, although the spearfisher indicate that these were not aggregations. However, the characteristics provided by informants in the interviews about possible seasonal aggregations in the AS1 artificial reef, as direct observation of the increase in the number of AGG, social behaviours, lunar period, colour patterns, and large individuals with a distended abdominal region (Colin, 1994; Koenig *et al.*, 2017), may indicate the existence of a spawn aggregation. Little is known in Brazil (Bueno *et al.*, 2016), especially in the Northeast region, where these events occur and it need to be investigated and validated by scientific expeditions, as they represent a critical point in the AGG life cycle (Bueno *et al.*, 2016; Giglio *et al.*, 2016; Pittman, Heyman, 2020).

Being close to the São Francisco River mouth, the AS1 artificial reef suffers from the influence of turbid waters brought from the continent and the constant sediments suspension by the shrimp trawling fleet, making it challenging to realize diving activities (Sampaio, Pinto, 2019). These factors may have resulted in less pressure from spearfishing, consequently protecting these aggregations. However, preventive conservation measures need to be applied, including the site closure for fishing during the reproductive period (Pittman, Heyman, 2020), in late spring and throughout the summer months, as proposed by Bueno *et al.* (2016).

The turbid waters of the SFR are rich in nutrients, providing food resources for AGG. When the river reaches the sea, these waters receive the influence of the Brazilian current and are carried southwards over the Sergipe coast (Carneiro, Arguelho, 2018). For this coast, two aggregations were described less than 100 km from the wreck at the SFR mouth, in addition to landing data (Giglio *et al.*, 2014b, 2016). The first aggregation embraces records of 22 immature AGG in estuaries, while the second includes eight adults in oil and gas structures, both recorded between 2017 and 2021. The proximity, environmental characteristics similarity (Carneiro *et al.*, 2018), adults' migration power (>300 km), and larval dispersion (Koenig *et al.*, 2017; Malinowski *et al.*, 2019) may indicate that Alagoas' South coast and the Sergipe's Coast might share the same population.

Alagoas' north and central coasts receive more attention from public managers, society, and scientists due to embracing a large portion of the "Costa dos Corais" Marine Protected Area and important mangroves and coral reefs. However, the results were significant for the south coast, especially for the distribution and abundance of juvenile and subadults of AGG documented in estuaries and shallow reefs, which is related to the ecological importance of the estuaries in this region, estuary such as the SFR, the Jequiá lagoon and the Coruripe River, and the conservation of its extensive mangroves (Correia, Sovierzoski, 2008; Sampaio *et al.*, 2015).

Located on the south coast, the area influenced by the São Francisco River remain poorly studied, despite presenting numerous and complex reef environments (Correia, 2011; Sampaio, Pinto, 2019). This area is strategic for connecting populations of endemic marine species along the Brazilian coast. It is considered a focal area on the National Action Plans for the Conservation of Reef Environments (PAN Corais) and the Conservation of Endangered Marine Elasmobranchs (PAN Tubarões). Rich in fishery resources, it represented a traditional fishing zone, with the largest and oldest shrimp trawl fleet with ports in the Brazilian Northeast (Sampaio, Oliveira, 2016; Sampaio, Pinto, 2019). The São Francisco River area of influence had the largest number of AGG records. Priority sites for conservation were also identified, such as nursery (ES2) and possible aggregation sites (AS1). This extension requires careful implementation of fisheries management and the expansion or creation of a Marine Protected Area (Giglio *et al.*, 2016; Bertoncini *et al.*, 2018).

The pressure of illegal fishing is one of the greatest threats to the species and hampers population recovery (Giglio *et al.*, 2014c). As found by Zapelini *et al.* (2017) for Brazil, our results show that only the moratorium that prohibits capture, transportation, and processing is not enough because environmental education and inspection programs are needed. Interviewees and photograph reveal illegal practices, like intentional catches and trade of the AGG. Due to morphological similarities, uncharacterized AGG are easily marketed as black groupers at the mean price of U$ 4.00/kg. These practices, found in Alagoas, reflect the fisher's lack of awareness and inspection deficiency (Giglio *et al.*, 2014c).

This study showed that ghost fishing is also a threat to AGG. Lost nets, mainly in mangroves, may impair recruitment and cause juvenile mortality. However, we did not find literature on the impact of ghost fishing on the species (MJCALJ, pers. obs.).

According to historical photographic records and interviewees' accounts, it is possible to understand that juvenile and adult AGG were common on the Alagoas coast,

especially in shallow coastal reefs, until the early 1990s. Experienced fishermen said that there was a decrease in abundance, a fact reinforced by the low number of records obtained by scientific diving, being observed only two juveniles in shallow coastal reefs and one adult in a wreck, in more than 100h of effort. In PLEC (1980) two juvenile specimens were collected using gillnets in estuarine area, with low collection effort, which may indicate that in the early 1980s AGG was even more abundant.

In Alagoas, artisanal fishing is intensively developed with few monitoring, management and enforcement actions. In addition to illegal fishing, mangroves and shallow reefs, especially those near cities areas, suffer from degradation through irregular urbanization, disorderly tourism, ghost fishing, pollution and mischaracterization (Correia, Sovierzoski, 2008; Santos, Sampaio, 2013; Sampaio, Oliveira, 2016). These factors added together may influence the abundance of the species, contributing to a local population decline, corroborating national and international assessments (Bertoncini et al., 2018; Bravo-Calderon et al., 2021).

In a marine environment, smaller AGG (juveniles and adults) can be distributed along natural shallow reefs and rocks sites, with depths of less than 10 m (Giglio et al., 2014b; Artero et al., 2015). Studies at LEK of artisanal fisher corroborate this information (Ferreira et al., 2014). Individuals with a TL between 30 and 80 cm were registered by scientific diving inhabiting coastal reef areas, confirming participatory data. The presence of AGG with sizes smaller than those at first maturity in marine habitats is widely discussed (Sadovy, Eklund 1999; Koenig et al., 2011; Artero et al., 2015). The shallow high-complex reef in the studied area may allow the presence of juveniles on these habitats, not to be restricted to mangroves areas as previously described (Koenig et al., 2011; Ferreira et al., 2018). We emphasize that in Alagoas, shallow reefs are essential for the development of juveniles since immature AGG were found on these reefs (MJCALJ, pers. obs.). However, studies on ontogenetic movements need to be developed to better understand the species distribution on different habitats.

The abundance of adults was higher in deeper waters (between 10 and 40 m depth) of artificial reefs, similar to what was found by Giglio et al. (2014b), Collins, Motta. (2017), and Bueno et al. (2016). Artificial reefs are usually represented by shipwrecks and oil rigs, which typically have high structural complexity with ample internal space and rigid surfaces that serve for the settlement and attraction of diverse organisms, including the AGG (Koenig et al., 2011; Bueno et al., 2016). However, this attraction raises concerns for species conservation since these structures are widely exploited, allowing the species to become more vulnerable to fishing (Bertoncini et al., 2018).

The increase in records between 2017 and 2021 is directly related to society's involvement in data collection, fostered by our research activities in Alagoas state. Proactive volunteers, especially sport fisher, spearfishing, and recreational divers, dedicated themselves to photographing/filming and recovering old records from the AGG, contributing to constructing the database used in this study, increasing sample effort. Despite the increase in the number of records in this period, this fact does not reflect the increase in the abundance of AGG on the Alagoas coast. It was also possible to observe the growth in the number of records starting from 2009, which is potentially associated with the technological advances of the last decades, with the popularization of waterproof sports cameras, smartphones, and social networks (Giglio et al., 2014a,b; Poushter, 2016).

The participation of informants from different activities and experience levels allows higher security and quality of accessed data (Reis-Filho, 2020). The interviewees were precise in describing the species' characteristics, consistent with the scientific literature (Bertoncini *et al.*, 2018). Amateur fisher and recreative divers demonstrated to be qualified for LEK assessment (Giglio *et al.*, 2014b,c; Jiménez-Alvarado *et al.*, 2019; Pita *et al.*, 2020). Nonetheless, professional fisher (artisanal) demonstrated higher knowledge about the AGG and a high expertise level describing in detail the species' occurrences and ecological aspects (Gerhardinger *et al.*, 2006; Freitas *et al.*, 2015; Zapelini *et al.*, 2017).

The mapping of occurrence sites and aggregation of threatened species are strategic for coastal conservation and management (Ferreira *et al.*, 2014). More than a third of the points mapped through the LEK was validated, reinforcing the veracity of the information collected and the importance of the trust relationship with the informants. Respondents from the South coast, especially professional fisher, contributed by providing a higher number of points and helping to identify areas where the AGG is more vulnerable, highlighting the importance of Alagoas' south Coast. These maps can be used to indicate areas where conservation actions for the species are a priority, such as nursery sites, aggregation sites and hotspots of occurrence. This way, enforcement and management actions can be encouraged, for example, such as the expansion or creation of MPAs (Gerhardinger *et al.*, 2009; Zapelini *et al.*, 2017).

The integration of non-destructive and participatory methodologies allowed the assessment and validation of important information about the ecology of the AGG. This approach needs to be broadly implemented in Alagoas, as it can be an effective research tool and contribute to cost reduction and field effort (Giglio *et al.*, 2014b,c; Pita *et al.*, 2020).

In addition, the use of participatory methods provided greater involvement of society in AGG conservation and valued the local knowledge. The incorporation of data from different methodological sources is allowed in national and international conservation status assessments of this species (Bertoncini *et al.*, 2018; Ferreira *et al.*, 2018). Our results can contribute to these evaluation processes, mainly on a regional scale, by indicating that although historically, the species was abundant on the coast of Alagoas, currently, it is rare and faces serious issues that put its conservation at risk.

Through the occurrences and reports of habitat specialization, we validated our hypothesis that juveniles and subadults of the AGG are not restricted to estuaries but also inhabits the continental shelf in areas of natural reefs in Alagoas. However, habitat use by different ontogenetic stages needs to be better studied.

We have identified the ES2 nursery and possible aggregations in the AS1 framework as priority areas for conservation. The entire south coast, especially these areas, needs greater attention from scientists, politicians, public administrators, and surveillance institutions. There is an urgent need to implement management plans for these areas, and the expansion/creation of new MPAs can be an alternative for the species' conservation. Short and long-term actions also need to be implemented to mitigate illegal fishing and trade, such as environmental education activities, dissemination of fisheries legislation and increased surveillance. Management programs must also consider traditional knowledge and social participation in decision-making. Furthermore, studies aiming at AGG must be continued and expanded to better understand the species' ecological and spatial distribution aspects.

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AUTHORS' CONTRIBUTION 🔴

Márcio J. C. A. Lima-Júnior: Conceptualization, Data curation, Formal analysis, Investigation, Writing–original draft.

José A. C. C. Nunes: Formal analysis, Supervision, Writing–original draft, Writing–review and editing.

Tiago Albuquerque: Investigation, Supervision, Writing–review editing.

Cláudio L. S. Sampaio: Data curation, Funding acquisition, Investigation, Methodology, Writing–original draft, Writing–review and editing.

ETHICAL STATEMENT

This study was approved by the Sistema Nacional de Informação Sobre Biodiversidade (SISBIO), permit: 79697-1 and 15080-9. Ethical committee, n°: 54178921.6.0000.0122.

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COMPETING INTERESTS

The authors declare no competing interests.

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