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# Changes or disappearance of the Atlantic goliath grouper *Epinephelus itajara* (Perciformes: Epinephelidae) spawning aggregation sites in southern Brazil

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Atlantic goliath grouper (*Epinephelus itajara*) form spawning aggregations, each with around 100 individuals. However no studies have been carried out comparing these aggregations in natural and artificial environments. In this article we determine patterns in aggregation abundance by observations we made between 2007 and 2014 on three natural and four artificial reefs in southern Brazil by comparing sightings-per-unit-effort (SPUE) among these reefs. Their abundance differed significantly among artificial and natural reefs. No aggregations were observed on natural reefs, however aggregations up to 54 atlantic goliath groupers were observed on artificial reefs. This changed pattern of abundance may be due to fishing pressure and/or attraction to artificial reefs. We discuss the potential ecological effects of diminished abundance on natural reefs and increased abundance on artificial reefs.

Keywords: Artificial reefs, Endangered species, Epinephelidae, Reef fish, South Atlantic.

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O mero (*Epinephelus itajara*) forma agregações reprodutivas, cada uma com cerca de 100 indivíduos. No entanto, nenhum estudo foi realizado comparando essas agregações em ambientes naturais e artificiais. Neste artigo, determinamos padrões de abundância de agregação por meio de observações que fizemos entre 2007 e 2014 em três recifes naturais e quatro recifes artificiais no sul do Brasil, comparando avistamentos por unidade de esforço (APUE) entre esses recifes. A sua abundância difere significativamente entre recifes artificiais e naturais. Nenhuma agregação foi observada em recifes naturais, porém agregações de até 54 meros foram observadas em recifes artificiais. Esta mudança no padrão de abundância pode ser devida à pressão da pesca e/ou atração por recifes artificiais. Discutimos os potenciais efeitos ecológicos da diminuição da abundância nos recifes naturais e do aumento da abundância nos recifes artificiais.

Palavras-chave: Atlântico Sul, Epinephelidae, Espécies ameaçadas, Peixes recifais, Recifes artificiais.

## INTRODUCTION

Atlantic goliath grouper (AGG), *Epinephelus itajara* (Lichtenstein, 1822), is one of the largest Epinephelidae in the Atlantic Ocean, and are threatened throughout their range (Craig *et al*., 2009; Ferreira *et al*., 2011; Barreiros, Coleman, 2023) and classified as Vulnerable (Bertoncini *et al*., 2018). In Brazil, the species is considered Critically Endangered due to population decline caused by overfishing and habitat loss (ICMBio, 2018). Atlantic goliath grouper grows to 2.5 m and 300 kg (Bullock *et al*., 1992), feeding mostly on crabs, other crustaceans and slow-moving fishes (Koenig, Coleman, 2009; Freitas *et al*., 2015), and they play an important role shaping reef communities and modifying the environment where they occur (Koenig *et al*., 2011).

*Epinephelus itajara* spawning aggregations are relatively small, about 100 individuals (Koenig *et al*., 2011; Bueno *et al*., 2016) when compared with other species of Epinephelidae. In Brazil their spawning aggregations seem to be even smaller, hitting a maximum of ~50 individuals (Bueno *et al*., 2016). These aggregations occur on shallow (*e.g*., < 50 m) natural and artificial reefs (Ferreira *et al*., 2011) that are spatially and temporally consistent, presenting strong interannual fidelity to spawning sites (Koenig *et al*., 2011; Bueno *et al*., 2016).

Reef fish, like Atlantic goliath grouper, migrate to form annual spawning aggregations during specific periods of the year (Domeier, Colin, 1997; Sadovy, Eklund, 1999), showing variable consistency of site use (Mitcheson, Colin, 2011) and plausibly representing a learned reproductive strategy (Helfman, Schultz, 1983). That said, aggregations can be eliminated by fishing pressure (Aguilar-Perera, 2006) or shift from natural to artificial reefs (this study).

Some impacts on the marine environment have been attributed to artificial reefs (Brickhill *et al*., 2005). Impacting their surrounding natural environments as they modify a pre-existent ecosystem that may affect adjacent natural reefs, soft bottoms and pelagic ecosystems (physical, chemical or ecological) (Brickhill *et al*., 2005).

Artificial reefs may provide cues beyond the evolutionary experience of fishes and elicit responses that are not necessarily adaptive, such as shifting aggregation sites to areas that lack currents that would transport developing larvae to essential juvenile habitat. One of these impacts is the attraction of large reef fish by these structures as studied and discussed by many authors (Bohnsack, 1989; Bohnsack *et al*., 1997; Lindberg, 1997; Mann *et al*., 2009; Hackradt *et al*., 2011). There is clear evidence of the ecological impacts that artificial reefs have on natural reef communities, especially on reef fish (Osenberg *et al*., 2002; Paxton *et al*., 2020a; Medeiros *et al*., 2021).

Many human-made structures intended for other purposes attract fish, including piers and docks, oil and gas platforms, power generation constructions and anti-trawling devices. Others are intentionally deployed to aggregate fishes, including scuttled boats and ships, scrap metal, rocks and concrete structures, thus creating better opportunities for anglers. All of these structures apparently attract AGGs and their aggregations (Sadovy, Eklund, 1999; Bohnsack *et al*., 1999; Seaman, 2002; Koenig, Coleman, 2009; Koenig *et al*., 2011; Bueno *et al*., 2016). The use of artificial reefs along the Brazilian coast has increased in recent years, encouraging research on this subject (Simon *et al*., 2011). However, the behavioral and environmental effects of enhancement need to be further studied, especially for AGG (Simon *et al*., 2011; Bueno *et al*., 2016).

The aim of this study is to evaluate the relationship between the disappearance of known AGG aggregations from natural rocky reefs and the installation of artificial reefs in southern Brazil and discusses how this shift in site affects the rocky reef environments, the distribution and success of this species.

## MATERIAL AND METHODS

**Study area.** The study areas were located in southern Brazil coast (states of Paraná and Santa Catarina), between 25° and 27° S latitude in the Western Atlantic. The region has distinct seasonality with summer (late December through late March) being the warmest period. During this time, moderate east and northeast winds predominate, bringing warm (up to 28°C) clear waters from the east. The weather is more variable in the fall (late March through late June), and spring (late September through late December) with an increase in large eastern and southeastern swells and coincident decrease in underwater visibility. Winter (late June through late September) is characterized by cold fronts that bring large swells from the south and southeast, decreasing water temperature (18°C) and increasing turbidity in coastal waters (Bueno *et al*., 2016).

Seven reef complexes were selected as sampling sites (Fig. 1), three natural reefs, including Arquipélago das Graças (AG), Tamboretes (TA) and Laje dos Lobos outcrops (LL) and four artificial reefs, including Balsa Sul (BS), Balsa Norte (BN), Recifes Artificiais Marinhos (RAM), and Monobóia (MB). The longest distance between sites is from BN (state of Paraná) to LL (state of Santa Catarina) ~91 km, the closest sites are MB and AG ~11 km distance, both in the state of Santa Catarina.

The natural reef sites (AG, TA and LL), are rocky reefs, close to coastal islands with a maximum depth of 19 m and presenting similar structural complexity and variable relief. These reefs are located in the northern region of the state of Santa Catarina.

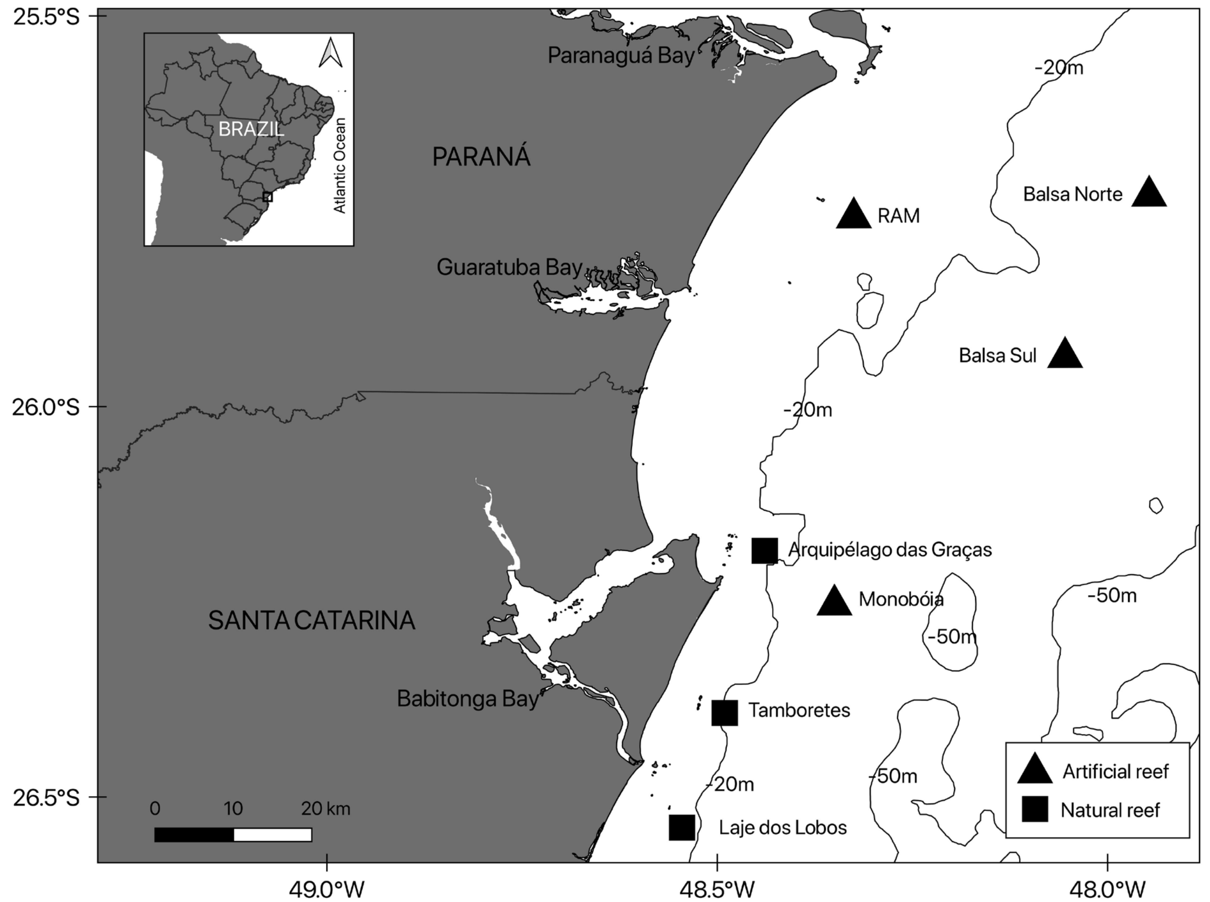


**FIGURE 1 |** Study areas in southern Brazil in the states of Paraná and Santa Catarina, between 25° and 27° S latitude in the Western Atlantic. Four artificial reefs Balsa Norte (BN), Recifes Artificiais Marinhos (RAM), Balsa Sul (BS), and Monobóia (MB). Three natural reefs: Arquipélago das Graças (AG), Tamboretes (TA), and Laje dos Lobos outcrops (LL).

The sites BS, BN and RAM are artificial reefs installed to encourage fishing tourism and discourage trawl fisheries. BS and BN are ~5 m high, ~75 m long, and ~11 m wide. These iron barges were intentionally sunk offshore on 21 January 2001, 27 m deep, over sandy bottom ~32 km from Pontal do Paraná, state of Paraná (Bueno *et al*., 2016).

The study site RAM is part of a large artificial reef program that includes ~ 40 reef areas ~12 km offshore formed by concrete blocks and reef balls ~1.5 m high (Fig. 2). For the present study two of those artificial reef areas were selected (sites: Parque dos Meros and RAM-G4). These two reefs are about 1.8 km apart and were considered a single site for abundance analyses (RAM), because of the great proximity and the registered easy movement of the AGG between these reefs. Both were sunk on 9 June 2000 at a depth of 18 m and in 2013 were included in the Currais Island National Marine Park, a marine protected area (Daros *et al*., 2012).

The MB site is an oil ship single point mooring buoy, installed 8 km offshore in 1977 at depth of ~24 m, composed by a vertical (bottom-surface) structure with many underwater structures such as pipelines, concrete, large anchors and chains, with approximately 300 m radius, off São Francisco do Sul, state of Santa Catarina (Bueno *et al*., 2016). These artificial sites offer large sheltering areas to AGG (Fig. 2).

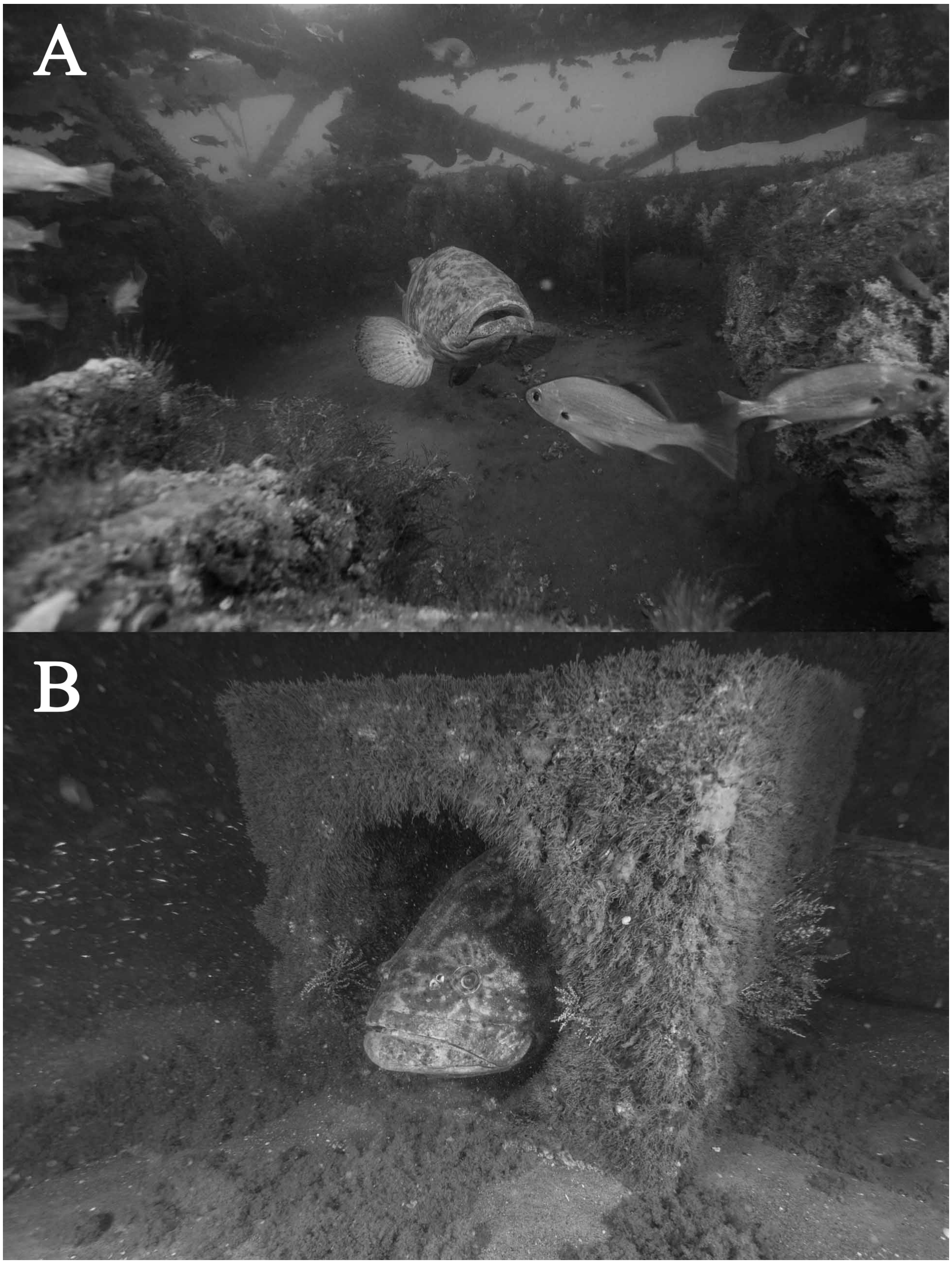


**FIGURE 2** | Atlantic goliath grouper *Epinephelus itajara* on artificial reefs in southern Brazil. **A.** Using the bottom structure under the Monobóia (MB); **B.** Seeking shelter in a quadrilateral-shape artificial reef on Recifes Artificiais Marinhos (RAM). Photos by Leonardo S. Bueno.

**Dive surveys.** Between October 2007 and March 2014, we conducted dive surveys on AGG at all seven study sites during each season, with higher frequency during austral summer, the known reproductive period (Bullock *et al*., 1992; Koenig, Coleman, 2009; Gerhardinger *et al*., 2009; Bueno *et al*., 2016; Koenig *et al*., 2017). Roving Diver Technique (RDT) (Jones, Thompson, 1978) were performed in which two scientific divers performed 30 min surveys whenever visibility was greater than three meters.

AGG with a total length greater than 100 cm are considered adults and suitable for reproduction (Bullock *et al*., 1992; Koenig *et al*., 2007; Bueno *et al*., 2016). Thus, to infer the reproductive period, all observed AGG had their total lengths estimated (Harvey *et al*., 2002) in two size classes (< 99 cm and > 100 cm). Natural reef locations chosen for RDT samples were obtained from local spearfishers taken on both aggregation and occurrence described sites (Gerhardinger *et al*., 2009) and artificial reefs were selected among well-known sites. On large artificial reefs RDT surveys were conducted over as much of the structure as practicable, but on shipwrecks (BS and BN) it was possible to survey all structures.

**Data analysis.** Diving surveys (RDT) were standardized as sightings-per-unit-effort (SPUE) (Equation: SPUE = N * (T/t); see Bueno *et al*., 2016). The unit of effort was 30 min, the approximate time of a survey. Where: SPUE = sightings per unit effort, N = number of AGG observed, T = duration in minutes of each survey and t = 30 min to standardize efforts.

To compare abundances between the seven sample areas and within areas (four artificial and three natural reefs) the non-parametric Kruskal-Wallis test was used. When significant differences ($p < 0.05$) were observed, the Mann-Whitney posteriori test was used (Sokal, Rohlf, 1995). Data were log (x+1) transformed prior to a hierarchical cluster analysis which was used to represent the average similarity (Bray-Curtis) among sampled sites. The consistency of visually defined clusters was tested through the analysis of similarity (ANOSIM).

## RESULTS

Three hundred and sixteen RDT surveys (160 on artificial reefs and 156 on natural reefs) distributed over the seven sites were performed, with approximately 192 total diving hours. The maximum SPUE was observed at MB with 54 AGGs, followed by RAM (32), BN (30), BS (10), TA (2), LL (2) and AG (1). The AGGs observed during RTD were considered adults, with estimated total length above 100 cm. Combined, natural reefs showed 11% frequency of occurrence of AGG, against 88% at artificial reefs with SPUE mean higher than 4 (Tab. 1).

The AGG abundance on artificial reefs was significantly ($p < 0.05$) higher than on natural reefs (Tab. 2). Maximum values of SPUE showed large differences, the artificial reefs being more abundant than the natural reefs group (Fig. 3). Except for MB and RAM in the artificial reefs group, no statistically significant differences ($p < 0.05$) were observed among the reef sites of each group. However, the groups were significantly different ($p < 0.05$) from one another (Tab. 2).

Comparing the abundances on natural and artificial reefs by seasons, AGG were more abundant in artificial reefs in all seasons. The artificial reefs had a higher abundance during spring and summer relative to fall and winter, whereas natural reef abundance remained low during all seasons (Fig. 4).

Comparing the abundance between natural and artificial reefs among years, there was low variance in the natural reefs abundance, never being higher than two AGG. On the artificial reefs some variation in abundance was observed, with the higher values being observed in 2011 and 2013. At artificial reef sites the mean abundance was always higher than 7 AGG for all years (Fig. 5). Cluster analysis resulted in the formation of two groups (Fig. 6), the artificial group and the natural group with the artificial reef group significantly different from the natural reefs (ANOSIM, R = 1, p = 0.029).

**TABLE 1** | Sightings-per-unit-effort SPUE for Atlantic goliath grouper *Epinephelus itajara* on artificial reefs: Monobóia (MB), Recifes Artificiais Marinhos (RAM), Balsa Norte (BN), and Balsa Sul (BS), and natural reefs: Tamboretes (TA), Arquipélago das Graças (AG), and Laje dos Lobos (LL), in southern Brazil. Samples (spring/summer/fall/winter in brackets, respectively) number of dive surveys; Max, maximum abundance of Atlantic Goliath Grouper; Mean, mean abundance; SD, standard deviation; frequency of occurrence (%); unit effort = 30 min survey.

| Sites/Reef type | Samples | Max | Mean | SD (±) | % |
|---|---|---|---|---|---|
| **Artificial reefs** | | | | | |
| MB | 52 [19/27/02/04] | 54 | 12.55 | 0.88 | 96 |
| RAM | 62 [05/34/19/04] | 32 | 7.73 | 10.18 | 74 |
| BN | 30 [01/18/08/03] | 30 | 4.73 | 5.07 | 100 |
| BS | 16 [02/06/06/02] | 10 | 4.09 | 3.21 | 63 |
| Sub-total | 160 [27/85/37/13] | 54 | 8.37 | 9.67 | 88 |
| **Natural reefs** | | | | | |
| TA | 65 [14/28/19/04] | 2 | 0.26 | 0.60 | 22 |
| AG | 40 [09/16/13/02] | 1 | 0.02 | 0.14 | 3 |
| LL | 51 [14/07/26/04] | 2 | 0.06 | 0.32 | 4 |
| Sub-total | 156 [37/51/58/10] | 2 | 0.14 | 0.45 | 11 |
| **Total** | **316 [64/136/95/23]** | **54** | **4.54** | **8.25** | **64** |

**TABLE 2** | Multiple comparison using data on Atlantic goliath grouper *Epinephelus itajara* abundance presenting p-value for the studied sites: Monobóia (MB); Recifes Artificiais Marinhos (RAM); Balsa Norte (BN); Balsa Sul (BS); Tamboretes (TA); Arquipélago das Graças (AG); Laje dos Lobos (LL). Sites are distributed according to reef types artificial or natural. Kruskal-Wallis test: H (6, N = 316) = 206.2508; p = 0.000 (*Significant values).

| Groups | Sites | MB | RAM | BN | BS | TA | AG | LL |
|---|---|---|---|---|---|---|---|---|
| Artificial | MB | | 0.0091* | 1.0000 | 1.0000 | < 0.001* | < 0.001* | < 0.001* |
| | RAM | 0.0091* | | 1.0000 | 1.0000 | < 0.001* | < 0.001* | < 0.001* |
| | BN | 1.0000 | 1.0000 | | 1.0000 | < 0.001* | < 0.001* | < 0.001* |
| | BS | 1.0000 | 1.0000 | 1.0000 | | 0.0023* | 0.0003* | 0.0002* |
| Natural | TA | < 0.001* | < 0.001* | < 0.001* | 0.0023* | | 1.0000 | 1.0000 |
| | AG | < 0.001* | < 0.001* | < 0.001* | 0.0003* | 1.0000 | | 1.0000 |
| | LL | < 0.001* | < 0.001* | < 0.001* | 0.0002* | 1.0000 | 1.0000 | |

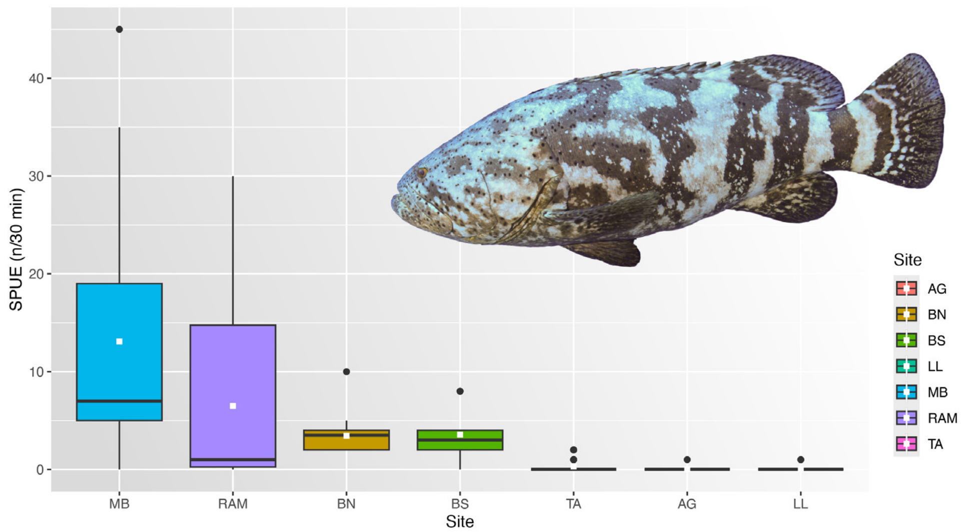


**FIGURE 3** | Boxplots of Atlantic goliath grouper *Epinephelus itajara* abundances by sampled sites: Artificial reefs (Monobóia (MB), N = 52; Recifes Artificiais Marinhos (RAM), N = 62; Balsa Norte (BN), N = 30; Balsa Sul (BS), N = 16) and natural rock reefs (Tamboretes (TA), N = 65; Arquipélago das Graças (AG), N = 40; Laje dos Lobos (LL), N = 51) in southern Brazil. RDT data pooled from 2007 to 2014. Black dots = outliers, horizontal line in box = median, white box = mean values.

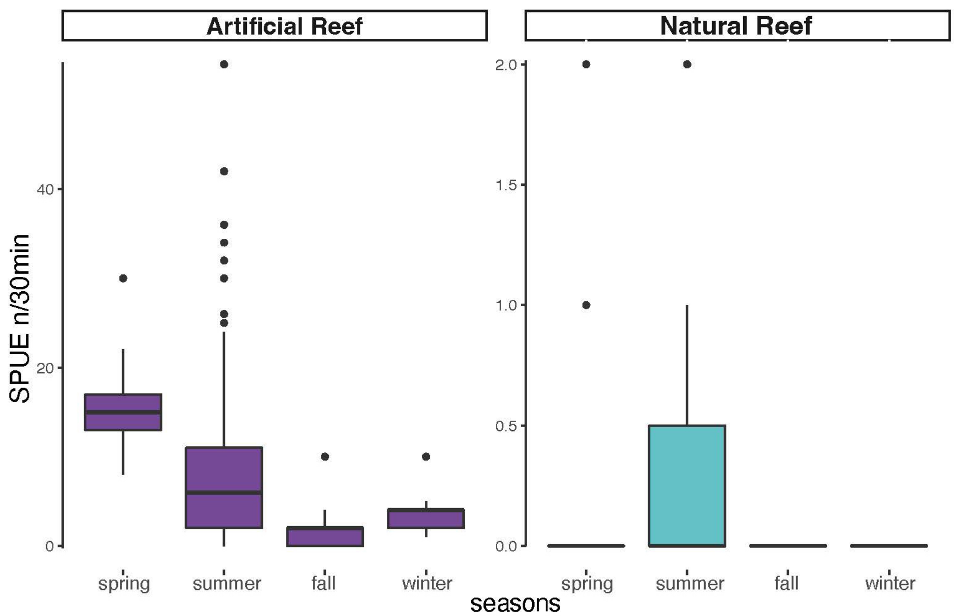


**FIGURE 4** | Boxplots of Atlantic goliath grouper *Epinephelus itajara* abundances by season in all sampled sites in southern Brazil divided into artificial reef group in purple (Monobóia, RAM, Balsa Norte, and Balsa Sul) (Spring N = 27; Summer N = 85; Fall N = 35; Winter N = 13) and natural reef group in teal (Tamboretes, Arquipélago das Graças, and Laje dos Lobos) (Spring N = 37; Summer N = 51; Fall N = 58; Winter N = 10), pooled years 2007 to 2014. Black dots = outliers, horizontal line in box = median.

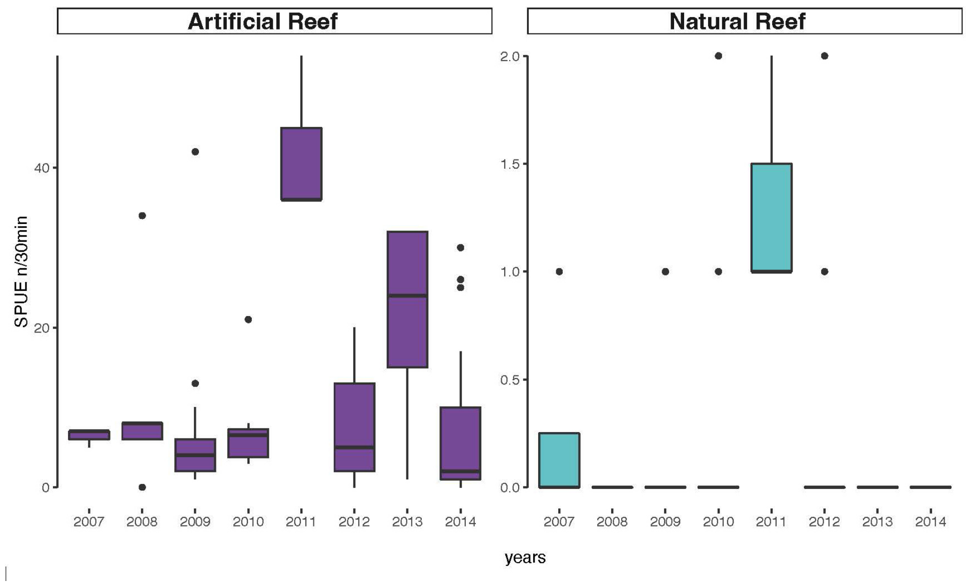


**FIGURE 5** | Boxplots of Atlantic goliath grouper *Epinephelus itajara* abundances in southern Brazil from 2007–2014 in all sampled sites divided into artificial reefs in purple (Monobóia, Recifes Artificiais Marinhos, Balsa Norte, and Balsa Sul) and natural reefs in teal (Tamboretes, Arquipélago das Graças, and Laje dos Lobos). Black dots = outliers, horizontal line in box = median.


**FIGURE 6** | Atlantic goliath grouper *Epinephelus itajara* abundance on southern Brazil study sites displayed in a similarity cluster diagram. Balsa Norte (BN); Balsa Sul (BS); Monobóia (MB); Recifes Artificiais Marinhos (RAM); Tamboretes (TA); Arquipélago das Graças (AG); Laje dos Lobos (LL). Triangles (▲) represent artificial reefs and diamonds (♦) represent natural reefs. Horizontal line defined at 67 % of similarity.

## DISCUSSION

This study showed that Atlantic goliath grouper no longer occurred on previously known spawning aggregation sites in southern Brazil, apparently preferring regional artificial reefs over the natural reefs. The apparent preference for artificial reefs may be the result of increased habitat relief and complexity and therefore refuge availability where structurally comparable natural habitats are rare (Fig. 2) (Coleman *et al*., 2010; Collins *et al*., 2015). Their greater abundance on artificial reefs was observed during spring and summer, coinciding with the reproductive period of this species in the studied region (Felix-Hackardt, Hackradt, 2008; Bueno *et al*., 2016). Similar patterns were observed by other researchers operating in other parts of their range (Bullock *et al*., 1992; Colin, 1994; Eklund, Schull, 2001; Sala *et al*., 2003; Koenig, Coleman, 2009; Collins *et al*., 2015), whereas their low abundance on natural reefs could result from direct heavy fishing pressure, which would diminish their abundance and possibly reduced their food resources. Reports from fishers in the same region indicating the same (Gerhardinger *et al*., 2006, 2009).

Considering the great number of artificial reefs deployed near the study sites, it is likely that AGG temporarily uses natural reefs while migrating from their resident reefs to staging areas (Nemeth, 2012). The flux of significant fish biomass from feeding grounds to aggregation sites to reproduce provides an important and largely overlooked ecological component of connectivity within marine ecosystems that alters habitat use, interspecific interactions, and energy transfer resulting from feeding and defecation (Nemeth, 2012). Although little information exists on predator-prey dynamics at aggregation sites, it is known that the AGG feeds at aggregation sites and probably along migratory pathways (Koenig, Coleman, 2009).

According to the local fishers, the natural reefs around AG, TA and LL were historically known as AGG spawning aggregation sites, with more than 60 AGG being seen on one site in a single day. LL was the site with the highest abundance of AGG (> 60) followed by TA (~15), and AG (~5) (Gerhardinger *et al*., 2009). Our surveys on these sites (LL, TA and AG) showed much lower abundance (highest SPUE; TA, 2; LL, 2 and AG, 1) and low frequency of occurrence (TA, 22%; LL, 4% and AG, 3%) even during the reproductive period (spring and summer). Such abundances suggest there is no longer a formation of spawning aggregations.

Experienced spearfishers have reported never observing more than 2 AGGs on any natural reef studied (LSB, pers. obs.). Also, no AGG were sighted on natural reefs close to site RAM in a reef fish study conducted from October 2008 to August 2009 (Daros *et al*., 2012). Similar results are found, while performing a checklist of the fishes of LL and nearby natural reef sites in 2006 (Adelir-Alves, Pinheiro, 2011). Studies with reef fish in the Currais Archipelago, Itacolumis Islands, Graças Archipelago and in the Tamboretes Archipelago, conducted between 2007 and 2010, also had similar results (Adelir-Alves *et al*., 2018; Daros *et al*., 2018). This suggests that the use of natural environments by AGG decreased concomitant with the increased deployment of artificial reefs at the end of 1999 and beginning of 2000.

The observed patterns of AGG aggregations, shifting from natural to artificial reefs suggests a significant behavioral change for these fishes in southern Brazil. So far, empirical research focusing on how climate change influences fish reproduction is limited but studies on Caribbean fishes have suggested a series of impacts on fish aggregations, from reduced habitat availability including suitable ocean spawning habitats (Gokturk *et al*., 2022) and increased fishing vulnerability, to range shifts correlated with temperature sensitivity (Fodrie *et al*., 2010; Maharaj *et al*., 2018). Such phenology appraisal (Gokturk *et al*., 2022) should be considered in future studies of AGG, given that the changes we have observed (aggregation shifts from natural to artificial reefs) may have ecological impacts on natural areas, precipitating the loss of an important reef predator and its significant seasonal energy contribution through spawning events. Having a large population of spawning adults can significantly modify food webs as their massive egg output can attract a wide variety of pelagic predators attempting to take advantage of this temporary and predictable food source (Nemeth, 2012).

Atlantic goliath groupers have a positive effect on the biodiversity and abundance of associated reef fishes based in large part on their excavating behavior (Koenig *et al*., 2011), similar to red grouper *Epinephelus morio*, which results in a positive influence on species richness at a local scale (Coleman *et al*., 2010). The excavations increase habitat complexity on reefs buried by sediment suspended by storms thereby increasing habitat complexity making additional structure available for other species (Coleman, Koenig, 2010). Reproductive aggregation events of reef fish, especially large species such as AGG, bring several ecological benefits to the marine ecosystem (*e.g*., nutrients), attracting several species (Mitcheson, Colin, 2011). Artificial reefs affect the distribution of ichthyofauna, attracting reef fishes that originally would stay on natural reefs (Osenberg *et al*., 2002). Also, large predatory fishes apparently abandon natural reefs in favor of artificial reefs which can alter ecological processes such as competition and predation (Simon *et al*., 2011) and perhaps reproductive success. Such changes alter the ecological stability of the ecosystem, consequently lowering resilience and resistance to invasions by exotics species relative to unaltered ecosystems (Stallings, 2009).

Crustaceans and slow-moving fishes constitute the primary food of the AGG (Koenig, Coleman, 2009; Freitas *et al*., 2015), and the low abundance of these animals combined with the high rugosity of natural reefs hampers the access to prey. The attraction of snappers and groupers to artificial reefs is related to a high prey concentration and lower energy cost for encountering food on artificial reefs (Simon *et al*., 2011).

Artificial reefs may not represent the solution or the ideal tool to increase fishing production (Bohnsack *et al*., 1999; Osenberg *et al*., 2002; Paxton *et al*., 2020b). Rather, they may simply affect distribution by artificial attracting fish from natural reefs and concentrating them upon artificial ones, making them more available to fishing, as we often see fishers at our artificial study sites. The availability of artificial reefs appears to modify AGG habitat choice (and therefore, distribution) either by providing additional resources that allow to support greater numbers of individuals overall or by simply aggregating individuals into greater densities than would be expected under natural conditions (Koenig, Coleman, 2009; Coleman, Koenig, 2010; Collins *et al*., 2015). If true, then resources currently spent on artificial reef programs may be misdirected, if not harmful, to natural reef systems (Osenberg *et al*., 2002).

Artificial reefs with good planning and effective protection, a remote goal in Brazil, may improve reproductive success in some species such as the AGG, but still remove this fish from natural reefs. If the nursery and growth (bottleneck) from the population occur in non-reef habitats, artificial reefs are unlikely to increase abundance or biomass of the species (Bohnsack, 1989), even if they spawn at these reefs. However, most of the studied artificial reefs do not have any laws or regulations to protect these species against fishing, and in those that have, enforcement is very poor. Unplanned installation of artificial reefs without enforcement or management can result in negative impacts on species that are attracted or that are spawning in the nearby areas. Groupers (Epinephelidae) and snappers (Lutjanidae) are two main fish families targeted by fishers in Brazil and therefore more affected by this problem.

In 2020, the Brazilian Energy Research Company (a governmental institution) reported the potential to generate 700 GW along the Brazilian coast, with offshore wind farms installed in areas up to 50m depth (IBAMA, 2022). To date, in spite of the many uncertainties regarding impacts (in land and offshore), the Brazilian government intends to carry on the licensing process, starting in 2023, of 70 projects along the coast (IBAMA, 2022), totaling 12,059 offshore wind turbines. As we are about to face such a huge deployment of artificial structures in the near future, and knowing a myriad of the impacts that will come along (Vasconcellos, Couto, 2021; Galparsoro *et al*., 2022; Lloret *et al*., 2022), offshore wind farms turbine structures will pose a new challenge in protecting and monitoring reef fish aggregations along these artificial reefs.

To better understand the dynamics and processes in the marine environment affected by artificial reefs, long-term monitoring and benthic habitat mapping are necessary (Simon *et al*., 2011). We do recommend the addition of new techniques such as passive-acoustic telemetry to monitor movement patterns, bioacoustics monitoring to identify specific behaviors and the expansion of the spearfisher collaboration network through participatory research and citizen science programs.

These findings provide evidence that artificial reefs support large fish predators, such as the Atlantic goliath grouper, highlighting the need to strengthen the protection of this endangered reef fish during the reproductive aggregations that occur mainly on artificial reefs in southern Brazil.

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## ETHICAL STATEMENT

This work activity was authorized through licenses issued by the Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio): SISBIO 15080–2 and SISBIO 31719–1.

## DATA AVAILABILITY STATEMENT

The data supporting the findings of this study are available from the corresponding author, upon reasonable request.

## COMPETING INTERESTS

The authors declare no competing interests.

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