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Unusual high coral cover in a Southwestern Atlantic subtropical reef

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Abstract

Subtropical Brazilian reefs are commonly composed by rocky frameworks with low coral abundance. Contrarily to most tropical reefs, our knowledge on coral assemblages in subtropical reefs is still developing. Queimada Grande is a subtropical island in the Brazilian coast lying 35 km offshore from the state of São Paulo (24ºS). Despite the partial protection bestowed to this island, recreational fishing and scuba diving are considered important pressures on this ecosystem. We used photo-quadrats to quantify the abundance of two dominant reef-building corals, *Madracis decactis* (Lyman, 1859) and the Brazilian endemic *Mussismilia hispida* (Verrill, 1902), on rocky reefs and in a previously unreported coral bank. The abundance of *M. decactis* and *M. hispida* accounted for 40–60% of the benthic cover, with the dominance of *M. decactis* in the coral bank and *M. hispida* in the rocky reefs. The coral cover at Queimada Grande Island is comparable to those in Brazilian tropical reefs and higher than those reported in corallith beds further south in Brazil, thus representing the southernmost reef with such high coral abundance in the Western Atlantic. Our study demonstrates the high tolerance of *M. decactis* and *M. hispida* and highlights this coral assemblage as a potential conservation hotspot. This is particularly important in the context of tropicalization, since subtropical areas might sustain great coralline communities in warmer scenarios driven by climate change.

Keywords Coral reef · Rocky reef · Scleractinia · Marginal · Brazil

Introduction

Reef ecosystems are one of the most diverse environments on Earth, commonly known to flourish in tropical areas (Spalding et al. 2001). Although the development of coral reefs and, thus, the production of a biogenic carbonate framework can be limited by abiotic factors such as temperature and light penetration, coral communities still thrive in a range of environmental settings (Kleypas et al. 1999; Perry and Larcombe 2003). In high latitude locations, scleractinian zooxanthelate coral assemblages typically establish over abiogenic structures, such as boulders in rocky reefs (Beger et al. 2014) and, in particular cases, can reach similar or even greater covers in comparison to biogenic coral reefs (Thomson and Frisch 2010; Denis et al. 2013). Due to the presence of corals in alternative environments, these ecosystems are considered marginal but could be potential refugia in future climate change scenarios (Camp et al. 2018; Mies et al. 2020).

Most Southwestern Atlantic shallow-water reefs occur throughout the Brazilian coast which comprises the only coral reefs in this region (Leão et al. 2003). Along more than 7000 km of coastline in Brazil, biogenic reefs are typically distributed from northern (3ºN) to eastern Brazil (19ºS), together with sandstone reefs in the northeastern (5ºS-10ºS; Leão et al. 2003; Moura et al. 2016). Rocky reefs prevail in southern Brazil (20ºS to 28ºS; Floeter et al. 2006) in addition to a sparse corallith bed recorded in the state of Santa Catarina at 27°S, which represents the southernmost

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limit of distribution of tropical corals (Capel et al., 2012). Brazilian reefs have high sedimentation rates and turbidity, low coral diversity with dominance of massive forms, and high endemism (~ 30%; Leão et al. 2003). Moreover, Brazilian corals tolerate environmental conditions common to these marginal environments (Leão et al. 2003; Banha et al. 2019), for example, by enhancing heterotrophic feeding (Mies et al. 2018). As Southwestern Atlantic reef formations and their distribution were not fully explored, new reefs keep being discovered and characterized (e.g., Moura et al. 2016; Mazzei et al. 2017; Pereira-Filho et al. 2019).

Subtropical Brazilian reefs have been described by extremely low coral cover (~ 2–10%; Leão et al. 2003; Aued et al. 2018), but areas with relevant coral occurrence or cover have been characterized recently in this region (Banha et al. 2019; Pereira-Filho et al. 2019). Most of these records are in the state of São Paulo (24ºS) where rocky shores occupy more than two-thirds of the state's coastline and the more than 50 coastal islands and islets of the state (Ministério do Meio Ambiente 2010). Until 2018, the southern latitudinal distribution of biogenic reefs in the Western Atlantic was known to be restricted to the Abrolhos Bank (19º30′S; Moura et al. 2013; Mazzei et al. 2017). Nevertheless, a recently described reef in subtropical Brazil built mostly by skeletons of the coral *Madracis decactis* has expanded the southern limit of biogenic reefs in the Atlantic Ocean to 24°S (Pereira-Filho et al. 2019). This newly described reef differs from the corallith bed described in South Brazil (27°S; Capel et al. 2012) not only for being larger but because it forms a biogenic framework that coralliths do not (Pereira-Filho et al. 2019). Therefore, subtropical environments are potential habitats for unassessed abundant coral assemblages, including high-latitude coral reefs and non-reef building coral communities (Beger et al. 2014). This is particularly important in the context of tropicalization, since these zones are likely to get more suitable for corals to thrive in future scenarios driven by climate change (Vergés et al. 2014).

In addition, coastal islands are valuable sites for conservation and targeted areas for tourism and recreation. Because of the proximity to the coast, these areas are explored by many recreational activities such as nautical tourism, scuba diving, and fishing (Ghermandi and Nunes 2013; Freire et al. 2016). Nevertheless, the usually complex context from multiple interests and intense use turn the effective management of these areas challenging. Poor management may contribute to negative environmental impacts, affecting the marine biota and ecosystem's services, which might impoverish future leisure experiences and influence the local economy (Tratalos and Austin 2001; Coleman et al. 2004; Marconi et al. 2020). Queimada Grande Island, located in the state of São Paulo, subtropical Brazil (~ 24°S), is within a marine partially protected area (MPA; Centre Coastal Marine Environmental Protection Area). Due to its marine diversity, this MPA is considered an important conservation site, and the area suffers high pressure from recreational fishing and scuba diving industry (Fundação Florestal 2019). Apart from studies in a newly coral reef described in the area (Pereira-Filho et al. 2019), coral assemblages in the surrounding rocky reefs have not been assessed. We characterized the benthic community in four sites around Queimada Grande Island and found the southernmost highest coral cover reported in Western Atlantic subtropical reefs, and a previously unknown coral bank similar to the one reported by Pereira-Filho et al. (2019). More specifically, we describe the occurrence and abundance of two dominant zooxanthellate scleractinian coral species, *Madracis decactis* (Lyman, 1859) and the endemic *Mussismilia hispida* (Verrill, 1902), which occur in the rocky reefs and in a coral bank around Queimada Grande Island. We also provide basic benthic cover information that could aid the management of this MPA and serve as a baseline for future coral monitoring programs.

Materials and methods

Study area

Queimada Grande Island (24º29′17″S, 46º40′32″W) is located approximately 35 km off the coast of southeastern Brazil (Fig. 1). The elongate island has a north–south orientation and the western coast is protected from prevailing winds and waves that arrive from the east, south, and southeast directions. The average sea surface temperature ranges from 21.2ºC in the winter (June to September) to 26.6ºC in the summer (December to March; Simons 2020).

Despite the protection status around Queimada Grande Island, marine activities in the area are poorly regulated and the surrounding reefs are used for recreational scuba diving due to the great water transparency and presence of two shipwrecks on the leeward side (Marconi et al. 2020). Other common uses are nautical tourism and recreational spearfishing, including hook and line fishing.

Sampling sites and data collection

We sampled the coral community during the austral summer of 2020 using 25×25 cm (625 cm^2) photoquadrats in four sites around the Queimada Grande Island (Fig. 1): two on the windward (eastern) side, in the areas known as Enseada (site 1) and Paredão Exposto (site 2), and two on the leeward (western) side, in the areas Entre Naufrágios (site 3) and Bananal (site 4). These sites were selected based on their high live coral cover, and in each site we conducted three to four 25-m long transects along which
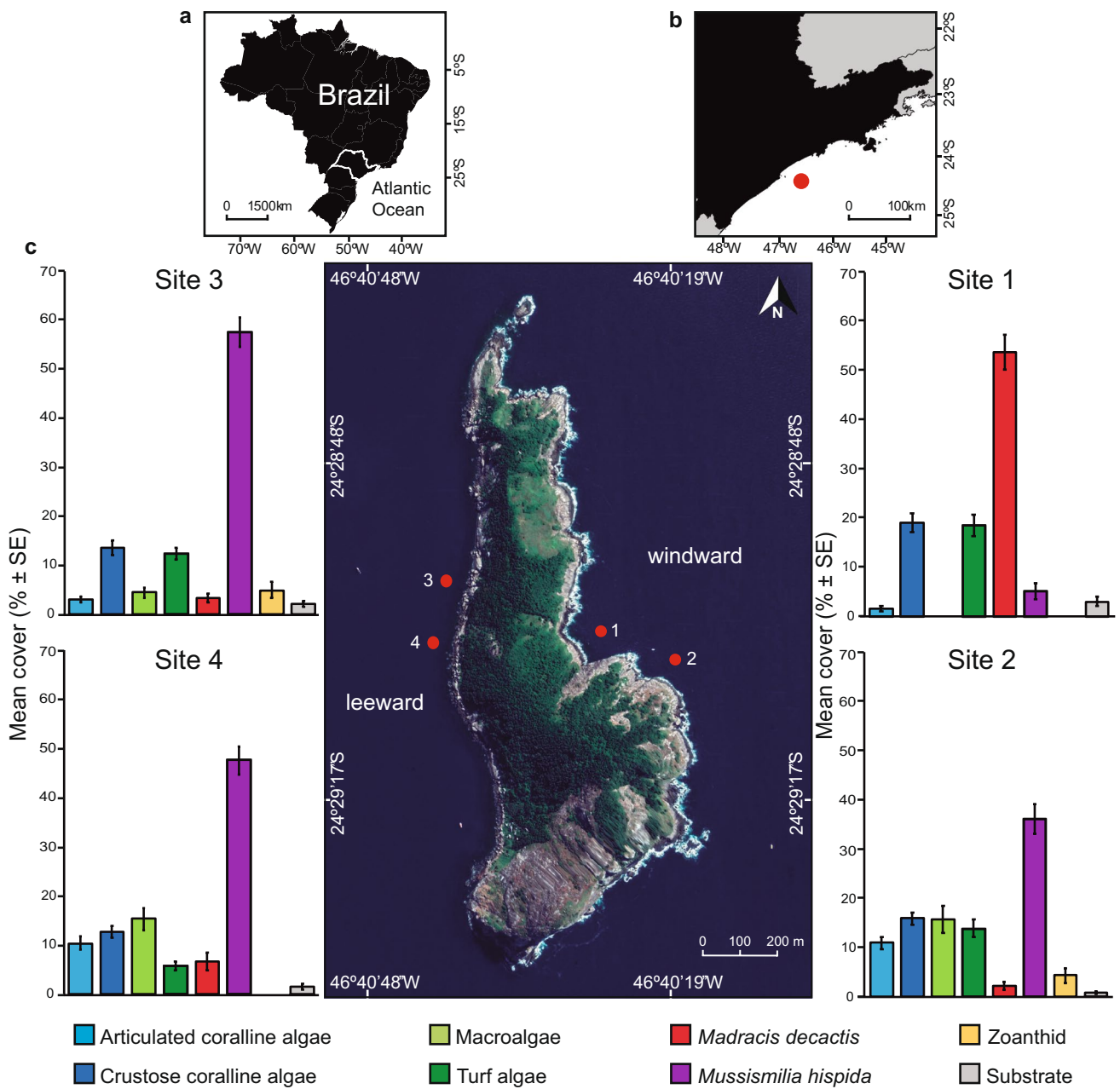
Fig. 1 Queimada Grande Island in Southwestern Atlantic **a, b** location of Queimada Grande Island in the state of São Paulo, southeastern Brazil; **c** sampling sites on the windward (1, 2) and leeward (3, 4) side of the island, and benthic cover (mean ± SE) of each category of organisms in the four study sites. Site 1 corresponds to a coral bank and sites 2, 3, and 4 to rocky reefs. Images: Instituto Brasileiro de Geografia e Estatística, Landsat 8 satellite

we took 20 photoquadrats per transect. Site 1 corresponds to a coral bank dominated by living colonies of the coral *M. decactis* on its top and built by skeletons of the same species, which can be visually identified in naturally occurring cross-sections of the reef. This is further supported by a recent study that characterized a similar coral reef around the same island (see Pereira-Filho et al. 2021).

Sites 2, 3, and 4 correspond to rocky reefs that sustain coral assemblages over the rocky framework.

In the first windward site (Fig. 1), we took photoquadrats along three parallel transects (13–17 m deep) within the coral bank area, totaling 60 photoquadrats. We also measured the perimeter of the bank using measuring tapes and calculated the area of the polygon. In the three remaining

rocky reef sites, we took photoquadrats along four transects adjacent to the coastline (10–15 m deep), totalizing 80 photoquadrats per site. Sampling sites were also visually characterized in terms of substrate structural complexity (modified from Roos et al. 2019), classified in one out of four categories considering the quantity of crevices and refuges: none, low, medium, and high.

Data analysis

We quantified the relative abundance of live corals for each site through the analysis of percent benthic cover in each site using the software photoQuad v1.4 (Trygonis and Sini 2012). Although the number of points needed to estimate benthic covers depend on the local community (Pante and Dustan 2012), we based our methodology on the study by Pereira-Filho et al. (2019) conducted in the same area, using 25 random points over each image. We identified the organism immediately under each point according to the following categories: articulated coralline algae (ACA), crustose coralline algae (CCA), macroalgae (including, for example, *Dictyota* spp., *Padina* spp., *Sargassum* spp., and *Canistrocarpus cervicornis*), turf algae (multispecific assemblage of short algae, < 2.5 cm, including red, green, and brown algae, usually filamentous, cyanobacteria, and trapped sediment; Lang et al. 2010), sponges, zoantharians (*Palythoa caribaeorum*, *P. grandiflora*, and *Zoanthus* spp.), scleractinian corals (*Madracis decactis* and *Mussismilia hispida*) and substrate (sand and gravel). Although it was possible to identify dead *M. decactis* skeletons covered by CCA or turf algae in some images, this was not consistent for all the images, so we recorded the overgrowing organism instead in the photoquadrats analyses.

To analyze the differences in percent cover of each benthic category (response variable) between the two sides of the island (leeward and windward, independent variables; with sites nested within sides), we fitted permutation ANOVA tests. We also performed a non-metric multidimensional scaling (nMDS) to graphically represent spatial similarities (Bray–Curtis) on the benthic community among sampling sites. A separate one-way analysis of similarity (ANOSIM) was used to test for differences among sites, and a similarity percentage analysis (SIMPER) was used to determine the contribution from the categories of organisms to the dissimilarities observed. Statistical tests were run using R software (R Core Team 2018, v. 1.3.1093).

Results

Live coral cover varied from ~ 40–60% in the four sites sampled at Queimada Grande Island (Fig. 1c; Supplementary Online Resource). The abundance of ACA, macroalgae,

and the coral *M. decactis* differed between the leeward and windward sides of the island (permutation ANOVA test, $p < 0.001$; Supplementary Online Resource). Regarding the sampling sites, the abundance of all categories of benthic organisms differed, except for CCA and zoanthids (Fig. 1c). The coral bank (site 1) was dominated by *M. decactis* which represented more than 50% of live benthic cover ($53 \pm 3\%$; mean $\pm$ SE), contrasting with < 7% cover in the remaining rocky reef sites (site 2: $2 \pm 0.8\%$; site 3: $3 \pm 1\%$; site 4: $7 \pm 2\%$; permutation ANOVA test, $p < 0.001$). In contrast, live cover of *M. hispida* was higher on rocky reefs (site 2: $36 \pm 3\%$; site 3: $57 \pm 3\%$; site 4: $47 \pm 3\%$) in comparison to the coral bank (site 1: $5 \pm 2\%$; permutation ANOVA test, $p < 0.001$). During this assessment, we did not observe any diseased or bleached coral colonies.

We found a significant difference on the benthic communities' composition among the sampling sites (ANOSIM: $R = 0.7336$, $p = 0.0001$; Fig. 2), with site 1 and sites 2, 3, and 4 having a dissimilarity between 61%-67% among them (SIMPER analysis; Table 1). This dissimilarity was mainly explained by the abundance of the corals *M. decactis* and *M. hispida*, which contributed to 67% of the dissimilarity between site 1 and site 2, 80% between site 1 and site 3, and 66% between site 1 and site 4.

We characterized different reef habitats, with site 1 being a living coral bank constructed and dominated by *M. decactis* (Fig. 3a), followed by CCA, which were often found overgrowing *M. decactis* skeletons, and turf algae. This bank extends from 11 to 18 m deep in a plateau area of approximately 500 m^2, presenting a low structural complexity on the top. The remaining sites are rocky reefs with numerous
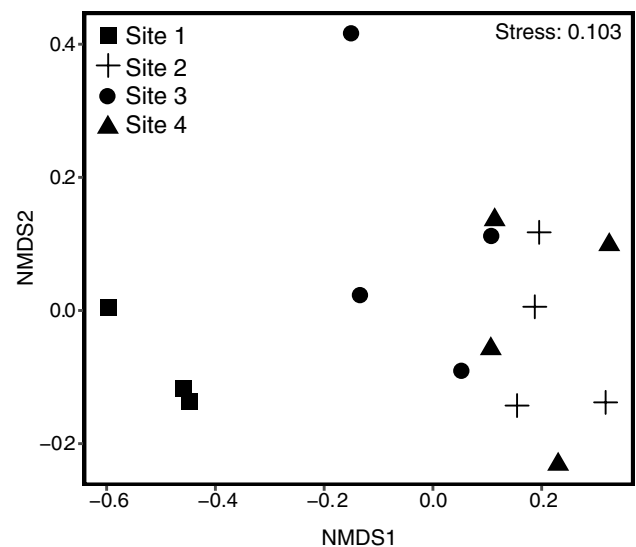

Fig. 2 Non-metric multidimensional scaling (nMDS) on the composition of the benthic community at the four sites sampled in Queimada Grande Island

Table 1 Overall dissimilarity (%) between benthic communities of the sites sampled in Queimada Grande Island based on SIMPER analysis

	Site 1 Coral bank	Site 2 Rocky reef	Site 3 Rocky reef
Site 2 Rocky reef	61.05%	-	-
Site 3 Rocky reef	63.85%	31.33%	-
Site 4 Rocky reef	67.03%	23.81%	27.13%

coral colonies, mostly of *M. hispida*, occurring over the rocky framework fringing the island at depths from 10 to 15 m (Fig. 3b) with a high substrate structural complexity. We also identified several colonies of the invasive cup corals *Tubastraea* spp. on a windward vertical boulder, about 100 m distant from the coral bank (site 1).

Discussion

Coral assemblages located at higher latitudes often deal with environmental conditions that would constrain the biological development of most tropical corals (Perry and Larcombe 2003). Brazilian subtropical reefs, for instance, are typically composed by rocky substrates with low coral abundance (Leão et al. 2016; Aued et al. 2018). Contradicting typical expectations of low coral cover, we recorded the southernmost highest coral cover in the Western Atlantic, in Queimada Grande Island, southeastern Brazil. Here, hermatypic coral cover ranges between 40 and 60%, which is higher than the cover described in a corallith bed at 27°S (Capel et al. 2012), and comparable or even higher than the coral cover reported in Brazilian tropical reefs (Aued et al. 2018; Teixeira et al. 2021). The corallith bed in South Brazil comprise small colonies, up to 15 cm in maximum width, occurring at a maximum of 80 coralliths/m^2 of variable sizes (Capel et al. 2012), while coral cover in Brazilian tropical reefs usually varies between 5 and 40% (Aued et al. 2018; Teixeira et al. 2021). We also documented the dominance of *M. hispida* in the rocky reefs and an undescribed bank of the coral *M. decactis*, similar to a biogenic reef previously reported at an adjacent area (Pereira-Filho et al. 2019; 2021).

Both coral species are widely distributed along the Brazilian coast and its oceanic islands, with *M. hispida* occurring from northern from Parcel do Manuel Luiz (0° latitude; Cordeiro et al. 2015) to São Paulo (24°S) and *M. decactis* from the Amazon Reefs (3°N; Moura et al. 2016) to Santa Catarina (27°S; Castro and Pires 2001; Leão et al. 2003) in Brazil but also occurring in the Caribbean and

Florida in the USA (Jaap et al. 1989; Vermeij and Bak 2003). The coral *M. decactis* is a nodular hermaphrodite and brooder species found in a variety of habitats, from shallow to more than 100 m deep areas (Moura et al. 2016), and from shadowed vertical substrates to lightened zones (Neves and Johnsson 2009), either in attached or free-living forms (Capel et al. 2012; Hoeksema et al. 2018). By having the widest distribution in the Western Atlantic, *M. decactis* demonstrates its great plasticity, dispersal ability, and tolerance to variable abiotic factors. The endemic and massive *M. hispida* is a hermaphrodite broadcast spawner (Neves and Pires 2002) resistant to high sedimentation rates (Leão et al. 2003; Segal and Castro 2011). Its high capacity to shift between autotrophic and heterotrophic modes of nutrition can help explain its wide distribution and abundance in higher latitude locations (Mies et al. 2018).

Some studies have also recorded a high coral cover in rocky reefs of the state of Rio de Janeiro (22°S), north from our study site in southeastern Brazil. The Cabo Frio region (22°35′–23°S), for instance, harbors coral assemblages on its rocky reefs comparable to tropical environments due to its hydrodynamic regime and high-nutrient upwelling waters (Ferreira et al. 2001). At Armação dos Búzios (22°44′S, 41°52′W), scleractinian cover has been recorded to reach 46% for the endemic species *Siderastrea stellata* and 7% for *M. hispida* (Oigman-Pszczol and Creed 2004); and at Arraial do Cabo (23°S, 42°W) the highest coral cover values can reach 12% for *S. stellata* (Lima and Coutinho 2016) but only 1% for *M. hispida* (Ferreira et al. 2001; Rogers et al. 2014). In contrast, previous coral cover assessments in subtropical rocky reefs of São Paulo, which is south from Rio de Janeiro, have recorded between 5 and 10% cover of *M. hispida* (Pereira 2007; Aued et al. 2018). Moreover, our results point to coral covers similar and sometimes greater than those of the largest reef complex in the South Atlantic (17°45′S, 39°0′W; Teixeira et al. 2021). This adds evidence that subtropical rocky reefs can sustain hermatypic coral assemblages as abundant as in tropical biogenic reefs and highlight this area as a conservation hotspot in the Southwestern Atlantic.

The southernmost Brazilian reef built by corals has been recently described in Queimada Grande Island as a senescent structure, older than 6,000 years, constructed by skeletons of *M. decactis* (Pereira-Filho et al. 2019; 2021). This 75,000 m^2 reef is located at the leeward side of the island and is mainly covered by ACA and macroalgae, while living *M. decactis* covers 0.5% and *M. hispida* ~6% of the reef (Pereira-Filho et al. 2019). Here, we report an additional coral bank similar to the reef described before, with a *M. decactis* framework, reaching an approximate height of 0.5 m, and with a similar abundance of *M. hispida* (5%). However, this coral bank lies on the opposite side of the island and bears a living

Fig. 3 Reef environments at
Queimada Grande Island **a**
Madracis decactis coral bank;
b rocky reef with dominance of
Mussismilia hispida
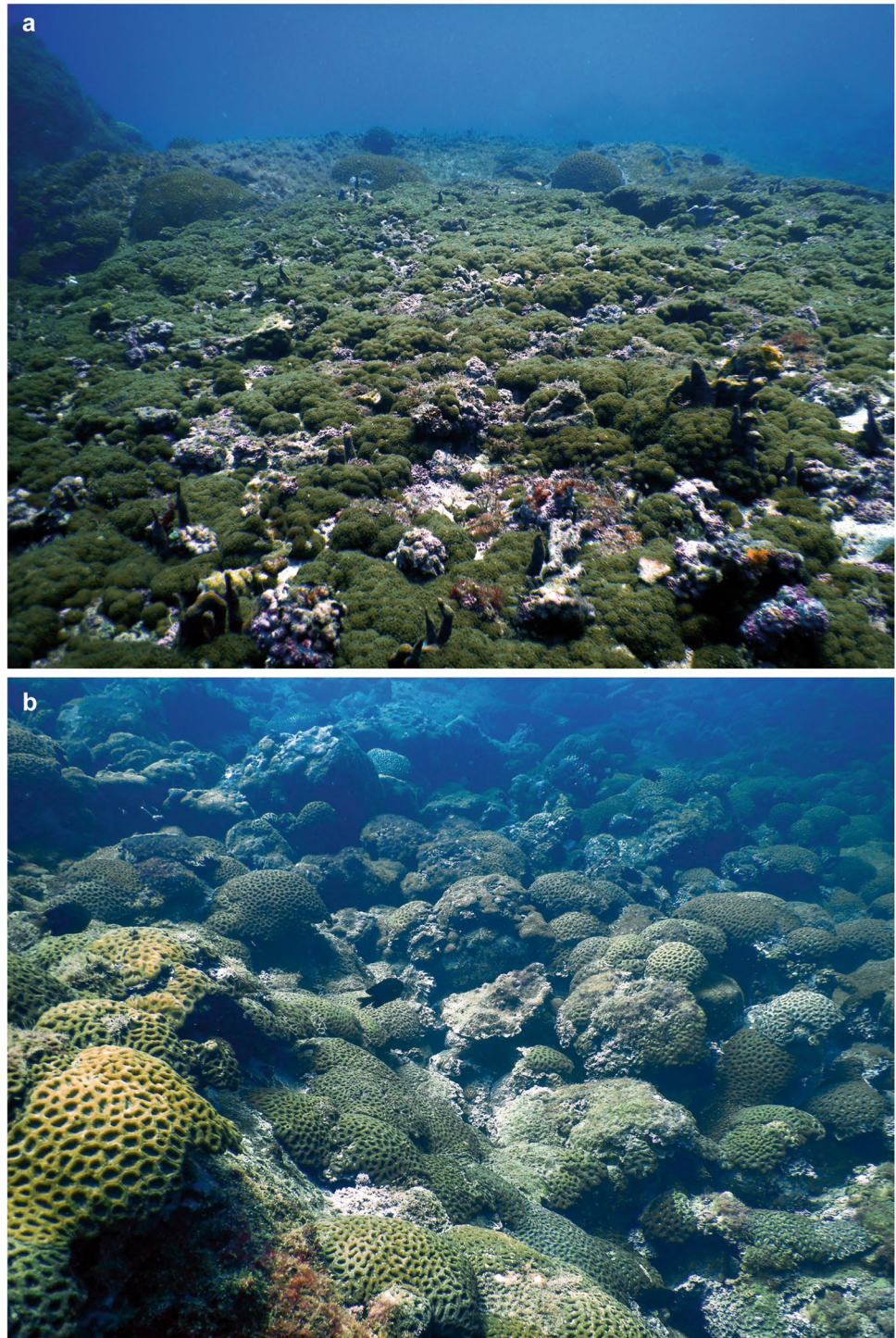
and higher coral coverage of *M. decactis* on its top (~53%). We used a similar methodology to estimate benthic cover as Pereira-Filho et al. (2019), with same photoquadrat size and number of points to analyze each image, but with the double number of photoquadrats ($N = 60$). The windward coral bank we studied is deeper (11–18 m) and smaller (500 m^2) in area when compared to the leeward reef (7–12 m, 75,000

m^2; Pereira-Filho et al. 2019). Apart from the difference in *M. decactis* abundance, the windward benthic community in this coral bank presents a higher cover of CCA (~19%) than the leeward coral reef (<5%; Pereira-Filho et al. 2019). These algae were found several times overgrowing *M. decactis* skeletons and forming rhodolith nodules among the *M. decactis* living colonies. This higher value of CCA

is comparable to the cover found in rhodolith beds observed at 15–20 m depth on the leeward coast (Pereira-Filho et al. 2019). Because the windward coral bank is covered by living corals and has a higher abundance of CCA, it might be possible that it is still producing and accreting calcium carbonate to the reef framework, in contrast to the leeward reef which presents no evidence of accretion over the last 2,000 years (Pereira-Filho et al. 2021).

Abiotic characteristics like temperature, waves, and substrate for settlement directly influence the structure of marine benthic communities in several forms (Becerro et al. 2006; Bauman et al. 2013). Despite their similarity in coral abundance, we found a distinction between coral species in the reef environments surrounding the island. While the biogenic coral bank was dominated by *M. decactis* (>50% cover), abiogenic rocky reefs were mostly covered by *M. hispida* (~47% cover). Coral banks of *M. decactis* were recorded both in the windward (present study) and in the leeward side of Queimada Grande Island (Pereira-Filho et al. 2019). In the windward site it occurs in a small sheltered area formed by the shores of the island that protects it from the prevailing southeastern winds and waves. On the opposite side, the leeward coast faces the mainland and offers a more protected area almost on its entire length, and it harbors a similar but more extensive coral reef (Pereira-Filho et al. 2019). Site 2, located in an exposed area on the windward side, presented the lowest coral abundance (36% for *M. hispida* and 2% for *M. decactis*) among all assessed sites and no coral reef formations, with coral colonies occurring over the rocky framework. On the three rocky reef sites of both coasts, the benthic community was also dominated by corals, but in this case, by *M. hispida*. The reason for such difference in coral dominance between the biogenic bank (dominated by *M. decactis*) and the adjacent rocky reefs (dominated by *M. hispida*) is unclear. However, while *M. decactis* is widely distributed in the Western Atlantic (Jaap et al. 1989; Capel et al. 2012) and presents high morphological plasticity, being able to encrust over several surfaces and to form coralliths (Hoeksema et al. 2018), the coral *M. hispida* has a massive growth form and is not frequent a major component in the construction of biogenic reefs (Leão et al. 2003), but is commonly abundant in subtropical rocky reefs (Banha et al. 2019). Therefore, differences in coral dominance can be more linked to biological attributes of each species regarding growth form and habitat use than to differences in abiotic variables at such a small spatial scale.

Our study presents one of the greatest abundances of the coral *M. hispida* on the Brazilian coast and on its southernmost limit of distribution. Although a decrease in population density on abiotic limits of a species range is expected (Kawecki 2008), coral populations in high latitudes have been found to present high fecundity and reproductive activity (Wilson and Harrison 2003; Nozawa et al. 2006). Our

Fig. 4 Bleached colonies of *Mussismilia hispida* recorded in March 2019 on rocky reefs of Queimada Grande Island, when the highest value of degree heating weeks was documented for subtropical Brazil (22.65 DHW)

results agree with another endemic Brazilian species, *S. stellata*, which sustains an equal or greater abundance than other populations of biogenic reefs at its southernmost range limit in Rio de Janeiro (Lima and Coutinho 2016). The high coral abundance at marginal areas points to the adaptation and tolerance of coral species to these environments. The coral *M. hispida* presents high heterotrophy, helping it persist through more stressful conditions of minimal and maximum temperatures (Mies et al. 2018), and is remarkably resilient to bleaching episodes (Banha et al. 2019). These characteristics might have facilitated the expansion of *M. hispida* population at the edge of its distribution. Additionally, global warming is causing the tropicalization of extratropical zones, in which tropical marine communities extend their ranges in poleward direction (Vergés et al. 2014). Therefore, a high coral abundance in subtropical reefs may also suggest that these areas might sustain great coralline communities in warmer scenarios or even act as steppingstones for corals to migrate southward in tropicalization scenarios.

Understanding the limits of coral distribution and conditions in which they can develop can help address the impacts of climate change and project coral's acclimation and distribution in future abiotic conditions (Camp et al. 2018). Climate change is currently degrading reef environments worldwide (Hughes et al. 2017), and the increase of sea surface temperatures is one of the main factors causing global-scale bleaching events and massive coral mortality on many reefs (Eakin et al. 2019; Duarte et al. 2020). However, some coral assemblages can thrive in a broad diversity of natural conditions, for example, in high-latitude and turbid environments (Kleypas et al. 1999; Perry and Larcombe 2003; Camp et al. 2018). These locations might mitigate the effect of thermal

stress events by increasing the environmental tolerance of corals due to a larger range of temperatures throughout the year (Schoepf et al. 2015) and protecting corals against high solar irradiance (Camp et al. 2018; Mies et al. 2020). The remarkably high abundance of the two occurring native hermatypic coral species in a Brazilian subtropical island recorded by this study, and the description of two coral reef frameworks in the same location (Pereira-Filho et al. 2019; present study) highlights the importance of studying marginal environments and increasing their attention as potential climate refugia (Banha et al. 2019; Mies et al. 2020).

While recent studies have shown the low post-bleaching mortality of Brazilian endemic coral species, particularly in São Paulo's rocky reefs (Banha et al. 2019; Mies et al. 2020), the more intense and frequent mass coral bleaching events are already disturbing less affected reefs (Duarte et al. 2020; Ferreira et al. 2021). During this study, we did not record any bleached coral colony surrounding Queimada Grande Island. Nevertheless, the austral summer of 2019 reached the maximum degree heating weeks value recorded for Queimada Grande Island (22.65 DHW; PacIOOS 2021), exceeding the highest documented value for subtropical Brazil in Alcatrazes Archipelago at the same period (20.5 DHW; Banha et al. 2019; PacIOOS 2021), when we observed a massive bleaching in the population of *M. hispida* on rocky reefs (Fig. 4). Therefore, although this species has demonstrated a remarkable tolerance to bleaching events (Banha et al. 2019), the implementation of monitoring programs is recommended to track coral health and the potential loss of cover throughout the more constant thermal anomalies predicted.

The reefs surrounding Queimada Grande Island have social and economic importance to the nearby communities mainly due to intense use as a recreational site. However, high use pressure allied to poor use ordering has resulted in a decrease in fish resources (Pivetta et al. 2012) and increase in marine debris, particularly lost fishing gear (reviewed in Link et al. 2019; authors pers. obs.). Queimada Grande Island is near (~ 130 km) to the most populous metropolitan area in South America and is one of the most visited locations for recreational fishing on the Brazilian coast (Pereira-Filho et al., 2019). Further local impacts to the benthic biodiversity are presented by the invasive cup corals *Tubastraea* spp., distributed on two locations around the island (Pereira-Filho et al. 2019; present study). Recently, a spatial zoning in the area explored for tourism 3 km around Queimada Grande Island has been determined. In this zone, commercial fishing is banned to avoid spatial conflicts with recreational users (Fundação Florestal 2020). Therefore, despite the uncertainties regarding the effectiveness of such strategy, this and other minor management and conservation initiatives involving multiple stakeholders suggest rising attention to the conservation status of the marine environment of Queimada Grande Island. Hence, our study adds information to the management plans of the MPA reinforcing the biological and ecological importance of this area and highlights subtropical coral assemblages as research and conservation opportunities, mainly in future climate change scenarios.

Declarations

Conflict of interest The authors declare no competing interests.

Ethics approval No animal testing was performed during this study.

Sampling and field studies All necessary permits for sampling and observational field studies have been obtained by the authors from the competent authorities and are mentioned in the acknowledgements.

Data availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Author contribution ACG and CFC conceived and designed the study, ACG and CFC collected data in the field, ACG analyzed the data and drafted the manuscript, and all authors revised, contributed, and approved the manuscript.

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