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# Coral health rapid assessment in marginal reef sites

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**ORIGINAL ARTICLE**

# Coral health rapid assessment in marginal reef sites

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## Abstract

The Brazilian reef fauna shows high levels of endemism, with both the continental coast and oceanic islands considered as unique biogeographic provinces divided in tropical coral reefs (northern and northeast) and subtropical rocky reefs (southern). While assessments and descriptions for the tropical reefs have reported different levels of impact in different regions, the southern ones have not yet been considered. In addition to a baseline assessment of benthic cnidarian cover, we evaluated the condition of the massive coral colonies of Arraial do Cabo, southeastern Brazil. Results indicated *Palythoa caribaeorum* as the most abundant cnidarian in all sites followed by *Millepora alcicornis*, octocorals and scleractinian corals. Most *Siderastrea stellata* colonies assessed had filamentous algae covering a major area of their tissues and roughly one-third of *Mussismilia hispida* colonies were also covered by algae. Bleaching was detected in less than 5% of colonies of these species. Coral deterioration in the region is historical and includes unreported diseases and bleaching with subsequent algal settlement and succession over colonies. The lack of previous monitoring programmes on benthic organisms makes the discernment of natural and anthropogenic impacts a difficult task. The scenario described here for native corals in Arraial do Cabo requires urgent action with further experimental work on factors that contribute to the demise of the corals.

**Key words**: *Rocky reefs, marine biodiversity, benthic organisms, anthropogenic impacts*

## Introduction

Over the past three decades intense degradation of tropical reefs has been detected on a global scale (Adey 2001; Hughes et al. 2005; Bellwood et al. 2004; Hoegh-Guldberg et al. 2007). Human activities such as overfishing, eutrophication and habitat modification have been affecting the health of corals and reef resilience (Jackson et al. 2010; Carilli et al. 2010). Disturbances associated with anthropogenic climate change have been regarded as some of the major threats to tropical reefs (Hughes et al. 2003; Wilkinson 2008; Jackson 2010).

Historically, Caribbean reefs have suffered more human impacts and natural catastrophes, including epidemics, when compared to the Indo-Pacific reefs (Raymundo et al. 2005). A reduction of roughly 80% of coral cover has been documented in the Caribbean due to the increase of pathogens (Weil 2004). The only true coral reefs in the South Atlantic are known from Brazil (Maida & Ferreira 1997; Paulay 1997). Although comparatively poor when compared to Caribbean and Indo-Pacific reefs, Brazilian reef fauna sustains high levels of endemism in fishes, corals, sponges and molluscs, with both the continental coast and oceanic

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islands proposed as a unique biogeographic province (Briggs 1995; Floeter et al. 2008). Reef systems occur along at least a third of the Brazilian coastline (total ca. 8000 km), with tropical coral reefs prevailing in the north and northeastern coasts (0°52′N–19°S) and subtropical rocky reefs in the south and southeastern coasts (20–28°S) (Floeter et al. 2001).

Both tropical and subtropical reefs of the Brazilian coast are unique in terms of morphology and biodiversity (Floeter et al. 2001; Leão et al. 2003), but reef systems along the entire Brazilian coastline are suffering from the impacts of unregulated housing and urbanization along the coast together with sedimentation, overfishing, the introduction of exotic species, physical changes to the habitat and pollution (Amado Filho et al. 1997; Maida & Ferreira 1997; Gasparini et al. 2005; Leão & Kikuchi 2005; Floeter et al. 2006). Coral diseases and bleaching events have also been reported (Francini-Filho et al. 2008). While impacts on corals have been reported for the tropical reefs of the northeastern coast (Leão et al. 2003; Francini-Filho et al. 2008; Barradas et al. 2010), few studies had considered the marginal, subtropical reefs (Migotto, 1997; Creed, 2006).

Identifying the cause of reef degradation is not easy, in part due to the scarcity of studies, but especially due to the lack of understanding of the basic ecological processes involved (e.g. production rates, herbivory and predation effects, population dynamics of most phyla). Overfishing is widespread and probably the most extensive impact documented on coastal reefs (Ferreira & Gonçalves 1999; Gasparini et al. 2005; Floeter et al. 2006), which contributes directly to the extirpation of essential functional roles of reef ecosystems (Floeter et al. 2007).

Despite being the major component of tropical reefs, corals have been relegated to one of secondary importance in peripheral, marginal reefs (Castro et al. 1995; Ferreira et al. 2001; Oigman-Pszczol & Creed 2006). Nevertheless, the functional role of corals in marginal sites can still be important by adding complexity and by providing refuge and nursery for other organisms (Ferreira et al. 2001; Capel et al. 2012; Pereira et al. 2012). Along the Brazilian coast, massive and encrusting forms of coral colonies dominate, but hydrocorals (milleporids) perform the most important role as ecological engineers (Coni et al. 2012), as branching corals (e.g. acroporids) do in other tropical coral reefs systems (Lewis 2006; Garcia et al. 2008).

On the subtropical reefs of Brazil few coral species occur (~13) compared to the northeastern tropical reefs (~25; Leão et al. 2003). Millepores (specifically *Millepora alcicornis* Linnaeus, 1758) are still abundant in the tropical to subtropical transition range, including Cabo Frio, Búzios and the Arraial do Cabo region (23° S) (Castro et al. 1995; Ferreira et al. 2001), together with some massive scleractinian species (Oigman-Pszczol & Creed 2006). The first reports in the 1960s describe the region as possessing high coral abundance (Laborel 1969). That is certainly a very different scenario from present times, after decades of ornamental exploration (Gasparini et al. 2005). While sustaining high diversity relative to early accounts and still retaining significant coral cover, the region lacks efficient management. In the last two decades, intense marine tourism (e.g. scuba diving), compounded by continuous fishing practices (e.g. hook and line, spearfishing, nets), has been affecting reef communities (Ferreira et al. 2001; Gasparini et al. 2005; Floeter et al. 2006). Recent research on fish assemblages provided clear signs of overfishing (Floeter et al. 2006), but the impact on benthic communities remains to be assessed. In fact, the few local studies dealing with reef benthos were comparative surveys (Castro et al. 1995; Ferreira et al. 2001), without an assessment of organism health status or impact descriptors.

The development of efficient monitoring strategy data is essential for understanding benthic dynamics and coral diseases (Green & Bruckner 2000). For these purposes, rapid assessment methodologies have been used in several parts of the world, providing a valuable snapshot of environmental conditions with low cost (Bradley et al. 2009; Price & Harris 2009).

The aims of the present study were first, to compare relative cnidarian abundance among sites encompassing a gradient of human access, and second, to characterize the health status of *Siderastrea stellata* Verrill, 1868 and *Mussismilia hispida* (Verrill, 1901), two Brazilian endemic massive corals that are abundant on the rocky reefs of Arraial do Cabo, SE Brazil. This knowledge is essential to generate future hypotheses to be tested considering causes and consequences of the impacts detected, as well as to generate baseline data in order to inform local stakeholders concerning the management of benthic organisms (e.g. corals).

## Material and methods

### *Study area*

Arraial do Cabo is located in Rio de Janeiro State (23° S–42°W). It is considered a transitional zone between the tropical and subtropical provinces. Due to coastal morphology and prevailing winds (NE and E), the region is bathed by upwelling water masses (Valentin 1984), which bring cold water (14–18°C) and nutrients from the bottom to the surface increasing local primary productivity, which in turn enhances fishing activities. The position of Cabo Frio Island in relation to the mainland creates a large embayment habitat where there is a long-time residence of surface water

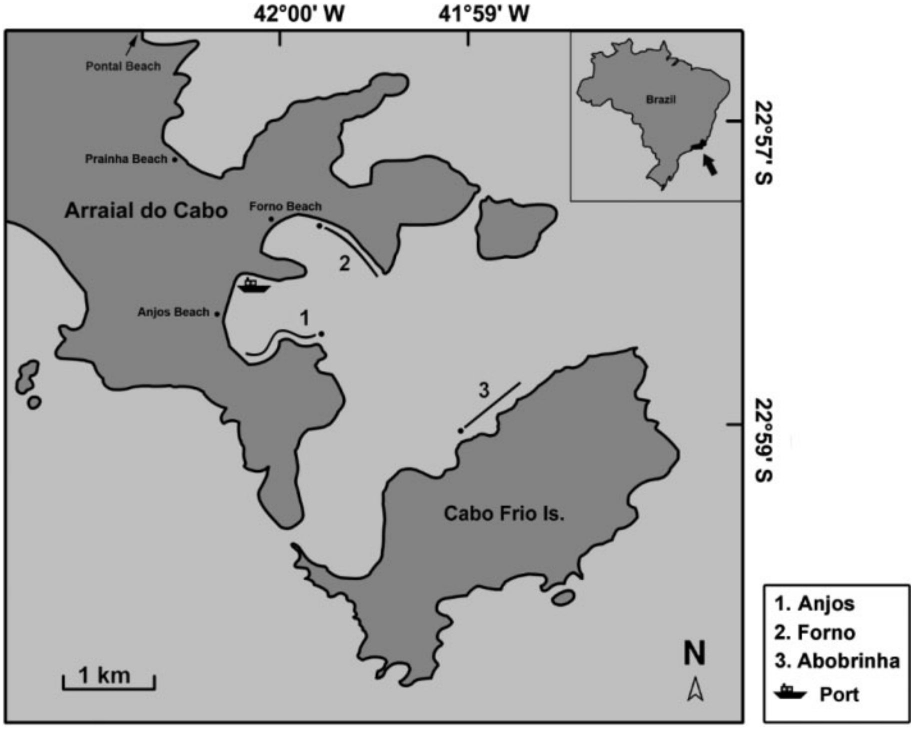

Figure 1. Map of Arraial do Cabo showing studied sites: (1) Anjos, (2) Forno and (3) Abobrinha. Lines indicate swimming transects performed by divers while photographing colonies of massive corals. Dots indicate specific sites where line transects were performed to estimate percent cover of benthos.

associated with shallow depths and this provides a mean water temperature higher than the exposed areas (mean = 22°C; Figure 1). These embayment conditions provide a haven for tropical fauna and flora, contrasting with the exposed and deeper nearby shore with typical subtropical and temperate components (Guimaraens & Coutinho, 1996; Ferreira et al. 2001).

In 1997, Arraial do Cabo (1.175 ha) was given the status of a marine extractive reserve (RESEXMAR), a model of conservation unit which allows the exploitation of local marine resources only by artisanal means (MMA SNUC 2000). The marine reserve also includes a small sanctuary, but because of the lack of enforcement and inefficient management, effective protection has not yet been achieved.

### *Underwater survey*

A rapid assessment method was used to estimate abundance and the health status of massive corals. The sampling design was divided into two different approaches over two weeks in December 2009. A first approach was applied to estimate cnidarian cover for future monitoring and a comparison of three different sites, Anjos, Forno and Abobrinha (Figure 1). The sampling design included massive forms, hydrocorals, zoanthids and octocorals. Random line transects ($n$ = 12) were performed perpendicularly over the rocky shore from the surface to the sand interface where, using a tape measure, every intersection which touched the substratum was recorded (Castro et al. 1995). As a result, the percentage of cover of each species or group along each transect was obtained. A minimum distance of 10 m was chosen to assure independence between replicates.

A second approach included an assessment of the colony health of the two most abundant massive corals in the region, *Siderastrea stellata* and *Mussismilia hispida* (Figure 1). The chosen sites represented a distance gradient from reefs, more populated (= disturbed) areas like Anjos Beach to less-accessible rocky shores of Forno Beach and Abobrinha on Cabo Frio Island. Massive corals were chosen because their superficial area is easily inspectable by means of underwater photographs of the whole colony. The colony size of both species was estimated visually by having a marked pole of known size placed on the coral for each photograph. Specifically for *S. stellata*, where fusion was observed, colonies were distinguished by lowered margins (Oigman-Pszczol & Creed 2004). *Millepora alcicornis*, although important and abundant in the region, will be analysed elsewhere.

Two divers, swimming at different depths (3–6 m and 6–9 m approximately, using SCUBA) off the rocky shore, searched for colonies of the two coral species and took pictures with a digital camera of all colonies detected. For each of the three sites, divers surveyed an approximate area of 2000 m$^2$ (Figure 1). Initial and final locations of each dive (sampling area) were marked using GPS. As the distribution of *S. stellata* and *M. hispida* at these sites does not reach the shallow zones of the rocky shores (less than 3 m), two divers could easily scrutinize the reef substratum searching for colonies, making the method very effective in accessing a significant proportion of the colonies within sampled sites. In order to ensure easy visual detection of colonies, dives and samples were performed only if water visibility exceeded 4 m.

Photographs were analysed using computers in order to list damaged characteristics (e.g. diseases, bleaching, algal cover). The percent coverage of damaged and healthy tissues of each colony were estimated independently by three of the authors, while a final mean was calculated based on all estimates.

### *Statistical analysis*

Differences in percent coverage of coral and non-coral substrata among sites (e.g. turf algae, sponges, bryozoans, ascidians, sea urchins, bare rock) were analysed using a one-factor permutational multivariate analysis of variance (PERMANOVA) with a Monte Carlo resample with 9999 permutations (Anderson et al. 2008). An additional cluster analysis using Bray–Curtis similarity (UPGMA) was applied to check for similarities among sites. Data were arc-sin transformed in order to achieve normality.

After a visual analysis of photographs of coral colonies, we calculated the percentage of damaged and healthy portions for all colonies sampled. Data on each species (*Siderastrea stellata* and *Mussismilia hispida*) for each site were then halved. Each half was separately randomized and after data transformation to arc-sin a pairwise test was applied comparing the healthy data of one half against the damaged data of the other half (Zar 2006). By doing this we ensured independence among replicates.

## Results

### *Benthos coverage*

Total cnidarian coverage including massive forms of scleractinians, hydrocorals, zoanthids and octocorals, was similar among sites ranging from 35% in Abobrinha to 40% in Anjos and 50% in Forno. The zoanthid *Palythoa caribaeorum* (Duchassaing & Michelotti, 1860) was the dominant species covering a greater proportion of reef substratum at all sites, but significantly lower in Abobrinha (= 11%; Figure 2). All massive corals, branching hydrocorals (*Millepora alcicornis*) and the octocoral *Phyllogorgia dilatata* (Esper, 1806) have shown a similar percentage cover among sites, as well as non-coral substrata (Table I). In decreasing order of percentage cover, *M. alcicornis* (mean = 8.5%) was the highest, followed by *Siderastrea stellata* (4.0%), *P. dilatata* (2.3%) and *Mussismilia hispida* (0.8%) (Figure 2).

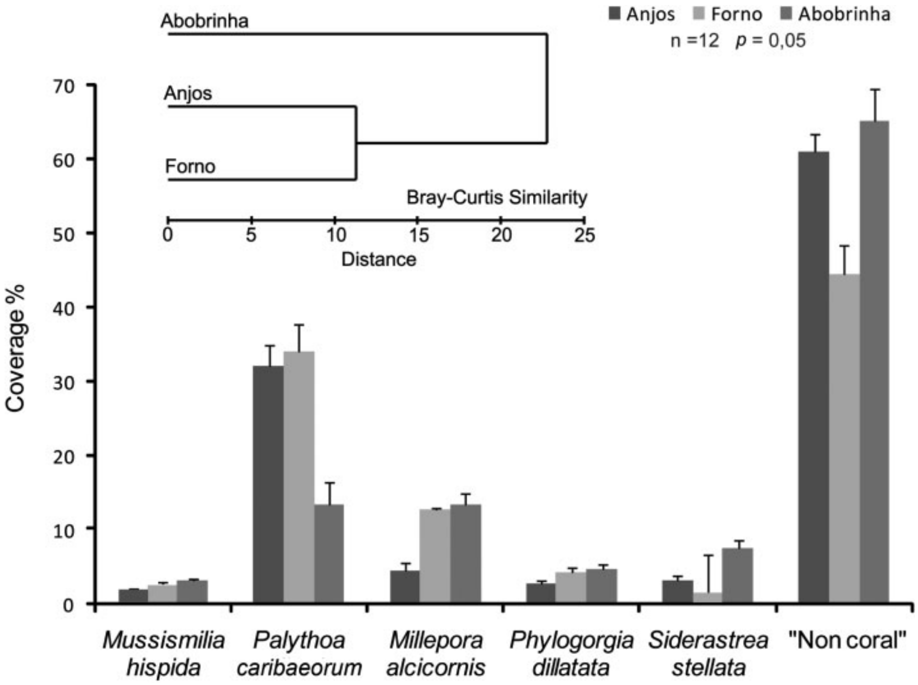

Figure 2. Average percent cover (± SD) of cnidarians and non-coral substratum among studied sites, plus cluster analysis for sites using Bray–Curtis Similarity index.

Table I. PERMANOVA results based on the Bray–Curtis matrix (arc-sen transformation) comparing the multivariate data of abundance among sites. *P*-values given were obtained using 9999 Monte Carlo samples from the asymptotic permutation distribution. The term used for the denominator mean square in each case is given in the column MS.

| Source | df | SS | MS | Pseudo-F | *p*(perm) | perms | P(MC) |
|---|---|---|---|---|---|---|---|
| Sites | 2 | 4,667.8 | 2333.9 | 91.428 | 0.0001 | 9941 | 0.0001 |
| Residue | 33 | 8,423.9 | 255.27 | | | | |
| Total | 35 | 13,092 | | | | | |

Average similarity between/within groups

| | Anjos | Forno | Abobrinha |
|---|---|---|---|
| Anjos | 81.711 | | |
| Forno | 77.96 | 78.059 | |
| Abobrinha | 69.283 | 70.058 | 77.408 |

Cluster analysis grouped locations according to the average abundance of corals. Two groups were observed, one composed of Anjos and Forno and another group containing the Abobrinha site (Figure 2). PERMANOVA results indicated significant differences between sites ($p$ (perm) = 0.0001; Table I), while the pairwise test pointed out that average similarity between Forno and Anjos (77.96) was higher than between both and Abobrinha (Forno vs. Abobrinha = 70.06 and Anjos vs. Abobrinha = 69.28), corroborating results from cluster analysis.

### *Coral colony health assessment*

For all sites combined, the two primary conflicts observed were algal overgrowth and bleaching. Algae covering corals included a diverse set of filamentous turfs (red and green) and articulated calcareous algae, but also cyanobacterial mats. *Siderastrea stellata* had a significantly higher proportion of colonies covered by algae than healthy ones (Forno and Abobrinha = 70%; Anjos = 82%; Figure 3). Bleaching was responsible for a very small percentage of damaged tissue, with 0.2% in Forno, 0.4% in Abobrinha and 0.02% in Anjos (Figure 3).

Different patterns were detected for *Mussismilia hispida*, with a smaller proportion of damaged tissue covered by algae (Forno = 13%; Abobrinha = 19%; Anjos = 23%; $p < 0.001$ – Figure 3). The percentage of bleaching was higher than that detected for *Siderastrea stellata*, with 4.3% in Forno, 4.8% in Abobrinha and 3.5% in Anjos ($p < 0.001$).

The percentage of coral tissue covered by algae was grouped into three classes, < 35%, 35–70% and > 70%, in order to estimate the varying proportion of algae covering all colonies analysed ($n$ = 703). The distribution pattern of classes for both corals was similar among sites but differed between the two species (Figure 4). For *S. stellata* there was a higher proportion of classes with high algal cover, with 50–70% of all colonies having algal cover ranging from 76 to 100% (Figure 4). The Anjos site showed major proportions of colonies in the last class.

For *M. hispida* the pattern of algal cover was quite different, with most colonies being in the lower algal cover classes (Figure 4). Colonies in the highest cover class were recorded in Abobrinha, but in low proportions (= 12%, Figure 4). For all sites, the majority of colonies (70–90%) were in the lower algal cover class (< 35%) and Forno was the site with the highest proportion of colonies in the lower algal cover class (= 91%, Figure 4).

### *Colony size*

Coral colonies had a similar size distribution for each species and among sites. Most colonies of *Siderastrea stellata* ranged from 20 to 50 cm in diameter, with a low proportion reaching larger sizes. The greatest number of big colonies (> 50 cm) was found in Anjos, followed by Abobrinha, while none were observed in Forno (Figure 5). For *Mussismilia hispida*, most colonies also ranged from 20 to 50 cm, with very few individual colonies falling outside this range.

As the effort to photograph colonies underwater was similar for all sites (e.g. dive distance, reef size, same divers) and visual detection of the two species did not change spatially, the number of colonies ($n$) registered in Figure 5 indicates a comparative relative abundance index. *Siderastrea stellata* was more abundant than *M. hispida* at all sites, and was found in similar numbers across all sites. *Mussismilia hispida* presented a clear decrease in the number of colonies, with the highest numbers found in Abobrinha and lowest in Anjos, while *S. stellata* apparently had similar relative abundances across the three sites (Figure 5).

## Discussion

### *Patterns of coral cover at marginal reef sites*

Cnidarian cover on the subtropical reefs of Arraial do Cabo reaches up to 50% of total substratum,

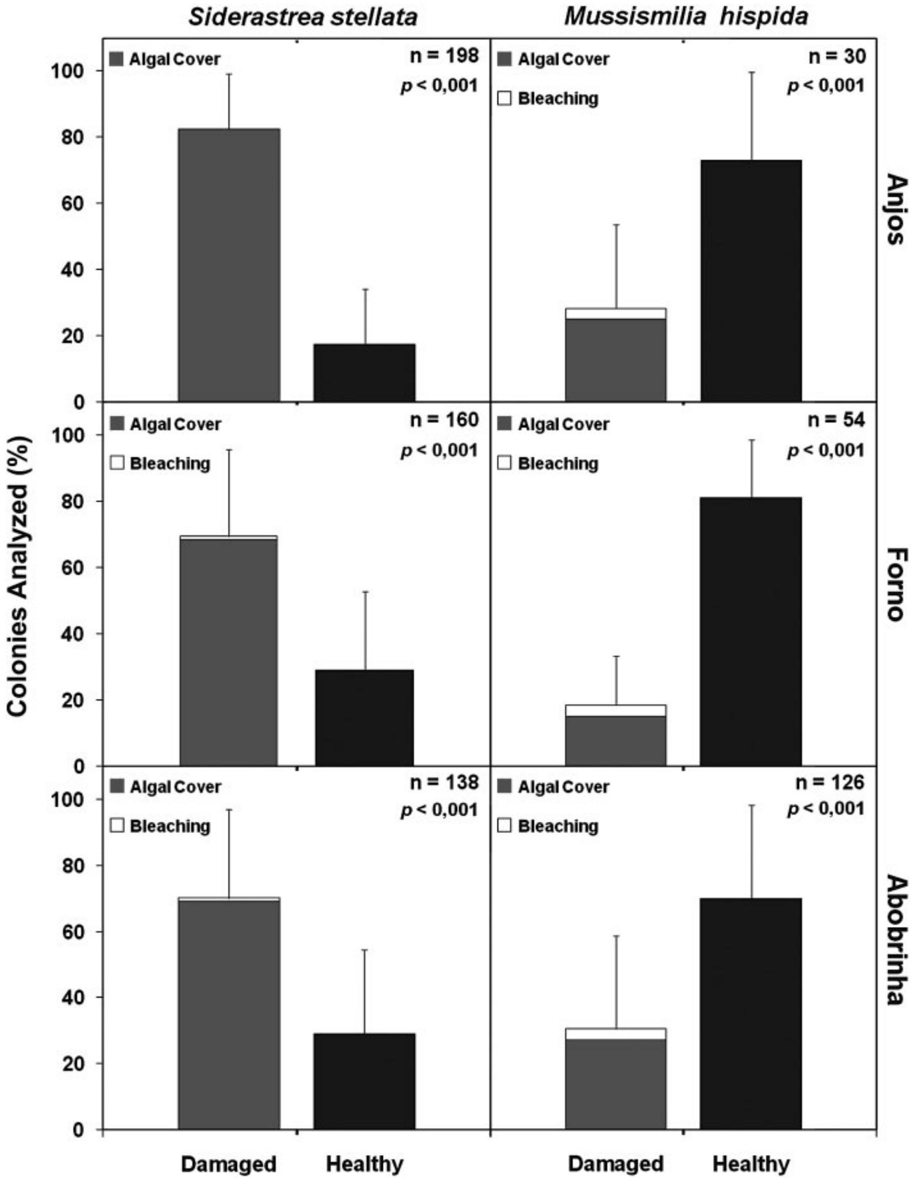

Figure 3. Comparison of the percent damaged and healthy colonies (± SD) of *Siderastrea stellata* and *Mussismilia hispida* among sites. Damaged categories were generalized as bleaching and algal cover. $n$ = number of replicates and $p$ = significance level of pairwise test.

sharing space with the epilithic algal community, which is dominated by calcareous articulated algae (mainly *Jania* spp. and *Amphiroa* spp.) and turf filaments (Ferreira et al. 1998a,b; 2001; Mendes et al. 2009). According to our observations, *Palythoa caribaeorum* was the main contributor to that pattern, covering 40% of reef substratum at some sites. This zoanthid is commonly found covering large parts of rocky reefs along the southeastern coast of Brazil (Castro et al. 1999; Castro & Pires 2001; Oigman-Pszczol & Creed 2004), and also in biogenic reefs of the northeastern coast (Villaça & Pitombo 1997; Ramos et al. 2010).

Hard coral cover estimates, including both massive forms and branching millepores, at the sites at Arraial do Cabo averaged 13% of reef substratum, which is similar to some sites of the tropical northeastern Brazilian coast (Ferreira & Maida 2006). It is interesting to note that even after at least two decades of intense aquarium collection (Gasparini et al. 2005) and more of fishing (Ferreira et al. 2001; Floeter et al. 2006), coral cover in subtropical marginal reefs can still be similar to tropical sites of the Brazilian coast. Coral exploration in the 1980s could remove a ton of coral in a couple of days in the region. Collectors filling vans with *Millepora alcicornis*, huge colonies of *Mussismilia hispida* and *Siderastrea stellata* plus large quantities of other invertebrates and fishes were a common sight at that time (Carlos Ferreira 1982, personal observation). These large pieces of reef were illegally extracted to supply the aquarium trade in São Paulo

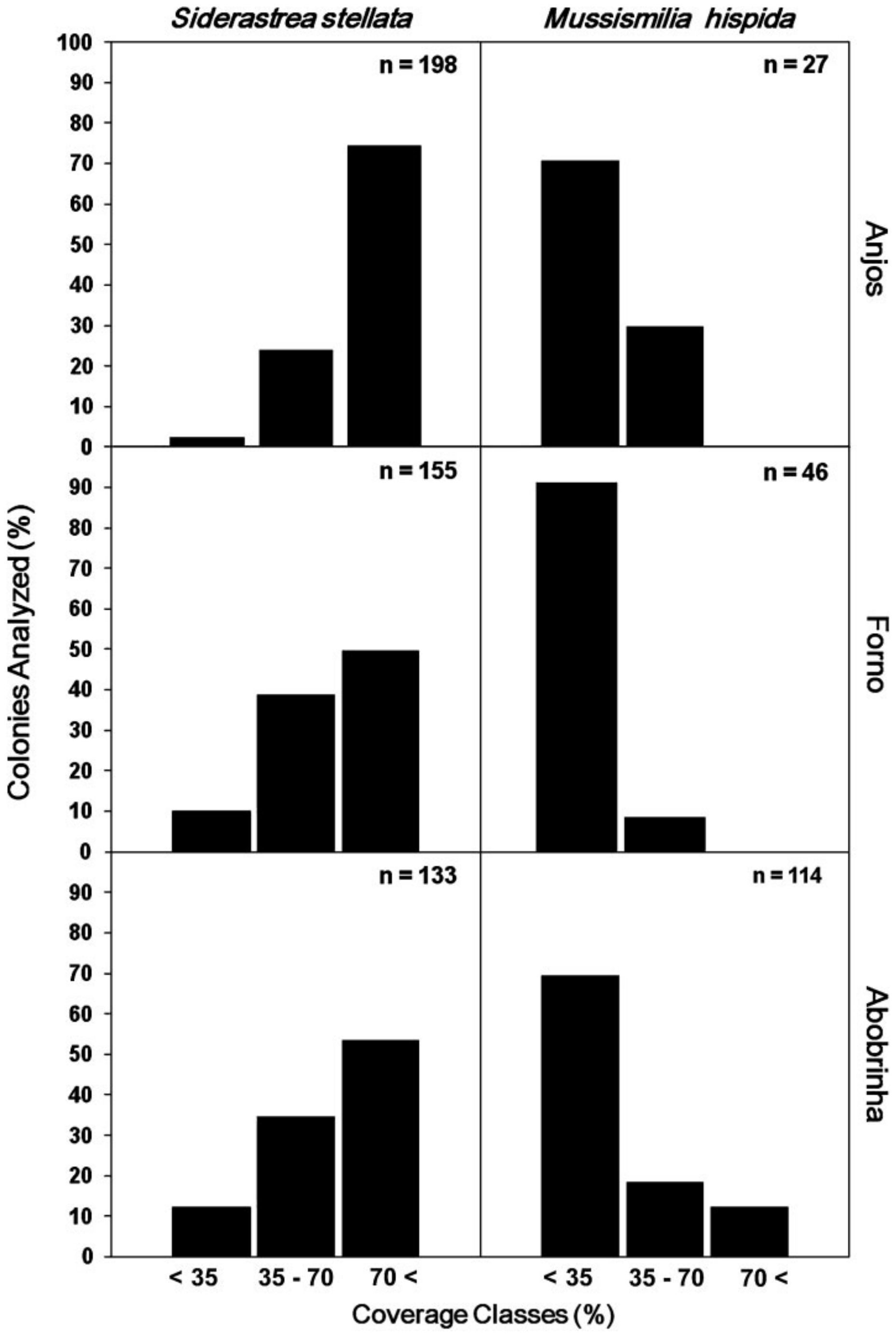

Figure 4. Comparative histogram of algal cover classes (%) among sites for *Siderastrea stellata* and *Mussismilia hispida*.

and Rio de Janeiro (the largest urban centres in Brazil). Shallow reef patches of *M. alcicornis* 1 m high and 10 m wide and abundant massive corals of 1 m in diameter were lost and never reported, suggesting a tremendous shift from the environmental baseline in that region in less than three decades. Based on local collectors' records, *M. alcicornis* once covered more than 50% of some local rocky reefs (Carlos Ferreira 1985, personal observation). The ecological engineering capacity of millepores is really unique considering that the tropical and subtropical reefs of Brazil lack branching scleractinian species. Many phyla, including many economically important reef fishes, make use of colonies as shelter and nursery grounds (Lewis 2006; Coni et al. 2012; Pereira et al. 2012).

The habitat complexity that was lost with this overexploitation, specifically of *M. alcicornis*, is a loss of diversity for this marginal system, where habitat complexity is limited to the surface structure of piles

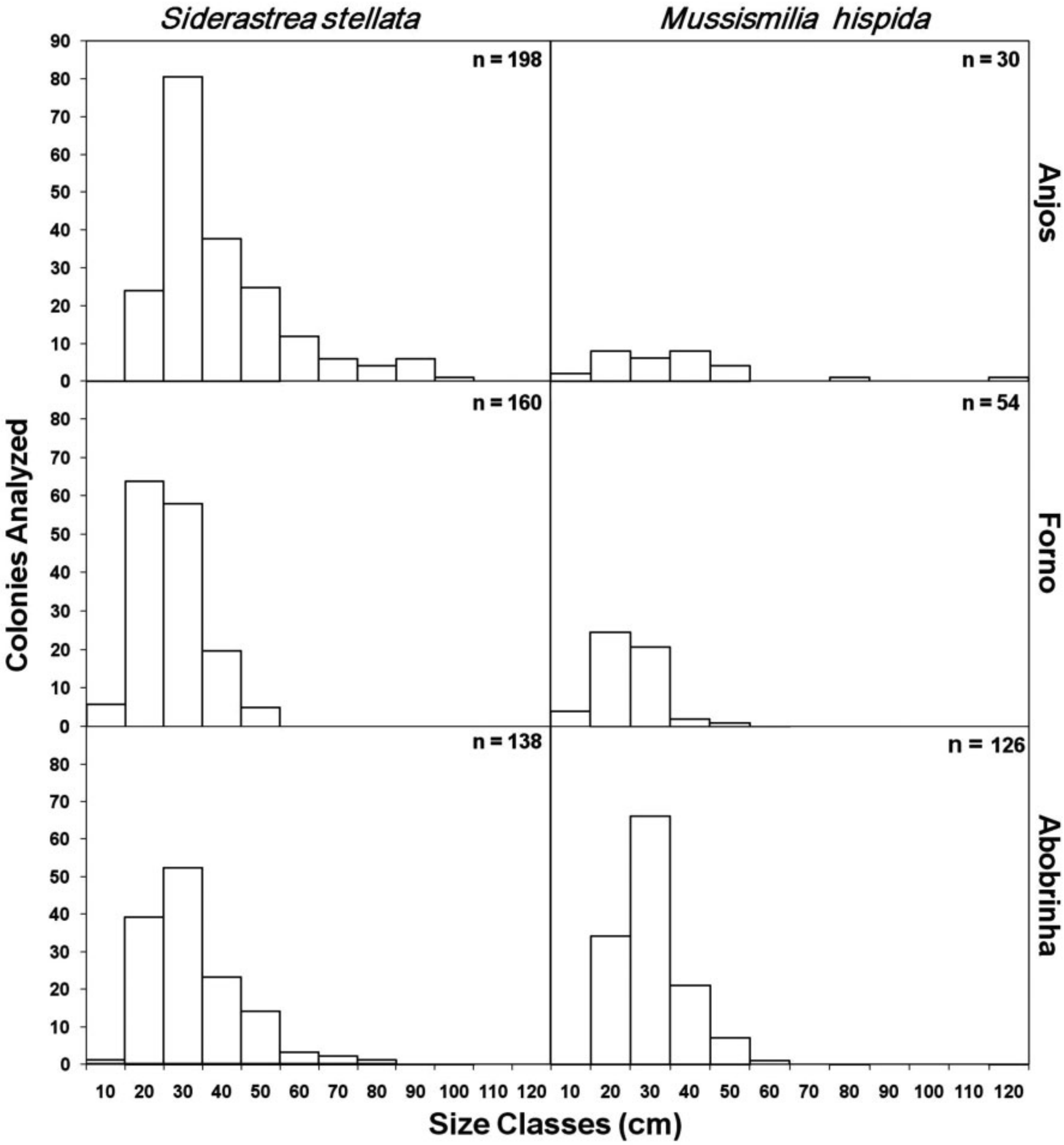

Figure 5. Comparative size classes histogram among sites for *Siderastrea stellata* and *Mussismilia hispida*.

of rocky boulders and holes formed among them (Ferreira et al. 2001; Floeter et al. 2007). Evidence of lost habitat complexity is clear when observing the present abundance of *M. alcicornis*, *S. stellata*, *M. hispida* and *Phyllogorgia dilatata*, which is higher in Abobrinha. This is the site furthest from main human accesses and disturbance (Figure 1). On the other hand, the abundance of *Palythoa caribaeorum*, a more resistant and better competitor for space (Suchanek & Green 1981), decreases with distance from the coast and with the abundance of hard corals. The analysis showed differences among sites, but the similarities of all were still high, as a result of their proximity.

Massive corals like *Mussismilia* and *Siderastrea* do not match milleporids as ecological engineers; however, they can add some complexity depending on size and shape (e.g. brain or plate-like form). Huge colonies of both species are rare nowadays in Arraial do Cabo, but can still be found in some shallow habitats of Praia dos Anjos (this survey). Otherwise, in the nearby Búzios region, large colonies of *Siderastrea* are still abundant and occur in the unique fringing reefs (Oigman-Pszczol & Creed 2004). The pattern detected at Arraial do Cabo with *Siderastrea* being more abundant than *Mussismilia* was also found in the Búzios region (Oigman-Pszczol & Creed 2004). These authors also detected comparatively larger sizes of *Siderastrea* colonies than for *Mussismilia* in Búzios. The reproductive strategy of *S. stellata* as a brooder, producing few large oocytes (Lins de Barros et al. 2000), probably facilitates settlement after release and could be responsible for the pattern of abundance mentioned above, while *M. hispida* is a broadcast spawner (Neves & Pires 2002). Additionally, broadcasters spawn only 2–3 times per year, while brooders such as *Siderastrea* have multiple reproductive cycles per year (Pires et al. 1999; Neves & Silveira 2003). Coral abundance is probably related not only to reproductive mode (brooding vs. broadcasting), but also to other characteristics of the species such as recruitment success, growth rates, mortality rate, and the ability to adapt to withstand stressful environments (Harrison & Wallace 1990). In particular, it seems that *Siderastrea* is a species capable of withstanding stressful conditions, and perhaps this is the reason that it is more abundant on those subtropical reefs. Our data on bleaching support this statement, with a much lower percentage of bleaching observed in *S. stellata* compared to *M. hispida*, suggesting the former species as more resilient to stressful conditions than the latter.

### *Coral health assessment*

The data gathered for massive coral health in Arraial do Cabo attested to a worrying scenario. Visual analysis of *Siderastrea stellata*, the most abundant massive coral in the region, confirmed that 50–70% of all colonies analysed ($n$ = 496) had more than 70% of total surface area with turf algae growing over it. For *M. hispida* algal cover was also widespread, with 35% cover being observed in 70–90% of all colonies surveyed ($n$ = 210). In sites like Anjos Beach, we witnessed what at first glance appeared to be solitary rocks covered by algae in the rocky reef/sand interface, but were in fact large, dead colonies of *M. hispida*.

The steady state of algal overgrowth observed in corals of Arraial do Cabo are most likely the result of past injuries from diseases or bleaching events leading to dead tissue, algal settlement and succession. This scenario was also detected for massive corals in the Caribbean as a consequence of different events (Borger 2005). In fact, substantial coral mortality around the Caribbean has led coral cover to be replaced by fleshy algae (Shulman & Robertson 1997; McClanahan & Muthiga 1998; Aronson & Pretch 1999; McClanahan et al. 1999). Over the last decade several unrecognized disorders were detected for massive corals (*Siderastrea* and *Mussismilia*), octocorals (*Phylogorgia*) and also sponges (*Aplysina*) in Arraial do Cabo, but unfortunately monitoring studies for causes and effects were not conducted. Bleaching events for the massive *S. stellata* and *M. hispida* were also detected in the past but were not monitored. In the present survey a small proportion of damaged tissue on colonies was confirmed as bleached, with a greater proportion of bleaching being observed in *M. hispida* compared to *S. stellata*.

The percentage of algal cover estimated by visual observation probably could have been overestimated due to the capacity of sediment accumulation over turf algae covering colonies. Although we had classified the visual damage to massive corals as just algal cover and bleached tissue, much of that turf community was associated with sediment and detritus. When sediment was manually removed, living tissue was often found in colonies of *S. stellata*, while tissues on colonies of *M. hispida* were most often confirmed as dead. *Siderastrea stellata* was indeed observed to accumulate more sediment and detritus over tissue than *M. hispida*. Despite its small polyp size, *S. stellata* appears to be more resistant to sedimentation than is *M. hispida*. This species is known to be broadly distributed along the Brazilian coast, occurring in very stressful conditions such as intertidal pools and reef tops and highly resistant to variations in temperature, salinity and water turbidity (Leão et al. 2003). *Mussismilia* species, on the other hand, like several other coral species inhabiting reefs of the Brazilian coast, have large polyps which can expel sediment (Leão et al. 2003; Segal & Castro 2011). However, if sediment sloughing is not effective, sediment accumulation smothers the polyp, leading to tissue death.

Some of the large colonies of *Siderastrea* that we photographed occurred in shaded habitats under or inside rocky boulders as plate-like forms. All of those without exception, as well as some small ones in shadow conditions, did not have algae or sediment over them. This is indeed an important clue for further hypothesis testing, considering light and sedimentation as potential stressors of coral tissue and causes of deterioration. UV light and sedimentation have been reported everywhere as potential stressors of corals (Dutra et al. 2004; Fabricius 2005; Torres et al. 2008; Bhandari & Sharma 2010; Maina et al. 2011).

### *Widespread sources of impacts*

The marine environment is threatened by numerous sources of impact, yet clearly identifying the agents responsible for the damage caused to corals in Arraial do Cabo will be a challenge. The region lacks any freshwater input to the sea, allowing coastal waters to remain comparatively clear of sediment inputs, as evidenced by its popularity as a

SCUBA diving site. However, three artificial waterways are connected to this coastline and are a potential source of stressors, including nutrients and pathogens. Only the waterway in Anjos Beach needs mention here. The other two are near Prainha and Pontal Beach, which need further sampling for future comparisons and impact detection (Figure 1). The discharge at Praia dos Anjos was originally built to drain pluvial water, but in reality ended up draining sewage as well. Use of this pathway for sewage disposal ceased 10 years ago, but sporadically, when rains are strong, the channel is artificially opened. As a result, this discharge continues to be a potential source of diseases (e.g. bacteria and viruses) and nutrient overload to the marine environment. The literature pointing out pollution sources as potential drivers of coral diseases and degradation is vast, but controversial (Harvell et al. 1999; Green & Bruckner 2000; Porter et al. 2001; Kuta & Richardson 2002; Alker et al. 2001). Nearby piers used for fishing and tourism, in addition to a commercial harbour, act synergistically as sources for liquid (sewage, hydrocarbons and TBT residues) and solid pollution to the Anjos Beach environment (Limaverde et al. 2007). Shipping traffic to the local harbour can also be a prospective source of sediment resuspension for the nearby rocky reefs of Anjos Beach, which actually presented the lowest coral cover and the greatest proportions of damaged coral.

Another source of local impact for coral communities and also locally unreported is SCUBA diving tourism. Careless SCUBA diving practices have been reported to cause serious damage to corals and other sedentary organisms (Guzner et al. 2010; Poonian et al. 2010; Luna-Perez et al. 2011). In the last two decades, the number of dive operators have increased from 4 to 23 in the region. As the activity goes unmanaged, the number of divers at a site can exceed the carrying capacity. Impacts on corals and other benthic organisms by recreational divers include physical contact and abrasion, sediment resuspension and direct dislodging of colonies (Guzner et al. 2010; Poonian et al. 2010; Luna-Perez et al. 2011). This is a real threat for the fragile *M. alcicornis*, but also for *S. stellata*, which can easily be displaced from the substratum with even a light touch, and consequently small colonies were frequently observed lying upside down on the bottom. The increasing numbers of dive and tour boats have also caused anchor damage to corals and reef habitats in general (Dinsdale & Harriot 2004; Saphier & Hoffmann 2005; Dinsdale 2009).

No long-term monitoring programme currently exists for benthic communities in Arraial do Cabo, which means that there is no baseline for the frequency and severity of disturbance events, whether due to natural or anthropogenic causes. A few reports dealing with the impacts on reef benthos in Brazil (Leão et al. 2003; Dutra et al. 2006; Francini-Filho et al. 2008) provide a snapshot of the damage that is occurring, but unfortunately afford insufficient information to determine how reefs are being impacted over time and how likely they might be to recover. In Arraial do Cabo the subtidal reef environment is still poorly understood in terms of the major processes and population dynamics; nevertheless, it is important to try to identify sources of impact and possible consequences. Whereas data collected here indicate poor health status for native corals, invasive coral species are thriving in the region and are spreading quickly (Ferreira 2003; Lages et al. 2006).

A recent review by Maina et al. (2011) discusses the ability of corals to recover from global changes such as increasing UV levels. The authors point out that this capacity is heavily conditioned to synergism with other stressors affecting the final recovering state. Thus, the detection and specific management of local impacts are highly relevant to unravelling the cause and effect of different stress signals on coral species. The rapid assessment applied to assess coral health in the subtropical reefs of Arraial do Cabo is a simple and low-cost methodology that allows coverage of a wide area. Additionally, this work was the first step towards a broad and more complete investigation associated with long-term monitoring programmes and hypothesis testing, which is necessary to improve our knowledge about reef community dynamics. These initiatives should bring together stakeholders, local users and scientists to improve conservation measures in Brazilian marine reserves. Also, there is a need to identify priorities for actions such as outreach to change people's attitude towards reef conservation and its value for the services provided by natural systems.

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