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Short Communication

Abnormal average increase in sea surface temperature may promote the first documented mortality event of a marine sponge in the Southeastern Brazil

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Abstract: Frequent heat waves and mass mortality events on marine biota are positively correlated to ocean warming. Although literature has indicated some species of marine sponges, and some oceanic regions, like the Brazilian Exclusive Economic Zone, may be less affected or seem to be more resilient under future scenarios of climate changes, few studies have focused on the species responses on the climate change issue along Brazilian coast. This paradigm was undone throughout 2019 after an exceptional average increase of 2 °C in the sea surface temperature (SST) and on precipitation values since 2015 at Ilha Grande Bay (IGB, SE Brazil). The combination of SST and precipitation average increase possibly favored an environmental context for the unprecedented strong population decline and mass mortality rate of the marine sponge species *Desmapsamma anchorata* in the austral spring. The species used to be one of the most frequent benthic species at IGB however it was only recorded in 41.7% sites (n = 12). From 162 individuals recorded at Abraãozinho along 180 m rocky shore, 83 individuals (51.2%) were healthy, 74 (45.7%) were intensively covered by cyanobacteria and locally bleached, and five (3.1%) were completely bleached or died. *Desmapsamma anchorata* population deterioration in a biogeographic transition zone (Rio de Janeiro state) may reflect a shift in the marine community of IGB, opening space for opportunistic species establishment and coverage increase, since IGB has a high species turnover. The three-dimensionality, the shelter for several species, the high competitive ability and the potential to indicate polluted or not polluted areas make *D. anchorata* a key species for IGB monitoring in a climate change scenario.
Keywords*: Climate changes; Desmapsamma anchorata; Population decline; Heat waves; Ilha Grande Bay.*

Aumento na temperatura média do mar pode ter causado o primeiro evento registrado de mortalidade de esponjas marinhas no Sudeste do Brasil

Resumo: Ondas de calor e eventos de mortalidade em massa da biota marinha são cada vez mais frequentes e estão positivamente correlacionados ao aquecimento do oceano. Embora a literatura tenha indicado que algumas espécies de esponjas marinhas e algumas regiões oceânicas, como a Zona Econômica Exclusiva do Brasil, podem ser menos afetadas ou serem mais resilientes em cenários futuros de mudanças climáticas, poucos estudos focaram na resposta das espécies à problemática das mudanças climáticas na costa brasileira. Esse paradigma foi desfeito em 2019 após um excepcional aumento médio de 2 °C na temperatura da superfície do mar e nos valores de precipitação, desde 2015 na Baía da Ilha Grande (BIG, SE Brasil). Essa combinação de fatores possivelmente favoreceu um contexto ambiental sem precedentes, levando ao forte declínio populacional e alta taxa de mortalidade da esponja marinha *Desmapsamma anchorata* na primavera austral. A espécie costuma ser uma das espécies bentônicas mais frequentes na BIG, mas só foi observada em 41,7% dos sítios (n = 12). De 162 indivíduos registrados em Abraãozinho ao longo de 180 m de costão rochoso, 83 indivíduos (51,2%) estavam saudáveis, 74 (45,7%) estavam cobertos por cianobactéria e localmente branqueados e cinco (3,1%) estavam completamente branqueados ou

mortos. A deterioração da população de *D. anchorata* na zona de transição biogeográfica (estado do Rio de Janeiro) pode refletir em uma alteração na comunidade marinha da BIG, abrindo espaço para o estabelecimento de espécies oportunistas, uma vez que a BIG possui alto *turnover*. A tridimensionalidade, o abrigo a diversas espécies, a alta capacidade competitiva e o potencial de indicar áreas poluídas ou não tornam *D. anchorata* uma espécie chave no monitoramento da BIG em um cenário de mudanças climáticas.
Palavras-chave: *Mudanças climáticas; Desmapsamma anchorata; Declínio populacional; Ondas de calor; Baía da Ilha Grande.*

Introduction

Ocean warming is one of the major events affecting marine biota from organism to ecosystem scales (Hoegh-Guldberg and Bruno 2010; Zhou et al. 2021). Marine species bleaching due to loss zooxanthellae and/or pigments (Glynn 1996), and mass mortality events on marine biota are positively correlated with this phenomenon, causing physiological changes, populations decline, interspecific relationships decrease, resulting in phase shift in the ecosystems (Yao and Somero 2014; Inagaki et al. 2020; Teixeira et al. 2021). Overall, ocean warming and diseases were surveyed on coral species from coral reefs, but other groups, such as Phylum Porifera, have also melted worldwide with global change (Vicente 1990; Fromont and Garson 1999; Pérez et al. 2000; Garrabou et al. 2009; Cebrian et al. 2011; Stevely et al. 2011; Rubio-Portillo et al. 2016). Understanding the response of different taxonomic groups into global change is the only way to promote practical restoration programs and constitute refugia zones.

Sponges have been considered winners under the stressful climate change phenomenon since their resilience in comparison to other groups (Fabricius et al. 2011; Peck et al. 2015; Bell et al. 2018). Some examples of sponges' tolerance to ocean warming were evidenced in the Great Barrier Reef (GBR, Schönberg and Ortiz 2008; Wisshak et al. 2012), Caribbean reefs (Duckworth et al. 2012), Bahia reefs, Brazil (Kelmo et al. 2013), sea-grass habitat at Peconic Bay (NY), USA (Duckworth and Peterson 2013) and Hawaiian reefs (Vicente et al. 2016). Bioeroding sponges were positively impacted with an increase in bioerosion rates (GBR, NY), while nonbioeroding sponges were not highly affected in their growth, survival, and biochemical synthesis (Duckworth et al. 2012). No effect on growth and survival of *Iotrochota birotulata* (Higgin, 1877) was evidenced after an experimental increase in 2.2 ºC in seawater temperature (Duckworth et al. 2012). An increase in the abundance of excavator sponges was the first response of boring species after a major coral bleaching event in GBR, suggesting that these sponges benefit from the warming of the oceans, as mortality of corals will possibly provide greater availability of space (Schönberg and Ortiz 2008). Specifically at Brazilian reefs, a sponge assemblage stability was found before and after an El Niño Southern Oscillation (ENSO) in 1997-98, which had increased the sea surface temperature (SST) by 2 °C (Kelmo et al. 2013). Even some sponges winning extreme thermal scenarios, it becomes irrelevant with the surrounding environment depreciation.

South Atlantic marine ecosystems have been documented as less impacted than Indo-Pacific and Caribbean ones in relation to thermal stress events (Baird and Marshall 2002; Perry et al. 2013; Kelmo et al. 2013; DeCarlo et al. 2017; Hughes et al. 2018; Mies et al. 2020). However, the impact of climate changes within Brazilian ZEE is poorly understood, with only local evidence of severe impacts on marine biota (Coutinho et al. 2016; Teixeira et al. 2019, 2021; Duarte et al. 2020; Gaspar et al. 2021). At Rio de Janeiro state, for example, Carvalho (2019) observed a persistent increase in air temperature overtaking 40 °C at Marambaia barrier island from September to February (austral spring and summer) in the XXI century, Skinner (2018a, b) have detected 33 ºC for SST with sensor *in situ*, in two sites of Ilha Grande Bay (IGB), from 2012 to 2017, and Coutinho et al. (2016) documented SST overtaking the daily range of 30 °C at Arraial do Cabo (RJ), a coastal city with historical predominance of cold waters, due to the influence of a strong upwelling during spring and summer months (Valentin 2001). These frequent and high SST values highlight the need for studies assessing the effect of rising SST on Brazilian coastal ecosystems.

The year of 2019 was exceptionally hot in Brazil causing an unprecedented mass mortality event on the major reef building hydrocoral *Millepora alcicornis* (Linnaeus, 1758) at the biggest coral reef of the South Atlantic, Abrolhos (Duarte et al. 2020), on the endemic coral species *Siderastrea stellata* Verrill, 1868 in the Rocas Atoll (Gaspar et al. 2021), and bleaching on cnidarians in Rio de Janeiro, Southeast Brazil (Santos et al. 2021). This heat wave throughout the year may also have caused a population decline and the first documented mortality event on the marine sponge species *Desmapsamma anchorata* (Carter, 1882) in the Southwestern Atlantic, Rio de Janeiro, IGB (Figure 1). The aim of this short communication is to report the population decline/ mass mortality of *D. anchorata* at IGB. It is a relevant report, as the species is ecologically important due high abundance, competition

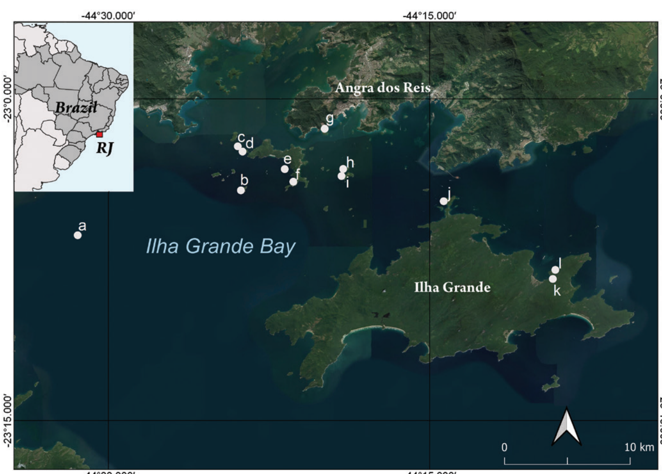

Figure 1. Map of the 12 sites where *Desmapsamma anchorata* was searched at Ilha Grande Bay, Rio de Janeiro (RJ), Brazil. Brazilian map is illustrated at the top-left corner. (a) Ilha da Laje Preta; (b) Ilha do Papagaio; (c) Ilha do Meio; (d) Ilha da Josefa; (e) Praia das flechas; (f) Praia do Dentista; (g) Ilha do Bonfim; (h) Ilha dos Porcos Pequena; (i) Ilha dos Porcos Grande; (j) Ilha dos Macacos; (k) Abraãozinho left rock shore; (l) Abraãozinho right rock shore.

with invasive species and potential for pollutant indicator (Silva 2018; Silva et al. 2017, 2022; Fortunato et al. 2020). Also, mass mortality of sponges was never documented along the Brazilian coastline, and there is scarce data of ocean warming affecting marine species at Rio de Janeiro state (Coutinho et al. 2016; Santos et al. 2021).

Material and Methods

Overall, IGB rocky shores are shallow, with average depth of 5.5 m in the Central channel, between 20 and 30 m depth on the west side and between 10 and 25 m on the east side (Creed 2009). Austral summer is 25–27 °C in SST average, and the benthic community is dominated by turf multispecies algae and the zoanthid *Palythoa caribaeorum* Duchassaing & Michelotti, 1860 (Creed et al. 2007; Mantelatto et al. 2022), but *D. anchorata* is commonly recorded as one of the major space-occupying species there (Mantelatto et al. 2013; Fortunato et al. 2020). An unusual absence of *D. anchorata* was observed during 20 minutes SCUBA dives at two depths (3 m – back and 10 m – forth), in 12 sites of IGB, in October 2019, aiming to collect the invasive ophiuroid *Ophiothela mirabilis* Verrill, 1867 being hosted by *D. anchorata*, as both species are intrinsically related in the region (Mantelatto et al. 2016; Tavares et al. 2019; Fortunato and Lôbo-Hajdu 2021). The absence of *D. anchorata* was recorded and a putative explanation is enlightened herein.

In the same survey,several individuals of *D. anchorata* were recorded at Abraãozinho beach rocky shores. Then, its population was quantified by three visual censuses along 30 × 1 m (30 m²) belts at 3 m depth and organisms were categorized as healthy (orange-pinkish color), unhealthy (pale color, locally bleached or covered by algae or cyanobacteria, and dead (partial or total necrosis). Arcsine transformed values for each category was statistically tested with ANOVA and Tukey *a posteriori* (JAMOVI Software) to identify how healthy the population was at that moment.

Monthly averaged SST dataset was obtained from Giovanni platform (Beaudoing and Rodell 2020) for the period 2015–2019, based on MODIS-Aqua satellite imagery with 4 km spatial resolution and compiled in an Excel file. ANOVA repeated measures was applied to evaluate statistical differences between years, after Shapiro-Wilk normality test indicate those values as normal (Jamovi 2021). Additionally, air temperature and precipitation dataset, for same time span, were obtained from an automatic station (Marambaia station) kept by the National Institute of Meteorology (INMET). It is an automatic station, located on the eastern side of the Marambaia barrier island (Rio de Janeiro southern coast). Therefore, oceanographic, and atmospheric data from IGB and Marambaia are comparable. Monthly and annually averages were computed for SST, air temperature and accumulated precipitation at MATLAB® to identify differences in the abiotic data from 2015 to 2019. Also, SST medians were statistically analyzed with the non-parametric Kruskal-Wallis test (Ernst 2004) using the PAST Software.

Results

From 12 sites where *D. anchorata* is routinely recorded at IGB, we only found the species in five sites (41.7%) indicating a strong decrease in the local population. From 162 individuals recorded at Abraãozinho, 83 individuals (51.2%) were healthy (Figure 2a–b),

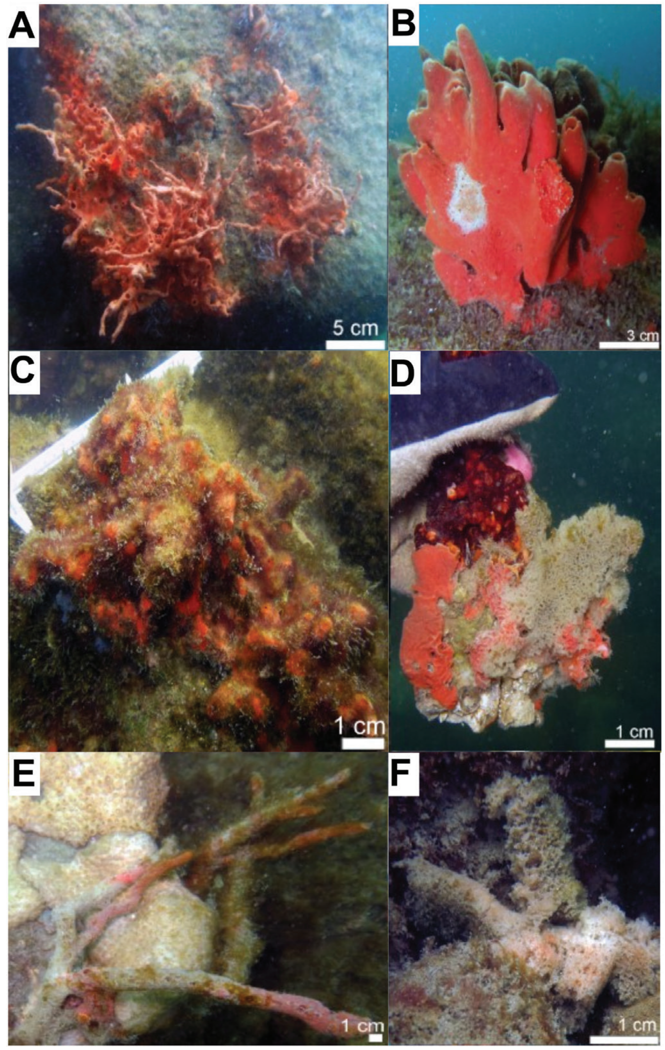

Figure 2. Life status of *Desmapsamma anchorata* at Abraãozinho in the austral spring of 2019. (a) Healthy pinkish arborescent specimen; (b) Lobate pink specimen with a bitten white mark; (c) Unhealthy massive specimen hugely covered by algae and cyanobacteria; (d) Partially healthy (pink) and dead (necrosed mass) in association with the bryozoan *Schizoporella errata* (Waters, 1878); (e) Unhealthy branching specimen with bleached and necrosed base and cyanobacteria cover in apical branches; (f) Dead digitiform specimen.

74 individuals (45.7%) were intensively covered by cyanobacteria and locally bleached (Figure 2c–e), and five individuals (3.1%) were completely bleached or died (Figure 2f). Statistical differences were only recorded for the died category in relationship to the others (One-Way ANOVA F: 7.36, $p = 0.01$; Post-Hoc Tukey test: healthy:died – $p < 0.001$ and unhealthy:died – $p = 0.001$).

Monthly averaged SST revealed an abnormal elevation of 2 °C (26.6 °C) for 2019 in comparison to other years (2015–2018), while 2019 air temperature was only 0.1 °C higher than previous years (Table 1). Also, average precipitation values for 2019 are much higher than the other years. When monthly averages were compared to other years, 2019 months had the highest SST values with exception for July (no variation) and November (−0.7 °C). October 2019 (26.5 °C) was 3.5 °C warmer than the average between 2015–2018 (23 °C), 2019 had the highest SST values for all seasons in average, with austral

Table 1. Annual average values of Sea Surface Temperature (SST) from Ilha Grande Bay and annual average values of air temperature (AIR), annual accumulated precipitation, and average accumulated monthly precipitation for each year in Marambaia meteorological station from 2015 to 2019. The last column indicates the difference between the 2019 data and the highest ever recorded since 2015. Standard deviation values are inside parentheses.

Factor	2015	2016	2017	2018	2019	Variation
SST	24.6 (±2.15)	24.4 (±2.50)	23.9 (±2.49)	24.5 (±2.15)	26.6 (±2.92)	2.0
AIR	23.8 (±2.22)	23.6 (±2.49)	23.1 (±2.40)	23.5 (±1.96)	23.9 (±2.19)	0.1
AAP	1102.0	876.4	1043.6	1178.2	1679.4	501.2
AMP	91.8 (±71.12)	73.0 (±68.52)	87.0 (±63.63)	98.2 (±73.10)	140.0 (±136.96)	41.8

Note: SST: sea surface temperature; AIR: air temperature; AAP: annual accumulated precipitation; AMP: average accumulated monthly precipitation for each year.

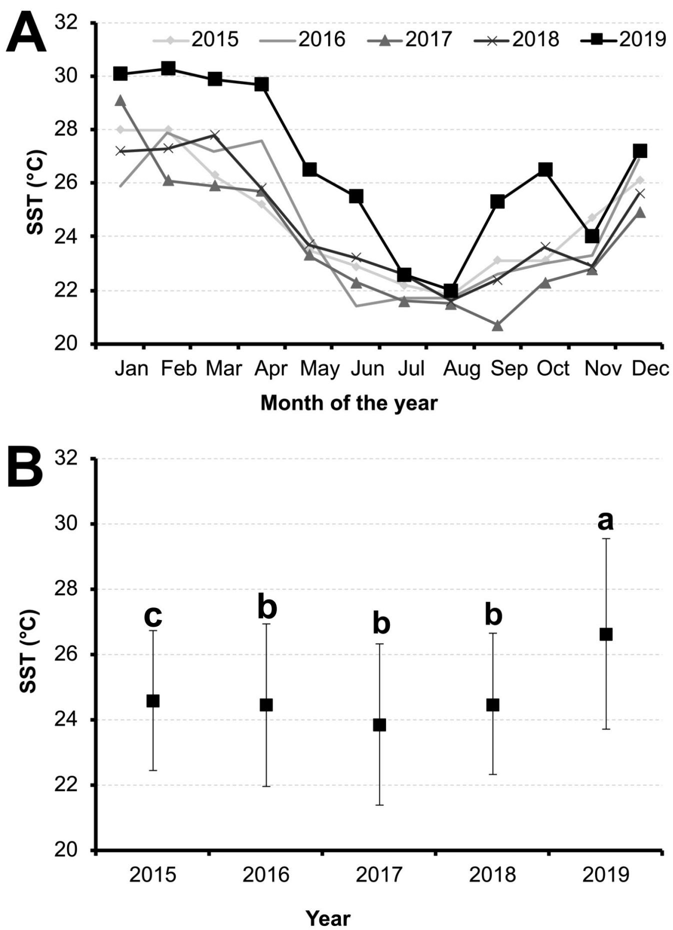

Figure 3. Sea surface temperature (SST) average values for both (a) months from 2015 to 2019, and (b) years obtained from Giovanni platform. In (b), statistical differences are shown by letters a, b (p ≤ 0.001), and c (p = 0.005) after ANOVA Repeated Measures and post-hoc Tukey test.

spring 1.6 °C warmer than the other years 2015–2018, and 2019 presented statistically higher values (Repeated Measures ANOVA F: 17.6, p < 0.001) SST than all compared years (Figure 3). The largest variations in air temperature occur during September (13.4−39.6 °C) and October (15.6−41.3 °C) (beginning of austral spring), while the largest accumulated precipitation values are recorded from January to March (281−473 mm) (austral summer and beginning of fall) (Supplementary Figure).

Discussion

Desmapsamma anchorata is widely spread in the Tropical Western Atlantic realm (Spalding et al. 2007), generally in high abundance, fast growing and aggressive competitive behavior (Aerts and van Soest 1997; McLean and Yoshioka 2008; Hajdu et al 2011; Silva et al. 2017). This sponge dominates Brazilian tropical bays rocky shores (Muricy and Hajdu 2006; Hajdu et al. 2011; Fortunato et al. 2020), but it also likes sedimented substrates from the Caribbean Sea to Rio de Janeiro state (McLean and Yoshioka 2008; Hajdu et al 2011; Fortunato et al. 2020). In general, few factors directly affect the species density in Brazil, such as presence of a more abundant species in Todos os Santos Bay (Bahia state) (see Oliveira and Lanna 2018) and hydrodynamics in IGB (Rio de Janeiro state) (see Fortunato et al. 2020).Specifically to IGB, it is one of the most frequent benthic species throughout the year in both abundance and relative cover in the bay side (Mantelatto et al. 2013, 2022; Fortunato et al. 2020). Their fragments presented fast growth from September to November during a manipulated experiment, doubling their volumes within a month (Ferreira 2016), and it can outgrow the invasive sun corals *Tubastraea* spp. locally (Silva et al. 2017, 2022). However, it seems sensitive to abrupt environmental changes through its distribution, such as high seawater temperature (Vilanova et al. 2004), pollution (Vilanova et al. 2004; Silva 2018) and storms (Wulff 2008). *Desmapsamma anchorata* may be considered as negatively affected to ocean warming in terms of gene expression, reproductive output, filtration capability, higher bleaching and necrosis due heat shock protein expression, and others (see Bell et al. 2018 for more examples). At IGB it is considered a putative sentinel species for urbanization pollutants (Silva 2018) and it is not observed in the assemblage close to thermal power plant water outlets (Vilanova et al. 2004).

Although 2019 SST was statistically warmer than other years at IGB, we cannot prove the direct relationship between the occurrence of high SST in 2019 and *D. anchorata*'s population decline and mortality, since we do not have information about annual cover or abundance data of the species for each year at IGB. However, an exceptional average increase of 2 °C in the SST since 2015 at Ilha Grande Bay (SE Brazil) and the species death are facts. Also, this year had extreme heat waves episodes that severely impacted Brazilian fauna in both Northeast (Duarte et al. 2020; Gaspar et al. 2021) and Southeast regions (Santos et al. 2021). In contrast to the survival of sponge assemblages after ENSO (Kelmo et al. 2013), Gaspar et al. (2021) suggests a higher impact on corals when ENSO and longer heat waves occur sequentially. Probably, this high SST in synergy with high precipitation values in

2019 (in comparison to other years) and more frequent and strong heat waves, favored an environmental context for this unprecedented strong population decline, bleaching and mortality rate of the marine sponge species *Desmapsamma anchorata* in the austral spring. While ocean warming may disrupt morphological and physiological changes in sponge species (Bell et al. 2018), run off may affects sponge species by increasing sedimentation that clog poriferans filtration system (i.e. Cerrano et al. 2001). Also, 45.7% of *D. anchorata* was intensively covered by cyanobacteria, a group favored by CO_2 rising (Visser et al. 2016) and harmful for corals (Ribeiro et al. 2018). The effect of this group on marine sponges is scarce (Rützler 1988; Webster 2007) but may not be underestimated.

Our biological record with marine sponges is the first along the Brazilian coast indicating population deterioration during an abnormal increase in the SST in the austral spring of 2019, when almost half of *D. anchorata* population was covered by cyanobacteria, macroalgae, bleached and/or necrosed and dead. Although some sponge species have tolerance to ocean warming and ocean acidification, most of the species are intensively affected by climate change (Peck et al. 2015; Bell et al. 2018), with several records of marine sponges death after high temperature and heat waves worldwide in the last years. It has been much more pronounced than historical mortality events (Smith 1941; Vacelet and Gallisian 1978; Rützler 1988; Webster 2007; Webster et al. 2002). Stronger heat waves and ocean warming provoke physiological and morphological lethal effects, benthic community shift from coral to seaweeds, cyanobacterial booms, and bacterial and viral diseases (Fromont and Garson 1999; Pérez et al. 2000; Stevely et al. 2011; Carballo and Bell 2017; Luter and Webster 2017). Outbreak in the *D. anchorata* population was possibly a synergy of several factors that we could not test. Physiologically and chemically monitoring the species is important to understand what factors may affect the species.

Desmapsamma anchorata population deterioration in the warmer austral spring from 2015–2019 in a climate change context in a biogeographic transition zone may reflect a shift in the marine community of IGB by decreasing the associated cryptic diversity and, in turn, opening space for other species arrival and coverage increase, since IGB has a high species turnover (Carlos-Júnior et al. 2019). Ilha Grande Bay holds about a thousand marine species and is considered a local biodiversity sanctuary (Creed et al. 2007). Absence of difference between healthy and unhealthy individuals of *D. anchorata* indicates a clear outbreak in its population. This collapse is dangerous once the species promotes three-dimensionality due its massive-arborescent shape plasticity, shelter for several species, high competitive ability and potential to indicate polluted or unpolluted areas. Therefore, *D. anchorata* is a key species for IGB monitoring in a climate change scenario.

Supplementary Material

The following online material is available for this article:

Figure S1 – Oceanographic and meteorological data from 2015 to 2019: (a) Monthly sea surface temperature variation in Ilha Grande Bay; (b) Monthly air temperature variation and (c) Monthly average accumulated precipitation in Marambaia station. Vertical bars are standard deviation values, dots are outliers above and below standard deviation, box represent 75% of the data and, line within box is the median.

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Author Contributions

Humberto Freitas de Medeiros Fortunato: Substantial contribution in the concept and design of the study; Contribution to data collection, Contribution to data analysis and interpretation; Contribution to manuscript preparation; Contribution to critical revision, adding intellectual content.

Amanda Guilherme da Silva: Substantial contribution in the concept and design of the study; Contribution to data collection; Contribution to data analysis and interpretation; Contribution to manuscript preparation; Contribution to critical revision, adding intellectual content.

Rafael Pereira Azevedo Teixeira: Substantial contribution in the concept and design of the study; Contribution to data collection; Contribution to manuscript preparation.

Breylla Campos Carvalho: Contribution to data collection; Contribution to data analysis and interpretation; Contribution to manuscript preparation; Contribution to critical revision, adding intellectual content.

Beatriz Grosso Fleury: Contribution to manuscript preparation; Contribution to data analysis and interpretation; Contribution to critical revision, adding intellectual content and financial support.

Conflicts of Interest

The authors declare that they have no conflict of interest related to the publication of this manuscript.

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