

Southward range expansion of *Siderastrea* spp. into Ilha Grande Bay: evidence of tropicalization in the Southwestern Atlantic

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Abstract

Climate-driven shifts in marine species distributions are increasingly reshaping coastal ecosystems, yet evidence for the widespread occurrence of tropicalization remains geographically uneven. Tropicalization, characterized by the poleward expansion of tropical species under warming conditions, has been increasingly documented, but its extent and generality across the Atlantic remain poorly understood. Here, we report a contemporary population of *Siderastrea* spp. in Ilha Grande Bay, Southwestern Atlantic, approximately 230 km south of the previously recognized southern distributional limit of the genus *Siderastrea* at Arraial do Cabo, Brazil. The occurrence of this population beyond the known southern limit of the genus, within a transitional biogeographic zone between the Tropical and Temperate Atlantic realms, provides an opportunity to examine a contemporary range shift in the context of long-term environmental change. We characterized population occurrence, structure, and associated benthic habitat and evaluated regional sea surface temperature (SST) trends using a 45-year time series. A total of 295 colonies were recorded at Sítio Forte Cove, with a mean density of 11.80 ± 20.24 colonies m^{-2} . Annual mean SST increased significantly from 1982 to 2025 at a rate of $0.149^{\circ}C$ decade $^{-1}$ ($R^2 = 0.192$, $p = 0.0029$). The contemporary southward occurrence of *Siderastrea* spp., together with persistent regional warming, is consistent with ongoing tropicalization of the Southwestern Atlantic. This range expansion provides empirical evidence consistent with ongoing tropicalization in a transitional marine region and highlights the potential for continued ocean warming to facilitate the southward redistribution of tropical reef organisms and reshape coastal communities.

INTRODUCTION

Climate-driven changes in the geographic distribution of marine species are increasingly altering the composition and structure of coastal ecosystems (Poloczanska et al., 2013; Pinsky et al., 2013; Meira et al., 2023). Among these changes, the tropicalization of temperate and transitional marine ecosystems is characterized by the poleward expansion of warm-affiliated species and the increasing contribution of tropical taxa to communities at higher latitudes (Vergés et al., 2014). Rising sea surface temperatures can modify the thermal suitability of habitats near species distributional boundaries, potentially facilitating the establishment and persistence of populations beyond previously recognized range limits. Such range shifts have been documented for tropical reef-building corals, including rapid poleward expansion associated with increasing sea surface temperatures (Yamano et al., 2011). More recently, climate projections have indicated that coral distributions in the Southwestern Atlantic may undergo substantial poleward shifts, providing evidence that tropicalization may become an increasingly important process shaping regional reef communities (Martello et al., 2024).

The Southwestern Atlantic provides an important natural setting in which to investigate these processes because its southeastern coast represents a biogeographic transition between tropical and warm-temperate environments (Spalding et al., 2007). Reef-associated communities in this region occur under strong environmental variability, including pronounced thermal fluctuations associated with coastal oceanographic processes such as the Cabo Frio upwelling (Castelao & Barth, 2006). Several tropical

reef-associated organisms reach their southern distributional limits along the southeastern Brazilian coast, making this region particularly sensitive to changes in environmental suitability and potentially responsive to climate-driven range shifts. The Cabo Frio region (22°59'S) has been considered the southern range limit for several scleractinian corals, including *Siderastrea stellata* Verrill, 1868 and *Porites branneri* (Rathbun, 1888), as well as other reef-associated organisms such as the hydrocoral *Millepora alcicornis* (Linnaeus, 1758) and the octocoral *Phyllogorgia dilatata* (Esper, 1806). Further south, between Cabo Frio and the coast of São Paulo State, lies the southern range limit of the brain coral *Mussismilia hispida* and the Brazilian coral province (Laborel-Deguen et al., 2019). Populations occurring near these limits may persist under conditions close to their physiological boundaries and may therefore respond rapidly to changes in temperature and other environmental factors (Kawecki, 2008; Beger et al., 2014; Schoepf et al., 2023).

Corals are particularly relevant indicators of tropicalization because their distributions are strongly constrained by temperature, while their persistence also depends on dispersal, recruitment, and habitat availability. The genus *Siderastrea* provides a useful system for examining these processes in the Southwestern Atlantic. *Siderastrea* is a genus of zooxanthellate scleractinian corals comprising four species: *Siderastrea savignyana* Milne Edwards & Haime, 1849, restricted to the Indo-Pacific, whereas *Siderastrea radians* (Pallas, 1766), *Siderastrea siderea* (Ellis & Solander, 1786), and *Siderastrea stellata* are restricted to the Atlantic. *Siderastrea radians* and *S. siderea* have broad distributions in the Western Atlantic, occurring in the Florida Bay, Caribbean, and Gulf of Mexico, with records extending to localities in northeastern Brazil and the Abrolhos Bank (Barbeitos et al., 2024). *Siderastrea radians* also has records farther south along the Brazilian coast, including the Aracruz region (20°S) in northern Espírito Santo (Barbeitos et al., 2024). In contrast, *S. stellata* was originally described as an endemic species of the Brazilian coast and has a distribution associated with the central-western tropical and Southwestern Atlantic. Historically, its distribution along the Brazilian coast has been delimited between Manuel Luís Reef (00°53'S) and the Arraial do Cabo region (23°S), where established populations occur under marginal environmental conditions (Lima & Coutinho, 2016). García et al. (2017) reported *S. stellata* from the Sistema Arrecifal Veracruzano National Park in the Gulf of Mexico (19°16'N), extending the known northern occurrence of the species in the Western Atlantic. The geographic overlap among species of the genus, together with their high morphological similarity, represents an important challenge for species-level identification and for accurately determining their distributional limits (Neves et al., 2008; Menezes et al., 2013). The occurrence of *Siderastrea* spp. near the southern boundary of the Brazilian coral province therefore provides an opportunity to examine whether changes in environmental conditions may be accompanied by shifts in its geographic distribution.

One relevant aspect of the southern distribution of *Siderastrea* in southeastern Brazil is the existence of isolated historical records beyond its currently recognized range limits. MNRJ (1971) reported the occurrence of *Siderastrea* spp. in the Ubatuba region (23°26'S), on the coast of São Paulo State (SiBBr, 2026). However, this record is exclusively qualitative and provides no information on abundance, density, or the extent of the occurrence, making it impossible to determine whether it represented an established population or the occasional presence of one or a few colonies. Moreover, the absence of the species

from faunal surveys and community studies south of the Arraial do Cabo region (Santos & Pires-Vanin, 2004; Creed et al., 2007; Lages and Meurer, 2007; Mantelatto et al., 2020, 2022) in subsequent decades makes it difficult to determine whether this occurrence persisted over time, whether the population underwent local extinction, or whether subsequent colonization events occurred. Thus, the historical occurrence of *Siderastrea* spp. in São Paulo raises questions regarding the temporal persistence and colonization dynamics of marginal populations beyond the known southern range limit.

Here, we report a contemporary population of *Siderastrea* spp. in Ilha Grande Bay, approximately 230 km south of the previously recognized southern limit at Arraial do Cabo. We characterize its occurrence, density, frequency, colony size structure, and associated benthic habitat, and examine this range extension in the context of a 45-year sea surface temperature time series from Ilha Grande Bay. Specifically, we assess whether the occurrence and apparent establishment of *Siderastrea* spp. beyond its previously recognized southern range limit are consistent with the ongoing tropicalization of the Southwestern Atlantic. By integrating a contemporary range extension with evidence of long-term regional warming, this study provides a local example of the potential redistribution of tropical reef organisms under changing environmental conditions along transitional coastal environments.

METHODS

Study site

Ilha Grande Bay (BIG) is located in southwestern Rio de Janeiro State, Brazil (23°05'–23°14'S; 44°05'–44°23'W), within a transitional area between the Tropical and Warm Temperate provinces of the Southwestern Atlantic (Spalding et al., 2007). The water masses present in the region result from the mixing of coastal waters with Tropical Water (TW) and South Atlantic Central Water (SACW), with greater intrusion of the latter during spring and summer (Kjerfve et al., 2021; Sousa et al., 2026). Sea surface temperature (SST) in the region ranges from 24.4–28.4°C in summer and 24–26°C in winter (Creed et al., 2007), although recent studies have recorded temperatures exceeding 30°C (Barboza & Skinner, 2021; Fortunato et al., 2022). Salinity ranges from 27–37 in shallow waters and from 32–38 at 30 m depth. Since 2019, 14 localities have been continuously monitored as part of a monitoring program focused on *Mussismilia hispida*. These localities include Ponta Grossa do Sítio Forte (PG), Ilha da Longa (IL), Gipóia (GI), Araçatiba (AR), Enseada do Bananal (BA), Enseada do Sítio Forte (SF), Ilha da Longa (IL), Ilha Queimada Grande (QG), Ilha Imboassica (IM), Ilha de Búzios (BU), Ilha do Brandão (BR), Ilha Sabacu (SA), Ilha dos Papagaios (PA), and Ilha dos Porcos (PO) (Fig. 1).

Sampling design

Between 4 and 6 June 2026, eight localities were surveyed in Ilha Grande Bay (BIG): Bananal Cove (BA), Sítio Forte Cove (SF), Ilha da Longa (IL), Queimada Grande Island (QG), Imboassica Island (IM), Búzios Island (BU), Brandão Island (BR), and Sabacu Island (SA). At each locality, two 20-m transects were

established, along which 100 sequential 50x50 cm photoquadrats were obtained, covering depths between 2 and 5 m. In addition, an active search for corals was conducted within a 20 × 1 m sampling area along each transect. At Sítio Forte Cove (23°07'58.31"S; 44°17'27.72"W), *Siderastrea* spp. was recorded on a shallow rocky reef located at approximately 2–3 m depth.

Sea Surface Temperature Time Series

Sea surface temperature (SST) data were obtained from the Global Ocean OSTIA Sea Surface Temperature and Sea Ice Reprocessed product (Worsfold et al. 2024), distributed by the Copernicus Marine Service. The product consists of daily, gap-free Level-4 foundation SST fields at a spatial resolution of 0.05° × 0.05°, generated from the combination of satellite and in situ observations.

The dataset covers the period from 1 October 1981 to 31 March 2026. SST data were extracted for a representative location within Ilha Grande Bay (23.125°S, 44.275°W) using the nearest grid cell available in the dataset. Daily SST observations were subsequently aggregated into monthly and annual means to characterize seasonal and interannual variability. Monthly climatological means were calculated by averaging SST values for each calendar month across the entire time series.

To assess long-term changes in SST, annual mean temperatures between 1982 and 2025 were analyzed using a linear regression, with year as the explanatory variable and annual mean SST as the response variable. The regression slope was expressed as °C decade⁻¹. The coefficient of determination (R^2) and significance level (p-value) were used to evaluate the strength and statistical significance of the temporal trend. A non-parametric Mann–Kendall test was additionally applied to assess the presence and direction of a monotonic temporal trend in annual mean SST, with Kendall's tau (τ) and the associated p-value used to quantify the strength and statistical significance of the trend. Sen's slope was calculated as a robust, non-parametric estimate of the magnitude of the temporal change and was expressed as °C decade⁻¹.

All SST data processing and statistical analyses were performed in Python. NetCDF files were read and processed using *xarray* and *netCDF4*, while *NumPy* and *pandas* were used for numerical operations and data aggregation.

Ecological data analysis

The abundance of *Siderastrea* spp. colonies was determined by counting colonies in the photoquadrats, and the mean and standard deviation of colony abundance were calculated. Frequency of occurrence was calculated as the ratio between sampling units in which the coral was present and the total number of sampling units. Population size structure was assessed by measuring the maximum diameter of *Siderastrea* colonies within the photoquadrats using ImageJ (Rueden et al., 2017). Percent cover was estimated using Coral Point Count with Excel extensions (CPCe; Kohler & Gill, 2006), based on 49 regularly spaced points arranged in a 7 × 7 grid. The data were square-root transformed prior to analysis.

Benthic community structure at Sítio Forte was analyzed using non-metric multidimensional scaling (nMDS) based on Bray–Curtis dissimilarities. Associations between benthic taxa and the ordination configuration were assessed using vector fitting (*envfit*), with significance determined using 9,999 permutations ($p < 0.05$). All analyses were conducted in R using the *vegan* package (Oksanen et al., 2018).

RESULTS

Long-term sea surface temperature trends

Annual mean SST was $24.32 \pm 0.68^{\circ}\text{C}$ and varied substantially among years, ranging from $23.66 \pm 1.63^{\circ}\text{C}$ in 1982 to $25.69 \pm 2.47^{\circ}\text{C}$ in 2019. Despite substantial interannual variability, annual mean SST exhibited a significant positive long-term trend, increasing at a rate of $0.149^{\circ}\text{C decade}^{-1}$ ($R^2 = 0.192$, $p = 0.0029$; Fig. 2). This increasing trend was corroborated by the Mann–Kendall test ($\tau = 0.296$, $p = 0.0048$), with a Sen's slope of $0.150^{\circ}\text{C decade}^{-1}$.

The lowest annual mean SSTs were recorded during the 1980s and 1990s, including $23.66 \pm 1.63^{\circ}\text{C}$ in 1982, $23.60 \pm 2.20^{\circ}\text{C}$ in 1988, and $23.80 \pm 2.24^{\circ}\text{C}$ in 1991. Lower values were also observed during the early-to-mid 2010s, reaching $23.78 \pm 1.92^{\circ}\text{C}$ in 2013 and $23.73 \pm 1.91^{\circ}\text{C}$ in 2014. In contrast, the highest annual mean SSTs occurred toward the latter part of the time series, with the highest value recorded in 2019 ($25.69 \pm 2.47^{\circ}\text{C}$), followed by 2020 ($24.95 \pm 1.84^{\circ}\text{C}$) and 2023 ($24.88 \pm 1.91^{\circ}\text{C}$). Despite these interannual fluctuations, the greater occurrence of higher annual mean SSTs toward the end of the time series is consistent with the significant long-term warming trend observed from 1982 to 2025.

Southward occurrence and population structure of *Siderastrea* spp.

A total area of 320 m^2 of rocky reef was surveyed, with 40 m^2 sampled at each locality. *Siderastrea* spp. (Fig. 3) was recorded exclusively at Sítio Forte Cove, where a total of 295 colonies were found, with a mean density of 11.80 ± 20.24 colonies m^{-2} and a frequency of occurrence of 49% across photoquadrats.

The 295 observed colonies of *Siderastrea* spp. were measured, yielding a mean colony diameter of $3.90 \pm 3.33 \text{ cm}$. Colony size ranged from 0.05 to 18.98 cm, and the size-frequency distribution was right-skewed, with a higher concentration of colonies in the smaller size classes and fewer colonies occurring in the larger size classes (Fig. 4). Juvenile colonies ($< 4 \text{ cm}$) accounted for 65.76% of the total number of colonies.

The benthic community at Sítio Forte Cove was dominated by turf algae ($73.82 \pm 28.23\%$), with substantial contributions from turf with sediment ($8.76 \pm 16.15\%$) and the zoanthid *Palythoa caribaeorum* ($10.69 \pm 19.77\%$), in addition to a high cover of sandy sediment ($9.96 \pm 20.78\%$). *Siderastrea* spp. had a mean cover of $2.79 \pm 5.61\%$, whereas *Mussismilia hispida* had a mean cover of $0.36 \pm 1.15\%$.

The nMDS ordination revealed clustering among samples based on benthic community composition (Fig. 5). Unconsolidated sediment, sand, and rubble showed the strongest negative correlations with axis 2 of the nMDS, whereas *Siderastrea* spp. and *Palythoa caribaeorum* showed the strongest positive correlations in the opposite direction.

DISCUSSION

This record of a *Siderastrea* spp. population, located more than 230 km south of Arraial do Cabo, represents the southernmost contemporary record of the genus in the region. The population structure observed in Ilha Grande Bay provides further context for interpreting the southward occurrence of *Siderastrea* spp. Mean colony size (3.90 ± 3.33 cm) was lower than values reported for *Siderastrea stellata* in Arraial do Cabo (10.7 cm; Lima & Coutinho, 2016) and Itacimirim, Bahia (9 cm; Kikuchi & Leão, 1998), but higher than that reported for Abrolhos (0.8 cm; Lins-de-Barros & Pires, 2006). Considering the growth rates reported for *S. stellata* in Brazil (2.4–6.8 mm yr⁻¹; Lins-de-Barros & Pires, 2006; Evangelista et al., 2018), the mean colony size observed (3.90 cm) would correspond, under a linear approximation, to approximately 6–16 years of growth (since 2010–2020). Although this estimate does not directly represent the age of the colonies or the population, it indicates a temporal scale compatible with relatively recent establishment.

One possible explanation for this establishment is that changes in environmental conditions have increased the suitability of Ilha Grande Bay for the colonization and persistence of *Siderastrea* spp. This interpretation is consistent with the significant long-term increase in SST observed in the bay over the study period and with the broader tropicalization hypothesis, whereby warming can facilitate the poleward redistribution and establishment of tropical marine organisms (Vergés et al., 2014; Martello et al., 2024). Similar poleward shifts of tropical corals have been documented elsewhere, including along the Japanese coast, where changes in coral distribution have coincided with increasing sea temperatures (Yamano et al., 2011). In this context, the contemporary establishment of *Siderastrea* spp. in Ilha Grande Bay may reflect the interaction between dispersal and increasingly suitable thermal conditions at the southern margin of its distribution. Although the available data do not demonstrate a causal relationship between warming and establishment, the temporal coincidence between the southward occurrence of *Siderastrea* spp. and the long-term warming of Ilha Grande Bay is consistent with a climate-driven shift in the southern range boundary and provides further evidence for the ongoing tropicalization of the Southwestern Atlantic.

Colony density at Sítio Forte Cove (11.8 colonies m⁻²) exceeded values reported for Arraial do Cabo (8.37 colonies m⁻²), Búzios (5.26 colonies m⁻²; Oigman-Pszczol & Creed, 2004), and Fernando de Noronha (6.62 colonies m⁻²; Lins-de-Barros & Pires, 2006; Maida et al., 1996), what can indicate a high larval supply and/or survivorship rate at our studied region, or even reduced competition with other benthic organisms. At the same time, coral cover (2.79%) was lower than that reported for Arraial do Cabo (7.1%; Lima & Coutinho, 2016) and Búzios (8.5%; Oigman-Pszczol & Creed, 2004), what also support the recent colonization hypothesis and suitable habitat being explored.

To our knowledge, this is the second report of *Siderastrea* spp. Southernmost than Arraial do Cabo. Voucher (MNRJ-CNI078) deposited in the Zoological Collection of the Museu Nacional do Rio de Janeiro (SiBBR, 2026) refers to one sample from Ubatuba (São Paulo state), collected in 1971. However, this historical record does not indicate whether the population was subsequently monitored, and no additional or recent records of *Siderastrea* have been found in studies of corals from the region (Mariano et al., 2026; Grillo et al., 2021; Gomes et al., 2019). In addition, several expeditions from São Paulo Oceanographic Institute was held at Ilha Grande bay during 1960–1980 decades, that has also a cove named “Ubatuba” and perhaps, this sample could refer to it but wrongly positioned at Ubatuba city (SP).

The high colony density, combined with low overall cover and a right-skewed size-frequency distribution, suggests that the predominance of small colonies may reflect two non-mutually exclusive processes: (i) relatively recent establishment of the population, resulting in a size structure dominated by young colonies; and/or (ii) the influence of limiting factors affecting colony growth in the shallow rocky habitats of Sítio Forte Cove. Colony size cannot be used directly as a proxy for age, but the predominance of small colonies is consistent with the hypothesis of recent establishment, particularly given the absence of recent records of *Siderastrea* in the region. Ilha Grande Bay has been extensively investigated through faunal surveys (Creed et al., 2007) and studies of benthic community structure (Lages and Meurer, 2007; Mantelatto et al., 2020, 2022), including within Sítio Forte Cove itself (Santos et al., 2022), making prolonged persistence of a population with the density and frequency observed here without detection less likely. Although local factors limiting colony growth cannot be excluded, the observed size structure, together with the paucity of historical records, is consistent with relatively recent establishment of *Siderastrea* spp. in Ilha Grande Bay. This pattern is also consistent with the long-term increase in SST observed in Ilha Grande Bay, supporting the hypothesis that warming conditions may have facilitated the establishment of tropical corals beyond their previously recognized southern range limit.

Although the colonies were identified here as *Siderastrea* spp., their occurrence in Ilha Grande Bay is most likely attributable to *S. stellata*, given its historically documented distribution, its southern range limit at Arraial do Cabo, and its high tolerance of variable environmental conditions and exposure to colder waters associated with coastal upwelling in southeastern Brazil (Lima & Coutinho, 2016; Barbeitos et al., 2024). *Siderastrea stellata* and *S. radians* are brooding species whose larvae have a planktonic period, differing between them by duration. Larvae of *S. stellata* remains viable from 72h to 15 days after hatching, as *S. radians* has a planktonic duration from 24-48h (Neves & da Silveira, 2003). Considering the distance from Arraial do Cabo and Ilha Grande bay, combined with the influence of El Niño events on the northmost proximity of Brazil Current (BC), and its velocity (de Paula et al, 2025), 15 days is enough to enable *S. stellata* larval transport and settlement, but not *S. radians*.

Local habitat characteristics may also contribute to the establishment of *Siderastrea* spp. at Sítio Forte Cove. The similar orientations of the *Siderastrea* spp. and *P. caribaeorum* vectors in the ordination indicate that these taxa were associated with similar environmental conditions. This pattern may reflect the occurrence of *Siderastrea* spp. in shallow substrates, as previously observed on Brazilian reefs (Lins-de-Barros & Pires, 2006; Evangelista et al., 2018), where *Palythoa caribaeorum* is also widespread in

shallow environments of Ilha Grande Bay (Castro, 1999; Lages & Meurer, 2007; Koutsoukos, 2015; Mantelatto et al., 2020). The benthic community at Sítio Forte was characterized by high turf-algal cover and relatively low *P. caribaeorum* cover compared with the regional average (20–50%) (Lages & Meurer, 2007; Koutsoukos, 2015). These conditions may provide suitable substrates for the recruitment and persistence of *Siderastrea* spp., particularly given the high recruitment rates reported for turf-dominated marginal reefs (Tanvet et al., 2022). The proximity to the sandy sediment interface was evident from the high contribution of sand to total benthic cover. In this area, the embayment floor includes remnants of mangroves and small streams that discharge onto nearby beaches, potentially increasing resuspension and sedimentation, particularly in this shallow environment. Such conditions may be tolerated by *S. stellata*, which has been reported to exhibit high resistance to sedimentation (Leão et al., 2003; Lins-de-Barros & Pires, 2006). Thus, local habitat characteristics may contribute to the establishment of *Siderastrea* spp. in Ilha Grande Bay, potentially interacting with the broader increase in thermal suitability associated with regional warming.

The final decision about species identification, despite all evidences, will only be possible examining both morphological characters and molecular analyses of the collected colonies, for further taxonomic studies and precisely identification to *S. stellata*. And finally, the dynamics of the southward range expansion of *Siderastrea* spp. in Ilha Grande Bay should be monitored over time. The establishment of this population, coinciding with the long-term increase in SST observed in the region, highlights the potential role of changing thermal conditions in facilitating the colonization of tropical corals beyond their previously recognized southern range limits. Continued monitoring will be essential to determine whether the population persists and expands locally and whether similar southward shifts occur in other tropical reef-associated organisms. Such changes could provide further evidence of an ongoing tropicalization of benthic communities along the Southwestern Atlantic and help elucidate its potential consequences for local biodiversity and community structure.

Declarations

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Author Contributions:

GLGP identified and documented the *Siderastrea* spp. population and was responsible for field records and photographs. GLGP and LFS jointly conceived, elaborated, conducted, and executed the study, including data analysis, interpretation of the results, and preparation of the manuscript. Both authors reviewed and approved the final version of the manuscript.

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Data availability

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

Ethical Statement

The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

Ethics approval

This study was conducted under research authorization from SISBIO (80994) and INEA (009/2025 and 016/2022).

Disclosure

The authors have no relevant financial or non-financial interests to disclose.

Conflict of interest

The authors declare no competing interests.

Clinical Trial Number

Not applicable.

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Figures

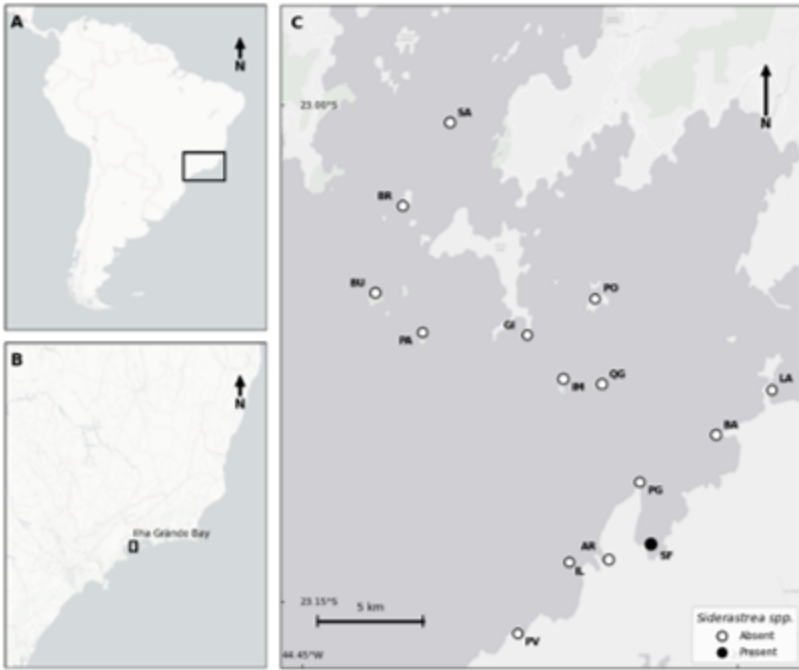


Figure 1

Study sites arranged from north to south: SA – Sabacu, BR – Brandão Island, BU – Búzios Island, BO – Porcos Island, PA – Papagaios Island, GI – Gipóia Island, IM – Imboassica Island, QG – Queimada Grande Island, LA – Lagoa Azul, BA – Bananal Cove, PG – Ponta Grossa do Sítio Forte, SF – Sítio Forte Cove, AR – Araçatiba, IL – Longa Island, and PV – Vermelha Beach

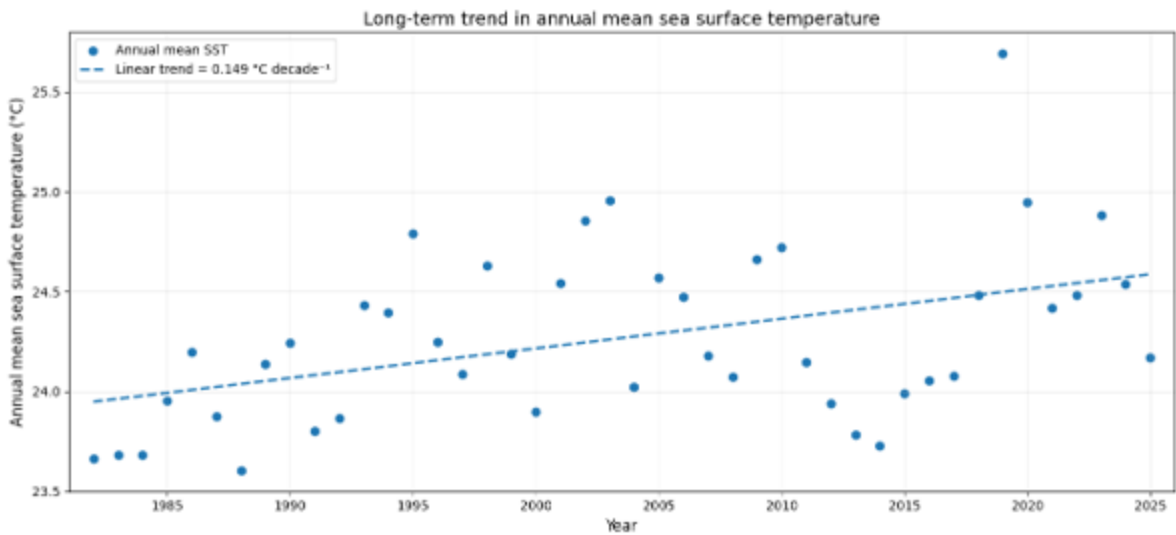


Figure 2

Long-term trend in annual mean sea surface temperature in Ilha Grande Bay (1982 – 2025).

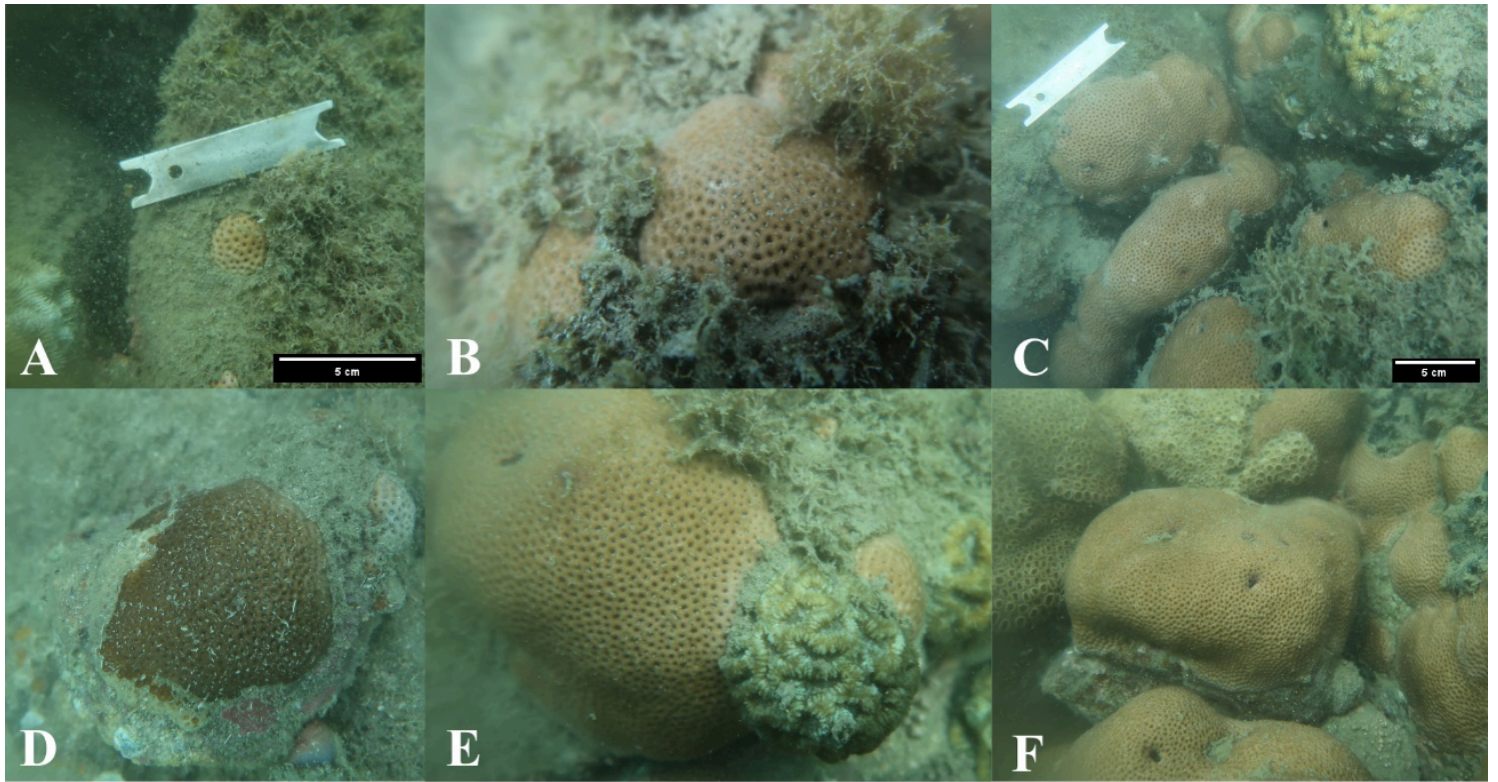


Figure 3

Records of *Siderastrea* spp. at Sítio Forte Cove, Ilha Grande Bay. (A) *Siderastrea* spp. recruit; (B, D, F) *Siderastrea* spp. colonies; (C) adult *Siderastrea* spp. colony; (E) *Siderastrea* spp. colony adjacent to *Mussismilia hispida*. Scale bar: 5 cm.

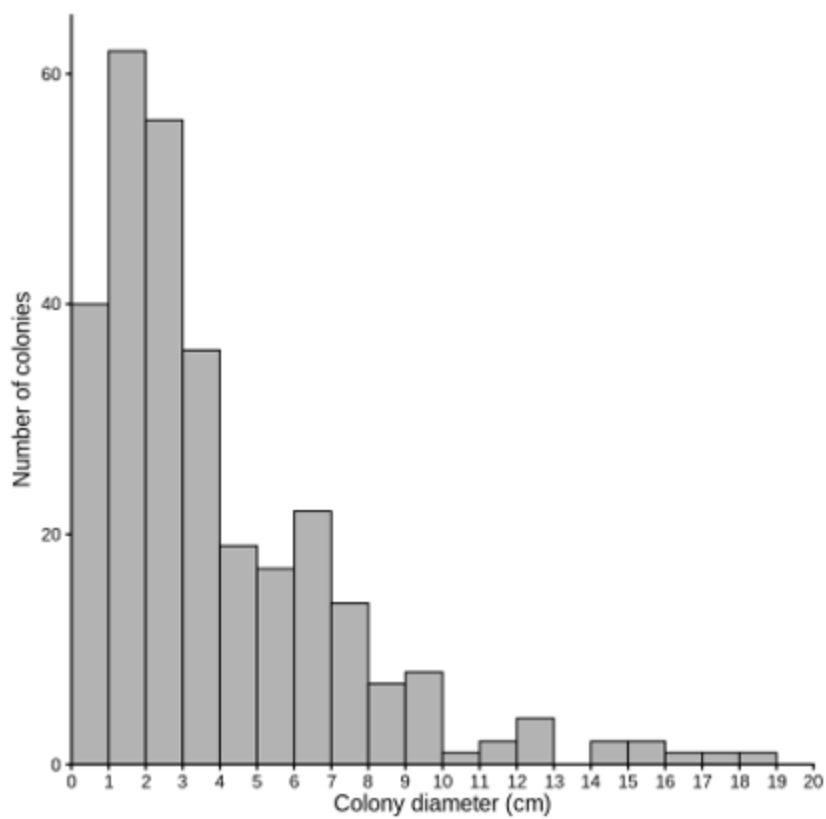


Figure 4

Size-frequency distribution of *Siderastrea* spp. colonies recorded at Sítio Forte, Ilha Grande Bay, Brazil.

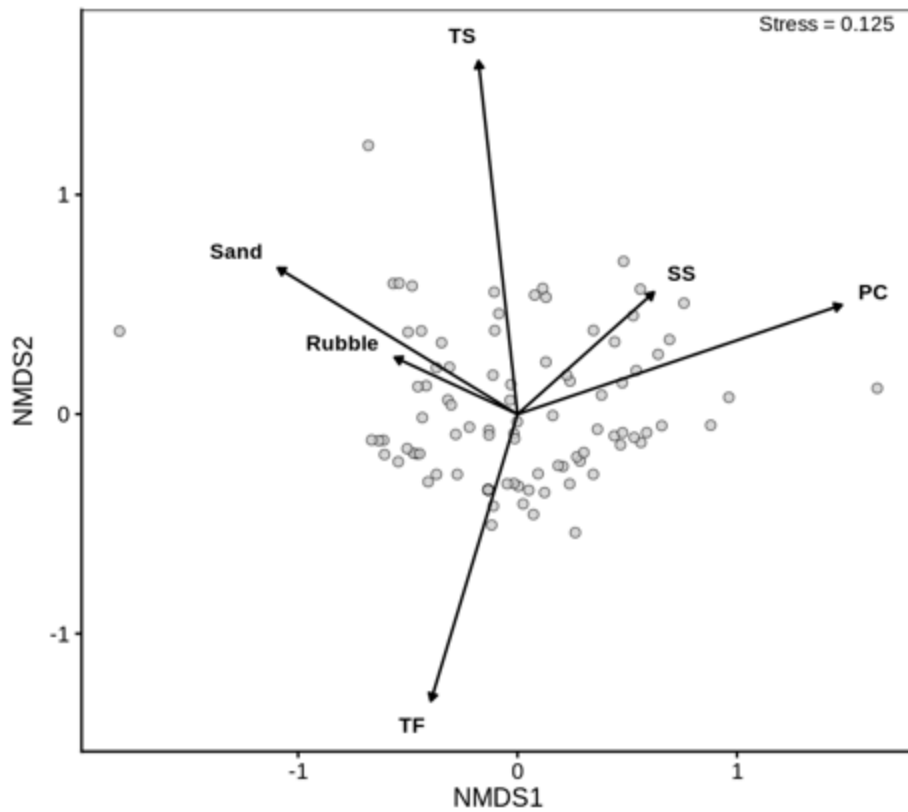


Figure 5

Non-metric multidimensional scaling (nMDS) ordination of benthic community composition and substrate categories at Sítio Forte, Ilha Grande Bay. Arrows represent significant associations of benthic taxa and substrate categories with the ordination configuration. TS – turf with sediment; SS – *Siderastrea* spp.; PC – *Palythoa caribaeorum*; TF – Turf; Stress = 0.125.