Smallmouth grunt (*Brachygenys chrysargyrea*) over a coral reef in Fernando de Noronha, Brazil
Credit: Zaira Matheus

BRAZIL

Authors

Beatrice P. **Ferreira**[1], Ana Lidia B. **Gaspar**[2], Thales J. **Vidal**[2], Ágatha N. **Ninow**[3], Guilherme O. **Longo**[4,5], Cesar A.M.M. **Cordeiro**[6], Miguel **Mies**[7,8], Camila B.L. **Silveira**[9], Thiago B.N. **Oliveira**[1], Kelly Y. **Inagaki**[4], Giovanna **Destri**[7], Ana Paula L. **Prates**[10]

[1]Department of Oceanography, Universidade Federal de Pernambuco, Recife, Pernambuco, Brazil | [2]Instituto Recifes Costeiros, Tamandaré, Pernambuco, Brazil | [3]National Center for Research and Conservation of Marine Biodiversity in the Northeast (CEPENE-Tamandaré ICMBio), Tamandaré, Pernambuco, Brazil | [4]Marine Ecology Laboratory, Department of Oceanography and Limnology, Universidade Federal do Rio Grande do Norte, Natal, Rio Grande do Norte, Brazil | [5]Department of Biology, University of Massachusetts Boston, Boston, USA | [6]Laboratório de Ciências Ambientais, Universidade Estadual do Norte Fluminense, Campos dos Goytacazes, Rio de Janeiro, Brazil | [7]Instituto Oceanográfico, Universidade de São Paulo, São Paulo, Brazil | [8]Instituto Coral Vivo, Santa Cruz Cabrália, Bahia, Brazil | [9]Departamento de Oceanografia, Universidade Federal da Bahia, Salvador, Bahia, Brazil | [10]Departamento de Oceano e Gestão Costeira, Ministério do Meio Ambiente e Mudança do Clima, Brasília, Distrito Federal, Brazil

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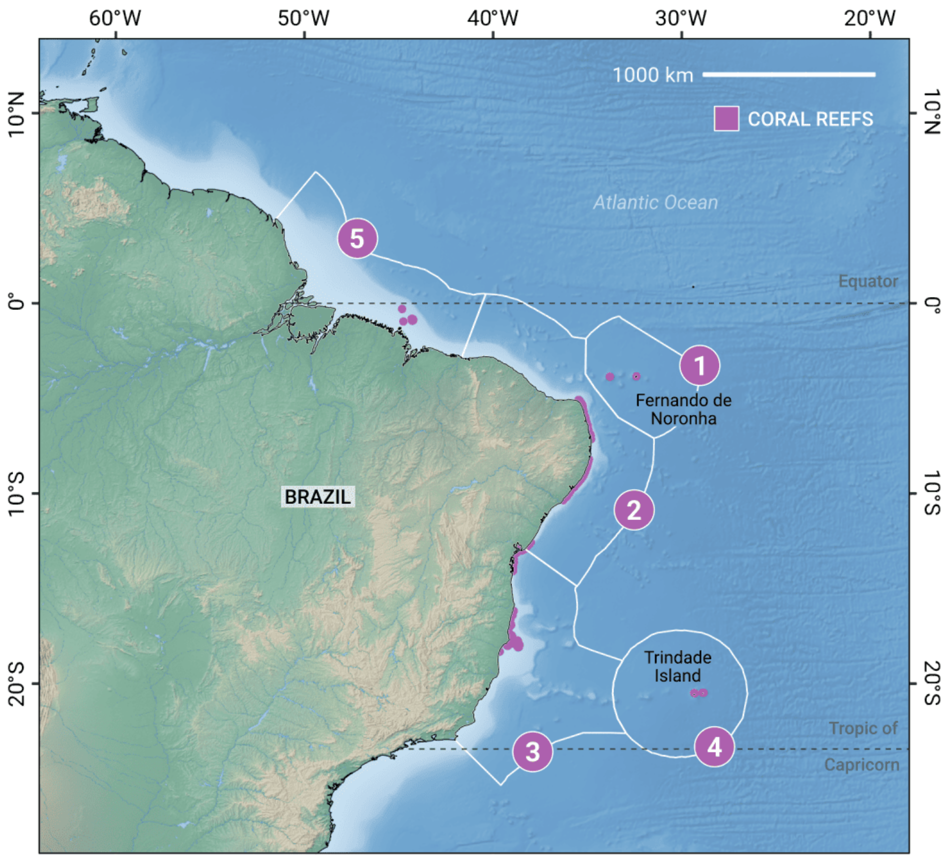
INTRODUCTION

The GCRMN Brazil region extends over a maritime area of around 2.6 million km^2, ranging across 32° of latitude and 28° of longitude. The region hosts 1,178 km^2 of coral reefs, representing 0.5% of the world's coral reef extent, and is the 9th-largest GCRMN region in terms of coral reef extent. Coral reefs in this region lie entirely within Brazil's exclusive economic zone, with shallow tropical reef formations occurring on oceanic islands and along the coastline, from Parcel de Manuel Luís in the north to the Abrolhos region in the east (Figure 2.2.1). These reefs support a relatively low-diversity coral fauna with a high level of endemism, including many relic species dating back to the Tertiary (Paleogene-Neogene periods). Reef formations are diverse and include shallow bank reefs near the coast, fringing reefs, coral knolls, patch reefs, isolated bank reefs, and coral pinnacles known locally as "chapeirões" [148]. The region also encompasses extensive mesophotic reefs [149], as well as rocky reef systems, such as those found west of Trindade Island [150].

For the purpose of this report, the GCRMN Brazil region was divided into five subregions (Figure 2.2.1). However, subregion 4 (Trindade and Martin Vaz Islands), although monitored, does not host true shallow carbonate-accretive coral reefs and is instead characterised by rocky reefs with encrusting coral colonies [151, 152].



▲ **Figure 2.2.1.** The distribution of coral reefs within the Brazil region and respective subregions. White polygons and numbers represent subregions. Subregion 1 = Fernando de Noronha and Rocas Atoll, Subregion 2 = North-eastern Brazil, Subregion 3 = Eastern Brazil, Subregion 4 = Trindade and Martin Vaz Islands, Subregion 5 = Amazonia. Coral reefs are delineated with a 20 km buffer to enhance interpretation, and only coral reefs within the region are represented. The scale bar provides distance at the equator and may not accurately represent distance over the entire latitudinal range of the region.

This subregion was therefore excluded from the analyses. Similarly, subregion 5 (Amazonia), where shallow reefs are represented by the unique Parcel de Manuel Luís formation off Maranhão state [153, 154], lacked long-term monitoring data and was also not included in this report. Subregion 3 (Eastern Brazil) hosts 56.9% of coral reefs in the region (670 km^2), whereas subregion 1 (Fernando de Noronha and Rocas Atoll), hosts only 0.8% of coral reefs in the region (10 km^2, Table A.1).

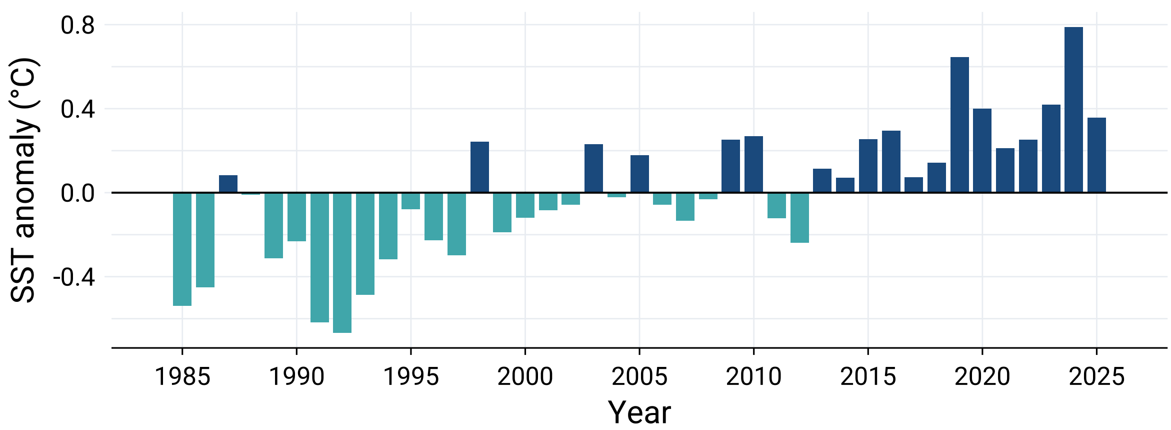
As of 2020, approximately 3.5 million inhabitants were living within 5 km of coral reefs. From 2000 to 2020, the region recorded a 36.3% increase in human populations residing within 5 km of coral reefs, representing an average annual increase of around 50,000 inhabitants. The greatest increase in populations over this period was recorded in subregion 2 (Northeastern Brazil), which also recorded the highest number of inhabitants in 2020 (Table A.2).

THREATS AND DISTURBANCES

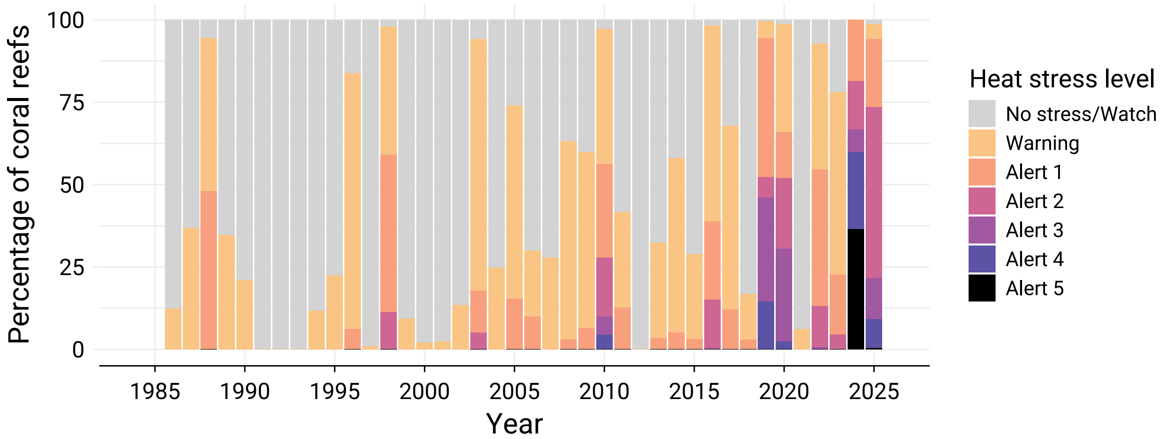
Heat stress

From 1985 to 2025, the long-term average of sea surface temperature (SST) recorded over coral reefs within the Brazil region was 26.65 °C. During this period, the SST over coral reefs in the region increased by 0.76 °C, corresponding to an average warming rate of 0.19 °C per decade (Table A.3).

Between 1986 and 2025, major episodes of heat stress affecting Brazil coral reefs occurred in 1998, 2010, 2016, 2019–2020, and 2024–2025. Among these, four correspond to global bleaching events (1998, 2010, 2016, and 2024) and one regional bleaching event (2019–2020). Although the intensity and impacts varied across subregions, the events of 2019, 2020, and 2024 rank among the most extreme heat-stress events ever recorded in the region (Figure 2.2.3).



▲ **Figure 2.2.2.** Annual mean sea surface temperature (SST) anomalies (°C) over the coral reefs of the Brazil region from 1985 to 2025. SST anomalies were calculated based on the long-term average over the period 1985–2025. Positive values (red bars) indicate SST warmer than the long-term average, whereas negative values (blue bars) indicate SST cooler than the long-term average. Derived from NOAA Coral Reef Watch data (Skirving *et al.* [107]; see Materials and Methods).



▲ **Figure 2.2.3.** Percentage of the coral reefs within the Brazil region experiencing heat stress levels per year, from 1986 to 2025. No stress/Watch (DHW = 0); Warning (possible bleaching, $0 < \text{DHW} < 4$); Alert 1 (reef-wide bleaching, $4 \leq \text{DHW} < 8$); Alert 2 (reef-wide bleaching and mortality of heat-sensitive corals, $8 \leq \text{DHW} < 12$); Alert 3 (multi-species mortality, $12 \leq \text{DHW} < 16$); Alert 4 (severe multi-species mortality, $16 \leq \text{DHW} < 20$); and Alert 5 (near-complete mortality, $\text{DHW} \geq 20$). Derived from NOAA Coral Reef Watch data (Skirving *et al.* [107]; see Materials and Methods).

Regional disturbances

Impacts on coral reefs across the entire Brazil region include mining [155] and the exploitation and transport of oil and gas in nearby areas, which may cause spills, such as the 2019 event [156], and which can act as vectors of invasive species such as the sun coral *Tubastrea* spp. [157]. The invasive lionfish (*Pterois* sp.) has been recorded along the Brazilian coast since 2020 [158], with occurrences in subregion 5 (Amazonia), subregion 3 (Eastern Brazil) and subregion 2 (Northeastern Brazil). To date, Fernando de Noronha Archipelago has recorded the highest lionfish densities, raising concerns about the potential impacts of this species on local biodiversity [159].

The continuous intensification of multiple local pressures, including increased overfishing and water quality deterioration, may reduce reef resilience and compromise post-disturbance recovery potential across the entire region, requiring broader national strategies to address the issues [160–162].

Subregion 1 comprises the Biological Reserve of Rocas Atoll and the Fernando de Noronha Archipelago, both located in oceanic waters that were intensely exploited by fisheries until the establishment of marine protected areas in the late 1970s and 1980s. Rocas Atoll is a no-take no-entry marine protected area that hosts a research station with a maximum occupation of six people. The Fernando de Noronha Archipelago hosts a permanent population of over 3,000 people [163] and receives over 100,000 visitors per year [164]. While tourism is the main economic activity, fishing is permitted in parts of the main island. Inadequate wastewater treatment is a challenge and associated negative effects on water quality have been reported [160].

Subregion 2 (Northeastern Brazil) holds coastal reef formations, located within 5 km from the coast. Chronic stressors include sedimentation resulting from deforestation for sugarcane cultivation, a practice that began during the colonial period, as well as coral extraction for lime production and construction [165]. In response to historical coral degradation and the need to manage growing pressures, marine protected areas were established in the late 1990s (*e.g.* Costa dos Corais environmental protection area) as well as ban of coral removal [166], which may have contributed to subsequent reef recovery. Today, tourism growth represents one of the main threats to the subregion, with compounding stress from increasing fishing pressure, land-based runoff, and coastal development [161, 167, 168].

Subregion 3 (Eastern Brazil) harbors inshore and offshore reef formations distributed on the extended Abrolhos shelf and encompasses the largest and richest coral reefs in the region [169]. The first marine protected area in subregion 3 was established in the 1980s (*e.g.* Parque Nacional Marinho dos Abrolhos). Stressors in the subregion include dredging, coastal development, and overfishing, including illegal fishing [170]. In 2015, a dam collapse reached the southern portion of the region through the Doce river [171, 172] with associated metal contamination detected in corals [173].

STATUS OF CORAL REEFS IN THE REGION

Hard coral cover

Pre-monitoring scenario (prior to 2002)

While the modelling output provides estimates from 2002 onwards, coral bleaching events were also recorded in 1993 [174] and 1998 [175]. The first documented bleaching event occurred during the austral summer of 1993–1994 in Eastern Brazil (subregion 3), when 50–90% of coral colonies were affected [174]. Subsequent reports only emerged in 1998 along the Brazilian coast, during the first global bleaching event [153, 175]. Due to the limited number of established reef monitoring programs in Brazil at the time, the national-scale impact of this event was not quantitatively assessed. Nevertheless, significant coral bleaching and some mortality rates, for sensitive species, were reported in regions such as Fernando de Noronha and Rocas Atoll (subregion 1), Tamandaré (within subregion 2) (Ferreira, B.P., *pers. obs.*; [165]), Abrolhos (within subregion 3) [148, 175] and Parcel de Manuel Luís (within subregion 5) [153].

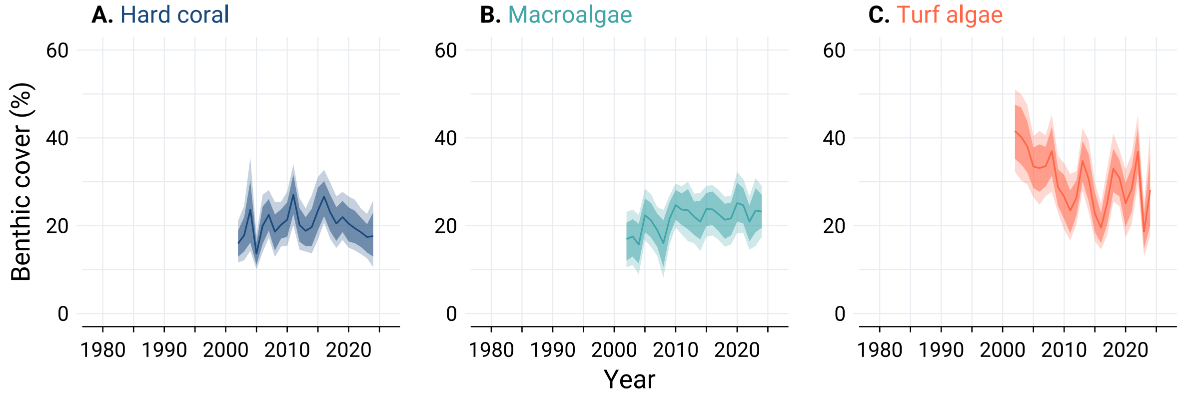
In coastal reefs (located in subregion 2 and subregion 3), chronic pressures such as sedimentation and the removal of corals contributed to a decline in hard coral cover until the 1990s [165, 175, 176]. In the 1970s, Laborel [169] reported estimated coral cover values of approximately 20–25% for subregion 2 (Northeastern Brazil) and up to 50% for subregion 3 (Eastern Brazil), indicating a marked decline compared with the hard coral cover recorded in 2002 (4.8% and 24.2%, respectively). Therefore, the beginning of the temporal trends presented in Figure 2.2.4 likely reflect reef conditions that were already experiencing some degree of degradation from multiple stressors.

Partial recovery and stabilization (2002–2016)

From the 1980s onward, five major marine protected areas were established across the studied subregions, with full implementation achieved by the 2000s. The positive effects of these and other management measures, combined with the absence of severe and widespread coral mortality associated with bleaching events after 1998, may have created favorable conditions for coral recovery. Indeed, hard coral cover in the region showed a relative increase of 66.9% between 2002 and 2016, rising from 15.9% (credible interval at 95% [$CrI_{95\%}$]: 11.6 – 21.1%) to 26.6% ($CrI_{95\%}$: 20.7 – 32.7%). This trend likely reflects the synergistic effects of successful management and relatively low heat stress during this period [177].

Sharp decline associated with repeated and intense bleaching events (2016–2024)

Although all three subregions experienced a notable increase in the intensity and



▲ **Figure 2.2.4.** Modeled temporal trends of benthic cover in the Brazil region from 1980 to 2024 for hard coral (A), macroalgae (B), and turf algae (C). The solid line represents the estimated median benthic cover while darker and lighter ribbons represent 80% and 95% credible intervals, respectively. Grey areas represent periods during which no field data were available.

frequency of significant heating events during 2016–2024 [177], the timing and maximum intensity of these events varied among subregions, as did the responses of benthic communities (see the Status of coral reefs in the subregions section). Nevertheless, trends in the region reflected the impact of the combined strong regional heat-stress event of 2019–2020 and the fourth global bleaching event of 2024, leading to a relative decline in hard coral cover of 33.8% between 2016 and 2024, decreasing from 26.6% ($CrI_{95\%}$: 20.7 – 32.7%) to 17.6% ($CrI_{95\%}$: 10.5 – 25.8%).

Macroalgal and turf algal cover

Macroalgal and turf benthic cover varied among subregions in both magnitude and temporal trends. These differences likely reflect multiple interacting factors, including latitude, distance from shore, local stressors, depth and monitoring zonation, as well as seasonality and species composition [83, 178].

Increase in macroalgal cover and decline in turf algae (2002–2010)

Between 2002 and 2010, macroalgal cover showed a relative increase of 46.1%, rising from 16.9% ($CrI_{95\%}$: 10.5 – 23.1%) to 24.7% ($CrI_{95\%}$: 19.6 – 29.6%). In contrast, turf algal cover showed a declining trend over the same period, with a relative decline of approximately 36.2%, ranging from 41.5% in 2002 ($CrI_{95\%}$: 32.3 – 51.0%) to 26.6% in 2010 ($CrI_{95\%}$: 19.1 – 34.2%) (Figure 2.2.4C).

Relative stabilization in macroalgal cover (2010–2024) and increase in turf algae (2016–2024)

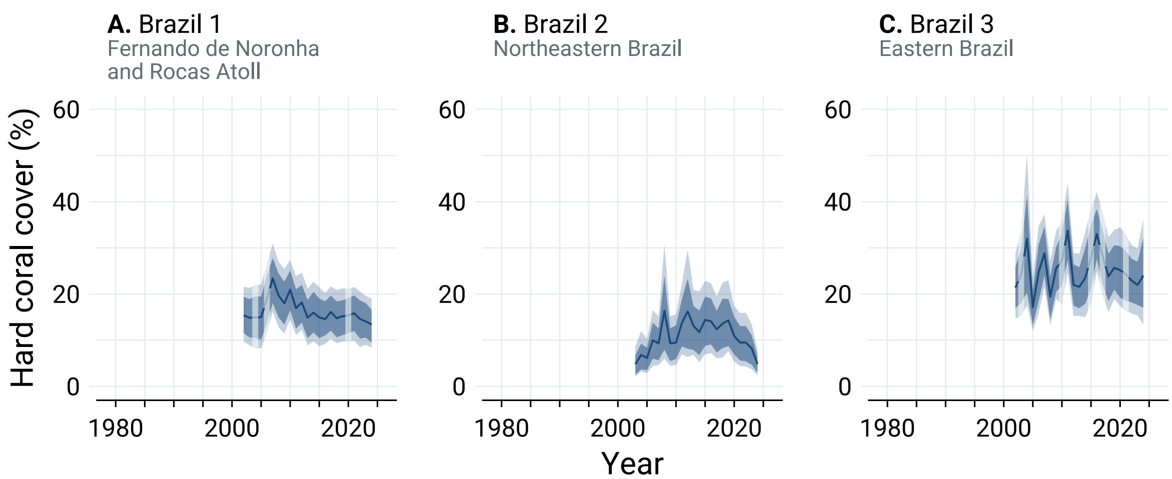
A relatively stable macroalgal cover across the region was observed from 2010 to 2024. This trend suggests this benthic category has not undergone major changes despite the intensification of thermal anomaly events at a regional scale [177]. For turf algal cover, the data show evidence of an increase between 2016 and 2024, rising from 19.5% ($CrI_{95\%}$: 14.6 – 24.9%) to 28.2% ($CrI_{95\%}$: 17.7 – 41.6%), corresponding to a 43.4% relative increase. This increase was likely associated with the rapid colonization of newly exposed substrates following coral mortality after successive bleaching events [131, 179].

STATUS OF CORAL REEFS IN THE SUBREGIONS

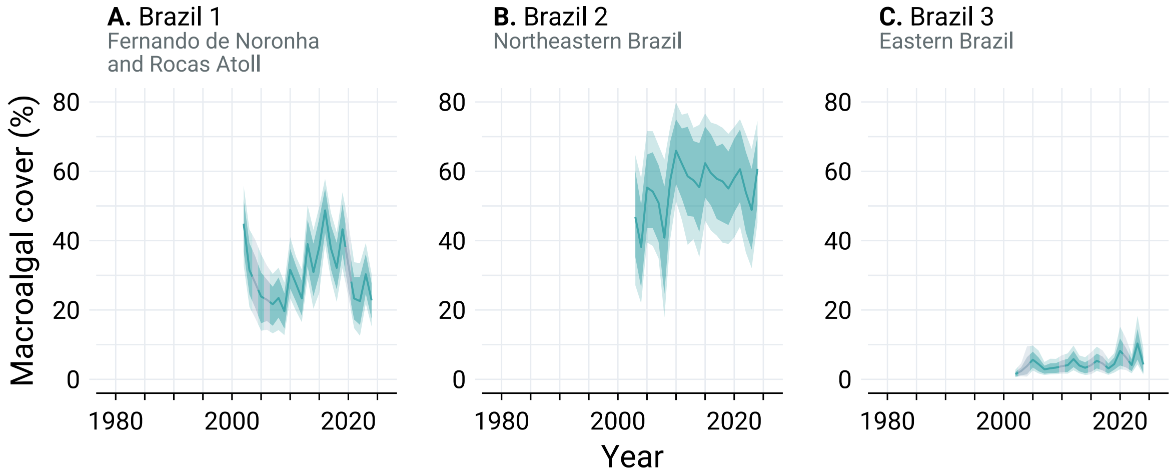
Brazil 1 - Fernando de Noronha and Rocas Atoll

Subregion 1 (Rocas Atoll and Fernando de Noronha) experienced changes in hard coral cover primarily driven by thermal anomaly events over the past decades. Although the impacts of the 1998 El Niño were not monitored, local accounts report widespread bleaching, which may help explain the recovery trajectory observed at the beginning of the study period in 2002. This is inferred from a relative increase of 36.4% between 2002 and 2010, with hard coral cover rising from 15.4% (CrI $_{95\%}$: 9.7 – 21.6%) to 21.0% (CrI $_{95\%}$: 14.5 – 27.4%). In 2010, a significant heat stress event exposed all coral reefs in the subregion to more than 4 DHW leading to mass bleaching and mortality [180]. Consecutive heat stress events occurred in 2019 and 2020, where all coral reefs were exposed to more than 4 DHW, and 8 DHW, respectively. In 2024, the most intense heat stress event on record in this subregion occurred, exposing all coral reefs to more than 16 DHW. Together, these events led to a relative decline of 35.7% in hard coral cover between 2010 and 2024, resulting in a hard coral cover of 13.4% (CrI $_{95\%}$: 8.4 – 19.0%) in 2024 (Figure 2.2.5A).

In contrast, macroalgal cover in subregion 1 (Rocas Atoll and Fernando de Noronha) showed no association with thermal anomaly events. A relative decline of 29.6% was observed between 2002 and 2010, with macroalgal cover decreasing from 44.9% (CrI $_{95\%}$: 32.9 – 55.9%) to 31.6% (CrI $_{95\%}$: 23.4 – 41.0%). This was followed by an increase in macroalgal cover until 2016, reaching levels similar to those recorded in 2002. After 2016, macroalgal cover declined again by 53.4% through 2024, reaching a macroalgal cover of 22.7% (CrI $_{95\%}$: 15.2 – 30.4%) by 2024 (Figure 2.2.6A). Turf algal cover fluctuated substantially over the period, averaging around 26.3% (CrI $_{95\%}$: 13.2 – 42.1%) (Figure 2.2.7). These observed patterns in macroalgae and turf algal cover may have been influenced by varying depths and pronounced seasonality in the subregion, coupled with the mismatch between monitoring efforts and seasonal cycles.



▲ **Figure 2.2.5.** Modeled temporal trends of hard coral cover in Brazil subregions from 1980 to 2024. The solid line represents the estimated median hard coral cover while darker and lighter ribbons represent 80% and 95% credible intervals, respectively. Grey areas represent periods during which no field data were available.

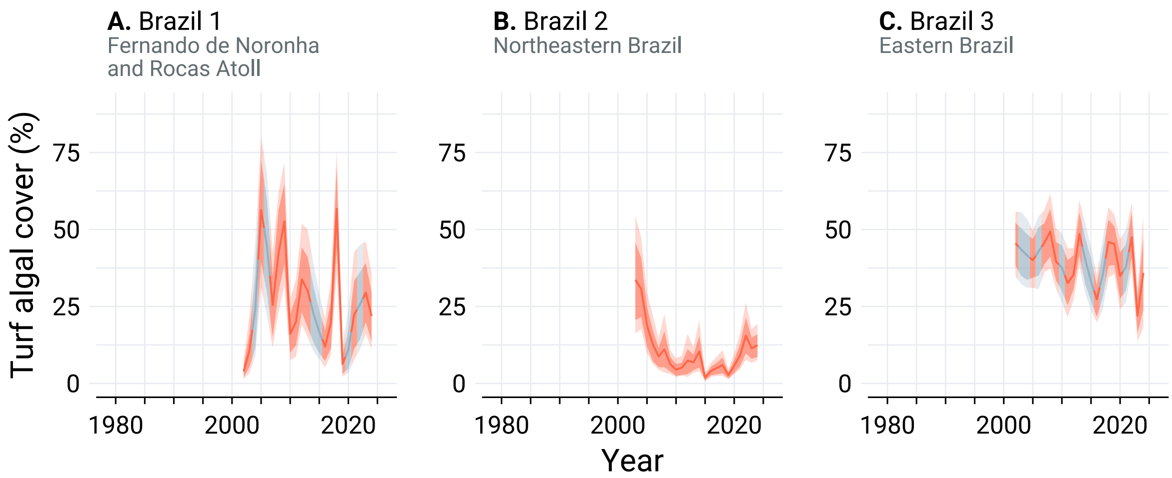


▲ **Figure 2.2.6.** Modeled temporal trends of macroalgal cover in Brazil subregions from 1980 to 2024. The solid line represents the estimated median macroalgal cover while darker and lighter ribbons represent 80% and 95% credible intervals, respectively. Grey areas represent periods during which no field data were available.

Brazil 2 - Northeastern Brazil

Formed by coastal reefs, subregion 2 (Northeastern Brazil) experienced declines in hard coral cover before 2002 when monitoring began, due to chronic impacts including land run-off, coral collection, and overexploitation of fisheries resources, as well as impacts from the 1998 El Nino, which exposed 90% of coral reefs to more than 4 DHW. These impacts were particularly felt by reefs closer to the coast [176, 181]. Following the establishment of a large marine protected area in the 1990s, the Costa dos Corais environmental protection area, and in the absence of severe bleaching events, hard coral cover showed a recovery trend, with a relative increase of approximately 97.1% from the 2003 to 2010, rising from 4.8% (CrI $_{95\%}$: 2.1 – 8.7%) to 9.5% (CrI $_{95\%}$: 4.6 – 15.6%). Despite a global coral bleaching event recorded in 2010, which exposed around 70% of coral reefs to more than 4 DHW, hard coral cover did not show evidence of change between 2003–2009 and 2020–2024. In 2019 and 2020, consecutive heat stress events exposed around 80% of coral reefs to more than 8 DHW, causing mass bleaching and high mortality in sensitive coral species such as *Millepora alcicornis* [161]. These events were associated with a 35.6% relative decline in hard coral cover between the 2010s and 2020s. Without sufficient time for hard coral cover recovery, Northeastern Brazil experienced the most intense heat stress recorded among all monitored subregions in 2024, with all coral reefs exposed to more than 12 DHW. Consequently, between 2019 and 2024, hard coral cover declined by 66.2%, dropping from 14.3% (CrI $_{95\%}$: 7.6 – 22.9%) to 4.8% (CrI $_{95\%}$: 2.3 – 8.0%) (Figure 2.2.5B).

Macroalgae have historically dominated benthic cover in the Northeastern Brazil subregion [167]. Macroalgal cover showed a relative increase of 19.8% from 2000s to 2010s. From 2019 to 2024, a relative increase of 9.6% was detected, with cover rising from 55.0% (CrI $_{95\%}$: 39.0 – 70.8%) to 60.7% (CrI $_{95\%}$: 45.2 – 74.5%) (Figure 2.2.6B). By contrast, turf algal cover showed a relative decline of 68.7% in trends between the 2000s and 2010s, possibly associated with reduced grazing pressure by sea urchins [182]. Following recent bleaching events, turf algal cover exhibited a relative increase between 2016 and 2024, rising from 4.0% (CrI $_{95\%}$: 2.1 – 6.7%) to 12.4% (CrI $_{95\%}$: 7.6 – 19.3%) (Figure 2.2.7B). This increase may be associated with coral mor-



▲ **Figure 2.2.7.** Modeled temporal trends of turf algal cover in Brazil subregions from 1980 to 2024. The solid line represents the estimated median turf algal cover while darker and lighter ribbons represent 80% and 95% credible intervals, respectively. Grey areas represent periods during which no field data were available.

tality, as turf algae are typically among the first colonizers of recently dead coral skeletons [179].

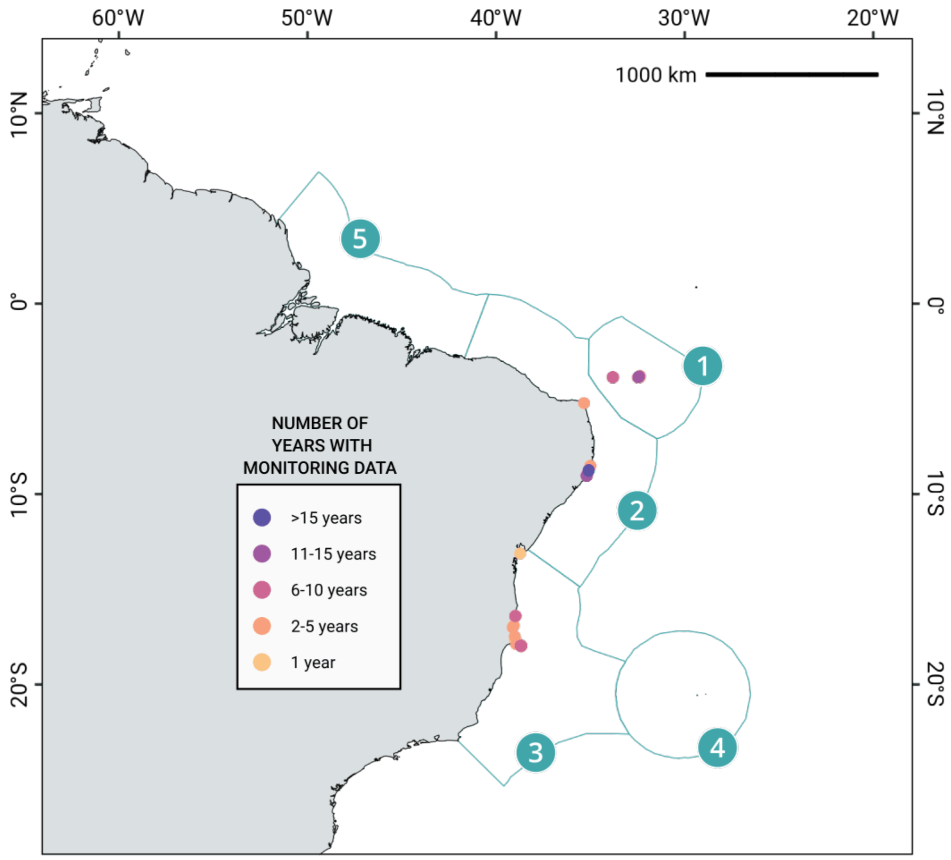
Brazil 3 - Eastern Brazil

Subregion 3 (Eastern Brazil) encompasses several locations monitored at different periods, from inshore to mid shelf reefs, including reef banks, pinnacles ("chapeirões") and island fringing formations. Hard coral cover in this subregion exhibited high fluctuation between 2002 and 2016, with a relative increase of 54.2%, rising from 21.4% ($CrI_{95\%}$: 14.7 – 28.8%) to 33.0% ($CrI_{95\%}$: 25.0 – 42.0%). No mass bleaching events associated with high subsequent coral mortality were reported in the subregion during this period [183], despite around 40% of coral reefs being exposed to more than 4 DHW in 2003 and 2010. The first record of severe bleaching occurred in 2016, where almost 80% of coral reefs in the subregion were exposed to more than 4 DHW, marking the onset of a continuous decline in hard coral cover in subsequent years [162, 183]. The most intense thermal anomaly was observed in 2019 [131, 179], when 95% of coral reefs were exposed to more than 12 DHW, producing a relative decline in hard coral cover of 22.0% between 2016 and 2019, with hard coral cover decreasing from 33.0% ($CrI_{95\%}$: 25.1 – 42.0%) to 25.7% ($CrI_{95\%}$: 18.9 – 33.9%). A similar decline in hard coral cover of approximately 15% was also reported by Carlos-Júnior *et al.* [162] in the subregion, along with shifts in coral assemblages, including the collapse of branching corals and an increase in weedy species. In 2024, around 60% of coral reefs were exposed to more than 8 DHW, but with no reports of severe bleaching or mortality [184]. After 2019, there was no evidence of a change in hard coral cover, with median hard coral cover estimated at 24.0% ($CrI_{95\%}$: 13.4 – 36.2%) in 2024 (Figure 2.2.5C).

Unlike subregions 1 and 2, macroalgal cover does not dominate total benthic cover in Eastern Brazil, which is instead largely represented by turf algae. There was strong evidence that macroalgal cover increased between 2002 and 2016, rising from 1.5% ($CrI_{95\%}$: 0.6 – 2.8%) to 5.3% ($CrI_{95\%}$: 2.4 – 9.4%). There was no evidence of change in macroalgal cover between 2016 and 2024 (Figure 2.2.6C). Other studies in the region have reported high spatial heterogeneity in macroalgal cover, with consistently low values (<5%) at offshore sites and pinnacle walls, as well as a region-wide decline between 2006 and 2017–2018 followed by relative stability until 2023 [162]. Turf algal cover, in turn, showed a relative decline of 40.0%, with cover decreasing from 45.5% ($CrI_{95\%}$: 34.8 – 55.8%) in 2002 to 27.3% ($CrI_{95\%}$: 19.9 – 35.2%) in 2016 (Figure 2.2.7C).

DESCRIPTION OF MONITORING DATA

Temporal trends in the percentage cover of benthic categories were estimated using data from four datasets encompassing 77 monitoring sites. These data were collected through 488 surveys conducted between 2002 and 2025, with 90% of surveys taking place after 2006 (Figure A.1).



▲ **Figure 2.2.8.** Spatio-temporal distribution of benthic cover monitoring sites across the Brazil region and respective subregions. Light blue polygons and numbers represent subregions. Subregion 1 = Fernando de Noronha and Rocas Atoll, Subregion 2 = Northeastern Brazil, Subregion 3 = Eastern Brazil, Subregion 4 = Trindade and Martin Vaz Islands, Subregion 5 = Amazonia. The scale bar provides distance at the equator and may not accurately represent distance over the entire latitudinal range of the region.

Of all surveys carried out in the region between 2002 and 2025, 37.1% (representing 40.3% of surveyed sites) were conducted in subregion 2 (Table A.4). Differences between the *Status of Coral Reefs of the World: 2020* GCRMN report [30] and this report are due to the inclusion of different datasets with different monitoring periods, which increased the number of sites in subregion 3 (Eastern Brazil).

CONCLUSIONS

The regional and subregional patterns of benthic cover trends in Brazilian coral reefs point to broader ecosystem transformations over the past three decades and provide insights into reef recovery potential as well as current and future risks. The absence of reported high coral mortality rates following global bleaching events [31], that nevertheless reached up to 16 DHWs in 2010, led to the belief that the region was a potential climate refugium and that local corals were less susceptible [185]. The subsequent regional thermal anomalies of 2019–2020 and the global bleaching event of 2024 however, leading to an overall reduction of approximately 34% in hard coral cover by 2024, highlighted the vulnerability of Brazilian reefs to recurrent and intense thermal anomalies [184].

Subregions showed distinct trends in hard coral and algal cover, reflecting varied responses to climate change and local pressures. Hard coral cover responses are linked to species composition, as taxa differ in thermal tolerance. The Eastern Brazil subregion, with higher hard coral cover and richer species composition [148], experienced smaller declines but reports indicated shifts in coral assemblages, including mortality of branching and massive endemic forms and an increase in "weedy" fast-growing species [162, 179].

Macroalgal cover generally increased across the region, while turf algal cover decreased, with temporary spikes likely related to post-bleaching coral mortality. Macroalgal cover is higher closer to the coast and in shallow areas, notably in subregion 2 (Northeastern Brazil). In subregion 1 (Fernando de Noronha and Rocas Atoll) and subregion 3 (Eastern Brazil), varied depths, distances from the coast, and exposure levels complicated the detection of response thresholds. Future monitoring should establish location-specific thresholds accounting for natural gradients (*e.g.* latitude, shelf position) and seasonality, and include more functional/morphological groups to enhance the resolution of algae as reef health indicators [83].

Despite the clear effects of climate change, marine protected areas are vital to maintaining key ecological processes that support coral recovery after extreme events. Enhancing reef resilience however will require reducing local stressors, improving coastal management, and limiting ocean warming, supported by long-term monitoring to guide adaptive management [186–188].

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DATA CONTRIBUTORS

Maria Bernadete Barbosa, Ana Lídia Bertoldi Gaspar, Iara Braga Sommer, Camila Brasil Louro Da Silveira, Maurizelia Brito, Thiago Buchianeri Numa De Oliveira, Eduardo Cavalcante De Macedo, Cesar A. M. M. Cordeiro, Mariana Coxey, Jarian Dantas, Graham J. Edgar, Beatriz Fernandes De Barros Bomfim Santana, Carlos E. L. Ferreira, Sérgio R. Floeter, Greg Hodgson, Thales Jean Vidal, Carlos Henrique Lacerda, Daniel Lino Lippi, Guilherme O. Longo, André Luza, Mauro Maida, Zaira Matheus, Miguel Mies, Ágatha Naiara Ninow, Fábio Negrão Ribeiro De Souza, Elizabeth Oh, Beatrice Padovani Ferreira, Luiza Pereira Gomes, Ana Paula Prates, Marina N. Sissini, Rick D. Stuart-Smith, Leonardo Tortoriello Messias, Caroline Vieira Feitosa.

Access to online supplementary materials

The modelled benthic cover data, detailed outputs from the data analyses, and the CRediT author contribution statement are available on Zenodo.

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