

REGIONAL REPORT V.0

Red List of Ecosystems assessment of Brazilian coral reefs

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ABSTRACT

Brazil's coral reefs are the only true known coral reefs in the South Atlantic and extend across approximately 3,000 km along the coast, from Parcel de Manuel Luís at 0°50'S to Esquecidos reef at 18°50'S. They present unique characteristics, including their distinct growth form, and harbor endemic species of coral, fish and invertebrates, supporting high levels of marine biodiversity. Representing 0.6% of the global coral reef extent, the region encompasses 5 coral reef ecoregions as defined by the MEOW approach (Spalding, 2007), which were further subdivided into 8

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KEYWORDS

Red List of Ecosystems; coral reefs; ecosystem collapse; risk assessment; Brazil; South Atlantic

ecoregions for the purposes of this assessment. The IUCN Red List of Ecosystems assessment, based on biological data collected by seven monitoring programs between 2000 and 2025, spatial data, and observed (1985-2025) and projected (2026-2075) DHW data, found that Brazilian coral reef ecosystems within five out of the eight ecoregions are at risk of collapse, while three were assessed as Data Deficient. Risk was primarily driven by future climatic projections and restricted geographic distribution, although biotic indicators also showed concerning levels of degradation. These results highlight the urgent need for management and conservation efforts aimed at reducing local pressures and enhancing resilience to climate change, particularly in areas that support local communities and livelihoods.

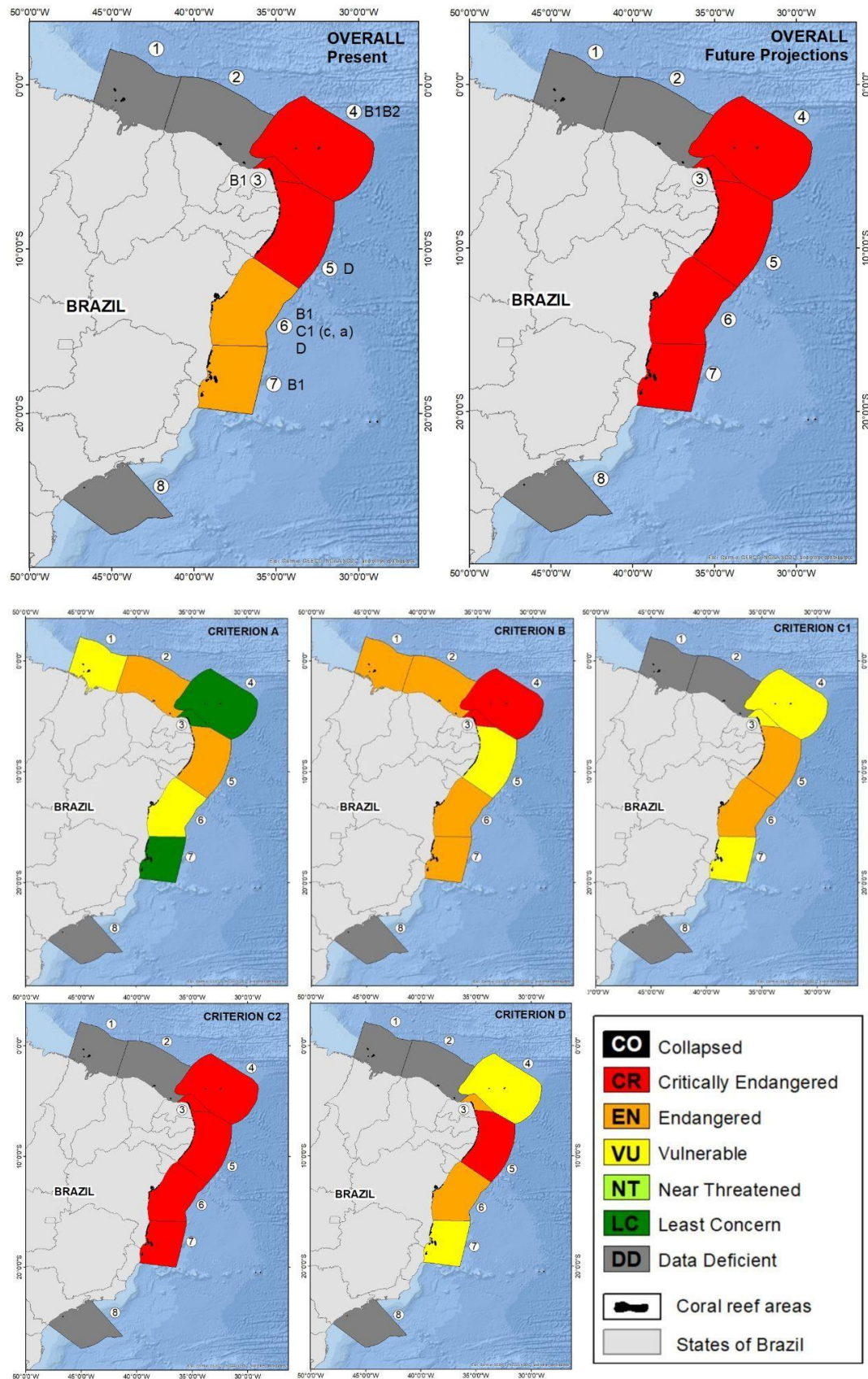


Figure 1. Distribution of the 8 coral reef ecoregions in Brazil. Panel A: Overall Red List of Ecosystems risk status. Panels B–E: Risk status results for criteria A–D. Black polygons represent coral reef area.

1. Study Area

This Red List of Ecosystems (RLE) assessment evaluates the risk of collapse for coral reefs across the Brazil region as of 2025. Brazil's shallow water coral reefs (IUCN Global Ecosystem Typology M1.3 - photic coral reefs) extend across approximately 3,000 km along the coast, from 0°50'S to 18°50'S, in the South Atlantic Ocean. This distribution covers mainly the northern, northeastern, and eastern Brazilian coast, including major formations such as the Parcel de Manuel Luís, the Costa dos Corais, and the Abrolhos Bank, the latter being the largest and richest South Atlantic reef complex. Additionally, these ecosystems encompass oceanic islands including the Rocas Atoll (the only atoll in the South Atlantic), and the Fernando de Noronha Archipelago. This assessment also includes a marginal reef, Queimada Grande, the southernmost Brazilian reef at 24°30'S.

The entire region covers approximately 1,100 km² of shallow coral reefs, as estimated in this report (see section 3). While this value is slightly below previous estimates (1,178 km²; Ferreira et al., 2026), the relative proportion in relation to the global coral reef extent has remained similar, at 0.6%. Brazilian shallow coral reefs are distributed along five Marine Ecoregions as per Spalding et al. (2007; Marine Ecoregions of the World - MEOW). Ecoregion boundaries were further redefined using published research (Leão, 1997; Maida & Ferreira, 1997; Castro & Pires, 2001) and expert judgement; as a result, the five (5) initial ecoregions were subdivided into eight (8) ecoregions: seven continuous ones, and another located within the Southeastern Brazil MEOW, which encompasses the Queimada Grande marginal reefs (Figure 2). These coral reef ecoregions capture ecological variation in coral reef biodiversity, ranging from coastal to oceanic reef formations, with many included within the limits of Marine Protected Areas under different management regimes, and are equivalent to level 4 of the IUCN Global Ecosystem Typology (regional sub-groups). Coral reefs in each ecoregion were independently assessed using the IUCN Red List of Ecosystems criteria (see details on data collection and monitoring in the Annex).

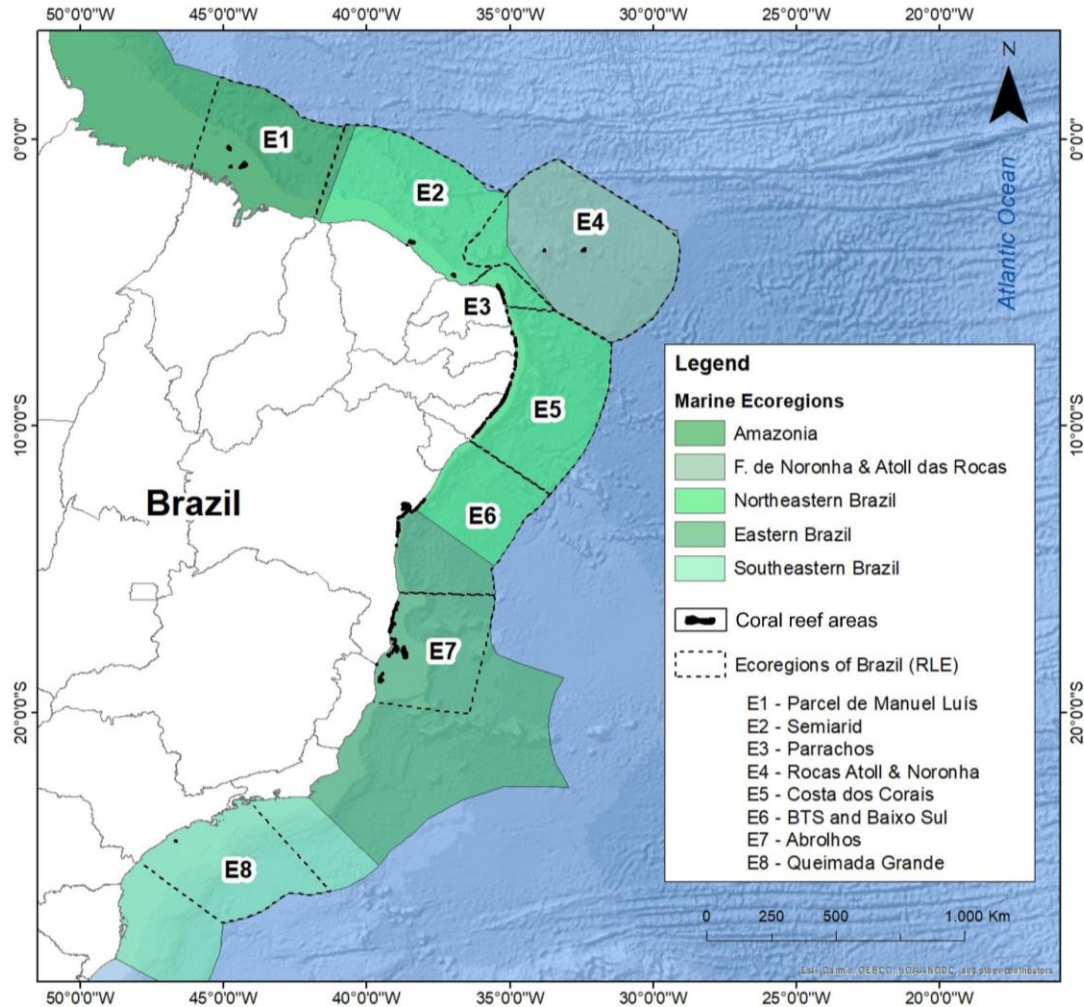


Figure 2. Coral reefs of the Brazil Region grouped within coral reef ecoregions (Units of Assessment) to be evaluated under the IUCN Red List of Ecosystems criteria, corresponding to Level 4 of the IUCN Global Ecosystem Typology. Red polygons indicate coral reef areas, dashed polygon boundaries delineate the eight Units of Assessment, and green shading indicates the five marine ecoregions as defined by Spalding et al. (2007).

2. Ecosystem Description

The South Atlantic Shallow Coral Reefs originated during the Late Quaternary and evolved under the influence of tropical waters, sea-level fluctuations, with transgressive and regressive seas marking different stages of reef development, and geographic isolation, resulting in reef communities with high levels of endemism (Leão & Dominguez, 2000; Floeter et al., 2008; Leão et al., 2016). Brazilian reefs encompass a wide diversity of reef formations, including fringing reefs, coral knolls, patch reefs, elongated mushroom-shaped pinnacles known as *chapeirões*, and oceanic coral reef formations, including the coral reef formations on the Rocas Atoll and the Fernando de

Noronha Archipelago (Maida & Ferreira, 1997; Leão et al., 2003, 2016) (Fig. 1). Those are true coral reefs, structures formed by carbonate accretion of coral reef calcifying organisms deposited over millenia (Kikuchi & Leão, 1998; Vasconcelos et al., 2018; Vieira et al., 2022; Santana et al., in prep). Despite differences in structural development, Brazilian reefs share many reef-building species, ecological processes, and associated biodiversity (Leão et al., 2016) (Fig. 1). A marginal reef located in the southeastern region of the country, specifically in Ecoregion 8, near Queimada Grande Island, was also included. There, regional oceanographic and climatic changes limited reef development and interrupted reef accretion during the Late Holocene (Pereira-Filho et al., 2021). Ecoregion 2 (Semiarid) is located further off the coast, of lower relief and uncertain origin. It is probably formed by carbonate accretion and was thus considered as a coral reef for the purpose of this assessment.

2.1. Key Biotic Components

Brazilian reefs are characterized by low diversity of scleractinian corals (21 scleractinian coral species and five hydrocoral species), high endemism, and unique mushroom-like formations that grow in columns expanded at the top, such as the Abrolhos *chapeirões*, or coalescing at the top in shallow waters and forming the extensive banks typical of coastal formations (Leão et al., 2016) (Fig. 3). Core composition reveals that in addition to corals, crustose coralline algae (Kikuchi, 1999; Vasconcelos et al., 2018; Vieira et al., 2022) and bryozoans, as is the case in the Abrolhos *chapeirões* (Bastos et al., 2018), play an important role as reef-building organisms, contributing to the formation of extensive and distinctive reef complexes in Brazil.

Benthic cover varies among non-reef-building organisms, such as macroalgae, sponges and soft corals (Aued et al., 2018; Coxey et al., 2024). Each region has intrinsic characteristics, with variations in the dominance of algal groups, soft corals, and hard corals. Nearshore reefs in ecoregions E3, E4, and E5 are characterized by high algal cover, differing in their morphofunctional groups, such as fleshy macroalgae and turf (Aued et al., 2018). In contrast, southwestern regions show a greater contribution of soft corals, crustose coralline algae, and turf (Coxey et al., 2024). In coastal ecoregions, such as Parrachos (E3) and Costa dos Corais (E5), macroalgae cover can represent over 50% of benthic cover (Ferreira et al., 2026). In contrast, in other ecoregions, such as Abrolhos (E7), turf algae are the dominant algae category (Francini-Filho et al., 2013; Aued et al., 2018; Ferreira et al., 2026). Across Brazilian reefs, Rhodophyta is the most represented algal phylum, followed by Chlorophyta and Ochrophyta (Figueiredo et al., 2008).

Invertebrates are important components of Brazilian reefs, and the diversity of sponges, mollusks, crustaceans, echinoderms, polychaetes, and bryozoans contributes to reef-building, consolidation, bioerosion, and trophic functioning within reef ecosystems (Barros et al., 2024; Cardial et al., 2024). Among crustaceans, lobsters such as *Panulirus*

meripurpuratus, *P. laevicauda* and *P. echinatus* act as benthic predators, consuming a variety of invertebrate groups (Cruz et al., 2021). Lobsters have high socioeconomic importance in Brazil, being a main target species of fisheries both for exportation and local consumption (Alencar et al., 2021; Cruz et al., 2021; Da Silveira & Ferreira, 2024). Along the coast, the most common species of sea urchin is *Echinometra lucunter*, known to form urchin barrens in some areas through intense grazing (Costa, 2013; Carvalho, 2016). Although showing what seem to be natural fluctuations through time, extreme increases in sea urchin populations have been attributed to overfishing (McClanahan & Muthiga, 1988; Humphries et al., 2020), an effect also suggested in Brazil (Carvalho, 2016). An acute and temporary population increase of the white sea urchin *Tripneustes ventricosus* was observed in the Fernando de Noronha Archipelago in the early 2000s (Machado, 2007).

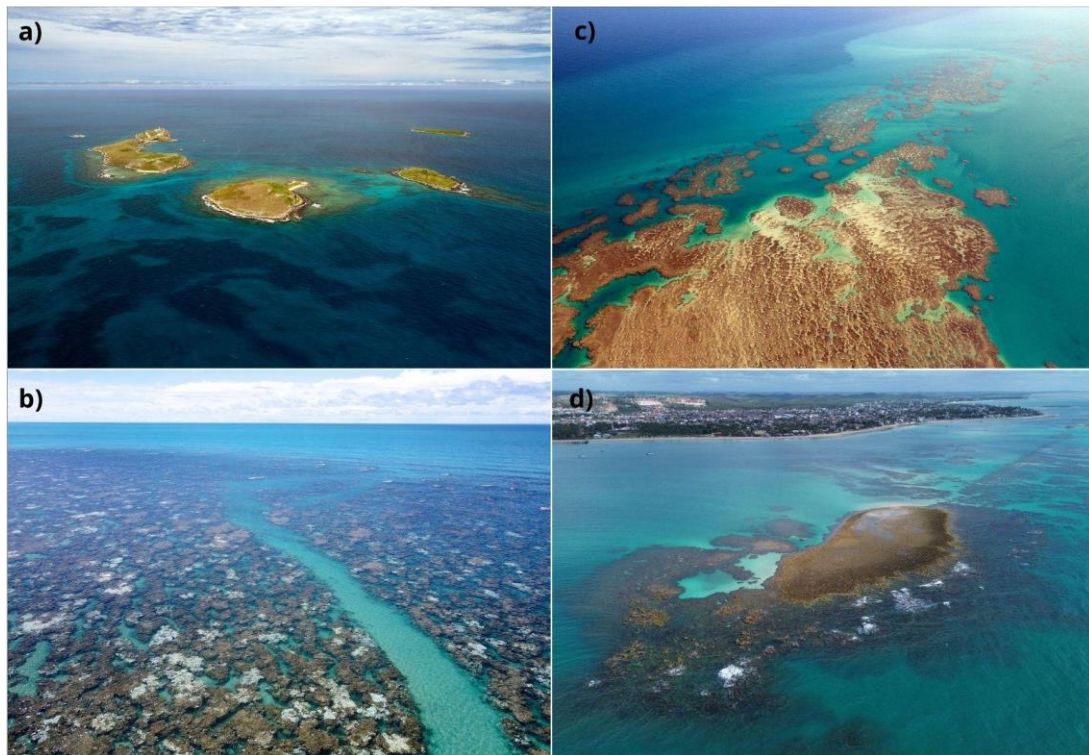


Figure 3. Aerial photographs of reef ecosystems along the Brazilian coast: a) Abrolhos Archipelago (E7); b) Rio do Fogo (E3); c) Abrolhos coastal reefs (E7); d) Tamandaré (E5).

The only group of reef-building organisms with a branched morphology in the South Atlantic are the hydrocorals of the Milleporidae family, which increase reef structural complexity and are predominantly represented by *Millepora alcicornis*, recorded across all ecoregions (Laborel, 1970; Amaral et al., 2002, 2008; Leão et al., 2016) (Figs. 4 and 5a, b and d). In addition, three endemic hydrocoral species (*M. braziliensis*, *M. nitida*, and *M. laboreli*) occur along the coast, although they are locally restricted (or endemic to certain regions) and far less abundant (Laborel, 1970; Amaral et al., 2008) (Fig. 4). *M. laboreli* has been described only for Parcel de Manuel Luís (E1) (Amaral et al., 2007).

(Fig. 4). *M. alcicornis* shows substantial cover in Ecoregions 3, 5, 6, and 7, where it forms large colonies with high structural complexity, particularly on reef crests and submerged tops (Laborel, 1970; Maida & Ferreira, 1997). In Fernando de Noronha (E4), *M. alcicornis* typically displays an encrusting morphology, forming finger-like protuberances as a response to the high local hydrodynamic conditions (Laborel, 1970; Amaral et al., 2008).

Massive corals, which are important for reef accretion, structural complexity and formation (Leão et al., 2003), are abundant and, together with encrusting and solitary coral species, can be broadly classified into three categories based on their reproductive strategies and growth rates (Darling et al., 2012; Carlos-Júnior et al., 2026). “Weedy” corals are mainly represented by species with a brooding reproductive strategy (McGuire, 1998), high fecundity, and relatively fast growth, such as *Porites* spp., *Agaricia* spp. (Fig. 5d), *Favia gravida*, and *Scolymia wellsi* (Fig. 5d) (Darling et al., 2012). The “fast-growing massive” group is primarily represented by the endemic genus *Mussismilia*, which includes *M. harttii* (Fig. 5d), *M. hispida* (Fig. 5f), and *M. braziliensis* (Carlos-Júnior et al., 2026). These species rely on a broadcast-spawning reproductive strategy (Pires et al., 1999; Neves & Pires, 2002) and exhibit faster development compared to the “slow-growing massive” corals, which include species such as *Montastraea cavernosa* (Fig. 5c) and *Siderastrea* spp. (Fig. 5e) (Darling et al., 2012). *Mussismilia braziliensis* has a restricted geographic distribution, occurring only in the BTS and Baixo Sul and Abrolhos ecoregions (E6 and E7). In contrast, *M. hispida* is widely distributed (Fig. 4).

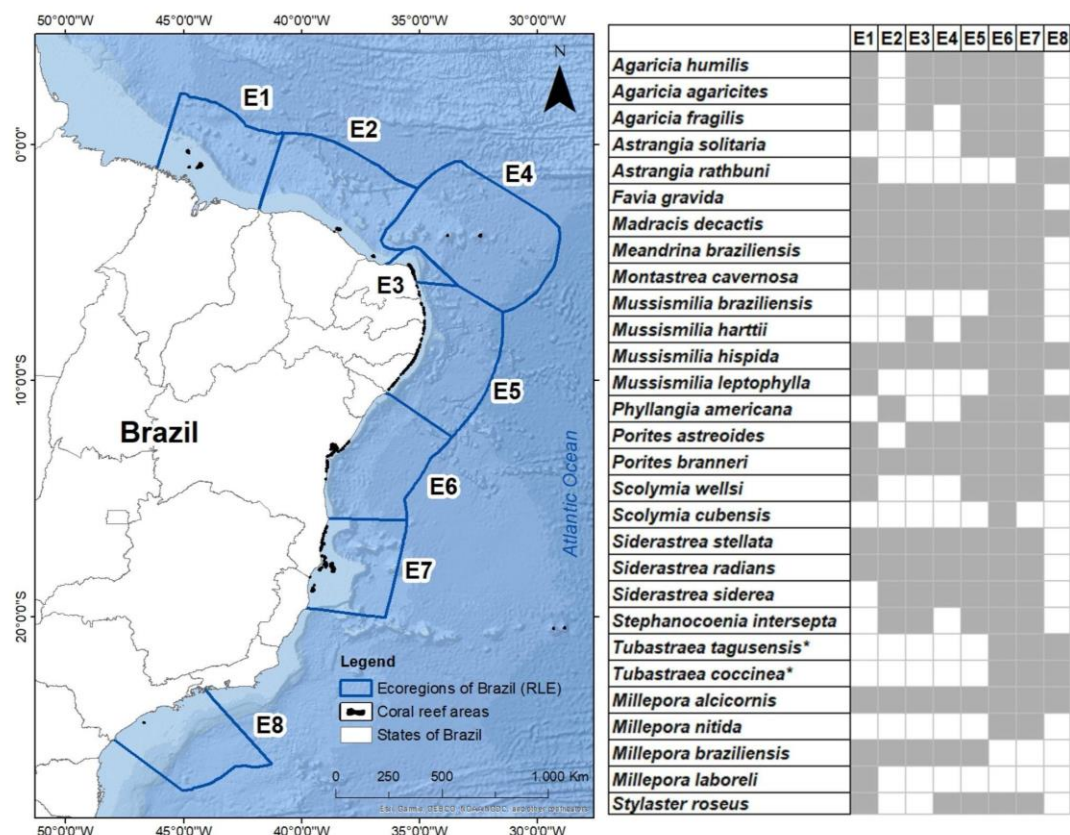


Figure 4. Map showing the delimitation of the eight ecoregions and the distribution of scleractinian corals and hydrocorals across the ecoregions. The gray squares indicate the presence of the species in the ecoregion. The asterisk indicates invasive species. Species distribution data were obtained from the Brazilian Biodiversity Extinction Risk Assessment System (SALVE - ICMBio, 2026) and from Leão et al., 2016.



Figure 5. Representative underwater photographs of coral reefs from five Brazilian ecoregions: a) Parcel de Manuel Luís (E1) and b) Rocas Atoll and Noronha (E4); c) and d) Costa dos Corais (E5); e) Parrachos (E3); f) BTS and Baixo Sul (E6); g) Abrolhos (E7); h) Queimada Grande (E8). For the purpose of this assessment, fish were grouped into herbivores and piscivores. The herbivores included the parrotfish (Labridae of the subfamily Scarinae) and the

surgeonfish (Acanthuridae). The piscivores/carnivores included species of groupers and snappers, main targets of fisheries in their area of occurrences.

Brazilian reefs exhibit lower reef fish diversity than the Indo-Pacific and the Caribbean, yet they represent an important center of endemism in the Southwestern Atlantic (Pinheiro et al., 2018; Feitosa et al., 2024). Approximately 24% of the Southwestern Atlantic ichthyofauna consists of endemic species, with most herbivorous fishes occurring exclusively in Brazilian waters (Pinheiro et al. 2018). Tropical roving herbivorous fishes, for example, comprise only 13 species, but eight of these are endemic (Pinheiro et al., 2018; Feitosa et al., 2024). In comparison, the Caribbean supports 17 species, whereas the Indo-Pacific harbors more than 130 (Siqueira et al. 2019a, b; Feitosa et al., 2024). Along the northeastern coast of Brazil, the most abundant herbivorous fish genera are the parrotfish *Scarus* and *Sparisoma* (Feitosa & Ferreira, 2015; Queiroz-Verás et al., 2023; Feitosa et al., 2024) and the surgeonfish *Acanthurus* (Ferreira et al., 2004; Feitosa et al., 2024). These are primarily represented by *Scarus zelindae* (Fig. 6b), *Scarus trispinosus*, *Sparisoma axillare*, *Sparisoma amplum*, *Sparisoma frondosum*, *Acanthurus bahianus*, *Acanthurus chirurgus* (Fig 6a), and *Acanthurus coeruleus* (Ferreira et al., 2004; Feitosa & Ferreira, 2015). Grouper species occurring along the tropical Brazilian coast belong to the family Epinephelidae and include large-bodied species such as *Epinephelus itajara*, *Epinephelus morio*, *Mycteroperca bonaci*, and *Dermatolepis inermis*, as well as smaller species such as *Cephalopholis fulva* and *Epinephelus adscensionis*.

Due to intense exploitation, large-bodied groupers are far more endangered than the small- or medium-bodied species (Sadovy de Mitcheson et al., 2013), and presently classified under threatened categories. As a result, protection measures have been implemented since the 2000s, including a fishing ban on the goliath grouper (*Epinephelus itajara*) (Brazil, 2002), recently updated by Ordinances MMA 1666 and 1667/2026 (Brazil, 2026a and 2026b), updating the Brazilian Red List of Threatened Species (ICMBIO, 2026) with 6 grouper species under threatened categories; as well as 5 parrotfish species and one snapper species (Table 1). High abundances of groupers and snappers are reported in protected areas (Ferreira et al., 2022; Rolim et al., 2022), such as aggregations of *Lutjanus jocu* (Fig 6c) on the Rocas Atoll (E4) and Parcel de Manuel Luís (E1) (Morais et al., 2017).



Figure 6. Representative species of the two functional groups used as fish indicators in the RLE analyses: herbivores, represented by (a) the surgeonfish *Acanthurus chirurgus* and (b) the Zelinda's parrotfish *Scarus zelindae*; and of piscivores, represented by (c) the dog snapper *Lutjanus jocu* and (d) the coney *Cephalopholis fulva*.

Table 1. Fish species used as indicators in the RLE analysis, including their functional group, taxonomic group, threat category, estimated population decline (%), and the reference period over which the decline was assessed according to the Brazilian Red List of Threatened Species (Brazil, 2026b).

Functional group	Taxonomic group	Species	Threat Category	Decline (%)	Reference period
Herbivores	Surgeonfish	<i>Acanthurus bahianus</i>	LC	0	-
		<i>Acanthurus chirurgus</i>	LC	0	-
		<i>Acanthurus coeruleus</i>	LC	0	-
	Parrotfish	<i>Scarus trispinosus</i>	CR	80	1980-2019
		<i>Scarus zelindae</i>	EN	50	2005-2029
		<i>Sparisoma amplum</i>	VU	30	1995-2025
		<i>Sparisoma axillare</i>	VU	30	1999-2020
		<i>Sparisoma frondosum</i>	VU	30	2008-2019
		<i>Sparisoma radians</i>	LC	0	-
Piscivores	Groupers	<i>Dermatolepis inermis</i>	DD	-	-
		<i>Epinephelus morio</i>	EN	50	1988-2035
		<i>Epinephelus morio</i>	EN	77.3	1970-2010
		<i>Mycteroperca bonaci</i>	EN	50	1975-2031
		<i>Mycteroperca interstitialis</i>	VU	30	1959-2025
		<i>Mycteroperca acutirostris</i>	EN	60	1974-2025
		<i>Cephalopholis fulva</i>	NT	30	2000-2021
		<i>Epinephelus adscensionis</i>	DD	-	-
		<i>Alphestes afer</i>	DD	-	-

Functional group	Taxonomic group	Species	Threat Category	Decline (%)	Reference period
		<i>Epinephelus itajara</i>	CR	80	1960-2020
	Snappers	<i>Lutjanus alexandrei</i>	DD	-	-
		<i>Lutjanus analis</i>	NT	30	1967-2017
		<i>Lutjanus cyanopterus</i>	VU	30	1990-2039
		<i>Lutjanus jocu</i>	NT	-	-
		<i>Lutjanus synagris</i>	DD	-	-
		<i>Ocyurus chrysurus</i>	DD	-	-

2.2. Key Abiotic components

The continental shelf along the tropical coast of Brazil varies considerably in shape and width, from very narrow in front of Salvador (E6; less than 10 km) to much wider in the Abrolhos ecoregion (E7), where it extends as far as 200 km. The shelf break sits at an average depth of 70-80 m and harbors mesophotic reef formations also found across the continental shelf, typically sediment-starved and carbonatic, and over oceanic sea mounts (Leão et al., 2003; Camargo et al., 2015). The inner shelf constitutes a mixing of siliciclastic and carbonate sediments; the siliciclastics originate from river discharges, coastal erosion, and reworked relict deposits, and the carbonates originate from calcareous organisms, such as red and green algae (Leão et al., 2003).

Seasonal alternation between dry and rainy periods further modulates turbidity, nutrient inputs, temperature, and salinity, generating distinct environmental conditions across ecoregions (Macêdo, 2009; Marques et al., 2019). Reefs occur along the entire carbonate province, but shallow coral reefs are absent near the Amazon River, where the massive sediment discharge results in highly turbid waters. Mesophotic reef formations or drowned reefs occur near the shelf edge (Moura et al., 2016; Francini-Filho et al., 2018) known as the Amazonian Reef System, extending along the coast as semi continuous formations of hard substrates below 50 m (Carneiro et al., 2022). The Parcel de Manuel Luís is the only shallow formation in the region, located at the southern end of the Amazon Reef System, comprising the northernmost reef formations of the Brazilian biogeographical province (Cordeiro et al., 2021). In contrast, the northeastern coast is predominantly influenced by the Brazil Current and generally experiences warmer waters, although local thermal conditions vary from northeast to east, as observed in the Costa dos Corais (24–30.5°C; mean 27.5°C) and Abrolhos (21.5–29°C; mean 26°C) ecoregions, based on NOAA's 1985–2026 historical sea surface temperature (SST) records (NOAA, 2026). Visibility in this region can exceed 20 m during summer but decreases seasonally with increased turbidity during winter (Maida & Ferreira, 1997).

The degree of terrigenous influence also varies substantially with distance from the coast. The Abrolhos Ecoregion (E7), for instance, encompasses both coastal and offshore reefs across the extensive Abrolhos Shelf, producing a pronounced gradient of fluvial influence with increasing distance from the coast (Leipe et al., 1999; Segal et al., 2008). Oceanic reef systems experience lower terrigenous inputs and remain oligotrophic

throughout the year. Nevertheless, strong winds can generate large swell waves that promote sediment resuspension, favoring coral development in deeper or wave-protected areas (Segal et al., 2008; Oliveira et al., 2021). The oceanic islands are directly influenced by the South Equatorial Current and are characterized by exceptionally clear waters, with visibility reaching up to 40 m, and relatively stable temperatures of 24–27°C (Maida & Ferreira, 1997).

2.3. Key processes and interactions

Brazilian shallow-water coral reefs, particularly those along the coast, form part of an interconnected seascape linked to mangroves, seagrass beds, and mesophotic reefs. Many species rely on these interconnected habitats across different stages of their life cycle; for example, snappers (Lutjanidae) utilize these connections throughout their development, facilitating energy transfer across ecosystems (Bastos et al., 2022). In oceanic islands, other shallow water habitats such as lagoons and tide pools may act as nursery areas, while connection between shallow and mesophotic reefs is more pronounced (Frédou & Ferreira, 2005; Aschenbrenner et al., 2016; França et al., 2021). For coral species, connectivity and recruitment success may also be influenced by reproductive strategies and environmental conditions (Peluso et al., 2018). Broadcast-spawning species have a high potential for larval dispersal but depend on sufficiently structured local populations to ensure effective external fertilization of gametes. In contrast, brooding species generally exhibit higher recruitment success, which may facilitate their recovery following mortality, as observed in fast-growing species described as “weedy” in the Abrolhos reefs (Carlos-Júnior et al., 2026).

The ecological dynamics of reefs is shaped by top-down and bottom-up trophic interactions, alongside stochastic recruitment pulses and source-and-sink dynamics (Grande et al., 2019; Shoemaker et al., 2019; Thomson et al., 2021; Ani et al., 2024). Top-down regulation is driven primarily by predators like fishes and lobsters, which control herbivore populations and indirectly structure benthic communities (Feitosa & Ferreira, 2015; Butler & Kintzing, 2016; Lippi et al., 2022). Herbivorous fishes play a vital role in suppressing macroalgal growth to maintain reef equilibrium (Adam et al., 2015; Harborne & Mumby, 2018; Topor et al., 2019), with their impact on benthic cover depending on their abundance, body size, and feeding strategies (Feitosa & Longo, 2018; Bonaldo et al., 2014; Longo et al., 2015). Marine protected areas, including no-take zones, aim to bolster top-down control and population recovery, showing localized success (Lippi et al., 2022). However, recent research indicates that top-down control can be disrupted by severe stressors such as herbivore overfishing, nutrient enrichment, and elevated sea temperatures (Bruno et al., 2019; Bégin et al., 2016; Russ et al., 2015).

While small-bodied herbivores are less effective at controlling macroalgae, they remain key grazers of filamentous algae (Feitosa et al., 2023). Additionally, sea urchins significantly influence Brazilian benthic reef structure through intense grazing and scraping; when present in persistently high densities, their feeding activity causes bioerosion that leads to long-term reductions in structural complexity (Costa, 2013). As

observed in other reef systems, their populations can be regulated by mobile invertebrate predators (McClanahan & Muthiga, 1988), but may also exhibit temporal fluctuations associated with environmental variability, which can influence food availability, reproductive output, larval recruitment, and juvenile survival (Levitan et al., 2023). Although high sea urchin abundance can enhance grazing pressure and influence benthic community composition, reefs with persistently high densities of these organisms may experience long-term reductions in structural complexity due to bioerosion caused by their feeding activity (Costa, 2013).

Regarding bottom-up processes, dissolved nutrient loads from land-based sources such as agriculture and waste water directly influence the composition and abundance of macroalgae (Feitosa et al., 2024). Century-old deforestation of the Atlantic forest along the northeast coast and development of sugar-cane agriculture have increased sedimentation, as well as the upload of nitrogen and other nutrients into coastal reefs (Maida & Ferreira, 1997). Rising temperatures, undoubtedly the most acute disturbance in the last decade, can alter species composition, favor thermotolerant taxa, and modify the structure of macroalgal communities in tropical reef environments (Schermer et al., 2016; Ji & Gao, 2021; Khen et al., 2025). Across Brazilian reefs, the response of macroalgal taxa to this stressor remains poorly understood. However, following declines in coral cover after bleaching events, increases in turf algae cover have been observed, as these communities can rapidly colonize the exposed skeletons of dead corals (Ferreira et al., 2026). The composition and cover of macroalgae and turf algae may also vary within the same ecoregion between coastal and offshore reefs due to differences in environmental conditions and protection regimes, as previously described for the Abrolhos ecoregion (E7) (Francini-Filho et al., 2013). The high macroalgal cover observed on Brazilian coastal reefs highlights the intense competition for space between corals and algae (Ribeiro et al., 2018; Feitosa et al., 2024). While the presence of crustose coralline algae on the substrate tends to enhance coral recruitment success, high macroalgal cover may limit recruitment success (Littler & Littler, 2007; Doropoulos et al., 2017). In BTS and Baixo Sul (E6), water quality has been associated with reduced coral recruitment (Menezes et al., 2026). Zoanthids and soft corals can also act as direct competitors of scleractinian corals. This group includes species that are often thermally tolerant and highly competitive, such as *Palythoa caribaeorum*, which may gain a competitive advantage over hard corals, particularly under thermal stress when corals become physiologically weakened (Grillo et al., 2018; Francini-Filho & Moura, 2010).

2.4. Main Threats

2.4.1 Main threats in the region

Across the Brazilian reef system, ecoregions share a set of anthropogenic pressures. Historical pressures range from those that have been banned or controlled since the late

1990s, such as direct coral removal for construction and ornamental purposes, to those that have persisted for centuries, such as land-based sediment and nutrient runoff from deforestation and agriculture, a chronic pressure that has persisted despite specific laws that protect riverine margins, such as the Brazilian Forest Code. The creation of Marine Protected Areas and specific legislation has limited coral removal and damage resulting from fishing and tourism, and contributed to the recovery of threatened species and fisheries resources (Ferreira et al., 2004; Lippi et al., 2022), although often counteracted by illegal fishing and poor enforcement.

More recently, increasing pressure from tourism and uncontrolled coastal development is overloading local infrastructure and increasing concerns around wastewater impact (Table 2). These stressors often act cumulatively, disrupting the natural balance of water quality and population dynamics on Brazilian reefs, and consequently directly affecting benthic and fish communities, reducing reef resilience, and compromising coral recovery following disturbances (Costa et al., 2008; Leão et al., 2016). The synergistic interaction between those stressors raises concerns around reduced coral recruitment success (Leão & Kikuchi, 2005; Dutra et al., 2006; Ricardo et al., 2016), intensified competition between macroalgae and corals (Costa et al., 2008; Leão et al., 2016; Feitosa et al., 2024), reduced coral growth (Cardoso et al., 2022), increased disease prevalence (Francini-Filho et al., 2008), and harmful microalgal blooms (Costa et al., 2025). Although these pressures are widespread, their intensity and expression vary among ecoregions due to differences in environmental settings, historical use, and management (see subtopic 2.4.2 and Table 2).

In addition, broadscale activities such as mining, oil and gas extraction, and shipping pose risks of contamination, accidents, and biological invasions. The 2019 oil spill affected extensive areas of the Brazilian coast (Soares et al., 2020), while the 2015 Samarco dam failure released iron-rich tailings that reached as far as the Abrolhos reefs (E7), negatively affecting coral growth rates (Cardoso et al., 2022) and potentially altering benthic community composition (Carneiro et al., 2026). Oil extraction and shipping facilitate the dispersal of invasive species such as the sun coral *Tubastraea* spp. (Fig. 2), which has spread along the Brazilian coast (Costa et al., 2014). In contrast, the lionfish (*Pterois* spp.), first reported in the region in 2020 (Luiz et al., 2021), has reached Brazilian waters by dispersing naturally from the Caribbean, crossing the Amazon barrier and expanding its distribution range (Maggioni et al., 2023; Soares et al., 2023). Despite their different introduction and dispersal pathways, both invasive taxa pose threats to local biodiversity due to their broad ecological niches and the apparent lack of natural predators capable of controlling their populations (Soares et al., 2023; Neves da Rocha et al., 2024).

Several species of reef fishes and lobsters are classified as threatened under the Brazilian Red List (Table 1), with overfishing being the main threat. Illegal, unreported and unregulated fisheries is a significant concern, and appropriate data on landings and catch composition are scarce, particularly in the northern and northeastern regions

(Eggertsen et al., 2024). In Brazil, as well as worldwide, herbivorous fish have been increasingly targeted by fisheries (Cunha et al., 2012; Roos et al., 2016; Callwood, 2021; Muraoka et al., 2022; Queiroz-Véras et al., 2025), both due to the decline of traditionally exploited carnivorous species such as groupers and snappers, and the demand of international markets (Queiroz-Véras et al., 2023). Several herbivorous fish species are now threatened in Brazilian waters, including the critically endangered parrotfish *Scarus trispinosus*, a large-bodied endemic Brazilian species (Table 1). Additionally, invertebrates such as lobsters and reef top predators (e.g., sharks, groupers, and other piscivorous fishes) are considered overfished, and fisheries targeting herbivores have been on the rise since the expansion of trap fisheries in the 1990s (Queiroz-Véras et al., 2023).

Marine Protected Areas (MPAs), particularly fully protected marine reserves, are recognized in Brazil as an important component of fisheries management strategies (Prates et al., 2007), locally contributing to the maintenance of fish populations and the conservation and sustainability of fish stocks. Both predatory fishes, such as groupers and snappers, and herbivores, such as parrotfishes, exhibit higher abundance and biomass within fully protected areas than on adjacent open-access reefs (Ferreira et al., 2004; Floeter et al., 2006; Ferreira & Maida, 2006; Anderson et al., 2014; Motta et al., 2021; Rolim et al., 2022; Lippi et al., 2022; Coxey et al., 2024). Although MPA coverage in Brazil is relatively extensive, encompassing approximately 26% of the country's marine jurisdiction, these areas do not evenly represent marine and coastal habitats and ecosystems (Mills et al., 2020). Moreover, most MPAs encompassing coral reefs fall under the Sustainable Use category, such as Environmental Protection Areas (APAs), and many have limited management and enforcement. The lower fish size and abundance observed in open-access areas compared with fully protected zones further reflect the effects of overfishing (Ferreira et al., 2004; Lippi et al., 2022). Many reef-associated species are also targeted for export markets, including small groupers and parrotfishes (Queiroz-Véras et al., 2023), with estimated population declines exceeding 87% between 1980 and 2019 for some species, such as *Scarus trispinosus* (ICMBio, 2026).

Marine heatwaves have emerged as the main contemporary challenge for Brazilian coral reefs, having triggered mass mortality of key coral species in important reef complexes (Mies et al., 2024; Vidal et al., 2025 and 2026; Carlos-Júnior et al., 2026; Ferreira et al., 2026) (Fig. 7). From 1986 to 2025, periods of major heat stress occurred in 1998, 2010, 2016, 2019, 2020 and 2024 across the eight ecoregions evaluated. Of these, four events were global (1998, 2010, 2016 and 2024) and two were regional (2019 and 2020). The 2016 event, considered one of the most intense worldwide mass bleaching events, resulted in low mortality on Brazil's reefs (Teixeira et al., 2019). Although the intensity and impacts varied among ecoregions (see subtopic 2.4.2), the 2019, 2020, and 2024 events were considered the most extreme for the region.

Different thermal-stress responses among ecoregions are partly driven by differences in the thermal tolerance of the dominant coral species, as well as by oceanographic

factors such as hydrodynamic circulation, depth, and light intensity. Species such as *Millepora alcicornis*, *Millepora braziliensis*, and *Mussismilia harttii* are known to be particularly sensitive to thermal stress. Severe population declines of those species have been documented following the two most recent mass bleaching events (2019/2020 and 2024), particularly across the northeastern Brazilian ecoregions (E3, E5, E6, E7) (Mies et al., 2024; Ferreira et al., 2026; Vidal et al., 2025, 2026; Carlos-Júnior et al., 2026). In contrast, species such as *Siderastrea* sp. and *Montastraea cavernosa* have shown comparatively greater resistance, with low mortality rates following these events (Vidal et al., 2026; Carlos-Júnior et al., 2026).

Overall, the continuous intensification of multiple local pressures leading to increased overfishing, water quality deterioration and intense heatwaves tends to reduce reef resilience and compromise post-disturbance recovery across the region, requiring broader national and local strategies.

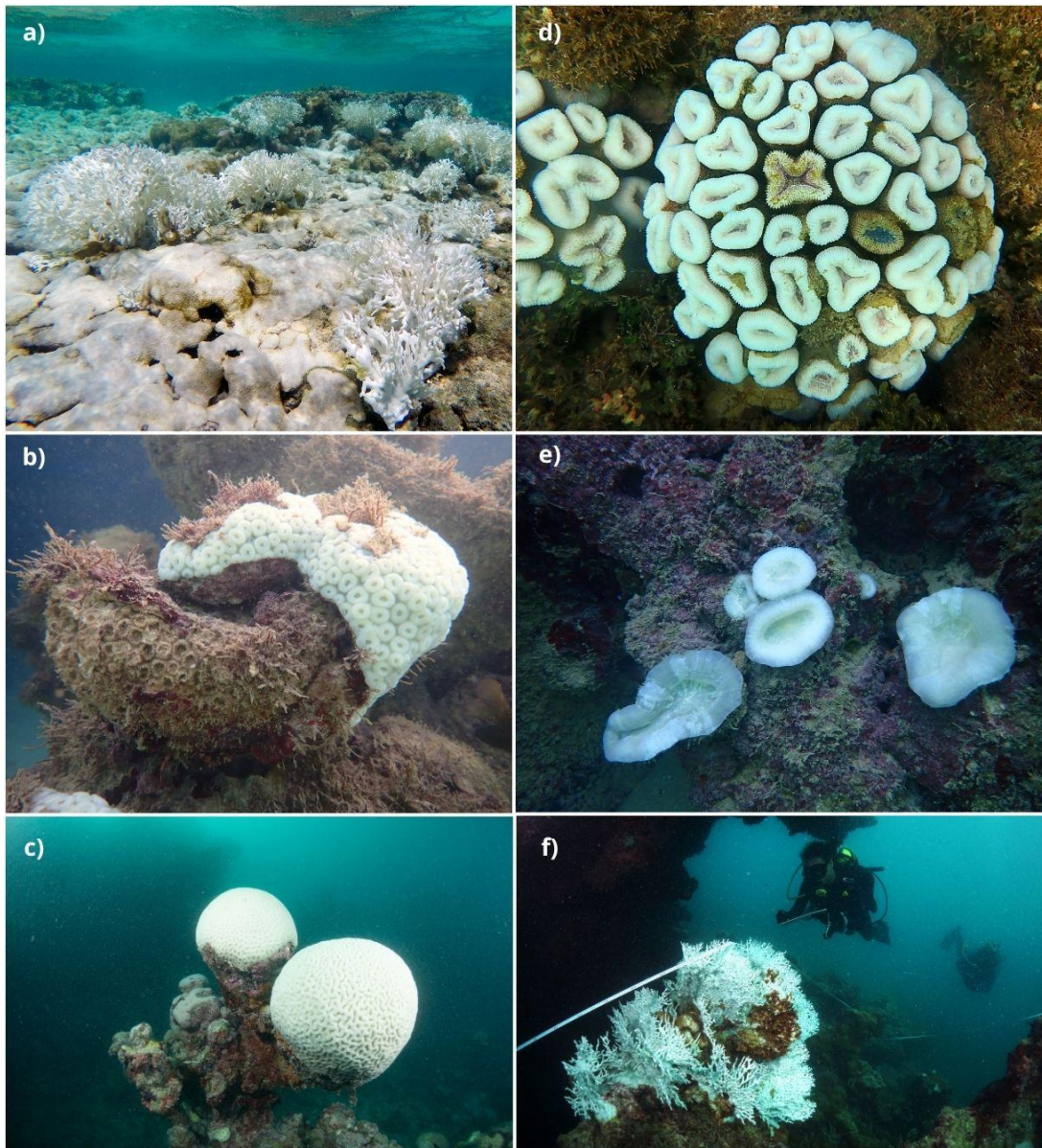


Figure 7. Records of bleaching events along the Brazilian coast. a) 2019/2020 bleaching event in Rio do Fogo (E3); b, d and e) 2024 bleaching event in Tamandaré and Maragogi (E5); c and f) 2019 bleaching event in Abrolhos (E7).

2.4.2 Spatial variation in threats across ecoregions

Impact levels vary according to the proximity to the source of pressures, with coastal reefs being subject to both historical and more intense pressures than offshore reefs, and to the level of protection, linked mainly to the existence and category of MPAs, which regulates uses.

Parcel de Manuel Luís (E1) raises concerns, as temperature anomalies and heat waves have been recorded in the ecoregion, and reports of mass bleachings date back to 1998 (Amaral et al., 2006). These reports point to a possible local demise of the endemic species *Millepora laborelli*. However, the ecoregion lacks systematic monitoring efforts

due to the difficult access and local conditions that make research in the area extremely challenging..

Oceanic environments such as ecoregion 4, which includes the Rocas Atoll and the Fernando de Noronha Archipelago, are less influenced by continental inputs with major impacts due to heat waves. The most significant bleaching events in the ecoregion were recorded in 2010, 2019/2020, and 2024, resulting in a progressive decline in coral cover (Ferreira et al., 2026). While Rocas Atoll is a Marine Reserve and benefits from strict protection and minimal human presence, the Fernando de Noronha Marine Park supports a resident population and high tourism pressure (Table 2), with challenges such as inadequate wastewater treatment leading to declines in water quality (Mello et al., 2025).

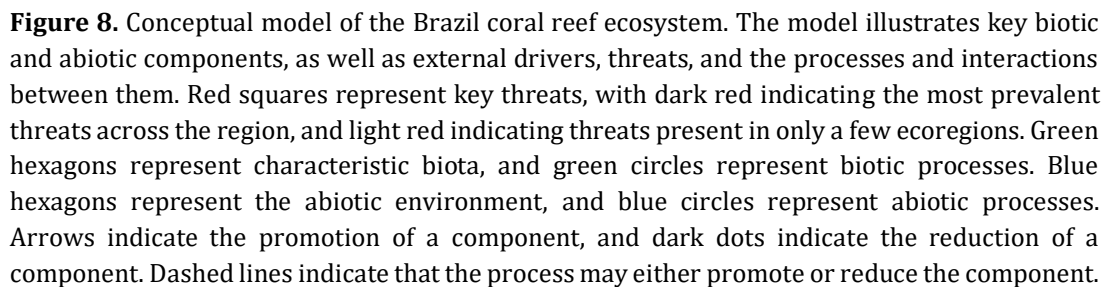
Ecoregions 3, 5, and 6 (Parrachos, Costa dos Corais and BTS and Baixo Sul) are characterized by coastal reef systems strongly influenced by land-based processes (Table 2). Historical deforestation and coral extraction for construction have resulted in chronic sedimentation and long-term degradation (Ferreira et al., 2006). Despite the establishment of marine protected areas in the late 1990s and the prohibition of coral removal (Brazil, 1998), contemporary pressures including tourism, fishing, land runoff, and coastal development remain the primary threats (Feitosa et al., 2023; Da Silveira & Ferreira, 2024; Vidal et al., 2025). Moreover, ecoregions 3 and 5 were the most affected by the 2024 bleaching event, resulting in mass mortality of key species (Mies et al., 2024; Ferreira et al., 2026; Vidal et al., 2026).

Ecoregion 7, encompassing the Abrolhos shelf, hosts the largest and most biodiverse reef formations in the region, distributed across both nearshore and offshore environments (Laborel, 1969). Although it experiences pressures such as fishing and coastal development, it is also affected by additional stressors like dredging and large-scale disturbance events (Table 2). Notably, the 2015 Fundão dam collapse transported contaminants via the Doce River to the southern portion of the region, resulting in metal contamination that was detected in corals (Cardoso et al., 2022). This ecoregion experienced the highest number of Alert Level-2 events throughout the time series (2003, 2010, 2016, and 2022). However, compared with other ecoregions, it was less severely affected by marine heatwaves in terms of bleaching intensity and subsequent coral mortality. The most intense thermal anomaly recorded occurred in 2019, triggering mass bleaching and significant mortality (Duarte et al., 2020); progressive mortality continued to be observed for two years after the event (Cardoso et al., 2025). In 2024, while the ecoregion was also affected by a heatwave, no mass coral bleaching or mortality were observed (Carlos-Júnior et al., 2026).

Table 2. Summary of current and emerging threats to coral reefs in each ecoregion categorised based on the IUCN Threat Classification Scheme. A ✓ (*tick*) indicates a threat currently impacting the ecoregion; a – (*dash*) indicates that the threat is not an issue; a + (*plus*) indicates an emerging threat likely to become relevant in the near future; and an (h) indicates a threat that occurred

historically but is no longer present. 1- Parcel de Manuel Luís; 2- Semiarid; 3- Parrachos; 4- Rocas Atoll and Noronha; 5- Costa dos Corais; 6- BTS and Baixo Sul; 7- Abrolhos; 8- Queimada Grande.

Threat type	Subcategory	Ecoregion							
		E1	E2	E3	E4	E5	E6	E7	E8
1. Residential & commercial development	1.1 Housing and urban areas	-	✓	✓	✓	✓	✓	✓	-
	1.2 Commercial and industrial areas	-	✓	-	✓	✓	✓	✓	-
	1.3 Tourism & recreation areas	-	-	✓	✓	✓	✓	✓	✓
2. Agriculture & aquaculture	2.4 Marine & freshwater aquaculture (2.4.2 Industrial aquaculture)	-	✓	✓	-	✓	✓	✓	-
3. Energy production & mining	3.1 Oil & gas drilling	+	✓	+	+	+	✓	+	+
	3.2 Mining & Quarrying	-	-	h	-	h	h	h	-
	3.3 Renewable Energy	+	+	+	-	-	-	-	-
4. Transportation & service corridors	4.3 Shipping lanes/Dredging	✓	✓	✓	✓	✓	✓	✓	-
5. Biological resource use	5.4.1 Intentional Use: subsistence/small scale	✓	✓	✓	✓	✓	✓	✓	✓
	5.4.3 Unintentional effects: subsistence/small scale	✓	✓	✓	✓	✓	✓	✓	✓
6. Human intrusions & disturbance	6.1 Recreational activities	-	✓	✓	✓	✓	✓	✓	✓
7. Natural system modifications	7.3 Other ecosystem modifications	-	✓	✓	+	✓	✓	✓	-
8. Invasive & problematic species	8.1.2 Invasive non-native species/named species	✓	✓	✓	✓	✓	✓	✓	+
	8.6 Diseases of unknown cause	-	-	-	-	-	-	✓	-
9. Pollution	9.1 Domestic & urban waste water (9.1.1 Sewage, 9.1.2 Run-off)	-	✓	✓	✓	✓	✓	✓	✓
	9.2 Industrial & military effluents (Oil spills)	+	+	h	+	h	✓	h	-
	9.2.2 Seepage from Mining	-	-	-	-	-	-	✓	-
	9.3 Agricultural & forestry effluents (9.3.1 Nutrient Loads, 9.3.2 Soil Erosion, Sedimentation)	-	-	✓	-	✓	✓	✓	+
	9.4 Garbage & Solid Waste	✓	✓	✓	✓	✓	✓	✓	✓
	9.6.2 Thermal pollution	-	-	-	✓	-	-	-	-
	9.6.3 Noise Pollution	-	+	✓	✓	✓	✓	✓	-
11. Climate change & severe weather	11.1 habitat shifting and alteration	✓	✓	✓	✓	✓	✓	✓	-
	11.3 Temperature extremes	✓	✓	✓	✓	✓	✓	✓	✓
	11.4 Storms & flooding	-	-	✓	-	✓	✓	-	-



Ecosystem collapse represents the final stage of degradation. It occurs when an ecosystem's defining biodiversity and features decline to levels where the ecosystem transforms into a different type or is completely lost. This state can result from a number of pathways that reduce the capacity of an ecosystem to sustain its characteristic biota, such as disease, overharvesting, or a persistent change in environmental conditions. Collapse can occur locally, for example in a single reef. For an ecosystem type to be classified as 'Collapsed', it must have fully declined or degraded across its entire distribution, although recovery may still be possible under conducive conditions.

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invertebrates. This state is also associated with low abundance and diversity of other key biodiversity including altered fish communities. In some cases, collapse corresponds to a simplified topographic structure or occurs where the geomorphological structure of coral reefs permanently disappears through land reclamation or coastal development. A collapsed reef may have an unsuitable abiotic environment due to declines in water quality, increases in temperature, as well as frequent and severe disturbance events.

Under the Red List of Ecosystems framework, collapse can be defined as when key biotic or abiotic indicators reach thresholds where the ecosystem's defining features are (or would be) lost.

For this assessment, coral reef ecosystem collapse is defined by any of the following:

- complete loss of coral reef area
- hard coral cover falling below **5%**;
- sea surface temperatures exceeding critical thresholds, resulting in frequent severe heatwaves and coral bleaching at an average return time between events of **3 years**

In addition, the following biotic indicators reflect severe functional degradation but not complete ecosystem collapse, and can be used to elevate risk levels:

- a) an **algal-to-coral** cover ratio exceeding **5:1**;
- b) severe depletion of key fish groups (**herbivores and piscivores**) to levels well below historical baselines.

Table 3. Key abiotic and biotic features and characteristics of the coral reef's ecoregions in Brazil coral reefs highlighting unique aspects of each ecosystem.

Ecoregion	Key Biotic	Key Abiotic	Key Threats
Parcel de Manuel Luís (E1)	Elongated pinnacles with flattened tops ("chapeirões"); presence of the regional endemic hydrocoral species <i>Millepora laboreli</i> ; and diverse reef fish assemblages, including herbivores and top predators such as groupers and sharks.	Oceanic systems; clear oligotrophic water;	Coral bleaching; fishing; development of rodolith mining; expansion of the oil industry.
Semiarid (E2)	Coral cover less than 5% of the bottom, which is dominated by algae and sponges. High diversity of sponges and macroalgae, with some degree of endemism. Most common coral species being <i>Siderastrea</i> spp., <i>Montastraea cavernosa</i> , and <i>Mussismilia hispida</i> . Diverse reef fish assemblages, including herbivores and top predators. The families Carangidae, Haemulidae, Labridae and Epinephelidae are the most diverse.	This area extends for about 1000 km in an SE-NW direction, and has distinct environmental conditions, such as a large interannual variability in rainfall, a predominance of small rivers, and a strong influence of wind on coastal landscapes.	Coral bleaching; local fishing; coastal development; tourism pressure; industrial effluents

Ecoregion	Key Biotic	Key Abiotic	Key Threats
Parrachos (E3)	Shallow patch reefs dominated by <i>Siderastrea</i> sp. and <i>Porites astreoides</i> , macroalgae and turf; and diverse reef fish assemblages, including herbivores as the endemic and endangered <i>Scarus trispinosus</i> .	Influence of riverine inputs; mild seasonality between rainy and dry periods, with fluctuations in nutrient input/primary productivity, sedimentation, salinity, and temperature.	Coral bleaching; local fishing; coastal development; tourism pressure
Rocas Atoll and Noronha (E4)	Atoll formations and reefs surrounding oceanic islands; pronounced depth stratification of coral species; and high abundance and biomass of reef fish, including herbivores and top predators such as groupers and sharks.	Oceanic systems; clear oligotrophic water; seasonal high swells.	Coral bleaching; fishing; tourism pressure (Fernando de Noronha); invasive species.
Costa dos Corais (E5)	Fringing reefs with coral knolls dominated by <i>Millepora alcornis</i> , <i>Siderastrea</i> sp. and <i>Mussismilia harttii</i> ; and diverse reef fish assemblages, including herbivores and top predators such as groupers and Lutjanidae.	Strong influence of riverine inputs; marked seasonality between rainy and dry periods, driving fluctuations in nutrient input/primary productivity, sedimentation, salinity, and temperature.	Coral bleaching; local fishing; Industrial effluents; coastal and urban development; sewage discharge; tourism pressure.
BTS and Baixo Sul (E6)	Shallow bank reefs and fringing reefs; dominated by corals such as <i>Montastraea cavernosa</i> , <i>Siderastrea</i> spp., and the endemic <i>Mussismilia</i> complex (<i>M. hispida</i> , <i>M. harttii</i> , <i>M. braziliensis</i>); high abundance of macroalgae and turf algae; registered phase shifts to the zoantharia <i>Palythoa</i> ; presence of invasive cup corals (<i>Tubastraea</i> spp.). Diverse ichthyofauna (notably Carangidae, Sciaenidae and Lutjanidae); extensive mangroves that cover emergent reef tops in some regions.	Third largest bay in Brazil; warm, shallow waters with tidal-dominated circulation; naturally high levels of turbidity and sedimentation; sediments primarily of siliciclastic and terrigenous origin; direct influence from major river systems (Paraguauçu, Subaé and Jaguaripe).	Coral bleaching; local fishing (including blast fishing); Industrial effluents; coastal and urban development; sewage discharge; tourism pressure; biological invasions (e.g. <i>Tubastraea</i> spp. and soft corals).
Abrolhos (E7)	Elongated pinnacles with flattened tops ("chapeirões") that typically coalesce in reefs closer to the shore and remain isolated offshore; reefs surrounding oceanic islands; high coral biodiversity for Brazilian reefs; presence of the regional endemic coral species <i>Mussismilia braziliensis</i> ; and diverse reef fish assemblages, including herbivores and top predators such as groupers and sharks.	Gradient of fluvial influence, coastal arc environments (~10 km from shore) are subjected to higher loads of suspended particulate matter and nutrient concentrations, particularly during the rainy season, whereas reefs located on the outer arc (~50 km offshore) experience more stable environmental conditions throughout the year.	Coral bleaching; local fishing; coastal development; tourism pressure; mining waste spill.
Queimada Grande (E8)	Reef primarily built by <i>Madracis decactis</i> and <i>Mussismilia hispida</i> , representing the southernmost known coral-built reef in the Atlantic Ocean.	Marked seasonality in the region is driven by the presence of seasonal thermoclines, which promote fluctuations in nutrient availability, primary productivity, and seawater temperature.	Coral bleaching; recreational fishing, spearfishing, diving tourism, and biological invasions by <i>Tubastraea</i> spp.

3. Criterion Assessment

Coral reefs in **8** ecoregions within **Brazil** were assessed using IUCN Red List of Ecosystems (RLE) Criteria A–D. The following section briefly describes the approach used for each criterion with the detailed methods presented in the Annex.

Criterion A — Decline in Distribution

Decline in distribution of coral reefs over the past 50 years was assessed using hard coral cover data and was calculated as the proportion of reef sites currently with less than 5% hard coral cover, which is an estimated minimum threshold for net accretion. Coral reefs in each ecoregion were classified as Vulnerable if they experienced a 30–50% decline, Endangered if the decline was 50–80%, and Critically Endangered if the decline exceeded 80%. Reefs with declines of 27–30% were classified as Near Threatened, and all others were considered Least Concern.

Criterion B — Restricted Geographic Distribution

Criterion B assesses the extent of occurrence (EOO) and area of occupancy (AOO) of the current distribution of coral reefs. EOO is the total area within the outer limits of the ecosystem's distribution, while AOO is the area occupied by the ecosystem, measured as the number of 10 by 10 km grid cells. Both were derived using the Millennium Coral Reef Layer, validated by regional experts. For both metrics the thresholds from the RLE guidelines were applied to assess risk, and additional conditions on continuing decline were evaluated using threat and biotic data from Criteria C and D.

Criterion C — Environmental Degradation

Criterion C evaluates the degradation of the abiotic environment and the risk this poses to ecosystem persistence. Globally, the most pertinent threat to coral reefs is the increasing occurrence of extreme marine heatwave events that cause coral bleaching and mortality. Under Criterion C, we evaluated historical changes in frequency of marine heat waves over the past 50 years (sub-criterion C1, 1975–2025) and projected changes over the next 50 years (sub-criterion C2, 2026–2075). For both periods, annual maximum Degree Heating Weeks (DHW), a satellite-derived measure of accumulated heat stress, was used to identify years in which widespread bleaching or severe mortality events occurred. Two complementary pathways to ecosystem collapse were assessed: a chronic pathway, capturing the progressive degradation driven by the long-term effects of frequently recurring bleaching events. This was assessed using the average return interval between severe bleaching events over a 30-year period. The second approach is a pulse pathway, capturing acute collapse driven by the clustering

of extreme high-mortality events within any 5-year window. For both C1 and C2, the relative severity of decline was calculated by comparing the magnitude of past and projected changes against initial conditions and thresholds for coral reef collapse. Collapse thresholds were set at one severe bleaching event every three years for the chronic pathway, and three severe mortality events within five years for the pulse pathway. For C2, analyses were conducted under three emissions scenarios (SSP2-4.5, SSP3-7.0, and SSP5-8.5), with SSP2-4.5 treated as the primary scenario. Risk categories were assigned using the severity–extent matrix, based on the proportion of reef area within each ecoregion experiencing different levels of relative decline. The most severe risk status across both chronic and pulse approaches and C1 and 2 was taken as the final risk status under Criterion C.

Criterion D — Disruption of Biotic Processes and Interactions

Criterion D assesses the disruption to four key biotic components over the past 50 years. This includes coral cover, algae-to-coral ratio, herbivore biomass, and piscivore biomass, derived from in-situ monitoring data. For each reef site, the decline in each indicator is measured relative to both the state of the reef 50 years ago and a hypothetical collapse threshold, representing the point at which that biotic component is no longer functional. The proportion of sites experiencing varying degrees of decline is then evaluated, and a risk matrix is used to determine the risk status for each indicator. Finally, a heuristic, step-wise approach across all indicators is applied to derive the overall risk status under Criterion D for each ecoregion.

Table 4. Methodology, parameters and collapsed thresholds used to assess Coral Reefs ecosystems in Brazil under the Red List of Ecosystem criteria.

Criterion	Sub-criterion	Indicator(s)	Data Sources	Collapse Threshold(s)	Criterion Assessed? (Yes/No)	Comments
A Reduction in geographic distribution	A1 – (Past 50 years)	Hard coral cover	Coral cover from benthic surveys	5% hard coral cover	Yes	Based on data collected during/after 2022 for the Abrolhos and Parcel de Manuel Luís ecoregions, and during/after 2024 for all other ecoregions.
B Restricted geographic distribution	B1 –Extent of Occurrence (EOO)	Extent of Occurrence (EOO) + ongoing decline or number of threat defined locations	Regional reef maps, expert knowledge	EOO < 50,000 km ² + ongoing decline or threats	Yes	Calculated per eco-region using minimum convex polygons
	B2 – Area of Occupancy (AOO)	Area of Occupancy (AOO) + ongoing decline or number of threat defined locations	Grid-based reef presence (10×10 km), monitoring data	AOO < 50 + ongoing decline or threats	Yes	Fluctuation data limited; AOO estimates incomplete

Criterion	Sub-criterion	Indicator(s)	Data Sources	Collapse Threshold(s)	Criterion Assessed? (Yes/No)	Comments
C	C1 – Environmental degradation	Degree Heating Weeks (DHW)	NOAA Coral Reef Watch	Return interval of ≤ 3 years between bleaching events or 3 severe marine heatwave events occurring within 5 years	Yes	Ecoregion average
C	C2 – Projected future degradation	Degree Heating Weeks (DHW)	Global Climate Projections (SSPs) of DHWs	Return interval of ≤ 3 years between bleaching events or 3 severe marine heatwave events occurring within 5 years	Yes	Ecoregion average
D	D1 – Disruption of biotic processes	Hard coral cover	Benthic cover from surveys	Hard coral cover $< 5\%$	Yes	
		Algae-coral ratio	Benthic cover from surveys	Algae:coral ratio = 0.83	Yes	Ratio followed WIO reference
		Herbivore and piscivore biomass	Fish biomass from UVC surveys (100m ²)	Biomass below 10% of baseline (50 years ago) for herbivores and 20% for piscivores	Yes	Eco-region average

4. Risk Status

Coral reefs across **five** of the eight ecoregions of Brazil were at a high risk of collapse (Vulnerable, Endangered or Critically Endangered), while three ecoregions were assessed as Data Deficiente for lack of functional criteria. Critical risk levels were driven by reduced area of occupation (criterion B), projected disruption to the abiotic environment caused by climate change (criterion C), and disruption to the biotic environment (criterion D).

Table 5. Summary of RLE assessment results for Brazil coral reef ecoregions. The overall *Red List of Ecosystems* status is the *highest* level of risk identified across all the assessed criteria.

Ecoregions		A	B	C	D	Observed change	Overall risk
1	Parcel de Manuel Luís	VU	EN	DD	DD	DD	DD
2	Semiarid	EN	EN	DD	DD	DD	DD
3	Parrachos	LC	CR	CR	EN	CR (B1)	CR (B1, C2)
4	Rocas Atoll and Noronha	LC	CR	CR	VU	CR (B1, B2)	CR (B1, B2, C2)
5	Costa dos Corais	EN	VU	CR	CR	CR (D1)	CR (C2, D1)
6	BTS and Baixo Sul	VU	EN	CR	EN	EN (B1, C1, D1)	CR (C2)
7	Abrolhos	LC	EN	CR	VU	EN (B1)	CR (C2)
8	Queimada Grande	DD	DD	DD	DD	DD	DD

Criterion A: Reduction in Geographic Distribution

Of the eight ecoregions assessed, four were classified within threatened categories, having lost a significant area of their coral reefs over the past 50 years. In the Costa dos Corais ecoregion, historical reef loss exceeded 50%, highlighting areas of concern where cumulative pressures such as bleaching and bleaching-induced mortality, overfishing, coastal development, uncontrolled tourism, and increased sedimentation and pollution are highest. Contrastingly, the Abrolhos, Rocas Atoll and Noronha, and Parrachos ecoregions were assessed as Least Concern. Queimada Grande was classified as Data Deficient, highlighting the need for long-term monitoring and improved data availability for future assessments in the area.

Table 6. Risk status of Brazilian coral reef ecoregions under Criterion A, determined from estimated declines in coral reef area.

Coral Reef Ecoregion	Proportion of reef sites below critical hard coral cover threshold	Risk status (A1)
Parcel de Manuel Luís	33%	VU
Semiarid	57%	EN
Parrachos	25%	LC
Rocas Atoll and Noronha	0%	LC
Costa dos Corais	69%	EN
BTS and Baixo Sul	39%	VU
Abrolhos	7%	LC
Queimada Grande	N/A	DD

Criterion B: Restricted Geographic Distribution

Under Criterion B, seven ecoregions were classified within threatened categories. Ecoregions with the most restricted distributions, specifically Parrachos and Rocas Atoll and Noronha, met the quantitative thresholds for the Critically Endangered status due to their highly limited Extent of Occurrence ($EOO \leq 2,000 \text{ km}^2$) and/or Area of Occupancy ($AOO \leq 2$ grid cells). Seven Brazilian ecoregions fulfilled the requirement for at least one sub-criterion related to risk, supported by evidence of continuing declines or imminent threatening processes. Most notably, the increasing frequency and severity of increased water temperatures and subsequent coral bleaching represent a critical threat likely to cause further deterioration in ecosystem conditions across all units within the next 20 years. One ecoregion (Queimada Grande) lacked sufficient monitoring data and evidence to support the assessment under this criterion, and was classified as Data Deficient.

Table 7. Risk status of Brazilian coral reef ecoregions under Criterion B, determined from distribution of coral reefs measured as the Extent of Occurrence (EOO) and Area of Occupancy (AOO).

Coral Reef Ecoregion	Extent of Occurrence (EOO, km ²)	Area of Occupancy (AOO cells, 10 km ² units)	Subcriterion B1 (EOO)	Subcriterion B2 (AOO)	Overall Criterion B Risk
Parcel de Manuel Luís	3256	14	EN	EN	EN
Semiarid	3746	7	EN	EN	EN
Parrachos	549	9	CR	EN	CR
Rocas Atoll and Noronha	997	2	CR	CR	CR
Costa dos Corais	31762	38	VU	VU	VU
BTS and Baixo Sul	7602	25	EN	VU	EN
Abrolhos	18014	40	EN	VU	EN
Queimada Grande	2	1	DD	DD	DD

Criterion C: Environmental Degradation

Under Criterion C, five assessed ecoregions were classified within a threat category. Based on observed DHW data and coral bleaching events from the past 40 years, three ecoregions were classified as Vulnerable, and two ecoregions were classified as Endangered under the chronic stress pathway. Based on pulse disturbance from mass mortality events, three ecoregions were classified as Endangered, one as Vulnerable, and one as Near Threatened. Based on DHW projections of future climate conditions (SSP2-4.5 and SSP3-7.0; next 50 years), all five assessed ecoregions were classified as Critically Endangered under both pathways.

Table 8. Risk status of Brazilian coral reef ecoregions under Criterion C, determined from estimated declines in abiotic conditions, specifically changes in extreme heat events.

Ecoregion	C1			C2		
	Chronic	Acute	Overall	Chronic	Acute	Overall
Parcel de Manuel Luís	DD			DD		
Semiarid	DD			DD		
Parrachos	VU	EN	EN	CR	CR	CR
Rocas Atoll and Noronha	VU	VU	VU	CR	CR	CR
Costa dos Corais	EN	EN	EN	CR	CR	CR
BTS and Baixo Sul	EN	EN	EN	CR	CR	CR
Abrolhos	VU	NT	VU	CR	CR	CR
Queimada Grande	DD			DD		

Criterion D: Disruption of biotic processes or interactions

Criterion D was assessed for five of the eight ecoregions for hard coral cover and algae-coral ratio, and four ecoregions were assessed for herbivores and piscivores. Data suggest moderate to severe levels of threat across all assessed ecoregions, indicating disruption of biotic processes. Rocas Atoll and Noronha and Abrolhos were classified as Vulnerable, Parrachos and BTS and Baixo Sul were classified as Endangered, and Costa dos Corais was assessed as Critically Endangered.

Table 9. Risk status of Brazilian coral reef ecoregions under Criterion D, determined from estimated historical declines in critical biotic components. The overall status is determined through a step-wise approach considering the risk of each indicator in ecological order from left to right. Ranges in risk, e.g. EN-CR, represent uncertainty in the outcomes, and where relevant the most likely category is presented (outside of the parentheses) in addition to the range. Overall risk considered DD if hard coral risk is DD.

Ecoregion	Hard coral cover	Algae-coral ratio	Herbivore biomass	Piscivore biomass	Overall
Parcel de Manuel Luís	DD	DD	DD	DD	DD
Semiarid	DD	DD	DD	DD	DD
Parrachos	EN	NT	LC-NT	EN	EN
Rocas Atoll and Noronha	VU	VU-EN	LC	LC-NT	VU
Costa dos Corais	CR	CR	VU	EN (EN-CR)	CR
BTS and Baixo Sul	EN	VU	DD	DD	EN
Abrolhos	VU	NT	NT	VU-EN	VU
Queimada Grande	DD	DD	DD	DD	DD

5. Conclusion and recommendations

Brazilian coral reefs currently face a high risk of ecosystem collapse due to compounding local and global pressures, with five of the eight assessed ecoregions being classified within a threatened category. Global pressures are primarily associated with climate change, particularly rising ocean temperatures and increasingly frequent and intense marine heatwaves that lead to mass coral bleaching and mortality. Even highly protected oceanic reefs are being affected by these large-scale environmental changes, despite their isolation and local protection, which are effective at reducing most human-induced pressures.

Local pressures (e.g., unsustainable fisheries, pollution, coastal development, and tourism) are particularly relevant for coastal coral reefs. Measures to mitigate these impacts are essential to enhance reef resilience against climate change and support local recovery. Improving water quality and wastewater treatment, regulating coastal development and tourism, promoting sustainable fisheries, and reducing other local stressors should be central to these efforts. Uncontrolled fisheries have reduced populations of some fish species, such as large groupers, and while herbivorous populations have not been as severely affected in the past, their functional role also appears to be at risk, along with the food security of local fisher communities whose livelihoods depend on those fisheries. Community-based and locally-managed areas, including Extractive Reserves (RESEX), should be strengthened to reconcile reef conservation with the sustainable use of natural resources. Existing marine protected areas should also be strengthened through effective management and enforcement,

while increasing the representation of no-take areas, prioritizing sites with high ecological integrity and resilience potential.

Substantial monitoring gaps also remain. Expanding and standardizing long-term monitoring of both benthic and fish indicators, particularly in Data Deficient ecoregions, and incorporating complementary indicators of community composition is essential not only to reduce uncertainty, but also to better understand ecosystem trajectories. Existing national conservation frameworks, particularly ProCoral and PAN Corais, provide important mechanisms to address these gaps and coordinate management, long-term monitoring and conservation efforts across Brazilian ecoregions; therefore, their continued implementation and strengthening should be prioritized.

Brazilian coral reefs retain substantial potential for resistance and recovery, while many of the ecological processes underlying these responses remain poorly understood. Forecast from projections under SSP2-4.5 scenario, reveals a risk of collapse for reefs should those conditions persist. Evidence of recovery from past disturbances and contrasting responses to recent marine heatwaves reinforces the importance of maintaining the environmental conditions that allow such recovery to occur as marine heatwaves become more frequent and intense. Ultimately, maintaining healthy and resilient reefs is essential not only for biodiversity conservation, but also for human well-being, food security, livelihoods, tourism and local economies. Brazilian reefs still retain the capacity to resist and recover, but whether this potential translates into long-term persistence will depend on the conservation and climate actions we take now.

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Figure 3. a) Ricardo Gomes, Instituto Mar Urbano; b) Guilherme Longo, De Olho Nos Corais; c) Ricardo Gomes, Instituto Mar Urbano; d) Thiago Buchianeri, Peld-TAMS.

Figure 5. a) Luiz Rocha; b) Zaira Matheus, All Angle; c) Thales Vidal, Reef Check Brasil; d) Zaira Matheus, All Angle; e) Kelly Inagaki, Onda Illoc; f) Repositório RECOR; g) Leo Francini, Rede Abrolhos; f) Miguel Mies, Coral Vivo.

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7. Peer review

This report was reviewed by the IUCN Red List of Ecosystems global team and by members of other regional coral reef assessment teams under the Global Red List of Coral Reef Ecosystems initiative.

8. Disclaimer

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9. Contributors

In the modified version of the CRediT (<https://credit.niso.org/>) table below, all contributors are listed with their specific contribution(s) to the RLE assessment and publication.

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10. Annex

10.1. Boundary definitions

Table 10. Table summarizing the key details of each Unit of Assessment.

Ecoregion	Coral Reef Area (km ²)	Boundary Description	Justification (Description as to why coral reefs in each ecoregion are different)
Parcel de Manuel Luís	219.6	The Parcel de Manuel Luís is a reef complex located on the western section of the Brazilian Equatorial Margin, ~84km off the coast of Maranhão state, in the outer continental shelf. It extends from -46.14 to -40.76 (longitude), and from -3.04 to 2.18 (latitude).	Ecoregion 1 - Parcel de Manuel Luís (Data Deficient)
Semiarid	83.3	Hard substrates occur between 20–50 m depth across most of the ecoregion, including CaCO ₃ -cemented sandstones and limestone supporting coral assemblages. It extends from -41.82 to -35.10 (longitude), and from -5.09 to 0.49 (latitude)	Ecoregion 2 - Semiarid (Data Deficient)
Parrachos	62.5	This ecoregion comprises shallow reefs along the northeastern coastline of Brazil. Reefs are located ~6 km from shore and spatialized as patches, building a unique formation called “ <i>parrachos</i> ,” with depths ranging from 0.5 to 6m. It extends from -36.44 to -33.36 (longitude) and from -6.00 to -4.33 (latitude)	Ecoregion 3 - Parrachos (Critically Endangered)
Rocas Atoll and Noronha	14.2	This ecoregion comprises the Rocas Atoll Biological Reserve and the Fernando de Noronha Marine National Park, both situated in oceanic waters. These systems represent the emergent peaks of the Fernando de Noronha Ridge. It extends from -36.63 to -29.05 (longitude), and from -7.09 to -0.70 (latitude).	Ecoregion 4 - Rocas Atoll and Noronha (Critically Endangered)

Ecoregion	Coral Reef Area (km ²)	Boundary Description	Justification (Description as to why coral reefs in each ecoregion are different)
Costa dos Corais	92.4	This ecoregion comprises fringing reefs arranged in coastal reef lines, located 1–5 km from shore at depths ranging from 3 to 20 m. It extends from -36.41 to -31.46 (longitude), and from -12.38 to -5.84 (latitude).	Ecoregion 5 - Costa dos Corais (Critically Endangered)
BTS and Baixo Sul	98.5	This ecoregion comprises reefs in the Todos os Santos (BTS) and Camamu Bays. BTS is the third largest bay in Brazil, covering approximately 1,200 km ² . The ecoregion extends from -39.07 to -33.61 (longitude), and from -15.90 to -10.51 (latitude).	Ecoregion 6 - BTS and Baixo Sul (Critically Endangered)
Abrolhos	504.9	This ecoregion encompasses some coastal reefs, as well as the Abrolhos Bank, a ~46,000 km ² widening of the Eastern Brazilian shelf. Reefs cover ~8,800 km ² and comprise emerging and near-emerging structures distributed in two arcs, one located 5–25 km offshore, and another 70 km offshore. It extends from -39.80 to -35.53 (longitude), and from -20.03 to -15.83 (latitude).	Ecoregion 7 - Abrolhos (Critically Endangered)
Queimada Grande	0.9	This ecoregion is located ~35 km offshore and represents a subtropical reef complex. It extends from -47.96 to -41.26 (longitude), and from -27.35 to -22.92 (latitude).	Ecoregion 8 - Queimada Grande (Data Deficient)

10.2. Data collection

Data for this report were obtained through voluntary responses to a national call initiated in 2023, when the Brazilian Ministry of the Environment (MMA) conducted a survey to identify coral reef monitoring programs and initiatives with relevant datasets and an interest in contributing to national and global assessments. This initial mapping supported Brazil's contribution to the Status of Coral Reefs of the World: 2025 and provided the basis for the subsequent national Red List of Ecosystems (RLE) assessment through a renewed invitation to potential data contributors. In total, eight initiatives provided datasets for the assessment (Table 11). For the in-person validation workshop, participation was further expanded to include researchers with expertise in specific reef regions and ecoregions, ensuring that relevant regional knowledge was incorporated into the assessment. The workshop was held from 2 to 6 March 2026 and brought together 22 participants from 13 institutions.

Table 11. List of datasets used in the Brazilian coral reef assessment and their respective ecoregion coverage. B - Benthic data; F - Fish data. BUD - Budiões Project; COV - Coral Vivo Project; DOC - De Olho nos Corais; PAB - PELD Abrolhos; PIL - PELD ILOC; PTA - PELD TAMS; RCB - Reef Check Brasil; REC - RECOR/ UFBA.

Datasets	BUD	COV	DOC	PAB	PIL	PTA	RCB	REC
Ecoregions								
<i>Parcel de Manuel Luís</i>	B	-	-	-	-	-	-	-
<i>Semiarid</i>	B	-	-	-	-	-	-	-
<i>Parrachos</i>	B/F	B	B/F	-	-	-	B/F	-
<i>Rocas Atoll and Noronha</i>	B/F	B	-	-	B	-	B/F	-
<i>Costa dos Corais</i>	B/F	B	-	-	-	B/F	B/F	-
<i>BTS and Baixo Sul</i>	B	B	-	-	-	-	B/F	B
<i>Abrolhos</i>	B/F	B	-	B	-	-	B/F	B
<i>Queimada Grande</i>	-	-	-	-	-	-	-	-

While the assessment was based on recent data, historical data were used on baseline estimations and/or exploratory analyses, helping support methodological decisions. Details on the time series and number of sites of each dataset across years and ecoregions may be found in the Supplementary Material A.

Because our analysis compiled benthic data from multiple monitoring programs that sometimes sample at the same site or at very close sites, we aggregated pairs or groups of sites within 500m of each other. Exceptions were made for some sites with contrasting natural features, which remained as separate sites despite being within 500m of each other. Site aggregation occurred at two levels: within-dataset and between-dataset. First, sites from the same monitoring program located within 500 meters of each other were aggregated. Then, the yearly mean cover for each benthic category was calculated at the site level using data from the latest survey conducted within each given year, averaging the benthic data across transects and/or quadrats. Subsequently, after all individual datasets were compiled, between-dataset aggregation aggregated sites from different monitoring programs and averaged their respective yearly mean covers. For both within-dataset and between-dataset site aggregations, the original sets of coordinates were replaced with the coordinates of the resulting aggregated centroid.

10.3. Methods description (detailed)

The Brazil coral reef assessment included eight benthic cover datasets and four fish abundance datasets (Table 11). The benthic data time series covered a period from 2000 to 2025, while fish data were available from 2002 to 2025, with some ecoregions having longer time series than others. Benthic data were available for 7 out of the 8 ecoregions, and fish data were available for 4 out of the 8 ecoregions. Benthic datasets encompassed

a range of monitoring methods, including photoquadrats (3 datasets), video transects (1 dataset), and point-intercept transects (4 datasets). Fish data were compiled through 100m² visual censuses.

Reef typology

To determine which coral reef types to include in this assessment, we used the IUCN Global Ecosystem Typology (GET) (Keith et al., 2022) to ensure a consistent and globally aligned definition of coral reef ecosystems.

Within the GET, true photic coral reefs are classified under the ecosystem functional group 'M1.3 Photic Coral Reefs' (<https://global-ecosystems.org/explore/groups/M1.3>). These ecosystems are characterised by active carbonate accretion and the development of a biogenic reef framework built by Scleractinia over millennial timescales, i.e. net biogenic accretion. However, coral communities also occur in marginal environments where environmental conditions or substrate constrain carbonate accretion and limit the development of reef structures. These systems were defined as 'marginal' coral reefs in this assessment.

To ensure the assessment captures the full diversity of coral reef ecosystems globally, an inclusive and standardised approach was adopted. Both true (Type A), corresponding to shallow water, biogenic photic reefs with millenar carbonate accretion, and marginal (Type B) reefs that occur in suboptimal conditions (temperature, turbidity) were included. Potentially confounding ecosystem types that may host similar coral communities were excluded from the assessment. These include mesophotic coral reefs and rocky reefs (Type C), which are classified under their own ecosystem functional groups in the GET (e.g. M1.6 Subtidal rocky reefs - <https://global-ecosystems.org/explore/groups/M1.6>). Care was taken not to exclude degraded coral reefs that may superficially resemble rocky or other reef systems, as these represent important expressions of coral reef degradation and are central to assessing collapse risk.

The occurrence and distribution of selected reef types within the region were delineated based on consolidated literature on the distribution of coral reefs in Brazil, including foundational studies by Laborel (1969), Maida and Ferreira (1997), and Leão et al. (2003). This distribution was subsequently refined through expert judgement, workshop discussions, and field observations, which informed the subdivision of ecoregions and the application of the RLE-recommended typology to the mapped reef distribution.

Criterion A: Reduction in geographic distribution

Criterion A assesses the reduction in the extent of an ecosystem over time, typically over a 50-year period. We focused on assessing Criterion A1, which measures the percentage of coral reef area lost across each ecoregion over the past 50 years (1975–2025). Criteria A2a, A2b or A3, requiring assessment into the future, were not evaluated. For coral reefs, historical mapped reef area data spanning ~50 years are rarely available. In addition,

coral reefs can undergo functional decline, without any visible change in the structural extent mapped by satellites. For that reason, using mapped area reduction is not possible for coral reefs. Our method uses recent hard coral cover estimates from monitoring data from the most recent years as a proxy for declines in reef area (Obura et al. 2022). Our recent window was defined based on the occurrence of recent severe bleaching events, which have caused substantial mortality and drastic reductions in hard coral cover, to ensure results captured the most up to date state of reefs. For the Abrolhos and Parcel de Manuel Luís ecoregions this was between 2022 – 2025, and for all other ecoregions between 2024 – 2025.

Each reef site was classified as either a functioning, net-accreting reef site or a degraded site, based on a threshold of 5% hard coral cover. This threshold was considered to represent a point where coral abundance is too low to maintain positive carbonate accretion on Brazilian reefs (Obura et al., 2022). A sensitivity analysis was conducted across a range of thresholds (1–10%) to assess how results varied (Supplementary Material B). Each site was assumed to represent an equal portion of reef area, and the overall decline in coral reef area was estimated by calculating the percentage of monitoring sites below the coral cover threshold. To ensure data relevance, we filtered out 53 sites based on two criteria, upon consultation with experts and evaluation of time series data: 1) sites that did not fit the coral reef typology as defined under this assessment (e.g., rocky reefs, mesophotic reefs, beach rock); and 2) sites with historically and naturally low coral cover (below 5%).

Expert judgment was used to evaluate whether the available data were sufficient to represent ecosystem-level decline and in cases where monitoring coverage was considered insufficient, the ecosystem was classified as Data Deficient (DD). For ecoregions with a low number of sites (under 10), results were validated by cross-checking them with published data, reports and/or by consulting with local experts.

Table 12. Summary of the number of aggregated sites with hard coral cover data used to assess Criterion A and the data coverage across each ecoregion.

Ecoregion	Number of sites
<i>Parcel de Manuel Luís</i>	3
<i>Semiarid</i>	7
<i>Parrachos</i>	8
<i>Rocas Atoll and Noronha</i>	7
<i>Costa dos Corais</i>	26
<i>BTS and Baixo Sul</i>	18
<i>Abrolhos</i>	55
<i>Queimada Grande</i>	0

Where data were adequate, risk categories were assigned by comparing the percentage of sites with current coral cover below the collapse threshold (5%) (as an estimate for decline in extent) with the Red List of Ecosystems thresholds for Criterion A1, i.e. declines of ≥80%: Critically Endangered, 50–80%: Endangered, 30–50%: Vulnerable, 27–30%: Near Threatened, and <27%: Least Concern.

Subcriterion	Time frame	CR	EN	VU
A1	Past (over the past 50 years)	≥ 80%	≥ 50%	≥ 30%
A2a	Future (over the next 50 years)	≥ 80%	≥ 50%	≥ 30%
A2b	Any 50-year period (including past, present and future)	≥ 80%	≥ 50%	≥ 30%
A3	Historical (since approximately 1750)	≥ 90%	≥ 70%	≥ 50%

Figure 9. Risk thresholds for sub-criteria (A1, A2a, A2b, A3) under Criterion A based on reductions in geographic distribution.

Criterion B: Restricted Geographic Distribution

Criterion B assesses ecosystems whose **geographic distribution is so limited** that they are at **risk of collapse** due to the chance occurrence of **one or a few threatening events**, such as a cyclone, bleaching event, or disease outbreak.

To assess Criterion B, the RLE uses **two standardised spatial metrics**:

- (i) **Sub-criterion B1: Extent of Occurrence (EOO)** – the area within the outer boundary of the ecosystem’s known distribution;
- (ii) **Sub-criterion B2: Area of Occupancy (AOO)** – the area occupied by the ecosystem, measured using 10 by 10 km grid cells.

The extent of an ecosystem's geographic distribution is a critical determinant of its vulnerability, as spatially explicit threats or catastrophes can impact a significant proportion of its total area.

For this assessment, we first developed an updated coral reef extent layer for the Brazil region. The primary basis for this layer was the Millennium Coral Reef layer maintained by the UNEP-WCMC (<https://data.unep-wcmc.org/datasets/1>), which, for the Brazilian coast, corresponds to shallow reef data mapped by the *Atlas dos recifes de coral do Brasil*. To improve accuracy, we performed local adjustments to correct projection variations and refined reef polygons using recent scientific publications (e.g., Da Silveira et al., 2021; Santiago, 2025; Cardoso et al., 2025) and updated nautical charts, as well as consultation with specialists. Additionally, high-resolution satellite imagery was used to identify submerged reefs at depths of up to 20 m that were not represented in previous mappings, such as those in the Rocas Atoll and Noronha ecoregions.

Once the validated coral reef extent layer was projected using the WGS 1984 (EPSG:4326) coordinate reference system, the *makeEOO* function in the *redlistr* package in R (version 4.5.2) was used to generate the minimum convex polygon representing the EOO of coral reefs within each ecoregion. The *getAreaEOO* function was then used to calculate the EOO area in km². For Criterion B2, a 10 x 10 km grid was overlaid over the reef extent layer using the *makeAOOGrid* function, and the number of grid cells containing coral reefs was counted to estimate the AOO. All grid cells whose cumulative area of the reef ecosystem was <1% were excluded from the AOO count (Keith et al., 2024).

In addition, to assess criterion B, we evaluated whether the geographic restriction of Brazilian coral reefs is associated with evidence of continuing decline or plausible future deterioration in ecosystem condition. Specifically, we considered whether documented and projected threats are likely to drive further declines in reef extent, environmental quality, or disruption of key biotic interactions within the next 20 years. For this assessment, the most relevant subcriteria were either or both: a (iii), “*a measure of disruption to biotic interactions appropriate to the characteristic biota of the ecosystem*”, and b, “*observed or inferred threatening processes that are likely to cause continuing declines in geographic distribution, environmental quality or biotic interactions within the next 20 years*”, supported by evidence of recurrent bleaching events, increasing sea surface temperatures, and projected climate-driven degradation as reported in Criteria A or B or by any available scientific evidence..

To determine the risk category under Criterion B, EOO and AOO values were compared against the thresholds defined in the Red List of Ecosystems (RLE) guidelines (Fig. 9). Ecoregions with EOO or AOO values within 10% of the VU thresholds were classified as Near Threatened (NT).

Subcriterion	Measure of geographic distribution	CR	EN	VU
B1	Area of a minimum convex polygon (km²) enclosing all occurrences (extent of occurrence, EOO) is: AND at least one of the following (a–c): (a) An observed or inferred continuing decline in ANY OF: i. spatial extent of the ecosystem; OR ii. environmental quality appropriate to the characteristic biota of the ecosystem; OR iii. biotic interactions* appropriate to the characteristic biota of the ecosystem. (b) Observed or inferred threatening processes that are likely to cause continuing declines in geographic distribution, environmental quality or biotic interactions within the next 20 years. (c) Ecosystem exists at:	≤ 2,000 1 threat-defined location	≤ 20,000 ≤ 5 threat-defined locations	≤50,000 ≤ 10 threat-defined locations
B2	The number of 10×10 km² grid cells occupied (area of occupancy, AOO) are: AND at least one of a–c above (same as for B1).	≤ 2	≤ 20	≤ 50
B3	A very small number of threat-defined locations (generally fewer than 5) AND prone to the effects of human activities or stochastic events within a very short time period, and thus capable of Collapse or becoming Critically Endangered (CR) within a very short time period (B3 can only lead to a listing as Vulnerable, VU).			VU

Figure 10. Thresholds and conditions for assessing ecosystems under Criterion B (restricted geographic distribution) of the IUCN Red List of Ecosystems - sub-criteria B1 (extent of occurrence), B2 (area of occupancy) and B3.

Criterion C

Criterion C evaluates the degradation of abiotic conditions that support an ecosystem's functioning and persistence. The goal is to evaluate whether abiotic conditions have changed to such an extent that they pose a significant risk to the ecosystem's ability to sustain its characteristic biota and ecological processes. Such changes may arise from alterations in disturbance regimes, including events such as floods, fires, or storms.

Ocean warming, and extreme heatwave events which cause widespread and severe coral bleaching (and mortality) have emerged as one of the biggest issues affecting coral reefs in many parts of the world, and the main threat affecting their persistence into the future (Hughes et al., 2018). This analysis is designed to capture broad-scale changes in the abiotic environment associated with increasing frequency of extreme marine heatwave events that cause coral bleaching (Emslie et al., 2024; Heron, Maynard, et al., 2016; Hughes et al., 2018), and determine how present and future environmental conditions threaten the survival and persistence of coral reef ecosystems.

Recurrent heat waves reduce the environmental suitability for reef-building corals through several pathways. A shift in disturbance regime increases the risk of large-scale coral mortality and affects the establishment and persistence of species (Elma et al., 2023; Mudge & Bruno, 2023). These changes can be associated with substantial declines in coral abundance, reduced structural complexity, and lower carbonate accretion rates (Williams et al., 2019; Williams & Graham, 2019). Additionally, recurrent bleaching episodes weaken coral communities, reduce reproductive output, and increase susceptibility to other stressors such as disease (Briggs et al., 2024; Byrne et al., 2025; Croquer & Weil, 2009). As these events become more frequent, intervals between disturbances are shortened, preventing meaningful coral recovery and increasing the likelihood of progressive ecosystem degradation and eventual collapse (Emslie et al., 2024; Hughes et al., 2018).

Indicator selection

To assess the likelihood of recurrent heat waves driving ecosystem collapse at regional scales, we assessed two plausible and distinct pathways, each requiring a different analytical approach.

The first is a **chronic (press) pathway**, driven by the cumulative effects of recurrent bleaching events that weaken coral communities, reduce growth and reproductive output, and increase susceptibility to secondary stressors such as disease. As bleaching events become more frequent, recovery intervals shorten, preventing meaningful recovery between disturbances and leading to progressive ecosystem degradation over time. The second is an **acute (pulse) pathway**, characterised by rapid decline following a small number of extreme heat stress events occurring over a short period. These events can cause widespread mortality across coral taxa, including stress-tolerant species, leading to near-complete coral loss and triggering collapse.

We assessed the relative change in disturbance conditions over:

- the past 50 years (1975–2025) as part of sub-criterion C1, and
- 50 years into the future (2026–2075) for sub-criterion C2

For the **chronic pathway**, the indicator is the expected number of severe bleaching events over a 30-year period, expressed as an average return interval (years between events).

For the **pulse pathway**, the indicator is the number of severe mortality events within a 5-year window.

Using DHW as a proxy for bleaching events

For both pathways, Degree Heating Weeks (DHW), a measure of the accumulation of heat stress over a rolling 12-week window, was used to approximate the occurrence of severe bleaching and mortality events (Liu et al., 2012).

Although data on historical bleaching observations exist (Donner et al., 2017; Eakin et al., 2026; van Woesik & Kratochwill, 2022), they are not spatially or temporally extensive. DHW data are globally available since 1985, including for future climate projections (Mellin et al., 2024; Skirving et al., 2019), and are underpinned by a well-documented, long-term relationship with coral bleaching across many regions globally (Heron, Johnston, et al., 2016; Liu et al., 2005; Sully et al., 2019). Values of **DHW ≥ 4** are associated with bleaching onset, while values of **DHW ≥ 8** or more are historically linked to widespread coral mortality (Kayanne, 2017; Liu et al., 2005; Skirving et al., 2019). In addition, DHW has been widely used in recent studies assessing bleaching risk under climate change (Beyer et al., 2018; Bozec et al., 2025; Mellin et al., 2024; Obura et al., 2022), and is supported by established thresholds linking DHW levels to bleaching severity developed by the NOAA Coral Reef Watch (https://coralreefwatch.noaa.gov/product/5km/index_5km_baa-max-7d.php). While DHW may not be the most precise predictor of bleaching severity at fine spatial or temporal scales, it provides a robust, scalable, and comparable indicator of bleaching risk suitable for capturing broad trends in disturbance regimes over time, and supports a standardised approach across ecoregions.

Data

Sub-criterion **C1** was assessed using satellite-measured DHW from NOAA Coral Reef Watch at a spatial resolution of 5 km (Liu et al., 2012). The standard RLE assessment timeframe is 50 years; however, satellite measurements of DHW began 40 years ago in 1985. For the period 1975–1984, thermal conditions were assumed to be broadly comparable to those observed during the earliest decade of the satellite record (1985–1995). This assumption is supported by the fact that the first global mass bleaching event occurred later, in 1997–1998 (Hoegh-Guldberg, 1999), and that global ocean heat content has been consistently above average since the mid-1990s, with ocean warming accelerating further since the late 90s and early 2000s (Cheng et al., 2017, 2023; Heron,

Maynard, et al., 2016; Merchant et al., 2025). The 1985–1995 period is therefore the closest available proxy for late-1970s thermal stress regimes. DHW values were spatially attributed to each reef pixel using a 50 km buffer, retaining only data from pixels within this distance of mapped reef extent, and assigning values through an interpolation process.

Sub-criterion **C2** used modelled climate projections of daily Degree Heating Weeks from Mellin et al. (2024) for 1985–2100, available for three climate pathways: **SSP2-4.5**, **SSP3-7.0**, and **SSP5-8.5**. The dataset did not include projections corresponding to the Paris Agreement pathway (SSP1-1.9; approximately 1.5–2°C warming by 2100), which is considered increasingly unrealistic given current global emissions trajectories (Tagomori et al., 2026). All three scenarios with data were assessed to explicitly demonstrate how the degree of climate mitigation affects risk outcomes for coral reefs. The highest emissions scenario (SSP5-8.5) represents an extreme case that is considered increasingly unlikely to eventuate (Sarofim et al., 2024), and the more moderate **SSP2-4.5** produced the highest risk classifications and was therefore treated as the primary scenario.

For both C1 and C2, daily DHW data were converted to an annual maximum value for each reef pixel by first calculating the monthly maximum, and then extracting the highest value recorded from each local summer season. In regions where the summer season straddles two calendar years (e.g. the thermal peak occurs during November–March), the seasonal maximum was attributed to the year the stress began. This produced an annual time series of maximum DHW for each reef pixel spanning the historical and future assessment periods.

Thresholds

To convert the annual maximum DHW data into a record of disturbance events, ecoregion-specific DHW thresholds were applied to classify each year as an event (value of 1) or not (value of 0). The DHW thresholds used for this classification differed between the two pathways, reflecting their distinct ecological mechanisms.

For the **chronic pathway**, a severe bleaching event is defined as one in which widespread bleaching occurs across approximately more than 50% of coral colonies. These events cause substantial loss of thermally sensitive species but may not typically reach the intensity required to cause widespread mortality of stress-tolerant taxa. For the **pulse pathway**, a severe mortality event is defined as an extreme, high-intensity thermal stress event that causes widespread mortality (more than 50% of colonies) across all coral taxa, including stress-tolerant species. Applying the thresholds produced two binary event time series for each reef pixel which forms the basis of the chronic and pulse analyses.

DHW thresholds corresponding to severe bleaching events (chronic pathway) and severe mortality events (pulse pathway) for each ecoregion were informed by historical

observations of coral reef responses to marine heatwaves, specifically the levels of thermal stress associated with widespread bleaching and coral mortality. These thresholds were not treated as fixed, as the DHW level required to trigger a given bleaching response is expected to change over time. For example, in the 1980s and 90s, relatively lower DHW values may have resulted in severe bleaching and mortality (Hoegh-Guldberg 1999), whereas coral communities today (or in the future) may be altered or acclimated, potentially requiring higher DHW values to trigger comparable responses (Heron, Maynard, et al., 2016; Pratchett et al., 2013; Sully et al., 2019). For C2, thresholds were informed by bleaching responses to thermal stress levels observed during the most recent years of the satellite record (2015–2025) and were adjusted upward into the future to account for anticipated species filtering, and potential thermal adaptation or acclimation. Thresholds were defined at the ecoregional level where locally relevant evidence supported this. To account for uncertainty in the exact level of heat stress that causes bleaching/mortality, two plausible DHW threshold values were applied for each pathway.

Ecoregion-specific thresholds were calibrated by matching documented observations of widespread bleaching and mortality with the corresponding DHW values. Earlier events were used to characterize thermal sensitivity near the beginning of the historical period, whereas observations from recent events, particularly 1998–2025, informed current thresholds. Thresholds were allowed to vary through time because comparable ecological responses may occur at different DHW levels as coral assemblages change through species turnover, selective loss of thermally sensitive taxa, acclimatization, or adaptation (Hoegh-Guldberg, 1999; Heron et al., 2016; Pratchett et al., 2013; Sully et al., 2019). Where recent observations indicated comparable responses only at higher thermal stress, thresholds were increased accordingly. For C2, plausible threshold ranges were used to represent uncertainty in future thermal sensitivity, including potential community filtering, acclimatization, and adaptation. All thresholds were reviewed using regional expert knowledge, and two plausible DHW values were evaluated for each pathway where uncertainty could not be resolved.

In Brazil, coral ecoregions exhibit distinct temporal patterns of thermal anomalies, resulting in spatially heterogeneous patterns of bleaching and mortality along the coast. In addition, coral community composition varies among ecoregions, leading to different responses to thermal anomalies depending on the thermotolerance of the species that predominate in reef cover and monitoring areas. Overall, the most significant bleaching events occurred in 1998, 2010, 2016, 2019, 2020, and 2024, with 2019, 2020, and 2024 showing the highest records of bleaching-related mortality. During the 1998 event, widespread bleaching supported initial bleaching thresholds of 1–4 DHW across ecoregions, with mortality thresholds ranging from 4–6 DHW. Following the 1998 event, both bleaching and mortality thresholds varied among ecoregions according to the intensity of subsequent heatwaves and the responses of their respective coral communities. In the Parrachos and Costa dos Corais ecoregions, recent thresholds range from 6–8 DHW for bleaching and 8–10 DHW for mortality, with the most severe thermal

event recorded in 2024. In Abrolhos and BTS and Baixo Sul, thresholds increased following the 2019 event, which represented the most intense thermal anomaly recorded in these ecoregions, resulting in current bleaching thresholds ranging from 8–12 DHW and a mortality threshold of approximately 12 DHW. In contrast, Rocas Atoll and Noronha currently show a bleaching threshold of approximately 4 DHW and mortality thresholds ranging from 10–12 DHW. For C2 ranges of 6–14 DHW were evaluated for widespread bleaching and 8–16 DHW for severe mortality, representing lower and higher levels of future thermal adaptation or acclimation.

Table 13. Ecoregional DHW thresholds representing thermal stress levels resulting in widespread bleaching for the chronic pathway.

Ecoregion	C1 – observed, past 50 years (1975–2025)		C2 – predicted, future 50 years (2026–2075)	
	Timeframe	Widespread bleaching (DHW range)	Timeframe	Widespread bleaching (DHW range)
Parcel de Manuel Luís	1985–2025	N/A	2026–2075	N/A
Semiarid	1985–2025	N/A	2026–2075	N/A
Parrachos	1985–1998	4	2026–2075	6–8
	1999–2025	6		
Rocas Atoll and Noronha	1985–1998	1	2026–2075	4–6
	1999–2010	4		
	2011–2020	4		
	2021–2025	4		
Costa dos Corais	1985–2017	4	2026–2075	6–8
	2018–2025	6		
BTS and Baixo Sul	1985–2010	4	2026–2075	8–10
	2011–2018	6		
	2019–2025	8		
Abrolhos	1985–1998	2–4	2026–2075	12–14
	1999–2016	4		
	2017–2020	8		
	2021–2025	12		
Queimada Grande	1985–2025	N/A	2026–2075	N/A

Table 14. Ecoregional DHW thresholds representing thermal stress levels resulting in severe mortality for the acute/pulse pathway.

Ecoregion	C1 – observed, past 50 years (1975–2025)		C2 – predicted, future 50 years (2026–2075)	
	Timeframe	Severe mortality (DHW range)	Timeframe	Severe mortality (DHW range)
Parcel de Manuel Luís	1985-2025	N/A	2026-2075	N/A
Semiarid	1985-2025	N/A	2026-2075	N/A
Parrachos	1985-1998	4	2026-2075	12-14
	1999-2025	10-12		
Rocas Atoll and Noronha	1985-1998	6	2026-2075	10-12
	1999-2010	6		
	2011-2020	8-10		
	2021-2025	10-12		
Costa dos Corais	1985-1998	4	2026-2075	8-10
	1999-2025	8		
BTS and Baixo Sul	1985-1998	2	2026-2075	12-14
	1999-2017	7		
	2018-2025	12		
Abrolhos	1985-1998	4	2026-2075	14-16
	1999-2016	5-8		
	2017-2020	12		
	2021-2025	12-14		
Queimada Grande	1985-2025	N/A	2026-2075	N/A

Calculation of decline and risk

Current values

To apply Criterion C, the RLE assesses the level of risk based on the **severity of decline** and the **proportion of the ecosystem affected**. Analyses were conducted independently for each pathway (chronic and pulse). The relative severity of decline for both sub-criteria C1 and C2 was calculated for each reef pixel using the formula:

$$\text{Relative severity of decline (\%)} = (\text{current conditions} - \text{initial conditions}) / (\text{collapse threshold} - \text{initial conditions}) \times 100$$

The **chronic pathway** is assessed in terms of the average return interval of severe bleaching events over a 30-year period (DeCarlo & Whitaker, 2025; Hughes et al., 2018). Return interval is an ecologically meaningful indicator because recovery from disturbance is a slow process, typically requiring 10–15 years for fast-growing species and considerably longer for the full complement of coral life histories and morphologies

(Gilmour et al., 2013; Robinson et al., 2019). As bleaching events become more prevalent and frequent, the combined effect of repeated mortality and shortened intervals between disturbances limiting recovery, drives cumulative coral loss and increases the likelihood of ecosystem-level collapse (Eakin et al., 2026, p. 201; Hughes et al., 2018; Pratchett et al., 2021).

Return intervals were estimated by fitting a binomial (logistic) regression model to the binary bleaching event time series for each reef pixel, where the probability of a severe bleaching event in any given year is modelled as a function of time (DeCarlo & Whitaker, 2025). This probabilistic approach provides a continuous, smoothed estimate of annual event probability. This reduces sensitivity to interannual variability and characterises the underlying trajectory of disturbance regimes, making it well suited to assessing chronic, long-term stress. The modelled annual probabilities were summed across all possible 30-year windows within the assessment periods of C1 (1985/6-2025) and C2 (2026-2075) to determine the expected number of severe bleaching events, which was then converted to an average return interval by dividing 30 years by the expected number of events. The current condition value was based on the shortest return interval (highest disturbance) over all 30-year periods. For C1, the model was fitted using observed DHW data (1985–2025), and for C2, the models were fitted using projected DHW data (1985–2100).

For the **pulse pathway**, current conditions were assessed using a 5-year moving window, applied across the full assessment periods of C1 and C2 for each reef pixel. The number of severe mortality events within each window were counted, with the maximum count across any 5-year period, representing the highest observed or projected clustering of extreme events, used as the current condition value. This event-based approach preserves temporal variability and is specifically designed to capture the clustering of extreme events that characterises the acute collapse pathway.

Initial values

To calculate relative severity of decline, initial values reflecting the baseline disturbance regime of each assessment period (C1 and C2) must be established.

For the **chronic pathway**, under C1, historical baseline conditions (circa the 1970s) are characterised by bleaching events occurring at most once every 10–15 years, equivalent to approximately 2–3 events per 30-year period. This reflects a natural disturbance regime in which sufficient time elapsed between events for meaningful coral recovery (Baker et al., 2008; Gilmour et al., 2013; Graham et al., 2011; Hughes et al., 2018; Robinson et al., 2019). For C2, the initial value is calculated from projected DHW data over the 30-year period immediately preceding 2026 (1996–2025), using the same probabilistic framework applied to the rest of the C2 analysis.

For the **pulse pathway**, under C1, the initial value is the maximum number of severe mortality events within any 5-year window at the start of the satellite time series (1985/86–1990/91). For C2, the initial value is the maximum number of severe

mortality events within any 5-year window during the decade immediately preceding 2026 (2016–2025).

Collapse thresholds

To complete the calculation of relative severity of decline, it is necessary to define a collapse threshold, when the frequency of damaging heat waves creates a high likelihood of collapse. For coral reefs, collapse is defined by the near or complete loss of hard corals, corresponding to a **hard coral cover below 5%**. The same collapse thresholds are applied to both C1 and C2 because conceptually similar environmental conditions should lead to similar ecological outcomes regardless of when they occur.

For the **chronic pathway**, the collapse threshold is defined as severe bleaching events occurring, on average, every 3 years over a 30-year period (approximately 10 events per 30-year window) (DeCarlo & Whitaker, 2025). At this frequency, recovery intervals are considered insufficient to permit meaningful coral recovery between disturbances, and the cumulative, iterative mortality caused by several events drives progressive and significant ecosystem degradation (Emslie et al., 2024; Hughes et al., 2018). As a sensitivity test, a threshold of one event every 5 years (~6 events per 30-year window) was also assessed as even these narrow recovery windows do not allow for full recovery, and will lead to substantial decline after multiple decades (Hughes et al., 2018). Annual severe bleaching is a commonly cited when predicting future reef outlooks (De Clippele et al., 2023; van Hooidonk et al., 2016; Zeng et al., 2025), however it is considered overly conservative as collapse will likely occur before we reach conditions conducive to yearly bleaching (Bland et al., 2017; Obura et al., 2022).

For the **pulse pathway**, the collapse threshold is defined as 2–3 severe mortality events occurring within any 5-year window. This formulation was adopted in response to evidence that the collapse threshold used by Obura et al. (2022) for the Western Indian Ocean, and Bland et al. 2017 for the Meso-American Reef of two severe bleaching events per decade (equivalent to approximately one event every 5 years), may be insufficient to drive collapse under current conditions. Several reefs, including the Great Barrier Reef and Little Cayman, have experienced two or more severe bleaching events within a decade between 2015/16 and 2025 without clear evidence of ecosystem collapse (Emslie et al., 2024; Henley et al., 2024; Pratchett et al., 2021). This suggests that reefs may be more resilient to moderate clustering of events than previously assumed, and that a higher frequency, specifically 2–3 extreme mortality events within a 5-year window, is required to reliably indicate conditions conducive to collapse. Risk status assignment

To assign the risk status under Criteria C1 and C2 for each ecoregion, relative severity of decline was interpreted in conjunction with reef extent using the **severity–extent matrix**. The relative extent of decline for each ecoregion was approximated from the cumulative proportion of reef area experiencing different levels of decline ($\geq 20\%$, $\geq 30\%$, $\geq 50\%$, $\geq 70\%$, $\geq 80\%$, and 100%).

Where results differ between the chronic and pulse pathways, the risk category was reported based on the pathway with the greatest confidence, or a range of outcomes presented across both pathways. Uncertainty across DHW thresholds, collapse thresholds, and initial values was incorporated by repeating the analysis across all plausible combinations of these parameters, producing a range of possible risk outcomes. The final reported risk status for each ecoregion for C1 was based on the mean decline across all combinations, while for C2, the final status corresponded to the best-case scenario of an intermediate climate pathway (SSP2-4.5) with coral adaptation (higher future DHW thresholds).

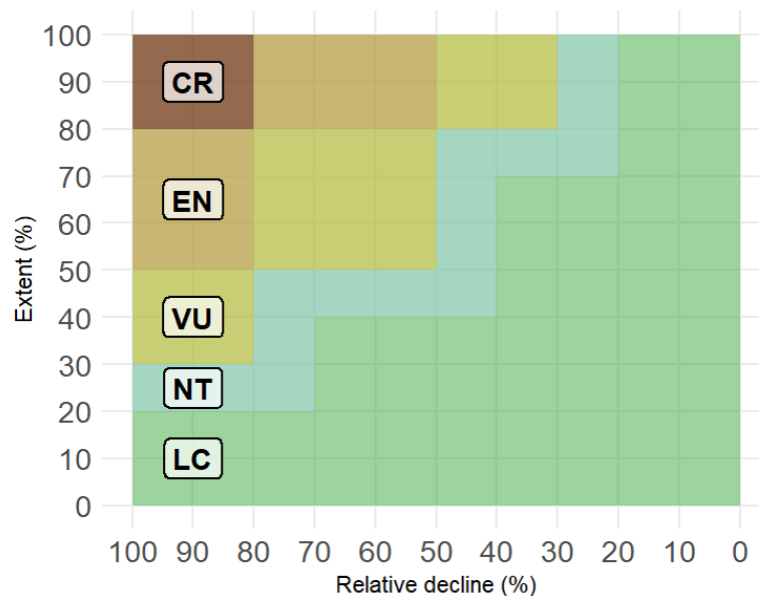


Figure 11. Risk matrix used to assign risk categories under Criteria C and D: relative extent of the ecosystem affected (y axis) versus relative severity of decline (x axis).

Criterion D: Disruption of Biotic Processes and Interactions

Criterion D was evaluated to identify ecosystems experiencing severe disruption to organisms and biotic processes and interactions. This includes declines in characteristic species, shifts in community structure, and the loss of ecological functions necessary for maintaining ecosystem identity. The approach enables identification of the most degraded ecosystem components and how this degradation contributes to the overall risk of collapse. This assessment evaluated the degradation over the past 50 years (sub-criterion D1), estimating how close each ecosystem component was to collapse or severe functional disruption.

Indicator selection

In Brazil, 4 key biotic components were assessed using data derived from standard underwater survey methods (point intercept transects, photo quadrats, video transects, and belt transects), and based on previous coral reef RLE assessments (Bland et al., 2017; Obura et al., 2022). These components include:

- Hard corals, as the keystone ecosystem taxa responsible for forming the habitat structure and accretion processes.
- Macroalgae and articulated calcareous algae, as the principal competitive taxa to hard corals;
- Herbivory, providing important top-down control of algae; and
- Piscivory, which helps regulate the food web and contribute to overall ecological balance.

For each component, indicators were selected based on ecological relevance, data availability, spatial coverage, sensitivity to ecosystem condition, and the ability to define both a reference state and a collapse threshold.

Hard coral cover was selected as the indicator of coral state, as it has been consistently used as a key measure of reef health over several decades (González-Rivero et al., 2026).

Algae-to-coral cover ratio was used to represent benthic competition, rather than algae cover alone, as this directly captures the dynamic balance between coral and algal dominance (Obura et al., 2022). Algae included articulated calcareous algae and fleshy algae. Turf algae were not included because this could have confounding effects on results, and because it represents patterns of decline that are similar (inverse) to those captured by hard coral cover. One dataset was excluded from this analysis because their classification of algae was unclear and could have introduced bias. The ratio was calculated as the total algae cover divided by the sum of algae and coral cover.

For herbivory, parrotfish and surgeonfish biomass was used as a proxy, as regional fish datasets were largely resolved at the family level and parrotfishes and surgeonfishes were among the most consistently recorded herbivores.

For piscivory, grouper and snapper biomass was selected as a suitable proxy for this trophic group because those groups are important fisheries resources and highly sensitive to overfishing (Sadovy de Mitcheson et al., 2013; Amorim et al., 2019). Although all the species considered within those families are not obligate piscivores and also consume other organisms - thus being more correctly classified as carnivorous, the term piscivorous was retained for standardization with other regional assessments.

Calculation of risk

Biotic degradation under Criterion D was assessed using the relative severity of decline. This metric compares the current state of each indicator to both a historical baseline (level approximately 50 years ago) and a hypothetical collapse threshold.

A reference state representing conditions of each indicator approximately 50 years ago (circa 1975) was established to quantify long-term change. Monitoring data from this period were generally unavailable, as consistent and standardised reef monitoring began in the 1990s and early 2000s (Leão et al., 1999; Ferreira et al., 2026). To determine the most suitable approach for deriving initial values, the first step was to

consider the likely condition of reefs in each ecoregion in the mid-1970s for the selected indicators, specifically, whether reefs were in better condition, relatively pristine, or already degraded. Historical data on coral cover is available for some ecoregions, derived from the descriptive work by Jacques Laborel (Laborel, 1969), which reported relatively higher coral cover values in the 1960s compared to current conditions. The final approach used to estimate initial values varied across indicators and ecoregions, and detailed descriptions may be found in the indicator-specific sections below.

Current and initial values

Hard coral cover

Current values for hard coral cover were calculated at the site level using monitoring data available from **2022-2025** for the Abrolhos and Parcel de Manuel Luís ecoregions, and from **2024-2025** for all other ecoregions except Queimada Grande, which lacked current values and was classified as Data Deficient. A “site” refers to a defined monitoring location where transects, quadrats, or other sampling units are situated, and at which data are aggregated. Where multiple records existed for a site within these periods, only data from the most recent year available were used.

Table 15. Mean current value of hard coral cover per ecoregion (n – number of sites).

Ecoregion	n	Mean	Std. dev	Min value	Max value
<i>Parcel de Manuel Luís</i>	3	5.50%	3.46%	1.50%	7.50%
<i>Semiarid</i>	7	5.15%	4.85%	0.00%	11.87%
<i>Parrachos</i>	8	7.20%	4.29%	0.00%	12.78%
<i>Rocas Atoll and Noronha</i>	7	14.50%	7.07%	5.83%	26.56%
<i>Costa dos Corais</i>	26	5.73%	6.00%	0.00%	24.17%
<i>BTS and Baixo Sul</i>	18	6.83%	5.54%	0.25%	22.44%
<i>Abrolhos</i>	55	15.80%	8.93%	0.00%	40.50%
<i>Queimada Grande</i>	0	N/A	N/A	N/A	N/A

The initial values were first estimated using the Mean Maximum Yearly Values (MMYV) approach, using long-term monitoring datasets to estimate baseline conditions. Sites with extended time series (≥ 10 years) were assumed to have experienced relatively good conditions at some point during the monitoring period. These records can provide an estimate of the ‘best’ conditions possible across reefs in an ecoregion, therefore acting as a proxy for “healthy” conditions around 1975. For each site, the maximum recorded value of each indicator (e.g., highest coral cover) across its monitoring history was extracted. The distribution of these maximum values across all sites within each ecoregion was then used to estimate a baseline distribution (mean and standard deviation). Estimates were subsequently validated or adjusted based on historical literature and consultations with local experts. The sites used in the MMYV approach were selected upon meeting two criteria: 1) maximum coral cover of at least 5%, and 2)

availability of at least two data points collected before 2020, with a monitoring range spanning a minimum gap of 10 years. The validation of baseline estimations resulted in the following ecoregion-specific treatments:

- 1) For the **Costa dos Corais** ecoregion, the estimated baseline (mean coral cover = $31.55\% \pm 15.56\%$) aligned well with historical reports from the 1960s (20-25%; Laborel, 1969) and was adopted.
- 2) For the **Abrolhos** ecoregion, the estimated baseline ($28.74\% \pm 13.16\%$) was considered by local experts to be lower than historical reports ($> 50\%$; Laborel, 1969). This discrepancy likely stems from natural variability in hard coral cover between coastal sites and sites located further from the coast. While Laborel observed areas with naturally higher cover (e.g., Parcel das Paredes), our dataset also includes coastal sites where coral cover may have never exceeded 30%. To reflect this uncertainty and spatial variability within the ecoregion, we replaced the mean baseline estimated through the MMYV method with 40%, which is the mid-point between our estimated baseline ($\sim 30\%$) and Laborel's observations from the 1960s ($\sim 50\%$).
- 3) Despite lacking historical references and/or data, the estimated baselines for the **Rocas Atoll and Noronha** and the **BTS and Baixo Sul** ecoregions were reviewed and validated by experts as being plausible estimates for historical conditions in the 1970s. Their mean baseline values sit well within the range reported for other ecoregions for which historical data is available.
- 4) The **Parrachos** ecoregion lacked sufficient data to produce reliable baseline estimates using the MMYV approach. As a result, its initial values were determined by applying the mean baseline hard coral cover estimated for the Costa dos Corais ecoregion (the nearest and most closely associated ecoregion in terms of hard coral diversity and abundance). The mean baseline used (31.55%) sits well within the range of what is considered a "Good" (20%) to "Very Good" (40%) coral cover, as determined by the Reef Health Index for the Caribbean (McField & Kramer 2007). The minimum, maximum, and standard deviation were calculated based on the entire time series available within the compiled dataset for this ecoregion.
- 5) The **Parcel de Manuel Luís** and **Semiarid** ecoregions lacked historical data for the MMYV approach, literature reporting past hard coral cover, and another ecoregion similar enough for values to be replicated. Therefore, they were classified as Data Deficient under this criterion.

Table 16. Mean initial values with variance measures for hard coral cover for each ecoregion (n – number of sites).

Ecoregion	Mean	Std. dev	Min. value	Max value	n
<i>Parcel de Manuel Luís</i>	N/A	N/A	N/A	N/A	N/A
<i>Parrachos</i>	31.55%	6.86	6.66%	41.25%	N/A
<i>Semiarid</i>	N/A	N/A	N/A	N/A	N/A

Ecoregion	Mean	Std. dev	Min. value	Max value	n
<i>Rocas Atoll and Noronha</i>	32.49%	15.21	10.58%	58.12%	11
<i>Costa dos Corais</i>	31.55%	15.56	8.75%	53.75%	10
<i>BTS and Baixo Sul</i>	22.19%	13.59	8.75%	36.25%	4
<i>Abrolhos</i>	40%	13.16	11.25%	68.12%	24
<i>Queimada Grande</i>	N/A	N/A	N/A	N/A	N/A

Algae:coral ratio

Current values for algae:coral ratio were calculated at the site level using monitoring data available from **2022-2025** for the Abrolhos and Parcel de Manuel Luís ecoregions, and from **2024-2025** for all other ecoregions except Queimada Grande, which lacked current values and was classified as Data Deficient. Where multiple records existed for a site within these periods, only data from the most recent year available were used.

Table 17. Mean current value of algae:coral ratio per ecoregion (n – number of sites).

Ecoregion	n	Mean	Std. dev	Min value	Max value
<i>Parcel de Manuel Luís</i>	3	0.89	0.74	0.82	0.97
<i>Semiarid</i>	7	0.92	0.07	0.83	1
<i>Parrachos</i>	7	0.46	0.40	0.32	1
<i>Rocas Atoll and Noronha</i>	6	0.73	0.09	0.60	0.87
<i>Costa dos Corais</i>	23	0.86	0.17	0.35	1
<i>BTS and Baixo Sul</i>	17	0.67	0.31	0.07	1
<i>Abrolhos</i>	52	0.44	0.31	0	1
<i>Queimada Grande</i>	N/A	N/A	N/A	N/A	N/A

For each site, initial values were calculated using algae and hard coral cover recorded in the year when maximum hard coral cover was observed across our entire time series of data. These years were assumed to represent optimal/pristine reef conditions in the mid-1970s. Sites were selected upon the availability of at least two data points collected before 2020, separated by a minimum gap of 10 years. Due to the lack of historical published data for this variable across all ecoregions, estimated baselines were presented to local experts for validation, resulting in the following ecoregion-specific treatments:

- 1) For the **Rocas Atoll and Noronha**, **Costa dos Corais**, **BTS and Baixo Sul**, and **Abrolhos** ecoregions, the estimated baselines were reviewed by experts and considered to be plausible estimates for historical conditions. For **BTS and Baixo Sul**, even though the number of sites was relatively low (n = 3), and the estimated mean initial value was comparatively high (0.70), this was considered to be consistent with observations in the ecoregion, where high algae cover has been consistently reported.

- 2) The **Parrachos** ecoregion lacked sufficient historical data to produce reliable baseline estimates. As a result, its initial values were determined by applying the baselines for the **Costa dos Corais** ecoregion.
- 3) The **Parcel de Manuel Luis** and **Semiarid ecoregions** lacked both historical data and a reliable alternative method to estimate baseline values and were classified as Data Deficient.

The estimation of initial values yielded four summary parameters for the baseline algae:coral ratios: mean, standard deviation (SD), minimum, and maximum (Table 18). For the analysis, initial values were selected within a range from 0 to 1 (plausible values for this indicator), centered at the mean baseline ratio.

Table 18. Mean initial values with variance measures for algae:coral ratio for each ecoregion (n – number of sites).

Ecoregion	Mean	Std. dev	Min. value	Max value	n
<i>Parcel de Manuel Luis</i>	N/A	N/A	N/A	N/A	N/A
<i>Parrachos</i>	0.53	0.19	0.20	0.85	9
<i>Semiarid</i>	N/A	N/A	N/A	N/A	N/A
<i>Rocas Atoll and Noronha</i>	0.47	0.22	0.16	0.75	9
<i>Costa dos Corais</i>	0.53	0.19	0.20	0.85	9
<i>BTS and Baixo Sul</i>	0.70	0.11	0.63	0.83	3
<i>Abrolhos</i>	0.22	0.22	0	0.70	17
<i>Queimada Grande</i>	N/A	N/A	N/A	N/A	N/A

Fish (Herbivory and Piscivory/Carnivory)

The indicators used to assess criterion D based on fish were the mean yearly biomass of herbivorous (surgeonfishes and parrotfishes) and piscivorous/carnivorous fishes (snappers and groupers) at the site level. Herbivores included 3 species of surgeonfish and 6 species of parrotfish, while piscivores were composed of 6 species of snappers and 10 species of groupers (Table 1).

There were no comparable baselines for fish, such as historical UVC data. Three methods were used to estimate initial values (baselines): the MMYV approach, an adaptation of the MMYV (aMMYV) and the Reef Health Thresholds (RHT) (McField et al., 2024). The three baseline estimation methods were presented to local experts for discussion. Based on their evaluation, the Reef Health Index (RHI) was considered the best available proxy for fish biomass 50 years ago and was therefore adopted as the historical baseline in this analysis (Table 19). Its reference values were considered more ecologically plausible than the highly variable and, in some cases, extreme values generated by the MMYV and aMMYV approaches (Tables 19 and 20).

Four baseline metrics were considered for each ecoregion: minimum baseline value, maximum baseline value, mean baseline value, and standard deviation. To reduce the disproportionate influence of extreme values associated with site selection, schooling events, or unusually low observations, baseline means and standard deviations for the MMYV and aMMYV approaches were calculated using the central 90% of site-level annual maximum biomass values, after excluding the upper and lower 5% of the distribution. Minimum and maximum baseline values were defined as the minimum and maximum yearly biomass values included within this central 90% distribution for each indicator and ecoregion. The conservation status of fish species according to the Brazilian red list of threatened species was also considered as a reference, as well as specialist opinion on past abundance to validate the metric calculations.

The Reef Health Thresholds (RHT) was obtained from the Reef Health Index (RHI), an integrated framework designed to evaluate the ecological condition of coral reef ecosystems in the Caribbean based on multiple complementary indicators (McField et al., 2024). Although originally developed for Caribbean reefs, the RHT provides standardized fish biomass values associated with healthy reef conditions, offering a common reference against which Brazilian ecoregions could be compared. It incorporates measures of coral cover, fleshy macroalgal cover, herbivorous fish biomass (surgeonfish and parrotfish), and commercially important fish biomass (snappers and groupers) to provide an overall assessment of reef health and resilience (McField et al., 2024). For each indicator, threshold values are used to classify reef condition into one of five categories, ranging from critical to very good. We used the mean of the threshold values for the “very good” (3.29 kg of herbivorous fish and 1.62 kg piscivorous fish biomass per 100m²) and “good” (2.74 kg herbivorous fish and 1.21 kg piscivorous fish biomass per 100m²) categories as a proxy for the biomass of herbivorous and piscivorous fishes 50 years ago across all ecoregions. This resulted in reference means of 3.0 kg of herbivorous and 1.4 for piscivorous fish per 100m² (Table 19), while standard deviation and maximum values were obtained from the aMMYV. Minimum baseline values were set to zero for all ecoregions.

The MMYV approach followed almost the same procedure adopted for coral cover. Sites included in the MMYV analysis were required to meet the criteria of availability of at least two yearly mean biomass estimates spanning a minimum interval of 10 years. Unlike the coral analyses, no restriction was imposed on the sampling period because fish biomass exhibits high temporal variability and may increase substantially in areas protected from fishing over long periods. Therefore, yearly observations from any sampling year were considered when identifying the maximum biomass values used to estimate the historical baseline. A total of 39 sites met the baseline requirements, however, none were available for Parrachos, while only 6 met the requirements for Rocas Atoll and Noronha (Table 20). The MMYV, however, produced very high baselines in ecoregions with higher contemporary fish biomass, as well as very low baselines where large fishes have been scarce since the beginning of monitoring series (Table 20). These produced unrealistic baselines that contrasted between high for better protected

regions and low for lower protection regions, rather than historical reference conditions.

The third approach was an adaptation of the MMYV approach (aMMYV). The requirement of a minimum 10-year interval between surveys was removed, thereby allowing a broader and more representative range of monitored sites, including both open and no take areas, to contribute to baseline estimation. With this approach, the number of sites increased 2,5-fold and kept a more even proportion of closed and open sites (Table 19). The standard deviation and the minimum and maximum reference values obtained from the aMMYV approach were used for the RHT approach.

Table 19. Mean initial values calculated from the adapted Mean Maximum Yearly Values Approach (aMMYV) and the Reef Health Thresholds (RHT), with standard deviation, minimum and maximum values for herbivore and piscivore indicators for each ecoregion (n – number of sites).

Ecoregion	Indicator	aMMYV Mean	RHT Mean	Std. dev	Min value	Max value	n
<i>Rocas Atoll and Noronha</i>	Herbivores	11.5	3.0	6.2	3.9	21.1	12
	Piscivores	4.0	1.4	2.1	0.8	7.6	12
<i>Parrachos</i>	Herbivores	7.3	3.0	5.7	2.1	17.3	12
	Piscivores	0.4	1.4	0.3	0.1	1.0	12
<i>Costa dos Corais</i>	Herbivores	2.7	3.0	1.7	0.8	6.0	36
	Piscivores	0.8	1.4	0.5	0.2	2.2	36
<i>Abrolhos</i>	Herbivores	8.7	3.0	6.1	1.5	25.7	50
	Piscivores	2.5	1.4	2.6	0.1	10.5	50

Table 20. Mean initial values calculated from the Mean Maximum Yearly Values Approach (MMYV), with standard deviation, minimum and maximum values for herbivore and piscivore indicators for each ecoregion (n – number of sites).

Ecoregion	Indicator	MMYV Mean	Std. dev	Min value	Max value	n
<i>Rocas Atoll and Noronha</i>	Herbivores	5.3	1.6	3.4	17.7	6
	Piscivores	4.6	1.7	1.3	7.4	6
<i>Parrachos</i>	Herbivores	NA	NA	NA	NA	0
	Piscivores	NA	NA	NA	NA	0
<i>Costa dos Corais</i>	Herbivores	3.1	2.5	0.8	13.2	20
	Piscivores	1.0	0.6	0.3	2.6	20
<i>Abrolhos</i>	Herbivores	13.7	8.9	3.3	44.5	13
	Piscivores	3.3	3.1	0.3	10.8	13

The recent dataset included mean yearly values from sites sampled in or after 2020. However, only sites with data available for at least two different years over the entire sampling period were included. No sites from the Parcel de Manuel Luís, Semiárid, Queimada Grande, or BTS and Baixo Sul ecoregions met this criterion; therefore, these ecoregions were classified as Data Deficient under this criterion. For the remaining ecoregions, a single mean value per site was calculated across all surveyed years after 2019 to better represent recent fish biomass while accounting for natural interannual variability (Table 21).

Table 21. Mean current value with standard deviation, minimum and maximum values for herbivore and piscivore indicators for each ecoregion (n – number of sites).

Ecoregion	Indicator	Mean	Median	Std. dev	Min value	Max value	n
<i>Rocas Atoll and Noronha</i>	Herbivores	10.4	10.0	5.2	2.3	20.3	9
	Piscivores	2.4	2.7	1.9	0.6	6.9	9
<i>Parrachos</i>	Herbivores	7.5	7.8	5.8	1.8	19.4	9
	Piscivores	0.3	0.3	0.2	0.02	0.7	9
<i>Costa dos Corais</i>	Herbivores	2.7	1.2	6.9	0.3	38.8	30
	Piscivores	0.4	0.2	0.8	0.04	4.3	30
<i>Abrolhos</i>	Herbivores	6.0	3.9	6.9	0.06	37.7	39
	Piscivores	1.7	0.7	2.2	0.01	8.6	39

Collapse thresholds

Collapse thresholds were defined for each indicator to represent the degradation point at which ecosystem function or identity is completely lost, and the ecosystem is fundamentally changed.

For benthic indicators, thresholds reflect a transformation in state, for example away from a coral-dominated ecosystem to one which is algae-dominated. For fish indicators, thresholds represented the loss of ecological function (e.g. insufficient herbivory or piscivory to influence ecosystem dynamics). Thresholds were based on published studies, empirical observations, and expert judgment on regional conditions, and were applied consistently across all ecoregions.

For hard coral cover, a threshold of **5%** was applied, representing the minimum level required to sustain positive carbonate accretion on a reef.

For the algae-to-coral ratio, a threshold of **0.833** (i.e. algae cover five times greater than coral cover) was used, indicating a persistent shift to algal dominance where recovery becomes unlikely.

For fish indicators, thresholds were defined relative to baseline conditions, with collapse occurring at **10%** of baseline levels for herbivores and **20%** for piscivores.

Calculating relative severity of decline

Relative severity of decline was calculated for each site with current data using the formula:

$$\text{relative severity of decline (\%)} = 100 \times \frac{\text{initial value} - \text{current value}}{\text{initial value} - \text{collapse threshold}}$$

Uncertainty in initial conditions was incorporated by applying a bootstrapping approach. For each ecoregion and indicator, initial values were represented as a normal distribution defined by the estimated mean, standard deviation, and observed range (min and max). Initial values were randomly sampled from this ecoregional distribution and assigned to each site.

The highest risk category was determined from the decline-extent matrix (Fig X), with the ecosystem extent calculated as the proportion of sites exceeding decline thresholds ($\geq 20\%$, $\geq 30\%$, $\geq 50\%$, $\geq 70\%$, $\geq 80\%$, and 100% decline). This process was repeated **750** times, and each time the resulting highest risk category for the iteration was recorded. To determine the final risk category for each indicator, the distribution of outcomes across all iterations was considered. Where $\geq 80\%$ of iterations produced the same category, this was assigned as the final status. When a dominant result was not returned, an appropriate category or range of categories was applied, e.g. if 50% of iterations were LC, and 50% VU, then the overall risk was NT.

The analysis assumed that monitoring sites broadly reflect conditions across the entire ecoregion. Where spatial coverage was uneven or limited, we assessed whether observed patterns were representative of the unsampled areas based on the distribution of pressures and environmental conditions. If the available data were considered insufficient to reliably characterise ecosystem-wide patterns, the ecoregion was classified as *Data Deficient*.

Determining final risk class for Criterion D

The overall risk category for Criterion D for each ecoregion was determined by integrating results across all indicators using a stepwise approach, following previous coral reef RLE assessments.

Indicators were evaluated in sequence according to their ecological role and interactions:

1. Hard corals (reef engineers);
2. Algae (competitive dynamics);
3. Herbivorous fish (algal control);
4. Piscivorous fish (trophic regulation).

The assessment used the coral condition as the baseline classification. At each subsequent step, the overall risk category was increased by one level if the next indicator was classified at a higher risk level than the cumulative status to that point. This approach ensures that hard coral, as the foundational component of reef ecosystems, had the greatest influence on the final classification, while still accounting for the contribution of other biotic components. It also prevented the overall assessment from being disproportionately driven by secondary indicators (e.g. fish)

Overall risk status

Once all applicable RLE criteria and sub-criteria had been assessed, the overall risk status for coral reefs in each ecoregion was determined. A precautionary approach, consistent with the principles of the Red List of Ecosystems framework was applied whereby the final classification reflected the most severe risk category assigned across

all evaluated criteria. This approach ensures that **any severe risk** which may drive collapse is not diluted or overlooked in the final assessment.

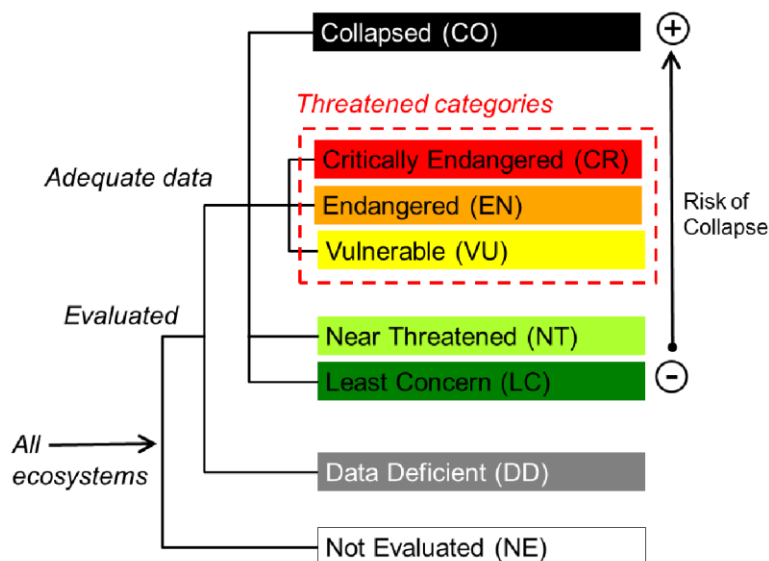


Figure 12. Fluxogram showing risk categories according to the IUCN Red List of Ecosystems (RLE) guidelines.

10.4. Discussion

Regional risk is mostly driven by projected thermal stress

This assessment reveals a widespread risk across Brazilian coral reefs, primarily driven by projected thermal stress. Restricted geographic distribution also influenced the risk of collapse for some ecoregions, while biotic degradation was critical in Costa dos Corais. While five of the eight assessed ecoregions were classified within threatened categories, three ecoregions were classified as Data Deficient due to the lack of data to estimate declines.

Climate impacts as the primary driver of the risk of collapse - Criterion C

The most significant threats to Brazilian coral reefs are projected severe bleaching and mortality events in the next 50 years, driven by the expected increase in the severity and frequency of marine heatwaves (Rodrigues et al., 2025; Gonzáles-Rivero et al., 2026). All ecoregions were classified as Critically Endangered under subcriterion C2 (SSP2-4.5 and SSP3-7.0). Lower-latitude ecoregions, such as Costa dos Corais, composed mainly by coastal reefs, were severely affected by both the 2019/2020 regional event (Vidal et al., 2025) and the 2024 global mass bleaching event, exhibiting severe loss of coral cover and near-total mortality of the less resilient, branching hydrocorals of the genus *Millepora* and the endemic *Mussismilia harttii* (Vidal et al., 2026). In the oceanic islands (e.g., E4), the main coral cover composing forms are the massive, thermal resistant *Siderastrea stellata* and *Montastraea cavernosa* (Leão et al., 2016), which may contribute to the ecoregion's resistance to thermal disturbance. The encrusting form of the

branching coral species *Millepora alcicornis* occurs in the shallow reefs, where losses have been observed since 2010.

Studies in the Abrolhos ecoregion have shown that the 2016 and 2019 marine heatwaves caused significant mortality and loss of coral cover in the area (Duarte et al., 2020; Carlos-Júnior et al., 2026). However, despite recorded thermal stress reflected in elevated DHW values, no bleaching or coral cover loss was reported in the ecoregion during the 2023-2024 global mass bleaching event (Mies et al., 2025). Shifts in coral assemblages, including the collapse of branching corals and the replacement of massive endemic forms by fast-growing, small, and typically brooding species in previous years (e.g., 2019) (Carlos-Júnior et al., 2026) may have favored the selection of stress-tolerant taxa and buffered the effects of recent bleaching events. This highlights the need to study community shifts and the role of species composition in how ecosystems respond to thermal stress. Local oceanographic conditions, including subsuperficial upwellings (Cirano and Lessa, 2007; Aguiar et al., 2018), may be operating at higher-latitude ecoregions and alleviating teleconnected surface ocean temperature increases. While resilience and better recovery potential are expected in reefs like those of the Abrolhos ecoregion, which supports the highest coral diversity in the Southwestern Atlantic (Leão et al., 2019; Martello et al., 2024), the projected worsening climate conditions in the upcoming decades could override these effects, endangering coral reefs even in ecoregions that for the past 50 years have managed to withstand and recover from thermal stress.

Consequences of restricted geographic distribution - Criterion B

Seven ecoregions were classified as threatened under Criterion B upon meeting specific restricted spatial thresholds and showing evidence of ongoing decline or threatening processes likely to cause continuing deterioration within the next 20 years. Across Brazil, these requirements were met due to naturally restricted spatial parameters coupled with the imminent threats of rising sea surface temperatures and recurrent marine heatwaves. Although the Brazilian reef province extends for approximately 3,000 km along the coast, shallow reef formations occupy relatively narrow areas, with most shallow reefs concentrated on the continental shelf and many occurring close to the coast (Leão et al., 2016, 2019). Some of the discontinuity observed in Brazilian coral reefs can be dictated by major biogeographical barriers of riverine origin that discharge massive volumes of freshwater and terrigenous sediments, leading to high water turbidity and low-salinity plumes that may prevent shallow reef development and restrict the larval connectivity and dispersal of photophilic coral species (Bleuel et al., 2024).

Under criterion B, the Parrachos and Rocas Atoll and Noronha ecoregions were assessed as Critically Endangered (CR) due to their extremely limited distributions, making a large proportion of their total extent potentially susceptible to individual disturbance events. The assessment of the Semiarid ecoregion involved uncertainty around ecosystem definition. Reef environments in this ecoregion comprise a heterogeneous

mosaic of non-framework-building communities, submerged patch reefs and shelf-edge biogenic reefs, with a substantial proportion occurring near or within the mesophotic depth range (Soares et al., 2019; Carneiro et al., 2022). This transitional character complicates the delimitation of the extent of the shallow coral reef ecosystems considered in this ecoregion and highlights the importance of improved habitat mapping for future assessments.

Evidence of ecosystem decline and biotic degradation - Criteria A and D

Criteria reflecting biotic degradation and ecosystem decline revealed marked spatial variation among Brazilian ecoregions. While contrasting responses to recent thermal stress events may help explain the coral cover patterns found across ecoregions, other factors still play a relevant role. In general, lower risk levels were found in the Abrolhos and Rocas Atoll and Noronha ecoregions for criteria based on hard coral cover. This may reflect the protective effect of various factors, including distance from the coast, higher protection from stricter MPAs, and local environmental and oceanographic conditions that contribute to maintaining ecological integrity. Regarding protection level, although reefs in most ecoregions are under some level of protection due to the presence of MPAs, only Rocas Atoll and Noronha and part of Abrolhos are under strict, no-take categories such as Marine Parks and Biological Reserves. Contrastingly, coastal ecoregions are exposed to local pressures such as overfishing, pollution, coastal development, sedimentation, and unsustainable tourism (Ferreira et al., 2004; Leão et al., 2019), which aggravate the effects of increasing thermal stress (Tedesco et al., 2017). The Costa dos Corais ecoregion, which already showed signs of degradation in the 1990s, benefited from several national and regional coral reef protection measures, including the creation of the largest Brazilian MPA (APA Costa dos Corais) in 1997. While these measures prompted the local recovery of coral cover in the following decades, recent losses have been reported due to heatwaves (Ferreira et al., 2026).

The Parrachos ecoregion diverged from this broader pattern for coastal ecoregions, being assessed as Least Concern under criterion A. While this apparent lower risk may partly reflect differences in direct exposure to land-based pressures, considering that the coast is semiarid and some of its major reef complexes occur ~5–7 km offshore (Araújo & Amaral, 2016; Mayal et al., 2009), it should be interpreted cautiously. The ecoregion's relatively small sample size and consequent lower spatial variability may have failed to encompass highly degraded areas alongside sites where coral cover has remained comparatively high. Moreover, the observed coral cover in Parrachos may be driven largely by the dominance of stress-tolerant *Siderastrea* spp., while several structurally and functionally important taxa have undergone severe declines or local losses (e.g., *Millepora* spp., *Millepora braziliensis*, *Agaricia* spp., and *Mussismilia harttii*) (Rodrigues et al., 2025; Carlos-Júnior, et al. 2026; Vidal et al., 2026; G.O. Longo, *pers. obs.*). These changes may be insufficiently represented in standard benthic transects because the affected taxa occupy potentially under-sampled reef zones (e.g., crests, crevices, and reef bases).

Other indicators showed that biotic degradation extends beyond changes in coral cover. In Rocas Atoll and Noronha, the estimated risk of collapse was higher based on algae:coral ratio than on hard coral cover. Factors that may contribute to the observed high algae cover in the area include higher productivity due to island subsuperficial upwelling (Tchamabi et al., 2017) and local nutrient enhancement. The latter can have natural causes, such as phosphorus enrichment from guano produced by seabirds, which contributes to the high macroalgae productivity (Fonseca et al., 2018), and anthropogenic ones, including inadequate wastewater treatment, which has been documented even within protected areas (Mello et al., 2025). It is important to note that macroalgae is a very broad category, and improving macroalgae descriptions is important for a more refined characterization of the current conditions of reefs in the face of climate change, given their distinct functions in reef ecosystems. For instance, articulated coralline algae contribute to carbonate production (Montaggioni & Braithwaite, 2009; Cornwall et al., 2023) and the provision of habitat and food resources for various associated organisms (Longo et al., 2015; Barros et al., 2024).

Results based on reef fish indicators reflected the level of protection from fishing. Large-bodied parrotfishes and groupers are currently assessed as threatened in Brazil (Brazil, 2026b), reflecting a long history of fishing exploitation and population declines (Bender et al., 2014; Queiroz-Véras et al., 2023). For groupers specifically, this matches a global trend for slow growing species (Sadovy de Mitcheson, et al. 2013; 2020). While snappers are mostly not under threat, many are considered overfished as per recent stock assessments (Ferreira et al., 2022; Soares et al., 2026). All surgeonfish species are classified as Least Concern (ICMBio, 2026). Rocas Atoll and Noronha was the only ecoregion in which neither herbivores nor piscivores reached a threatened category. These oceanic reefs are fully or partially protected from fishing and have high snappers biomass. Parrachos and Abrolhos also showed comparatively low degradation levels based on herbivore biomass, potentially reflecting some of the remaining populations of the endemic and largest parrotfish species *Scarus trispinosus* (Roos et al., 2019; Queiroz-Véras et al., 2023, 2025; Roos, 2025). For Costa dos Corais, herbivores were classified as Vulnerable, despite evidence of higher biomass at no-take zones (Lippi et al., 2022) and indicators of sustainability of small scale fisheries targeting those species (Da Silveira and Ferreira, 2024). Piscivores/carnivores were assessed as threatened in three out of four ecoregions. In Costa dos Corais, their biomass was mainly represented by medium-sized groupers and juvenile snappers. Even with higher numbers observed within no-take zones of multiple-use MPAs (Lippi et al., 2022), those appear insufficient to support high biomass levels across the ecoregion.

Data limitations and caveats to the method

Data limitations were particularly important for the Parcel de Manuel Luís, Semiárid, and Queimada Grande ecoregions. The decision to classify them as Data Deficient was made in consultation with local experts based on the lack of monitoring data to estimate baseline conditions and to support the assessment of functional criteria. For Parcel de Manuel Luís, despite reports of unquantified but severe bleaching in the past (Amaral et

al., 2006, 2007), the remoteness and difficult access have constrained regular monitoring efforts in the area, leaving major gaps regarding historical and recent ecosystem responses to bleaching events, historical ecosystem conditions, and the status of reef-fish assemblages. For the Semiarid and Queimada Grande ecoregions, this uncertainty also applies to the extent of coral reef formations, as previously discussed here. The Queimada Grande ecoregion was assessed as Data Deficient under all criteria. While its restricted geographic distribution could indicate substantial vulnerability to collapse, especially considering the projected impacts of climate change, the actual extent of its coral reef ecosystem remains poorly known and may be underestimated. Additionally, as the southernmost assessed ecoregion, its oceanographic conditions could confer some degree of refuge from climate impacts. However, limited monitoring data prevent us from determining how its coral reefs have responded to marine heatwaves or establishing their current status. Due to the lack of reliable evidence of ecosystem decline, the ecoregion did not fulfill the requirement for assessment under criterion B, despite being subject to mapping efforts. These gaps highlight the need for improved ecological monitoring in Parcel de Manuel Luís and the Semiarid ecoregion, and habitat mapping in Queimada Grande.

Criterion D was also constrained by spatial and temporal gaps in biological monitoring, with data being unavailable for many of the assessed ecoregions and no monitoring series extending back 50 years. It is important to note that hard coral cover, fish biomass, and algae-to-coral ratio provide useful and comparable indicators across large spatial scales, but do not capture changes in species composition, functional diversity, size structure, recruitment, or the loss of particularly sensitive taxa.

Comparison with the 2025 Status of the Reefs Report

The results shown here point to a bleaker scenario than the one presented recently under González-Rivero et al. (2026), which indicated a no-change scenario for the Brazil region as a whole, considering begin and end values weighted by reef area. Regional differences, a detailed account of gains and losses over time and their implications are detailed in the Brazil Chapter of the aforementioned publication (chapter 2, Ferreira et al., 2026).

The apparent differences between the two assessments reflect their differing scopes and analytical approaches. Since the status report is based on changes in hard coral and algae cover only, its comparison with this assessment is limited to the results of Criteria A1 and D. The first difference between these assessments relates to baselines. Under the GRMN status report, changes are evaluated within the span of monitoring years, which for Brazil ranges from 2002 to 2025. As such, it uses a more recent time reference (~20 years) compared with the 50-year estimated baseline used within the RLE assessment. By 2002, many Brazilian reefs, particularly the coastal ones, were already depauperated due to multiple local stressors and possibly due to losses caused by the 1998 El Niño, that although with its effects largely unchecked, are known to have impacted reefs in the region. As such, the initial state reported in Ferreira et al. (2026) already reflected

stressed conditions. The Costa dos Corais area, for instance, sustained recovery following the implementation of protection measures in the late 1990s, but was severely affected by recent bleaching and mortality events. By comparing the start and end of the data time series, the apparent stability fails to encompass such intermediate recovery. Abrolhos, on the other hand, experienced the least overall coral loss, since it was not affected by the 2024 mass bleaching event, and was classified as Least Concern under criterion A, matching the trend for the ecoregion as shown in the GCRMN report.

Summary and next steps

The consistency of high-risk outcomes across multiple criteria provides strong evidence that Brazilian coral reefs are undergoing substantial change. The combination of existing ecological degradation, disruption of biotic processes, and severe projected deterioration in environmental conditions due to climate change indicates that strong and effective local management and global climate change mitigation efforts will be necessary to reduce the risk of ecosystem collapse. The effectiveness of environmental protection measures, either through regulatory laws or Marine Protected Areas (MPAs), was evident, with positive intervention outcomes observed at all protection levels, represented by better indicators in fully protected areas and recovery trajectories in depauperated reefs. This highlights the need for continued coral reef management measures aimed at mitigating immediate anthropogenic stressors to support population recovery, coupled with key interventions, including participatory fisheries management and regulating agricultural runoff and municipal wastewater to optimize water quality. Designation of MPAs may provide structural refugia from overexploitation and improve connectivity between shallow areas and their continuum, including mesophotic reefs and rodolith beds. These measures are crucial to buy time and allow for local adaptations to climate-mediated transformations, as projections point to difficult times for coral reefs and those who depend on their services for their well-being and survival.

Brazilian reefs have historically been considered relatively resistant to thermal stress compared with many Caribbean and Indo-Pacific reefs, partly because high turbidity and the dominance of stress-tolerant coral species may buffer some effects of elevated temperatures (Costa et al., 2001; Leão et al., 2016; Mies et al., 2020). However, studies and observations from recent mass bleaching and mortality events have shown that the increasing marine heat waves can lead to significant mortality and loss of coral cover throughout the Brazilian coast (Duarte et al., 2020; Mies et al., 2025; Vidal et al., 2025 and 2026; Ferreira et al., 2026). The exact outcome will ultimately depend on the adaptation and filtering of resistant coral taxa, as well as on local environmental quality that may either support or add further stress on coral reef ecosystems.

10.5. References

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Criterion C – Environmental Degradation: supplementary figures

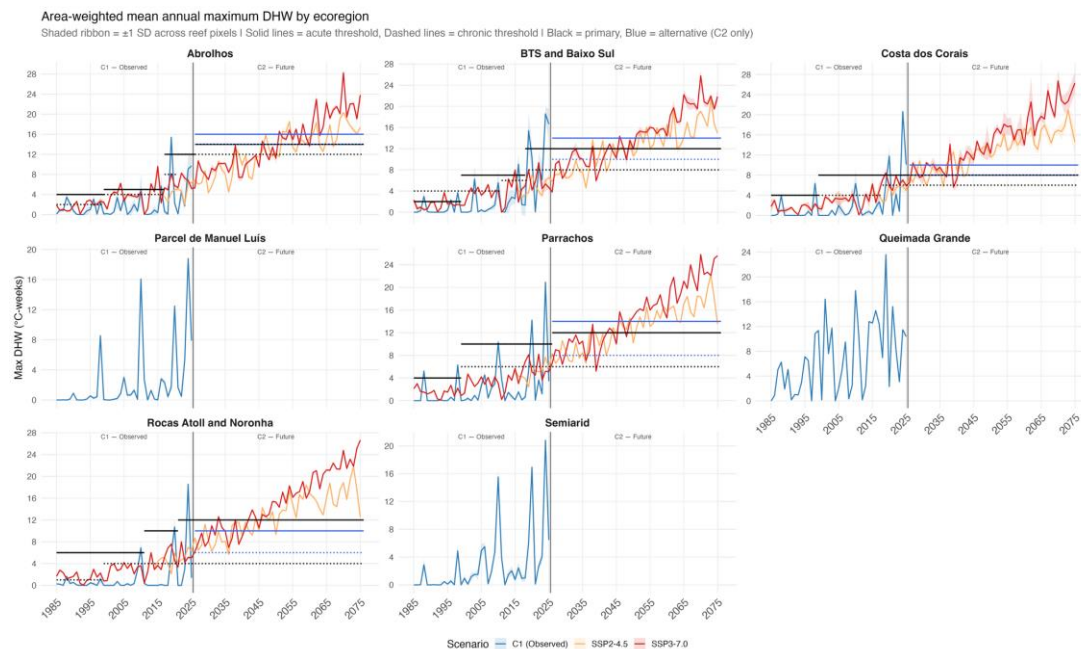


Figure S1. Annual maximum Degree Heating Weeks (DHW) averaged across coral reefs within each ecoregion from 1985-2075 for four trajectories: observed data used to assess sub-criterion C1 from 1985-2025 (blue line), and projections under three Shared Socioeconomic Pathways — SSP2-4.5 (orange), SSP3-7.0 (red), and SSP5-8.5 (purple). Shaded ribbons represent ± 1 SD in DHW across reef pixels within each ecoregion, reflecting spatial variability in thermal exposure. Horizontal lines show ecoregion-specific DHW thresholds at various points in time corresponding to severe bleaching events (chronic stress pathway; dashed lines) and severe mortality events (acute stress pathway; solid lines). Black lines indicate primary thresholds, and blue lines indicate alternative thresholds (C2 period only, 2026–2075). The vertical grey line marks the boundary between the observed (C1 - 1985-2025) and projected (C2 - 2026-2075) assessment periods.

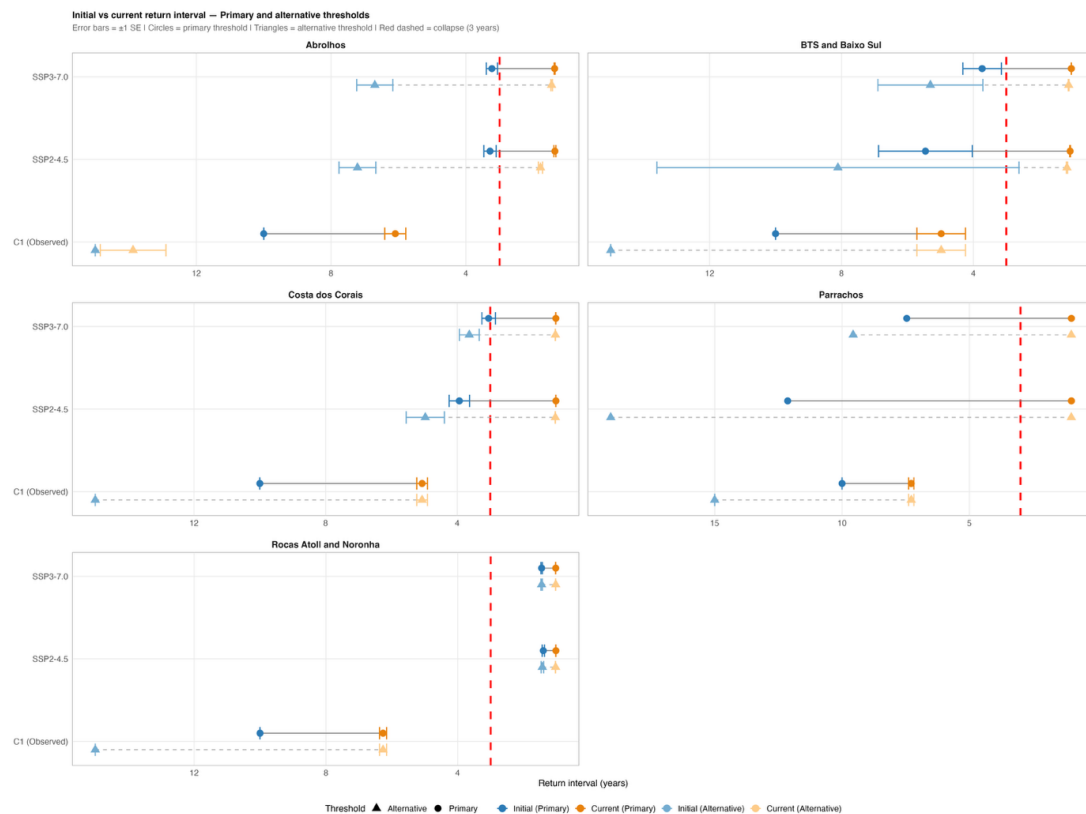


Figure S2. Change in the average return interval between severe bleaching events (years) for each ecoregion (x-axis), comparing initial conditions (blue) to current or projected future conditions (orange) across four trajectories (y-axis): observed data (C1) and projections under SSP2-4.5, SSP3-7.0, and SSP5-8.5. Connecting lines indicate the direction and magnitude of change between initial and current conditions. Return intervals were estimated for the chronic pathway by fitting a binomial regression model to the binary bleaching event time series for each reef pixel, with values representing the shortest return interval identified over each assessment period (C1: 1985–2025; C2: 2026–2075). Results are shown for both primary (filled circles) and alternative (filled triangles) DHW thresholds. For C1, initial conditions are assumed to reflect historical disturbance regimes prior to the satellite record, corresponding to a return interval of 10 years (primary threshold) and 15 years (alternative threshold). For C2, initial conditions are calculated from projected DHW data over 1996–2025 using the same probabilistic model. Error bars represent ± 1 SE across reef pixels within each ecoregion. The red dashed vertical line marks the collapse threshold of a 3-year return interval, below which disturbance frequency is considered sufficient to prevent meaningful coral recovery and drive progressive ecosystem degradation. Note that the x-axis is reversed such that movement from left to right represents a shortening return interval and worsening conditions.



Figure S3. Mean number of severe mortality events per 5-year period, averaged across coral reef pixels within each ecoregion, under two trajectories: observed data used to assess sub-criterion C1 (blue bars, 1985–2025) and projections under SSP2-4.5 (orange bars, 1985–2075). Severe mortality events are defined as years in which annual maximum DHW exceeded ecoregion-specific acute stress thresholds associated with widespread coral mortality. Error bars represent ± 1 SD across reef pixels within each ecoregion, reflecting spatial variability in the frequency of severe thermal exposure. The red dashed horizontal line indicates the collapse threshold of 3 severe mortality events within a 5-year window. The vertical grey line marks the boundary between the observed (C1, 1985–2025) and projected (C2, 2026–2075) assessment periods.

Appendices: Factsheets – 2 pages per ecoregion

Ecoregion 1 - Parcel de Manuel Luís (Data Deficient)

Spatial distribution (boundaries, area of coral reef)

The Parcel de Manuel Luís reef is located on the western Brazilian Equatorial Margin, approximately 84km off the coast of Maranhão State, on the outer continental shelf. It is composed of a series of patch reefs and pinnacles, composed mostly of coralline algae, rising from the seafloor and reaching varying shallow depths of up to 1m (Cordeiro et al., 2021). Its position on the outer shelf and absence of any emerging portion have made it one of the most notorious ship cemeteries, with approximately 200 shipwrecks (Maida & Ferreira, 1997; Maranhão, 2023). The difficult access to this region made it one of the least studied reefs in Brazil. The area was designated a Marine State Park in 1991, although no enforcement was implemented, and its management plan was only made available in 2023 (Maranhão, 2023).

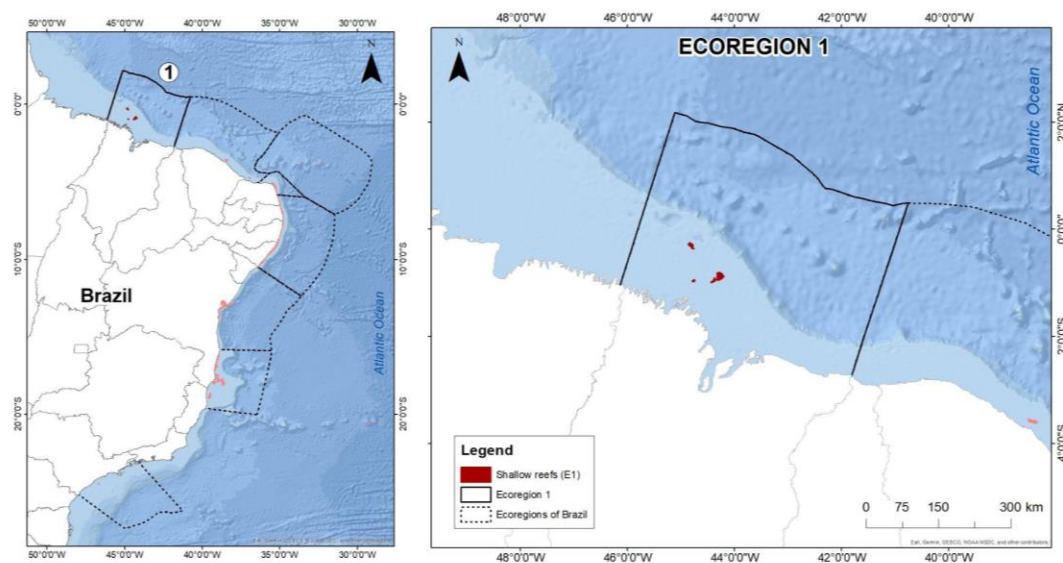


Figure 1. Map of the Brazil region highlighting Ecoregion 1 (Parcel de Manuel Luís).

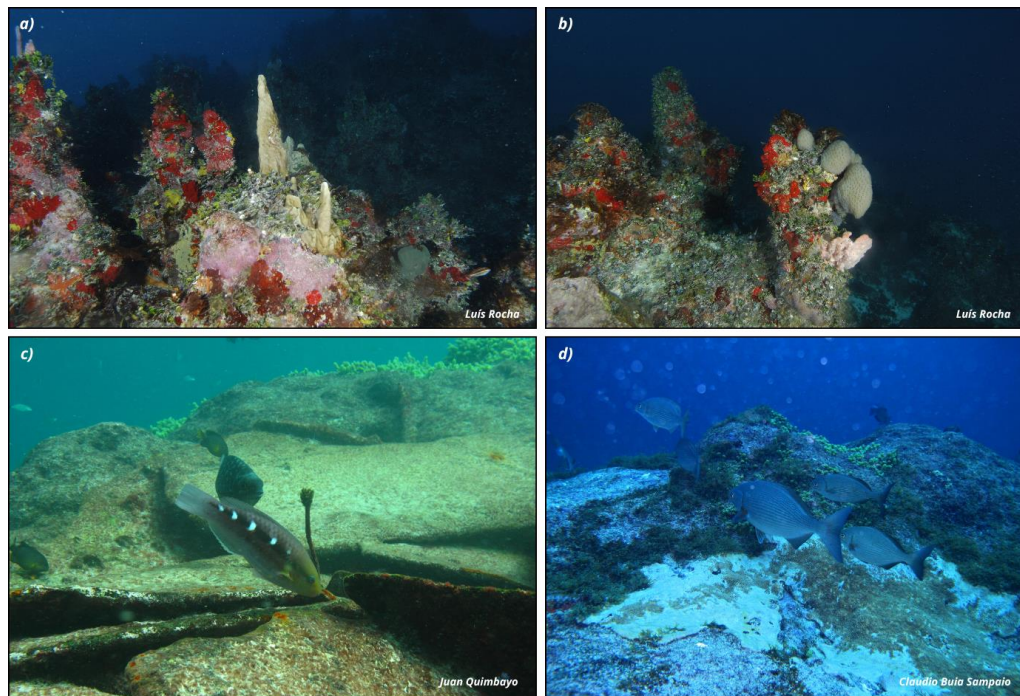


Figure 2. Representative underwater photos of coral reefs from Ecoregion 1, taken in 2012 in the Parcel de Manuel Luís reef complex, Maranhão state.

Ecosystem description

The lack of proper studies on the nature of the reef limits our understanding of its formation and framework composition. The low coral cover and high abundance of coralline algae and sponges have led to hypotheses that these are likely the main reef builders (Cordeiro et al., 2021). The most comprehensive studies on the local composition of coral species were conducted by Amaral et al. (2008) and Amaral et al. (2007), which recorded 12 Scleractinia species and described the endemic hydrocoral *Millepora laboreli*. The benthic cover is dominated by macroalgae and turf, with coral accounting for less than 1% (Cordeiro et al., 2021). The first reef fish assessment reported 137 species (Rocha & Rosa, 2001), while a more recent account showed the dominance of herbivores-detritivores and mobile invertebrate feeders (Cordeiro et al., 2021).

The main threats to Parcel de Manuel Luís are fisheries and climate change; bleaching events have been reported in 1998, making it one of the first reports for the Brazilian coast (Amaral et al., 2006). Cordeiro et al. (2021) highlight the development of rodolith mining and the expansion of the oil industry along the equatorial margin as future threats to these unique reefs. In 2025, the invasive lionfish (*Pterois* spp.) was detected in the Parcel reef complex, representing another challenge to the conservation of this reef complex.

Ecoregion	Key Biotic	Key Abiotic	Key Threats
Parcel de Manuel Luís (E1)	Elongated pinnacles with flattened tops ("chapeirões"); presence of the regional endemic hydrocoral species <i>Millepora laboreli</i> ; and diverse reef fish assemblages, including herbivores and top predators such as groupers and sharks.	Oceanic systems; clear oligotrophic water.	Coral bleaching; fishing; development of rodolith mining; expansion of the oil industry.

Key values

Proportion of coral reef lost over the last 50 years (Criterion A)	Distribution (Criterion B)		Biotic Indicator Values (Criterion D)		
	EOO (km²)	AOO Cells	Indicators	Baseline	Current
33%	3256	14	Hard coral cover	DD	DD
			Algae-coral ratio	DD	DD
			Herbivore biomass	DD	DD
			Piscivore biomass	DD	DD

Criteria Assessment

Overall, the risk of collapse of the coral reefs in **Parcel de Manuel Luís** was assessed as **Data Deficient (DD)**. Summary of the assessment:

CRITERION			
A. Reduction in Geographic Distribution	A1	A2	A3
	Past 50 years	Future or any 50y period	Historical (1750)
	VU	NE	NE
B. Restricted Geo. Distribution	B1	B2	B3
	Extent of Occurrence	Area of Occupancy	# Threat-defined Locations < 5?
	EN	EN	NE
C. Environmental Degradation	C1	C2	C3
	Past 50 years (1975)	Future or any 50y period	Historical (1750)
	DD	DD	NE
D. Disruption of biotic processes	D1	D2	D3
	Past 50 years (1975)	Future or Any 50y period	Historical (1750)
	DD	NE	NE
E. Quantitative Risk analysis	NE		
OVERALL RISK CATEGORY	DD		

DD = Data Deficient; LC = Least Concern; NT = Near Threatened; VU = Vulnerable; EN = Endangered; CR = Critically Endangered; CO = Collapsed; NE = Not Evaluated

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Ecoregion 2 - Semiarid (Data Deficient)

Spatial distribution (boundaries, area of coral reef)

Historically, the continental shelf along the SAC is considered poor in terms of shallow biogenic reef occurrence. The shallower sector of this continental shelf is subject to

intense wind-driven longshore sediment drifts, and large biogenic reefs are absent (Maida & Ferreira, 1997). Hard substrates occur across most of the SAC continental margin, mainly at 20–50 m depth, including CaCO₃-cemented sandstones (submerged beachrock) and biogenic reefs. Landsat images and bathymetry mapped these rocky structures, revealing a semi-continuous ridge of consolidated substrate parallel to the coast along the entire SAC middle shelf (Carneiro et al., 2022). However, the nature and biological composition of these reefs are not typical of true coral reefs, as coral may cover less than 5% of the bottom, which is dominated by algae and sponges (Soares et al., 2017). The hallmark of these systems is high diversity of sponges and macroalgae, with some degree of endemism (Lotufo et al., 2006).

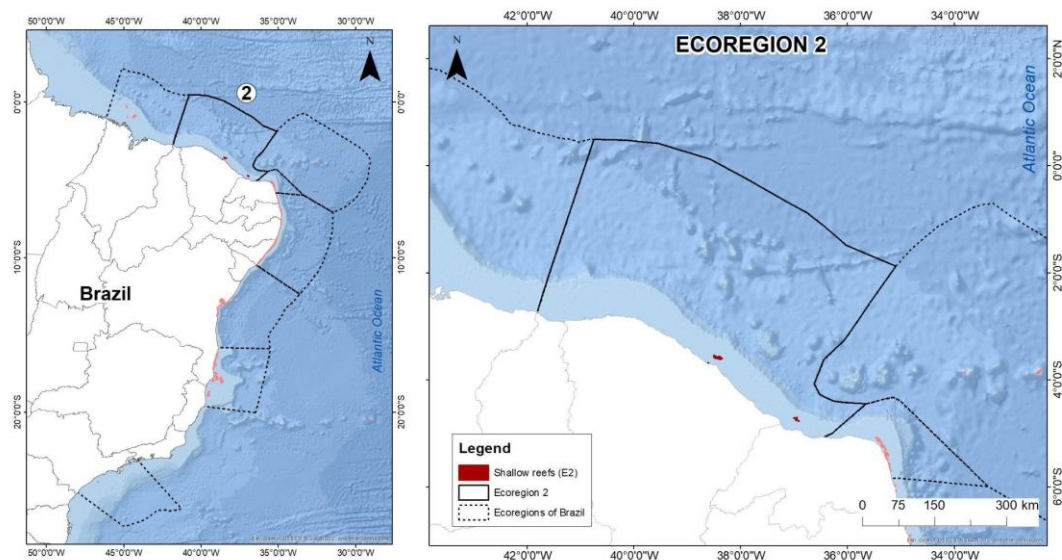


Figure 1. Map of the Brazil region highlighting Ecoregion 2 (Semiarid).

Ecosystem description

In terms of scleractinians, the semiarid ecoregion is not considered rich, with the most common species being *Siderastrea* spp., *Montastraea cavernosa*, and *Mussismilia hispida*. Coralline algae are also present but less abundant than foliose or filamentous macroalgae in terms of bottom cover (Soares et al., 2017). The reef fish assemblage composition is typical of other Brazilian reefs and similar to that of the northern Brazilian province reefs (De Freitas & Lotufo, 2015). The families Carangidae, Haemulidae, Labridae, and Epinephelidae are the most diverse.

The semiarid coast is among the least developed in Brazil, but it has been increasingly occupied and industrialized. Historically, impacts on these reefs were mainly related to artisanal fisheries, but the oil industry has also affected them. The Ceara basin was the

first offshore site developed by Petrobras, with renewed interest in recent years (Belopolsky et al., 2015). The recent push to reduce carbon emissions has increased interest in offshore wind farms along the equatorial margin, which poses a real threat to these reefs in the future. During the latter half of the 20th century, the lobster fisheries in this region underwent changes through the use of both bottom gillnets and artificial habitats, but most of the fleet has since abandoned these fisheries due to stock collapse (Cruz et al., 2021).

Ecoregion	Key Biotic	Key Abiotic	Key Threats
Semiarid (E2)	Coral cover represents less than 5% of the bottom, which is dominated by algae and sponges. High diversity of sponges and macroalgae, with some degree of endemism. Most common coral species being <i>Siderastrea</i> spp., <i>Montastraea cavernosa</i> , and <i>Mussismilia hispida</i> . Diverse reef fish assemblages, including herbivores and top predators. The families Carangidae, Haemulidae, Labridae, and Epinephelidae are the most diverse.	This area extends for about 1000 km in an SE-NW direction, and has distinct environmental conditions, such as a large interannual variability in rainfall, a predominance of small rivers, and a strong influence of wind on coastal landscapes.	Coral bleaching; local fishing; coastal development; tourism pressure; industrial effluents

Key values

Proportion of coral reef lost over the last 50 years (Criterion A)	Distribution (Criterion B)		Biotic Indicator Values (Criterion D)		
	EOO (km ²)	AOO Cells	Indicators	Baseline	Current
57%	3746	7	Hard coral cover	DD	DD
			Algae-coral ratio	DD	DD
			Herbivore biomass	DD	DD
			Piscivore biomass	DD	DD

Criteria Assessment

Overall, the risk of collapse of the coral reefs in the Semiarid was assessed as **Data Deficient (DD)**. Summary of the assessment:

CRITERION			
A. Reduction in Geographic Distribution	A1	A2	A3
	Past 50 years	Future or any 50y period	Historical (1750)
	EN	NE	NE
B. Restricted Geo. Distribution	B1	B2	B3
	Extent of Occurrence	Area of Occupancy	# Threat-defined Locations < 5?
	EN	EN	NE
C. Environmental Degradation	C1	C2	C3
	Past 50 years (1975)	Future or any 50y period	Historical (1750)
	DD	DD	NE
D. Disruption of biotic processes	D1	D2	D3
	Past 50 years (1975)	Future or Any 50y period	Historical (1750)
	DD	NE	NE
E. Quantitative Risk analysis	NE		
OVERALL RISK CATEGORY	DD		

DD = Data Deficient; LC = Least Concern; NT = Near Threatened; VU = Vulnerable; EN = Endangered; CR = Critically Endangered; CO = Collapsed; NE = Not Evaluated

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Ecoregion 3 - Parrachos (Critically Endangered)

Spatial distribution (boundaries, area of coral reef)

Ecoregion 3 comprises shallow reefs along the northeastern coastline of Brazil, which are important for marine biodiversity, socioeconomic and touristic activities. Reefs are located at ~6 km off the coast and spatialized as patches, building a unique formation called “*parrachos*”, with depths ranging from 0.5 to 6m (Roos et al., 2019). These patches are part of the “APA dos Recifes de Corais” Marine Protected Area, comprising a total area of 136,000 hectares, involving multiple uses (IDEMA, 2025).

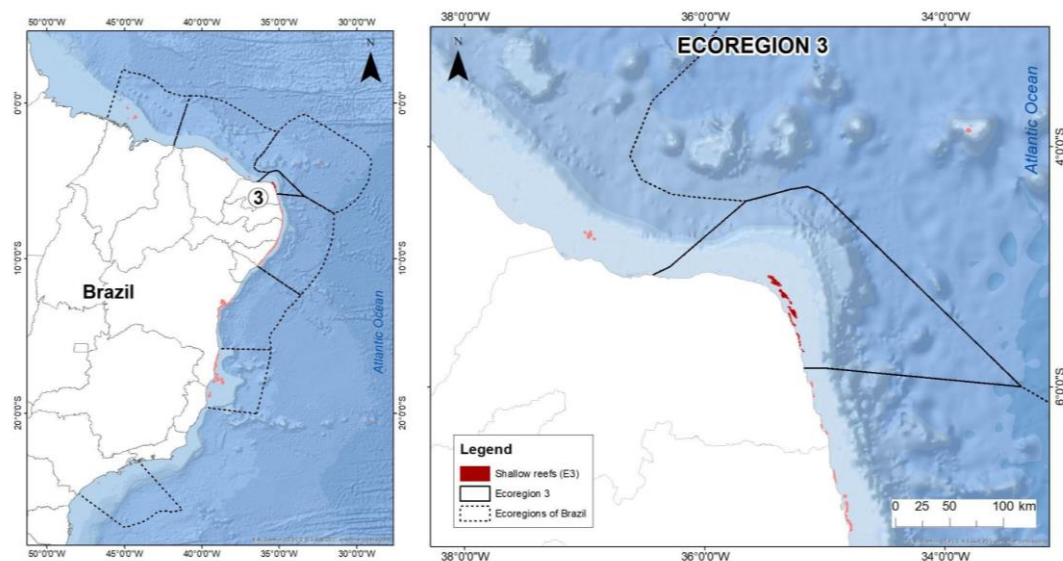


Figure 1. Map of the Brazil region highlighting Ecoregion 3 (Parrachos).

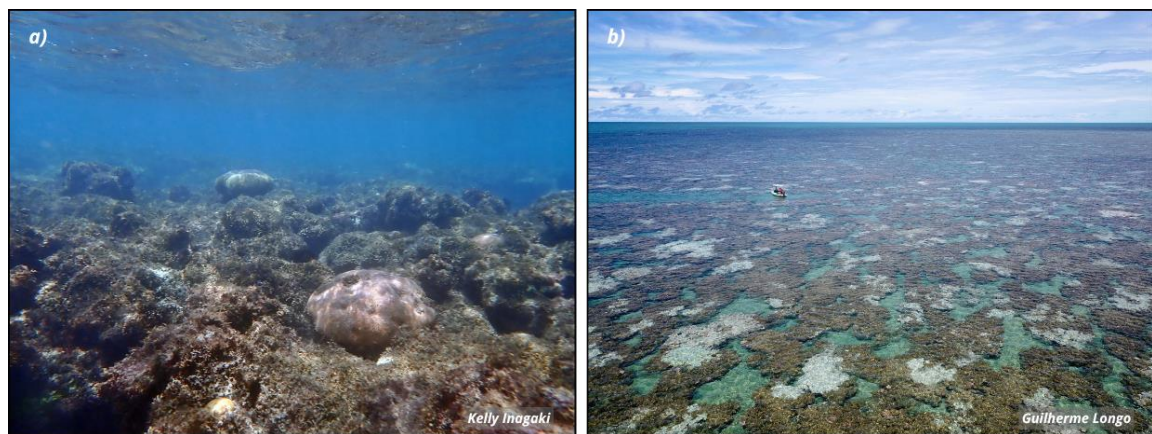


Figure 2. Representative underwater photos of coral reefs from Ecoregion 3 in the complex reef in Parrachos/ Rio do Fogos, Rio Grande do Norte.

Ecosystem description

The Parrachos coral reefs are dominated by macroalgae (mean cover >50%), an increasing cover of zoanthids (mean cover = ~20%), and scleractinian corals (mean cover = 5-10%). The latter group is mainly represented by the star-coral *Siderastrea stellata*, but also by *Porites astreoides*, *Favia graviora*, *Agaricia* sp., and the hydrocoral *Millepora alcicornis* (Aued et al., 2018; Roos et al., 2019; Rodrigues et al., 2025). The endemic hydrocoral *Millepora braziliensis*, once common in this ecoregion, has faced near local extinction—a decline consistent with its population trends in similar areas (Silva et al., 2025). This region is one of the most important areas for parrotfishes in

Brazil (Roos et al., 2019), including the endemic and endangered *Scarus trispinosus*, which is heavily fished in the area (Roos et al., 2025).

Fishers employ artisanal gears to capture mainly reef fish, octopus and lobsters. Tourism has been increasing over the last decade, attracting more than 100,000 tourists in 2025 (IDEMA, 2025). While tourism in the area is important to support socio-economical development, it has also led to an increase in the occurrence of acute impacts. In the last decade, heatwaves have become more intense and frequent in this ecoregion (Rodrigues et al., 2025), leading to ~70%-80% declines in coral cover, with some coral species presenting declines >90%, such as *Agaricia* sp., *M. alcicornis* and *M. braziliensis* (Mies et al., 2025).

Eco-region	Key Biotic	Key Abiotic	Key Threats
Parrachos (E3)	Shallow patch reefs dominated by <i>Siderastrea</i> sp. and <i>Porites astreoides</i> , macroalgae and turf; and diverse reef fish assemblages, including herbivores as the endemic and endangered <i>Scarus trispinosus</i> .	Influence of riverine inputs; mild seasonality between rainy and dry periods, with fluctuations in nutrient input/primary productivity, sedimentation, salinity, and temperature.	Coral bleaching; local fishing; coastal development; tourism pressure

Key values

Proportion of coral reef lost over the last 50 years (Criterion A)	Distribution (Criterion B)		Biotic Indicator Values (Criterion D)		
	E00 (km2)	A00 Cells	Indicator	Baseline	Current
25%	549	9	Hard coral cover	31.55%*	7.20%
			Algae-coral ratio	0.53*	0.46
			Herbivore biomass	3.0	7.5
			Piscivore biomass	1.4	0.3

*The baseline values shown above were used to assess Criterion D for the Parrachos ecoregion, but calculated based on data from the Costa dos Corais ecoregion (see details in the methods section of the full report).

Criteria Assessment

Overall, the risk of collapse of the coral reefs in Parrachos was assessed as Critically Endangered (CR). Summary of the assessment:

CRITERION			
A. Reduction in Geographic Distribution	A1	A2	A3
	Past 50 years	Future or any 50y period	Historical (1750)
	LC	NE	NE

CRITERION			
A. Reduction in Geographic Distribution	A1	A2	A3
	Past 50 years	Future or any 50y period	Historical (1750)
	LC	NE	NE
B. Restricted Geo. Distribution	B1	B2	B3
	Extent of Occurrence	Area of Occupancy	# Threat-defined Locations < 5?
	CR	EN	NE
C. Environmental Degradation	C1	C2	C3
	Past 50 years (1975)	Future or any 50y period	Historical (1750)
	EN	CR	NE
D. Disruption of biotic processes	D1	D2	D3
	Past 50 years (1975)	Future or Any 50y period	Historical (1750)
	EN	NE	NE
E. Quantitative Risk analysis	NE		
OVERALL RISK CATEGORY	CR (observed change) / CR (overall risk)		

DD = Data Deficient; LC = Least Concern; NT = Near Threatened; VU = Vulnerable; EN = Endangered; CR = Critically Endangered; CO = Collapsed; NE = Not Evaluated

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Ecoregion 4 - Rocas Atoll and Noronha (Critically Endangered)

Spatial distribution (boundaries, area of coral reef)

Ecoregion 4 comprises the Rocas Atoll Biological Reserve and the Fernando de Noronha Marine National Park, both situated in oceanic waters that provide important habitats for sharks and sea turtles, including nursery, feeding, and breeding areas (Marcovaldi & Marcovaldi, 1999; Garla et al., 2006; UNESCO, 2001). These systems represent the emergent peaks of the Fernando de Noronha Ridge, a volcanic seamount chain that promotes ecological connectivity between the Brazilian coast and the insular environments (UNESCO, 2001; Tosetto et al., 2024).

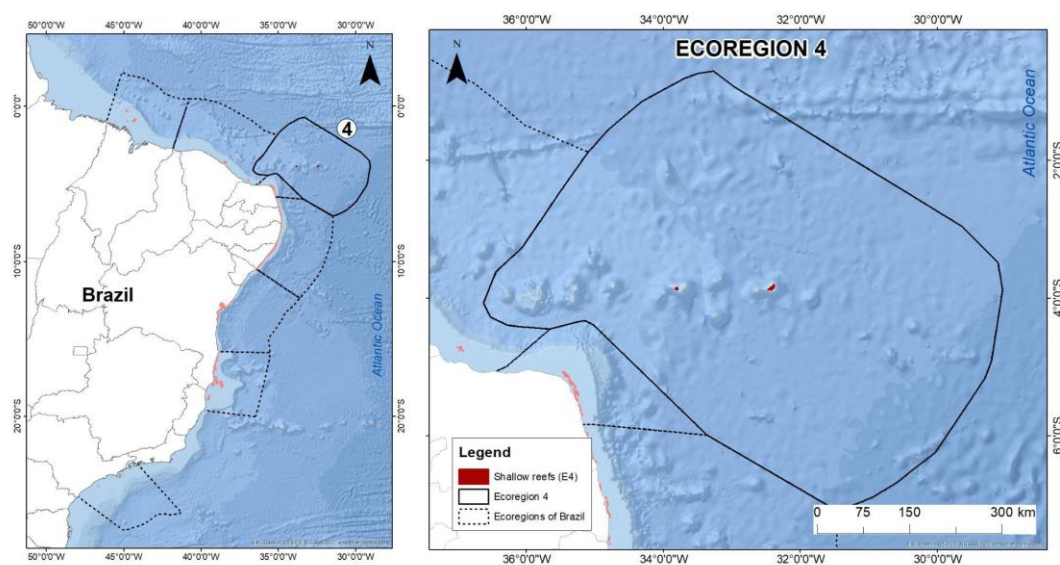


Figure 1. Map of the Brazil region highlighting Ecoregion 4 (Rocas Atoll and Noronha).



Figure 2. Representative underwater photos of coral reefs from Ecoregion 4 in the complex reef of Fernando de Noronha.

Ecosystem description

At Atol das Rocas (Rocas Atoll), the reef rim consists of a continuous algal ridge primarily built by crustose coralline algae, particularly *Porolithon* cf. *pachydermum* (Gherardi & Bosence, 1999, 2001). Corals, vermetid gastropods, polychaetes, and foraminifera also contribute to reef formation, with *Siderastrea stellata* being the dominant reef-building coral (Maida & Ferreira, 1997; Kikuchi, 1999).

In Fernando de Noronha, benthic composition varies with depth. *Millepora alcicornis* and *Siderastrea* sp. occur mainly in shallow areas, showing an encrusting morphology with small protuberances as an adaptation to local hydrodynamic conditions, while *Montastraea cavernosa* dominates deeper reefs (Laborel, 1970; Amaral et al., 2006; Matheus et al., 2019; Coxey et al., 2024). Reef habitats also support extensive cover of calcareous algae and macroalgae (Matheus et al., 2019).

Reef fish assemblages are characterized by high levels of endemism and strong biogeographic similarity between the two systems (Floeter et al., 2001). Mobile herbivorous fishes dominate fish abundance and biomass in Fernando de Noronha, while at Atol das Rocas the assemblage structure differs between open and closed pools, with *Acanthurus* spp. being particularly abundant in closed pools (Ferreira et al., 2004; Krajewski & Floeter, 2011; Longo et al., 2015). Piscivorous fishes occur as part of the reef fish assemblages in both Fernando de Noronha and Rocas Atoll, contributing to the trophic structure of these systems and including species such as serranids and carangids (Ferreira et al., 2004; Krajewski & Floeter, 2011).

Since 2010, the ecoregion has experienced increasingly frequent and intense thermal stress events, resulting in declines in coral cover and health, particularly in shallow reefs (Ferreira et al., 2013, 2021; Destri et al., 2025). Historically impacted by fishing, both areas are now protected by MPAs. Fernando de Noronha currently faces pressures related to tourism, declining water quality, and the invasion of *Pterois volitans* (Mello et al., 2025; Luiz et al., 2021; Maggioni et al., 2023). At Atol das Rocas, the main threats include proposed offshore oil exploration in adjacent areas and the accumulation of marine debris transported by ocean currents (Soares et al., 2011; ICMBio, 2020).

Eco-region	Key Biotic	Key Abiotic	Key Threats
Rocas Atoll and Noronha (E4)	Atoll formations and reefs surrounding oceanic islands; pronounced depth stratification of coral species; and high abundance and biomass of reef fish, including herbivores and top predators such as groupers and sharks.	Oceanic systems; clear oligotrophic water; seasonal high swells.	Coral bleaching; fishing; tourism pressure (Fernando de Noronha); invasive species.

Key values

Proportion of coral reef lost over the last 50 years (Criterion A)	Distribution (Criterion B)		Biotic Indicator Values (Criterion D)		
	EOO (km ²)	AOO Cells	Indicators	Mean Baseline	Mean Current
0%	997	2	Hard coral cover	32.49%	14.50%
			Algae-coral ratio	0.47	0.73
			Herbivore biomass	3.0	10.4
			Piscivore biomass	1.4	2.4

Criteria Assessment

Overall, the risk of collapse of the coral reefs in Rocas Atoll and Noronha was assessed as Critically endangered (CR). Summary of the assessment:

CRITERION			
A. Reduction in Geographic Distribution	A1	A2	A3
	Past 50 years	Future or any 50y period	Historical (1750)
	LC	NE	NE
B. Restricted Geo. Distribution	B1	B2	B3
	Extent of Occurrence	Area of Occupancy	# Threat-defined Locations < 5?
	CR	CR	NE
C. Environmental Degradation	C1	C2	C3
	Past 50 years (1970)	Future or any 50y period	Historical (1750)
	VU	CR	NE
D. Disruption of biotic processes	D1	D2	D3
	Past 50 years (1970)	Future or Any 50y period	Historical (1750)
	VU	NE	NE
E. Quantitative Risk analysis	NE		
OVERALL RISK CATEGORY	CR (observed change) / CR (overall risk)		

DD = Data Deficient; LC = Least Concern; NT = Near Threatened; VU = Vulnerable; EN = Endangered; CR = Critically Endangered; CO = Collapsed; NE = Not Evaluated

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Ecoregion 5 - Costa dos Corais (Critically Endangered)

Spatial distribution (boundaries, area of coral reef)

Ecoregion 5 comprises reefs of high ecological and socioeconomic importance, supporting local coastal development (Ferreira et al., 2001; Da Silva and Ferreira, 2024). The ecoregion is characterized by fringing reefs arranged in coastal reef lines, located 1–5 km from shore at depths ranging from 3 to 20 m (Ferreira and Maida, 2007; Laborel, 1970). Laborel (1970) reported coral cover values of up to 20–25% for reefs in this ecoregion, providing an important historical baseline.

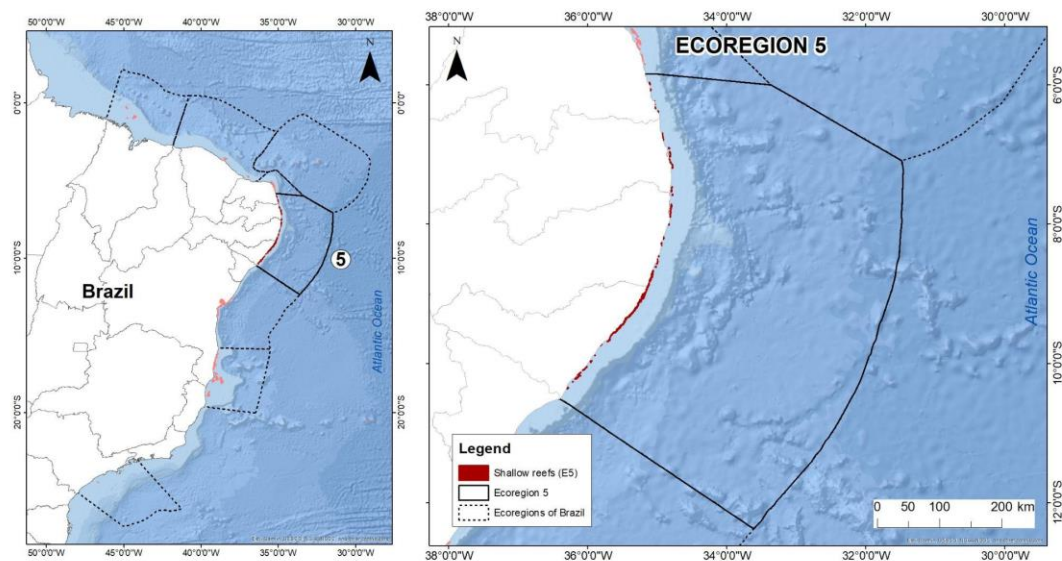


Figure 1. Map of the Brazil region highlighting Ecoregion 5 (Costa dos Corais).

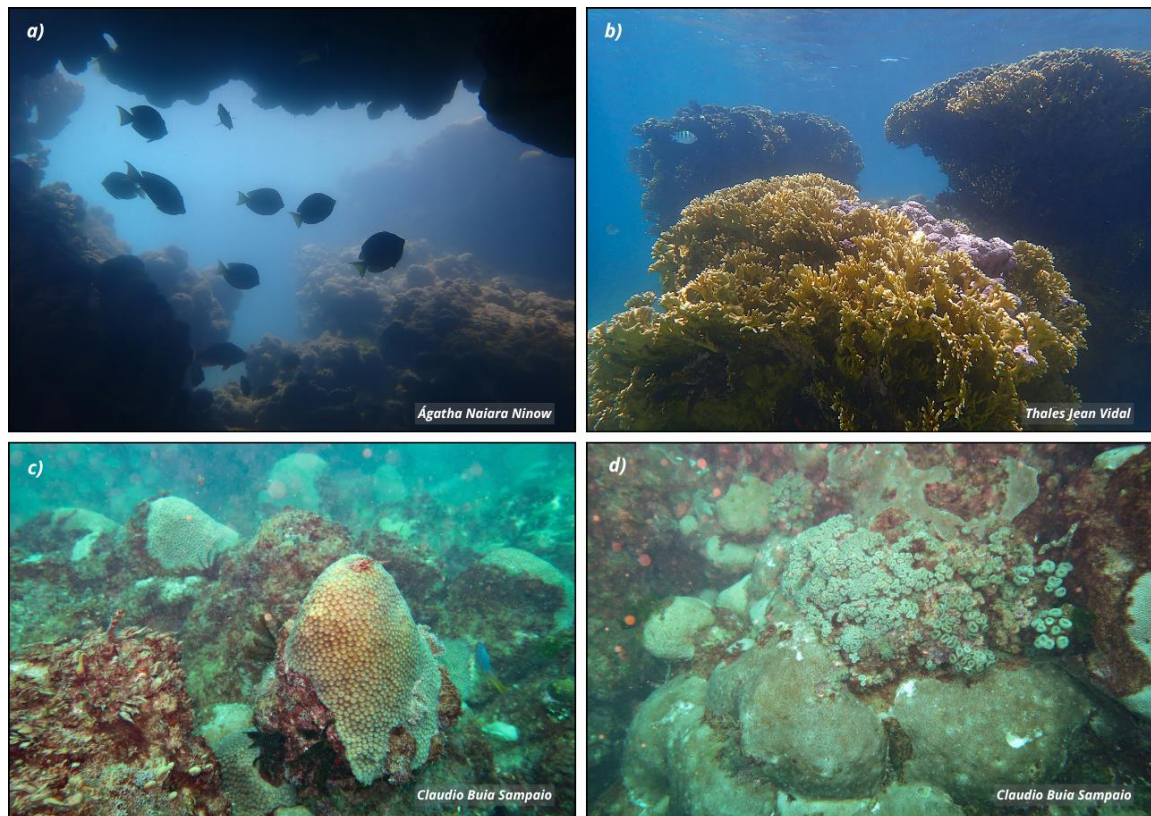


Figure 2. Representative underwater photographs of coral reefs from Ecoregion 5. a) and b) Reef complexes in Tamandaré, Pernambuco; c) and d) Coral reefs in the São Francisco River region, Sergipe.

Ecosystem description

These reefs are naturally dominated by macroalgae (>50% cover) (Feitosa and Longo, 2018; Aued et al., 2018; Souza et al., 2023; Coxey et al., 2024), particularly rhodophytes (Figueiredo et al., 2008). Coral assemblages are primarily dominated by *Millepora alcicornis* (reef crest and shallow tops), *Mussismilia harttii* (reef walls), and *Montastraea cavernosa* (reef walls and, less abundantly, on the crest and shallow tops) (Laborel, 1970; Ferreira & Maida, 2006; Aued et al., 2018; Da Silveira et al., 2021).

Chronic impacts, particularly sedimentation associated with deforestation for sugarcane cultivation and the manual removal of corals for ornamental purposes (Maýal, 1986), drove a substantial decline (~80%) in coral cover between 1970 and the early 2000s (Maida & Ferreira, 1997; Ferreira & Maida, 2006). The establishment of marine protected areas, such as the Costa dos Corais Environmental Protection Area (APACC), helped regulate degrading activities and supported partial recovery from 1997 onward, even after the first reported bleaching event of 1998 (Ferreira et al., 2021). However, since 2019, recurrent and more severe bleaching events have led to

widespread mortality of sensitive coral species in this ecoregion (Pereira et al., 2022; Vidal et al., 2024; Mies et al., 2025).

Herbivorous fishes strongly interact with benthic cover and can shape its structure (Feitosa and Longo, 2018), making them key indicators of reef health (Ferreira and Maida, 2006). Along the northeastern Brazilian coast, the most abundant genera are *Scarus* and *Sparisoma* (parrotfishes) (Feitosa & Ferreira, 2015), and *Acanthurus* (surgeonfishes) (Ferreira et al., 2004). However, historical overfishing is evident, reflected in reduced fish size and abundance in open-access areas compared to fully protected zones (Ferreira & Maida, 2007; Lippi et al., 2022).

Eco-region	Key Biotic	Key Abiotic	Key Threats
Costa dos Corais (E5)	Fringing reefs with coral knolls dominated by <i>Millepora alcicornis</i> , <i>Siderastrea</i> sp. and <i>Mussismilia harttii</i> ; and diverse reef fish assemblages, including herbivores and top predators such as groupers and Lutjanidae.	Strong influence of riverine inputs; marked seasonality between rainy and dry periods, driving fluctuations in nutrient input/primary productivity, sedimentation, salinity, and temperature.	Coral bleaching; local fishing; Industrial effluents; coastal and urban development; sewage discharge; tourism pressure.

Key values

Proportion of coral reef lost over the last 50 years (Criterion A)	Distribution (Criterion B)		Biotic Indicator Values (Criterion D)		
	EOO (km2)	AOO Cells	Indicator	Baseline	Current
69%	31762	38	Hard coral cover	31.55%	5.73%
			Algae-coral ratio	0.53	0.86
			Herbivore biomass	3.0	2.7
			Piscivore biomass	1.4	0.4

Criteria Assessment

Overall, the risk of collapse of the coral reefs in Costa dos Corais was assessed as Critically Endangered (CR). Summary of the assessment:

CRITERION			
A. Reduction in Geographic Distribution	A1	A2	A3
	Past 50 years	Future or any 50y period	Historical (1750)
	EN	NE	NE
B. Restricted Geo. Distribution	B1	B2	B3
	Extent of Occurrence	Area of Occupancy	# Threat-defined Locations < 5?
	VU	VU	NE

CRITERION			
A. Reduction in Geographic Distribution	A1	A2	A3
	Past 50 years	Future or any 50y period	Historical (1750)
	EN	NE	NE
C. Environmental Degradation	C1	C2	C3
	Past 50 years (1970)	Future or any 50y period	Historical (1750)
	EN	CR	NE
D. Disruption of biotic processes	D1	D2	D3
	Past 50 years (1970)	Future or Any 50y period	Historical (1750)
	CR	NE	NE
E. Quantitative Risk analysis	NE		
OVERALL RISK CATEGORY	CR (observed change) / CR (overall risk)		

DD = Data Deficient; LC = Least Concern; NT = Near Threatened; VU = Vulnerable; EN = Endangered; CR = Critically Endangered; CO = Collapsed; NE = Not Evaluated

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Ecoregion 6 - BTS and Baixo Sul (Critically Endangered)

Spatial distribution (boundaries, area of coral reef)

Ecoregion 6, which includes Todos os Santos Bay (BTS) and Camamu Bay, is a vital biodiversity hotspot. BTS is the third largest bay in Brazil, covering approximately 1,200 km² (Leão et al., 2019; Lessa et al., 2018). Coral reefs in this ecoregion hold immense ecological and socioeconomic importance, providing essential services such as shoreline protection, nutrient cycling, and recreation opportunities. Furthermore, the reefs support the livelihoods of numerous traditional communities through artisanal fishing and emerging marine tourism.

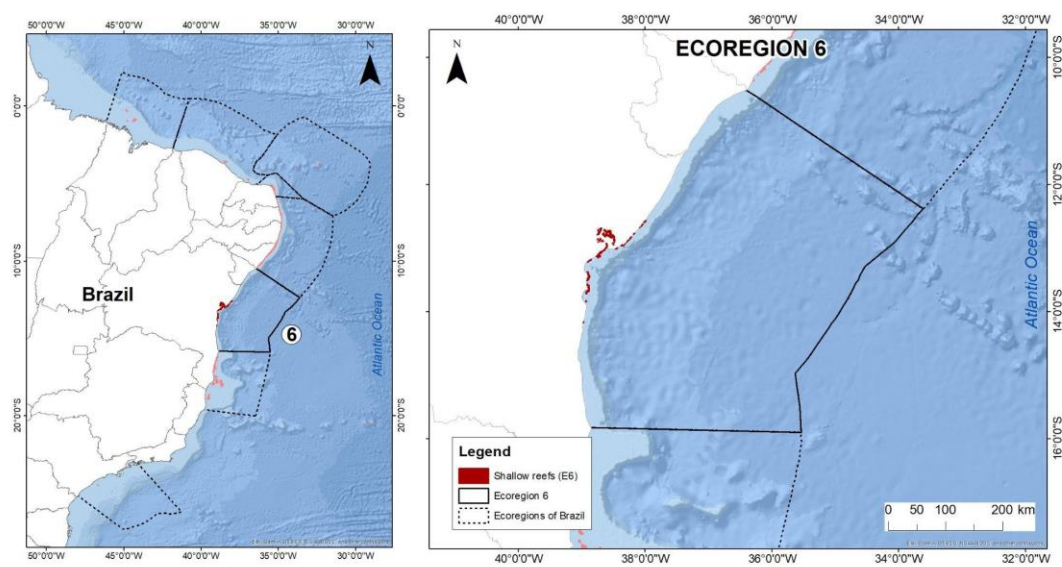


Figure 1. Map of the Brazil region highlighting Ecoregion 6 (BTS and Baixo Sul).



Figure 2. Representative underwater photographs of coral reefs from Ecoregion 6. a) and b) Coral reefs in the Todos os Santos Bay; and c) *Mussismilia braziliensis*, in Baixo Sul region.

Ecosystem description

The benthic communities in this ecoregion are frequently dominated by algae, including filamentous turf and macroalgae, which can cover up to 80% of shallow reef surfaces (Dutra et al., 2006; Cruz et al., 2009; Kikuchi et al., 2010). A significant ecological concern is the recorded phase shift to the zoantharian *Palythoa cf. variabilis*, which has displaced native corals in several areas (Cruz et al., 2016; Campos et al., 2020). The primary reef-building species include *Montastraea cavernosa*, the *Siderastrea stellata* complex, and the endemic species of the *Mussismilia* complex, particularly *M. hispida*, *M. harttii*, and *M. braziliensis* (Laborel, 1970; Dutra et al., 2006; Leão et al., 2010).

These reefs suffer from chronic impacts, primarily high levels of turbidity and sedimentation driven by unplanned urban growth, port dredging, and industrial effluents from local refineries and chemical plants (Dutra & Haworth, 2009). Historical degradation was also caused by lime mining, while modern threats include overfishing and illegal blast fishing with explosives (Melo-Souza et al., 2024). To mitigate these pressures, the region is protected by Marine Protected Areas, such as the Todos os Santos Bay and Tinharé-Boipeba Environmental Protection Areas (APAs).

Ecological health is closely tied to the ichthyofauna, which serves as a critical indicator of reef integrity. The dominance of zoanthids during phase shifts has been shown to reduce fish species richness by 25% and alter trophic structures (Cruz et al., 2015).

Furthermore, reef resilience depends on habitat connectivity with adjacent mangroves and seagrasses, though native biodiversity is currently challenged by the invasion of the alien cup-corals *Tubastraea* spp. (Miranda et al., 2016; Franklin et al., 2026).

Eco-region	Key Biotic	Key Abiotic	Key Threats
BTS and Baixo Sul (E6)	Shallow bank reefs and fringing reefs; dominated by corals such as <i>Montastraea cavernosa</i> , <i>Siderastrea</i> spp, and the endemic <i>Mussismilia</i> complex (<i>M. hispida</i> , <i>M. harttii</i> , <i>M. braziliensis</i>); high abundance of macroalgae and turf algae; registered phase shifts to the zoantharia <i>Palythoa</i> ; presence of invasive cup corals (<i>Tubastraea</i> spp.). Diverse ichthyofauna (notably Carangidae, Sciaenidae and Lutjanidae); extensive mangroves that cover emergent reef tops in some regions.	Third largest bay in Brazil; warm, shallow waters with tidal-dominated circulation; naturally high levels of turbidity and sedimentation; sediments primarily of siliciclastic and terrigenous origin; direct influence from major river systems (Paraguauçu, Subaé and Jaguaripe).	Coral bleaching; local fishing (including blast fishing); Industrial effluents; coastal and urban development; sewage discharge; tourism pressure; biological invasions (e.g. <i>Tubastraea</i> spp. and soft corals).

Key values

Proportion of coral reef lost over the last 50 years (Criterion A)	Distribution (Criterion B)		Biotic Indicator Values (Criterion D)		
	EOO (km2)	AOO Cells	Indicators	Baseline	Current
39%	7602	25	Hard coral cover	22.19%	6.83%
			Algae-coral ratio	0.70	0.67
			Herbivore biomass	DD	DD
			Piscivore biomass	DD	DD

Criteria Assessment

Overall, the risk of collapse of the coral reefs in BTS and Baixo Sul was assessed as Critically endangered. Summary of the assessment:

CRITERION			
A. Reduction in Geographic Distribution	A1	A2	A3
	Past 50 years	Future or any 50y period	Historical (1750)
	VU	NE	NE
	B1	B2	B3

CRITERION			
A. Reduction in Geographic Distribution	A1	A2	A3
	Past 50 years	Future or any 50y period	Historical (1750)
	VU	NE	NE
B. Restricted Geo. Distribution	Extent of Occurrence	Area of Occupancy	# Threat-defined Locations < 5?
	EN	VU	NE
C. Environmental Degradation	C1	C2	C3
	Past 50 years (1975)	Future or any 50y period	Historical (1750)
	EN	CR	NE
D. Disruption of biotic processes	D1	D2	D3
	Past 50 years (1975)	Future or Any 50y period	Historical (1750)
	EN	NE	NE
E. Quantitative Risk analysis	NE		
OVERALL RISK CATEGORY	EN (observed change) / CR (overall risk)		

DD = Data Deficient; LC = Least Concern; NT = Near Threatened; VU = Vulnerable; EN = Endangered; CR = Critically Endangered; CO = Collapsed; NE = Not Evaluated

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Ecoregion 7 - Abrolhos (Critically Endangered)

Spatial distribution (boundaries, area of coral reef)

Ecoregion 7 encompasses the Abrolhos Bank, a ~46,000 km² widening of the Eastern Brazilian shelf that hosts the largest and richest Southwestern Atlantic reefs (Laborel, 1970; Leão et al., 2003, Moura et al., 2013). Reefs occupy ~8,800 km² and were first described by Darwin (1842) and Hartt (1870), who remarked on their unusual mushroom-shaped pinnacles (*“chapeirões”*) and relatively low species richness. The best studied reefs comprise emerging and near-emerging structures distributed in two arcs, one located 5–25 km offshore and another 70 km offshore (Bastos et al., 2018). Non-emerging and shelf edge reefs, as well as sinkholes and incised valleys, are still poorly mapped and occur across the region (Bastos et al., 2016; Castro et al., 2023; Moura et al., 2013, 2026). The mid- and outer-shelf are dominated by the world's largest rhodolith bed, with ~21,000 km² (Amado-Filho et al., 2012).

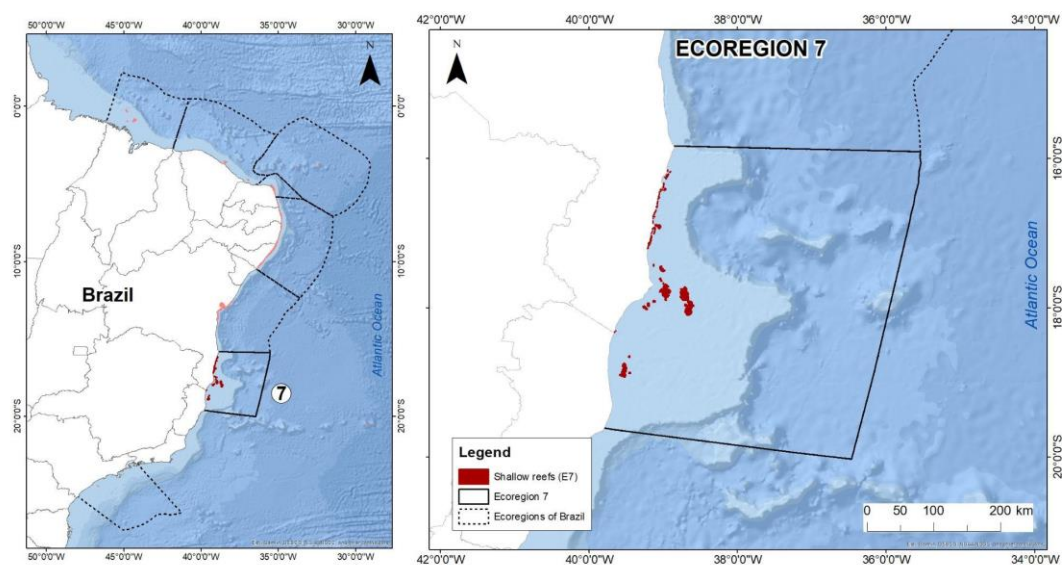


Figure 1. Map of the Brazil region highlighting Ecoregion 7 (Abrolhos).

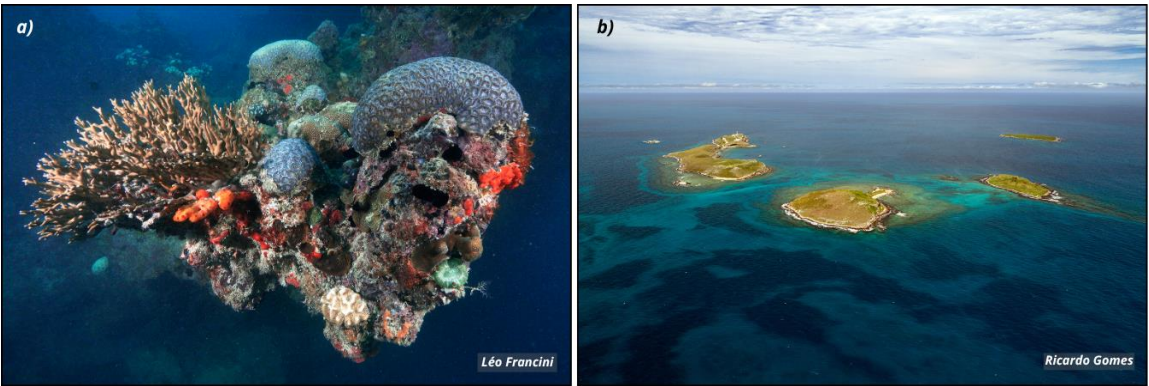


Figure 2. Representative underwater photos of coral reefs from Ecoregion 7, in the coral reefs in the Abrolhos Banks, Bahia.

Ecosystem description

Coral assemblages on pinnacle tops comprise ~20 species and are dominated by Brazilian-endemics such as *Mussismilia braziliensis* and *M. harttii*, whereas walls and non-emerging structures are dominated by *Montastraea cavernosa* and *Siderastrea* spp. (Laborel, 1970; Francini-Filho et al., 2013; Bastos et al., 2018; Moura et al., 2013, 2026). Reef framework was largely built by bryozoans and crustose coralline algae, with corals playing a secondary role (Bastos et al., 2018; Dechnik et al., 2021).

Reef fish assemblages comprise ~270 species and include ~80% of all Southwestern Atlantic endemic reef fishes (Moura and Francini-Filho, 2006). A single Brazilian-endemic categorized as Endangered, *Scarus trispinosus*, may account for ~30% of total fish biomass on shallow reefs (Francini-Filho and Moura, 2008a, b; Freitas et al., 2019). Functional redundancy is relatively low when compared with species-rich regions, leading to higher vulnerability (Francini-Filho and Moura, 2008b). Habitat structure and management regimes are the best predictors of fish community structure (Rolim et al., 2022; Hernández-Andreu et al., 2025).

Anthropogenic stressors such as coastal deforestation, dredging and the 2015 Fundão dam disaster, together with recurrent heatwaves, have driven mass bleaching and unprecedented coral mortality, with insidious functional shifts escalating since 2019 (Cardoso et al., 2025; Carlos-Júnior et al., 2026).

Eco-region	Key Biotic	Key Abiotic	Key Threats
Abrolhos (E7)	Elongated pinnacles with flattened tops (“chapeirões”) that typically coalesce in reefs closer to the shore and remain isolated offshore; reefs surrounding oceanic islands; high coral biodiversity for Brazilian reefs; presence of the regional endemic coral species <i>Mussismilia braziliensis</i> ; and	Gradient of fluvial influence, coastal arc environments (~10 km from shore) are subjected to higher loads of suspended particulate matter and nutrient concentrations, particularly during the rainy season, whereas	Coral bleaching; local fishing; coastal development; tourism pressure; mining waste spill .

Eco-region	Key Biotic	Key Abiotic	Key Threats
	diverse reef fish assemblages, including herbivores and top predators such as groupers and sharks.	reefs located on the outer arc (~50 km offshore) experience more stable environmental conditions throughout the year.	

Key values

Proportion of coral reef lost over the last 50 years (Criterion A)	Distribution (Criterion B)		Biotic Indicator Values (Criterion D)		
	EOO (km2)	AOO Cells	Indicators	Baseline	Current
7%	18014	40	Hard coral cover	40%	15.80%
			Algae-coral ratio	0.22	0.44
			Herbivore biomass	3.0	6.0
			Piscivore biomass	1.4	1.7

Criteria Assessment

Overall, the risk of collapse of the coral reefs in Abrolhos was assessed as Critically Endangered (CR). Summary of the assessment:

CRITERION			
A. Reduction in Geographic Distribution	A1	A2	A3
	Past 50 years	Future or any 50y period	Historical (1750)
	LC	NE	NE
B. Restricted Geo. Distribution	B1	B2	B3
	Extent of Occurrence	Area of Occupancy	# Threat-defined Locations < 5?
	EN	VU	NE
C. Environmental Degradation	C1	C2	C3
	Past 50 years (1970)	Future or any 50y period	Historical (1750)
	VU	CR	NE
D. Disruption of biotic processes	D1	D2	D3
	Past 50 years (1970)	Future or Any 50y period	Historical (1750)
	VU	NE	NE
E. Quantitative Risk analysis	NE		
OVERALL RISK CATEGORY	EN (observed change) / CR (overall risk)		

DD = Data Deficient; LC = Least Concern; NT = Near Threatened; VU = Vulnerable; EN = Endangered; CR = Critically Endangered; CO = Collapsed; NE = Not Evaluated

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Ecoregion 8 - Queimada Grande (Data Deficient)

Spatial distribution (boundaries, area of coral reef)

This ecoregion comprises a coral reef system of exceptional ecological significance within the Southwestern Atlantic Province. Located ~35 km offshore from São Paulo state, southern Brazil, Queimada Grande Island represents a subtropical reef complex situated within a tropical–subtropical transition zone influenced by the warm Brazil Current, cooler South Atlantic Central Water intrusions, and marked seasonal oceanographic variability, resulting in a highly heterogeneous environmental setting (Pereira-Filho et al., 2019).

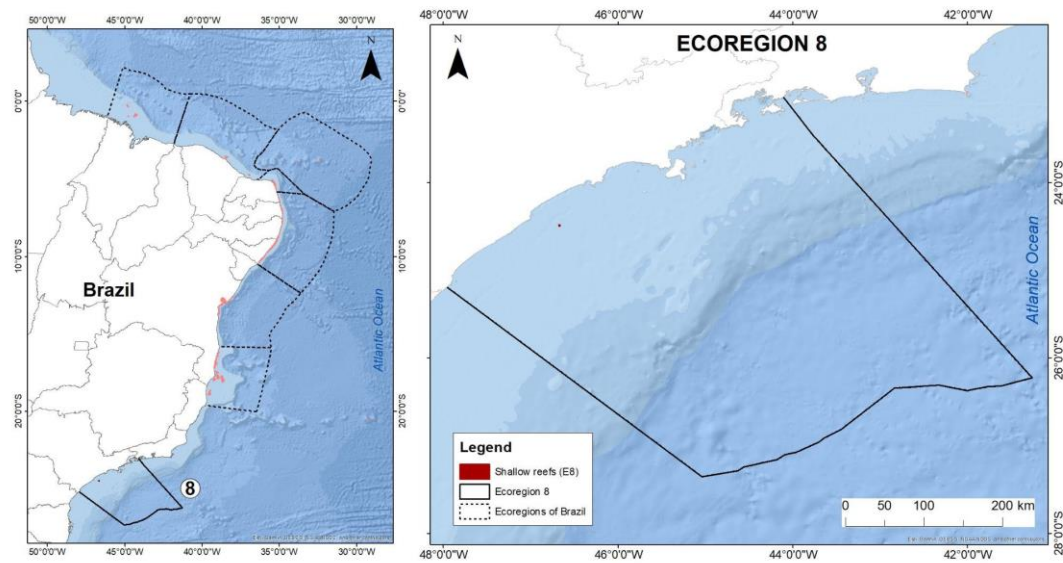


Figure 1. Map of the Brazil region highlighting Ecoregion 8 (Queimada Grande).

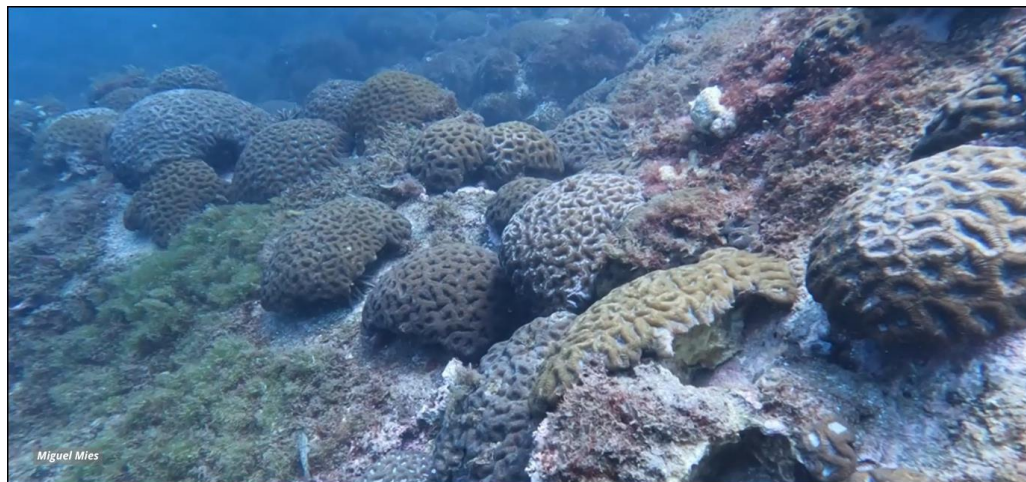


Figure 2. Representative underwater photos of coral reefs from Ecoregion 8, Queimada Grande, São Paulo.

Ecosystem description

The reef complex comprises two distinct coral-associated environments: (i) rocky reefs dominated by exceptionally high live cover of the endemic coral *Mussismilia hispida*, with some areas reaching ~90% coral dominance (Grillo et al., 2021; Mies,

unpublished data). Although these assemblages are likely to contribute to local carbonate accretion, this process remains unquantified; (ii) a biogenic carbonate reef primarily built by *Madracis decactis*, representing the southernmost known coral-built reef in the Atlantic Ocean (Pereira-Filho et al., 2019; Grillo et al., 2021). This reef extends over approximately 75,000 m² at depths of 7-12 m along the leeward side of the island and is associated with adjacent rhodolith beds, increasing habitat complexity and ecological relevance. Additional *Ma. decactis* coral banks with live coral cover ranging from 40-60% have also been reported on the windward side (Grillo et al., 2021).

These two reef environments exhibit distinct ecological dynamics. While *Mu. hispida* dominated rocky reefs sustain exceptionally high live coral cover, the *Ma. decactis* reef framework was already largely senescent when first described, with limited living coral cover and no clear understanding of the causes of historical mortality (Pereira-Filho et al., 2019). Despite its ecological significance, this system faces chronic anthropogenic and climate-related pressures, including marine heat anomalies linked to bleaching, recreational fishing, spearfishing, diving tourism, and biological invasions by *Tubastraea* spp. (Pereira-Filho et al., 2019; Grillo et al., 2021). Given its oceanographic singularity, unusual coral dominance at subtropical latitudes, and biogeographic importance, Queimada Grande constitutes a high-priority coral ecosystem for conservation and long-term monitoring.

Eco-region	Key Biotic	Key Abiotic	Key Threats
Queimada Grande (E8)	Reef primarily built by <i>Madracis decactis</i> and <i>Mussismilia hispida</i> , representing the southernmost known coral-built reef in the Atlantic Ocean.	Marked seasonality in the region is driven by the presence of seasonal thermoclines, which promote fluctuations in nutrient availability, primary productivity, and seawater temperature.	Coral bleaching; recreational fishing, spearfishing, diving tourism, and biological invasions by <i>Tubastraea</i> spp.

Key values

Proportion of coral reef lost over the last 50 years (Criterion A)	Distribution (Criterion B)		Biotic Indicator Values (Criterion D)		
	EOO (km ²)	AOO Cells	Indicators	Baseline	Current
DD	DD	DD	Hard coral cover	DD	DD
			Algae-coral ratio	DD	DD
			Herbivore biomass	DD	DD
			Piscivore biomass	DD	DD

Criteria Assessment

Overall, the risk of collapse of the coral reefs in **Queimada Grande** was assessed as **Data Deficient (DD)**. Summary of the assessment:

CRITERION			
A. Reduction in Geographic Distribution	A1	A2	A3
	Past 50 years	Future or any 50y period	Historical (1750)
	DD	NE	NE
B. Restricted Geo. Distribution	B1	B2	B3
	Extent of Occurrence	Area of Occupancy	# Threat-defined Locations < 5?
	DD	DD	NE
C. Environmental Degradation	C1	C2	C3
	Past 50 years (1975)	Future or any 50y period	Historical (1750)
	DD	NE	NE
D. Disruption of biotic processes	D1	D2	D3
	Past 50 years (1975)	Future or Any 50y period	Historical (1750)
	DD	NE	NE
E. Quantitative Risk analysis	NE		
OVERALL RISK CATEGORY	DD		

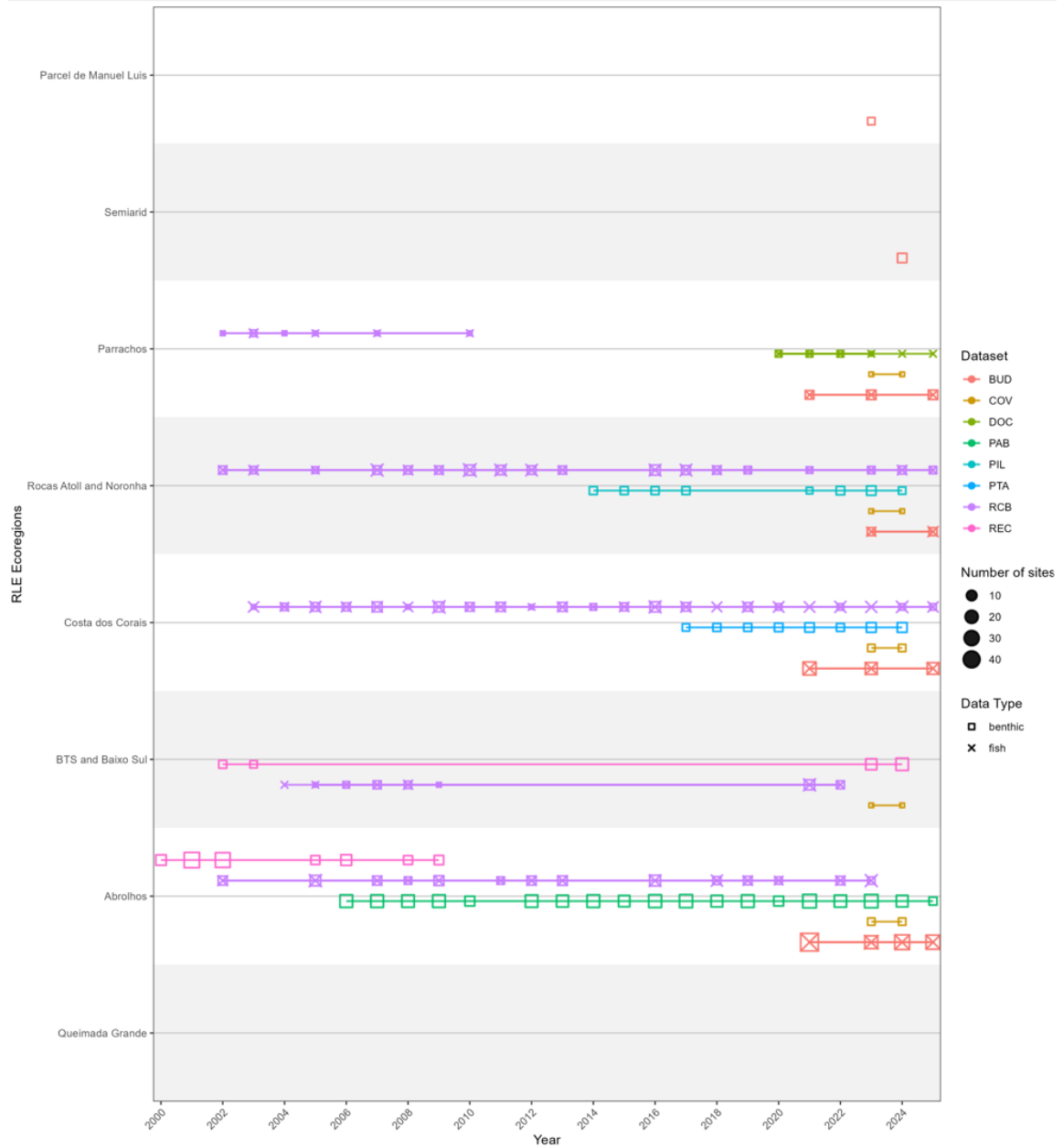
DD = Data Deficient; LC = Least Concern; NE = Not Evaluated

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Supplementary Material A

Figure 1. Time series of benthic and fish data available across ecoregions and datasets. BUD - Budiões Project. COV - Coral Vivo Project. DOC - De Olho Nos Corais Project. PAB - PELD Abrolhos. PIL - PELD ILOC. PTA - PELD TamS. RCB - Reef Check Brasil. REC - RECOR/ UFBA.



Supplementary Material B

Criteria-related data visualization resources

Criterion A

Sensitivity analysis

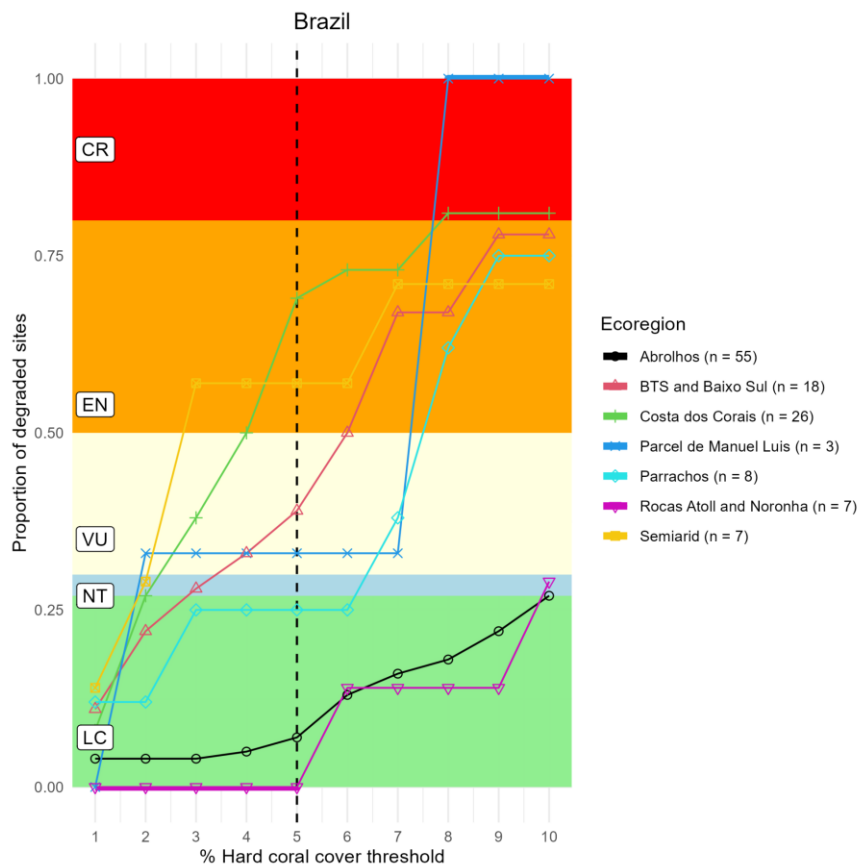
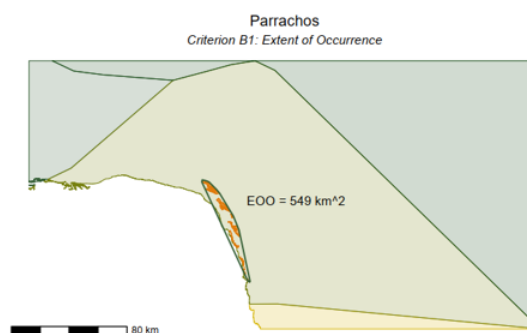
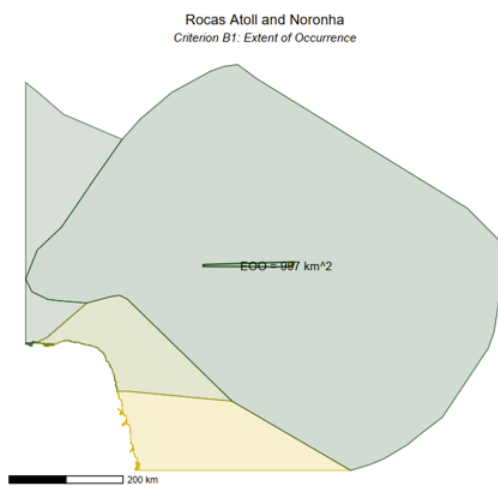
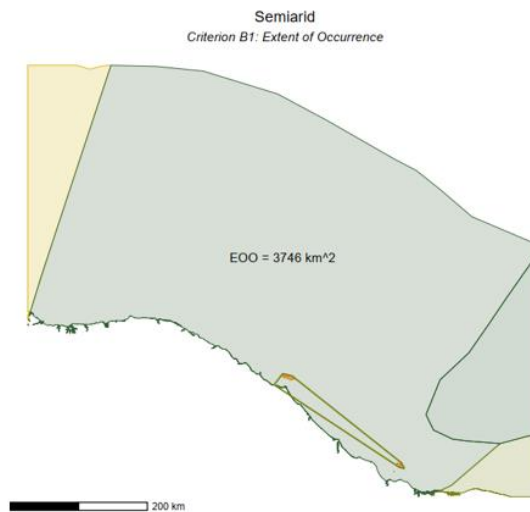
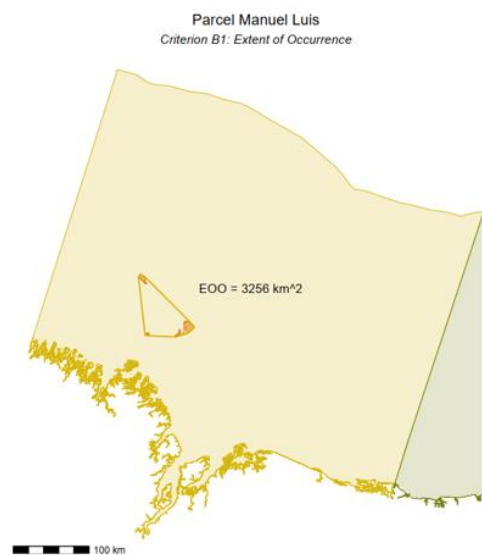
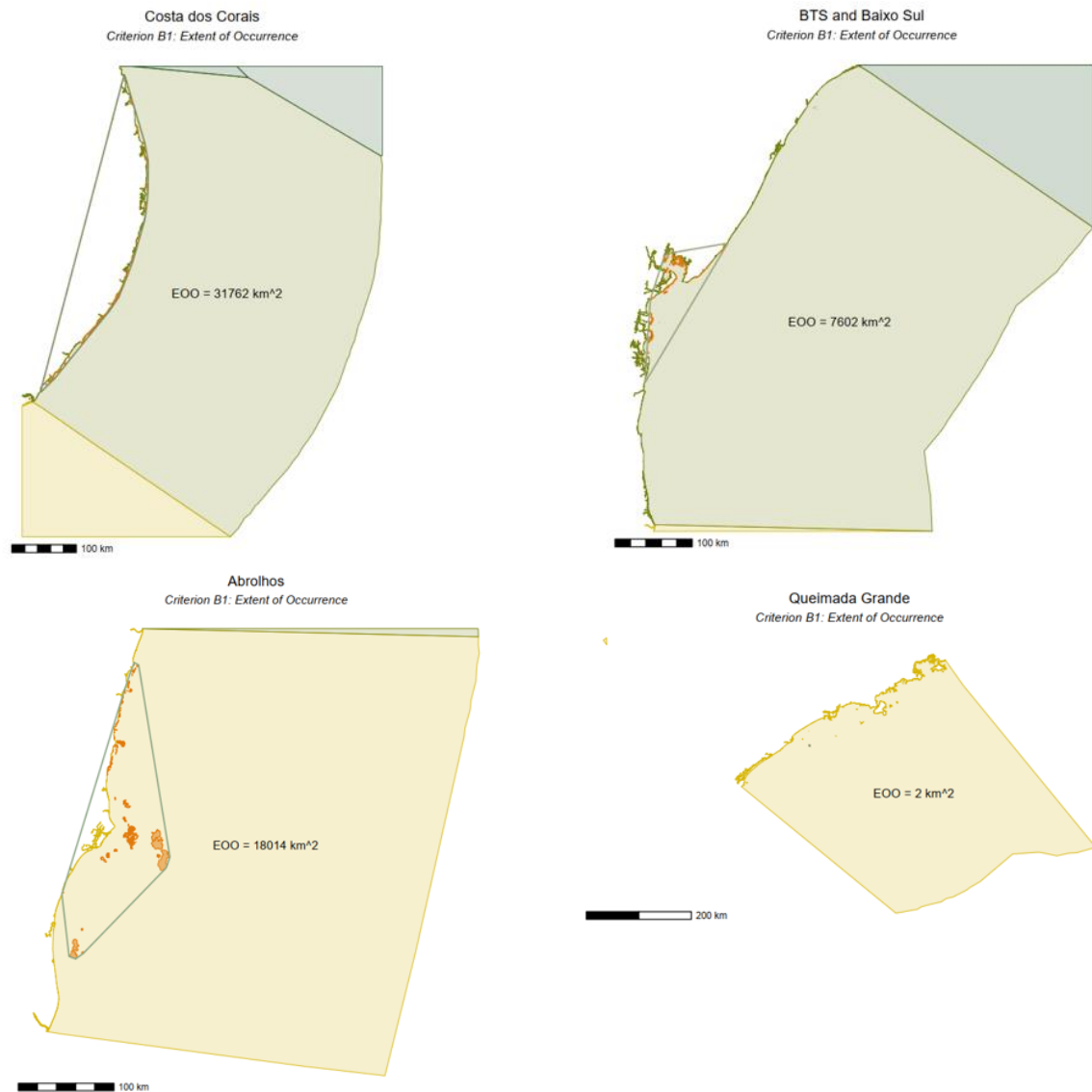
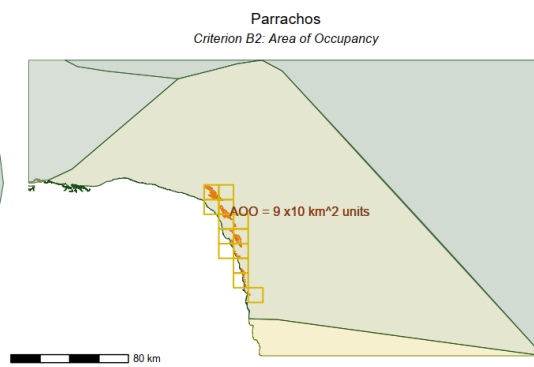
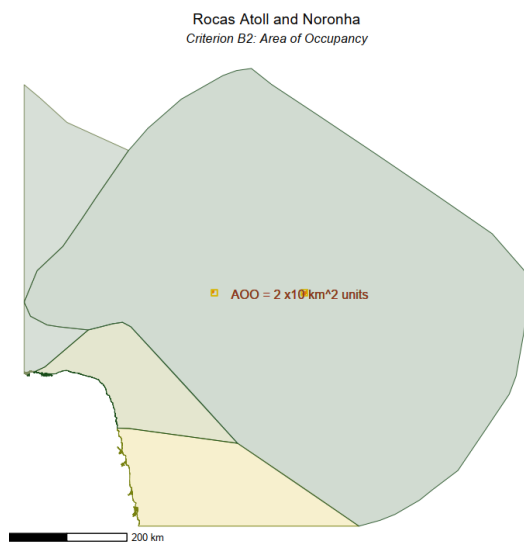
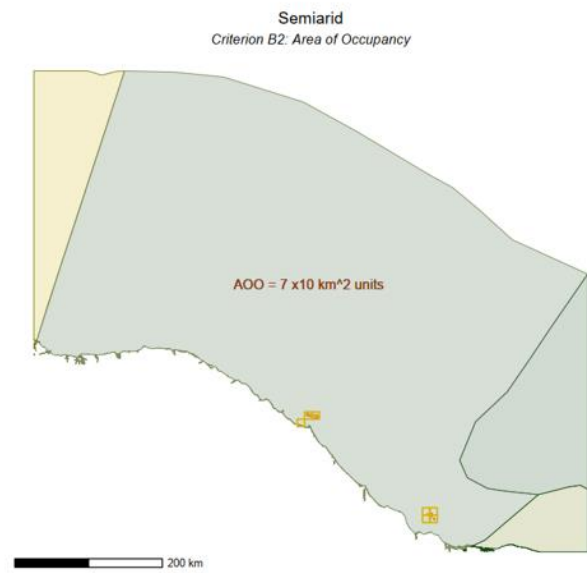
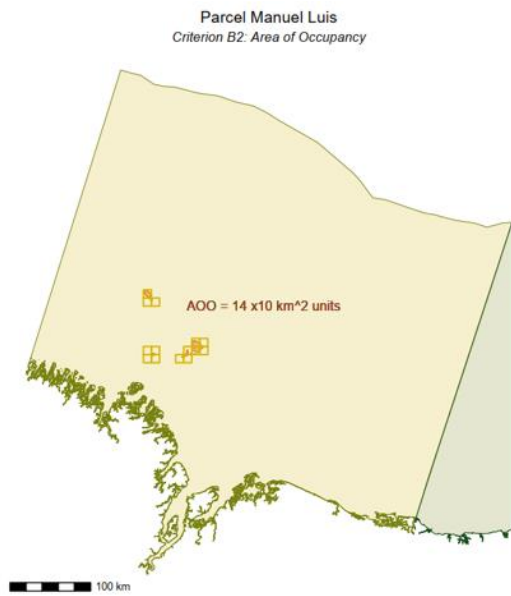


Figure 1. Proportion of degraded sites across Brazilian ecoregions at different collapse thresholds. The black dashed line represents the collapse threshold selected under this assessment (5% hard coral cover).

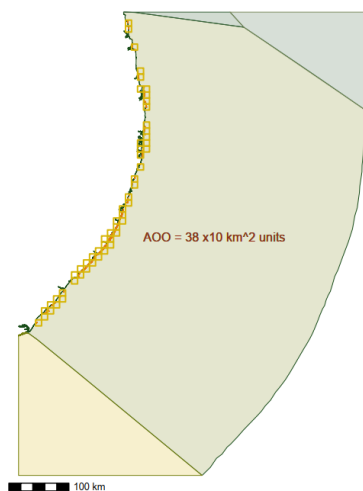
Criterion B***Extent of occurrence (EOO) of coral reefs across Brazilian ecoregions.***



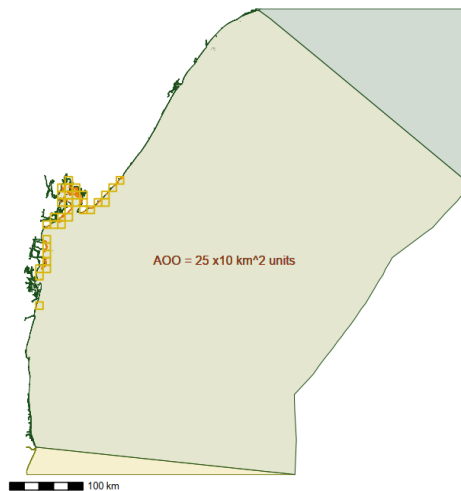
Area of occurrence (AOO) of coral reefs across Brazilian ecoregions.



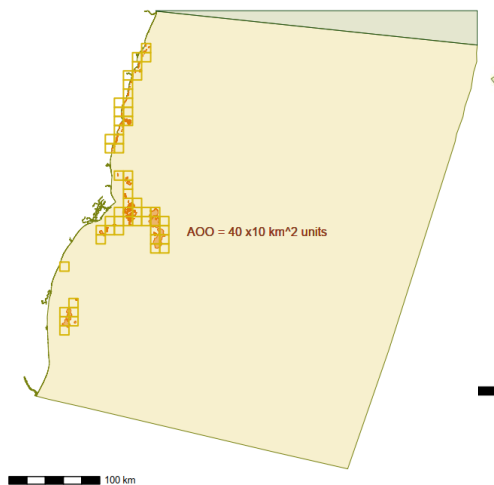
Costa dos Corais
Criterion B2: Area of Occupancy



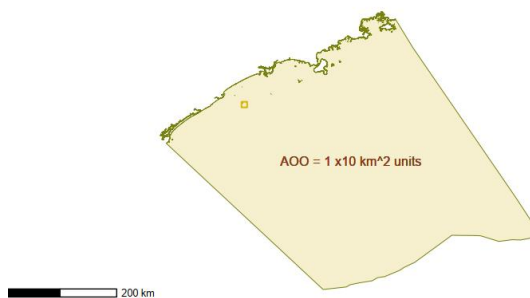
BTS and Baixo Sul
Criterion B2: Area of Occupancy



Abrolhos
Criterion B2: Area of Occupancy



Queimada Grande
Criterion B2: Area of Occupancy



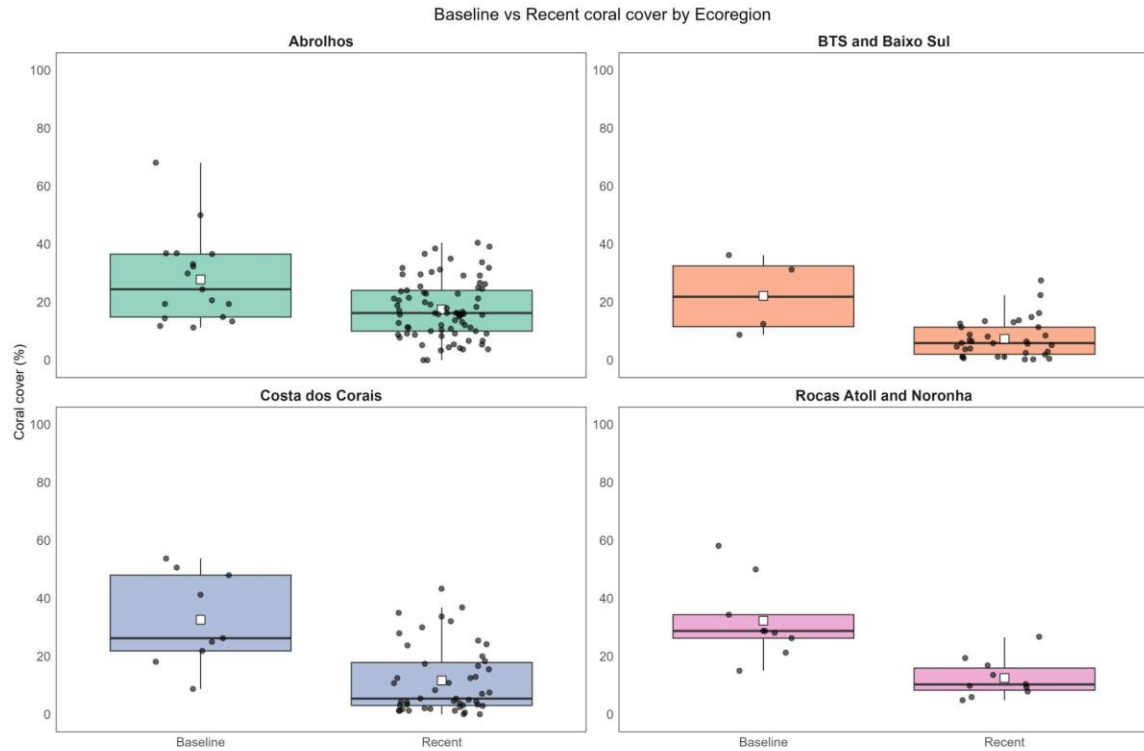
Criterion D***Initial vs. Recent values for each biotic indicator***

Figure 4. Baseline vs. current levels of hard coral cover across Brazilian ecoregions. Ecoregions not shown in this figure lacked sufficient data to estimate baselines.

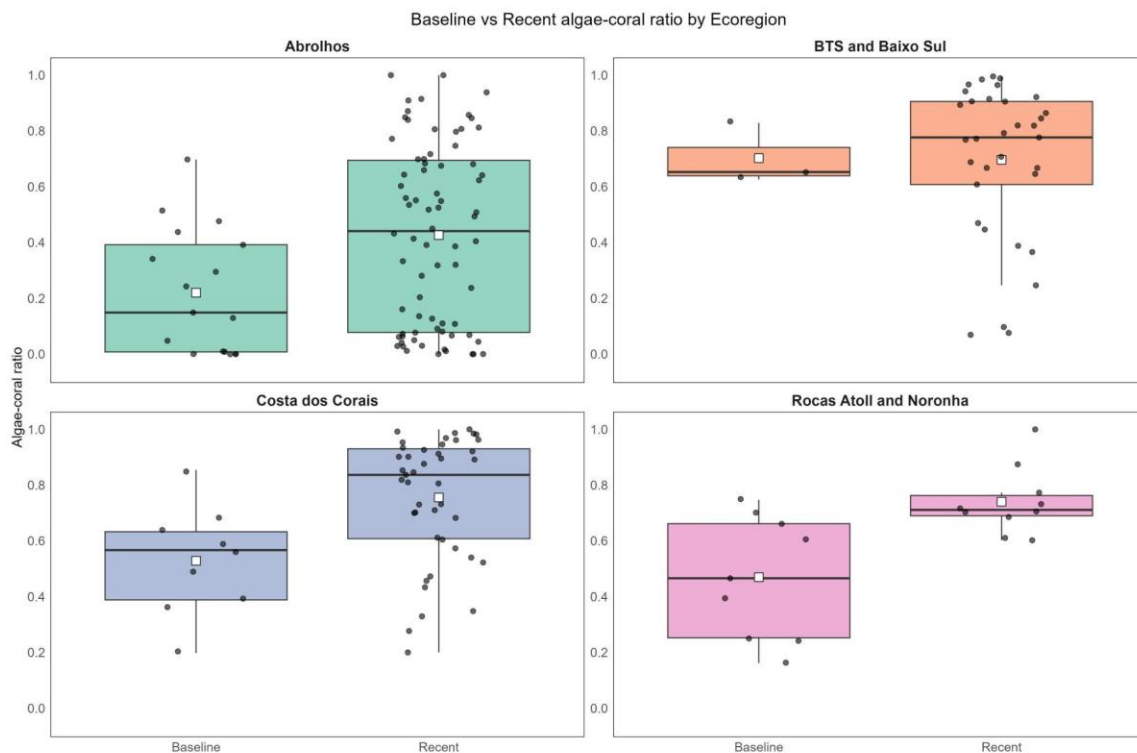


Figure 5. Baseline vs. current levels of algae:coral ratio across Brazilian ecoregions. Ecoregions not shown in this figure lacked sufficient data to estimate baselines.

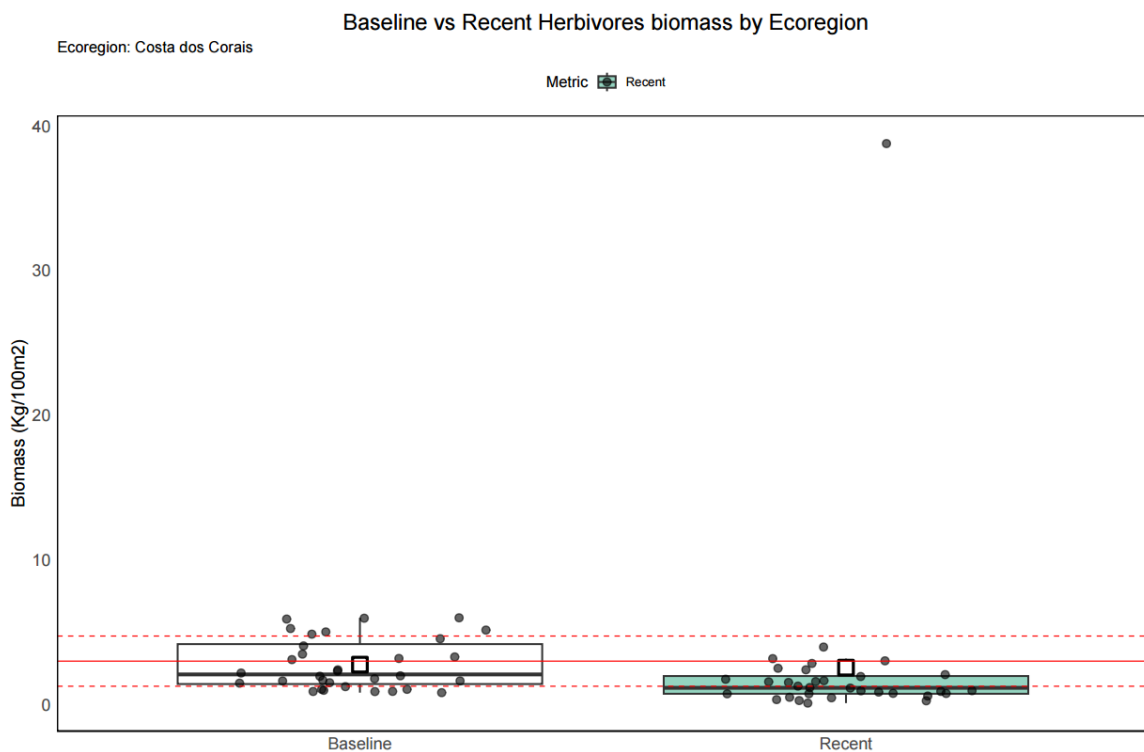


Figure 6. Boxplots of adapted Maximum Mean Yearly Values (aMMYV) and current herbivore fish biomass in the Costa dos Corais ecoregion. The solid red line represents the Reef Health Threshold (RHT) adopted as the historical baseline, and the dashed red lines represent the standard deviation calculated from the central 90% of aMMYV values.

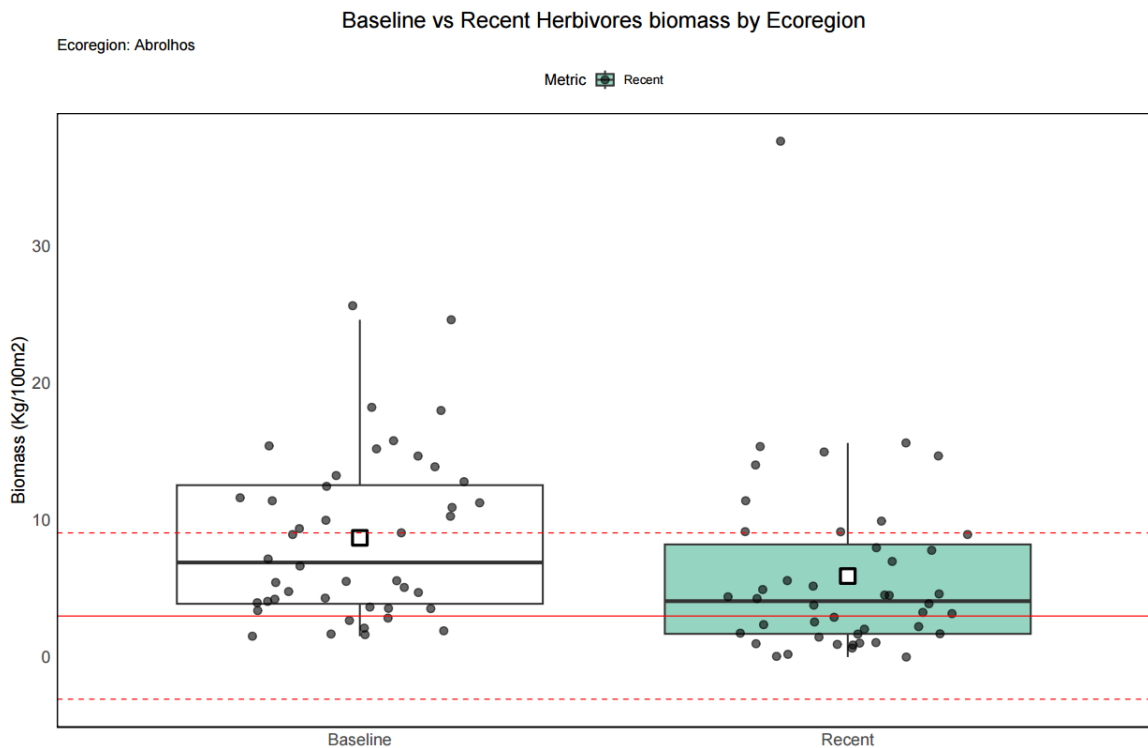


Figure 7. Boxplots of adapted Maximum Mean Yearly Values (aMMYV) and current herbivore fish biomass in the Abrolhos ecoregion. The solid red line represents the Reef Health Threshold (RHT) adopted as the historical baseline, and the dashed red lines represent the standard deviation calculated from the central 90% of aMMYV values.

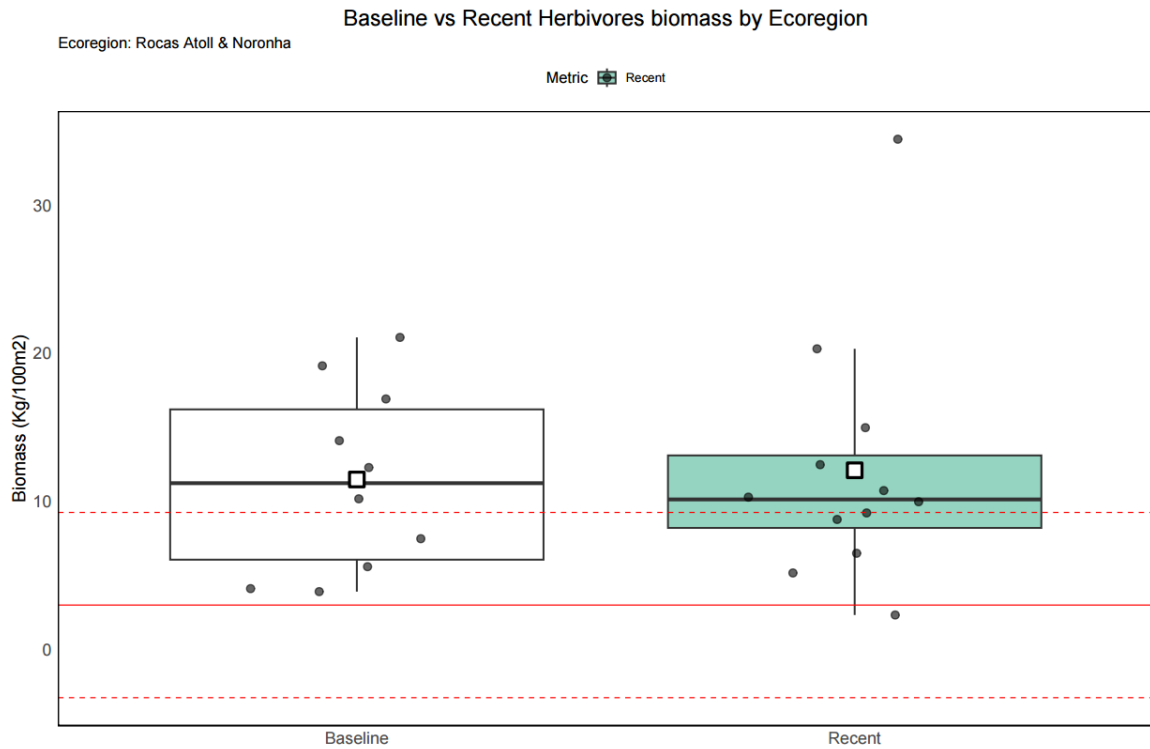


Figure 8. Boxplots of adapted Maximum Mean Yearly Values (aMMYV) and current herbivore fish biomass in the Rocas Atoll and Noronha ecoregion. The solid red line represents the Reef Health Threshold (RHT) adopted as the historical baseline, and the dashed red lines represent the standard deviation calculated from the central 90% of aMMYV values.

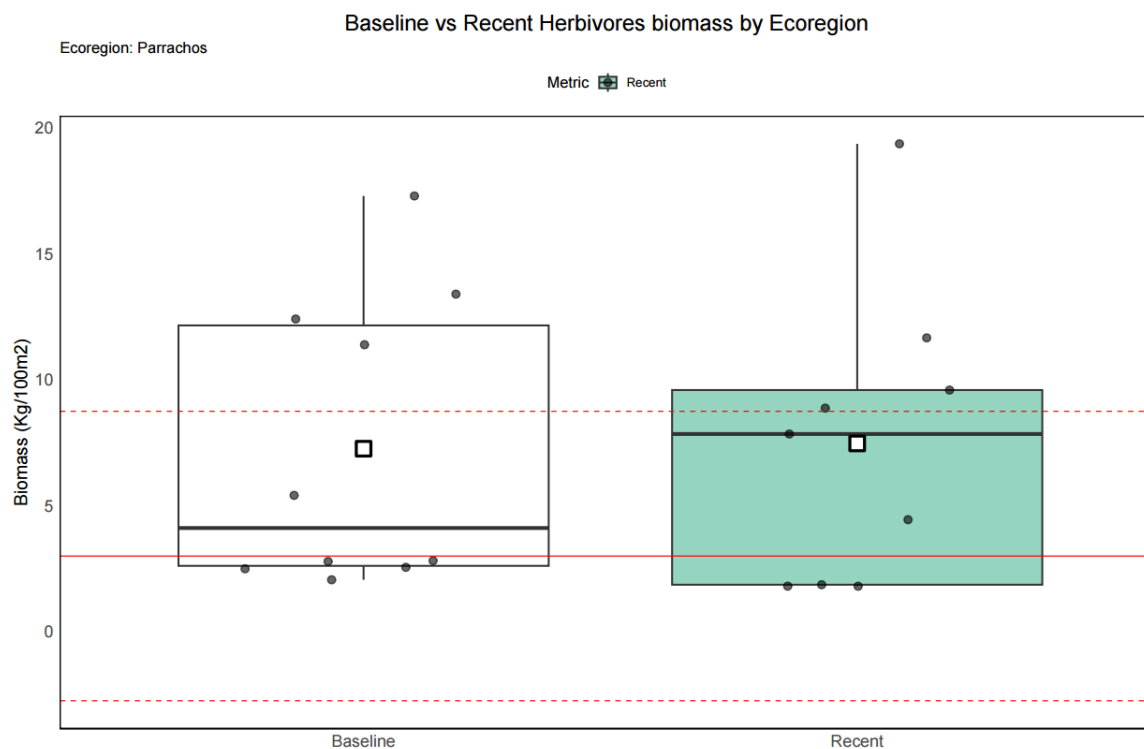


Figure 9. Boxplots of adapted Maximum Mean Yearly Values (aMMYV) and current herbivore fish biomass in the Parrachos ecoregion. The solid red line represents the Reef Health Threshold (RHT) adopted as the historical baseline, and the dashed red lines represent the standard deviation calculated from the central 90% of aMMYV values.

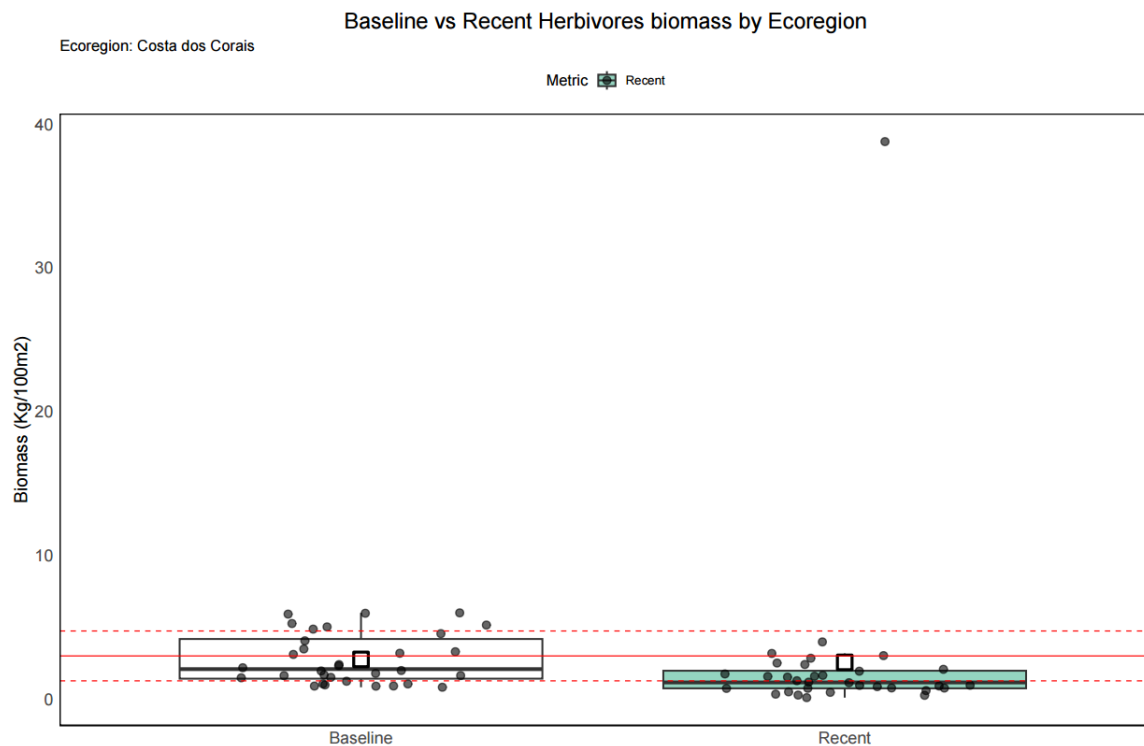


Figure 10. Boxplots of adapted Maximum Mean Yearly Values (aMMYV) and current piscivore fish biomass in the Costa dos Corais ecoregion. The solid red line represents the Reef Health Threshold (RHT) adopted as the historical baseline, and the dashed red lines represent the standard deviation calculated from the central 90% of aMMYV values.

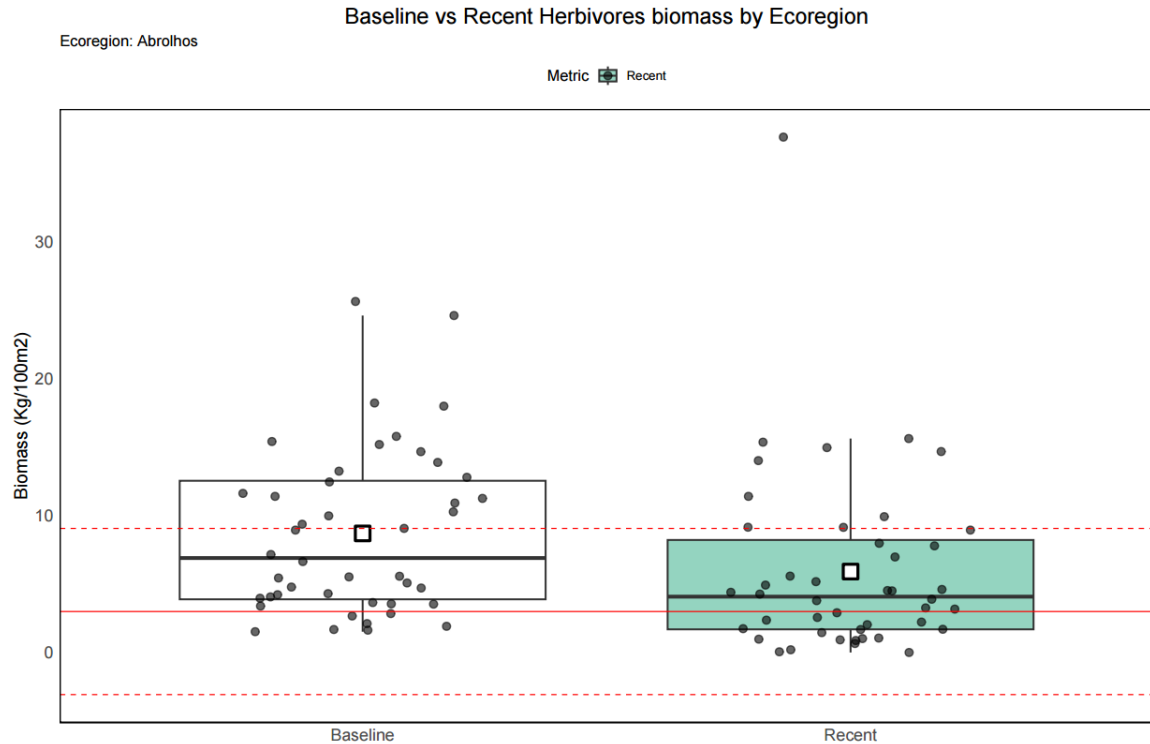


Figure 11. Boxplots of adapted Maximum Mean Yearly Values (aMMYV) and current piscivore fish biomass in the Abrolhos ecoregion. The solid red line represents the Reef Health Threshold (RHT) adopted as the historical baseline, and the dashed red lines represent the standard deviation calculated from the central 90% of aMMYV values.

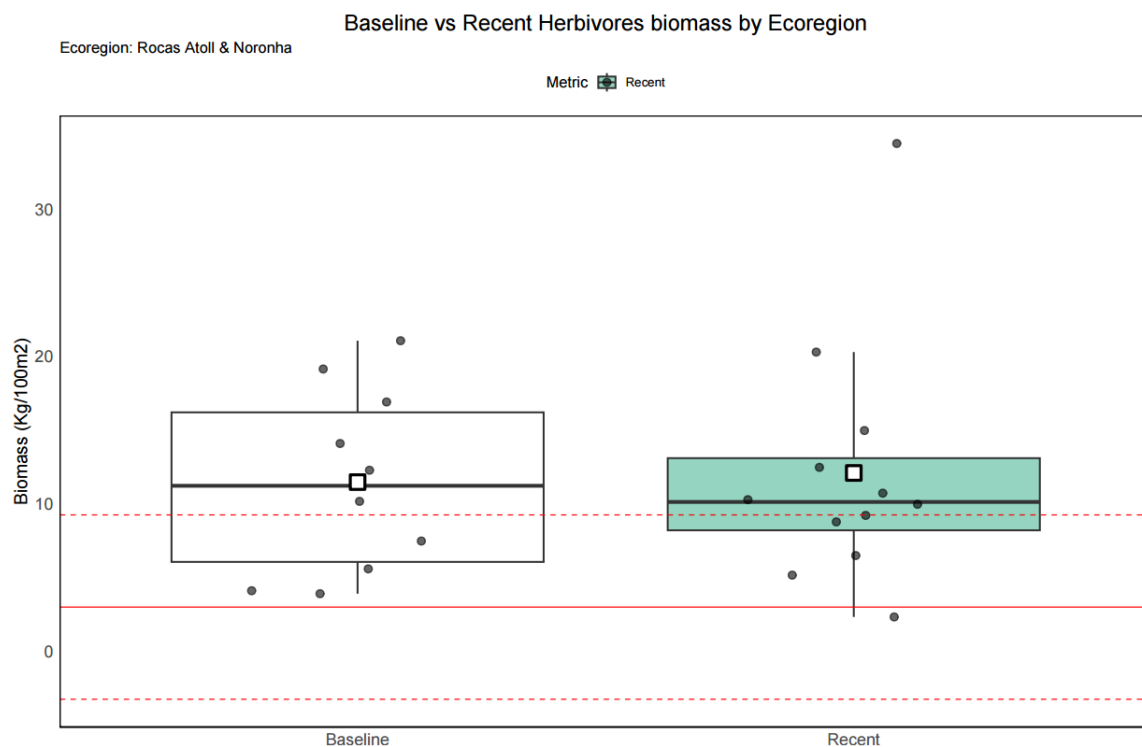


Figure 12. Boxplots of adapted Maximum Mean Yearly Values (aMMYV) and current piscivore fish biomass in the Rocas Atoll and Noronha ecoregion. The solid red line represents the Reef Health Threshold (RHT) adopted as the historical baseline, and the dashed red lines represent the standard deviation calculated from the central 90% of aMMYV values.

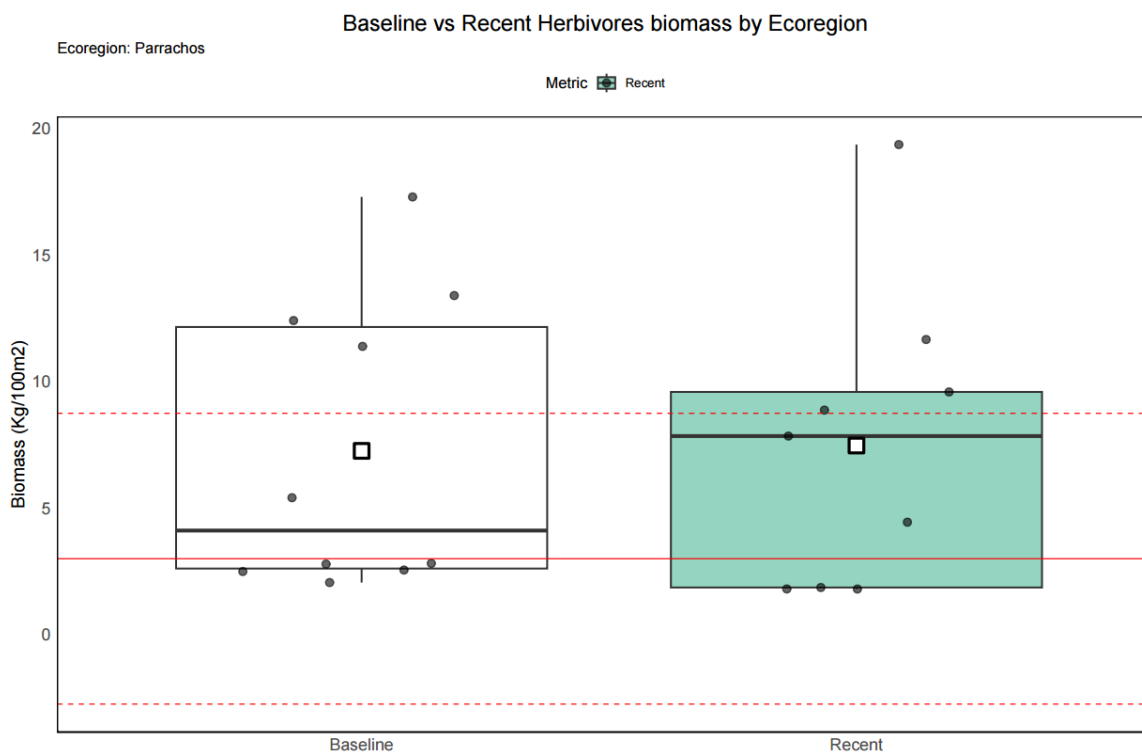


Figure 13. Boxplots of adapted Maximum Mean Yearly Values (aMMYV) and current piscivore fish biomass in the Parrachos ecoregion. The solid red line represents the Reef Health Threshold (RHT) adopted as the historical baseline, and the dashed red lines represent the standard deviation calculated from the central 90% of aMMYV values.

Risk classification across iterations and ecoregions for each biotic indicator

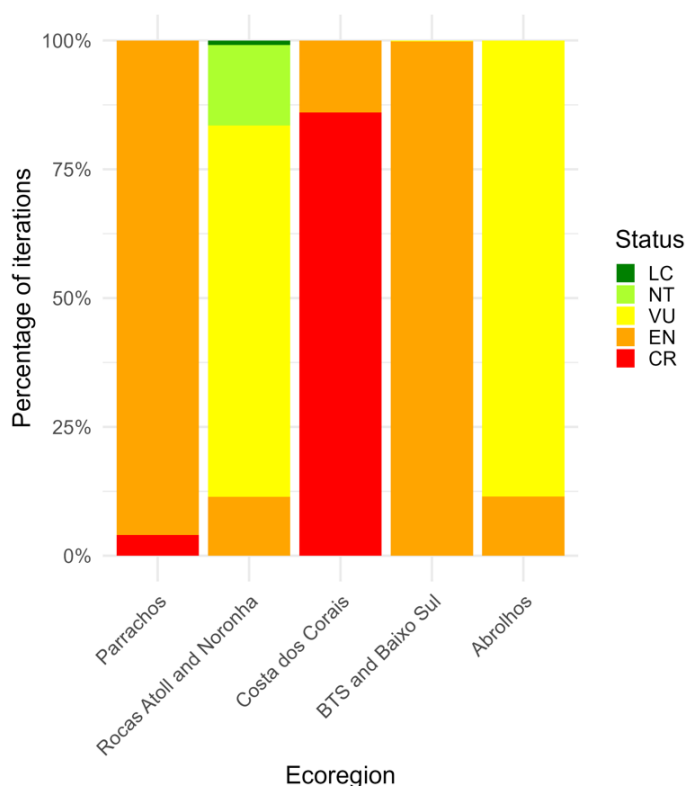


Figure 14. Percentage of iterations resulting in each collapse risk category based on hard coral cover.

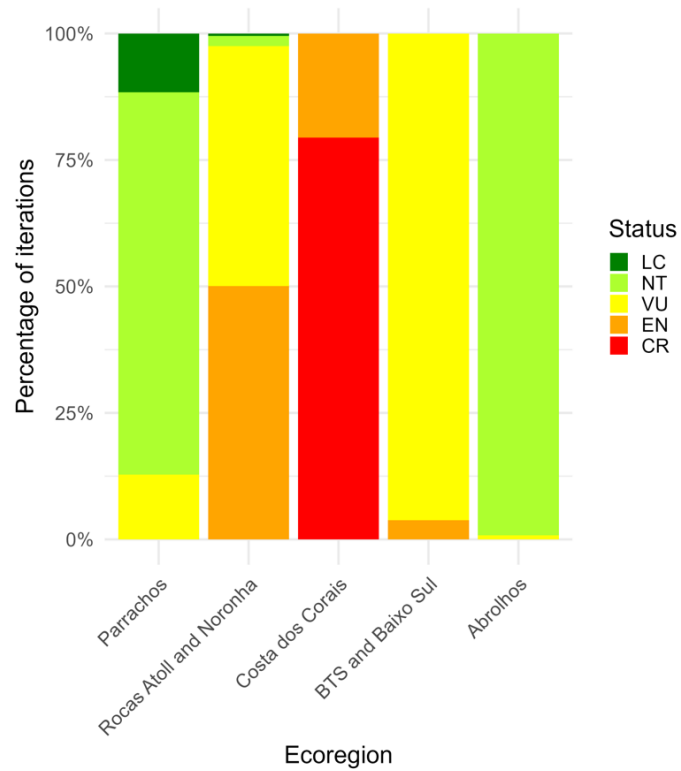


Figure 15. Percentage of iterations resulting in each collapse risk category based on algae:coral ratio.

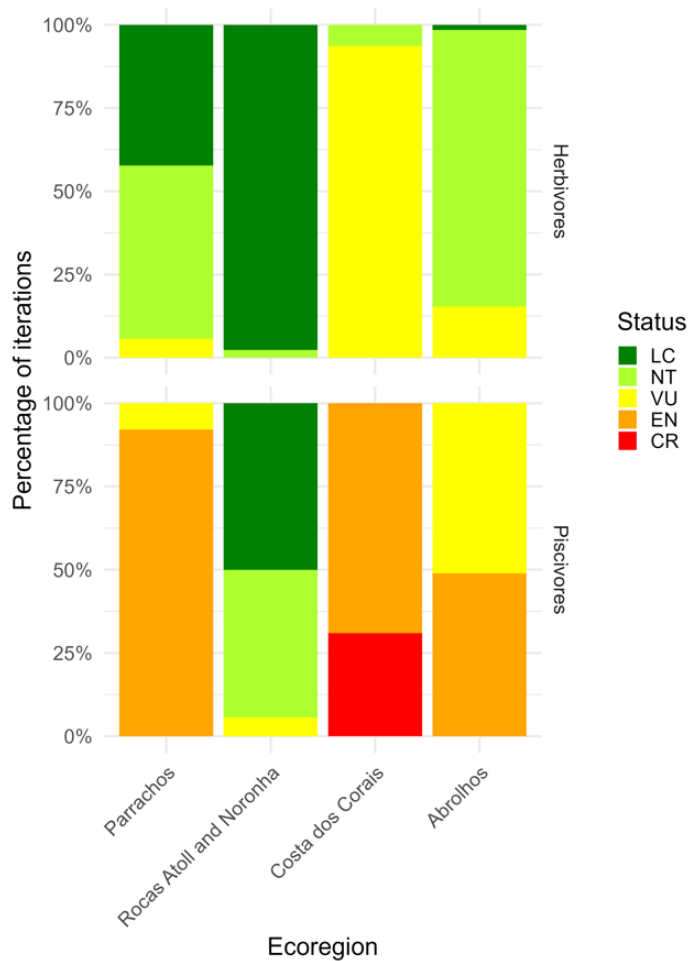


Figure 16. Percentage of iterations resulting in each collapse risk category based on fish indicators (top - herbivores; bottom - piscivores)

Supplementary Material B

Detailed risk classification across criteria and ecoregions

(1) Parcel de Manuel Luís	(5) Costa dos Corais	
(2) Semiarid	(6) BTS and Baixo Sul	
(3) Parrachos	(7) Abrolhos	
(4) Rocas Atoll and Noronha	(8) Queimada Grande	

