REGIONAL REPORT V.0

Red List of Ecosystems assessment of Western Indian Ocean coral reefs

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KEYWORDS

Red List of Ecosystems; coral reefs; ecosystem collapse; risk assessment; Western Indian Ocean

ABSTRACT

Western Indian Ocean (WIO) coral reefs extend across the East African coastline from Somalia to South Africa, and eastward to include the Îles Éparses and island states of Madagascar, the Comoros, Seychelles and Mauritius, and the French territories of Mayotte and Réunion. The total mapped area of photic coral reef ecosystems is approximately 8,000 km^2, representing approximately 4.3 % of the global ecosystem extent, and for this assessment they were grouped into 13 ecoregions representing distinct coral reef types across the WIO.

The region hosts 350-400 scleractinian coral species and approximately 2,400 reef fish species (~850 endemic to the Indian Ocean), the second most diverse region after the Coral Triangle. These ecosystems face increasing pressure from marine heatwaves causing mass bleaching, overfishing and destructive fishing, land-based pollution and sedimentation, and unsustainable coastal development and tourism practices.

This 2026 IUCN Red List of Ecosystems assessment found that coral reef ecosystems across all evaluated ecoregions of the Western Indian Ocean are at a very high risk of collapse. This is

principally due to the severity of climate change induced warming predicted to occur over the next 50 years. Heat stress already places all ecoregions at a high risk having experienced widespread impacts from bleaching in 1998, 2016 and 2024. These impacts, compounded by local stressors such as pollution and overfishing, have led to significant declines in the biotic community in nine ecoregions over the past 50 years. Ten ecoregions, making up 89.7 % of WIO coral reefs, are classified as Endangered or Critically Endangered based on observed declines.

The results highlight that countries must urgently act to increase holistic, inclusive and equitable approaches to prevent these precious ecosystems from collapsing. This involves immediate and drastic action on climate change alongside implementing solutions to tackle local threats which will not only offer the best chance for coral reefs to recover after climate-driven disturbances, but also provide wide-ranging ecological, environmental and societal benefits beyond coral reefs.

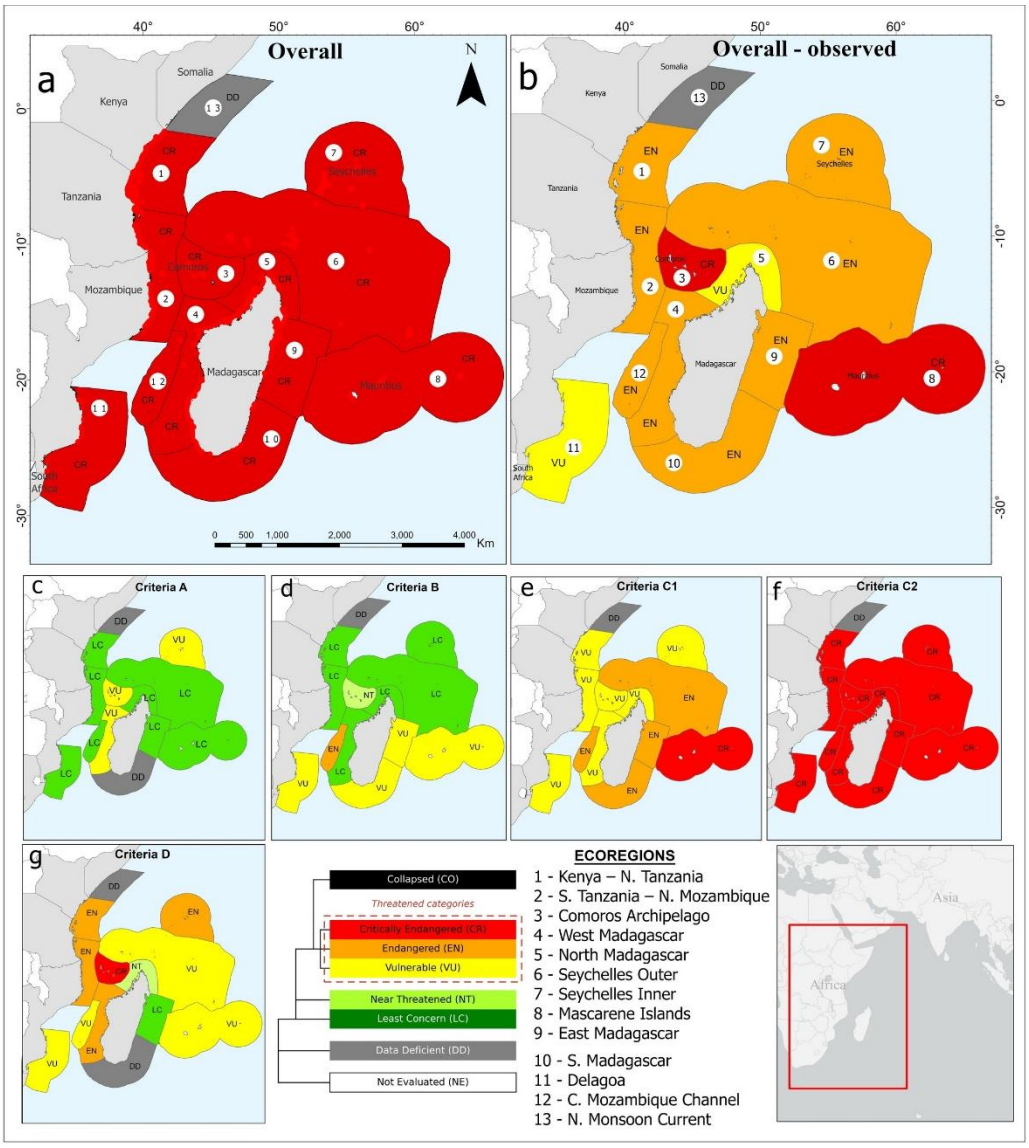


Figure 1. Distribution of the 13 coral reef ecoregions in the Western Indian Ocean. **Panel a**: Overall Red List of Ecosystems status. **Panel b**: Risk due to observed changes only (Criteria A, B, C1, D). **Panels c–g**: risk status under each criterion and sub-criterion; **c**, Criterion A (Reduction in geographic distribution); **d**, Criterion B (Restricted geographic distribution); **e**, sub-criterion C1 (Environmental degradation, observed change 1975–2025); **f**, sub-criterion C2 (Environmental degradation, projected change 2026–2075 under SSP2-4.5); **g**, Criterion D (Disruption of biotic processes or interactions).

1. Study Area

This Red List of Ecosystems (RLE) assessment evaluates the risk of collapse for coral reefs across the Western Indian Ocean (WIO) as of 2025. WIO coral reefs (IUCN Global Ecosystem Typology M1.3 - photic coral reefs) extend from southern Somalia, southwards along the East African coast to northern South Africa, and across the Southwest Indian Ocean islands of Îles

Éparses, Madagascar, the Comoros Archipelago, Seychelles, Mauritius, and Réunion. Overall, the region contains an estimated 8048.6 km² of coral reefs, representing 2.8% of the global coral reef extent.

Coral reefs of the WIO were grouped into 13 ecoregions drawing on the Marine Ecoregions of the World (MEOW) framework developed by (Spalding et al., 2007) (Figure 2). Boundaries were refined using coral reef-specific regional and global classifications proposed by Obura et al. (Obura, 2012; 2021) and (Veron et al., 2015), respectively. This assessment differs from the previous regional coral reef RLE (Obura et al., 2021) principally through the inclusion of the Northern Monsoon Current Coast (Somalia) and Central Mozambique Channel ecoregions. The 13 coral reef ecoregions capture ecological variation in coral reef biodiversity, biogeographic distinctiveness, abiotic conditions, and exposure to threats, and are equivalent to level 4 of the IUCN Global Ecosystem Typology (regional sub-groups) (Keith et al., 2022). Coral reefs in each ecoregion were independently assessed using the IUCN Red List of Ecosystems criteria (details on data collection/ monitoring in annex 1).

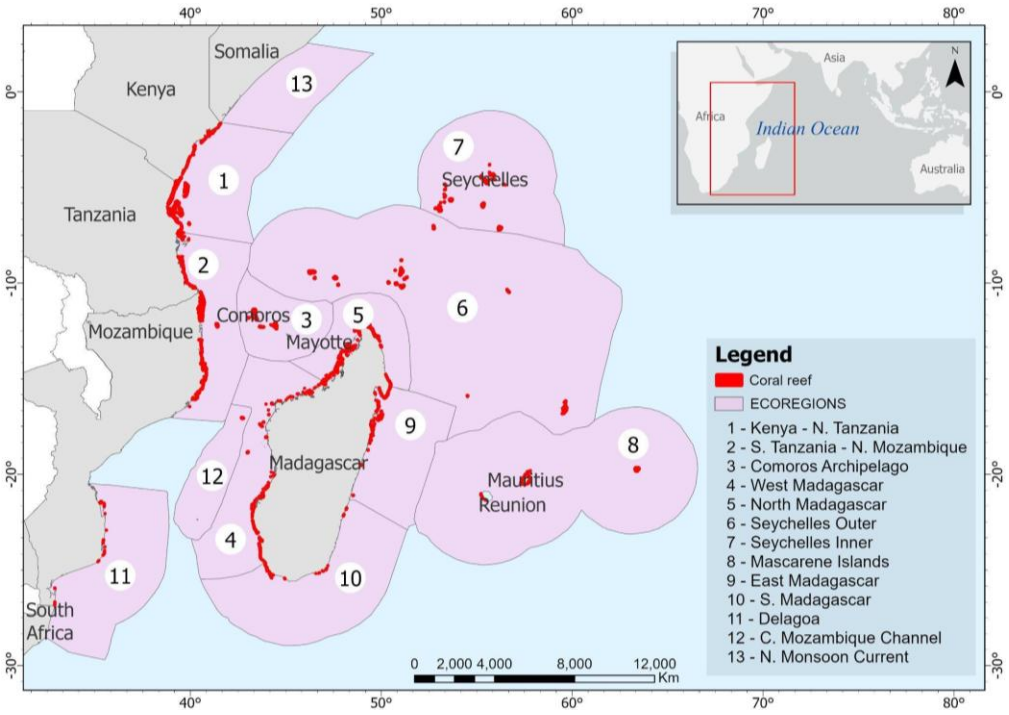


Figure 2. Coral reefs of the Western Indian Ocean, grouped within coral reef ecoregions (Units of Assessment) to be evaluated under the IUCN Red List of Ecosystems criteria and corresponding to Level 4 of the IUCN Global Ecosystem Typology.

2. Ecosystem Description

Coral reefs of the Western Indian Ocean (WIO) are biogenic carbonate structures formed primarily by scleractinian corals and other calcifiers, creating the complex three-dimensional habitats that underpin the region's marine biodiversity (Obura et al., 2021). They are highly productive ecosystems providing food security, coastal protection and tourism-based livelihoods (Ferrario et al., 2014; Woodhead et al., 2019; Samoilysetal-ResilientCoasts-book-2015-lowRes). Yet these regions face increasing risk of degradation and collapse under accelerating local and global pressures (Richmond, 2011; Eddy et al., 2021; Obura et al., 2021; Yao and Wang, 2026)

Coral reefs of the WIO occur mainly as fringing reefs with narrow lagoons around islands and continental coasts, but also form as barrier reefs, atoll and patch types (Obura, 2012). Kenyan and northern Tanzanian reefs are narrow fringing systems with lagoons, while southern Tanzania and northern Mozambique support more complex systems including the Quirimbas (Mayorga-Adame et al., 2017). The Seychelles have wide (>2 km) fringing flats in the granitics plus outer atolls, Mauritius and South Africa have thin reef veneers. Rodrigues has well-developed reefs, whereas Madagascar has discontinuous fringing and barrier reefs (Turner et al., 2000; Turner and Klaus, 2005; ASCLME, 2012; coral-reefs-andavadoaka)

2.1 Key Biotic Components

Scleractinian corals are the key ecosystem engineers, with productivity driven by mutual symbiotic photosynthetic zooxanthellae (Richmond, 2011; Obura et al., 2021). An estimated 350–400 scleractinian species occur regionally (369 formally recorded), ~90% of which are shared with the wider Indo-Pacific, while ~5% are restricted to the western and northern Indian Ocean (Obura, 2012; D. Obura et al., 2017; Obura et al., 2021). Species richness peaks at mid-latitudes, with the northern Mozambique Channel hotspot (Quirimbas, Nacala, southern Tanzania, Diego-Vohemar and adjacent islands) supporting local assemblages of 250–300 species (Obura, 2012; Birrell et al., 2022; McClanahan et al., 2024). Mainland East African reefs show higher abundance of stress-tolerant, massive coral taxa (Poritidae, Faviidae, Pocilloporidae), whereas oceanic islands (Seychelles, Comoros, northern Madagascar) support a higher abundance of fast-growing branching Acroporidae (Obura, 2012; McClanahan et al., 2014). Endemics include *Acropora branchi*, *A. roseni*, *Horastrea indica*, *Pocillopora indiania* and *Stylophora madagascarensis*, alongside range-restricted species such as *Ctenella chagius* (Chagos Archipelago and Mauritius) (Obura, 2012; DeVantier and Turak, 2017). Other important benthic organisms include various forms of algae including turf, macro/fleshy and calcareous (e.g. *Halimeda*), crustose coralline algae (CCA) which cement the reef framework, and soft corals particularly on marginal reefs such as in Delagoa. Sea urchins are also a key part of the ecosystem as grazers and bioeroders.

The WIO hosts ~2,400 reef fish species (~850 Indian Ocean endemics) (Kulbicki et al., 2013), making it the second most diverse region after the Coral Triangle (Barber and Meyer, 2015; Obura et al., 2021). East African continental reefs support between 600–960 species (Parravicini et al., 2013), with the Mascarenes in the east hosting the highest endemism in

the region (Allen, 2008; Obura et al., 2021). The Mozambique Channel supports the region's highest fish abundance and diversity (Samoilys et al., 2022). Herbivorous fish (Scarinae, Acanthuridae, Siganidae) graze algae and maintain settlement space, while reef-associated piscivores, such as groupers, regulate lower trophic levels but depend on structural complexity (Green and Bellwood, 2009; Knoester et al., 2023; M. A. Samoilys et al., 2025). Endangered green turtles (*Chelonia mydas)* frequent the reefs and nest on undisturbed sandy shores in localised areas (Dalleau et al., 2019), and the endemic giant clam, *Tridacna rosewateri*, occurs at reef depths on the Saya de Malha and Nazareth (Cargados Carajos) Banks of the Mascarene Plateau (Ramah et al., 2022; Corbari et al., 2025).

2.2 Key Abiotic components

The distribution of photic coral reefs across the WIO is dictated by physicochemical properties of the ocean including light radiance, nutrients, salinity, temperature, sedimentation and alkalinity (Kleypas et al., 1999; Obura, 2012).

WIO photic coral reefs include true accreting reefs, built by net calcium carbonate accumulation over millenia, and marginal reefs, where relatively low temperature, high turbidity, or localized salinity limit accretion and net accumulation (Polidoro et al., 2022). Accreting reefs dominate the northern and central WIO where clear, relatively nutrient-poor water with temperatures between 22–30°C favour the development of reefs with greater structural complexity and vertical growth, which support higher fish biomass (Obura et al., 2021; Polidoro et al., 2022). In Delagoa ecoregion in the south, the flow of water from the Mozambique Channel and Agulhas Current results in relatively cooler temperatures of 16–28°C, limiting calcification and driving communities characterised by stress-tolerant and soft-coral assemblages (Schleyer and Celliers, 2003; Lutjeharms, 2007; Porter et al., 2017; Schleyer et al., 2018).

This distribution is also structured by large-scale geomorphology and oceanographic processes such as depth and currents. The eastern boundary is the Seychelles Plateau and Mascarene Ridge, beyond which deep water isolates WIO reefs from the Maldives and Chagos (Spalding et al., 2001; Richmond, 2011). On the mainland and Madagascar coasts lower water clarity from land-based inputs generally limits coral reef communities to depths of < 30 m, while reefs around some of the smaller, remote islands extend to approximately 60m (Obura et al., 2021). Abiotic conditions limit reef development south of Mauritius, Réunion and Madagascar into marginal conditions at the southern reef limit in Maputaland, northern South Africa (McClanahan et al., 2011; Obura, 2012; Porter et al., 2013; Porter and Schleyer, 2019). The northern Somali limit of the WIO is set by monsoon-driven upwelling (McClanahan and Muthiga, 1988; Obura, 2012). The South Equatorial Current splits in Madagascar into the North-East and South-East Madagascar currents, feeding the Agulhas system and warm anticyclonic Mozambique Channel eddies. The East African Coastal Current flows northward year-round while the Somali Current reverses seasonally (McClanahan et al., 2009; Mahongo and Shaghude, 2014; Jacobs et al., 2021).

Reef geomorphology reflects volcanic activity, continental fragmentation, carbonate deposition and sea-level change (Montaggioni and Martin-Garin, 2020). Most islands are volcanic, while Madagascar and the Seychelles Inner are continental remnants (Richmond, 2011; Veron et al., 2015). Fringing reefs dominate the mainland coast, interrupted where riverine inputs (Zambezi/Sofala Bank, Tana-Sabaki, Rufiji, Betsiboka, Onilahy and Fiherenana) deliver sediment and freshwater, reducing salinity and increasing turbidity; through mesoscale circulation these conditions account for large areas of coast devoid of reefs (Obura, 2001; Richmond, 2011; ASCLME, 2012) and strong spatial and temporal hydrographic variability in salinity (Ullgren et al., 2012).

2.3 Key processes and interactions

The symbiosis between reef-building corals and photosynthetic dinoflagellates (Symbiodiniaceae) zooxanthellae enables the dinoflagellate algae to fix sufficient energy from sunlight and facilitate the coral skeletal development that builds up the reef framework over time. Once environmental conditions move beyond ideal conditions, particularly temperature thresholds, this relationship can break down with catastrophic effects on ecosystem engineers.

Reef function depends on energy and nutrient flows through processes such as herbivory, detrital cycling and trophic interactions (Brandl et al., 2019; Beese et al., 2023). Algae are the principal alternative benthic cover and drive successional dynamics. Turf algae rapidly colonises substrate following coral mortality; while fleshy macroalgae proliferate under nutrient enrichment and reduced herbivory, outcompeting corals and inhibiting recruitment (Graham et al., 2015; D. Obura et al., 2017; Elma et al., 2023; Gudka et al., 2023). Herbivory by Acanthuridae, Siganidae, and Scarinae reef fish, regulate this balance through grazing and browsing, partially mitigating shifts to macroalgal dominance and potentially supporting recovery and resilience (Osuka et al., 2018; Obura et al., 2021; M. A. Samoilys et al., 2025). Sea urchins have frequently become key grazers and bioeroders on reefs where fishing has depleted their predators (Carreiro-Silva and McClanahan, 2001; McClanahan and Muthiga, 2016). Predatory groupers, snappers, emperors and sharks exert top-down control and stabilise fish community structure (Green and Bellwood, 2009; Knoester et al., 2023; M. Samoilys, Osuka, et al., 2025), preventing trophic cascades toward smaller, prey-dominated assemblages (Samoilys et al., 2018; Obura et al., 2021; M. A. Samoilys et al., 2025), and urchin outbreaks (Wallner-Hahn et al., 2015). Other benthic competitors can also become locally important, including soft corals which can dominate in high-sediment or high-wave energy areas and on marginal reefs such as in Delagoa (Schleyer et al., 2008; D. Obura et al., 2017; Porter et al., 2017; Porter and Schleyer, 2019; Obura et al., 2021; Elma et al., 2026) and corallimorpharians such as *Rhodactis rhodostoma* which can become abundant on disturbed or nutrient-enriched reefs (Kuguru et al., 2004; Elma et al., 2026).

Recruitment and replenishment of coral populations depend on larval supply, settlement and post-settlement survival. Recruits have varying levels of sensitivity to substrate condition, hydrodynamics, water quality, light and macroalgae (Mangubhai et al., 2007; O'Leary et al., 2013; Vogt-Vincent et al., 2024), with CCA often promoting coral larvae settlement (O'Leary

and McClanahan, 2010; D. Obura et al., 2017; Karisa et al., 2020). Herbivory and bioerosion (scraping, excavation) by parrotfish, urchins and microborers is natural and creates and maintains settlement space for new recruits. However, where it exceeds carbonate production it weakens the framework and reduces accretion. This has been previously documented in Seychelles after bleaching and on degraded Kenyan reefs (Carreiro-Silva and McClanahan, 2001; Januchowski-Hartley et al., 2017).

2.4 Main Threats

Threats to WIO reefs operate across varying scales and fall into five interacting categories (Figure 3): climate change, overfishing and destructive fishing, land-based pollution and sedimentation, coastal development, and secondary biological disruptions (Table 1) (D. Obura et al., 2017; M. Samoilys, Osuka, et al., 2025).

Climate change is the most severe and widespread threat facing coral reefs. Major bleaching events driven by marine heat waves during El Niño and positive Indian Ocean Dipole phases have caused region-wide coral bleaching and mortality in 1998, 2016, and 2024 (D. Obura et al., 2017; Gudka, D. O. Obura, et al., 2018; Reimer et al., 2024; Johnson et al., 2025; Moejes et al., 2026; Spady et al., 2026). Repeated thermal stress has driven localized collapse of coral reefs (e.g. Seychelles in 1998 and 2016) and shifted communities towards stress-tolerant taxa or algal domination, reducing coral diversity, structural complexity and reef fish populations (Graham et al., 2007; Darling et al., 2019; Karisa et al., 2020). Levels of heat stress in the region have increased rapidly to record highs over the past 5 years, likely signaling a trend of greater intensity and frequency of events into the future (Saranya et al., 2022). In addition, coral bleaching, acidification, and coral disease interact synergistically (McClanahan et al., 2007; Gudka, D. O. Obura, et al., 2018) while sea-level rise of 3.85 ± 0.3 mm yr^{-1} since 1993 has contributed to erosion, flooding, and saltwater intrusion across SWIO islands (World Meteorological Organization, 2025).

Overfishing is a region-wide threat which removes herbivores and piscivores, weakening top-down control of algae and reef recovery capacity (McClanahan et al., 2011; Samoilys et al., 2017, 2019; M. A. Samoilys et al., 2025; M. Samoilys, Osuka, et al., 2025). In the Mozambique Channel and along the Kenyan coast, overfishing of predators has triggered trophic cascades toward smaller, prey-dominated assemblages (D. Obura et al., 2017; Samoilys et al., 2017; M. Samoilys, Roche, et al., 2025). Destructive practices, including localized but persistent dynamite fishing along sections of the Tanzanian coast, damage three-dimensional framework and suppress coral recruitment (Sawall et al., 2013; Braulik et al., 2015; Carneiro and Martins, 2021; Leitman et al., 2026).

Cyclones destroy reef frameworks and individual colonies, while also generating rubble that can continue to damage already weakened, slow-calcifying frameworks over time (Obura et al., 2021; Carter et al., 2022). The South West Indian Ocean (SWIO) experienced 13 tropical storms in 2024, including Cyclone Chido, the region's costliest on record (Nicet et al., 2025; World Meteorological Organization, 2025; Moejes et al., 2026).

Land-based pollution and coastal development are dominant chronic pressures that reduce water quality. Nutrients, pesticides, microplastics and heavy metals from agriculture and urbanization drive eutrophication and macroalgal overgrowth that suppresses coral recruitment (Mwaura et al., 2017; Honorato-Zimmer et al., 2022; Ripanda and Miraji, 2022), as well as directly reduce the health of corals, symbionts and the reef microbiome. Elevated levels of pesticides and herbicides have been detected in South African corals and sponges, though impacts remain undetermined (Porter et al., 2018; Tyohemba et al., 2022). Sedimentation from land-use change and greater river discharge reduces light, photosynthesis and calcification (Maina et al., 2013; D. Obura et al., 2017), while plastic debris accumulates on both nearby and remote reefs (ASCLME, 2012; Honorato-Zimmer et al., 2022; Hassan et al., 2024; Choppy, 2025; Raharinaivo et al., 2025). Coastal urbanization, port expansion, land reclamation and dredging cause direct reef loss, increased sedimentation and persistent hydrodynamic change (Burke et al., 2011). In many places this is compounded by maritime traffic causing grounding damage and pollution (Erftemeijer et al., 2012; Raymundo et al., 2018; Van Der Schyff et al., 2020), as well as anchoring and trampling damage through irresponsible tourism (Freed and Granek, 2014) .

These cumulative pressures also drive secondary disruptions. Crown-of-thorns starfish (*Acanthaster* spp.) outbreaks and elevated coral disease have caused rapid acute coral loss in Seychelles, Madagascar, the Mascarenes and Zanzibar (Tanzania). These pressures are expected to continue to intensify under further climate stress (D. Obura et al., 2017; Ussi et al., 2024). Invasive non-native species pose an emerging risk to competitive and trophic dynamics as environmental conditions change (Bax et al., 2003; Awad, 2011; Salimi et al., 2021).

Recovery from bleaching events can be further constrained by interacting stressors, including elevated nutrient levels, reduced herbivory and more frequent storm disturbances (D. Obura et al., 2017; Good and Bahr, 2021). Their occurrences across the thirteen WIO ecoregions, classified using the IUCN Threat Classification Scheme, is summarized in Table 1.

Table 1. Occurrence of major threats impacting coral reefs in each ecoregion categorized based on the IUCN Threat Classification Scheme. ✓ = currently impacting; + = emerging / likely in the near future; – = not a significant issue. Ecoregions: 1 Kenya - North Tanzania; 2 South Tanzania - North Mozambique; 3 Comoros Archipelago; 4 West Madagascar; 5 North Madagascar; 6 Seychelles Outer; 7 Seychelles Inner; 8 Mascarene Islands; 9 East Madagascar; 10 South Madagascar; 11 Delagoa; 12 Central Mozambique Channel; 13 Northern Monsoon Current.

Threat type	Subcategory	Ecoregion												
		1	2	3	4	5	6	7	8	9	10	11	12	13
1. Residential & commercial development	1.1 Housing & urban areas	✓	✓	✓	+	✓	✓	✓	✓	+	✓	+	–	✓
	1.3 Tourism & recreation areas	✓	✓	✓	+	✓	+	✓	✓	+	✓	+	+	–
2. Agriculture & aquaculture	2.1 Annual & perennial non-timber crops (runoff)	✓	✓	✓	✓	✓	–	–	✓	✓	✓	+	+	–
	2.4 Marine & freshwater aquaculture	+	+	+	+	+	–	–	+	+	+	–	–	–
3. Energy production & mining	3.1 Oil & gas drilling	+	+	+	–	+	–	–	–	–	–	+	+	+
	3.2 Mining & quarrying (coral/sand mining)	✓	✓	✓	✓	✓	–	–	–	✓	✓	+	–	✓
4. Transportation & service corridors	4.3 Shipping lanes	✓	✓	✓	✓	✓	+	✓	✓	+	+	✓	+	✓
5. Biological resource use	5.4 Fishing & harvesting aquatic resources	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
6. Human intrusions & disturbance	6.1 Recreational activities	✓	+	✓	+	✓	+	✓	✓	+	✓	+	+	–
	6.2 War, civil unrest & military exercises	–	✓	+	–	–	–	–	–	–	–	–	–	+
7. Natural system modifications	7.2 Dams & water management/ use (altered freshwater flows)	+	✓	+	✓	✓	–	–	+	✓	✓	+	–	–
	7.3 Other ecosystem modifications	✓	✓	✓	✓	✓	-	✓	✓	✓	✓	+	–	–
8. Invasive & problematic species	8.1 Invasive non-native species	+	+	+	+	+	+	+	+	+	+	+	+	–
	8.2 Problematic native species (COTS, urchin overabundance)	+	✓	✓	✓	✓	✓	✓	✓	✓	✓	+	+	–
9. Pollution	9.1 Domestic & urban wastewater	✓	✓	✓	✓	✓	–	✓	✓	+	✓	+	–	+
	9.2 Industrial & military effluents (Oil spills)	✓	✓	✓	+	✓	–	+	✓	+	+	+	–	+
	9.3 Agricultural & forestry effluents	✓	✓	✓	✓	✓	–	–	✓	✓	✓	✓	–	–
	9.4 Garbage & solid waste (plastics, marine debris)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	+	✓	+
11. Climate change & severe weather	11.1 Habitat shifting & alteration	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	+
	11.3 Temperature extremes	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Threat type	Subcategory	Ecoregion												
		1	2	3	4	5	6	7	8	9	10	11	12	13
	11.4 Storms & flooding	+	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	+
	11.5 Other impacts: ocean acidification	+	+	+	+	+	+	+	+	+	+	+	+	+

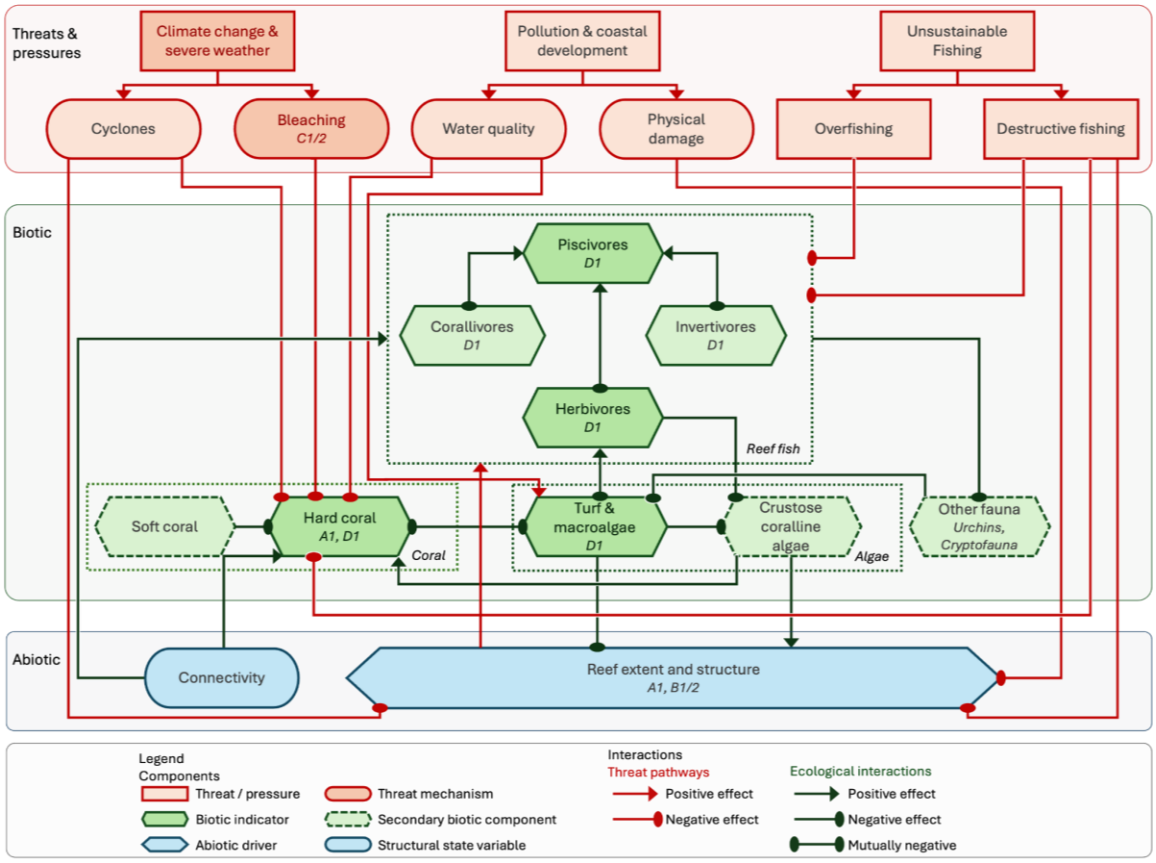


Figure 3. Conceptual model of the WIO coral reef ecosystems. The model illustrates key biotic and abiotic components, as well as external drivers, threats, and the processes and interactions between them.

2.5 Definition of the collapsed state of the ecosystem

Ecosystem collapse represents the final stage of degradation, occurring when an ecosystem's defining biodiversity and features decline to levels where it transforms into a different ecosystem type or when the ecosystem is lost entirely (Keith et al., 2013; Bland et al., 2018). This can result from habitat transformation (e.g. land reclamation), disease, overharvesting, or a persistent change in environmental conditions, and may occur locally on a single reef. An ecosystem-wide classification as 'Collapsed' under the RLE requires full decline or degradation across the entire coral reef distribution. Collapse is not always a permanent state, and coral reefs may recover under conducive conditions.

For coral reefs, collapse is signaled by the near or complete loss of hard corals to levels where defining processes such as carbonate accretion are absent or negligeable (Obura et al., 2021). A collapsed coral reef is characterized by low coral cover, richness and diversity, with communities dominated by a few weedy or stress-tolerant species. Typically, this is accompanied by a phase shift toward turf and fleshy algae, rubble, or filter-feeding invertebrates, along with altered fish communities (Bellwood et al., 2004; McManus and Polsenberg, 2004; Norström et al., 2009; Robinson et al., 2019). Collapse may also involve a

simplified reef topography or permanent loss of geomorphological structure through land reclamation or coastal development. Collapse may also be driven directly by an unsuitable abiotic environment resulting from declining water quality, rising temperature, and frequent severe disturbance events.

Under the Red List of Ecosystems framework, collapse is defined as the point at which key biotic or abiotic indicators reach thresholds where the ecosystem's defining features are lost. For this assessment, coral reef collapse is defined by any of the following: (a) complete loss of coral reef area; (b) hard coral cover falling below 5%; or (c) frequent severe heatwaves that cause coral bleaching at an average return interval of 3 years or less over a 30-year period or that occur 3 times within 5 years. Three further biotic indicators reflect severe functional degradation but not complete ecosystem collapse and can be used to elevate risk: an algal-to-coral cover ratio exceeding 5:1; and severe depletion of key fish groups, parrotfish (herbivores) and groupers (piscivores), to levels below 10% and 20%, respectively, of the historical baselines (Obura et al., 2021).

Table 2. Key abiotic and biotic features and characteristics of the coral reefs' ecoregions in the WIO (see Figure 2), highlighting unique aspects of each ecosystem.

Ecoregion	Key Biotic	Key Abiotic	Key Threats
1. Kenya - North Tanzania	Narrow-shelf fringing-reefs that support taxonomically diverse but spatially heterogeneous coral and reef fish assemblages. Kenya supports an estimated local coral species richness ranging from 177 species at Kiunga to 239 in Southern Kenya, reflecting a northward decline in coral diversity associated with the increasing influence of the Somali current system (Obura, 2012). Reef fish assemblages are similarly diverse but remain incompletely characterized at the ecoregional scale; studies have documented variation in species richness and community composition among Kenyan reefs with earlier documentation by (Samoilys, 1997), estimating the marine fish at approximately 350 species, while surveys of 19 selected families at Tanzanian sites estimated approximately 319 species (McClanahan and Kaunda-Arara, 1996; Samoilys et al., 2022). Post-disturbance coral community reassembly, mainly initiating from the 1998 bleaching event, has shifted hard coral assemblages to non-*Acropora* dominance, alongside rising dead coral and rubble, pulses of turf and fleshy algae, and localized soft coral or corallimorph dominance.	The shelf is narrow and tidal range large (4 m), with spring tides exposing reef flats and driving temperature and light extremes in shallow lagoons. Warm surface East African Coastal Current flows continuously northward along the coasts of Tanzania and Kenya (Painter, 2020). Major river inputs (Tana, Sabaki, Pangani, Wami) deliver freshwater and high sediment and nutrient pulses, making nearby reefs sensitive to terrestrial runoff (Brakel, 1984). Northern reefs sit in between warm coral-coast conditions and colder Somali Current influence and are relatively isolated from southern larval sources.	Overfishing is a chronic stressor via non-selective and destructive gear (e.g. small mesh gill nets) resulting in larger scrapers (e.g. parrotfish), browsers and piscivores (e.g. groupers) depleted on unprotected reefs (Lokrantz et al., 2009). Mass bleaching main acute stressor (1998, 2010, 2016, 2020, 2024). Nutrient/sediment pollution around urban centers (Mombasa, Dar es Salaam, Tanga, Zanzibar) (Mwaura et al., 2017; Staehr et al., 2018; Bravo et al., 2021) and reefs adjacent to estuaries like those in Watamu MPAs. Larger scrapers, browsers and piscivores depleted on unprotected reefs (Lokrantz et al., 2009). Loss of triggerfish (*Balistapus undulatus*) increasing urchin density and bioerosion and localised CoTS outbreaks (McClanahan and Muthiga, 2016).
2. South Tanzania - North Mozambique	Northern Mozambique Channel diversity hotspot, with high local species richness and structurally complex fringing reefs (Quirimbas) (Obura, 2012; Birrell et al., 2022). Among the regions highest reef-fish abundance and diversity, with comparatively intact predator and herbivore communities (Samoilys et al., 2022).	Extensive fringing reef systems on a warm, moderate-stress coast driven by the East African Coastal Current and the northern Mozambique Channel eddies (McClanahan et al., 2014). Localized river sediment inputs (e.g. Ruvuma and Rufiji River) (Porter et al., 2017), creating potential thermal refugia in southern Tanzania	Persistent dynamite fishing generating rubble (Sawall et al., 2013; Carneiro and Martins, 2021), sedimentation, mass bleaching. Emerging: rapid coastal and offshore gas development (Cabo Delgado).
3. Comoros Archipelago	Fringing reefs around young volcanic islands, with Mayotte's barrier reef enclosing a large lagoon and is part of the northern Mozambique Channel diversity hotspot with diverse assemblages (Obura et al., 2021).	Young volcanic islands in the warm northern Mozambique Channel and Mayotte's barrier–lagoon system is the most developed reef structure (Montaggioni and Martin-Garin, 2020).	Land-based runoff in Mayotte and Moheli; coral and sand extraction in Grande Comore, Mohéli, and Anjouan; coastal pollution and overfishing associated with Mayotte; (Thomassin et al., 2010), high human pressure (Freed and Granek, 2014), and climate-related disturbances, particularly tropical cyclones, such as Chido, Kenneth, and coral bleaching events (Adjeroud et al., 2026; Moejes et al., 2026).
4. West Madagascar	Fringing and barrier reefs along the north-west coast with moderate-to-high diversity and strong mangrove–reef connectivity (Richmond, 2011). Extensive reefs in this ecoregion can be found in the south-west, including	West coast under Mozambique Channel circulation, with major sediment delivery from the Betsiboka River creating turbid nearshore zones (Richmond, 2011). The Southwest	Catchment deforestation and land-use change driving sedimentation (Maina et al., 2013), overfishing, coastal development, and bleaching.

Ecoregion	Key Biotic	Key Abiotic	Key Threats
	the Great Reef of Toliara (Nomenisoa et al., 2024) and the Bay of Ranobe, the Reefs of Nosy-Ve Androka and Andavadoaka.	Madagascar Coastal Current (SMACC) is a shallow (<300m) and narrow (<100km wide) coastal current that influences the larval transport patterns and the connectivity with the Agulhas Current (Ramanantsoa et al., 2018).	
5. North Madagascar	Part of the northern Mozambique Channel diversity hotspot, with very high coral richness (e.g. Diego-Vohemar; (Randrianarivo et al., 2025) and diverse fish assemblages influenced by larval retention within the channel (McClanahan et al., 2011; Obura, 2012).	Warm, moderate-stress waters of the northern Mozambique Channel that support high diversity and include areas that have been identified as potential thermal refugia (McClanahan et al., 2011, 2024).	Overfishing, sedimentation, emerging tourism and coastal development. Thermal-stress exposure is comparatively lower but rising.
6. Seychelles Outer	Remote atoll and carbonate-platform reefs (Aldabra, Amirantes, Farquhar) with relatively intact communities and functioning coral recruitment, important for connectivity as larval source sites (Koester et al., 2021). At Farquhar, (Friedlander et al., 2014) documented low coral cover but exceptionally high fish biomass, including abundant groupers, snappers, jacks, Napoleon wrasse and bump head parrotfish. Strong herbivory limited macroalgal dominance and promoted crustose coralline algae. At Aldabra, bleaching altered coral composition, but juvenile coral abundance tripled between 2016 and 2019, demonstrating substantial but spatially variable replenishment potential (Cerutti et al., 2020; Koester et al., 2021). At Poivre, free-living mesophotic corals locally contributed up to 75% live coral cover and facilitated reef development on unconsolidated sediments (Samimi-Namin et al., 2025).	Oceanic atolls and carbonate platforms with very low direct human influence (Montaggioni and Martin-Garin, 2020). Warm oceanic waters, with cyclone exposure in the southern atolls. Seychelles Marine Spatial Plan Atlas 2025 (SMSP Atlas) identifies areas of persistently cool water and potential climate refugia near the Amirantes Group and Alphonse Group. It also identifies potential cold-water refugia on the southern Amirantes Plateau (SMSP Atlas). At Aldabra, daily lagoon temperature variability was more than three times that of shallow seaward reefs, potentially increasing coral thermal tolerance (Koester et al., 2021).	Tropical cyclones (e.g. Fantala at Farquhar (Duvat et al., 2017) and bleaching, accumulation of land-derived plastic debris on remote shores (Duhec et al., 2015; Honorato-Zimmer et al., 2022; Choppy, 2025). Local anthropogenic pressure is generally low.
7. Seychelles Inner	Wide fringing reefs on granitic bases, historically *Acropora*-rich. Reef recovery is driven by branching *Acropora*, often replacing massive corals (Robinson et al., 2019), but varies from coral dominance to persistent macroalgal–rubble states with limited recruitment (Chong-Seng et al., 2014;) Graham et al., 2015). Structural complexity loss reduces fish richness and functional diversity (Graham et al., 2006). Fish assemblages partially recover alongside corals; reversal of macroalgal dominance remains uncommon and spatially restricted (Graham et al., 2015, 2024).	Granitic continental-remnant islands on the shallow Seychelles Plateau, with reef flats >2 km wide around Mahé and Praslin (Turner et al., 2000; ASCLME, 2012). Warm equatorial waters with high thermal-stress exposure. Granitic substrates generally provide relatively stable settlement surfaces, whereas carbonate reefs may contain extensive unconsolidated rubble that limits the establishment and long-term survival of coral colonies (Chong-Seng et al., 2014);(Dajka et al., 2019).	Severe mass bleaching (1998, 2016, 2024), with over half of monitored sites high-to-extreme in 2016 (Gudka, D. Obura, et al., 2018), macroalgal regime shifts, coastal development, tourism and nutrient loading. Severe post-bleaching regime shifts to macroalgae on some reefs alongside recovery on others (Graham et al., 2015). Bleaching-driven coral loss has reduced carbonate budgets and accretion (Januchowski-Hartley et al., 2017).
8. Mascarene Islands	Highest Indo-Pacific peripheral fish endemism in the WIO, with several rare coral and fish species and possible local extinctions in Mauritius (McClanahan et al., 2021; Obura et al., 2021). Coral recruitment is spatially variable (Jouval et al., 2019).	Volcanic islands with thin reef veneers over volcanics in Mauritius, well-developed reefs with extensive flats around Rodrigues, and narrow fringing reefs at Réunion (Spalding et al., 2001; Turner and Klaus, 2005).	Land-based runoff and coastal pollution, elevated bioerosion (Réunion; (Chazottes et al., 2002), cyclones (e.g. Garance 2025); tourism and coastal development (Mauritius) and significant bleaching. Small, isolated coral

Ecoregion	Key Biotic	Key Abiotic	Key Threats
			populations vulnerable to extinction. Localized oil spills in Mauritius.
9. East Madagascar	Discontinuous, high-energy fringing and barrier reefs with lower-diversity, exposure-adapted communities (Richmond, 2011; Randrianarivo et al., 2022).	Exposed eastern coast under strong south-east trade winds, high levels of wave exposure, the South-East Madagascar Current (Richmond, 2011).	Tropical cyclones (e.g. Gamane, NE Madagascar; (World Meteorological Organization, 2025); sedimentation from steep river catchments, artisanal fishing, and bleaching.
10. South Madagascar	Colder/higher nutrient fauna and habitats. Lower coral diversity (Obura, 2012).	The 'Grand Sud' of Madagascar is a temperature enclave influenced by cool upwelling, creating a temperate, marginal coral reef environment (Obura, 2012). Locally cooler waters influenced by the SMACC (Ramanantsoa et al., 2018).	Intense artisanal fishing (Behivoke et al., 2021, 2026) and gleaning (Andréfouët et al., 2013), sedimentation(Sheridan et al., 2014) cyclones (Côté-Laurin et al., 2017; Carter et al., 2022) and bleaching.
11. Delagoa	High-latitude marginal communities dominated by soft corals and stress-tolerant, slow-accreting assemblages of distinct composition, and high biodiversity (Schleyer and Celliers, 2003; Porter et al., 2013; Schleyer et al., 2018; Porter and Schleyer, 2019; Obura et al., 2021). Carbonate framework is severely restricted with most reefs composed of aeolinite sandstone rather than biogenic carbonate (Ramsay, 1994; Perry, 2003).	Cooler 16–28°C water from the Mozambique Channel and Agulhas Current limit carbonate accretion and accumulation (Schleyer and Celliers, 2003; Lutjeharms, 2007; Porter and Schleyer, 2019). Seasonality in water temperatures and upwelling in the south (Porter et al., 2017, 2021; Porter and Schleyer, 2019).	Marginal cool-water stress and climate-driven community change, cyclones, coastal development, tourism (Birrell et al., 2022) and unsustainable fishing practices (Menezes et al., 2011). Historically lower thermal-stress exposure than northern ecoregions, but warming is increasing (Gudka, D. Obura, et al., 2018; Porter et al., 2021).
12. Central Mozambique Channel	Remote oceanic reefs (French Scattered Islands) with near-pristine, low-impact communities that serve as important regional reference and refugia sites.	Isolated atolls and carbonate platforms in warm Mozambique Channel waters with anticyclonic eddies and within the area predicted to persist as a climate refugium (Montaggioni and Martin-Garin, 2020; McClanahan et al., 2024).	Very low direct human pressure. Principal threats are climate-driven (bleaching, cyclones), with illegal/unregulated fishing and marine debris.
13. Northern Monsoon Current	Marked urbanization gradient, from moderately diverse scleractinian assemblages at remote sites to macroalgal-dominated, disturbance-tolerant assemblages with depressed accretion at urban sites (Schleyer et al., 1999; Carbone and Accordi, 2000)	Northern range limit of WIO reefs, set by the seasonally reversing Somali Current and intense SW-monsoon upwelling (McClanahan, 1988; Obura, 2012; Jacobs et al., 2021). Site-level variation from intact fossil-coral-cliff reef flats to sand-encroached fossil paleo reef platforms(Carbone and Accordi, 2000; ASCLME, 2012).	Chronic upwelling cool-water stress, minimal monitoring and governance. Emerging local pressures at urban sites: untreated wastewater, solid waste, litter (Hassan et al., 2024), coral and sand extraction, overexploitation of reef megafauna (*Tridacna* spp., manta rays). (Carbone and Accordi, 2000; ASCLME, 2012). Sparse baseline data.

3. Criterion Assessment

Coral reefs in 13 ecoregions within the Western Indian Ocean 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 (Perry, 2003). 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 area of a minimum convex polygon (convex hull) drawn around all mapped reef occurrences (Fig. S2), while AOO is the number of 10 × 10 km grid cells containing reef (Fig. S3), counting only cells in which reef occupies at least 1% of the cell area. 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 represent marine heat waves. Ecoregional DHW thresholds related to widespread bleaching and severe mortality events were established based on historical observations of reef responses to global and local bleaching events (Table 12 and 13). Using these thresholds, DHW data was converted into two binary event time series for the annual occurrence of: a) bleaching events, b) severe bleaching events that cause significant coral mortality.

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 (Fig. S5). The second approach is a pulse pathway, capturing acute collapse driven by the clustering of extreme high-mortality events within any 5-year window (Fig. S6). For both C1 and C2, the relative severity of decline at a reef 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 a severe bleaching event occurring on average every three years for the chronic pathway, and three severe mortality events within five years for the pulse pathway (Table 14). For example, for the chronic pathway, if a reef had no severe mortality events in 1975, and 2 events in the last 5 years (2021-2025), the relative severity of decline under C1 for that reef is calculated as:

$$Relative\ severity\ of\ decline\ (\%) = \frac{initial\ level - current\ level}{initial\ level - collapse\ threshold} \times 100 = \frac{0-2}{0-3} \times 100 = 66.7\%$$

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 (Fig. 6), based on the proportion of reef area within each ecoregion experiencing different levels of relative decline. For example, if 50% of reefs (relative extent) in an ecoregion have declined by more than 50% (relative decline), the overall risk classification is VU. 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 hard coral cover, algae-to-coral ratio, parrotfish and grouper abundance derived from in-situ monitoring data. For each reef site, the severity of decline in each indicator is measured relative to both the estimated state of the reef 50 years ago (Tables 17-19) and a hypothetical collapse threshold (Table 3), representing the point at which that biotic component is no longer functional (see formula under Criterion C). The proportion of sites experiencing varying degrees of decline is then evaluated, and a risk matrix (Fig 6) is used to determine the risk status for each indicator. For example, if coral cover at 50% of reef sites (relative extent) in an ecoregion have declined by more than 80% (relative to initial and collapse levels), the risk classification under the hard coral indicator is 'EN'. This approach is repeated 1000 times for each indicator to account for variation in initial values, with a final risk (or range of risks) determined based on the frequency of results returned. Finally, a heuristic, stepwise approach is applied to combine the risk status across all four indicators into the overall risk status under Criterion D. Indicators are considered sequentially in order of ecological interaction: hard coral, coral-to-algae ratio, herbivores, and groupers. The risk status of hard coral is the starting cumulative status. At each subsequent step, the cumulative status is compared with that of the next indicator and increased by one risk category only if the indicator risk is higher than the cumulative; otherwise, it is retained.

Table 3. Methodology, parameters and collapse thresholds used to assess Coral Reefs ecosystems in the Western Indian Ocean under the Red List of Ecosystem criteria.

Criterion	Sub-criterion	Indicator(s)	Data Sources	Risk and Collapse Threshold(s)	Criterion Assessed	Comments
A - Reduction in geographic distribution	A1 – Past 50 years	Proportion of monitored reef sites with hard coral cover	Hard coral cover	5% coral cover indicating local collapse	Yes	Based on reef monitoring surveys using a mix of benthic data collection methods (photo quadrats, Line Intercepts and Point Intercept Transects)
B - Restricted geographic distribution	B1 –Extent of Occurrence (EOO)	EOO + ongoing decline or threat	Global and regional reef maps	Threatened status: EOO ≤ 50,000 km^2 + ongoing decline or threats	Yes	Calculated per eco-region using minimum convex polygons
	B2 – Area of Occupancy (AOO)	AOO + ongoing decline or threat	Global and regional reef maps	Threatened status: AOO ≤ 50 + ongoing decline or threats	Yes	Grid-based reef presence (10×10 km)
C - Environmental degradation	C1 – Past 50 years	Degree Heating Weeks (DHW))	NOAA Coral Reef Watch	Collapse: Return interval of ≤ 3 years between bleaching events or 3 severe marine heatwave events occurring within 5 years	Yes	DHW levels that trigger severe bleaching event/mortality for each ecoregion indicated in Tables 12 and 13 (Annex)
	C2 – Projected future degradation	Projected Degree Heating Weeks (DHW)	Global Climate Projections	Collapse: Return interval of ≤ 3 years between bleaching events or 3 severe marine heatwave events occurring within 5 years	Yes	DHW levels that trigger severe bleaching event/mortality for each ecoregion indicated in Tables 12 and 13 (Annex)
D - Disruption of biotic processes	D1 – Past 50 years	Hard coral cover, Algae-coral cover ratio (ACR)	Benthic cover from reef monitoring surveys	Collapse: Hard coral cover ≤ 5%, ACR = 0.833 (5:1)	Yes	Derived from reef monitoring surveys using a mix of benthic data collection methods (photo quadrats, Line Intercepts and Point Intercept Transects)
		Fish (Parrotfish & Grouper)	Fish density or biomass from monitoring data	Collapse: Groupers: 20% of initial levels Parrotfish: 10% of initial levels	Yes	Biomass and density data was used in different ecoregions based on coverage across ecoregions and availability of baseline values from reference locations. A mixture of Belt transects, and point count methods contributed to monitoring data.

4. Risk Status

Coral reef ecosystems across all evaluated ecoregions of the Western Indian Ocean are at the highest risk of collapse (Critically Endangered) due to the severity of climate change induced warming (sub-criterion C2). Based on observed declines, eight of the 13 ecoregions, accounting for 83.7% of coral reefs in the WIO, were classified as having an Endangered status. Two ecoregions were classified as Vulnerable with the Mascarene Islands and Comoros Archipelago considered Critically Endangered. These risks were primarily due to severe biotic and abiotic degradation (Criteria C1+D), highlighting the widespread and escalating pressures already facing reefs in the region. Only one ecoregion, Northern Monsoon Current, was Data Deficient due to a lack of data.

Table 4. Summary of RLE assessment results for the WIO coral reef ecoregions. The overall *Red List of Ecosystems* status is the highest level of risk identified across all the assessed criteria. 'Observed' represents the highest risk due to historical changes (Criteria A, B, C1, D), whereas 'Future' is risk based on future abiotic change (sub-criterion C2). Criteria and sub-criteria driving risk outcomes are included in parentheses. (LC - Least Concern, NT - Near Threatened, VU - Vulnerable, EN - Endangered, CR - Critically Endangered, DD - Data Deficient, NE - Not Evaluated).

	Criteria Risk Status							
Ecoregion	A	B	C1	C2	D	Observed	Future (C2)	Overall Risk
1. Kenya - North Tanzania	LC	LC	VU	CR	EN	EN (D)	CR	CR (C2)
2. South Tanzania - North Mozambique	LC	LC	VU	CR	EN	EN (D)	CR	CR (C2)
3. Comoros Archipelago	VU	NT	VU	CR	CR	CR (D)	CR	CR (C2, D)
4. West Madagascar	VU	LC	VU	CR	EN	EN (D)	CR	CR (C2)
5. North Madagascar	LC	LC	VU	CR	NT	VU (C1)	CR	CR (C2)
6. Seychelles Outer	LC	LC	EN	CR	VU	EN (C1)	CR	CR (C2)
7. Seychelles Inner	VU	LC	VU	CR	EN	EN (D)	CR	CR (C2)
8. Mascarene Islands	LC	VU	CR	CR	VU	CR (C1, D)	CR	CR (C1,2, D)
9. East Madagascar	LC	VU	EN	CR	LC	EN (C1)	CR	CR (C2)
10. South Madagascar	DD	VU	EN	CR	DD	EN (C1)	CR	CR (C2)
11. Delagoa	LC	VU	VU	CR	VU	VU (B, C1,D)	CR	CR (C2)
12. Central Mozambique Channel	LC	EN	EN	CR	VU	EN (B,C1)	CR	CR (C2)
13. Northern Monsoon Current	DD	DD	DD	DD	DD	DD	DD	DD

Criterion A: Reduction in Geographic Distribution

Under Criterion A, three ecoregions were classified within threatened categories (Vulnerable; VU), with an estimated 30-50% of monitored sites falling below 5% hard coral cover presently. These losses can be attributed to cumulative pressures such as coastal development, land-based pollution and agricultural runoff, unregulated fishing and recurrent coral bleaching. Eight ecoregions were assessed as Least Concern (LC), and two ecoregions (Northern Monsoon Current and South Madagascar) were Data Deficient (DD).

Table 5. Risk status of the WIO coral reef ecoregions under Criterion A1, based on the proportion of sites with hard coral cover below 5%: LC, <27%; NT: 27-30%; VU ≥30 –50%; EN, ≥50–80%; and CR, ≥80%. Ecoregions with fewer than 10 sampled sites are classified as DD.

Coral Reef Ecoregion	Proportion of reef sites below critical hard coral cover threshold (5%)	Criterion A Risk Status
1. Kenya - North Tanzania	0.14	LC
2. South Tanzania - North Mozambique	0.09	LC
3. Comoros Archipelago	0.38	VU
4. West Madagascar	0.34	VU
5. North Madagascar	0.03	LC
6. Seychelles Outer	0.04	LC
7. Seychelles Inner	0.32	VU
8. Mascarene Islands	0.07	LC
9. East Madagascar	0.00	LC
10. South Madagascar	DD	DD
11. Delagoa	0.12	LC
12. Central Mozambique Channel	0.00	LC
13. Northern Monsoon Current	DD	DD

Criterion B: Restricted Geographic Distribution

Under Criterion B, one (Central Mozambique Channel) of the 12 assessed ecoregions was assessed as Endangered (EN), and none as Critically Endangered (CR). Of the remaining 11, four were assessed as Vulnerable (VU), one as Near Threatened (NT), and six as Least Concern (LC). The Northern Monsoon current ecoregion holds no validated reef layer and was treated as Data Deficient (DD). Ecoregions with limited or highly fragmented reef area, such as the Central Mozambique Channel (AOO = 11) and South Madagascar (AOO = 25), meet the thresholds for restricted AOO. To formally assign the risk status to threatened ecoregions under Criterion B1 or B2, experts verified that coral reefs in these ecoregions faced ongoing risk from ocean warming and associated coral bleaching, pollution, coastal development and/or overfishing (Table 1).

Table 6. Risk status of Western Indian Ocean 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 (km²)	Criterion B1 Risk Status	Area of Occupancy (AOO)	Criterion B2 Risk Status	Criterion B Risk Status
1. Kenya - North Tanzania	76,697	LC	174	LC	LC
2. South Tanzania - North Mozambique	126,170	LC	174	LC	LC
3. Comoros Archipelago	53,402	NT	64	LC	NT
4. West Madagascar	220,695	LC	105	LC	LC
5. North Madagascar	88,408	LC	123	LC	LC

Coral Reef Ecoregion	Extent of Occurrence EOO (km²)	Criterion B1 Risk Status	Area of Occupancy (AOO)	Criterion B2 Risk Status	Criterion B Risk Status
6. Seychelles Outer	809,061	LC	78	LC	LC
7. Seychelles Inner	108,205	LC	61	LC	LC
8. Mascarene Islands	73,799	LC	39	VU	VU
9. East Madagascar	31,291	VU	75	LC	VU
10. South Madagascar	79,196	LC	25	VU	VU
11. Delagoa	73,957	LC	29	VU	VU
12. Central Mozambique Channel	42,135	VU	11	EN	EN
13. Northern Monsoon Current	DD	DD	DD	DD	DD

Criterion C: Environmental Degradation

Based on historical and projected thermal stress conditions under Criterion C, all the ecoregions assessed were classified as Critically Endangered. Only one ecoregion (Northern Monsoon Current Coast) was Data Deficient.

Based on warming over the past 50 years (C1, 1975–2025), risk is more varied, but all ecoregions are still threatened. The Mascarene Islands were assessed as Critically Endangered (CR); East Madagascar, South Madagascar, Seychelles Outer and the Central Mozambique Channel as Endangered (EN); and the remainder of the assessed ecoregions as Vulnerable (VU). Under the future assessment (C2 (2026-2075), SSP245), every assessed ecoregion reaches the collapse threshold within the assessment window.

Table 7. Risk status of Western Indian Ocean coral reef ecoregions under Criterion C, determined from estimated declines in abiotic conditions, specifically changes in the frequency of extreme heat events measured through Degree Heating Weeks (DHW). C1 reflects observed conditions (1975–2025); C2 reflects projections under SSP2 -4.5.

Coral Reef Ecoregion	Criterion C1 Risk Status	Criterion C2 Risk Status	Criterion C Risk Status
1. Kenya - North Tanzania	VU	CR	CR
2. South Tanzania - North Mozambique	VU	CR	CR
3. Comoros Archipelago	VU	CR	CR
4. West Madagascar	VU	CR	CR
5. North Madagascar	VU	CR	CR
6. Seychelles Outer	EN	CR	CR
7. Seychelles Inner	VU	CR	CR
8. Mascarene Islands	CR	CR	CR
9. East Madagascar	EN	CR	CR
10. South Madagascar	EN	CR	CR
11. Delagoa	VU	CR	CR
12. Central Mozambique Channel	EN	CR	CR
13. Northern Monsoon Current	DD	DD	DD

Criterion D: Disruption of biotic processes or interactions

Coral reefs within nine ecoregions have experienced significant biotic degradation over the past 50-year and met the threshold for threatened status, with herbivore and piscivore

abundance driving moderate to severe disruption of trophic interactions across several ecoregions. North and East Madagascar were assessed as Near Threatened and Least Concern respectively, however both regions lacked sufficient fish data (<10 sites with recent data). Northern Monsoon Current and South Madagascar were classified as Data Deficient (DD).

Table 8. Overall risk status of WIO coral reef ecoregions under Criterion D, determined from estimated historical declines in four critical biotic components. The overall status is determined through a stepwise approach considering the risk of each indicator in ecological order from left to right. Ranges in risk e.g. EN-CR, represents uncertainty in the outcomes, and where relevant the most likely category is presented in addition to the range (outside of the parentheses). Overall risk considered DD if hard coral risk is DD.

Coral Reef Ecoregion	Hard corals	Algae- coral ratio	Parrotfish	Groupers	Criterion D Risk Status
1. Kenya - North Tanzania	VU	VU	EN	EN-CR	EN
2. South Tanzania - North Mozambique	NT	NT (NT-LC)	CR	CR	EN
3. Comoros Archipelago	EN	LC	EN	CR	CR
4. West Madagascar	VU	VU	VU	EN	EN
5. North Madagascar	NT	LC	DD	DD	NT
6. Seychelles Outer	VU	VU	VU	NT	VU
7. Seychelles Inner	VU	EN (VU-EN)	EN	VU	EN
8. Mascarene Islands	VU (VU-NT)	VU	LC	NT	VU
9. East Madagascar	LC	LC	DD	DD	LC
10. South Madagascar	DD	DD	DD	DD	DD
11. Delagoa	VU	NT	NT (NT-VU)	LC (LC-NT)	VU
12. Central Mozambique Channel	VU	VU	NT	VU (VU-NT)	VU
13. Northern Monsoon Current	DD	DD	DD	DD	DD

5. Conclusion and recommendations

Coral reef ecosystems of the Western Indian Ocean face a very high risk of collapse in the next 50 years. Under future warming projections, even at moderate warming scenarios (SSP2-4.5), all assessed ecoregions are *Critically Endangered*. The Critically Endangered status of all the assessed ecoregions is further evidence that climate warming poses an alarming threat to the survival of coral reefs. The increasing frequency and intensity of marine heat events will most likely exceed the ecological limits for coral reef function by 2075, driving loss in biodiversity and derived ecosystem services. In addition, heat stress already places all ecoregions at a high risk having experienced widespread impacts from bleaching in 1998, 2016 and 2024. To address this, international and regional bodies, including the Nairobi Convention and its Contracting Parties, must advocate for ambitious global mitigation, ensuring the overshoot is as close to the Paris Agreement limit of 1.5°C as possible.

The impacts of bleaching events compounded by local stressors such as pollution and overfishing over the past 50 years have resulted in nine ecoregions threatened under Criterion D. It should be noted that survey coverage following the 2024 marine heatwave remains incomplete, so these categories likely understate the risk based on observed change. It is imperative that in a warming ocean, management tackles local threats, not only to offer the best chance for coral reefs to recover after climate-driven disturbances, but because this will provide wide-ranging ecological, environmental and societal benefits beyond coral reefs. Governments must address land-based pollution and sedimentation caused by coastal development, as well as strengthen fisheries governance through no-take zones and community managed areas. Other effective area-based conservation measures (OECMs) are formally recognized under the Kunming-Montreal Global Biodiversity Framework and represent a potential mechanism in which community managed areas can support countries commitment towards the 30% protection and management of their ocean by 2030.

This assessment shows that coral reefs in the WIO are at a high risk of collapsing, and countries must urgently act to increase holistic, inclusive and equitable approaches to protect these ecosystems. Importantly, this must involve substantial investment in the most vulnerable coastal communities, to ensure they build resilience and can adapt to the impacts of a rapidly changing climate.

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11. Peer review

This report was peer-reviewed by Dr Ena Suarez from IUCN Red List of Ecosystems global team, who is an RLE expert and lead author of the global mangrove assessment. It was also reviewed by Rickdane Gomez, Lucas Yutaka Kimura (Faculty of Science, University of the Ryukyus, Japan) who are co-authors of the East Asia coral reef RLE, and Dr Benjamin Cownburn who is a research associate with CORDIO East Africa.

Earlier versions of the report were reviewed by Yves Olatoundji (IUCN Red List of Ecosystems global team).

12. Disclaimer

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13. 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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Annex

1.Boundary definitions

Coral reefs of the WIO were grouped into 13 ecoregions drawing on the Marine Ecoregions of the World (MEOW) framework developed by (Spalding et al., 2007) (Figure 2). Boundaries were refined using coral reef-specific regional and global classifications proposed by (Obura, 2012; Obura et al., 2021) and (Veron et al., 2015) respectively. This assessment differs from the previous regional coral reef RLE (Obura et al., 2021) principally through the inclusion of Northern Monsoon Current Coast (Somalia) and Central Mozambique Channel ecoregions.

Table 9. Summary of units of Assessment within the WIO, including ecoregions assessed, countries or territories included, estimated coral reef area, their ecological and biogeographic characteristics supporting their delineation as distinct units of assessment.

Ecoregion	Country/ Territory	Coral Reef Area (km^2)	Boundary Description	Justification (Description as to why coral reefs in each ecoregion are different)
1. Kenya - North Tanzania	Kenya; Tanzania (including Zanzibar islands)	1253.4	Aligns with the MEOW East Africa Coral Coast ecoregion and the Northern Monsoon Current Coast (Spalding et al., 2007), subdivided based on (Obura, 2012) and (Obura et al., 2021). Limit the Kenya/northern Tanzania ecoregion at the Kenya-Somali border due to lack of data from reefs north of this point. Southern boundary at the Rufiji delta.	Near-continuous fringing reef of a narrow shelf influenced by the warm northward-flowing East African Coastal Current and free of major riverine input north of the Rufiji. Among the heavily fished reefs in the region, conditions are shaped by extraction and land-based pressure as much as thermal stress.
2. South Tanzania - North Mozambique	Tanzania (Mafia, Songo Songo, Mtwara); Mozambique (Quirimbas, Nacala)	1906.1	The Tanzania/Mozambique continental coast in the East African Coral Coast (1) and Northern Mozambique Channel (2). Southern limit due to Zambezi River creating conditions unsuitable for coral reef habitat	Core of the Northern Mozambique Channel, it holds the highest coral species richness in the WIO and is characterized by strong eddies which drives larval connectivity along the Tanzania- Mozambique coast.
3. Comoros Archipelago	Comoros (Grande Comore, Mohéli, Anjouan); Mayotte, Îles Glorieuses	730.3	Separation of Comoros archipelago from mainland Eastern Africa and Madagascar	Comorian archipelago within the Northern Mozambique Channel (2), distinguished by fish fauna (3).
4. West Madagascar	Madagascar	435.4	West coast of Madagascar in the Mozambique Channel, with boundaries determined by (4), to support national processes.	The widest shelf in Madagascar, carrying the region's most extensive barrier and fringing reef complexes, but receiving high sediment and freshwater loads from the large west-coast rivers. Sedimentation and intense artisanal fishing distinguish its reefs from the oceanic systems of the channel.
5. North Madagascar	Madagascar	774.2	West coast of Madagascar in the Mozambique Channel, with boundaries determined by (4), to support national processes.	Sits within the Northern Mozambique Channel and shares its high coral diversity and connectivity with the Comoros and the East African coast. Sheltered bay and island reefs around Nosy Be contrast with the exposed, current-swept reefs off Cap d'Ambre.
6. Seychelles Outer	Seychelles (Aldabra group, Farquhar group, Alphonse group); Mauritius (Agaléga, St	998.1	Subdivision of the single Seychelles ecoregion of MEOW following (Obura, 2012) and (Obura et al., 2021), with the boundary drawn at the edge of the Seychelles (Mahé) Plateau. Extends west	Separating the northern granitic island on the Seychelles bank which are more populated/visited islands, from the remoter outer islands

Ecoregion	Country/ Territory	Coral Reef Area (km^2)	Boundary Description	Justification (Description as to why coral reefs in each ecoregion are different)
	Brandon); Tromelin		to the Aldabra group where it meets the Northern Mozambique Channel, and southeast across the isolated banks of Alphonse, Providence, Farquhar, Saya de Malha, Nazareth, Cargados Carajos and Tromelin, to the limit of the Mascarene Islands.	including the isolated banks (Saya de Malha, Nazareth and Cargados Carajos and Tromelin)
7. Seychelles Inner	Seychelles (All granitic islands on Mahe plateau and Denis & Bird; Coetivy, and, Amirantes group)	805.2	The granitic Seychelles bank, separated from the outer islands in (Obura, 2012) and (Obura et al., 2021) as a subdivision of the single MEOW Seychelles ecoregion. It is bounded by the edge of the Mahe Plateau on a continuous shallow structure.	Separating the northern granitic island on the Seychelles bank which are more populated/visited islands, from the remoter outer islands including the isolated banks
8. Mascarene Islands	Mauritius (Mauritius, Rodrigues); France (Réunion)	477.8	The remote southwestern islands of Reunion, Mauritius, Rodrigues (as in (1) and (2))	Isolated islands, furthest east and host the highest fish endemism in the region
9. East Madagascar	Madagascar	400.8	West coast of Madagascar in the Mozambique Channel, with boundaries determined by (4), to support national processes.	Narrow shelf exposed to open Indian Ocean swell and the southward East Madagascar Current, with reef development limited to discontinuous fringing structures. Frequent cyclone damage and high wave energy, rather than thermal stress, are the dominant drivers of reef condition.
10. South Madagascar	Madagascar	110.9	West coast of Madagascar in the Mozambique Channel, with boundaries determined by (4), to support national processes.	The 'Grand Sud' of Madagascar as in (2), is a temperature enclave influenced by cool upwelling 11. Marginal coral reef environment.
11. Delagoa	Mozambique (Bazaruto, Inhambane, Inhaca); South Africa (KwaZulu-Natal)	58.7	Matching the boundaries of (1) including all coral reefs of southern Mozambique and northern South Africa.	Abiotic conditions (temperature) limit reef development into marginal conditions at the southern reef limit in Maputaland

Ecoregion	Country/ Territory	Coral Reef Area (km^2)	Boundary Description	Justification (Description as to why coral reefs in each ecoregion are different)
12. Central Mozambique Channel	Îles Éparses — Bassas da India, Europa, Juan de Nova	97.7	Northern limit at Juan De Nova, southern limit at Europa and Bassas da India, with no shelf connection to either margin.	Remote oceanic island and atoll reef systems with unique biodiversity and no/very low anthropogenic stress
13. Northern Monsoon Current	Somalia	DD	Northern boundary at the monsoon-driven upwelling front. Southern boundary at Kenyan border	Strong seasonal upwelling driven by the Somali Current and the northeast monsoon produces cool, turbid, nutrient-rich conditions that suppress reef accretion.

2. Methods description

2.1 Data

The Global Coral Reef Monitoring Network (GCRMN) WIO node, operating through the Nairobi Convention Coral Reef Technical Working Group, is the main aggregator of coral reef data within this region. Together with additional contributed data compiled through national coordination networks, national monitoring programmes, research projects, published literature, individual/institutional data providers, and databases such as the MERMAID platform, the data collated for the WIO provided the biological data used in the Criterion D assessment. Benthic data were reported from a mix of survey methods, including photo quadrats, Line Intercepts and Point Intercept Transects. Data from 35 sources across the WIO were compiled for 1985–2025. Fish biomass and density were assessed using a combination of belt transects and point count methods. The compiled fish data covered the period 1987–2025, from 33 data sources across WIO.

Table 10. Data sources of a) Benthic cover and b)Fish abundance (biomass and density) per country across Western Indian Ocean for Criterion D assessment (ALG-Algae; AMAC-Macroalgae; ATRF-Turf algae, HC - Hard Coral)

a)

Country	Monitoring variable	Primary sources (n)	Survey years reported
Comoros	ALG, AMAC, ATRF, HC	2	1999–2024
France (WIO territories)	ALG, HC	4	1998–2025
Kenya	AMAC, ATRF, HC	7	1985–2025
Madagascar	ALG, AMAC, ATRF, HC	12	1998–2025
Mauritius	HC	1	1999–2003
Mozambique	AMAC, ATRF, HC	8	1997–2025
Seychelles	ALG, AMAC, ATRF, HC	8	1994–2025

Country	Monitoring variable	Primary sources (n)	Survey years reported
South Africa	AMAC, ATRF, HC	2	1993–2025
Tanzania	ALG, AMAC, ATRF, HC	6	1996–2025

b)

Country	Monitoring variable	Primary sources (n)	Survey years reported
Comoros	Scarinae, Epinephelidae	1	2010-2024
France (WIO territories)	Scarinae, Epinephelidae	7	2002-2024
Kenya	Scarinae, Epinephelidae	5	1987-2025
Madagascar	Scarinae, Epinephelidae	11	2001-2025
Mayotte	Scarinae, Epinephelidae	2	2001-2025
Mozambique	Scarinae, Epinephelidae	4	1997-2025
Reunion	Scarinae, Epinephelidae	3	2001-2025
South Africa	Scarinae, Epinephelidae	1	2001-2005
Seychelles	Scarinae, Epinephelidae	7	1994-2025
Tanzania	Scarinae, Epinephelidae	6	1996-2025

2.2 Reef typology

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

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 characterized 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 standardized approach was adopted. Both true (Type A) and marginal (Type B) reefs were therefore included, recognizing that marginal systems can represent dominant and ecologically important reef types in some ecoregions. 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 using published research, with the main occurrence of marginal reefs occurring in the high-latitude Delagoa and South Madagascar ecoregions.

2.3 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 between 2020 – 2025 as a proxy for declines in reef area (Obura et al., 2021).

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 represents an established point where coral abundance is too low to maintain positive carbonate accretion on a reef, and the reef would be considered functionally collapsed (Perry et al., 2013; Obura et al., 2021). A sensitivity analysis was conducted across a range of thresholds 1–10% to assess how results varied (Fig. S1). 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 (proportion of collapsed sites). We assumed that all monitored sites represented functioning coral reefs around 1975; and that the proportion of sites currently below the coral cover threshold reflects the proportion of reef area that has since degraded or been lost. Only sites with at least one hard coral cover survey between 2020 and 2025 were included in the final analysis restricting the dataset to 752 monitoring sites across 12 ecoregions. Where multiple surveys were undertaken at a site in this window, the mean hard coral cover across all surveys was used.

These monitoring sites were mapped against the spatial extent of coral reefs to determine the coverage and representativeness of existing monitoring efforts. Spatial representativeness was assessed by comparing the area of a polygon enclosing all monitoring sites with the total mapped Extent of Occurrence (EOO) of coral reefs within each ecoregion (see Criterion B1). To further assess data adequacy, the proportion of 10*10 km grid cells containing monitoring data was assessed relative to the total number of grid cells with coral reefs i.e. Area of Occupancy (AOO) (see Criterion B2). 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, defined as fewer than 10 sites per

ecoregion, the ecosystem was classified as Data Deficient (DD) (South Madagascar, Northern Monsoon Current) (Table 11).

Table 11. A summary of the number of sites with hard coral cover data used to assess Criterion A and the data coverage across each ecoregion.

Ecoregion	Number of sites	Proportion of EOO covered	Proportion of AOO covered
1. Kenya - North Tanzania	236		
2. South Tanzania - North Mozambique	134		
3. Comoros Archipelago	32		
4. West Madagascar	99		
5. North Madagascar	67		
6. Seychelles Outer	25		
7. Seychelles Inner	53		
8. Mascarene Islands	14		
9. East Madagascar	25		
10. South Madagascar	6		
11. Delagoa	49		
12. Central Mozambique Channel	12		
13. Northern Monsoon Current	DD		

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 (see Figure 4).

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 4. Thresholds and assessment timeframes for Criterion A, showing the four sub criteria(A1,A2a,A2b,A3) under which an ecosystem may qualify based on reductions in geographic distribution over specified time periods. Adopted from Bland et al. (2017)

2.4 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 standardized 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.

Selection and validation of coral reef extent layer

The analysis requires a spatial layer representing the current distribution of coral reefs. The base layer is the Global Distribution of Warm-Water Coral Reefs, version 4.1, curated by UNEP-WCMC and compiled from multiple sources including the Millennium Coral Reef Mapping Project (Spalding et al., 2001; Global Distribution of Coral Reefs; Millennium Corals – USF IMaRS). For ecoregions where higher-resolution national or territorial mapping was available, these were substituted for or merged with the global layer: French Indian Ocean territories (Europa, Bassas da India, Juan de Nova, Glorieuses, Mayotte and Tromelin) South Africa and Seychelles. The resulting layer comprises 8,570 reef features across the 12 ecoregions, with the contributing source retained as an attribute for each feature.

Coverage by source: the Central Mozambique Channel is mapped entirely from territorial layers (Europa, Bassas da India, Juan de Nova); Seychelles Inner from the Seychelles national layer; Seychelles Outer from Seychelles and Tromelin layers with the global layer retained elsewhere; the Comoros from Glorieuses and Mayotte layers plus the global layer; and Delagoa from the South Africa layer plus the global layer. The remaining ecoregions use the global layer alone.

Before merging, each contributing layer was standardized where any Z dimension was dropped, geometries were repaired and validated, reprojected to WGS 84 (EPSG:4326), reduced to their polygonal components and recast as multipolygons, with empty and zero-area features removed; attributes were reduced to a single field identifying the contributing source. All layers were retained in full except South Africa, which was filtered to the "Reef" and "Prominent ridge" classes. To prevent double counting where a territorial layer overlapped the global layer, a replacement footprint was constructed as the union of the convex hull of each territorial layer buffered by 0.05°, and global-layer polygons falling within that footprint were erased. The territorial layers and the remaining global-layer polygons were then combined, and each feature assigned to an ecoregion by spatial intersection with the ecoregion boundaries.

All spatial analyses were carried out in R version 4.6.0 using sf (Pebesma, 2018) and redlistr version 2.0.0 (Redlistr: tools for the IUCN Red Lists of ecosystems and threatened species in R). Once merged the validated coral reef extent layer was projected to WGS 84 / UTM zone 37S (EPSG:32737), makeEOO() was used to generate the minimum convex polygon representing the EOO of each ecoregion (Fig. S2), and getAreaEOO() to calculate the EOO area in km^2. For Criterion B2, a 10 x 10 km grid was overlaid over the reef extent layer using the *makeAOOGrid* function (Fig. S3) and the number of grid cells containing coral reefs was counted using getAOO() to estimate the AOO. All grid cells whose cumulative area of the reef ecosystem was < 1% were excluded from the AOO count.

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 (Figure. 5). Ecoregions with EOO or AOO values within 10% of the VU thresholds were classified as Near Threatened (NT).

Finally, to formally assign the risk status under Criterion B1 or B2 for each ecoregion, experts were required to justify observed or inferred declines to reefs, or the presence of current threats, such as ocean warming, pollution, coastal development, or overfishing, that are presenting an ongoing risk to coral reefs.

Subcriterion	*Measure of geographic distribution*	*CR*	*EN*	*VU*
B1	Area of a minimum convex polygon (km^2) 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 km^2 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 5. Thresholds and conditions for assessing ecosystems under Criterion B (restricted geographic distribution) of the IUCN Red List of Ecosystems, showing sub-criteria B1 (extent of occurrence), B2 (area of occupancy) and B3. Adopted from Bland et al. (2017).

2.5 Criterion C: Environmental Degradation

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., 2017). 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 (Heron et al., 2016; Hughes et al., 2018; Emslie et al., 2024a), 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 and Bruno, 2023). These changes can be associated with substantial declines in coral abundance, reduced structural complexity, and lower carbonate accretion rates (Williams and Graham, 2019; Williams et al., 2019). Additionally, recurrent bleaching episodes weaken coral communities, reduce reproductive output, and increase susceptibility to other stressors such as disease (Croquer and Weil, 2009; Levitan et al., 2014; Briggs et al., 2024; Byrne et al., 2025). 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 (Hughes et al., 2018; Emslie et al., 2024a).

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, characterized 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; van Woesik and Kratochwill, 2022; Eakin et al., 2026), they are not spatially or temporally extensive. DHW data are globally available since 1985, including for future climate projections (Skirving et al., 2019; Mellin et al., 2024), and are underpinned by a well-documented, long-term relationship with coral bleaching across many regions globally (Liu et al., 2005; Heron et al., 2016; 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 (Liu et al., 2005; Kayanne, 2017; Skirving et al., 2019). In addition, DHW has been widely used in recent studies assessing bleaching risk under climate change (Beyer et al., 2018; Obura et al., 2021; Mellin et al., 2024; Bozec et al., 2025), and is supported by established thresholds linking DHW levels to bleaching severity developed by the NOAA Coral Reef Watch (CRW). 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 standardized 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) (Fig. S4) (https://coralreefwatch.noaa.gov). Data for each region were downloaded using R's `rerddap::griddap()` function, where the bounding box for data extraction was set by regional boundaries. 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 (Heron et al., 2016; Cheng et al., 2017, 2023; 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 at a 0.5° resolution (~50-55 km) from Mellin et al. (2024) for 1985–2100, available for three climate pathways: SSP2-4.5, SSP3-7.0, and SSP5-8.5 (Fig. S4) (https://adelaide.figshare.com/articles/dataset/Global_projections_of_sea_surface_temperature_and_coral_bleaching_risk_in_the_21st_century/25143128). The data were based on an ensemble average of five CMIP6 models ('ens5'). Extraction boundaries for each region coincided with the bounding box for Criterion C1 using R's `stars::st_crop()` function. 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. SSP5-8.5 represents an extreme case that is increasingly unlikely (Sarofim et al., 2024), so SSP2-4.5 and SSP3-7.0 were explored further, with SSP2-4.5 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 using R's `stars::aggregate()` function, 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. Annual maximum DHW values were assigned to each coral reef polygon using the sf::st_intersection function. 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) (Table 12) and severe mortality events (pulse pathway) (Table 13) 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. Thresholds were established using the historical DHW time series for each ecoregion and corresponding thermal stress peaks in that record against documented coral bleaching events. For every year in which the DHW record showed a notable peak, regional experts were asked to record whether widespread bleaching had been observed across a large proportion of the ecoregion, and whether that stress had driven significant mortality. This considered the global mass bleaching events of 1998, 2010, 2016 and 2024 and localized events. Thresholds were identified by contrasting years in which widespread bleaching occurred against years in which comparable or lower thermal stress produced no such response. The lowest DHW value consistently associated with a widespread response, and above which no non-response was recorded, was taken as the lower limit for that period, corroborated where possible across multiple events. Where DHW in a given year substantially exceeded that threshold, bleaching was assumed to have begun once stress reached the identified threshold, with the additional accumulated heat stress contributing to greater severity and mortality rather than indicating a higher threshold for onset. Bleaching and mortality thresholds were identified for each ecoregion with the mortality threshold consistently higher of the two.

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 (Pratchett et al., 2013; Heron et al., 2016; Sully et al., 2019). Changes in thresholds were based on years where the observed response to a given level of thermal stress changed and differ between ecoregions according to the timing of their documented events.

For C2, thresholds were informed by bleaching responses to thermal stress levels observed during the most recent years of the satellite record (~2020–2025) and were adjusted upward into the future to account for anticipated species filtering, and potential thermal adaptation or acclimation. To account for any uncertainty in the exact level of heat stress that causes bleaching/mortality, a range of plausible DHW threshold values were applied for each pathway, and the results considered.

Table 12. Ecoregional DHW thresholds representing thermal stress levels resulting in widespread bleaching for the chronic pathway. Thresholds are time-varying to represent changing coral responses and increased warming.

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)
1. Kenya - North Tanzania	1985 - 1998 1999- 2017	3-4 4	2026 - 2075	8 - 10
2. South Tanzania - North Mozambique	1985 - 2016 2017 - 2025	4 4-5	2026 - 2075	6 - 8
3. Comoros Archipelago	1985 - 2018 2019 - 2025	3.5 - 4 8	2026 - 2075	8 - 12
4. West Madagascar	1985 - 2015 2016 - 2025	4 5	2026 - 2075	6 - 8
5. North Madagascar	1985 - 2015 2016 - 2025	4 4-5	2026 - 2075	6 - 8
6. Seychelles Outer	1985 - 2019 2020 - 2025	4 4-5	2026 - 2075	8 - 12
7. Seychelles Inner	1985 - 1999 2000 - 2025	2-3 3-4	2026 - 2075	4 - 8
8. Mascarene Islands	1985 - 1999 2000 - 2019 2020 - 2025	3-4 4 5	2026 - 2075	6 - 8
9. East Madagascar	1985 - 2005 2006 - 2025	3 4	2026 - 2075	6 - 8
10. South Madagascar	1985 - 2015 2016 - 2025	4 5	2026 - 2075	6 - 8
11. Delagoa	1985 - 2015 2016 - 2025	3-4 5	2026 - 2075	6 - 8
12. Central Mozambique Channel	1985 - 2019 2020 - 2025	4 5	2026 - 2075	8 - 10
13. Northern Monsoon Current	-	-	-	-

Table 13. Ecoregion-specific DHW thresholds (°C-weeks) for the chronic pathway of Criterion C. Thresholds rise through time to reflect acclimatization following repeated thermal stress; the range spans the primary (low adaptive capacity) and alternative (higher adaptive capacity) estimates and is applied identically across all emissions scenarios. C1 is the observed record from 1985; C2 is the 2026–2075 projection. The Northern Monsoon Current holds no mapped reef area and was not assessed.

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)
1. Kenya - North Tanzania	1985 - 2016 2017 - 2025	4-5 8-10	2026 - 2075	12 - 16

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)
2. South Tanzania - North Mozambique	1985 - 2016 2017 - 2025	4-5 6-8	2026 - 2075	8 - 12
3. Comoros Archipelago	1985 - 2018 2019 - 2025	5 - 6 8-12	2026 - 2075	12 - 16
4. West Madagascar	1985 - 2015 2016 - 2025	4 8 - 10	2026 - 2075	12 - 16
5. North Madagascar	1985 - 2016 2017 - 2025	5 - 6 8	2026 - 2075	8 - 12
6. Seychelles Outer	1985 - 1999 2000-2016 2017 - 2025	4-5 6-8 8-12	2026 - 2075	12 - 16
7. Seychelles Inner	1985 - 1999 2000 - 2025	3-4 4-5	2026 - 2075	6 - 10
8. Mascarene Islands	1985 - 1999 2000 - 2019 2020 - 2025	3-4 4 - 5 6 - 8	2026 - 2075	8 - 12
9. East Madagascar	1985 - 2005 2006 - 2025	3 7	2026 - 2075	8 - 12
10. South Madagascar	1985 - 2015 2016 - 2025	5 8-12	2026 - 2075	12 - 16
11. Delagoa	1985 - 2015 2016 - 2025	2-4 8	2026 - 2075	8 - 10
12. Central Mozambique Channel	1985 - 2019 2020 - 2025	4 5	2026 - 2075	8 - 12
13. Northern Monsoon Current	-	-	-	-

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:

Relative severity of decline (%) = (current conditions – initial conditions) / (collapse threshold – initial conditions) × 100

The chronic pathway is assessed in terms of the average return interval of severe bleaching events over a 30-year period (Hughes et al., 2018; DeCarlo and Whitaker, 2025) (Fig. S5).

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 (Hughes et al., 2018; Pratchett et al., 2021; Eakin et al., 2026).

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 and Whitaker, 2025). This probabilistic approach provides a continuous, smoothed estimate of annual event probability. This reduces sensitivity to interannual variability and characterizes 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 (Fig. S6). 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 characterizes 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 characterized 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; Graham et al., 2011; Gilmour et al., 2013; 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 of C1, we applied a uniform initial value of 0 to all reefs, assuming that no high mortality events occurred in the 5 years around 1975. This is based on evidence that

most major, widespread bleaching events started occurring in 1982/83 onwards. We also tested an initial value of one high mortality event occurring but found that this resulted in an LC assignment for ecoregions with known bleaching impacts over the past 50 years, therefore producing inaccurate results. 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 and 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 (Hughes et al., 2018; Emslie et al., 2024b). 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 (van Hooidonk et al., 2016; De Clippele et al., 2023; Zeng et al., 2025), however it is considered overly conservation as collapse will likely occur before we reach conditions conducive to yearly bleaching (Bland et al., 2018; Obura et al., 2021).

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., 2021) 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 (Pratchett et al., 2021; Emslie et al., 2024b; Henley et al., 2024). 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.

Table 14. Summary of parameters used to assess Criterion C under the chronic and acute pathways. DHW, Degree Heating Weeks; SSP, Shared Socioeconomic Pathway.

Component	Sub-criterion	Chronic (press) pathway	Acute (pulse) pathway
Rationale	–	Cumulative effects of recurrent bleaching events; as events become more frequent, recovery intervals shorten, preventing meaningful recovery and leading to progressive degradation (Hughes et al. 2018; Emslie et al. 2024)	Rapid decline following a small number of extreme heat stress events over a short period, causing widespread mortality across coral taxa, including stress-tolerant species, and near-complete coral loss
Indicator	–	Expected number of severe bleaching events over a 30-year period, expressed as an average return interval (years between events)	Number of severe mortality events within a 5-year window
Assessment period	C1	1975–2025 (DHW data available 1985–2025)	
	C2	2026–2075 (projections available 1985–2100)	
DHW data	C1	Daily DHW from NOAA Coral Reef Watch, 5 km resolution, 1985–2025 (Liu et al. 2012)	
	C2	Modelled daily DHW projections, 1985–2100 (Mellin et al. 2024); SSP2-4.5 as the primary scenario, with SSP3-7.0 also explored	
DHW thresholds	C1	Ecoregional DHW at which severe bleaching events occur (widespread bleaching affecting more than about 50% of colonies), identified from historical bleaching responses; time-varying	Ecoregional DHW at which severe mortality events occur (mortality of more than 50% of colonies across all taxa, including stress-tolerant species); equal to or higher than the bleaching threshold; time-varying
	C2	Informed by responses in the most recent years of the satellite record (about 2020–2025) and, where appropriate, adjusted upwards to account for potential adaptation; aligned with NOAA Coral Reef Watch alert levels (4, 8, 12, 16, 20 DHW) where appropriate	
Current value	C1, C2	Logistic regression of annual event probability against time for each reef polygon (C1: 1985–2025; C2: 1985–2100); probabilities summed over each 30-year window to give expected events, converted to return interval (30 years ÷ expected events); shortest return interval across windows in the assessment period	Maximum number of severe mortality events in any 5-year moving window across the assessment period, for each reef polygon
Initial value	C1	Return interval of 10–15 years (Baker et al. 2008; Gilmour et al. 2013; Hughes et al. 2018)	0 events in a 5-year window, as major widespread bleaching began only from 1982/83; an initial value of 1 event was tested
	C2	Return interval calculated from projected DHW for 1996–2025 using the same logistic regression	Maximum number of severe mortality events in any 5-year window between 2016–2025
Collapse threshold	C1, C2	Severe bleaching on average every 3 years over 30 years (about 10 events); sensitivity test of one event every 5 years (about 6 events) (DeCarlo & Whitaker 2025)	3 severe mortality events within any 5-year window; sensitivity test of 2 events

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 areas experiencing different levels of decline (≥20%, ≥30%, ≥50%, ≥70%, ≥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).

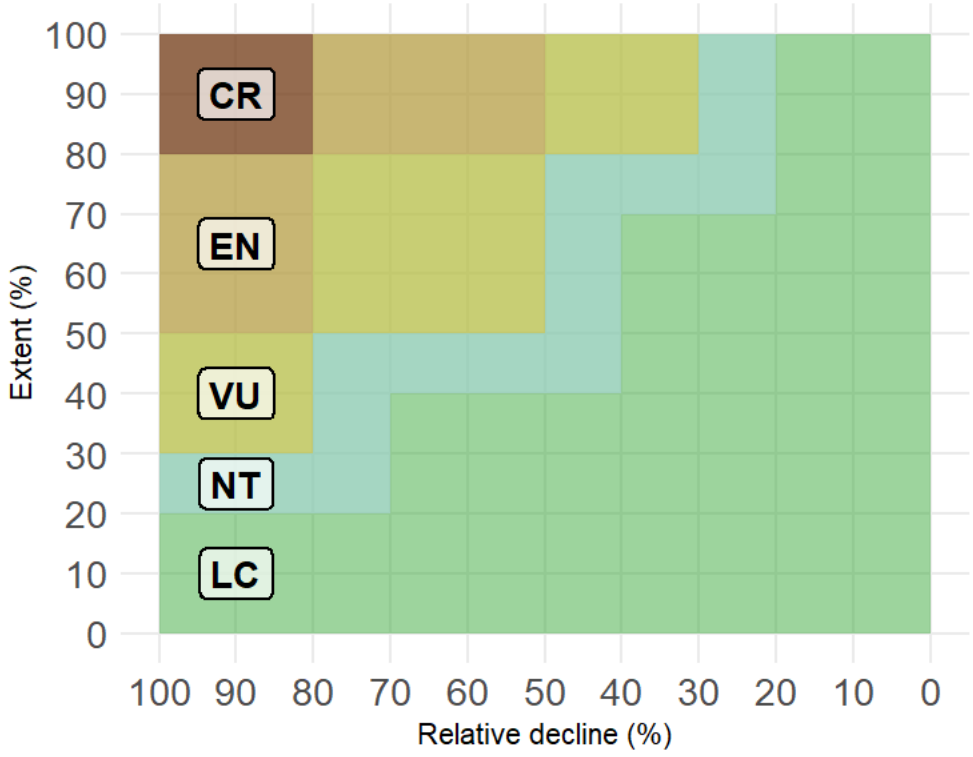


Figure 6. Risk matrix - Relative extent of an ecosystem (y-axis) vs relative severity of decline (x-axis) used to assign risk classifications under Criterion C and D

2.6 Criterion D: Disruption of Biotic Processes and Interactions

Criterion D was evaluated to identify ecosystems experiencing severe disruption to biotic organisms, 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 the WIO , four key biotic components were assessed based on previous RLE assessments (Bland et al., 2015; Obura et al., 2021), and using data derived from standard underwater survey methods [e.g. point intercept transects and belt transects]. These components include:

- Hard corals, as the keystone ecosystem taxa responsible for forming the habitat structure and accretion processes.
- Algae (macro/fleshy and turf), as the principal competitive taxa to hard corals;
- Herbivory, which provides an 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.

Algal-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. Algae included a mix of turf, and fleshy algae, to account for inconsistencies in taxonomic resolution across monitoring programs. The ratio was calculated as the total algae cover divided by the sum of algae and coral cover.

Parrotfish abundance (biomass and density) was used as a proxy metric for herbivory, as regional fish datasets were largely resolved at the family level and parrotfishes were among the most consistently recorded herbivores.

Grouper abundance (biomass and density) was selected as a suitable proxy metric for piscivory because they comprised the majority of piscivorous fish recorded in the available datasets and are highly sensitive to fishing**.**

For both fish indicators, four ecoregions were assessed using biomass (kg/ha), while eight ecoregions were assessed using density (ind/ha) based on data availability.

Additional indicators identified in the conceptual model could not be included in the assessment due to insufficient spatial or temporal coverage, inconsistent monitoring methods, or loss of functional resolution. These included coral recruitment, reef connectivity, structural complexity and rugosity, soft coral cover, crustose coralline algae, water quality, and other fauna such as sea urchins and corallivores. In some cases, contributed data were aggregated into broad taxonomic groups; for example, surgeonfish data reported only at family level prevented the assessment from capturing species-specific functional roles, such as grazing and bioerosion (The functional roles of surgeonfishes on coral reefs: past, present and future | Reviews in Fish Biology and Fisheries | Springer Nature Link). Although these indicators were not directly assessed, they were retained in the conceptual model because of their recognized importance to the coral reef condition, functioning and resilience, and they represent priorities for future monitoring.

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.

Current values

Current values for each indicator were calculated at the site level using monitoring data available from the last five years [2020–2025] (Tables 15-17). 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 this period, the mean value across all records within the period was used.

Table 15. Mean current value (2020-2025) of hard coral cover (%) and algae-coral-ratio (dimensionless) indicators per ecoregion (n – number of sites).

Ecoregion	Indicator	n	Mean	Std. dev	Min value	Max value
N Tanzania-Kenya	Hard coral	236	22.93	17.24	0.00	77.96
S Tanzania-N Mozambique	Hard coral	134	30.99	20.40	1.02	100.00
Comoros Archipelago	Hard coral	32	9.09	15.21	0.72	64.67
West Madagascar	Hard coral	99	21.44	17.42	0.67	80.00
North Madagascar	Hard coral	67	35.63	18.18	4.66	78.33
Seychelles Outer	Hard coral	25	21.22	13.28	3.48	71.23
Seychelles Inner	Hard coral	53	17.66	13.79	0.05	59.23
Mascarene Islands	Hard coral	14	29.49	12.54	2.33	72.92
East Madagascar	Hard coral	25	44.97	19.23	8.57	77.75
South Madagascar	Hard coral	6	45.27	10.84	29.50	64.50
Delagoa	Hard coral	49	23.05	20.46	1.67	77.44
Central Mozambique Channel	Hard coral	12	31.70	24.44	8.33	69.00
N Tanzania-Kenya	Algae-coral-ratio	236	0.667	0.220	0.00	1.00
S Tanzania-N Mozambique	Algae-coral-ratio	134	0.369	0.30	0.00	0.955
Comoros Archipelago	Algae-coral-ratio	27	0.513	0.31	0.00	0.980
West Madagascar	Algae-coral-ratio	98	0.587	0.20	0.111	0.949
North Madagascar	Algae-coral-ratio	63	0.356	0.21	0.006	0.888
Seychelles Outer	Algae-coral-ratio	25	0.639	0.18	0.054	0.953
Seychelles Inner	Algae-coral-ratio	36	0.516	0.42	0.00	0.994
Mascarene Islands	Algae-coral-ratio	14	0.675	0.14	0.236	0.974
East Madagascar	Algae-coral-ratio	25	0.338	0.18	0.06	0.768
South Madagascar	Algae-coral-ratio	6	0.367	0.17	0.145	0.645
Delagoa	Algae-coral-ratio	36	0.408	0.34	0.00	0.972
Central Mozambique Channel	Algae-coral-ratio	12	0.482	0.323	0.00	0.855
Northern Monsoon Current	**DD**	**DD**	**DD**	**DD**	**DD**	**DD**

Table 16. Current values of a) fish density (indiv./ha) and b) biomass(kg/ha) by ecoregion for Criterion D. Presented as mean, standard deviation (SD) for parrotfish and grouper for the period 2020 to 2025.

a)

Ecoregion	Indicator	Mean	Std. dev	Min value	Max value	n
West Madagascar	Parrotfish	587.5	1349.1	11.1	5660	24
North Madagascar	Parrotfish	504.8	556.9	0	190	9
Seychelles Outer	Parrotfish	204.9	182.3	7.2	666.7	32
Seychelles Inner	Parrotfish	298.2	247.3	25.5	930.7	26
Mascarene Islands	Parrotfish	199.1	177.7	13.3	553.3	18
East Madagascar	Parrotfish	588.1	651.8	266.7	1752.8	5
South Madagascar	Parrotfish	101.1	85.6	0	211.1	6
Delagoa	Parrotfish	179.1	136.9	0	600	30
West Madagascar	Grouper	314.8	652.2	0	2466.7	23
North Madagascar	Grouper	37.5	60.32	0	1520	9
Seychelles Outer	Grouper	125.9	130.9	3.4	666.7	32
Seychelles Inner	Grouper	129.2	183.9	0	714.3	26
Mascarene Islands	Grouper	143.3	69.4	33.3	300	18
East Madagascar	Grouper	61.4	97.1	8.3	234.7	5
South Madagascar	Grouper	28.9	32	0	842.2	6
Delagoa	Grouper	160.7	208.3	0	800	27

b)

Ecoregion	Indicator	Mean	Std. dev	Min value	Max value	n
N Tanzania-Kenya	Parrotfish	74.4	109	0	667.4	195
S Tanzania - N Mozambique	Parrotfish	15.7	38.2	0	179.3	105
Comoros Archipelago	Parrotfish	55.5	74.7	3.4	663.6	38
Central Mozambique Channel	Parrotfish	236.2	158.4	41.1	599.2	15
N Tanzania-Kenya	Grouper	14.2	29.9	0	245.2	186
S Tanzania - N Mozambique	Grouper	3.1	11.2	0	98.3	118
Comoros Archipelago	Grouper	44.8	81.3	1.9	349.2	38
Central Mozambique Channel	Grouper	668.9	598.7	11.4	1781	15

Initial values

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 standardized reef monitoring began in the 1990s (D. Obura et al., 2017).

Baseline conditions were therefore reconstructed using a combination of empirical data, literature, and expert knowledge. These estimates represent conditions across the whole ecosystem within each ecoregion and were derived as distributions (e.g. mean and standard deviation) rather than single values to account for natural variability and to incorporate uncertainty.

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.

Method 1 – Literature-derived benthic baselines

Regional experts assumed that reef condition in the 1970s was generally better than at present, and that 1997/8, the year of the first widespread global bleaching event, represented a major turning point in reef condition. Several reefs prior to 1998 were considered broadly representative of earlier (1970s) conditions, with only localized degradation in places (Obura et al., 2021; Gudka et al., 2023).

A literature review was conducted to compile benthic data from early reef surveys, primarily from the 1980s and 1990s. Sites identified as being in relatively healthy condition prior to 1998 and representative of broader reef benthic conditions were selected. These site data were aggregated to estimate ecoregional mean values and variance for hard coral and algae coral ratio indicators. These literature-based baseline estimates for each ecoregion are published in Obura et al., 2021 and Gudka et al., 2023.

Method 2 – Maximum value approach for benthic baselines

An alternative approach used 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). Where available, these estimates were compared with published historical survey data (1960s–1990s) for validation.

Hard coral baseline estimation: For each ecoregion, a hierarchical decision process supported by expert consultation was used to select between the literature-derived and monitoring-derived estimates. Published estimates were prioritized when based on adequate sample sizes (n>=10) and considered spatially representative of the ecoregion. Where both estimates were similar, the published estimate was selected. The monitoring-derived estimate was used when no published estimate was available or when it provided stronger spatial coverage and representation (Table 17).

Table 17. Mean initial values with variance measures for hard coral cover for each ecoregion (n – number of sites).

Ecoregion	N	Mean	Std. dev	Min value	Max value	Source
1. Kenya - North Tanzania	44	37.5	14.8	15.0	78.2	Literature

Ecoregion	N	Mean	Std. dev	Min value	Max value	Source
2. South Tanzania - North Mozambique	32	44.2	15.9	20.0	80.0	Literature
3. Comoros Archipelago	4	56.5	18.0	52.6	97.2	Literature
4. West Madagascar	13	41.8	13.8	0.00	80.0	Monitoring
5. North Madagascar	3	48.2	20.5	1.5	78.3	Monitoring
6. Seychelles Outer	20	32.4	13.0	1.00	86.0	Monitoring
7. Seychelles Inner	10	30.2	10.6	14.8	46.4	Literature
8. Mascarene Islands	46	47.6	18.5	20.5	88.0	Literature
9. East Madagascar	13	60.2	14.7	8.02	84.0	Monitoring
10. South Madagascar	-	DD	-	-	-	-
11. Delagoa	13	41.4	27.5	9.8	90.6	Literature
12. Central Mozambique Channel	12	49.5	22.4	6.6	82.3	Monitoring
13. Northern Monsoon Current	-	DD	-	-	-	-

Algae-coral-ratio baseline estimate: Given the limited pre-1998 data available for algae cover at all but two ecoregions, we followed the approach of (Obura et al., 2021) and applied a regional baseline for all ecoregions except Mascarene Islands and N Tanzania - Kenya (which both had sufficient data to calculate independent estimates). This regional estimate was calculated using the data from Gudka et al., 2023 and resulted in an overall estimate of 0.281 (SD=0.244, n=28) (Table 18). The algae-coral ratio baseline estimates from Gudka et al., 2023 were directly used for the Mascarene Islands and N Tanzania - Kenya ecoregions (Table 18).

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

Ecoregion	Mean	Std. dev	n
1. Kenya - North Tanzania	0.380	0.190	32
2. South Tanzania - North Mozambique	0.281	0.244	28
3. Comoros Archipelago	0.281	0.244	28
4. West Madagascar	0.281	0.244	28
5. North Madagascar	0.281	0.244	28
6. Seychelles Outer	0.281	0.244	28
7. Seychelles Inner	0.281	0.244	28
8. Mascarene Islands	0.380	0.183	42
9. East Madagascar	0.281	0.244	28
10. South Madagascar	DD	-	-
11. Delagoa	0.281	0.244	28

Ecoregion	Mean	Std. dev	n
12. Central Mozambique Channel	0.281	0.244	28
13. Northern Monsoon Current	DD	-	-

Baseline estimation for fish indicators

Baseline values for fish indicators were estimated using a space-for-time substitution approach. Fishing pressure was considered to have been lower in the 1970s, particularly for exploited fish groups, and their abundance/biomass was therefore expected to have been higher than under current conditions. Because comparable fish surveys from the 1970s were unavailable for the WIO, contemporary fish assemblages at well-protected and ecologically comparable reference sites were consequently used as proxies for pre-1970 conditions. A definitive reference location for fish baseline calculation was a site that was from well-managed, no-take marine protected areas (MPAs) with at least 10 years of protection. We used monitoring data for each fish indicator from these sites between the period 2009-2019 (extended to 2021 for Bazaruto sites in Delagoa to increase the sample size) (Tables 19a and 19b). Data from the last ~ 5 years was not considered to make a distinction with the current window (2020-2025) and because declining habitat due to bleaching events in recent years will have started to impact fish populations despite protection.

The reference locations used in this assessment were the same as the RLE 2019 (Obura et al 2021) with a few adjustments. Chagos Archipelago sites in the central Indian Ocean were not used as reference sites, to allow for more ecoregionally-relevant estimates. The reference sites and corresponding rationale to calculate baseline values include:

- A single baseline for the East African coast, covering Kenya, Tanzania, and northern Mozambique to increase the number of reference locations, which included Kisite, Watamu, Chumbe, Mafia, Vamizi, Metundo and Mnazi Bay, all highly protected MPAs. Therefore, the N Tanzania- Kenya and N Mozambique - S Tanzania shared baseline reference values.
- Comoros Archipelago used reference locations from Mohéli, Mayotte, and Glorieuses sites.
- Seychelles Inner (referred as Seychelles North in RLE 2019) ecoregion maintained Baie Ternay and Port Laurnay reference locations
- Mascarene ecoregion contribution of current data was limited to Réunion with a reference location of Etang Sale (same as RLE 2019).
- Seychelles Outer Islands use Aldabra and Tromelin as reference locations.
- Madagascar (East, West, North, and South) - adopted a single Madagascar-wide baseline value due to only a few reference locations across the country. We added to the reference site of Velondriake NTZs used in the 2019 RLE with MB Tanikely and

Loky sites within Corridor Marin des 7 Baies locations following recommendations from local experts.

- Central Mozambique channel (Europa, Bassas da India, Juan de Nova) since all the sites are remote and unfished, the initial values were calculated using all sites from the three islands.

Table 19. Initial values of a) density(ind/ha) and b) biomass(kg/ha) calculated as mean with standard deviation from reference MPA sites for parrotfish and grouper for each ecoregion (n – number of sites, with n for East African Coast (N Tanzania-Kenya & N Mozambique - S Tanzania) and Madagascar ecoregions are shared sites).

a)

Ecoregion	Indicator	Mean	Std. dev	Collapse threshold	Min Value	Max value	n
West Madagascar	Parrotfish	328.6	229.3	32.86	0	7381.3	10
North Madagascar	Parrotfish	328.6	229.3	32.86	0	2975	10
Seychelles Outer	Parrotfish	280.8	253.4	28.08	0	3750	15
Seychelles Inner	Parrotfish	1060.2	332.2	106.02	0	6518.4	6
Mascarene Islands	Parrotfish	45.8	5.9	4.58	0	1425	4
East Madagascar	Parrotfish	328.6	229.3	32.86	8.3	2666.7	10
South Madagascar	Parrotfish	328.6	229.3	32.86	0	1175	10
Delagoa	Parrotfish	215.4	166.3	21.5	0	600	16
West Madagascar	Grouper	168	216	33.6	0	2466.7	10
North Madagascar	Grouper	168	216	33.6	0	600	10
Seychelles Outer	Grouper	108.5	54.4	21.7	0	775	15
Seychelles Inner	Grouper	102.8	50.3	20.56	0	876.6	6
Mascarene Islands	Grouper	141.7	189.9	28.34	0	1886.7	4
East Madagascar	Grouper	168	216	33.6	8.3	1366.7	10
South Madagascar	Grouper	168	216	33.6	0	3080	10
Delagoa	Grouper	27.9	27	5.58	0	800	16

b)

Ecoregion	Indicator	Mean	Std. dev	Collapse threshold	Min value	Max value	n
N Tanzania - Kenya	Parrotfish	202.4	142.4	20.24	0	7295.6	29
S Tanzania - N Mozambique	Parrotfish	202.4	142.4	20.24	0	567	29
Comoros Archipelago	Parrotfish	129.2	147.9	12.92	0	2519.5	42
Central Mozambique Channel	Parrotfish	222.4	263.5	22.24	0	1180.6	8
N Tanzania - Kenya	Grouper	47.5	45.8	9.5	0	678.29	29
S Tanzania - N Mozambique	Grouper	47.5	45.8	9.5	0	344.72	29
Comoros Archipelago	Grouper	159.7	315.6	31.94	0	4485.1	42

Ecoregion	Indicator	Mean	Std. dev	Collapse threshold	Min value	Max value	n
Central Mozambique Channel	Grouper	307.2	392.9	61.44	2.3	2876.2	18

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, and were applied consistently across all ecoregions except where otherwise specified.

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% and 20% of baseline fish population abundance levels for parrotfish groupers, respectively (Obura et al., 2021)(Tables 19a and b).

Calculating relative severity of decline

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

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

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 6), with the ecosystem extent calculated as the proportion of sites exceeding decline thresholds (≥20%, ≥30%, ≥50%, ≥70%, ≥80%, and 100% decline). This process was repeated 1000 times, and each time the resulting highest risk category for the iteration was recorded (Fig S8, S10, S13). To determine the final risk category for each indicator, the distribution of outcomes across all iterations was considered. Where ≥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 characterize ecosystem-wide patterns (n<10 sites with current data), the ecoregion was classified as *Data Deficient* (South Madagascar, Northern Monsoon Current – all indicators, North and East Madagascar – fish indicators).

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 structural 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 such as fish.

2.7 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.

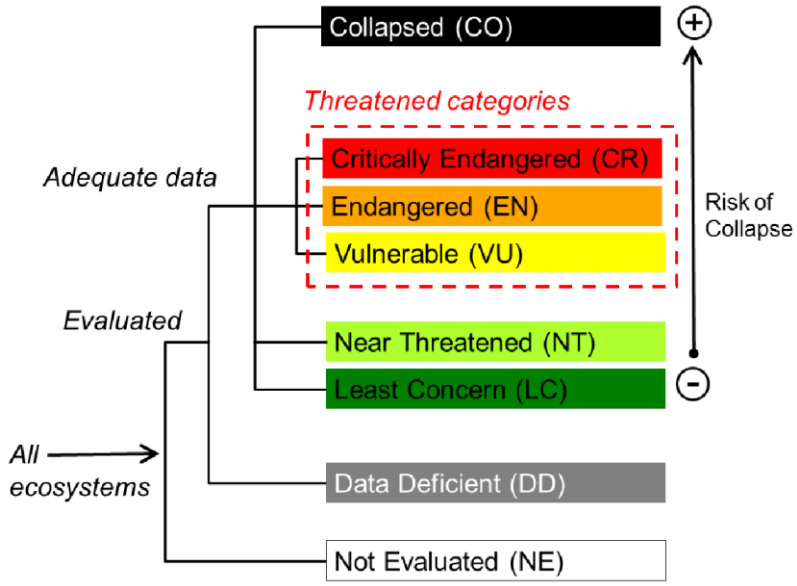


Figure 7. Risk categories for ecosystems from the IUCN Red List of Ecosystems (RLE)

3.Discussion

The services provided by coral reefs in the WIO are valued at approximately $8 billion annually (D. O. Obura et al., 2017). They are integral to the livelihoods of small-scale fishers, provide vital seafood to coastal communities, offer protection to valuable coastlines, and underpin diving and snorkeling tourism. This assessment shows that through the cumulative effects of localized threatening processes and marine heatwaves driven by climate change, coral reefs, and the biodiversity and services they support, are under enormous threat.

Key results, broad regional patterns/comparisons across ecoregions

Degradation of the essential biotic components of coral reefs has increased in the five years since the first RLE of WIO coral reefs was undertaken (Obura et al., 2021). Under Criterion D, our results show a general increase in risk status across six ecoregions relative to the original assessment (which used data from 2013-2019). Whereas the original assessment classified only one ecoregion as Endangered, with the remainder in lower risk categories, our updated analysis finds one ecoregion is now Critically Endangered, four ecoregions are Endangered and four are Vulnerable, with only two coral reef ecosystems remaining non-threatened (NT or LC) i.e. North and East Madagascar (though both these ecoregions lacked sufficient data on fish). This continued degradation can largely be attributable to the impacts of the 2016 and 2024 global mass coral bleaching event, which caused widespread and severe coral mortality across the region (Gudka et al., 2018; Gudka et al., 2020; Mbugua et al., 2024; Gudka, 2025; Mayfield, 2025; Moejes et al., 2026).

Despite this overall increase in risk in ecosystem collapse, the relative contribution of individual threatening processes has remained broadly consistent between assessments. The fish indicators were in greatest decline, particularly in Kenya & Northern Tanzania, Southern

Tanzania & Northern Mozambique, and Comoros. Groupers continue to be identified among the biotic components under greatest threat, reflecting sustained pressure from overfishing on this functionally important group, as well as potential habitat degradation and loss of complex reef structure (Obura et al., 2021; M. Samoilys, Osuka, et al., 2025; M. Samoilys, Roche, et al., 2025). Seychelles Outer, Mascarene islands (Reunion) and Delagoa, were the only three ecoregions not falling within the threatened classifications, likely due to remoteness or effective protection measures reducing fishing pressure. As with (Obura et al., 2021), Parrotfish generally showed lower levels of threat compared to Groupers, though still falling within threatened classifications across seven ecoregions.

Hard coral cover decline was the greatest in Comoros (EN) and the algal coral ratio was least favourable in the inner Seychelles (EN). For five ecoregions the highest risk within observed criteria to date was based solely on the disruption of ecosystem processes (D). Declines in these critical ecosystem components may be driven by local human pressures as well as historical climate pressures (see Table 1). Parrotfish and groupers are affected by unsustainable fishing, the algal-coral ratio can indicate bottom-up nutrient enrichment and/or trophic cascades from low herbivorous fish populations. Hard coral cover is affected by all pressures compounding on the reef system. These impacts are already starting to impact the area of functional coral reef ecosystems across Seychelles Inner, West Madagascar and Comoros ecoregions, with over 30% of reefs already undergoing local collapse (<5% coral cover) (Vulnerable under Criterion A). Managers and decision makers must consider local pressures in detail to decide which management options would be most effective at supporting critical ecosystem processes.

Historical changes and climate change impacts

Our inclusion of sub-criterion C1 represents a methodological advancement on the original assessment, which considered only the future-looking C2. Under C1, all ecoregions already sit within a threatened category as a result of historical climate warming, with seven of twelve ecoregions classified as Vulnerable, four as Endangered, and one as Critically Endangered. For seven ecoregions, severity of past thermal stress (C1) was the highest (or joint highest) risk criterion based on observed changes (i.e. not including C2). This result is in line with expectations based on the well-documented historical impacts of major marine heatwaves in the WIO in 1998, 2016 and 2024, each of which drove widespread and, in places, severe coral bleaching and mortality (Wilkinson et al., 1999; Obura et al., 2017; Gudka et al., 2020; Randrianarivo et al., 2025).

Future climate change impacts

Criterion C2 assesses how changing ocean conditions over the next 50 years could threaten the persistence of coral reefs. Our results for the WIO indicate that the frequency of intense marine heatwaves is projected to increase dramatically over this period, even under a relatively moderate Shared Socioeconomic Pathway (SSP2 - 4.5). Under this scenario, global greenhouse gas emissions result in about 2.1°C to 3.5°C of warming by the year 2100 (IPCC, 2021). The fourth global coral bleaching event (2023-2025), and the imminent 'Super El Nino' (Dinneen, 2026; World's Fourth Mass Coral Bleaching Event Likely Ended in 2025),

demonstrate that the impacts and risks posed are real and imminent. For coral reefs in the region and globally, this may result in regime shifts as the intervals and magnitude of bleaching events no longer allow for coral recovery (Hughes et al., 2017, 2018; Emslie et al., 2024). 2025 already saw global mean temperatures reaching 1.43°C above pre-industrial levels (State of the Global Climate 2025), and with the Paris Agreement limit of 1.5°C set to be crossed within the next few years, it is imperative for international and regional bodies, including the Nairobi Convention and its Contracting Parties, to advocate for ambitious global mitigation, ensuring the overshoot is as low and as short as possible.

There was a marked increase in projected risk under sub-criterion C2 compared to Obura et al. 2021. While the first assessment found the island ecoregions to all be highly threatened (EN or CR, except Seychelles Inner), the mainland ecoregions were classified as Least Concern. In contrast, our updated analysis finds that all ecoregions have progressed to Critically Endangered under C2. This shift is at least partly attributable to differences in the underlying climate projections used across the two assessments. The original assessment drew on downscaled sea-surface-temperature projections generated from CMIP5 (Coupled Model Intercomparison Project Phase 5) climate models under the Representative Concentration Pathway (RCP) framework (van Hooidonk et al., 2016), the standard global climate modelling suite available at the time. Our updated analysis instead uses more recent projections (Mellin et al., 2024), generated using CMIP6 models under the Shared Socioeconomic Pathway (SSP) framework, which incorporate more recent observed warming trends and improvements in climate modelling (UNEP, 2020). Notably, CMIP6-based coral bleaching projections have been shown to project the onset of annual severe bleaching conditions several years earlier, on average, than equivalent CMIP5/RCP8.5-based projections, indicating that the earlier generation of climate models underestimated the near-term severity of ocean warming (UNEP, 2020). The shift from a mixed threat status to universal CR classification under C2 provides further evidence that the trajectory of ocean warming is already accelerating more rapidly than earlier projections anticipated. The other major advancement between the assessments is the latest approach considers the changes in conditions across the relative extent (spatially) of coral reefs in each ecoregion rather than relying on a single average value.

While our results reinforce what is already well established, that climate change this century through coral bleaching poses a severe risk to coral reef survival and the biodiversity reefs support (Hoegh-Guldberg et al., 2007; Hughes et al., 2017; Bozec et al., 2025). However, these results should not be interpreted as predictions of how individual reefs will respond, but rather as an indication of how the broader thermal environment is expected to change, and the risks this place to coral reef ecosystems as a whole. In addition, several other important caveats should be considered when interpreting these results.

First, the blanket Critically Endangered (CR) classification applied across all ecoregions is based on projected DHW data at a relatively coarse spatial resolution (~55 kilometres), so finer-scale variation in warming is not captured. Not all reef areas will warm at the rate suggested by these coarse projections, and some locations, for example those subject to localized upwelling or shading, may act as thermal refugia (McClanahan et al., 2024;

Randrianarivo et al., 2025). However, given the extent of warming observed during the 2024 bleaching event and the intensity of projected future warming, such refugia are likely to be limited (Dixon et al., 2022). Second, although the analysis accounts for potential thermal adaptation of corals or their algal symbionts (zooxanthellae) by testing higher DHW thresholds related to bleaching in the future, these thresholds are defined at the ecoregional scale and cannot capture finer-scale variation in how coral communities respond to warming, which is difficult to predict.

Third, the projected DHW data used in this assessment are derived from an ensemble of climate models and therefore other models, or alternative combinations within the ensemble, may project less severe warming trajectories than the ensemble mean applied here. Fourth, the analysis relies on a single metric, DHW, to characterize thermal stress exposure. While DHW has a strong and well-established association with observed bleaching events, it does not fully capture the more nuanced dynamics of thermal stress and coral bleaching responses, such as the rate of temperature change or range of temperature variability (Ateweberhan and McClanahan, 2010). Incorporating this additional nuance is difficult to reconcile with the standardized, threshold-based approach required under the RLE framework, but it should nonetheless be recognized as a limitation of the current approach. Future assessments should continue to refine approaches using the latest available projections at finer spatial resolution.

Criterion D assesses the risk of ecosystem collapse resulting from the disruption of biotic processes and interactions, and for coral reefs this primarily relies on coarse metrics such as hard coral cover. This is an appropriate indicator within the RLE framework, as it captures whether a system remains, by definition, a coral reef, or has been fundamentally transformed through the loss (or near-complete loss) of its iconic, reef-building biota. However, hard coral cover alone does not capture other important dimensions of degradation within the coral community, such as changes in species composition, structural complexity, or broader biodiversity loss (McClanahan et al., 2014). Where sufficient data are available and reasonable baselines can be established, indicators such as changes in coral recruitment rates and reef rugosity would provide valuable complementary lines of evidence for assessing Criterion D.

Management under a changing climate

Despite this worrying outlook driven by climate change, continued and strengthened local action remains critical, as any disruption of biotic function driven by climate change can be compounded by local stressors such as land-based pollution and sedimentation, coastal development, overfishing and destructive fishing practices (Ateweberhan et al., 2013; Donovan et al., 2021). Which management option is most relevant in each context is dependent on the most severe pressure(s) affecting specific reefs, which is beyond the scope of this assessment. Management tools include tried and tested techniques such as no-take MPAs to more novel techniques such as coral restoration and manipulations of the coral microbiome.

In our regional context, spatial protections (i.e. MPAs) have been enhanced by facilitating expansion and enforcement of community managed areas. Where governance is well

supported, these locally managed marine areas (LMMAs) can enhance community stewardship and have been shown to improve herbivore biomass (Rocliffe et al., 2014). In addition, these community managed areas can support countries' commitment towards the 30% protection and management of their ocean by 2030 if they are formally recognised as Other effective area-based conservation measures (OECMs) (Rocliffe et al., 2014; Jonas et al., 2024).

Some regional governments (e.g. Kenya) have shown a strong interest in Blue Economy initiatives, many of which are underpinned by natural resources (https://kemfsed.org/wp-content/uploads/2026/02/National-Blue-Economy-Strategy_FACTSHEETNo1-final.pdf). This interest has mobilized much-needed resources towards the ocean and presents an opportunity to strengthen conservation and the sustainable use of ecosystems and biodiversity. This will ensure that associated activities and investment do not contribute to the continued degradation of nature, but instead actively work to reduce the risk faced by ecosystems. Through this, countries in the region can build more holistic approaches to reef and ocean conservation by managing stressors at their source on land, before they reach the ocean. Minimizing the input of pollutants and sediment would ensure coastal water quality is clean and safe for recreational use, and that other coastal and marine ecosystems which are less susceptible to the impacts of climate change such as mangroves and seagrasses continue to thrive and provide benefits to society. Maintaining the best possible local conditions through sustainable management will maximize the benefits derived from surviving corals and associated biodiversity, and support post-disturbance reef recovery.

This re-assessment of WIO coral reefs has several direct applications for policy. The RLE is a headline indicator (A.1) under the Kunming-Montreal Global Biodiversity Framework, meaning this assessment directly supports national reporting obligations under the Convention on Biological Diversity (Nicholson et al., 2024). Countries can integrate national and transboundary risk results directly into domestic policy and legislation, to afford higher levels of protection to threatened ecosystems. Results should further be used to inform and update resolutions under regional instruments such as the UNEP Nairobi Convention, to increase and prioritize action on coral reefs and other threatened ecosystems across the region.

This assessment also highlights that the long-term monitoring frameworks coordinated under the Nairobi Convention are critical to understanding the status and trajectory of the region's ecosystems and require continued and expanded investment. Coral reefs in Somalia (Northern Current Coast ecoregion), for example, could not be included in this assessment due to a lack of available monitoring data, underscoring the need for investment in establishing baseline and ongoing monitoring in this country. In addition, a lack of data across parts of Madagascar, particularly in the south, and for fish in North and East Madagascar, result in missing and underestimation of declines and risk under Criterion D. Similarly, the assessment of the Mascarene Islands did not include data from Mauritius, highlighting the need for renewed investment in national monitoring capacity and full, active participation in regional monitoring networks. Extending similar networks and standardized monitoring

approaches to related ecosystems, such as seagrass and mangroves, would provide comparable benefits for future assessments of these systems.

References

Adjeroud, M., Carlot, J., Brandl, S., Bigot, L., Guilhaumon, F., Job, S., Kayal, M., Maréchal, J.-P., et al. (2026) Coral reef monitoring in French overseas territories: status, knowledge gaps, and improvements to meet national and European environmental policy objectives. *Environ. Sustain. Indic.*, **30**, 101255.

Allen, G. R. (2008) Conservation hotspots of biodiversity and endemism for Indo-Pacific coral reef fishes. *Aquat. Conserv. Mar. Freshw. Ecosyst.*, **18**, 541–556.

Andréfouët, S., Guillaume, M. M. M., Delval, A., Rasoamanendrika, F. M. A., Blanchot, J., and Bruggemann, J. H. (2013) Fifty years of changes in reef flat habitats of the Grand Récif of Toliara (SW Madagascar) and the impact of gleaning. *Coral Reefs*, **32**, 757–768.

ASCLME (2012) Transboundary Diagnostic Analysis (TDA) of the Large Marine Ecosystems of the Western Indian Ocean — Volume 1: Baseline. Agulhas and Somali Current Large Marine Ecosystems Project (ASCLME) and South West Indian Ocean Fisheries Project (SWIOFP).

Ateweberhan, M., Feary, D. A., Keshavmurthy, S., Chen, A., Schleyer, M. H., and Sheppard, C. R. C. (2013) Climate change impacts on coral reefs: Synergies with local effects, possibilities for acclimation, and management implications. *Mar. Pollut. Bull.*, **74**, 526–539.

Ateweberhan, M. and McClanahan, T. R. (2010) Relationship between historical sea-surface temperature variability and climate change-induced coral mortality in the western Indian Ocean. *Mar. Pollut. Bull.*, **60**, 964–970.

Awad, A. (2011) REPORT ON THE INVASIVE SPECIES COMPONENT OF THE MEDA's, TDA & SAP FOR THE ASCLME PROJECT. Cape Town, South Africa.

Baker, A. C., Glynn, P. W., and Riegl, B. (2008) Climate change and coral reef bleaching: An ecological assessment of long-term impacts, recovery trends and future outlook. *Estuar. Coast. Shelf Sci.*, **80**, 435–471.

Barber, P. H. and Meyer, C. P. (2015) Pluralism explains diversity in the Coral Triangle. In Mora, C. (ed), *Ecology of Fishes on Coral Reefs*. Cambridge University Press, pp. 258–263.

Bax, N., Williamson, A., Aguero, M., Gonzalez, E., and Geeves, W. (2003) Marine invasive alien species: a threat to global biodiversity. *Mar. Policy*, **27**, 313–323.

Beese, C. M., Mumby, P. J., and Rogers, A. (2023) Small-scale habitat complexity preserves ecosystem services on coral reefs. *J. Appl. Ecol.*, **60**, 1854–1867.

Behivoke, F., D'Agata, S., Guitton, J., Etienne, M.-P., Randriatsara, R. M., Ranaivoson, E., Mahafina, J., and Léopold, M. (2026) Fine-scale fishery patterns reveal challenges and opportunities for coastal management and conservation in Madagascar. *Aquat. Living Resour.*, **39**, 6.

Behivoke, F., Etienne, M.-P., Guitton, J., Randriatsara, R. M., Ranaivoson, E., and Léopold, M. (2021) Estimating fishing effort in small-scale fisheries using GPS tracking data and random forests. *Ecol. Indic.*, **123**, 107321.

Bellwood, D. R., Hughes, T. P., Folke, C., and Nyström, M. (2004) Confronting the coral reef crisis. *Nature*, **429**, 827–833.

Beyer, H. L., Kennedy, E. V., Beger, M., Chen, C. A., Cinner, J. E., Darling, E. S., Eakin, C. M., Gates, R. D., et al. (2018) Risk-sensitive planning for conserving coral reefs under rapid climate change. *Conserv. Lett.*, **11**, e12587.

Birrell, C., Sola, E., and Costa, H. (2022) *A contribution to Mozambique's biodiversity offsetting scheme: Framework to assess the ecological condition of coral reefs*. Wildlife Conservation Society, Maputo, Mozambique.

Bland, L. M., Keith, D. A., Miller, R. M., Murray, N. J., and Rodríguez, J. P. (eds) (2015) *Guidelines for the application of IUCN Red List of ecosystems categories and criteria*. IUCN International Union for Conservation of Nature.

Bland, L. M., Rowland, J. A., Regan, T. J., Keith, D. A., Murray, N. J., Lester, R. E., Linn, M., Rodríguez, J. P., et al. (2018) Developing a standardized definition of ecosystem collapse for risk assessment. *Front. Ecol. Environ.*, **16**, 29–36.

Bottlenecks to coral recovery in the Seychelles | Coral Reefs | Springer Nature Link.

Bozec, Y.-M., Adam, A. A. S., Arellano-Nava, B., Cresswell, A. K., Haller-Bull, V., Iwanaga, T., Lachs, L., Matthews, S. A., et al. (2025) A rapidly closing window for coral persistence under global warming. *Nat. Commun.*, **16**, 9704.

Brakel, W. H. (1984) Seasonal dynamics of suspended-sediment plumes from the Tana and Sabaki Rivers, Kenya: Analysis of landsat imagery. *Remote Sens. Environ.*, **16**, 165–173.

Brandl, S. J., Rasher, D. B., Côté, I. M., Casey, J. M., Darling, E. S., Lefcheck, J. S., and Duffy, J. E. (2019) Coral reef ecosystem functioning: eight core processes and the role of biodiversity. *Front. Ecol. Environ.*, **17**, 445–454.

Braulik, G., Wittich, A., Macaulay, J., Kasuga, M., Gordon, J., Gillespie, D., and Davenport, T. R. B. (2015) Fishing with explosives in Tanzania: spatial distribution and hotspots. Wildlife Conservation Society, Zanzibar, Tanzania.

Bravo, H., Cannicci, S., Huyghe, F., Leermakers, M., Sheikh, M. A., and Kochzius, M. (2021) Ecological health of coral reefs in Zanzibar. *Reg. Stud. Mar. Sci.*, **48**, 102014.

Briggs, N. D., Page, C. A., Giuliano, C., Alessi, C., Hoogenboom, M., Bay, L. K., and Randall, C. J. (2024) Dissecting coral recovery: bleaching reduces reproductive output in Acropora millepora. *Coral Reefs*, **43**, 557–569.

Burke, L. M., Reytar, K., Spalding, M., and Perry, A. (2011) Reefs at risk revisited. World Resources Institute, Washington, DC.

Byrne, M., Clements, M., Kingsford, M., Foo, S. A., Ramjus, N., and Waller, A. (2025) Marine heatwave-driven mortality of bleached colonies of the massive coral Goniopora is exacerbated by a black band disease epizootic. *Proc. R. Soc. B Biol. Sci.*, **292**, 20251912.

Carbone, F. and Accordi, G. (2000) The Indian Ocean Coast of Somalia. *Mar. Pollut. Bull.*, **41**, 141–159.

Carneiro, M. and Martins, R. (2021) Destructive Fishing Practices and their Impact on the Marine Ecosystem. In Leal Filho, W., Azul, A. M., Brandli, L., Lange Salvia, A., and Wall, T. (eds), *Life Below Water*, Encyclopedia of the UN Sustainable Development Goals. Springer International Publishing, Cham, pp. 1–11.

Carreiro-Silva, M. and McClanahan, T. R. (2001) Echinoid bioerosion and herbivory on Kenyan coral reefs: the role of protection from fishing. *J. Exp. Mar. Biol. Ecol.*, **262**, 133–153.

Carter, A. L., Gilchrist, H., Dexter, K. G., Gardner, C. J., Gough, C., Rocliffe, S., and Wilson, A. M. W. (2022) Cyclone Impacts on Coral Reef Communities in Southwest Madagascar. *Front. Mar. Sci.*, **9**, 753325.

Cerutti, J. M. B., Burt, A. J., Haupt, P., Bunbury, N., Mumby, P. J., and Schaepman-Strub, G. (2020) Impacts of the 2014–2017 global bleaching event on a protected remote atoll in the Western Indian Ocean. *Coral Reefs*, **39**, 15–26.

Chazottes, V., Le Campion-Alsumard, T., Peyrot-Clausade, M., and Cuet, P. (2002) The effects of eutrophication-related alterations to coral reef communities on agents and rates of bioerosion (Reunion Island, Indian Ocean). *Coral Reefs*, **21**, 375–390.

Cheng, L., Abraham, J., Trenberth, K. E., Fasullo, J., Boyer, T., Mann, M. E., Zhu, J., Wang, F., et al. (2023) Another Year of Record Heat for the Oceans. *Adv. Atmos. Sci.*, **40**, 963–974.

Cheng, L., Trenberth, K. E., Fasullo, J., Boyer, T., Abraham, J., and Zhu, J. (2017) Improved estimates of ocean heat content from 1960 to 2015. *Sci. Adv.*, **3**, e1601545.

Choppy, T. P. (2025) Paradise threatened: a look at Seychelles in the anthropocene era. **8**, 341–360.

Cooke, A. (2022) (PDF) MARINE AND COASTAL ECOSYSTEMS MARINE AND COASTAL BIODIVERSITY AND CONSERVATION. *ResearchGate*.

coral-reefs-andavadoaka.

Corbari, L., Bouchet, P., Le Gall, L., Hourdez, S., Frutos, I., Gouillieux, B., Vassard, E., Moutardier, G., et al. (2025) New insights in benthic biodiversity of the saya de Malha Bank. *Deep Sea Res. Part II Top. Stud. Oceanogr.*, **222**, 105500.

Côté-Laurin, M.-C., Benbow, S., and Erzini, K. (2017) The short-term impacts of a cyclone on seagrass communities in Southwest Madagascar. *Cont. Shelf Res.*, **138**, 132–141.

Croquer, A. and Weil, E. (2009) Changes in Caribbean coral disease prevalence after the 2005 bleaching event. *Dis. Aquat. Organ.*, **87**, 33–43.

Dalleau, M., Kramer-Schadt, S., Gangat, Y., Bourjea, J., Lajoie, G., and Grimm, V. (2019) Modeling the emergence of migratory corridors and foraging hot spots of the green sea turtle. *Ecol. Evol.*, **9**, 10317–10342.

Darling, E. S., McClanahan, T. R., Maina, J., Gurney, G. G., Graham, N. A. J., Januchowski-Hartley, F., Cinner, J. E., Mora, C., et al. (2019) Social–environmental drivers inform strategic management of coral reefs in the Anthropocene. *Nat. Ecol. Evol.*, **3**, 1341–1350.

De Clippele, L. H., Díaz, L. A., Andradi-Brown, D. A., Lazuardi, M. E., Iqbal, M., Zainudin, I. M., Prabuning, D., van Hooidonk, R., et al. (2023) Evaluating annual severe coral bleaching risk for marine protected areas across Indonesia. *Mar. Policy*, **148**, 105428.

DeCarlo, T. M. and Whitaker, H. V. (2025) Coral Bleaching Projections for the Great Barrier Reef Throughout the 21st Century. *Geophys. Res. Lett.*, **52**, e2025GL119834.

DeVantier, L. and Turak, E. (2017) Species Richness and Relative Abundance of Reef-Building Corals in the Indo-West Pacific. *Diversity*, **9**, 25.

Dinneen, J. (2026) The super El Niño is cooking coral reefs — can lullabies and probiotics save them? *Nature*, **658**, 22–24.

Dixon, A. M., Forster, P. M., Heron, S. F., Stoner, A. M. K., and Beger, M. (2022) Future loss of local-scale thermal refugia in coral reef ecosystems. *PLOS Clim.*, **1**, e0000004.

Donner, S. D., Rickbeil, G. J. M., and Heron, S. F. (2017) A new, high-resolution global mass coral bleaching database. *PLOS ONE*, **12**, e0175490.

Donovan, M. K., Burkepile, D. E., Kratochwill, C., Shlesinger, T., Sully, S., Oliver, T. A., Hodgson, G., Freiwald, J., et al. (2021) Local conditions magnify coral loss after marine heatwaves. *Science*, **372**, 977–980.

Duhec, A. V., Jeanne, R. F., Maximenko, N., and Hafner, J. (2015) Composition and potential origin of marine debris stranded in the Western Indian Ocean on remote Alphonse Island, Seychelles. *Mar. Pollut. Bull.*, **96**, 76–86.

Duvat, V. K. E., Volto, N., and Salmon, C. (2017) Impacts of category 5 tropical cyclone Fantala (April 2016) on Farquhar Atoll, Seychelles Islands, Indian Ocean. *Geomorphology*, **298**, 41–62.

Dynamic fragility of oceanic coral reef ecosystems | PNAS.

Eakin, C. M., Heron, S. F., Connolly, S. R., Devotta, D. A., Liu, G., Geiger, E. F., De La Cour, J. L., Gomez, A. M., et al. (2026) Severe and widespread coral reef damage during the 2014-2017 Global Coral Bleaching Event. *Nat. Commun.*, **17**, 1318.

Eddy, T. D., Lam, V. W. Y., Reygondeau, G., Cisneros-Montemayor, A. M., Greer, K., Palomares, M. L. D., Bruno, J. F., Ota, Y., et al. (2021) Global decline in capacity of coral reefs to provide ecosystem services. *One Earth*, **4**, 1278–1285.

Elma, E., Gullström, M., Yahya, S. A. S., Jouffray, J.-B., East, H. K., and Nyström, M. (2023) Post-bleaching alterations in coral reef communities. *Mar. Pollut. Bull.*, **186**, 114479.

Elma, E., Jouffray, J.-B., Yahya, S. A. S., Gullström, M., Jiddawi, N. S., and Nyström, M. (2026) Recovery without resilience? Contrasting benthic recovery trajectories six years after a mass coral bleaching event. *Mar. Environ. Res.*, **221**, 108223.

Emslie, M. J., Logan, M., Bray, P., Ceccarelli, D. M., Cheal, A. J., Hughes, T. P., Johns, K. A., Jonker, M. J., et al. (2024a) Increasing disturbance frequency undermines coral reef recovery. *Ecol. Monogr.*, **94**, e1619.

Emslie, M. J., Logan, M., Bray, P., Ceccarelli, D. M., Cheal, A. J., Hughes, T. P., Johns, K. A., Jonker, M. J., et al. (2024b) Increasing disturbance frequency undermines coral reef recovery. *Ecol. Monogr.*, **94**, e1619.

Erftemeijer, P. L. A., Riegl, B., Hoeksema, B. W., and Todd, P. A. (2012) Environmental impacts of dredging and other sediment disturbances on corals: A review. *Mar. Pollut. Bull.*, **64**, 1737–1765.

Ferrario, F., Beck, M. W., Storlazzi, C. D., Micheli, F., Shepard, C. C., and Airoldi, L. (2014) The effectiveness of coral reefs for coastal hazard risk reduction and adaptation. *Nat. Commun.*, **5**, 3794.

Freed, S. and Granek, E. F. (2014) Effects of Human Activities on the World's Most Vulnerable Coral Reefs: Comoros Case Study. *Coast. Manag.*, **42**, 280–296.

Friedlander, A. M., Obura, D., Aumeeruddy, R., Ballesteros, E., Church, J., Cebrian, E., and Sala, E. (2014) Coexistence of Low Coral Cover and High Fish Biomass at Farquhar Atoll, Seychelles. *PLoS ONE*, **9**, e87359.

Gilmour, J. P., Smith, L. D., Heyward, A. J., Baird, A. H., and Pratchett, M. S. (2013) Recovery of an Isolated Coral Reef System Following Severe Disturbance. *Science*, **340**, 69–71.

Global Distribution of Coral Reefs *UNEP-WCMC Resour.*

Good, A. M. and Bahr, K. D. (2021) The coral conservation crisis: interacting local and global stressors reduce reef resiliency and create challenges for conservation solutions. *SN Appl. Sci.*, **3**, 312.

Graham, N. A. J., Jennings, S., MacNeil, M. A., Mouillot, D., and Wilson, S. K. (2015) Predicting climate-driven regime shifts versus rebound potential in coral reefs. *Nature*, **518**, 94–97.

Graham, N. A. J., Nash, K. L., and Kool, J. T. (2011) Coral reef recovery dynamics in a changing world. *Coral Reefs*, **30**, 283–294.

Graham, N. A. J., Wilson, S. K., Benkwitt, C. E., Bonne, R., Govinden, R., and Robinson, J. P. W. (2024) Increased resilience and a regime shift reversal through repeat mass coral bleaching. *Ecol. Lett.*, **27**, e14454.

Graham, N. A. J., Wilson, S. K., Jennings, S., Polunin, N. V. C., Robinson, J., Bijoux, J. P., and Daw, T. M. (2007) Lag Effects in the Impacts of Mass Coral Bleaching on Coral Reef Fish, Fisheries, and Ecosystems. *Conserv. Biol.*, **21**, 1291–1300.

Green, A. L. and Bellwood, D. R. (eds) (2009) *Monitoring functional groups of herbivorous reef fishes as indicators of coral reef resilience: a practical guide for coral reef managers in the Asia Pacific region*. 2009 edition. International Union for Conservation of Nature, Gland, Switzerland.

Gudka, M., Aboud, S., and Obura, D. (2023) Establishing historical benthic cover levels for coral reefs of the Western Indian Ocean. *West. Indian Ocean J. Mar. Sci.*, **22**, 103–115.

Gudka, M., Obura, D., Mwaura, J., Porter, S., Yahya, S., and Mabwa, R. (2018) Impact of the 3rd Global Coral Bleaching Event on the Western Indian Ocean in 2016.

Gudka, M., Obura, D. O., Mbugua, J., Ahamada, S., Kloiber, U., and Holter, T. (2019) Participatory reporting of the 2016 bleaching event in the Western Indian Ocean. *Coral Reefs*.

Gudka, M., Obura, D. O., Mwaura, J., Porter, S., Yahya, S., and Mabwa, R. (2018) Impact of the 3rd Global Coral Bleaching Event on the Western Indian Ocean in 2016. *GCRMN/IOC*.

Gudka, M. S. (2025) Assessing resilience and collapse risk of coral reefs to support conservation action. *Find Expert Univ. Melb.*

Hassan, H. O., Ayeta, E. G., Ibrahim, A. A., Omar, M. F., Abdi, S. M., Houmed, Y. K., Dirie, A. M., and Faseyi, C. A. (2024) The first assessment of marine litter on Somalian coast: The case of Liido Beach, Mogadishu. *Heliyon*, **10**, e26593.

Henley, B. J., McGregor, H. V., King, A. D., Hoegh-Guldberg, O., Arzey, A. K., Karoly, D. J., Lough, J. M., DeCarlo, T. M., et al. (2024) Highest ocean heat in four centuries places Great Barrier Reef in danger. *Nature*, **632**, 320–326.

Heron, S. F., Maynard, J. A., van Hooidonk, R., and Eakin, C. M. (2016) Warming Trends and Bleaching Stress of the World's Coral Reefs 1985–2012. *Sci. Rep.*, **6**, 38402.

Hoegh-Guldberg, O. (1999) Climate change, coral bleaching and the future of the world's coral reefs. *Mar. Freshw. Res.*, **50**, 839–866.

Hoegh-Guldberg, O., Mumby, P. J., Hooten, A. J., Steneck, R. S., Greenfield, P., Gomez, E., Harvell, C. D., Sale, P. F., et al. (2007) Coral Reefs Under Rapid Climate Change and Ocean Acidification. *Science*, **318**, 1737–1742.

Honorato-Zimmer, D., Weideman, E. A., Ryan, P. G., and Thiel, M. (2022) Amounts, Sources, Fates and Ecological Impacts of Marine Litter and Microplastics in the Western Indian Ocean Region: A Review and Recommendations for Actions. *Oceanography and Marine Biology: An Annual Review, Volume 60*. CRC Press, Boca Raton, pp. 533–589.

van Hooidonk, R., Maynard, J., Tamelander, J., Gove, J., Ahmadia, G., Raymundo, L., Williams, G., Heron, S. F., et al. (2016) Local-scale projections of coral reef futures and implications of the Paris Agreement. *Sci. Rep.*, **6**, 39666.

https://kemfsed.org/wp-content/uploads/2026/02/National-Blue-Economy-Strategy_FACTSHEETNo1-final.pdf.

Hughes, T. P., Anderson, K. D., Connolly, S. R., Heron, S. F., Kerry, J. T., Lough, J. M., Baird, A. H., Baum, J. K., et al. (2018) Spatial and temporal patterns of mass bleaching of corals in the Anthropocene. *Science*, **359**, 80–83.

Hughes, T. P., Kerry, J. T., Álvarez-Noriega, M., Álvarez-Romero, J. G., Anderson, K. D., Baird, A. H., Babcock, R. C., Beger, M., et al. (2017) Global warming and recurrent mass bleaching of corals. *Nature*, **543**, 373–377.

IPCC (2021) Summary for Policymakers. *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 3–32.

Jacobs, Z. L., Yool, A., Jebri, F., Srokosz, M., Van Gennip, S., Kelly, S. J., Roberts, M., Sauer, W., et al. (2021) Key climate change stressors of marine ecosystems along the path of the East African coastal current. *Ocean Coast. Manag.*, **208**, 105627.

Januchowski-Hartley, F. A., Graham, N. A. J., Wilson, S. K., Jennings, S., and Perry, C. T. (2017) Drivers and predictions of coral reef carbonate budget trajectories. *Proc. R. Soc. B Biol. Sci.*, **284**, 20162533.

Johnson, G. C., Lumpkin, R., Beckley, B., Bellas-Manley, A., Carter, B. R., Cetinić, I., Chambers, D. P., Chan, D., et al. (2025) Global Oceans. *Bull. Am. Meteorol. Soc.*, **106**, S173–S232.

Jonas, H. D., Bingham, H. C., Bennett, N. J., Woodley, S., Zlatanova, R., Howland, E., Belle, E., Upton, J., et al. (2024) Global status and emerging contribution of other effective area-based conservation measures (OECMs) towards the '30x30' biodiversity Target 3. *Front. Conserv. Sci.*, **5**, 1447434.

Jouval, F., Latreille, A. C., Bureau, S., Adjeroud, M., and Penin, L. (2019) Multiscale variability in coral recruitment in the Mascarene Islands: From centimetric to geographical scale. *PLOS ONE*, **14**, e0214163.

Karisa, J. F., Obura, D. O., and Chen, C. A. (2020) Spatial heterogeneity of coral reef benthic communities in Kenya. *PLOS ONE*, **15**, e0237397.

Kayanne, H. (2017) Validation of degree heating weeks as a coral bleaching index in the northwestern Pacific. *Coral Reefs*, **36**, 63–70.

Keith, D. A., Ferrer-Paris, J. R., Nicholson, E., Bishop, M. J., Polidoro, B. A., Ramirez-Llodra, E., Tozer, M. G., Nel, J. L., et al. (2022) A function-based typology for Earth's ecosystems. *Nature*, **610**, 513–518.

Keith, D. A., Rodríguez, J. P., Rodríguez-Clark, K. M., Nicholson, E., Aapala, K., Alonso, A., Asmussen, M., Bachman, S., et al. (2013) Scientific Foundations for an IUCN Red List of Ecosystems. *PLoS ONE*, **8**, e62111.

Kleypas, J. A., Mcmanus, J. W., and Meñez, L. A. B. (1999) Environmental Limits to Coral Reef Development: Where Do We Draw the Line? *Am. Zool.*, **39**, 146–159.

Knoester, E. G., Plug, V. E., Murk, A. J., Sande, S. O., and Osinga, R. (2023) Fisheries restrictions and their cascading effects on herbivore abundance and macroalgae removal at Kenyan coral reefs. *J. Exp. Mar. Biol. Ecol.*, **559**, 151850.

Koester, A., Ford, A. K., Ferse, S. C. A., Migani, V., Bunbury, N., Sanchez, C., and Wild, C. (2021) First insights into coral recruit and juvenile abundances at remote Aldabra Atoll, Seychelles. *PLOS ONE*, **16**, e0260516.

Kuguru, B. L., Mgaya, Y. D., Ohman, M. C., and Wagner, G. M. (2004) The reef environment and competitive success in the Corallimorpharia. *Mar. Biol.*, **145**, 875–884.

Kulbicki, M., Parravicini, V., Bellwood, D. R., Arias-Gonzàlez, E., Chabanet, P., Floeter, S. R., Friedlander, A., McPherson, J., et al. (2013) Global Biogeography of Reef Fishes: A Hierarchical Quantitative Delineation of Regions. *PLoS ONE*, **8**, e81847.

Leitman, A. S., Hampton-Smith, M., Growns, I., Bell, S. L., and Mathias, R. H. (2026) Benthic Community Composition of Coral Reefs Is Associated with the Time Since Last Blast Fishing Event. *Biology*, **15**, 1584.

Levitan, D. R., Boudreau, W., Jara, J., and Knowlton, N. (2014) Long-term reduced spawning in Orbicella coral species due to temperature stress. *Mar. Ecol. Prog. Ser.*, **515**, 1–10.

Liu, G., Eakin, C. M., Rauenzahn, J. L., Christensen, T. R. L., Li, J., Skirving, W., Strong, A. E., and Burgess, T. (2012) NOAA Coral Reef Watch's Decision Support System for Coral Reef Management.

Liu, G., Strong, A., Skirving, W., and Arzayus, F. (2005) Overview of NOAA coral reef watch program's near-real time satellite global coral bleaching monitoring activities. *Proc 10th Int Coral Reef Symp*, **1**, 1783–1793.

Lokrantz, J., Nyström, M., Norström, A. V., Folke, C., and Cinner, J. E. (2009) Impacts of artisanal fishing on key functional groups and the potential vulnerability of coral reefs. *Environ. Conserv.*, **36**, 327–337.

Lutjeharms, J. R. E. (2007) Three decades of research on the greater Agulhas Current. *Ocean Sci*.

Mahongo, S. and Shaghude, Y. (2014) Modelling the dynamics of the Tanzanian coastal waters. *J. Oceanogr. Mar. Sci.*, **5**, 1–7.

Maina, J., De Moel, H., Zinke, J., Madin, J., McClanahan, T., and Vermaat, J. E. (2013) Human deforestation outweighs future climate change impacts of sedimentation on coral reefs. *Nat. Commun.*, **4**, 1986.

Mangubhai, S., Harrison, P., and Obura, D. (2007) Patterns of coral larval settlement on lagoon reefs in the Mombasa Marine National Park and Reserve, Kenya. *Mar. Ecol. Prog. Ser.*, **348**, 149–159.

Mayfield, A. B. (2025) A Citizen Science Approach for Documenting Mass Coral Bleaching in the Western Indian Ocean. *Environments*, **12**, 276.

Mayorga-Adame, C. G., Batchelder, H. P., and Spitz, Yvette. H. (2017) Modeling Larval Connectivity of Coral Reef Organisms in the Kenya-Tanzania Region. *Front. Mar. Sci.*, **4**.

Mbugua, J., Aboud, S., and Obura, D. (2024) Western Indian Ocean – Regional Coral Bleaching Report 2024. CORDIO East Africa.

McClanahan, T. (1988) Seasonality in East Africa's coastal waters. *Mar. Ecol. Prog. Ser.*, **44**, 191–199.

McClanahan, T., Ateweberhan, M., Graham, N., Wilson, S., Sebastián, C., Guillaume, M., and Bruggemann, J. (2007) Western Indian Ocean coral communities: bleaching responses and susceptibility to extinction. *Mar. Ecol. Prog. Ser.*, **337**, 1–13.

McClanahan, T., Munbodhe, V., Naggea, J., Muthiga, N., and Bhagooli, R. (2021) Rare coral and reef fish species status, possible extinctions, and associated environmental perceptions in Mauritius. *Conserv. Sci. Pract.*, **3**, e527.

McClanahan, T. R., Ateweberhan, M., Darling, E. S., Graham, N. A. J., and Muthiga, N. A. (2014) Biogeography and Change among Regional Coral Communities across the Western Indian Ocean. *PLoS ONE*, **9**, e93385.

McClanahan, T. R., Cinner, J. E., Graham, N. A. J., Daw, T. M., Maina, J., Stead, S. M., Wamukota, A., Brown, K., et al. (2009) Identifying Reefs of Hope and Hopeful Actions: Contextualizing Environmental, Ecological, and Social Parameters to Respond Effectively to Climate Change. *Conserv. Biol.*, **23**, 662–671.

McClanahan, T. R., Darling, E. S., Beger, M., Fox, H. E., Grantham, H. S., Jupiter, S. D., Logan, C. A., Mcleod, E., et al. (2024) Diversification of refugia types needed to secure the future of coral reefs subject to climate change. *Conserv. Biol. J. Soc. Conserv. Biol.*, **38**, e14108.

McClanahan, T. r. and Kaunda-Arara, B. (1996) Fishery Recovery in a Coral-reef Marine Park and Its Effect on the Adjacent Fishery. *Conserv. Biol.*, **10**, 1187–1199.

McClanahan, T. R., Maina, J. M., and Muthiga, N. A. (2011) Associations between climate stress and coral reef diversity in the western Indian Ocean: INDIAN OCEAN STRESS AND CORAL DIVERSITY. *Glob. Change Biol.*, **17**, 2023–2032.

McClanahan, T. R. and Muthiga, N. A. (1988) Changes in Kenyan coral reef community structure and function due to exploitation. *Hydrobiologia*, **166**, 269–276.

McClanahan, T. R. and Muthiga, N. A. (2016) Geographic extent and variation of a coral reef trophic cascade. *Ecology*, **97**, 1862–1872.

McManus, J. W. and Polsenberg, J. F. (2004) Coral–algal phase shifts on coral reefs: Ecological and environmental aspects. *Prog. Oceanogr.*, **60**, 263–279.

Mellin, C., Brown, S., Cantin, N., Klein-Salas, E., Mouillot, D., Heron, S. F., and Fordham, D. A. (2024) Cumulative risk of future bleaching for the world's coral reefs. *Sci. Adv.*, **10**, eadn9660.

Menezes, A., Eide, A., and Raakjær, J. (2011) Moving Out of Poverty: Conditions for Wealth Creation in Small-Scale Fisheries in Mozambique. In Jentoft, S. and Eide, A. (eds), *Poverty Mosaics: Realities and Prospects in Small-Scale Fisheries*. Springer Netherlands, Dordrecht, pp. 407–425.

Merchant, C. J., Allan, R. P., and Embury, O. (2025) Quantifying the acceleration of multidecadal global sea surface warming driven by Earth's energy imbalance. *Environ. Res. Lett.*, **20**, 024037.

Millennium Corals – USF IMaRS.

Moejes, K., O'Brien, A. H., Bigot, L., Porter, S. N., Eylem, E., Gendron, G., Léo, B., Wickel, J., et al. (2026) Chapter 10 - Western Indian Ocean. In González-Rivero, M., Dallison, T., Wicquart, J., Brigdale, A., Logan, M., Fobert, E. K., Staub, F., and Planes, S. (eds), *Status of Coral Reefs of the World: 2025*. Global Coral Reef Monitoring Network and International Coral Reef Initiative.

Montaggioni, L. F. and Martin-Garin, B. (2020) Quaternary development history of coral reefs from West Indian islands: a review. *Int. J. Earth Sci.*, **109**, 911–930.

Mudge, L. and Bruno, J. F. (2023) Disturbance intensification is altering the trait composition of Caribbean reefs, locking them into a low functioning state. *Sci. Rep.*, **13**, 14022.

Mwaura, J., Umezawa, Y., Nakamura, T., and Kamau, J. (2017) Evidence of chronic anthropogenic nutrient within coastal lagoon reefs adjacent to urban and tourism centers, Kenya: A stable isotope approach. *Mar. Pollut. Bull.*, **119**, 74–86.

Nicet, J.-B., Facon, M., Poignant, A., Pinault, M., Beaufort, M., and Wickel, J. (2025) Impact du cyclone Chido et de la tempête Dikeledi sur les récifs coralliens de Mayotte - Effets cumulés avec le blanchissement corallien massif de 2024. MAREX / CREOCEAN, Mayotte, France.

Nicholson, E., Andrade, A., Brooks, T. M., Driver, A., Ferrer-Paris, J. R., Grantham, H., Gudka, M., Keith, D. A., et al. (2024) Roles of the Red List of Ecosystems in the Kunming-Montreal Global Biodiversity Framework. *Nat. Ecol. Evol.*, **8**, 614–621.

Nomenisoa, A. L. D., Todinanahary, G., Edwin, H. Z., Razakarisoa, T., Israel, J. B., Raseta, S., Jaonalison, H., Mahafina, J., et al. (2024) Remote sensing of coral reef habitats in Madagascar using Sentinel-2 satellite images. *West. Indian Ocean J. Mar. Sci.*, **23**, 41–56.

Norström, A., Nyström, M., Lokrantz, J., and Folke, C. (2009) Alternative states on coral reefs: beyond coral–macroalgal phase shifts. *Mar. Ecol. Prog. Ser.*, **376**, 295–306.

Obura, D. (2012) The Diversity and Biogeography of Western Indian Ocean Reef-Building Corals. *PLoS ONE*, **7**, e45013.

Obura, D., Gudka, M., Fouad Abdou Rabi, Suraj Bacha Gian, Bigot, L., Bijoux, J., Freed, S., Maharavo, J., et al. (2017) Coral Reef Status Report for the Western Indian Ocean (2017). Global Coral Reef Monitoring Network (GCRMN)/International Coral Reef Initiative (ICRI).

Obura, D., Gudka, M., Samoilys, M., Osuka, K., Mbugua, J., Keith, D. A., Porter, S., Roche, R., et al. (2021) Vulnerability to collapse of coral reef ecosystems in the Western Indian Ocean. *Nat. Sustain.*, **5**, 104–113.

Obura, D. O. (2001) Can differential bleaching and mortality among coral species offer useful indicators for assessment and management of reefs under stress? *Bull. Mar. Sci.*, **69**, 421–442.

Obura, D. O., Smits, M., Chaudhry, T., McPhillips, J., Beal, D., and Astier, C. (2017) Reviving the Western Indian Ocean Economy. WWF International, Gland, Switzerland, WWF International, Gland, Switzerland.

O'Leary, J. K. and McClanahan, T. R. (2010) Trophic cascades result in large-scale coralline algae loss through differential grazer effects. *Ecology*, **91**, 3584–3597.

O'Leary, J. K., Potts, D., Schoenrock, K., and McClahanan, T. (2013) Fish and sea urchin grazing opens settlement space equally but urchins reduce survival of coral recruits. *Mar. Ecol. Prog. Ser.*, **493**, 165–177.

Osuka, K., Kochzius, M., Vanreusel, A., Obura, D., and Samoilys, M. (2018) Linkage between fish functional groups and coral reef benthic habitat composition in the Western Indian Ocean. *J. Mar. Biol. Assoc. U. K.*, **98**, 387–400.

Painter, S. C. (2020) The biogeochemistry and oceanography of the East African Coastal Current. *Prog. Oceanogr.*, **186**, 102374.

Parravicini, V., Kulbicki, M., Bellwood, D. R., Friedlander, A. M., Arias-Gonzalez, J. E., Chabanet, P., Floeter, S. R., Myers, R., et al. (2013) Global patterns and predictors of tropical reef fish species richness. *Ecography*, **36**, 1254–1262.

Pebesma, E. (2018) The R Journal: Simple Features for R: Standardized Support for Spatial Vector Data. *R J.*, **10**, 439–446.

Perry, C. T. (2003) Coral reefs in a high-latitude, siliciclastic barrier island setting: reef framework and sediment production at Inhaca Island, southern Mozambique. *Coral Reefs*, **22**, 485–497.

Perry, C. T., Murphy, G. N., Kench, P. S., Smithers, S. G., Edinger, E. N., Steneck, R. S., and Mumby, P. J. (2013) Caribbean-wide decline in carbonate production threatens coral reef growth. *Nat. Commun.*, **4**, 1402.

Polidoro, B., Rossi, S., Sheppard, C. R. C., Porter, S. N., and Keith, D. A. (2022) M1.3 Photic coral reefs. In Keith, D. A., Ferrer-Paris, J. R., Nicholson, E., Bishop, M. J., Polidoro, B. A., Ramirez-Llodra, E., Tozer, M. G., Nel, J. L., *et al.* (eds), *The IUCN Global Ecosystem Typology v2.1: Descriptive profiles for Biomes and Ecosystem Functional Groups. Appendix S4 in: A function-based typology for Earth's ecosystems*. Nature, pp. 513–518.

Porter, S. N., Branch, G. M., and Sink, K. J. (2013) Biogeographic patterns on shallow subtidal reefs in the western Indian Ocean. *Mar. Biol.*, **160**, 1271–1283.

Porter, S. N., Branch, G. M., and Sink, K. J. (2017) Changes in shallow-reef community composition along environmental gradients on the East African coast. *Mar. Biol.*, **164**, 101.

Porter, S. N., Humphries, M. S., Buah-Kwofie, A., and Schleyer, M. H. (2018) Accumulation of organochlorine pesticides in reef organisms from marginal coral reefs in South Africa and links with coastal groundwater. *Mar. Pollut. Bull.*, **137**, 295–305.

Porter, S. N. and Schleyer, M. H. (2019) Environmental Variation and How its Spatial Structure Influences the Cross-Shelf Distribution of High-Latitude Coral Communities in South Africa. *Diversity*, **11**, 57.

Porter, S. N., Sink, K. J., and Schleyer, M. H. (2021) The Third Global Coral Bleaching Event on the Marginal Coral Reefs of the Southwestern Indian Ocean and Factors That Contribute to Their Resistance and Resilience. *Diversity*, **13**, 464.

Pratchett, M. S., Heron, S. F., Mellin, C., and Cumming, G. S. (2021) Recurrent Mass-Bleaching and the Potential for Ecosystem Collapse on Australia's Great Barrier Reef. In Canadell, J. G. and Jackson, R. B. (eds), *Ecosystem Collapse and Climate Change*. Springer International Publishing, Cham, pp. 265–289.

Pratchett, M. S., McCowan, D., Maynard, J. A., and Heron, S. F. (2013) Changes in Bleaching Susceptibility among Corals Subject to Ocean Warming and Recurrent Bleaching in Moorea, French Polynesia. *PLoS ONE*, **8**.

Programme, U. N. E. (2020) *Projections of Future Coral Bleaching Conditions using IPCC CMIP6 Models: Climate Policy Implications, Management Applications, and Regional Seas Summaries*.

Raharinaivo, L., Rina, Todinanahary, G., Delroisse, J., Raquez, J.-M., Bittencourt, C., Maherizo, T. G. F., Lavitra, T., and Eeckhaut, I. (2025) Quantification of anthropogenic debris from small-scale fisheries and community-based aquaculture in marine and coastal ecosystems of Southwestern Madagascar. *Mar. Pollut. Bull.*

Ramah, S., Kaullysing, D., and Bhagooli, R. (2022) First in-situ observation of the endemic giant clam Tridacna rosewateri from the Nazareth Bank, Mascarene Plateau. *West. Indian Ocean J. Mar. Sci.*, 193–196.

Ramanantsoa, J. D., Penven, P., Krug, M., Gula, J., and Rouault, M. (2018) Uncovering a New Current: The Southwest MAdagascar Coastal Current. *Geophys. Res. Lett.*, **45**, 1930–1938.

Ramsay, P. J. (1994) Marine geology of the Sodwana Bay shelf, southeast Africa. *Mar. Geol.*, **120**, 225–247.

Randrianarivo, M., Guilhaumon, F., Tsilavonarivo, J., Razakandrainy, A., Philippe, J., Botosoamananto, R. L., Penin, L., Todinanahary, G., et al. (2022) A contemporary baseline of Madagascar's coral assemblages: Reefs with high coral diversity, abundance, and function associated with marine protected areas. *PLOS ONE*, **17**, e0275017.

Randrianarivo, M., Rakotomanga, S., Razafindramasy, F., Ravelojaona, D. K., Ranaivoson, T., Rakotomalala, D., and Ratsimbazafy, R. (2025) Coral reefs in the Mahafaly Seascape (SW Madagascar) as potential climate refugia following the 2024 mass bleaching event. *PeerJ*, **13**, e20319.

Raymundo, L. J., Licuanan, W. L., and Kerr, A. M. (2018) Adding insult to injury: Ship groundings are associated with coral disease in a pristine reef. *PLOS ONE*, **13**, e0202939.

Redlistr: tools for the IUCN Red Lists of ecosystems and threatened species in R.

Reimer, J. D., Peixoto, R. S., Davies, S. W., Traylor-Knowles, N., Short, M. L., Cabral-Tena, R. A., Burt, J. A., Pessoa, I., et al. (2024) The Fourth Global Coral Bleaching Event: Where do we go from here? *Coral Reefs*, **43**, 1121–1125.

Richmond, M. (2011) *A Field Guide to the Seashores of Eastern Africa and the Western Indian Ocean Islands*. Revised third edition. Sida/WIOMSA: Sweden.

Ripanda, A. and Miraji, H. (2022) A Review on the Occurrence and Impacts of Nutrient Pollution in the Aquatic Ecosystem of Sub-Saharan Countries.

Robinson, J. P. W., Wilson, S. K., Jennings, S., and Graham, N. A. J. (2019) Thermal stress induces persistently altered coral reef fish assemblages. *Glob. Change Biol.*, **25**, 2739–2750.

Rocliffe, S., Peabody, S., Samoilys, M., and Hawkins, J. P. (2014) Towards A Network of Locally Managed Marine Areas (LMMAs) in the Western Indian Ocean. *PLOS ONE*, **9**, e103000.

Salimi, A. P., Creed, J. C., Esch, M. M., Fenner, D., Jaafar, Z., Levesque, J. C., Montgomery, A. D., Alidoost Salimi, M., et al. (2021) A review of the diversity and impact of invasive non-native species in tropical marine ecosystems. *Mar. Biodivers. Rec.*, **14**, 11.

Samimi-Namin, K., Woodall, L. C., Stefanoudis, P. V., Talma, S., and Hoeksema, B. W. (2025) Aggregations of free-living corals facilitate reef expansion at upper mesophotic depth off Poivre Island, Seychelles. *Mar. Biodivers.*, **55**, 79.

Samoilys, M. A. (1997) Periodicity of spawning aggregations of coral trout Plectropomus leopardus (Pisces: Serranidae) on the northern Great Barrier Reef. *Mar. Ecol. Prog. Ser.*, **160**, 149–159.
Samoilys, M. A., Halford, A., and Osuka, K. (2019) Disentangling drivers of the abundance of coral reef fishes in the Western Indian Ocean. *Ecol. Evol.*, **9**, 4149–4167.
Samoilys, M. A., Osuka, K., Maina, G. W., and Obura, D. O. (2017) Artisanal fisheries on Kenya's coral reefs: Decadal trends reveal management needs. *Fish. Res.*, **186**, 177–191.
Samoilys, M. A., Roche, R. C., Gudka, M., Thouless, C. J., Obura, D., Rowlands, S., Mbugua, J., and Osuka, K. (2025) Fish as indicators of coral reef ecosystem status. *Ecol. Indic.*, **179**, 114137.
Samoilys, M., Alvarez-Filip, L., Myers, R., and Chabanet, P. (2022) Diversity of Coral Reef Fishes in the Western Indian Ocean: Implications for Conservation. *Diversity*, **14**, 102.
Samoilys, M., Osuka, K. E., Roche, R., Koldewey, H., and Chabanet, P. (2025) Effects of protection on large-bodied reef fishes in the western Indian Ocean. *Conserv. Biol.*, **39**, e14430.
Samoilys, M., Roche, R. C., Gudka, M., Thouless, C. J., Obura, D., Rowlands, S., Mbugua, J., and Osuka, K. (2025) Fish as indicators of coral reef ecosystem status. *Ecol. Indic.*, **179**, 114137.
Samoilys, M., Roche, R., Koldewey, H., and Turner, J. (2018) Patterns in reef fish assemblages: Insights from the Chagos Archipelago. *PLOS ONE*, **13**, e0191448.
Samoilysetal-ResilientCoasts-book-2015-lowRes.
Saranya, J. S., Roxy, M. K., Dasgupta, P., and Anand, A. (2022) Genesis and Trends in Marine Heatwaves Over the Tropical Indian Ocean and Their Interaction With the Indian Summer Monsoon. *J. Geophys. Res. Oceans*, **127**, e2021JC017427.
Sarofim, M. C., Smith, C. J., Malek, P., McDuffie, E. E., Hartin, C. A., Lay, C. R., and McGrath, S. (2024) High radiative forcing climate scenario relevance analyzed with a ten-million-member ensemble. *Nat. Commun.*, **15**, 8185.
Sawall, Y., Jompa, J., Litaay, M., Maddusila, A., and Richter, C. (2013) Coral recruitment and potential recovery of eutrophied and blast fishing impacted reefs in Spermonde Archipelago, Indonesia. *Mar. Pollut. Bull.*, **74**, 374–382.
Schleyer, M. H., Baldwin, R., and Box, P. O. (1999) Somali Natural Resources Management Programme.
Schleyer, M. H. and Celliers, L. (2003) Biodiversity on the marginal coral reefs of South Africa: What does the future hold? *Zool. Verh.*, **345**, 387–400.
Schleyer, M. H., Floros, C., Laing, S. C. S., Macdonald, A. H. H., Montoya-Maya, P. H., Morris, T., Porter, S. N., and Seré, M. G. (2018) What can South African reefs tell us about the future of high-latitude coral systems? *Mar. Pollut. Bull.*, **136**, 491–507.
Schleyer, M. H., Kruger, A., and Celliers, L. (2008) Long-term community changes on a high-latitude coral reef in the Greater St Lucia Wetland Park, South Africa. *Mar. Pollut. Bull.*, **56**, 493–502.
Sheridan, C., Baele, J. M., Kushmaro, A., Fréjaville, Y., and Eeckhaut, I. (2014) Terrestrial runoff influences white syndrome prevalence in SW Madagascar. *Mar. Environ. Res.*, **101**, 44–51.
Skirving, W. J., Heron, S. F., Marsh, B. L., Liu, G., De La Cour, J. L., Geiger, E. F., and Eakin, C. M. (2019) The relentless march of mass coral bleaching: a global perspective of changing heat stress. *Coral Reefs*, **38**, 547–557.
SMSP Atlas *Seychelles Mar. Spat. Plan Initiat.*

Spady, B. L., Skirving, W. J., De La Cour, J. L., Geiger, E. F., Liu, G., Hoegh-Guldberg, O., Norrie, A., Heron, S. F., et al. (2026) The 4th global coral bleaching event: ushering in an era of near-annual bleaching. *Coral Reefs*.

Spalding, M. D., Fox, H. E., Allen, G. R., Davidson, N., Ferdaña, Z. A., Finlayson, M., Halpern, B. S., Jorge, M. A., et al. (2007) Marine Ecoregions of the World: A Bioregionalization of Coastal and Shelf Areas. *BioScience*, **57**, 573–583.

Spalding, M. D., Ravilious, C., and Green, E. P. (2001) *World Atlas of Coral Reefs*. University of California Press.

Staehr, P. A., Sheikh, M., Rashid, R., Ussi, A., Suleiman, M., Kloiber, U., Dahl, K., Tairova, Z., et al. (2018) Managing human pressures to restore ecosystem health of zanzibar coastal waters. *J. Aquac. Mar. Biol.*, **7**, 62–65.

State of the Global Climate 2025.

Sully, S., Burkepile, D. E., Donovan, M. K., Hodgson, G., and van Woesik, R. (2019) A global analysis of coral bleaching over the past two decades. *Nat. Commun.*, **10**, 1264.

Tagomori, I. S., Diuana, F. A., Baptista, L. B., Bertram, C., Dafnomilis, I., Drouet, L., Fosse, F., Fragkiadakis, D., et al. (2026) Promising climate progress from net-zero ambitions to the Paris Agreement goal. *Nat. Clim. Change*, **16**, 550–557.

The functional roles of surgeonfishes on coral reefs: past, present and future | Reviews in Fish Biology and Fisheries | Springer Nature Link.

Thomassin, B. A., Garcia, F., Sarrazin, L., Schembri, T., Wafo, E., Lagadec, V., Risoul, V., and Wickel, J. (2010) Coastal Seawater Pollutants in the Coral Reef Lagoon of a Small Tropical Island in Development: The Mayotte Example (N Mozambique Channel, SW Indian Ocean). In Ceccaldi, H.-J., Dekeyser, I., Girault, M., and Stora, G. (eds), *Global Change: Mankind-Marine Environment Interactions*. Springer Netherlands, Dordrecht, pp. 401–407.

Turner, J. and Klaus, R. (2005) Coral reefs of the Mascarenes, Western Indian Ocean. *Philos. Trans. R. Soc. Math. Phys. Eng. Sci.*, **363**, 229–250.

Turner, N. J., Ignace, M. B., and Ignace, R. (2000) TRADITIONAL ECOLOGICAL KNOWLEDGE AND WISDOM OF ABORIGINAL PEOPLES IN BRITISH COLUMBIA. *Ecol. Appl.*, **10**, 1275–1287.

Tyohemba, R. L., Humphries, M. S., Schleyer, M. H., and Porter, S. N. (2022) Accumulation of commonly used agricultural herbicides in coral reef organisms from iSimangaliso Wetland Park, South Africa. *Environ. Pollut.*

Ullgren, J. E., Van Aken, H. M., Ridderinkhof, H., and De Ruijter, W. P. M. (2012) The hydrography of the Mozambique Channel from six years of continuous temperature, salinity, and velocity observations. *Deep Sea Res. Part Oceanogr. Res. Pap.*, **69**, 36–50.

Uncovering drivers of juvenile coral density following mass bleaching | Coral Reefs | Springer Nature Link.

Ussi, A. M., Mohammed, M. S., Rashid, R. J., Sheikh, M. A., Staehr, P. A., Muhando, C. A., Yahya, S., and Dahl, K. (2024) Status and long-term changes of coral reefs around Zanzibar. *Front. Mar. Sci.*, **11**, 1334235.

Van Der Schyff, V., Du Preez, M., Blom, K., Kylin, H., Kwet Yive, N. S. C., Merven, J., Raffin, J., and Bouwman, H. (2020) Impacts of a shallow shipwreck on a coral reef: A case study from St. Brandon's Atoll, Mauritius, Indian Ocean. *Mar. Environ. Res.*, **156**, 104916.

Veron, J., Stafford-Smith, M., DeVantier, L., and Turak, E. (2015) Overview of distribution patterns of zooxanthellate Scleractinia. *Front. Mar. Sci.*, **1**.

Vogt-Vincent, N. S., Burt, A. J., Van Der Ven, R. M., and Johnson, H. L. (2024) Coral reef potential connectivity in the southwest Indian Ocean. *Coral Reefs*, **43**, 1037–1051.

Wallner-Hahn, S., De La Torre-Castro, M., Eklöf, J. S., Gullström, M., Muthiga, N. A., and Uku, J. (2015) Cascade effects and sea-urchin overgrazing: An analysis of drivers behind the exploitation of sea urchin predators for management improvement. *Ocean Coast. Manag.*, **107**, 16–27.

Wilkinson, C., Linden, O., Cesar, H., Hodgson, G., Rubens, J., and Strong, A. (1999) Ecological and socioeconomic impacts of 1998 coral mortality in the Indian Ocean: An ENSO impact and a warning of future change? *Ambio*, **28**, 188–196.

Williams, G. J. and Graham, N. A. J. (2019) Rethinking coral reef functional futures. *Funct. Ecol.*, **33**, 942–947.

Williams, G. J., Graham, N. A. J., Jouffray, J.-B., Norström, A. V., Nyström, M., Gove, J. M., Heenan, A., and Wedding, L. M. (2019) Coral reef ecology in the Anthropocene. *Funct. Ecol.*, **33**, 1014–1022.

van Woesik, R. and Kratochwill, C. (2022) A global coral-bleaching database, 1980–2020. *Sci. Data*, **9**, 20.

Woodhead, A. J., Hicks, C. C., Norström, A. V., Williams, G. J., and Graham, N. A. J. (2019) Coral reef ecosystem services in the Anthropocene. *Funct. Ecol.*, **33**, 1023–1034.

World Meteorological Organization (2025) *State of the Climate in Africa 2024*. United Nations, Erscheinungsort nicht ermittelbar.

World's Fourth Mass Coral Bleaching Event Likely Ended in 2025 *Natl. Environ. Satell. Data Inf. Serv.*

Yao, Y. and Wang, C. (2026) Record-Breaking Marine Heatwaves Across Global Coral Reefs in 2024. *Geophys. Res. Lett.*, **53**, e2026GL122086.

Zeng, K., He, S., and Zhan, P. (2025) Inevitable global coral reef decline under climate change-induced thermal stresses. *Commun. Earth Environ.*, **6**, 827.

Factsheets

1. Northern Tanzania - Kenya (CR)

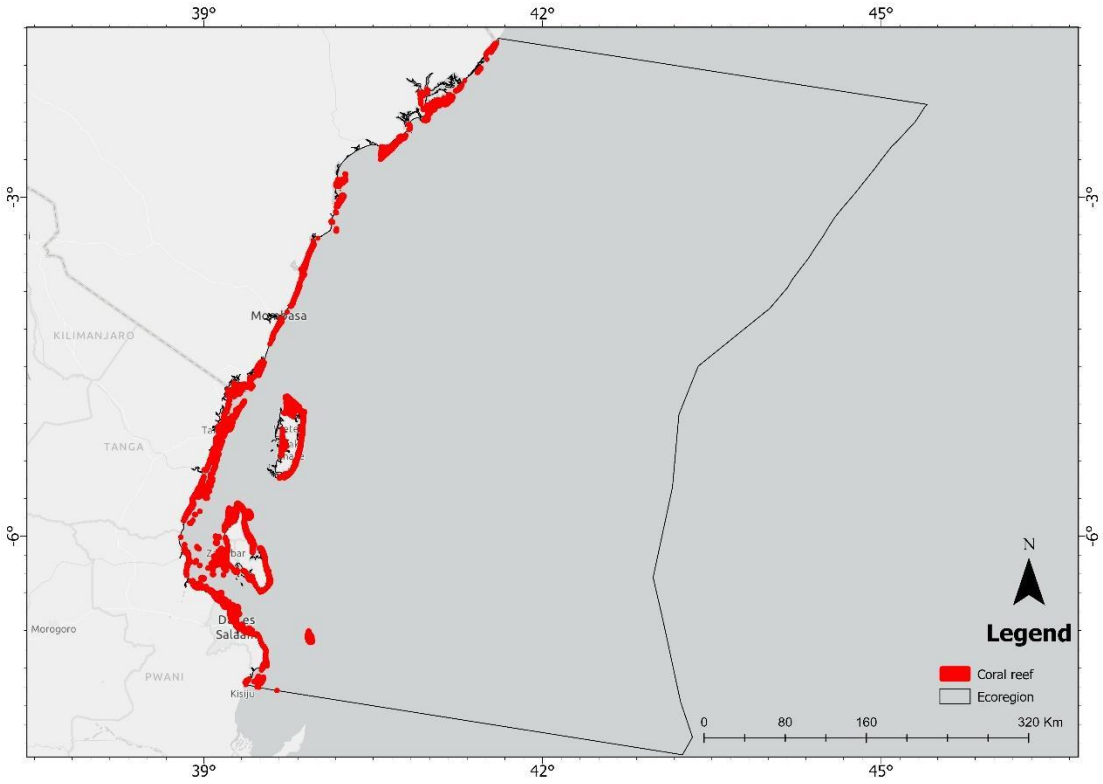


Figure 1. Kenya - N Tanzania Ecoregion with the reef extent.



Figure 2. A coral reef community picture from Kisite Mpunguti National marine Park, Kenya. Ewout Knoester - Wageningen University & Research, Netherlands ©

Spatial distribution (boundaries, area of coral reef)

The Kenya - North Tanzania Ecoregion extends along the East African coast from the Kenya–Somalia border in the north near Kiunga to the Rufiji Delta in the south, encompassing Kenyan and northern Tanzanian coastal reefs including the offshore islands of Zanzibar (Pemba and Unguja). Reefs occur predominantly as fringing systems on the narrow continental shelf of the mainland coast and the offshore islands, forming shallow reef flats and lagoons. Patch, platform and lagoonal reefs occur around the Lamu archipelago, Pemba, Unguja and the Tanga coast. The Tanga area has numerous inner and outer patch reefs on the shelf, while most of Pemba's fringing reefs lie on its western side and drop steeply into the deep Pemba Channel. The estimated coral reef area is 1253.4 km^2, based on the unified regional reef extent layer compiled for this assessment.

Ecosystem description

Coral reefs of the Northern Tanzania - Kenya Ecoregion form an ecologically distinct coastal unit characterized by diverse coral and reef-fish assemblages, with a northward decreasing gradient in coral richness. Large tidal fluctuations periodically expose reef flats, creating pronounced temperature and light variability in shallow lagoons.

The warm, northward-flowing East African Coastal Current is the dominant oceanographic influence, while northern reefs experience increasing influence from the Somali Current

system (Painter, 2020). This transition contributes to environmental differentiation along the coast and declining coral richness towards northern Kenya (Obura, 2012). The convergence of the EACC with the seasonal Somali Current creates a cold-water, upwelling-influenced system in northern Kenya, resulting in patchy, discontinuous reefs with low reef development there. Further south, reefs form a virtually continuous fringing chain along the Kenyan and northern Tanzanian coast, broken only at the mouths of rivers such as the Tana, Sabaki, Pangani and Wami.

The 1997–98 bleaching event initiated substantial community reassembly causing 50–90% coral mortality on the most affected reefs in the Ecoregion, reducing *Acropora* dominance and increasing dead coral, rubble and, locally, algal, soft-coral or corallimorph cover. Mortality in several subsequent heatwaves (e.g. 2010, 2016, 2020) was relatively minor, until 2024 when the region experienced severe heat again. Though peer-reviewed papers are yet to appear, preliminary reports from southern Kenya recorded coral mortality of 50-80% in 2024. Chronic fishing pressure depletes larger herbivores and predators, altering trophic structure, while urban pollution and catchment runoff impose additional pressures and interrupt recovery. Dynamite fishing was widespread along the Tanzanian coast in the 1980s and 1990s, leaving persistent rubble fields, and declining piscivore populations led to a Vulnerable listing in the previous assessment. Nevertheless, some well-managed protected reefs demonstrate recovery, highlighting spatial variation in ecological trajectories.

The combination of narrow-shelf fringing morphology, contrasting current influences, river-mediated environmental gradients and interacting fishing and bleaching disturbances supports assessment of Northern Tanzania - Kenya as a distinct Ecoregion.

Table 1. Key biotic and abiotic characteristics and key threats across Kenya- Tanzania Ecoregion.

Ecoregion	Key Biotic	Key Abiotic	Key Threats
1. Kenya - North Tanzania	Narrow-shelf fringing-reefs that support taxonomically diverse but spatially heterogeneous coral and reef fish assemblages. Kenya supports an estimated local coral species richness ranging from 177 species at Kiunga to 239 in Southern Kenya, reflecting a northward decline in coral diversity associated with the increasing influence of the Somali current system (Obura, 2012). Reef fish assemblages are similarly diverse but remain incompletely characterized at the ecoregional scale; studies have documented variation in species richness and community composition among Kenyan reefs with earlier documentation by (Samoilys, 1997), estimating the marine fish at approximately 350 species, while surveys of 19 selected families at Tanzanian sites estimated approximately 319 species (McClanahan and Kaunda-Arara, 1996; Samoilys et al., 2022). Post-disturbance coral community reassembly,	The shelf is narrow and tidal range large (4 m), with spring tides exposing reef flats and driving temperature and light extremes in shallow lagoons. Warm surface East African Coastal Current flows continuously northward along the coasts of Tanzania and Kenya (Painter, 2020). Major river inputs (Tana, Sabaki, Pangani, Wami) deliver freshwater and high sediment and nutrient pulses, making nearby reefs sensitive to terrestrial runoff (Brakel, 1984). Northern reefs sit in between warm coral-coast conditions and colder Somali Current influence and are relatively isolated from southern larval sources.	Overfishing is a chronic stressor via non-selective and destructive gear (e.g. small mesh gill nets) resulting in larger scrapers (e.g. parrotfish), browsers and piscivores (e.g. groupers) depleted on unprotected reefs (Lokrantz et al., 2009). Mass bleaching main acute stressor (1998, 2010, 2016, 2020, 2024). Nutrient/sediment pollution around urban centers (Mombasa, Dar es Salaam, Tanga, Zanzibar) (Mwaura et al., 2017; Staehr et al., 2018; Bravo et al., 2021) and reefs adjacent to estuaries like those in Watamu MPAs. Larger scrapers, browsers and piscivores depleted on unprotected reefs (Lokrantz et al., 2009). Loss of triggerfish (*Balistapus undulatus*) increasing urchin density and bioerosion and localised CoTS outbreaks (McClanahan and Muthiga, 2016).

Ecoregion	Key Biotic	Key Abiotic	Key Threats
	mainly initiating from the 1998 bleaching event, has shifted hard coral assemblages to non-*Acropora* dominance, alongside rising dead coral and rubble, pulses of turf and fleshy algae, and localized soft coral or corallimorph dominance.		

Key values

Table 2. Key coral reef biotic, environmental and geographic distribution values used to assess Kenya - North Tanzania Ecoregion against IUCN Red List Criteria A-D.

Proportion of coral reef lost over the last 50 years (Criterion A)	Distribution (Criterion B)		SST-anomaly past 50 years (Criterion C)	Biotic Indicator Values (Criterion D)		
	EOO (km^2)	AOO			Baseline	Current
14%	76697	174		hard coral cover (%)	37.5	22.9
				algae-coral ratio	0.380	0.667
				herbivore abundance (kg/ha)	202.4	74.4
				piscivore abundance (kg/ha)	47.5	14.2

Criteria Assessment

Overall, the risk of collapse of the coral reefs in Kenya- North Tanzania Ecoregion was assessed as Critically Endangered (CR)

Summary of the assessment:

Table 3. Summary of IUCN Red List Criteria assessment for coral reefs, showing the evaluation of Criteria A-E and the resulting overall risk category.

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?
	LC	LC	No
C. Environmental Degradation	C1	C2	C3

CRITERION			
A. Reduction in Geographic Distribution	A1	A2	A3
	Past 50 years	Future or any 50y period	Historical (1750)
	LC	NE	NE
	Past 50 years (1970)	Future or any 50y period	Historical (1750)
	VU	CR	DD
D. Disruption of biotic processes	D1	D2	D3
	Past 50 years (1970)	Future or Any 50y period	Historical (1750)
	EN	NE	DD
E. Quantitative Risk analysis	NE		
OVERALL RISK CATEGORY	CR		

DD = Data Deficient; LC = Least Concern; CR = Critically Endangered; EN = Endangered; NE = Not Evaluated

Key findings

- Criterion A: Least Concern; 14% of monitored sites had hard coral cover below the assessment's 5% collapse threshold.
- Criterion B: Least Concern; geographic distribution did not meet the assessment's threatened-category thresholds.
- Criterion C1: Vulnerable; historical changes in thermal-stress frequency over 1975–2025 indicate environmental degradation.
- Criterion C2: Critically Endangered; projected thermal degradation during 2026–2075 under SSP2–4.5 threatens recovery intervals and ecosystem persistence.
- Criterion D: Endangered. Parrotfish Endangered; groupers Endangered; coral and algae-coral-ratio VU.
- Overall risk: Critically Endangered, including future thermal degradation. Observed risk is Endangered.

Recommendations

- Strengthen fisheries enforcement and community governance to conserve herbivores and piscivores, including effective no-take areas and restrictions on destructive gear.
- Reduce sediment and nutrient delivery through catchment erosion control, wastewater treatment and safeguards for coastal development.
- Maintain repeated surveys of coral cover, algal dominance, fish abundance, recruitment and reef structural complexity, including post-bleaching assessments.
- prioritize recovery sites for sustained protection while supporting emissions mitigation and climate adaptation for reef-dependent communities.

2. Northern Mozambique - Southern Tanzania (CR)

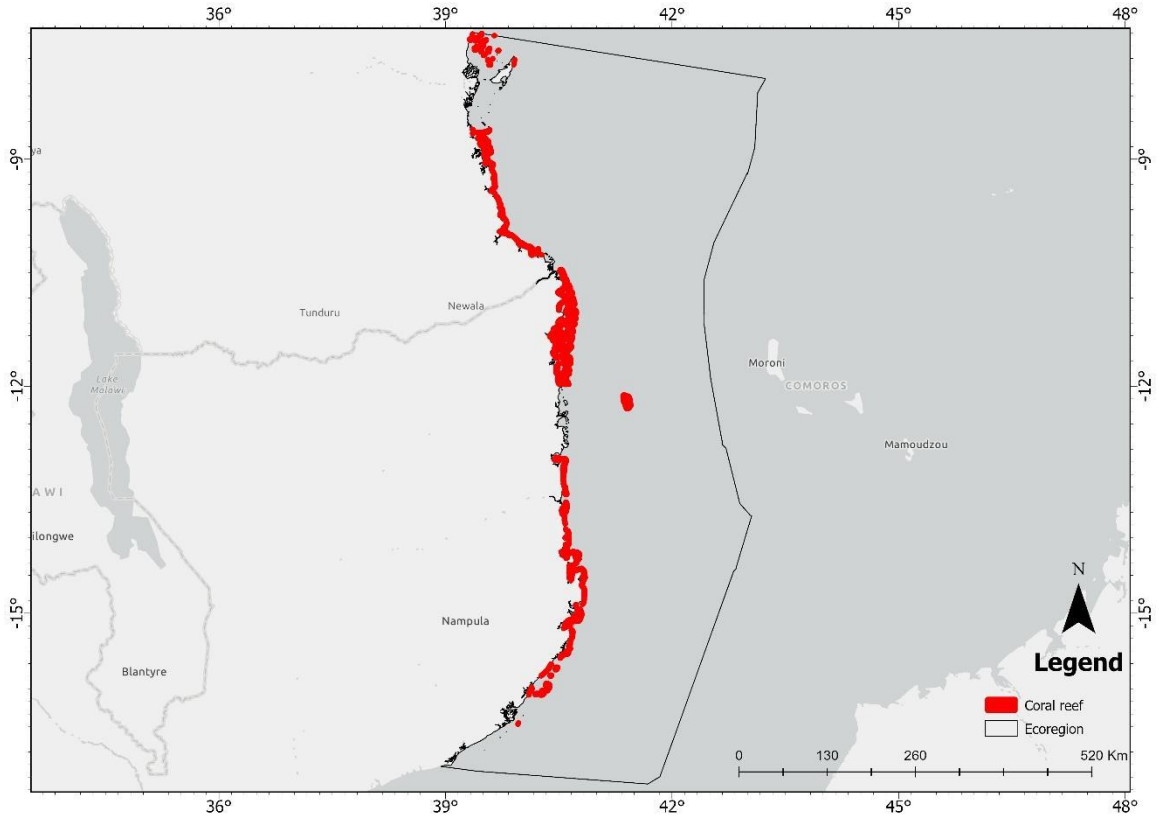


Figure 1. South Tanzania - North Mozambique Ecoregion with the reef extent.

Spatial distribution (boundaries, area of coral reef)

The Northern Mozambique - South Tanzania Ecoregion encompasses the mainland coast from the Rufiji delta in Tanzania southwards to the Zambezi river in Mozambique. It includes Mafia, Songo Songo and Mtwara in Tanzania, and Quirimbas archipelago and Nacala in Mozambique. Its southern limit is set by the Zambezi River, whose discharge creates conditions unsuitable for coral reef habitat. Reefs are predominantly fringing, with structurally complex systems in the Quirimbas. The estimated coral reef area is 1,906.1 km^2, the largest of all Ecoregions in this assessment, based on the unified regional reef extent layer compiled for this assessment.

Ecosystem description

Coral reefs of the Northern Mozambique - Southern Tanzania Ecoregion form a compositionally distinct Ecoregion characterized by their position at the core of the Northern Mozambique Channel diversity hotspot, where local species richness is the highest in the Western Indian Ocean and fringing reefs are structurally complex, particularly in the Quirimbas (Obura, 2012; Birrell et al., 2022).

The Ecoregion also supports among the region's highest reef-fish abundance and diversity, with comparatively intact predator and herbivore communities (Samoilys et al., 2022). Reefs

are predominantly extensive fringing systems developed along a warm, moderate-stress continental coast.

Circulation is driven by the East African Coastal Current and the eddy field of the northern Mozambique Channel, which together sustain strong larval connectivity along the Tanzania–Mozambique coast . Localized river sediment inputs, notably from the Ruvuma and Rufiji rivers, create turbid nearshore zones and potential thermal refugia in southern Tanzania (Porter et al., 2017), The southern boundary of the Ecoregion is set by the Zambezi, whose discharge renders the coast beyond unsuitable for reef development.

Persistent dynamite fishing has generated extensive rubble fields along parts of the coast (Sawall et al., 2013; Carneiro and Martins, 2021), compounded by sedimentation and mass bleaching. Rapid coastal and offshore gas development in Cabo Delgado is an emerging pressure.

The combination of exceptional coral and fish diversity, eddy-driven larval connectivity, riverine influence and a disturbance regime dominated by destructive fishing creates unique ecological dynamics for the coral reefs of this Ecoregion.

Table 1. Key biotic and abiotic characteristics and key threats across South Tanzania - North Mozambique Ecoregion.

Ecoregion	Key Biotic	Key Abiotic	Key Threats
. South Tanzania - North Mozambique	Northern Mozambique Channel diversity hotspot, with high local species richness and structurally complex fringing reefs (Quirimbas) (Obura, 2012; Birrell et al., 2022). Among the regions highest reef-fish abundance and diversity, with comparatively intact predator and herbivore communities (Samoilys et al., 2022).	Extensive fringing reef systems on a warm, moderate-stress coast driven by the East African Coastal Current and the northern Mozambique Channel eddies (McClanahan et al., 2014). Localized river sediment inputs (e.g. Ruvuma and Rufiji River) (Porter et al., 2017), creating potential thermal refugia in southern Tanzania	Persistent dynamite fishing generating rubble (Sawall et al., 2013; Carneiro and Martins, 2021), sedimentation, mass bleaching. Emerging: rapid coastal and offshore gas development (Cabo Delgado).

Key values

Table 2. Key coral reef biotic, environmental and geographic distribution values used to assess South Tanzania - North Mozambique ecoregion against IUCN Red List Criteria A-D

Proportion of coral reef lost over the last 50 years (Criterion A)	Distribution (Criterion B)		SST-anomaly past 50 years (Criterion C)	Biotic indicator values (Criterion D)		
	EOO (km2)	AOO			Baseline	Current
9%	126170	174		hard coral cover (%)	44.2	231.0
				algae-coral ratio	0.281	0.369
				herbivore abundance (kg/ha)	202.4	15.7
				piscivore abundance (kg/ha)	47.5	3.07

Criteria Assessment

Overall, the risk of collapse of the coral reefs in the Southern Tanzania - Northern Mozambique Ecoregion was assessed as Critically Endangered (CR).

Summary of the assessment:

Table 3. Summary of IUCN Red List Criteria assessment for coral reefs in Southern Tanzania - Northern Mozambique Ecoregion, showing the evaluation of Criteria A-E and the resulting overall risk category.

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?
	LC	LC	No
C. Environmental Degradation	C1	C2	C3
	Past 50 years (1970)	Future or any 50y period	Historical (1750)
	VU	CR	DD
D. Disruption of biotic processes	D1	D2	D3
	Past 50 years (1970)	Future or Any 50y period	Historical (1750)
	EN	NE	DD
E. Quantitative Risk analysis	NE		
OVERALL RISK CATEGORY	CR		

DD = Data Deficient; LC = Least Concern; CR = Critically Endangered; EN = Endangered; NE = Not Evaluated

Key findings

- Criterion A: Least Concern; 9% of monitored sites had hard coral cover below the assessment's 5% collapse threshold.
- Criterion B: Least Concern; geographic distribution did not meet the assessment's threatened-category thresholds.
- Criterion C1: Vulnerable; historical changes in thermal-stress frequency over 1975–2025 indicate environmental degradation.
- Criterion C2: Critically Endangered; projected thermal degradation during 2026–2075 under SSP2–4.5 threatens recovery intervals and ecosystem persistence.
- Criterion D: Endangered. Both fish indicators CR despite NT coral and algae-coral-ratio.
- Overall risk: Critically Endangered, including future thermal degradation. Observed risk is Endangered.

Recommendations

- Prioritize elimination of dynamite fishing and reduction of fishing mortality on herbivores and piscivores through enforcement and locally supported management.
- Protect structurally complex reefs and evaluate potential refugial sites using local temperature records and observed bleaching responses.
- Control catchment sediment delivery and require reef-protection safeguards for coastal and offshore development.
- Expand repeated fish and benthic surveys across mainland and island reefs to track functional recovery and post-bleaching change.

3. Comoros Archipelago (CR)

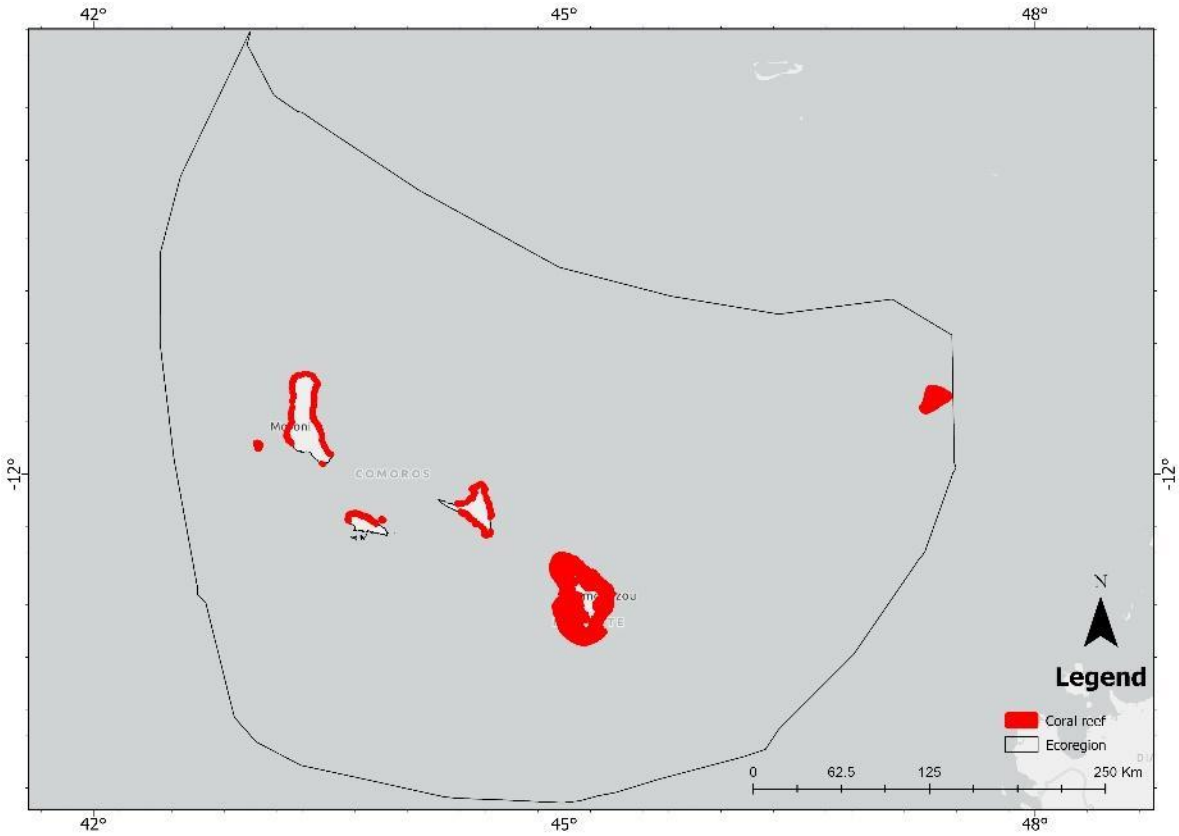


Figure 1. Comoros Archipelago Ecoregion with the reef extent.



Figure 2. A coral reef community picture from Moheli National Park in Comoros. Knoester E. Wageningen University, Netherlands ©

Spatial distribution (boundaries, area of coral reef)

The Comoros Archipelago Ecoregion encompasses the island-associated reefs of Grande Comore, Mohéli and Anjouan, Mayotte and the Îles Glorieuses, within the Northern Mozambique Channel. Its boundaries distinguish these oceanic island reef systems from the continental reefs of East Africa and the coastal reefs of Madagascar. Reef distribution is therefore centred on the archipelago's islands rather than a continuous continental shelf, mainly fringing reefs around young volcanic islands; Mayotte carries the most developed reef structure in the Ecoregion, a barrier reef enclosing a large lagoon. The estimated coral reef area is 725.3 km^2, based on the unified regional reef extent layer compiled for this assessment.

Ecosystem description

Coral reefs of the Comoros Archipelago form a compositionally distinct Ecoregion characterized by fringing reefs around young volcanic islands, set within the Northern Mozambique Channel diversity hotspot and supporting diverse assemblages (Obura et al., 2021). The archipelago is separated from mainland Eastern Africa and Madagascar by deep water, and its fish fauna distinguishes it from the surrounding Ecoregions.

Reef development reflects the youth of the islands. Most reefs are narrow fringing systems, but Mayotte's barrier reef and lagoon form the most developed reef structure in the Ecoregion (Montaggioni & Martin-Garin, 2020).

The islands sit in the warm waters of the northern Mozambique Channel, and reef condition across the archipelago reflects the interaction of this warm, high-connectivity setting with steep volcanic topography and narrow shelves.

Threats differ between islands. Land-based runoff affects Mayotte and Mohéli; coral and sand extraction occur on Grande Comore, Mohéli and Anjouan; and coastal pollution and overfishing are associated with high human pressure ((Thomassin et al., 2010; Freed and Granek, 2014). Climate-related disturbances are prominent, particularly tropical cyclones such as Chido and Kenneth, and coral bleaching events (Adjeroud et al., 2026; Moejes et al., 2026).

The combination of young volcanic substrates, a distinct fish fauna, high and unevenly distributed human pressure, and a disturbance regime dominated by cyclones and bleaching creates unique ecological dynamics for the coral reefs of this Ecoregion.

Table 1. Key biotic and abiotic characteristics and key threats across Comoros Archipelago Ecoregion.

Ecoregion	Key Biotic	Key Abiotic	Key Threats
3. Comoros Archipelago	Fringing reefs around young volcanic islands, with Mayotte's barrier reef enclosing a large lagoon and is part of the northern Mozambique Channel diversity hotspot with diverse assemblages (Obura et al., 2021).	Young volcanic islands in the warm northern Mozambique Channel and Mayotte's barrier–lagoon system is the most developed reef structure (Montaggioni and Martin-Garin, 2020).	Land-based runoff in Mayotte and Moheli; coral and sand extraction in Grande Comore, Mohéli, and Anjouan; coastal pollution and overfishing associated with Mayotte; (Thomassin et al., 2010), high human pressure (Freed and Granek, 2014), and climate-related disturbances, particularly tropical cyclones, such as Chido, Kenneth, and coral bleaching events (Adjeroud et al., 2026; Moejes et al., 2026).

Key values

Table 2. Key coral reef biotic, environmental and geographic distribution values used to assess Comoros Archipelago Ecoregion against IUCN Red List Criteria A-D

Proportion of coral reef lost over the last 50 years (Criterion A)	Distribution (Criterion B)		SST-anomaly past 50 years (Criterion C)	Biotic indicator values (Criterion D)		
	EOO (km2)	AOO			Baseline	Current
38%	53402	64		hard coral cover (%)	56.5	9.09
				algae-coral ratio	0.281	0.513
				herbivore abundance (kg/ha)	129.2	55.5
				piscivore abundance (kg/ha)	159.7	44.8

Criteria Assessment

Overall, the risk of collapse of the coral reefs in the Comoros Archipelago Ecoregion was assessed as Critically Endangered (CR).

Summary of the assessment:

Table 3. Summary of IUCN Red List Criteria assessment for coral reefs in Comoros Archipelago Ecoregion, showing the evaluation of Criteria A-E and the resulting overall risk category

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?
	NT	LC	No
C. Environmental Degradation	C1	C2	C3
	Past 50 years (1970)	Future or any 50y period	Historical (1750)
	VU	CR	DD
D. Disruption of biotic processes	D1	D2	D3
	Past 50 years (1970)	Future or Any 50y period	Historical (1750)
	CR	NE	DD
E. Quantitative Risk analysis	NE		
OVERALL RISK CATEGORY	CR		

DD = Data Deficient; LC = Least Concern; CR = Critically Endangered; EN = Endangered; NE = Not Evaluated

Key findings

- Criterion A: Vulnerable; 38% of monitored sites had hard coral cover below the assessment's 5% collapse threshold.
- Criterion B: Near Threatened; geographic restriction approaches the threatened-category threshold.
- Criterion C1: Vulnerable; historical changes in thermal-stress frequency over 1975–2025 indicate environmental degradation.
- Criterion C2: Critically Endangered; projected thermal degradation during 2026–2075 under SSP2–4.5 threatens recovery intervals and ecosystem persistence.
- Criterion D: Critically Endangered. Groupers CR; coral and parrotfish EN; algae-coral-ratio LC.
- Overall risk: Critically Endangered, including future thermal degradation. Observed risk is Critically Endangered.

Recommendations

- Reduce fishing pressure on groupers and herbivores through enforceable, locally supported closures and gear controls.

- Control wastewater, catchment erosion and extraction of reef-building material, particularly near vulnerable coastal and lagoon habitats.
- prioritize protection of remaining coral habitats and assess recruitment and substrate stability before selecting recovery interventions.
- Coordinate island-level monitoring of fish, benthos, water quality and post-cyclone damage to identify spatial differences in recovery.

4. West Madagascar (CR)

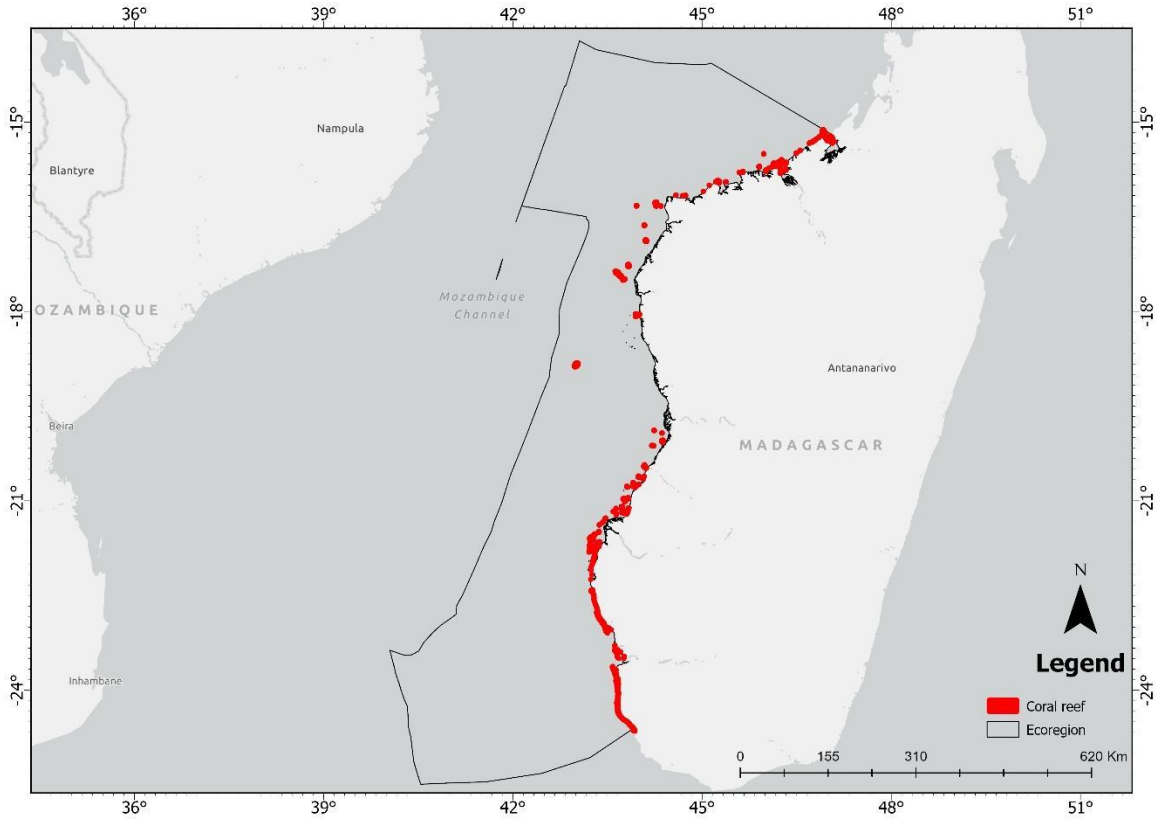


Figure 1. West Madagascar Ecoregion with the reef extent.

Spatial distribution (boundaries, area of coral reef)

The West Madagascar Ecoregion encompasses coral reefs along the west coast of Madagascar bordering the Mozambique Channel with boundaries adopted for this assessment to support national processes. Reefs occur across a broad continental shelf in Madagascar and the region's most extensive barrier and fringing reef complexes, including the Great Reef of Toliara, the Bay of Ranobe, the reefs of Nosy Ve–Androka and Andavadoaka. The estimated coral reef area is 435.4 km^2, based on the unified regional reef extent layer compiled for this assessment.

Ecosystem description

Coral reefs of the West Madagascar Ecoregion form a compositionally distinct Ecoregion characterized by fringing and barrier reefs of moderate-to-high diversity with strong mangrove–reef connectivity (Richmond, 2011). The Ecoregion carries the widest shelf in Madagascar and the most extensive reef complexes in the country, including the Great Reef of Toliara (Nomenisoa et al., 2024), the Bay of Ranobe, the reefs of Nosy Ve–Androka and Andavadoaka.

The west coast lies under Mozambique Channel circulation, with major sediment delivery from the Betsiboka River creating turbid nearshore zones (Richmond, 2011). The Southwest Madagascar Coastal Current, a shallow (<300 m) and narrow (<100 km) coastal current, influences larval transport patterns and connectivity with the Agulhas Current (Ramanantsoa et al., 2018). These conditions set the Ecoregion apart from the oceanic systems of the channel: sediment and freshwater loads from the large west-coast rivers, rather than thermal stress alone, shape where and how reefs develop.

Catchment deforestation and land-use change are driving sedimentation (Maina et al., 2013), alongside overfishing, coastal development and bleaching.

The combination of an unusually wide shelf, the most extensive barrier and fringing reef complexes in Madagascar, strong terrestrial influence and a coastal current that governs connectivity creates unique ecological dynamics for the coral reefs of this Ecoregion.

Table 1. Key biotic and abiotic characteristics and key threats across West Madagascar Ecoregion.

Ecoregion	Key Biotic	Key Abiotic	Key Threats
4. West Madagascar	Fringing and barrier reefs along the north-west coast with moderate-to-high diversity and strong mangrove–reef connectivity (Richmond, 2011). Extensive reefs in this ecoregion can be found in the south-west, including the Great Reef of Toliara (Nomenisoa et al., 2024) and the Bay of Ranobe, the Reefs of Nosy-Ve Androka and Andavadoaka.	West coast under Mozambique Channel circulation, with major sediment delivery from the Betsiboka River creating turbid nearshore zones (Richmond, 2011). The Southwest Madagascar Coastal Current (SMACC) is a shallow (<300m) and narrow (<100km wide) coastal current that influences the larval transport patterns and the connectivity with the Agulhas Current (Ramanantsoa et al., 2018).	Catchment deforestation and land-use change driving sedimentation (Maina et al., 2013), overfishing, coastal development, and bleaching.

Key values

Table 2. Key coral reef biotic, environmental and geographic distribution values used to assess West Madagascar Ecoregion against IUCN Red List Criteria A-D

Proportion of coral reef lost over the last 50 years (Criterion A)	Distribution (Criterion B)		SST-anomaly past 50 years (Criterion C)	Biotic indicator values (Criterion D)		
	EOO (km2)	AOO			Baseline	Current
34%	220695	105		hard coral cover (%)	41.8	21.4
				algae-coral ratio	0.281	0.587
				herbivore abundance (ind/ha)	328.6	587.5
				piscivore abundance (ind/ha)	168	314.8

Criteria Assessment

Overall, the risk of collapse of the coral reefs in the West Madagascar Ecoregion was assessed as Critically Endangered (CR).

Summary of the assessment:

Table 3. Summary of IUCN Red List Criteria assessment for coral reefs in West Madagascar Ecoregion, showing the evaluation of Criteria A-E and the resulting overall risk category

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?
	LC	LC	No
C. Environmental Degradation	C1	C2	C3
	Past 50 years (1970)	Future or any 50y period	Historical (1750)
	VU	CR	DD
D. Disruption of biotic processes	D1	D2	D3
	Past 50 years (1970)	Future or Any 50y period	Historical (1750)
	EN	NE	DD
E. Quantitative Risk analysis	NE		
OVERALL RISK CATEGORY	CR		

DD = Data Deficient; LC = Least Concern; CR = Critically Endangered; EN = Endangered; NE = Not Evaluated

Key findings

- Criterion A: Vulnerable; 34% of monitored sites had hard coral cover below the assessment's 5% collapse threshold.
- Criterion B: Least Concern; geographic distribution did not meet the assessment's threatened-category thresholds.
- Criterion C1: Vulnerable; historical changes in thermal-stress frequency over 1975–2025 indicate environmental degradation.
- Criterion C2: Critically Endangered; projected thermal degradation during 2026–2075 under SSP2–4.5 threatens recovery intervals and ecosystem persistence.
- Criterion D: Endangered. Groupers EN; coral, algae-coral-ratio and parrotfish VU.
- Overall risk: Critically Endangered, including future thermal degradation. Observed risk is Endangered.

Recommendations

- prioritize erosion control and catchment rehabilitation where river-derived sediments affect reef habitats.
- Strengthen community fisheries management to reduce grouper depletion and maintain herbivory.
- Manage reefs, mangroves and connected coastal habitats together, with safeguards against damaging coastal development.
- Repeat benthic and fish surveys along sediment-exposure gradients to distinguish local pressure effects from bleaching-related change.

5. North Madagascar (CR)

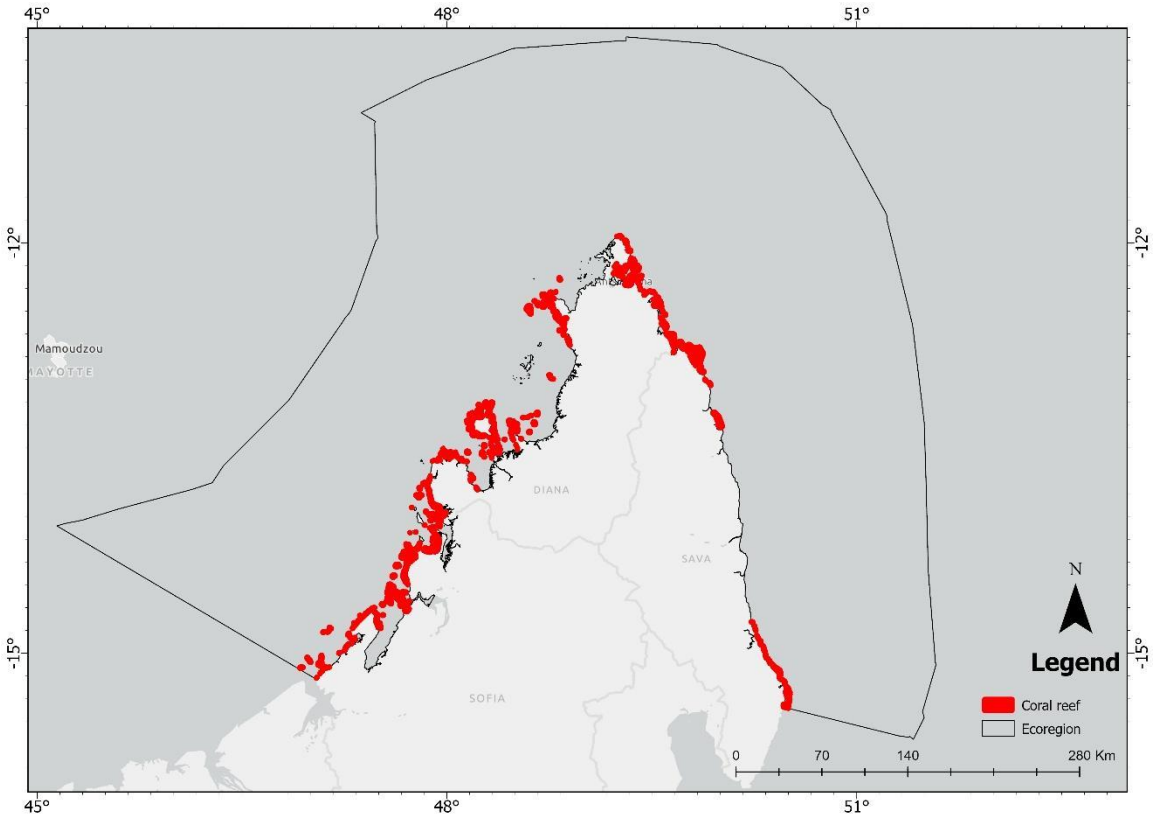


Figure 1. North Madagascar Ecoregion with the reef extent.

Spatial distribution (boundaries, area of coral reef)

The North Madagascar Ecoregion encompasses reefs around the northern tip of Madagascar within the Northern Mozambique Channel, with boundaries adopted in this assessment to support national processes. Sheltered bay and island reefs around Nosy Be contrast with the exposed, current-swept reefs off Cap d'Ambre. Reef distribution spans contrasting sheltered and current exposed coastal settingThe estimated coral reef area is 774.2 km^2, based on the unified regional reef extent layer compiled for this assessment.

Ecosystem description

Coral reefs of the North Madagascar Ecoregion form a compositionally distinct Ecoregion characterized by very high coral richness, for example at Diego-Vohemar (Randrianarivo et al., 2022), and diverse fish assemblages influenced by larval retention within the Northern Mozambique Channel (McClanahan et al., 2011; Obura, 2012). The Ecoregion sits within the channel's diversity hotspot and shares its connectivity with the Comoros and the East African coast.

Reef development spans a strong exposure gradient. Sheltered bay and island reefs around Nosy Be contrast with the exposed, current-swept reefs off Cap d'Ambre at the northern tip.

The warm, moderate-stress waters of the northern Mozambique Channel support this high diversity and include areas identified as potential thermal refugia (McClanahan et al., 2011; Obura, 2012). Thermal-stress exposure is comparatively lower than in Ecoregions to the north, although it is rising.

Overfishing and sedimentation are the main chronic pressures, with emerging tourism and coastal development adding to them.

The combination of very high coral richness, larval retention within the channel, a marked sheltered-to-exposed gradient and comparatively low but rising thermal exposure creates unique ecological dynamics for the coral reefs of this Ecoregion.

Table 1. Key biotic and abiotic characteristics and key threats across North Madagascar Ecoregion.

Ecoregion	Key Biotic	Key Abiotic	Key Threats
5. North Madagascar	Part of the northern Mozambique Channel diversity hotspot, with very high coral richness (e.g. Diego-Vohemar; (Randrianarivo et al., 2025) and diverse fish assemblages influenced by larval retention within the channel (McClanahan et al., 2011; Obura, 2012).	Warm, moderate-stress waters of the northern Mozambique Channel that support high diversity and include areas that have been identified as potential thermal refugia (McClanahan et al., 2011, 2024).	Overfishing, sedimentation, emerging tourism and coastal development. Thermal-stress exposure is comparatively lower but rising.

Key values

Table 2. Key coral reef biotic, environmental and geographic distribution values used to assess North Madagascar Ecoregion against IUCN Red List Criteria A-D

Proportion of coral reef lost over the last 50 years (Criterion A)	Distribution (Criterion B)		SST-anomaly past 50 years (Criterion C)	Biotic indicator values (Criterion D)		
	EOO (km2)	AOO			Baseline	Current
3%	88408	123		hard coral cover (%)	48.2	35.6
				algae-coral ratio	0.281	0.356
				herbivore abundance (ind/ha)	328.6	504.8
				piscivore abundance (ind/ha)	168	37.5

Criteria Assessment

Overall, the risk of collapse of the coral reefs in the North Madagascar Ecoregion was assessed as Critically Endangered (CR).

Summary of the assessment:

Table 3. Summary of IUCN Red List Criteria assessment for coral reefs in North Madagascar Ecoregion, showing the evaluation of Criteria A-E and the resulting overall risk category

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?
	LC	LC	No
C. Environmental Degradation	C1	C2	C3
	Past 50 years (1970)	Future or any 50y period	Historical (1750)
	VU	CR	DD
D. Disruption of biotic processes	D1	D2	D3
	Past 50 years (1970)	Future or Any 50y period	Historical (1750)
	VU	NE	DD
E. Quantitative Risk analysis	NE		
OVERALL RISK CATEGORY	CR		

DD = Data Deficient; LC = Least Concern; CR = Critically Endangered; EN = Endangered; NE = Not Evaluated

Key findings

- Criterion A: Least Concern; 3% of monitored sites had hard coral cover below the assessment's 5% collapse threshold.
- Criterion B: Least Concern; geographic distribution did not meet the assessment's threatened-category thresholds.
- Criterion C1: Vulnerable; historical changes in thermal-stress frequency over 1975–2025 indicate environmental degradation.
- Criterion C2: Critically Endangered; projected thermal degradation during 2026–2075 under SSP2–4.5 threatens recovery intervals and ecosystem persistence.
- Criterion D: Near Threatened. Hard coral Near Threatened and algae-coral-ratio Least Concern; both fish indicators Data Deficient, limiting assessment of trophic disruption.
- Overall risk: Critically Endangered, including future thermal degradation. Observed risk is Vulnerable.

Recommendations

- Close fish-monitoring gaps through repeated, standardized surveys of herbivores and piscivores across representative habitats.
- Validate candidate refugia using local thermal records, bleaching observations and recruitment measurements before prioritizing protection.
- Maintain high-diversity reef habitats through effective fisheries governance and controls on sediment-generating development.

6. Seychelles Outer (CR)

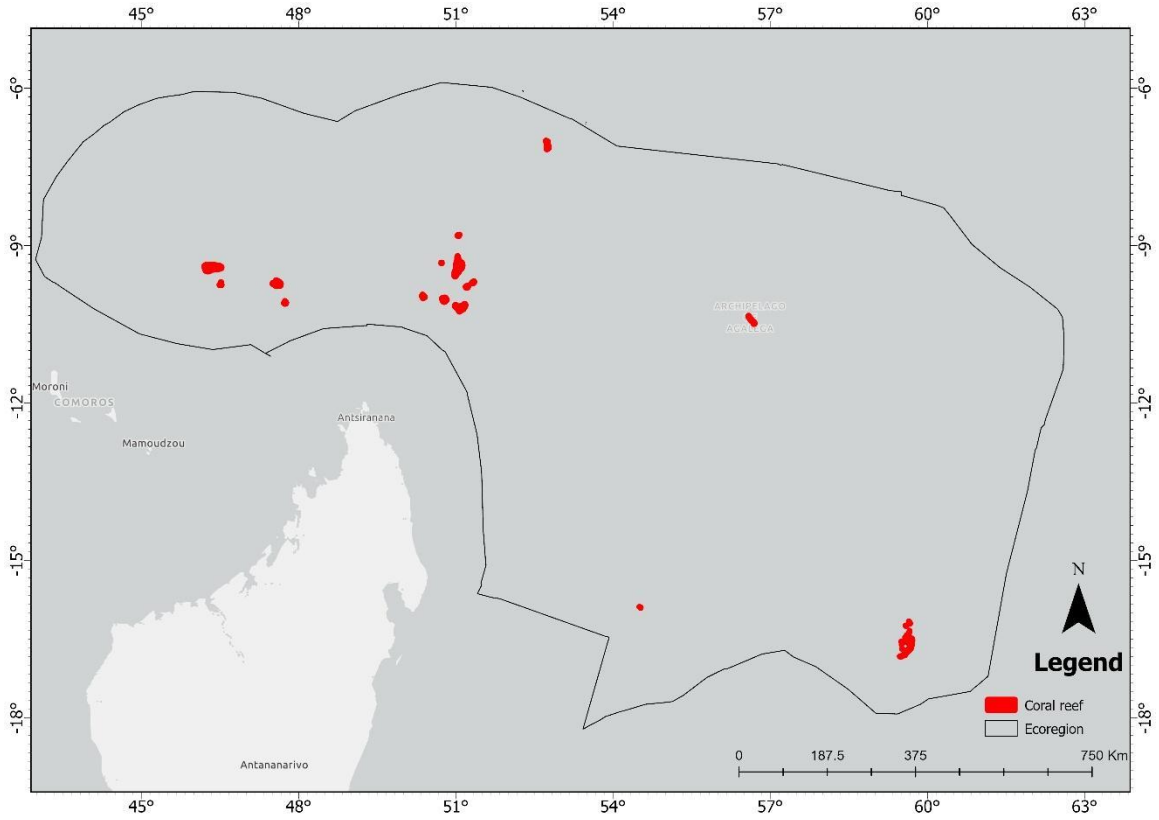


Figure 1. Seychelles Outer Ecoregion with the reef extent.



Figure 2. A coral reef community picture from _Assumption, Seychelles taken in March 2026. Barret L - Island Biodiversity & Conservation Centre, Seychelles&Bee Ecological Consulting, Seychelles ©

Spatial distribution (boundaries, area of coral reef)

The Seychelles Outer Ecoregion comprises the Seychelles outer islands of Aldabra, Farquhar and Alphonse groups, together with Agaléga and St Brandon (Mauritius) and Tromelin (Figure 1). It is a subdivision of the single MEOW Seychelles Ecoregion, bounded at the edge of the Seychelles (Mahé) Plateau, extending west to Aldabra and southeast across the isolated banks of Providence, Saya de Malha, Nazareth and Cargados Carajos. Reefs are oceanic atolls and carbonate platforms. The estimated coral reef area is 998.1 km^2, based on the unified regional reef extent layer compiled for this assessment.

Ecosystem description

Coral reefs of the Seychelles Outer Ecoregion form a compositionally distinct Ecoregion characterized by remote atoll and carbonate-platform reefs at Aldabra, the Amirantes and Farquhar, with relatively intact communities, functioning coral recruitment, and importance for connectivity as larval source sites (Koester et al., 2021).

Reef condition varies across the Ecoregion. At Farquhar, low coral cover occurs alongside exceptionally high fish biomass, including abundant groupers, snappers, jacks, napoleon wrasse and bumphead parrotfish, with strong herbivory limiting macroalgal dominance and promoting crustose coralline algae (Friedlander et al., 2014). At Aldabra, bleaching altered coral composition, but juvenile coral abundance tripled between 2016 and 2019, demonstrating substantial if spatially variable replenishment potential (Cerutti et al., 2020; Koester et al., 2021). At Poivre, free-living mesophotic corals contributed up to 75% of live coral cover locally and facilitated reef development on unconsolidated sediments (Samimi-Namin et al., 2025). These are oceanic atolls and carbonate platforms with very low direct human influence (Montaggioni and Martin-Garin, 2020)), in warm oceanic waters with cyclone exposure in the southern atolls. Areas of persistently cool water and potential climate refugia have been identified near the Amirantes and Alphonse groups and on the southern Amirantes Plateau (SMSP Atlas). At Aldabra, daily lagoon temperature variability was more than three times that of shallow seaward reefs, potentially increasing coral thermal (Koester et al., 2021).

Principal threats are tropical cyclones (e.g. Fantala at Farquhar (Duvat et al., 2017) and bleaching, together with accumulation of land-derived plastic debris on remote shores (Duhec et al., 2015; Honorato-Zimmer et al., 2022; Choppy, 2025). Local anthropogenic pressure is generally low.

The combination of geographic isolation, intact trophic structure, identified thermal refugia and a disturbance regime dominated by cyclones rather than local pressure creates unique ecological dynamics for the coral reefs of this Ecoregion.

Table 1. Key biotic and abiotic characteristics and key threats across Seychelles Outer Ecoregion.

Ecoregion	Key Biotic	Key Abiotic	Key Threats
6. Seychelles Outer	Remote atoll and carbonate-platform reefs (Aldabra, Amirantes, Farquhar) with relatively intact communities and functioning coral	Oceanic atolls and carbonate platforms with very low direct human influence (Montaggioni and Martin-Garin, 2020). Warm	Tropical cyclones (e.g. Fantala at Farquhar (Duvat et al., 2017) and bleaching, accumulation of land-derived

Ecoregion	Key Biotic	Key Abiotic	Key Threats
	recruitment, important for connectivity as larval source sites (Koester et al., 2021). At Farquhar, (Friedlander et al., 2014) documented low coral cover but exceptionally high fish biomass, including abundant groupers, snappers, jacks, Napoleon wrasse and bump head parrotfish. Strong herbivory limited macroalgal dominance and promoted crustose coralline algae. At Aldabra, bleaching altered coral composition, but juvenile coral abundance tripled between 2016 and 2019, demonstrating substantial but spatially variable replenishment potential (Cerutti et al., 2020; Koester et al., 2021). At Poivre, free-living mesophotic corals locally contributed up to 75% live coral cover and facilitated reef development on unconsolidated sediments (Samimi-Namin et al., 2025).	oceanic waters, with cyclone exposure in the southern atolls. Seychelles Marine Spatial Plan Atlas 2025 (SMSP Atlas) identifies areas of persistently cool water and potential climate refugia near the Amirantes Group and Alphonse Group. It also identifies potential cold-water refugia on the southern Amirantes Plateau (SMSP Atlas). At Aldabra, daily lagoon temperature variability was more than three times that of shallow seaward reefs, potentially increasing coral thermal tolerance (Koester et al., 2021).	plastic debris on remote shores (Duhec et al., 2015; Honorato-Zimmer et al., 2022; Choppy, 2025). Local anthropogenic pressure is generally low.

Key values

Table 2. Key coral reef biotic, environmental and geographic distribution values used to assess Seychelles Outer Ecoregion against IUCN Red List Criteria A-D

Proportion of coral reef lost over the last 50 years (Criterion A)	Distribution (Criterion B)		SST-anomaly past 50 years (Criterion C)	Biotic indicator values (Criterion D)		
	EOO (km2)	AOO			Baseline	Current
4%	809061	78		hard coral cover (%)	32.4	21.2
				algae-coral ratio	0.281	0.639
				herbivore abundance (ind/ha)	280	205
				piscivore abundance (ind/ha)	108.5	125.9

Criteria Assessment

Overall, the risk of collapse of the coral reefs in the Seychelles Outer Ecoregion was assessed as Critically Endangered (CR).

Summary of the assessment:

Table 3. Summary of IUCN Red List Criteria assessment for coral reefs in Seychelles Outer Ecoregion, showing the evaluation of Criteria A-E and the resulting overall risk category

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?
	LC	LC	No
C. Environmental Degradation	C1	C2	C3
	Past 50 years (1970)	Future or any 50y period	Historical (1750)
	EN	CR	DD
D. Disruption of biotic processes	D1	D2	D3
	Past 50 years (1970)	Future or Any 50y period	Historical (1750)
	VU	NE	DD
E. Quantitative Risk analysis	NE		
OVERALL RISK CATEGORY	CR		

DD = Data Deficient; LC = Least Concern; CR = Critically Endangered; EN = Endangered; NE = Not Evaluated

Key findings

- Criterion A: Least Concern; 4% of monitored sites had hard coral cover below the assessment's 5% collapse threshold.
- Criterion B: Least Concern; geographic distribution did not meet the assessment's threatened-category thresholds.
- Criterion C1: Endangered; historical changes in thermal-stress frequency over 1975–2025 indicate environmental degradation.
- Criterion C2: Critically Endangered; projected thermal degradation during 2026–2075 under SSP2–4.5 threatens recovery intervals and ecosystem persistence.
- Criterion D: Vulnerable. Hard coral, algae-coral-ratio and parrotfish Vulnerable; groupers Near Threatened.
- Overall risk: Critically Endangered, including future thermal degradation. Observed risk is Endangered.

Recommendations

- Maintain protection of remote reefs and enforce controls on illegal or unregulated fishing to retain trophic functions.
- Monitor juvenile corals, adult assemblages and fish alongside temperature variability to evaluate recovery and proposed refugial value.
- Implement coordinated post-bleaching and post-cyclone surveys across lagoon and seaward habitats.
- Reduce marine-debris inputs through regional coordination while sustaining local habitat protection and climate mitigation advocacy.

7. Seychelles Inner (CR)

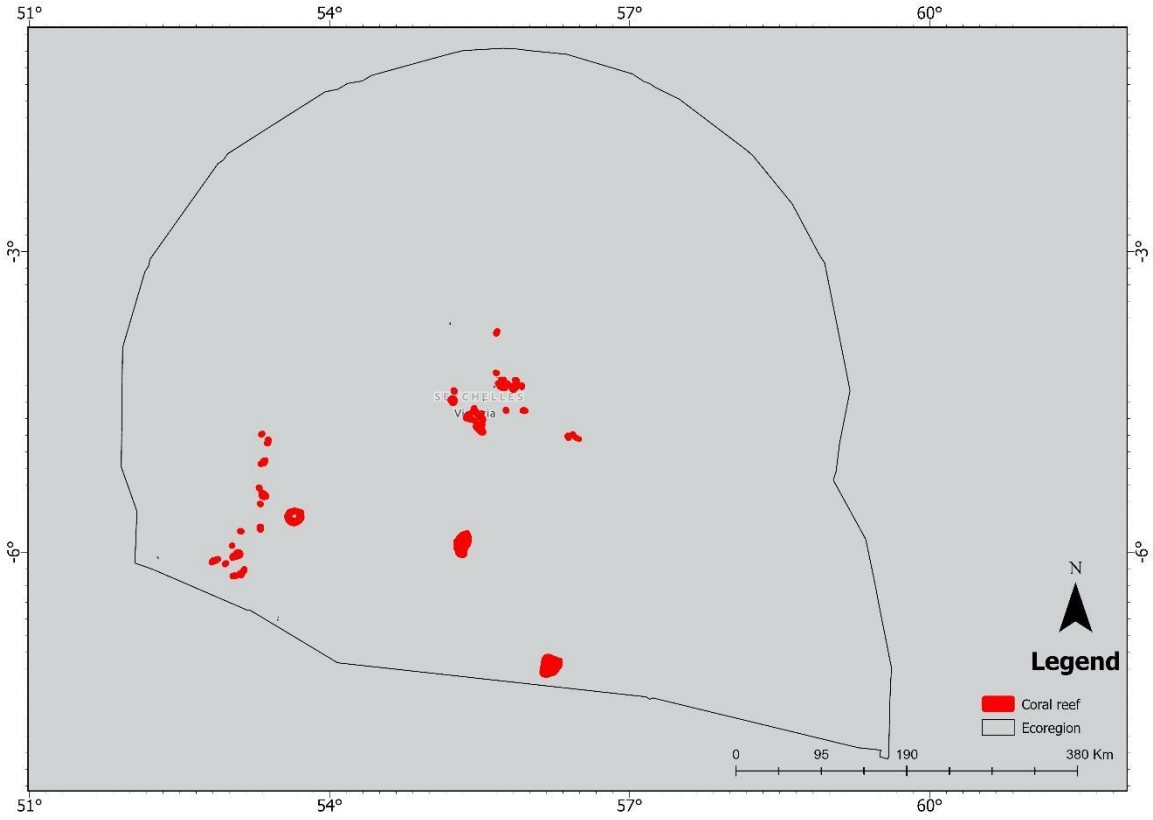


Figure 1.Seychelles Inner Ecoregion with the reef extent.



Figure 2. A coral reef community picture from Cote Dor Praslin, Seychelles taken in April 2025. Barret L - Island Biodiversity & Conservation Centre, Seychelles&Bee Ecological Consulting, Seychelles ©

Spatial distribution (boundaries, area of coral reef)

The Seychelles Inner Ecoregion covers the granitic islands of the Mahé Plateau including Mahé, Praslin and La Digue, together with Denis, Bird, Coetivy and the Amirantes group, bounded by the edge of the plateau on continuous shallow structure. Reefs are wide fringing systems on granitic bases, with reef flats more than 2 km wide around Mahé and Praslin. The estimated coral reef area is 805.2 km^2, based on the unified regional reef extent layer compiled for this assessment.

Ecosystem description

Coral reefs of the Seychelles Inner Ecoregion form a compositionally distinct Ecoregion characterized by wide fringing reefs on granitic bases, historically Acropora-rich. Recovery is driven by branching Acropora, often replacing massive corals (Robinson et al., 2019)but trajectories vary from coral dominance to persistent macroalgal–rubble states with limited recruitment limited recruitment (Chong-Seng et al., 2014;) Graham et al., 2015). Loss of structural complexity reduces fish richness and functional diversity (Graham et al., 2006), and while fish assemblages partially recover alongside corals, reversal of macroalgal dominance remains uncommon and spatially restricted (Graham et al., 2015, 2024).

The islands are granitic continental remnants on the shallow Seychelles Plateau, with reef flats more than 2 km wide around Mahé and Praslin (Turner et al., 2000; ASCLME, 2012). Granitic substrates generally provide relatively stable settlement surfaces, whereas carbonate reefs may contain extensive unconsolidated rubble that limits establishment and long-term survival of coral colonies (Chong-Seng et al., 2014);(Dajka et al., 2019).

The Ecoregion lies in warm equatorial waters with high thermal-stress exposure. Severe mass bleaching occurred in 1998, 2016 and 2024, with over half of monitored sites recording high-to-extreme stress in 2016 (Gudka, D. Obura, et al., 2018), Bleaching-driven coral loss has reduced carbonate budgets and accretion (Januchowski-Hartley et al., 2017), and severe post-bleaching regime shifts to macroalgae have occurred on some reefs alongside recovery on others (Graham et al., 2015). Coastal development, tourism and nutrient loading add chronic pressure.
The combination of granitic substrate, exceptionally wide reef flats, high thermal exposure and divergent post-bleaching trajectories creates unique ecological dynamics for the coral reefs of this Ecoregion.

Table 1. Key biotic and abiotic characteristics and key threats across Seychelles Inner Ecoregion.

Ecoregion	Key Biotic	Key Abiotic	Key Threats
7. Seychelles Inner	Wide fringing reefs on granitic bases, historically *Acropora*-rich. Reef recovery is driven by branching *Acropora*, often replacing massive corals (Robinson et al., 2019), but varies from coral dominance to persistent macroalgal–rubble states with limited recruitment (Chong-Seng et al., 2014;) Graham et al., 2015). Structural complexity loss reduces fish richness and functional diversity (Graham et al., 2006). Fish assemblages partially recover alongside corals; reversal of macroalgal dominance remains uncommon and spatially restricted (Graham et al., 2015, 2024).	Granitic continental-remnant islands on the shallow Seychelles Plateau, with reef flats >2 km wide around Mahé and Praslin (Turner et al., 2000; ASCLME, 2012). Warm equatorial waters with high thermal-stress exposure. Granitic substrates generally provide relatively stable settlement surfaces, whereas carbonate reefs may contain extensive unconsolidated rubble that limits the establishment and long-term survival of coral colonies (Chong-Seng et al., 2014);(Dajka et al., 2019).	Severe mass bleaching (1998, 2016, 2024), with over half of monitored sites high-to-extreme in 2016 (Gudka, D. Obura, et al., 2018), macroalgal regime shifts, coastal development, tourism and nutrient loading. Severe post-bleaching regime shifts to macroalgae on some reefs alongside recovery on others (Graham et al., 2015). Bleaching-driven coral loss has reduced carbonate budgets and accretion (Januchowski-Hartley et al., 2017).

Key values

Table 2. Key coral reef biotic, environmental and geographic distribution values used to assess Seychelles Inner Ecoregion against IUCN Red List Criteria A-D

Proportion of coral reef lost over the last 50 years (Criterion A)	Distribution (Criterion B)		SST-anomaly past 50 years (Criterion C)	Biotic indicator values (Criterion D)		
	EOO (km2)	AOO			Baseline	Current
32%	108205	61		hard coral cover (%)	30.2	17.7
				algae-coral ratio	0.281	0.516
				herbivore abundance (ind/ha)	1060.2	298.19

Proportion of coral reef lost over the last 50 years (Criterion A)	Distribution (Criterion B)		SST-anomaly past 50 years (Criterion C)	Biotic indicator values (Criterion D)		
	EOO (km2)	AOO			Baseline	Current
				piscivore abundance (ind/ha)	102.8	129.2

Criteria Assessment

Overall, the risk of collapse of the coral reefs in the Seychelles Inner Ecoregion was assessed as Critically Endangered (CR).

Summary of the assessment:

Table 3. Summary of IUCN Red List Criteria assessment for coral reefs in Seychelles Inner Ecoregion, showing the evaluation of Criteria A-E and the resulting overall risk category.

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?
	LC	LC	No
C. Environmental Degradation	C1	C2	C3
	Past 50 years (1970)	Future or any 50y period	Historical (1750)
	VU	CR	DD
D. Disruption of biotic processes	D1	D2	D3
	Past 50 years (1970)	Future or Any 50y period	Historical (1750)
	EN	NE	DD
E. Quantitative Risk analysis	NE		
OVERALL RISK CATEGORY	CR		

DD = Data Deficient; LC = Least Concern; CR = Critically Endangered; EN = Endangered; NE = Not Evaluated

Key findings

- Criterion A: Vulnerable; 32% of monitored sites had hard coral cover below the assessment's 5% collapse threshold.
- Criterion B: Least Concern; geographic distribution did not meet the assessment's threatened-category thresholds.
- Criterion C1: Vulnerable; historical changes in thermal-stress frequency over 1975–2025 indicate environmental degradation.

- Criterion C2: Critically Endangered; projected thermal degradation during 2026–2075 under SSP2–4.5 threatens recovery intervals and ecosystem persistence.
- Criterion D: Endangered. Parrotfish Endangered; algae-coral-ratio Endangered; coral and grouper indicators Vulnerable.
- Overall risk: Critically Endangered, including future thermal degradation. Observed risk is Endangered.

Recommendations

- Conserve herbivorous fish and reduce nutrient enrichment to maintain grazing and limit persistent macroalgal dominance.
- prioritize sustained protection of recovering reefs and evaluate recruitment barriers on macroalgal and rubble-dominated sites.
- Track coral recruitment, community composition, structural complexity and carbonate budgets alongside coral cover.
- Reduce wastewater and tourism-related physical damage and maintain repeated post-bleaching assessments across contrasting reef states.

8. Mascarene Islands (CR)

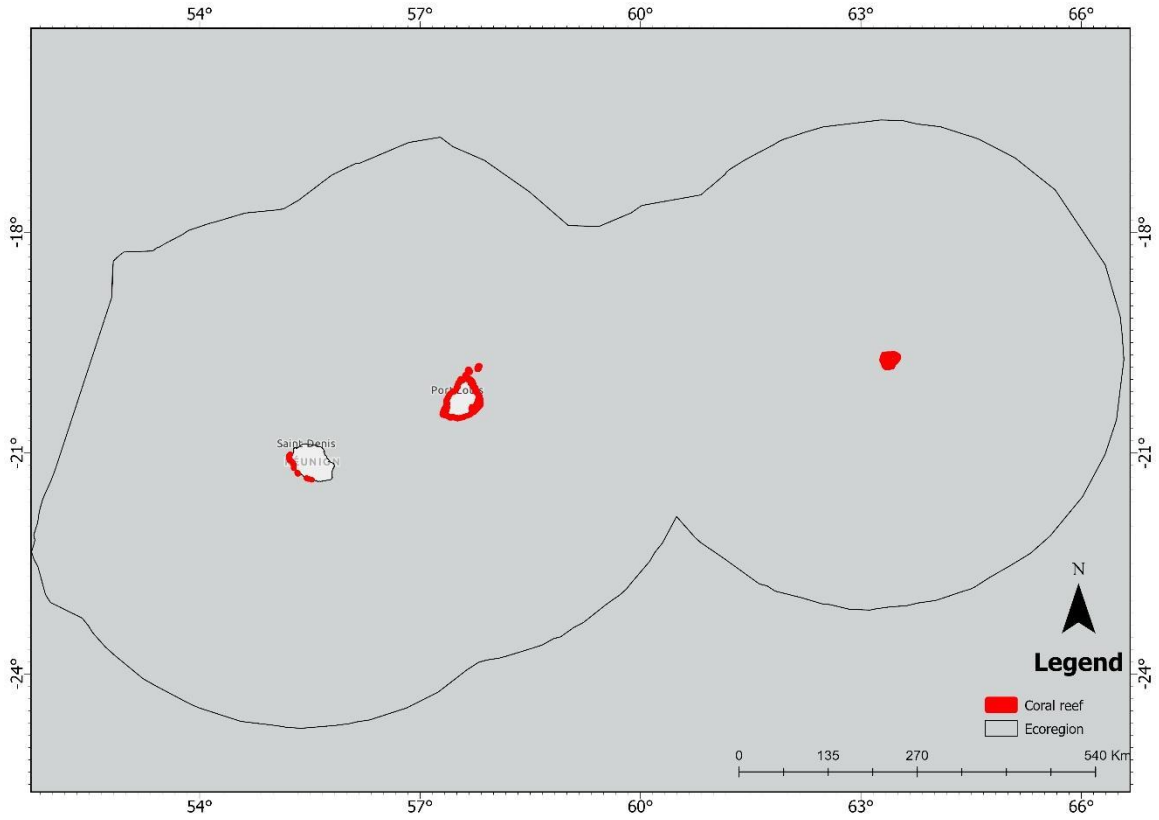


Figure 1. Mascarene Islands Ecoregion with the reef extent.

Spatial distribution (boundaries, area of coral reef)

The Mascarene Islands Ecoregion covers the remote south-western islands of Mauritius, Rodrigues and Réunion, the easternmost Ecoregion in this assessment (Figure 1). Reef development differs markedly between the three: thin reef veneers over volcanics in Mauritius, well-developed reefs with extensive flats around Rodrigues, and narrow fringing reefs at Réunion. The estimated coral reef area is 477.8 km^2, based on the unified regional reef extent layer compiled for this assessment.

Ecosystem description

Coral reefs of the Mascarene Islands form a compositionally distinct Ecoregion characterized by the highest Indo-Pacific peripheral fish endemism in the Western Indian Ocean, with several rare coral and fish species and possible local extinctions in Mauritius (McClanahan et al., 2021; Obura et al., 2021). Coral recruitment is spatially variable across the ecoregion (Jouval et al., 2019). Reef development differs markedly between the three islands: thin reef veneers over volcanics in Mauritius, well-developed reefs with extensive flats around Rodrigues, and narrow fringing reefs at Réunion (Spalding et al., 2001; Turner and Klaus, 2005). As the furthest east and most isolated Ecoregion in the assessment, its reefs support small, geographically restricted populations that are vulnerable to extinction, and the endemism that distinguishes the Ecoregion is itself a product of that isolation.

Threats include land-based runoff and coastal pollution, elevated bioerosion at Réunion (Chazottes et al., 2002), cyclones such as Garance in 2025, tourism and coastal development in Mauritius, significant bleaching, and localized oil spills in Mauritius.

The combination of geographic isolation, the region's highest fish endemism, small and vulnerable populations, and volcanic island settings with contrasting reef development creates unique ecological dynamics for the coral reefs of this Ecoregion.

Table 1. Key biotic and abiotic characteristics and key threats across Mascarene Islands Ecoregion.

Ecoregion	Key Biotic	Key Abiotic	Key Threats
8. Mascarene Islands	Highest Indo-Pacific peripheral fish endemism in the WIO, with several rare coral and fish species and possible local extinctions in Mauritius (McClanahan et al., 2021; Obura et al., 2021). Coral recruitment is spatially variable (Jouval et al., 2019).	Volcanic islands with thin reef veneers over volcanics in Mauritius, well-developed reefs with extensive flats around Rodrigues, and narrow fringing reefs at Réunion (Spalding et al., 2001; Turner and Klaus, 2005).	Land-based runoff and coastal pollution, elevated bioerosion (Réunion; (Chazottes et al., 2002), cyclones (e.g. Garance 2025); tourism and coastal development (Mauritius) and significant bleaching. Small, isolated coral populations vulnerable to extinction. Localized oil spills in Mauritius.

Key values

Table 2. Key coral reef biotic, environmental and geographic distribution values used to assess Mascarene islands Ecoregion against IUCN Red List Criteria A-D

Proportion of coral reef lost over the last 50 years (Criterion A)	Distribution (Criterion B)		SST-anomaly past 50 years (Criterion C)	Biotic indicator values (Criterion D)		
	EOO (km2)	AOO			Baseline	Current
7%	73799	39		hard coral cover (%)	47.6	29.5
				algae-coral ratio	0.380	0.675
				herbivore abundance (ind/ha)	45.8	199.1
				piscivore abundance (ind/ha)	141.1	143.3

Criteria Assessment

Overall, the risk of collapse of the coral reefs in the Mascarene Islands Ecoregion was assessed as Critically Endangered (CR).

Summary of the assessment:

Table 3. Summary of IUCN Red List Criteria assessment for coral reefs in Mascarene Islands Ecoregion, showing the evaluation of Criteria A-E and the resulting overall risk category.

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

CRITERION				
A. Reduction in Geographic Distribution	A1		A2	A3
	Past 50 years		Future or any 50y period	Historical (1750)
	LC		NE	NE
	Extent of Occurrence		Area of Occupancy	# Threat-defined Locations < 5?
	LC		VU	No
C. Environmental Degradation	C1		C2	C3
	Past 50 years (1970)		Future or any 50y period	Historical (1750)
	CR		CR	DD
D. Disruption of biotic processes	D1		D2	D3
	Past 50 years (1970)		Future or Any 50y period	Historical (1750)
	VU		NE	DD
E. Quantitative Risk analysis	NE			
OVERALL RISK CATEGORY	CR			

DD = Data Deficient; LC = Least Concern; CR = Critically Endangered; EN = Endangered; NE = Not Evaluated

Key findings

- Criterion A: Least Concern; 7% of monitored sites had hard coral cover below the assessment's 5% collapse threshold.
- Criterion B: Vulnerable; restricted geographic distribution combined with ongoing threats increases collapse risk.
- Criterion C1: Critically Endangered; historical changes in thermal-stress frequency over 1975–2025 indicate environmental degradation.
- Criterion C2: Critically Endangered; projected thermal degradation during 2026–2075 under SSP2–4.5 threatens recovery intervals and ecosystem persistence.
- Criterion D: Vulnerable. Hard coral Vulnerable; algae-coral-ratio Vulnerable; parrotfish Least Concern and groupers Near Threatened. Missing Mauritius data limits representativeness.
- Overall risk: Critically Endangered, including future thermal degradation. Observed risk is Critically Endangered.

Recommendations

- Re-establish Mauritius participation in standardized benthic and fish monitoring and improve coverage across all three island systems.
- prioritize reef habitats supporting endemic and range-restricted taxa within coastal planning and effective protection.
- Reduce runoff, wastewater, physical tourism damage and spill risks affecting coastal reef habitats.
- Monitor recruitment, bioerosion and post-bleaching or cyclone recovery to evaluate island-specific ecological trajectories.

9. East Madagascar (CR)

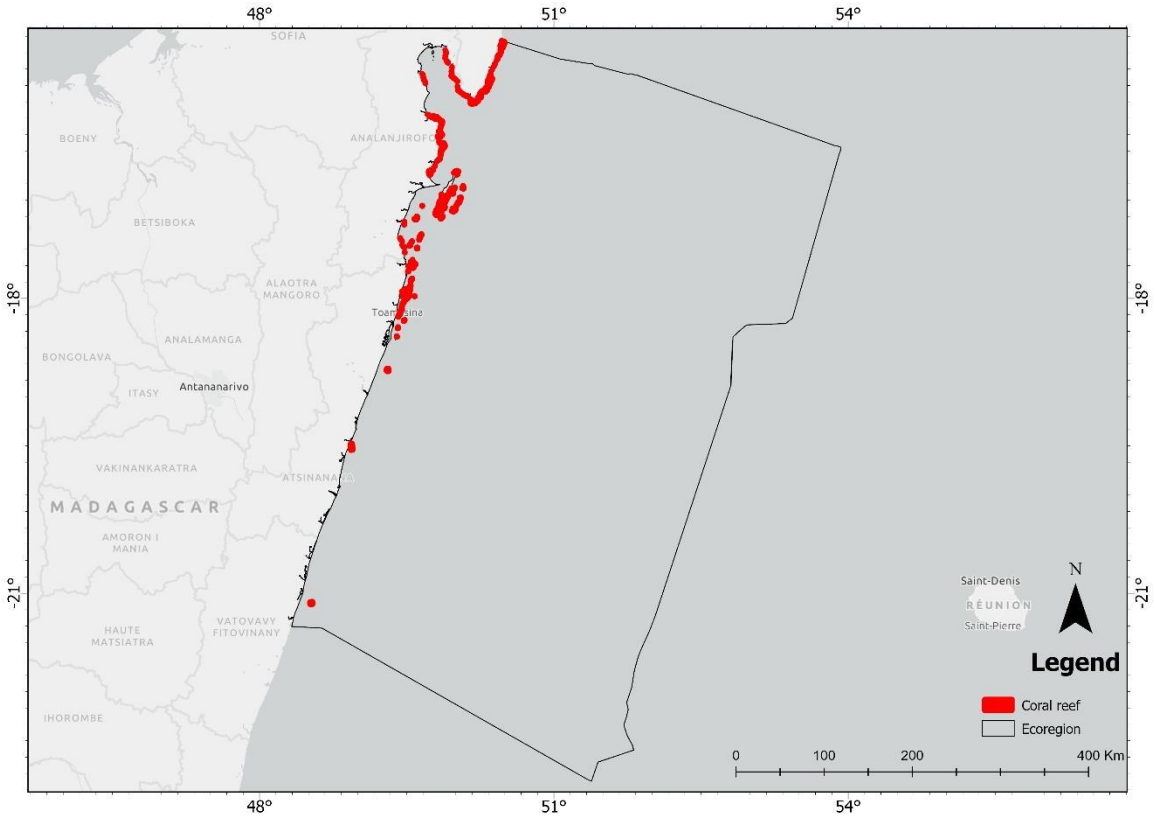


Figure 1. East Madagascar Ecoregion with the reef extent.

Spatial distribution (boundaries, area of coral reef)

The East Madagascar Ecoregion follows the exposed eastern coast of Madagascar facing the open Indian Ocean (Figure 1), with boundaries adopted in this assessment to support national processes. Reef development is discontinuous and limited to high-energy fringing and barrier structures on a narrow shelf. The estimated coral reef area is 400.8 km^2, based on the unified regional reef extent layer compiled for this assessment.

Ecosystem description

Coral reefs of the East Madagascar Ecoregion form a compositionally distinct Ecoregion characterized by discontinuous, high-energy fringing and barrier reefs supporting lower-diversity, exposure-adapted communities (Richmond, 2011; Randrianarivo et al., 2022). Reef development is constrained by the physical setting. The narrow eastern shelf is exposed to open Indian Ocean swell under strong south-east trade winds, producing high wave exposure, and the coast is influenced by the South-East Madagascar Current communities (Richmond, 2011). Reef structures are consequently patchy and restricted compared with the channel coast on the other side of the island.

This exposure regime, rather than thermal stress, is the dominant control on reef condition in the Ecoregion – a contrast with every other Madagascar Ecoregion in the assessment.

Tropical cyclones are the principal acute disturbance, for example Gamane in north-east Madagascar (World Meteorological Organization, 2025). Sedimentation from steep river catchments, artisanal fishing and bleaching add further pressure.

The combination of a narrow, high-energy shelf, exposure-adapted and lower-diversity assemblages, a southward-flowing boundary current and a cyclone-dominated disturbance regime creates unique ecological dynamics for the coral reefs of this Ecoregion.

Table 1. Key biotic and abiotic characteristics and key threats across East Madagascar Ecoregion.

Ecoregion	Key Biotic	Key Abiotic	Key Threats
9. East Madagascar	Discontinuous, high-energy fringing and barrier reefs with lower-diversity, exposure-adapted communities (Richmond, 2011; Randrianarivo et al., 2022).	Exposed eastern coast under strong south-east trade winds, high levels of wave exposure, the South-East Madagascar Current (Richmond, 2011).	Tropical cyclones (e.g. Gamane, NE Madagascar; (World Meteorological Organization, 2025); sedimentation from steep river catchments, artisanal fishing, and bleaching.

Key values

Table 2. Key coral reef biotic, environmental and geographic distribution values used to assess East Madagascar Ecoregion against IUCN Red List Criteria A-D

Proportion of coral reef lost over the last 50 years (Criterion A)	Distribution (Criterion B)		SST-anomaly past 50 years (Criterion C)	Biotic indicator values (Criterion D)		
	EOO (km2)	AOO			Baseline	Current
0%	31291	75		hard coral cover (%)	60.2	45.0
				algae-coral ratio	0.281	0.338
				herbivore abundance (ind/ha)	328.6	588.1
				piscivore abundance (ind/ha)	168	61.4

Criteria Assessment

Overall, the risk of collapse of the coral reefs in the East Madagascar Ecoregion was assessed as Critically Endangered (CR).

Summary of the assessment:

Table 3. Summary of IUCN Red List Criteria assessment for coral reefs in East Madagascar Ecoregion, showing the evaluation of Criteria A-E and the resulting overall risk category.

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?
	VU	LC	No
C. Environmental Degradation	C1	C2	C3
	Past 50 years (1970)	Future or any 50y period	Historical (1750)
	EN	CR	DD
D. Disruption of biotic processes	D1	D2	D3
	Past 50 years (1970)	Future or Any 50y period	Historical (1750)
	NT	NE	DD
E. Quantitative Risk analysis	NE		
OVERALL RISK CATEGORY	CR		

DD = Data Deficient; LC = Least Concern; CR = Critically Endangered; EN = Endangered; NE = Not Evaluated

Key findings

- Criterion A: Least Concern; no monitored sites had hard coral cover below 5% although his does not establish an absence of degradation across the Ecoregion.
- Criterion B: Vulnerable; restricted geographic distribution combined with ongoing threats increases collapse risk.
- Criterion C1: Endangered; historical changes in thermal-stress frequency over 1975–2025 indicate environmental degradation.
- Criterion C2: Critically Endangered; projected thermal degradation during 2026–2075 under SSP2–4.5 threatens recovery intervals and ecosystem persistence.
- Criterion D: Least Concern. Coral and algae-coral-ratio LC; both fish indicators DD, limiting assessment of trophic disruption.
- Overall risk: Critically Endangered, including future thermal degradation. Observed risk is Endangered.

Recommendations

- Expand recent fish surveys and repeat benthic monitoring across representative exposed and sheltered reef habitats.
- Integrate bleaching and cyclone damage assessments to distinguish thermal mortality from physical habitat loss.
- Reduce catchment erosion and sediment delivery while maintaining locally supported fisheries controls.
- Protect remaining reef habitats from coastal development and assess recruitment and structural complexity beyond coral cover alone.

10. South Madagascar (CR)

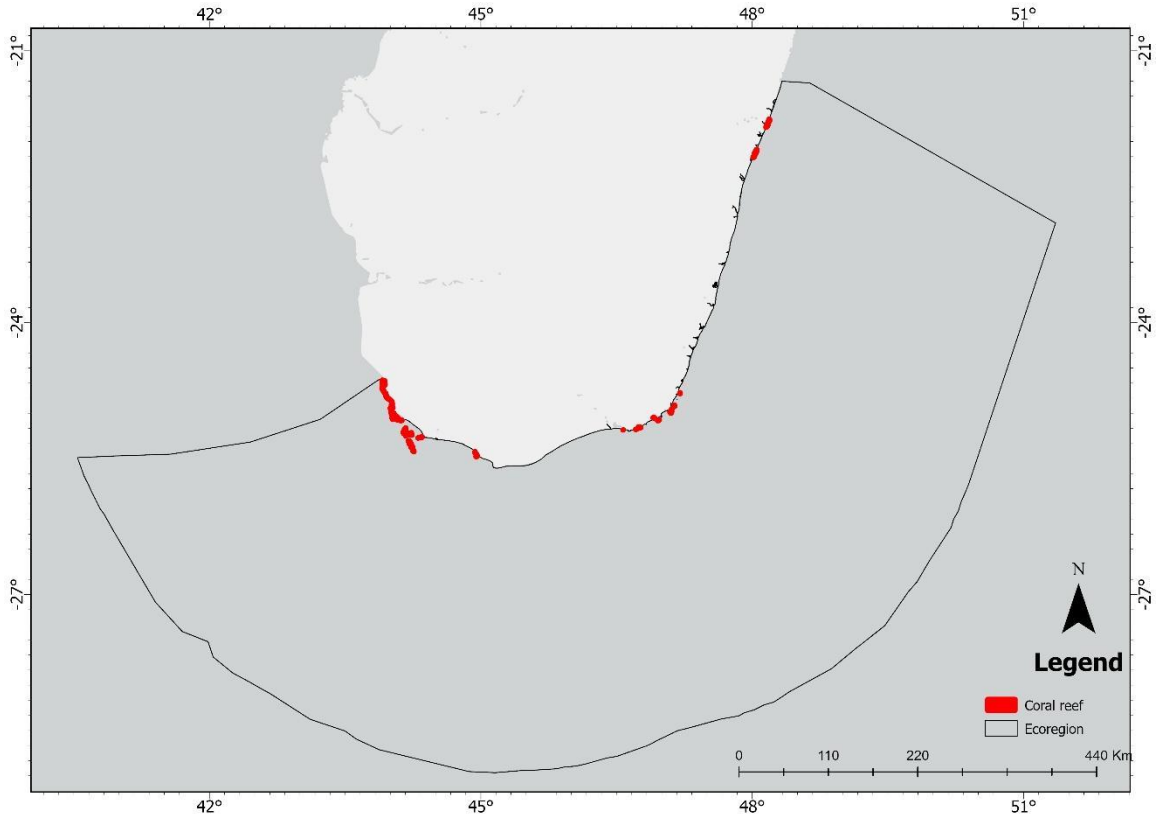


Figure 1. South Madagascar Ecoregion with the reef extent.



Figure 2. A coral reef community picture taken in southwest reefs in Mahafaly seascape area in Madagascar. Randrianarivo M. WWF-Madagascar ©

Spatial distribution (boundaries, area of coral reef)

The South Madagascar Ecoregion covers the 'Grand Sud' of Madagascar (Figure 1), a temperature enclave influenced by cool upwelling and a marginal coral reef environment. Reefs are fringing and continuous barrier systems along the exposed, drier south and west coast, including Toliara and Andavadoaka. The estimated coral reef area is 110.9 km^2, based on the unified regional reef extent layer compiled for this assessment.

Ecosystem description

Coral reefs of the South Madagascar Ecoregion form a compositionally distinct Ecoregion characterized by fringing and massive, continuous barrier reefs, for example at Toliara and Andavadoaka, with well-studied herbivore communities. Coral communities have become more spatially restricted towards the exposed areas of the south coast (Cooke, 2022).

The 'Grand Sud' of Madagascar is a temperature enclave influenced by cool upwelling, making this a marginal coral reef environment. The exposed, drier south and west coast carries barrier-like reefs, and the Ecoregion recorded comparatively lower thermal-stress exposure in 2024, with periodic cyclone impacts and locally cooler waters influenced by the Southwest Madagascar Coastal Current (SMACC) (Ramanantsoa et al., 2018).

These conditions place the Ecoregion at the margin of reef development in Madagascar, where cool upwelling rather than warming sets the limits on coral community composition and distribution.

Intense artisanal fishing and gleaning are the dominant chronic pressures fishing (Behivoke et al., 2021, 2026), alongside sedimentation (Sheridan et al., 2014) cyclones such as cyclones (Côté-Laurin et al., 2017; Carter et al., 2022), and bleaching.

The combination of cool-water upwelling, marginal reef development, continuous barrier structures and intense small-scale fishing pressure creates unique ecological dynamics for the coral reefs of this Ecoregion.

Table 1. Key biotic and abiotic characteristics and key threats across South Madagascar Ecoregion.

Ecoregion	Key Biotic	Key Abiotic	Key Threats
10. South Madagascar	Colder/higher nutrient fauna and habitats. Lower coral diversity (Obura, 2012).	The 'Grand Sud' of Madagascar is a temperature enclave influenced by cool upwelling, creating a temperate, marginal coral reef environment (Obura, 2012). Locally cooler waters influenced by the SMACC (Ramanantsoa et al., 2018).	Intense artisanal fishing (Behivoke et al., 2021, 2026) and gleaning (Andréfouët et al., 2013), sedimentation(Sheridan et al., 2014) cyclones (Côté-Laurin et al., 2017; Carter et al., 2022) and bleaching.

Key values

Table 2. Key coral reef biotic, environmental and geographic distribution values used to assess South Madagascar Ecoregion against IUCN Red List Criteria A-D

Proportion of coral reef lost over the last 50 years (Criterion A)	Distribution (Criterion B)		SST-anomaly past 50 years (Criterion C)	Biotic indicator values (Criterion D)		
	EOO (km2)	AOO			Baseline	Current
0%	79196	25		hard coral cover (%)	-	-
				algae-coral ratio	-	-
				herbivore abundance (ind/ha)	328.6	101.1
				piscivore abundance (ind/ha)	168	28.9

Criteria Assessment

Overall, the risk of collapse of the coral reefs in the South Madagascar Ecoregion was assessed as Critically Endangered (CR).

Summary of the assessment:

Table 3. Summary of IUCN Red List Criteria assessment for coral reefs in South Madagascar Ecoregion, showing the evaluation of Criteria A-E and the resulting overall risk category.

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?
	LC	VU	No
C. Environmental Degradation	C1	C2	C3
	Past 50 years (1970)	Future or any 50y period	Historical (1750)
	EN	CR	DD
D. Disruption of biotic processes	D1	D2	D3
	Past 50 years (1970)	Future or Any 50y period	Historical (1750)
	DD	NE	DD
E. Quantitative Risk analysis	NE		
OVERALL RISK CATEGORY	CR		

DD = Data Deficient; LC = Least Concern; CR = Critically Endangered; EN = Endangered; NE = Not Evaluated

Key findings

- Criterion A: Data Deficient; insufficient monitoring prevents estimation of the proportion of sites below 5% hard coral cover.
- Criterion B: Vulnerable; restricted geographic distribution combined with ongoing threats increases collapse risk.
- Criterion C1: Endangered; historical changes in thermal-stress frequency over 1975–2025 indicate environmental degradation.
- Criterion C2: Critically Endangered; projected thermal degradation during 2026–2075 under SSP2–4.5 threatens recovery intervals and ecosystem persistence.
- Criterion D: Data Deficient. All four indicators were Data Deficient; insufficient data prevent reliable quantification of biotic degradation.
- Overall risk: Critically Endangered, including future thermal degradation. Observed risk is Endangered.

Recommendations

- Establish representative baseline and repeated surveys of benthic condition, herbivores and piscivores before inferring degradation severity.
- Use local temperature measurements and bleaching observations to test the extent and persistence of cooling-related refugial conditions.
- Support community fisheries management that reduces destructive extraction while addressing reef-dependent livelihoods.
- Combine sediment controls and post-cyclone assessments with protection of the limited remaining reef habitats.

11. Delagoa (CR)

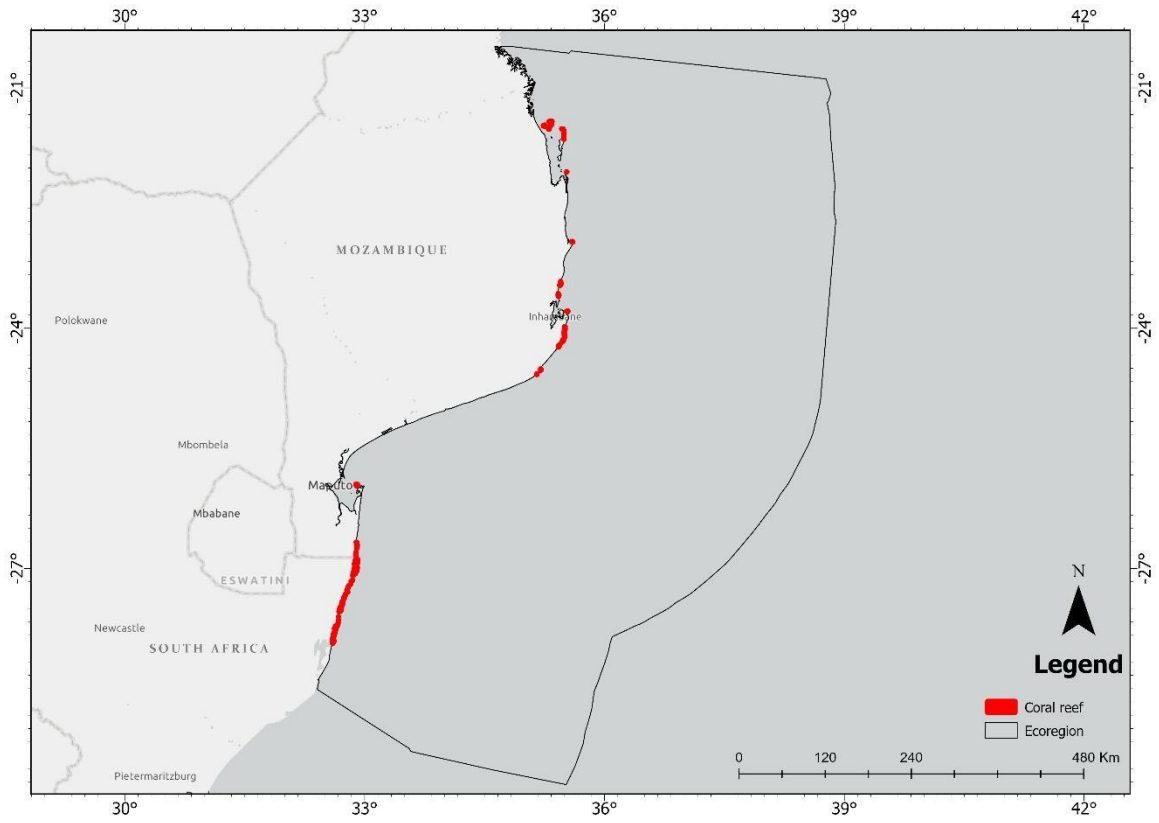


Figure 1. Delagoa Ecoregion with the reef extent.



Figure 2. A soft coral dominated community from Sodwana Bay, iSimangaliso Wetland Park World Heritage Site, South Africa. Porter SN – Oceanographic Research Institute ©

Spatial distribution (boundaries, area of coral reef)

The Delagoa Ecoregion encompasses coral reefs of southern Mozambique and northern South Africa, extending from Bazaruto and Inhambane southwards through Inhaca to KwaZulu-Natal (Figure 1). These are the southernmost reefs in the region, where cooler water limits carbonate accretion and reef development becomes marginal at the southern reef limit in Maputaland. The estimated coral reef area is 58.7 km^2, making it the smallest of the reef-bearing Ecoregions, based on the unified regional reef extent layer compiled for this assessment.

Ecosystem description

Coral reefs of the Delagoa Ecoregion form a compositionally distinct Ecoregion characterized by high-latitude marginal communities dominated by soft corals and stress-tolerant, slow-accreting assemblages of distinct composition and high biodiversity (Schleyer and Celliers, 2003; Porter et al., 2013; Schleyer et al., 2018; Porter and Schleyer, 2019; Obura et al., 2021). (Figure 2).

Reef formation here is unlike anywhere else in the region. The carbonate framework is severely restricted, and most reefs are composed of aeolianite sandstone rather than biogenic carbonate (Ramsay, 1994; Perry, 2003). Consequently, coral communities grow as a thin veneer on pre-existing substrate rather than building one.

Cooler 16–28°C water from the Mozambique Channel and the Agulhas Current limits carbonate accretion and accumulation (Lutjeharms, 2007; Porter & Schleyer, 2019; Schleyer & Celliers, 2005), with marked seasonality in water temperature and upwelling in the south (Porter et al., 2017, 2021; Porter and Schleyer, 2019). Threats are dominated by marginal cool-water stress and climate-driven community change, together with cyclones, coastal development, tourism (Birrell et al., 2022) and unsustainable fishing practices (Menezes et al., 2011). Thermal-stress exposure has historically been lower than in the northern Ecoregions, but warming is increasing (Gudka, D. Obura, et al., 2018; Porter et al., 2021).

The combination of a high-latitude marginal setting, non-biogenic reef substrate, soft-coral dominated assemblages and a cool-water temperature regime creates unique ecological dynamics for the coral reefs of this Ecoregion.

Table 1. Key biotic and abiotic characteristics and threats across the Delagoa Ecoregion.

Ecoregion	Key Biotic	Key Abiotic	Key Threats
11. Delagoa	High-latitude marginal communities dominated by soft corals and stress-tolerant, slow-accreting assemblages of distinct composition, and high biodiversity (Schleyer and Celliers, 2003; Porter et al., 2013; Schleyer et al., 2018; Porter and Schleyer, 2019; Obura et al., 2021). Carbonate framework is severely restricted with most reefs composed of aeolinite sandstone rather than biogenic carbonate (Ramsay, 1994; Perry, 2003).	Cooler 16–28°C water from the Mozambique Channel and Agulhas Current limit carbonate accretion and accumulation (Schleyer and Celliers, 2003; Lutjeharms, 2007; Porter and Schleyer, 2019). Seasonality in water temperatures and upwelling in the south (Porter et al., 2017, 2021; Porter and Schleyer, 2019).	Marginal cool-water stress and climate-driven community change, cyclones, coastal development, tourism (Birrell et al., 2022) and unsustainable fishing practices (Menezes et al., 2011). Historically lower thermal-stress exposure than northern ecoregions, but warming is increasing (Gudka, D. Obura, et al., 2018; Porter et al., 2021).

Key values

Table 2. Key coral reef biotic, environmental and geographic distribution values used to assess the Delagoa Ecoregion against IUCN Red List Criteria A-D

Proportion of coral reef lost over the last 50 years (Criterion A)	Distribution (Criterion B)		SST-anomaly past 50 years (Criterion C)	Biotic indicator values (Criterion D)		
	EOO (km2)	AOO			Baseline	Current
12%	73957	29		hard coral cover (%)	41.4	23 .1
				algae-coral ratio	0.281	0.408
				herbivore abundance (ind/ha)	215.4	179
				piscivore abundance (ind/ha)	27.9	160.7

Criteria Assessment

Overall, the risk of collapse of the coral reefs in the Delagoa Ecoregion was assessed as Critically Endangered (CR).

Summary of the assessment:

Table 3. Summary of IUCN Red List Criteria for coral reefs in the Delagoa Ecoregion, showing the evaluation of Criteria A-E and the resulting overall risk category.

CRITERION			
A. Reduction in Geographic Distribution	**A1**	**A2**	**A3**
	Past 50 years	Future or any 50y period	Historical (1750)
	LC	**NE**	**NE**
B. Restricted Geographic Distribution	**B1**	**B2**	**B3**
	Extent of Occurrence	Area of Occupancy	# Threat-defined Locations < 5?
	LC	**VU**	**No**
C. Environmental Degradation	**C1**	**C2**	**C3**
	Past 50 years (1970)	Future or any 50y period	Historical (1750)
	VU	**CR**	**DD**
D. Disruption of biotic processes	**D1**	**D2**	**D3**
	Past 50 years (1970)	Future or Any 50y period	Historical (1750)
	VU	**NE**	**DD**
E. Quantitative Risk analysis	**NE**		
OVERALL RISK CATEGORY	**CR**		

DD = Data Deficient; LC = Least Concern; CR = Critically Endangered; EN = Endangered; NE = Not Evaluated

Key findings

- Criterion A: Least Concern; 12% of monitored sites had hard coral cover below the assessment's 5% collapse threshold.
- Criterion B: Vulnerable; restricted geographic distribution combined with ongoing threats increases collapse risk.
- Criterion C1: Vulnerable; historical changes in thermal-stress frequency from 1975–2025 indicate environmental degradation.
- Criterion C2: Critically Endangered; projected thermal degradation during 2026–2075 under SSP2–4.5 threatens recovery intervals and ecosystem persistence.
- Criterion D: Vulnerable. Hard coral VU; algae-coral ratio NT; parrotfish NT and groupers LC.
- Overall risk: Critically Endangered, including future thermal degradation. Observed risk is Vulnerable.

Recommendations

- Monitor hard and soft coral cover and composition, macro-algae cover, coral recruitment and reef structural condition to detect changes specific to marginal reef communities.
- Monitor a selection of appropriate fish families/species
- Maintain effective fisheries protection while reducing physical damage from tourism and coastal development.
- Couple local temperature and upwelling observations with bleaching surveys to evaluate fine-scale thermal exposure.
- Coordinate monitoring and management across southern Mozambique and northern South Africa to capture transboundary ecological conditions and change.

12. Central Mozambique Channel (CR)

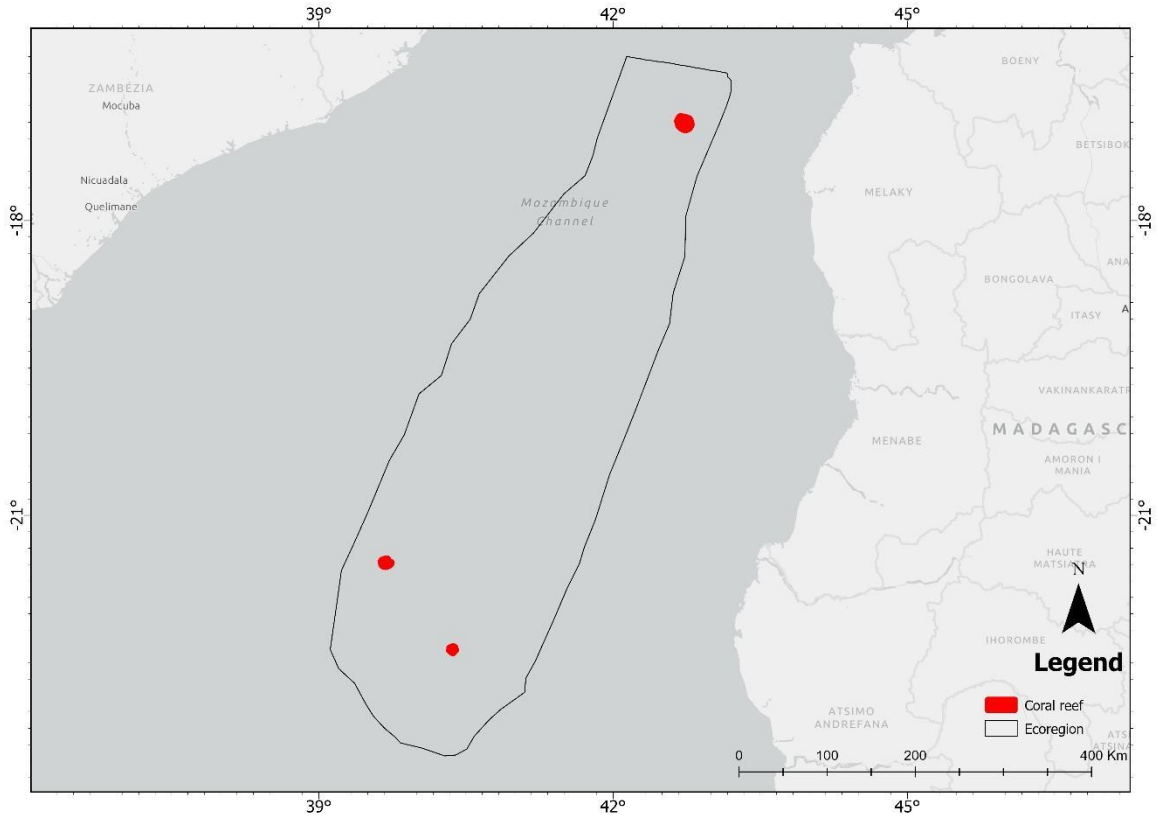


Figure 1. Central Mozambique Channel Ecoregion with the reef extent.

Spatial distribution (boundaries, area of coral reef)

The Central Mozambique Channel Ecoregion comprises the Îles Éparses – Bassas da India, Europa and Juan de Nova – isolated in the middle of the Mozambique Channel with no shelf connection to either margin (Figure 1). The northern limit is at Juan de Nova and the southern limit at Europa and Bassas da India. Reefs are remote oceanic island and atoll systems. The estimated coral reef area is 97.7 km^2, based on the unified regional reef extent layer compiled for this assessment.

Ecosystem description

Coral reefs of the Central Mozambique Channel Ecoregion form a compositionally distinct Ecoregion characterized by remote oceanic reefs of the French Scattered Islands with near-pristine, low-impact communities that serve as important regional reference and refugia sites.

Reefs are isolated atolls and carbonate platforms in warm Mozambique Channel waters, influenced by anticyclonic eddies, and fall within the area predicted to persist as a climate refugium (Montaggioni and Martin-Garin, 2020; McClanahan et al., 2024). The Ecoregion has no shelf connection to either the African or the Madagascar margin, which isolates these reefs both physically and from land-based pressure.

Direct human pressure is very low, and the Ecoregion is therefore one of the few places in the region where reef condition reflects climate forcing almost in isolation from local stressors – making it a regional reference point.

Principal threats are climate-driven, chiefly bleaching and cyclones, with illegal and unregulated fishing and marine debris as secondary pressures.

The combination of extreme isolation, near-absent local anthropogenic stress, predicted climate-refugium status and oceanic atoll reef development creates unique ecological dynamics for the coral reefs of this Ecoregion.

Table 1. Key biotic and abiotic characteristics and key threats across Central Mozambique channel Ecoregion.

Ecoregion	Key Biotic	Key Abiotic	Key Threats
12. Central Mozambique Channel	Remote oceanic reefs (French Scattered Islands) with near-pristine, low-impact communities that serve as important regional reference and refugia sites.	Isolated atolls and carbonate platforms in warm Mozambique Channel waters with anticyclonic eddies and within the area predicted to persist as a climate refugium (Montaggioni and Martin-Garin, 2020; McClanahan et al., 2024).	Very low direct human pressure. Principal threats are climate-driven (bleaching, cyclones), with illegal/unregulated fishing and marine debris.

Key values

Table 2. Key coral reef biotic, environmental and geographic distribution values used to assess Central Mozambique Channel Ecoregion against IUCN Red List Criteria A-D

Proportion of coral reef lost over the last 50 years (Criterion A)	Distribution (Criterion B)		SST-anomaly past 50 years (Criterion C)	Biotic indicator values (Criterion D)		
	EOO (km2)	AOO			Baseline	Current
0%	42135	11		hard coral cover (%)	49.5	31.7
				algae-coral ratio	0.281	0.482
				herbivore abundance (kg/ha)	222.5	236.2
				piscivore abundance (kg/ha)	307.2	668.9

Criteria Assessment

Overall, the risk of collapse of the coral reefs in the Central Mozambique Channel Ecoregion was assessed as Critically Endangered (CR).

Summary of the assessment:

Table 3. Summary of IUCN Red List Criteria assessment for coral reefs in Central Mozambique Channel Ecoregion, showing the evaluation of Criteria A-E and the resulting overall risk category.

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?
	VU	EN	No
C. Environmental Degradation	C1	C2	C3
	Past 50 years (1970)	Future or any 50y period	Historical (1750)
	EN	CR	DD
D. Disruption of biotic processes	D1	D2	D3
	Past 50 years (1970)	Future or Any 50y period	Historical (1750)
	VU	NE	DD
E. Quantitative Risk analysis	NE		
OVERALL RISK CATEGORY	CR		

DD = Data Deficient; LC = Least Concern; CR = Critically Endangered; EN = Endangered; NE = Not Evaluated

Key findings

- Criterion A: Least Concern; no monitored sites had hard coral cover below 5%. However, this does not establish an absence of degradation across the Ecoregion.
- Criterion B: Endangered; restricted geographic distribution combined with ongoing threats increases collapse risk.
- Criterion C1: Endangered; historical changes in thermal-stress frequency over 1975–2025 indicate environmental degradation.
- Criterion C2: Critically Endangered; projected thermal degradation during 2026–2075 under SSP2–4.5 threatens recovery intervals and ecosystem persistence.
- Criterion D: Vulnerable. Hard coral and algae-coral-ratio VU; parrotfish NT; groupers VU.
- Overall risk: Critically Endangered, including future thermal degradation. Observed risk is Endangered.

Recommendations

- Maintain protection against illegal or unregulated fishing and physical habitat damage.
- Extend repeated benthic and fish surveys across all three island systems and contrasting reef habitats.
- Validate potential refugial conditions with local thermal records and observed bleaching responses.

- Coordinate event-response monitoring and marine-debris management, recognizing the vulnerability of geographically restricted reef systems.

13. Northern Monsoon Current (DD)

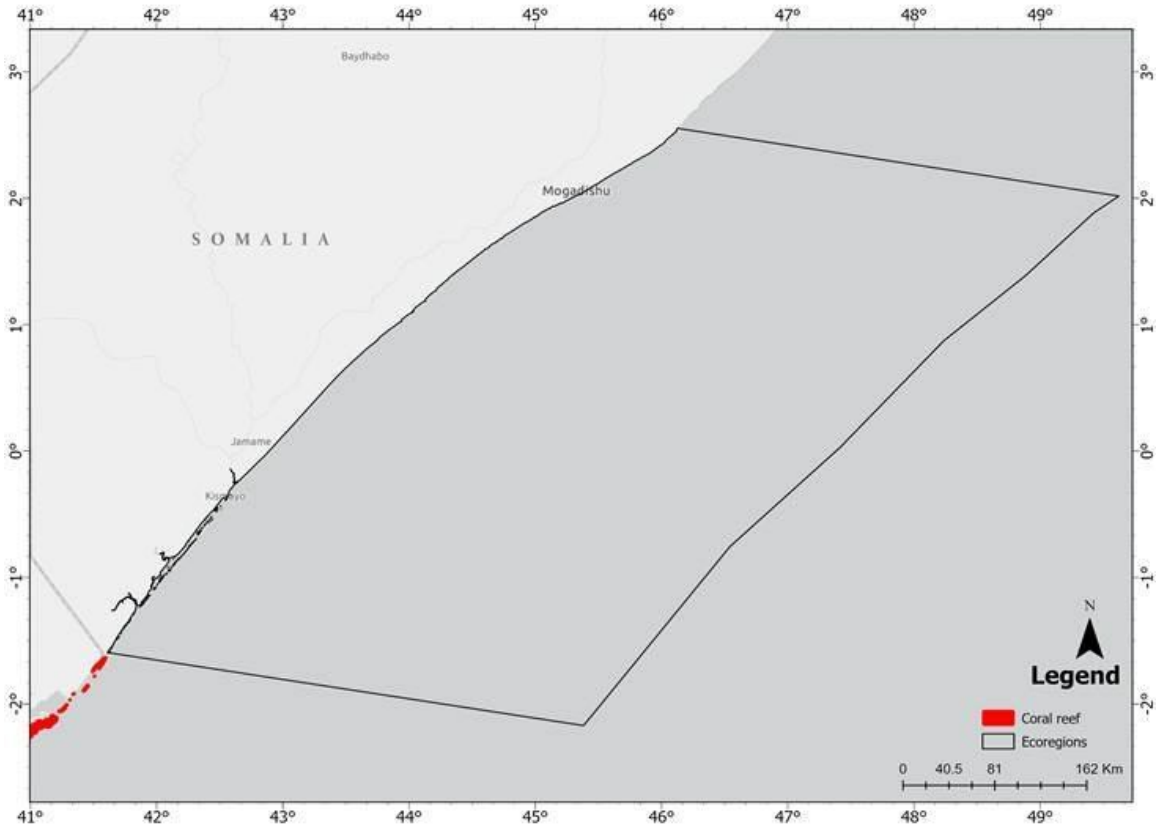


Figure 1. Northern Monsoon Current Ecoregion with the reef extent.

Spatial distribution (boundaries, area of coral reef)

The Northern Monsoon Current Ecoregion covers the Somali coast (Figure 1), bounded to the north by the monsoon-driven upwelling front and to the south by the Kenyan border. It marks the northern range limit of Western Indian Ocean coral reefs. Reef habitats include fossil coral reef flats and platforms with development constrained by seasonally reversing currents and intense southwest-monsoon upwelling. No validated coral reef area could be mapped within the Ecoregion from the regional reef extent layer, and the Ecoregion is treated as Data Deficient throughout this assessment.

Ecosystem description

Coral reefs of the Northern Monsoon Current Ecoregion form a compositionally distinct Ecoregion characterized by a marked urbanization gradient, from moderately diverse scleractinian assemblages at remote sites to macroalgal-dominated, disturbance-tolerant assemblages with depressed accretion at urban sites (Carbone and Accordi, 2000; Schleyer et al. 1999).

This is the northern range limit of Western Indian Ocean reefs, set by the seasonally reversing Somali Current and intense south-west monsoon upwelling (McClanahan, 1988; Obura, 2012; Jacobs et al., 2021). Reef development varies at site level from intact fossil-coral-cliff

reef flats to sand-encroached fossil palaeoreef platforms (Carbone and Accordi, 2000; ASCLME, 2012).

Chronic upwelling cool-water stress, together with minimal monitoring and governance, defines the Ecoregion. Emerging local pressures at urban sites include untreated wastewater, solid waste and litter (Hassan et al., 2024), coral and sand extraction, and overexploitation of reef megafauna such as Tridacna spp. and manta rays (Carbone and Accordi, 2000; ASCLME, 2012).

Baseline data are sparse. No validated coral reef area could be mapped within the Ecoregion for this assessment, and it is consequently Data Deficient under every criterion for which an assessment was attempted.

The combination of a monsoon-driven upwelling range limit, cool-water suppression of accretion, a steep urbanization gradient and almost no monitoring coverage creates unique ecological dynamics for the coral reefs of this Ecoregion.

Table 1. Key biotic and abiotic characteristics and key threats across Northern Monsoon Current Ecoregion.

Ecoregion	Key Biotic	Key Abiotic	Key Threats
13. Northern Monsoon Current	Marked urbanization gradient, from moderately diverse scleractinian assemblages at remote sites to macroalgal-dominated, disturbance-tolerant assemblages with depressed accretion at urban sites (Carbone and Accordi, 2000; Schleyer et al. 1999)	Northern range limit of WIO reefs, set by the seasonally reversing Somali Current and intense SW-monsoon upwelling (McClanahan, 1988; Obura, 2012; Jacobs et al., 2021). Site-level variation from intact fossil-coral-cliff reef flats to sand-encroached fossil paleo reef platforms(Carbone and Accordi, 2000; ASCLME, 2012).	Chronic upwelling cool-water stress, minimal monitoring and governance. Emerging local pressures at urban sites: untreated wastewater, solid waste, litter (Hassan et al., 2024), coral and sand extraction, overexploitation of reef megafauna (*Tridacna* spp., manta rays). (Carbone and Accordi, 2000; ASCLME, 2012). Sparse baseline data.

Key values

Table 2. Key coral reef biotic, environmental and geographic distribution values used to assess Northern Monsoon Current Ecoregion against IUCN Red List Criteria A-D

Proportion of coral reef lost over the last 50 years (Criterion A)	Distribution (Criterion B)		SST-anomaly past 50 years (Criterion C)	Biotic indicator values (Criterion D)		
	EOO (km2)	AOO			Baseline	Current
DD	NE	NE		hard coral cover (%)	-	-
				algae-coral ratio	-	-
				herbivore abundance	-	-
				piscivore abundance	-	-

Criteria Assessment

Overall, the risk of collapse of the coral reefs in the Northern Monsoon Current Ecoregion was assessed as Data Deficient (DD).

Summary of the assessment:

Table 3. Summary of IUCN Red List Criteria assessment for coral reefs in Northern Monsoon Current Ecoregion, showing the evaluation of Criteria A-E and the resulting overall risk category.

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**	**No**
C. Environmental Degradation	**C1**	**C2**	**C3**
	Past 50 years (1970)	Future or any 50y period	Historical (1750)
	VU	**CR**	**DD**
D. Disruption of biotic processes	**D1**	**D2**	**D3**
	Past 50 years (1970)	Future or Any 50y period	Historical (1750)
	EN	**NE**	**DD**
E. Quantitative Risk analysis	**NE**		
OVERALL RISK CATEGORY	**DD**		

DD = Data Deficient; LC = Least Concern; CR = Critically Endangered; EN = Endangered; NE = Not Evaluated

Recommendations

- Validate reef extent and habitat identity using field observations and suitable mapping before calculating spatial risk metrics.
- Establish baseline and repeated benthic, fish, water-quality and temperature monitoring across remote and urban settings.
- Distinguish naturally constrained reef accretion from anthropogenic degradation when defining reference conditions and collapse thresholds.
- Address wastewater, solid waste and reef-material extraction while building national monitoring capacity and regional data-sharing links.

Appendices:

Supplementary Information

Criterion A-Reduction in geographic distribution

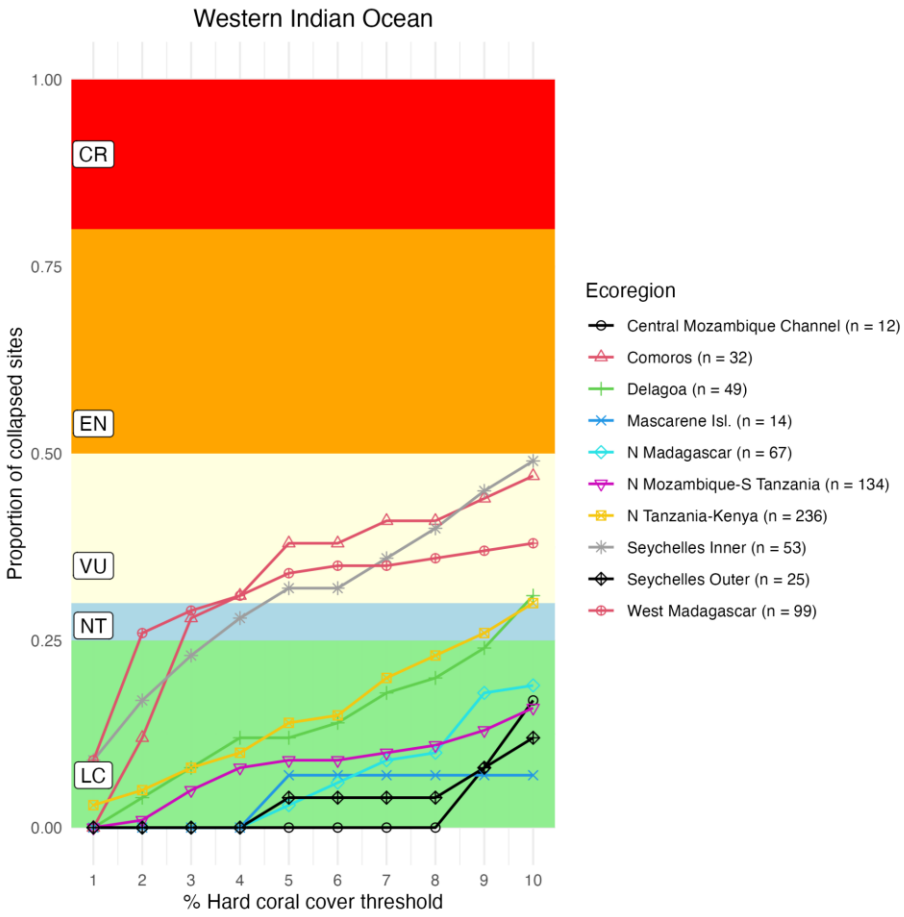


Figure S1. Sensitivity analysis of Criterion A to the collapse threshold for hard coral cover varying from 1% to 10%.

Criterion B-Restricted geographic distribution

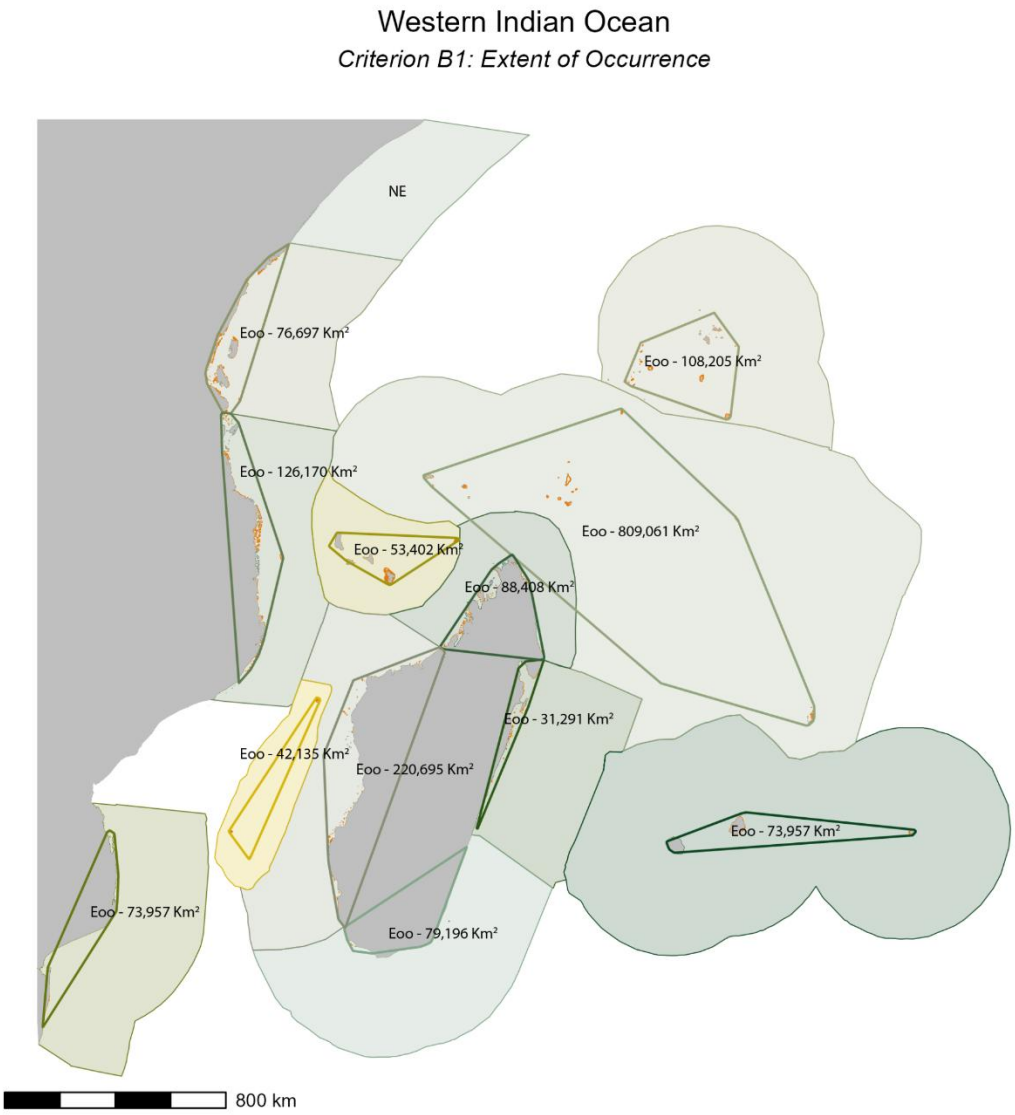


Figure S2. Extent of occurrence (EOO) of coral reefs in each WIO ecoregion, shown as the minimum convex polygon enclosing all mapped reefs.

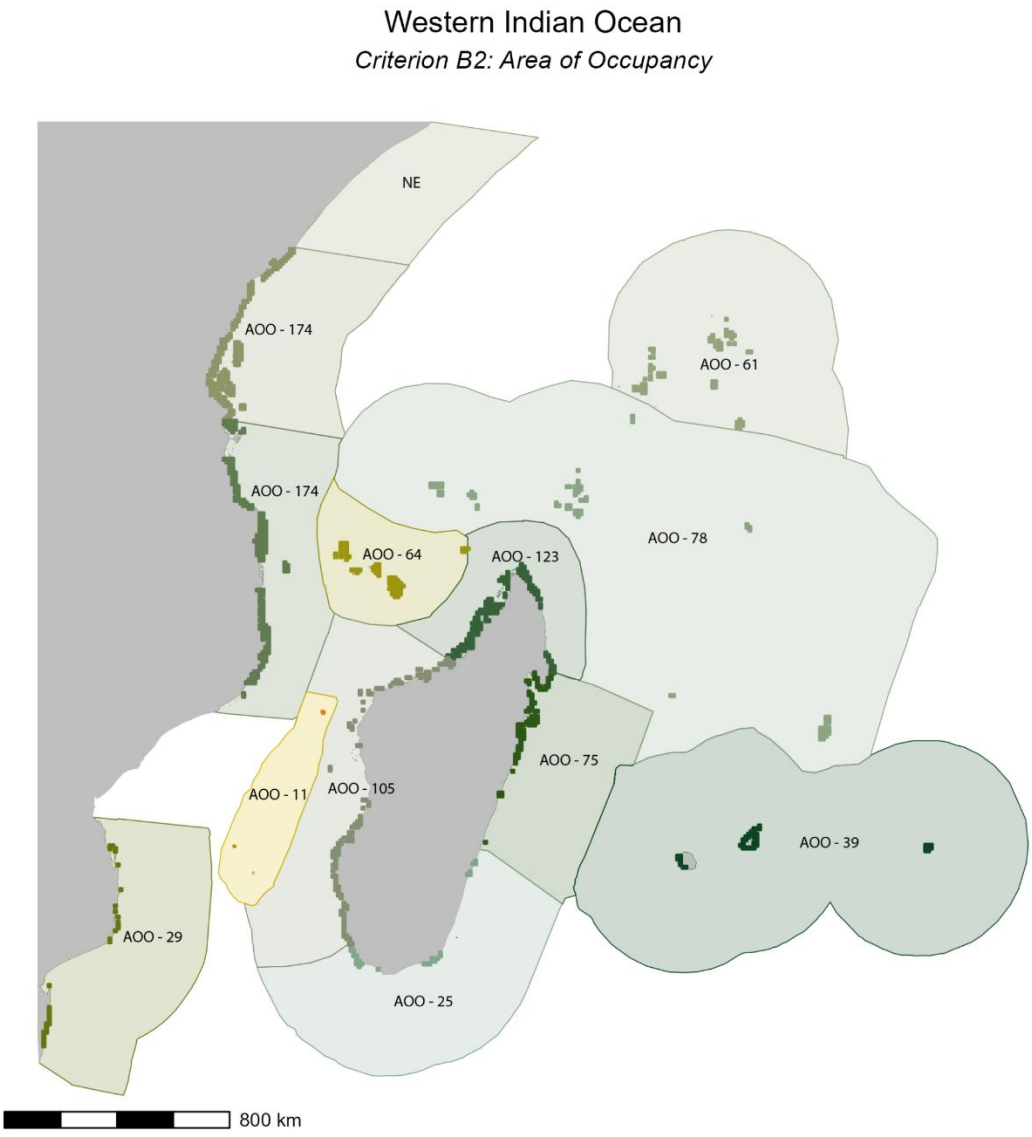


Figure S3. Area of occupancy (AOO) of coral reefs in each WIO ecoregion, shown as the number of occupied 10 × 10 km grid cells.

Criterion C-Environmental Degradation

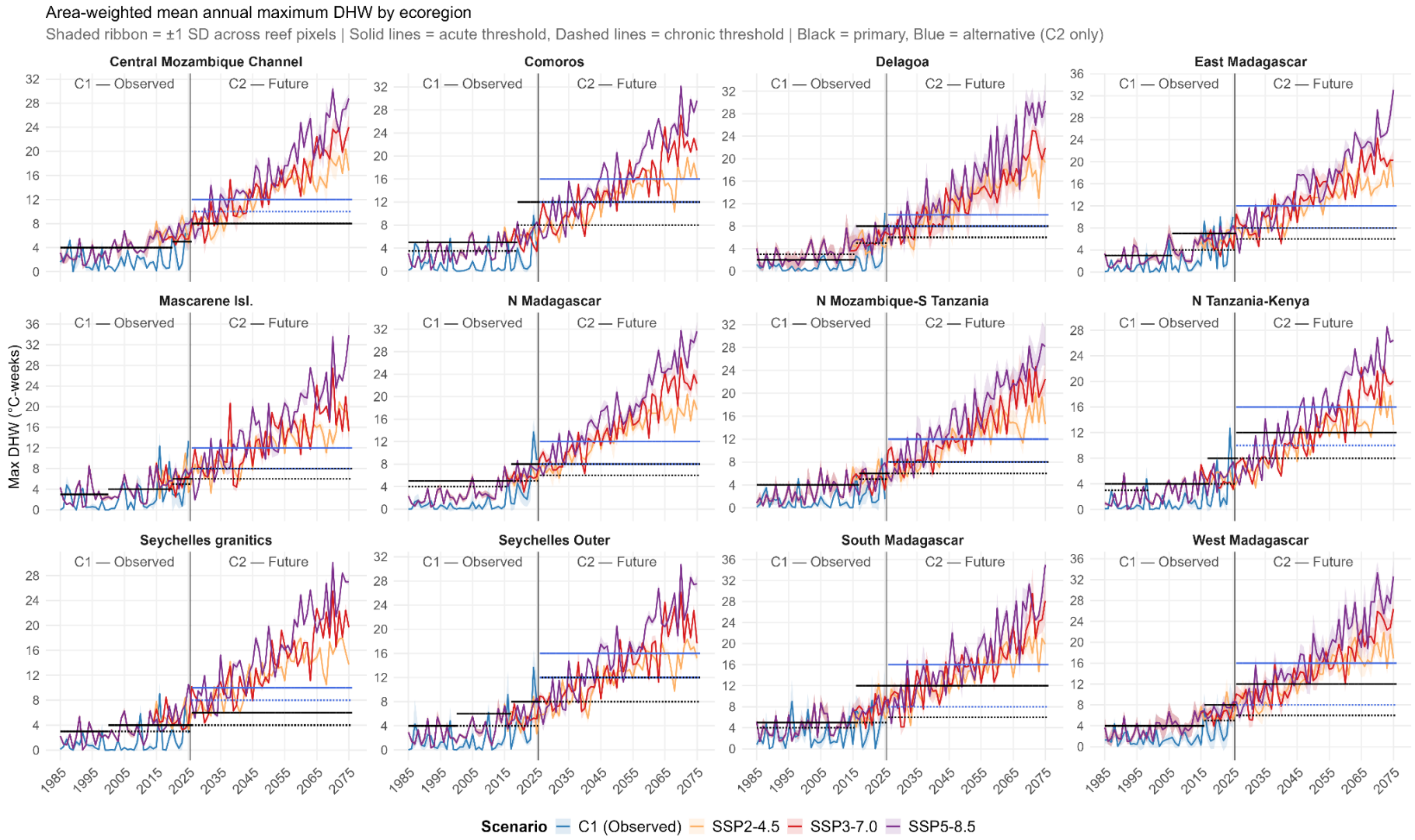


Figure S4: Annual maximum Degree Heating Weeks (DHW) averaged across coral reefs within each ecoregion from 1985-2075 for four trajectories: observed data used to assess sub-criterion C1 from 1985-2025 (blue line), and projections under three Shared Socioeconomic Pathways — SSP2-4.5 (orange), SSP3-7.0 (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.

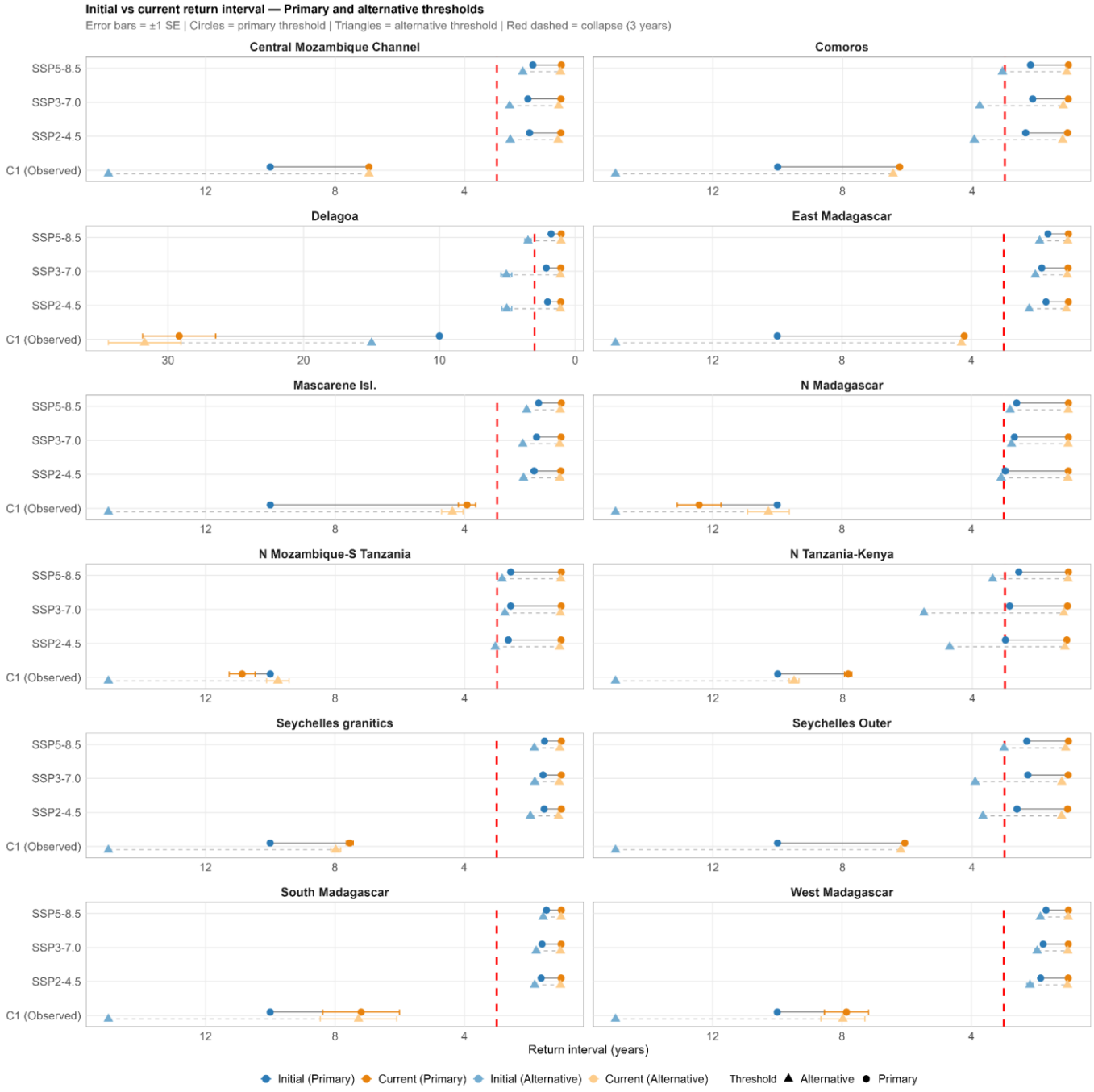


Figure S5: Change in the average return interval between severe bleaching events (years) for each ecoregion (x-axis), comparing initial conditions (blue) to current or projected future conditions (orange) across four trajectories (y-axis): observed data (C1) and projections under SSP2-4.5, SSP3-7.0, 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 S6. 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.

Criterion D-Biotic disruption

Benthic

Distribution of baseline and current hard coral values across the monitored sites

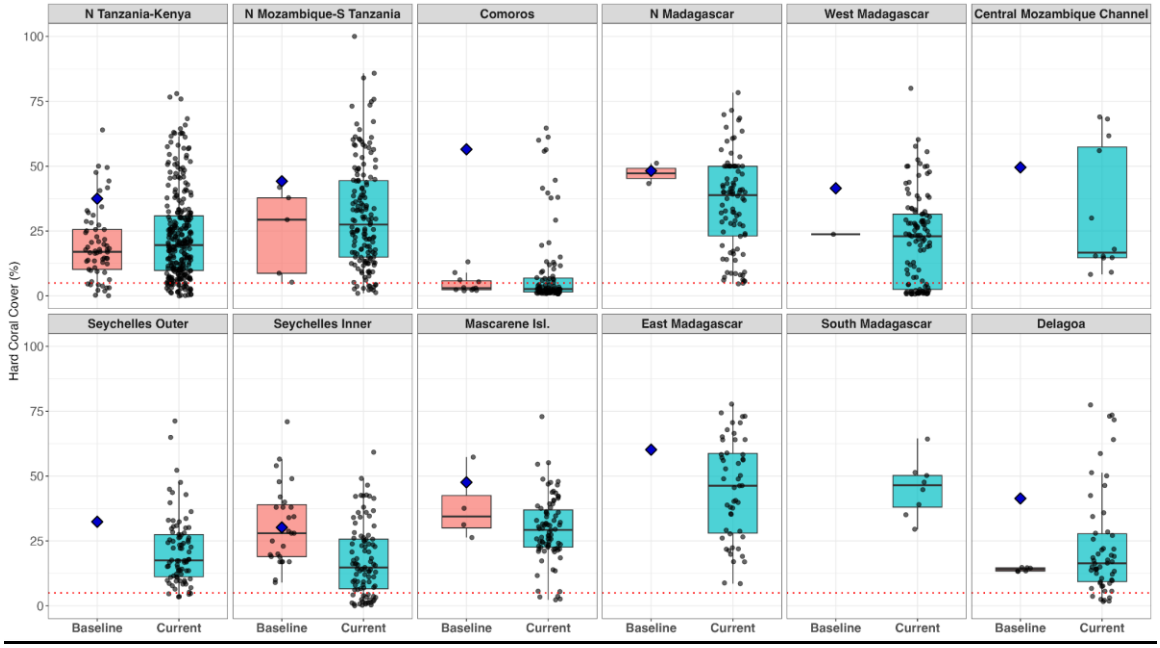


Figure S7. Baseline and current hard coral cover across the assessed WIO ecoregions. Baseline observations represent 1998 or earlier and current observations cover 2020-2025. Black points show individual observations; boxes show the median and interquartile range, with the median indicated by the horizontal line. Whiskers extend to the most extreme values within the interquartile range. The red dotted line marks the 5% hard coral cover collapse threshold used under Criterion D and the blue diamonds indicate the baseline value used for each ecoregion. Hard coral iteration plot

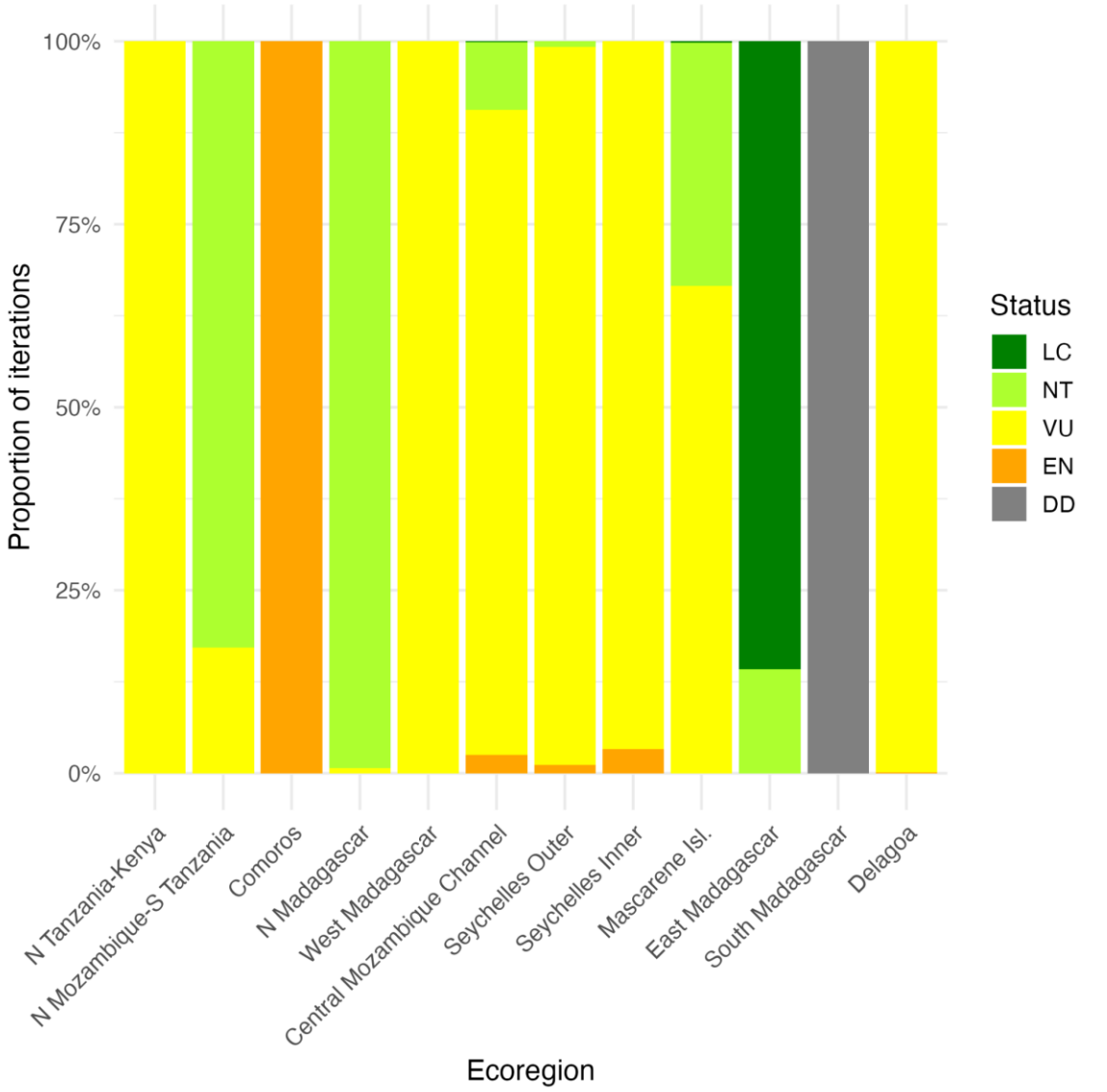


Figure S8. Hard coral percentage of iterations returning each risk level of 1,000 iterations randomly selected baseline values. The status shows the risk level assigned to each ecoregion and the final level is determined for each ecoregion in Table 4.

Distribution of baseline and current algae-coral-ratio values across the monitored sites

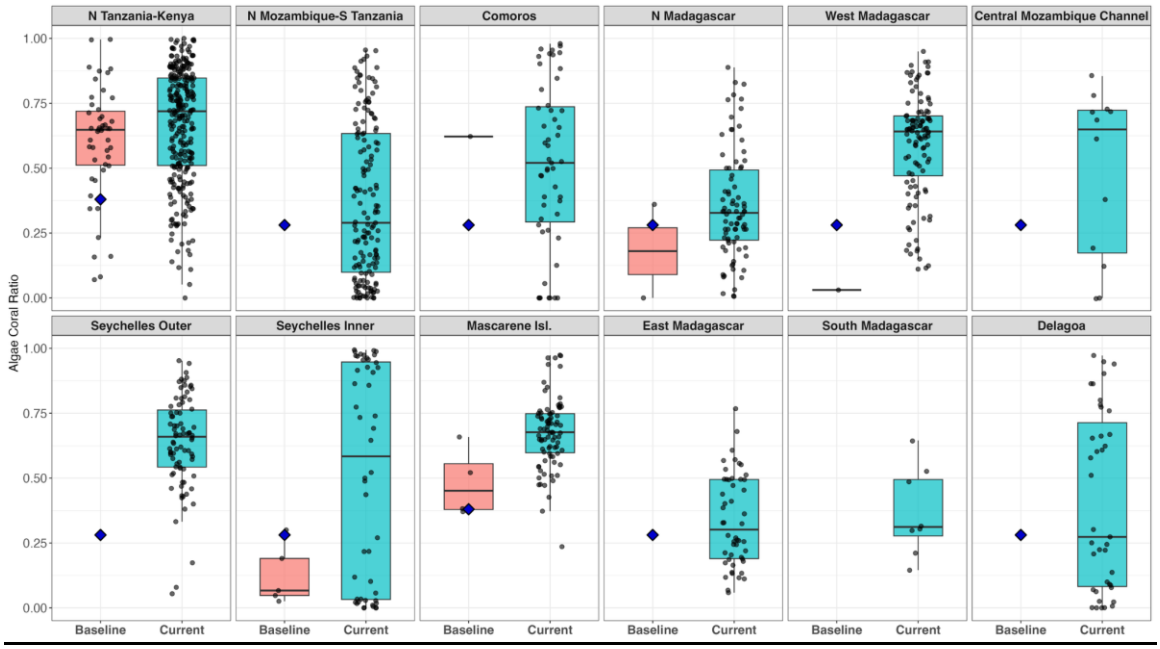


Figure S9: Baseline and current algae-coral-ratio (ACR) across the assessed WIO ecoregions. Baseline observations represent 1998 or earlier, and current observations cover 2020-2025. Black points show individual observations; boxes show the interquartile range with the median indicated by the horizontal line. The blue diamonds indicate the literature-derived baseline value used for each ecoregion.

Algal-coral-ratio iteration plot

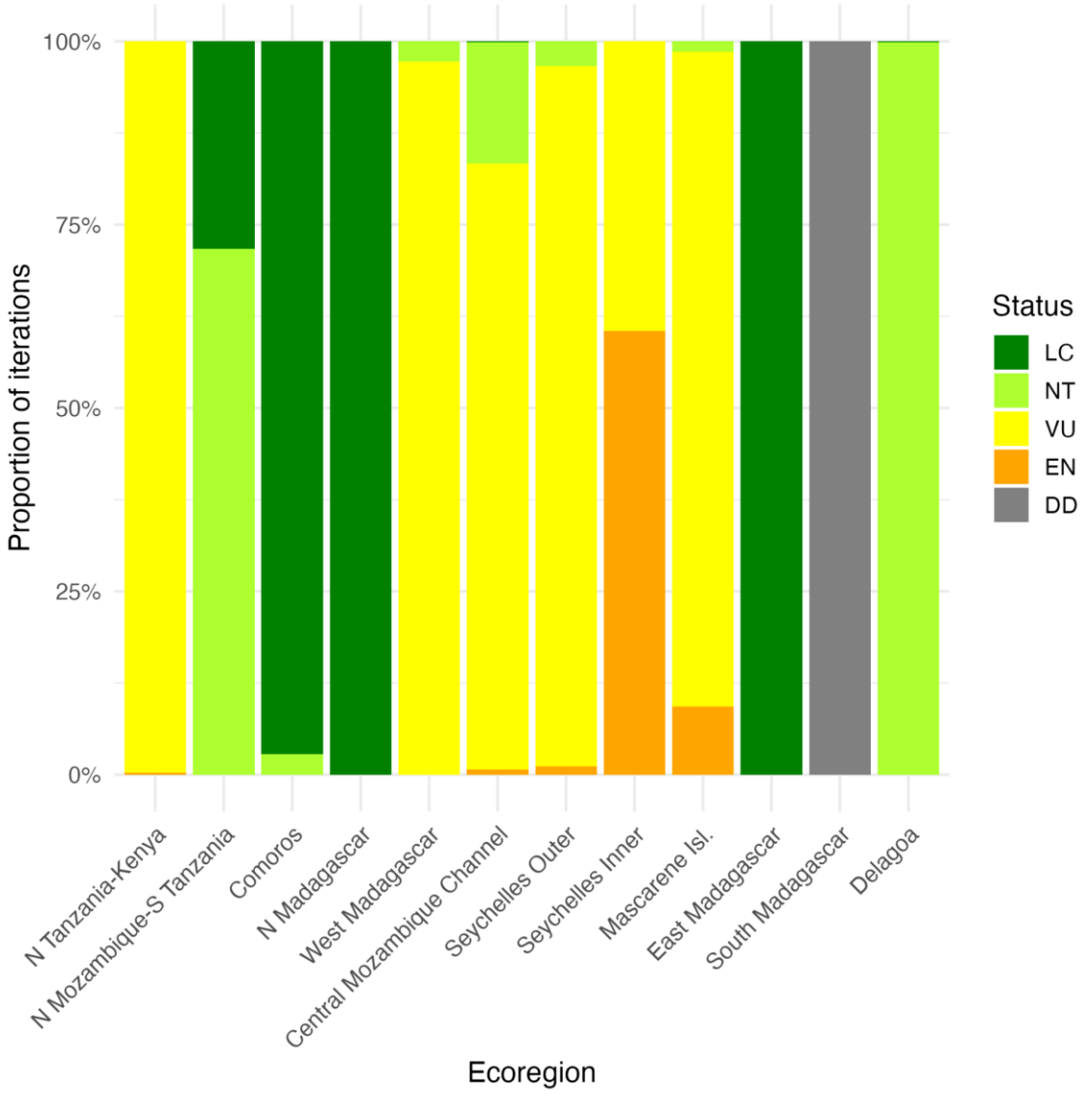
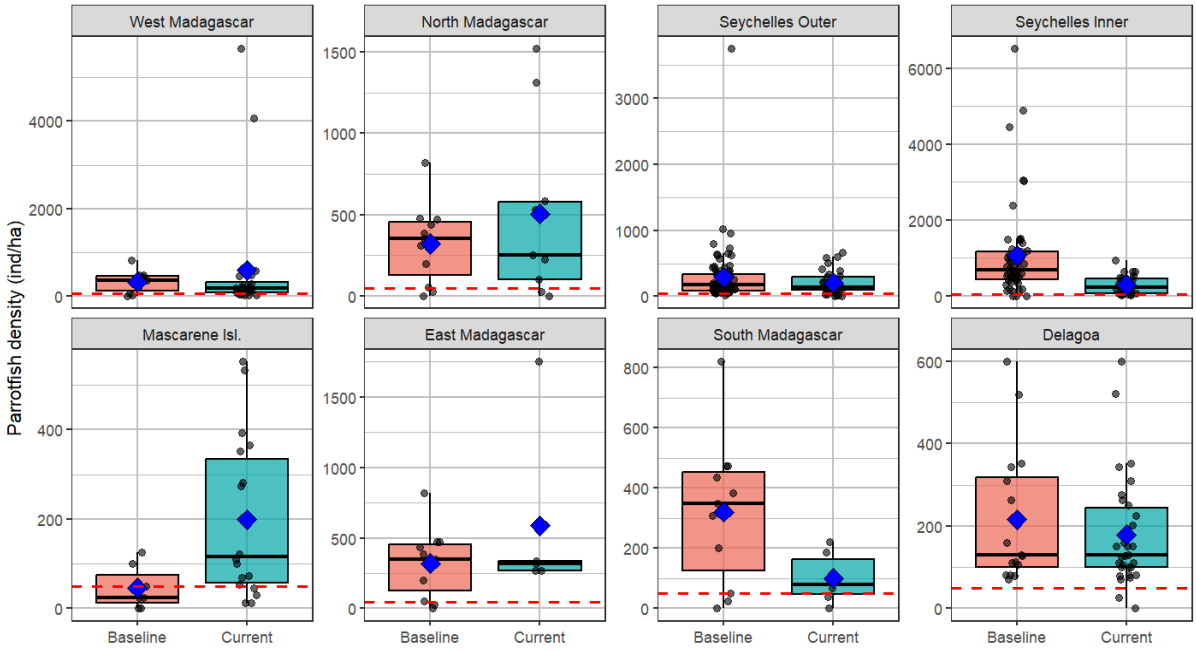


Figure S10. Algae to coral ratio percentage of iterations returning each risk level of 1,000 iterations randomly selected baseline values. The status shows the risk level assigned to each ecoregion and the final level is determined for each ecoregion in Table 4.

Fish

a)



b)

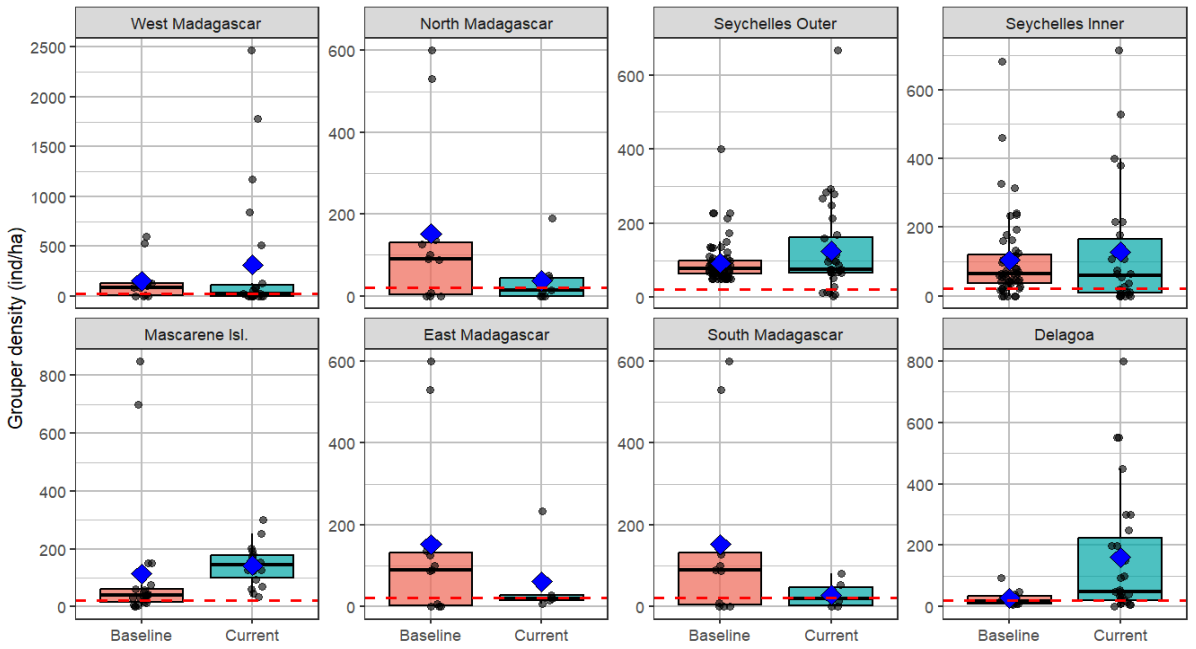
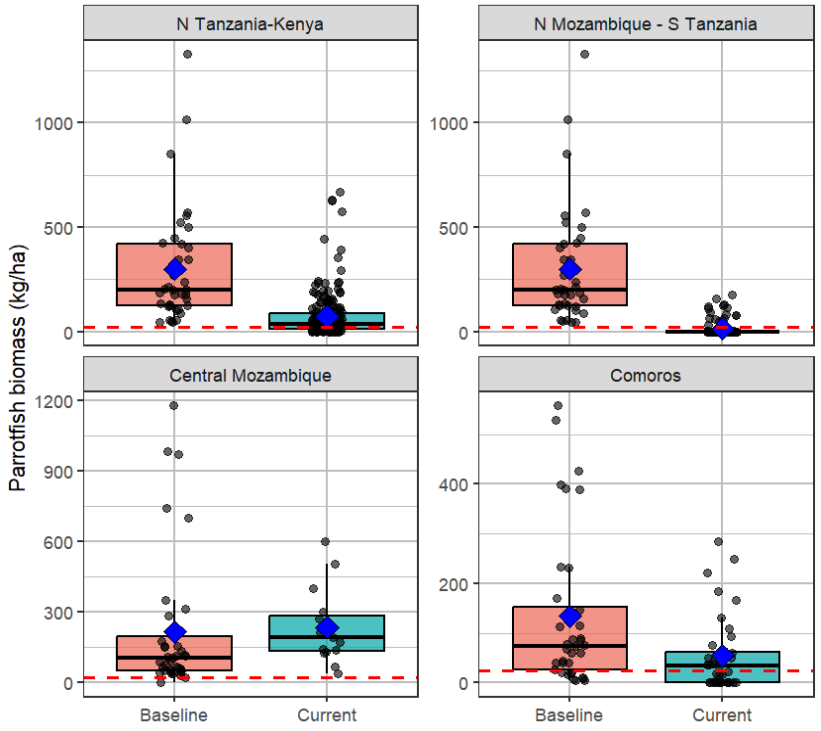


Figure S11. *Baseline and recent a) parrotfish and b) grouper density across WIO ecoregions. Boxplots show the distribution of fish density (ind ha^{-1}) at baseline period (2009-2019 with 2021 extension for Delagoa ecoregion) and during the recent assessment period (2020-2025). Black points represent individual observations, while blue diamonds indicate mean density. The red dotted line marks the 10% parrotfish and 20% grouper collapse threshold used under Criterion D.*

a)



b)

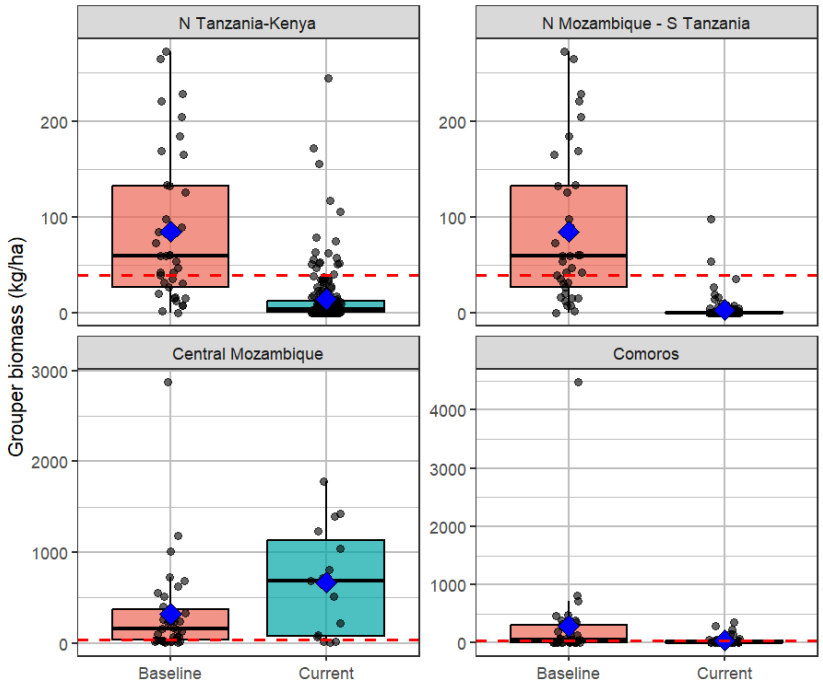


Figure S12 *Baseline and recent a) parrotfish and b) grouper biomass across WIO ecoregions. Boxplots show the distribution of fish biomass (ind ha^{-1}) at baseline period (2009-2019 with 2021 extension for Delagoa ecoregion) and during the recent assessment period (2020-2025). Black points represent individual observations, while blue diamonds indicate mean biomass. The red dotted line marks the 10% parrotfish and 20% grouper collapse threshold used under Criterion D.*

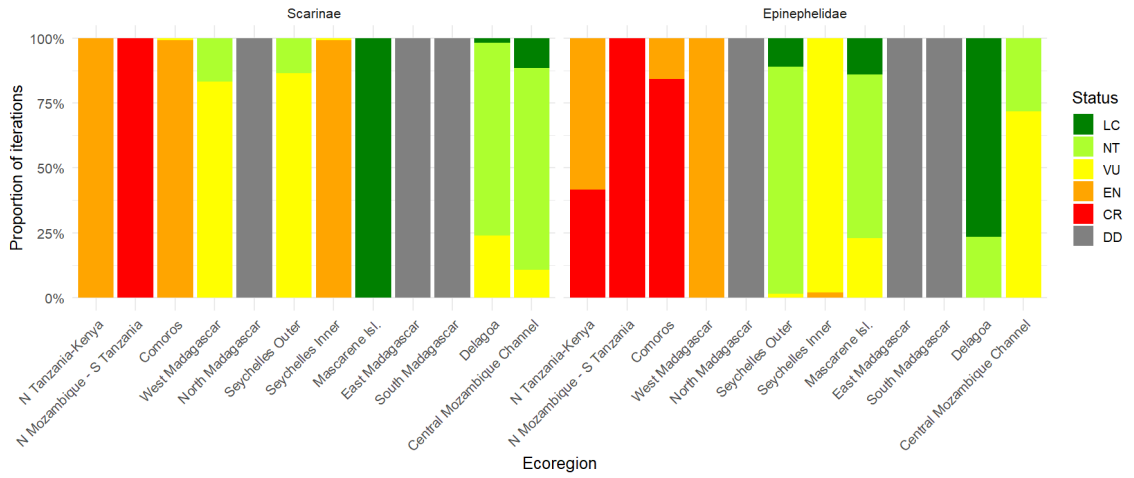


Figure S13. Proportion of model iterations resulting from assessment per IUCN Red List threat status across ecoregions for parrotfish and groupers under Criterion D (biotic disruption). Bars show the percentage of iterations assigned to each status category, with results presented separately for the two families.