REGIONAL REPORT V.0

Red List of Ecosystems assessment of Pacific coral reefs

Mathilde Maslin[1], Vania Andreoli[2], Kristina Heidrich[2], Ben Fitzpatrick[2], Jack Johnson[3], Johanna Johnson[4], Sangeeta Mangubhai[5], Mohsen Kayal[6], Mehdi Adjeroud[7], Helen Sykes[8], Karen Stone[9], Lucy Southworth[10], Sheila McKenna[11], Tom Heintz[12], Sandrine Job[13], Laurent Wantiez[14], Eric Brown[15], Alan Friedlander[16], Lindsey Kramer[17], Mishal Gudka[18,19], Franz Smith[20]

[1]MAREPOLIS, Teva i Uta, Tahiti, French Polynesia.
[2]Oceanwise, Perth, Australia.
[3]Independent researcher, UK.
[4]C2O Pacific, Vanuatu.
[5]Talanoa Consulting, Suva, Fiji.
[6]UMR ENTROPIE (IRD, IFREMER, Université de La Réunion, Université de la Nouvelle-Calédonie), EMR SantEco, Université de la Nouvelle-Calédonie, Nouméa, New Caledonia.
[7]UMR ENTROPIE (IRD, CNRS, IFREMER, Université de La Réunion, Université de la Nouvelle-Calédonie), Perpignan, France.
[8]Marine Ecology Consulting, Suva, Fiji.
[9]Vava'u Environmental Protection Association (VEPA), Neiafu, Tonga.
[10]College of Science and Engineering, James Cook University, Townsville, Queensland, Australia.
[11]National Park Service, Pacific Island Inventory and Monitoring Network, Volcano, Hawaii, USA.
[12]GINGER-SOPRONER, Nouméa, New Caledonia.
[13]CORTEX (Coral Reef Technical Expertise), Nouméa, New Caledonia.
[14]University of New Caledonia (UNC), UMR ENTROPIE, Nouméa, New Caledonia.
[15]National Park Service, Honolulu, HI, USA.
[16]Hawai'i Institute of Marine Biology, University of Hawai'i, Kaneohe, HI, USA.
[17]Hawai'i Wildlife Fund, Kealakekua, HI, USA.
[18]University of Melbourne, Melbourne, Australia.
[19]CORDIO East Africa, Mombasa, Kenya.
[20]Independent Researcher, New Zealand.

ARTICLE INFO

Regional report v.0
Published 22 October 2026
Preprint: EcoEvoRxiv

CORRESPONDING AUTHOR

Mathilde Maslin
maslinmathilde@gmail.com

CITATION

Maslin M, Andreoli V, Heidrich K, Fitzpatrick B, Johnson J, Johnson J, Mangubhai S, Kayal M, Adjeroud M, Sykes H, Stone K, Southworth L, McKenna S, Heintz T, Job S, Wantiez L, Brown E, Friedlander A, Kramer L, Gudka M, Smith F (2026). Red List of Ecosystems assessment of Pacific coral reefs. Regional report, Global Red List of Coral Reef Ecosystems. IUCN, Gland, Switzerland. EcoEvoRxiv.

KEYWORDS

ABSTRACT

Coral reefs of the Pacific region extend across approximately 30°N to 30°S, covering roughly 35 500 km². They range from tropical waters of Papua New Guinea in the West to subtropical latitudes, such as Southeastern Pitcairn or Northern Hawaii borders. This encompasses 21 coral reef ecoregions as defined by the Marine Ecoregions Of the World (MEOW) and Marine and Coastal Biodiversity Management in Pacific Island Countries (MACBIO) classifications. The region hosts exceptionally diverse coral and reef fish communities, the latter featuring high levels of endemism in various locations, and is characterised by extensive tropical archipelagos and atolls spanning wide gradients in ocean productivity, human influence, remoteness, geomorphology and climatic conditions. These ecosystems face increasing pressure from ocean warming and marine heatwaves, acidification, extreme weather events, invasive and harmful species outbreaks, overfishing, coastal development and pollution. The IUCN Red List of Ecosystems assessment, based on the benthic and fish datasets from the Global Coral Reef Monitoring Network (1993-

Red List of Ecosystems; coral reefs; ecosystem collapse; risk assessment; Pacific Islands

2024) and the NOAA Degree Heating Weeks (DHW) dataset (1985-2025), found that coral reefs within all 21 Pacific ecoregions were at a high risk of collapse (i.e. featuring declining attributes to levels where the ecosystem transforms into a different type or is completely lost). This result was, however, largely driven by future climate change projections. Indeed, several criteria assessed in this work are still showing optimistic trends at the regional scale, especially when looking at the actual distribution of Pacific coral reefs or when comparing past and recent estimates of coral cover decline. Under Criterion A (decline in hard coral cover distribution), about 72% of the Pacific reef surface area (14 ecoregions) was classified as Least Concern, while 14% (3 ecoregions) was Vulnerable and 13% (4 ecoregions) was Endangered. Under Criterion B (restricted distribution), about 95% of the Pacific reef area (17 ecoregions) was Least Concern, while 3% (encompassing 3 ecoregions) was Vulnerable. Under Criterion C1 (observed thermal stress), the trend is reversed, with 49% of the reef area (9 ecoregions) classified as Vulnerable, 19% (6 ecoregions) as Endangered and the remaining 32% as either Near Threatened (5 ecoregions) or Least Concern (New Caledonia only). Criterion C2 (projected thermal stress) drives the entire Pacific reef area and all 21 ecoregions to Critically Endangered. Under Criterion D (alteration of biotic interactions), about 52% of the reef area (7 ecoregions) was either Least Concern or Near Threatened, 16% (7 ecoregions) was Vulnerable and 32% (7 ecoregions) was either Endangered or Critically Endangered. These results highlight the need to consolidate reef resilience towards future climate change and to reinforce the conservation of coral reef habitats through strengthened area-based management, sustainable fisheries operation, climate adaptation measures and accelerated global efforts to reduce greenhouse gas emissions.

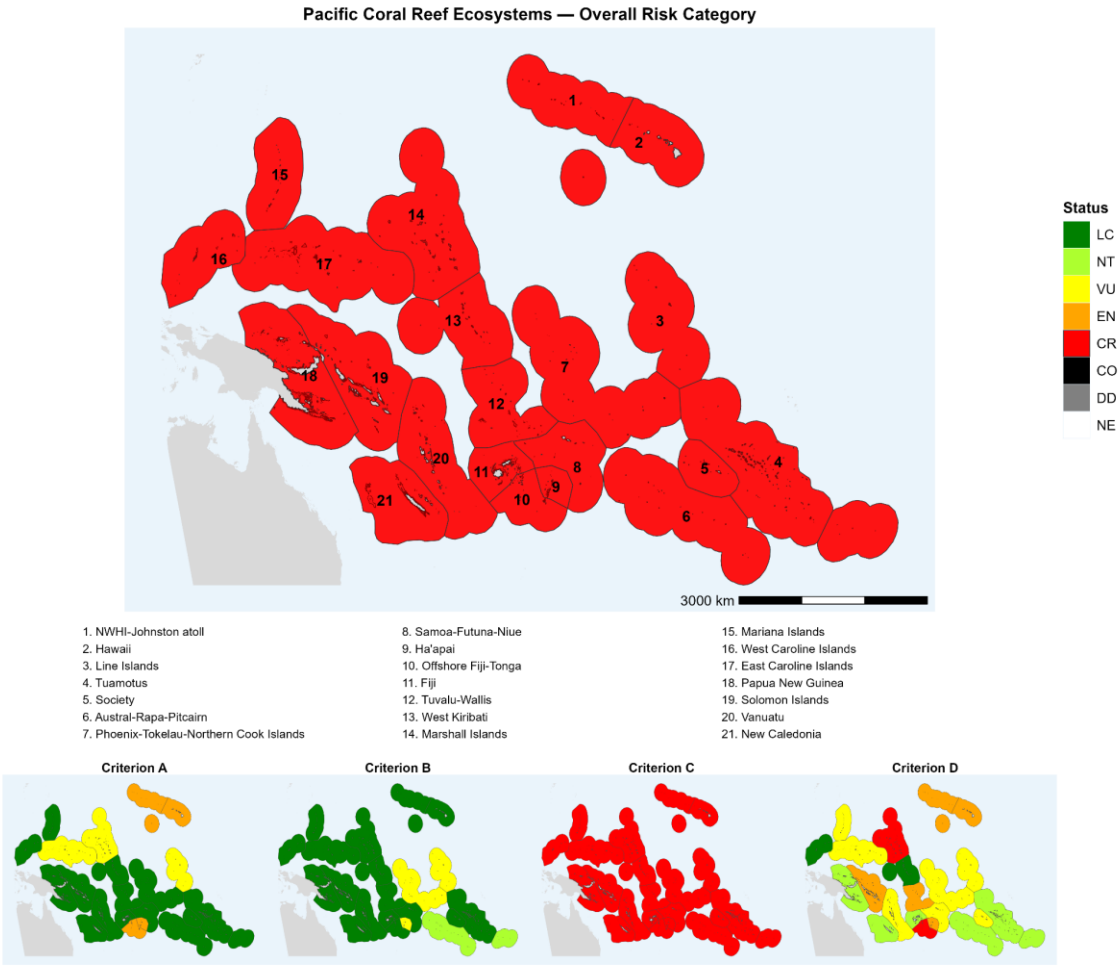


Figure 1. Distribution of the 21 coral reef ecoregions in the Pacific. Map above: overall IUCN Red List of Ecosystems risk status. Maps below : risk status results for Criteria A–D. Risk categories are listed as follows : NE = Not Evaluated, DD = Data Deficient, CO = Collapsed, CR = Critically Endangered, EN = Endangered, VU = Vulnerable, NT = Near Threatened, LC = Least Concern.

1. Study Area

This IUCN Red List of Ecosystems assessment evaluates the risk of collapse (as defined in Section 2) for coral reefs across the Pacific region as of 2025. Pacific coral reefs (IUCN Global Ecosystem Typology M1.3 - photic coral reefs) extend across tropical and subtropical latitudes, from approximately 30°N to 30°S, spanning thousands of oceanic and continental islands as well as smaller archipelagos. Overall, the region contains an estimated 35 500 km^2 of coral reefs (see Table 1 in the Appendix).

Coral reefs of the Pacific were grouped into 21 ecoregions drawing on the Marine Ecoregions of the World (MEOW) framework developed by Spalding et al. (2007). Boundaries were

refined using the outcomes of the Marine and Coastal Biodiversity Management in Pacific Island Countries (MACBIO) project (Beger et al., 2020). In addition, an expert elicitation process was used to define similarities in coral reef functions, major impacting threats and morphological attributes across the Pacific. The subsequent coral reef ecoregions capture variation in ecological traits, geomorphology, dominant coral genera, human/natural impacts, thermal bleaching occurrence and are equivalent to level 4 of the IUCN Global Ecosystem Typology (regional sub-groups). Coral reefs in each ecoregion were independently assessed using the IUCN Red List of Ecosystems criteria (see details in Section 10. Annex).

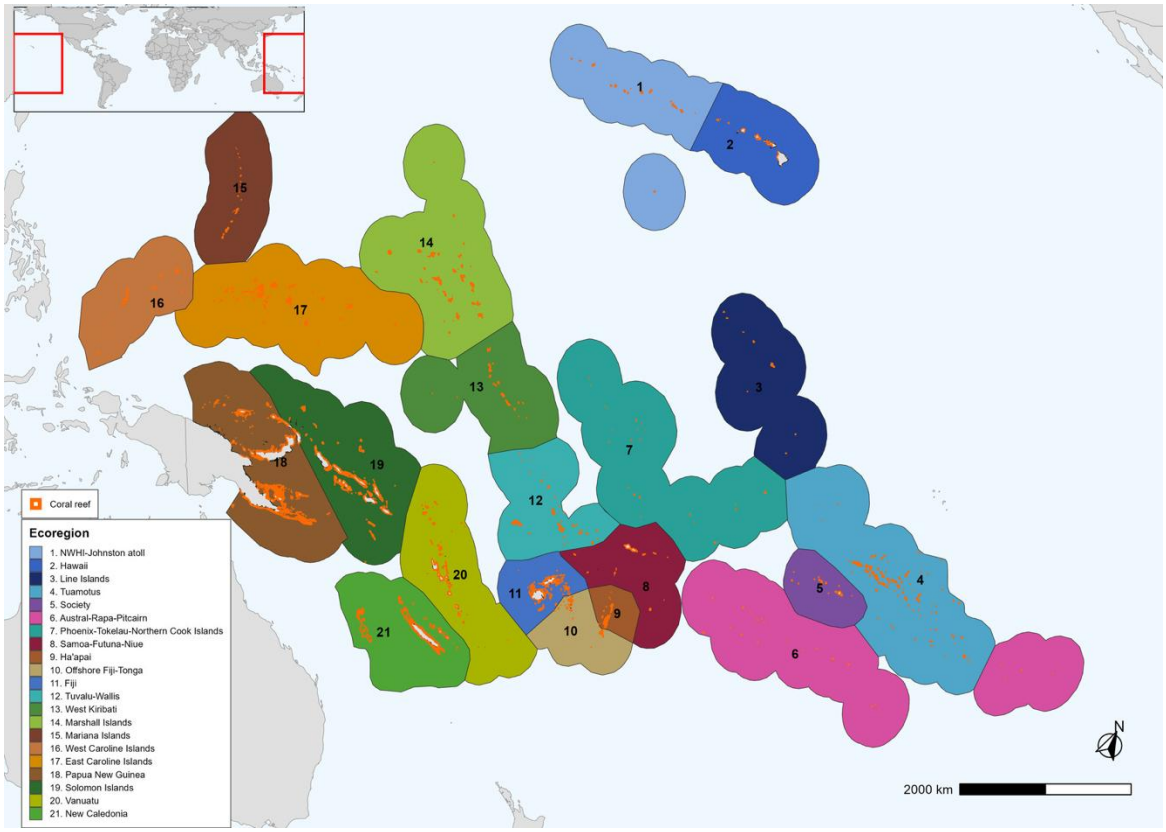


Figure 2. Coral reefs of the Pacific, grouped within 21 coral reef ecoregions (Units of Assessment) to be evaluated under the IUCN Red List of Ecosystems criteria and corresponding to Level 4 of the IUCN Global Ecosystem Typology. All spatial analysis uses an equal-area Mollweide projection centred on the Pacific (+proj=moll +lon_0=180).

2. Ecosystem Description

Pacific coral reefs encompass a broad continuum of reef ecosystems distributed across the three cultural sub-regions of Melanesia, Micronesia and Polynesia. The region includes both framework-building and actively accreting coral reefs (type A) and more marginal reef systems where cooler temperatures or environmental variability constrain reef accretion (type B) (Spalding et al., 2007). Type A reefs dominate warm equatorial Pacific areas ranging from Papua New Guinea to the Tuamotu archipelago in French Polynesia. In contrast, type B

reef systems occur toward subtropical margins or environmentally variable islands, such as Pitcairn or southern French Polynesia (Rapa, Austral Islands and Gambier Islands), where lower temperatures, episodic upwelling, or reduced calcification rates limit vertical reef development (Kleypas et al., 1999). Despite differences in accretion potential and biodiversity, both reef types support similar ecological functions, including habitat provision, coastal protection, nutrient cycling and fisheries productivity, while sharing many coral genera and trophic interactions.

Vast island chains, continental margins and extensive seamount platforms span through the Pacific region. The evolutionary and geological history of Pacific coral reefs is therefore closely linked to plate tectonics and volcanism associated with the Pacific Ring of Fire, as well as long-term sea-level fluctuations (Montaggioni, 2005). Classic atoll formation, first conceptualized by Darwin, remains a defining feature of Pacific reef evolution: fringing reefs progressively develop into barrier reefs and eventually atolls as volcanic islands subside over geological timescales (Darwin, 1889). Repeated glacial–interglacial sea-level oscillations during the Quaternary further shaped reef distribution, connectivity and species diversification across the basin. Strong seasonal and interannual variation in abiotic parameters still influence productivity, larval dispersal, species connectivity and resilience across the region.

2.1. Key Biotic Components



Figure 3. A characteristic Pacific outer barrier reef assemblage (Reao atoll, Tuamotus ecoregion) showing dominance of *Acropora*, *Pocillopora* and *Montipora* coral genera and a remaining substrate largely covered by Crustose Coralline Algae (CCA). ©*Mathilde MASLIN*

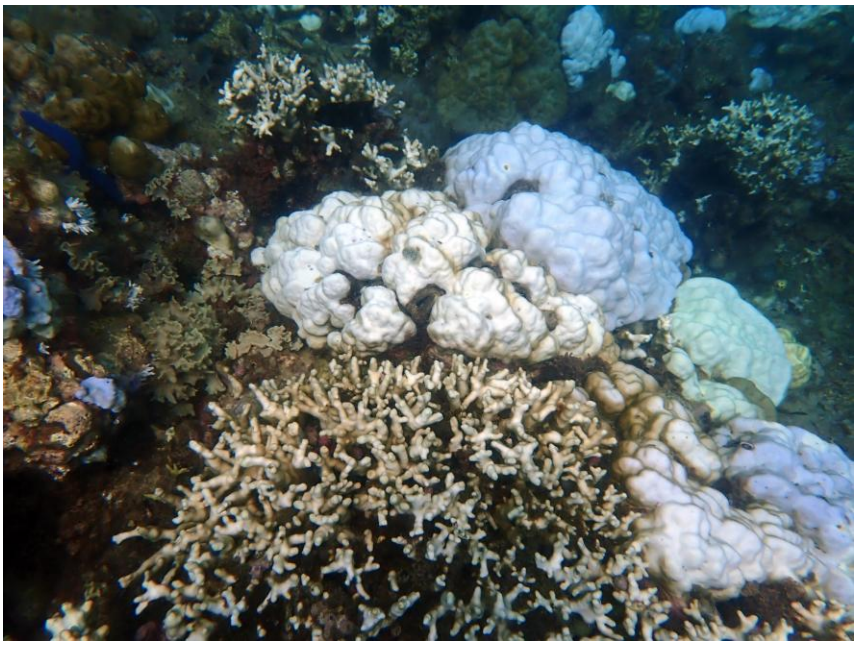


Figure 4. Coral colonies from Kimbe Bay (New Britain island, Papua New Guinea ecoregion) undergoing a bleaching reaction from the recent 2024-25 heat stress event. Shallow coastal areas, including enclosed lagoons, usually show more abundant massive growth forms, higher cover of macroalgae and turf as well as a more land-derived substrate compared to the barrier reef. ©*Coral Sea Foundation*

Pacific coral reefs harbor some of the most extensive and diverse coral reef ecosystem types on earth (Planes et al., 2019; Pellerin et al., 2025). They sustain a vast array of reef-building scleractinian corals, especially within the eastern Coral Triangle area and parts of Melanesia (Papua New Guinea, Solomon Islands, New Caledonia) where coral species richness peaks globally. Over 600 hard coral species have been reported from this area, corresponding to at least 75% of global coral richness worldwide (Galand et al., 2023 ; Rafferty, 2025). Commonly widespread genera such as *Acropora*, *Porites*, *Montipora* and *Pocillopora* contribute amongst others to complex reef frameworks. They create high structural diversity, enhancing habitat complexity that underpins reef biodiversity across the Pacific. Macroalgae, CCA and turf algae, together with other encrusting components such as sponges and soft corals, determine benthic heterogeneity through positive or negative influences on both substrate availability (space competition, overgrowth) and coral recruitment (allelopathy) dynamics.

The Pacific supports exceptionally diverse fish communities (GCRMN & ICRI, 2018), notably including economically valuable herbivores (e.g. surgeonfish, parrotfish) and apex predators (e.g. groupers, trevallies). Herbivorous fishes regulate algal growth, providing space for coral recruitment, while a diversity of predators helps maintain trophic balance. The highest species richness is centered around the Coral Triangle (Papua New Guinea to the Solomon Sea), with over 1 500 fish species recorded. Diversity progressively declines toward remote eastern archipelagos, such as French Polynesia which accounts with only about 800 fish species documented (Messmer et al., 2012). There is thus a marked west-to-east decline in coral reef fish diversity across the Pacific basin (Drew & Amatangelo, 2017).

Due to numerous isolated and remote island systems, many Pacific reef species often show high levels of endemism, reflecting a biogeographic complexity and a challenging spatial connectivity within the region (Kulbicki et al., 2013). The geographic remoteness of some isolated Pacific archipelagos, such as Hawaii and French Polynesia, are notably promoting speciation in fish and strong geographic structuring of coral lineages compared to internally similar Indo-Pacific locations. Barriers to larval dispersal have led to evolutionary divergence, recognized today as distinct ecological units by major biogeographic frameworks (Spalding et al., 2007).

2.2. Key Abiotic components

Pacific coral reefs can be found ranging from shallow to moderate depths (usually < 50 m), allowing photosynthesis by coral symbionts while hard carbonate substrates support significant reef accretion and benthic diversity.

Substrate stability and geomorphology vary in time with tectonic activity, wave exposure and sea level changes across the Pacific. Several archipelagos in the region such as Tonga, Vanuatu, Fiji, the Solomon Islands and Papua New Guinea, occur along the "Pacific Ring of Fire" (Morante-Carballo et al., 2024). The New Hebrides and Kermadec Tonga trenches are notably known to display active subduction, volcanism, uplift and seismicity. Approximately 75% of the world's active volcanoes and 90% of global earthquakes occur within this belt (Kaza et al., 2025).

The region belongs to the largest ocean in the world, therefore reefs are often located far from major landmasses and human influence (Freeman et al., 2012). The remoteness of many Pacific coral reefs is widely recognized as a key factor contributing to generally good water quality - low turbidity and relatively low nutrient concentrations compared with reefs located near densely populated continental coastlines (Maritorena, 1996). Evidence of higher fish biomass in non-populated areas is also numerous, given that fishing pressure and other human exploitation of marine resources are limited (Friedlander & DeMartini, 2002; Stevenson et al., 2007; Williams et al., 2010).

Major influences on reef distribution and biodiversity across the Pacific operate at both broad oceanographic and local environmental scales. At the regional scale, sea surface temperature, the position and variability of the Western Pacific Warm Pool, upwelling intensity, trade winds, and major ocean currents - including the East Australian, Equatorial Counter and South Equatorial Currents - strongly influence the distribution, productivity and connectivity of coral reef ecosystems, with many of these processes varying in association with El Niño Southern Oscillation (ENSO) climate variability (Glynn & Ault, 2000). Most tropical Pacific coral reefs develop within relatively warm waters, generally around 26–30°C, which provide favourable conditions for coral growth, calcification and symbiotic productivity (Kleypas et al., 1999). However, regional oceanographic gradients create substantial environmental variability, and reefs in subtropical or upwelling-influenced areas, including southern New Caledonia and parts of French Polynesia such as Rapa and Pitcairn, may periodically experience temperatures below 24°C, particularly during cooler seasons or anomalous climatic conditions (Fiedler & Talley, 2006). At smaller spatial scales, reef biodiversity is

further influenced by local physicochemical conditions, including salinity, carbonate chemistry, freshwater and terrestrial inputs, nutrient availability, sedimentation and water quality. Across the tropical Pacific, salinity is generally around 34–36 ppt, while seawater pH typically falls within approximately 7.9–8.2, although both parameters can vary locally in response to freshwater discharge, coastal runoff, biological activity and oceanographic mixing (Hoegh-Guldberg et al., 2007). Together, these interacting regional and local drivers create strong environmental gradients that contribute to differences in reef distribution, species composition and biodiversity across the Pacific.

During El Niño events, trade winds and upwelling tend to decrease whereas average oceanic temperatures rise, increasing coral bleaching risk (Claar et al., 2018). Although a shift to La Niña phase can temporarily reduce bleaching risk in some Pacific ecoregions by lowering sea surface temperatures (SSTs), it may also increase storm and cyclone activity in western locations or promote outbreaks of coral predators such as the crown-of-thorns starfish *Acanthaster* sp. (Houk et al., 2020). Thus ENSO phases remain a variable source of influence on environmental conditions that affect coral reefs across the Pacific region.

2.3. Key processes and interactions

Coral recruitment in the Pacific depends on both larval supply from nearby or distant reefs, local reproduction efforts as well as the availability and quality of benthic settlement substrate for scleractinian populations. Within geographically close reef systems, such as those found around the Solomon Sea, larval connectivity promotes demographic exchange and gene flow among neighbouring populations, potentially facilitating population persistence and recovery following disturbance (Kool et al., 2011; Hamilton et al., 2021). Conversely, in more isolated reef systems such as remote Hawaiian islands, physical retention and limited external larval supply can increase the relative importance of local recruitment and self-seeding, although episodic long-distance connectivity may still occur (Wood et al., 2014; Tsounis & Edmunds, 2016). CCA plays a critical ecological role by stabilizing reef frameworks, consolidating carbonate substrates and providing chemical settlement cues that promote larval attachment and metamorphosis of many scleractinian corals (Harrington et al., 2004). Reefs dominated by CCA-covered hard substrates generally exhibit higher coral recruitment rates than reefs dominated by fleshy macroalgae, turf algae or unstable rubble (Price, 2010).

Predator-prey interactions regulate fish community structure within the trophic chain, whereas bioeroders (e.g. sea urchins, parrotfish) moderate carbonate budgets for benthic settlement like corals. In the tropical Pacific, herbivorous species such as parrotfishes and surgeonfishes are known to incidentally predate coral spats (Penin et al., 2011). However, they can indirectly facilitate coral recruitment by grazing macroalgae and maintaining exposed CCA surfaces suitable for larval settlement.

Habitat stability has shifted toward macroalgal dominance in many locations where abiotic conditions (e.g. light, high nutrient concentrations) are in favor of invasive photosynthetic organisms spreading. In several island groups (e.g. French Polynesia, Western Micronesia, Fiji), proliferation of canopy-forming brown macroalgae such as *Turbinaria ornata* and

Sargassum spp. has been documented following coral mortality events or reductions in herbivory (Kayanne et al., 2005; Fa'anunu, 2011; Adjeroud et al., 2016; Stuart et al., 2026). They contribute to reducing recruitment success by monopolizing space, trapping sediments and limiting access to stable settlement surfaces (Birrell et al., 2008).

2.4. Main Threats

Over the last five decades, the nature and intensity of threats affecting Pacific coral reefs have changed substantially. Historically, reef degradation across many Pacific island ecosystems was primarily driven by localized anthropogenic pressures, including overfishing, coastal development and land-based pollution (Birkeland, 1997; Newton et al., 2007; Morrison et al., 2013). In densely populated or rapidly developing islands, removal of key herbivorous fishes such as parrotfishes and surgeonfishes reduced grazing pressure on benthic algae, while poor land-use practices, mining activity or erosion due to bushfires increased sediment and nutrient runoff into lagoons and nearshore reefs (Bellwood et al., 2004; Fabricius, 2011). Together, these stressors promoted shifts toward macroalgal dominance, reduced coral recruitment and weakened the natural recovery capacity of reef ecosystems.

Since the 1990s, however, global climate-related disturbances have progressively emerged as major drivers of coral reef decline throughout the Pacific basin (Hoegh-Guldberg, 1999). Increasing sea-surface temperatures associated with anthropogenic climate change and recurrent ENSO anomalies have intensified the frequency and severity of marine heatwaves, leading to widespread coral bleaching and mortality events (Glynn, 1993; Miller et al., 2008; Eakin et al., 2026). Major bleaching episodes were recorded during the 1997–1998, 2015–2017 and 2023–2024 global marine heatwaves, the latter representing the first instance where extensive areas of the Pacific exceeded historical Degree Heating Weeks (DHW) exposure ranges and entered newly defined extreme thermal stress categories (NOAA Coral Reef Watch, 2024). Repeated bleaching events have reduced live coral cover, altered community composition and are compromising reef resistance to marine heatwaves in the future (Sully et al., 2019).

Ocean acidification has simultaneously emerged as an additional large-scale chronic stressor on coral reefs. Declining seawater pH and carbonate ion availability reduce coral calcification rates and weaken reef framework accretion, potentially compromising the long-term structural integrity and shoreline protection functions of reef systems (Kleypas et al., 1999; Hoegh-Guldberg et al., 2007). Although its effects are often less immediately visible than bleaching, acidification is expected to increasingly constrain reef growth and post-disturbance recovery throughout the century (Anthony et al., 2011).

Climate-related disturbances also interact with biological stressors that further influence reef trajectories. Coral diseases, including white syndromes, brown band and black band diseases, along with outbreaks of coral predators such as crown-of-thorns starfish (*Acanthaster* spp.), have become increasingly documented across Pacific reefs (Adjeroud et al., 2001; Myers & Raymundo, 2009; Ushijima et al., 2012). These disturbances contribute to tissue necrosis, skeletal erosion and colony mortality. They are frequently associated with elevated thermal

stress, post-bleaching physiological weakening and localized anthropogenic disturbance gradients (Galloway et al., 2009; Bruno et al., 2007).

Last but not least, many Pacific reef systems are periodically exposed to acute physical disturbances caused by tropical cyclones and storms. Their occurrence is unevenly distributed across the basin, with the highest frequencies observed in the western and southwestern Pacific (e.g. Micronesia, the Mariana Islands, Solomon Islands, Vanuatu, Fiji, Tonga) where warm SSTs (> 26.5°C) favor cyclone formation (Basher & Zheng, 1995; Walsh et al., 2012). Cyclones can cause extensive physical damage to reef frameworks through coral breakage, sediment resuspension and rubble formation, often reducing reef structural complexity and habitat availability for associated fauna and flora (Harmelin-Vivien, 1994; Guillemot et al., 2010). Repeated storm exposure may therefore limit reef recovery and carbonate accretion, particularly when combined with chronic climate stress.

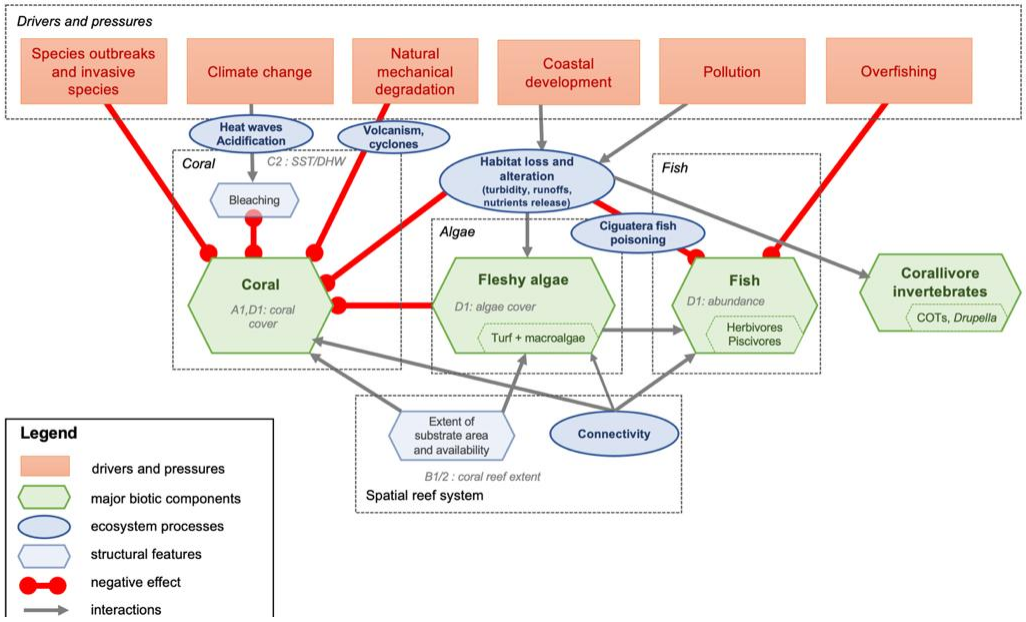


Figure 5. Conceptual model of Pacific coral reef ecosystems. The model illustrates key biotic and abiotic components, as well as external drivers, threats and the processes and interactions between them. Capital letters (A-D) refer to the four risk assessment criteria presented in this work.

Table 1. Occurrence of major threats impacting coral reefs in each ecoregion categorised based on the IUCN Threat Classification Scheme. Markings are used as follows : ✓ = the threat is currently having an impact, – = the threat is not an issue for now, + = the threat is emerging and likely to become an issue in the near future. 1 = NWHI-Johnston atoll, 2 = Hawaii, 3 = Line Islands, 4 = Tuamotus, 5 = Society, 6 = Austral-Rapa-Pitcairn, 7 = Phoenix-Tokelau-Northern Cook Islands, 8 = Samoa-Futuna-Niue, 9 = Ha'apai, 10 =Offshore Fiji-Tonga, 11 = Fiji, 12 = Tuvalu-Wallis, 13 = West Kiribati, 14 = Marshall Islands, 15 = Mariana Islands, 16 = West Caroline Islands, 17 = East Caroline Islands, 18 = Papua New Guinea, 19 = Solomon Islands, 20 = Vanuatu, 21 = New Caledonia.

Threat type	Subcategory	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1. Residential & commercial development	1.3 Tourism & recreation areas	–	✓	–	+	✓	–	–	✓	–	+	✓	–	–	+	✓	–	–	+	+	+	✓
2. Agriculture & aquaculture	2.4 Marine & freshwater aquaculture	–	✓	–	–	+	–	–	–	–	–	✓	–	–	–	+	–	–	+	–	+	✓
3. Energy production & mining	3.1 Oil & gas drilling	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	✓	+	–	–
	3.2 Mining & quarrying	+	+	–	–	–	–	–	–	–	–	✓	–	–	–	–	–	–	–	–	–	✓
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	–	✓	–	+	✓	–	–	+	–	–	✓	–	–	–	✓	–	–	–	–	–	✓
7. Natural system modifications	7.1 Fire & fire suppression	–	✓	–	–	+	–	–	–	–	–	✓	–	–	–	–	–	–	✓	+	+	✓
8. Invasive & problematic species	8.1 Invasive non-native/alien species/diseases	✓	✓	–	–	+	–	–	+	–	–	✓	–	–	+	✓	+	–	✓	✓	+	✓
9. Pollution	9.1 Domestic & urban waste water	–	✓	–	–	✓	–	–	✓	–	–	–	✓	–	+	✓	–	–	✓	+	+	✓
	9.2 Industrial & military effluents	✓	✓	–	–	+	–	–	–	–	–	✓	–	–	+	✓	–	–	✓	–	–	✓
	9.3 Agricultural & forestry effluents	–	✓	–	–	+	–	–	✓	–	–	✓	✓	–	–	–	–	–	✓	✓	+	✓
	9.4 Garbage & solid waste	✓	✓	–	+	+	–	–	–	–	–	✓	✓	–	✓	✓	+	–	–	+	+	✓
10. Geological events	10.2 Earthquakes & tsunamis	✓	✓	–	–	–	–	–	✓	✓	✓	–	–	–	✓	✓	✓	✓	✓	✓	✓	–
11. Climate change & severe weather	11.1 Habitat shifting & alteration	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	11.3 Temperature extremes	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	11.4 Storms & flooding	✓	✓	–	–	+	+	–	✓	✓	–	–	✓	–	+	✓	–	–	✓	✓	✓	✓

2.5. Definition of the collapsed state of the ecosystem

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

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 negligible). A collapsed reef would have extremely low coral richness and diversity, with communities dominated by a few fast-growing or stress-tolerant species. Collapsed coral reefs are often characterised by a phase shift from coral dominance to high abundances of other benthic components, such as turf and fleshy algae, rubble and filter-feeding invertebrates. This state is also associated with low abundance and diversity of other key biodiversity, including altered fish communities. In some cases, collapse corresponds to a simplified topographic structure or occurs where the geomorphological structure of coral reefs permanently disappears through land reclamation or coastal development. A collapsed reef may have an unsuitable abiotic environment due to declines in water quality, increases in temperature, as well as frequent and severe disturbance events.

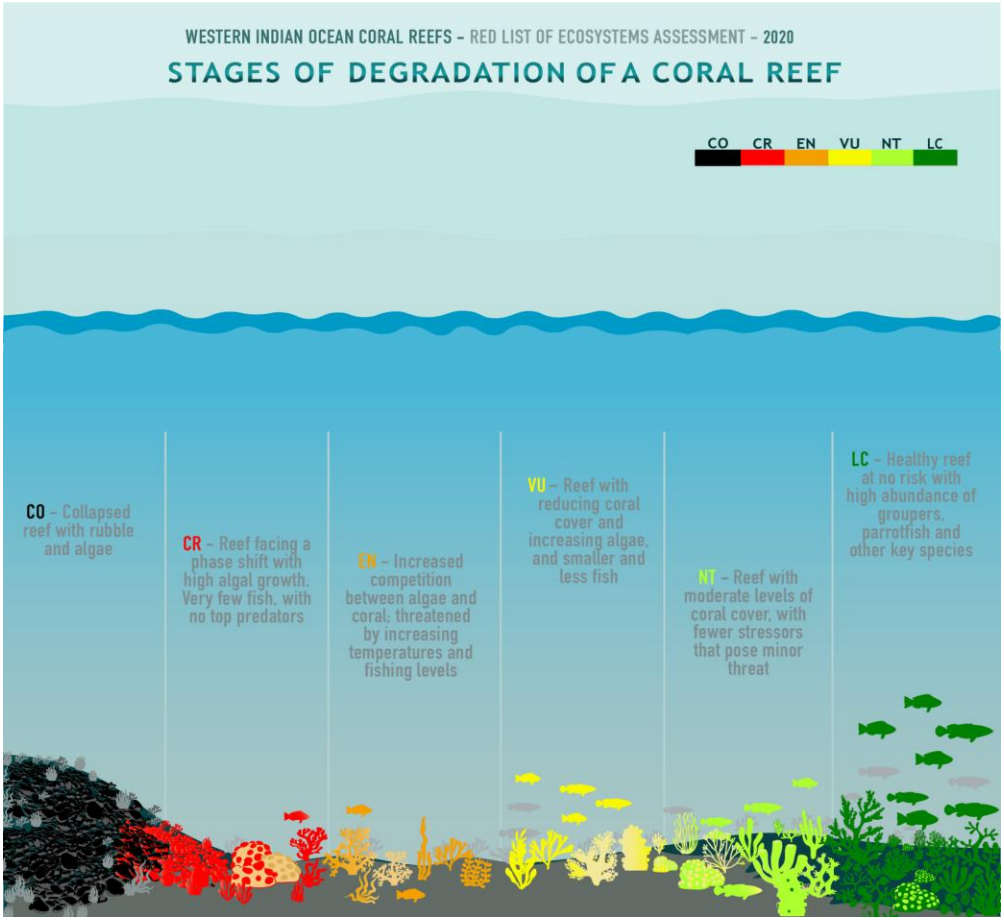


Figure 6. The different stages of coral reef degradation, featuring the distinct IUCN status categories and their transposition into biological and ecological alterations (©CORDIO East Africa).

Under the IUCN Red List of Ecosystems framework, collapse can be defined as when key biotic or abiotic indicators reach thresholds where the ecosystem's defining features are (or would be) lost. For this assessment, coral reef ecosystem collapse is defined by any of the following:

a) complete loss of coral reef habitat area;
b) hard coral cover falling below 5% at all reefs in an ecoregion;
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.

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

a) an macroalgae:coral cover ratio exceeding 5:1;
b) severe depletion of key fish groups (e.g., parrotfishes, surgeonfishes, rabbitfishes and damselfishes as main herbivores and trevallies, groupers, cods and snappers as main piscivores) to levels well below historical baselines.

Table 2. Key abiotic and biotic features and threats to coral reef ecoregions in the Pacific, highlighting unique aspects of each ecosystem.

Ecoregion	Key Biotic	Key Abiotic	Key Threats
NHWI-Johnston atoll	High endemism; apex predator-dominated reefs; abundant CCA cover.	Subtropical oligotrophic waters; cooler SSTs; volcanic and atoll geomorphologies; strong wave exposure.	Marine heatwaves and coral bleaching, invasive algae, habitat degradation, ocean acidification.
Hawaii	High endemism; dominant Porites and Montipora reefs; important herbivorous fish assemblages.	Volcanic islands; clear oligotrophic waters; subtropical thermal variability; localized freshwater inputs.	Bleaching, coastal urbanization, invasive macroalgae, sedimentation, coral disease.
Line Islands	High live coral cover dominated by Acropora, Pocillopora and Porites; exceptional apex predator biomass.	Remote oceanic atolls; oligotrophic waters; limited terrestrial runoff; strong ENSO and South Equatorial Current influence.	Marine heatwaves, acidification, localised overfishing, coastal development.
Tuamotus	High fish biomass; strong lagoon-ocean bioconnectivity.	Large carbonate atolls; clear waters; strong flushing and nutrient limitation.	Bleaching, ocean acidification, pearl farming impacts, sea-level rise, crown-of-thorns outbreaks.
Society	High coral diversity; shark and herbivore populations.	Oceanic high islands and lagoons; oligotrophic waters; moderate ENSO influence.	Tourism pressure, bleaching, coastal development, crown-of-thorns outbreaks.
Austral-Rapa-Pitcairn	Subtropical reefs and species assemblages with lower coral diversity and temperate affinities; high endemism.	Isolated volcanic islands; cooler SSTs; high wave exposure.	Marine heatwaves, invasive species, reduced calcification, storm damage, limited recovery due to isolation.
Phoenix - Tokelau - Northern Cook Islands	High predator biomass; intact trophic structure.	Remote near-pristine oligotrophic atolls; strong ENSO influence; minimal terrestrial runoff.	Marine heatwaves and coral bleaching, ocean acidification, illegal fishing.
Samoa-Futuna-Niue	Dominant Acropora and Pocillopora reefs; culturally important reef fisheries.	High rainfall tropical islands; volcanic geomorphology; moderate turbidity near coasts.	Cyclones, crown-of-thorns outbreaks, sediment runoff, bleaching, overfishing.
Ha'apai	Important spawning fish habitats; turtle nesting areas.	Patch reefs and lagoon systems with tectonically active island arc; cyclone-prone tropical waters.	Cyclones, bleaching, tsunami impacts, localized overfishing.
Offshore Fiji - Tonga	Reef systems with pelagic connectivity; shark and tuna corridors.	Deep oceanic reefs featuring strong currents; active tectonics; deep-water passages; cyclone exposure.	Marine heatwaves, ocean acidification, pelagic overfishing, cyclone damage.
Fiji	Very high reef diversity; soft coral communities; strong herbivore assemblages.	Tropical oceanic climate; cyclone exposure; volcanic and barrier reef systems.	Cyclones, bleaching, overfishing, watershed sedimentation, crown-of-thorns outbreaks.
Tuvalu-Wallis	Dominant Acropora and Porites reefs; important lagoon fisheries.	Very low elevation atolls; high thermal variability; clear oceanic waters.	Sea-level rise, marine heatwaves, coastal erosion, pollution, storm surges, overfishing.
West Kiribati	Low-diversity reefs; herbivore-dominated fish communities; important seabird-linked nutrient subsidies.	Low-lying atolls; oligotrophic waters; high ENSO exposure limited freshwater influence.	Sea-level rise, bleaching, freshwater scarcity, coastal erosion, overfishing.
Marshall Islands	Productive lagoon fisheries; seabird nutrient inputs.	Low-lying atolls; oligotrophic waters; strong ENSO sensitivity.	Sea-level rise, bleaching, storm surges, groundwater salinization, overfishing.
Mariana Islands	Diverse coral and fish fauna	Deep reef habitats; active volcanism and tectonics; typhoon exposure.	Typhoons, bleaching, military/coastal impacts, crown-of-thorns outbreaks.
West Caroline Islands	High coral and reef fish diversity with strong Coral Triangle influence.	Warm oligotrophic waters; typhoon exposure.	Typhoons, bleaching, coastal development, destructive fishing.
East Caroline Islands	Diverse coral reefs and seagrass systems; important tuna-linked pelagic productivity.	Warm tropical waters; strong current systems; high rainfall islands and atolls.	Bleaching, sediment runoff, overfishing, storm damage.

Ecoregion	Key Biotic	Key Abiotic	Key Threats
Papua New Guinea	Among the world's richest coral reef biodiversity; extensive mangrove and seagrass connectivity.	Coral Triangle core region; complex currents; volcanic and tectonic activity.	Sedimentation from logging/mining, overfishing, bleaching, coral disease.
Solomon Islands	Extremely high Coral Triangle biodiversity; mangrove-reef connectivity; important spawning aggregations.	High rainfall and sediment delivery; tectonically active islands.	Logging runoff, overfishing, bleaching, earthquakes, tsunamis.
Vanuatu	High coral and fish diversity (vicinity of Coral Triangle); turtle nesting habitats.	Volcanic islands; tectonically active; cyclone-prone tropical waters.	Cyclones, earthquakes, bleaching, overfishing, coastal development, crown-of-thorns outbreaks.
New Caledonia	Exceptional coral and seagrass diversity; dugong and turtle habitats.	Extensive barrier reefs and lagoons; ultramafic geology; cyclone exposure.	Mining runoff, bleaching, cyclones, invasive species, crown-of-thorns outbreaks, coastal development.

3. Criterion Assessment

Coral reefs in **21** ecoregions within the Pacific were assessed using IUCN Red List of Ecosystems 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 10% hard coral cover, which is an estimated minimum threshold for net accretion (Perry et al. 2013). 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 falling below 27% were considered Least Concern.

Criterion B — Restricted Geographic Distribution

Criterion B assesses the extent of occurrence (EOO) and area of occupancy (AOO) of the current distribution of coral reefs. EOO is the total area within the outer limits of the ecosystem's distribution, while AOO is the area occupied by the ecosystem, measured as the number of 10 by 10 km grid cells. Both were derived using the Millennium Coral Reef Layer, validated by regional experts. For both metrics the thresholds from the IUCN Red List of Ecosystems 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 DHW, a satellite-derived measure of accumulated heat stress, was used to identify years in which widespread bleaching or severe mortality events occurred. Two complementary pathways to ecosystem collapse were assessed: a chronic pathway, capturing the progressive degradation driven by the long-term effects of frequently recurring bleaching events. This was assessed using the average return interval between severe bleaching events over a 30-year period. The second approach is a pulse pathway, capturing acute collapse driven by the clustering of extreme high-mortality events within any 5-year window. For both C1 and C2, the relative severity of decline was calculated by comparing the magnitude of past and projected changes against initial conditions and thresholds for coral reef collapse. Collapse thresholds were set at one severe bleaching event every three years for the chronic pathway and three severe mortality events within five years for the pulse pathway. For C2, analyses were conducted under three emissions scenarios (SSP2-4.5, SSP3-7.0 and SSP5-8.5), with SSP2-4.5 treated as the primary

scenario. Risk categories were assigned using the severity–extent matrix, based on the proportion of reef area within each ecoregion experiencing different levels of relative decline. The most severe risk status across both chronic and pulse approaches and C1 and C2 was taken as the final risk status under Criterion C.

Criterion D — Disruption of Biotic Processes and Interactions

Criterion D assesses the disruption to 4 key biotic components over the past 50 years. This includes coral cover, macroalgae:coral ratio, herbivore biomass and piscivore biomass derived from in-situ monitoring data. For each reef site, the decline in each indicator is measured relative to both the state of the reef 50 years ago and a hypothetical collapse threshold, representing the point at which that biotic component is no longer functional. The proportion of sites experiencing varying degrees of decline is then evaluated and a risk matrix is used to determine the risk status for each indicator. Finally, a heuristic, stepwise approach across all indicators is applied to derive the overall risk status under Criterion D for each ecoregion.

Table 3. Methodology, parameters and collapsed thresholds used to assess Coral Reefs ecosystems in the Pacific under the Red List of Ecosystem criteria.

Criterion	Sub-Criterion	Indicator(s)	Data Sources	Collapse Threshold(s)	Criterion Assessed?	Comments
A. Reduction in geographic distribution	A1 – Decline in coral reef area/extent over the past 50 years	Reef habitat extent from remote sensing	UNEP-WCMC	90% loss of extent over 50 years	Yes	Based on satellite-derived habitat extent time series
B. Restricted geographic distribution	B1 – Extent of Occurrence (EOO)	EOO + ongoing decline or number of threats defined locations	MEOW, regional reef maps, expert knowledge	EOO < 50,000 km^2 + ongoing decline or threats	Yes	Calculated per eco-region using minimum convex polygons
	B2 – Area of Occupancy (AOO)	AOO + ongoing decline or number of threats defined locations	Grid-based reef presence (cells of 10×10 km), monitoring data	AOO < 50 cells of 10x10 km + ongoing decline or threats	Yes	Calculated per eco-region within pre-established EOO limits
C. Decline in abiotic environmental conditions	C1 – Past environmental degradation	DHW	NOAA Coral Reef Watch	Return interval of ≤ 2 years between bleaching events or 3 severe marine heatwave events occurring within 5 years	Yes	
	C2 – Projected future degradation	DHW	Global Climate Projections	Return interval of ≤ 2 years between bleaching events or 3 severe marine heatwave events occurring within 5 years	Yes	Ecoregion average
D. Decline in key biotic components	D1 – Disruption of biotic processes over the past 50 years	Hard coral cover, algae-coral ratio, herbivore biomass, piscivore biomass	Benthic cover from photo-quadrats and fish counts from UVC surveys	Hard coral cover < 5%, ACR 0.833, herbivore biomass < 20% of initial levels, piscivores < 10% of initial levels	Yes	Calculated per ecoregion using baseline estimates from past equivalent of pristine areas

4. Risk Status

For all related figures and tables in this section, the following abbreviations were used regarding the different risk categories : LC = Least Concern, NT = Near Threatened, VU = Vulnerable, EN = Endangered, CR = Critically Endangered, CO = Collapsed, DD = Data Deficient.

Coral reefs across **all** ecoregions of the Pacific are at a **future** high risk of collapse, an outcome largely driven by severe projected thermal stress under Criterion C for which all 21 of the 21 ecoregions are classified as Critically Endangered. Yet, the present work only reflects current severe biotic degradation and disruption of ecological processes under Criterion D for 2 ecoregions (namely NHWI-Johnston atoll and Offshore Fiji-Tonga). In a similar way, under Criterion A (decline in distribution), about 72% of the Pacific reef surface area (14 ecoregions) is classified as Least Concern, while 14% (3 ecoregions) is Vulnerable and 13% (4 ecoregions) is Endangered. Under Criterion B (restricted distribution), about 95% of the reef area (17 ecoregions) is Least Concern, while only 3% (encompassing the 3 following ecoregions : Line Islands, Phoenix-Tokelau-Northern Cook Islands and Ha'apai) is Vulnerable. Under Criterion C1 (observed thermal stress), the tendency is reversed with 49% of the reef area (9 ecoregions) classified as Vulnerable, 19% (6 ecoregions) as Endangered, when the remaining 32% is either Near Threatened (5 ecoregions) or Least Concern (New Caledonia only). As previously stated, Criterion C2 (projected thermal stress) pushes the entire reef area and all 21 ecoregions to Critically Endangered. Under Criterion D (alteration of biotic interactions), about 52% of the reef area (7 ecoregions) is either Least Concern or Near Threatened, 16% (7 ecoregions) is Vulnerable, 32% (7 ecoregions) is either Endangered or Critically Endangered.

Table 4. Summary of the IUCN Red List of Ecosystems assessment results for Pacific coral reef ecoregions. The overall *Red List of Ecosystems* status is the *highest* level of risk identified across all the assessed criteria. The criterion driving the final risk status for each ecoregion is in brackets.

	Ecoregion	A	B	C	D	Overall
1	NWHI-Johnston atoll	EN	LC	CR	EN	CR (C2)
2	Hawaii	EN	LC	CR	EN	CR (C2)
3	Line Islands	VU	VU	CR	VU	CR (C2)
4	Tuamotus	LC	LC	CR	NT	CR (C2)
5	Society	LC	LC	CR	VU	CR (C2)
6	Austral-Rapa-Pitcairn	LC	NT	CR	NT	CR (C2)
7	Phoenix-Tokelau-Northern Cook Islands	LC	VU	CR	VU	CR (C2)
8	Samoa-Futuna-Niue	LC	LC	CR	VU	CR (C2)
9	Ha'apai	EN	VU	CR	EN	CR (C2)
10	Offshore Fiji-Tonga	EN	LC	CR	CR	CR (C2, D)
11	Fiji	LC	LC	CR	NT	CR (C2)
12	Tuvalu-Wallis	LC	LC	CR	EN	CR (C2)
13	West Kiribati	LC	LC	CR	LC	CR (C2)
14	Marshall Islands	VU	LC	CR	CR	CR (C2, D)
15	Mariana Islands	LC	LC	CR	VU	CR (C2)
16	West Caroline Islands	LC	LC	CR	LC	CR (C2)

Ecoregion		A	B	C	D	Overall
1	NWHI-Johnston atoll	EN	LC	CR	EN	CR (C2)
17	East Caroline Islands	VU	LC	CR	VU	CR (C2)
18	Papua New Guinea	LC	LC	CR	NT	CR (C2)
19	Solomon Islands	LC	LC	CR	EN	CR (C2)
20	Vanuatu	LC	LC	CR	VU	CR (C2)
21	New Caledonia	LC	LC	CR	NT	CR (C2)

Criterion A: Reduction in Geographic Distribution

Of the 21 ecoregions assessed, 7 were classified within threatened categories, having lost a significant area of their coral reefs over the past 50 years. In particular, historical reef loss of Hawaii, the Northwestern Hawaiian Islands (NWHI-Johnston atoll) area, Ha'apai and the Offshore Fiji-Tonga ecoregions all triggered the 50% of collapsed reef sites threshold for the Endangered category. Such proportions highlight areas of concern where cumulative anthropogenic (pollution, coastal development, overfishing, deep-sea mining, invasive species) and/or natural (tectonic activity, storms, corallivores outbreaks, ocean warming/acidification) pressures are highest and where coral species feature a weak capacity for acclimating to the rapid climate-driven changes in abiotic parameters (Mayfield et al., 2017; Prouty et al., 2017). The remaining 14 ecoregions were assessed as Least Concern / Near Threatened.

Table 5. Risk status of Pacific coral reef ecoregions under Criterion A, determined from estimated declines in coral reef area over the last 50 years.

Ecoregion	Proportion of reef sites below critical hard coral cover threshold	Risk status
NWHI-Johnston atoll	0.71	EN
Hawaii	0.66	EN
Line Islands	0.30	VU
Tuamotus	0.00	LC
Society	0.03	LC
Austral-Rapa-Pitcairn	0.06	LC
Phoenix-Tokelau-Northern Cook Islands	0.01	LC
Samoa-Futuna-Niue	0.00	LC
Ha'apai	0.71	EN
Offshore Fiji-Tonga	0.69	EN
Fiji	0.03	LC
Tuvalu-Wallis	0.25	LC
West Kiribati	0.00	LC
Marshall Islands	0.39	VU
Mariana Islands	0.17	LC
West Caroline Islands	0.00	LC
East Caroline Islands	0.34	VU

Ecoregion	Proportion of reef sites below critical hard coral cover threshold	Risk status
NWHI-Johnston atoll	0.71	EN
Hawaii	0.66	EN
Line Islands	0.30	VU
Tuamotus	0.00	LC
Society	0.03	LC
Austral-Rapa-Pitcairn	0.06	LC
Phoenix-Tokelau-Northern Cook Islands	0.01	LC
Papua New Guinea	0.03	LC
Solomon Archipelago	0.21	LC
Vanuatu	0.18	LC
New Caledonia	0.22	LC

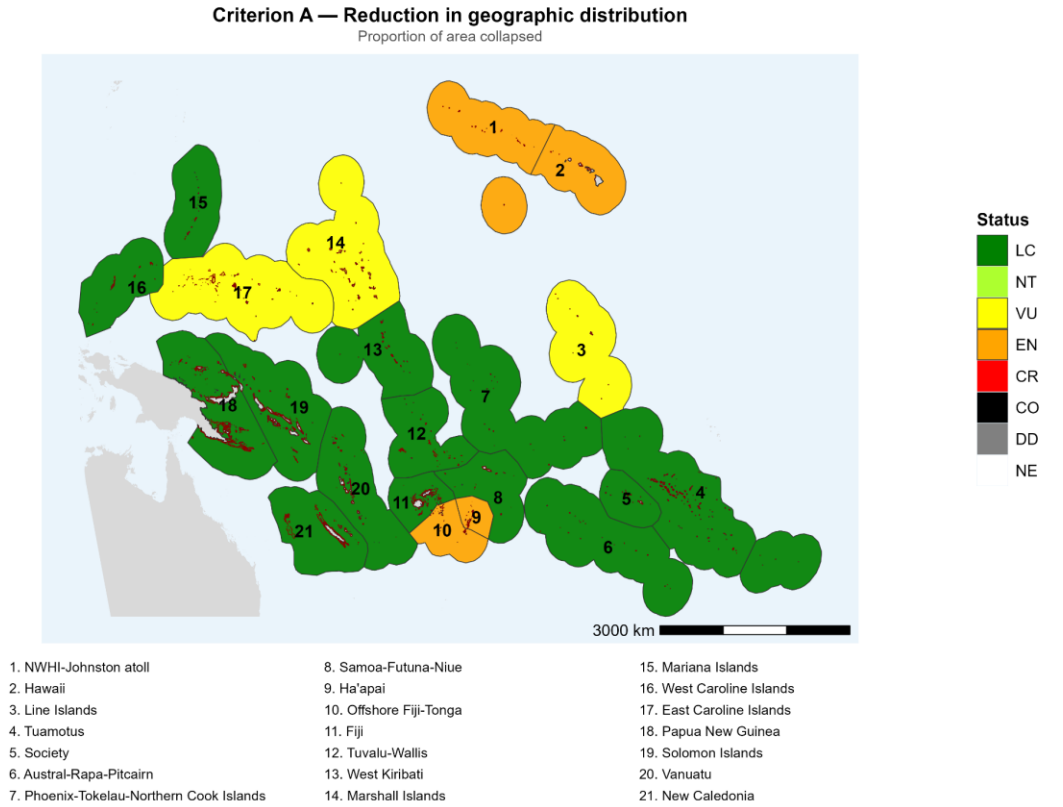


Figure 7. Red List of Ecosystems risk status for the 21 coral reef ecoregions of the Pacific under Criterion A.

Criterion B: Restricted Geographic Distribution

Under Criterion B, none of the 21 ecoregions were assessed as Endangered or Critically Endangered, 3 were assessed as Vulnerable, 1 was assessed as Near Threatened while the remaining 17 were assessed as Least Concern. Smaller ecoregions, such as the Line Islands

and the Phoenix-Tokelau-Northern Cook Islands meet the threshold of < 55 x10 km^2 for restricted AOO, especially when combined with ongoing threats such as recurring marine heatwaves associated with ENSO, ocean acidification, nutrients/heavy metals enrichment or cyclones (Sandin et al., 2008; Houk et al., 2015; Fox et al., 2021). Ha'apai is the only ecoregion restricted from its EOO value compared to the < 55 000 km^2 threshold.

Table 6. Risk status of Pacific coral reef ecoregions under Criterion B, determined from distribution of coral reefs measured as the Extent of Occurrence (EOO) and Area of Occupancy (AOO).

Ecoregion	Extent of Occurrence EOO (km^2)	Area of Occupancy AOO (10 x 10 km)	Risk Status Overall
NWHI-Johnston atoll	720 450	81	LC
Hawaii	85 817	75	LC
Line Islands	375 081	31	VU
Tuamotus	1 213 637	379	LC
Society	70 517	60	LC
Austral-Rapa-Pitcairn	1 821 634	53	NT
Phoenix-Tokelau-Northern Cook Islands	1 370 416	45	VU
Samoa-Futuna-Niue	410 614	72	LC
Ha'apai	26 068	82	VU
Offshore Fiji-Tonga	147 701	94	LC
Fiji	158 124	403	LC
Tuvalu-Wallis	485 508	162	LC
West Kiribati	347 945	100	LC
Marshall Islands	1 032 624	296	LC
Mariana Islands	86 728	60	LC
West Caroline Islands	333 613	94	LC
East Caroline Islands	1 091 097	327	LC
Papua New Guinea	1 125 974	1 101	LC
Solomon Islands	879 325	671	LC
Vanuatu	625 330	284	LC
New Caledonia	399 364	519	LC

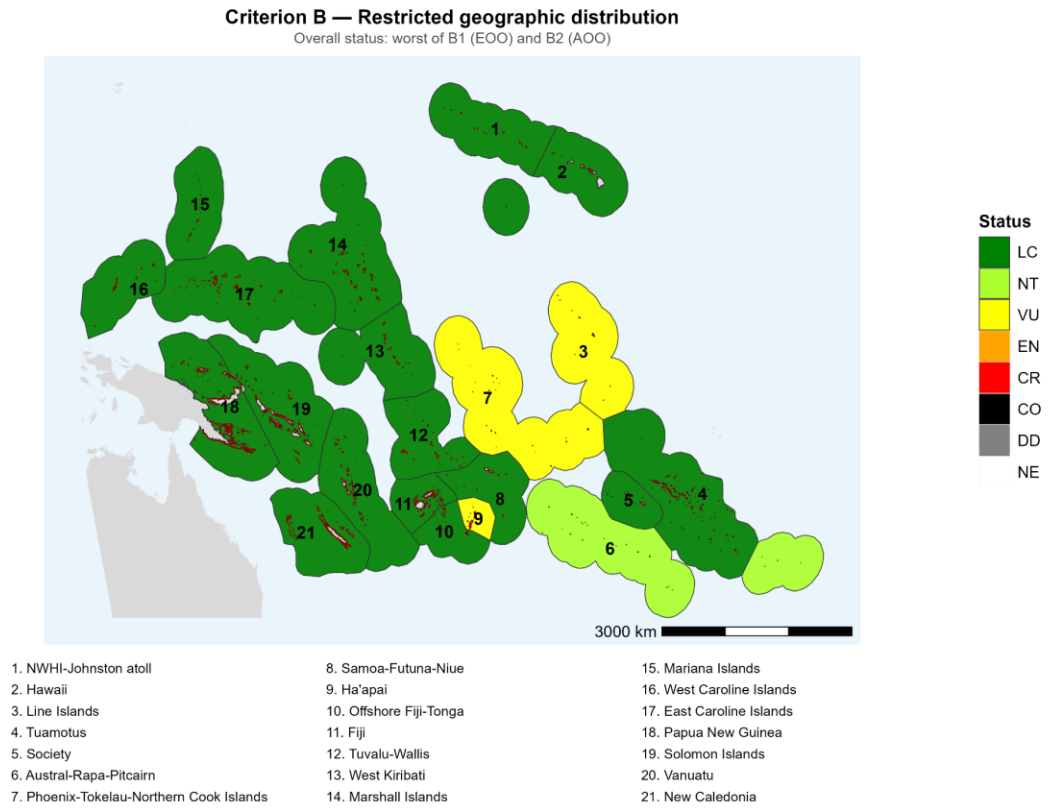


Figure 8. Red List of Ecosystems risk status for the 21 coral reef ecoregions of the Pacific under Criterion B.

Criterion C: Environmental Degradation

Based on historical and projected DHW records (Criterion C2), 21 out of 21 ecoregions were classified as Critically Endangered under Criterion C. This result is yet driven entirely by projected future thermal stress, when comparing the current output to every Representative Concentration Pathways emission scenarios examined. The current picture, however - based on historical DHW records alone under Criterion C1 - is considerably more variable : 9 ecoregions were classified as Vulnerable, 6 as Endangered, 5 as Near Threatened and 1 (New Caledonia) as Least Concern. This reflects that observed thermal stress to date has not yet reached the severity projected for the coming decades.

Table 7. Risk status of Pacific coral reef ecoregions under Criterion C, determined from estimated declines in abiotic conditions, specifically changes in extreme heat events.

Ecoregion	Risk Status Criterion C1	Risk Status Criterion C2	Risk Status Overall
NWHI-Johnston atoll	VU	CR	CR
Hawaii	VU	CR	CR
Line Islands	EN	CR	CR
Tuamotus	VU	CR	CR
Society	NT	CR	CR
Austral-Rapa-Pitcairn	NT	CR	CR

Ecoregion	Risk Status Criterion C1	Risk Status Criterion C2	Risk Status Overall
Phoenix-Tokelau-Northern Cook Islands	VU	CR	CR
Samoa-Futuna-Niue	VU	CR	CR
Ha'apai	EN	CR	CR
Offshore Fiji-Tonga	VU	CR	CR
Fiji	VU	CR	CR
Tuvalu-Wallis	VU	CR	CR
West Kiribati	EN	CR	CR
Marshall Islands	NT	CR	CR
Mariana Islands	EN	CR	CR
West Caroline Islands	EN	CR	CR
East Caroline Islands	EN	CR	CR
Papua New Guinea	VU	CR	CR
Solomon Islands	NT	CR	CR
Vanuatu	NT	CR	CR
New Caledonia	LC	CR	CR

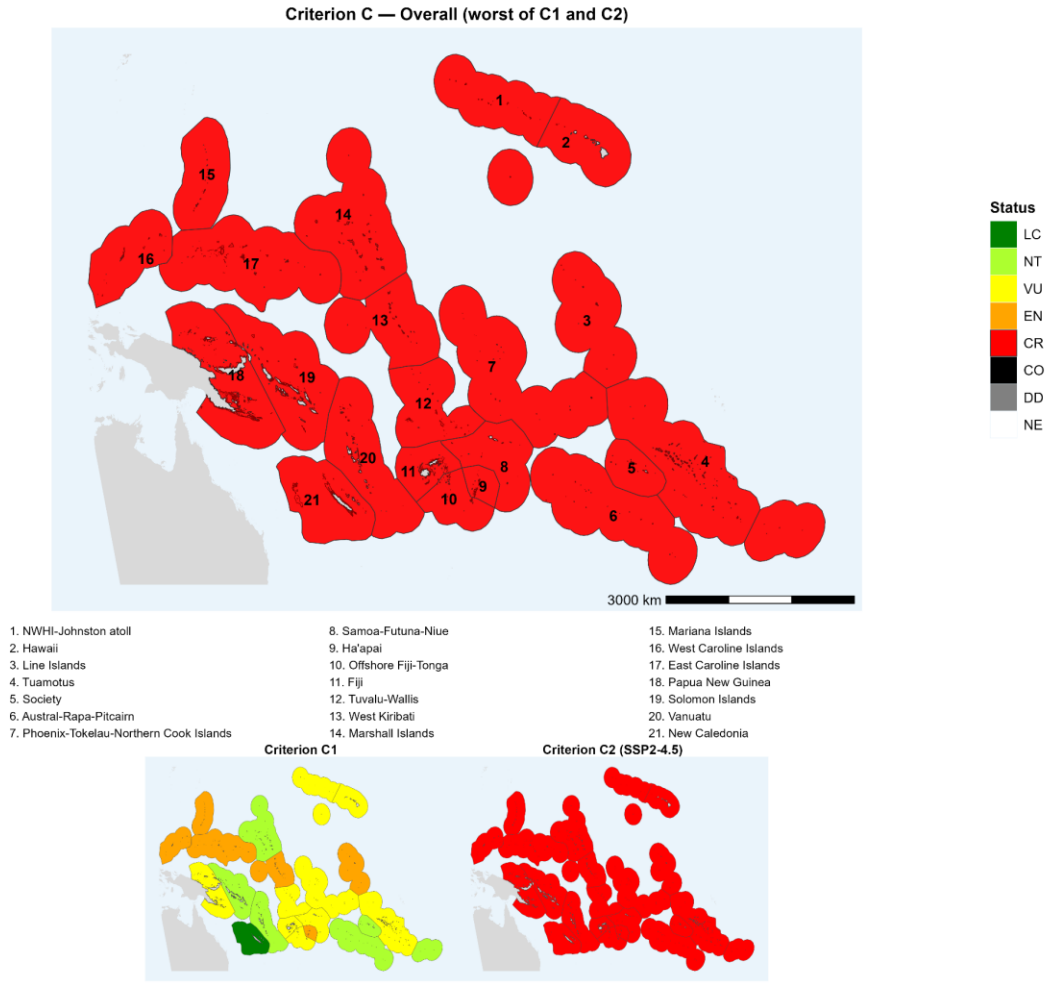


Figure 9. Red List of Ecosystems risk status for the 21 coral reef ecoregions of the Pacific under Criterion C (above : overall; below : C1 (left) and C2 (right)).

Criterion D: Disruption of biotic processes or interactions

Under Criterion D, 14 of the 21 ecoregions met the threshold for threatened status (Vulnerable or above), while 5 (Tuamotus, Austral-Rapa-Pitcairn, Fiji, Papua New Guinea and New Caledonia) were assessed as Near Threatened and 2 (West Kiribati and West Caroline Islands) as Least Concern. Some ecoregions were classified as Data Deficient for one or more indicators, especially regarding fish populations. Yet, available data on herbivore biomass suggest moderate disruption of trophic interactions in most ecoregions of the Pacific, while piscivores taxa seem to be more sensitive to regional fishing pressure.

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

Ecoregion	Hard corals	Algae-coral ratio	Herbivores	Piscivores	Overall
NWHI-Johnston atoll	EN (EN-CR)	VU	VU	NT-VU	EN
Hawaii	EN	NT	VU-EN	VU	EN
Line Islands	VU	VU	NT	NT-VU	VU
Tuamotus	NT	LC	DD	DD	NT
Society	NT	LC	LC	VU	VU
Austral-Rapa-Pitcairn	LC	LC	LC	VU (NT-VU)	NT
Phoenix-Tokelau-Northern Cook Islands	NT	LC-NT	EN (VU-EN)	NT-VU	VU
Samoa-Futuna-Niue	LC	LC	NT	VU-EN	VU
Ha'apai	EN	LC (LC-NT)	LC	VU	EN
Offshore Fiji-Tonga	CR (EN-CR)	VU	LC (LC-NT)	NT	CR
Fiji	NT	LC	DD	LC	NT
Tuvalu-Wallis	NT	DD	EN (NT-EN)	EN (VU-EN)	EN
West Kiribati	LC	LC	DD	DD	LC
Marshall Islands	EN	NT-VU	CR (EN-CR)	NT-VU	CR
Mariana Islands	NT	NT	NT	VU	VU
West Caroline Islands	LC	LC	DD	DD	LC
East Caroline Islands	VU	LC	DD	DD	VU
Papua New Guinea	NT	LC	DD	DD	NT
Solomon Islands	EN	LC	DD	DD	EN
Vanuatu	VU	LC	NT	VU-EN	VU
New Caledonia	NT-VU	LC	LC	NT	NT

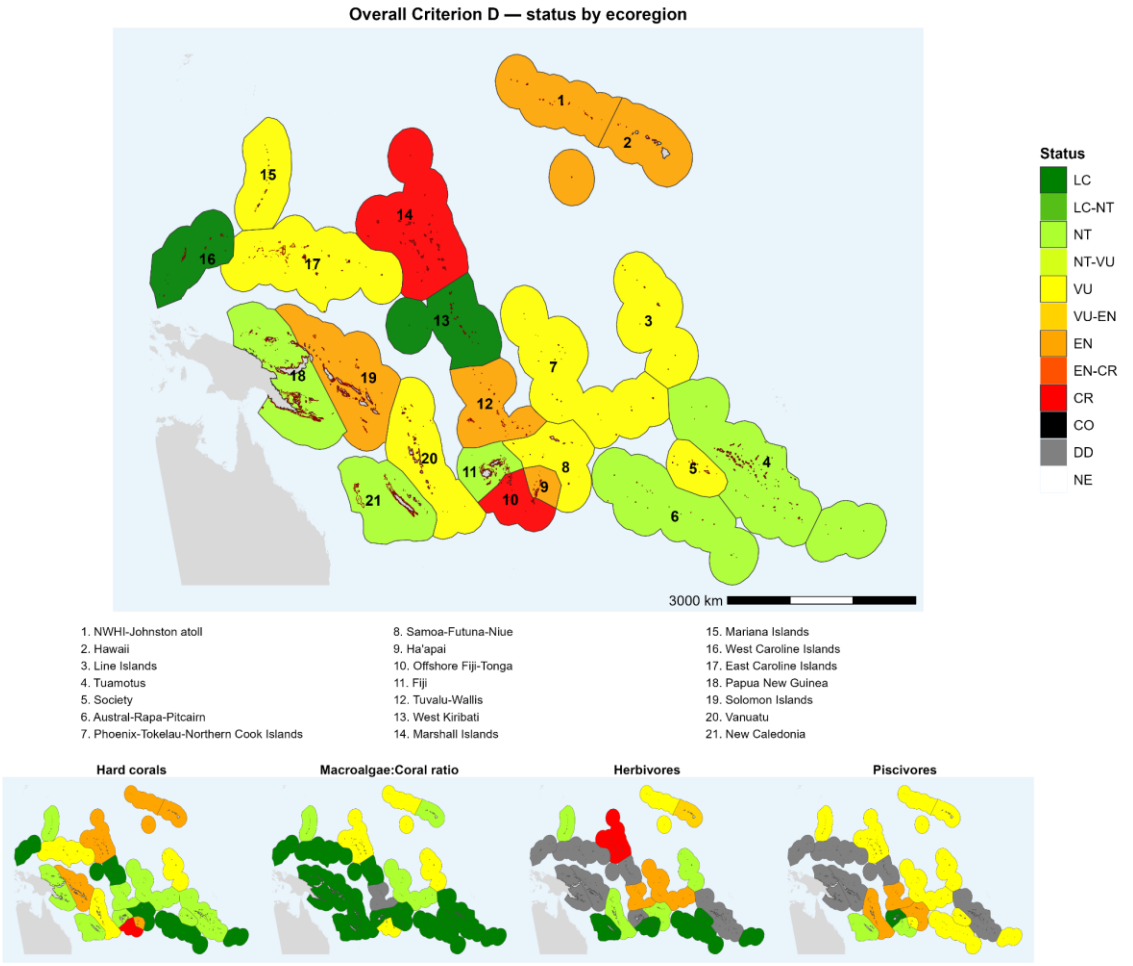


Figure 10. Red List of Ecosystems risk status for the 21 coral reef ecoregions of the Pacific under Criterion D (above : overall; below (from left to right) : hard corals, macroalgae:coral ratio, herbivores, piscivores).

5. Conclusion and recommendations

The Pacific coral reef ecosystems assessed here are at a future high risk of collapse, with all 21 ecoregions classified within a Critically Endangered category regarding dynamic projections of thermal anomalies in the upcoming decades (Criterion C2). However, current degradation is highly heterogeneous across the region and the subsequent comparison with past estimates leads to much more mitigated risk categorization. Under Criterion A and Criterion B, the majority of ecoregions were classified in the Least Concern category. In terms of hard coral cover decline (Criterion A), 7 of 21 ecoregions showed a proportion of collapsed sites beyond the Vulnerable threshold. When talking about reef area scarcity and low connectivity potential within ecoregion boundaries (Criterion B), only 3 are actually raising concern as being Vulnerable. Historical thermal stress (Criterion C1) places 15 ecoregions in Vulnerable or Endangered categories, while 5 ecoregions were Near Threatened and 1

ecoregion was Least Concern (New Caledonia). A total of 2 ecoregions showed elevated levels of key biotic processes disruption (Criterion D), as being Critically Endangered under hard coral cover decline (Offshore Fiji–Tonga) or herbivores biomass (Marshall Islands). Amongst the remaining ones, were assessed under a minor biotic preoccupation status (Tuamotus, Austral-Rapa-Pitcairn, Fiji, West Kiribati, West Caroline Islands, Papua New Guinea and New Caledonia).

Thus, the present assessment identified climate-driven thermal stress as the dominant regional driver of overall risk, highlighting that continued warming represents the primary long-term threat to reef persistence. These findings therefore highlight that global climate mitigation and local reef management are complementary rather than interchangeable priorities. Rapid reductions in greenhouse-gas emissions are necessary to limit the magnitude of future climate impacts on coral reefs, while *in situ* conservation and restoration efforts can reduce local pressures, maintain ecological functions and enhance reef resilience to unavoidable climate stress. The latter should be scaled to prioritize the protection and effective management of remaining reefs with relatively intact coral cover, trophic structure and/or lower observed thermal exposure, while strengthening monitoring efforts in degraded reefs to keep assessing recovery potential.

Priority actions include, but are not limited to :

- rapidly phase down fossil-fuel use : prioritise renewable energy systems (particularly solar, wind and other locally appropriate low-carbon sources), redirect public investment toward low-carbon infrastructure, decarbonise electricity and transport;
- reduce methane and other non-CO_2 greenhouse gases emissions where relevant : improve waste management, landfill-gas capture and wastewater treatment;
- integrate climate mitigation into marine and coastal planning : assess the carbon implications of major infrastructure, tourism, transport and energy projects, prioritise low-carbon development pathways whenever possible, implement territorial greenhouse gas emissions reduction targets;
- protect and restore carbon-rich ecosystems such as mangroves, seagrass meadows and coastal wetlands;
- strengthen area-based management networks (e.g. protected areas, conserved areas, locally and/or traditionally-managed areas), while ensuring the creation of biodiversity corridors for improved connectivity of reef habitats;
- improve fisheries management, while respecting subsistence traditions, cultural practice and values; and
- prevent major anthropogenic disturbances (e.g. land-based pollution, damaging coastal habitat development) and implement nature-based solutions.

These key priorities are consistent with the regional objectives of the past (2021-2025) and current (2026-2030) Pacific Islands Framework for Nature Conservation and Protected Areas, as well as the Pacific Coral Reef Action Plan (2021-2030). They should also more broadly contribute to the strengthening of the Global Biodiversity Framework (2022-2030)

and the implementation of the 2050 Blue Pacific Continent Strategy, particularly through strengthened regional cooperation, science-based decision-making and ecosystem resilience.

This report also highlights substantial monitoring gaps that should be addressed to improve future risk assessments and management decisions. Fish biomass data are particularly limited in several ecoregions, while long-term benthic observations are often lacking accurate representation in terms of sites (number and distribution across the ecoregion), consecutive years of surveys and technical protocols used. Regional monitoring should therefore not only maintain standardized measurements for all biotic components commonly surveyed, such as hard coral, macroalgae and fish populations, but also include key components in upcoming monitoring to comply with future estimates of reef resilience (i.e. bleaching extent, disease occurrences, density/diversity of invertebrates including crown-of-thorns starfish or other corallivorous taxa). In addition, greater spatial representation across remote and poorly sampled reefs is still currently an important requirement across the Pacific region to ensure better representation of distinct reef habitats that are known to function differently.

Regarding threshold values, global standardisation has often prevailed over more small-scaled expert decisions. As an example, severe bleaching-level marine heatwaves recurring every ≤ 3 years are indeed indicative of chronic degradation and high collapse risk, yet for Pacific coral reefs complete collapse is more consistently associated with recurrence intervals approaching annual to ≤ 2 years severe heatwaves conditions (Hughes et al., 2003; Adjeroud et al., 2018). Going from 3 to 2 years as a collapse interval between frequent severe heatwaves over a 30-year period could influence Criterion C outcomes if tried out thereafter.

To conclude, the hereby work provides a first evaluation of Pacific coral reefs under the Red List of Ecosystems workframe established by the IUCN to support effective management and prime conservation actions. It comes with levels of uncertainty and every step of the evaluation is based on a number of acknowledged definitions and assumptions. In order for such an analytical tool to remain relevant over the long term, future analyses would be required to improve the understanding of changes in the status of coral ecosystems over time through providing additional new monitoring data and adjusting current predictive models.

6. References

Adjeroud, M. andréfouët, S., & Payri, C. (2001). Mass mortality of macrobenthic communities in the lagoon of Hikueru atoll (French Polynesia). *Coral Reefs*, *19*(3), 287-291.

Adjeroud, M., Kayal, M., Iborra-Cantonnet, C., et al. (2018). Recovery of coral assemblages despite acute and recurrent disturbances on a South Central Pacific reef. *Scientific Reports*, *8*(1), 9680.

Adjeroud, M., Wallace, C. C., Bosserelle, P., et al. (2016). Reefs at the edge: coral community structure around Rapa, southernmost French Polynesia. *Marine Ecology*, *37*(3), 565-575.

Aeby, G. S., Williams, G. J., Franklin, E. C., et al. (2011). Patterns of coral disease across the Hawaiian archipelago: relating disease to environment. PloS one, 6(5), e20370.

Anthony, K. R., Maynard, J. A., Díaz-Pulido, G., et al. (2011). Ocean acidification and warming will lower coral reef resilience. *Global Change Biology*, *17*(5), 1798-1808

Basher, R. E., & Zheng, X. (1995). Tropical cyclones in the southwest Pacific: Spatial patterns and relationships to Southern Oscillation and sea surface temperature. *Journal of Climate*, *8*(5), 1249-1260.

Beger, M., Wendt, H., Sullivan, J., et al. (2020). National-scale marine bioregions for the Southwest Pacific. *Marine pollution bulletin*, *150*, 110710.

Bellwood, D. R., Hughes, T. P., Folke, C., & Nyström, M. (2004). Confronting the coral reef crisis. *Nature*, *429*(6994), 827-833.

Birkeland, C. (1997). Symbiosis, fisheries and economic development on coral reefs. *Trends in ecology & evolution*, *12*(9), 364-367.

Birrell, C. L., McCook, L. J., Willis, B. L., & Diaz-Pulido, G. A. (2008). Effects of benthic algae on the replenishment of corals and the implications for the resilience of coral reefs. In *Oceanography and marine biology* (pp. 31-70). CRC Press.

Bruno, J. F. & Selig, E. R. (2007). Regional decline of coral cover in the Indo-Pacific. PLoS ONE 2:e711.

Bruno, J. F., Selig, E. R., Casey, K. S., et al. (2007). Thermal stress and coral cover as drivers of coral disease outbreaks. *PLoS biology*, *5*(6), e124.

Burke, L., Reytar, K., Spalding, M., & Perry, A. (2011). Reefs at risk. *World Resources Institute, Washington, DC*, *124*, 86.

Claar, D. C., Szostek, L., McDevitt-Irwin, J. M., et al. (2018). Global patterns and impacts of El Niño events on coral reefs: A meta-analysis. *PLoS One*, *13*(2), e0190957.

Coles, S. L., DeFelice, R. C., & Minton, D. (2001). Marine species survey of Johnston Atoll, Central Pacific Ocean, June 2000. Bishop Mus. Tech. Rep, 19, 1.

Darling, E. S., McClanahan, T. R., Maina, J., et al. (2019). Social–environmental drivers inform strategic management of coral reefs in the Anthropocene. *Nature ecology & evolution*, *3*(9), 1341-1350.

Darwin, C. (1889). *The structure and distribution of coral reefs* (Vol. 15). D. Appleton.

De'Ath, G., Fabricius, K. E., Sweatman, H., & Puotinen, M. (2012). The 27–year decline of coral cover on the Great Barrier Reef and its causes. *Proceedings of the National Academy of Sciences*, *109*(44), 17995-17999.

Drew, J. A., & Amatangelo, K. L. (2017). Community assembly of coral reef fishes along the Melanesian biodiversity gradient. *PloS one*, *12*(10), e0186123.

Eakin, C. M., Heron, S. F., Connolly, S. R., Devotta, D. A., Liu, G., Geiger, E. F., ... & Shedrawi, G. (2026). Severe and widespread coral reef damage during the 2014-2017 Global Coral Bleaching Event. *Nature Communications*, 17(1), 1318.

Fabricius, K. E. (2005). Effects of terrestrial runoff on the ecology of corals and coral reefs: review and synthesis. *Marine pollution bulletin*, *50*(2), 125-146.

Fa'anunu, K. M. (2011). *Fishing pressure and benthic associations: Herbivorous fishes on reef flats in Fiji*. University of Hawai'i at Hilo.

Fabricius, K. (2011). River discharge reduces reef coral diversity in Palau. *Marine Pollution Bulletin*.

Fiedler, P. C., & Talley, L. D. (2006). Hydrography of the eastern tropical Pacific: A review. *Progress in oceanography*, *69*(2-4), 143-180.

Fey, P., Parravicini, V., Bănaru, D., et al. (2021). Multi-trophic markers illuminate the understanding of the functioning of a remote, low coral cover Marquesan coral reef food web. Scientific reports, 11(1), 20950.

Fox, M. D., Cohen, A. L., Rotjan, R. D., et al. (2021). Increasing coral reef resilience through successive marine heatwaves. *Geophysical Research Letters*, *48*(17), e2021GL094128.

Friedlander, A. M., & DeMartini, E. E. (2002). Contrasts in density, size and biomass of reef fishes between the northwestern and the main Hawaiian Islands: the effects of fishing down apex predators. *Marine Ecology Progress Series*, *230*, 253-264.

Friedlander, A., Aeby, G., Brainard, R., et al. (2004). Status of coral reefs in the Hawaiian Archipelago. In C. Wilkinson (Ed.), Status of coral reefs of the world: 2004 (Vol. 2, pp. 411-430). Australian Institute of Marine Science.

Friedlander, A., Aeby, G., Brainard, R., et al. (2005). The state of coral reef ecosystems of the Northwestern Hawaiian Islands. *The state of coral reef ecosystems of the United States and Pacific Freely Associated States*, *73*, 263-306.

Freeman, L. A., Miller, A. J., Norris, R. D., & Smith, J. E. (2012). Classification of remote Pacific coral reefs by physical oceanographic environment. *Journal of Geophysical Research: Oceans*, *117*(C2).

Friedlander, A., Aeby, G., Brainard, R., et al. (2005). The state of coral reef ecosystems of the Northwestern Hawaiian Islands. *The state of coral reef ecosystems of the United States and Pacific Freely Associated States*, *73*, 263-306.

Friedlander, A. M., & Brown, E. K. (2019). The Hawaiian Archipelago. In C. Sheppard (Ed.), World seas: An environmental evaluation: Volume II—The Indian Ocean to the Pacific (2nd ed., pp. 713–741). Academic Press. https://doi.org/10.1016/B978-0-08-100853-9.00053-1.

Galand, P. E., Ruscheweyh, H. J., Salazar, G., et al. (2023). Diversity of the Pacific Ocean coral reef microbiome. *Nature Communications*, *14*(1), 3039.

Galloway, S. B., Woodley, C. M., & Bruckner, A. W. (2009). Coral health and disease in the Pacific: Vision for action.

Gilmour, J. P., Smith, L. D., Heyward, A. J., et al. (2013). Recovery of an isolated coral reef system following severe disturbance. *Science*, *340*(6128), 69-71.

Global Coral Reef Monitoring Network (GCRMN) and International Coral Reef Initiative (ICRI), (2021). Status of coral reefs of the world: 2018 report.

Glynn, P. W., & Ault, J. S. (2000). A biogeographic analysis and review of the far eastern Pacific coral reef region. *Coral reefs*, *19*(1), 1-23.

Guillemot, N., Chabanet, P., & Le Pape, O. (2010). Cyclone effects on coral reef habitats in New Caledonia (South Pacific). *Coral Reefs*, *29*(2), 445-453.

Hamilton, R. J., Lozano-Cortés, D., Bode, M., et al. (2021). Larval dispersal and fishing pressure influence recruitment in a coral reef fishery. *Journal of Applied Ecology*, 58(12), 2924-2935.

Harmelin-Vivien, M. L. (1994). The effects of storms and cyclones on coral reefs: a review. *Journal of Coastal Research*, 211-231.

Harrington, L., Fabricius, K., De'Ath, G., & Negri, A. (2004). Recognition and selection of settlement substrata determine post-settlement survival in corals. *Ecology*, *85*(12), 3428-3437.

Hoegh-Guldberg, O. (1999). Climate change, coral bleaching and the future of the world's coral reefs. *Marine and freshwater research*, *50*(8), 839-866.

Hoegh-Guldberg, O., Mumby, P. J., Hooten, A. J., et al. (2007). Coral reefs under rapid climate change and ocean acidification. *science*, *318*(5857), 1737-1742.

Houk, P., Benavente, D., Iguel, J., et al. (2014). Coral reef disturbance and recovery dynamics differ across gradients of localized stressors in the Mariana Islands. *PloS one*, *9*(8), e105731.

Houk, P., Yalon, A., Maxin, S., et al. (2020). Predicting coral-reef futures from El Niño and Pacific Decadal Oscillation events. *Scientific Reports*, *10*(1), 7735.

Hughes, T. P., Baird, A. H., Bellwood, D. R., et al. (2003). Climate change, human impacts and the resilience of coral reefs. *science*, *301*(5635), 929-933.

Hughes, T.P., Kerry, J. T., Álvarez-Noriega, M., et al. (2017). Global warming and recurrent mass bleaching of corals. *Nature*, 543:373–377.

Hunter, C. L. (1995). Review of status of coral reefs around American flag Pacific islands and assessment of need, value and feasibility of establishing a coral reef fishery management plan for the western Pacific region. *Final report, prepared for the Western Pacific Regional Fishery Management Council, Honolulu, Hawai'i*.

Kayanne, H., Hata, H., Kudo, S., et al. (2005). Seasonal and bleaching-induced changes in coral reef metabolism and CO2 flux. *Global Biogeochemical Cycle*s, 19(3).

Kaza, V. S., Reddy, C. K. K., & Reddy, K. S. S. (2025). Eruptions in the Pacific Ring of Fire. *Innovations in Data Analytics: Selected Papers of ICIDA 2024, Volume 1*, *1*, 51.

Keith, D. A., Ferrer-Paris, J. R., Nicholson, E., et al. (2022). A function-based typology for Earth's ecosystems. *Nature*, 610(7932), 513-518.

Kleypas, J. A., McManus, J. W., & Meñez, L. A. (1999). Environmental limits to coral reef development: where do we draw the line?. *American zoologist*, *39*(1), 146-159.

Kool, J. T., Paris, C. B., Barber, P. H., & Cowen, R. K. (2011). Connectivity and the development of population genetic structure in Indo-West Pacific coral reef communities. *Global Ecology and Biogeography*, 20(5), 695-706.

Kulbicki, M., Parravicini, V., Bellwood, D. R., et al. (2013). Global biogeography of reef fishes: a hierarchical quantitative delineation of regions. *PloS one*, *8*(12), e81847.

Lamb, J. B., Willis, B. L., Fiorenza, E. A., et al. D. (2018). Plastic waste associated with disease on coral reefs. *Science*, *359*(6374), 460-462.

Lovell, E., Sykes, H., Deiye, M., et al. (2004). Status of Coral Reefs in the South West Pacific: Fiji, Nauru, New Caledonia, Samoa, Solomon Islands, Tuvalu and Vanuatu. Status of coral reefs of the world, 2, 337-362.

Maragos, J. E., & Jokiel, P. L. (1986). Reef corals of Johnston Atoll: one of the world's most isolated reefs. *Coral Reefs*, *4*(3), 141-150.

Maritorena, S. (1996). Remote sensing of the water attenuation in coral reefs: a case study in French Polynesia. *International Journal of Remote Sensing*, *17*(1), 155-166.

Mayfield, A. B., Chen, C. S., & Dempsey, A. C. (2017). Biomarker profiling in reef corals of Tonga's Ha'apai and Vava'u archipelagos. *PLoS One*, *12*(11), e0185857.

Messmer, V., Jones, G. P., Munday, P. L., & Planes, S. (2012). Concordance between genetic and species diversity in coral reef fishes across the Pacific Ocean biodiversity gradient. *Evolution*, *66*(12), 3902-3917.

Miller, J., Maragos, J., Brainard, R., et al. (2008). The state of coral reef ecosystems of the Pacific Remote Island Areas. *The state of coral reef ecosystems of the United States and Pacific Freely Associated States*, *3542386*.

Miller, K. A., Thompson, K. F., Johnston, P., & Santillo, D. (2018). An overview of seabed mining including the current state of development, environmental impacts and knowledge gaps. Frontiers in Marine Science, 4, 312755.

Montaggioni, L. F. (2005). History of Indo-Pacific coral reef systems since the last glaciation: development patterns and controlling factors. *Earth-Science Reviews*, *71*(1-2), 1-75.

Morante-Carballo, F., Pinto-Ponce, B., Santos-Baquerizo, E., et al. (2024). Systematic Review on Seismic Hazards in the Coastal Regions of the Pacific Ring of Fire. *International Journal of Safety & Security Engineering*, 14(5).

Morrison, R. J., Denton, G. R. W., Tamata, U. B., & Grignon, J. (2013). Anthropogenic biogeochemical impacts on coral reefs in the Pacific Islands—An overview. *Deep Sea Research Part II: Topical Studies in Oceanography*, 96, 5-12.

Myers, R. L., & Raymundo, L. J. (2009). Coral disease in Micronesian reefs: a link between disease prevalence and host abundance. *Diseases of Aquatic Organisms*, *87*(1-2), 97-104.

Newton, K., Côté, I. M., Pilling, G. M., et al. (2007). Current and future sustainability of island coral reef fisheries. *Current Biology*, *17*(7), 655-658.

NOAA - National Environmental Satellite, Data and Information Service. 2024. Pacific Climate Update. Coral Bleaching Heat Stress Analysis and Seasonal Guidance through September 2024.

Obura, D., Gudka, M., Samoilys, et al. (2022). Vulnerability to collapse of coral reef ecosystems in the Western Indian Ocean. *Nature Sustainability*, 5(2), 104-113.

Paulay, G. (1997). Diversity and distribution of reef organisms.

Pellerin, F., Espel, D., Ballard, J., et al. (2025). Snapshots of coral reef biodiversity. In *The Future of Coral Reefs: Evidence from Research* (pp. 187-241). Cham: Springer Nature Switzerland.

Penin, L., Michonneau, F., Carroll, A., & Adjeroud, M. (2011). Effects of predators and grazers exclusion on early post-settlement coral mortality. *Hydrobiologia*, 663(1), 259-264.

Perry, C. T., Murphy, G. N., Kench, P. S., et al. (2013). Caribbean-wide decline in carbonate production threatens coral reef growth. *Nature communications*, *4*(1), 1402.

Planes, S., Allemand, D., Agostini, S., et al. (2019). The Tara Pacific expedition - A pan-ecosystemic approach of the "-omics" complexity of coral reef holobionts across the Pacific Ocean. *PLoS biology*, *17*(9), e3000483.

Price, N. (2010). Habitat selection, facilitation, and biotic settlement cues affect distribution and performance of coral recruits in French Polynesia. *Oecologia*, 163(3), 747-758.

Prouty, N. G., Cohen, A., Yates, K. K., et al. (2017). Vulnerability of coral reefs to bioerosion from land-based sources of pollution. *Journal of Geophysical Research: Oceans*, *122*(12), 9319-9331.

Rafferty, J. P. "Coral Triangle". Encyclopedia Britannica, 10 Oct. 2025, https://www.britannica.com/place/Coral-Triangle.

Rodgers, K. U. S., Jokiel, P. L., Brown, E. K., Hau, S., & Sparks, R. (2015). Over a decade of change in spatial and temporal dynamics of Hawaiian coral reef communities. Pacific Science, 69(1).

Roff, G., & Mumby, P. J. (2012). Global disparity in the resilience of coral reefs. Trends in ecology & evolution, 27(7), 404-413.

Sandin, S. A., Smith, J. E., DeMartini, E. E., et al. (2008). Baselines and degradation of coral reefs in the Northern Line Islands. *PloS one*, *3*(2), e1548.

Spalding, M. D., Fox, H. E., Allen, G. R., et al. (2007). Marine ecoregions of the world: a bioregionalization of coastal and shelf areas. *BioScience*, *57*(7), 573-583.

Stevenson, C., Katz, L. S., Micheli, F., et al. (2007). High apex predator biomass on remote Pacific islands. *Coral reefs*, *26*(1), 47-51.

Stuart, C., Benkwitt, C., Stamoulis, K., et al. (2026). Integrating spatial patterns of herbivorous fish functional diversity to inform coral reef management. *Marine Ecology Progress Series*, *780*, 1-20.

Sully, S., Hodgson, G., & van Woesik, R. (2022). Present and future bright and dark spots for coral reefs through climate change. *Global change biology*, *28*(15), 4509-4522.

Tsounis, G., & Edmunds, P. J. (2016). The potential for self-seeding by the coral Pocillopora spp. in Moorea, French Polynesia. *PeerJ*, 4, e2544.

UNEP-WCMC, WorldFish Centre, WRI, TNC (2021).

Ushijima, B., Smith, A., Aeby, G. S., & Callahan, S. M. (2012). Vibrio owensii induces the tissue loss disease Montipora white syndrome in the Hawaiian reef coral Montipora capitata.

Van Dover, C. L., Ardron, J. A., Escobar, E., et al. (2017). Biodiversity loss from deep-sea mining. *Nature Geoscience*, *10*(7), 464-465.

Veron, J., Stafford-Smith, M., DeVantier, L., & Turak, E. (2015). Overview of distribution patterns of zooxanthellate Scleractinia. *Frontiers in Marine Science*, *1*, 81.

Walsh, K. J., McInnes, K. L., & McBride, J. L. (2012). Climate change impacts on tropical cyclones and extreme sea levels in the South Pacific - A regional assessment. *Global and Planetary Change*, *80*, 149-164.

Wilkinson, C. R., & Souter, D. (2008). Status of Caribbean coral reefs after bleaching and hurricanes in 2005.

Williams, I. D., Richards, B. M., Sandin, S. A., et al. (2011). Differences in reef fish assemblages between populated and remote reefs spanning multiple archipelagos across the central and western Pacific. *Journal of Marine Sciences*, *2011*(1), 826234.

Wood, S., Paris, C. B., Ridgwell, A., & Hendy, E. J. (2014). Modelling dispersal and connectivity of broadcast spawning corals at the global scale. *Global Ecology and Biogeography*, 23(1), 1-11.

Work, T. M., & Rameyer, R. A. (2005). Characterizing lesions in corals from American Samoa. *Coral Reefs*, *24*(3), 384-390.

7. Acknowledgments

We acknowledge the contribution of all collaborating institutions within the Pacific, whose inputs were invaluably helpful to come up with the present achievement. We would like to thank the Mediterranean Shipping Company (MSC) Foundation for providing funding to support this assessment through covering data gathering / analysis time and providing opportunities to engage with regional experts and governments through workshop attendance, especially during the 2nd Pacific Island Ocean Conference (Honiara, Solomon Islands), the 16th International Coral Reef Symposium (Auckland, New Zealand) and the 11th Pacific Islands Conference on Nature Conservation (Noumea, New Caledonia).

8. Peer review

The peer-reviewing process was performed by designated coral reef experts who contributed to the data provision and, more broadly, to the assessment itself. Two other regions covered by the Coral Reef Red List of Ecosystems initiative, namely Australia and Western Indian Ocean, were also invited to provide comments in establishing the final version of the present work.

9. Disclaimer

The designation of geographical entities in this publication and the presentation of the material, do not imply the expression of any opinion whatsoever on the part of IUCN concerning the legal status of any country, territory, or area, or of its authorities, or concerning the delimitation of its frontiers or boundaries.

The views expressed in this publication do not necessarily reflect those of IUCN or other participating organisations.

10.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 IUCN Red List of Ecosystems assessment and publication.

Contributor	Data provision	Data curation	Formal analysis	Meeting attendance	Project administration	Advisory group/ Expert input	Validation	Writing input
Biosphere Foundation	X							
C2O Pacific	X			X		X	X	X
CCMI		X	X	X				
Coral Sea Foundation	X							
CRIOBE	X							
Service Territorial de l'Environnement de Wallis-et-Futuna	X			X			X	
Gouvernement de la Nouvelle-Calédonie	X							
Hawai'i Wildlife Fund	X					X	X	X
IRD	X			X		X	X	X
James Cook University	X			X		X	X	
MAREPOLIS	X	X	X	X	X	X	X	X
Marine Ecology Consulting	X			X		X	X	X
Micronesia Coral Reef Monitoring	X							X
National Geographic Society	X							
US National Park Service	X			X		X	X	X
NOAA	X							
OceanWise		X	X	X				X
Province Iles de la Nouvelle-Calédonie	X							
Province Nord de la Nouvelle-Calédonie	X							
Province Sud de la Nouvelle-Calédonie	X							
Reef Check	X			X				
RORC	X			X		X	X	X
Sea Women of Melanesia	X							
SLN	X							
GINGER-SOPRONER	X			X		X	X	X

Contributor	Data provision	Data curation	Formal analysis	Meeting attendance	Project administration	Advisory group/ Expert input	Validation	Writing input
Talanoa Consulting	X			X		X	X	X
UBC	X							
UCSD	X							
University of Hawai'i	X					X	X	X
UNC	X			X		X	X	X
Vava'u Environment	X			X		X	X	X
Waitt Institute	X							

11. Annex

11.1. Boundary definitions

Coral reefs of the Pacific were grouped into 21 ecoregions to capture the broad ecological variation in ecosystem types. The base scheme for this was the Marine Ecoregions of the World (MEOW; Spalding et al., 2007) bioregionalization effort, filtered to the 24 MEOW ecoregions the Global Coral Reef Monitoring Network (GCRMN) classifies as "Pacific" within its Global Report 2020.

On top of this base, the project applied a custom modification layer based on coral reef expert opinions and other bioregionalisation efforts (Veron et al., 2015 ; Beger et al., 2020) : several MEOW ecoregions were further subdivided (e.g. separating the Northwest Hawaiian Islands from the main Hawaii territory; reshaping the Fiji/Samoa/Tonga initial groupings) using a project- drawn splitting shapefile, while others were merged (e.g. Bismarck Sea, Solomon Sea and Southeast Papua New Guinea into one "Papua New Guinea" ecoregion; Southern Cook/Austral Islands and Rapa-Pitcairn into one "Austral-Rapa-Pitcairn" ecoregion). Lastly, three MEOW ecoregions (Coral Sea, Ogasawara Islands, Marquesas) were dropped entirely as outside the assessment's scope (they fall within the East Asia region) or featuring reefs considered marginal (Fey et al., 2021).

Below is a summary table featuring total coral reef areas within each ecoregion. Papua New Guinea and New Caledonia are the areas hosting the largest proportions of coral reef habitats, consistent with those being large barrier-rich regions either directly within or in the immediate vicinity of the Coral Triangle.

Table I. Total coral reef area per Pacific ecoregion.

Ecoregion	Country/ Territory	Coral reef area (km^2)	Reef proportion of total area (%)	Boundary justification
NWHI-Johnston atoll	USA	2 643	7.5	Based on Veron et al. (2015) boundary, split from eastern part reflecting differences in reef geomorphology

Ecoregion	Country/ Territory	Coral reef area (km^2)	Reef proportion of total area (%)	Boundary justification
Hawaii	USA	824	2.3	Based on Veron boundary, split from western part reflecting differences in geomorphology
Line Islands	Kiribati	236	0.7	MEOW boundary (Spalding et al., 2007)
Tuamotus	French Polynesia	2 332	6.6	MEOW boundary
Society	French Polynesia	393	1.1	MEOW boundary
Austral-Rapa-Pitcairn	French Polynesia	378	1.1	Based on MEOW and MACBIO (Beger et al., 2020) boundaries, aggregating whole southern French Polynesia with Pitcairn Islands to reflect ecological uniformity and biological endemism
Phoenix-Tokelau-Northern Cook Islands	Kiribati New Zealand	281	0.8	MEOW boundary
Samoa-Futuna-Niue	Samoa France New Zealand Tonga	378	1.1	Based on MEOW and MACBIO boundaries, grouped with Niuas as sharing similar geomorphological features and natural threats
Ha'apai	Tonga	715	2.0	Separated from main Tonga Islands to reflect varying ecological traits in connectivity and human impacts
Offshore Fiji-Tonga	Fiji Tonga	594	1.7	Separated from main Fiji and Tonga Islands as featuring reduced anthropogenic impacts and deep-waters passages for reef-associated pelagic fauna
Fiji	Fiji	2 477	7.0	MEOW boundary minus offshore low-lying islands and atolls (see above)
Tuvalu-Wallis	Tuvalu France	1 676	4.7	Based on MACBIO boundary within the MEOW Gilbert-Ellis Islands to reflect similar latitudinal vulnerabilities and geomorphological origin
West Kiribati	Republic of Kiribati	1 699	4.8	MEOW boundary minus Tuvalu region (see above)
Marshall Islands	Republic of the Marshall Islands	1 995	5.6	MEOW boundary
Mariana Islands	USA	336	0.9	MEOW boundary
West Caroline Islands	Republic of Palau	776	2.2	MEOW boundary
East Caroline Islands	Federated States of Micronesia	2 909	8.2	MEOW boundary
Papua New Guinea	Independent State of Papua New Guinea	6 106	17.2	Grouped MEOW Bismarck Sea, Solomon Sea and Southeast Papua New Guinea as showing same reef assemblages, morphology and disturbances
Solomon Islands	Solomon Islands	3 039	8.6	MEOW boundary
Vanuatu	Republic of Vanuatu	1 110	3.1	MEOW boundary
New Caledonia	France	4 577	12.9	MEOW boundary

11.2. Methods description (detailed)

Data

Geophysical and spatial datasets

The reef extent layer underlying the analysis combines three independently-sourced reef datasets, spatially intersected with the project's Pacific ecoregion boundaries :

- UNEP-WCMC Global Distribution of Coral Reefs, version 4.1 (2021 release, dataset WCMC008) downloaded from the official UNEP-WCMC distribution webpage and compiled from multiple sources including the Millennium Coral Reef Mapping Project (https://resources.unep-wcmc.org/products/061360436733483686 3f5c0c10e452bf).
- NOAA Hawai'i Coral Reef Mapping, a Hawaii Statewide GIS Program layer (474 features, metadata dated 2019-10-05) derived from NOAA raster nautical charts (2002). Used in place of the UNEP layer for the Hawaiian ecoregions, where it offers finer local details (https://us-shallow-coral-reef-mapping-priorities-noaa.hub.arcgis.com/).
- NOAA NCCOS shallow-water benthic habitat maps for Guam, American Samoa and the Commonwealth of the Northern Mariana Islands (https://products.coastalscience.noaa.gov/collections/benthic/default.aspx). Comprises 18 individual island/atoll shapefiles, filtered to the "Coral Reef and Hardbottom" habitat class only (excluding unconsolidated sediment, other delineations and unknown substrate).

Benthic monitoring data

The benthic cover data underpinning this assessment were assembled from a large number of independently sourced monitoring datasets across the Pacific, each carrying its own survey protocol, taxonomy conventions and level of metadata completeness. For a full list of datasets, see **Table II** below.

These datasets ranged from long-running photo-quadrat and point-count series to line-intercept transect datasets and smaller site-specific monitoring efforts, some spanning well over a decade and others covering only a handful of site-visits. Before any of these datasets could be combined, each was passed through a standardization pipeline that reclassified taxa recorded under widely varying naming conventions into a common set of benthic categories - Hard coral, Macroalgae, Turf algae, Coralline algae and Other fauna - with genus-level records (e.g. *Acropora*, *Porites*) retained separately. Once cleaned and harmonized, the combined records were aggregated to one percent-cover value per site, year and benthic category, then spatially assigned to the 21 Pacific ecoregions using each site's coordinates. This ecoregion-tagged, site-year-category dataset is the common foundation that every downstream benthic indicator in the report draws from. The compiled dataset spans 1993–2025, though coverage varies considerably by ecoregion : Tuvalu-Wallis has the shortest temporal record (2019–2024), followed by Phoenix-Tokelau-Northern Cook Islands (2015–2023) and Line Islands (2009–2019). West Kiribati and Tuvalu-Wallis also have among the fewest monitoring sites overall, while ecoregions such as NWHI-Johnston atoll and Phoenix-Tokelau-Northern Cook Islands combine a short time span with substantial spatial replication.

Table II. Benthic monitoring data coverage per ecoregion, showing the number of contributing datasets, their source programmes, the full time range of available survey years

and the number of unique monitoring sites for the combined Hard coral and Macroalgae indicators.

Ecoregion	Number of datasets	Sources*	Time range	Number of sites
NWHI-Johnston atoll	1	0013	2013-2024	703
Hawaii	2	0013, 0020	2006-2024	2514
Line Islands	4	0005, 0014, 0037, 0043	2009-2019	362
Tuamotus	3	0005, 0015, 0043	1994-2023	75
Society	4	0004, 0005, 0015, 0049	1993-2025	82
Austral-Rapa-Pitcairn	3	0005, 0015, 0043	1997-2021	21
Phoenix-Tokelau-Northern Cook Islands	2	0011, 0014	2015-2023	255
Samoa-Futuna-Niue	7	0005, 0011, 0015, 0020, 0043, 0050, 0534	1997-2024	1019
Ha'apai	3	0015, 0052, 0053	2002-2022	92
Offshore Fiji-Tonga	4	0005, 0015, 0053, 0502	1999-2022	30
Fiji	37	0015, 0025, 0026, 0027, 0031, 0032, 0033, 0034, 0045, 0500, 0501, 0503, 0504, 0505, 0506, 0507, 0508, 0509, 0510, 0511, 0512, 0513, 0514, 0515, 0517, 0518, 0519, 0520, 0521, 0522, 0524, 0526, 0527, 0529, 0530, 0531, 0533	1997-2025	1158
Tuvalu-Wallis	1	0050	2019-2024	8
West Kiribati	3	0015, 0018, 0606	2011-2025	34
Marshall Islands	3	0014, 0015, 0022	2002-2020	214
Mariana Islands	4	0012, 0015, 0020, 0022	1997-2022	1508
West Caroline Islands	5	0015, 0022, 0043, 0238, 0700	1997-2024	142
East Caroline Islands	4	0015, 0022, 0043, 0249	2000-2025	191
Papua New Guinea	4	0015, 0030, 0249, 0516	1998-2025	298
Solomon Islands	6	0015, 0016, 0237, 0532, 0535, 0536	2005-2024	105
Vanuatu	6	0015, 0061, 0237, 0523, 0525, 0528	2004-2025	161

Ecoregion	Number of datasets	Sources*	Time range	Number of sites
New Caledonia	5	0015, 0019, 0021, 0024, 0048	1997-2025	681

*Rights holders : 0004 = CRIOBE - MPA; 0005 = CRIOBE - Polynesia Mana; 0011 = NCRMP - American Samoa; 0012 = NCRMP - CNMI and Guam; 0013 = NCRMP - Hawaii; 0014 = NCRMP - PRIA; 0015 = Reef Check Foundation; 0016 = Biosphere Foundation; 0018 = Kiribati; 0019 = SLN; 0020 = PACN; 0021 = RORC NC; 0022 = MCRMP; 0024 = Laurent Wantiez; 0025 = 2011_Southern Bua (MERMAID); 0026 = 2012_Western Bua (MERMAID); 0027 = 2009-2011_Kubulau (MERMAID); 0030 = PNG BAF 2019 (MERMAID); 0031 = 2017_Northern Lau (MERMAID); 0032 = 2013-2014_Vatu-i-Ra (MERMAID); 0033 = 2019_Dama Bureta (MERMAID); 0034 = 2020_NamenaAndVatuira (MERMAID); 0037 = Khen et al. 2022; 0043 = 100 Island Challenge; 0045 = SRMR and Combe Reef (MERMAID); 0048 = Kayal, Penin, and Adjeroud (NC); 0049 = Kayal, Penin, and Adjeroud (Mo.); 0050 = FEO; 0052 = Vava'u Ocean Initiative 2017; 0053 = Vava'u Ocean Initiative 2022; 0061 = C2O Pacific (b); 0237 = NGS - Solomon Islands; 0238 = NGS - Palau; 0249 = Sea Women of Melanesia; 0500–0536 = MERMAID; 0606 = Donner Kiribati; 0700 = SEA Project WWF.

Reef fish monitoring data

Reef fish data were compiled from an ensemble of four monitoring programmes, encompassing both herbivorous and piscivorous trophic groups : Reef Life Survey (RLS), a total of 4 NOAA National Coral Reef Monitoring Program (NCRMP) survey series and Reef Check. Additional literature-derived estimates were used, as a baseline source only, for ecoregions lacking an adequate empirical no-take baseline (see fish baseline estimation). Where more than one programme covers the same ecoregion, RLS and NOAA NCRMP data are always preferred over Reef Check. Reef Check is used only in ecoregions where no other source has data surveyed within the last 10 years, applied at the ecoregion level so that a higher-priority source which has stopped monitoring does not silently exclude genuinely current Reef Check coverage in the same ecoregion.

All programmes use underwater visual census (UVC) belt-transect methods, with individual counts and size-class estimates converted to biomass via species-specific length-weight relationships (FishBase a/b coefficients) rather than density alone and standardised to biomass per unit area (g/m^2) using each record's own surveyed transect area. Species or family-level identification is performed in the field; Reef Check records a smaller subset of taxa to coarser, non-taxonomic group labels (e.g. "Parrotfish", "Grouper") rather than species or genus.

The compiled dataset spans 1999–2025, though coverage varies considerably by ecoregion : several, including West Caroline Islands, West Kiribati, Papua New Guinea and Solomon Islands, have very few qualifying monitoring sites for one or both fish indicators, whereas East Caroline Islands, Tuamotus and West Caroline Islands lack an adequate site-level baseline entirely. Ecoregions classified Data Deficient for the fish indicators under Criterion D reflect cases where no defensible current-condition value, baseline, or both, could be established from the available monitoring or literature data - see fish baseline estimation and the current fish biomass indicator methods above for the specific adequacy and plausibility checks applied.

Table III. Fish monitoring data coverage per ecoregion, showing the number of contributing datasets, their source programmes, the full time range of available survey years, and the number of unique monitoring sites.

Ecoregion	Number of datasets	Sources	Time range	Number of sites
NWHI-Johnston atoll	2	NOAA NCRMP	2007-2024	1206
Hawaii	2	NOAA NCRMP, Reef Life Survey	2011-2024	1393
Line Islands	1	NOAA NCRMP	2015-2018	376
Tuamotus	2	Reef Check, Reef Life Survey	1999-2013	70
Society	2	Reef Check, Reef Life Survey	2000-2025	81
Austral-Rapa-Pitcairn	1	Reef Life Survey	2009-2018	20
Phoenix-Tokelau-Northern Cook Islands	3	NOAA NCRMP, Reef Life Survey	2012-2023	266
Samoa-Futuna-Niue	2	NOAA NCRMP, Reef Life Survey	2011-2024	855
Ha'apai	1	Reef Life Survey	2009-2024	48
Offshore Fiji-Tonga	1	Reef Life Survey	2012-2024	12
Fiji	1	Reef Life Survey	2024-2025	20
Tuvalu-Wallis	1	Reef Life Survey	2024-2024	34
West Kiribati	1	Reef Check	2011-2011	2
Marshall Islands	2	NOAA NCRMP, Reef Life Survey	2014-2025	145
Mariana Islands	1	NOAA NCRMP	2014-2025	1436
West Caroline Islands	1	Reef Check	2000-2006	5
East Caroline Islands	1	Reef Check	2000-2008	31
Papua New Guinea	2	Reef Check, Reef Life Survey	2001-2011	43
Solomon Islands	2	Reef Check, Reef Life Survey	2005-2011	24
Vanuatu	1	Reef Life Survey	2024-2024	29
New Caledonia	1	Reef Life Survey	2021-2024	16

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 characterised by active carbonate accretion and the development of a biogenic reef framework built by Scleractinia over millennial timescales, i.e. net biogenic accretion. However, coral communities also occur in marginal environments where environmental conditions or substrate constrain carbonate accretion and limit the development of reef structures. These systems were defined as 'marginal' coral reefs in this assessment.

To ensure the assessment captures the full diversity of coral reef ecosystems globally, an inclusive and standardised approach was adopted. Both true (Type A) and marginal (Type B, such as those occurring in subtropical latitudes resulting in lower temperatures as well as limited coral species diversity - i.e. found in the NHWI-Johnston atoll ecoregion) reefs were therefore included, recognising that marginal systems can represent dominant and ecologically important reef types in some regions. 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, such as found in the Marquesas Islands), 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 expert reviewing and fieldwork observations.

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., 2022). An exception was made for three ecoregions with limited site coverage at that cutoff, respectively Line Islands, Austral-Rapa-Pitcairn and East Caroline Islands, for which a 2018 - 2025 cutoff was applied instead. Sites with no post-2018 data are excluded.

After a sensitivity analysis was conducted across a range of thresholds (1–10%) to assess how results varied, each reef site was classified as either a functioning, net-accreting reef site or a degraded site based on a threshold of **10%** hard coral cover. This threshold has been proposed as an approximate ecological boundary below which carbonate production typically becomes insufficient to maintain a positive reef carbonate budget and continued reef accretion (Perry et al., 2013; Darling et al., 2019).

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.

Current (and additional degraded) 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, the ecosystem was classified as Data Deficient (DD).

Table IV. Summary of the number of sites (2020-2025) 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
NWHI-Johnston atoll	210	14.6%	28.4%
Hawaii	362	80.2%	55.4%
Line Islands	242	40.5%	38.7%
Tuamotus	40	48.4%	2.9%
Society	33	15.6%	19.0%
Austral-Rapa-Pitcairn	18	7.5%	10.7%
Phoenix-Tokelau-Northern Cook Islands	96	1.0%	8.7%
Samoa-Futuna-Niue	248	14.8%	29.6%
Ha'apai	34	42.5%	18.3%
Offshore Fiji-Tonga	13	0.4%	7.3%
Fiji	286	29.0%	13.4%
Tuvalu-Wallis	8	0.0%	2.4%
West Kiribati	16	0.3%	10.2%

Ecoregion	Number of sites	Proportion of EOO covered	Proportion of AOO covered
Marshall Islands	38	1.9%	7.8%
Mariana Islands	482	77.6%	61.0%
West Caroline Islands	90	14.8%	29.7%
East Caroline Islands	106	23.6%	14.3%
Papua New Guinea	218	55.9%	5.4%
Solomon Islands	52	2.5%	2.5%
Vanuatu	74	16.7%	7.4%
New Caledonia	284	63.4%	18.4%

Where data were adequate, risk categories were assigned by comparing the percentage of sites with current coral cover below the collapse threshold (10%) (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 (Figure A).

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 A. IUCN Red List of Ecosystems thresholds applied for the assessment of Criterion A.

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 Red List of Ecosystems uses two standardised spatial metrics :

(i) **Sub-criterion B1: Extent of Occurrence (EOO)** – the area within the outer boundary of the ecosystem's known distribution;

(ii) **Sub-criterion B2: Area of Occupancy (AOO)** – the area occupied by the ecosystem, measured using 10 by 10 km grid cells.

No B3 (number of locations / quasi-extinction dynamics) analysis was performed in the current Pacific assessment.

Selection and validation of coral reef extent layer

The analysis requires a spatial layer representing the current distribution of coral reefs. Two satellite-derived global coral reef maps were considered: the Millennium Coral Reef Mapping Project layer curated by the UNEP World Conservation Monitoring Centre (UNEP-WCMC) and the Allen Coral Atlas (ACA) global reef map. Both layers were interrogated by regional experts to determine the most suitable layer for each ecoregion. Where available, global datasets were replaced with more accurate or higher-resolution national reef maps (see Data section above).

Once the validated coral reef extent layer was projected using the Mollweide projection centred on the Pacific (+proj=moll +lon_0=180) coordinate reference system, the *makeEOO* function in the *redlistr* package (v2.0.0) in R was used to generate the minimum convex polygon representing the EOO of each ecoregion. The *getAreaEOO* function was then used 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 and the number of grid cells containing coral reefs was counted to estimate the AOO. All grid cells whose cumulative area of the reef ecosystem was < 1% were excluded from the AOO count.

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

Figure B. IUCN Red List of Ecosystems thresholds applied for the assessment of Criterion B.

Criterion C : Degradation of Abiotic Conditions

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 (Emslie et al., 2024; Heron, Maynard, et al., 2016; Hughes et al., 2018) and determine how present and future environmental conditions threaten the survival and persistence of coral reef ecosystems.

Recurrent heat waves reduce the environmental suitability for reef-building corals through several pathways. A shift in disturbance regime increases the risk of large-scale coral mortality and affects the establishment and persistence of species (Elma et al., 2023; Mudge & Bruno, 2023). These changes can be associated with substantial declines in coral

abundance, reduced structural complexity and lower carbonate accretion rates (Williams et al., 2019; Williams & Graham, 2019). Additionally, recurrent bleaching episodes weaken coral communities, reduce reproductive output and increase susceptibility to other stressors such as disease (Briggs et al., 2024; Byrne et al., 2025; Croquer & Weil, 2009; Levitan et al., 2014). As these events become more frequent, intervals between disturbances are shortened, preventing meaningful coral recovery and increasing the likelihood of progressive ecosystem degradation and eventual collapse (Emslie et al., 2024; Hughes et al., 2018).

Indicator selection

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

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

We assessed the relative change in disturbance conditions over :

- the past 50 years (1975–2025) as part of sub-criterion C1
- 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.

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

Although data on historical bleaching observations exist (Donner et al., 2017; Eakin et al., 2026; van Woesik & Kratochwill, 2022), they are not spatially or temporally extensive. DHW data are globally available since 1985, including for future climate projections (Mellin et al., 2024; Skirving et al., 2019) and are underpinned by a well-documented, long-term relationship with coral bleaching across many regions globally (Heron, Johnston, et al., 2016; Liu et al., 2005; Sully et al., 2019). Values of **DHW ≥ 4** are associated with bleaching onset, while values of **DHW ≥ 8** or more are historically linked to widespread coral mortality (Kayanne, 2017; Liu et al., 2005; Skirving et al., 2019). In addition, DHW has been widely used in recent studies assessing bleaching risk under climate change (Beyer et al., 2018; Bozec et al., 2025; Mellin et al., 2024; Obura et al., 2021) and is supported by established thresholds

linking DHW levels to bleaching severity developed by the NOAA Coral Reef Watch (https://coralreefwatch.noaa.gov/product/5km/index_5km_baa-max-7d.php). While DHW may not be the most precise predictor of bleaching severity at fine spatial or temporal scales, it provides a robust, scalable and comparable indicator of bleaching risk suitable for capturing broad trends in disturbance regimes over time and supports a standardised approach across ecoregions.

Data

Sub-criterion **C1** was assessed using satellite-measured DHW from NOAA Coral Reef Watch at a spatial resolution of 5 km (Liu et al., 2012). The standard Red List of Ecosystems assessment timeframe is 50 years; however, satellite measurements of DHW began 40 years ago in 1985. For the period 1975–1984, thermal conditions were assumed to be broadly comparable to those observed during the earliest decade of the satellite record (1985–1995). This assumption is supported by the fact that the first global mass bleaching event occurred later, in 1997–1998 (Hoegh-Guldberg, 1999) and that global ocean heat content has been consistently above average since the mid-1990s, with ocean warming accelerating further since the late 90s and early 2000s (Cheng et al., 2017, 2023; Heron, Maynard, et al., 2016; Merchant et al., 2025). The 1985–1995 period is therefore the closest available proxy for late-1970s thermal stress regimes. DHW values were spatially attributed to each reef pixel using a 50 km buffer, retaining only data from pixels within this distance of mapped reef extent and assigning values through an interpolation process.

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

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

Thresholds

To convert the annual maximum DHW data into a record of disturbance events, ecoregion-specific DHW thresholds were applied to classify each year as an event (value of 1) or not

(value of 0). The DHW thresholds used for this classification differed between the two pathways, reflecting their distinct ecological mechanisms.

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

DHW thresholds corresponding to severe bleaching events (chronic pathway) and severe mortality events (pulse pathway) for each ecoregion were informed by historical observations of coral reef responses to marine heatwaves, specifically the levels of thermal stress associated with widespread bleaching and coral mortality. These thresholds were not treated as fixed, as the DHW level required to trigger a given bleaching response is expected to change over time. For example, in the 1980s and 90s, relatively lower DHW values may have resulted in severe bleaching and mortality (Hoegh-Guldberg 1999), whereas coral communities today (or in the future) may be altered or acclimated, potentially requiring higher DHW values to trigger comparable responses (Heron, Maynard, et al., 2016; Pratchett et al., 2013; Sully et al., 2019). For C2, thresholds were informed by bleaching responses to thermal stress levels observed during the most recent years of the satellite record (2015–2025) and were adjusted upward into the future to account for anticipated species filtering and potential thermal adaptation or acclimation. Thresholds were defined at the ecoregional level where locally relevant evidence supported this. To account for uncertainty in the exact level of heat stress that causes bleaching/mortality, two plausible DHW threshold values were applied for each pathway. For each ecoregion, the DHW threshold associated with severe bleaching was established by comparing years with documented bleaching observations against the thermal stress recorded in those same years (see Figure S4). Years with lower recorded DHW that did not produce widespread bleaching also allowed a minimum threshold to be identified as the approximate stress level above which severe bleaching reliably occurred. Thresholds are defined separately for chronic and acute stress. Each ecoregion's threshold is specified for a series of historical periods (from 1985 to present) as well as a future period (2026–2100), reflecting evidence that the DHW level associated with severe bleaching has increased over time in many ecoregions. Such indication is a result of prior thermal stress history and consequential acclimatization or shifts in community composition. For each period, a primary threshold value is reported alongside an alternative value, reflecting uncertainty in the underlying evidence.
For example, in New Caledonia, a DHW threshold value of 4 from 1985 to 1996 resulted from the absence of widespread severe coral bleaching before January 1996. This turning point, when thermal anomalies exceeded 4°C-Weeks above regional averages, affected more than 80% of reef formation and led to coral mortality rates of 80–90% on shallow reef flats around Noumea (Gardes & Salvat, 2008). The following DHW value of 8 from 1997 to 2016

corresponded to an increase in thermal tolerance of coral populations up until an unprecedented bleaching event that registered above 8°C-Weeks values in March and April 2016 (Benzoni et al., 2017; Payri et al., 2018). During a 19-year time interval which ended in the austral summer of 2016, the reefs of New Caledonia had been spared from massive bleaching events, meaning that DHW anomalies below 8 did not trigger any severe widespread event. As for the 2023-2024 bleaching event, the Coral Reef Observation Network reported only 5 deteriorated sites out of 101 monitored on a yearly basis compared to 2022 (RORC, 2024). Reefs were mostly found in satisfactory health (only 15% of them declared in "bad state" while 60% of them remained stable or improved in condition over the past decade), with their vitality remaining stable over time (RORC, 2024).

Table V. Ecoregional DHW thresholds representing thermal stress levels resulting in widespread bleaching for the chronic pathway. Thresholds can be 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)
NWHI-Johnston atoll	1985-2005	4	2026-2100	8-10
NWHI-Johnston atoll	2006-2014	4		
NWHI-Johnston atoll	2015-2025	8-9		
Hawaii	1985-1999	2	2026-2100	4-6
Hawaii	2000-2017	4		
Hawaii	2018-2025	4		
Line Islands	1985-2003	4	2026-2100	8-10
Line Islands	2004-2017	8		
Line Islands	2018-2025	8		
Tuamotus	1985-1999	2.5	2026-2100	4-6
Tuamotus	2000-2025	3-4		
Society	1985-2007	1	2026-2100	3-4
Society	2008-2016	2		
Society	2017-2025	3		
Austral-Rapa-Pitcairn	1985-2025	8	2026-2100	8
Phoenix-Tokelau-Northern Cook Islands	1985-2004	4	2026-2100	4-8
Phoenix-Tokelau-Northern Cook Islands	2005-2017	4		
Phoenix-Tokelau-Northern Cook Islands	2018-2025	4		
Samoa-Futuna-Niue	1985-1994	3	2026-2100	8-10
Samoa-Futuna-Niue	1995-2003	3-4		
Samoa-Futuna-Niue	2004-2015	4		
Samoa-Futuna-Niue	2016-2025	6-7		
Ha'apai	1985-2003	4	2026-2100	6-8
Ha'apai	2004-2025	6		
Offshore Fiji-Tonga	1985-2001	5	2026-2100	10-12
Offshore Fiji-Tonga	2002-2015	7		
Offshore Fiji-Tonga	2016-2025	10		
Fiji	1985-2004	4	2026-2100	8-10
Fiji	2005-2017	6		
Fiji	2018-2025	7-6		
Tuvalu-Wallis	1985-2017	3	2026-2100	6-8

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)
Tuvalu-Wallis	2018-2025	4		
West Kiribati	1985-2006	6	2026-2100	12-14
West Kiribati	2007-2011	8		
West Kiribati	2012-2025	12		
Marshall Islands	1985-2004	1	2026-2100	6-8
Marshall Islands	2005-2019	5		
Marshall Islands	2020-2025	6		
Mariana Islands	1985-2003	2	2026-2100	4-6
Mariana Islands	2004-2016	3-4		
Mariana Islands	2017-2025	3-4		
West Caroline Islands	1985-1998	3	2026-2100	6-8
West Caroline Islands	1999-2017	3		
West Caroline Islands	2018-2025	4		
East Caroline Islands	1985-1998	1	2026-2100	6-8
East Caroline Islands	1999-2017	5		
East Caroline Islands	2018-2025	6		
Papua New Guinea	1985-2003	4	2026-2100	10-12
Papua New Guinea	2004-2017	6-8		
Papua New Guinea	2018-2025	10-12		
Solomon Islands	1985-2002	3-4	2026-2100	7-10
Solomon Islands	2003-2010	4		
Solomon Islands	2011-2021	6		
Solomon Islands	2022-2025	6-7		
Vanuatu	1985-2002	3	2026-2100	6-8
Vanuatu	2003-2017	4		
Vanuatu	2018-2025	5-6		
New Caledonia	1985-1996	4	2026-2100	12-14
New Caledonia	1997-2016	8-7		
New Caledonia	2017-2025	12-10		

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)
NWHI-Johnston atoll	1985-2005	5	2026-2100	12-16
NWHI-Johnston atoll	2006-2014	8		
NWHI-Johnston atoll	2015-2025	12		
Hawaii	1985-1999	2	2026-2100	8-12
Hawaii	2000-2017	5-6		
Hawaii	2018-2025	8		
Line Islands	1985-2003	8	2026-2100	12-16
Line Islands	2004-2017	12		
Line Islands	2018-2025	12		
Tuamotus	1985-1999	3	2026-2100	6-8
Tuamotus	2000-2025	4-5		
Society	1985-2007	4	2026-2100	4-6
Society	2008-2016	4		
Society	2017-2025	4		
Austral-Rapa-Pitcairn	1985-2100	12	2026-2100	12
Phoenix-Tokelau-Northern Cook Islands	1985-2004	5	2026-2100	10-12

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)
Phoenix-Tokelau-Northern Cook Islands	2005-2017	8		
Phoenix-Tokelau-Northern Cook Islands	2018-2025	8-10		
Samoa-Futuna-Niue	1985-1994	4	2026-2100	10-12
Samoa-Futuna-Niue	1995-2003	4		
Samoa-Futuna-Niue	2004-2015	4-5		
Samoa-Futuna-Niue	2016-2025	8-10		
Ha'apai	1985-2003	6	2026-2100	8-12
Ha'apai	2004-2025	7		
Offshore Fiji-Tonga	1985-2001	6	2026-2100	12-16
Offshore Fiji-Tonga	2002-2015	8		
Offshore Fiji-Tonga	2016-2025	12		
Fiji	1985-2004	6	2026-2100	8-12
Fiji	2005-2017	6		
Fiji	2018-2025	8		
Tuvalu-Wallis	1985-2017	4	2026-2100	8-12
Tuvalu-Wallis	2018-2025	8-6		
West Kiribati	1985-2006	8	2026-2100	14-16
West Kiribati	2007-2011	10		
West Kiribati	2012-2025	14		
Marshall Islands	1985-2004	1	2026-2100	8-12
Marshall Islands	2005-2019	6		
Marshall Islands	2020-2025	8		
Mariana Islands	1985-2003	4	2026-2100	6-8
Mariana Islands	2004-2016	4		
Mariana Islands	2017-2025	5-6		
West Caroline Islands	1985-1998	4	2026-2100	8-12
West Caroline Islands	1999-2017	4-5		
West Caroline Islands	2018-2025	6-8		
East Caroline Islands	1985-1998	1	2026-2100	8-12
East Caroline Islands	1999-2017	4-6		
East Caroline Islands	2018-2025	8-10		
Papua New Guinea	1985-2003	5	2026-2100	12-16
Papua New Guinea	2004-2017	8		
Papua New Guinea	2018-2025	12-16		
Solomon Islands	1985-2002	5	2026-2100	8-12
Solomon Islands	2003-2010	5-6		
Solomon Islands	2011-2021	7-8		
Solomon Islands	2022-2025	8-9		
Vanuatu	1985-2002	4	2026-2100	8-12
Vanuatu	2003-2017	6		
Vanuatu	2018-2025	8		
New Caledonia	1985-1996	5	2026-2100	14-16
New Caledonia	1997-2016	10		
New Caledonia	2017-2025	14-16		

Calculation of decline and risk

Current values

To apply Criterion C, the Red List of Ecosystems 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 (DeCarlo & Whitaker, 2025; Hughes et al., 2018). Return interval is an ecologically meaningful indicator because recovery from disturbance is a slow process, typically requiring 10–15 years for fast-growing species and considerably longer for the full complement of coral life histories and morphologies (Gilmour et al., 2013; Robinson et al., 2019). As bleaching events become more prevalent and frequent, the combined effect of repeated mortality and shortened intervals between disturbances limiting recovery, drives cumulative coral loss and increases the likelihood of ecosystem-level collapse (Eakin et al., 2026, p. 201; Hughes et al., 2018; Pratchett et al., 2021).

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

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

Initial values

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

For the **chronic pathway**, under C1, historical baseline conditions (circa the 1970s) are characterised by bleaching events occurring at most once every 10–15 years, equivalent to approximately 2–3 events per 30-year period. This reflects a natural disturbance regime in

which sufficient time elapsed between events for meaningful coral recovery (Baker et al., 2008; Gilmour et al., 2013; Graham et al., 2011; Hughes et al., 2018; Robinson et al., 2019). For C2, the initial value is calculated from projected DHW data over the 30-year period immediately preceding 2026 (1996–2025), using the same probabilistic framework applied to the rest of the C2 analysis.

For the **pulse pathway**, under C1, the initial value is the maximum number of severe mortality events within any 5-year window at the start of the satellite time series (1985/86–1990/91). For C2, the initial value is the maximum number of severe mortality events within any 5-year window during the decade immediately preceding 2026 (2016–2025).

Collapse thresholds

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

For the **chronic pathway**, the collapse threshold is defined as severe bleaching events occurring, on average, every 3 years over a 30-year period (approximately 10 events per 30-year window) (DeCarlo & Whitaker, 2025). At this frequency, recovery intervals are considered insufficient to permit meaningful coral recovery between disturbances and the cumulative, iterative mortality caused by several events drives progressive and significant ecosystem degradation (Emslie et al., 2024; Hughes et al., 2018). As a sensitivity test, a threshold of one event every 5 years (~6 events per 30-year window) was also assessed as even these narrow recovery windows do not allow for full recovery and will lead to substantial decline after multiple decades (Hughes et al., 2018). Annual severe bleaching is a commonly cited when predicting future reef outlooks (De Clippele et al., 2023; van Hooidonk et al., 2016; Zeng et al., 2025), however it is considered overly conservation as collapse will likely occur before we reach conditions conducive to yearly bleaching (Bland et al., 2017; 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 (Emslie et al., 2024; Henley et al., 2024; Pratchett et al., 2021). This suggests that reefs may be more resilient to moderate clustering of events than previously assumed and that a higher frequency, specifically 2–3

extreme mortality events within a 5-year window, is required to reliably indicate conditions conducive to collapse.

Risk status assignment

To assign the risk status under Criteria C1 and C2 for each ecoregion, relative severity of decline was interpreted in conjunction with reef extent using the **severity–extent matrix** (Figure C). 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).

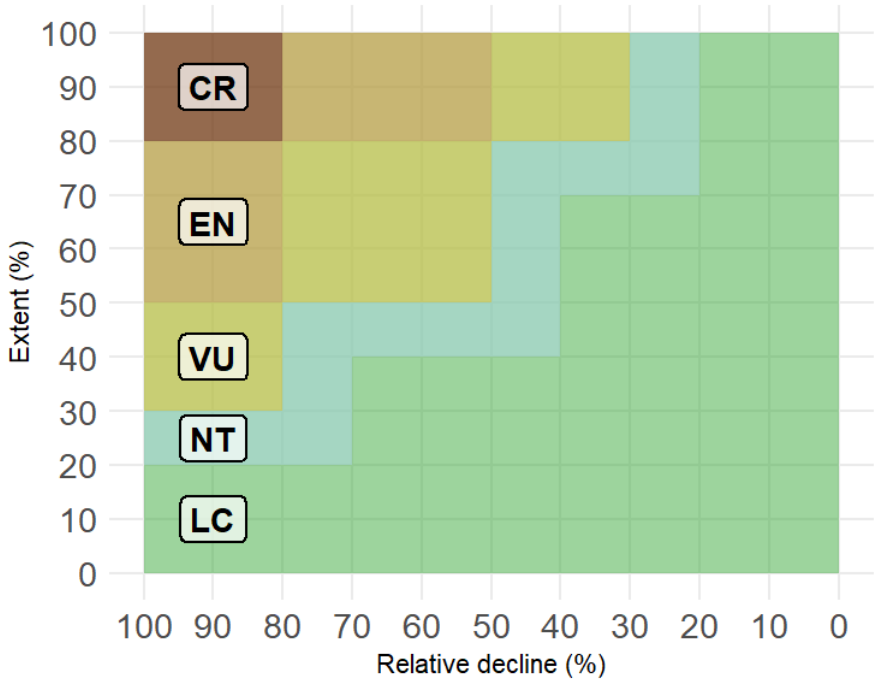


Figure C. Severity-extent matrix applied for the assessment of Criterion C.

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 Pacific, four key biotic components were assessed based on past Red List of Ecosystems assessments (Bland et al., 2017; Obura et al. 2022) and using data derived from standard underwater survey methods. These components include:

- Hard corals, as the keystone ecosystem taxa responsible for forming the habitat structure and accretion processes;
- Algae-to-coral cover ratio, to represent benthic competition between macroalgae and hard corals;
- Herbivory, providing important top-down control of algae;
- 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.

Macroalgae:coral cover ratio was used to represent benthic competition, rather than algae cover alone, as this directly captures the dynamic balance between coral and algal dominance (Obura et al. 2022). The ratio was calculated as the total macroalgae cover, as macroalgal dominance was proved incompatible with reef recovery through interference with coral recruitment (Webster et al., 2015), then divided by the sum of macroalgae and coral cover. This methodology is excluding turf and calcareous algae due to excessive heterogeneity in monitoring methods for the former and the beneficial aspects to coral growth demonstrated for the latter (Li et al., 2016).

Both fish indicators are measured as biomass (g/m^2), derived from length-weight conversion of individual fish counts (species-specific FishBase a/b coefficients where available, functional-group mean coefficients as a fallback for records identified only to a Reef Check group label).
Herbivore biomass is the proxy for grazing/browsing pressure controlling algal growth. It aggregates 114 taxa across six families: Acanthuridae (surgeonfish, 38 species), Scaridae (parrotfish, 34 species, plus a family-level fallback entry and Reef Check's "Parrotfish" group

label), Pomacentridae (algae-farming damselfish, 19 species), Tetraodontidae (11 species), Kyphosidae (8 species) and Siganidae (rabbitfish, 3 species).
Piscivore biomass is the proxy for predatory trophic regulation. It aggregates 134 taxa, dominated by Serranidae (groupers and coral cod, 54 species) and Epinephelidae (2 species, taxonomically split from Serranidae in some source records), together with Carangidae (jacks and trevallies, 15 species), Scorpaenidae (scorpionfish and lionfish, 15 species), Lutjanidae (snappers, 14 species), Scombridae (tunas and mackerels, 10 species), Synodontidae (lizardfish, 10 species), Sphyraenidae (barracudas, 4 species), Fistulariidae (cornetfish, 2 species), Labridae (large predatory wrasses, 2 species), Antennariidae (frogfish, 1 species) and Apogonidae (cardinalfish, 1 species). A small number of records are resolved only to a Reef Check group-level or aggregate category (Grouper, Snapper, Barramundi Cod, Grouper Total) rather than species or family.

Species-to-indicator assignment

Fish species lists are drawn from a single expert-reviewed reference table (248 entries total, spanning both indicators). To matching various species to herbivores or piscivores categories, a four-phases methodology was applied so that no record is missed : (1) exact species-name match, (2) genus-level fallback for records not resolved at species level, (3) family-level fallback (used for a small number of entries recorded only as e.g. "Carangidae spp." or "Scaridae spp.") and (4) Reef Check's non-taxonomic group labels (e.g. "Parrotfish", "Grouper"), matched on the recorded label itself since these records carry no scientific name.

Schooling-pulse exclusion (piscivores only)

A small number of records reflect a single large transient schooling aggregation rather than a representative predator community - for example a passing school of giant trevally recorded at unusually high biomass. These are identified and excluded where a single species contributes more than 50% of that site-visit's total piscivore biomass and total piscivore biomass at that visit exceeds 300 g/m^2, restricted to species from three classically pelagic, schooling-prone families (Carangidae, Sphyraenidae, Scombridae). Site-specific reef residents that can also occur in numbers - groupers (Serranidae) or snappers (Lutjanidae) - are deliberately retained, since their dominance more plausibly reflects genuine community structure than a sampling artefact. Three species are retained as named exceptions regardless of family membership, since none forms the kind of large transient reef-top school the rule targets: *Caranx melampygus*, *Caranx lugubris* and *Thunnus albacares*. In total, 196 site-visit records are excluded by this rule, 126 of them dominated by *Caranx ignobilis* (giant trevally); 15 records that would otherwise have been flagged were retained under the reef-resident exception and a further 9 under the three named species-level exceptions.

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 for benthic indicators (hard coral cover and macroalgae:coral ratio)

Current values for the benthic indicators were calculated at the site level using monitoring data available from the last five years (2020–2025). A "site" refers to a defined monitoring location, uniquely identified by its originating dataset and locality, at which 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 average across all qualifying surveys was used.

For three ecoregions - Line Islands, Austral-Rapa-Pitcairn and East Caroline Islands - an extended 2018–2025 window was used instead to acknowledge recent monitoring efforts and prevent those ecoregions from falling into Data Deficient category.

Table VI. Mean current value of benthic indicators per ecoregion (n – number of sites).

Ecoregion	Indicator	n	Mean	Std. dev	Min value	Max value
NWHI-Johnston atoll	Hard coral cover	210	9.64	14.6	0	76.8
	macroalgae:coral ratio	209	0.619	0.331	0	1
Hawaii	Hard coral cover	362	10.6	14.1	0	72.3
	macroalgae:coral ratio	357	0.391	0.331	0	1
Line Islands	Hard coral cover	242	21.1	15.3	0	66
	macroalgae:coral ratio	241	0.596	0.243	0	1
Tuamotus	Hard coral cover	40	44.9	21.0	11.7	90.2
	macroalgae:coral ratio	36	0.260	0.202	0.005	0.846
Society	Hard coral cover	33	33.1	18.0	8.70	86.9
	macroalgae:coral ratio	25	0.178	0.162	0	0.625
Austral-Rapa-Pitcairn	Hard coral cover	18	24.7	9.51	7.41	42.7
	macroalgae:coral ratio	15	0.216	0.198	0	0.685
Phoenix-Tokelau-Northern Cook Islands	Hard coral cover	96	39.0	16.5	9.17	74.8
	macroalgae:coral ratio	96	0.394	0.164	0.0754	0.801
Samoa-Futuna-Niue	Hard coral cover	248	35.5	13.6	10	95
	macroalgae:coral ratio	245	0.357	0.137	0	0.791
Ha'apai	Hard coral cover	34	7.83	6.37	0	23.2
	macroalgae:coral ratio	33	0.396	0.233	0	0.95
Offshore Fiji-Tonga	Hard coral cover	13	8.37	10.5	0.718	31.8
	macroalgae:coral ratio	13	0.517	0.333	0.052	0.968
Fiji	Hard coral cover	286	38.4	17.5	0	96.7
	macroalgae:coral ratio	285	0.161	0.193	0	1
Tuvalu-Wallis	Hard coral cover	8	18.3	7.82	5.62	28.8
	macroalgae:coral ratio	8	0.321	0.247	0.071	0.780
West Kiribati	Hard coral cover	16	38.8	11.8	14.5	59.7
	macroalgae:coral ratio	16	0.157	0.209	0	0.654
Marshall Islands	Hard coral cover	38	16.1	14.0	0.903	64.9
	macroalgae:coral ratio	38	0.528	0.282	0	0.969
Mariana Islands	Hard coral cover	482	18.9	9.63	0	67.7
	macroalgae:coral ratio	482	0.465	0.171	0	1
West Caroline Islands	Hard coral cover	90	44.0	13.6	10.2	74.6
	macroalgae:coral ratio	90	0.230	0.170	0.0303	0.768
East Caroline Islands	Hard coral cover	106	19.6	14.3	0.487	57.2
	macroalgae:coral ratio	106	0.449	0.282	0	0.984
Papua New Guinea	Hard coral cover	218	33.7	14.8	3.5	91.4
	macroalgae:coral ratio	218	0.242	0.209	0	0.920
Solomon Islands	Hard coral cover	52	19.3	10.8	3.80	56.0
	macroalgae:coral ratio	52	0.264	0.250	0	0.783
Vanuatu	Hard coral cover	74	26.3	17.6	0	89

Ecoregion	Indicator	n	Mean	Std. dev	Min value	Max value
	macroalgae:coral ratio	73	0.251	0.241	0	0.885
New Caledonia	Hard coral cover	284	23.8	15.3	0	74.5
	macroalgae:coral ratio	211	0.127	0.204	0	0.900

Current values for fish indicators (herbivore and piscivore biomass)

Current values for the fish indicators were calculated at the site level using each site's own most recent 5 years of monitoring data - a per-site rolling window, rather than a fixed calendar period. This differs from the benthic indicators' approach because fish survey years are not synchronised across sites: a fixed window (e.g. 2020–2025) would apply unevenly, capturing five full years of data at a recently-surveyed site but excluding a site last monitored in, say, 2018 altogether. A fixed calendar cutoff would also unevenly straddle the 2019–2023 regional bleaching disruption depending on when each site happened to be surveyed. Where multiple surveys existed for a site within its own 5-year window, the **median** (not the mean) across those surveys was used as the site's current value - the median was adopted after testing showed that a small number of unusually large single-survey records could otherwise dominate a site's average.

Minimum site threshold for current-condition adequacy

An ecoregion is classified Data Deficient for the fish indicators if its *current* monitoring coverage is too sparse to reliably represent present-day biotic condition - specifically, if it has fewer than 10 monitoring sites, or fewer than 2 distinct survey years, within the most recent 10 years.

This check is currently applied at the ecoregion level rather than separately for each trophic group, so a shortfall in either herbivore or piscivore sampling can trigger Data Deficient status for the whole ecoregion, even where the other group has adequate data on its own.

Five remote, low-survey-effort ecoregions - Austral-Rapa-Pitcairn, Tuvalu-Wallis, Offshore Fiji-Tonga, Vanuatu, and Ha'apai - are exempted from this threshold: their sparse sampling is judged to still validly represent these small, remote territories, so they are not automatically scored Data Deficient. They instead carry a lower-confidence caveat rather than being treated as high-confidence.

A further three ecoregions - West Kiribati, West Caroline Islands, and East Caroline Islands - carry the same lower-confidence caveat for a different reason: their only available data source identifies fish to Reef Check's coarse group level rather than species level.

Table VII. Mean current value of each fish indicator per ecoregion (n – number of sites). Biomass results are expressed in g/m^2.

Ecoregion	Indicator	n	Mean	Std. dev	Min value	Max value
Austral-Rapa-Pitcairn	Herbivore	20	52.41	47.26	1.352	136.53

Ecoregion	Indicator	n	Mean	Std. dev	Min value	Max value
Austral-Rapa-Pitcairn	Piscivore	20	11.26	9.12	0.395	29.94
East Caroline Islands	Herbivore	—	—	—	—	—
East Caroline Islands	Piscivore	7	23.93	12.31	11.391	46.18
Fiji	Herbivore	20	22.8	16.06	4.36	61.9
Fiji	Piscivore	20	6.3	8.98	0.295	38.45
Ha'apai	Herbivore	48	32.5	23.87	5.332	107.45
Ha'apai	Piscivore	45	2.3	3.29	0.01	15.63
Hawaii	Herbivore	1385	23.78	26.65	0.011	383.84
Hawaii	Piscivore	1152	21.26	33.69	0.004	271.72
Line Islands	Herbivore	376	36.74	27.69	0.504	274.25
Line Islands	Piscivore	361	68.23	83.08	3.12	1194.16
Mariana Islands	Herbivore	1436	25.02	25.23	0.006	265.4
Mariana Islands	Piscivore	1388	23.77	39.7	0.05	501
Marshall Islands	Herbivore	145	53.42	306.43	1.018	3709.71
Marshall Islands	Piscivore	142	33.63	42.18	0.379	273.54
NWHI-Johnston atoll	Herbivore	1201	31.59	41.17	0.005	566.07
NWHI-Johnston atoll	Piscivore	997	84.92	90.94	0	855.35
New Caledonia	Herbivore	16	63.44	63.89	17.485	271.31
New Caledonia	Piscivore	15	68.33	119.09	0.45	422.11
Offshore Fiji-Tonga	Herbivore	12	10.99	5.41	3.982	22.28
Offshore Fiji-Tonga	Piscivore	12	7.74	17.14	0.041	61.68
Papua New Guinea	Herbivore	9	60.91	61.58	8.914	214.39
Papua New Guinea	Piscivore	15	24.82	58.53	0.502	234.15
Phoenix-Tokelau-Northern Cook Islands	Herbivore	266	33.32	58.31	0.771	729.32
Phoenix-Tokelau-Northern Cook Islands	Piscivore	247	79.98	92.74	0.45	911.75
Samoa-Futuna-Niue	Herbivore	855	35.59	31.14	0.17	372.88
Samoa-Futuna-Niue	Piscivore	838	19.72	29.55	0.137	325.42

Ecoregion	Indicator	n	Mean	Std. dev	Min value	Max value
Society	Herbivore	16	39.68	24.86	12.271	89.82
Society	Piscivore	18	5.37	4.87	0.447	16.67
Solomon Islands	Herbivore	5	35.99	19.02	21.159	66.9
Solomon Islands	Piscivore	14	12.8	12.59	2.43	40.99
Tuamotus	Herbivore	49	76.65	61.3	7.101	316.93
Tuamotus	Piscivore	49	54.5	55.71	1.581	267.92
Tuvalu-Wallis	Herbivore	34	55.7	48.31	6.17	223.29
Tuvalu-Wallis	Piscivore	33	6.4	6.52	0	25.32
Vanuatu	Herbivore	29	28.5	51.09	2.077	273.05
Vanuatu	Piscivore	29	5.09	13.49	0.095	71.17
West Caroline Islands	Herbivore	—	—	—	—	—
West Caroline Islands	Piscivore	—	—	—	—	—
West Kiribati	Herbivore	—	—	—	—	—
West Kiribati	Piscivore	2	23.25	4.76	19.887	26.61

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 standardised reef monitoring began in the 1990s in the Pacific.

Baseline/initial 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, that is whether reefs were in better condition, relatively pristine, or already degraded. Based on literature evidence, it was found and later corroborated by reef experts that reef condition prior to the 2000s was globally better than at present, disregarding the occurrence of major cataclysms (i.e. active volcanism or cyclones). The year 1997/98, corresponding to the first major global mass bleaching event that hit the Pacific as well as the rest of the globe simultaneously (NOAA, WWF, AIMS), was kept as a baseline triggering a major turning point in reef condition across many parts of the region.

Benthic baseline estimation

Baselines for the benthic indicators (hard coral cover and macroalgae:coral ratio) were derived at the site level from the longest available monitoring records, then aggregated to the ecoregion level. Long-term monitoring sites were assumed to have experienced relatively good conditions at some point during the monitoring history. Taken together, 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. A site qualified to contribute to a data-derived baseline only if it had more than one year of monitoring, a span of at least ten years between its first and last survey and (to exclude non-reef or already-degraded sites) a historical maximum hard coral cover above 5%. Because a decline in reef condition is expressed as a decrease in hard coral cover or as an increase in the macroalgae:coral ratio, the two indicators used mirrored approaches: for hard coral cover, each qualifying site's baseline was taken as the highest cover value recorded across all of its monitored years; for macroalgae:coral ratio, each qualifying site's baseline was taken as its lowest recorded ratio. In both cases, the historical extreme value is used as a proxy for the site's condition prior to sustained decline. Ecoregion-level baselines were then calculated as the mean and standard deviation of qualifying sites' site-level baseline values.

Where an ecoregion had no site meeting these criteria, or where the data-derived value fell outside a plausible historical range, a substitution approach was applied: a literature-derived baseline, drawn from published historical descriptions, was used instead and expressed as a range when one was reported. For the Offshore Fiji-Tonga ecoregion, neither sufficient monitoring data nor an ecoregion-specific literature estimate for the macroalgae:coral ratio were available; a baseline was thus instead borrowed from Fiji, its nearest ecologically and geographically similar ecoregion with a data-derived value.

Table VIII. Mean initial (baseline) values with variance measures for benthic indicators for each ecoregion (n – number of sites). Hard coral cover is expressed as a percentage of total benthic cover. Where n is not reported, the value is a literature-derived or borrowed substitute rather than a site-based estimate.

Ecoregion	Indicator	Mean	Std. dev	Min value	Max value	n
NWHI-Johnston atoll	Hard coral cover	57.5	6.25	45	70	–
	macroalgae:coral ratio	0.201	0.189	0	0.690	12
Hawaii	Hard coral cover	28.8	16.9	5.0	68.7	27
	macroalgae:coral ratio	0.129	0.116	0	0.553	27
Line Islands	Hard coral cover	45.8	14.4	20.1	60.6	8
	macroalgae:coral ratio	0.0955	0.0358	0.024	0.167	–
Tuamotus	Hard coral cover	65	7.5	50	80	–
	macroalgae:coral ratio	0.128	0.0518	0.024	0.231	–
Society	Hard coral cover	45.8	18.5	16.9	91.9	39
	macroalgae:coral ratio	0.0248	0.0530	0	0.222	31
Austral-Rapa-Pitcairn	Hard coral cover	26.0	16.2	10.3	42.7	3

Ecoregion	Indicator	Mean	Std. dev	Min value	Max value	n
	macroalgae:coral ratio	0.382	0.100	0.182	0.583	–
Phoenix-Tokelau-Northern Cook Islands	Hard coral cover	60	7.5	45	75	–
	macroalgae:coral ratio	0.138	0.056	0.026	0.250	–
Samoa-Futuna-Niue	Hard coral cover	42.5	3.75	35	50	–
	macroalgae:coral ratio	0.314	0.0738	0.167	0.462	–
Ha'apai	Hard coral cover	50	5	40	60	–
	macroalgae:coral ratio	0.205	0.064	0.077	0.333	–
Offshore Fiji-Tonga	Hard coral cover	55	10.5	–	–	–
	macroalgae:coral ratio	0.0126	0.0234	–	–	–
Fiji	Hard coral cover	57.2	10.5	39.2	76.9	19
	macroalgae:coral ratio	0.0126	0.0234	0	0.0858	19
Tuvalu-Wallis	Hard coral cover	25	2.5	20	30	–
	macroalgae:coral ratio	0.286	0.0715	0.143	0.429	–
West Kiribati	Hard coral cover	50	5	40	60	–
	macroalgae:coral ratio	0.205	0.064	0.077	0.333	–
Marshall Islands	Hard coral cover	47.5	6.25	35	60	–
	macroalgae:coral ratio	0.295	0.279	0.00460	0.561	3
Mariana Islands	Hard coral cover	27.3	14.2	8.50	51.1	31
	macroalgae:coral ratio	0.109	0.150	0	0.527	31
West Caroline Islands	Hard coral cover	55	5	45	65	–
	macroalgae:coral ratio	0.160	0.0448	0.071	0.250	–
East Caroline Islands	Hard coral cover	53.8	13.8	34.2	72.4	7
	macroalgae:coral ratio	0.0347	0.0220	0.00700	0.0723	7
Papua New Guinea	Hard coral cover	52.5	3.75	45	60	–
	macroalgae:coral ratio	0.164	0.0432	0.077	0.250	–
Solomon Islands	Hard coral cover	55	5	45	65	–
	macroalgae:coral ratio	0.190	0.0592	0.071	0.308	–
Vanuatu	Hard coral cover	50	5	40	60	–
	macroalgae:coral ratio	0.264	0.0605	0.143	0.385	–
New Caledonia	Hard coral cover	39.1	17.7	6.18	83.6	246
	macroalgae:coral ratio	0.0162	0.0505	0	0.382	205

Fish baseline estimation

Initial/baseline values for the two fish indicators (herbivore biomass and piscivore biomass, g/m^2) were estimated using a four-step cascading approach, applied identically to both trophic groups. 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. Therefore, the value being estimated here is a pre-decline reference biomass for herbivorous and piscivorous fish in each ecoregion.

This is the level against which current biomass is compared to calculate the proportional decline used in the Criterion D risk assessment. No fish survey data exists anywhere in the Pacific around the 1970s or any other pre-exploitation period, so this reference value cannot be measured directly and must instead be approximated.

The approach adopted is a space-for-time substitution : rather than looking back in time, the assessment looks across space, to reef sites that are currently subject to little or no fishing pressure to act as proxies. Because fishing pressure is the dominant driver of change in reef fish biomass - considerably more so than the other pressures affecting reef condition over this period - a well-enforced no-take marine protected area today is expected to carry a fish community reasonably close to what a no-fishing reef would have looked like historically. This makes verified no-take zones the best available proxy for the missing historical baseline, and is the same logic used elsewhere in reef science whenever direct historical survey data does not exist for a system that has changed as a result of exploitation.

No-take status is not recorded anywhere in the raw Pacific monitoring tables, so it was reconstructed by spatially joining monitoring sites against the WDPA protected-areas layer (https://www.protectedplanet.net/en/thematic-areas/wdpa?tab=WDPA), filtered to strictly no-take MPA polygons. Because this reconstruction offers no basis for treating herbivores and piscivores differently by fishing vulnerability, the same priority order is used for both groups; this is a simplification, flagged as a limitation below rather than presented as a deliberate design choice.

Baseline priority order (herbivores and piscivores)

1. No-take space-for-time baseline. Monitoring sites falling within a strict no-take WDPA polygon with data ranging from 2009 to 2019, are averaged to a per-site mean biomass and then to an ecoregion × trophic-group mean and SD. This is used only where at least 3 qualifying sites exist (n_sites_notake ≥ 3); 8 of 21 ecoregions clear this bar for at least one indicator. The baseline is a straight multi-site mean over the window.
2. Donor ecoregion's no-take baseline. Where an ecoregion lacks an adequate no-take baseline derived from its own MPAs, it borrows the no-take baseline of an ecologically similar donor ecoregion (or the average across several), based on MEOW biogeographic province together with expert-reviewed refinement of that grouping (reef type, exposure, human-impact regime). Six ecoregions borrow this way, one (West Kiribati) averaging across three donor ecoregions. Two large biogeographic provinces (Tropical Southwestern Pacific and Eastern Coral Triangle, covering Fiji, Ha'apai, Offshore Fiji-Tonga, Vanuatu, New Caledonia, Solomon Islands, Papua New Guinea) were found to contain no ecoregion with an adequate own no-take baseline at all, so nothing is available to borrow within them; these fall through to step 3.
3. Upper end of the literature-derived historical biomass range. Where no ecoregion in the same group has an adequate no-take baseline (Steps 1–2 above), the baseline instead draws on published historical estimates of total reef fish biomass. This

consists of a small set of named studies and monitoring reports describing Pacific reef fish biomass before the recent intensification of fishing pressure (broadly, the 1980s–90s), compiled for each ecoregion from published studies and monitoring reports. Seven ecoregions reach this step. Six of them (Fiji, Ha'apai, Vanuatu, New Caledonia, Solomon Islands and Papua New Guinea) have their own ecoregion-specific estimate. Offshore Fiji-Tonga has none and uses the Fiji estimate as its nearest ecologically and geographically similar ecoregion. Each source gives a *total* fish biomass range (low–high) rather than a single value. These total biomass ranges are split into herbivore and piscivore components using that same source's own reported community composition - the proportion of the total biomass composed of herbivores and piscivores separately. Every other ecoregion is assigned the study judged most ecologically and geographically representative of it. The *upper* bound of the range is used at this step specifically (rather than the midpoint, used elsewhere when literature is the sole reference) as the more conservative figure where no donor-ecoregion estimate exists to cross-check against.

4. Data Deficient, applied where no baseline can be constructed at any of the above steps, or where the resulting baseline is implausible relative to that ecoregion's own observed current-biomass range (outside 0.1×–10× of the observed min–max) - 4 ecoregion × indicator combinations fail this plausibility check.

Percentile-based (top-10%/25%) baseline

An alternative baseline candidate was also tested, based on the highest-density readings at long-term monitoring sites (those with at least a 10-year monitoring span). However, this approach yielded unrealistic values and does not form part of the final baseline calculation.

Uncertainty propagation

Baseline uncertainty is carried through the assessment using a Monte Carlo simulation of 1,000 iterations. In each iteration, one baseline value is drawn per ecoregion × trophic group from a truncated normal distribution, bounded by that ecoregion × group's own observed minimum and maximum current biomass; the same drawn value is then applied to every monitoring site within that group for that iteration. This approach has one known limitation that has not yet been addressed. Where a baseline's standard deviation exceeds its mean - a coefficient of variation above 100% - the current method has no alternative distribution to fall back on. Several borrowed and literature-sourced baselines fall into this category (Marshall Islands ecoregion, for example, have a standard deviation for herbivores biomass roughly six times its mean). In these cases, the truncated-normal draws tend to cluster near the lower bound of the observed range rather than reflecting the genuine right-skew that such a high variance implies, which can understate the spread of plausible baseline values for the affected ecoregions.

Table IX. Mean initial values with variance measures calculated from reference MPA sites for herbivores and piscivores indicators for each ecoregion (n – number of sites). Biomass results are expressed in g/m^2.

Ecoregion	Indicator	Mean	Std. dev	Min value	Max value	n
Austral-Rapa-Pitcairn	Herbivore	15.53	3.61	12.443	20.73	4
Austral-Rapa-Pitcairn	Piscivore	9.48	8.74	0.93	19.74	4
East Caroline Islands	Herbivore	—	—	—	—	—
East Caroline Islands	Piscivore	32.46	41.28	—	—	—
Fiji	Herbivore	12.32	1.54	—	—	—
Fiji	Piscivore	1.84	0.23	—	—	—
Ha'apai	Herbivore	15.4	1.93	—	—	—
Ha'apai	Piscivore	2.3	0.29	—	—	—
Hawaii	Herbivore	46.22	34.73	1.03	117.61	22
Hawaii	Piscivore	19.81	21.86	2.202	91.43	19
Line Islands	Herbivore	36.74	27.69	0.504	274.25	376
Line Islands	Piscivore	68.23	83.08	3.12	1194.16	361
Mariana Islands	Herbivore	21.66	17.1	2.72	75.88	24
Mariana Islands	Piscivore	10.32	20.4	0.344	94.98	21
Marshall Islands	Herbivore	59.65	360.02	1.018	3709.71	105
Marshall Islands	Piscivore	32.46	41.28	0.379	273.54	102
NWHI-Johnston atoll	Herbivore	33.53	44.54	0.005	566.07	925
NWHI-Johnston atoll	Piscivore	84.59	92.03	0	855.35	758
New Caledonia	Herbivore	18.67	2.07	—	—	—
New Caledonia	Piscivore	8.55	0.95	—	—	—
Offshore Fiji-Tonga	Herbivore	12.32	1.54	—	—	—
Offshore Fiji-Tonga	Piscivore	1.84	0.23	—	—	—
Papua New Guinea	Herbivore	18.48	2.31	—	—	—
Papua New Guinea	Piscivore	2.76	0.34	—	—	—
Phoenix-Tokelau-Northern Cook Islands	Herbivore	29.88	64.59	0.771	729.32	175
Phoenix-Tokelau-Northern Cook Islands	Piscivore	84.31	104.57	0.45	911.75	166

Ecoregion	Indicator	Mean	Std. dev	Min value	Max value	n
Samoa-Futuna-Niue	Herbivore	28.91	24.14	0.17	135.82	224
Samoa-Futuna-Niue	Piscivore	27.02	35.65	0.137	325.42	218
Society	Herbivore	15.53	3.61	—	—	—
Society	Piscivore	9.48	8.74	—	—	—
Solomon Islands	Herbivore	21.56	3.08	—	—	—
Solomon Islands	Piscivore	3.22	0.46	—	—	—
Tuamotus	Herbivore	15.53	3.61	—	—	—
Tuamotus	Piscivore	9.48	8.74	—	—	—
Tuvalu-Wallis	Herbivore	59.65	360.02	—	—	—
Tuvalu-Wallis	Piscivore	32.46	41.28	—	—	—
Vanuatu	Herbivore	15.4	2.31	—	—	—
Vanuatu	Piscivore	2.3	0.34	—	—	—
West Caroline Islands	Herbivore	—	—	—	—	—
West Caroline Islands	Piscivore	—	—	—	—	—
West Kiribati	Herbivore	—	—	—	—	—
West Kiribati	Piscivore	59.85	74.43	—	—	—

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 (notably Obura et al., 2022 following the Western Indian Ocean assessment), empirical observations and expert judgment and were applied consistently across all ecoregions.

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

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

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

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 X), 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. 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 characterise ecosystem-wide patterns, the ecoregion was classified as *Data Deficient*.

Determining final risk class for Criterion D

The overall risk category for Criterion D for each ecoregion was determined by integrating results across all indicators using a stepwise approach, following previous Coral Reef Red List of Ecosystems assessments.

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

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

The assessment used the coral condition as the baseline classification. At each subsequent step, the overall risk category was increased by one level if the next indicator was classified

at a higher risk level than the cumulative status to that point. This approach ensures that hard coral, as the foundational component of reef ecosystems, had the greatest influence on the final classification, while still accounting for the contribution of other biotic components. It also prevented the overall assessment from being disproportionately driven by secondary indicators (e.g. fish).

Overall risk status

Once all applicable Red List of Ecosystems 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.

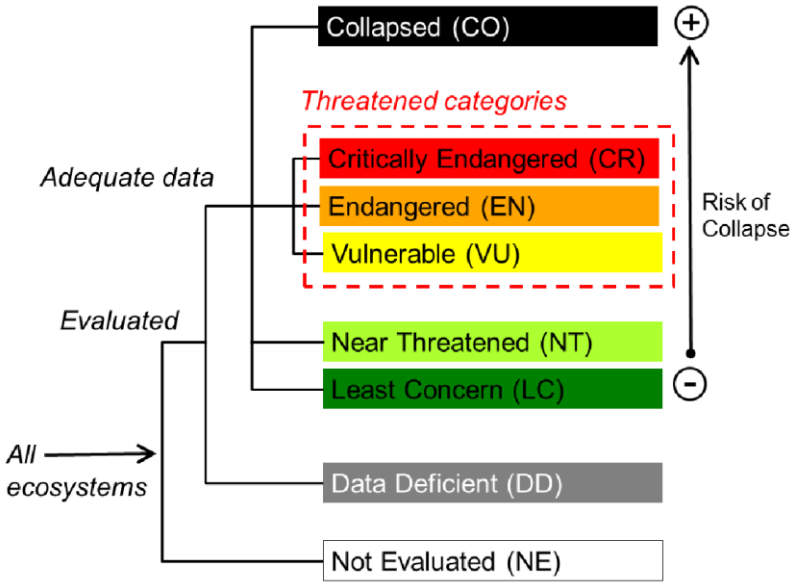


Figure D. Structure of the IUCN Red List of Ecosystems categories and assessment hierarchy, illustrating the evaluation pathways from unassessed ecosystems to risk categories reflecting increasing risk of collapse.

11.3. Discussion

The assessment reveals a strong contrast between the observed condition of Pacific coral reefs and their overall risk of collapse once projected heat stress is included. Present-day degradation is heterogeneous across the region, with most ecoregions retaining extensive reef habitat and relatively moderate levels of biotic degradation. In contrast, projected thermal stress under Criterion C2 represents a pervasive and substantially worrisome threat : all 21 ecoregions were classified as Critically Endangered. Such a distinction is important because it indicates that the regional risk of coral reef collapse is not currently driven by a

uniform, basin-wide loss of reef habitat or by widespread disruption of all key biotic processes, but increasingly by a shift towards a disturbing thermal regime under which recovery may become progressively more difficult. This is consistent with broader regional assessments showing a long-term decline in Pacific hard coral cover, with particularly marked declines following major El Niño-associated bleaching events (GCRMN, 2021 & 2025) and with evidence that increasing thermal stress is becoming the principal global threat to reef persistence (Hughes et al., 2018; Sully et al., 2019).

The relatively moderate results under Criteria A and B contrast with the much more severe results under Criterion C. When considering the reduction in geographic distribution of hard coral cover (Criterion A), the majority of ecoregions remained Least Concern, although 7 showed sufficient proportions of sites below the 10% hard-coral-cover threshold to reach at least the Vulnerable range. This indicates that, at the scale of the 21 assessment units, the **physical distribution of reef habitat has generally persisted despite substantial ecological degradation**. The limited geographic distribution of Pacific coral reefs (Criterion B) was even less restrictive, with 3 ecoregions classified as Vulnerable, 1 as Near Threatened and 17 as Least Concern. However, such an **apparent stability of mapped reef extent** should not be interpreted as evidence that reef function has remained intact. Coral reefs can retain their geomorphological footprint while undergoing substantial declines in live coral cover, structural complexity, carbonate production and associated biodiversity. The use of hard coral cover as a proxy for functional reef extent therefore provides a conservative representation of some dimensions of ecosystem degradation, while potentially **overlooking changes in reef accretion, structural complexity and community composition** (Perry et al., 2013; Darling et al., 2019).

The strongest regional signal was obtained for the degradation of abiotic conditions (Criterion C). Historical thermal stress (C1) was already elevated across much of the Pacific, with 9 ecoregions classified as Vulnerable and 6 as Endangered. Importantly, this spatial pattern of historical thermal risk was not uniform : some subtropical and historically heat-exposed systems showed different thermal thresholds and disturbance histories from more equatorial reefs when considering mass bleaching and mortality amongst coral populations. This reflects regional differences in temperature variability, ENSO exposure, oceanographic circulation and in the setting of thermally tolerant coral assemblages. Such differences may partly explain why some ecoregions have experienced relatively high DHW exposure without displaying equivalent levels of current biotic degradation.
In contrast, all 21 ecoregions reached Critically Endangered under projected future thermal stress (C2), demonstrating that the assessment is primarily identifying a **future climate-driven risk rather than a present-day basin-wide collapse**. This result is consistent with projections showing that increasing marine heatwave frequency will progressively shorten the intervals available for coral recovery (Hughes et al., 2018; Sully et al., 2022).

The disruption of biotic processes (Criterion D) provides a complementary perspective by showing that, although it is already substantial in many parts of the Pacific, it remains considerably more heterogeneous than the projected thermal signal above discussed. A total

of 14 ecoregions were classified as Vulnerable or above, while only 5 were Near Threatened and 2 were Least Concern. Spatial heterogeneity observed in Criterion D reflects differences in human pressure, management regimes, reef geomorphology and connectivity. Hard coral cover generally emerged as the most consistently degraded benthic indicator, whereas the macroalgae:coral ratio remained comparatively low-risk in many ecoregions. This suggests that widespread regional coral decline has **not universally translated into persistent macroalgal dominance**. Where herbivore populations remained relatively intact, grazing may continue to limit the establishment of canopy-forming macroalgae and maintain suitable substrate for coral recruitment. Conversely, the elevated herbivore depletion identified particularly in the Marshall Islands and the higher piscivore risk observed across several ecoregions like Tuvalu-Wallis, Samoa-Futuna-Niue and Vanuatu, indicate that trophic degradation may reduce the capacity of some reefs to resist or recover from climate-driven coral mortality.

Previous comparisons of populated and remote Pacific reefs have demonstrated strong differences in reef-fish assemblages and trophic structure associated with human pressure (Williams et al., 2011). Protection of key fish species can therefore represent an important local resilience strategy, especially in densely populated islands generally exposed to a greater combination of fishing, coastal development and land-based pollution. However, it cannot offset the fundamental effects of continued ocean warming (Williams et al., 2019).

Those results should be interpreted in light of several important uncertainties. First, monitoring coverage is highly uneven among ecoregions. Some regions are represented by hundreds of monitoring sites, whereas others contain only a small number of them. Consequently, the absence of evidence for severe degradation in data-poor ecoregions should not necessarily be interpreted as evidence of low risk. The example of Data Deficient classifications for several fish indicators illustrate this limitation.

Second, the use of hard coral cover as a principal indicator cannot capture changes in coral species composition, colony size structure, structural complexity, recruitment, disease prevalence or carbonate accretion. Coral cover can remain relatively high while communities become dominated by smaller, stress-tolerant taxa with reduced functional complexity. Conversely, substantial coral-cover loss does not necessarily indicate irreversible ecosystem collapse where larval supply, herbivory, suitable substrate and water quality remain favourable.

Last but not least, the thermal component of the assessment is inherently sensitive to the DHW thresholds used to define severe bleaching and mortality. Coral responses to heat stress vary among species, locations and historical thermal regimes. Then, populations may undergo acclimation, adaptation or compositional shifts following repeated warming. The use of ecoregion-specific and time-varying thresholds attempts to account for some of this variation, but cannot fully capture differences in coral thermal tolerance at local scales. Similarly, the future Criterion C2 assessment should be interpreted as a projection of risk under specified climate scenarios rather than as a deterministic prediction of future collapse.

Overall, the assessment indicates that Pacific coral reefs are **not undergoing a spatially uniform present-day collapse**, but are entering a period in which **increasing thermal**

stress may progressively overwhelm existing ecological resilience. The contrast between relatively moderate risk under Criteria A and B (observed change) and widespread Critically Endangered status under Criterion C2 (projected heat stress) highlights the importance of distinguishing observed ecosystem condition from projected changes. Local conservation and management remain essential for maintaining herbivory, trophic structure, recruitment processes, water quality and reef connectivity, thereby maximising the capacity of reefs to recover from unavoidable disturbances. However, these measures should be viewed as complementary to, rather than substitutes for, rapid global reductions in greenhouse-gas emissions, which remain necessary to limit the magnitude and frequency of future thermal stress. Prioritising protection of remaining relatively intact reefs, while improving monitoring and management of degraded and data-poor systems, will therefore be critical for maintaining recovery potential across the Pacific.

Supplementary Tables and Figures

For all related figures and tables in this section, the following abbreviations were used regarding the different risk categories : LC = Least Concern, NT = Near Threatened, VU = Vulnerable, EN = Endangered, CR = Critically Endangered, CO = Collapsed, DD = Data Deficient.

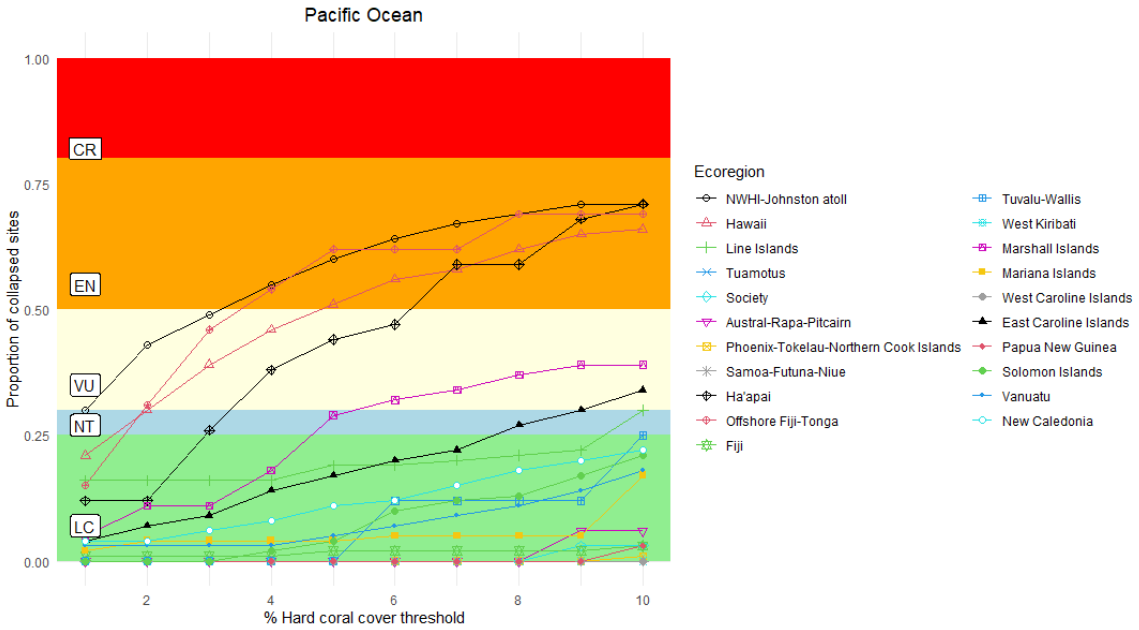


Figure S1. Sensitivity of Criterion A collapse classification to hard coral cover threshold selection. Proportion of monitoring sites classified as collapsed for each ecoregion, computed across an uncapped range of possible collapse thresholds (1–10% hard coral cover).

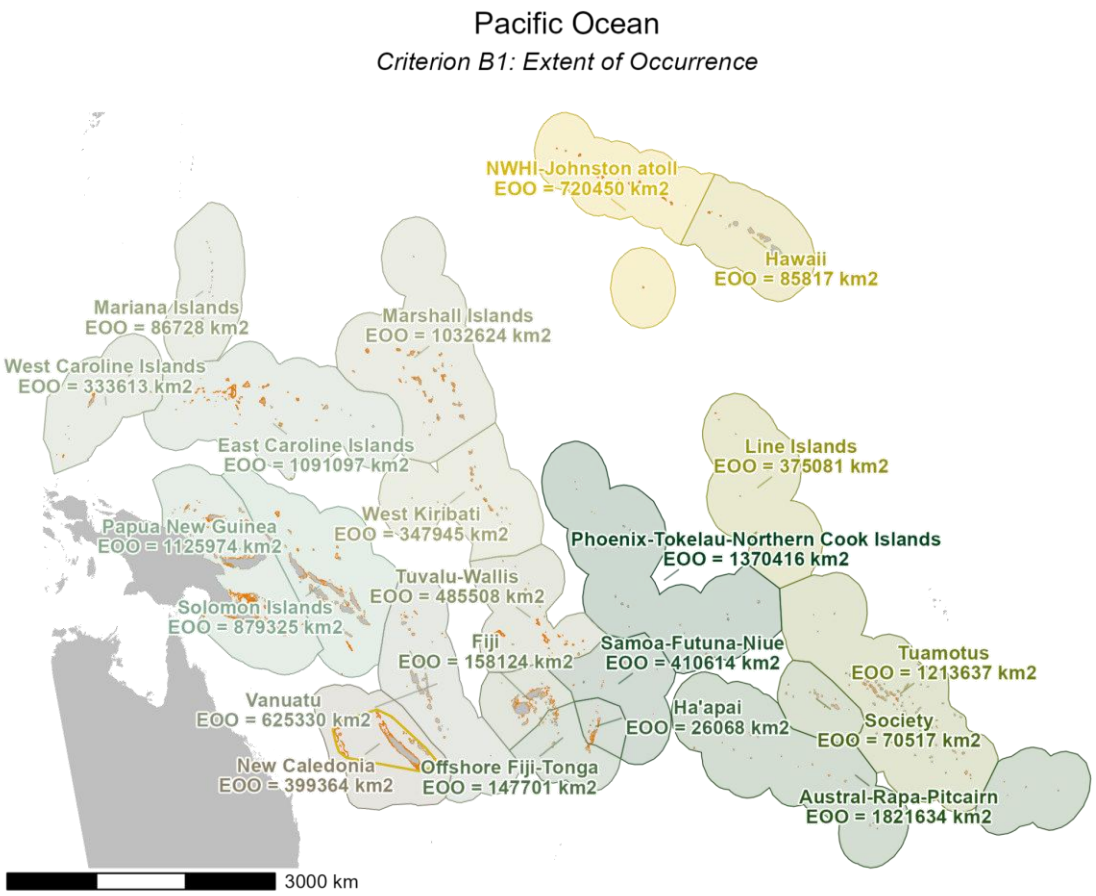


Figure S2. Extent of Occurrence (EOO) by ecoregion under Criterion B1, for the 21 Pacific coral reef ecoregions. EOO is calculated as the minimum convex polygon encompassing all known coral reef occurrences within each ecoregion (km^2).

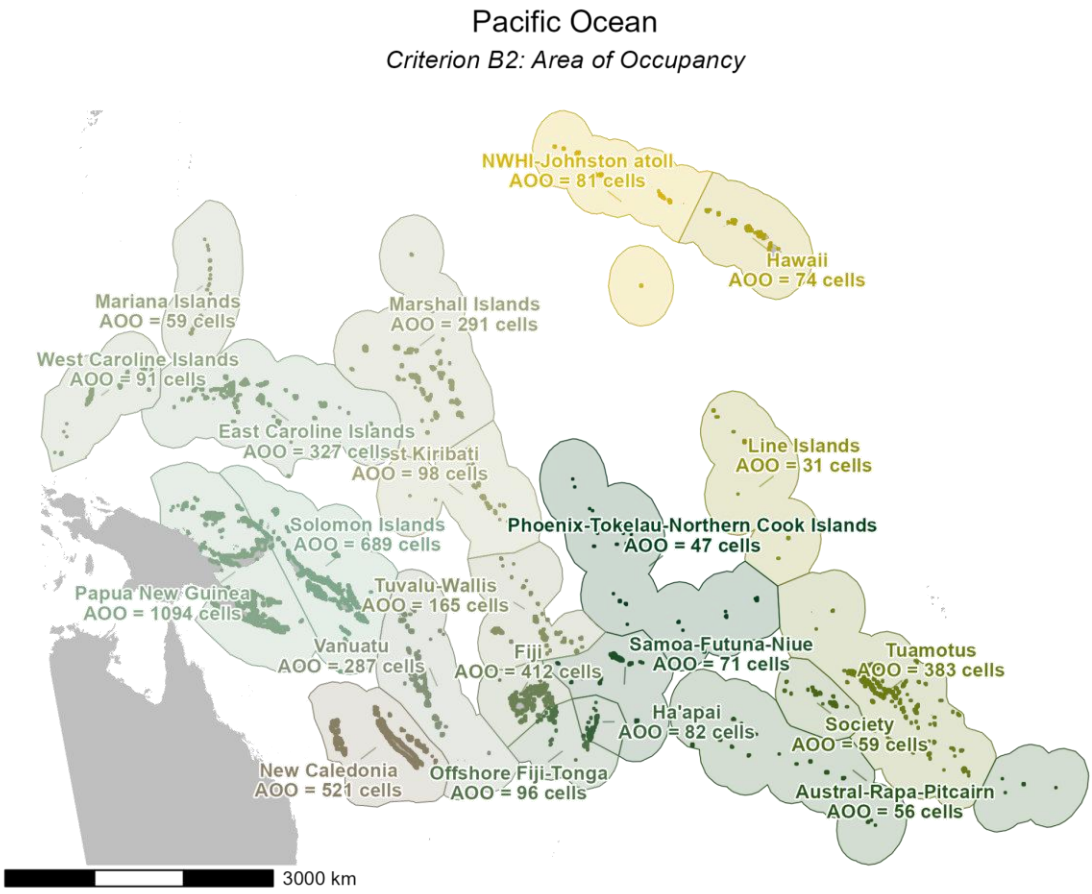
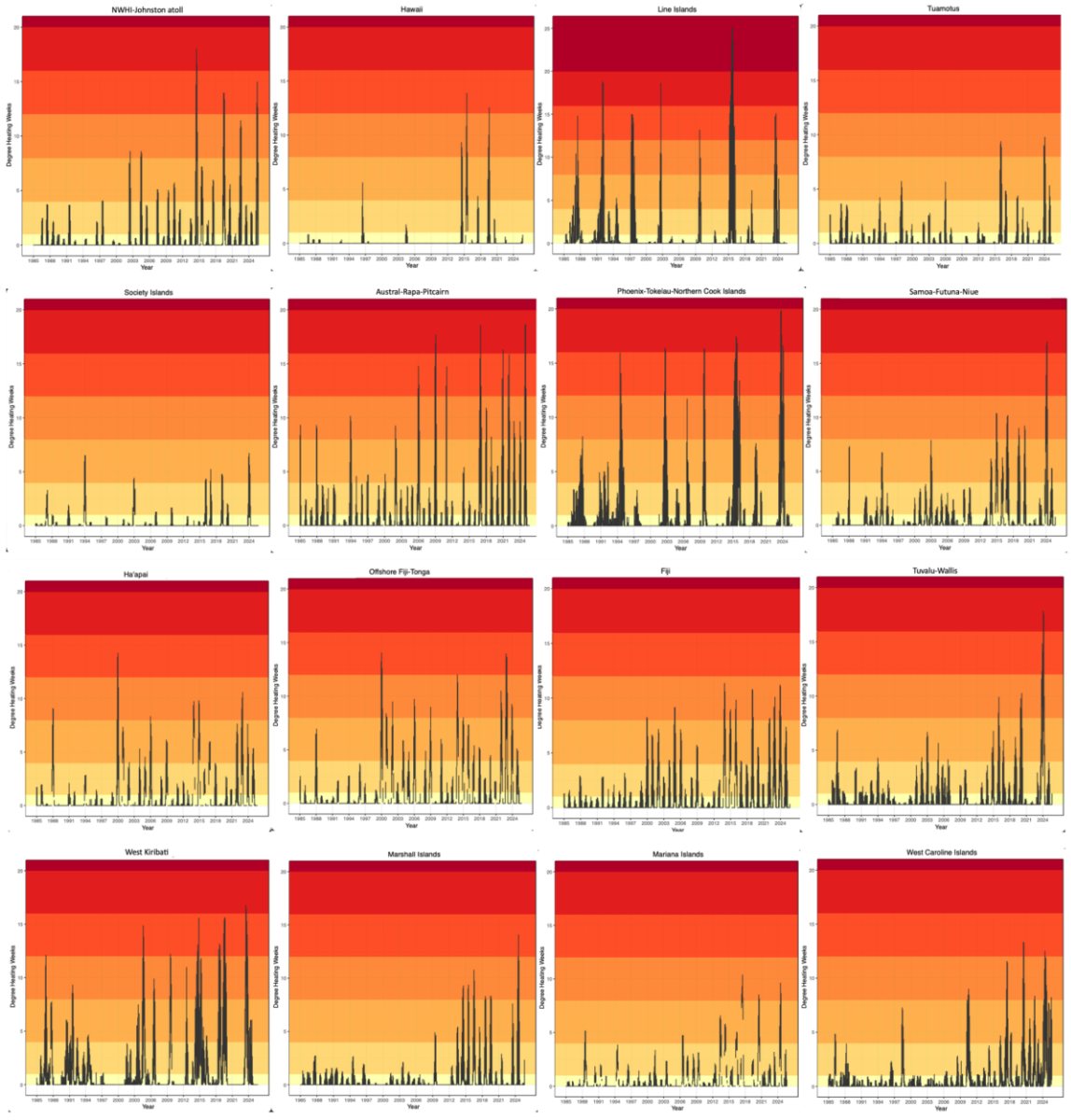


Figure S3. Area of Occupancy (AOO) by ecoregion under Criterion B2, for the 21 Pacific coral reef ecoregions. AOO is calculated as the number of occupied 10 × 10 km grid cells containing coral reef habitat within each ecoregion.


NWHI-Johnston atoll
Hawaii
Line Islands
Tuamotus
Society Islands
Austral-Rapa-Pitcairn
Phoenix-Tokelau-Northern Cook Islands
Samoa-Futuna-Niue
Ha'apai
Offshore Fiji-Tonga
Fiji
Tuvalu-Wallis
West Kiribati
Marshall Islands
Mariana Islands
West Caroline Islands
Degree Heating Weeks
Year

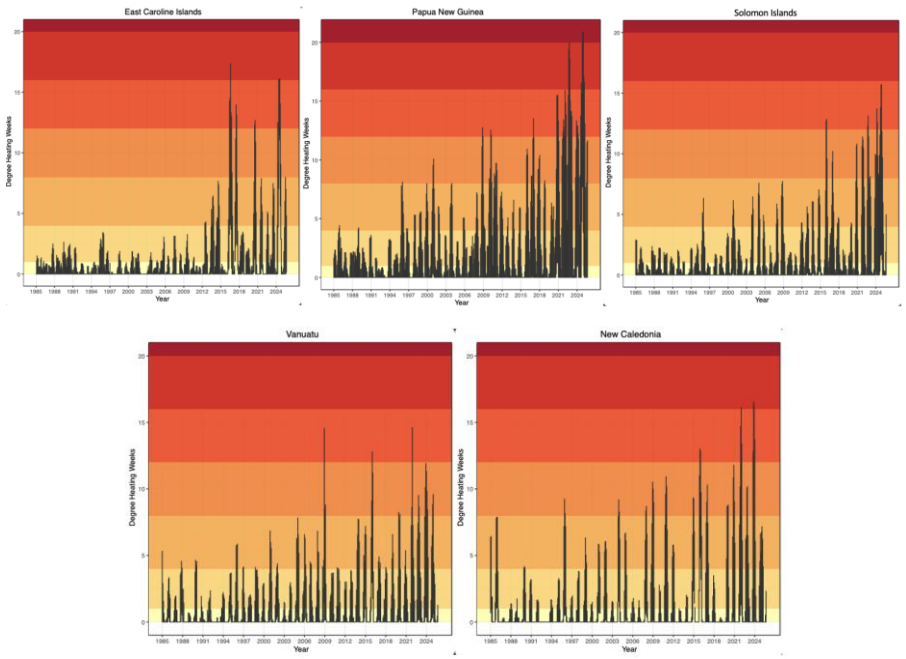


Figure S4. DHW plot by year and ecoregion. Each vertical spike spans the range of DHW values recorded per year for the ecoregion, from observed satellite data.

Table SI. Percentage of 1000 Monte Carlo iterations assigning each Pacific ecoregion to each IUCN Red List of Ecosystems risk category for Criterion D (hard coral cover) under a 5% collapse threshold.

Ecoregion	LC (%)	NT (%)	VU (%)	EN (%)	CR (%)
NWHI-Johnston atoll	0	0	0	78	22
Hawaii	0	0	0	100	0
Line Islands	0	0	100	0	0
Tuamotus	0.8	99.2	0	0	0
Society	11.7	85.8	2.5	0	0
Austral-Rapa-Pitcairn	99.3	0.7	0	0	0
Phoenix-Tokelau-Northern Cook Islands	0	99.6	0.4	0	0
Samoa-Futuna-Niue	100	0	0	0	0
Ha'apai	0	0	0	100	0
Offshore Fiji-Tonga	0	0	0	35.9	64.1
Fiji	0	100	0	0	0
Tuvalu-Wallis	1.6	98.2	0.2	0	0
West Kiribati	99.3	0.7	0	0	0

Ecoregion	LC (%)	NT (%)	VU (%)	EN (%)	CR (%)
Marshall Islands	0	0	4.5	95.5	0
Mariana Islands	0	99.7	0.3	0	0
West Caroline Islands	100	0	0	0	0
East Caroline Islands	0	0	99.8	0.2	0
Papua New Guinea	0	100	0	0	0
Solomon Islands	0	0	0	100	0
Vanuatu	0	0	100	0	0
New Caledonia	0	55.1	44.9	0	0

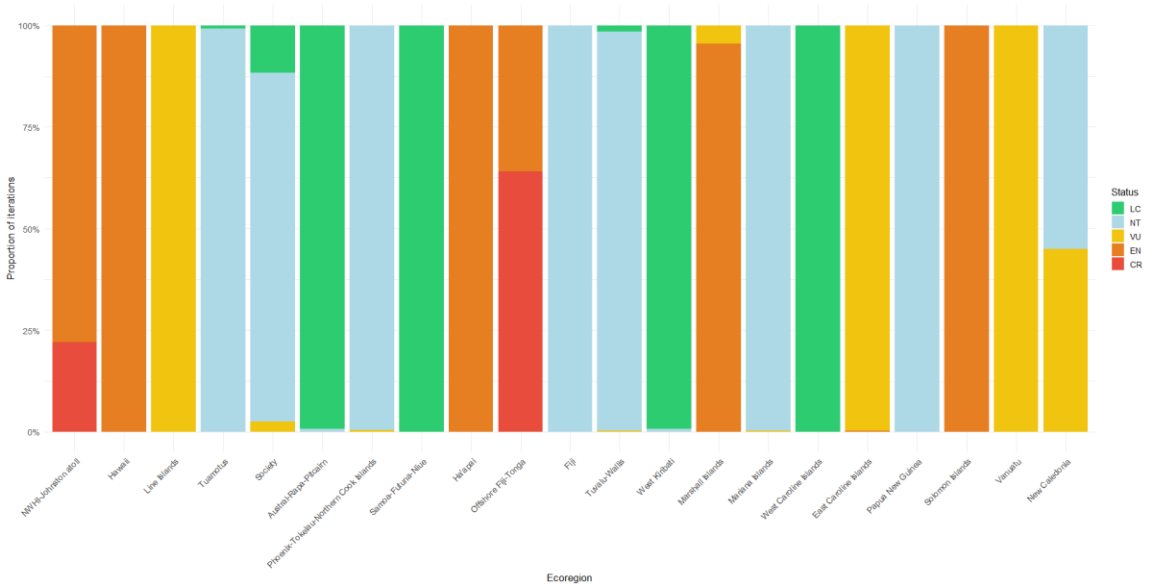


Figure S5. Proportion of 1000 Monte Carlo iterations landing in each IUCN Red List of Ecosystems risk category, by Pacific ecoregion, for Criterion D (hard coral cover) under a 5% collapse threshold.

Table SII. Percentage of 1000 Monte Carlo iterations assigning each Pacific ecoregion to each IUCN Red List of Ecosystems risk category for Criterion D (macroalgae:coral ratio) under a 0.833 collapse threshold.

Ecoregion	LC (%)	NT (%)	VU (%)	EN (%)	CR (%)
NWHI-Johnston atoll	0	0	100	0	0
Hawaii	0	100	0	0	0
Line Islands	0	0	100	0	0
Tuamotus	100	0	0	0	0

Ecoregion	LC (%)	NT (%)	VU (%)	EN (%)	CR (%)
Society	100	0	0	0	0
Austral-Rapa-Pitcairn	100	0	0	0	0
Phoenix-Tokelau-Northern Cook Islands	57.1	42.9	0	0	0
Samoa-Futuna-Niue	100	0	0	0	0
Ha'apai	67.4	32.6	0	0	0
Offshore Fiji-Tonga	0	0	100	0	0
Fiji	100	0	0	0	0
Tuvalu-Wallis	0	0	0	0	0
West Kiribati	100	0	0	0	0
Marshall Islands	0	42.3	57.7	0	0
Mariana Islands	0	100	0	0	0
West Caroline Islands	100	0	0	0	0
East Caroline Islands	0	100	0	0	0
Papua New Guinea	100	0	0	0	0
Solomon Islands	100	0	0	0	0
Vanuatu	100	0	0	0	0
New Caledonia	100	0	0	0	0

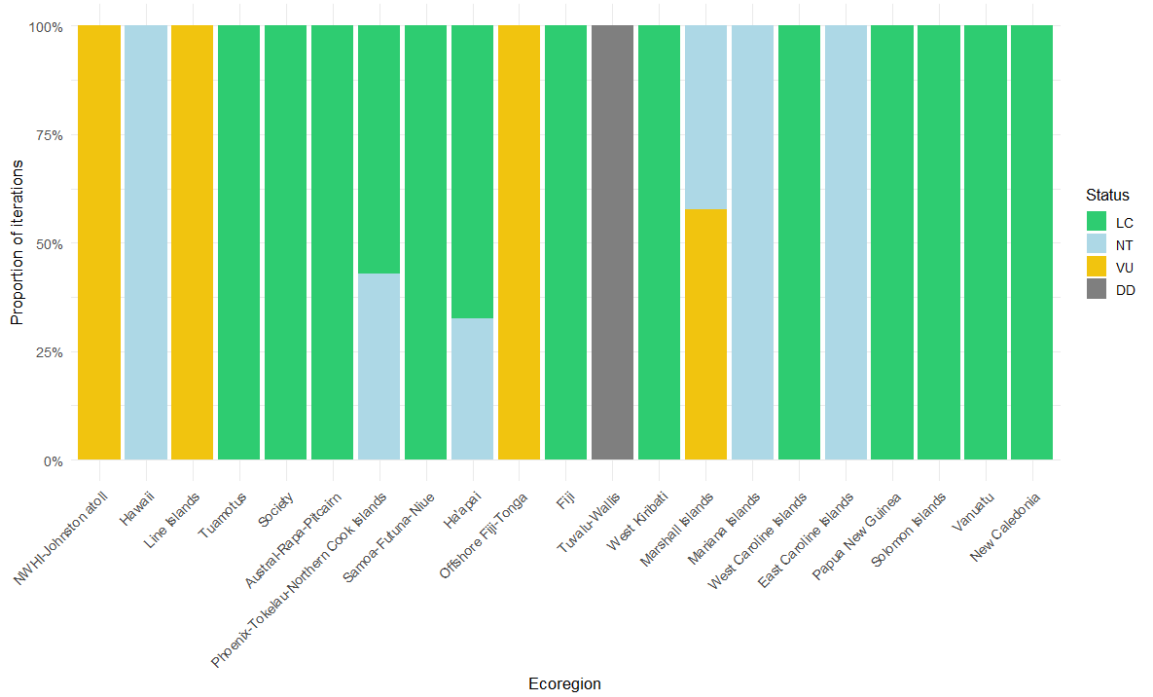


Figure S6. Proportion of 1000 Monte Carlo iterations landing in each IUCN Red List of Ecosystems risk category, by Pacific ecoregion, for Criterion D (macroalgae:coral ratio) under a 0.833 collapse threshold.

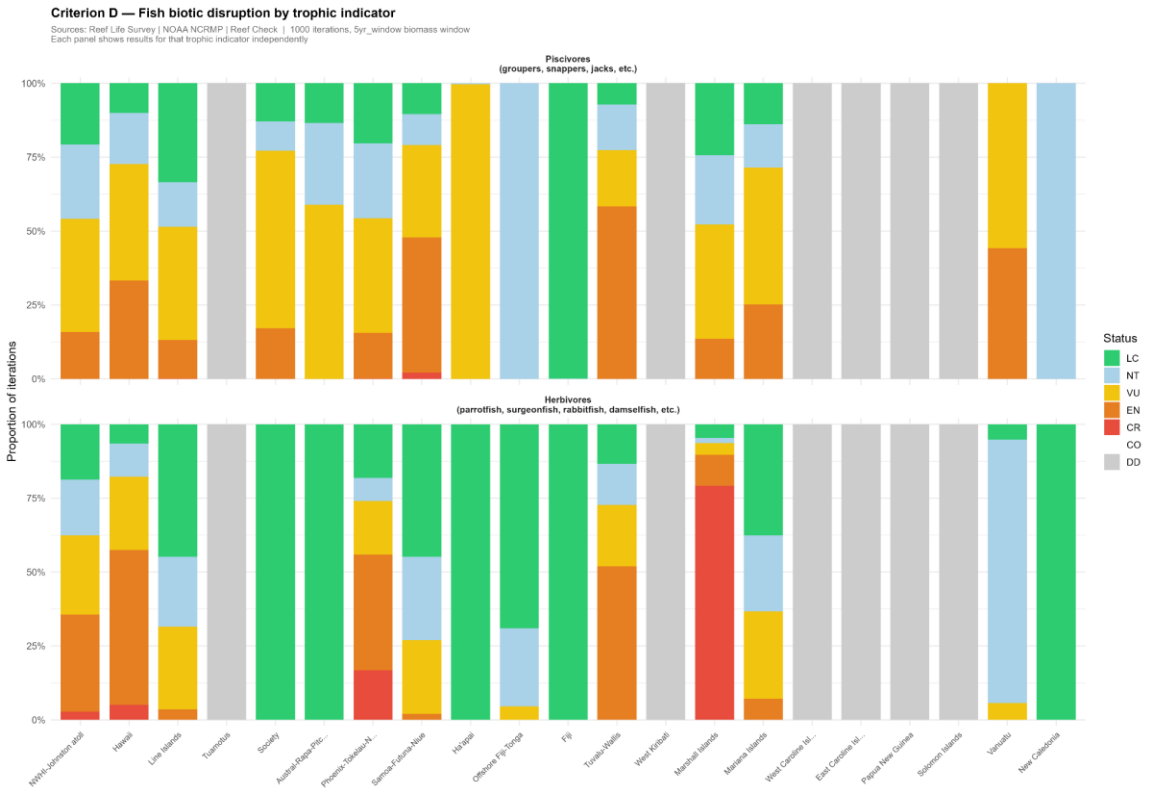


Figure S7. Proportion of Monte Carlo simulation iterations landing in each IUCN Red List of Ecosystems risk category, by Pacific ecoregion, for Criterion D (above : herbivores biomass / below : piscivores biomass).

Criterion C – Environmental Degradation: supplementary figures

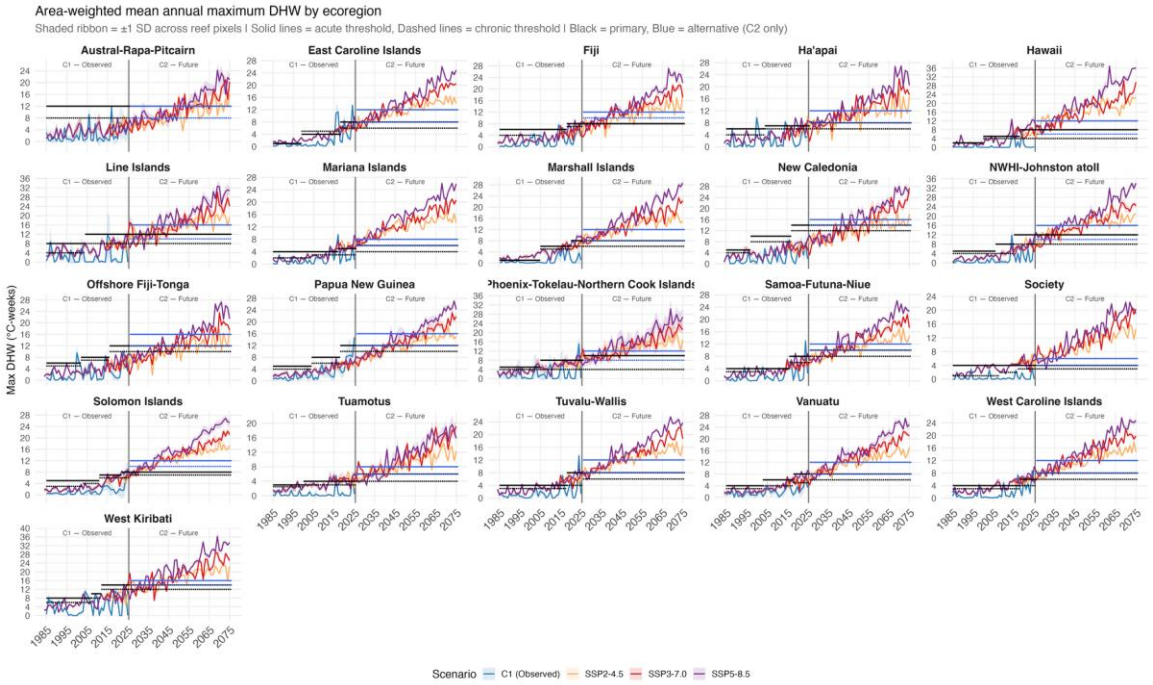


Figure S8. Annual maximum Degree Heating Weeks (DHW) averaged across coral reefs within each ecoregion from 1985-2075 for four trajectories: observed data used to assess sub-criterion C1 from 1985-2025 (blue line), and projections under three Shared Socioeconomic Pathways — SSP2-4.5 (orange), SSP3-7.0 (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 S9. 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.

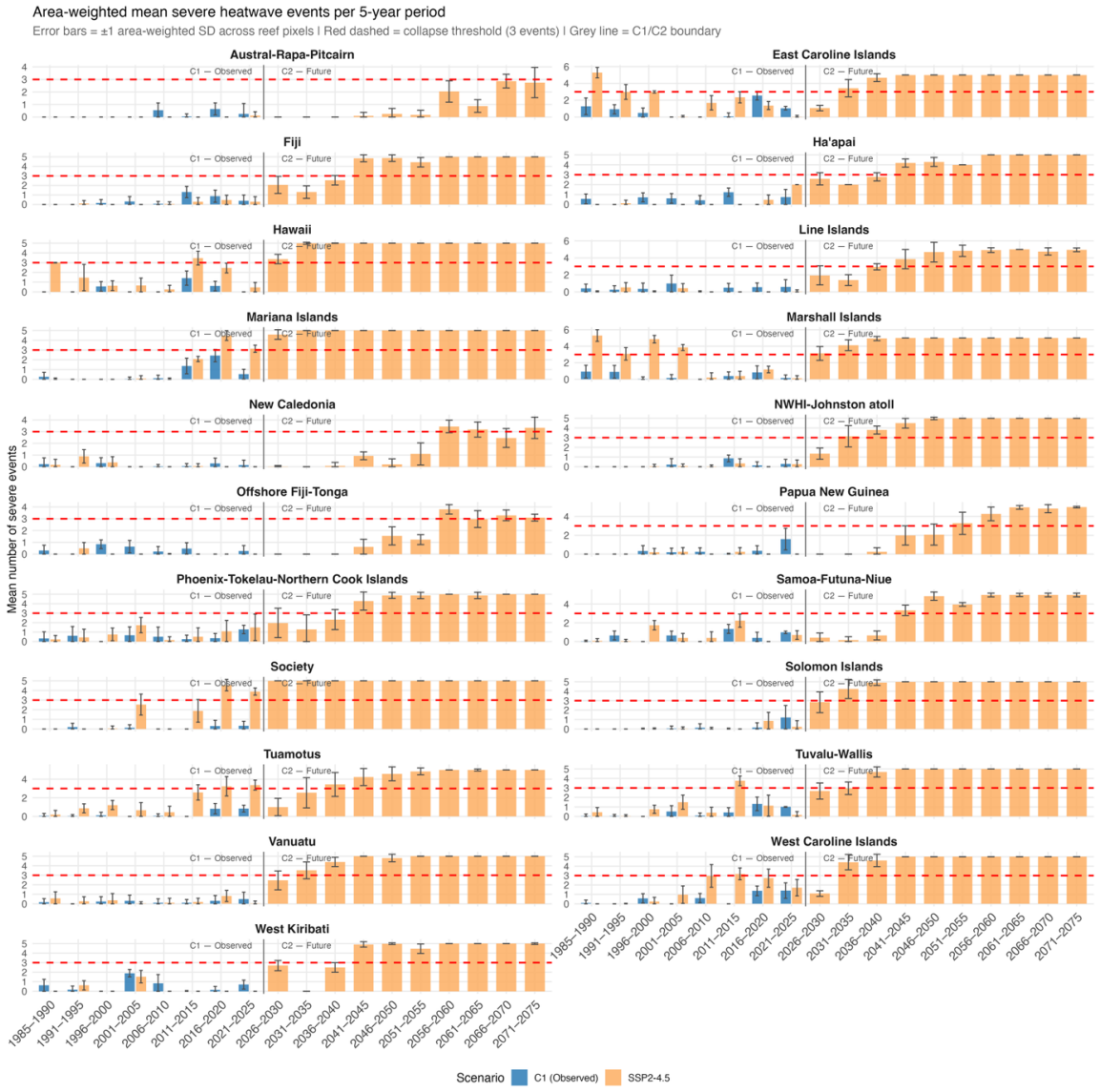


Figure S10. Mean number of severe mortality events per 5-year period, averaged across coral reef pixels within each ecoregion, under two trajectories: observed data used to assess sub-criterion C1 (blue bars, 1985–2025) and projections under SSP2-4.5 (orange bars, 1985–2075). Severe mortality events 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.