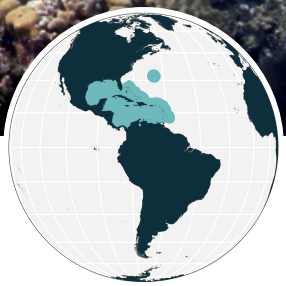
Coral reef in Puerto Morelos, Mexico
Credit: Lorenzo Álvarez-Filip



CARIBBEAN

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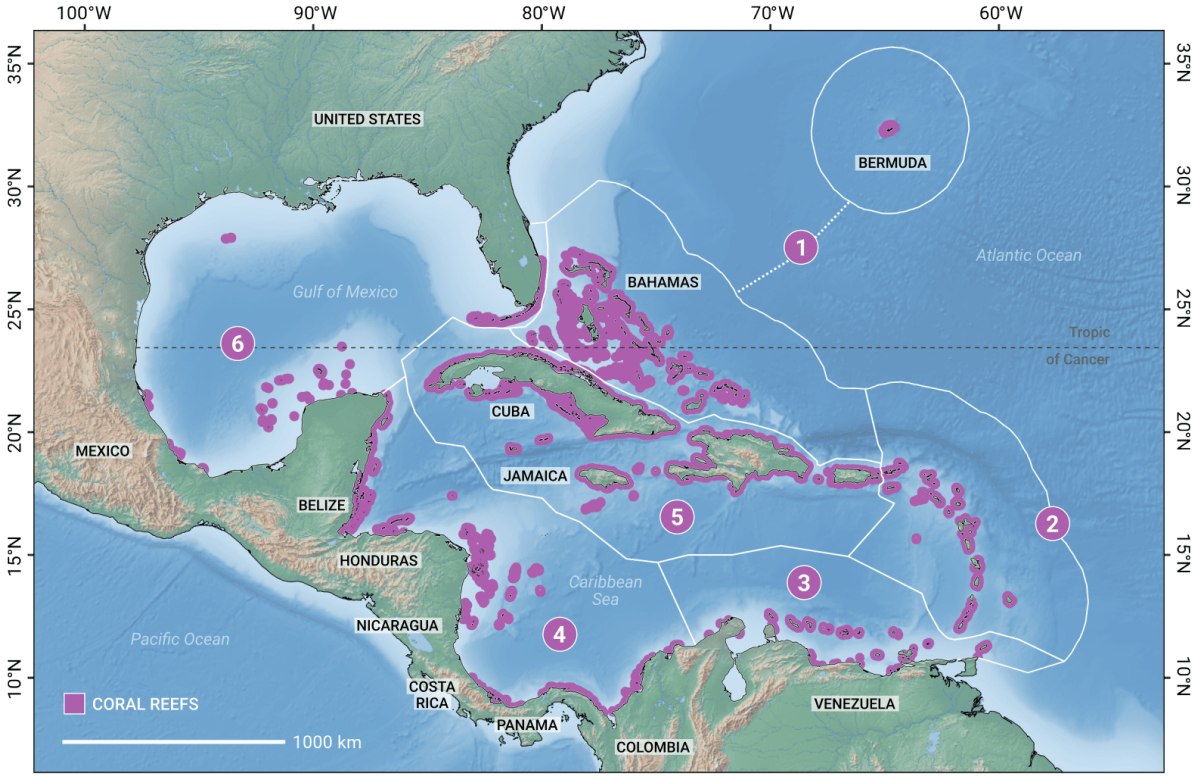
INTRODUCTION

The GCRMN Caribbean region extends over a maritime area of approximately 6.4 million km^2. Ranging across 28° of latitude and 42° of longitude, it encompasses a wide range of oceanographic conditions, reef types, and disturbance regimes. With 24,671 km^2 of coral reefs, it is the fourth-largest GCRMN region by coral reef extent, representing about 10% of the world's coral reef extent. Coral reefs can be found in the territorial waters of 44 countries and territories, from Bermuda in the North to Colombia in the South, and from Barbados in the East to Mexico in the West (Figure 2.3.1).

For this report, the Caribbean region was divided into six subregions (Figure 2.3.1). The largest, subregion 5 (Greater Antilles), hosts 32.8% of Caribbean coral reefs (8,089 km^2) whereas the smallest, subregion 2 (Eastern Caribbean), hosts only 7% of Caribbean coral reefs (1,709 km^2, Table A.1).

As of 2020, a total of 15.7 million inhabitants lived within 5 km of coral reefs, representing a 43.5% increase since 2000 (approximately 238,000 additional inhabitants per year). The greatest rate of population increase over this period was recorded in subregion 5 (Greater Antilles), which also had the largest number of inhabitants in 2020 (Table A.2).



▲ **Figure 2.3.1.** The distribution of coral reefs within the Caribbean region and respective subregions. White polygons and numbers represent subregions. Subregion 1 = Bahamas and Bermuda, Subregion 2 = Eastern Caribbean, Subregion 3 = Southern Caribbean, Subregion 4 = Western Caribbean, Subregion 5 = Greater Antilles, Subregion 6 = Florida and Gulf of Mexico. Coral reefs are delineated with a 20 km buffer to enhance interpretation, and only coral reefs within the region are represented. The scale bar provides distance at the equator and may not accurately represent distance over the entire latitudinal range of the region.

THREATS AND DISTURBANCES

Heat stress

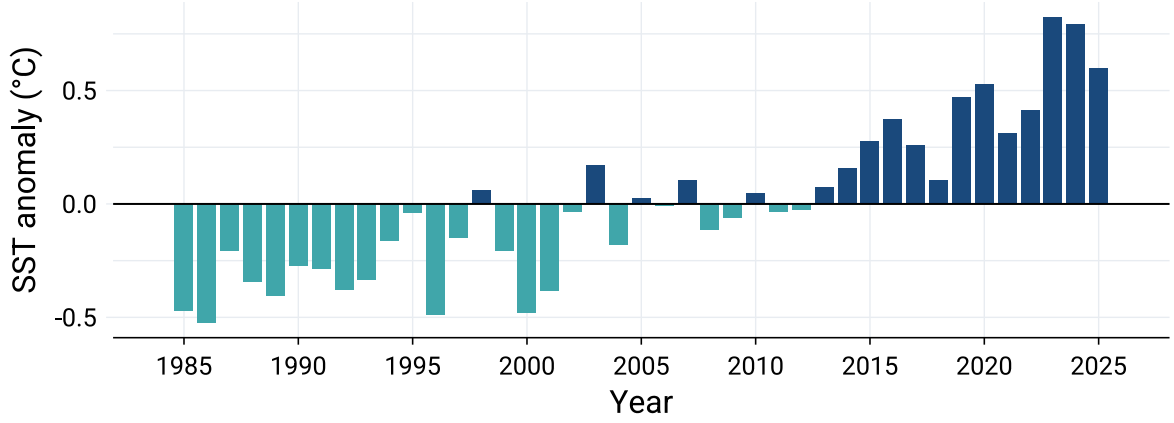
Annual mean sea surface temperature (SST) anomalies (°C) show an increasing trend from 1985 to 2025 (Figure 2.3.2). In addition, maximum degree heating weeks (DHW) show increasingly frequent and more severe bleaching alerts over time, culminating in extreme region wide stress during 2023–2024. From 1985 to 2025, the SST over coral reefs in the region increased by 1.03 °C, corresponding to an average warming rate of 0.26 °C per decade (Table A.3).

Major heatwaves in 1987, 1995, 1998, 2005, 2010, 2015–2017, 2019–2020, and 2023–2025 caused bleaching of varying extent. The 1998 event had regionwide impacts (especially severe in the Bahamas), while later events showed spatial variability: 2005 affected the Greater Antilles and Eastern Caribbean, 2010 the Southern Caribbean, and 2015–2017 the Gulf of Mexico and Western Caribbean [189]. The 2023–2024 phase of the fourth global bleaching event caused severe, widespread bleaching and mortality, with DHW exceeding 20 °C-weeks in some areas and exposure to bleaching-level stress for almost all Caribbean reefs in 2023 ([47], Figure 2.3.3). Impacts on *Acropora* spp. corals are especially alarming, with reports of catastrophic losses and local extirpations despite their previously lower bleaching susceptibility [190–192].

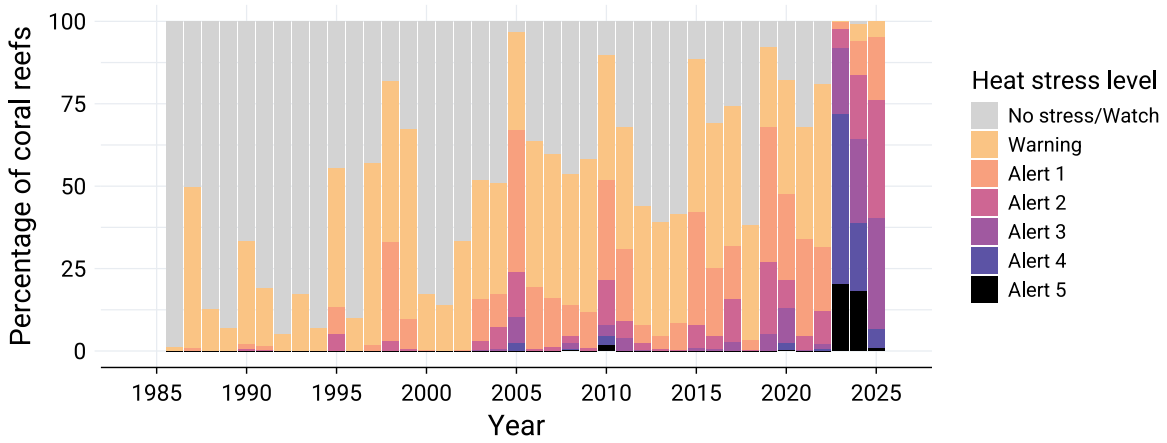
Hurricanes

In the Caribbean region, cyclones are known as hurricanes. Increasingly intense hurricanes have contributed to declines in Caribbean reef structural complexity and coral cover. Between 1980 and 2025, 180 hurricanes passed within 100 km of reefs, an average of 4 $\pm$ 2.5 per year ([108], Figure 2.3.4). Impacts of hurricanes are uneven across the region, with storms typically tracking through the Lesser Antilles and northern Caribbean. For instance, the Bahamas experienced 54 hurricanes (1980–2024), while Costa Rica and Panama recorded only one [193, 194].

Hurricane intensity has increased in recent decades, particularly after 2005, likely linked to climate change [195].



▲ **Figure 2.3.2.** Annual mean sea surface temperature (SST) anomalies (°C) over the coral reefs of the Caribbean region from 1985 to 2025. SST anomalies were calculated based on the long-term average over the period 1985–2025. Positive values (red bars) indicate SST warmer than the long-term average, whereas negative values (blue bars) indicate SST cooler than the long-term average. Derived from NOAA Coral Reef Watch data (Skirving *et al.* [107]; see Materials and Methods).



▲ **Figure 2.3.3.** Percentage of the coral reefs within the Caribbean region experiencing heat stress levels per year, from 1986 to 2025. No stress/Watch (DHW = 0); Warning (possible bleaching, 0 < DHW < 4); Alert 1 (reef-wide bleaching, 4 ≤ DHW < 8); Alert 2 (reef-wide bleaching and mortality of heat-sensitive corals, 8 ≤ DHW < 12); Alert 3 (multi-species mortality, 12 ≤ DHW < 16); Alert 4 (severe multi-species mortality, 16 ≤ DHW < 20); and Alert 5 (near-complete mortality, DHW ≥ 20). Derived from NOAA Coral Reef Watch data (Skirving *et al.* [107]; see Materials and Methods).

Notable high-intensity events include Hurricane Allen (1980; 306 km.h^{-1}), Hurricane Irma (2017; 287 km.h^{-1}), and Hurricane Maria (2017; 260 km.h^{-1}) (Figure 2.3.5). Even single storms can reduce reef structural complexity [196], while stronger hurricanes drive abrupt declines in live coral cover [197].

Diseases

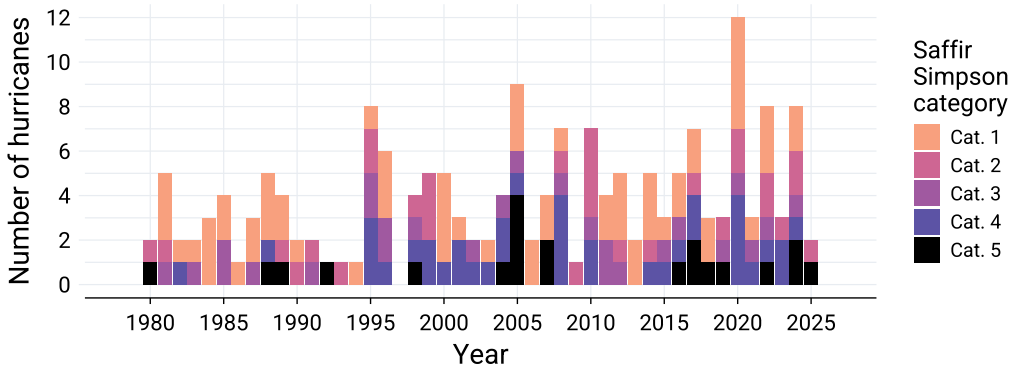
Coral diseases are a major driver of reef decline in the Caribbean, causing rapid and widespread mortality [197]. In the late 1970s, white-band disease devastated key *Acropora* spp. populations. Since then, outbreaks of white plague and yellow-band disease have further affected reef-building corals such as *Orbicella* spp. [198]. The emergence of Stony Coral Tissue Loss Disease (SCTLD) in 2014 triggered an unprecedented regional crisis, leading to severe coral losses across multiple subregions since 2019 [199, 200]. Additionally, mass die-offs of long-spined sea urchin (*Diadema antillarum*) in 1983–1984 and again in 2022 reduced herbivory, promoting algal overgrowth and weakening reef resilience [201].

Coastal development

Rapid coastal population growth, tourism, and infrastructure expansion since the 1980s have intensified pressure on Caribbean reefs. Resort and port construction have caused direct damage while increasing sedimentation and nutrient inputs [202]. Agriculture, deforestation, and inadequate wastewater treatment have elevated nitrogen and phosphorus runoff. Major rivers, including the Magdalena, Amazon, Orinoco, and Mesoamerican river systems, contribute to sedimentation and eutrophication [203, 204]. Pollution has also increased, with plastics dominating marine debris and chemical residues accumulating in reef environments, further degrading water quality and coral health [205].

Unsustainable fishing

Fishing pressure has intensified over time, depleting predatory fish such as groupers and snappers and collapsing spawning aggregations [206]. In response, over 70% of Caribbean fisheries nations now harvest parrotfish species, a key group of herbivores, disrupting food webs and enabling



▲ **Figure 2.3.4.** Number of hurricanes that passed within 100 km of the coral reefs of the Caribbean region from 1980 to 2025. Colors correspond to the Saffir–Simpson category of the hurricane along its entire track. Derived from IBTrACS data (Knapp *et al.* [118]; see Materials and Methods).

the growth of macro- and turf algae [207]. Invertebrate fisheries targeting spiny lobsters and queen conch are also heavily exploited, often including illegal harvest. Fully protected areas (no fishing), have proven effective in supporting fish population recovery [208, 209].

Sargassum

Since 2011, the Caribbean coral reefs are experiencing a new, potentially irreversible, regime shift triggered by the massive recurring influx of *Sargassum fluitans* and *S. natans* [210]. These massive influxes are characterized by reduced light availability, severe hypoxia, localized water acidification, and the release of toxic leachates and gases [211, 212]. In this new regime, mass mortalities of marine organisms are more frequent, resetting their ecological succession under lower recruitment conditions, and negatively affecting human health [213, 214].

Invasive species

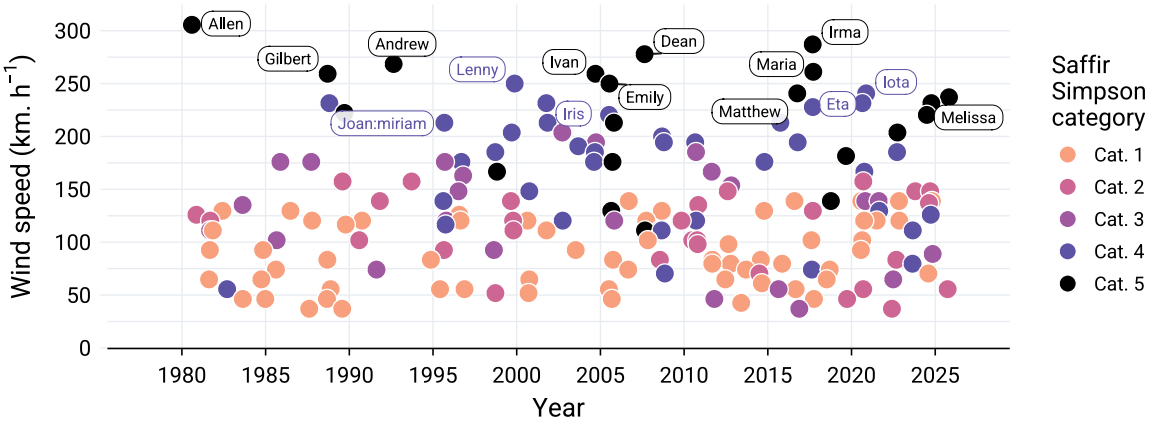
Invasive species such as lionfish (*Pterois* spp.) and invertebrates like *Unomia stolonifera* [215], *Xenia umbellata* [216] and *Latissimia ningalooensis* [217] have also spread widely across Venezuelan, Puerto Rican, and Cuban reefs, outcompeting native species and altering reef community structure and ecosystem function [218]. More recently, patches of the Indo-Pacific acroporid *Acropora tenuis* were documented in reefs of Morrocoy National Park, Venezuela [219], further indicating that invasions of soft and hard corals are becoming more frequent.

STATUS OF CORAL REEFS IN THE REGION

Hard coral cover

Across the Caribbean region, median hard coral cover decreased from 19.5% (credible interval at 95% [CrI $_{95\%}$]: 17.1 – 21.9%) in 1980–2009 to 11.0% (CrI $_{95\%}$: 10.3 – 11.8%) in 2020–2024, representing a 43.4% relative decline. There is strong evidence of a long-term decline from 1980 to 2024. Major decreases in hard coral cover are evident in 1982–1985, 1997–2000, 2004–2006, and 2023–2024, coinciding with periods of bleaching induced high heat stress and outbreaks of coral diseases across the region.

The marked declines observed during the 1980s reflect the convergence of multiple acute and chronic stressors. White-band disease, which spread widely across the

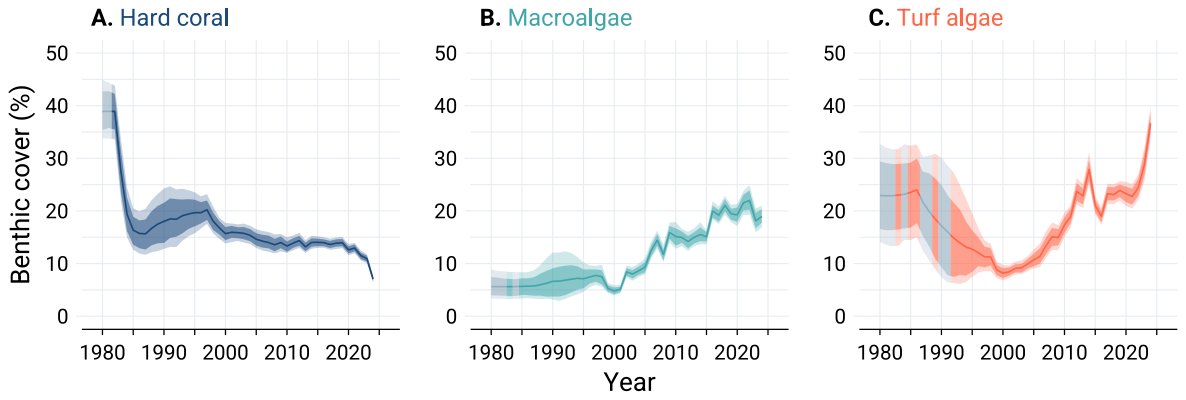


▲ **Figure 2.3.5.** Maximum sustained wind speed of hurricanes that passed within 100 km of a coral reef in the Caribbean region between 1980 and 2025. Colors correspond to the Saffir–Simpson category of the hurricane along its entire track. However, the values of sustained wind speed are extracted from the nearest hurricane position from a coral reef. For this reason, some sustained wind speed values are below the lower threshold of category 1 Saffir–Simpson scale (*i.e.* 119 km.h^{-1}). Derived from IBTrACS data (Knapp *et al.* [118]; see Materials and Methods).

Caribbean from the late 1970s through the early 1990s, caused catastrophic mortality of acroporid corals, previously among the most important reef-building taxa in the region. In parallel, the 1983–1984 mass mortality of the herbivorous sea urchin *D. antillarum* removed a major source of grazing pressure. Combined with continued, chronic unsustainable fishing of herbivorous fishes and increasing nutrient enrichment in coastal waters, this loss of herbivory facilitated widespread algal proliferation, likely impairing coral recruitment and constraining post-disturbance recovery [220].

In addition to these local and regional pressures, anomalously high sea surface temperatures in 1987 and 1995 triggered bleaching across roughly one-fifth of Caribbean reefs, further contributing to coral losses during the late 1980s and early 1990s. The first global bleaching event in 1998, associated with a strong El Niño, led to a clear regional decline in hard coral cover, with a further 2.3 percentage point decline (about 13.0%) in comparison to 2000. A second, particularly severe thermal disturbance in 2005 affected much of the basin, and an unprecedented hurricane season likely compounded physical damage to reefs while also providing some localized thermal relief through mixing. More recent marine heatwaves in 2010 and 2015–2017 led to a regional decline in hard coral cover, with a further 2.8 percentage point decline (about 20.4%) in comparison to the 2020s.

This trajectory shifted again after 2020. Between 2022 and 2024, modeled hard coral cover declined by 4.5 percentage points, equivalent to a further 38.7% relative loss, with the majority of this reduction concentrated in 2023 and 2024. This decline is consistent with the fourth global bleaching event, during which widespread bleaching and mortality were documented across multiple Caribbean locations. The magnitude of this decline is likely underestimated due to limited survey coverage in 2024 in the context of ongoing bleaching. These thermal impacts occurred alongside the continued spread of SCTLD, which reached nearly all Caribbean countries and territories by 2023. Collectively, these results indicate that Caribbean reefs have experienced nearly five decades of progressive coral loss, driven by the interplay of bleaching, disease, trophic



▲ **Figure 2.3.6.** Modeled temporal trends of benthic cover in the Caribbean region from 1980 to 2024 for hard coral (A), macroalgae (B), and turf algae (C). The solid line represents the estimated median benthic cover while darker and lighter ribbons represent 80% and 95% credible intervals, respectively. Grey areas represent periods during which no field data were available.

imbalance, local anthropogenic pressures, and increasingly frequent and intense marine heatwaves, with the most recent years marking a new, and potentially accelerating phase of regional decline.

Despite differences in modelling approaches, the hard coral cover trends presented here are broadly consistent with previous regional syntheses, including the recent *Status and Trends of Caribbean Coral Reefs: 1970–2024* report [45]. Estimates of hard coral cover change during the 1980s fall within the ranges reported by previous Caribbean-wide assessments and values for the 2000s closely match those documented by independent analyses [221]. While some earlier reconstructions suggest larger absolute losses since the 1970s, differences in baselines, spatial coverage, and survey approaches limit direct comparability. Importantly, 1980 should not be interpreted as a pristine reference point, as substantial coral degradation had already occurred by that time, particularly through the collapse of *Acropora palmata* and *A. cervicornis* populations beginning in the 1960s due to direct anthropogenic impacts.

Macroalgal cover

Median macroalgal cover increased from 7.6% ($CrI_{95\%}$: 6.2 – 9.4%) in 1980–2009 to 20.0% ($CrI_{95\%}$: 18.3 – 21.7%) in 2020–2024 at the regional scale, representing a relative gain of 162.7%. The results show strong evidence of an increasing trend, which reflects the widespread shift from coral to algal-dominated reef states documented throughout much of the Caribbean [220, 221].

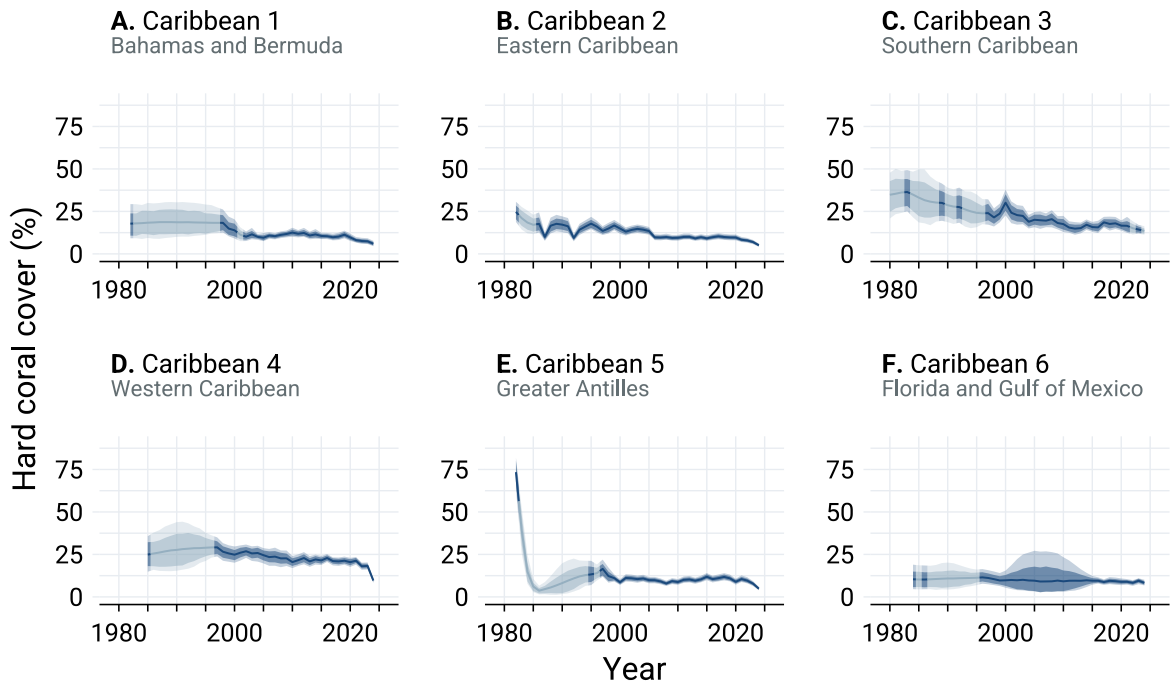
Overall, data show an increasing rate of macroalgal cover, particularly from the mid-2000s, which appears to have accelerated following major coral mortality events. For instance, macroalgal cover increased 5.2% on average (a relative increase of 55.4%) following the 2005 heatwave in comparison to 2007, a pattern consistent with the rapid colonization of newly available benthic space created by coral loss. Although data show an average decline in macroalgal cover from 1998–2000 (35.9% decline), we suspect this trend may be caused by a reduction in monitoring sites that occurred in 2000. More recently, macroalgal cover increased further in 2023 and 2024, coinciding with the sharp decline in hard coral associated with the fourth global bleaching event and the continued spread of SCTLD. These coupled trajectories underscore the tight ecological linkage be-

tween coral mortality and macroalgal expansion at the basin scale.

A critical early trigger of this long-term macroalgal expansion was the Caribbean-wide mass mortality of the herbivorous sea urchin *D. antillarum* in 1983–1984, during which *D. antillarum* population densities declined up to 100% on reefs throughout the Caribbean [222]. Although partial compensatory grazing by herbivorous fishes occurred at some locations, *D. antillarum* populations have remained well below historical densities across most of the region for more than four decades, limiting the recovery of this critical herbivory function. A second regional mass mortality of *D. antillarum* was documented in 2022 [201]. Although this event likely reduced grazing pressure in affected areas, absolute population declines appear smaller than during the 1983–1984 die-off, suggesting more limited basin-wide consequences for macroalgal proliferation.

Chronic human pressures have reinforced conditions favoring macroalgal dominance on Caribbean reefs. Coastal development, agriculture, and poor wastewater treatment have increased nutrient inputs, sedimentation, and turbidity, promoting macroalgal growth while inhibiting coral recruitment and survival. At the same time, unsustainable fishing of key herbivores, especially parrotfishes (Scaridae) and surgeonfishes (Acanthuridae), has reduced grazing pressure and allowed algal biomass to expand [220]. Some countries, including Bonaire, Bermuda, the Dominican Republic, Mexico, Guatemala, and Honduras, have implemented protections for herbivorous fish to counter these trends.

Overall, macroalgal cover has increased consistently over the past four decades, closely linked to declining hard coral cover. This shift reflects the combined effects of herbivore loss, chronic local stressors, and repeated climate disturbances.



▲ **Figure 2.3.7.** Modeled temporal trends of hard coral cover in Caribbean subregions from 1980 to 2024. The solid line represents the estimated median hard coral cover while darker and lighter ribbons represent 80% and 95% credible intervals, respectively. Grey areas represent periods during which no field data were available.

The recent acceleration of macroalgal dominance suggests reinforcing feedbacks between coral loss, reduced structural complexity, and algal expansion, further weakening reef resilience under ongoing climate change.

Turf algal cover

The data indicate a long-term regional increase in turf algal cover from 15.6% ($CrI_{95\%}$: 11.5 – 19.9%) in 1980–2009 to 27.2% ($CrI_{95\%}$: 25.4 – 29.3%) in 2020–2024 (Figure 2.3.6C), a change supported by strong evidence. This corresponds to an absolute increase of 11.7 percentage points, or a relative increase of 74.7%. Unfortunately, major data gaps and potential inconsistencies in how turf were categorized between 1980 and 1990 make it challenging to discern clear temporal patterns in turf algal cover during this period.

Between the 2000s and 2010s, turf algal cover increased 11.0 percentage points on average, a relative increase of 100.1%. This increase is likely associated with similar factors as macroalgal cover, including the decline of hard coral cover after bleaching events, which creates available substrate for colonization [223]. Additionally, bottom-up processes such as nutrient enrichment [221, 224] may have promoted turf algae proliferation, while top-down controls may have weakened due to declines in herbivorous fish populations [225, 226] and *D. antillarum* sea urchins [227], resulting in reduced grazing pressure. Turf algal cover also increased 5.1% on average from 2010–2020, a 23.1% increase in total.

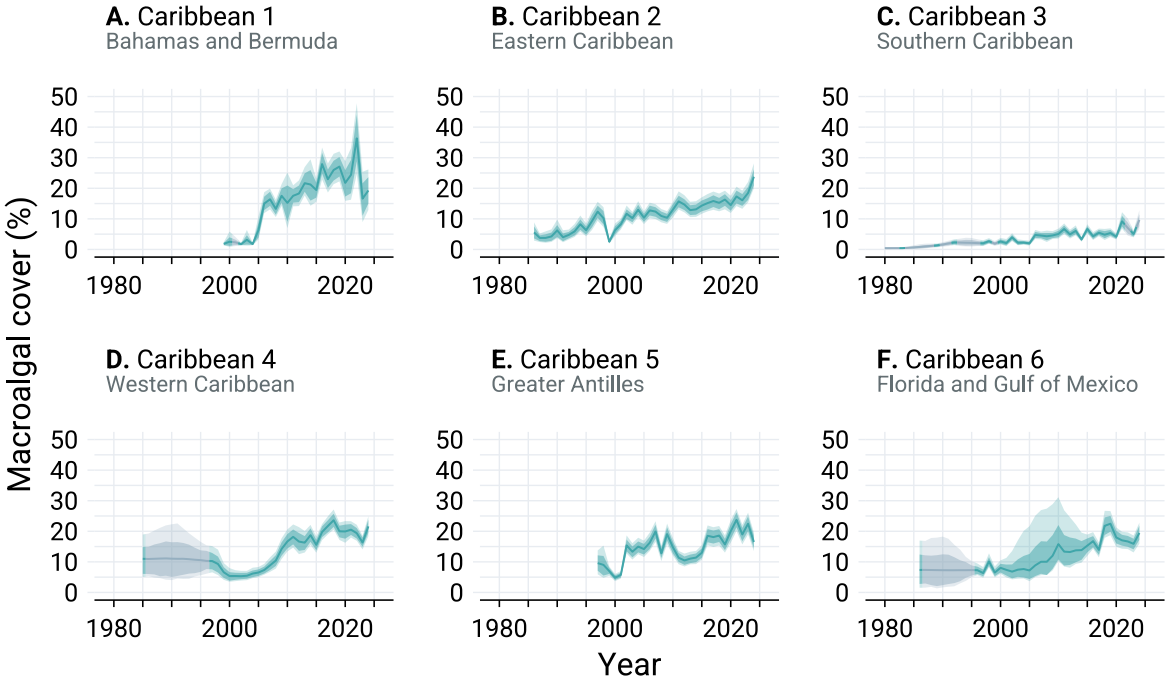
Due to limited data availability at the subregion scale, and inconsistencies in categorization among monitoring programs, trends in turf algal cover were not considered at the subregion scale.

STATUS OF CORAL REEFS IN THE SUBREGIONS

Caribbean 1 - Bahamas and Bermuda

The Bahamas and Bermuda subregion shows a distinct reef trajectory relative to the Caribbean as a whole. Hard coral cover increased modestly from the early 1980s to the late 1990s before entering a prolonged period of stagnation and gradual decline through the 2000s and 2010s (Figure 2.3.7A). Overall trends show hard coral cover decreased from 15.8% to 7.8% and macroalgal cover increased from 7.0% to 23.8% between 1982–2009 and 2020–2024, respectively (Figure 2.3.7A and Figure 2.3.8A).

Environmental conditions strongly shape reef trends in Bermuda and the Bahamas but these reef systems are inherently different. The modelled data are primarily from the Bahamas, with only one dataset from Bermuda. Although periodic cold stress from cooler winters slows coral growth and recovery, and marine heatwaves, storms, and high wave energy can cause damage, the differences between these locations today are due to differential impacts of coral diseases and fisheries management. SCTLD has not affected Bermuda but has reduced hard coral cover at some locations in the Bahamas [228]. Other diverse coral diseases occur in Bermuda, but these have low incidence rates [229], and coral bleaching is generally mild in Bermuda with very little mortality, in contrast to the Bahamas [31]. Additionally, Bermuda removed non-specific fish traps in 1990 [230] and protected all parrotfishes in 1993, resulting in Scarid populations showing a strong recovery across Bermuda's reefs [231], while Sherman *et al.* [232] pointed to the growing harvest of scarids in the Bahamas. Thus, through fisheries management practices and low prevalence of coral disease, Bermuda's



▲ **Figure 2.3.8.** Modeled temporal trends of macroalgal cover in Caribbean subregions from 1980 to 2024. The solid line represents the estimated median macroalgal cover while darker and lighter ribbons represent 80% and 95% credible intervals, respectively. Grey areas represent periods during which no field data were available.

reefs remain healthy with moderate coral cover and low algal abundance [233–235].

Caribbean 2 - Eastern Caribbean

The Eastern Caribbean extends from the U.S. and British Virgin Islands to Saint Vincent and the Grenadines. Overall trends show hard coral cover decreased from 15.0% to 7.6% and macroalgal cover increased from 7.6% to 18.0% between 1982–2009 and 2020–2024, respectively (Figure 2.3.7B and Figure 2.3.8B).

This subregion lies within the Atlantic hurricane belt and is frequently impacted by severe storms, causing extensive damage to shallow reefs. Many islands are Small Island Developing States (SIDS) with limited capacity for monitoring, enforcement, and wastewater and fisheries management. High coastal population density and intensive tourism further increase pressures from development, nutrient enrichment, and sediment runoff. Together, these stressors have accelerated coral decline and reinforced persistent macroalgal dominance, highlighting the vulnerability of Eastern Caribbean reefs.

Caribbean 3 - Southern Caribbean

The southern Caribbean subregion includes the eastern mainlands of Colombia and Venezuela, as well as Aruba, Bonaire, Curaçao, and Trinidad and Tobago, and is reflective of wider region-wide trends. Overall trends show hard coral cover decreased from 19.5% to 11.0% and macroalgal cover increased from 2.1% to 7.0% between 1980–2009 and 2020–2024, respectively (Figure 2.3.7C and Figure 2.3.8C).

This subregion comprises extensive oceanic reefs, banks, and archipelagos influenced by large river plumes from the Amazon and Orinoco, seasonal upwelling, and exposure to storms. Economies depend heavily on tourism and reef-based fisheries. The region is also increasingly threatened by invasive species, particularly the

soft coral *Unomia stolonifera* and related xeniids, which have rapidly expanded along Venezuelan coasts and displaced native reef communities [216, 236]. However, even in highly anthropogenic areas, there is still hope. The Varadero reef, located just off of a highly polluted bay off Cartagena, hosts a diverse coral community, with hard coral cover peaking at 50–60% [237].

Caribbean 4 - Western Caribbean

The western Caribbean encompasses the Mesoamerican Reef system of Mexico, Belize, Guatemala, Honduras, and the reefs of Nicaragua, Costa Rica, Panama, and Caribbean Colombia. Overall trends show hard coral cover decreased from 26.4% to 17.6% and macroalgal cover increased from 9.4% to 19.6% between 1985–2009 and 2020–2024, respectively (Figure 2.3.7D and Figure 2.3.8D).

This subregion faces severe land-based and disease-driven pressures, distinguishing it from other Caribbean subregions. Influenced by sediment and nutrient inputs from deforested agricultural catchments, *Sargassum* blooms, and expanding coastal settlements, elevated turbidity has degraded nearshore reefs, suppressing coral recruitment and promoting persistent macroalgal growth. Coastal development, particularly along the Mexican Caribbean, Belizean cayes, and the Bay Islands of Honduras, exacerbates these challenges, compounded by significant impacts from SCTLD and the 2023–2024 marine heatwave that have decimated critical reef-building corals. Other countries, such as Nicaragua, Costa Rica, Panama, and Caribbean Colombia, are starting to face threats for unsustainable tourism development. However, some reefs still thrive, as is the case for the Cayman Crown reef between Belize and Guatemala. This reef's relatively high live hard coral cover (>50%) is a testament to the effectiveness of conservation efforts [238].

Caribbean 5 - Greater Antilles

The Greater Antilles include Cuba, Jamaica, Haiti, the Dominican Republic, and Puerto Rico. Overall trends show hard coral cover decreased from 13.5% to 8.3% and macroalgal cover increased from 9.7% to 20.3% between 1982–2009 and 2020–2024, respectively (Figure 2.3.7E and Figure 2.3.8E).

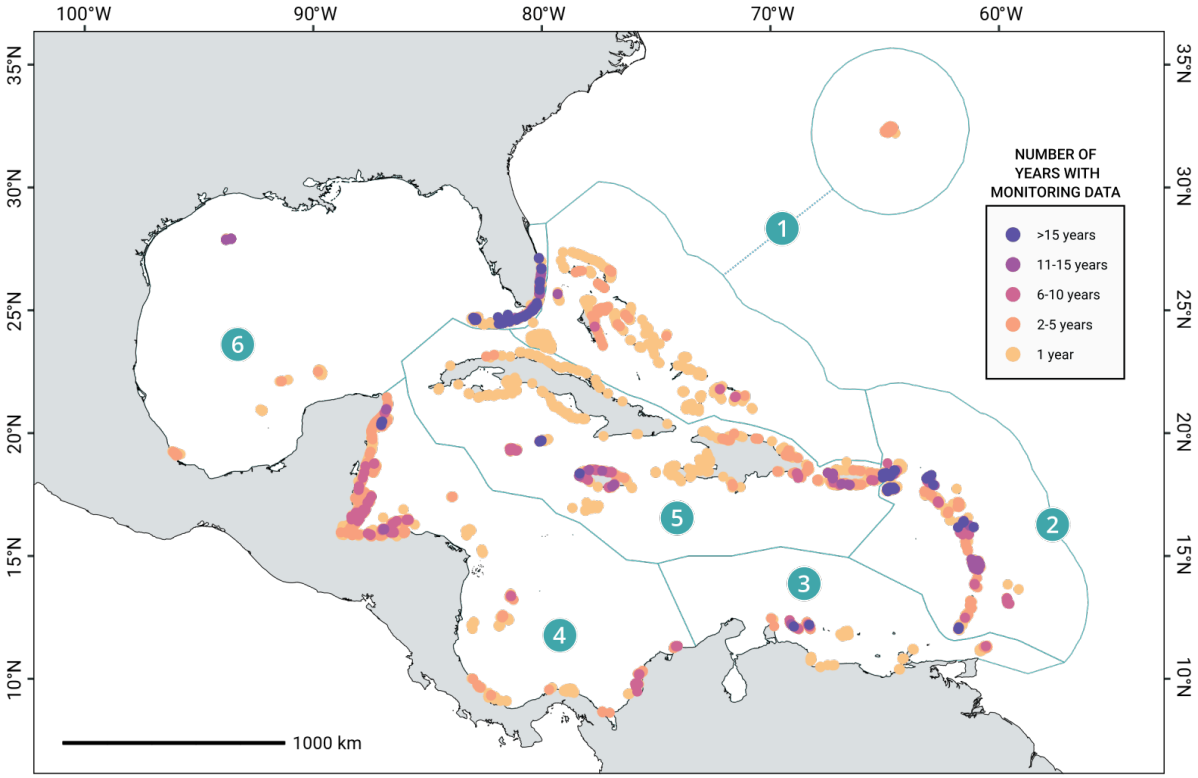
The Greater Antilles host extensive coral reefs, but face limited financial and technical resources, weak enforcement, and high dependence on marine fisheries for food security and livelihoods. Reef conditions are shaped by the combined effects of recurrent marine heatwaves, hurricanes, coral disease, and persistent water quality challenges, which have reduced structural complexity and coral recruitment while favoring stress-tolerant taxa such as macroalgae. Although localized management actions — such as improved wastewater controls, herbivore protection, and community-based fisheries management — have shown positive effects in some areas, these gains remain uneven and vulnerable to extreme events. Strengthening regulatory enforcement and integrated management across climate, water quality, and fisheries is essential to support coral reef recovery and regional resilience.

Caribbean 6 - Florida and Gulf of Mexico

This subregion is a significant marine ecosystem spanning over 1.5 million km^2, with a continental shelf of approximately 360,000 km^2, yet less than 1% of this area consists of coral reefs. Reefs in this subregion are connected but highly ecologically interdependent [239], and are mainly located in the Veracruz Reef System, Campeche Bank in Mexico and Florida Keys. Overall trends show that hard coral cover decreased from 10.8% to 8.8% and macroalgal cover increased from 8.4% to 17.4%, between 1984–2009 and 2020–2024, respectively

(Figure 2.3.7F and Figure 2.3.8F). However, it's important to acknowledge that this report does not contain information on the healthiest coral reefs, or on whether these reefs are outliers, and their cover may not significantly contribute to the regional trend.

Despite their limited extent, these coral reefs provide critical ecosystem services, including fisheries, tourism, and coastal protection. However, both global and local stressors have degraded reef health in recent decades. Rising sea temperatures have driven mass coral bleaching and mortality, while hurricanes and land-based runoff further damage coral reef systems. Additional pressures from unsustainable fishing, unregulated tourism, agricultural pollution, and oil activities continue to undermine ecosystem stability [240, 241]. Notably, some sites in the Flower Garden Banks and parts of the Campeche Bank still maintain relatively high hard coral cover in contrast with highly degraded reefs in the Florida Keys. Coral reefs in the East and West Flower Garden Banks for example, still harbor high live hard coral cover (~56%), dominated by *Orbicella* spp., and host healthy populations of herbivorous fishes [242], in contrast to highly degraded reefs in the Florida Keys.



▲ **Figure 2.3.9.** Spatio-temporal distribution of benthic cover monitoring sites across the Caribbean region and respective subregions. Light blue polygons and numbers represent subregions. Subregion 1 = Bahamas and Bermuda, Subregion 2 = Eastern Caribbean, Subregion 3 = Southern Caribbean, Subregion 4 = Western Caribbean, Subregion 5 = Greater Antilles, Subregion 6 = Florida and Gulf of Mexico. The scale bar provides distance at the equator and may not accurately represent distance over the entire latitudinal range of the region.

DESCRIPTION OF MONITORING DATA

Temporal trends in the percentage cover of benthic categories were estimated using data from 72 datasets, encompassing 14,076 monitoring sites. These data were collected from 24,011 surveys, with 90% conducted after 2002 (Figure A.1). Of all surveys carried out in the region between 1973 and 2025, 34.9% (representing 41.5% of surveyed sites) were conducted in subregion 2, whereas only 4.9% (3% of sites) were conducted in subregion 1 (Table A.4).

CONCLUSIONS

Caribbean coral reefs have experienced over forty years of decline, driven by anthropogenic climate impacts, coral disease, coastal development, unsustainable fishing practices, and the introduction of invasive species. Collectively, these stressors have resulted in a 51.8% decrease in hard coral cover between 1980–2023, with an additional decline from 2023–2024 associated with the fourth global bleaching event and continued spread of SCTLD. At the same time, macroalgal cover has increased, signaling possible shifts to new ecosystem structures. Though management successes demonstrate that targeted interventions can yield measurable benefits for Caribbean reefs, broadly consistent declines in health are evident across all subregions.

Altering this trajectory is essential to preserving coral reef ecosystem services that directly or indirectly benefit millions of people. The implementation of conservation measures such as fully protected areas, improved water quality and wastewater management, amelioration of coastal impacts, strengthened fisheries management, restoration, research on genetically resilient species and other mitigation approaches (alongside urgent global reductions in greenhouse gas emissions) are critical to bolstering the climate-resilience of Caribbean coral reefs. Additionally, standardizing reef monitoring approaches, establishing effective data sharing across global and regional initiatives — particularly through open access datasets, and building regional consistency in classifying key benthic indicators of reef health (*e.g.* turf algae) will facilitate more effective reef health tracking.

DATA CONTRIBUTORS

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Access to online supplementary materials

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

CASE STUDY 3

Effective strategies for rebuilding Caribbean reef fish populations

Authors

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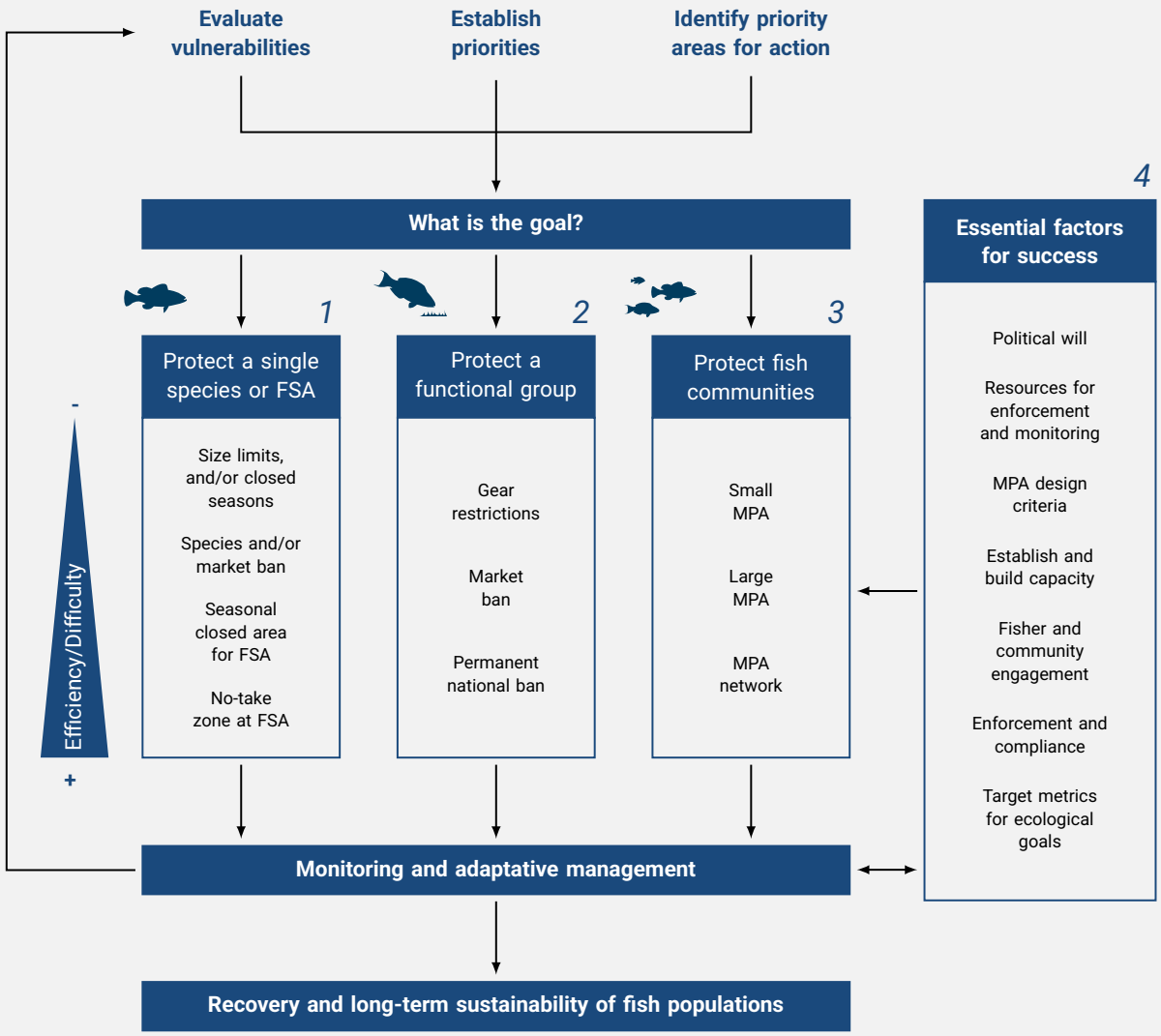
Caribbean coral reefs support a rich diversity of reef fish that play essential roles in maintaining ecosystem health. However, these fish populations have experienced dramatic declines in recent decades, primarily due to overfishing and habitat degradation [221, 225]. The loss of key fish species not only threatens the ecological balance of the reefs, but also impacts the livelihoods of coastal communities that depend on healthy fisheries for food and income. Recognizing the urgency of this crisis, Caribbean nations and territories have adopted a suite of science-based management strategies aimed at rebuilding vulnerable fish populations and restoring reef resilience. The key aspects of these strategies include 1) evaluating vulnerabilities, 2) establishing priorities, 3) targeting areas needing improvement, and, most importantly, 4) identifying target metrics for achieving ecological goals and socio-economic needs that inhibit progress for sustainable fisheries (Figure C3.1). Case studies from the US Virgin Islands, Bonaire, the Dominican Republic, and the broader Mesoamerican Reef illustrate both the challenges and successes of strategies for rebuilding vulnerable fish populations, protecting ecologically important fish, harmonizing transboundary fish management, and investing in effective marine management.

Rebuilding vulnerable fish populations

Many commercially and ecologically important reef fishes form spawning aggregations, where hundreds to thousands of individuals gather for reproduction at predictable times and locations. Once discovered by fishers, these large gatherings are very vulnerable to overfishing and population collapse [243].

In the US Virgin Islands, the decline of Nassau grouper (*Epinephelus striatus*) and red hind (*Epinephelus guttatus*) populations prompted a comprehensive conservation response focused on fish spawning aggregations. Regulatory actions developed with community participation, such as harvest bans and possession prohibitions, were enacted to protect these species during critical spawning periods. Spatial closures, including the Red Hind Bank Marine Conservation District in 1990 and the Grammanik Bank in 2005, provided safe havens for spawning aggregations. Adaptive management, informed by acoustic telemetry and ongoing monitoring over several decades, allowed for the refinement of protected areas and closure periods to maximize conservation outcomes.



▲ **Figure C3.1.** The decision tree for rebuilding sustainable fish populations is designed to help natural resource managers evaluate vulnerable fish populations, establish ecological and socio-economic priorities, and target areas needing improvement. The ecological goals recognize the different management approaches needed to address the vulnerabilities of (1) individual species, especially those that form fish spawning aggregations (FSA), (2) ecologically important functional groups such as parrotfishes, and (3) biologically complex fish communities. The level of difficulty of implementing the various management alternatives does not necessarily translate to greater success of reaching ecological goals. The success of any one of these management alternatives in rebuilding sustainable fish populations is largely dependent upon seven essential social-economic components (4). These components range from strong leadership that provides thoughtful, integrative and inclusive planning and implementation strategies to achieve ecological goals, to sufficient resources to build capacity for science-based management, monitoring, and enforcement. Regular evaluation of target progress, via monitoring and fisher engagement, are required to adapt management actions to new information, and recover and stabilize vulnerable fish populations. As seen in the case studies, it can take decades for depleted fish populations to recover, and recovery timelines are dependent on individual species life history patterns.

The involvement of local fishers was crucial for compliance, and the results were striking. The Marine Conservation District (41 km^2) was changed to a permanent no-take zone in 1999 and, after 30 years of protection, red hind populations showed significant gains in size (35% increase) and density; and spawning potential increased to its highest levels [244–246]. The 1.5 km^2 Grammanik Bank, a three-month seasonal closed area, allowed Nassau grouper abundance to increase from 30 individuals to over 1,000 individuals in 20 years [247]. Due to their continued vulnerability, Nemeth *et al.* [248] recommended that the Grammanik Bank be expanded from 1.5 to 6.5 km^2 and the closed period extended to five months. Enacting these changes would increase spatial and temporal protection of the Nassau grouper spawning population to 95%.

The key to recovery of these vulnerable populations in the US Virgin Islands and elsewhere is long-term, dedicated collaborative and adaptive management based on research and monitoring data, and highlights the importance of protecting fish spawning aggregation sites as a critical management tool [249, 250]. Because fish spawning aggregation sites are used for reproduction by multiple species, like groupers and snappers, but at different times of year, protecting a single spawning aggregation site will have far-reaching benefits for rebuilding spawning populations of many important functional groups.

Protecting ecologically important fish

Herbivorous fish, especially parrotfish, are a cornerstone of reef health, as their grazing prevents algae from overgrowing corals and facilitates coral recruitment. Both Bonaire and the Dominican Republic have implemented regulations to protect parrotfish, including harvest bans and gear restrictions [251]. Bonaire's success in parrotfish protection is attributed to strong enforcement, sustainable funding through a reef usage tax, and systematic ecological monitoring; which, combined, have stabilized parrotfish populations and boosted coral recruitment [252]. In contrast, the Dominican Republic's efforts have been hampered by a higher demand on parrotfish as a staple food source, weak enforcement, insufficient funding, and inconsistent monitoring, leading to continued declines in parrotfish numbers and diminished conservation effectiveness [253].

Strengthening protection through enforcement and adaptive management based on consistent long-term monitoring data will provide the protection needed to help rebuild key ecological fish populations. In the Mesoamerican Reef, species-specific fisheries regulations have become important tools to protect key functional groups. Belize pioneered regional action in 2009 by banning the harvest of herbivorous fishes, setting a precedent later followed in Honduras, Guatemala, and Mexico through national bans, protected species listings, and restrictions on destructive fishing gear in reef areas [254]. Parrotfish in the wider Caribbean region are protected under the Specially Protected Areas and Wildlife (SPAW) Protocol, a regional environmental treaty among 19 countries. In 2023, all parrotfish species were added to Annex III, which requires countries to regulate their sustainable use.

Harmonizing fish management across borders

Harmonizing fish management across borders is central to rebuilding fish populations in the Mesoamerican Reef and relies on a complementary set of management strategies. These include the protection of fish spawning aggregations through layered spatial measures (*e.g.* no-take zones within Marine Protected Areas (MPAs)), national and regional fisheries bans

(*e.g.* parrotfish), and species and gear-specific regulations implemented inside and outside protected areas. Evidence from across the Mesoamerican Reef demonstrates that fully protected areas consistently sustain much higher fish biomass (~1,200 g.100 m^{-2}) compared to general-use or unprotected areas (500 g.100 m^{-2}). Cozumel (Mexico) exemplifies how these strategies can act synergistically: while much of the reef system is under some form of protection, approximately 35% of the surrounding marine area is fully protected, resulting in fish biomass levels that are roughly double those of less protected areas [254].

Regional cooperation has led to species-specific bans, gear restrictions, and seasonal closures, but enforcement and coverage of protected areas remain below international targets. The most promising path forward involves strategic expansion of fully protected reserves, science-based regulations, robust enforcement, and cross-border collaboration and advocacy, such as the Healthy Reefs for Healthy People Initiative.

Investing in essential components for success

Key factors contributing to MPA success in restoring Caribbean reef fish populations include ongoing commitment to science-based adaptive management, strong enforcement, fisher engagement and compliance, strategic MPA design, and regional collaboration [255].

Significant progress is being made through multifaceted strategies that integrate regulatory protections, spatial and temporal closures, long-term monitoring, and robust stakeholder engagement.

Looking ahead, priority actions should include protecting vulnerable and ecologically important fish species, especially those forming spawning aggregations, expanding fully protected marine reserves, and securing sustainable funding. Together, these are essential steps towards the long-term recovery and sustainability of fish populations and the sustained resilience of reef ecosystems (Figure C3.1).

CASE STUDY 4

Adaptive coral reef restoration in The Bahamas: the MSC Foundation's Ocean Cay Restoration Programme

Authors

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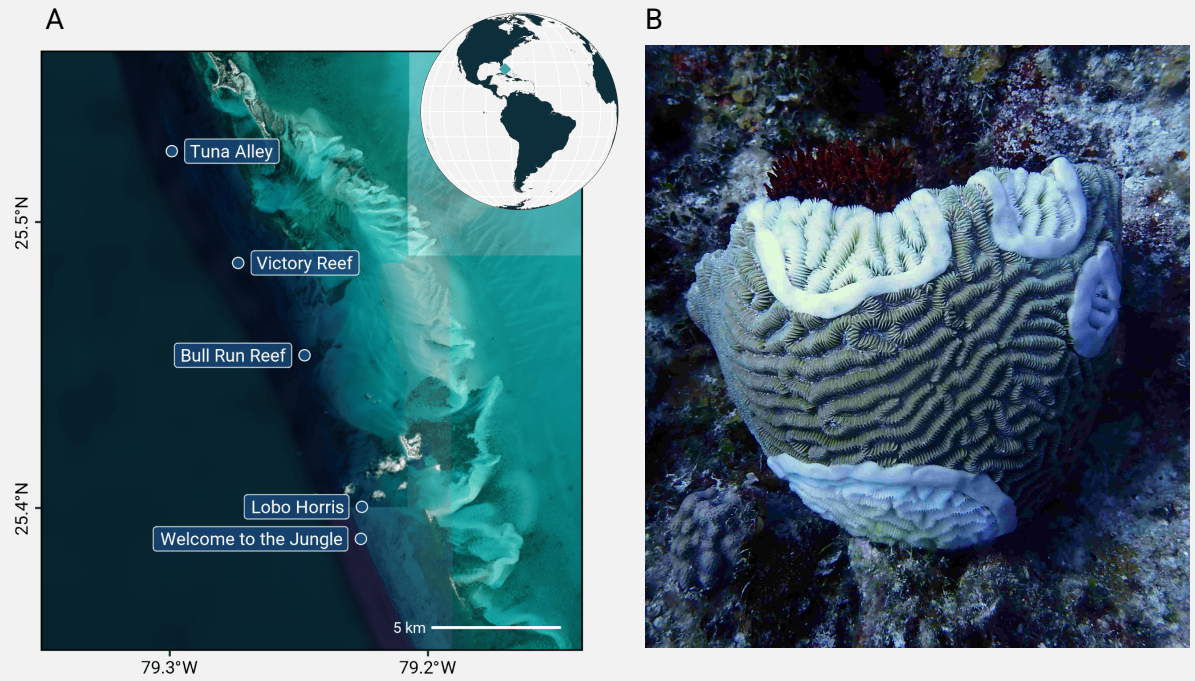
The MSC (Mediterranean Shipping Company) Foundation's marine conservation programme at Ocean Cay (The Bahamas) constitutes a science-based restoration initiative designed to restore ecologically resilient coral reef ecosystems while helping to further develop national capacity in The Bahamas. Integrating coral restoration, applied research, education, and public engagement, the programme aims to enhance the resilience of coral reef ecosystems to environmental stressors whilst maintaining and, where possible, enhancing local biodiversity. Implementation of the programme is underpinned by strong collaboration with experts around the world, international institutes, including the Perry Institute for Marine Science, University of Miami, Nova Southeastern University, and national institutions such as the University of The Bahamas and The Bahamas Agriculture and Marine Science Institute. This global collaboration enables the MSC Foundation to align international technical expertise with national knowledge and priorities.

To establish robust ecological baselines and quantify reef condition trajectories, Perry Institute for Marine Science, supported by the MSC Foundation, conducted Rapid Ecological Assessments in 2019 and 2025 (Figure C4.1), applying standardised Atlantic and Gulf Rapid Reef Assessment (AGRRA) protocols alongside permanent photomosaic monitoring ($\geq$100 m^2 plots with georeferenced markers). These assessments captured reef dynamics in the context of acute and chronic stressors, including the 2023 marine heatwave and the regional expansion of Stony Coral Tissue Loss Disease (SCTLD).

Across surveyed sites, live hard coral cover remained persistently low (2–5.5%), with no statistically significant temporal change at most locations between 2019 and 2025, although one site exhibited a decline from ~5% to ~2%, potentially influenced by fine-scale habitat heterogeneity. Notwithstanding this apparent stability in overall hard coral cover, pronounced shifts in coral community composition were detected. Coral assemblages documented in 2019 exhibited higher species richness and more even relative abundances, whereas by 2025, declines in thermally sensitive coral taxa, including *Agaricia agaricites* and *A. tenuifolia*, and to a lesser extent *Porites furcata*, were evident, consistent with impacts from the fourth global bleaching event. In contrast, relatively thermally tolerant species such as *Porites astreoides* and *Siderastrea siderea* increased in proportional abundance. Importantly, the persistence of remnant populations of sensitive coral taxa suggests potential local acclimatory or adaptive capacity that may be leveraged in restoration planning.



▲ **Figure C4.1.** Location of the five surveyed sites, in Cat Cays, The Bahamas (A). A diseased *Colpophyllia natans* colony in Bull Run Reef, May 2026 (B) (credit: Emeline Bouchet).

Disease emergence represents a compounding pressure. SCTLD, first recorded nationally in 2019, was not observed at Ocean Cay until 2024 but expanded to multiple sites by 2025, affecting several susceptible coral species. Coral disease progression has been quantified using high-resolution photogrammetry and digital reef "twins", enabling colony-scale tracking of lesion dynamics. Active *in situ* mitigation, including antibiotic treatment trials, is being implemented to slow tissue loss and preserve reproductively viable colonies. These results, and active mitigation measures, highlight Ocean Cay as a site of particular conservation importance as a refuge for relatively intact breeding populations of SCTLD-susceptible species within The Bahamas.

Fish assemblages remained broadly stable over the assessment period, with spatial variability attributed primarily to recruitment dynamics rather than directional environmental change. Densities of key functional groups, including herbivorous parrotfish, snappers, and grunts, showed no consistent temporal decline, although a localised increase in juvenile *Scarus taeniopterus* was recorded in 2025.

Informed by these findings, the MSC Foundation's Marine Conservation Center, located at Ocean Cay, prioritises increasing coral biomass and structural complexity through integrated restoration strategies that combine asexual propagation (*in situ* and land-based nurseries) with sexual reproduction (larval rearing, settlement, and outplanting). These interventions are coupled with continuous environmental monitoring and targeted disease mitigation to enable adaptive management. Through coordinated implementation with national partners, the programme aligns with broader conservation objectives, contributing to the protection and long-term resilience of Bahamian coral reef ecosystems while advancing scalable restoration approaches relevant to the wider Caribbean.

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