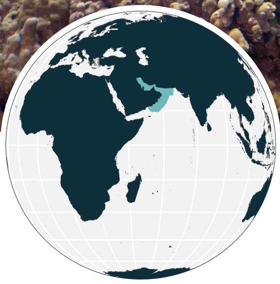
Coral reef in the Gulf of Oman
Credit: Christophe Chellapermal



ROPME SEA AREA

Authors

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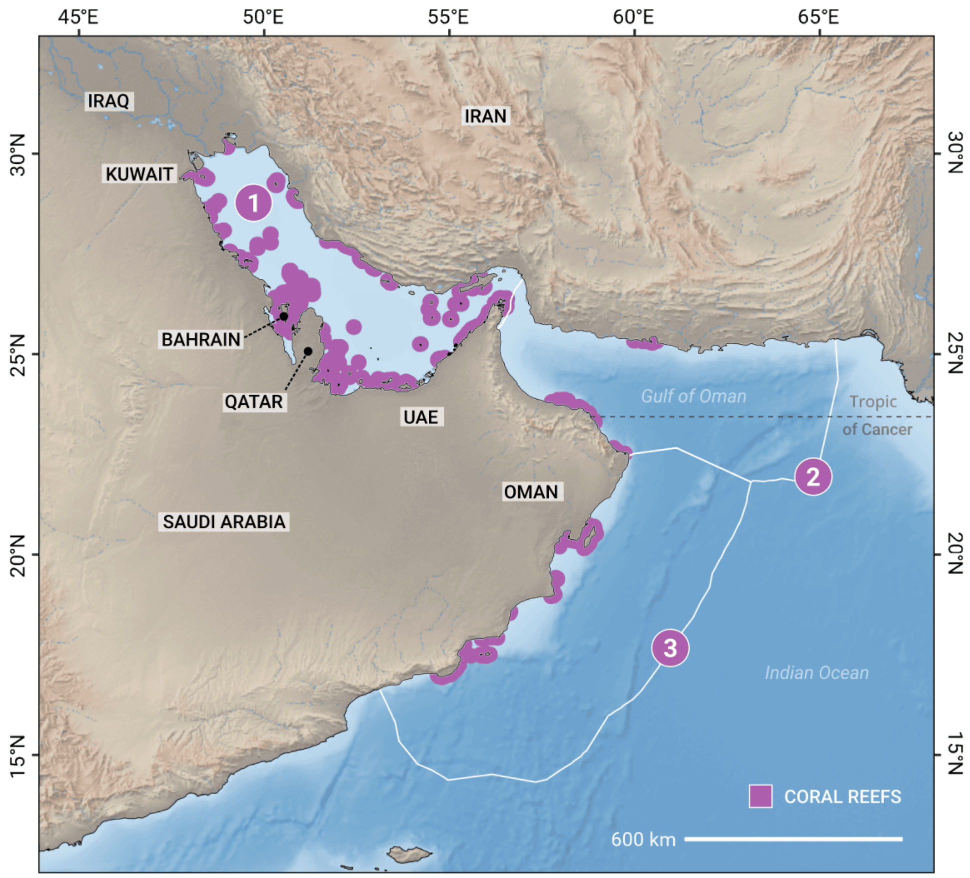
INTRODUCTION

The Regional Organization for the Protection of the Marine Environment (ROPME) Sea Area GCRMN region extends over a maritime area of around 1 million km^2, ranging across 17° of latitude and 19° of longitude. The region hosts 1,808 km^2 of coral reefs, representing 0.7% of the world's coral reef extent, ranking it as the eighth largest GCRMN region based on total coral reef extent. Coral reefs reside within the exclusive economic zones of eight countries in the region, ranging from Kuwait and Iraq in the northwest, to Iran in the East, and Oman in the South (Figure 2.8.1)[1].

For the purpose of this report, the ROPME Sea Area region was divided into three subregions (Figure 2.8.1), with subregion 1 (Persian/Arabian Gulf), subregion 2 (Gulf of Oman), and subregion 3 (Southern Oman) hosting 73.2% (1,324 km^2), 9.9% (178 km^2) and 16.9% (306 km^2) of the regional coral reefs extent, respectively (Table A.1).



▲ **Figure 2.8.1.** The distribution of coral reefs within the ROPME Sea Area region and respective subregions. White polygons and numbers represent subregions. Subregion 1 = Persian/Arabian Gulf, Subregion 2 = Gulf of Oman, Subregion 3 = Southern Oman. 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.

[1] The area of reef extent is slightly lower in this report compared with the 2020 GCRMN report due to a shift in the southern border to the Oman-Yemen border, whereas the 2020 report included parts of eastern Yemen in the outer ROPME Sea Area.

Coral reefs represent an important socio-economic resource for coastal communities in the ROPME Sea Area, as well as a growing focus for scientific research on climate adaptation. As of 2020, a total of 3.4 million people were living within 5 km of coral reefs across the ROPME region (Table A.2). From 2000 to 2020, the region recorded over a threefold (208.2%) increase in human populations residing within 5 km of coral reefs, representing an average annual increase of approximately 114,000 inhabitants. The greatest population increase over this period was recorded in subregion 1 (Persian/Arabian Gulf), which hosted the vast majority (95.9%) of regional reef-adjacent inhabitants in 2020 (Table A.2).

THREATS AND DISTURBANCES

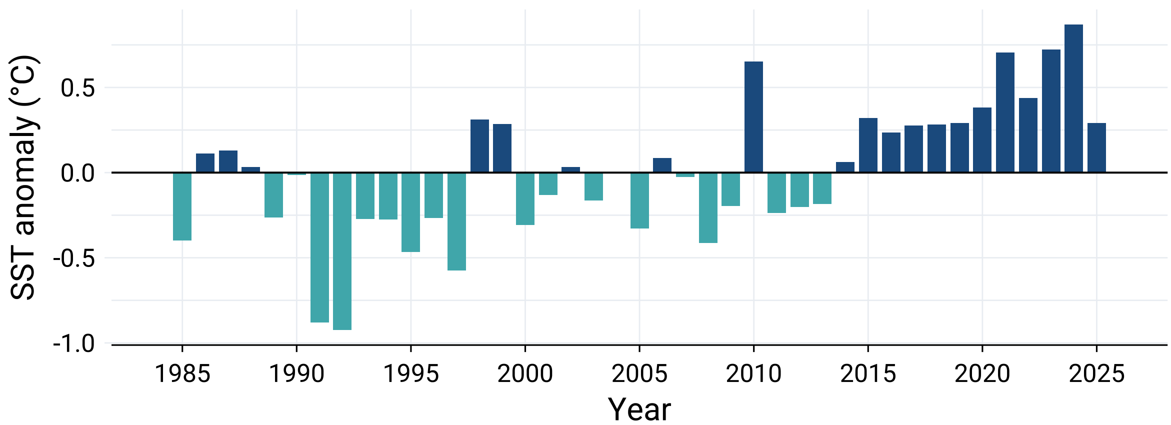
Heat stress

Between 1985 and 2025, the long-term average of sea surface temperature (SST) recorded over coral reefs was 26.76 °C across the entire ROPME region. During this period, the SST over regional coral reefs increased by 0.5 °C, corresponding to an average warming rate of 0.12 °C per decade (Table A.3).

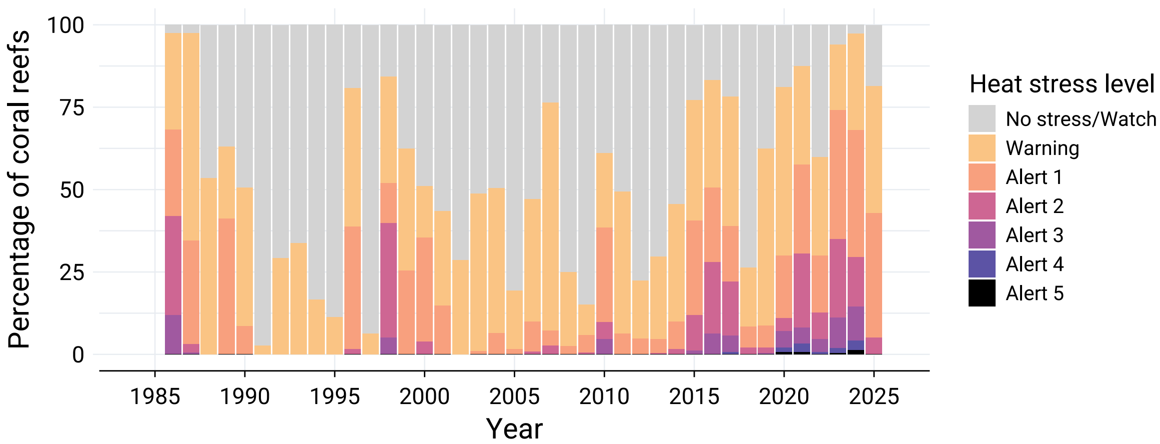
Between 1986 and 2025, major heat stress (Bleaching Alert 1–5) affected ROPME reefs in distinct pulses: the mid-1980s (1986–1987), a strong late-1990s/early-2000s cluster (1996–2002, peaking in 1998), and renewed events around 2010 in multiple years (Figure 2.8.3). During the third global bleaching event from 2014–2017, regional heat stress became more frequent and began reaching higher alert levels across a substantial fraction of reefs. Since 2020, severe heat stress has occurred annually, with a larger proportion of reefs being exposed to Alert 2–4, and the maximum Alert 5 heat stress level occurring in most years, consistent with accelerating regional heat stress exposure [391].

Coastal development

Coastal development represents a major non-climatic pressure on reefs in the ROPME Sea Area, particularly in subregion 1 (Persian/Arabian Gulf), where coastal urbanized area expanded by 55% between 2001 and 2021 [392].



▲ **Figure 2.8.2.** Annual mean sea surface temperature (SST) anomalies (°C) over the coral reefs of the ROPME Sea area 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 2.8.3.** Percentage of the coral reefs within the ROPME Sea area region experiencing heat stress levels per year, from 1986 to 2025. No stress/Watch (DHW = 0); Warning (possible bleaching, $0 < \text{DHW} < 4$); Alert 1 (reef-wide bleaching, $4 \leq \text{DHW} < 8$); Alert 2 (reef-wide bleaching and mortality of heat-sensitive corals, $8 \leq \text{DHW} < 12$); Alert 3 (multi-species mortality, $12 \leq \text{DHW} < 16$); Alert 4 (severe multi-species mortality, $16 \leq \text{DHW} < 20$); and Alert 5 (near-complete mortality, $\text{DHW} \geq 20$). Derived from NOAA Coral Reef Watch data (Skirving *et al.* [107]; see Materials and Methods).

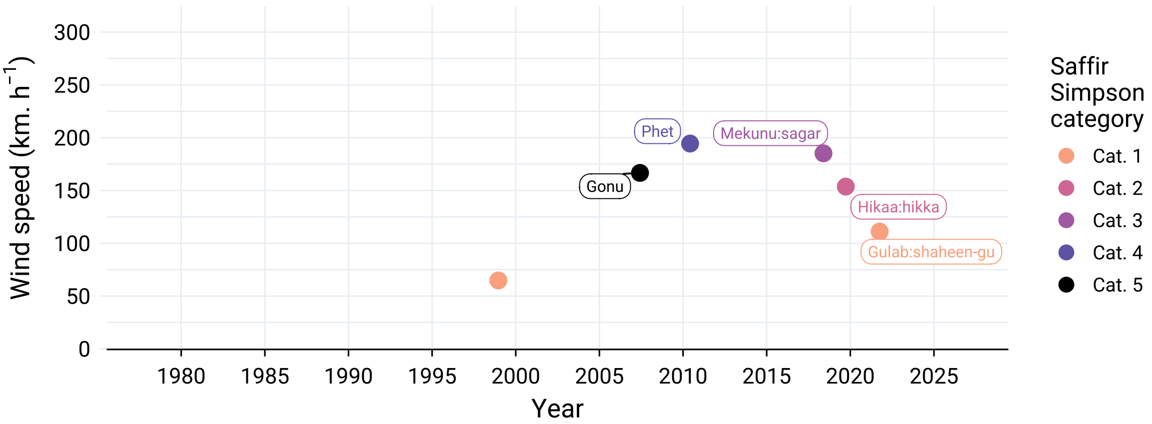
Large-scale reclamation, dredging, and channelization have resulted in the direct loss of reef habitat and extensive sediment plumes that degrade adjacent reef systems [393]. Such developments have also occurred in subregions 2 and 3, but at far lower intensities and with more limited reef impacts, except around the Muscat capital area in Oman [394].

Harmful algal blooms

Harmful algal blooms have emerged as an episodic but consequential disturbance. While typically confined to lagoons and embayments, the persistent 2008–2009 harmful algal bloom and associated anoxia extended across much of subregion 2 and into subregion 1, causing widespread mortality from which many reefs have yet to fully recover [395]. Increasing coastal wastewater input and rising SSTs suggest that harmful algal bloom frequency and extent are likely to intensify [396].

Fishing pressure

Fishing pressure affects reefs across the region, but uneven monitoring effort prevents reliable inference about where its impacts are greatest. Regionally common fishing gear, including *gargoors* (traditional wire fish traps), seine nets, drift nets, and others, can cause direct physical damage to reef habitats through placement, dragging, and incidental breakage during removal [397, 398]. Beyond these direct effects, fishing pressure may influence reef resilience through the selective removal of key functional groups, especially herbivorous and predatory fishes, with potential consequences for benthic recovery trajectories and ecosystem functioning [397, 398]. These indirect effects are likely to interact with disturbance history and local environmental conditions, rather than acting in isolation. Additional understudied pressures, including pollution, localized hypoxia, and location-specific seasonal macroalgal and turf algal overgrowth, further compound the vulnerability of coral reefs across the ROPME region.



▲ **Figure 2.8.4.** Maximum sustained wind speed of cyclones that passed within 100 km of a coral reef in the ROPME Sea Area region between 1980 and 2025. Colors correspond to the Saffir–Simpson category of the cyclone along its entire track. However, the values of sustained wind speed are extracted from the nearest cyclone 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).

Cyclones and storms

Between 1980 and 2025, a total of six cyclones passed within 100 km of coral reefs in the ROPME Sea Area (average 0.2 ± 0.4 SD cyclones per year, Figure 2.8.4). Cyclone tracks and impacts are exclusively confined to ROPME subregions 2 and 3 (Gulf of Oman and, particularly, Southern Oman). The category 5 cyclone Gonu in 2007 had the greatest impacts on the coral reefs, which led to severe wave-related damage to exposed reefs across the UAE and Oman's Gulf of Oman coasts and islands, with some reefs also experiencing cyclone-induced sedimentation impacts [394]. It is also possible that cyclones have impacted reefs in southern Oman in ROPME subregion 3, but limited reef monitoring activities in that area hamper interpretation. In addition to cyclones, several tropical storms have also impacted coral reefs in the ROPME Sea Area [399].

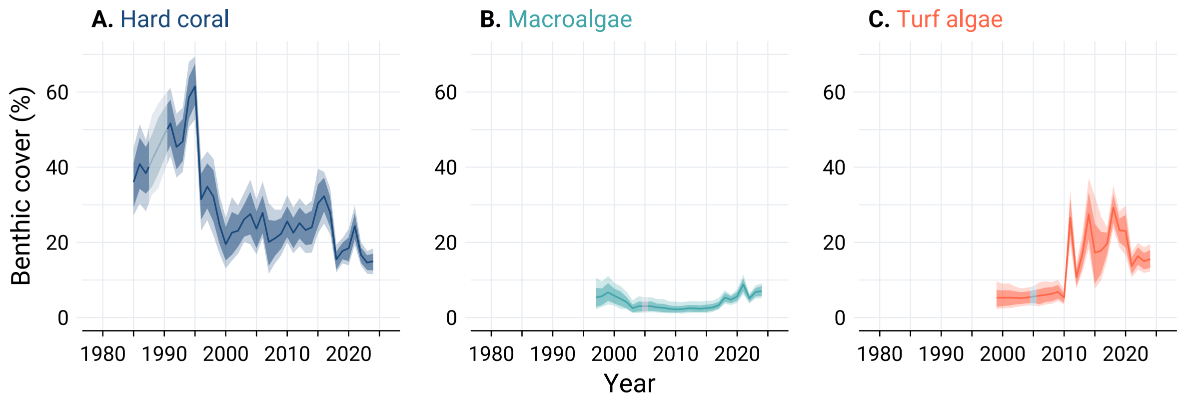
STATUS OF CORAL REEFS IN THE REGION

The modeled trajectories of benthic cover across the ROPME region show how hard coral and macroalgal communities changed from 1985 to 2024 (Figure 2.8.5). They reveal repeated disturbance-recovery cycles, followed more recently by persistently low hard coral cover, driven primarily by recurrent marine heatwaves and bleaching, with subregional influence from cyclones, harmful algal blooms, and coastal pressures.

Hard coral cover

High hard coral cover in the 1980s and early 1990s

The reconstructed timelines indicate hard coral cover was high across the region during the 1980s, averaging nearly 40% of the benthos in 1985 and increasing into the early 1990s (Figure 2.8.5A). Although monitoring data from this period are limited (see Description of monitoring data), the estimates are consistent with historical accounts describing exten-



▲ **Figure 2.8.5.** Modeled temporal trends of benthic cover in the ROPME Sea area 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.

sive coral assemblages across subregions 1 and 2 before major late-1990s SST extremes (Figure 2.8.2 and Figure 2.8.3) [400–404]. Much of this baseline reflected widespread *Acropora*-dominated communities, particularly in subregion 1, which were structurally important but highly sensitive to heat stress [34, 400]. The early 1990s therefore likely represent a pre-disturbance regional baseline before recurrent marine heatwaves became a defining feature of the system.

Abrupt decline following back-to-back bleaching events (1996 and 1998)

The most pronounced feature of the trajectory is the sharp decline in hard coral cover beginning in the mid-1990s. Over the five years to 2000, regional hard coral cover more than halved, from 61% in 1995 to 23% in 2000 (Figure 2.8.5A). This collapse reflects the severe impacts of the 1996 and 1998 marine heatwaves (Figure 2.8.3) associated with the first global bleaching event [34], which caused widespread mortality across subregion 1 (Persian/Arabian Gulf) and the near-extirpation of branching corals in many areas [405–409]. The magnitude and timing of the modeled decline closely match field observations, and mark the first major regional shift in benthic community structure during the modern warming era. This reflects the concentration of extreme late-1990s heat stress in subregion 1, whereas comparable impacts were less evident in subregions 2 and 3.

Partial recovery and a suppressed post-disturbance equilibrium (2000–2016)

Following the late 1990s collapse, hard coral cover recovered gradually, but incompletely, during the 2000s and early 2010s, exceeding 30% by 2015 but never returning to the >50% levels of the early 1990s (Figure 2.8.5A). Field observations indicate that this recovery was often driven by heat-tolerant massive and encrusting corals rather than the formerly dominant branching *Acropora*, especially in the southern Persian/Arabian Gulf [98, 407, 410]. This partial rebound occurred during a relative lull between the late-1990s heat-stress cluster and the more frequent severe events after 2016, with localized heat stress around 2010 (Figure 2.8.3) producing only modest impacts on regional cover [411]. The period thus represents the longest interval without major regional mortality in the monitoring record, yet the failure to fully recover to high former hard coral cover levels suggests that earlier bleaching had already reduced structural complexity and recovery capacity, shifting reefs toward a lower-cover state.

Renewed decline following the 2017 and 2021 bleaching events

From 2016 to 2024, the modeled trajectory enters a renewed decline that aligns with more frequent high-level heat stress during the mid-2010s and annual severe heat stress after 2020 (Figure 2.8.3). The downturn intensified in 2017, when subregion 1 (Persian/Arabian Gulf) experienced its hottest summer on record, with reef temperatures exceeding 37 °C at several monitored sites [412]. This event caused widespread mortality across the southern and western Gulf, including reefs where *Acropora* had previously regained dominance, and drove average regional hard coral cover below 20% for the first time on record in 2018 (Figure 2.8.5A).

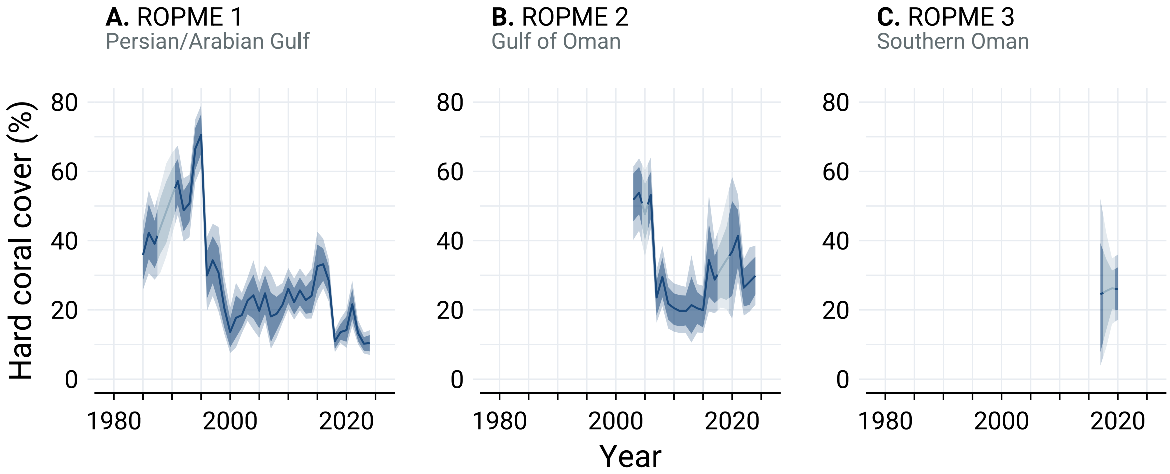
A further decline followed the severe 2021 SST anomaly (Figure 2.8.2), which affected much of subregion 1 and parts of subregion 2 (Gulf of Oman). Particularly strong impacts fell on remnant *Acropora* refugia, showing that thermally sensitive branching assemblages remained the principal source of regional vulnerability (*e.g.* Sir Bu Nair Island on the UAE's Gulf coast and Khor Fakkan on the UAE's Gulf of Oman coast). These stands, already greatly reduced by earlier disturbances but partially recovered, suffered renewed mortality during the 2021 marine heatwave [413]. The modeled trajectory captures this decline, with hard coral cover of 24% in early 2021 falling by roughly one-third the following year.

Additional bleaching in 2023, observed in both the southern Gulf and the Muscat area (subregions 1 and 2), further affected already depleted coral populations. A more extreme event followed in 2024 (Figure 2.8.2 and Figure 2.8.3), beginning in the Gulf of Oman in July and extending across most reefs in the southern Arabian Gulf in subsequent months. By then, monitoring data showed the lowest average hard coral cover yet reported for the region, with no evidence of rebound (median regional hard coral cover in 2024: 15%) (Figure 2.8.5A). Collectively, these trends indicate recovery intervals are now shorter than disturbance intervals under near-annual heat stress, and point to a declining regional capacity for resilience.

Macroalgal cover

Low and stable algal cover through the 1990s and 2000s

Macroalgal cover was very low (<5%) in the mid-1990s, which is consistent with the high hard coral cover, and thus limited substrate availability, during this period. Although monitoring data are not available, literature descriptions indicate algal communities primarily consisted of macroalgae and turf, and encrusting calcareous algae occupied minor space as well; transient seasonal macroalgal blooms were common on regional reefs (*e.g.* during spring in subregion 1 and during monsoonal upwelling in subregion 3) [398, 414]. After the 1996 and 1998 bleaching events, macroalgal cover increased modestly to ~5% (Figure 2.8.5B), consistent with early successional dynamics in which turf and fleshy algae were reported to colonize newly dead coral skeletons [398, 414]. However, the increase in macroalgae was negligible in magnitude relative to the substantial hard coral loss that occurred during this period, reflecting observations at that time of limited algal colonization of dead reef framework [407]. This indicates that, at the regional scale, turf and macroalgal expansion in the wake of these early bleaching events through the 2000s was limited by environmental conditions and/or grazing pressure.



▲ **Figure 2.8.6.** Modeled temporal trends of hard coral cover in ROPME Sea area 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.

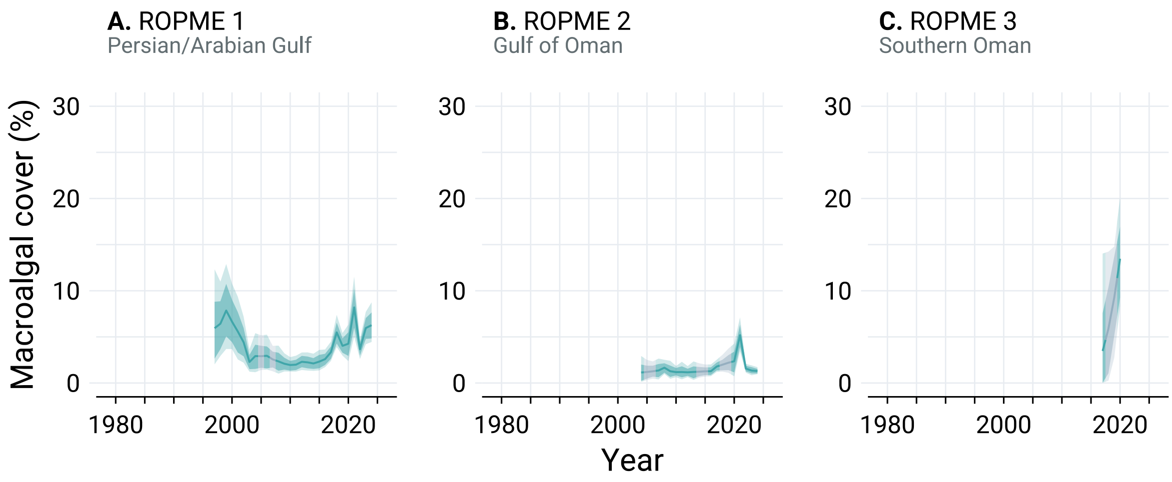
Gradual upward trajectory after 2010, without a region-wide phase shift

A feature of the modeled estimates is the gradual, low-magnitude rise in macroalgal cover from 2010 onward, and an abrupt rise in turf algae (Figure 2.8.5B and Figure 2.8.5C). Macroalgal cover increased steadily into the early 2020s, with a particular upward inflection after the 2017 bleaching event, with a peak macroalgal cover of ∼9% in 2021 (Figure 2.8.5B). This trend suggests that, while regional macroalgal abundance has increased over time, particularly following 2017 and 2021 coral mortality events, there has not been a widespread transition to macroalgal dominance at the scale of the entire ROPME region, despite substantial declines in live hard coral cover at the regional scale. That said, turf algae, rather than macroalgae, has become an increasingly common member of the benthic community in parts of the region (Figure 2.8.5C), rapidly occupying coral skeletons in the wake of bleaching. Although variable, turf algae since 2011 has hovered between 15 and 30% coverage, compared with ~5% in the early 2000s, representing a substantial component of the benthos in recent years, and often exceeding the amount of regional live hard coral cover (Figure 2.8.5A).

Overall, the trajectory suggests that macroalgal cover has responded to repeated coral mortality events but remains a minor component of regional benthic structure. Despite substantial hard coral cover loss, the continued absence of region-wide macroalgal dominance indicates that herbivory may still play a role in limiting macroalgal expansion, although the relative contributions of grazing versus environmental constraints cannot be resolved with the available data. Further integration of herbivorous fishes and urchins into regional monitoring is warranted. Turf algae, however, has become a dominant member of the benthos, likely impairing coral recovery via direct space occupation and trapping of sediments that reduce larval coral settlement rates [415].

Synthesis and implications for resilience

When considered together, the modeled trends for hard coral and algae illustrate that the ROPME Sea Area as a whole is undergoing prolonged ecological restructuring. Average hard coral cover has declined from



▲ **Figure 2.8.7.** Modeled temporal trends of macroalgal cover in ROPME Sea area 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.

a high of >50% in the 1990s to ~15% by 2024, with the partial recovery that occurred in the mid-2000s giving way to a second, more persistent and extreme decline after 2017.

In contrast to the trajectory following the 1996 and 1998 bleaching events, when hard coral cover rebounded to ~30%, the most recent downturn shows no sign of recovery, showing instead a near continual decline over the past decade, reflecting more frequent marine heatwaves superimposed on reefs already weakened by earlier bleaching, harmful algal bloom impacts, cyclones, and local pressures.

Macroalgal cover, while increasing gradually over the monitoring period, remains comparatively low, while turf algae has become increasingly common on regional reefs since 2010. The steady upward trend in macroalgae and, particularly, turf algae suggests growing competitive pressure on juvenile coral recruitment and highlights the likely importance of herbivore communities in maintaining reefs in non-algal-dominated states. Alongside heat stress, changes in grazing communities may further influence recovery potential by modifying key ecological processes, even where reefs have not transitioned to macroalgal dominance.

Taken together, these patterns depict a regional coral reef system that has undergone multiple disturbance cycles and is currently facing increasing recovery challenges, resulting in lower region-wide hard coral cover than in the past. The declining recovery ceiling, compounded by recent recurrent severe bleaching events (2017, 2021, 2023, 2024), suggests regional resilience is being eroded by chronic exposure to extreme temperatures. The trajectories modeled here therefore reinforce the conclusion that the ROPME Sea Area, despite hosting the world's most thermally tolerant corals [416], is increasingly vulnerable as warming trends accelerate and the frequency of extreme events continues to rise with climate change.

STATUS OF CORAL REEFS IN THE SUBREGIONS

The modeled trajectories show clear subregional contrasts in reef condition and recovery pathways (Figure 2.8.6 and Figure 2.8.7). Subregion 1 largely determines the regional pattern because it contains the most reef area and monitoring effort, and shows the strongest long-term decline: high hard coral cover in the 1980s, collapse after the 1996 and 1998 bleaching events, partial recovery through the 2000s, and renewed decline after 2017. By contrast, subregion 2 exhibits a later and more punctuated disturbance-recovery sequence, with declines linked first to cyclone Gonu and the 2008–2009 harmful algal bloom event, followed by recovery through the 2010s and renewed losses under recent bleaching. Subregion 3 remains too data-limited for robust temporal comparison, as only two datasets are available; therefore interpretation is necessarily qualitative.

ROPME 1 - Persian/Arabian Gulf

Subregion 1 most closely mirrors, and largely drives, the region-wide trajectory, consistent with the dominance of this subregion in the overall dataset (28 of 34 datasets). Hard coral cover was high during the 1980s, before declining sharply in the late 1990s following the 1996 and 1998 bleaching events (Figure 2.8.6A). This collapse, one of the most consequential in the history of Gulf reef systems, resulted in widespread mortality of branching corals and shifts toward thermally tolerant massive coral taxa [98, 407]. The modeled decline is substantial and sustained, with hard coral cover stabilizing at 20 to 30% through much of the 2000s and early 2010s.

The partial recovery during this period reflects both the resilience of surviving coral taxa and the absence of major Gulf-wide disturbance events. However, as seen in the regional trend, hard coral cover did not return to its earlier high levels, suggesting a lower post-disturbance equilibrium. Following the 2017 bleaching event, hard coral cover in subregion 1 declined again, with losses continuing after widespread bleaching-induced mortality in 2021 (Figure 2.8.6A). The 2024 bleaching event likely contributed to the protracted downward trajectory. By this time, hard coral cover reached its lowest recorded levels (~10%, the lowest of all subregions), highlighting the cumulative impact of repeated heat stress in a subregion already experiencing the highest summer sea temperatures globally.

Macroalgal cover in subregion 1 remains low across the entire time series (Figure 2.8.7A). Slight increases occurred in 2000 and between 2017 and 2021, likely reflecting the colonization of dead coral substrate that followed episodic bleaching events. However, the macroalgal cover did not exceed an average of 5% in modeled estimates. This is consistent with the historically low macroalgal abundance reported for Gulf reefs [407, 410], where localized herbivory, paired with extreme environmental conditions, may limit macroalgal growth. Following 2017 and 2021, a modest increase in macroalgal cover occurred that mirrors regional patterns, but with no transition to macroalgal dominance.

ROPME 2 - Gulf of Oman

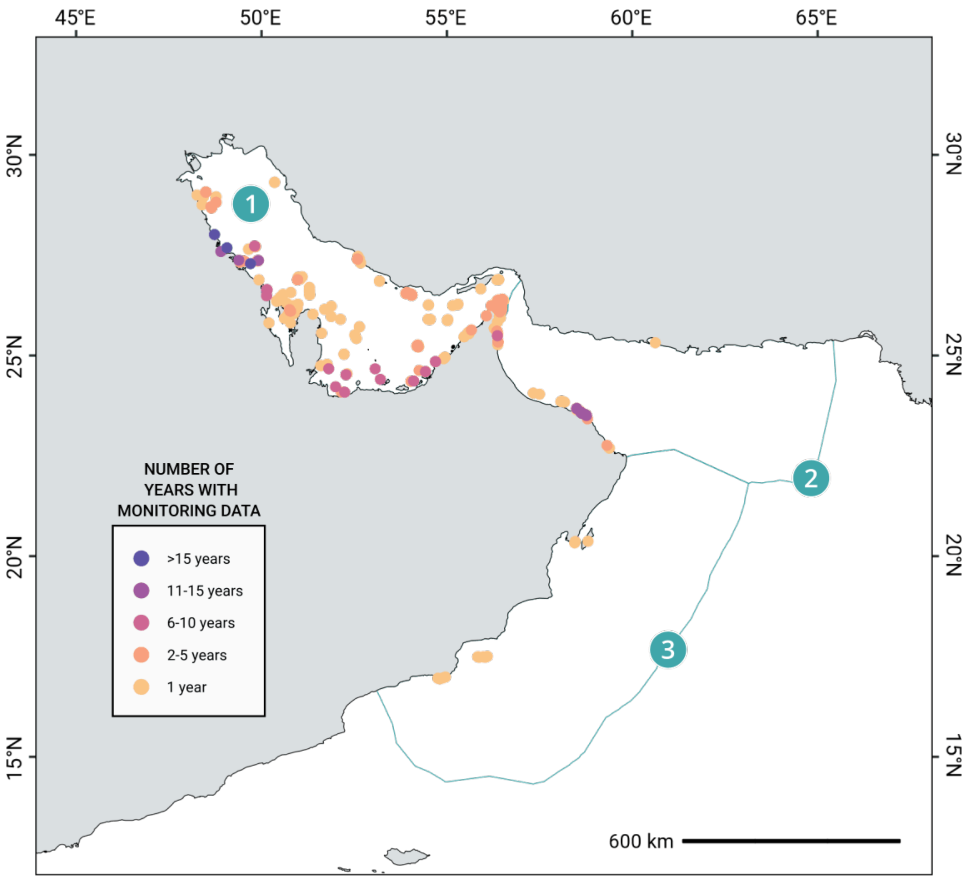
Unlike subregion 1, the Gulf of Oman exhibits a distinct trajectory shaped first by cyclone and impacts from harmful algal blooms [394, 398], and only later by severe bleaching [413] (Figure 2.8.6B). The time series for hard coral cover began in 2003, when average hard coral cover exceeded 50%, reflecting the high diversity and variety of growth forms that is typical for this subregion. A pronounced decline in subregion 2 hard coral cover follows shortly thereafter, driven first by cyclone Gonu in 2007, and then by the 2008–2009 harmful algal blooms-associated anoxia event. In the wake of these events, the lowest hard coral cover of ~25% was recorded in 2012.

Recovery was evident through the 2010s, with the average hard coral cover increasing to over 35% by 2020 (Figure 2.8.6B). This resurgence likely reflects both natural recovery processes and the generally cooler summer temperatures associated with upwelling, which historically reduced the propensity for bleaching in the Gulf of Oman [394]. However, this recovery trajectory was interrupted in the early 2020s (Figure 2.8.6B). Significant coral bleaching occurred in 2021, with profound impacts on the reefs throughout the Gulf of Oman, particularly in areas dominated by branching corals such as *Acropora* [413]. Although the magnitude of decline is more limited than in subregion 1 (from a median of ~41% to 30% between 2021 and 2024), the trend shows clear sensitivity to thermal anomalies, suggesting that even upwelling-influenced systems are increasingly vulnerable to intensified warming.

In subregion 2, macroalgal cover remains very low (averaging ~1–2%) throughout most of the time series, with only a modest rise after 2015 (Figure 2.8.7B). The subdued trajectory may reflect high grazing pressure and the episodic nature of disturbances. The model does not indicate a sustained subregional-scale macroalgal proliferation, despite being more nutrient-enriched compared to subregion 1 [394, 398].

ROPME 3 - Southern Oman

In contrast to subregions 1 and 2, subregion 3 cannot yet be robustly compared because interpretation is constrained by limited data, with only two time points (2017 and 2020) informing the model.



▲ **Figure 2.8.8.** Spatio-temporal distribution of benthic cover monitoring sites across the ROPME Sea Area region and respective subregions. Light blue polygons and numbers represent subregions. ROPME 1 = Persian/Arabian Gulf, ROPME 2 = Gulf of Oman, ROPME 3 = Southern Oman. The scale bar provides distance at the equator and may not accurately represent distance over the entire latitudinal range of the region.

The broad credible intervals reflect this uncertainty. Hard coral cover appears moderate (~20%), but highly uncertain, and macroalgal cover shows an apparent increase toward 2020, though this pattern should not be over-interpreted (Figure 2.8.6C and Figure 2.8.7C). Given the paucity of data, no firm spatial or temporal conclusions can be drawn. Increased monitoring surveys are warranted for this subregion.

DESCRIPTION OF MONITORING DATA

Temporal trends in the percentage cover of benthic categories discussed above were estimated using data from 34 datasets encompassing 379 monitoring sites (Figure 2.8.8). These data were collected through 862 surveys conducted between 1985 and 2024, with 90% of surveys taking place after 1993 (Figure A.1). The vast majority of sites (69.9%) were surveyed only within a single year (*i.e.* snapshot assessments), and only 4.2% of sites had survey data greater than a decade (Figure A.3); only three of the 379 reef sites had survey data extending beyond 15 years. While this indicates that long-term data availability remains a challenge, there have been dramatic improvements in recurrent monitoring in recent years, with 30.1% of sites now surveyed over 2–5 year time spans, compared with just 2.9% of sites in the 2020 regional assessment [417].

Of all surveys carried out in the region between 1985 and 2024, nearly three-quarters (73.1%, representing 76.8% of surveyed sites) were conducted in subregion 1 (Persian/Arabian Gulf), whereas only 1.7% (4.0% of sites) of surveys were conducted in subregion 3 (Southern Oman) (Table A.4). Subregion 1 also had the longest monitoring period, spanning four decades from 1985 to 2024, compared with the understudied subregion 3, where only two datasets are available in 2017 and 2020. Enhanced coral reef monitoring in Southern Oman is highly warranted, particularly given the unusual ecology of these pseudo-high-latitude reefs and the deficiencies in knowledge on status and trends [394, 398, 404].

CONCLUSIONS

Coral reefs of the ROPME Sea Area remain globally distinctive for their persistence under extreme environmental conditions, yet the evidence synthesized here indicates regional resilience is being progressively eroded. Across the region, hard coral cover has declined markedly from the high values observed in the 1980s and early 1990s, with repeated marine heatwaves and bleaching events driving stepwise losses, particularly in subregion 1 (Persian/Arabian Gulf), which dominates the regional signal. Subregion 2 (Gulf of Oman) follows a different but still concerning trajectory, shaped by cyclones, harmful algal blooms, and more recent thermal anomalies, while inference for subregion 3 (Southern Oman) remains constrained by limited monitoring. At the regional scale, macroalgal cover remains comparatively low, but the increasing prominence of turf algae indicates growing constraints on coral recovery and reinforces concern over future benthic restructuring. These trajectories point to a system increasingly characterized by shortened recovery intervals, recurrent disturbance, and declining structural complexity. Strengthened and more spatially balanced long-term monitoring, especially in Southern Oman, is now essential, as is management that reduces local stressors and protects herbivore and habitat function. Despite the exceptional thermal tolerance of these reefs, continued warming is likely to intensify vulnerability across the region.

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 8

Data diplomacy in the world's hottest sea

Authors

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Introduction

The ROPME Sea Area, including the Arabian/Persian Gulf, Gulf of Oman, and Southern Oman, supports coral reefs occurring in some of the world's most extreme marine conditions. Summer sea temperatures exceed 35°C and salinities surpass 42 PSU, compared with 29°C and 35 PSU typical of tropical systems, and coastal development is intense. These reefs also face mounting pressures from marine heatwaves, and recent assessments show a 40% decline in coral cover since the mid-1990s, and exceeding 80% in some areas [418]. However, the 2020 Global Coral Reef Monitoring Network (GCRMN) report emphasized gaps in the scientific record that inhibited the use of the ROPME Sea Area data for management and conservation. Data gaps include limited time series, geographic omissions, and inconsistent methodologies [417].

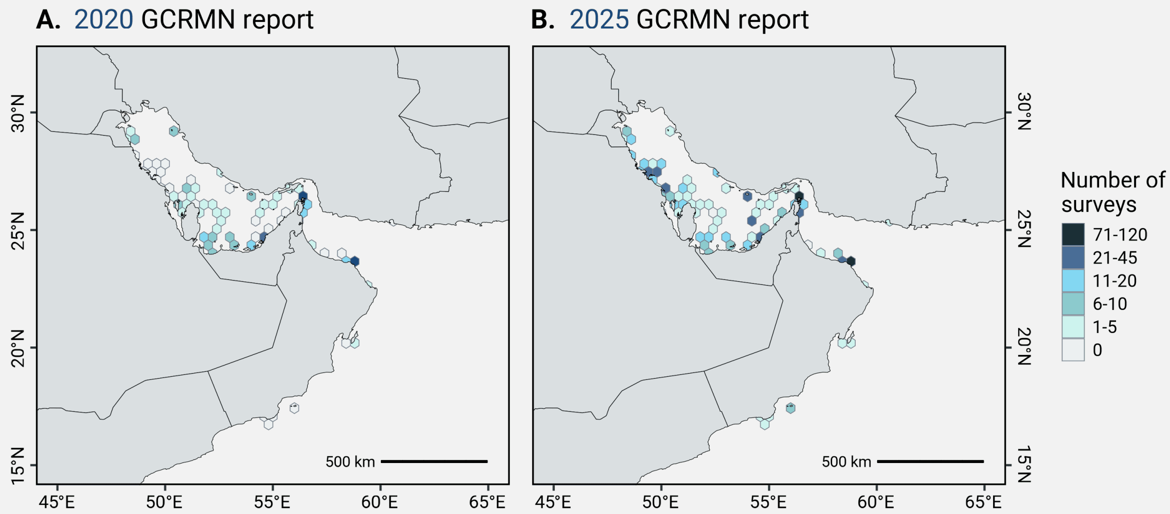
To address these limitations, scientists from seven coastal nations (Bahrain, Iran, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates) launched a "data diplomacy" initiative in an effort to share, standardize, and jointly interpret coral reef monitoring data across borders. This case study describes the initiative's development, scientific outputs, and broader relevance.

Genesis of data diplomacy

The 2020 ROPME regional assessment for GCRMN was based on only 68 sites, most surveyed only once, and using varied or undocumented methods [417]. Recognizing the need for consistency, stakeholders from across the regional nations endorsed three principles: (1) methodological convergence via standardized photo-quadrat protocols and metadata; (2) open but protected data access, with formal credit to data contributors; and (3) neutral stewardship by a trusted regional institution, with open-access co-authorship to ensure transparency.

Building a regional repository

A 2023 workshop at New York University (NYU) Abu Dhabi convened 46 stakeholders (all ROPME Sea Area nations except Iraq) who agreed to adopt a unified protocol. In 2024, a follow-up workshop trained participants in the MERMAID and ReefCloud platforms, piloting a data workflow from image collection to centralized archiving. These tools enabled AI-supported annotation and standardized data sharing with GCRMN. A formal data-sharing agreement was signed, with contributors guaranteed authorship in a public scientific dataset. By March 2025, over 2,000 georeferenced transects from 379 sites (1985–2024) had been compiled, five times the number in 2020, increasing not only the temporal depth of data but additionally the spatial extent of coverage across the region (Figure C8.1). New elements including reef complexity and fish assemblage data for ecosystem-level analysis are also increasingly being incorporated.



▲ **Figure C8.1.** Map showing the spatial distribution of ROPME region coral reefs (polygons), shaded by the number of reef monitoring surveys that were contributed for the 2020 (A) versus 2025 (B) GCRMN assessment.

Scientific and policy insights

The expanded dataset has clarified spatial-temporal patterns of reef condition. While 2017 and 2023 bleaching events caused high mortality in the southern Gulf, reefs in the northern Gulf and Strait of Hormuz fared better. These differences, linked to local wind-driven cooling and hydrodynamic mixing, were previously undocumented. These analyses were only possible due to methodological harmonization, and this dataset will be critical for supporting management and conservation decisions, including the first regional IUCN Red List of Ecosystems (RLE) for coral reefs. Preliminary findings suggest strong signals under RLE Criteria A (reduction in geographic distribution) and C (abiotic environmental degradation). The architecture also supports evaluation of protected areas and transboundary conservation planning.

Lessons for other regions

Five lessons emerge from the ROPME Sea Area initiative: 1) neutral custodianship builds trust; 2) early methodological agreement prevents data incompatibility; 3) reciprocal credit encourages participation; 4) alignment with international frameworks ensures policy relevance; and 5) digital infrastructure supports scalability. Implementing these principles transformed fragmented efforts into a shared regional asset.

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