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Status of Coral Reefs of the World: 2020

Chapter 4. Status and trends of coral reefs of the ROPME Sea Area

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Chapter 4.

Status and trends of coral reefs of the ROPME Sea Area

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1. Geographic information and context

Key numbers:

- Total area of coral reefs: 2,009km^2
- Proportion of the world's coral reefs: 0.77%
- Number of countries with coral reefs: 9
- Number of Marine Ecoregions of the World (MEOW) ecoregions: 3

Regional Context:

The Regional Organization for the Protection of the Marine Environment (ROPME) Sea Area is situated to the northeast of the Arabian plate. It is divided into three geographically and environmentally distinct parts. The division referred to as the Inner ROPME Sea Area consists of the marine area west of 56°E longitude that extends along the NW/SE axis from the north State of the boundary of the ROPME Sea Area to the north of Strait of Hormuz. The Middle ROPME Sea Area covers the Sea of Oman, and the Outer ROPME Sea Area stretches over the entire southern boundary of the RSA across the Arabian Sea that starts from Ra's Al-Hadd to the southern border of Oman. Each of these areas overlaps with Marine Ecoregions of the World (MEOW) ecoregions[1] (Fig. 4.1). The region contains just under 1% (2,009 km^2) of the total global area of coral reefs. Nearly three-quarters of the total reef area occurs within the Inner ROPME Sea Area ecoregion (Tab. 4.1), with the remainder largely bordering coastal Oman. Marine environments in this region vary dramatically, with extreme temperatures characterizing the Inner ROPME Sea Area and monsoon-related upwelling influencing seasonal temperatures and productivity in the Arabian Sea[2,3]. As a result, reefs across the region vary markedly in terms of their structure, biodiversity, proximity to urban stressors and frequency and intensity of natural or climate-related disturbances.

The GCRMN region known as the ROPME Sea Area is bordered by the eight member nations of ROPME (Bahrain, Iran, Iraq, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates) and Yemen,

[1] Spalding, M. D., E. H. F., Allen, G. R., Davidson, N., Ferdaña, Z. A., Finlayson, M., Halpern, B. S., Jorge, M. A., Lombana, A., Lourie, S. A., Martin, K. D., McManus, E., Molnar, J., Recchia, C. A., & Robertson, J. (2007). Marine Ecoregions of the World: A Bioregionalization of Coastal and Shelf Areas, BioScience, Volume 57, Issue 7, Pages 573–583, https://doi.org/10.1641/B570707

[2] Vaughan GO, Al-Mansoori N, Burt J (2019) The Arabian Gulf. In: Sheppard C (ed) World Seas: An Environmental Evaluation, second edition. Elsevier Science, Amsterdam, NL, pp1-23 https://doi.org/10.1016/B978-0-08-100853-9.00001-4

[3] Claereboudt MR (2019) Oman. In: Sheppard C (ed) World Seas: an Environmental Evaluation (Second Edition). Academic Press, pp25-47 https://doi.org/10.1016/B978-0-08-100853-9.00002-6

each of which contain coral communities. Coral reefs are the most biodiverse ecosystem in this arid region, and they support a fisheries sector that is second only to petroleum as an economic sector[4]. Since the oil boom of the 1970s, population growth rates in the region have been nearly double the global average, growing nearly threefold from 46.5 million people in 1970 to approximately 150 million by 2010. However, populations vary considerably along coastlines, ranging from 5.4 million people in cities such as Dubai, to large stretches of coastal Oman where only isolated villages occur, which influences the amount of coastal development and urban pressure being applied to reefs[2,3,5]. There are also dramatic differences in fishing pressure among regional nations, with landings ranging from 11,810 tonnes in Iraq to 5,518,100 tonnes in Iran, leading to variation in direct and indirect impacts to reefs from fishing activities.

Table 4.1. The subregions comprising the ROPME Sea Area, the area of reef they support.

Subregion	Reef Area (km^2)*	Proportion of Reef Area within the ROPME Sea Area (%)	ROPME Sea Area Regions
1	1,482	73.77	90: Inner ROPME Sea Area
2	196	9.78	91: Middle ROPME Sea Area
3	330	16.46	92: Outer ROPME Sea Area

*World Resources Institute. Tropical Coral Reefs of the World (500-m resolution grid), 2011. Global Coral Reefs composite dataset compiled from multiple sources for use in the Reefs at Risk Revisited project incorporating products from the Millennium Coral Reef Mapping Project prepared by IMaRS/USF and IRD.
https://datasets.wri.org/dataset/tropical-coral-reefs-of-the-world-500-m-resolution-grid

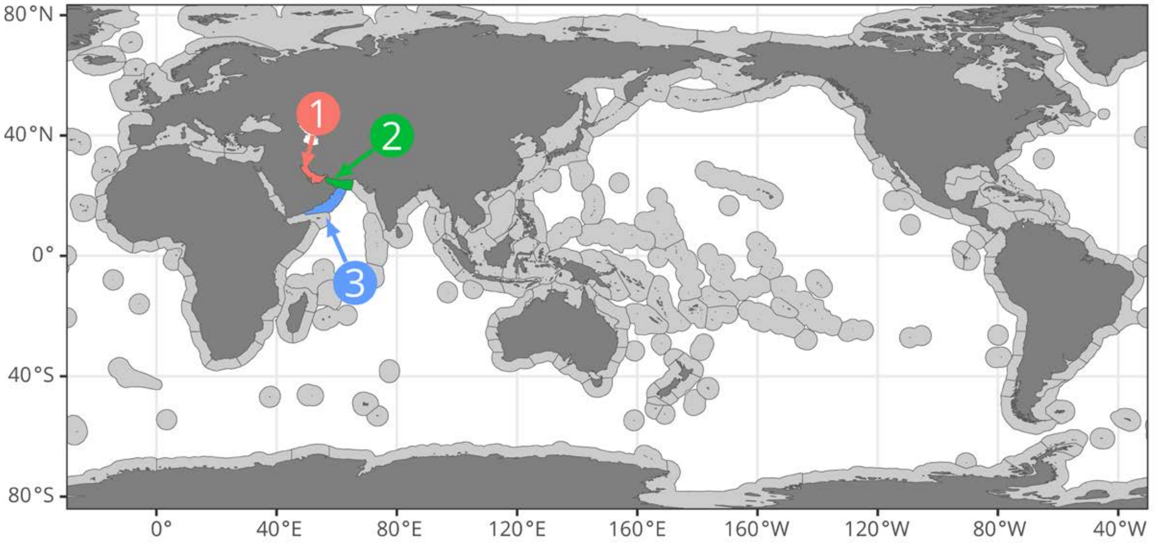

Figure 4.1. Map of each subregion comprising the ROPME Sea Area. The number ascribed to each subregion corresponds with that in Table 4.1.

4 van Lavieren H, Burt J, Feary D, Cavalcante G, Marquis E, Benedetti L, Trick C, Kjerfve B, Sale PF (2011) Managing the growing impacts of development on fragile coastal and marine systems: Lessons from the Gulf. A Policy Report, United Nations University - Institute for Water, Environment, and Health. Hamilton, ON, Canada.

5 Burt JA, Coles S, van Lavieren H, Taylor O, Looker E, Samimi-Namin K (2016) Oman's coral reefs: A unique ecosystem challenged by natural and man-related stresses and in need of conservation. Mar Pollut Bull 105:498-506 https://doi.org/http://dx.doi.org/10.1016/j.marpolbul.2015.11.010

2. Summary of data contributed to this report

Key numbers:

- Number of countries from which monitoring data were used: 7 (of 9)
- Number of sites: 68
- Number of observations: 45,477
- Longest time series: 12 years

General features:

Over 45,000 observations collected across 68 sites were available for the ROPME Sea Area, representing nearly 5% of the overall global dataset. The vast majority of these records (90% of observations and 77% of sites) occurred within the Inner ROPME Sea Area subregion (Tab. 4.2), with nearly all of the remainder occurring in the Middle ROPME Sea Area subregion; only two observations at one site occurred in the Outer ROPME Sea Area subregion. Within the Inner ROPME Sea Area subregion, observations were available for all nations except Iraq, which contains only one recently discovered reef community, although data were not available from all known reefs within Inner ROPME Sea Area nations (Fig. 4.2). In the Middle ROPME Sea Area subregion, observations were available for most known major reef habitats, while data were available from only two sites in the Outer ROPME Sea Area. The vast majority of sites have less than a single year of survey data available (77%; Fig. 4.2, Fig. 4.3A), and no sites in the ROPME Sea Area contain long-term (>15 years) monitoring records (Tab. 4.1; Fig. 4.3A). Only 7% of records extend beyond a decade (Fig. 4.3A), and these occur exclusively around Muscat in the Middle ROPME Sea Area subregion (Fig. 4.2). Photo-quadrats were used for most surveys (82%), although unknown methods were employed for 10% of all surveys (Fig. 4.4).

Table 4.2. Summary statistics describing data contributed from the ROPME Sea Area. An observation is a single record within the global dataset (i.e. one row). A site is a unique GPS position where data were recorded. A site was considered a long-term monitoring site if the time between the first survey and the most recent survey was greater than 15 years. Such sites may have been surveyed multiple times during the intervening period.

ROPME subregions	Observations		Sites		Long term monitoring sites	
	Total Number	Proportion of global dataset	Total Number	Proportion of global dataset	Total Number	Proportion of global dataset
All	45,477	4.69	68	0.56	0	0
1	40,696	4.2	52	0.43	0	0
2	4,779	0.49	15	0.12	0	0
3	2	0	1	0.01	0	0

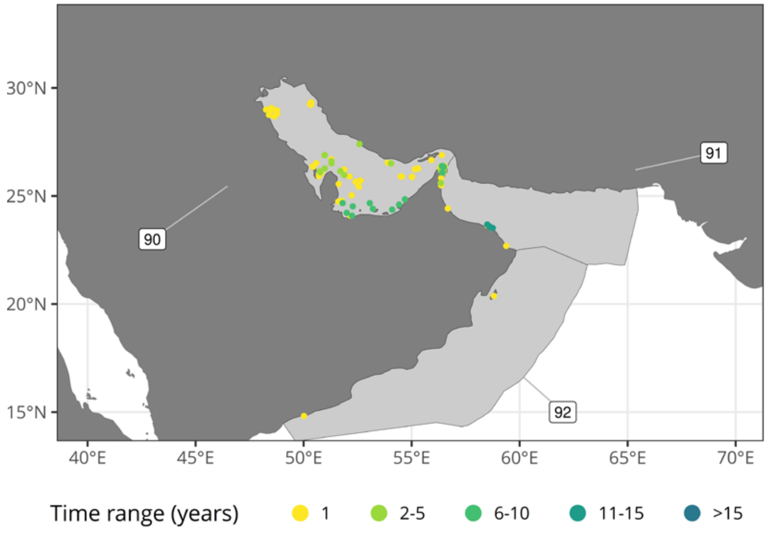

Figure 4.2. The distribution and duration of monitoring at sites across the ROPME Sea Area. The colours of dots represent the time span between the first survey and the most recent survey at each site. Numbers refer to the MEOW ecoregions listed in Table 4.1.

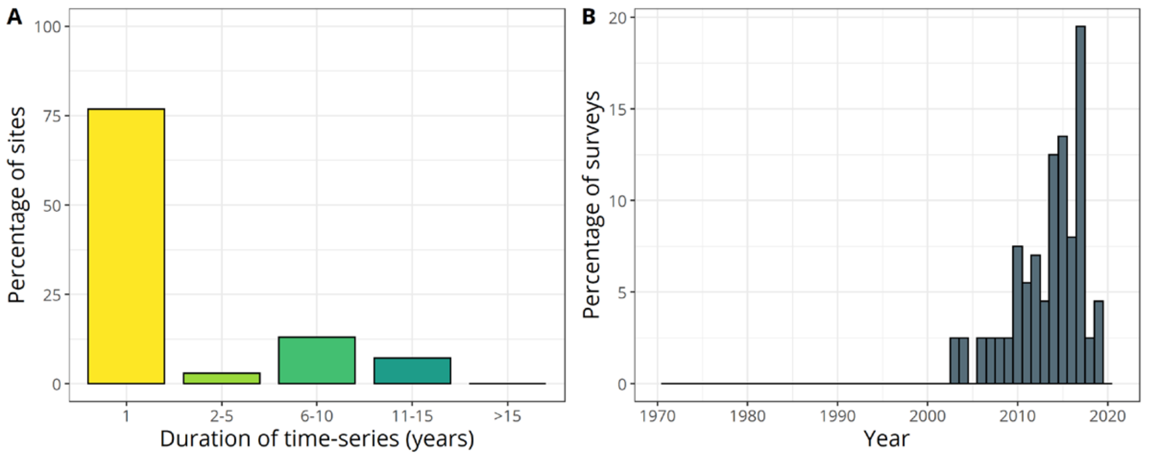

Figure 4.3. The proportion of sites in the ROPME Sea Area within each category describing the time span between the first and most recent surveys (A), and the proportion of the total number of surveys conducted in each year (B). The total number of surveys was 200.

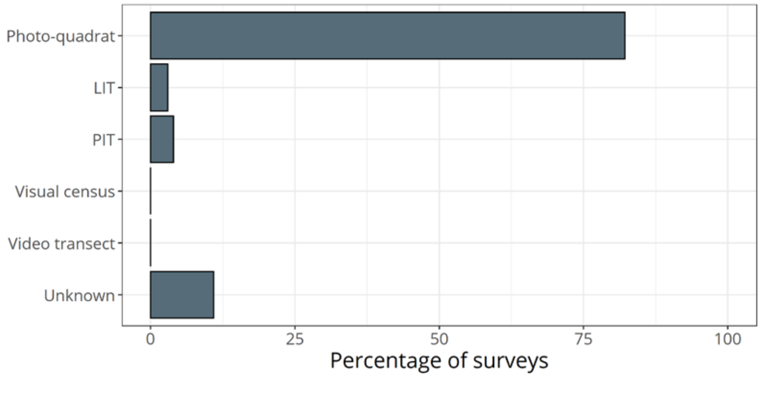

Figure 4.4. The proportion of the total number of surveys conducted in the ROPME Sea Area using each survey method. PIT: Point Intercept Transect; LIT: Line Intercept Transect.

3. Status of coral reefs in the GCRMN ROPME Sea Area

- Regional trends in the cover of live hard coral and algae

Between 1997, when monitoring began, and 2002, estimated average live coral cover declined from 30.1% to 18.0% (Fig. 4.5A), representing a loss of 40.1% of the cover of living coral from the region. This coincides with the occurrence of two severe back-to-back bleaching events in 1996 and 1998 that caused widespread coral mortality, particularly in the Inner ROPME Sea Area subregion[6]. From 2002, there was a long period of recovery that extended over a decade, with average live hard coral cover peaking again in 2015, when it reached 30.2%, a level comparable to the earliest pre-bleaching records. This was followed by an abrupt decline in coral cover to a record low of 17.9% in 2019, which followed bleaching during the hottest summer on record in the Inner ROPME Sea Area in 2017[7]. This equates to an overall loss of 40.1% of the living coral cover between 1996 and 2019 in the region, or approximately 20% per decade since monitoring began.

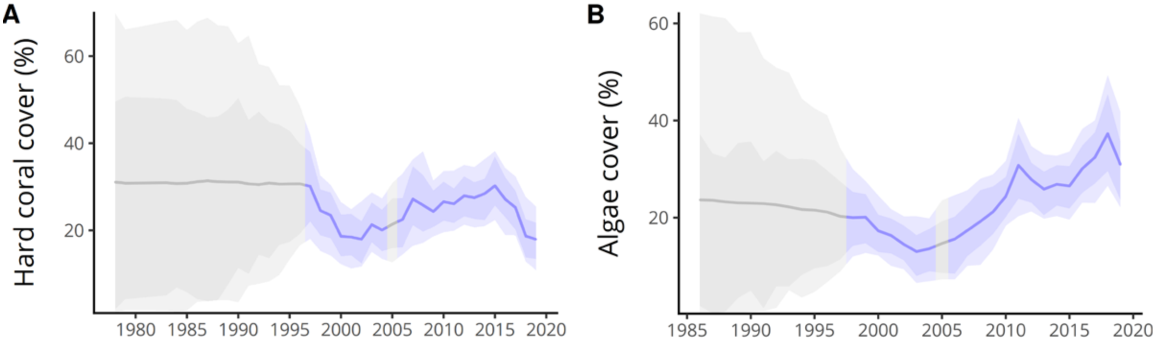

Figure 4.5. Estimated regional average cover of live hard coral (A) and algae (B) for the ROPME Sea Area. The solid line represents the estimated mean and associated 80% (darker shade) and 95% (lighter shade) credible intervals, which represent levels of uncertainty. Grey areas represent periods during which no field data were available.

Comparisons of the average hard coral cover between five-year periods (2005-09, 2010-14, 2015-19) indicate that despite the uncertainty in individual yearly estimates, there is a high degree of confidence (~82%) in long-term declines and that the greatest decline occurred in the last five years (2015-19) (Tab. 4.3). Recovery in live coral cover was observed between 2005-09 and 2010-14 (a near 20% increase in relative cover), but this was more than offset by a 26.9% decline in the subsequent 2015-19 period. Changes in hard coral cover at the regional scale may not be representative of changes within the Outer ROPME Sea Area owing to a scarcity of data and the different ecology of the reefs in this subregion[2,4].

Table 4.3. Probability and magnitude of mean absolute and relative change in the percent cover of live hard coral in the ROPME Sea Area between each of the three five-year periods comprising the last 15 years.

Comparison	Probability of change (%)	Mean absolute change (%)	Mean relative change (%)
2005-09 - 2010-14	80	2.9	18.2
2010-14 - 2015-19	96	-6.1	-26.9
2005-09 - 2015-19	82	-3.2	-14.4

[6] Riegl B, Johnston M, Purkis S, Howells E, Burt J, Steiner S, Sheppard C, Bauman A (2018) Population collapse dynamics in Acropora downingi, an Arabian/Persian Gulf ecosystem‐engineering coral, linked to rising temperature. Global Change Biology 24:2447–2462 https://doi.org/10.1111/gcb.14114

[7] Burt JA, Paparella F, Al-Mansoori N, Al-Mansoori A, Al-Jailani H (2019) Causes and consequences of the 2017 coral bleaching event in the southern Persian/Arabian Gulf. Coral Reefs 38:567-589 https://doi.org/10.1007/s00338-019-01767-y

The average cover of algae across the region has been increasing since the early 2000s, from a low of 13% in 2003 to a peak of 37.3% in 2018 (Fig. 4.5B), presumably reflecting algal overgrowth on dead coral skeletons following the summer 2017 coral bleaching event in the Inner ROPME Sea Area subregion. Increases in algal growth were observed in all periods compared (Tab. 4.4), with average algal cover more than doubling (~115%) between the 2005-09 and 2015-19 periods.

Table 4.4. **Probability and magnitude of mean absolute and relative change in the percent cover of algae in the ROPME Sea Area region between each of the three five-year periods comprising the last 15 years.**

Comparison	Probability of change (%)	Mean absolute change (%)	Mean relative change (%)
2005-09 - 2010-14	99	8.3	68.5
2010-14 - 2015-19	92	5.1	28.2
2005-09 - 2015-19	100	13.4	115.4

- The primary causes of change in the cover of live hard coral and algae

In the ROPME Sea Area, coral bleaching is the primary cause of coral loss, although considerable localized degradation and loss has also occurred as a result of coastal development[3,5,6]. The substantial declines in coral cover recorded between 1997 and 2002 coincide with the occurrence of two back-to-back coral bleaching events in 1996 and again in 1998 that affected reefs across the Inner ROPME Sea Area (which contains 74% of regional coral reef habitat; Table 4.1)[5]. Similarly, the dramatic decline in coral cover between 2015 and 2019 coincides with the 2017 coral bleaching event[6], when sea surface temperatures were the highest ever recorded in the Inner ROPME Sea Area, as well as a bleaching event in the Middle ROPME Sea Area in 2015. Coral bleaching is rare for the Outer ROPME Sea Area, as monsoonal upwelling cools temperatures during the late summer[2]. The cause of the long-term increase in cover of algae on regional reefs is unclear, as it counterintuitively matches increasing trends in coral cover over time (Fig. 4.5A). This may simply reflect a transition from categories previously classified as 'dead coral' being later classified as algae due to overgrowth as regional reefs transitioned after the impact of the 1996/1998 coral bleaching events.

- Changes in resilience of coral reefs within the ROPME Sea Area

The ROPME Sea Area contains the most thermally tolerant corals in the world, but they live at the limits of their physiological tolerance and can be pushed over the edge during extreme thermal anomalies[5]. The average cover of live coral declined from 30.1 % to 18.0% in the wake of the 1996 and 1998 coral bleaching events, which resulted in loss of 40% of the corals across the region. However, reefs showed capacity to recover, with coral cover returning to pre-bleaching levels a decade later in 2015, despite the Inner ROPME Sea Area being the hottest sea in the world during each of these years and the documented occurrence of minor to moderate coral bleaching events in 2007, 2010, 2011 and 2012 that had limited impact on region-wide coral cover (Fig. 4.5A)[5,6]. However, this recovery was reset by the extreme coral bleaching event in 2017, when reef bottom temperatures of 37.7 °C were recorded[6] causing a second major decline in which 40% of the living coral in the region was lost by 2019 (Fig. 4.5A).

4. Subregional trends in the cover of live hard coral and algae in ROPME Sea Area

Within the ROPME Sea Area, trends in hard coral cover among the subregions vary (Fig. 4.6), reflecting heterogeneity in the type, magnitude and frequency of disturbance as well as recovery dynamics, indicating a need for continued region-wide monitoring. Subregion 1 (The Inner ROPME Sea Area) showed trends that mirror the larger ROPME Sea Area, reflecting the heavy weighting of this subregion in the regional-scale analyses (77% of regional reef area). In contrast, coral cover declined by nearly half between 2005 and 2010 in the Sea of Oman (subregion 2), reflecting the localized impacts from super-cyclone Gonu (2007) and cyclone Phet (2010) as well as a large-scale algal bloom (2008/9)[2,4], although recovery began thereafter. Coral cover has remained stable in the Outer ROPME Sea Area (subregion 3), likely reflecting low disturbance in this relatively unpopulated area (although limited temporal sampling makes trend analysis difficult).

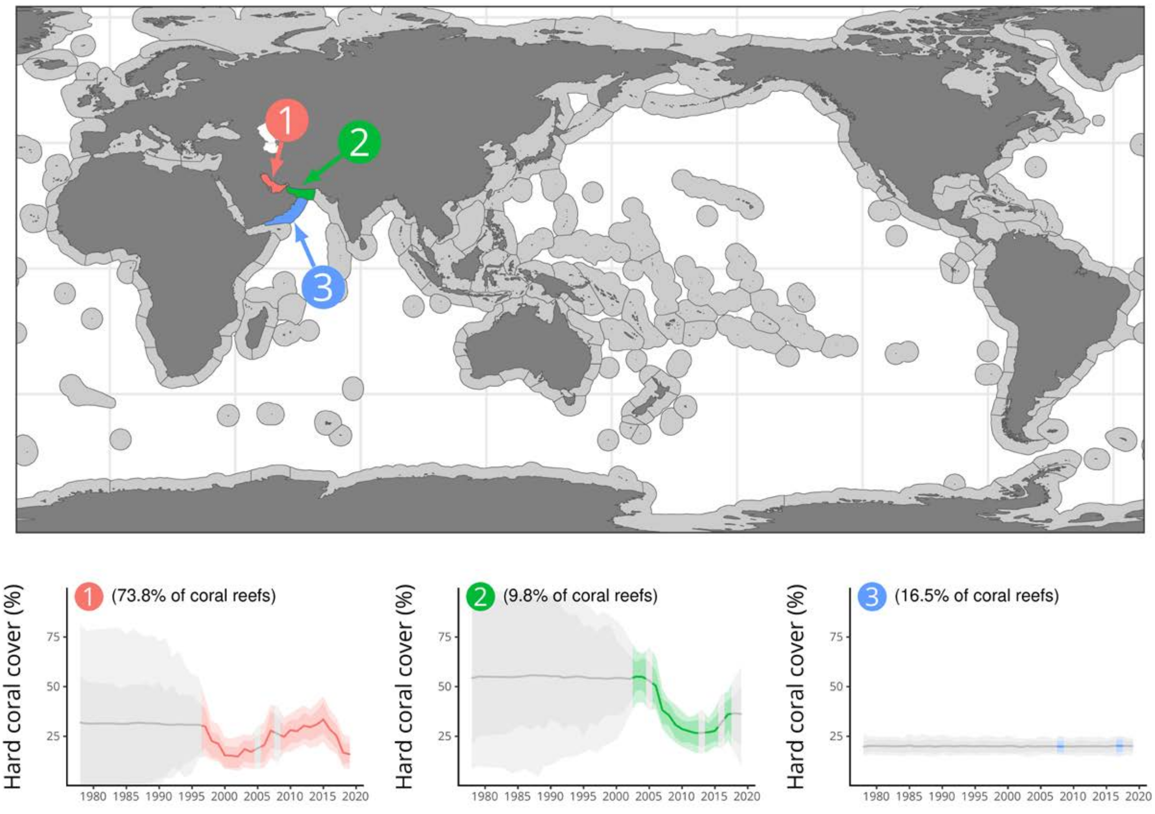

Figure 4.6. Estimated average cover of live hard coral within each subregion comprising the ROPME Sea Area. The solid line represents the estimated mean and associated 80% (darker shade) and 95% (lighter shade) credible intervals, which represent levels of uncertainty. Grey areas represent periods during which no field data were available. The proportion of all coral reefs in the ROPME Sea Area within each subregion is indicated by the % of coral reefs.

In general, it appears that the cover of algae has increased regionally (Fig. 4.7). A trend towards increasing cover of algae has clearly occurred in the Inner ROPME Sea Area and the Sea of Oman, suggesting a phase shift in reef communities in the wake of disturbances on these reefs, with the cover of algae increasing by more than two to three times what it was in the early 2000s (in subregions 1 & 2, respectively). Insufficient temporal monitoring data were available for analyses of long-term trends in the Outer ROPME Sea Area (subregion 3), but it is well known that algal density varies seasonally (high cover in late summer following monsoon upwelling, low cover in spring)[2], suggesting that the timing of surveys can influence monitoring results.

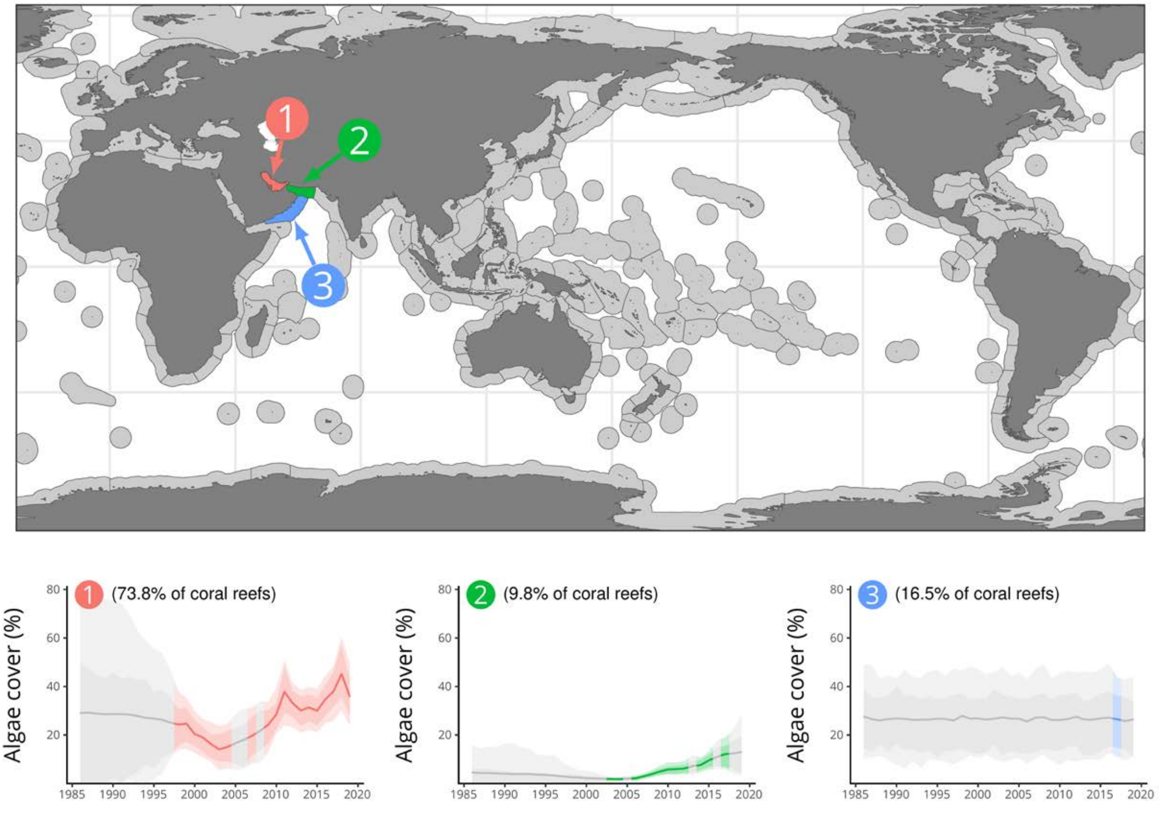

Figure 4.7. Estimated average cover of algae within each subregion comprising the ROPME Sea Area. The solid line represents the estimated mean and associated 80% (darker shade) and 95% (lighter shade) credible intervals, which represent levels of uncertainty. Grey areas represent periods during which no field data were available. The proportion of all coral reefs in the ROPME Sea Area within each subregion is indicated by the % of coral reefs.

Box 2.

Ocean Acidification

Alexander A. Venn, Andreas Andersson, Sylvie Tambutté

The world's oceans have taken up more than a third of the CO_2 produced by human activities, altering seawater carbonate chemistry in a process termed 'Ocean Acidification'[1]. These chemical changes, involving decreases in seawater pH, carbonate ion concentration [CO_3^{2}] and the saturation state of calcium carbonate minerals (Ω), have been unequivocally documented at long-term monitoring stations since the 1980s[2].

Ocean acidification is predicted to continue unabated in coming decades, posing a major threat to coral reefs in both shallow tropical seas and deep cold water habitats[3]. Synthesis of multiple experimental studies shows that ocean acidification interacts with ocean warming to impair the capacity of most corals and many other marine calcifiers to deposit their $CaCO_3$ skeletons[4,5]. Corals may be particularly vulnerable in their juvenile stages[6], potentially diminishing the capacity of reefs to restock and recover after disturbances. In addition, ocean acidification has been shown to increase $CaCO_3$ sediment dissolution and bioerosion on coral reefs[7,8], which may weaken the three-dimensional framework and increase the vulnerability of coral reefs to physical and mechanical erosion.

Observations from reefs exposed to naturally low pH conditions show a cessation of reef growth at certain thresholds, and indicate that ocean acidification changes community composition and decreases reef biodiversity[9]. Field studies suggest that modern-day net reef calcification has decreased over the last few decades[10] and may already be significantly

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1 Sabine CL, Feely RA, Gruber N, Key RM, Lee K, Bullister JL, Wanninkhof R, Wong CS, Wallace DW, Tilbrook B, Millero FJ, Peng TH, Kozyr A, Ono T, Rios AF. The oceanic sink for anthropogenic CO2. Science. 2004 Jul 16;305(5682):367-71. doi: 10.1126/science.1097403. PMID: 15256665.

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9 Fabricius, K., Langdon, C., Uthicke, S. et al. Losers and winners in coral reefs acclimatized to elevated carbon dioxide concentrations. Nature Clim Change 1, 165–169 (2011). https://doi.org/10.1038/nclimate1122

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lower than during pre-industrial times[11]. Overall, the direct and indirect effects of ocean acidification could have far-reaching implications for the roles and functions of coral reef ecosystems such as the provision of habitat, protection from shoreline erosion, and provision of nutrition to human communities[12].

There are local actions that can ensure the health of coral reefs and maximize their resilience to ocean acidification and other environmental stressors[13]. Water quality management can assist in reducing the effects of global acidification at the reef scale as inputs of organic matter and eutrophication from anthropogenic sources can be important drivers of local acidification of reef waters exacerbating the long-term effects of rising atmospheric CO_2[14,15]. In addition, fisheries management can limit destructive practices that directly damage reef structure, which ultimately promotes reef growth[16]. Other actions focus on assisting the acclimatization and adaptation potential of coral reefs by using corals of different strains, species, environmental history and geographical origin to build reef resilience against climate change and ocean acidification[17]. All of these actions are potentially valuable, but relatively restricted to local scales. Protection of coral reefs from the threat of ocean acidification on global and long time scales ultimately depends on significant and rapid reductions in emissions of CO_2.

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