Global Coral Reef Monitoring Network

International Coral Reef Initiative

Australian Government

Australian Institute of Marine Science

Status of Coral Reefs of the World: 2020

Chapter 9. Status and trends of coral reefs of the Pacific region

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Chapter 9.

Status and trends of coral reefs of the Pacific region

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(**Note:** This is the list of contacts, not the list of people to acknowledge. The full list of contributors to be acknowledged will be obtained from the various data sharing agreements.)

1. Geographic information and context

Key numbers:

- Total area of coral reefs: 69,424 km^2
- Proportion of the world's coral reefs: 26.73%
- Number of countries with coral reefs: 17
- Number of Marine Ecoregions of the World (MEOW) ecoregions: 24

General context:

The Pacific region is by far the largest of the GCRMN regions in terms of surface area and is unique in that the coral reefs occur mainly around oceanic islands. It includes more than 25,000 islands and supports almost 27% (about 69,424 km^2) of the total global area of coral reefs. Spread across such a large area, these reefs vary considerably in terms of proximity to continents, reef structure, and biodiversity, as well as the frequency and intensity of natural disturbances.

Pacific islands and archipelagos include sovereign states as well as associated states or territories of continental countries. Coral reefs are an integral part of Pacific culture and provide a significant amount of dietary protein (25-100%). The human population has grown significantly during the last century, and islands of the Pacific Ocean now support around, 13.5 million people, of which 9 million live in Papua New Guinea. However, population density is not uniform within or between islands, ranging from 475 people per km^2 in Tuvalu, to 15 people per km^2 in Papua New Guinea and New Caledonia. There are also considerable economic disparities between Pacific nations and territories, with per capita Gross Domestic Product (GDP) ranging from USD1,035 in Tokelau to USD54,500 in Hawaii (United States of America), with populations more or less dependent on coral reefs.

The GCRMN Pacific region includes nine Marine Ecoregions of the World (MEOW) ecoregions[1] (Tab. 9.1, Fig. 9.1). Data from each ecoregion except Easter Island are reported here.

Table 9.1. **The subregions comprising the Pacific region, the area of reef they support, and the constituent Marine Ecoregions of the World (MEOW)[1].**

Subregion	Reef Area (km^2)*	Proportion of Reef Area within the Pacific Region (%)	Constituent Marine Ecoregions of the World
1	6,408	9.2	121: Mariana Islands 122: Ogasawara Islands 124: East Caroline Islands 125: West Caroline Islands
2	20,144	29.0	134: Bismarck Sea 135: Solomon Archipelago 136: Solomon Sea 137: Southeast Papua New Guinea
3	21,172	30.5	146: Kingdom of Tonga 147: Fiji Islands 148: Vanuatu 149: New Caledonia 150: Coral Sea
4	4,504	6.5	152: Hawaiian Islands
5	8,155	11.7	153: Marshall Islands 154: Gilbert/Ellis Island
6	2,315	3.3	155: Line Islands 156: Phoenix/Tokelau/Northern Cook Islands/Wallis 157: Samoa Islands
7	6,726	9.7	158: Tuamotu 162: Marquesas Islands 159: Rapa-Pitcairn 160: Southern Cook/Austral Islands 161: Society Islands

*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

[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

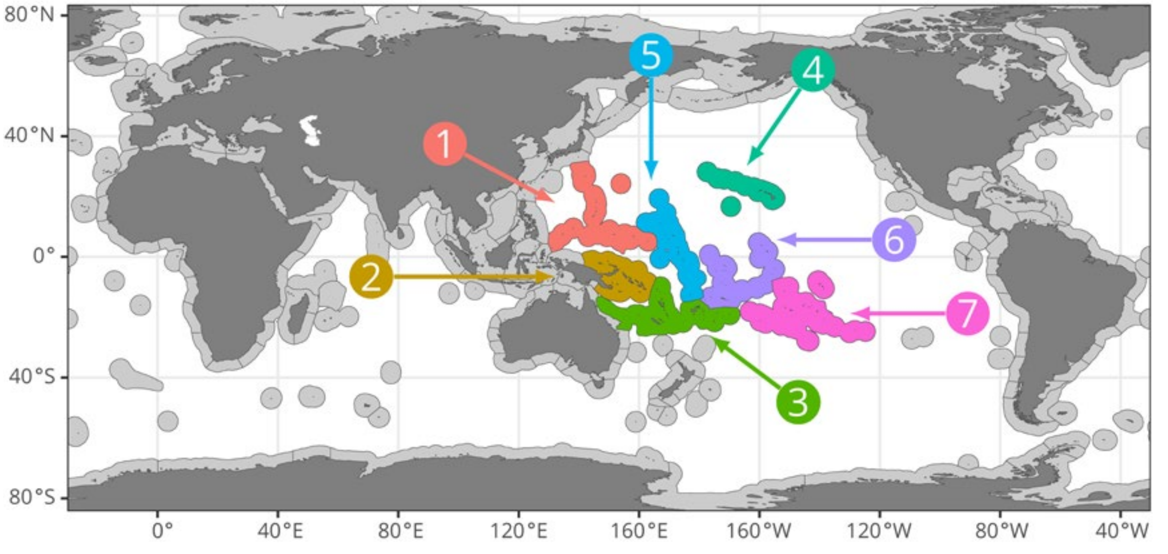

Figure 9.1. Map of each subregion comprising the Pacific region. The number ascribed to each subregion corresponds with that in Table 9.1.

2. Summary of data contributed to this report

Key numbers:

- Number of countries from which monitoring data were used: 15 (of 17)
- Number of sites: 4,050
- Number of observations: 438,803
- Longest time series: 29 years

General features:

The status of, and trends in, coral reefs presented below are based on almost 440,000 observations collected since 1987 from 4,050 sites in 15 different countries within the Pacific region (Tab. 9.2). These data were collected primarily using photo-quadrat or transect-based methods (Fig. 9.4), and comprise 45% of the global dataset that underpins this GCRMN *Status of Coral Reefs of the World: 2020* report.

The distribution of monitoring effort across the Pacific region reflects the commitment to monitoring by national governments, organisations and programs. The most surveyed subregions within the Pacific were subregions 1 (Mariana Islands, Ogasawara Islands, East and West Caroline Islands) and 6 (Line Islands, Phoenix/Tokelau/Northern Cook Islands/Wallis, Samoa Islands), which are included in the NOAA Coral Reef Monitoring Program. Monitoring in subregions 3 (Kingdom of Tonga, Fiji Islands, Vanuatu, New Caledonia, Coral Sea) and 7 (Tuamotu, Marquesas Islands, Rapa-Pitcairn, Southern Cook/ Austral Islands, Society Islands) was conducted primarily as part of long-term programs supported by France and based in New Caledonia and French Polynesia.

Long-term monitoring (>15 years between the first survey and the most recent survey) has occurred at 50 sites within the Pacific region, with the longest time series recorded from any site being 29 years

(Tab. 9.2, Fig. 9.2 and 9.3A). The vast majority of long-term monitoring sites occurred either within subregion 3 (25) or 7 (14) and were part of long-term programs supported by France (Tab. 9.2).

The distribution of monitoring effort over time was driven primarily by responses to disturbance events. Only a small amount of monitoring occurred between 1987, when the earliest data contributed to this report were collected, and 1998. However, considerable increases in monitoring effort were evident in response to mass coral bleaching events in 1998, 2010 and 2015, although this has not been maintained in recent years (Fig. 9.3B).

Table 9.2. Summary statistics describing data contributed from the Pacific region. 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.

Pacific 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	438,803	45.26	4,050	33.31	50	8.5
1	105,783	10.91	1,080	8.88	0	0
2	56,057	5.78	74	0.61	8	1.36
3	49,841	5.14	377	3.1	25	4.25
4	66,288	6.84	1,002	8.24	0	0
5	16,617	1.71	219	1.8	0	0
6	109,204	11.26	1,149	9.45	3	0.51
7	35,013	3.61	149	1.23	14	2.38

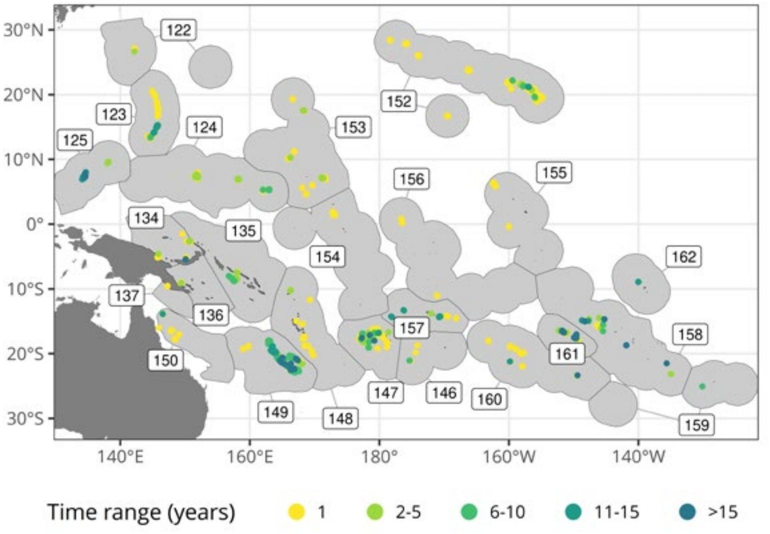

Figure 9.2. The distribution and duration of monitoring at sites across the Pacific region. The colours of dots represent the time span between the first survey and the most recent survey at each site. Numbers refer to the MEOW ecoregions listed in Table 9.1.

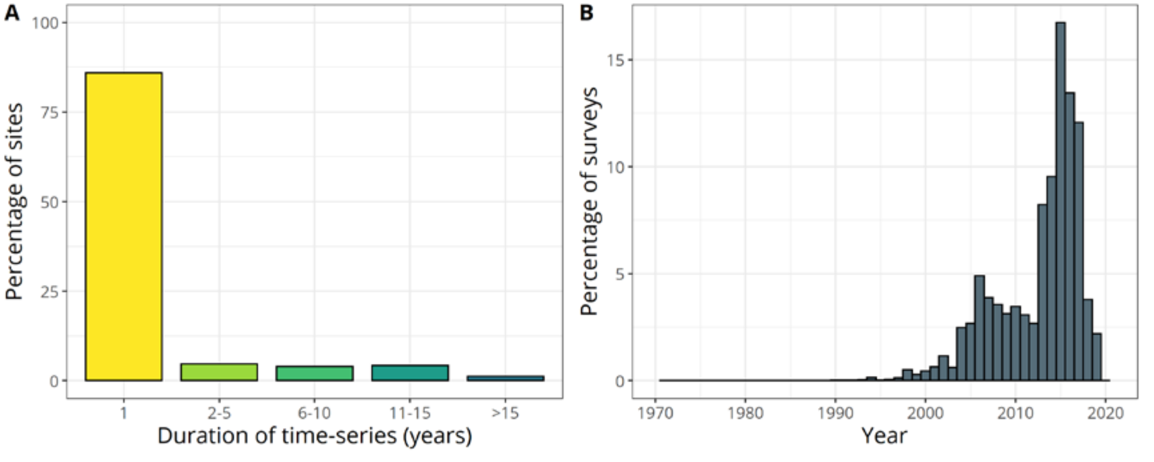

Figure 9.3. The proportion of sites in the Pacific region within each category describing the time span between the first and most recent surveys (A), and the proportion of the total number of surveys conducted in each year (B). The total number of surveys was 7,585.

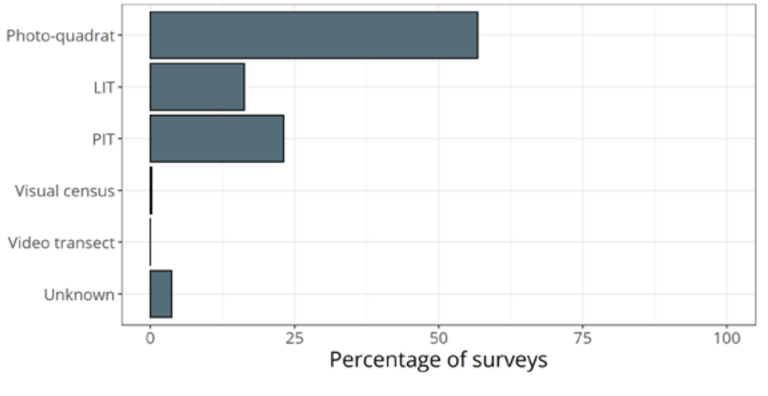

Figure 9.4. The proportion of the total number of surveys conducted in the Pacific region using each survey method. PIT: Point Intercept Transect; LIT: Line Intercept Transect.

3. Status of coral reefs in the Pacific region

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

Prior to 1998, the estimated average cover of live hard coral was relatively high and stable, ranging between 37.0% and 37.7% (Fig. 9.5A). Since 1998, there has been a general decline in coral cover to 31.3% in 2019. Although the overall trend declined, periods of recovery occurred between 2009 and 2011 and, more recently, between 2017 and 2019, with average coral cover increasing by 1.1% and 1.7% respectively. The impacts of the 1998 El Niño in the Pacific event were evident in a 2.3% decline in average coral cover between 1999 and 2001. El Niño events in 2015 and 2016 caused considerable coral mortality which was apparent in the 2.7% decline in average coral cover across the region between 2015 and 2017. This suggests that successive El Niño events have had greater impacts, which will need to be considered in future monitoring.

The trend in the average cover of algae over the last 35 years was the opposite of hard coral cover, with relatively low (~15%) but stable cover between 1987 and 1999, followed by a progressive increase during the last two decades, peaking in 2018 at 20.8% (Fig. 9.5B).

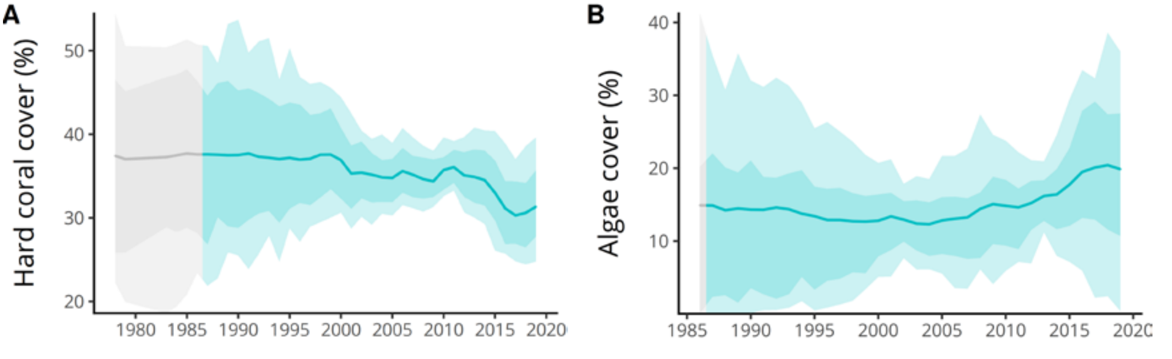

Figure 9.5. Estimated regional average cover of live hard coral (A) and algae (B) for the Pacific region. The solid line represents the estimated mean and associated 80% (darker shade) and 95% (lighter shade) credible intervals, which represent levels of uncertainty. Grey areas represent periods during which no field data were available.

Comparison of the average hard coral cover between the three five-year periods comprising the last 15 years (2005-09, 2010-14, 2015-19, Tab. 9.3) indicated that there was a high degree of confidence (93%) in the long-term decline, despite the uncertainty in individual yearly estimates. Further, the vast majority (90%) of this decline occurred between 2010-14 and 2015-19, suggesting that the rate of decline in hard coral cover has accelerated during the last five years (Tab.3).

Table 9.3. Probability and magnitude of mean absolute and relative change in the percent cover of live hard coral in the Pacific 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	61	-0.4	-1.3
2010-14 - 2015-19	95	-3.9	-15.8
2005-09 -2015-19	93	-4.3	-16.8

Comparison of the average algal cover between the three five-year periods comprising the last 15 years (2005-09, 2010-14, 2015-19) suggested a moderate probability (87%) of a long-term increase in the average cover of algae on Pacific reefs in the order of 5.9% (87.5% relative increase), and that the majority of this increase has occurred between 2010-14 and 2015-19 (Tab. 9.4).

Table 9.4. Probability and magnitude of mean absolute and relative change in the percent cover of algae in the Pacific 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	84	1.9	27.5
2010-14 - 2015-19	82	4.1	42.6
2005-09 -2015-19	87	5.9	87.5

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

In the Pacific region, coral bleaching has been the main cause of coral loss. The decline in average hard coral cover across the Pacific region began in 1998, corresponding with the first global mass coral bleaching event, and more recent declines were attributable to global-scale coral bleaching events in 2014, 2015 and 2016 (Fig. 9.5A). The frequency of these successive bleaching events provided limited opportunity for corals to recover between events, which accelerated the rate of coral loss, particularly between 2015 and 2017.

Coral bleaching has also occurred at smaller scales at several locations within the Pacific during the last two decades, notably in 2002-03 in the Phoenix Islands and Kiribati, in 2004-05 in the Gilbert Islands, Kiribati and Tuvalu, and in 2009-10 in the Gilbert, Phoenix and Line Islands. However, because these coral bleaching events were relatively localized, they did not have a large influence on the average coral cover at the scale of the entire Pacific region.

- Changes in resilience of coral reefs within the Pacific region

Increases in the frequency of disturbances to Pacific coral reefs may have changed long-term disturbance-recovery patterns to a point that many reefs are not recovering completely between one disturbance and the next. The result is a stepwise decline in hard coral cover. In the Pacific region, there were 120 sampling units that had been surveyed repeatedly over a period of at least 15 years and had, at some point, experienced a relative decline in hard coral cover of at least 20% (Tab. 9.5). At more than half (69) of these sampling units, the hard coral cover did not recover to at least 90% of their pre-disturbance level. On average, hard coral cover declined by 7% between the first survey and the most recent survey at these sites, representing a loss of 21.4% of the existing hard coral. The average maximum decline in absolute hard coral cover was 24.7%, representing a loss of 73.3% of the hard coral at these sampling units (Tab. 9.5).

Table 9.5. The mean maximum decline and the mean difference between first and last survey expressed as absolute and relative declines in percent live coral cover. N is the total number of sampling units for which >15 years of data were available and had experienced a relative decline in live coral cover of at least 20 percent. n is the number of sampling units that did not exhibit recovery to 90 percent of the initial live coral cover. Percent is the proportion of the total number of sampling units that did not exhibit recovery to 90 percent of the initial live coral cover. A sampling unit is defined as the specific area that was surveyed repeatedly. Depending on the survey methods used and how the data were provided, a sampling unit could be a transect, a quadrat or even a site.

N	n	Percent	Mean maximum absolute decline	Mean maximum relative decline	Mean long-term absolute decline	Mean long-term relative decline
120	69	57.5	24.7	73.3	7.0	21.4

4. Subregional trends in the cover of live hard coral and algae within the Pacific region

Within the Pacific region, the trends in hard coral cover among the different subregions varied, indicating some heterogeneity in exposure to disturbance and subsequent recovery, and highlighting the need to survey all subregions (Fig. 9.6). Subregions 1, 3, 5 and 6 all show declines in average hard coral cover that are consistent with the overall trend of the Pacific region, while subregion 2 (PNG, Solomon Islands, New Caledonia, Vanuatu, and Fiji) and 4 (Hawaii) were stable, and subregion 7 (French Polynesia) increased until 2010 after which it exhibited a substantial decline in average hard coral cover during the last decade. Although impossible to determine from the available data, there was evidence that the impact of bleaching varied among coral families.

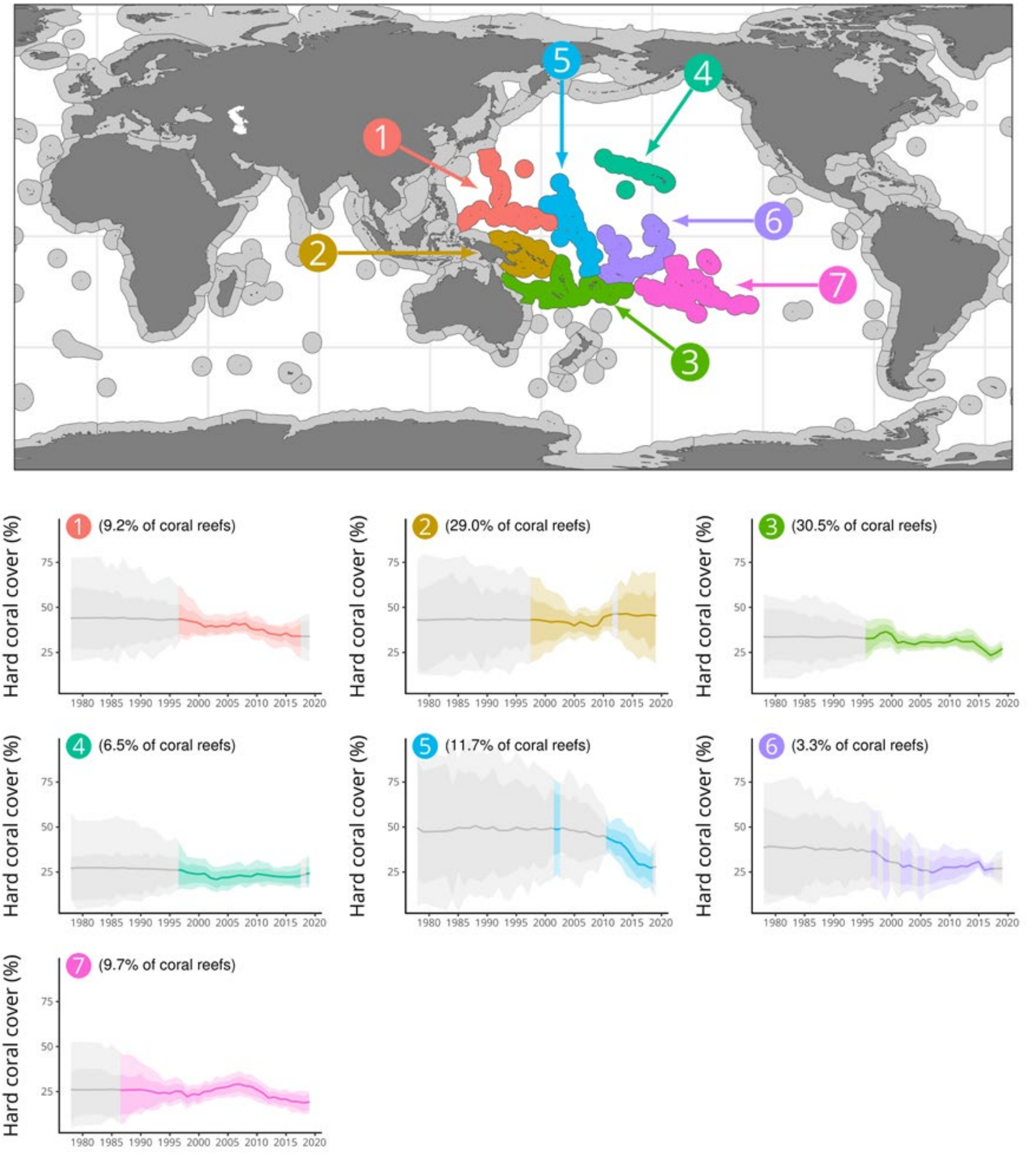

Figure 9.6. Estimated average cover of live hard coral within each subregion comprising the Pacific region. The solid line represents the estimated mean and associated 80% (darker shade) and 95% (lighter shade) credible intervals, which represent levels of uncertainty. Grey areas represent periods during which no field data were available. The proportion of all coral reefs in the Pacific region within each subregion is indicated by the % of coral reefs.

Similar to hard coral cover, trends in the percent cover of algae varied among different subregions (Fig. 9.7). The average cover of algae remained reasonably stable within subregions 2, 3 and 7, but in subregion 4, the cover of algae had clearly increased, and in subregions 1 and 5, it had doubled in the last 10-15 years. While the substantial increase in the number of surveys conducted in the last 10-15 years may have overemphasised more recent trends, the overall increase in the cover of algae suggests a substantial shift from hard coral dominance towards algal dominance within these ecosystems.

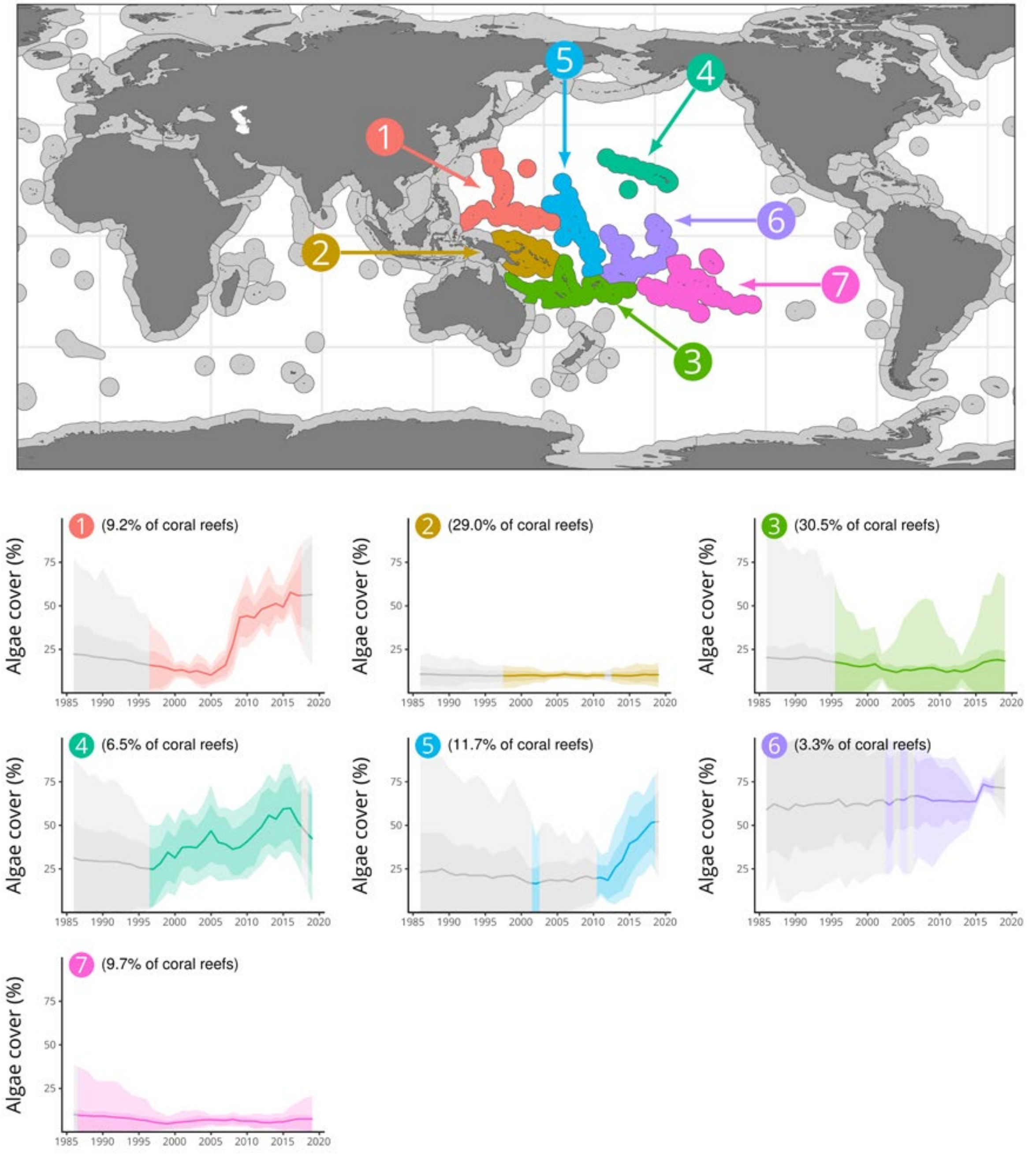

Figure 9.7. Estimated average cover of algae within each subregion comprising the Pacific region. The solid line represents the estimated mean and associated 80% (darker shade) and 95% (lighter shade) credible intervals, which represent levels of uncertainty. Grey areas represent periods during which no field data were available. The proportion of all coral reefs in the Pacific region within each subregion is indicated by the % of coral reefs.

Box 7.

Mesophotic Coral Ecosystems are unique 'bright spots' of biodiversity

The thought of coral reefs conjures up visions of abundant bright and colourful organisms living in shallow, tropical, waters. While these sunlit waters support extensive coral growth and diversity, some hard coral species can be found at depths as great as 172 m in mesophotic coral ecosystems (MCEs)[1,2], but unlike reefs in the photic zone (<30 m), MCEs are poorly studied and conserved.

Hard corals rely on the products of photosynthesis by symbiotic zooxanthellae (*Symbiodiniaceae*) living within the tissues of the coral polyp to fuel up to 90% the coral's energy requirements for growth and reproduction[3]. As a consequence, the depths at which corals can survive is constrained by the exponential decrease in irradiance (<1% of surface light at 100 m depth), the change of the spectral composition of light (e.g. dominated by blue), the drop in seawater temperature[4], and low hydrodynamic and nutrient enrichment. In order to cope with these constraints, corals living in MCEs demonstrate several adaptations, including increasing zooxanthellae density, flattening skeleton morphology, shifting *Symbiodiniaceae* composition, reducing the number of polyps per surface area, increasing heterotrophy, decreasing tissue thickness and decreasing reproductive effort[5,6,7,8]. Research on MCEs reveals new knowledge of the biological and evolutionary mechanisms employed by corals to withstand such marginal environmental conditions, and provides insights regarding the adaptive capacity of corals.

Historically, interest in MCEs centred on their potential as refuges. The Deep Reef Refugia

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1 Rouzé, H., Galand, P.E., Medina, M. et al. Symbiotic associations of the deepest recorded photosynthetic scleractinian coral (172 m depth). ISME J 15, 1564–1568 (2021). https://doi.org/10.1038/s41396-020-00857-y

2 Baker EK, Puglise KA, Harris PT (2016) Mesophotic coral ecosystems – a lifeboat for coral reefs?. The United Nations Environment Programme and GRID-Arendal, Nairobi and Arendal

3 Muscatine L (1990) The role of symbiotic algae in carbon and energy flux in reef corals. In: Dubinsky Z (ed) Coral reefs. Ecosystems of the world. vol 25. Elsevier, Amsterdam, pp 75–87

4 Rooney, J., Donham, E., Montgomery, A., Spalding, H., Parrish, F., Boland, R., Fenner, D., Gove, J., Vetter, O. (2010). Mesophotic coral ecosystems in the Hawaiian Archipelago. Coral Reefs 29: 361-367. https://doi.org/10.1007/s00338-010-0596-3

5 Smith TB, Maté JL, Gyory J (2017) Thermal refuges and refugia for stony corals in the eastern tropical Pacific. In: Glynn WP, Manzello PD, Enochs CI (eds) Coral reefs of the eastern tropical Pacific: persistence and loss in a dynamic environment. Springer Netherlands, Dordrecht, pp 501–515

6 Bongaerts P, Frade PR, Hay KB et al (2015b) Deep down on a Caribbean reef: lower mesophotic depths harbor a specialized coral-endosymbiont community. Sci Rep 5:7652

7 Muir P, Wallace C, Bridge TC, Bongaerts P (2015) Diverse staghorn coral fauna on the mesophotic reefs of north-east Australia. PLoS ONE 10:e0117933

8 Lesser MP, Slattery M, Stat M et al (2010) Photoacclimatization by the coral Montastraea cavernosa in the mesophotic zone: light, food, and genetics. Ecology 91:990–1003

Hypothesis (DRRH) states that deep reefs may act as refuges against major disturbances (e.g., bleaching, pollution) and could provide a source of larvae to reseed decimated shallow reefs[9]. However, recent studies have shown that the vertical connectivity between deep and shallow reefs is far less than previously thought, and more complex, depending on species and geographic areas.

MCEs are generally divided into lower and upper zones, with a faunal break around 60 m. Upper MCEs support species of coral that can occur in both upper and lower MCEs, and are more likely to play a role as a potential refuge for shallow water coral reef species[10]. Lower MCEs support distinct assemblages of deep adapted corals and unique biodiversity (some of it undescribed and potentially endemic to this light-limited zone) that have inherent biological and conservation value. MCEs represent "bright spots" in the mesophotic zone, supporting unusually high coral cover and unique species diversity and assemblages at unexpected depths (e. g. Maui's 'Au'au channel in Hawaii[11]), which, in turn, provide fish refuges, socio-ecological services for human populations .

Although some studies argue that MCEs are less affected than shallow-water reefs by the multitude of human and environmental pressures of the Anthropocene era, MCEs are exposed to threats such as oil spills and overfishing and require appropriate protection. Innovations in diving technology (e.g. closed-circuit rebreathers) and submersibles offer the possibility to better explore the world's deepest coral reef ecosystems and enhance our scientific understanding of their extent, ecology and the importance of their contribution to coral reef functioning in order to prioritize management actions and conserve these unique ecosystems.

9 Bongaerts P, Ridgway T, Sampayo EM, Hoegh-Guldberg O (2010) Assessing the 'Deep Reef Refugia' hypothesis: focus on Caribbean reefs. Coral Reefs 29:309–327

10 Kahng S, Copus JM, Wagner D (2017) Mesophotic coral ecosystems. In: Rossi S, Bramanti L, Gori A, Orejas C (eds) Marine animal forests. Springer.

11 Pyle RL, Boland R, Bolick H et al (2016) A comprehensive investigation of mesophotic coral ecosystems in the Hawaiian Archipelago. PeerJ 4:e2475

Box 8.

Recovery of hard coral cover: the case of Moorea

Jérémy Wicquart, Serge Planes

Ecosystems face a variety of disturbances that modify their structure and processes, sometimes dramatically. Forest fires that ravage hundreds of hectares are probably among the best known and most striking disturbances. Hence, there have been numerous studies of the capacity of forest ecosystems to recover, or to return to their pre-disturbance state. These studies have been central to research on the temporal dynamics of ecosystems.

On coral reef ecosystems, major disturbances include tropical storms, coral bleaching events and crown-of-thorns starfish (*Acanthaster* spp.) outbreaks. These disturbances impact the foundation species of reefs - the hard corals - either by breaking their skeleton or by partially or totally killing the colonies. This reduces the complex habitats they form and shelter they provide, which, in turn, can have cascading impacts on species that depend on hard corals, such as fish and invertebrates. Like forest ecologists, coral reef ecologists are working to determine how long it takes for coral reefs to recover to pre-disturbance states.

Coral reefs in Moorea in French Polynesia have been monitored since the late 1970s making this one of the world's longest monitoring time series. The history of coral reefs in Moorea has not always been peaceful and hard corals have been through several important disturbance events[1]. The last sequence of major disturbances involved the proliferation of the coral predator *Acanthaster* spp., between 2006 and 2010, and cyclone Oli in 2010, which decreased hard coral cover from 50% (Fig. 1A) to nearly 0% (Fig. 1B)[2]. Between 2010 and 2018, hard coral cover gradually recovered almost to pre-disturbance levels (Fig. 1D). This recovery resulted from the recruitment of young corals (Fig. 3C) by larval dispersion[3]. In some cases, recovery has also occurred through remnant coral, either by "re-sheeting" of dead skeletons from patch of tissue that survived (the "phoenix effect"[4]) or through the growth of a fragment from a broken colony (a process similar to cuttings).

[1] Lamy, T., Galzin, R., Kulbicki, M., Lison de Loma, T., & Claudet, J. (2016). Three decades of recurrent declines and recoveries in corals belie ongoing change in fish assemblages. Coral Reefs, 35(1), 293–302. doi:10.1007/s00338-015-1371-2

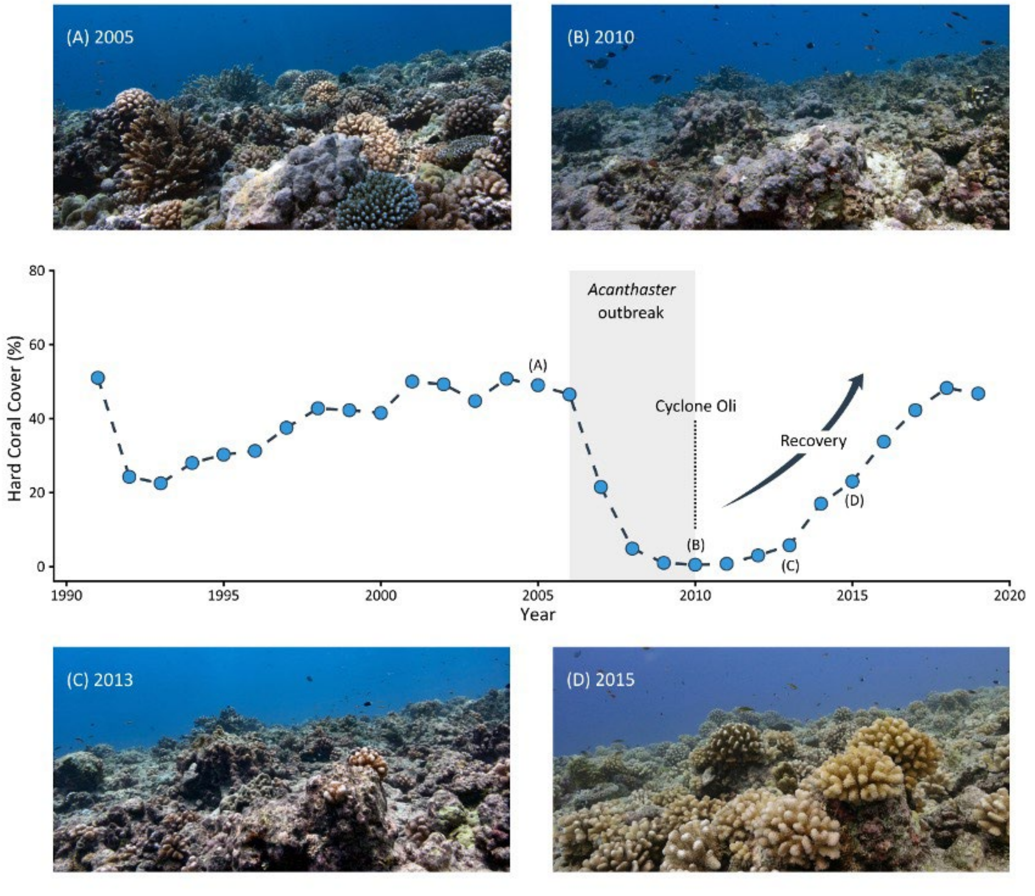
[2] Adjeroud, M., Kayal, M., Iborra-Cantonnet, C., Vercelloni, J., Bosserelle, P., Liao, V., ... Penin, L. (2018). Recovery of coral assemblages despite acute and recurrent disturbances on a South Central Pacific reef. Scientific Reports, 8(1), 1–8. doi:10.1038/s41598-018-27891-3

[3] Holbrook, S. J., Adam, T. C., Edmunds, P. J., Schmitt, R. J., Carpenter, R. C., Brooks, A. J., ... Briggs, C. J. (2018). Recruitment Drives Spatial Variation in Recovery Rates of Resilient Coral Reefs. Scientific Reports, 1–11. doi:10.1038/s41598-018-25414-8

[4] Roff, G., Bejarano, S., Bozec, Y.-M., Nugues, M., Steneck, R. S., & Mumby, P. J. (2014). Porites and the Phoenix effect: unprecedented recovery after a mass coral bleaching event at Rangiroa Atoll, French Polynesia. Marine Biology. doi:10.1007/s00227-014-2426-6

The good news is that hard coral cover can recover. However, coral reefs have adapted to recover in response to "natural" disturbance regimes, characterized by a given frequency and intensity range. If climate change modifies these disturbance regimes by increasing frequency and intensity of coral bleaching events, coral cover may no longer have the time to recover before they are subjected to subsequent disturbances. In order to limit the impacts of global climate change on coral reef ecosystems, greenhouse gas emissions must be reduced. In addition, to improve resistance and/or decrease recovery times from disturbances, local-scale chronic pressures, such as sedimentation, pollution and overfishing, must be mitigated[5].

Figure 1. Trends in live hard coral cover between 1990 and 2020 on the outer slope of the ATPP long-term monitoring site, in Moorea, French Polynesia. Blue points indicate mean values of hard coral cover between the different replicates. The photographs provide an illustration of the condition of the reef at the monitoring site (Photo credit: Yannick Chancerelle, CRIOBE).



5 Lam, V. Y. Y., Doropoulos, C., Bozec, Y. M., & Mumby, P. J. (2020). Resilience Concepts and Their Application to Coral Reefs. Frontiers in Ecology and Evolution, 8(March), 1–14. doi:10.3389/fevo.2020.00049

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