GCRMN
Global Coral Reef Monitoring Network

ICRI
International Coral Reef Initiative

Australian Government

Australian Institute of Marine Science

Status of Coral Reefs of the World: 2020

Chapter 2. Status of Coral Reefs of the World

Edited by: David Souter, Serge Planes, Jérémy Wicquart, Murray Logan, David Obura and Francis Staub

Australian Government
Department of Foreign Affairs and Trade

Gouvernement Princier
Principauté de Monaco

Government Offices of Sweden
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Chapter 2.

Status of coral reefs of the World

Status and trends in the global average cover of hard coral

Trends in the estimated annual global average cover of hard coral between 1978, when the earliest data contributed to this report were collected, and 2019 are presented in figure 4.1. Between 1978 and 1997, the global average cover of hard coral was high and stable, ranging between 32.1% and 32.5%. However, because data were scarce and regional representation within the global dataset was poor in these early years, there is comparatively high uncertainty associated with these estimates.

In 1998, the first global-scale coral bleaching event occurred, affecting nearly all coral reef regions. As a consequence, global average hard coral cover declined from 32.5% to 30% between 1997 and 2002. This represented a loss of 7.8% of the world's hard coral, or the equivalent of approximately 6,500 km^2 of coral during these five years. To put this into context, this represents more than the total amount of hard coral living in any one of the Caribbean, Red Sea and Gulf of Aden, South Asia or Western Indian Ocean regions.

The 1998 mass coral bleaching event also triggered a substantial increase in global monitoring effort to measure the impacts of this event on the world's coral reefs. As a result, estimates of global average coral cover were more precise as more data were available. Since then, most monitoring programs have been maintained and new programs have been established, often in response to more recent mass coral bleaching events, resulting in even greater confidence in coral cover estimates.

Between 2002 and 2009, global average hard coral cover returned to pre-1998 levels, reaching 33.3% in 2009. This demonstrates that in the absence of major global disturbances, many of the world's coral reefs have remained resilient and capable of recovering, despite the influence of local stressors.

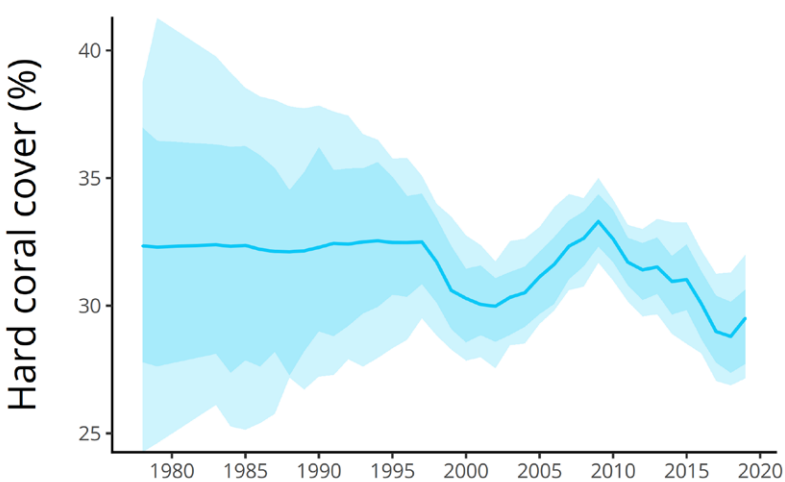

Figure 2.1. Estimated global average cover of hard coral (solid blue line) and associated 80% (darker shade) and 95% (lighter shade) credible intervals, which represent levels of uncertainty.

Since 2009, the overwhelming trend in global average hard coral cover has been downward. Between 2009 and 2018, global average hard coral cover declined from 33.3% to 28.8%, which represents a loss of 13.5% of the world's hard coral. To put this into context, this equates to about 11,700 km^2 of coral, which is approximately the equivalent of losing all the hard coral currently living on Australia's coral reefs. Although fewer data were available for 2019, global average coral cover showed the first signs of recovering, with an increase of 0.7%.

The robustness of recent trends described above was confirmed by comparing global average coral cover between each of the three five-year periods comprising the last 15 years (Tab. 2.1). This period corresponds with when most data were available and when confidence in estimates of annual global average hard coral cover was greatest (Fig. 2.1). There was strong evidence (> 90% probability) that global average coral cover declined between 2005-09 and 2010-14 and again between 2010-14 and 2015-19. These declines suggest that, on average, there was 13.7% less hard coral on reefs in 2015-19 compared with 2005-09 (Tab. 2.1).

Table 2.1. Probability and magnitude of mean absolute and relative change in the percent cover of live hard coral on the world's coral reefs 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	90	-1.2	-5.2
2010-14 - 2015-19	96	-2.0	-8.8
2005-09 - 2015-19	99	-3.2	-13.7

Status and trends in the global average cover of algae

The global average cover of algae was low and relatively stable between 1986, when the first algal cover data contributed to this report were collected, and 2011, ranging between 14.9% (1997) and 16.5% (1986) (Fig. 2.2). However, since 2011, the cover of algae on the world's coral reefs has increased progressively from 15.4% to a maximum of 19.3% in 2018, before a small (0.3%) decline in 2019 (Fig. 2.2). This indicates that during the last decade, the amount of algae on the world's coral reefs has increased by approximately 20%.

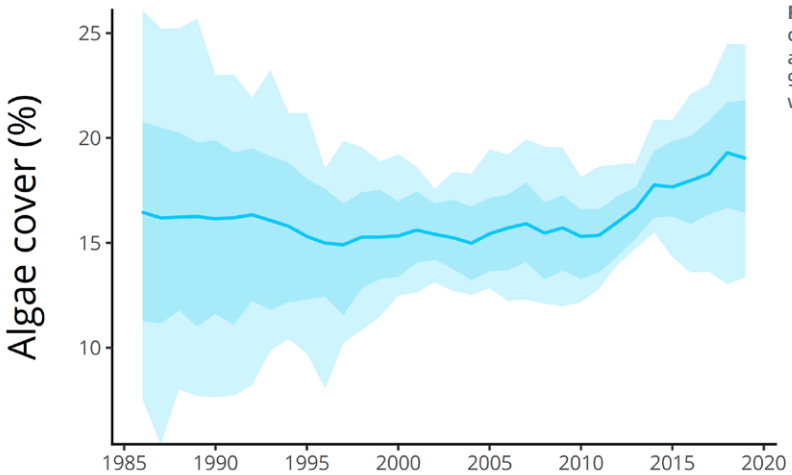

Figure 2.2. Estimated global average cover of algae (solid blue line) and associated 80% (darker shade) and 95% (lighter shade) credible intervals, which represent levels of uncertainty.

In contrast with hard coral cover, the global average cover of algae did not change in response to the 1998 global coral bleaching event. However, the cover of algae increased substantially between 2011 and 2019 (Fig. 2.2), which corresponded with the decline in global average hard coral cover that began in 2009 (Fig. 2.1). Comparison of the global average cover of algae during the three five-year periods comprising the last 15 years (2005-09, 2010-14 and 2015-19) provides strong evidence (>84% probability) that the amount of algae on the world's coral reefs has increased during this time (Tab. 2.2). On average, the absolute change in the cover of algae between 2005-09 and 2015-19 was 3.1%, which translates to 26.3% more algae on the world's coral reefs in 2015-19 compared with 2005-09 (Tab. 2.2). These results provide strong evidence that generally, the amount of algae on the world's reefs is increasing while the amount of hard coral is decreasing, which is a strong indication that the condition of the world's reefs is declining.

Table 2.2. Probability and magnitude of mean absolute and relative change in the percent cover of algae on the world's coral reefs 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	1.1	9.2
2010-14 - 2015-19	88	2.0	15.5
2005-09 - 2015-19	93	3.1	26.3

Trends in the ratio between the global average covers of live hard coral and algae

Changes in the global average covers of hard coral and algae are reflected in the trend in the ratio between these two important indicators of coral reef condition (Fig. 2.3). Between 1986 and 1997, the ratio was relatively stable, ranging between a minimum of 2.1 (1991) and a maximum of 2.3 (1997), indicating that during this period there was, on average, more than twice as much coral on the world's coral reefs as there was algae. Following the 1998 global coral bleaching event, the coral:algae ratio declined to 2.0 in 2002, due to the bleaching-related coral mortality and subsequent loss of coral cover. As coral cover recovered during the course of the next decade, the ratio of coral:algae also increased, reaching a maximum of 2.4 in 2010. However, since 2010, the ratio of coral to algae has progressively declined, reaching a minimum of 1.6 in 2018, before a slight increase to 1.7 in 2019. This decline in the coral:algae ratio corresponds with both the loss in coral cover (Fig. 2.1) and the increase in algae cover (Fig. 2.2) observed during the last decade.

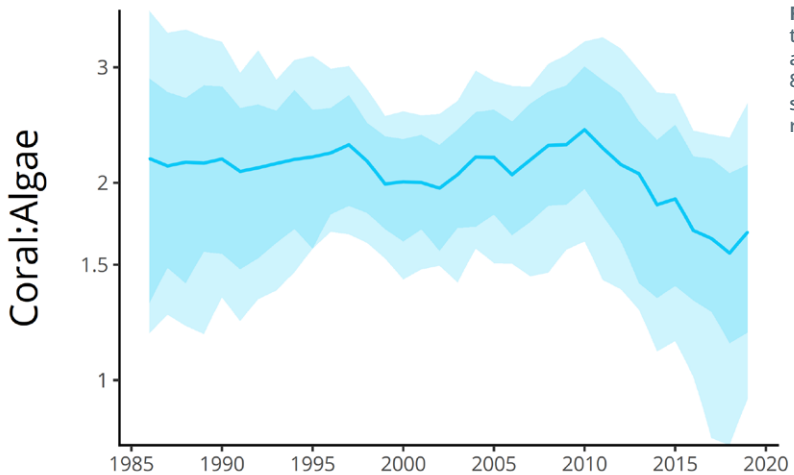

Figure 2.3. Estimated ratio between the global average covers of coral and algae (solid blue line) and associated 80% (darker shade) and 95% (lighter shade) credible intervals, which represent levels of uncertainty.ainty.

The relatively high uncertainty in the coral:algal ratio prior to 1998 was a consequence of the scarcity of available data and poor geographic representation within the global dataset in these early years.

Status and trends in the cover of hard coral in each region

In regions where historical data (e.g. pre-1995) were available (Caribbean, East Asian Seas, Western Indian Ocean, Pacific and Australia), coral cover (and associated uncertainty) was relatively high and showed little change or only a slight decline (Fig. 2.4).

From 1997/98, steep declines in hard coral cover were evident in South Asia, particularly in the Chagos Archipelago and Maldives, in the Western Indian Ocean (WIO), especially the East African Coral Coast and Seychelles, in Western Australia (Exmouth to Broome), South Kuroshio, and some areas of the Caribbean (Southern Caribbean and Greater Antilles). Smaller declines were recorded in the Northern and Central Red Sea and the Inner ROPME Sea Area, the Western Caroline Islands, New Caledonia, Hawaii and Samoa Islands. Some of these trends have been partially described in recent GCRMN regional reports for the Caribbean, Western Indian Ocean and Pacific.

Increases in global average live hard coral cover between 2002 and 2008 were driven primarily by reefs in South Asia (Chagos and Maldives), the WIO, Australia (Western Australia, and to a smaller extent Torres Strait and the Northern Great Barrier Reef), Brazil (Northeastern and Eastern Brazil), the Inner ROPME Sea Area and the Red Sea and Gulf of Aden (North and Central Red Sea) regions. The Fiji Islands and Solomon Archipelago subregions within the Pacific also showed an increase in live hard coral cover during this period, but coral cover on reefs within other Pacific subregions remained stable. The greatest increases in coral cover were observed in regions where the impacts of the 1998 coral bleaching event were greatest, demonstrating that recovery in hard coral cover can occur in less than 10 years.

During the last 15 years, almost all regions have experienced a decline in average coral cover, with South Asia, Australia, the Pacific, the ROPME Sea Area and the East Asian Seas regions exhibiting the greatest declines (Tab. 2.3). In these regions, probabilities of decline exceeded 82% in these regions (Tab. 2.3). Together, these regions support almost 50% of the world's coral reefs. The only exceptions were the Brazil and Caribbean regions which showed increases in average hard coral cover of 3% and 1.6% respectively (Tab. 2.3).

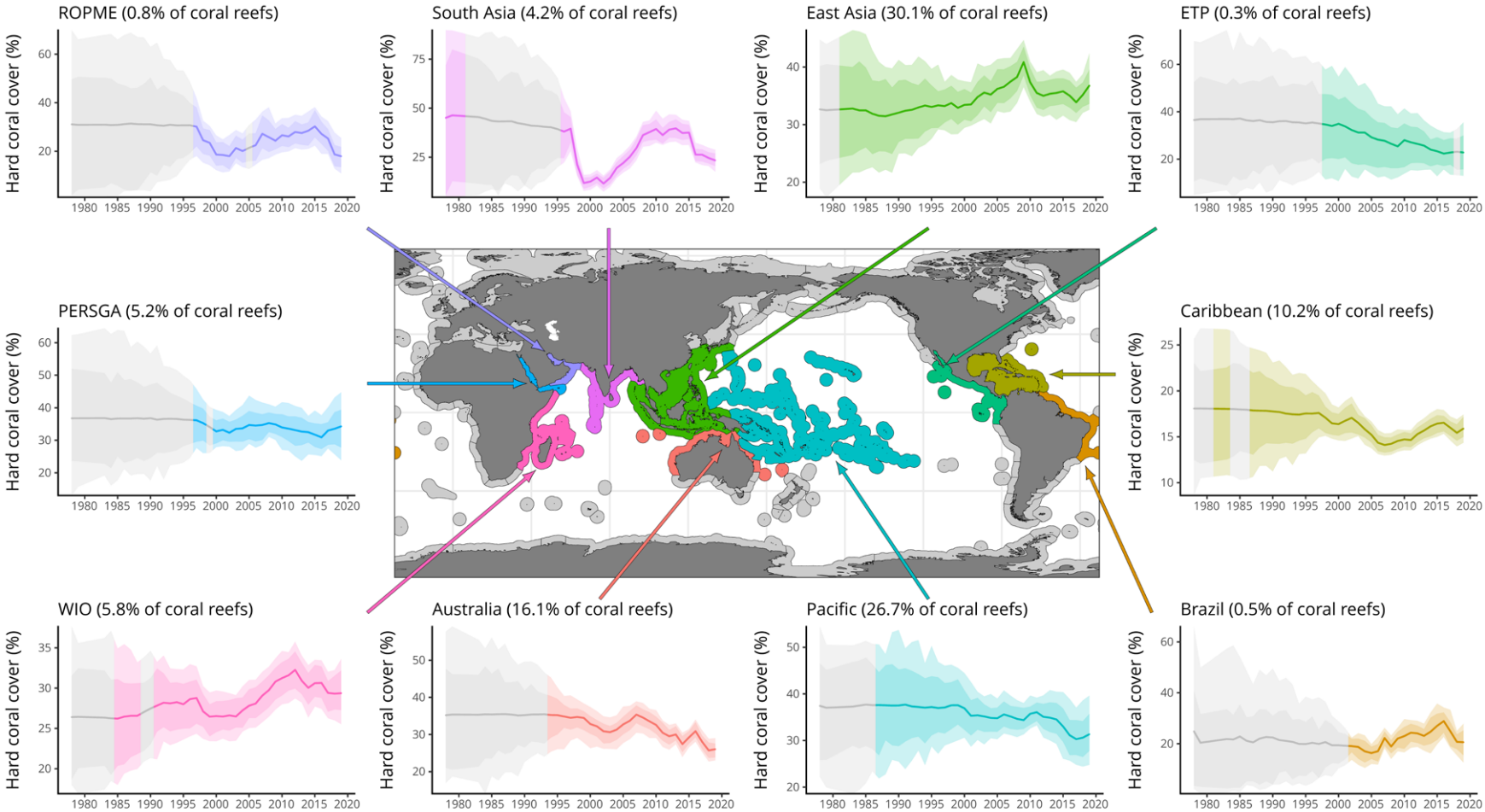

Figure 2.4. Long-term trends in the average cover of live hard coral in each of the ten GCRMN regions. The solid line represents the estimated mean with 80% (darker shade) and 95% (lighter shade) credible intervals, which represent levels of uncertainty. Grey areas represent periods for which no observed data were available. Trends are coloured to match the GCRMN regions represented on the central map. The proportion of the world's coral reef area supported by each region is indicated by % of coral reefs. ETP is the Eastern Tropical Pacific. PERSGA is the Red Sea and Gulf of Aden. ROPME is the ROPME Sea Area. WIO is the Western Indian Ocean.

Table 2.3. Mean absolute change in percent live hard coral cover (and associated probability as a percentage) between pairs of five-year periods within the last 15 years in each region.

Region	Comparison 2005-09 - 2010-14	Comparison 2010-14 – 2015-19	Comparison 2005-09 – 2015-19
Australia	-4.6 (99%)	-1.7 (89%)	-6.6 (100%)
Brazil	4.1 (98%)	-1.0 (69%)	3.0 (92%)
Caribbean	1.2 (99%)	0.3 (70%)	1.6 (99%)
East Asian Seas	-2.7 (96%)	-0.2 (54%)	-2.8 (96%)
Eastern Tropical Pacific	-0.9 (53%)	-0.6 (54%)	-1.4 (54%)
Pacific	0.4 (61%)	-3.9 (95%)	-4.3 (93%)
Red Sea and Gulf of Aden	-2.0 (76%)	0.2 (47%)	-1.7 (71%)
ROPME Sea Area	2.9 (80%)	-6.1 (96%)	-3.2 (82%)
South Asia	4.3 (94%)	-12.9 (100%)	-8.7 (100%)
Western Indian Ocean	1.3 (88%)	-1.4 (84%)	-0.1 (52%)

Resilient coral reefs experience fluctuations in coral cover over time as disturbances, which cause declines in coral cover, are interspersed with periods of recovery during which coral cover is restored. To identify changes in the resilience of coral reefs, patterns of disturbance and recovery were examined within sampling units in each region 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%. Among the eight regions with such sampling units, all had a proportion of sampling units that did not recover fully following disturbance (i.e. did not recover to at least 90% of their pre-disturbance coral cover, Tab. 2.4) . The average proportion of long-term sampling units that did not fully recover was 71%, with the greatest proportions occurring within the Eastern Tropical Pacific (100%), South Asia (93%), Caribbean (81%) and Australian (77%) regions (Tab. 2.4).

Long-term declines in average hard coral cover among those sampling units examined ranged between 1.7% in the East Asian Seas region and 60.4% in the Eastern Tropical Pacific, with most regions experiencing long-term declines between 4.1% and 7.2% (Table 4.4). The Eastern Tropical Pacific (60.4%), South Asia (20.8%) and Australian (10%) regions experienced the greatest absolute declines in coral cover where long-term monitoring was conducted. Relatively little long-term monitoring occurred in the Western Indian Ocean, ROPME Sea Area, Red Sea and Gulf of Aden, Eastern Tropical Pacific and Brazil regions, either because sites were not repeatedly sampled or because sites had not been monitored for 15 years or more.

Table 2.4. The mean maximum decline and the mean difference between the first and last survey (long-term decline) 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.

Region	N	n	Percent	Mean maximum absolute decline (%)	Mean maximum relative decline (%)	Mean long-term absolute decline (%)	Mean long-term relative decline (%)
Australia	135	104	77	24.0	80.3	10.0	45.3
Brazil	11	7	63.6	10.4	38.8	5.8	17.2
Caribbean	247	199	80.6	12.3	77.6	7.2	57.4
East Asian Seas	55	25	45.5	18.9	69.3	1.7	4.7
Eastern Tropical Pacific	6	6	100	63.5	96.7	60.4	95.1
Pacific	120	69	57.5	24.7	73.3	7.0	21.4
Red Sea and Gulf of Aden	10	5	50	20.5	57.1	4.1	13.6
ROPME Sea Area	0	-	-	-	-	-	-
South Asia	30	28	93.3	27.2	65.6	20.8	55.1
Western Indian Ocean	0	-	-	-	-	-	-

Status and trends in the average cover of algae in each region

Regional trends in the average cover of algae were generally the inverse of those exhibited by regional average coral cover, with most regions showing increases (Fig. 2.5). Over the period for which data were available in each region, increases in algal cover were most pronounced in Australia, Brazil and the ROPME Sea Area (Fig. 2.5). Moderate increases in the cover of algae were recorded in the Caribbean, Eastern Tropical Pacific, Pacific, South Asia and the Red Sea and Gulf of Aden regions, while there was little overall change in the Western Indian Ocean region. The East Asian Seas region was the only region in which the average cover of algae decreased (Fig. 2.5).

Based on a comparison of the three five-year periods comprising the last 15 years (Tab. 2.5), the probability that the cover of algae increased between 2005-09 and 2015-19 was 100% in Australia, Brazil, the Caribbean and the ROPME Sea Area, and 99% in South Asia. On average, increases in the cover of algae within these regions over this period ranged between 3.9% (South Asia) and 13.4% (ROPME Sea Area). In the Pacific, the Red Sea and the Gulf of Aden and the Eastern Tropical Pacific, the probability of increases in algal cover were more moderate ranging between 73% and 87%, and increases in algal cover ranged between 3.1% and 5.9% (Tab. 2.5) . Together, these regions comprise 64% of the world's coral reefs, indicating that two-thirds of the world's coral reefs are experiencing an increase in algae cover. In contrast, the East Asian Seas and Western Indian Ocean regions exhibited moderate probabilities of declines in the cover of algae in the order of 1.1% and 2.9% respectively during the last 15 years (Tab. 2.5).

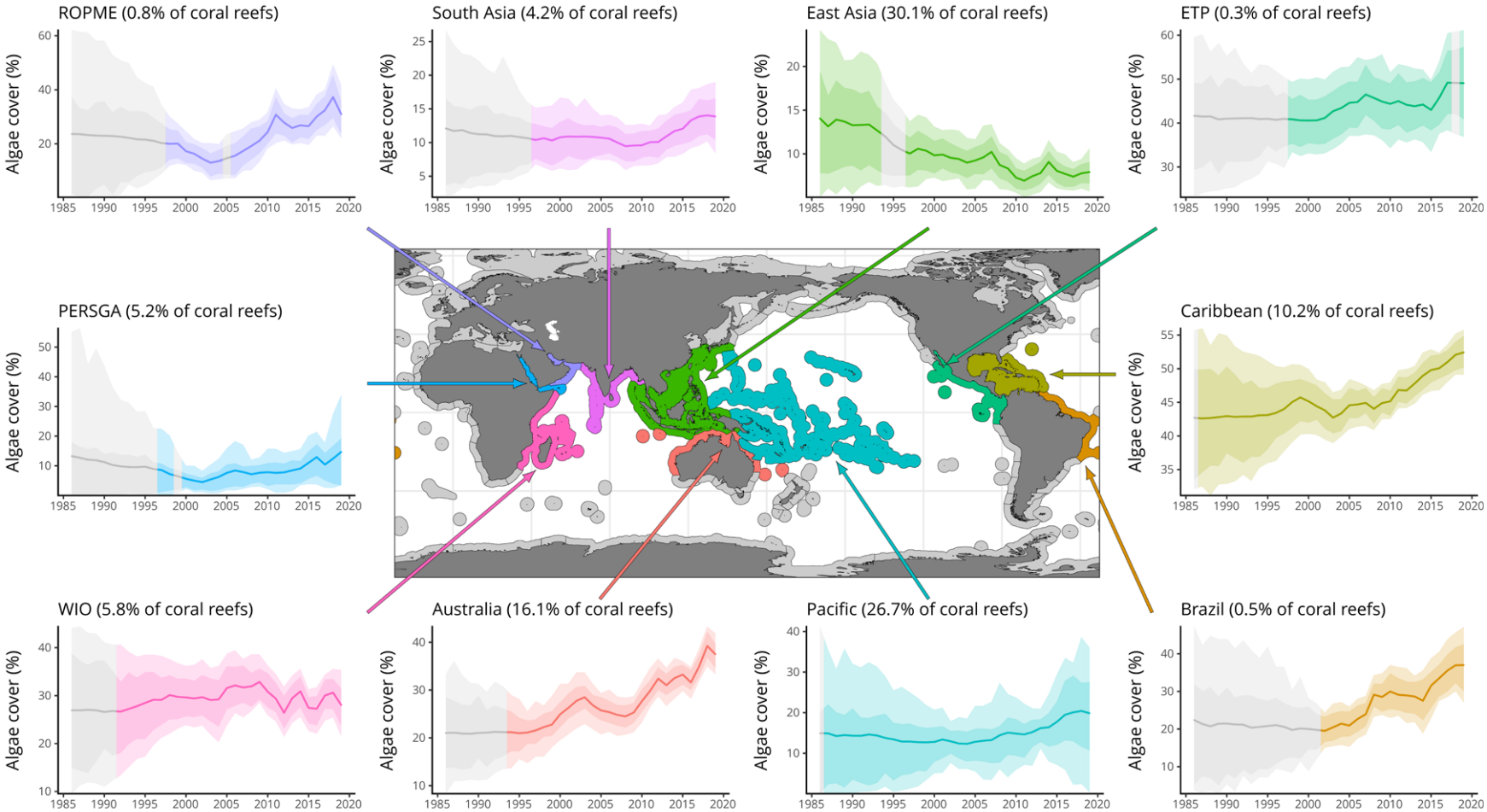

Figure 2.5. Long-term trends in the average cover of algae in each of the ten GCRMN regions. The solid line represents the estimated mean with 80% (darker shade) and 95% (lighter shade) credible intervals, which represent levels of uncertainty. Grey areas represent periods for which no observed data were available. Trends are coloured to match the GCRMN regions represented on the central map.The proportion of the world's coral reef area supported by each region is indicated by % of coral reefs. ETP is the Eastern Tropical Pacific. PERSGA is the Red Sea and Gulf of Aden. ROPME is the ROPME Sea Area. WIO is the Western Indian Ocean.

Table 2.5. Mean absolute change in percent cover of algae (and associated probability as a percentage) between pairs of five-year periods within the last 15 years in each region.

Region	Comparison 2005-09 – 2010-14	Comparison 2010-14 – 2015-19	Comparison 2005-09 – 2015-19
Australia	6.3 (100%)	4.0 (100%)	10.2 (100%)
Brazil	2.4 (88%)	6.6 (99%)	9.0 (100%)
Caribbean	3.3 (100)	3.4 (99%)	6.7 (100%)
East Asian Seas	-0.9 (87%)	-0.1 (59%)	-1.1 (86%)
Easter Tropical Pacific	-1.2 (32%)	4.3 (83%)	3.1 (74%)
Pacific	1.9 (84%)	4.1 (82%)	5.9 (87%)
Red Sea and Gulf of Aden	1.0 (68%)	3.8 (81%)	4.8 (85%)
ROPME Sea Area	8.3 (99%)	5.1 (92%)	13.4 (100%)
South Asia	1.1 (79%)	2.8 (95%)	3.9 (99%)
Western Indian Ocean	-3.2 (91%)	0.3 (53%)	-2.9 (88%)

Long-term changes in the average cover of algae were examined in each region within sampling units that had been surveyed repeatedly over a period of at least 15 years and had, at some point, experienced a relative increase in algal cover of at least 20%. Among the eight regions with sampling units that matched these criteria, all had a proportion of sampling units within which the cover of algae remained elevated (Tab. 2.6). The average proportion of long-term sampling units that did not fully recover was 82%, with the greatest proportions occurring within the Brazil (100%), Eastern Tropical Pacific (100%) and Red Sea and Gulf of Aden (100%) regions (Tab. 2.6).

Long-term increases in the average cover of algae among those sampling units examined ranged between 2% in South Asia and 49% in the Eastern Tropical Pacific (Tab. 2.6). The Eastern Tropical Pacific (49%), Brazil (34.3%) and Australia (21.1%) experienced the greatest absolute increases in the cover of algae where long-term monitoring was conducted. South Asia (2%), East Asian Seas (4.1%) and the Pacific (5.9%) recorded the smallest absolute increases in the cover of algae where long-term monitoring was conducted.

Table 2.6. The mean maximum increase and the mean difference between the first and last survey (long-term increase) expressed as absolute and relative increases in average percent cover of algae. N is the total number of sampling units for which >15 years of data were available and had experienced a relative increase in the cover of algae of at least 20 percent. n is the number of sampling units that did not recover to 110 percent (i.e. 10% above) of the initial algal cover. Percent is the proportion of the total number of sampling units that did not recover to 110 percent of the initial algal 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

Region	N	n	Percent	Mean maximum absolute increase (%)	Mean maximum relative increase (%)	Mean long-term absolute increase (%)	Mean long-term relative increase (%)
Australia	135	112	84	37.4	203	21.1	154
Brazil	15	15	100	43.1	389	34.3	327
Caribbean	198	160	81	30.3	614	15.2	321
East Asian Seas	50	29	58	26.0	527	4.1	142
Eastern Tropical Pacific	5	5	100	51.3	264	49.0	254
Pacific	86	52	60	25.8	266	5.9	130
Red Sea and Gulf of Aden	2	2	100	27.5	642	13.1	357
ROPME Sea Area	0	0	0	-	-	-	-
South Asia	13	10	76	8.0	303	2.0	153
Western Indian Ocean	0	0	0	-	-	-	-

Trends in the ratio between average covers of live hard coral and algae in each region

The ratio of average live hard coral cover to average algal cover varies between regions from approximately 0.5 (which indicates more algae than coral) in the ROPME Sea Area, Eastern Tropical Pacific and Caribbean, to approximately 1 (indicating similar average covers of coral and algae) in the Western Indian Ocean, Australia and Brazil to more than 2 (indicating at least twice the average cover of coral compared with algae) in South Asia, East Asian Seas, Red Sea and Gulf of Aden and the Pacific regions (Fig. 2.6). Moreover, the temporal trends also vary across regions, and do so independently of whether coral or algae was initially dominant.

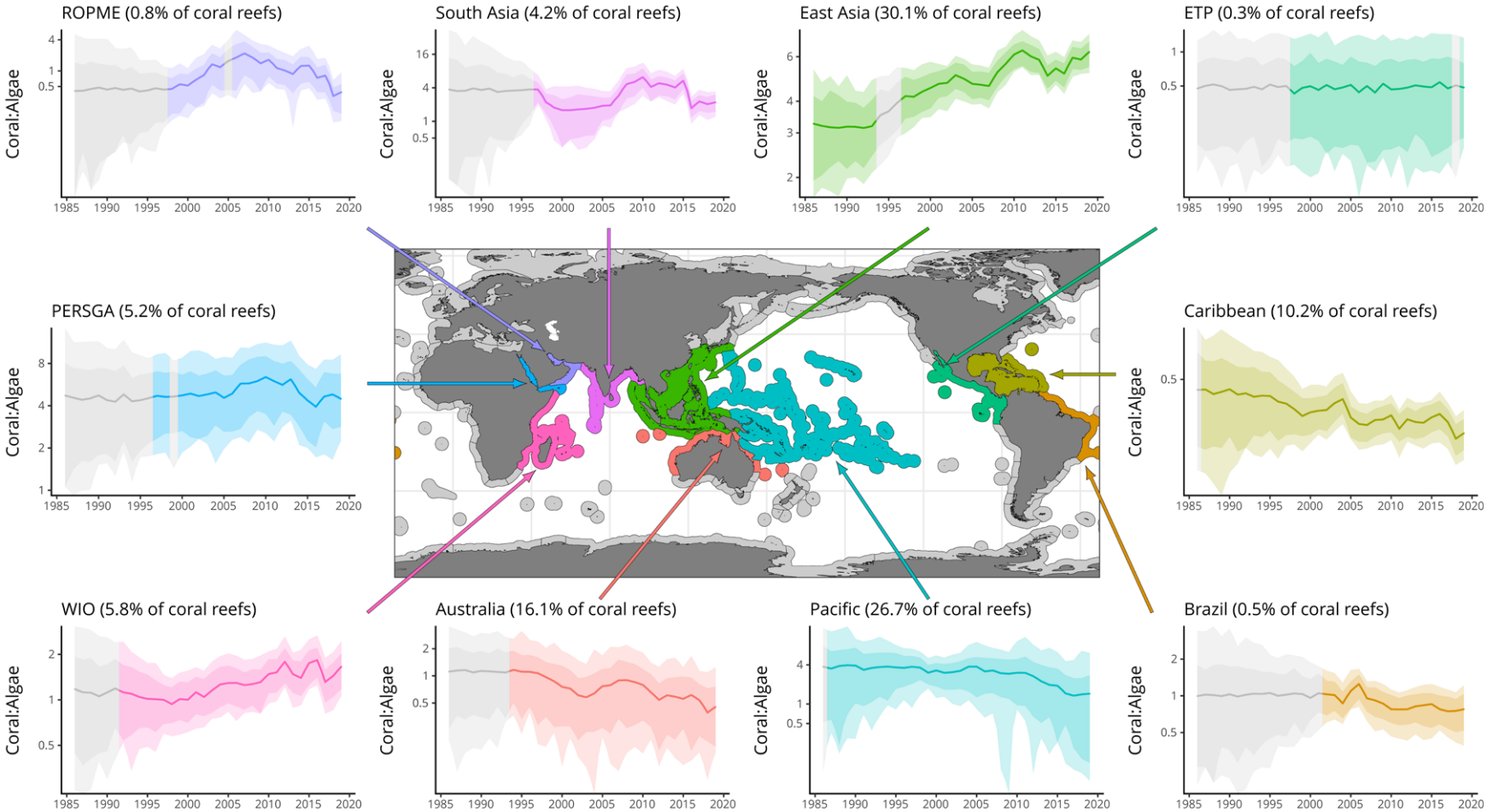

Figure 2.6. Long-term trends in the ratio between the average covers of live hard coral and algae in each of the ten GCRMN regions. The solid line represents the estimated ratio with 80% (darker shade) and 95% (lighter shade) credible intervals, which represent levels of uncertainty. Grey areas represent periods for which no observed data were available. Trends are coloured to match the GCRMN regions represented on the central map. The proportion of the world's coral reef area supported by each region is indicated by % of coral reefs. ETP is the Eastern Tropical Pacific. PERSGA is the Red Sea and Gulf of Aden. ROPME is the ROPME Sea Area. WIO is the Western Indian Ocean.

Overall, there is variation between the regions in terms of the dominance of coral in benthic reef communities and in the trends in the ratio of the average covers of coral:algae. While this variation is likely to be due to differences in reef community status, composition and resilience, and the stressors affecting them, further investigation of the drivers of this heterogeneity is required not only to improve our overall understanding of the differences observed, but also to help strengthen adaptive management actions that enhance natural resilience capabilities.

In contrast to most other regions, the East Asian Seas region, which includes the Coral Triangle, the center of global hard coral diversity, and accounts for nearly a third of the world's coral reefs by area, shows a progressive increase in coral cover until 2010 (Fig. 2.7A), then a sharp decline as a consequence of the second global coral bleaching event occurred in 2010. In addition, the average covers of cover of algae shows a marked decline prior to 2010, after which it stabilizes (Fig. 2.7B). The ratio of the average covers of coral:algae changed dramatically from >2 in the 1980s to ≈5 in 2010 (Fig. 2.7C). Despite thermal stresses in the East Asian Seas region being similar to those experienced in other regions, hard coral cover at the regional scale appears less affected until the last decade when the impacts of coral bleaching events in 2010 and 2016 were evident (Fig. 2.7A). The smaller impact of ocean warming events to coral reefs in the East Asian Seas region warrants further investigation as they may provide important insights into the factors that promote coral reef resilience.

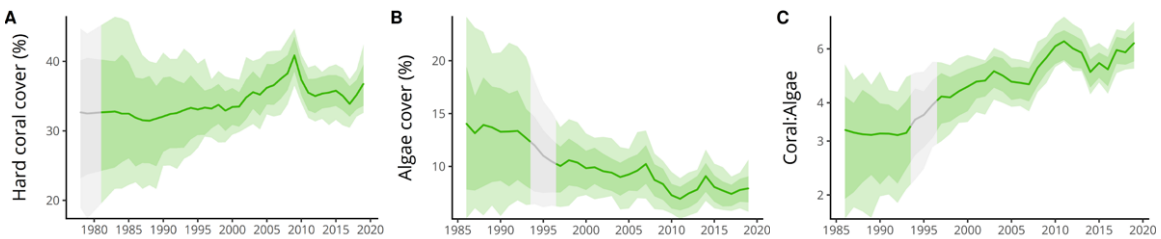

Figure 2.7. Estimated average cover of hard coral (A), and algae (B), and ratio of the average covers of hard coral to algae (C) for the East Asian Seas region. The solid line represents the estimated mean with 80% (darker shade) and 95% (lighter shade) credible intervals, which represent levels of uncertainty. Grey areas represent periods for which no observed data were available.

Global climatic drivers

Since global trends in the average cover of hard coral were derived from the aggregation of many localized trends, obvious changes in global trends, such as those that occurred following the large scale mass coral bleaching events in 1998, 2010 and 2016, were only apparent when similar changes occurred simultaneously across a large proportion of the world's coral reefs. While coral reefs are affected by numerous different types of disturbances (e.g. tropical storms, sedimentation, eutrophication, destructive fishing), only those that occur at very large scales will have sufficient impact to influence global trends. Hence, in exploring the drivers of change in global trends in average coral cover, the most obvious candidates were large-scale, climate-driven events.

Figure 2.8 examines the relationship between trends in the global average cover of hard coral cover and sea surface temperature (SST) anomalies during the last four decades. Trends in global average coral cover showed strong associations with mean global sea surface temperature (SST) anomalies. In particular, periods of decline in global average coral cover coincided with two features of the trend in SST anomaly: consecutive months of rapid increases in SST anomaly (dark red bars); and periods of sustained high SST anomalies (lighter red bars) (Fig. 2.8). All three global coral bleaching events (1997-98, 2010 and 2015-2017) that resulted in declines in global average coral cover coincided with consecutive months of rapidly increasing SST anomalies (Fig. 2.8), while sustained high SST anomalies after the 2010 event and from 2013 onwards (Fig. 2.8) may have hindered the recovery of corals and facilitated progressive increases in the cover of algae. The relationship between trends in global average coral cover and fluctuations in the El Niño Southern Oscillation Index was also examined, but no association was found.

Additional analyses at regional scales will determine if the global relationship between average hard coral cover and the SST anomaly holds at smaller spatial scales, or if the ENSO signal or local stressors are more important at these scales. The influence of SST anomalies on global average coral cover reinforces the importance of real time monitoring of SST to coral reef management and conservation (see NOAA Coral Reef Watch Box).

The strong association between SST anomaly and declines in global average coral cover resulting from large-scale coral bleaching events emphasises the importance of climate-related factors as primary drivers of the long-term health of the world's coral reefs, particularly as climate also influences other smaller scale disturbances that affect coral reefs, such as tropical storms, terrestrial run-off and coral disease.

Further, while the SST anomaly has progressively increased since the 1970s (Fig. 2.8), global average coral cover has only declined during periods when the SST anomaly has rapidly increased or exceeded 0.45 (Fig. 2.8). However, in 2019, global average coral cover increased despite the SST anomaly being at historically high levels. This suggests that world's coral reefs still retain their ability to recover from disturbances, despite the unfavourable climate conditions, and that potentially, corals are demonstrating some capacity for acclimation and adaptation. However, the limits to such adaptive capacity is as yet, unknown, and anecdotal evidence suggests that adaptive capacity is not equal among all coral species, resulting in shifts in community composition.

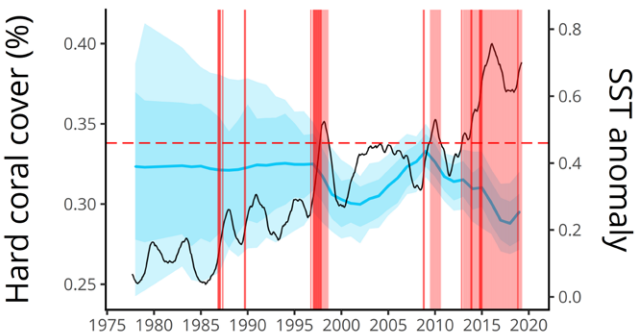

Figure 2.8. Estimated global average hard coral cover with the sea surface temperature (SST) anomaly from 1977 to 2020 superimposed. The blue line is the estimated global average hard coral cover with 80% (darker blue) and 95% (lighter blue) credible intervals. The black line represents the SST anomaly smoothed with an 18 month rolling mean. Periods of rapid increase in SST anomaly (darker red vertical lines) were calculated by estimating the derivatives (via numerical integration) of the smoothed SST anomaly time series. Darker red vertical red bars indicate when the rate of smoothed SST change exceeded 0.15 for two consecutive months. Lighter red vertical bars indicate when the smoothed SST anomaly exceeded. 0.45 (marked by horizontal red dashed line).

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