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Australian Institute of Marine Science

Status of Coral Reefs of the World: 2020

Chapter 12. Status and trends of coral reefs of the Caribbean region

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 12.

Status and trends of coral reefs of the Caribbean region

Data providers: A. Acosta-Chaparro, Lorenzo Alvarez-Filip, Juan José Alvarado, Jesus Ernesto Arias Gonzalez, Francisco Armando Arias Isaza, Fabien Barthelat, Paulo Bertuol, Tadzio Bervoets, Claude Bouchon, Yolande Bouchon-Navaro, José Luis Cabrera Pérez, Ruleo Camacho, Belkis Carolina Montalvan, Juan Carrasco Navas, Julien Chalifour, Michael Colella, Rachel Collin, Nicole Craig, Marcia Creary Ford, Aldo Croquer, Monique Curtis, Thomas Dallison, Ian Drysdale, Caren Eckrich, Peter Edmunds, Dan Exton, Graham E. Forrester, Roxanne-Liana Francisca, Jan Freiwald, David Gilliam, Ana Giro, Martha Catalina Gomez-Cubillos, Diana Gómez-López, J. Gonzalez-Corredor, Silvia Patricia González Díaz, Carlos González-Gándara, Luis Andres Gradiz Villalobos, Hector Guzman, Nicole Hayes, Mike Helion, Alex Henderson, Quetzalli Hernández, Emma Hickerson, Jerry Jermain Enoe, Michelle Johnston, Kimani Kitson-Walters, Patricia Kramer, Ayumi Kuramae Izioka, Jean-Philippe Maréchal, Gloria Marino, Melanie McField, Melanie Meijer zu Schlochtern, Fiama Molina, Peter Mumby, Thaddeus J.T. Murdoch, R. Navas-Camacho, Marissa Nuttall, Yunier Olivera, Hazel Oxenford, Fernando J. Pardo-Urrutia, Esmeralda Pérez Cervantes, Horacio Pérez España, Fabian Pina Amargos, Angela Randazzo-Eisemann, Andrea Rivera-Sosa, Joaquín Rodrigo Garza Pérez, Robert Ruzicka, L. Sanchez-Valencia, G.P. Schmahl, Janina Seemann, Nuno Simões, Melina Soto, Johan Stapel, Robert Steneck, Ruben Torres, Erica K. Towle, Ewan Trégarot, Henri Valles, Jelle van der Velde, Mark J.A. Vermeij, Gabrielle-Jae Watson, Sven Zea

Co-writers: Mary E. Allen, Tadzio Bervoets, Emma Doyle, Peter E.T. Edwards, Jane Hawkridge, Jean-Philippe Maréchal, Melanie McField, Maria Pena, Sandrine Pivard, David Souter, Erica K. Towle

1. Geographic information and context

Key numbers:

- Total area of coral reefs: 26 397 km^2
- Proportion of the world's coral reefs: 10.17%
- Number of countries with coral reefs: 25
- Number of Marine Ecoregions of the World (MEOW) ecoregions: 10

Regional Context:

The Caribbean Region represents only 1% of Earth's marine surface but hosts 10% of the world's coral reefs, including fringing reefs, which are most common, barrier reefs such as the Mesoamerican Reef, which is the largest barrier reef in the Western Hemisphere, bank reefs, patch reefs, and a few atolls.

Caribbean shallow and mesophotic reefs are characterized by relatively low coral species diversity (70 hard coral species including two Acroporid species: *Acropora palmata* and *A. cervicornis*) and high levels of endemism, making them unique among the world's reefs.

The physical geography of the Caribbean region is also complex with continental coasts (north, central, and south America), large continental islands (Greater Antilles), numerous small sandy islands (The Bahamas), volcanic islands (most of the Lesser Antilles), and coral islands (some Lesser Antilles islands).

The Caribbean is politically and culturally diverse with 30 sovereign states (continental and insular) and 16 European overseas territories or outermost regions (British, Dutch, and French), and considerable economic disparities between nations (e.g. per capita Gross Domestic Product in the USA was USD63,544 compared with less than USD1,200 in Haïti)[1].

About 70% of people in the Caribbean live near the coast. Indeed, Caribbean economies depend heavily on coral reefs and associated ecosystems (seagrasses and mangroves) for recreation and tourism (e.g., sandy beaches, snorkeling, and SCUBA diving), livelihoods, food (e.g., fishes, queen conch, lobsters), and other social, cultural, and economic benefits. Socio-economic monitoring (SocMon) in the Caribbean region, carried out largely according to the GCRMN SocMon protocol, is in use as an approach for coral reef managers and provides valuable insights on how coastal communities value and depend on coral reefs. Thus, SocoMon assessments have been conducted for almost 20 years in the region, including a series of workshops conducted recently beginning in 2016 (Jamaica) to the most recent in 2019 (MesoAmerica) by SPAW-RAC and supported by a NFWF-funded project to develop and refine a set of integrated coral reef monitoring guidelines that explicitly include human dimensions characteristics. For a detailed analysis of the SocMon Caribbean socio-economic assessments, please see the Global SocMon report that is forthcoming in 2022.

Socio-economic monitoring is important in order to understand the human interactions with coral ecosystems so that we can mitigate negative effects to coral reefs while promoting positive benefits that reefs provide [http://socmon.icriforum.org/]. SocMon has been part of the wider GCRMN effort since 1997 and was developed with the intent for socio-economic monitoring to complement biophysical monitoring. While SocMon data are not included in the present analysis, future work should and will seek to integrate Caribbean node socio-economic data with biophysical data.

The Caribbean is divided into 10 Marine Ecoregions of the World (MEOW) Ecoregions[2] that were grouped into five subregions for the analyses underpinning this report (Tab. 1). There are coral reef marine protected areas (MPAs) in many countries in the Caribbean, as well as MPA networks such as MPAConnect and CaMPAM. The MPAs are usually small and generally located in nearshore areas. Efforts to support coral monitoring and capacity-building are underway with support from partner organisations such as the UN Environment Programme/ Cartagena Convention Secretariat, the National Oceanic and Atmospheric Administration (United States of America), the Gulf and Caribbean Fisheries Institute, the Specially Protected Areas and Wildlife protocol and its regional activity center (SPAW-RAC), through regional projects and via multi-national programmes. MPA financing, enforcement, fisheries management, monitoring and communications are among the top management capacity building needs identified by coral reef managers to implement effective marine protection.

[1] World Bank database (https://data.worldbank.org/indicator/NY.GDP.PCAP.CD)

[2] 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

Table 12.1. The subregions comprising the Caribbean region, the area of reef they support, and the constituent Marine Ecoregions of the World (MEOW).

Subregion	Reef Area (km²)*	Proportion of Total Reef Area within the Caribbean Region (%)	Constituent Marine Ecoregions of the World
1 (BER/ BAH)	5,698	21.6	062: Bermuda 063: Bahamian
2 (E, S Carib)	2,913	11.0	064: Eastern Caribbean 066: Southern Caribbean
3 (Ant)	8,640	32.7	065: Greater Antilles
4 (SW W Carib)	7,197	27.3	067: Southwestern Caribbean 068: Western Caribbean
5 (GoM, FL)	1,949	7.4	043: Northern Gulf of Mexico 069: Southern Gulf of Mexico 070: Floridia

*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

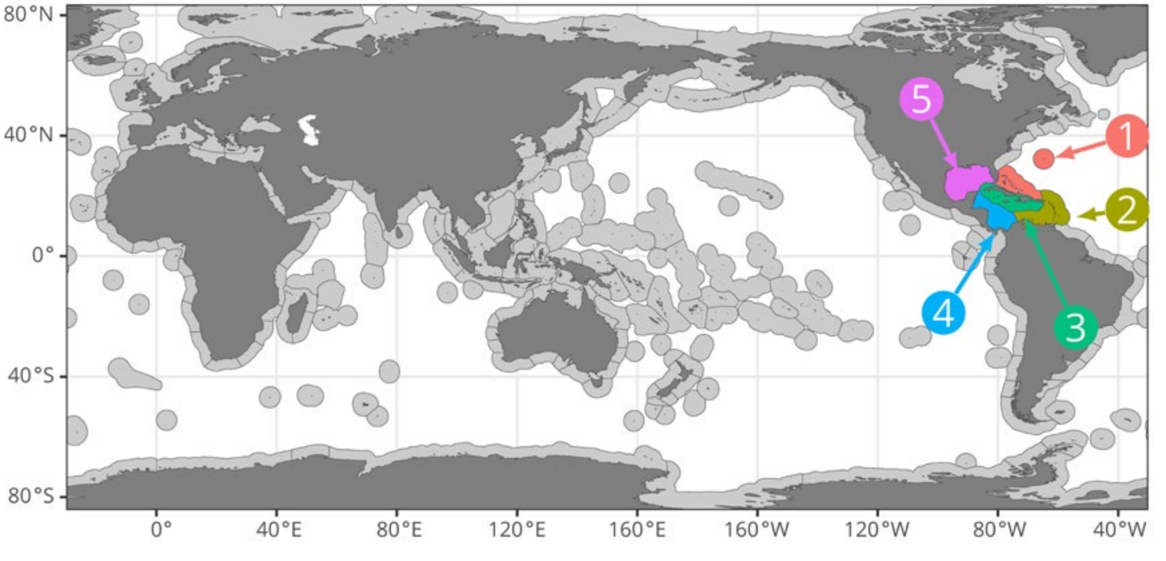

Figure 12.1. Map of each subregion comprising the Caribbean region. The number ascribed to each subregion corresponds with that in Table 1.

2. Summary of data contributed to this report

Key numbers:

- Number of countries from which monitoring data were used: 20 (of 25)
- Number of sites: 3,166
- Number of observations: 209,823
- Longest time series: 29 years

General features:

The status and trends in the cover of hard coral and algae on coral reefs in the Caribbean region presented below are based on almost 210,000 observations collected using a diverse range of methods (Fig. 12.4) by more than 30 entities from 3,166 sites distributed across 20 countries (Tab. 12.2). The first observations contributed to this report were collected in 1983 (Fig. 12.3B). Most observations (36.64%) collected within the Caribbean region were collected in the Eastern and Southern Caribbean (subregion 2). A smaller number of observations were recorded in subregions 1: Bermuda and The Bahamas (12.91%), 3: Greater Antilles (9.36%), 4: Southwestern and Western Caribbean (19.14%) and 5: Gulf of Mexico and Florida (21.96%) (Tab. 12.2).

Table 12.2. Summary statistics describing data contributed from the Caribbean region. An observation is a single record within the global dataset (*i.e.* one row) and may represent a single indivisible observation or the sum or mean of several observations depending on how aggregated the data were when they were contributed to this analysis. 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 that period.

Caribbean subregions	Observations			Sites			Long term monitoring sites		
	Total Number	Proportion of regional dataset	Proportion of global dataset	Total Number	Proportion of regional dataset	Proportion of global dataset	Total Number	Proportion of regional dataset	Proportion of global dataset
All	209,823	100	21.64	3,166	100	26.04	135	100	22.96
1 (BER/BAH)	27,088	12.91	2.79	618	19.52	5.08	0	0	0
2 (E, S Carib)	76,877	36.64	7.93	904	28.55	7.43	41	30.37	6.97
3 (Ant)	19,632	9.36	2.02	389	12.29	3.2	2	1.48	0.34
4 (SW W Carib)	40,157	19.14	4.14	668	21.10	5.49	25	18.52	4.25
5 (GoM, FL)	46,069	21.96	4.75	587	18.54	4.83	67	49.63	11.39

A limited number of sites in this dataset were surveyed between 1983 and 1995, but after 1996 the number of surveys increased dramatically through 2016 (Fig. 12.3B). The number of surveys from which data were provided declined after 2016, particularly in 2018 and 2019, which may be a consequence of the time required to process and share more recently collected data at the time the call for data was announced for this meta-analysis in 2019. The vast majority of sites (80%) had only a single year of survey data (Fig. 12.2 & 12.3A). However, about 6% of sites were monitored for more than a decade, and 4% of sites were monitored for more than 15 years (Fig. 12.2 & 12.3A). Long-term monitoring (>15 years between the first survey and the most recent survey) occurred at 135 sites within the Caribbean region, particularly within the Gulf of Mexico and Florida (67), the Eastern and Southern Caribbean (41), and the Southwestern and Western Caribbean (25) (Tab. 12.2).

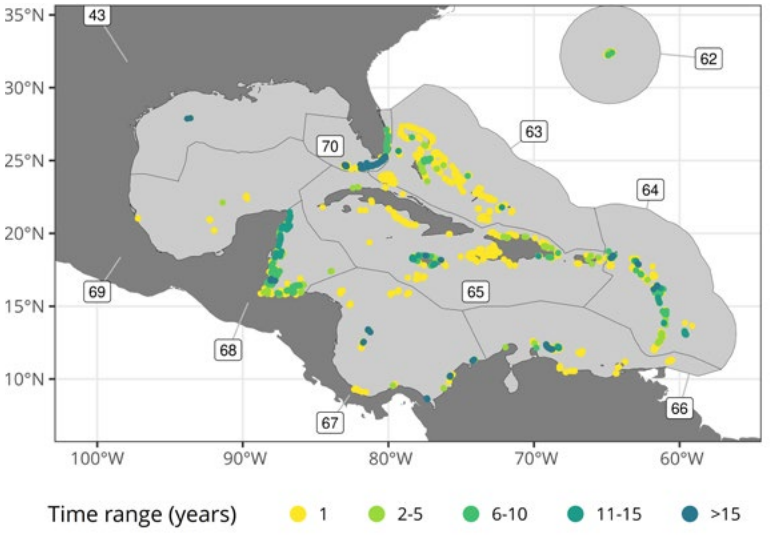

Figure 12.2. The distribution and duration of monitoring at sites across the Caribbean region. The colours of dots represent the time span between the first survey and the most recent survey at each site. Numbers refer to the MEOW ecoregions listed in Table 12.1.

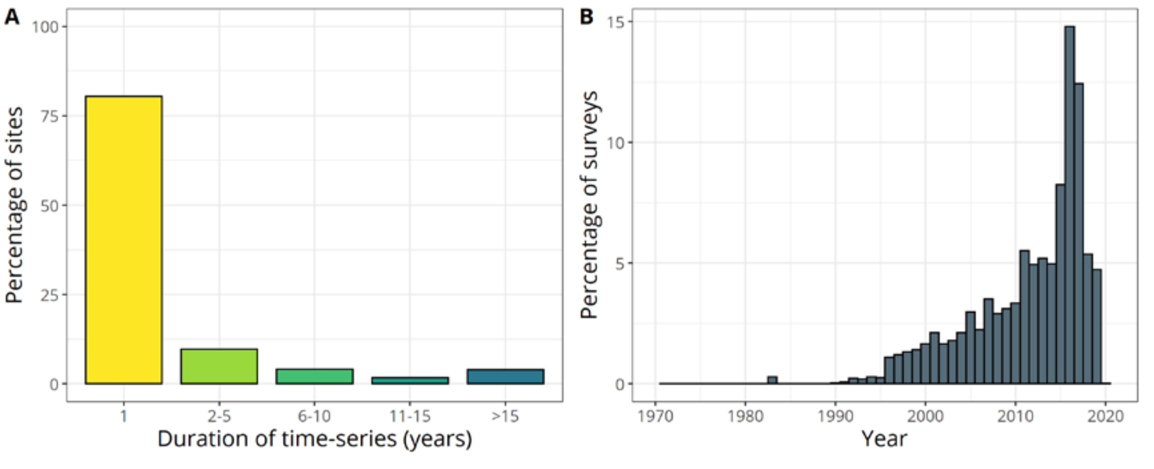

Figure 12.3. The proportion of sites in the Caribbean region within each category describing the time span between the first and most recent surveys (A), and the proportion of the total number of surveys conducted in each year (B). The total number of surveys was 7,127.

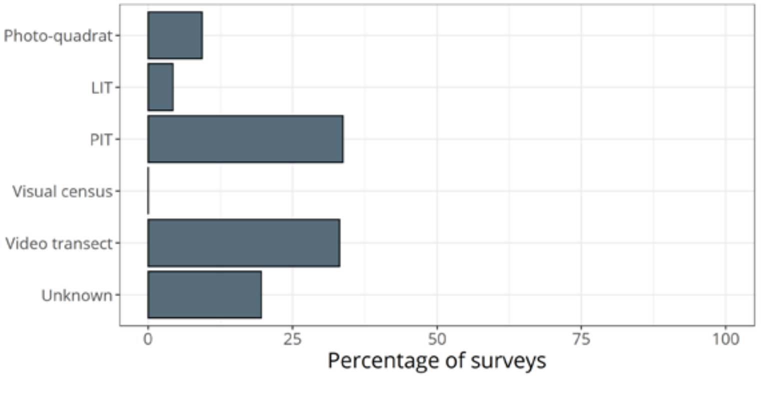

Figure 12.4. The proportion of the total number of surveys conducted in the Caribbean region using each survey method. PIT: Point Intercept Transect; LIT: Line Intercept Transect.

3. Status of coral reefs in the Caribbean region

- Region-wide status of hard coral cover

In 1983 when the earliest data contributed to this report were collected, the estimated average live hard coral cover for the entire Caribbean region (all five subregions pooled) was 18% (Fig. 12.5A), which already represents substantial decline from the average (35%) reported for the period between 1970-1983[3]. The trend from this analysis suggests continued decline in mean hard coral cover during the subsequent 16 years from 1983 (18%) to 1999 (16.5%); however, it should be noted that there is considerable uncertainty surrounding these early estimates due to the scarcity of data available during this time (Fig. 12.5A). Additional declines continued with a mean coral cover of 15.2% in 2005 and 14.6% in 2011 (Fig. 12.5A). Data from this meta-analysis suggest that mean coral cover was 15.9% in 2019, the last year in the current dataset. Overall, the trend suggests that at a region-wide scale, mean coral cover has declined from approximately 18% in 1983 to 15.9% in 2019, (a 2.1% overall decrease in that 36 year period).

The results of this meta-analysis with respect to coral cover may be surprising to those familiar with the region who may have expected steeper declines. The overall decrease presented in this analysis would have been had it included the 1970-1983 baseline from Jackson *et al*. (2014)[3]. It is also important to note that wide variability exists throughout the Caribbean region and data included in this meta-analysis reflect a wide range of degraded to healthy sites throughout the Caribbean. The trends seen in figure 12.5A should be interpreted with two contextual notes.

First, coral reefs in the Caribbean region suffered significant disturbances from hurricanes and/or mass coral bleaching in 1998 and 2005. As a consequence, average hard coral cover across the entire region was at a historical low level (14.1% in 2007). In the absence of further large-scale disturbances between approximately 2007 to 2013, hard coral cover may have recovered in some Caribbean subregions and not in others. Second, this analysis was designed to examine changes in average hard coral cover at the broad regional scale. While the estimate of the region-wide Caribbean average coral cover does consider average coral cover at the five subregional scales, the contribution of the different subregions was weighted according to the area of coral reefs (km^2) in each subregion. The subregions within the Caribbean region that had the greatest area of coral reefs was subregion 3, which was the only subregion that exhibited marginal increases in average coral cover between 1983-2019 (Fig. 12.6). As a consequence, additionally, it should be noted that data from the United States Caribbean territories (included within subregions 2 and 5) are experiencing a much steeper decline than the overall region-wide trend from this meta-analysis. Trends analyses in coral cover for the U.S. Caribbean indicate significant declines in coral cover between 2013-2019[4]. In 2019, mean coral cover was approximately 5% or less in all regions[4].

[3] Jackson JBC, Donovan MK, Cramer KL, Lam VV (editors). (2014) Status and Trends of Caribbean Coral Reefs: 1970-2012. Global Coral Reef Monitoring Network, IUCN, Gland, Switzerland.

[4] Edwards KF, Blondeau J, Grove LJW, Groves SH, Hile SD, Johnson MW, Langwiser C, Siceloff L, Towle EK, Viehman TS, Williams B (2021). National Coral Reef Monitoring Program Biological monitoring summary U.S. Virgin Islands and Puerto Rico: 2019. Coral Reef Conservation Program (U.S.). NOAA technical memorandum CRCP 40. DOI: https://doi.org/10.25923/fdp6-qv15

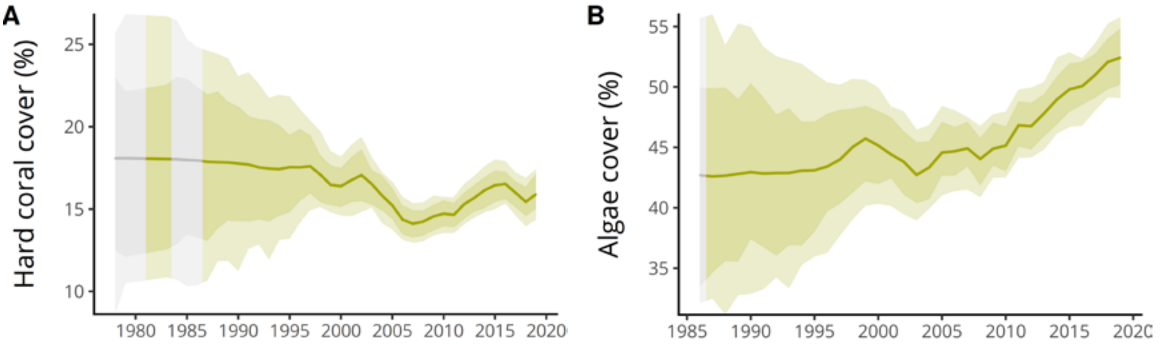

Figure 12.5. Estimated regional average cover of live hard coral (A) and algae (B) for the Caribbean region. The solid line represents the estimated mean and associated 80% (darker shade) and 95% (lighter shade) confidence intervals, which represent levels of uncertainty. Grey areas represent periods during which no field data were available in the Caribbean region.

Table 12.3. Probability and magnitude of mean absolute and relative change in the percent cover of live hard coral in the Caribbean region among 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	1.2	10.3
2010-14 - 2015-19	70	0.3	2.6
2005-09 - 2015-19	99	1.6	13.1

Data from this meta-analysis show that region-wide (all five subregions pooled) mean hard coral cover in the Caribbean declined by 2.1% between 1983 (18%) and 2019 (15.9%). This decline would likely appear much steeper had it included the 1970-1983 (35%) baseline data from Jackson *et al.* (2014)[3]. This analysis was also weighted by area of coral reef (km^2), and the largest subregion was also the only subregion to experience a marginal increase (subregion 3) in hard coral cover over the last two decades. However, all subregions other than subregion 3 experienced overall declines in hard coral cover between 1999-2019, with subregion 2 experiencing the largest overall decline.

- Status of algae cover

As with coral cover, estimates of the average cover of algae (all types) across the Caribbean region prior to about 2001 have large uncertainties owing to the scarcity of data (Fig. 12.5B). Despite this uncertainty in early estimates, the average algal cover remained relatively stable between 1987 (42.6%), when the earliest data contributed to this report were collected, and 1994 (43.1%). From 1995, the algal cover increased until it reached 45.7% in 1999, before declining to 42.7% in 2003. However, since 2003, the average algal cover within the region has progressively increased, reaching 52.4% in 2019 (Fig. 12.5B).

The increase in algal cover between 2005-09 and 2015-19 is unequivocal , with on average almost 31% more algae on Caribbean reefs during the period 2015-19 (Tab. 12.4).

Table 12.4. Probability and magnitude of mean absolute and relative change in the percent cover of algae in the Caribbean 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	100	3.3	14.3
2010-14 - 2015-19	99	3.4	14.6
2005-09 - 2015-19	100	6.7	30.9

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

At least three widespread ecological disturbances have strongly negatively impacted Caribbean coral reefs during the last five decades: i. White-Band-Disease in the 1970s and 1980s caused the collapse of *Acroporid* populations (*A.palmata* and *A.cervicornis*) which were the main coral reef builders in very shallow coastal environments of the Caribbean; ii. the die-off of sea urchin (*Diadema antillarum)* populations, which are among the most efficient invertebrate herbivores in the Caribbean, that occurred between 1983 and 1984 due to a pathogen; and iii. the mass coral bleaching event that affected the entire Caribbean in 2005.

In addition to large-scale ecological disturbances, more local, chronic threats to Caribbean coral reefs have increased during the last several decades. Coastal water pollution and eutrophication, stemming partially from resident and tourist population growth in concert with inadequate sewage treatment and land-use changes in watersheds, have been significant factors responsible for reducing coral health. Water pollution and eutrophication may facilitate coral disease outbreaks and macroalgal blooms due to increased nutrient inputs. Herbivorous fish and *Diadema* urchins have historically helped contain algal populations at low levels but overfishing and the pathogen that caused *Diadema* die-off have dramatically reduced their numbers and therefore, their ability to help control algal overgrowth. As such, the Caribbean region has been experiencing a phase shift from coral-dominated to algal-dominated reefs. It was caused in part by declines in live coral cover due to storms, disease, and bleaching, algal overgrowth related to eutrophication of coastal waters, and in part by reduced grazing by invertebrate and fish herbivores due to disease and overfishing. Specifically, the overfishing of key herbivorous fish like parrotfishes has greatly contributed to algal overgrowth and proliferation on Caribbean reefs. There are disparities throughout the region in the application and availability of fisheries management tools, as well as in fisheries enforcement and policy-making which impact coral reef health and resilience. Additionally, more frequent and more intense coral bleaching events as well as hurricanes continue to threaten Caribbean reefs. More recently, Caribbean coral reefs have faced a series of new emerging threats from invasive lionfish, to pelagic *Sargassum* influx (since 2011), and the emergence and spread of the novel, highly virulent Stony Coral Tissue Loss Disease (SCTLD).

SCTLD was first observed in Florida in 2014 and affects at least 34 species of stony corals in the Caribbean, including the primary reef-building species in the Atlantic-Caribbean region. The disease has a very large geographic range and as of October 5, 2021 has been confirmed in 19 countries and territories across the wider Caribbean region[5,6]. Prevalence rates of this disease in highly susceptible species have been documented at 66-100% (compared with 3-5% prevalence rates observed with other coral diseases). Most infected coral colonies die. Unlike coral bleaching, individual coral polyps

5 https://www.agrra.org/coral-disease-outbreak/

6 https://oref.maps.arcgis.com/apps/dashboards/54b5df5c111b4fcc986e300c6aea63a3and

cannot recover from SCTLD, although colonies may survive, particularly when treated. SCTLD spreads and progresses very rapidly across reef areas and within individual colonies. Complete mortality within several weeks has been observed in relatively large coral colonies[7]. SCTLD continues to spread across the Caribbean. Many countries in the Caribbean region that have been affected by this disease rely heavily on coral reefs to support their local economies and fisheries and do not currently have adequate resources and capacity to respond to the disease. While the losses suffered as a result of SCTLD are still being evaluated, losses in coral cover of up to 60% have been observed at some reefs in the Virgin Islands[8], and other affected countries have now documented losses of up to 50% of their coral cover[9]. Because so much of the devastation caused by SCTLD in the Caribbean has occurred within only the last several years, its effects are not fully reflected in the present analysis.

- Changes in resilience of coral reefs within the Caribbean region

To identify changes in the resilience of coral reefs in the Caribbean region, patterns of disturbance and recovery were examined within 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%. It should be noted that resilience is based on many more factors than solely percent coral cover, but for this global analysis, that was the only metric widely available. Among the 247 such sampling units within the Caribbean, 199 (80.6%) did not recover to at least 90% of their pre-disturbance hard coral cover (Tab. 5). On average, hard coral cover declined by 7.2% between the first and most recent survey of these sampling units, which represents a loss of more than half (57.4%) of the hard coral at these sites. The average maximum decline in hard coral cover was 12.3%, which represents a loss of 77.6% of that hard coral within these sampling units (Tab. 12.5).

Increases in the frequency and intensity of disturbances to coral reefs in the Caribbean (especially bleaching and major hurricanes) compounded by chronic water pollution have changed long-term disturbance-recovery patterns as Caribbean reefs have begun to face back-to-back disturbances year-after-year. Consequently, many reefs are not recovering completely between disturbances and the combination of chronic stressors and more frequent disturbances may overwhelm the reefs' ability to recover.

Table 12.5. 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
247	199	80.6	12.2	77.6	7.2	57.4

[7] https://www.agrra.org/wp-content/uploads/2019/07/ONLINE-SCTLD-Infographic_22-02_19.png

[8] University of the Virgin Islands, 2021

[9] Estrada-Saldívar, 2021

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

- Subregional trends in hard coral cover

The trends in hard coral cover varied among the five Caribbean subregions (Fig. 12.6) within the period covered by the database. In Bermuda and The Bahamas (subregion 1), the early data from 1999 showed an average coral cover of 17.6%. A substantial decline in coral cover was observed between 2002 and 2005 followed by failure to recover. The results presented here indicate that long-term mean coral cover has decreased between 1999 (17.6%) and 2019 (13.3%), representing an approximate average decline of 4.3% in those 10 years.

The longest historical time series in the Caribbean region was from subregion 2, which includes the Lesser Antilles, Trinidad and Tobago, the Southern Dutch Caribbean ABC islands, and Venezuela (Fig. 12.6). The data indicate that coral cover has progressively declined within subregion 2 since 1999 when mean coral cover was approximately 26.2% to 14.5% by 2019. This represents an approximate 11.7% live coral cover decrease in this region during the last two decades.

The Greater Antilles (subregion 3) was the only subregion in the Caribbean that exhibited an overall increase in average coral cover over the period for which data were contributed (Fig. 12.6). While slight declines occurred between 1997 and 1999 and between 2005 and 2007, the average coral cover increased by approximately 5.4%, from 10.7% in 1999 to 16.1% in 2019.

Coral reefs in subregion 4, which includes Colombia, Panama, Costa Rica, Nicaragua, Honduras, Belize, Guatemala, and Mexico, exhibited subtle changes in trajectory (Fig. 12.6). Average coral cover slowly decreased from approximately 22.6% average coral cover in 1999 to 21.6% in 2019.

Average coral cover has progressively declined on reefs in the Gulf of Mexico and Florida (Subregion 5) from approximately 13.3% in 1999 to 9.1% in 2019, representing an overall average decrease of 4.2% in that 20-year period (Fig. 12.6).

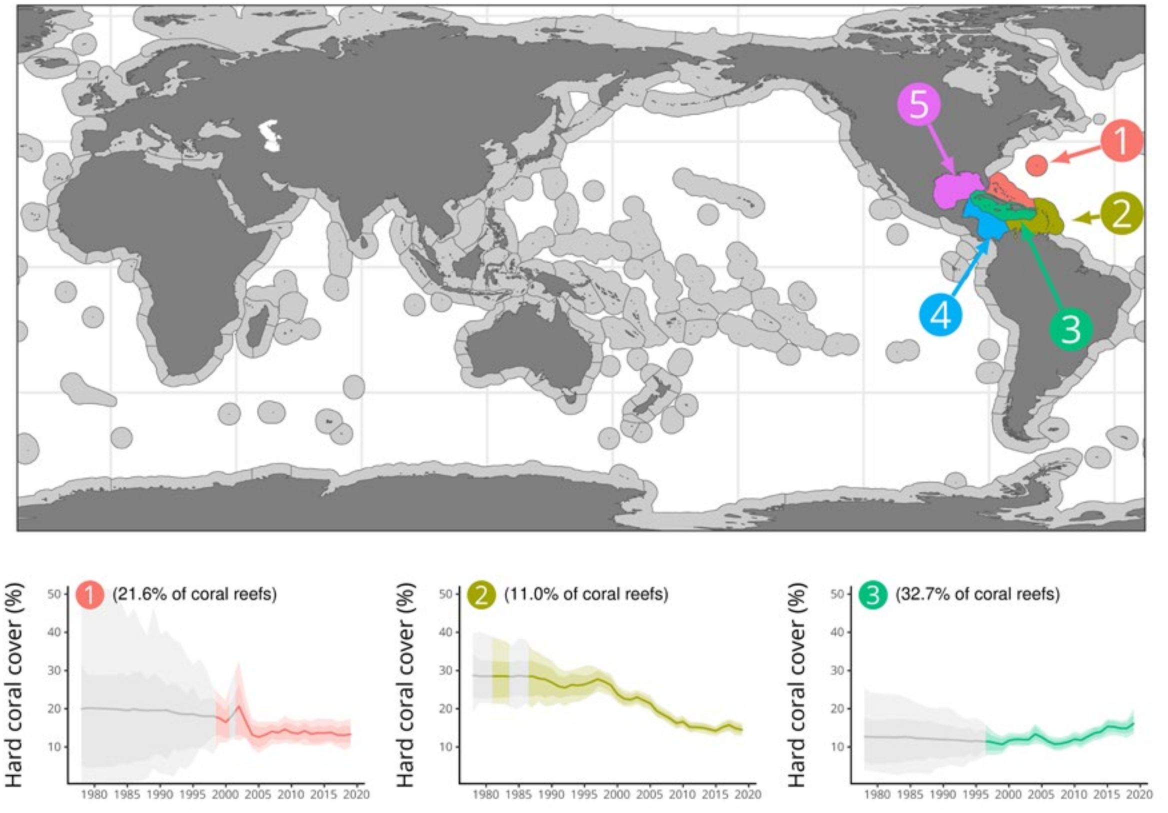

Figure 12.6. Estimated average cover of live hard coral within each subregion comprising the Caribbean region. The solid line represents the estimated mean and associated 80% (darker shade) and 95% (lighter shade) credible intervals, which represent levels of uncertainty. Grey areas represent periods during which no field data were available. The proportion of all coral reefs in the Caribbean region within each subregion is indicated by the % of coral reefs.

- Subregional trends in algal cover

While the period for which data describing the cover of algae varied among the five different subregions (Fig. 12.7), algae constituted a large proportion of the reef community in each subregion, particularly in subregions 1, 3, and 4. It should be noted that macroalgal cover is highly variable by the timing/seasonality of sampling, reef substrate/habitat type, and specific functional group or species of macroalgae. Subregions 3 and 4 exhibited high initial average algal covers of 54.9% and 45%, respectively, and relatively little change over time (Fig. 12.7). Subregion 1 also exhibited a high initial average algal cover of 44.8% in 1999, but greater variation over the next 12 years ranging between 37.5% and 44.8%. However, between 2011 and 2019, the average cover of algae in subregion 1 progressively increased to 64.4% in 2019 (Fig. 12.7).

Slightly longer time-series were made available from subregions 2 and 5 (Fig. 12.7). In both subregions, the initial average cover of algae was considerably lower and has since increased over time. In subregion 2, the initial average cover of algae was 17.2% in 1987. During the next 33 years, the amount of algae on these reefs almost tripled, reaching 48.3% in 2019. In subregion 5, algal cover also increased over time, particularly from 2006 onward. Between 1992 when the first data were collected and 2005, algae cover decreased from 22% to 16.9% (Fig. 12.7). However, between 2006 and 2015, algal cover increased approximately 2.3-fold reaching 39% in 2015.

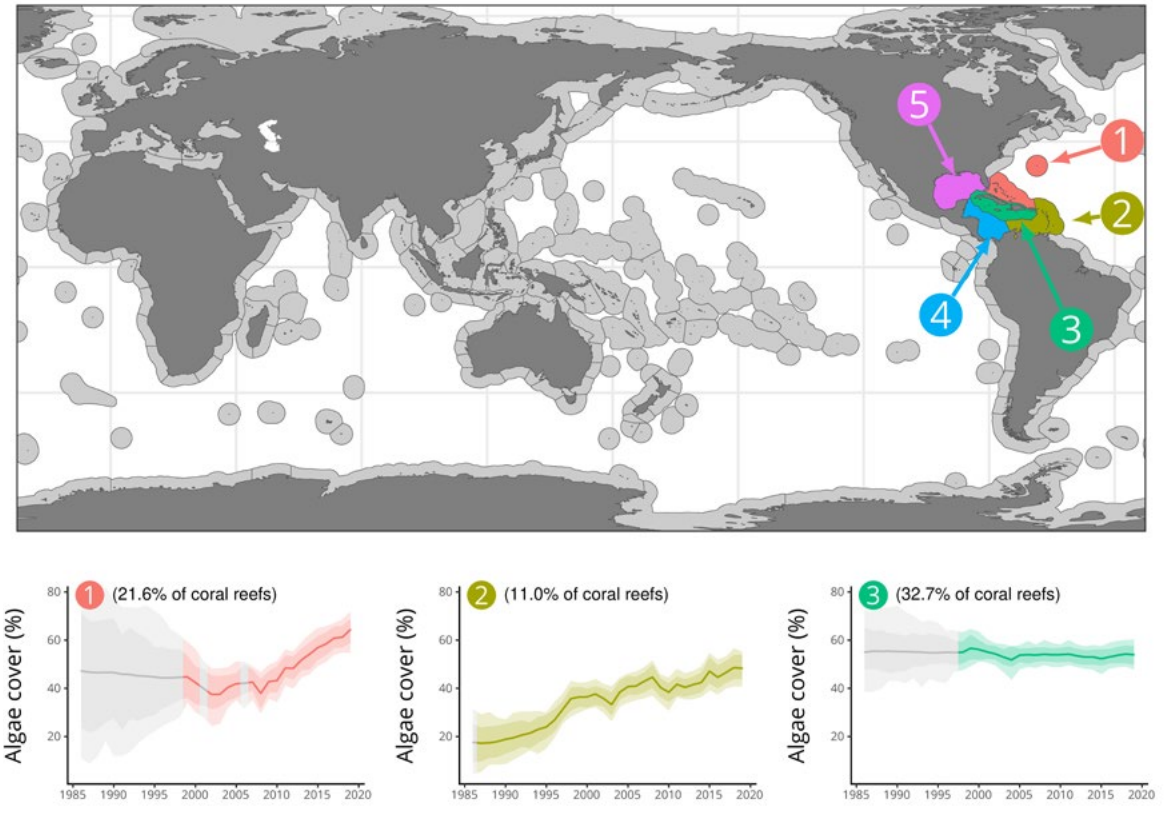

Figure 12.7. Estimated average cover of algae within each subregion comprising the Caribbean region. The solid line represents the estimated mean and associated 80% (darker shade) and 95% (lighter shade) credible intervals, which represent levels of uncertainty. Grey areas represent periods during which no field data were available. The proportion of all coral reefs in the Caribbean region within each subregion is indicated by the % of coral reefs.

Conclusion:

This regional chapter confirms, as in Jackson *et al.* (2014)[3], that live coral cover and algal cover have reverse trajectories. Comparative trends over the period indicate an acceleration of the shift in subregions 2, 3, and 4 of the Caribbean.

Widespread overexploitation of herbivorous fish, heavy development in coastal areas, more frequent and intense coral bleaching events as well as stronger hurricanes are threatening Caribbean reefs that are also facing emerging issues such as lionfish, *Sargassum* influx, and SCTLD. Increases in the frequency and intensity of disturbances to coral reefs in the Caribbean compounded by chronic water pollution have disrupted long-term disturbance-recovery patterns, particularly since Caribbean reefs have begun to face back-to-back disturbances year-after-year.

The GCRMN-Caribbean Steering Committee suggests the following recommendations to stakeholders and decision makers:

- Reduce runoff in coastal areas, as well as ship discharges;
- Manage ballast water throughout the wider Caribbean region;

- Ban the use of destructive fishing gear (spearguns, gill nets, fish traps, trammel nets);
- Reduce parrotfish fishing, and consider fishery bans on large herbivorous species and large groupers;
- Implement restoration plans for other key herbivores such as *Diadema;* and
- Enhance overall biodiversity and resilience by implementing more fully protected replenishment zones within existing and/or new MPAs.

The GCRMN-Caribbean Steering Committee strongly calls for a more holistic approach for the next global status report and to start organising the data for such an approach. In particular; socio-economic monitoring (SocMon) that provides essential data on the human dimensions of coral reefs should not stand alone, but should be considered integral to GCRMN data collection on biophysical conditions. It is not only critical to better understand the desired ecosystem services, drivers and pressures of change, state of the ecosystem, and appropriate responses, but also absolutely needed for successful coral reef conservation and effective management. In the same way, more biophysical data, including fish and other benthic fauna, should also be included in the next global report.

Box 10.

NOAA Coral Reef Watch: Providing Decision Support Products to Enhance Coral Reef Ecosystem Management in a Warming World

Derek Manzello[1] and Jacqueline De La Cour[1,2]

[1]NOAA/NESDIS/STAR Coral Reef Watch
[2]Earth System Science Interdisciplinary Center/ Cooperative Institute for Satellite Earth System Studies, University of Maryland

First observed in the early 1980s, mass coral bleaching (i.e., widespread bleaching spanning >100s km) has become one of the most visible and damaging marine ecological impacts of increasing ocean temperatures. If a coral is severely bleached, and/or subjected to repeated bleaching, it will likely die. The corals that survive are usually immunocompromised, as well as having impaired reproduction and growth for years after the heat stress subsides. Severe coral bleaching has become more extensive, frequent, and intense. This can be seen in the acceleration of heat stress events that cause mass bleaching, and in new multi-decadal bleaching observation datasets. As manifested by the devastating 2014-2017 global coral bleaching event (considered the longest, most widespread and most damaging bleaching event ever) and by other, recent, severe, large-scale bleaching events on different reef areas (including, in 2020, on the Great Barrier Reef, many South Pacific and Indian Ocean reefs, Southeast Asia, Taiwan, and the coast of Brazil), mass bleaching events often last many months; are beginning to occur near-annually in some locations; and are impacting reefs that never bleached before (including reefs far-removed from direct human impacts). It is clear that consistent, remote monitoring of coral reefs and the development of actionable intelligence are critical for early detection, on-the-ground response, communication, and future resilience planning to better protect these ecosystems from further degradation and loss.

In response to these concerns, the U.S. National Oceanic and Atmospheric Administration (NOAA) established the Coral Reef Watch (CRW) program. Since 2000, CRW has utilized remote sensing, modeled and *in situ* data to observe, predict, and report to its users on the coral reef environment worldwide. CRW provides the only global early-warning system of coral reef ecosystem environmental changes. Its next-generation daily, global and regional 5 km-resolution satellite coral bleaching heat stress products and modeled Four-Month Coral

Bleaching Outlook have successfully and accurately monitored and predicted all major mass bleaching events observed globally since 1997. CRW's products help resource managers, scientists, decision makers, monitoring networks, and the public monitor climate impacts to reef ecosystems; better understand links between environmental conditions and ecosystem impacts; and implement timely, protective responses and adaptation actions (including restoration efforts), improving coral reef management in a warming world. In response to CRW products, users have reduced local stressors during high heat stress (e.g., closing scuba diving and fishing areas), rescued rare corals, and shaded/cooled key nursery reefs.

NOAA CRW provides essential environmental intelligence. Its extensive partnership network with data providers, scientists, and reef managers allows CRW to leverage key U.S. and international partner efforts to undertake research to develop the best possible products for its users, and to better understand how stakeholders use its tools. CRW works closely with its users from product conceptualization through to operationalization, providing training in appropriate product use, and garnering feedback to improve management tools. This places CRW at the forefront of providing services to improve understanding of climate change threats to coral reefs, and establishes sound practices for the use of its products to enhance resilience-based coral reef management.

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The scientific results and conclusions, as well as any views or opinions expressed herein, are those of the author(s) and do not necessarily reflect the views of NOAA or the Department of Commerce.

Box 11.

Stony coral tissue loss disease (SCTLD) - novel threats to coral reefs

Margaret Miller, Lorenzo Alvarez-Filip, Rosa Rodríguez-Martínez, Jennifer Koss.

In 2014, a new threat to the integrity of coral reefs emerged in Florida and was termed stony coral tissue loss disease (SCTLD). SCTLD affects more than 30 coral species, and colonies of highly susceptible species can die within weeks. Given the large number of species affected, the rapid spread of the disease across reefs and regions, and the temporal persistence of the disease (6 years and still going), this disease outbreak is the most lethal disturbance ever recorded in the Caribbean[1,2,3]. The rapid spread of SCTLD across the Caribbean has reef scientists, managers, and the general population highly concerned. Reports have now registered for the Western Caribbean, Bahamas, Puerto Rico, the US Virgin Islands and the Lesser and Greater Antilles (https://www.agrra.org/coral-disease-outbreak/). Population losses range from > 90% on highly susceptible species to <10% in less affected species[1,2,3]. Stony coral diversity, density, and amount of live tissue correspond with differential SCTLD susceptibility and have resulted in significant changes in the structure and composition of coral communities, further impairing the integrity of coral reefs across the entire geography of the regions that have been impacted.

The emergence of the disease occurred in association with a severe thermal bleaching event and a dredging project, at ground zero, in a highly impacted, urban reef area[3]. However, subsequent studies have found no clear link between high water temperatures and the spread or prevalence of SCTLD[4] s. Ecological (e.g. coral density and composition) and environmental conditions, including nutrient concentrations and turbidity, are likely to influence disease prevalence and progression.

Given the intensity of this emerging threat, SCTLD has also been the target of unprecedented research efforts to determine the cause and ecology of the disease, and intervention efforts to minimize mortality from the disease. Although the modes of transmission and specific causative agents are not yet fully understood, the disease is clearly transmitted through

1 Alvarez-Filip, L., Estrada-Saldívar, N., Pérez-Cervantes, E., Molina-Hernández, A., and González-Barrios, F. J. (2019). A rapid spread of the stony coral tissue loss disease outbreak in the Mexican Caribbean. PeerJ 7:8069. doi: 10.7717/peerk.8069

2 Dahlgren C, Pizarro V, Sherman K, Greene W and Oliver J (2021) Spatial and Temporal Patterns of Stony Coral Tissue Loss Disease Outbreaks in The Bahamas. Front. Mar. Sci. 8:682114. doi: 10.3389/fmars.2021.682114

3 Gintert, B. E., Precht, W. F., Fura, R., Rogers, K., Rice, M., Precht, L. L., et al. (2019). Regional coral disease outbreak overwhelms impacts from local dredge project. Environ. Monit. Assess. 191, 1–39. doi: 10.1007/s10661-019-7767-7767

4 Estrada-Saldívar N, Quiroga-García BA, Pérez-Cervantes E, Rivera-Garibay OO and Alvarez-Filip L (2021) Effects of the Stony Coral Tissue Loss Disease Outbreak on Coral Communities and the Benthic Composition of Cozumel Reefs. Front. Mar. Sci. 8:632777. doi: 10.3389/fmars.2021.632777

seawater, bacteria are involved at some level in disease progression[5], and viruses of the algal symbionts have been reported in pathological studies. Complex interactions of primary and secondary pathogens are likely involved.

Despite a lack of definitive disease causation, novel and effective, if labor-intensive interventions have been developed and applied to stop disease progression. Topical amoxicillin (antibiotic) embedded in a silicon-based paste and applied to the lesion margins can arrest tissue loss along the treated margin in multiple coral species[6,7,8]. Still, new lesions can appear on the same colony over time, and repeated treatments are commonly required[7,8,9]. There has also been some benefit demonstrated from applying endemic probiotic bacteria (of the genus *Pseudoalteromonas*) in arresting disease progression. Unfortunately, the expense and labour-intensity of these interventions likely put them beyond reach for widespread implementation in many affected regions. Local responses to SCTLD outbreaks have also involved local communities in disease surveillance and 'strike teams', ramping up of genetic archiving[10] (Grosso-Becerra et al. 2021) and restoration activities. In some cases, unaffected colonies from areas ahead of the disease front have been removed to captivity to provide material for future repopulation efforts.

Figure 1. map showing the spread of SCTLD in the Caribbean showing where it is absent (green) versus present (red). Source: Kramer, P.R., Roth, L., and Lang, J. 2019. Map of Stony Coral Tissue Loss Disease Outbreak in the Caribbean. www.agrra.org. ArcGIS Online. [29 September 2021].

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[5] Aeby GS, Ushijima B, Campbell JE, Jones S, Williams GJ, Meyer JL, Häse C and Paul VJ (2019) Pathogenesis of a Tissue Loss Disease Affecting Multiple Species of Corals Along the Florida Reef Tract. Front. Mar. Sci. 6:678. doi: 10.3389/fmars.2019.00678

[6] Neely KL, Macaulay KA, Hower EK, Dobler MA. 2020. Effectiveness of topical antibiotics in treating corals affected by Stony Coral Tissue Loss Disease. PeerJ 8:e9289 https://doi.org/10.7717/peerj.9289

[7] Walker BK, Turner NR, Noren HKG, et al (2021) Optimizing Stony Coral Tissue Loss Disease (SCTLD) Intervention Treatments on *Montastraea cavernosa* in an Endemic Zone. Frontiers in Marine Science 8:746. https://doi.org/10.3389/fmars.2021.666224

[8] Shilling, E. N., Combs, I. R., and Voss, J. D. (2021). Assessing the effectiveness of two intervention methods for stony coral tissue loss disease on *Montastraea cavernosa*. Sci. Rep. 11:8566. doi: 10.1038/s41598-021-86926-4

[9] Neely K, Shea C, Macaulay K, Hower E, Dobler M. 2021 Short- and Long-Term Effectiveness of Coral Disease Treatments. Front Mar Sci 8:1031. DOI=10.3389/fmars.2021.675349

[10] Grosso-Becerra, M.V., Mendoza-Quiroz, S., Maldonado, E. et al. Cryopreservation of sperm from the brain coral Diploria labyrinthiformis as a strategy to face the loss of corals in the Caribbean. Coral Reefs 40, 937–950 (2021). https://doi.org/10.1007/s00338-021-02098-7

Figure 2. disease front on Meandrina meandrites

Figure 3. SCTLC infecting multiple adjacent colonies and multiple lesions on individual colonies. Photos: Lorenzo Alvarez.

Box 12.

The Human Dimensions of Coral Reef Management and Monitoring

Author:

Mary E. Allen, Ph.D.
Social Scientist and Socioeconomics Coordinator
National Oceanic and Atmospheric Administration
Coral Reef Conservation Program
Silver Spring, Maryland, USA

The Role of Social Values in Ecosystem-based Management

Coral reefs are among the most productive and biologically diverse ecosystems on Earth, but are facing a number of complex pressures, such as mass coral bleaching, ocean acidification, coral disease, and the impacts from human activities. Despite the recognition of anthropogenic impacts on coral reefs, a vast majority of research tends to focus on the biophysical rather than the human dimensions of reef ecosystems, which can limit our understanding of social relationships with these environments as well as potential solutions for reef recovery. Ecological and biophysical data are an essential component, yet management questions cannot be fully addressed with this information alone. The effectiveness and success of management strategies or mitigation actions will ultimately depend on society's values and preferences.

In practice, coral reef resources are managed for society. People are an integral participant in this ecosystem. Their actions may influence pressures upon the ecosystem, but they are also the beneficiaries of the services produced by that ecosystem. These ecosystem services are the benefits created by particular sets of ecological conditions and processes that are explicitly linked to social value and human wellbeing. Millions of people around the world depend on coral reefs for a variety of ecosystem services, including food production, jobs and income, tourism, recreation, protection from storm damage and coastal erosion, aesthetic and cultural value. All of these services are things that people care about – the "so what" of coral reefs.

Efforts to successfully "conserve and sustainably use marine resources" (Sustainable Development Goal 14) are dependent upon the human dimensions of coral reef management[1]. The manner in which reefs are managed in different ways for various purposes is a reflection of what society wants from those reefs. The ways in which society values coral reefs are

[1] See GCRMN Global Societal Priorities at https://gcrmn.net/about-gcrmn/global-societal-priorities/.

diverse and these values form the basis for how people interact with the ecosystem and respond to coral reef issues. Management is far more complex than simply "preserving" the resource. Rather, it seeks to achieve a balance between the social and environmental goals in the research, monitoring, and management context in order to sustain the ecosystem services valued by society.

We have shifted into an ecosystem-based management (EBM) approach which recognizes that: 1) the biophysical and human components of an ecosystem interact in many complex ways and lead to tradeoffs between social and ecological conditions, 2) society relies upon and benefits from the ecosystem through ecosystem services, and 3) ecosystem services are directly and indirectly affected by multiple human activities/uses. Implementing EBM requires an interdisciplinary and collaborative effort that places questions of human uses and values at the center of their approach for research and monitoring.

Socioeconomic Monitoring of Global Coral Reefs

Similar to ecological parameters, changes in human values and behaviors associated with coral reefs should be measured over time. Socioeconomic monitoring is important in order to track how people use and depend on coral reefs, and to understand human impacts on coral ecosystems so that we can mitigate negative effects while promoting positive benefits. The Global Socioeconomic Monitoring Initiative for Coastal Management (SocMon/SEM-Pasifika) fills this critical need by advancing a global and regional understanding of human interactions with and dependence on coastal resources.

SocMon has been part of the wider GCRMN monitoring effort since 1997. Like GCRMN, SocMon works through a network of stakeholders with the primary goal of supporting management and conservation of coral reefs. The SocMon program was developed with the intent for socioeconomic monitoring to complement biophysical monitoring. There are seven regions throughout the world that are conducting socioeconomic monitoring through SocMon. These regions include the Caribbean, Central America, Southeast Asia, Western Indian Ocean, Pacific Islands, South Asia and Brazil.

Since its inception, SocMon has excelled in expanding socioeconomic monitoring across the world's coral reefs - providing social science training, developing products and tools for monitoring and management, and being involved with communities to address local issues. To date, there have been at least 140 socioeconomic assessments conducted in 42 countries, resulting in over 21,000 surveys and interviews conducted worldwide. A key aspect of these assessments is community involvement to address local management issues. The goals for site assessments are tailored to each site's needs and have focused on a variety of topics regarding community concerns of coastal management including:

- Development of socioeconomic profiles for fisheries
- Identifying priority issues based on how people value and depend on reefs, their perceptions of resource conditions and changes over time, and perceived threats to reefs
- Assessment of management effectiveness of MPAs to inform and adapt management
- Evaluating tradeoffs between the use and protection of coral reef resources; limits of acceptable change in conditions

- Evaluating stakeholder support for or opposition to different management strategies, and which stakeholders are negatively or positively impacted
- Determining the adaptive capacity of coastal communities to climate change
- How to target communication and outreach for enhanced stewardship or behavior change.

Concurrent with this status report, a Global SocMon report is being prepared on the status of socioeconomic factors affecting coral reefs and includes case studies of SocMon data collected in each region. For more information on SocMon or access to publications, visit http://socmon.icriforum.org/.

Moving Forward

Support for Socioeconomic Monitoring. It is critical to recognize that SocMon is essential for successful conservation and effective management. Without good global-level social and economic data, we have only a limited understanding of how people value and depend on coral reefs. Moving forward, a major issue that needs addressed is the recognition of socioeconomic monitoring and its inclusion in GCRMN. While SocMon has been acknowledged as a need, there needs to be more effort to include social scientists in GCRMN discussions and planning. The socioeconomic component should not be considered separately or after the fact.

The lack of funding and organizational priorities for SocMon have made it difficult for each region to maintain monitoring efforts. More people are recognizing the importance of social-economic science, but priorities and budgets tend to favor biological data monitoring. Moving forward, the SocMon coordinators are searching for alternative funding opportunities. But we can begin to overcome some of these challenges by sharing the value of socioeconomic monitoring and our success stories, while expanding the GCRMN network with new opportunities for collaboration and partnership.

A Holistic Approach for GCRMN. There is a pressing need to integrate biophysical and socioeconomic monitoring to better inform holistic ecosystem-based management. Essential data on the human dimensions of coral reefs should not stand alone, but should be considered integral to GCRNM data collection on biophysical conditions. SocMon is meant to complement the biophysical monitoring and can be used in a comprehensive holistic approach to better understand the desired ecosystem services, drivers and pressures of change, state of the ecosystem, and appropriate responses[2].

Increased collaboration and interdisciplinary work within the GCRMN is needed to understand the links within the social-ecological system. GCRMN and SocMon must collaborate to integrate biophysical and socioeconomic monitoring data and to gain new perspectives. Effective coastal resource management is only possible if biophysical and social science disciplines work together at the inception of any monitoring program. This involves aligning our goals and combining complementary research questions in order to evaluate the status

[2] Kelble, C.R., Loomis, D.K., Lovelace, S., Nuttle, W.K., Ortner, P.B., Fletcher, P., Cook, G.S., Lorenz, J.J., and Boyer, J.N. (2013). The EBM-DPSER conceptual model: Integrating ecosystem services into the DPSIR framework. PLoS ONE, 8(8), e70766.

of coral reefs, and depends on our ability to provide desired ecosystem services and respond to emerging threats in coastal-marine areas.

Integration of social and biophysical information has been acknowledged by the Caribbean regional node of GCRMN[3]. The GCRMN-Caribbean developed a framework for monitoring programs to contribute comparable data that support a regional understanding of status and trends of Caribbean coral reefs and will allow us to assess the basic socioeconomic impacts of large-scale future changes in coral reef health in the Caribbean region. An integrated approach is needed in all regions of GCRMN for a holistic understanding of the status of coral reefs and the communities who depend on those reefs.

Conclusion

The incorporation of human dimensions will significantly enrich our understanding of the complex interactions between society and coral reef ecosystems. By integrating socioeconomic and biophysical monitoring, we can unravel the drivers of change and assess the interdependence of factors associated with the ecosystem. This is imperative if society is going to have a more sustainable relationship with natural resources, services, values, and the ecosystems on which they are reliant. If socioeconomic monitoring (SocMon) cannot be sustained long-term, however, integrated comprehensive monitoring will not be possible and management will lack critical information necessary to manage coral reefs on behalf of society.

[3] GCRMN-Caribbean. (2017). Combined Biophysical and SocMon Report of the GCRMN Caribbean Capacity Building for Coral Reef and Human Dimensions Monitoring within the Wider Caribbean Workshop. https://gcrmn.net/wp-content/uploads/2019/08/GCRMN-Caribbean-capacity-building-workshop-report-Oct-2017.pdf

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