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Impact of the 3rd Global Coral Bleaching Event on the Western Indian Ocean in 2016

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Edited by
Mishal Gudka, David Obura, Jelvas Mwaura, Sean Porter, Saleh Yahya and Randall Mabwa

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Maps were produced from open source country and coral reef layers by James Mbugua, CORDIO East Africa. The designation of geographical entities in this report, and the presentation of the material, do not imply the expression of any opinion whatsoever concerning the legal status of any country, territory, or area, or of its authorities, or concerning the delimitation of frontiers or boundaries.

Executive Summary

The third global coral bleaching event started in the North Pacific in the summer of 2014, and continued for a record 3 years, only dissipating in 2017. It affected the Western Indian Ocean (WIO) between January and May 2016, and was the strongest bleaching event to occur in the region since 1998.

The **main objective** of this report is to provide updated information on the status of coral reefs in the region after the 2016 mass coral bleaching event. Secondary objectives are to a) update the national and regional databases on coral reef health, and b) strengthen coral reef monitoring networks in the region.

This assessment was based on the approach used for the 2017 GCRMN WIO coral reef status report. Post-bleaching data were collected at long-term monitoring sites in September and October 2017 in four countries: Tanzania, Kenya, Madagascar and Comoros. In addition, data were gathered from various organizations, researchers, institutions and programmes across the region that had conducted their own post-bleaching surveys. The analysis included 153 reef sites from 6 countries with both pre-bleaching (June 2016 and earlier) and post-bleaching (July 2016 and later) data.

In 2016 thermal stress was nearly equivalent to that experienced in 1998. Overall, hard coral cover in the region declined by 20% and fleshy algae cover increased by almost 35% following bleaching in 2016. This is a significant acute loss in living coral, and represents a similar, although not quite as dramatic step-change in benthic composition to what happened after the 1998 event (25% loss of coral cover, 2.5 times increase in algae). Seychelles was the worst hit country, followed by Madagascar. Parts of Mauritius, Kenya and Tanzania were also badly impacted, while Comoros showed only slight impact. The increase in fleshy algae post-bleaching has closed the gap between hard coral and fleshy algae cover on a regional scale, with reefs in some countries experiencing a shift to greater dominance by algae rather than corals.

Nevertheless, some two thirds of corals that bleached in 2016 recovered, implying a degree of resistance to thermal stress which enabled recovery. This is a significant positive message: that resistance to bleaching may be higher than it was in 1998 when thermal stress was broadly similar but mortality was higher. However the amount of mortality indicates resistance is still not enough to withstand warming completely.

The monitoring response to the 2016 bleaching event across the region was low, with a lack of effort to undertake nationwide post-bleaching surveys in most countries. With bleaching projected to become more frequent and intense in the future, it is vital that governments develop national responses to prepare and respond effectively in the future. Reefs in the region have shown the ability to recover from bleaching events, however with the likely future increases in thermal stress it will become much more challenging for reefs to resist and recover unassisted. Therefore drastic improvements to management strategies and policies must be made at local, national and regional scales.

Summary of results *from data submitted for this report showing the total number of sites from each country, the number of sites with coral and algae data used in comparisons between pre- and post-bleaching periods and the percent change (%) and the post-bleaching cover levels (in parentheses) for coral and fleshy algae.*

Country	# sites			% change (post % cover)		Observations/interpretation
	total	data for both periods				
		coral	algae	coral	algae	
Comoros	9	5	0	5% (62%)	-	• Low impact of bleaching: post-bleaching (2017) coral cover high (55%), fleshy algae low
Kenya	30	21	21	0% (24%)	9% (36%)	• Lamu (north) most affected region with 51% loss in coral cover at 2 sites • Fleshy algae cover higher than coral cover post-bleaching
Madagascar	41	41	40	-13% (46%)	56% (14%)	• Only data from west coast, most severe impacts in northwest. • Relatively high coral cover and low fleshy algae post-bleaching
Mauritius	5	5	5	~ 0% (35%)	~ 0% (7%)	• Single site reported, from Anse La Raie Lagoon.
Seychelles	50	43	32	-50% (17%)	~45% (42%)	• Inner Islands more severely impacted than Outer Islands (60% loss vs. 17%, respectively) • Maximum mortality of 80% at North Island. • 4 sites with no impact or positive gain in the Inner Islands (NW Mahe and Cerf Island)
South Africa	5	5	0	~0% (20%)	<5% (21%)	• Negligible bleaching and no mortality
Tanzania	25	16	16	-10% (39%)	25% (15%)	• Lower mortality compared to bleaching indicates substantial recovery and survival of corals. • Highest impacts on west coast of Unguja Island
REGIONAL	160	131	114	-20% (33%)	~35% (26%)	• Approximately 20% decline in coral cover across 131 sites in 6 countries and 35% increases in fleshy algae cover across 114 sites in 5 countries

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1. Regional Chapters

1.1 Introduction

The status of coral reefs in the Western Indian Ocean region was most recently updated in a regional report of the Global Coral Reef Monitoring Network (GCRMN) published in 2017 (Obura et. al 2017). It included data recorded up to 2015. But several factors made an update in 2017 necessary. First, the 3rd Global Coral Bleaching event, which extended from 2014 to 2017 had a significant presence in the region during 2016 (see fig. 1.1.3). This event was not captured in the quantitative records of reef cover in the 2017 report, though the progression of the event was covered in a dedicated chapter (Gudka & Obura, 2017). Second, many countries in the region have had limited resources for coral reef monitoring since 2012, which was visible in the 2017 report as a significant gap in recent data records. Thus, obtaining a new, updated data record as soon as possible following the 2016 coral bleaching event was seen as a high priority, to strengthen the value of the long-term datasets into the future.

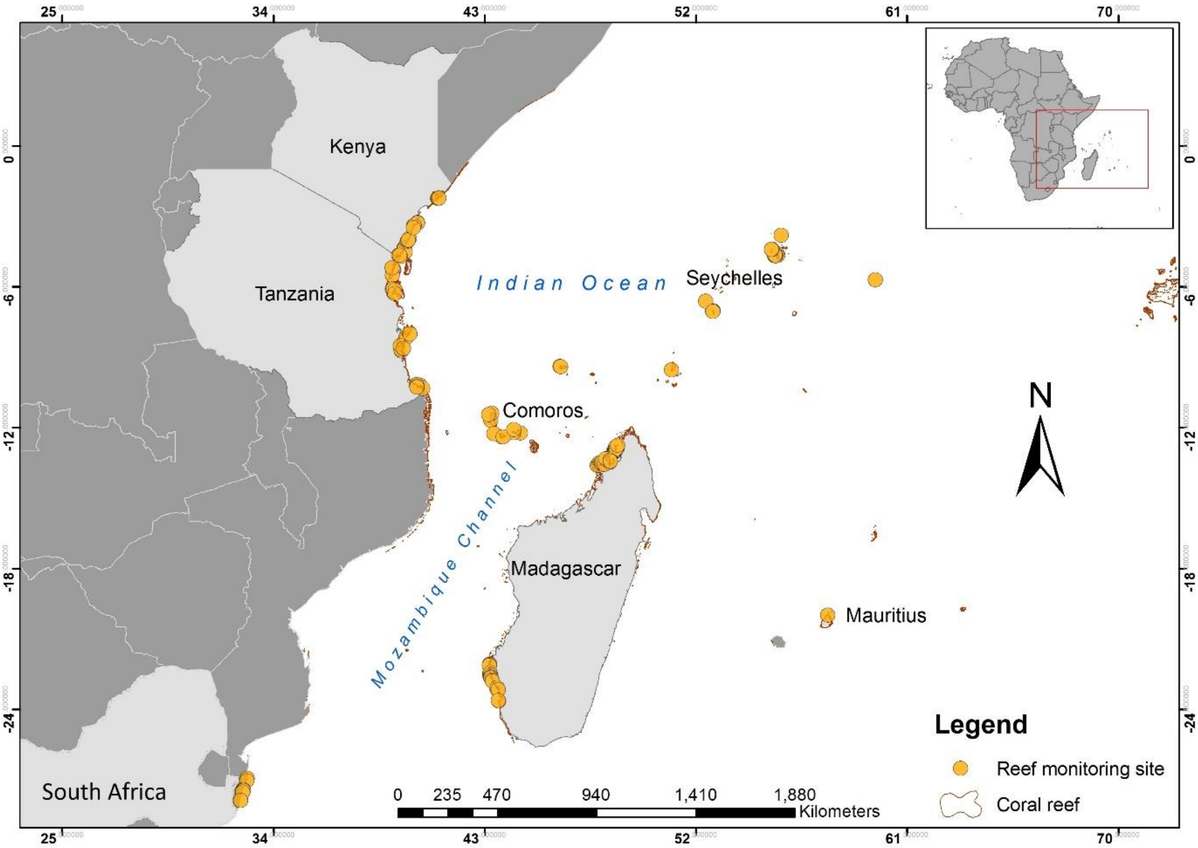

Figure 1.1.1. All monitoring sites from across the WIO for which data were included in this analysis.

The Indian Ocean Commissions' Biodiversity Project, funded by the European Union, is aimed at strengthening national and regional capacities in the management of biodiversity and coastal ecosystems to contribute to the conservation and sustainable use of resources (promotion of bio-sustainable applications). It thus approved a 'post-bleaching assessment' of coral reef health to be undertaken, to strengthen national and regional capacities for management of coral reef ecosystems.

The objectives of the project were to:

- support sampling at long-term monitoring sites in the Biodiversity Projects beneficiary countries (Comoros, Kenya, Madagascar, Mauritius, Seychelles, Tanzania) to plug the gap in monitoring since 2012 and document the full impact of the 2016 bleaching event;
- update the national and regional databases on coral reef health and report on it in an update to the 2017 GCRMN report;
- further strengthen capacity and standards for monitoring in the regional and national coral reef networks, including involvement of the non-beneficiary countries (Mozambique, South Africa, France).

1.1.1 Recent status of coral reefs in the Western Indian Ocean

The regional report on coral reef health, updated to 2015, found that coral reefs in the WIO underwent a step-change as a result of the global bleaching event in 1998. Coral cover declined by 25% and algal cover increased 2.5 times. While many reefs that were heavily impacted by bleaching in 1998 did show some recovery, particularly in Kenya and the Seychelles, other reefs failed to recover, and some reefs that escaped that event still showed significant decline. In the intervening period there was a significant increase in general pressures from human population and economic growth, with increased fisheries, coastal development and pollution throughout the region. At the same time, minor bleaching events affected different locations at different times, with significant events in 2005 and 2010 (McClanahan et al., 2011; Souter & Linden, 2005). Overall, the picture is of a reef system struggling to recover from a major acute stress (in 1998) while increasing chronic stresses chip away at its resilience. With algal populations approaching the same cover as hard corals, it is possible that the reefs may be approaching a threshold beyond which dominance by hard corals becomes less and less likely, particularly if a major stress event induces significant coral mortality from which the coral community cannot repopulate.

Coming into the bleaching event of 2016, the regional report speculated that a second step-decline in reef health in the WIO may be possible. Thermal stress in the global event in 2015-17 appeared to be greater than the 1998 event, and with coral and algal levels more or less equivalent, the fear was that further suppressing coral cover may result in a permanent shift whereby algal cover exceeds coral cover and causes a continuous downward spiral of coral cover.

1.1.2 Progression of the 2016 bleaching event in the WIO

In October 2015, the National Oceanic and Atmospheric Administration (NOAA) declared the current event, which began in the North Pacific in summer 2014, as the third global coral bleaching event after those in 1998 and 2010[1]. It continued for a record 3 years, only dissipating globally in 2017.

[1] http://www.noaanews.noaa.gov/stories2015/100815-noaa-declares-third-ever-global-coral- bleaching-event.html. Accessed 20 November 2016.

The climatic conditions in the WIO in 2016 were comparable to those experienced in 1998. Between 1981 and 2017, the two highest mean sea surface temperatures were recorded in 1998 and 2016, with 2016 the only year where mean temperature exceeded 29.5°C (fig. 1.1.2). Interestingly, the trend seems to indicate a bleaching threshold at 29°C, as both the major bleaching events of 1998 and 2016, and the less extreme events in 2005 and 2010 occurred when this value was surpassed.

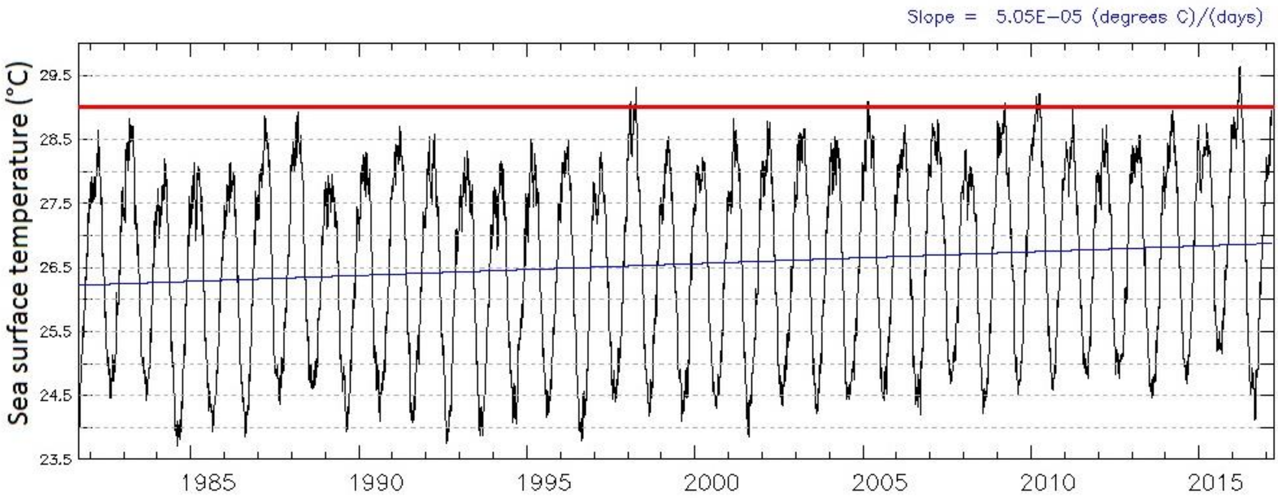

Figure 1.1.2. *Remotely sensed mean daily sea surface temperature (°C) for the Western Indian Ocean from 1981 – 2017 with trendline (blue line) and 29°C bleaching threshold (red line). Data from NOAA High Resolution SST AVHRR provided by the NOAA OAR ESRL, available at http://las.incois.gov.in/las/.*

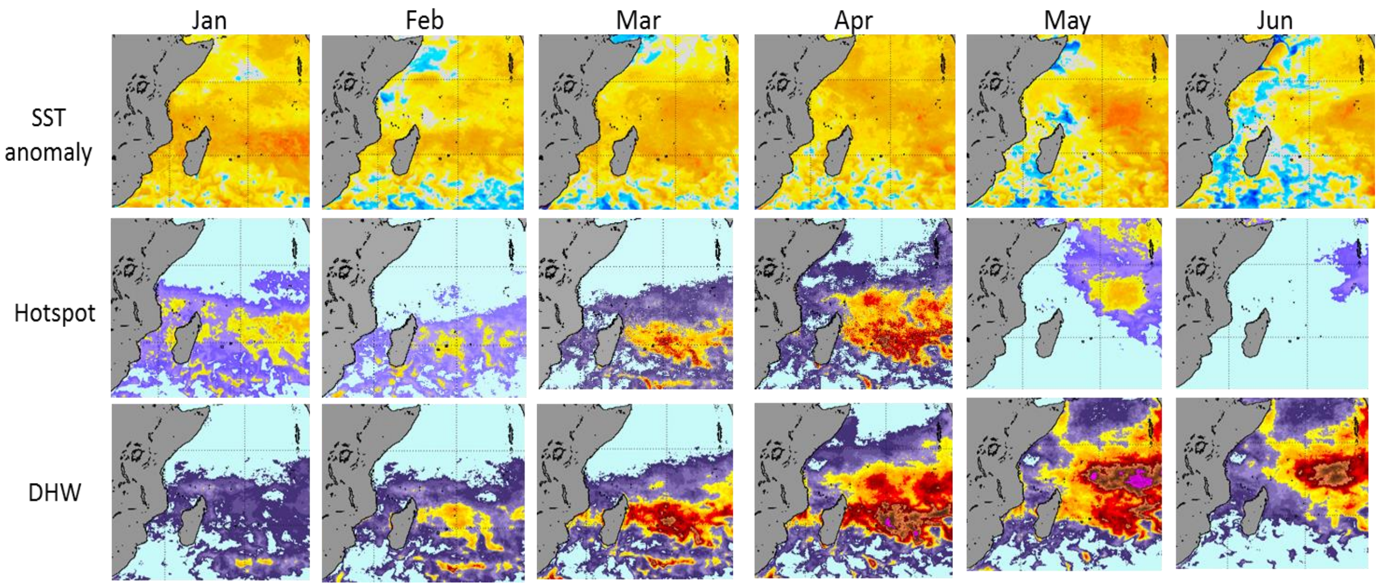

Figure 1.1.3*. NOAA Coral Reef Watch 5km Satellite Coral Bleaching Heat Stress Monitoring in the WIO for the 15th of each month from January to June 2016. SST anomaly, hotspot and degree-heating-weeks (DHW) are shown.*

The year began very hot, with sea-surface temperatures (SST) 1-2°C above long-term averages (yellow and orange colors) in Mozambique, Tanzania and Seychelles (fig. 1.1.3). Thermal stress is present in January, shown by the hotspot and DHW readings, and builds to a peak in April as can be seen by the 'hotter' red and yellow colours and then dissipates by June. Moderate DHW levels can be seen in the Mozambique Channel and on the East African coast in March and April, whilst very high DHW and hotspot build up are present east of Madagascar, around Reunion and Mauritius. A strong hotspot is also present over Seychelles. In March and April, hot conditions begin moving northwards, leaving some cool areas in the south and by May there are some cool spots in the Northern Mozambique Channel and north of Madagascar.

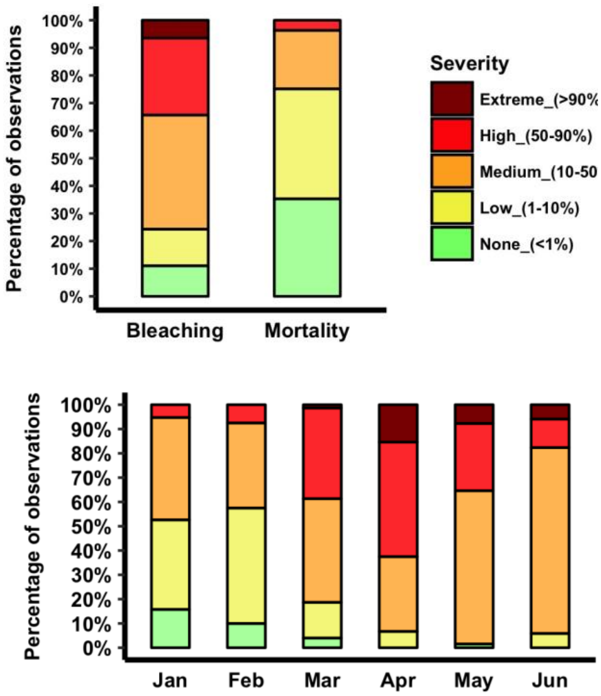

__Figure 1.1.4.__ Breakdown of coral bleaching and mortality observations for six countries in the Western Indian Ocean in 2016 - __top)__ coral bleaching from January-May (n=300) and mortality from May-December 2016 (n=153); __bottom)__ monthly breakdown of bleaching observations (Jan; n=18, Feb; n=40, Mar; n=75, Apr; n=103, May; n=64, Jun; n=33). Categories represent the severity of bleaching/mortality reported as percentage of coral cover bleached/dead at a site.

Observations of coral bleaching during the event were recorded through an online reporting system set up by CORDIO and partners in early 2016. Submissions were based on visual estimates of bleaching at reef sites by observers and were split into five broad bleaching categories (none (<1% of coral cover), low (1-10%), medium (10-50%), high (50-90%), extreme (>90%)). The results were compiled in the regional GCRMN report (Gudka & Obura, 2017) and have been summarized here for the six countries included in this analysis (fig. 1.1.4). Overall, bleaching increased until April, when more than half of all reports were of high or extreme bleaching levels (fig. 1.1.4, bottom). Of all the bleaching reports received from all WIO countries, 30% were of high or extreme bleaching, but mortality levels were much lower (fig. 1.3.7, Gudka & Obura, 2017).

1.1.1 Justification for this study

While these bleaching reports give an important indication of bleaching levels, they are biased towards bleaching, as few observers make the effort to report the absence of bleaching. Hence the need for the quantitative post-bleaching assessment contained in this report; to provide an unbiased estimate of the impact of the 2016 bleaching event on coral reefs of the WIO, and to update and strengthen the national and regional coral reef monitoring programmes to provide quality data on the health of coral reefs.

1.2 Methodology

1.2.1 Overall approach

The 2017/18 post bleaching assessment was based on the approach used for the 2017 GCRMN WIO coral status report. We sought to extend the datasets compiled for that process (which included data up to 2015 and early 2016), by adding more recent survey data from late 2016 and 2017, as well as data from new sources.

1.2.2 Data collection and management

As with the 2017 GCRMN WIO coral status report, CORDIO played the role of the regional coordinator and led planning, data collection, analysis and report writing, under the auspices of the GCRMN and coral reef networks for the WIO, and the regional Coral Reef Task Force. Data for the assessment was collected through two channels. Funding provided by the Biodiversity Project was used to organize field surveys to collect post-bleaching data in September and October 2017 in four of the project's beneficiary countries; Tanzania, Kenya, Madagascar and Comoros. Surveys were organized by National Coordinators in each country, who led teams to collect benthic, fish, coral condition and recruit data at a number of long-term monitoring sites. Long-term monitoring sites were selected to maintain consistency in time-series datasets, with a priority for sites that had not yet been monitored after the 2016 bleaching event. As most sites with historical data in the Seychelles had already been surveyed post-bleaching, additional surveys were not funded. Unfortunately, due to logistical and administrative challenges, post-bleaching surveys could not be organized in Mauritius during the project implementation phase.

In addition to the above surveys, data were gathered from various organizations, researchers, institutions and programmes across the region, through the coral reef networks/Coral Reef Task Force for the WIO. Calls for data were made by email, during a webinar about the project on the Reef Resilience platform in July 2017 (http://www.reefresilience.org/western-indian-ocean-post-bleaching-assessment-training/), and at a special session held at the WIOMSA Scientific Symposium on the 2nd of November 2017. A data sheet template was provided for contributors to compile their data, and a Data Sharing Agreement was signed. Data were only requested at a site-summary level (i.e. mean values at site levels) to encourage sharing and collaboration. No raw-data were requested. Efforts were also made to include WIO countries that are not beneficiaries of the Biodiversity Project, i.e. Mozambique, France and South Africa, and data were obtained from South Africa.

Data cleaning, handling, management and compilation was mainly done using R studio. Overall, we obtained data from 33 monitoring programmes or individuals, comprising 862 surveys of corals and 729 surveys of algae, from 153 locations across 6 countries (Table 1.2.1).

Table 1.2.1. Summary of data collected from the Western Indian Ocean for the post-bleaching assessment

	Coral	Fleshy Algae
Countries	6	5
Locations/Sites/Stations	153	131
Site surveys	862	729
Start Year	1992	1992
End Year	2017	2017
Years surveyed	26	26

Some bleaching figures presented in this report were used in the 2017 GCRMN WIO coral status report and have been referenced accordingly. The bleaching data were collected using methods of varying levels (visual estimates, quantitative quadrats and transects) and submitted to CORDIO during the 2016 bleaching dataset via an online form and emails. The full list of data contributors is provided in the annex (Section 1.7).

Data contributors:
Organisations:
AIDE Comoros, Kenya Marine and Fisheries Research Institute, Kenya Wildlife Service, AROCHA Kenya, CORDIO, EAWS, WWF, Blue Ventures, Frontier Madagascar, Madagascar Research and Conservation Institute (MRCI), WCS Madagascar, Reef Conservation, Seychelles National Parks Authority, Global Vision International, Seychelles Islands Foundation (SIF), Island Conservation Society (ICS), Green Islands Foundation (GIF), Marine Conservation Society Seychelles, Oceanographic Research Institute (ORI) South Africa, South African National Biodiversity Institute (SANBI) Institute of Marine Sciences University of Dar es Salaam, Tanga Coelacanth Marine Park, Chumbe Island Coral Park (CHICOP).

Individuals:
Ahamada S., Freed. S, Madi Bamdou M., Maharavo J., Mouhhidine J., Nicet J.B, Ali Ussi.

Fieldwork teams:
Madagascar: Ihando Andrainjafy (National Coordinator), RANDRIANANDRASANA José, RADONIRINA Lebely, ZAKANDRAINY Andriamanjato, ANDRIALOVANIRINA Nicolas, Lope Jean Charles, BAKARY Gisèle, Zavatra Jean Baptiste, Rajesy Farcy.
Kenya: Mwaura Jelvas (National Coordinator), Josephine Mutiso, Albert Gamoe, Joseph Kilonzo, Peter Musembi.
Tanzania: Saleh Yahya (National Coordinator), January Ndagala, Ali M. Ussi, Mohammed S. Mohammed, Hassan Kalombo.
Comoros: Mmadi Ahamada (National Coordinator), Nassur Ahamada Mdroimana, Rachad Mourid, Zamil Mannfou, Jaffar Mouhidine, Adfaon Mchinda, Mouchtadi Madi Bounou
South Africa: Sean Porter (National Coordinator), Kerry Sink, Michael Schleyer, David Pearton, Camilla Floros, Mari-Lise Franken, Stuart Laing.

1.2.3 Analysis

The main objective of the post-bleaching assessment was to quantify the impact of the bleaching event in 2016 on coral cover in the form of direct mortality, and corresponding changes in algal cover. Benthic cover data collected using different GCRMN-approved methods were used in the analysis (Obura et. al., 2017). To ensure consistency in reporting on the status of coral reefs in the WIO region, figures and graphical representations are akin to the 2017 WIO GCRMN coral reef status report.

Bleaching has direct impacts on living coral, and the knock-on or longer-term consequences of coral mortality are changes in algal cover, coral recruitment and fish population structures. Because of the short timeframe of this assessment in relation to the bleaching in 2016, and the principal data collected by teams in the region (Obura et. al., 2017), it was decided that hard coral cover and fleshy algal cover were the most appropriate variables for analysis and presentation. Coral recruitment and fish populations were not analysed because of the time-lag for impacts to manifest, the number of other factors apart from bleaching that could affect them, and the paucity and quality of datasets. Due to differences in how various algal communities are measured and defined by different monitoring programmes, turf, filamentous, macro and *Halimeda* were combined into a single variable called fleshy algae. This was also done to align with other recent regional reports on coral health.

Comparisons of coral and fleshy algae cover across the bleaching event, was done in two ways. First, we compiled the long-term data to look at trends across the 'break' in 2016. Where this break is provided in the data, we portray two lines - one up to June 2016 (pre-bleaching) and the other from July 2016 onwards into 2017 (post-bleaching). Second, to focus on the effect of coral mortality, we use data from sites in the period 2012 - June 2016 (pre-bleaching) paired with data from July 2016-2017 (post-bleaching). Because our sampling focused on long-term monitoring sites, many of which had not been sampled for several years (see Obura et al. 2017) the wide pre-bleaching window of 2012-June 2016 was necessary to enable analysis of sufficient samples (sites). We assumed that any mortality from this period to July 2016 onwards was due to the bleaching event, though there could have been other causes of coral mortality. For each site, we selected the most recent date in the pre-bleaching and post-bleaching windows for analysis.

To improve the reliability of results, several quality control measures were applied to filter the data before analysis. Firstly, only data collected using GCRMN methods were included in the analysis, and data were aggregated to the broadest, most basic level to cater for issues arising from the combination of data collected via different methods and levels. Additionally, only sites with both pre- and post-bleaching data were used in the analysis, to increase the accuracy of comparisons before and after the 2016 bleaching event. Comparisons between hard coral and fleshy algae were made only using sites where both variables were measured.

Analysis was done at national and regional levels. For both mean coral and fleshy algae (for those countries where data were available) cover, trends over time were traced together with a 95% confidence interval (fig. 1.2.1a), with the break in time series before/after bleaching in 2016 shown by different lines. The difference between ‘pre-bleaching’ (2012 - June 2016) and ‘post-bleaching’ (July 2016 – 2017) periods is shown by column graphs (mean ± s.e), using the most recent value at each monitoring site for each period (fig. 1.2.1b). The graphical representation is based on the GCRMN WIO 2017 report.

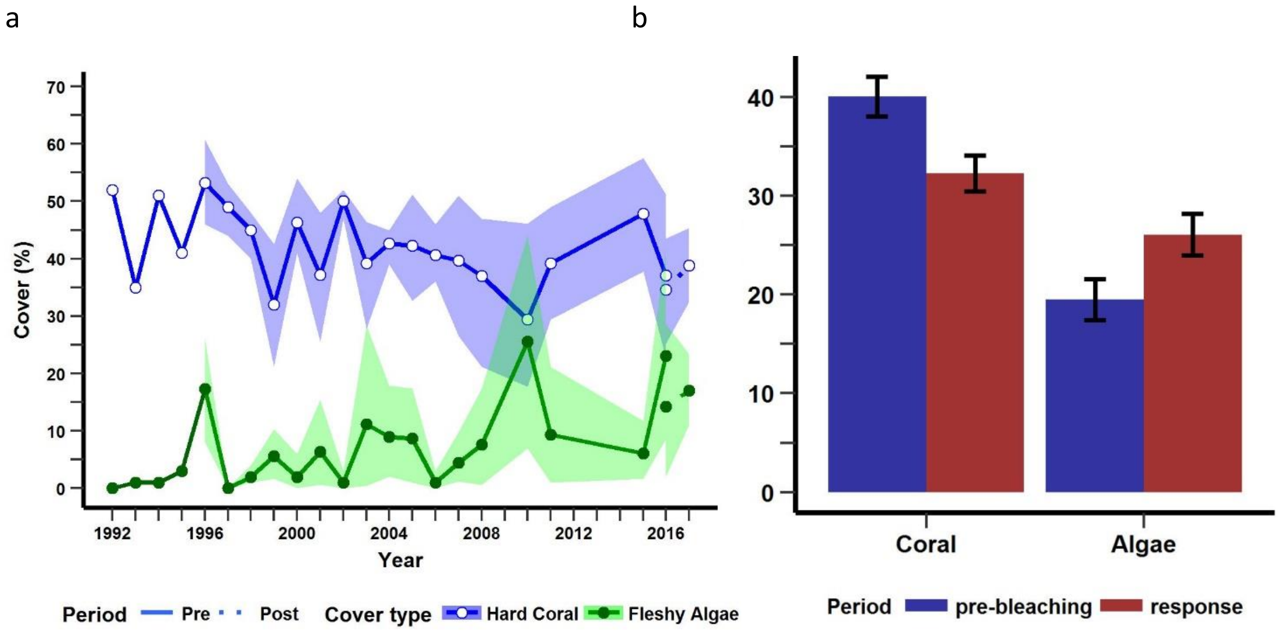

*Figure 1.2.1. Illustration of the analyses presented in this report: **a)** Trend in mean cover of live coral (blue, open circles) and macro algae (green, closed circles) before (solid lines) and after (dotted lines) the bleaching event **b)** national mean coral and algae cover before and after (response) the bleaching event. Data from Tanzania.*

Due to the nature of this analysis, compiling data from different programmes that use different methods, different levels of expertise and different levels of identification, there are limitations to the analysis and results. Secondly, inconsistency in monitoring effort at sites across years means that trends shown in the graphs may reflect sampling artifacts, rather than real changes in coral reef health. The long temporal gaps between monitoring at sites, especially in recent years, makes pre- and post-bleaching comparisons less accurate. There were also no coherent nation-wide monitoring responses to the bleaching event, so data are mainly from ad hoc responses or NGO monitoring programmes. For the regional results, unequal representation of samples from countries biases the results. For some countries, such as Mauritius and Comoros, the number of sites included is very small, due to lack of participation and monitoring, and is not representative of historical monitoring in the countries. Also, data from Mozambique, South Africa and France were not included in the overall regional analysis.

An issue we identified as significant, and that monitoring programmes need to address is the repeated monitoring of precisely the same locations from one year to another. Some sites have very patchy corals, and different observers working in different years may simply be placing transects in different locations, resulting in high variance in the data that don't reflect real changes in the water. Greater standardization and reliability of methods is essential to improve future reliability.

1.2.4 Data archiving and access

The efforts undertaken by CORDIO during the 2017 GCRMN regional reporting process, brought together historical coral reef (benthic and fish) data into central regional datasets for the first time. This post-bleaching assessment has updated the datasets with data from 2016 and 2017. The next steps to continue efforts to increase data sharing and availability, are to make these datasets publicly available with the permission of all the data contributors on a secure data repository, and visible through portals such as Ocean Biographic Information

System (OBIS). However, some kind of data citation and sharing-agreement must be developed to facilitate this process.

1.3 Regional Results

1.3.1 Introduction

This section presents the regional results of the post-bleaching assessment using summary benthic data submitted from six countries; Comoros, Kenya, Madagascar, Mauritius, Seychelles and Tanzania. Only sites with both pre-bleaching (earlier than July 2016) and post-bleaching (later than June 2016) data were used. The analysis included a total of 153 sites, with Seychelles having the greatest number of samples with 43 sites and Mauritius the least number of sites, with 5.

1.3.2 Coral cover

The trend in mean hard coral cover between 1992 and 2017 for most of the countries is very erratic, largely as a result of inconsistency in sites sampled from year to year (fig. 1.3.1). The mean cover of coral initially declines between 1992 and 2006 from about 40% to 20-30%, then shows an improvement till 2015, returning to 40%. It then declines again, which can be directly attributed to the 2016 bleaching event. Kenya, Madagascar and Seychelles show recoveries in hard coral cover from the 1998 bleaching event up to 2016, but Comoros, Mauritius and Tanzania show no apparent trend. For all countries except Tanzania, hard coral cover decreased after the 2016 bleaching event. In 2017, Comoros and Madagascar had the highest coral cover at over 45%, Tanzania and Mauritius were close to the regional mean at 35%, and Seychelles and Kenya had the lowest coral cover of below 30%.

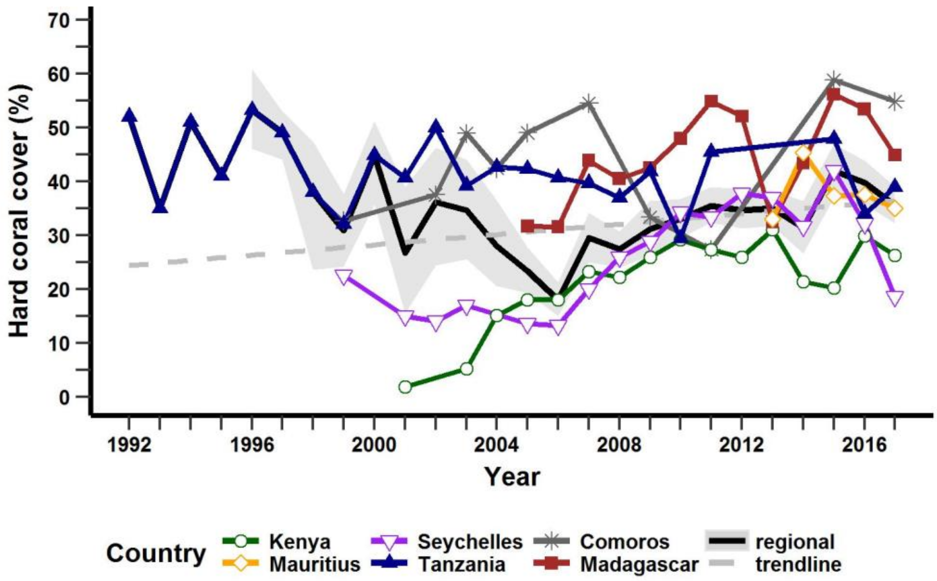

Figure 1.3.1. Mean hard coral cover across all 6 countries with data in the WIO (colored lines with symbols), the regional mean with 95% confidence limits around the mean (black line and grey shading) and a linear regression line on the regional mean (grey dashed line, y = 0.480x + 24.367).

The number and consistency of monitoring sites through the years has varied greatly among countries (fig. 1.3.2). Kenya and Seychelles have consistent and large-scale monitoring effort over time. Madagascar has shown a strong response to the bleaching event with a large increase in samples in 2016 and 2017, while Tanzania has gaps in monitoring for some years, and Comoros and Mauritius have very sporadic samples. It should be noted that sites monitored in the past (see Obura et. al., 2017) but that were not sampled after the 2016 bleaching event have not been included in this analysis, so there are a significant number of coral reef monitoring sites in all six countries that are excluded from this analysis. The fact that these sites have not been monitored is a further sign of the challenge of maintaining regular and reliable monitoring programmes in the region (Obura, 2013).

The scatterplots (fig. 1.3.2) show that up to early 2016, Seychelles, Comoros, Kenya and Madagascar all show an increase in coral cover. Mauritius and Tanzania show a very slight decline in coral cover.

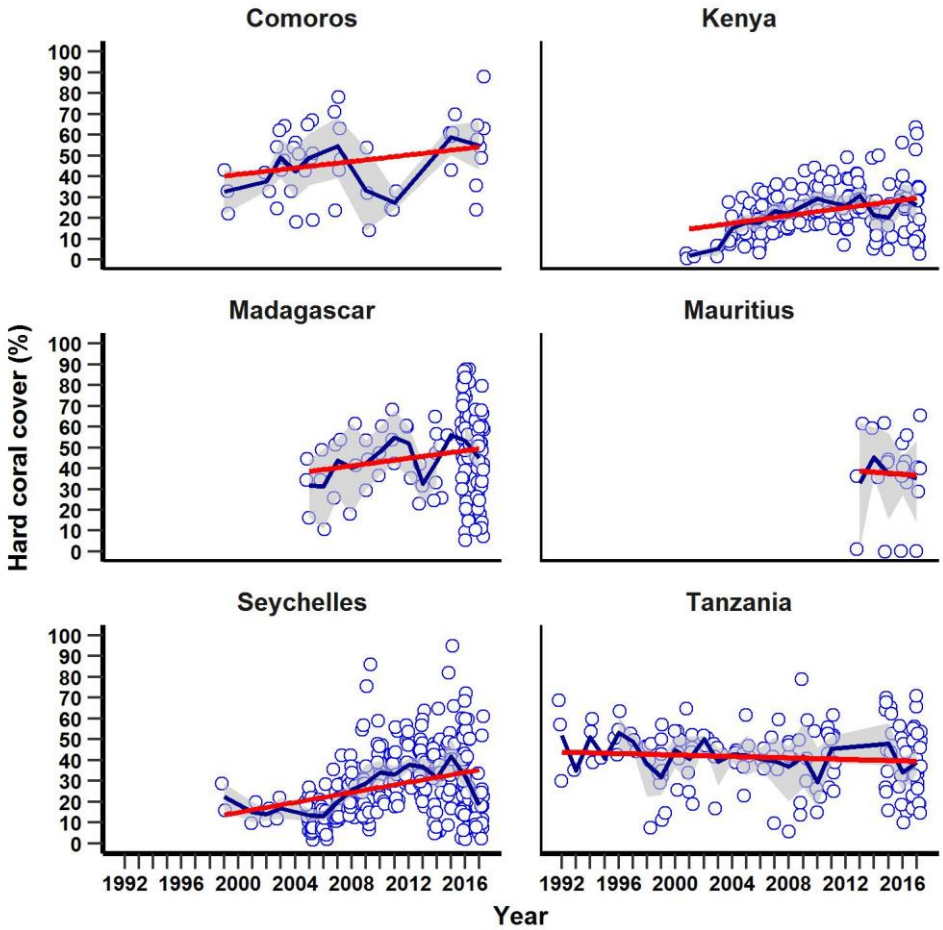

Figure 1.3.2. Hard coral cover by country for the period 1992-2017 (excluding sites without both pre-bleaching and post-bleaching data). Individual site records (blue open circles), the mean and 95% confidence interval (dark blue line and grey shading) and linear regression (red line) are shown.

1.3.3 Fleshy algae

Fleshy algae and hard coral cover were both measured in five of the six countries. Fleshy algae was declining from a peak of close to 40% in 2004, but began an upward trend in 2013, which continued through the 2016 bleaching event into 2017 (fig. 1.3.3). These trends complement the overall change in coral cover, including the clear break and decline in hard corals between the pre- and post-bleaching periods.

A pattern is discernible and follows that reported in the latest regional reef monitoring report (Obura et al. 2017), that coral and fleshy algal covers reversed in dominance after the 1998 bleaching event, then from 2006 corals recovered and became more dominant again. Now from the 2016 event the same flip may be happening but from a starting point where the gap is much smaller than in 1998. It will take a few years to see if coral cover increases and fleshy algae declines again.

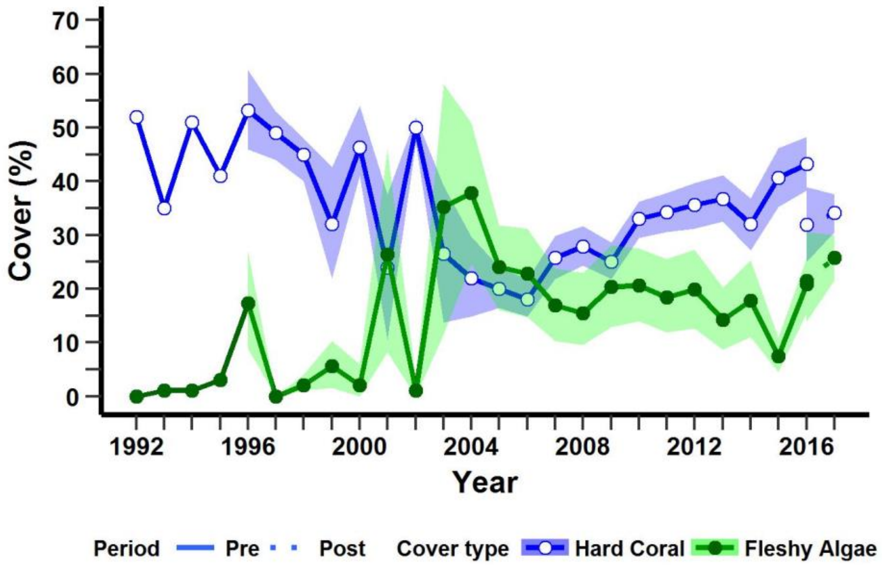

Figure 1.3.3. Regional average of hard coral (blue line, open circles) and fleshy algae (green line, closed circles) cover pre- and post-bleaching (mean and 95% confidence interval) (n = 131). Post-bleaching period is from July 2016 onwards and is represented by a dotted line, and pre-bleaching is a solid line.

Looking at the relationship between fleshy algae and hard coral in each country individually, algae abundance is relatively low in Madagascar, Mauritius and Tanzania in 2017 at under 20%, whilst Kenya and Seychelles both have algae levels greater than hard coral, at over 40% (fig. 1.3.4).

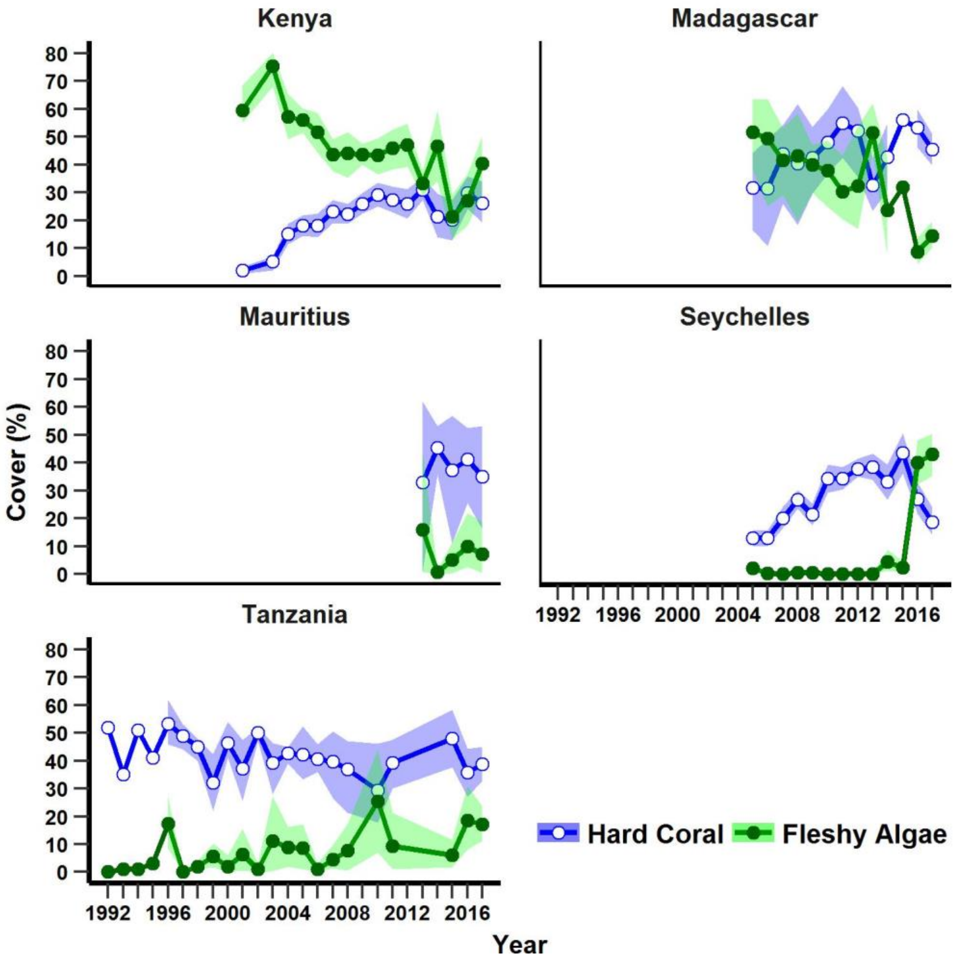

Figure 1.3.4. Trends in fleshy algae (green line, closed circles) and hard coral cover (blue line, open-circles) in countries where algal cover was collected. The shaded areas represent the 95% confidence interval and mean. Only countries with hard coral cover and fleshy algae data were included in the analysis.

1.3.4 Coral/algal interactions

Just before the bleaching event in 2016, the hard-coral cover for five countries in the WIO stood at 40 ± 2% (mean ± se) after which it fell by 20% to 32 ± 1.8% due to the bleaching event (fig. 1.3.5). During the same period, fleshy algae cover increased by approximately 34% from 19 ± 2% to 26 ± 2%.

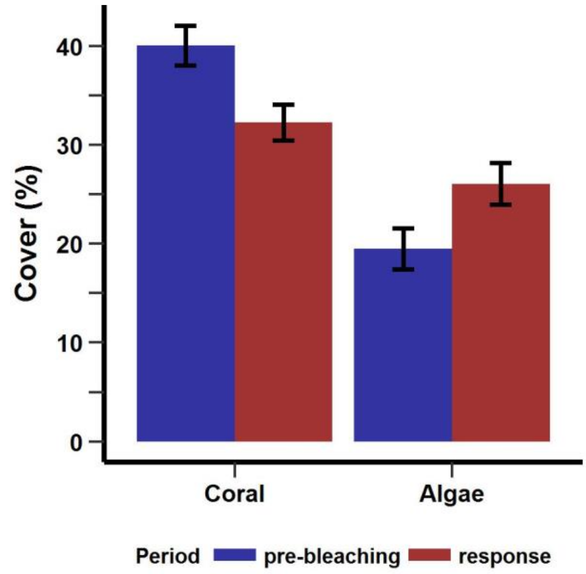

Figure 1.3.5. *Hard coral and fleshy algae mean cover and standard error for pre-bleaching and post-bleaching (response) periods for all sites where both variables were reported. Pre-bleaching data are from 2012- June 2016 and post-bleaching (response) data are from July 2016 – 2017 (n = 114).*

1.4 Discussion

The WIO was affected by the 3rd global coral bleaching event in the regional summer of 2016 as El Niño conditions reached record levels. This event was in many ways equivalent to the 1998 event in the WIO in the amount of heat stress (fig. 1.1.2), with the 3rd and 4th most severe thermal stress events happening in 2010 and 2005, respectively.

Mass bleaching took place across all the countries of the WIO between January and May 2016, and bleaching persisted at several reefs for months after conditions had cooled (Gudka & Obura, 2017). Aggregating across 131 survey sites from 6 countries, hard coral cover declined from 41 ± 1.9% (mean ± se) to 33 ± 1.8%, a drop of 20%. For 114 survey sites from 5 countries, fleshy algae cover increased by ~35% from 19 ± 2% to 26 ± 2%. The comparable responses in 1998 of hard coral and algae were 25% and 150% respectively.

Thus, although bleaching was widespread, the subsequent coral mortality was not as extensive as the bleaching, and was less than mortality in 1998. This recovery from bleaching and lower mortality implies a degree of resistance to bleaching, which enabled corals to survive the high thermal stress and recover. This is a significant positive message; that resistance to bleaching may be higher than it was in 1998. However, the amount of mortality indicates it is still not enough to resist warming completely, and the increase in algal cover to a higher level than after the 1998 event is cause for concern (Obura et. al. 2017).

The measure of coral mortality reported here is more precise than the estimate provided by visual observations of bleaching (Gudka & Obura, 2017). The visual observation method enabled us to state that "10% of sites experienced high or extreme mortality (>50%) after bleaching" (and about 20% of sites experienced moderate mortality), which corresponds to the quantitative value of 20% mortality reported here.

Coral mortality among countries was heterogeneous. Seychelles was the worst-hit country (Table 1.4.1), while Madagascar also experienced a sharp decline in coral cover. Comoros and Kenya showed very low impacts, while Mauritius and Tanzania were relatively unaffected. Following the bleaching event, reefs in Madagascar, Comoros and Mauritius had some of the highest coral cover levels in the region, with moderate levels in Tanzania, and low levels in Kenya and Seychelles. Because one third of sites reported here were from the Seychelles, the overall mortality level of 20% may slightly overestimate the average mortality across the region.

Table 1.4.1 *Summary of results from data submitted for this report showing the total number of sites from each country, the number of sites with coral and algae data used in comparisons between pre- and post-bleaching periods and the percent change (%) and the post-bleaching cover levels (in parentheses) for coral and fleshy algae.*

Country	# sites			% change (post % cover)		Observations/interpretation
	total	data for both periods		coral	algae	
		coral	algae			
Comoros	9	5	0	5% (62%)	-	• Low impact of bleaching: post-bleaching (2017) coral cover high (55%), fleshy algae low
Kenya	30	21	21	0% (24%)	9% (36%)	• Lamu (north) most affected region with 51% loss in coral cover at 2 sites • Fleshy algae cover higher than coral cover post-bleaching
Madagascar	41	41	40	-13% (46%)	56% (14%)	• Only data from west coast, most severe impacts in northwest. • Relatively high coral cover and low fleshy algae post-bleaching
Mauritius	5	5	5	~ 0% (35%)	~ 0% (7%)	• Single site reported, from Anse La Raie Lagoon.
Seychelles	50	43	32	-50% (17%)	~45% (42%)	• Inner Islands more severely impacted than Outer Islands (60% loss vs. 17%, respectively) • Maximum mortality of 80% at North Island. • 4 sites with no impact or positive gain in the Inner Islands (NW Mahe and Cerf Island)
South Africa	5	5	0	~0% (20%)	<5% (21%)	• Negligible bleaching and no mortality
Tanzania	25	16	16	-10% (39%)	25% (15%)	• Lower mortality compared to bleaching indicates substantial recovery and survival of corals. • Highest impacts on west coast of Unguja Island
REGIONAL	160	131	114	-20% (33%)	~35% (26%)	• Approximately 20% decline in coral cover across 131 sites in 6 countries and 35% increases in fleshy algae cover across 114 sites in 5 countries

In the ten years preceding the bleaching event, there was an upward trend in regional hard coral cover, reflecting recovery from the 1998 bleaching event. But this has now reversed as a result of the 2016 bleaching event. The trajectory of coral cover at country levels shows high levels of variation (fig. 1.3.1), with many peaks and troughs due to localized changes in reef health as well as sampling inconsistencies. With this degree of variation, and particularly the changing and irregularity of monitoring sites being measured and reported, it is difficult to make strong conclusions.

The increase in fleshy algae post-bleaching, has closed the gap between hard coral and fleshy algae cover on a regional scale. Seychelles and Kenya now have on average higher levels of algae than coral cover, indicating that they may be close to experiencing a phase-shift to more algal dominated reef systems (Hughes et. al. 2007; McManus et. al. 2004). Alternatively, low algal abundance in Madagascar, coupled with the high coral cover indicates that these reefs are in a healthier state.

Aggregation of data to the regional level, as we have done here, involves many challenges. Unequal, limited and non-representation of data from countries restricted our ability to make a comprehensive assessment of the region. It is impractical to acquire all relevant data from each country, but it is important that participation and data sharing increase over time, to improve the power and accuracy of results.

An important outcome from this and previous regional initiatives, is demonstration of the erratic monitoring effort over time in some countries. Seychelles and Kenya have shown the most consistent monitoring, but other countries have large gaps, leading to years where no data are available (and see Obura, 2013). After the 1998 bleaching event, there was an increase in effort and establishment of new monitoring programmes over a period of several years (Obura et. al., 2017). One of the goals of this project was to ensure the gap in monitoring after the 2016 bleaching event was shortened in beneficiary countries. However more stable funding for monitoring is needed from internal resources within countries and programmes. To match the expanded effort that occurred after the 1998 event, WIO countries and their partners need to invest in monitoring within the next one or two years and ensure the variation in sites being regularly monitored is reduced.

Most of the monitoring reported here was headed by NGOs and other monitoring programmes, rather than national institutions, with the exception of Kenya Wildlife Service. Given the importance of coral reefs to national economies and livelihoods, and that major bleaching events will repeat at greater frequency (van Hooidonk et al., 2016, Hughes et al., 2018), it is vital that governments develop national responses to bleaching events to allow them to prepare and respond effectively. This will involve the ability to mobilize funding to carry out consistent and emergency monitoring, and to use this information to manage reefs to maximize their sustainability and find ways to adapt users and economic sectors to the changing status of coral reefs.

This project has allowed the first update to the WIO benthic dataset since it was developed during the 2017 GCRMN reporting process. It has also helped promote networking and partnerships between researchers in the region and is continuing to stimulate the process of data sharing and collaborations. It is important for institutions and researchers to maintain this effort so the WIO coral reef science community can continue to move towards an open-data science approach.

Reefs in the region have shown the ability to recover from bleaching events in the past (Obura et. al., 2017), for example in Seychelles and Kenya, however with bleaching projected to become more frequent and intense (Hughes et. al., 2018), it will become much more challenging for reefs to recover unassisted. It is notable that East African reefs figure prominently in a very recent analysis of which of the world’s reefs face the most promising climate futures (Beyer et al. 2018). The coasts of Tanzania, Kenya, south Somalia, northwest Madagascar and Comoros appear to have favourable futures, so if well managed could both persist in reasonable health and be key source reefs for other reef areas that will face greater climate threats. Therefore, drastic improvements to management strategies and policies must be made soon at local, national and regional scales.

1.5 Recommendations

Based on the current state of the coral reefs in the region, and their response to the coral bleaching of 2016, as well as long-term trends, the following recommendations are made:

Monitoring and understanding coral reef health

1) Coral reef monitoring should be more strongly supported at key long-term sites, as well as expanded to include more sites and other parameters. Therefore, it is essential that countries re-evaluate their funding strategies and sources, and prioritize monitoring of these key resources.

2) Establish contingency funds to enable responsive monitoring to particular events.

3) Establish national coral bleaching response plans to include preparation, funding, monitoring and communications (awareness creation) capacity. This will allow national research institutions to respond more effectively to future coral bleaching.

4) Invest in efforts to develop or trial existing databases for improved storage and access of coral reef and other marine biodiversity data. Support training of technical staff in general principals of data management as well as in database use.

5) Continue to collate historical coral reef health data into a central, safe database for secure storage and ease of access at national and regional levels. To support this, a system to share metadata on coral reefs will make it easier to share information among organisations and foster greater collaboration.

6) Identify regional strategies to source and allocate funding for consistent and continued coral reef monitoring through the GCRMN and the Nairobi Convention's Coral Reef Task Force.

7) Standardize coral reef monitoring methodologies and site selection between countries and programmes so that monitoring at long-term sites is maintained and prioritized.

Maintaining and improving the health of coral reefs

8) Promote management strategies that help to control fleshy algae on reefs. These may be through fisheries, to protect herbivore populations and the role of herbivory, water quality management, to minimize fertilization of algae, or other measures.

9) Improve coral reef management effectiveness and increase the scale of management measures.

10) Mitigate controllable and avoidable local threats to coral reefs as much as possible through smart management strategies.

11) Control and regulate nearshore and coastal activities that can be damaging to nearby coral reefs e.g. dredging, illegal extraction, pollution, agricultural run-off etc.

12) Trials of restoration interventions for conserving and repairing coral reefs need to be supported, with transparent evaluations of effectiveness and success based on area impacted and cost.

Policy and research

13) Targeted research on the differential response of reefs to thermal stress and coral bleaching should be undertaken, to identify if there are resilient reefs (bleaching refuges), and what can be done to protect such sites and to promote seeding of other reefs.

14) Research to understand the long-term effects of the 2016 bleaching event on coral recruitment and fish populations at badly impacted sites.

15) Coral reefs sustain many important business sectors, including tourism and fisheries, and are among the most valuable ecosystems providing services and food to the poor. Better understanding their value can be achieved through understanding them as key assets in supporting the Sustainable Development Goals, and this can elevate their importance in national and regional policy circles for protection and management.

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1.7 Annex

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2. National Chapters

2.1 Comoros

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2.1.1 Background to the 2016 bleaching event

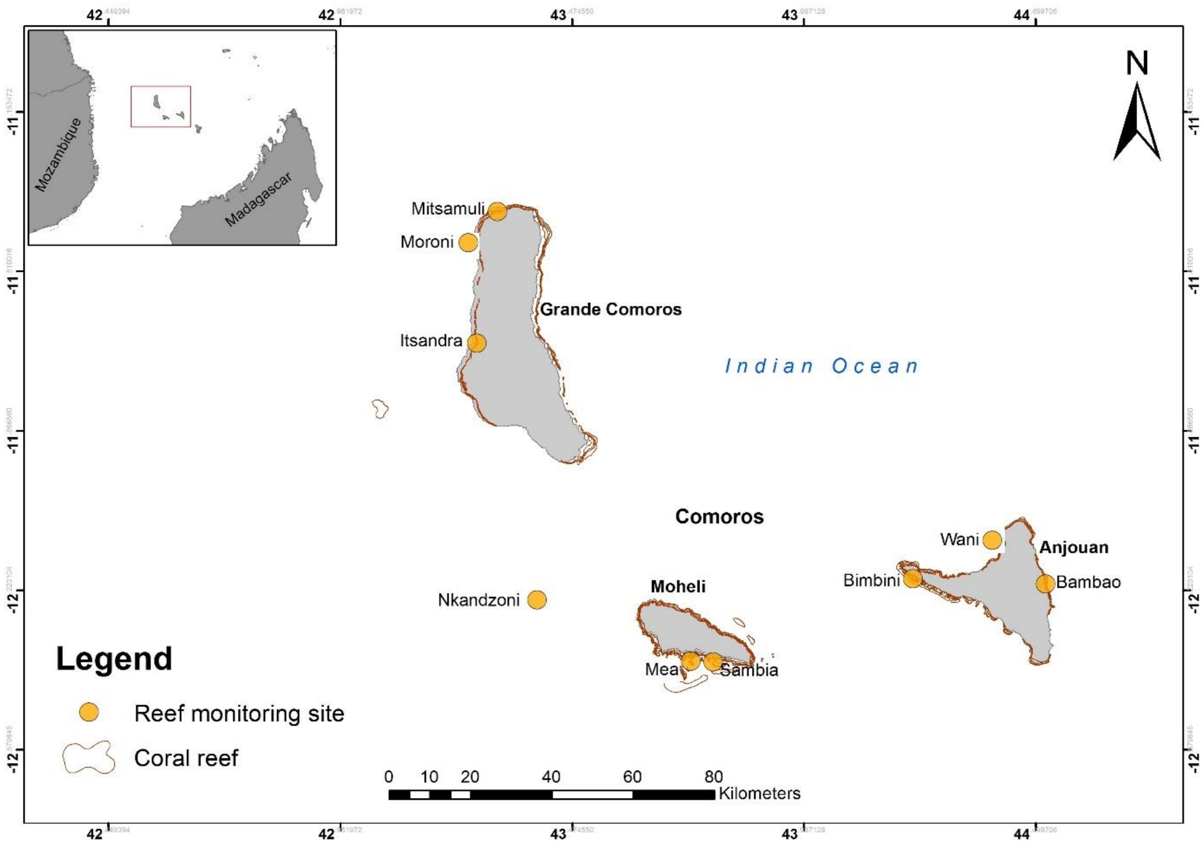

Figure 2.1.1. *Coral reef monitoring stations in Comoros for which data were included in this study.*

2.1.1.1 History of coral bleaching events in the Comoros

The Comorian islands of Grande Comore, Moheli and Anjouan were affected by the first global bleaching event in 1998 with bleaching reported at between 10-50% across various sites and mortality estimated at 50% thereafter (Quod & Bigot, 2000). At Moheli Island mortality of hard corals was recorded at 45% overall and 15% at Mitsamiouli reef (Ahamada et al., 2004). A decline in coral cover over the period between 1998/99 to 2002 was reported, with low to negligible recovery rates (Quod & Bigot, 2000). Live hard coral cover by the year 2002 had dropped to approximately 40%, down from averages of about 76%, one year before the 1998 global bleaching event (Ahamada et al., 2004).

Data contributors: *The data presented in this report remains the property of the organisations and individuals who collected them.*

2.1.1.2 Progression of the 2016 coral bleaching event

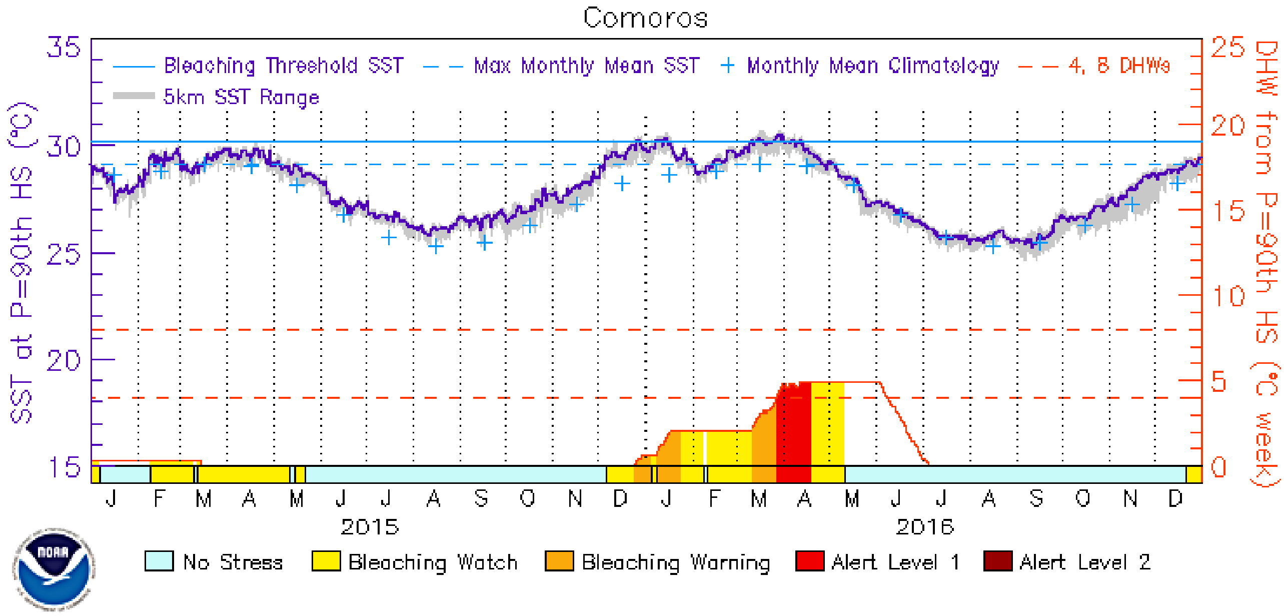

Figure 2.1.2. *National Oceanic and Atmospheric Administration (NOAA) Coral Reef Watch satellite bleaching products, showing the bleaching related climatic conditions present at a remote monitoring station in Comoros.*

Remote sensing of sea-surface temperature around the Comoros showed milder conditions than experienced in most other WIO countries. Bleaching stress started to pick-up from mid-March 2016, with less than a month in alert level 1 in April and only reached a maximum of 5 degree-heating-weeks (fig. 2.1.2).

Bleaching was observed at several monitoring sites as early as November 2015. An average of over 40% of corals were bleached across seven sites surveyed in April 2016 with some signs of early-mortality at all sites (fig. 2.1.3). Stress had completely dissipated by early May.

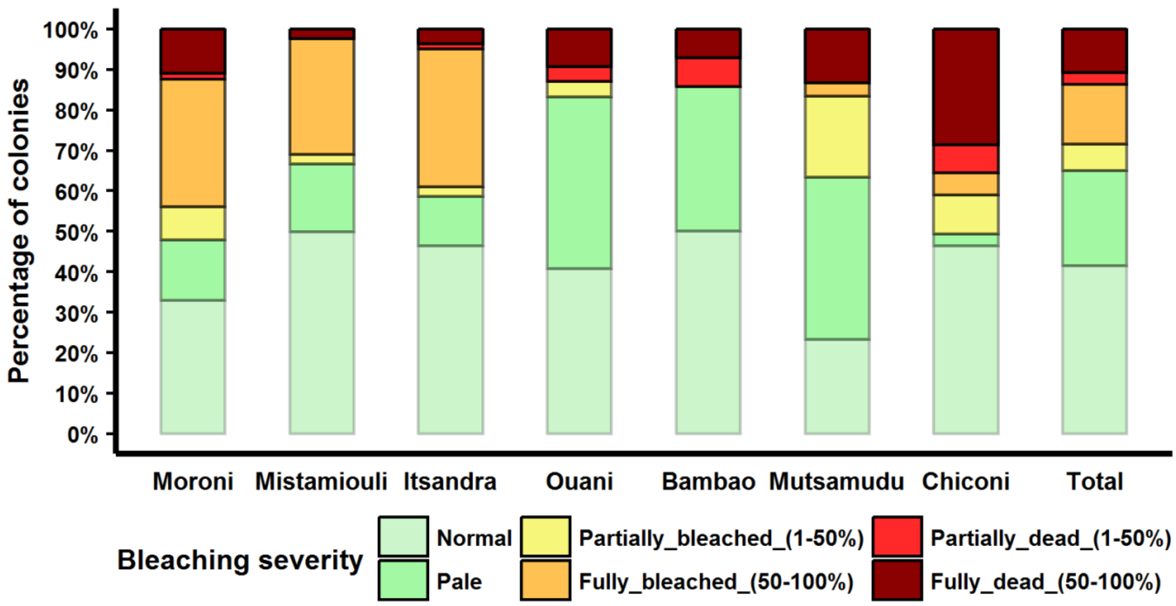

Figure 2.1.3. *Coral bleaching and associated mortality recorded at seven sites in the Comoros in 2016. Categories represent the severity of bleaching and associated mortality reported as a percentage of coral colonies at a site. (Freed et.al, 2017)*

2.1.2 Results

In total, data from 9 sites (Bambao, Bimbini, Itsandra, Mea, Mitsamiouli, Moroni, Nkandzoni, Sambia and Wani) across the islands Anjouan, Grande Comore and Moheli were assessed between 1999 and 2017.

After the 1998 bleaching event, the mean coral cover was around 33% in 1999, and this slowly increased to 55% in 2007 (fig. 2.1.4). Coral cover declined between 2007 and 2011, mainly due to some bleaching in 2010, to a low of just under 30%, but then recovered once more to over 55% by 2015. After the bleaching event in 2016, coral cover was slightly lower than in 2015, at 55% in 2017.

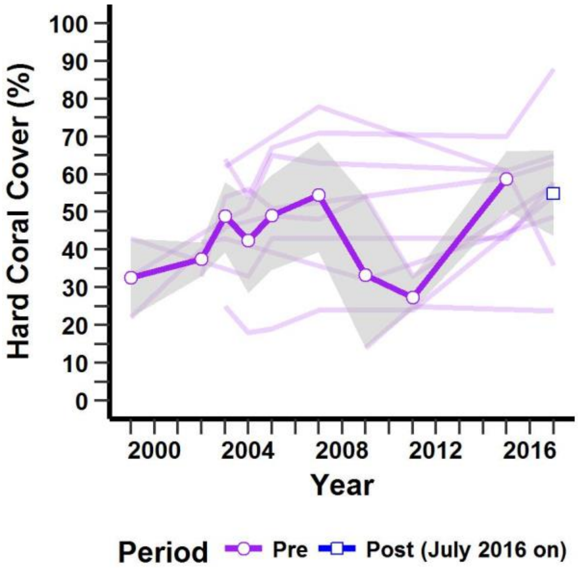

Figure 2.1.4. Trends in hard coral cover on Comorian reefs before and after the 2016 bleaching event (national mean (dark bold line) split into historical pre-bleaching data (purple line, open-circles) and post-bleaching data from July 2016 onwards (blue line, open-squares), 95% confidence limit (grey shaded area), individual monitoring stations (faded background lines)). Only stations with data for both periods were included in the analysis (n=9).

For nine sites monitored in 2017, average fleshy algae abundance was lower than 5%, with six of these sites having no algae. At the five sites with data immediately pre-bleaching (i.e. 2012-2015) and post-bleaching, mean coral cover was equivalent, at 59 ± 4.4% and 62 ± 8.3% (mean ± se) respectively (fig. 2.1.5a).

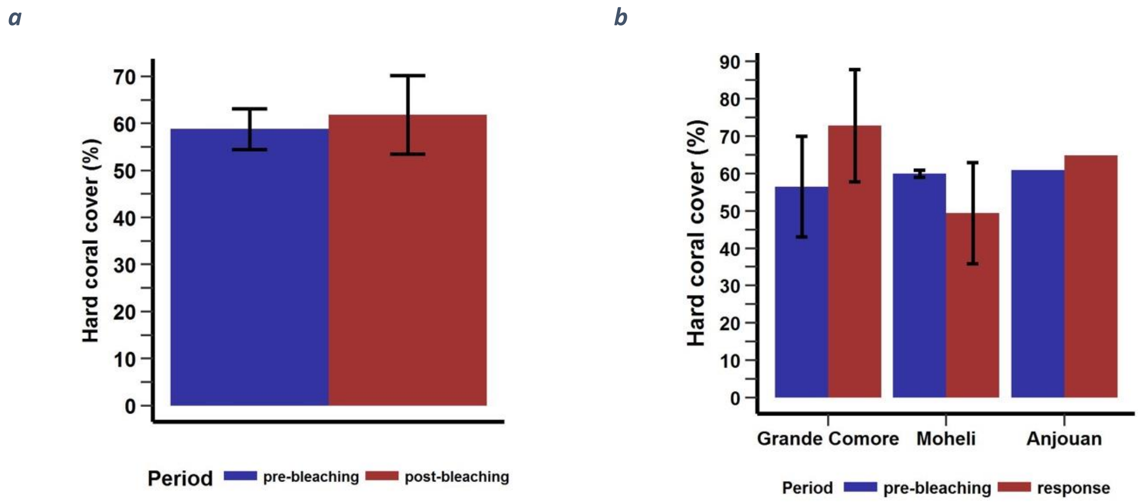

Figure 2.1.5 *Pre and post-bleaching (response) mean hard coral cover (with standard error bars)* ***a)*** *for all Comoros reef sites (n=5)* ***b)*** *for Grande Comore, Moheli and Anjouan sites (Grande Comore n=2, Moheli n=2, Anjouan n=1). Pre-bleaching data are from 2015 and 'response' data are from September 2017. Only sites with data for both periods were included in the analysis.*

When comparing the impact of the bleaching across the 3 islands, reefs on Grande Comore showed a 30% increase in live hard coral cover from 57 ± 13.5% (pre-bleaching) to 73 ± 15% (post-bleaching) (fig. 2.1.5b). In Moheli there was close to a 20% decline in hard coral cover

(60 ± 1.0% to 49 ± 13.5%) and at one site in Anjouan, there was a rise in hard coral cover by just over 5% (61% to 65%).

2.1.3 Discussion

Even after the bleaching event, Comoros coral reefs retain moderate to high coral cover, with close to 55% on average in 2017. Mortality due to bleaching in 2016 was low as there was no significant change in coral cover after the bleaching event, and several sites showed increases in coral cover. This was despite significant bleaching being observed at a number of sites at the peak of the event, therefore it seems that there was substantial recovery rather than mortality. This was likely due to the fact that temperatures had subsided by early May, truncating the period of thermal stress endured by the corals, allowing for greater recovery and survival. Reef sites at Moheli seem to have been the most badly impacted.

An important finding is that of the 9 sites surveyed in 2017, there were very low levels of fleshy algae, and high levels of bare substrate. This will provide good conditions for recovery by potentially increasing larval settlement and survival rates. Management measures should aim to maintain this low-algal level through maintaining herbivory on reefs and ensuring low nutrient run-off.

Unfortunately, due to intermittent monitoring efforts, especially recently, the number of sites and years included in the analysis was low thereby limiting the overall conclusions that can be made. There were only 10 time points over the 19-year period of analysis.

Although reefs around Comoros appear to be in a healthy, resilient state post-bleaching, authorities should be proactive in their management and conservation efforts, including increased monitoring, as pressures will undoubtedly continue to rise through climate change, over-fishing, pollution and erosion from land-based activities.

2.1.4 Recommendations

Maintaining and improving the health of coral reefs

1) Maintain the current healthy state of reefs with respect to low algal cover. For this, the importance of fisheries management to ensure herbivory is maintained may be important. Monitor herbivore populations and put in place measures to ensure they remain at healthy levels and are protected from over-fishing.

2) Address and minimize local threats – sedimentation and pollution from sand harvesting, agricultural run-off and coastal/urban developments should be controlled and reduced through improved planning, soil conservation and legislation.

Monitoring and understanding coral reef health

3) Ensure consistent annual monitoring is carried out at key long-term reef sites to track likely changes in coral reef health.

4) Bleaching monitoring – develop national and organizational level bleaching response plans to help prepare for future events.

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2.2 Kenya

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2.2.1 Background to the 2016 bleaching event

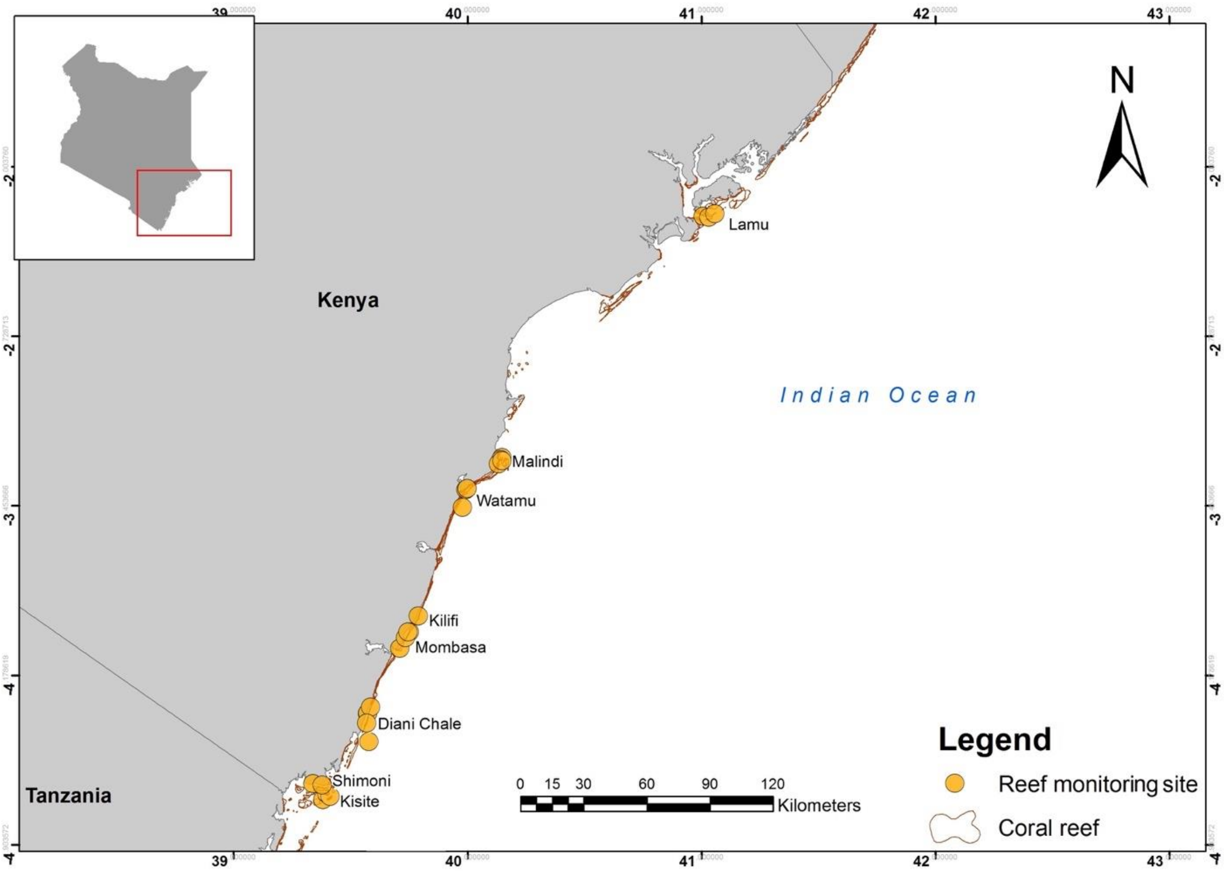

Figure 2.2.1. *Coral reef monitoring sites in Kenya for which data were included in this study.*

2.2.1.1 History of coral bleaching events in Kenya

Kenya's coral reefs rank among the richest and most valuable ecosystems in the entire Western Indian Ocean, harbouring a diverse array of marine organisms, and providing critical ecosystems services such as fisheries, tourism and coastal protection (Obura et al., 2017). The estimated value of Kenya's marine ecosystems is around US$ 2.5 billion per year (some 4% of its GDP), of which 70% is from tourism, which is highly dependent on coral reefs.

However, just like in many reef regions worldwide, the future of coral reefs in Kenya is under imminent threat from climate change and its associated impacts (McClanahan, 2000; Obura, 2005; Hoegh-Guldberg et al., 2009). The 1997/98 worldwide bleaching event greatly impacted

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Data contributors and acknowledgements:
The data presented in this report remains the property of the organisations and individuals who collected them.
Fieldwork team: *Mwaura Jelvas (National Coordinator), Josephine Mutiso, Albert Gamoe, Joseph Kilonzo, Peter Musembi*

Kenya, with some reefs losing 50% to 90% of living corals (Obura, 1999; Wilkinson et al., 1999; Goreau et al., 2000). Overall, coral cover declined to around 10% after this major bleaching event (McClanahan et al., 2002). Recovery of reefs from 1998 to date has been moderate and patchy (Obura, 2002), with some reefs showing no recovery (Muthiga et al., 2008). Other milder bleaching events have been noted in 1987 and 1994 (McClanahan et al., 2001), and more recently in 2002, 2005 and 2010.

2.2.1.2 Progression of the 2016 coral bleaching event

Thermal stress measured by satellite began to develop in March with the sun overhead and the calming of monsoon winds, and subsequently increased but only to mild levels (fig.2.2.2). At the end of April sea-surface temperatures (SST) reached 31°C and Degree-Heating-Weeks (DHW) reached 3.5. Thermal stress had dissipated by mid-May. Kenya was one of only two countries in the region to not experience stress constituting alert level 1 or 2.

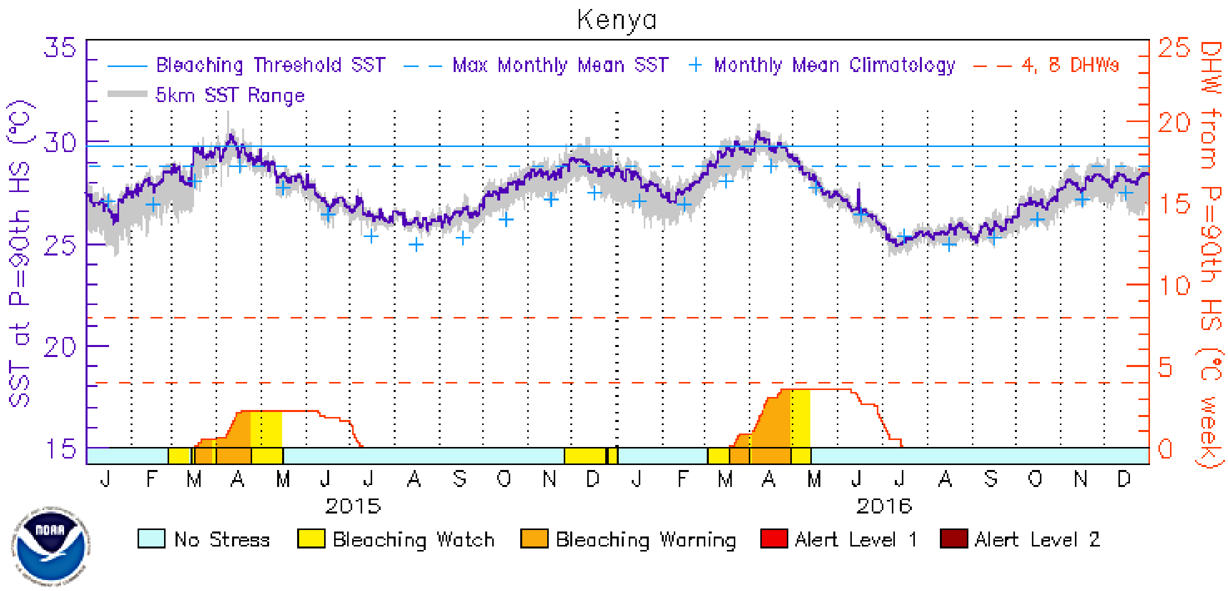

Figure 2.2.2. *National Oceanic and Atmospheric Administration (NOAA) Coral Reef Watch satellite bleaching products, showing the bleaching related climatic conditions present at a remote monitoring station in Kenya.*

The severity of coral bleaching in 2016 was relatively low but varied among locations, with less than 10% of reefs showing high or extreme bleaching between January and May (fig. 2.2.3a). Reefs in Malindi and Shimoni, which are dominated by the bleaching susceptible coral genera *Acropora* and *Pocillopora*, had the highest number of bleached and recently dead colonies (Mwaura et. al., 2017). Bleaching peaked in April and May with the only reports of extreme and high bleaching (fig. 2.2.3b). Subsequent mortality of corals was limited, with only 10% of reports indicating medium level mortality between May and September.

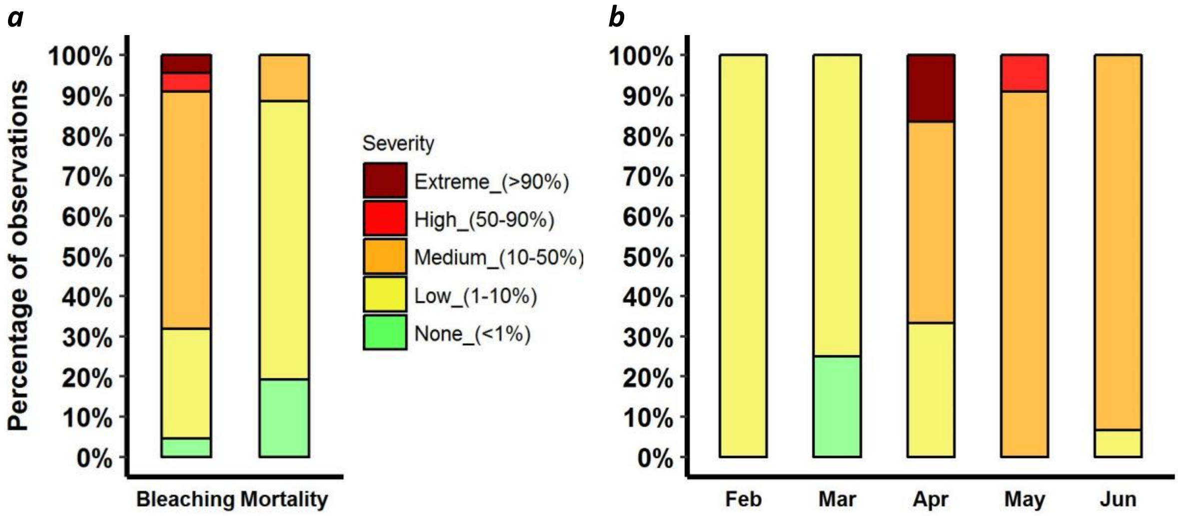

***Figure 2.2.3**. Breakdown of observations collected in Kenya in 2016 for **a)** coral bleaching (n=22) from Jan-May and mortality (n=26) from May-September 2016 and **b)** bleaching each month (Feb; n=1, Mar; n=4, Apr; n=6, May; n=11, Jun; n=15). Categories represent the severity of bleaching/mortality reported as percentage of coral cover bleached/dead at a site.*

2.2.2 Results

In total the analysis included data from 30 sites in 8 areas (Shimoni, Kisite, Diani-Chale, Mombasa, Kilifi, Watamu, Malindi and Lamu) between 2001 and 2017.

From 2001 and 2017, mean coral cover increased progressively from below 5% to approximately 31% by 2013 (fig. 2.2.4). Coral cover settles at between 25-27% after the 2016 bleaching event.

At sites for which algal cover was measured alongside coral cover, algal cover shows a steady decline from around 60% in 2001 to about 30% between 2013-15 and stays at about the same level in 2017 (fig. 2.2.5).

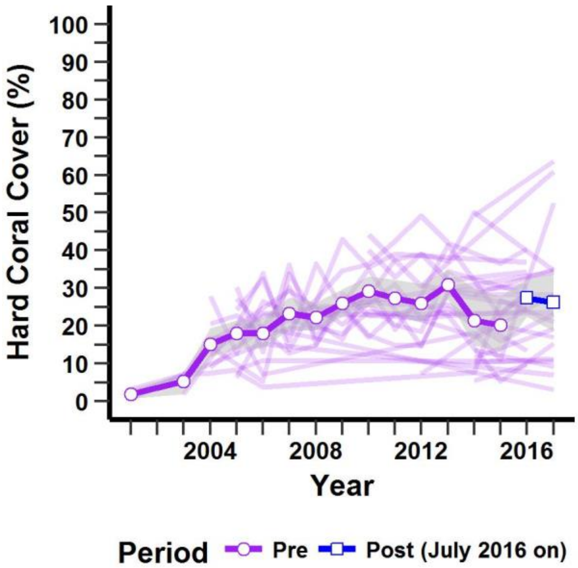

***Figure 2.2.4** Trends in hard coral cover on Kenyan coral reef sites before and after the 2016 bleaching event (national mean (dark bold line) split into historical pre-bleaching data (purple line, open-circles) and post-bleaching data from July 2016 onwards (blue line, open-squares), 95% confidence limit (grey shaded area), individual monitoring stations (faded background lines)). Only stations with data for both periods were included in the analysis (n=30).*

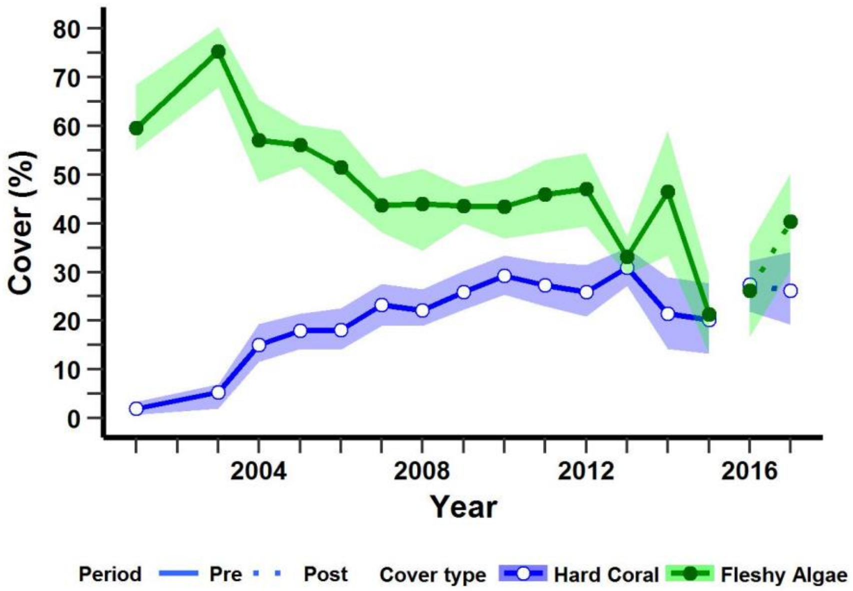

__Figure 2.2.5.__ Trends in fleshy algae (green line, closed circles) and hard coral cover (blue line, open-circles) in Kenya before (solid line) and after (dotted line) the 2016 bleaching event. Shaded areas represent the 95% confidence limit. Only stations with data for both periods and with both fleshy algae and hard coral cover were included in the analysis (n=30). The post-bleaching period is from July 2016 onwards.

At a national level, a comparison of coral and fleshy algae cover for sites with data before (2012-June 2016) and after (since July 2016) the bleaching event showed live hard coral cover remained at around 24%, and a nominal (but not significant) increase in fleshy algae cover from 33 ± 4.6% (mean ± se) to 36 ± 4.8% (fig. 2.2.6a).

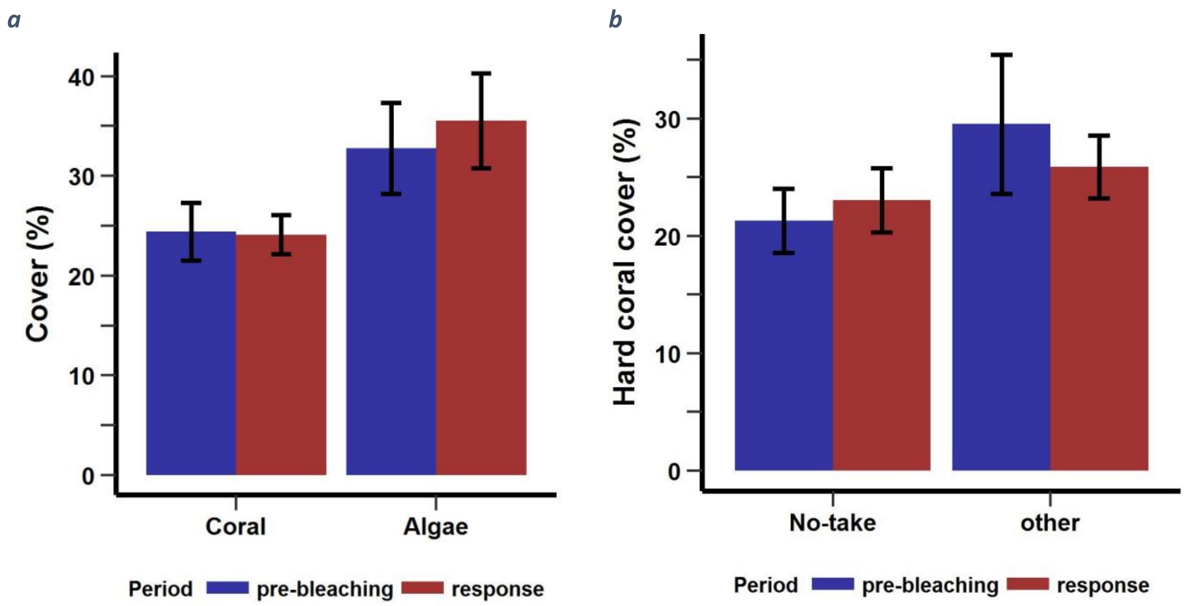

Figure 2.2.6 *Pre- and post-bleaching (response) mean cover (with standard error bars) for **a)** hard coral and fleshy algae for all Kenyan reef sites with both fleshy-algae and hard coral cover data (n=21) and **b)** hard coral for no-take and other management zones (n=13 no-take zone, n=8 other). Pre-bleaching data are from 2012-June 2016 and 'response' data are from July 2016 -2017. Only sites with data for both periods were included in the analysis.*

When comparing the impact of the bleaching on reefs within no-take zones (protected areas) and other zones (marine reserves, community conservation areas and open access areas), there were no significant differences between them. Nevertheless, coral cover within no-take zones increased slightly from 21 ± 2.7% (mean ± se) (pre-bleaching) to 23 ± 2.7% (post-bleaching), but decreased in the other zones, from 30 ± 5.9% to 26 ± 2.7% (fig. 2.2.6b).

There were varying levels of coral mortality between different areas of the coast in 2016, with sites around Lamu in the north and Mombasa the only two regions to experience substantial declines of 51% and 10% respectively (Table 2.2.1). Reef sites in Watamu and Kilifi showed no change in coral cover, whilst Shimoni and Malindi showed positive changes.

Table 2.2.1. *Average percentage change in live hard coral cover across all sites for six Kenyan regions, comparing coral cover before (2012-June 2016) and after (July 2016 – 2017) the bleaching event.*

Area	Percentage change in coral cover	Pre-bleaching mean coral cover ± sd	Post-bleaching mean coral cover ± sd	Number of sites
Lamu	-51	39 ± 24.7	19 ± 2.8	2
Mombasa	-10	29 ± 2.6	26 ± 9.1	4
Watamu	0	19 ± 10.2	19 ± 9.2	5
Kilifi	0	18	18	1
Shimoni	14	28 ± 15.7	32 ± 3.6	4
Malindi	35	17 ± 13.1	23 ± 11.6	5

2.2.3 Discussion

Overall, Kenya escaped from the 2016 bleaching event relatively lightly compared to other countries in the region and also compared to the severe impacts felt in the country from the first global bleaching event in 1998. This may be due to its northern location and therefore later onset of warm conditions as the sun moves north which coincided with an early switch in the monsoon winds, resulting in a shorter period of heat stress compared to more southern locations. Additionally, while widespread bleaching was reported across the country between January and May 2016, the lack of coral mortality suggests stress was not so severe, and that there is potentially strong resilience in the coral population. However, not all sites were unaffected, with 6 sites experiencing significant losses in coral: Pezali Rock and Majongooni in Lamu, Nyali and Starfish in Mombasa Marine Park and Reserve, Coral Gardens in Watamu and Wasini CCA in Shimoni. While reefs in no-take areas coped with the bleaching event better than reefs in other management regimes, the result is not conclusive enough to determine if they have higher resilience.

Although our results showed no change in coral cover after the bleaching event, this may be slightly misleading as bleaching surveys undertaken did show some mortality at sites. The resolution of our analysis and methods were not able to capture this subtle change in coral cover, highlighting the need for greater and more consistent monitoring at sites.

Despite a declining trend over time, fleshy algae cover in Kenya is high, compared to other countries. At 35%, algal cover is currently greater than hard coral cover in Kenya, which is about 20%. The difference in levels had been decreasing over time, but there are now signs that the gap could widen once again, indicating that Kenyan reefs could be on the verge of a phase-shift towards a permanently algal dominated state. It is therefore imperative that the relevant authorities put in place policy and management measures that reverse this trend and improve resilience to maintain coral reef functioning and service provision.

2.2.4 Recommendations

In order to strengthen the conservation of coral reefs in Kenya it is important that a number of measures are implemented at various levels:

Monitoring and understanding coral reef health

1) National research institutions to organize regular and country-wide annual monitoring at long-term coral reef sites to track changes in habitat characteristics, biota and ecological processes as well as natural threats, such as coral diseases and outbreaks of the crown-of-thorns starfish.
2) Establish effective national coral bleaching response plans with the capacity to include preparation, funding, monitoring and communications (awareness creation). Individual research programmes, NGOs and others can develop their own tailored coral bleaching response plans to help them prepare for future bleaching events.

Maintaining and improving the health of coral reefs

3) Improve local management of coral reefs to enhance resilience and recovery potential. Specific emphasis should be placed on reversing the sudden increase in algal cover, to facilitate coral recovery.
4) Increase areas of coral reefs under no-take management regimes – either through co-management solutions with communities or government protected areas.
5) Support trials of restoration interventions for conserving and repairing coral reefs with transparent evaluations of effectiveness and success based on area impacted and cost.

Policy and research

6) Targeted research on coral reef ecology, especially on factors enhancing or delaying the recovery of coral reefs from large-scale impacts should be encouraged. Such studies are useful in identifying nodes of reef resilience for conservation of reefs under climate change.
7) Improved control and regulation of coastal and near-shore activities that can cause damage to coral reefs e.g. dredging, coastal development, agricultural run-off, waste disposal.
8) Regular monitoring of water quality specifically near coastal towns, agricultural farms and industries.

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2.3 Madagascar

Data contributors: Blue Ventures, Frontier Madagascar, Madagascar Research and Conservation Institute (MRCI), WCS Madagascar.

Coordination and data collection: Ihando Andrainjafy (National Coordinator), RANDRIANANDRASANA José, RADONIRINA Lebely, ZAKANDRAINY Andriamanjato, ANDRIALOVANIRINA Nicolas, Lope Jean Charles, BAKARY Gisèle, Zavatra Jean Baptiste, Rajesy Farcy.

2.3.1 Background to the 2016 bleaching event

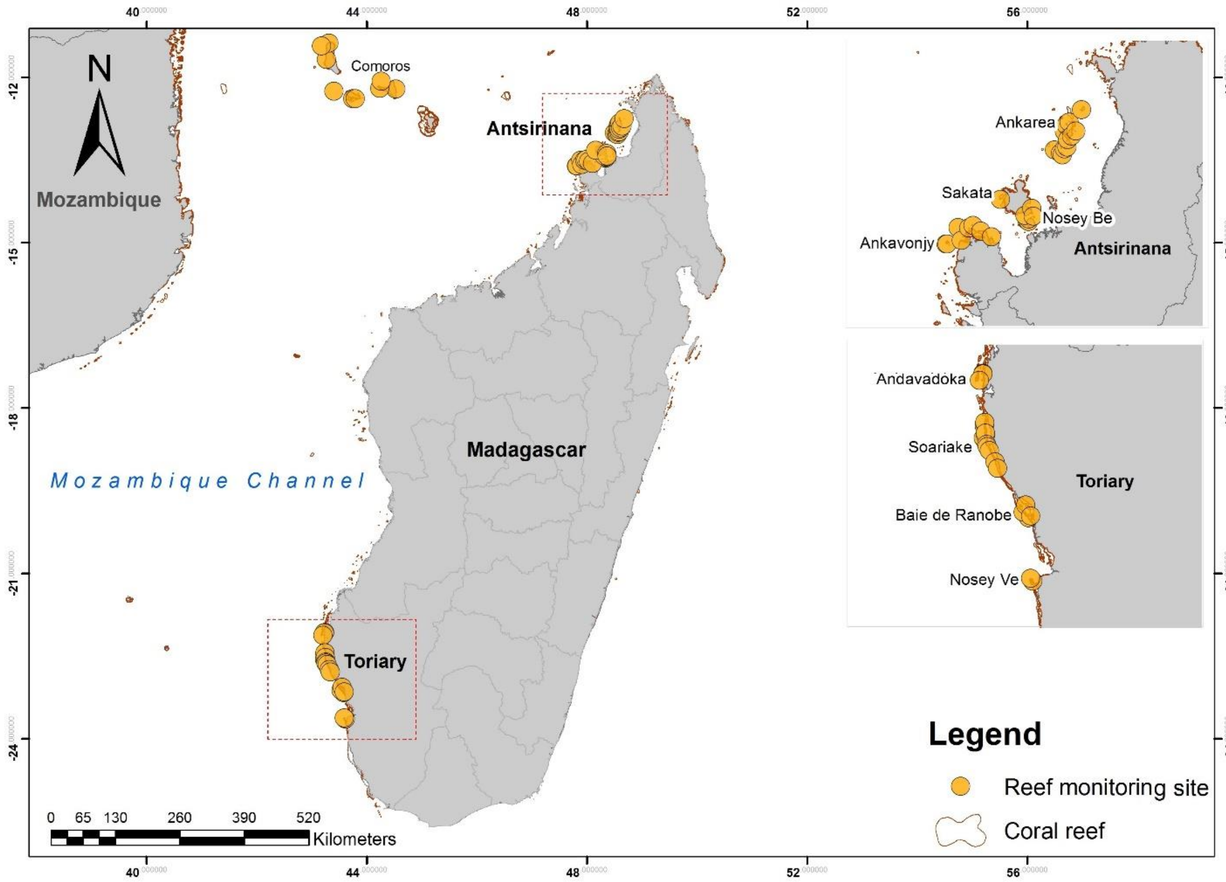

Figure 2.3.1. *Coral reef monitoring stations in Madagascar for which data were included in this study.*

2.3.1.1 History of coral bleaching events in Madagascar

During the first global bleaching event in 1998, Madagascar experienced a 2°C sea-surface temperature rise above the threshold and seasonal average (Webster & McMahon, 2002). Coral bleaching and subsequent mortality were reported in a few areas such as the Southwest region of Toliara (Ahamada et al., 2002) and in some sites mortality rates were as high as 80 – 90% (McClanahan & Obura, 1998; Souter et al., 2000).

Despite this, in general, reefs around Madagascar were less affected by this event compared to coral reefs in other countries in the Western Indian Ocean (Ahamada et al., 2002).

2.3.1.2 Progression of the 2016 coral bleaching event

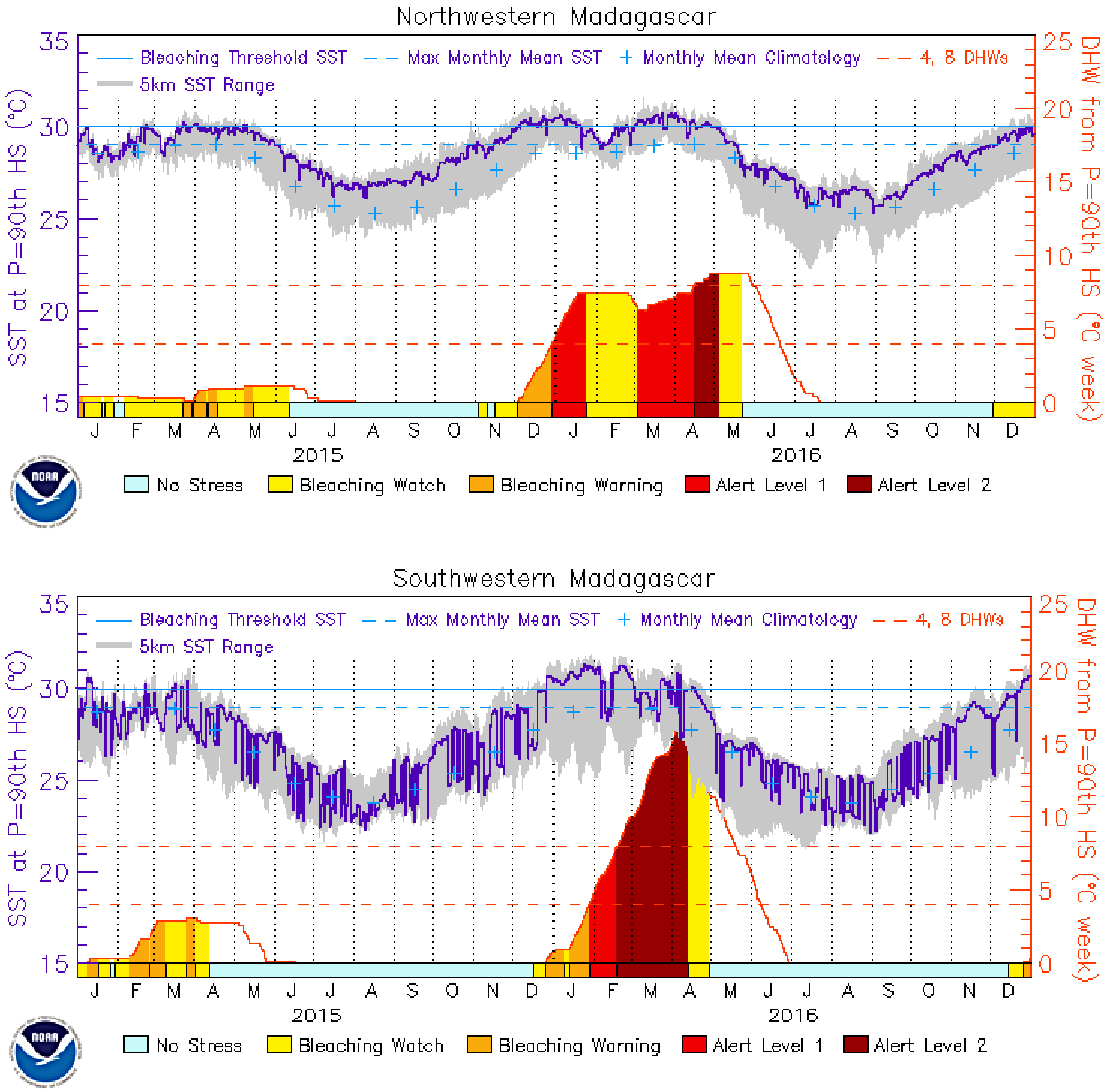

Figure 2.3.2. *National Oceanic and Atmospheric Administration (NOAA) Coral Reef Watch satellite bleaching products, showing the bleaching related climatic conditions present at remote monitoring stations in Southwestern (top) and Northwestern Madagascar (bottom).*

From sea-surface temperatures recorded by satellite from fixed stations in SW and NW Madagascar, both started to experience thermal stress in December, with the NW showing more severe conditions and a faster rise in January (fig. 2.3.2). At the end of January, thermal stress peaked in the north and remained around 8 DHW into May, only reaching alert level 2 for about 2 weeks in April. By contrast, thermal stress in the SW continued to rise from January to April, with alert level 2 conditions persisting for 2 months and reaching a peak of 15 DHW in April-May. Sea-surface temperatures in both regions were generally above the bleaching-threshold of 30°C from January to mid-April 2018, but with short phases below the threshold in both cases.

Coral bleaching in 2016 was widespread in Madagascar, with almost 40% of reefs experiencing bleaching of more than half their coral cover between the months of January and May (fig. 2.3.3a). Bleaching was reported as early as mid-January in the SW, and this soon spread to all parts with reports from the LMMAs in the east and NW as well. Bleaching was prevalent through to June (fig. 2.3.3b). Bleaching surveys conducted in May 2016 in the NW showed varying bleaching levels across genera, and high levels of bleaching at some sites (Maharavo et al., 2017).

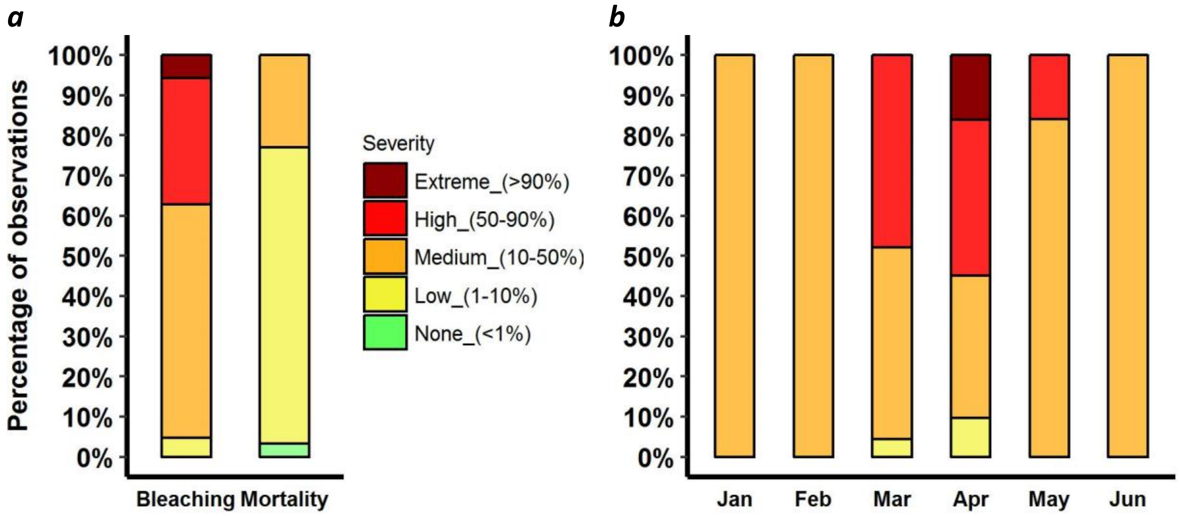

Figure 2.3.3. *Breakdown of observations collected in Madagascar in 2016 of* ***a)*** *coral bleaching (n=86) from Jan-May and mortality (n=61) from May-December 2016 and* ***b)*** *coral bleaching each month (Jan; n=2, Feb; n=5, Mar; n=23, Apr; n=31, May; n=25, Jun; n=3). Categories represent the severity of bleaching/mortality reported as a percentage of coral cover bleached/dead at a site.*

2.3.2 Results

In total, data from 41 sites from Soriake and Andavadoaka in the SW and Nosy Komba, Nosy Be and Ankarea in the NW, between 2005 and 2017, were included in this analysis.

In the initial years (2005-2013) data are only for 3 sites in Andavadoaka (fig. 2.3.4). In 2005, the mean coral cover was approximately 31%, and this increased to approximately 55% by 2012. However, this was followed by a sharp decline in coral cover in 2013. In 2014, the addition of four sites from Nosy Be meant mean coral cover increased to around 43%.

The addition of pre-bleaching data from 32 sites in 2016 from three more areas on the west coast gives a pre-bleaching coral cover level of just over 50%. The increase in coral cover between pre- and post-bleaching 2016 and the difference between post-2016

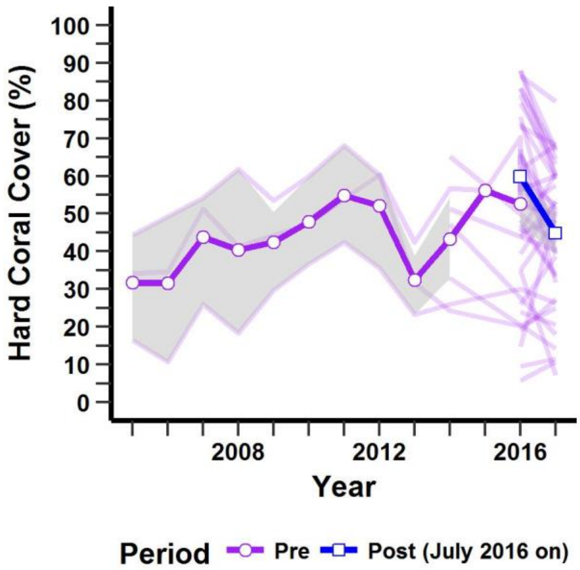

Figure 2.3.4 *Trend in hard coral cover on Madagascar coral reef sites before and after the 2016 bleaching event (national mean (dark bold line) split into historical pre-bleaching data (purple line, open-circles) and post-bleaching data from July 2016 onwards (blue line, open-squares), 95% confidence limit (grey shaded area), individual monitoring stations (faded background lines)). Only stations with data for both periods were included in the analysis (n=41).*

and 2017 values is due to differences in sites represented. However, the final value for coral cover in 2017 is at a value lower than the 2016 pre-bleaching level, at approximately 45% in 2017 (fig. 2.3.4).

At sites for which algal cover was measured alongside coral cover, fleshy algae cover shows a decreasing trend between 2005 and 2016 from over 50% to less than 10%. In 2017, after the bleaching event, there looks to be little difference in fleshy algae cover compared to 2016 pre-bleaching values (fig. 2.3.5).

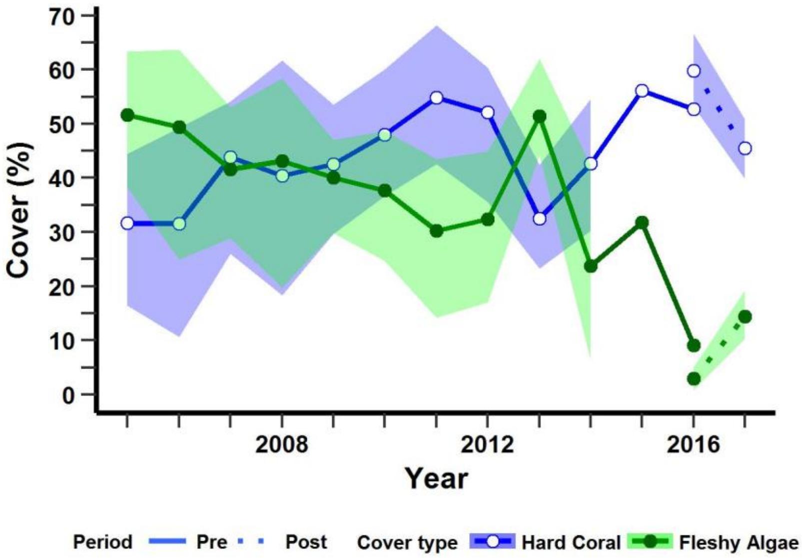

__Figure 2.3.5__ Trends in fleshy algae (green line, closed circles) and hard coral cover (blue line, open-circles) in Madagascar before (solid line) and after (dotted line) the 2016 bleaching event. Shaded areas represent the 95% confidence limit. Only stations with data for both periods and with both fleshy algae and hard coral cover were included in the analysis (n=40). The post-bleaching period is from July 2016 onwards.

When comparing national coral and algae cover levels before (2012 – June 2016) and after the bleaching event, only sites with data for both periods and with both fleshy algae and hard coral cover were included in the analysis (fig. 2.3.6). There was a 13% decrease in live hard coral cover from 53 ± 3.6% (mean ± se) to 46 ± 2.8%. A complementary increase in fleshy algae abundance over the same period occurred, with mean cover increasing from the pre-bleaching period (9 ± 2.5%) to the post-bleaching period (14 ± 2.4%).

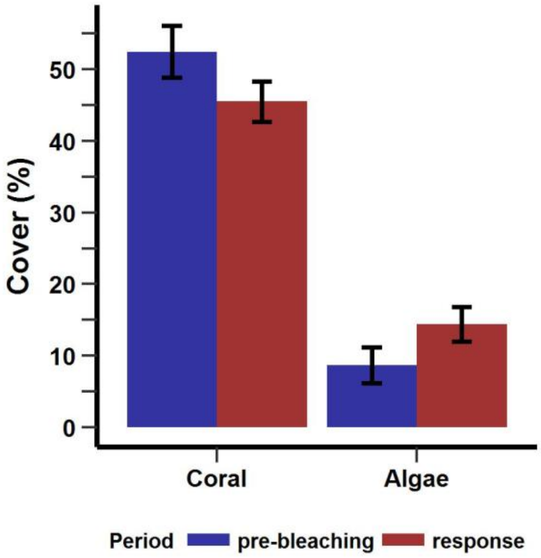

Figure 2.3.6. Hard coral and fleshy algae cover for pre-bleaching and post-bleaching (response) years: mean and standard error of all Madagascar reef sites (n=40). Pre-bleaching data are from 2012-June 2016 and 'response' data are from July 2016 -2017. Only sites with data for both periods and with both fleshy-algae and hard coral cover were included in the analysis.

Comparing the changes in hard coral cover in various areas on the west coast of Madagascar, Nosy Be, Nosy Komba and Ankarea in the NW lost about 20-40% coral cover, while Andavadoaka, and Soariake in the SW and Ankivonjy in the NW maintained about the same level of coral cover (fig. 2.3.7).

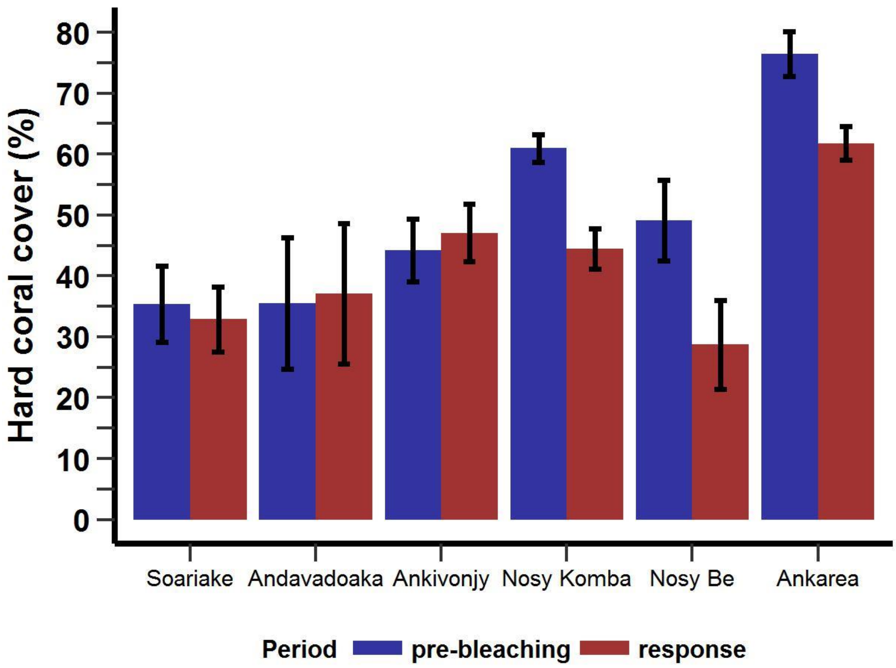

Figure 2.3.7. Mean hard coral cover for pre-bleaching and post-bleaching (response) years, for no-take and other management zones (with standard error bars). Pre-bleaching data are from 2012-June 2016 and 'response' data are from July 2016 -2017. Only stations with data for both periods were included in the analysis. Sites are ordered from South to North. (Soariake; n=11, Andavadoaka; n=3, Ankivonjy; n=8, Nosy Komba; n=3, Nosy Be; n=4, Ankarea; n=12).

In late 2017 Baie de Ranobe and Nosy Ve Anakao in Toliara (SW) and four sites in Nosy Be (NW) were surveyed. Both the southwest areas had hard coral cover around 35% and fleshy algae cover around 40%, and at the four sites in Nosy Be, hard coral was at 40% and fleshy algae at 5%.

2.3.3 Discussion

The results presented here suggest that the 2016 bleaching event had a noticeable impact on the coral cover of the reefs on the west coast of Madagascar, however this impact was more severely felt in the NW of the island. It is important to note that sites reported here are exclusively from the west coast of Madagascar, so conclusions don't apply to the east coast.

Across all sites, Madagascar had a relatively high coral cover compared to other countries in the region, with over 50%. However, with the bleaching event this has declined to approximately 45%, a change of almost 10% in living coral, although this is still relatively good. Pre-bleaching, sites in the NW had significantly higher coral cover than sites in the SW, but there is more parity between them now. Fortunately, fleshy algae cover after the event remains quite low at under 15%, indicating that reefs are not in any immediate danger of experiencing a phase-shift.

The SW coast of Madagascar is identified as a 'climate hotspot' - among the top 10 or 20 marine sites showing the highest rates of warming and associated climate change (Pecl et al., 2017). Bleaching is reported there on an annual basis, in some years with high mortality, in other years with low mortality. In 2016, sites at Andavadoaka in the SW experienced significant bleaching during peak stress in March and April, but seemingly recovered very well as there was no significant mortality post-bleaching. This was in spite of the SW experiencing much harsher bleaching conditions than the NW (fig. 2.3.2). It is likely that the SW reefs are more resistant to thermal stress than their counterparts in the north, due to high levels of exposure in the past, and resulting acclimatization or adaptation to these conditions. However, they may still suffer high mortality if conditions get too severe, and it may be that the rapid dissipation in bleaching stress from mid-April onwards, due to a sharp and significant drop in SST, helped prevent the reefs crossing their threshold into a high-mortality phase. In the NW, bleaching conditions began as early as December but did not become as extreme as in the SW, continuing at moderate level to mid-May. Nevertheless, conditions were sufficiently severe to cause significant mortality of corals.

Apart from the sites analyzed in this chapter, other reefs from across Madagascar were affected by moderate to high bleaching including at Toliara, Nosy Valiha, Bay de Ranobe and others (Maharavo et al., 2017).

Madagascar's reefs are unique biodiversity hotspots and have previously been defined by high amounts of live coral cover. However, over the last 20 years, coral cover began to decline relatively rapidly (Maharavo et al., 2017), and this trend has continued at some sites due to the bleaching in 2016. These areas could now be at risk of permanent degradation if recovery is restricted by local factors or repeat severe bleaching events in the future. The long-term future of Madagascar's reefs is therefore uncertain, particularly as the rate of degradation is expected to accelerate in coming years, making it as important as ever that significant investment is made to monitor and manage these vital economic and ecological resources.

2.3.4 Recommendations

Maintaining and improving the health of coral reefs

1) Improve management measures with an aim to minimize avoidable local threats and damage as much as possible. Strategies should be adaptive, with decisions being science-driven as much as possible and human intervention should be trialed where cost-effective and appropriate.

Monitoring and understanding coral reef health

2) Monitoring of coral reef health should be carried out by all reef stakeholders including NGOs, marine park authorities, universities, research programmes, individual researchers etc. with consistency in sites, methods and frequency. It is key to maintain monitoring at long-term monitoring sites, ensuring any new research programmes do the same.
3) Increase monitoring and reporting focus of reefs on the east coast of Madagascar.
4) Establish effective coral bleaching response plans to include preparation, funding, monitoring and communications (awareness creation) strategies. Individual research programmes, NGOs and others can develop their own tailored coral bleaching response plans to help them prepare for future bleaching events.
5) Data storage - ensure that a central repository is used to securely store coral reef health data including historical data making it easily accessible for reporting for management and policy.

Policy and research

6) Social resilience building – develop measures to increase the adaptability and resilience of Madagascar's public to the consequences of changes in the ecosystem services these resources provide.
7) Undertake studies to assess the bleaching vulnerability, susceptibility and resistance of various coral populations in the southwest and northwest.

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2.4 Mauritius

Data contributors: Reef Conservation

2.4.1 Background to the 2016 bleaching event

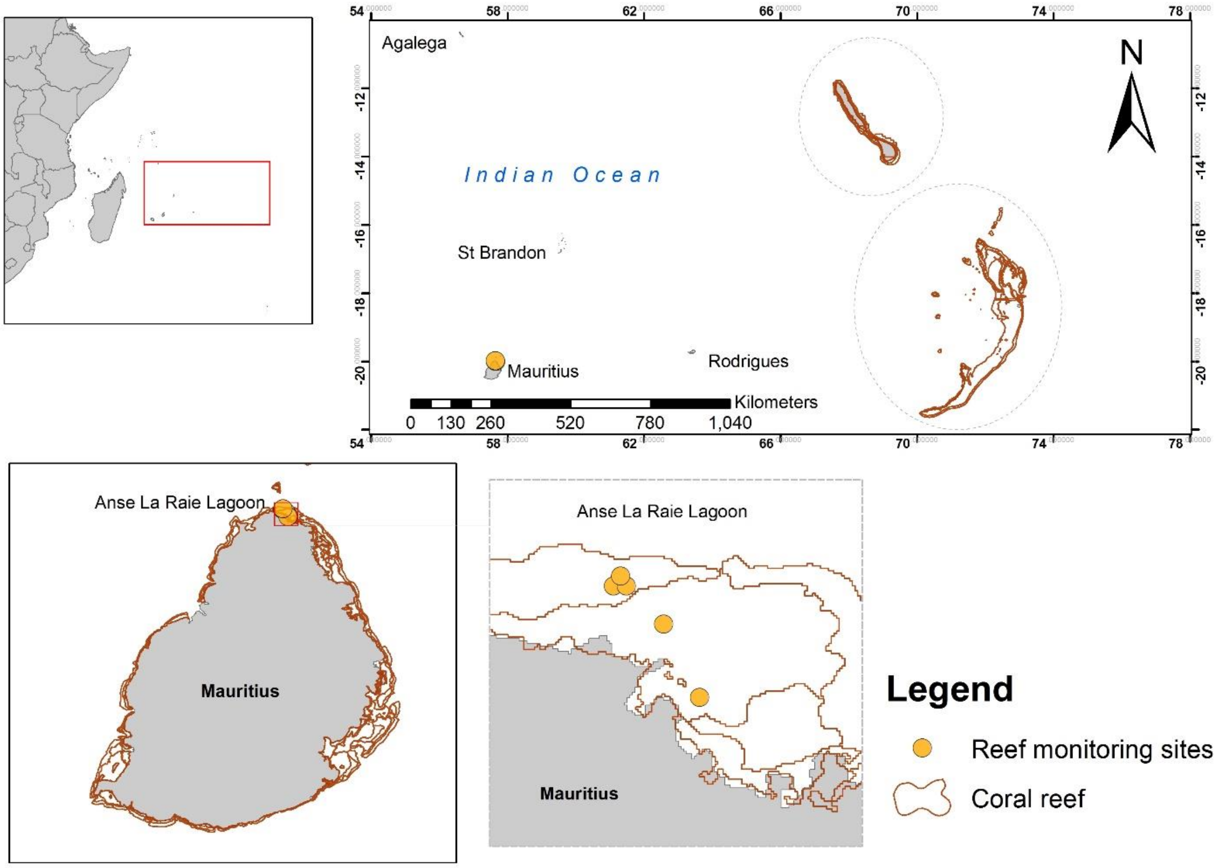

Figure 2.4.1. *Coral reef monitoring stations in Republic of Mauritius for which data were included in this study.*

2.4.1.1 History of coral bleaching events in Mauritius

Mauritius was least affected by the 1998 global bleaching event among the countries in the WIO, as the reefs suffered comparatively low mortalities (Wilkinson et al., 1999; Quod, 1999). A 1.5°C sea-surface temperature anomaly was recorded that caused bleaching of up to 85% in places (Spencer et al., 2000). However, the substantial recovery from bleaching was attributed to high resilience at some of the reefs (Turner, 1999; Obura, 2005) and mixing of deeper cooler waters caused by the tropical cyclone Anacelle (Quod, 1999).

Since 1998 low recovery rates have been noted with minor bleaching events occurring through the period to 2016 (Obura, 2005; Bacha Gian et al., 2017).

2.4.1.2 Progression of the 2016 coral bleaching event

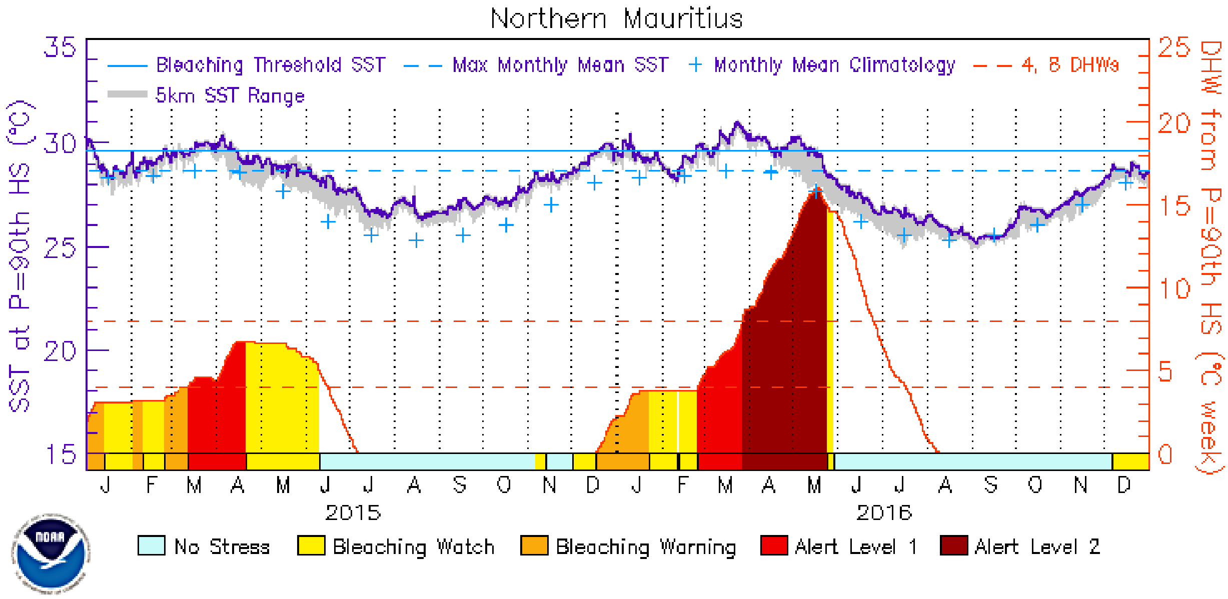

Figure 2.4.2. *National Oceanic and Atmospheric Administration (NOAA) Coral Reef Watch satellite bleaching products, showing the bleaching-related climatic conditions at a site on the north shore of Mauritius island.*

According to remote satellite monitoring in Northern Mauritius, bleaching stress began to accumulate as early as mid-December 2015 and started building rapidly towards the end of February 2016 (fig. 2.4.2). Alert level 2 was reached just before April and continued for almost 2 months till the end of May, when thermal stress peaked at a region high of 16 degree-heating weeks. After this, temperatures dropped, and thermal stress dissipated completely.

Bleaching was widespread across Mauritius Island, with over 40% of coral cover partially bleached (Bacha Gian et. al., 2017). All sites had some degree of bleaching, with the most affected sites such as Belle Mare, Flic en Flac and Ile aux Benitiers having more than 65% of corals affected, whilst Blue Bay, Bel Ombre and Mon Choisy had less than 15% bleaching (Bacha Gian et. al., 2017).

Overall, approximately 35% of observations reported severe bleaching (greater than 50% coral cover bleached) between January and May 2016 (fig. 2.4.3a). Recorded bleaching mirrored the climatic conditions closely, with severe bleaching peaking in March and April and then declining (fig. 2.4.3b).

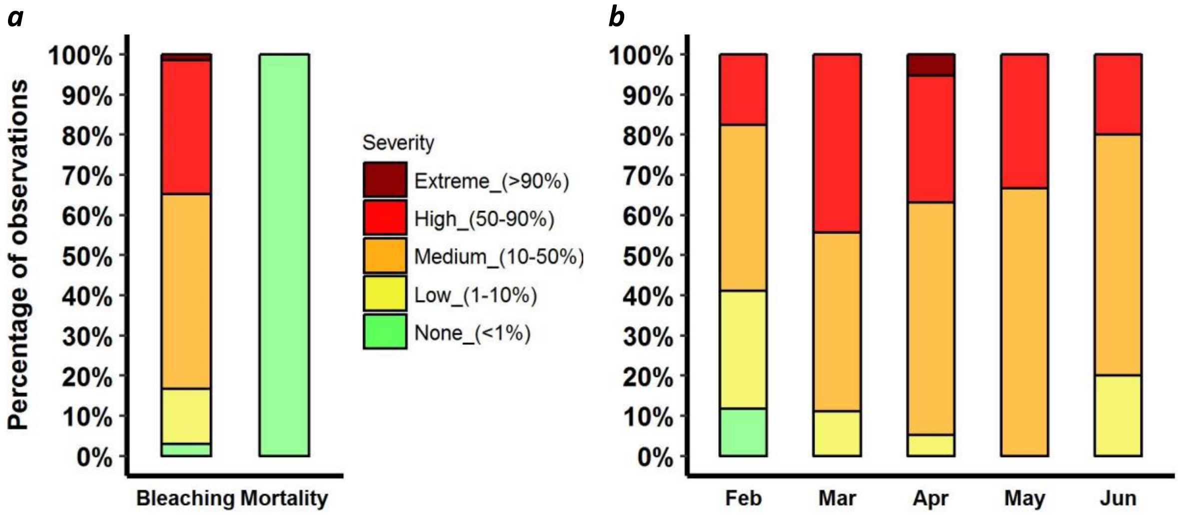

*Figure 2.4.3. Breakdown of observations collected in Mauritius in 2016 of **a**) coral bleaching (n=66) from Jan-May and mortality (n=1) from May-September 2016 and **b**) bleaching each month (Feb; n=17, Mar; n=27, Apr; n=19, May; n=3, Jun; n=5). Categories represent the severity of bleaching/mortality reported as percentage of coral cover bleached/dead at a site.*

2.4.2 Results

In total, data from 5 sites in Anse La Raie Lagoon in the North of Mauritius Island between 2013 and 2017 were included in the analysis, as other sites in the national coral reef monitoring network (ref to GCRMN chapter, 2017) have not been monitored after the bleaching event.

Overall, cover of hard coral in Anse La Raie has stayed approximately the same from 2013 to 2017, without any visible impact of the 2016 bleaching event. Prior to the bleaching event, values of 32-45% were recorded, though there is no significant difference between these (fig. 2.4.4).

A measurement of hard coral cover of 45% immediately after the event in late 2016 is not likely to reflect a true increase in coral cover and follows the same pattern as in prior years. The hard-coral cover in 2017 was 35%.

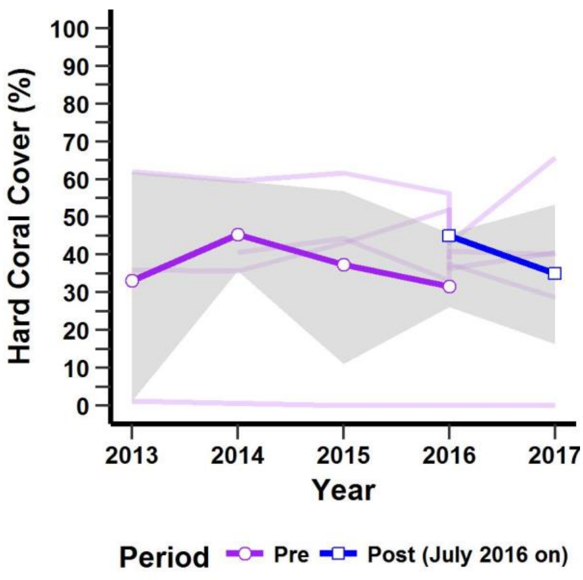

Figure 2.4.4. Trends in hard coral cover on Mauritius coral reef sites before and after the 2016 bleaching event (national mean (dark bold line) split into historical pre-bleaching data (purple line, open-circles) and post-bleaching data from July 2016 onwards (blue line, open-squares), 95% confidence limit (grey shaded area), individual monitoring stations (faded background lines)). Only stations with data for both periods were included in the analysis (n=5).

The fleshy algae data recorded from the same sites shows a reciprocal pattern to hard coral cover, and also cannot be interpreted in relation to impacts of the 2016 bleaching event (fig. 2.4.5).

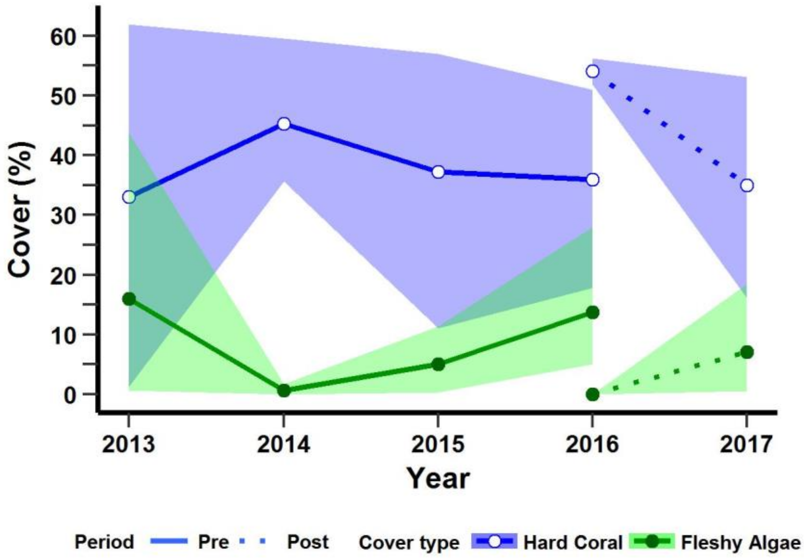

Figure 2.4.5. *Trends in fleshy algae (green line, closed circles) and hard coral cover (blue line, open-circles) in Mauritius before (solid line) and after (dotted line) the 2016 bleaching event. Shaded areas represent the 95% confidence limit. Only stations with data for both periods and with both fleshy-algae and hard coral cover were included in the analysis (n=5). The post-bleaching period is from July 2016 onwards.*

2.4.3 Discussion

Overall the results suggest that there was no change in hard coral cover as a result of the bleaching event in Anse La Raie Lagoon. Given the very strong bleaching conditions remotely measured through satellites for Northern Mauritius, and high levels of bleaching measured at these sites in the early-part of the year, this result is quite surprising. Other studies of bleaching on Rodrigues Island found that reefs around the island were not as fortunate with widespread bleaching and possibly some of the worst coral mortality in the region (Klaus, 2016; F. Jouval pers. comm.).

Unfortunately, data from survey sites in only a single area were submitted for this report. Given that there were several reports of strong bleaching at sites across Mauritius in the early part of 2016, it is likely that mortality on both Mauritius and Rodrigues islands was significant and needs to be documented as soon as possible.

2.4.4 Recommendations

The following recommendations can be made from this report:

1) Greater standardization of the monitoring programme at Anse La Raie Lagoon is needed, to ensure that change measured from year to year can be reliably attributed to relevant causes.
2) Revitalization of the national Coral reef monitoring network is needed, to ensure data are collected regularly and reliably, and contributed into regional reporting processes.

2.4.5 References

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2.5 Seychelles

Data contributors: Seychelles National Parks Authority (SNPA), Global Vision International (GVI), Seychelles Islands Foundation (SIF), Island Conservation Society (ICS), Green Islands Foundation (GIF), Marine Conservation Society Seychelles.

2.5.1 Background to the 2016 bleaching event

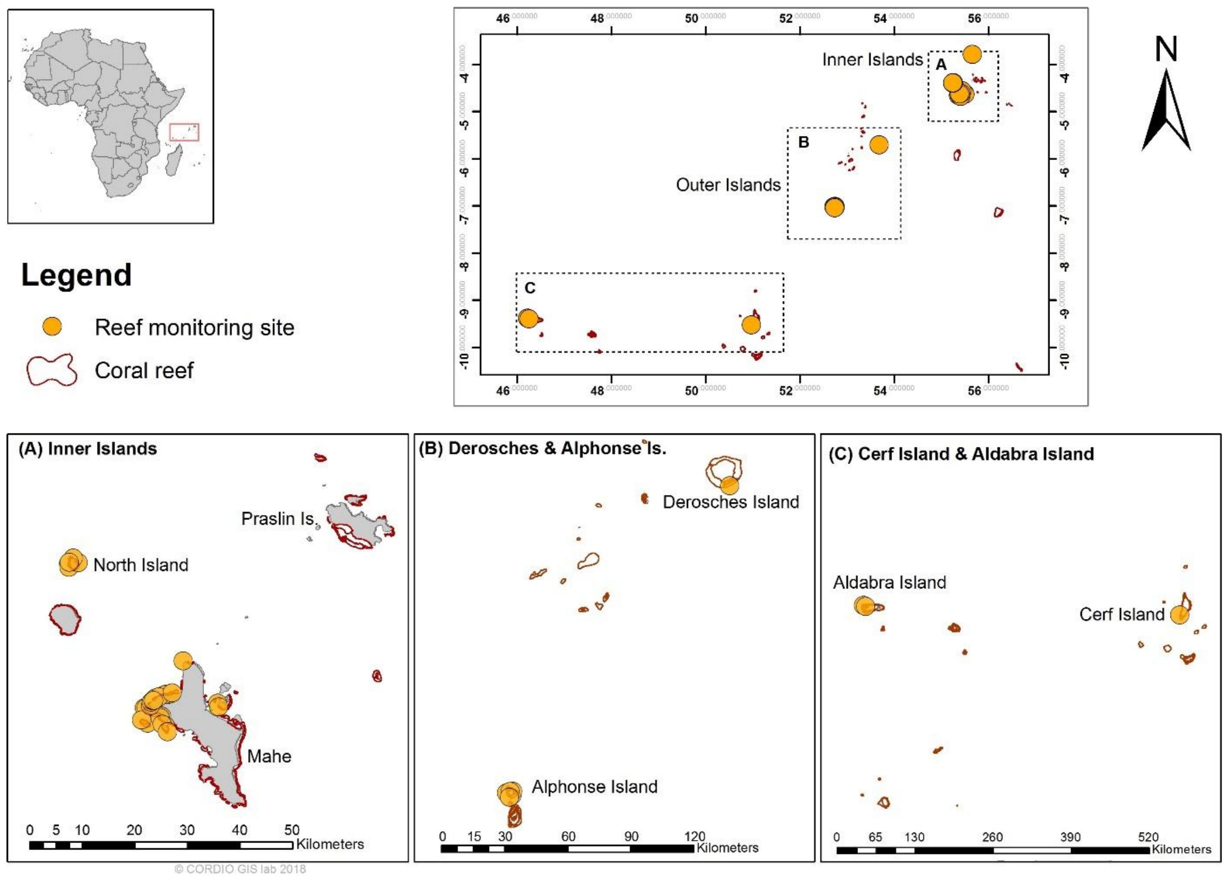

Figure 2.5.1. *Coral reef monitoring stations in Seychelles for which data were included in this study.*

2.5.1.1 History of coral bleaching events in the Seychelles

The Inner Islands of the Seychelles were particularly badly affected by the first global bleaching event in 1998. The granitic islands of Mahé and Praslin lost on average between 75-90% of live coral cover (Amia, 2014; Harris et al., 2014). Shallow water over the extensive banks surrounding the Inner Islands generally heats to very high temperatures during the local summer, and temperatures were exacerbated by the extreme conditions in 1998. The Outer Islands of the Seychelles are generally atolls or islands surrounded by deep waters, thus experience less heating and have refuge habitats for corals living in cooler, deeper water. However, they were also significantly affected by bleaching (Engelhardt et. al., 2002; Graham et al., 2007).

2.5.1.2 Progression of the 2016 coral bleaching event

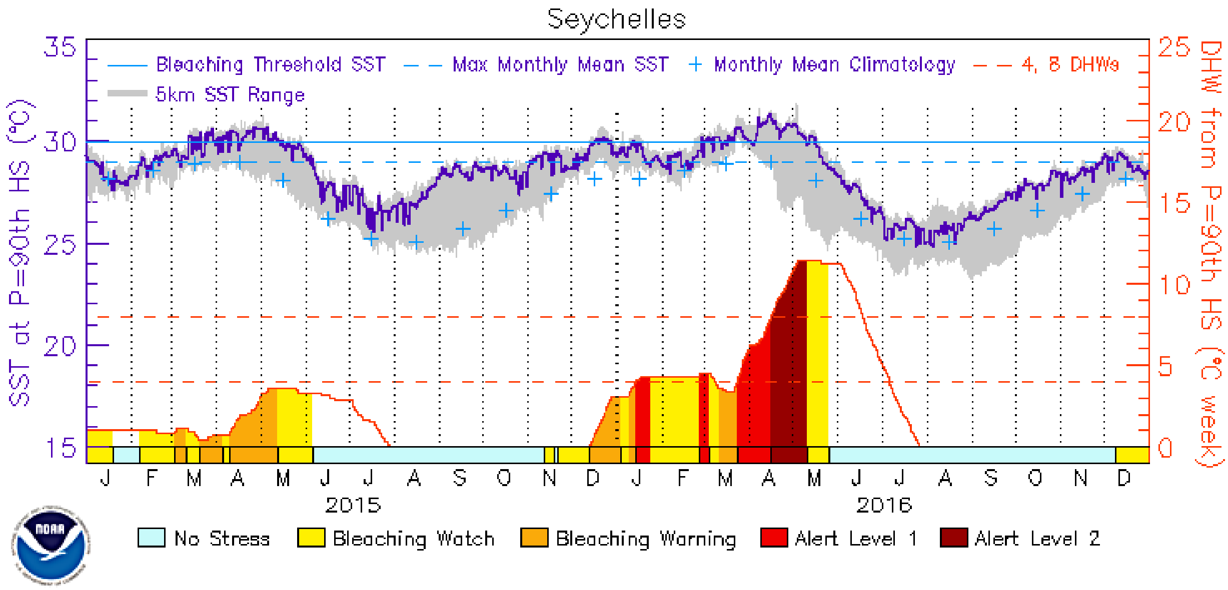

Figure 2.5.2. *National Oceanic and Atmospheric Administration (NOAA) Coral Reef Watch satellite bleaching products, showing the bleaching related climatic conditions present at a remote monitoring station in Seychelles.*

Sea-surface temperatures recorded by satellite from a fixed station in the Seychelles show extreme thermal stress building up from December 2015 to May 2016 (fig. 2.5.2.). Bleaching warning and alert level 1 were reached early in January, then intensified in late March. SST reached its highest value in April, well above the SST threshold for bleaching, and the bleaching alert level reached the maximum value of 2 at the beginning of April. Thermal stress peaked at 12 Degree Heating Weeks for 3 weeks in late April/early May.

The first reports of coral bleaching were made in early January at Aldabra Atoll. As the temperatures rose in March and April, more sites across several Outer Islands became affected by bleaching, including Providence and St. Pierre, and by early April, bleaching was reported from Alphonse and Desroches in the Amirantes (Bijoux et. al., 2017). The level of bleaching varied between and within island sites, with the west-side of Alphonse being the most affected.

In the Inner Islands, several sites were impacted. On the northwest coast of Mahé, *Pocillopora* and *Acropora* showed first signs of bleaching at all depths (Bijoux et. al., 2017). By early August 2016 some corals were still showing signs of bleaching despite sea temperatures having returned to normal since May (Bijoux et. al., 2017). Extensive coral mortality was observed from May onwards.

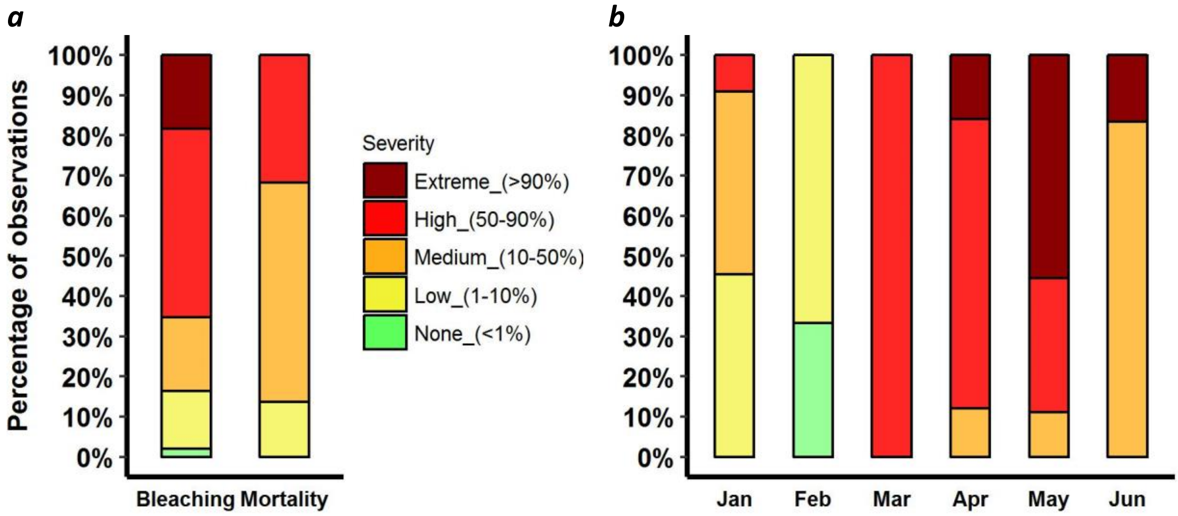

__Figure 2.5.3.__ Breakdown of observations in the Seychelles in 2016 of __a)__ coral bleaching from January-May (n=49) and mortality from May-September 2016 (n=22); __b)__ bleaching each month (Jan; n=11, Feb; n=3, Mar; n=1, Apr; n=25, May; n=9, Jun; n=6). Categories represent the severity of bleaching/mortality reported as percentage of coral cover bleached/dead at a site.

Overall, during the peak bleaching months (Jan-May) approximately 65% of sites reported severe bleaching levels (greater than 50% of coral cover bleached), with just over 30% of sites reporting severe mortality from May onwards (fig. 2.5.3a). The monthly progression of bleaching (fig. 2.5.3b) mirrored the increasing thermal stress.

2.5.2 Results

In total, data from 50 sites from 6 islands (North, Mahe, Alphonse, Aldabra, Desroches and Cerf) between 1999 and 2017 were included in this analysis.

In 1999, just after the 1998 bleaching event, the mean coral cover was 24%, and after an initial decline till 2006, this steadily increased to approximately 37% just before the bleaching event in 2016 (fig. 2.5.4). Sites surveyed after the bleaching event during late 2016 and early 2017 had a mean cover between 18 and 27% (see fig. 2.5.4). The downward slope in the graph linking post-bleaching sites measured in 2016 and 2017 is because different sites were reported, it does not reflect a further decline in coral cover.

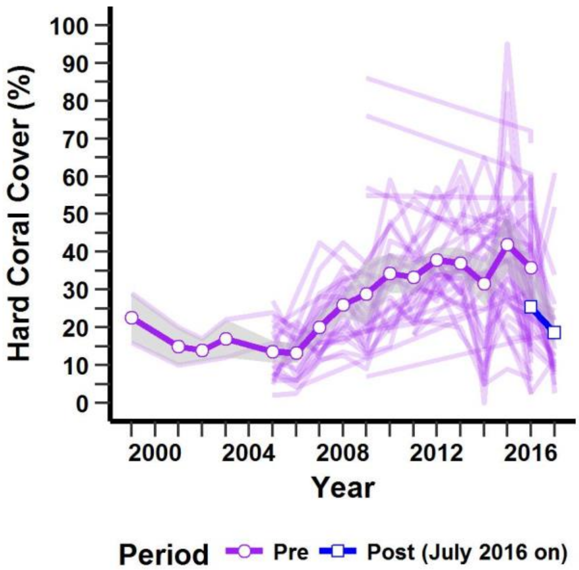

__Figure 2.5.4.__ Trends in hard coral cover on Seychelles islands' reefs before and after the 2016 bleaching event (national mean (dark bold line) split into historical pre-bleaching data (purple line, open-circles) and post-bleaching data from July 2016 onwards (blue line, open-squares), 95% confidence limit (grey shaded area), individual monitoring stations (faded background lines)). Only stations with data for both periods were included in the analysis (n=50).

At sites for which algal cover was measured alongside coral cover, fleshy algal cover increased drastically from 2015 to 2016 (before the bleaching event), which may be an artifact of sampling, but did not change significantly after the bleaching event (fig. 2.5.5). For these sites, a greater decline in coral cover was recorded from over 30% pre-bleaching to between 8 – 20% after.

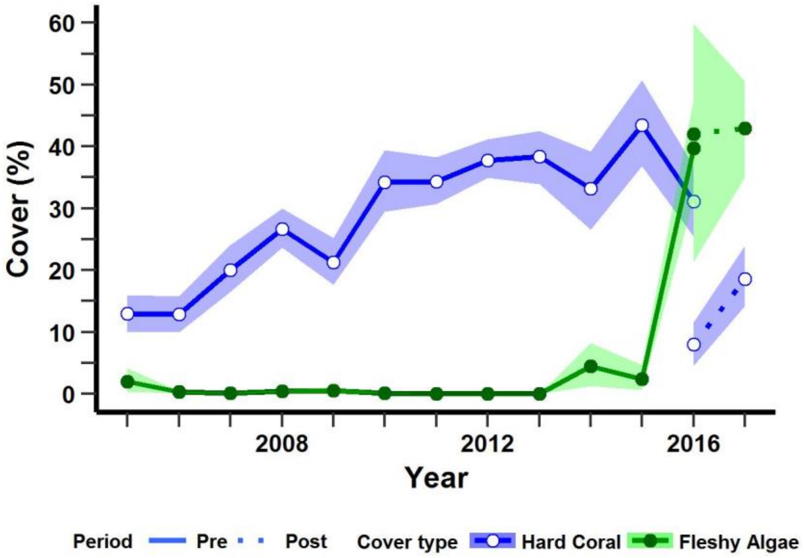

Figure 2.5.5 *Trends in fleshy algae (green line, closed circles) and hard coral cover (blue line, open-circles) in the Seychelles before (solid line) and after (dotted line) the 2016 bleaching event. Shaded areas represent the 95% confidence limit. Only stations with data for both periods and with both fleshy-algae and hard coral cover were included in the analysis (n=32). The post-bleaching period begins in July 2016.*

At a national level, a comparison of coral and fleshy algae cover before (2012-June 2016) and after (since July 2016) the bleaching event showed that there has been a 50% decrease in live hard coral cover from 34 ± 2.8% (mean ± se) to 17 ± 2.2% (fig. 2.5.6a). In response to that there has been an approximately 45% increase in fleshy algae abundance over the same period with mean cover changing from 29 ± 4.3% pre-bleaching to 42 ± 3.8% post-bleaching.

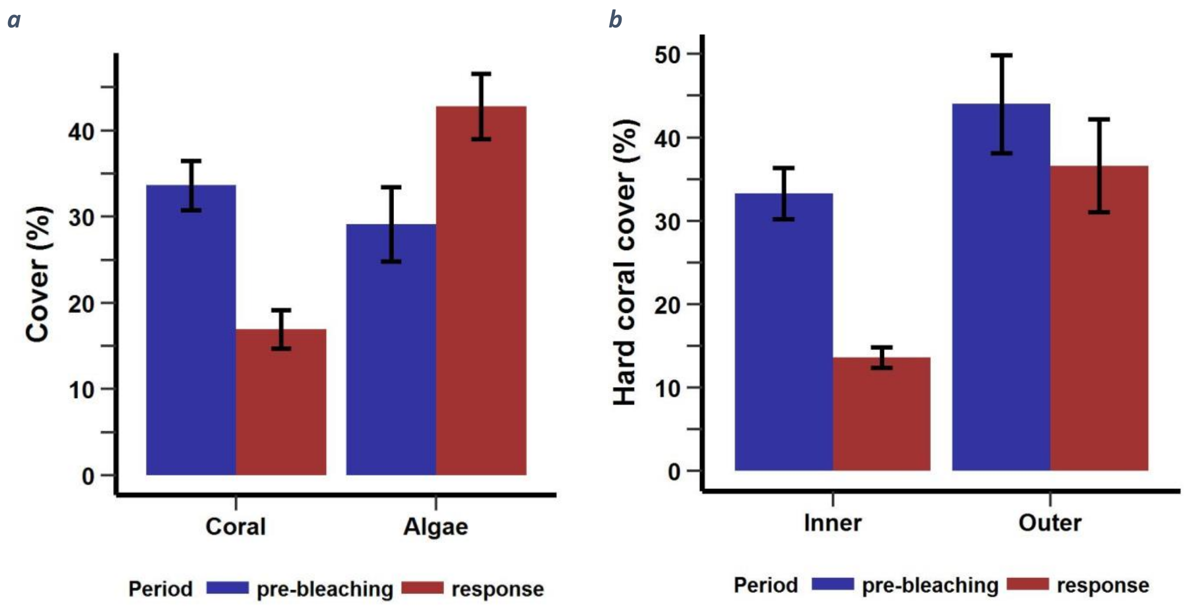

Figure 2.5.6. *Pre- and post-bleaching (response) mean (with standard error bars) for **a)** hard coral and fleshy algae cover of all Seychelles' reef sites with both fleshy-algae and hard coral cover data (n=32), and **b)** hard coral cover for Inner and Outer Island reef sites in Seychelles (n=14 Outer, n=29 Inner). Pre-bleaching data are from 2012-June 2016 and 'response' data are from July 2016-2017. Only sites with data for both periods were included in the analysis.*

When comparing the Inner and Outer Islands, there has been an almost 60% decline in live hard coral cover from 33 ± 3.1% to 13 ± 1.2% in the Inner Islands, compared to a 17% decline in the Outer Islands (44 ± 5.8% to 37 ± 5.6%) (fig. 2.5.6b).

Almost all Seychelles islands experienced high levels of coral mortality in 2016, with sites around North Island being the most affected with an 81% decline in living hard coral on average, and sites around Aldabra, Desroches and the northwest of Mahe losing over half of their live coral (Table 2.5.1).

Table 2.5.1. *Average percentage change in live hard coral cover for six Seychelles islands, across all sites analyzed at each Island, comparing coral cover before (1996 -June 2016) and after (July 2016 – 2017) the bleaching event.*

Island	Percentage change in live coral cover	Pre-bleaching mean coral cover ± sd	Post-bleaching mean coral cover ± sd	Number of sites
North	-81	43 ± 26.3	8 ± 4.9	5
Aldabra	-55	24 ± 9.2	11 ± 4.2	2
Desroches	-54	44 ± 43.9	20 ± 6.9	3
Mahe (NW)	-53	31 ± 13.6	15 ± 6.3	24
Alphonse	-13	54 ± 9	47 ± 19.3	6
Cerf	32	37 ± 12.5	49 ± 13.7	3

2.5.3 Discussion

Seychelles was once again one of the worst hit countries in the WIO by a regional bleaching event. Across all sites there was a 50% decrease in live hard coral cover, and an almost equivalent increase in fleshy algae abundance over the same period. However, although very high, mortality in 2016 was not as high as in 1998 (Turner et al., 2000). This is despite the fact that the 2016 El Niño was longer lasting and more extensive than the 1997-1998 episode.

Another pattern that mirrored the 1998 bleaching event was that the Inner Islands were more severely impacted than the Outer Islands, with some sites losing over 80% of their live hard coral cover. This is likely in part due to the warmer conditions experienced over the shallow banks surrounding the Inner Islands resulting in greater thermal stress.

Despite this, some sites experienced only minor, if any, bleaching-related mortality in 2016. Corsaire Reef in northwest Mahe was the only site from this area that showed a positive change in coral cover, and the three sites on Cerf Island appeared to escape relatively undamaged. Other sites with only minor impact of bleaching were found around the island of Praslin at the Baie Ste Anne jetty and at Chauve Souris, within the Curieuse Marine National Park (Bijoux et. al., 2017). The reasons for low bleaching at these sites are not clear, however high resistance to bleaching at the Baie Ste Anne jetty has been reported in other years between the 1998 and 2016 events (Grimsditch & Salm, 2005; Souter & Linden, 2005).

After two major bleaching events 18 years apart, and a number of smaller more localized bleaching events in between, the corals of the Seychelles could be more acclimated and resilient to hot conditions. It is also significant that coral cover returned to pre-1998 levels over the 18 years, suggesting that if managed well, and given enough time, the reefs could have the potential to naturally respond and recover from the 2016 bleaching event. However, the rapidly changing climate is expected to cause more frequent and severe bleaching events at shorter intervals in the future (van Hooidonk et al., 2016; Hughes et al., 2018), and it is therefore likely that the reefs will not have the luxury of 18 years to recover before the next major bleaching event. Additionally, in 2016 there has been a large step-increase in fleshy algae, which could hinder the ability of corals to recover. It is therefore imperative that coral reef health is closely tracked, and management measures are enhanced promptly to provide the necessary support for reefs to recover.

2.5.4 Recommendations

In order to strengthen the conservation of coral reefs in the Seychelles the following measures should be implemented at various levels:

Monitoring and understanding coral reef health:

1) Monitoring of coral reef health should be carried out by all reef stakeholders including NGOs, marine park authorities, universities, research programmes, individual researchers etc. with consistency in sites, methods and frequency.

2) Establish effective coral bleaching response plans on each island with sufficient capacity (including preparation, funding, monitoring and communications/awareness creation). Individual research programmes, NGOs and others can develop their own tailored coral bleaching response plans to help them prepare for future bleaching events.

3) Collate all historical coral reef health data into a central, safe database for secure storage and ease of access so the baseline and change in health of Seychelles coral reefs is clear. To support this, a system to share metadata on coral reefs will make it easier to share information among organisations and foster greater collaboration.

Maintaining and improving the health of coral reefs

4) Improve local management of coral reefs to enhance resilience and recovery potential. Specific emphasis should be placed on reversing the sudden increase in algal cover, to facilitate coral recovery.

5) Trials of restoration interventions for conserving and repairing coral reefs need to be supported, with transparent evaluations of effectiveness and success based on area impacted and cost.

6) Identify naturally resilient coral reef areas that can act as climate refuges and larval sources, to ensure they are well protected through appropriate management measures.

Policy and research

7) Develop a policy for the conservation of coral reefs. This should be drafted and discussed with all stakeholders and be in line with the Seychelles Sustainable Development Strategy (SSDS) and the National Biodiversity Strategy and Action Plan (NBSAP).

8) Targeted research on coral reef ecology and resilience, especially on factors enhancing or delaying the resistance and recovery of coral reefs from large-scale impacts should be encouraged along with active collaboration among organisations (government, NGOs, CBOs, academia) at the local and international level.

9) Many of the recommendations require joint action by government and non-government actors, in a coordinated network. This can be done through the Seychelles National Coral Reef Network (SNCRN), if strengthened through e.g. a national coral reef policy, and

supported through the emerging Marine Spatial Planning initiative to maintain the natural capital of the Seychelles.

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2.6 South Africa

Authors: Sean N. Porter[1], Michael H. Schleyer[1], Kerry J. Sink[2] and David J. Pearton[1]

2.6.1 Background to the 2016 bleaching event

2.6.6.1 History of coral bleaching events in South Africa

During the largest mass coral bleaching and mortality event that impacted much of the Western Indian Ocean (WIO) in 1998 (Goreau et al., 2000; Wilkinson, 2000), only negligible coral bleaching was recorded on South African reefs (Schleyer & Celliers, 2000). While some reefs in the WIO experienced more than 90% mortality due to bleaching (Wilkinson et al., 1999), less than 1% of the hard corals bleached in South Africa (Schleyer & Celliers, 2000; Jordan & Samways, 2001). This was mostly due to bleaching in widely spaced colonies of the hard coral genus *Montipora* (Schleyer & Celliers, 2000). No bleaching was recorded in the following year in 1999 (Celliers & Schleyer, 2002). Subsequently, Floros et al., (2004) recorded an increase in bleaching across the coral community of between 5-10% in 2000-2001. *Montipora* spp. were again detected as being the most commonly bleached genus. The bleaching was associated with increased sea temperatures characterized by high seasonal peaks, as well as high radiation levels during the summer months of 2000 (Celliers & Schleyer, 2002).

During this period (2000), Celliers & Schleyer (2002) measured similar levels of bleaching of the total living cover of up to 12% at Sodwana Bay. This was largely restricted to Two-mile Reef with the other reefs in the Central Complex either showing no bleaching or levels of ~1%. They found that the majority of hard corals that bleached belonged to the genera *Montipora* and *Alveopora*, and that an encrusting sponge *Suberites kelleri* was also found to bleach. Of the coral colonies that manifested bleaching, 47% were completely white whilst 44% were partially bleached. No whole colony mortality was ever recorded but partial mortality was detected in 9% of bleached corals. Bleaching was also inconsistent among colonies of the same species of *Montipora*, as colonies displayed variable levels of bleaching across the two reefs where bleaching was detected (Celliers & Schleyer, 2002).

Bleaching was not documented again in South Africa until 2005, when the bleaching response index across all hard coral taxa was as high as 40 during a warm-water anomaly in the southern Indian Ocean (McClanahan et al*.,* 2007). *Montipora* spp. were again found to show the highest incidences of bleaching, with bleaching response indexes of up to 65. Ruiz Sebastian et al. (2009) recorded bleaching responses across the coral community during this time, ranging from 11 at Nine-mile Reef in the Central Complex to 30 at Timm's Tridacna, Saxon Reef in the Northern Complex. Generally, deeper sites suffered less from bleaching (Ruiz Sebastian et al., 2009). Since then, only negligible levels of bleaching have been recorded up until 2016, when bleaching of 9.4% of the coral cover occurred on Two-mile Reef (Porter, 2017).

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Affiliations: *[1]Oceanographic Research Institute; [2]South African National Biodiversity Institute*

Over the last twenty years, bleaching-induced mortality on South African reefs has been minimal and, as such, the cover of hard coral has remained relatively consistent for the past decade (Porter & Schleyer, 2017) (fig. 2.6.1). The high latitude of these coral reefs in South Africa has provided them some protection from bleaching in the past (Celliers & Schleyer, 2002). The reefs are also located in relatively deep water that is naturally turbulent and experience periodic upwelling events which help to cool the surface waters where corals reside (Celliers & Schleyer, 2002; Riegl & Piller, 2003). However, the characteristically clear water of this region can exacerbate bleaching (Celliers & Schleyer, 2002; Porter et al., 2017).

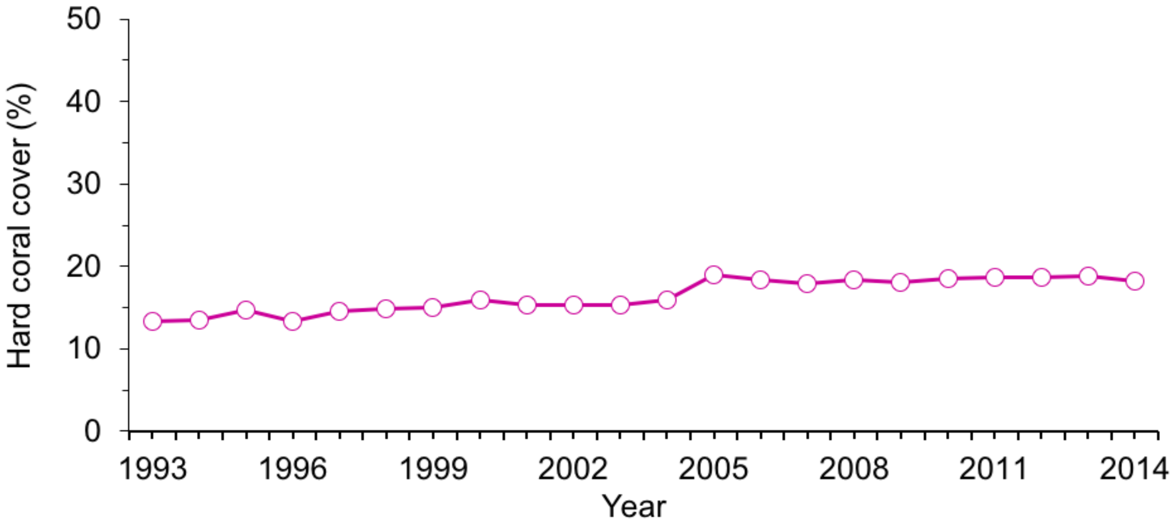

Figure 2.6.1. *Trend in hard coral cover at Nine-mile Reef, Sodwana Bay, South Africa over the past 20 years (Porter & Schleyer, 2017). No bleaching has been recorded at the monitoring site although several colonies showed signs of paling in March 2016.*

2.6.6.2 Assessing the impact of the 2016 coral bleaching event

The impact of the 2016 coral bleaching event on South African reefs and the subsequent response in the coral community was assessed by the Oceanographic Research Institute (ORI) and the South African National Biodiversity Institute (SANBI) using different, but complementary methods. ORI surveys were undertaken along 10-m transects using the line-intercept method to estimate the percentage coral cover bleached at five sites haphazardly selected on Two-mile Reef in the Central Reef Complex (fig. 2.6.2). These surveys were repeated at the same five sites in December 2015 (pre-bleaching), May 2016 (peak-bleaching) and September 2016 (post-bleaching response) to assess the progression and response of corals during this anomalously warm period.

SANBI conducted bleaching surveys of hard coral colonies in late April 2016 to assess peak-bleaching levels, using a bleaching index derived by McClanahan (2004). This method allows for taxon- and site-specific bleaching indices to be calculated, as well as the determination of the proportion of hard coral colonies bleached relative to the total number of hard coral colonies assessed. These surveys were conducted at twelve sites situated across all three reef complexes (fig. 2.6.2).

In total, 1 822 line-intercept points and 3 554 hard coral colonies were assessed by ORI and SANBI respectively. The data utilized in this report were derived from routine monitoring projects conducted independently by both organisations.

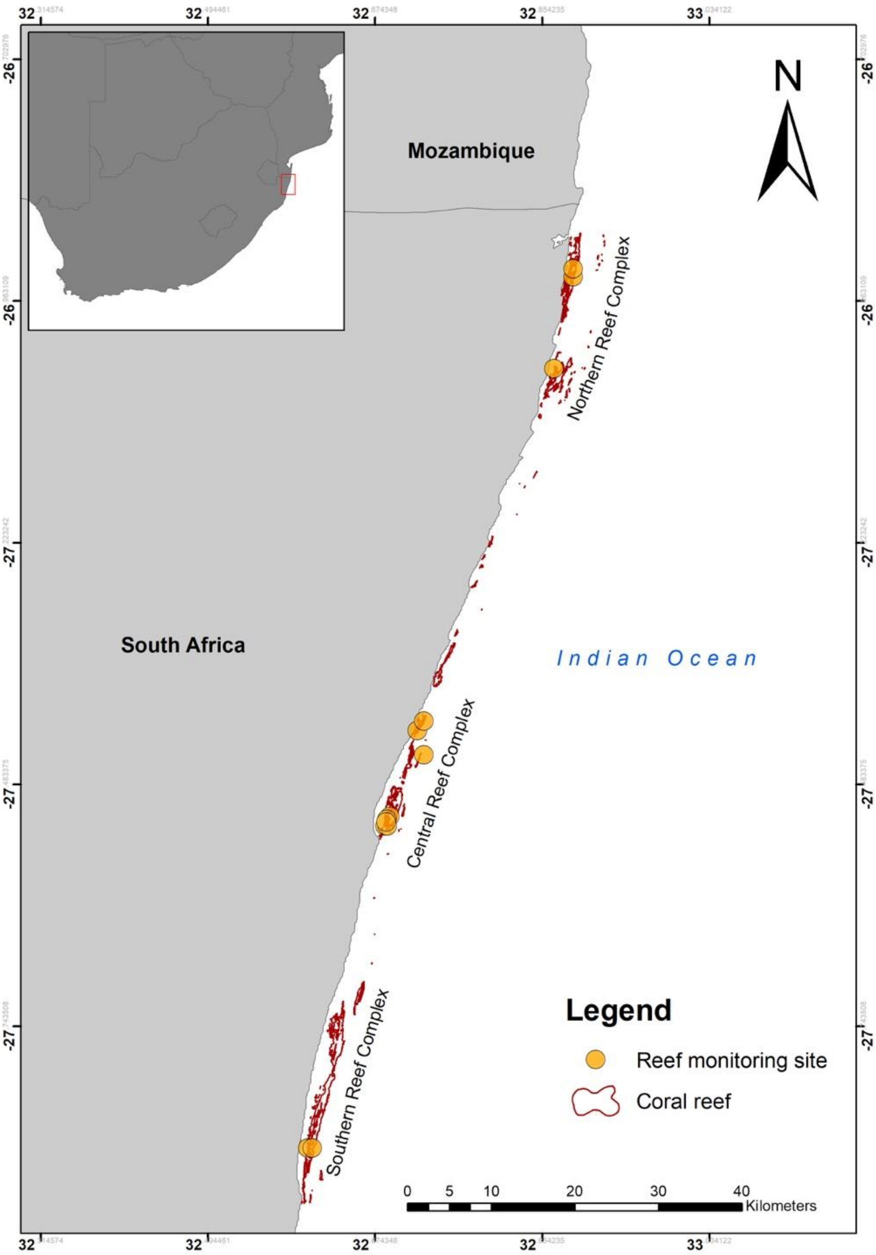

Figure 2.6.2. *Monitoring sites used to assess levels of coral bleaching in South Africa.*

2.6.6.3 Progression of the 2016 coral bleaching event

During the 2015-2016 warming event, average monthly subtidal (18 m) temperatures at Nine-mile Reef rose from 24.1°C in October 2015 to 25.4°C in December 2015, before peaking in March 2016 at 27.4°C. During this period, a maximum temperature of 29.0°C was sustained for ~9 consecutive hours in March 2016 (fig. 2.6.3). NOAA regional sea-surface temperature warnings prompted a "bleaching watch" in January 2016 with temperatures peaking in February and again in March for several weeks at ~28°C; these triggered two separate "bleaching warnings" for a week in February and for most of March (fig. 2.6.4). Subsequent to March 2016, temperatures decreased at a faster rate than they rose before March.

The first indications of bleaching were observed during December 2015, when 3.6 ± 2.8% of the coral cover manifested paling on Two-mile Reef. Four genera (*Acropora*, *Pocillopora*, *Montipora* and *Astreopora*) were found to be affected with minor paling at this stage. Full bleaching developed several months later, with 14–56% (Ave. ± SD = 39.0 ± 11.3%) of hard corals assessed at sites with some degree of either paling (25.7 ± 6.6%) or bleaching (13.4 ± 6.9%) across sites in the three reef complexes (fig. 2.6.5a). Bleaching indices at sites ranged from 3.5–18.3 (Ave. ± SD = 11.5 ± 4.0). During this period, 4.1–17.5% (Ave. ± SD = 9.4 ± 5.9%) of the total coral cover at all sites on Two-mile Reef manifested either paling or bleaching (fig. 2.6.5b)

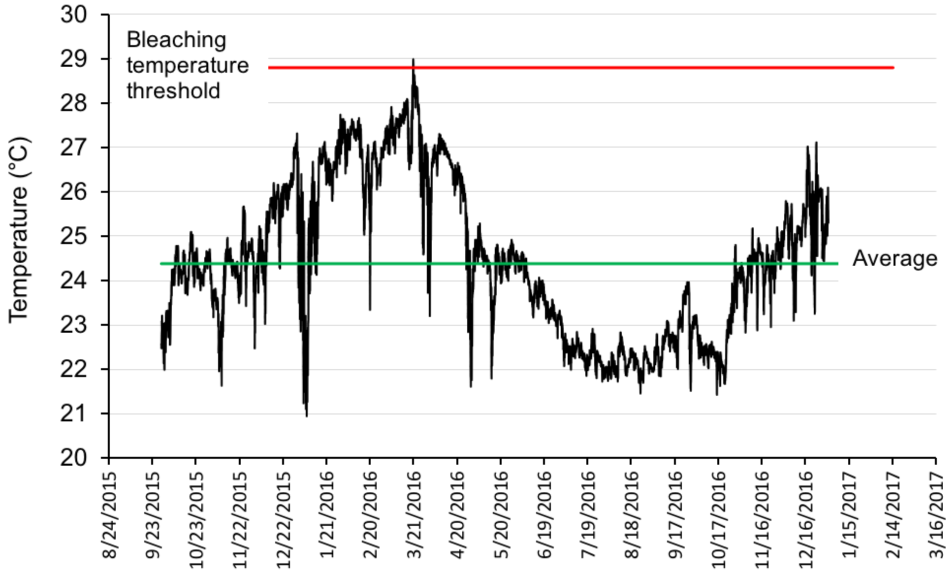

Figure 2.6.3. Hourly water temperatures at the Nine-mile Reef long-term monitoring site, Sodwana Bay from September 2015 to December 2016. The red line indicates the temperature threshold at which bleaching is known to occur on local reefs (Celliers & Schleyer, 2002). The green line indicates the long-term average temperature at the monitoring site (Porter & Schleyer, 2017).

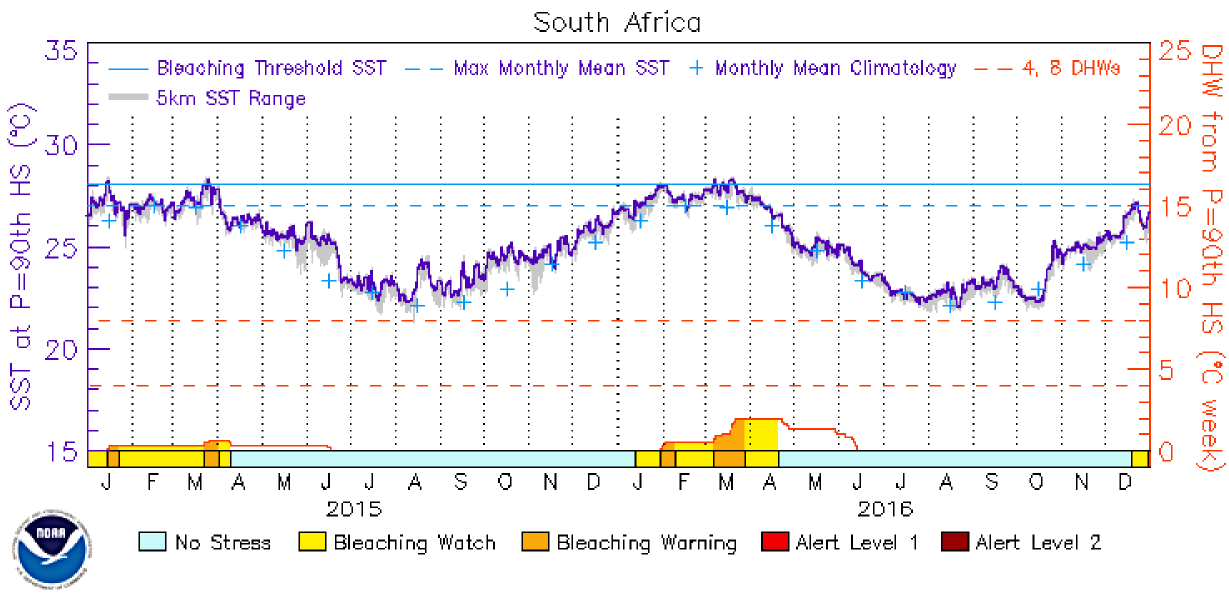

***Figure 2.6.4.** National Oceanic and Atmospheric Administration (NOAA) Coral Reef Watch satellite bleaching products, showing the bleaching-related climatic conditions at Sodwana Bay, South Africa.*

Of the coral genera that exhibited some form of heat stress during peak bleaching, *Montipora* was by far the most commonly bleached genus, comprising 63% of the bleached coral cover on Two-mile Reef, followed by *Favia* (10%) and *Pocillopora* (7%). When corals were bleached, 49% of this coral cover was pale but not white, whilst the remaining 51% were white. In the case of *Montipora*, some of the paling colonies exhibited a fluorescing blue colour. Mortality during peak bleaching averaged 0.3 ± 0.6% of coral colonies assessed, was restricted to only three sites, and reached a maximum of 2.3% at a site.

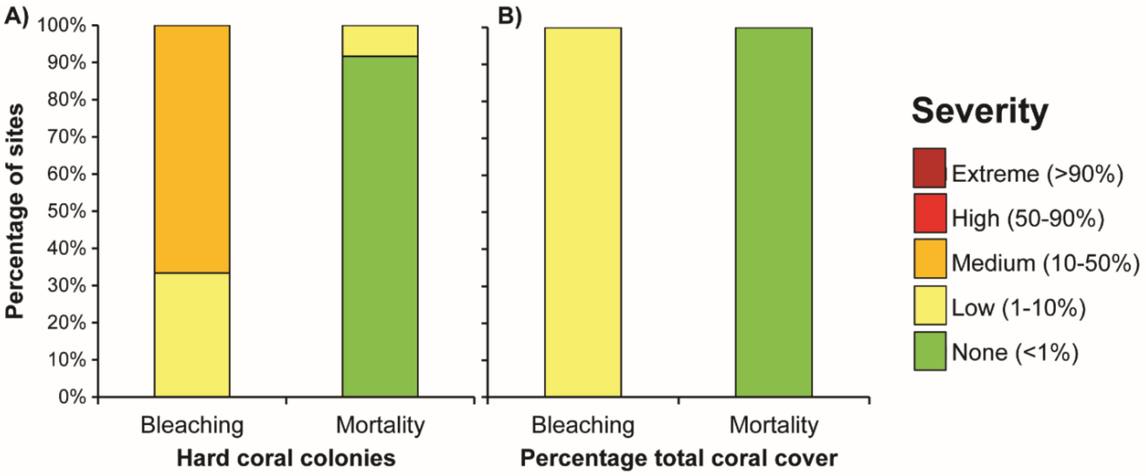

Figure 2.6.5 *Observations of coral bleaching (including paling) and associated mortality recorded in South Africa in April-May 2016 during peak bleaching as A) a percentage of hard coral colonies (n = 12) and as B) a percentage of total coral cover (n = 5). Categories represent the severity of bleaching/mortality reported as a result of bleaching at a site.*

During the period of peak bleaching, spatial and depth-related patterns in bleaching prevalence were evident in the region. The bleaching index at sites declined significantly with latitude, as sites in the Southern Complex exhibited lower bleaching indices than sites in the Northern Complex (fig. 2.6.6). Similarly, bleaching indices manifested a decreasing trend with depth, although the relationship was not significant (fig. 2.6.7).

By late September 2016, some corals were still showing signs of paling despite sea temperatures having returned to normal for over two months (fig. 2.6.3).

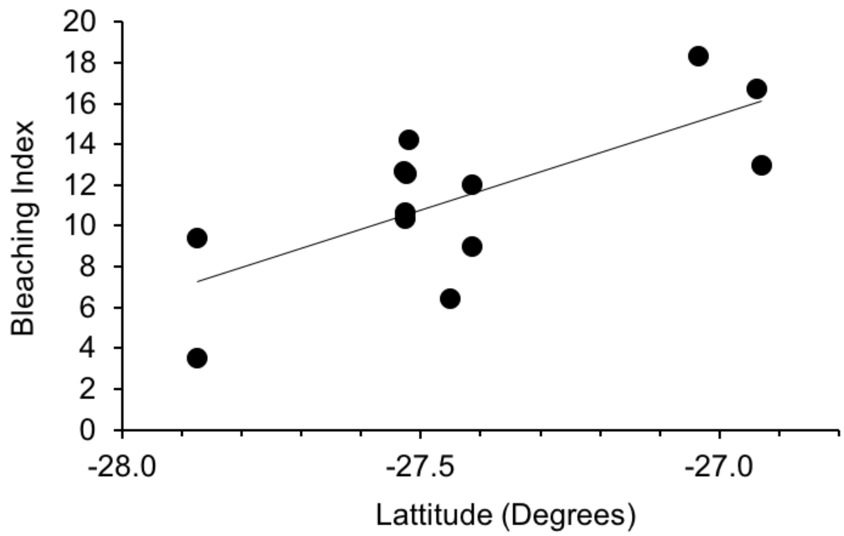

Figure 2.6.6. *Bleaching index versus latitude at twelve sites situated across all three reef complexes in South Africa during late April 2016, based on records of a total of 3554 hard coral colonies. A positive and significant relationship (r^2 = 0.52; p < 0.01) was found between bleaching index and decreasing latitude.*

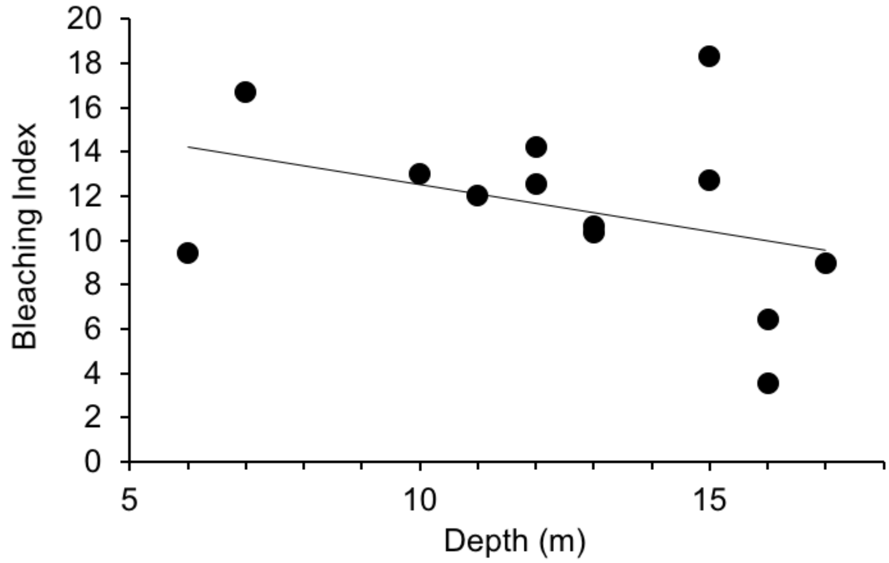

Figure 2.6.7. *Bleaching index versus depth for twelve sites situated across all three reef complexes in South Africa during late April 2016, based on a total of 3554 hard coral colonies. A negative but non-significant relationship (r^2 = 0.14; p = 0.24) was found between bleaching index and increasing depth.*

2.6.2 Results

During peak-bleaching, 4.6% of the coral cover on Two-mile Reef in the Central Reef Complex was bleached, whilst 4.8% was pale (fig. 2.6.8). The post-bleaching recovery survey revealed that the condition of the corals was on par with pre-bleaching levels, with <5% of the total coral cover manifesting only paling, but no signs of bleaching or recent mortality (fig 2.6.8). Average (±SD) total coral cover during the pre-bleaching period was 49.3 ± 9.7% and negligibly more (54.2 ± 10.3%) during the post-bleaching assessment (fig. 2.6.9). Similarly, the cover of fleshy algae differed little from pre- (18.8 ± 10.2%) and post-bleaching (21.4 ± 3.2%) levels (fig. 2.6.9).

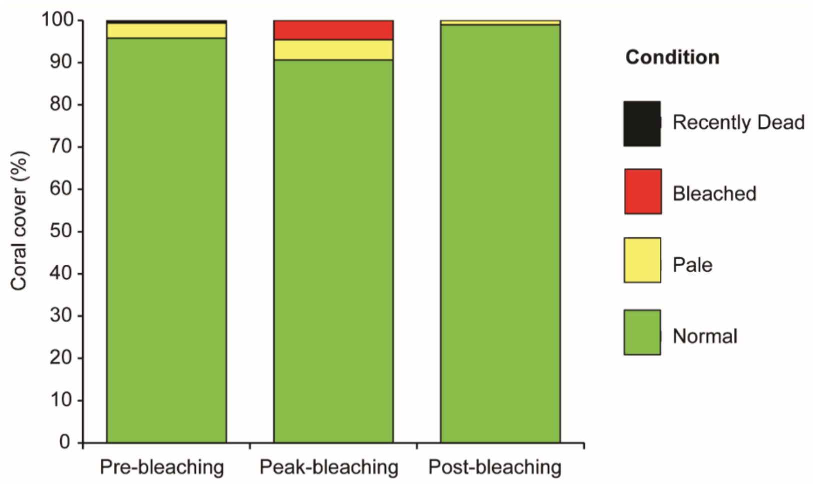

Figure 2.6.8. Condition of the coral cover assessed prior to bleaching, during peak-bleaching and several months later after post-bleaching recovery on Two-mile Reef, Sodwana Bay (n = 5).

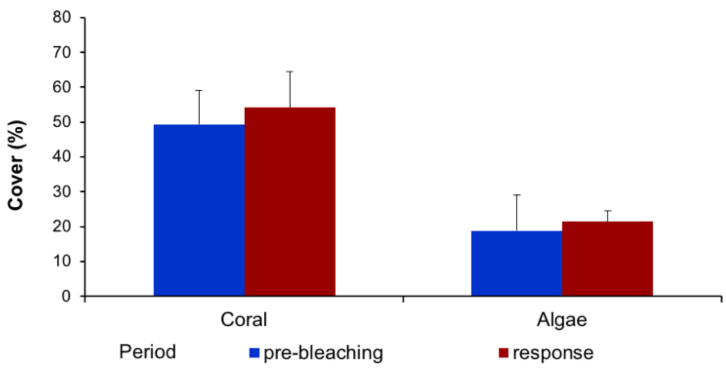

Figure 2.6.9. Mean ± SD percentage coral and algal cover in the pre-bleaching and post-bleaching (response) periods at five sites on Two-mile Reef, Sodwana Bay. Pre-bleaching data are from December 2015 and 'response' data are from September 2016. Only sites with data for both periods were included in the analysis.

The average cover of hard coral on Two-mile Reef during the pre-bleaching survey was found to approximate 20%, in line with the ~20% cover that has persisted over the last decade at the Nine-mile long-term monitoring site. It, too, changed by only a small percentage between the pre- (19.3 ± 5.2%) and post-bleaching (16.9 ± 3.8%) periods (Table 2.6.1). No material decrease in coral cover and concomitant increase in fleshy algae cover could therefore be detected as a result of the 2015-2016 coral bleaching event.

__Table 2.6.1.__ Average percentage change in coral cover at five Sodwana Bay sites on Two-mile Reef in the Central Complex, comparing coral cover before and after the bleaching event.

Site	Percentage change in total coral cover	Percentage change in hard coral cover
Arches	-18.0	0.6
Chain	21.2	-5.4
Coral Gardens	-1.8	-11.4
Eden	22.3	4.8
Simons Cave	0.8	-0.3
Ave ± SD	4.9 ± 17	-2.3 ± 6.2

2.6.3 Discussion

As in previous bleaching events and periods of warming, South African coral reefs were only negligibly affected relative to more northern countries in the region. Importantly, no bleaching-related mortality was recorded in post-bleaching recovery surveys on Two-mile Reef in the Central Complex. Furthermore, there was no material change in the cover of total coral, hard coral or fleshy algae. The negligible change measured probably reflects the naturally high within-site variation in coral and other living cover that could not be accounted for in the follow-up survey, despite sampling at the same sites.

The levels of bleaching varied among sites and this was largely attributable to the interaction of latitude and depth. Shallow sites in the north were generally more affected than deep sites in the south, which was previously noted by Ruiz Sebastian *et al*. (2009), who also found that deeper sites generally had less bleaching. The latitudinal gradient in bleaching indices is likely to be a function of the decreasing trend in sea-surface temperature with increasing latitude that characterizes the region (Porter et al., 2017).

The South African coral reefs have remained healthy over the last two decades and they have not experienced significant levels of bleaching in recorded history. The most severe bleaching event probably occurred in 2000, when 12% of the total living cover manifested some degree of bleaching (Celliers & Schleyer, 2002). Evidence in this report suggests that the 2016 bleaching event was therefore less severe than that experienced in 2000. This despite the fact that the 2015-2016 El Niño, on a global scale, was longer in duration and more extensive than the 1997-1998 episode that caused widespread mortality to coral communities in the western Indian Ocean (Goreau et al., 2000; Jacox et al., 2016; Zhai, 2016).

2.6.4 Recommendations

In order to maintain and enhance the conservation and proactive management of coral reefs in South Africa, it is important that several attributes be acknowledged, and new measures implemented at various levels:

1) South Africa’s coral reefs should be acknowledged as nationally important natural barometers in indicating climate change.

2) A multi-disciplinary Centre of Excellence, with specialist skills in coral reef ecology, climate science and monitoring, should be identified and supported with consistent and adequate funding to conduct bleaching monitoring and general reef health assessments.

3) Research proposals aimed at investigating the potential effects of climate change on these marginal coral reefs should be prioritized and given adequate funding.

4) Coral reef monitoring should be conducted routinely and on an annual basis, and not just during periods of El Niño or during other threats. Fixed transects should be used to reduce natural variation to enhance precision for detecting temporal changes.

5) Management should ensure that anthropogenic stressors and disturbances on coral reefs are kept to a minimum to maintain and enhance coral reef resilience in the face of anticipated future warming events.

6) The role of the Maputaland and St Lucia Marine Reserves in the iSimangaliso Wetland Park, in climate adaptation and mitigation, should be recognized (Simard et al., 2016). The high levels of protection and world heritage site status must be maintained for the climate mitigation and adaptation benefits of this globally important MPA to be secured into the future (Roberts et al., 2017).

7) Coral monitoring and the development of a bleaching response plan must be incorporated into the National Adaptation Plan as outlined in South Africa's Intended Nationally Determined Contribution submitted to the United Nations Framework Convention on Climate Change (UNFCCC).

8) The prioritization of mitigation interventions that significantly contribute to a peak, plateau and decline greenhouse gas emission trajectory in accordance with South Africa's Intended Nationally Determined Contribution and the National Climate Change Response: White Paper. In particular, interventions within the energy, transport and industrial sectors.

2.6.5 References

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2.7 Tanzania

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2.7.1 Background to the 2016 bleaching event

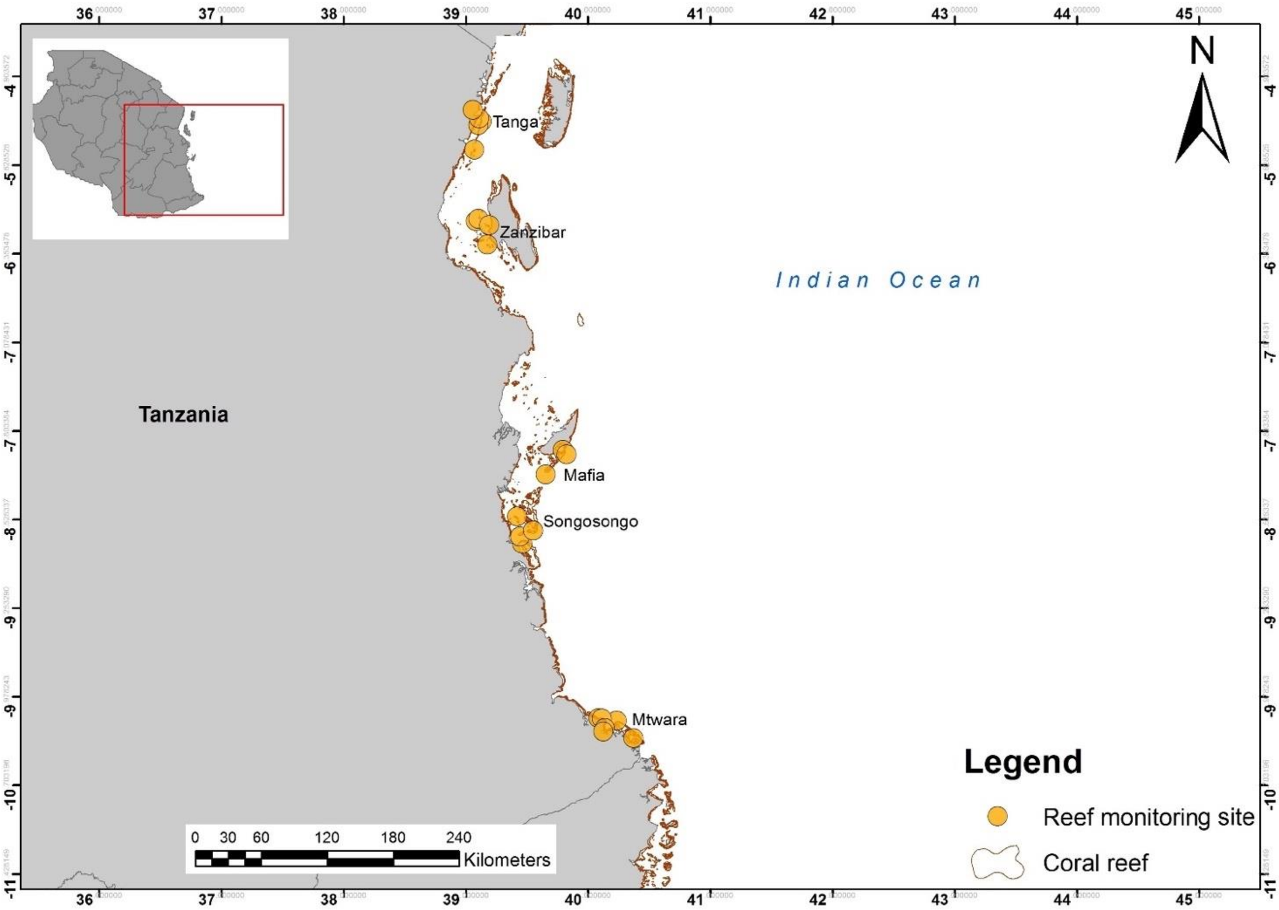

Figure 2.7.1. *Coral reef monitoring stations in Tanzania for which data were included in this post-bleaching study.*

2.7.1.1 History of coral bleaching events in Tanzania

Coral reefs in Tanzania were severely impacted by the first global bleaching event in 1998, losing up to 90% of hard coral cover in places (Obura, 2002; Wagner, 2004). Impacts were felt more on reef flats than on deeper reef slopes.

Sites around Pemba such as on Misali Island lost up to 70% of hard coral cover. Reefs around Unguja Island were also impacted, with losses of 24% of hard coral cover at Chumbe and Kwale reefs, approximately 30% at Chole Bay, and about 50% at Kitanga, Taa and Chanjale reefs (Muhando and Mohammed, 2002). There was over 80% loss of coral cover in various sites at Mafia, over 65% loss in

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***Fieldwork team:** Saleh Yahya (National Coordinator), January Ndagala, Ali M. Ussi, Mohammed S. Mohammed, Hassan Kalombo.*

Mnazi Bay and between 10-75% in Tanga (McClanahan et al., 2007). Reefs in Songo Songo were the only sites not to experience significant losses (McClanahan et al., 2007).

2.7.1.2 Progression of the 2016 coral bleaching event

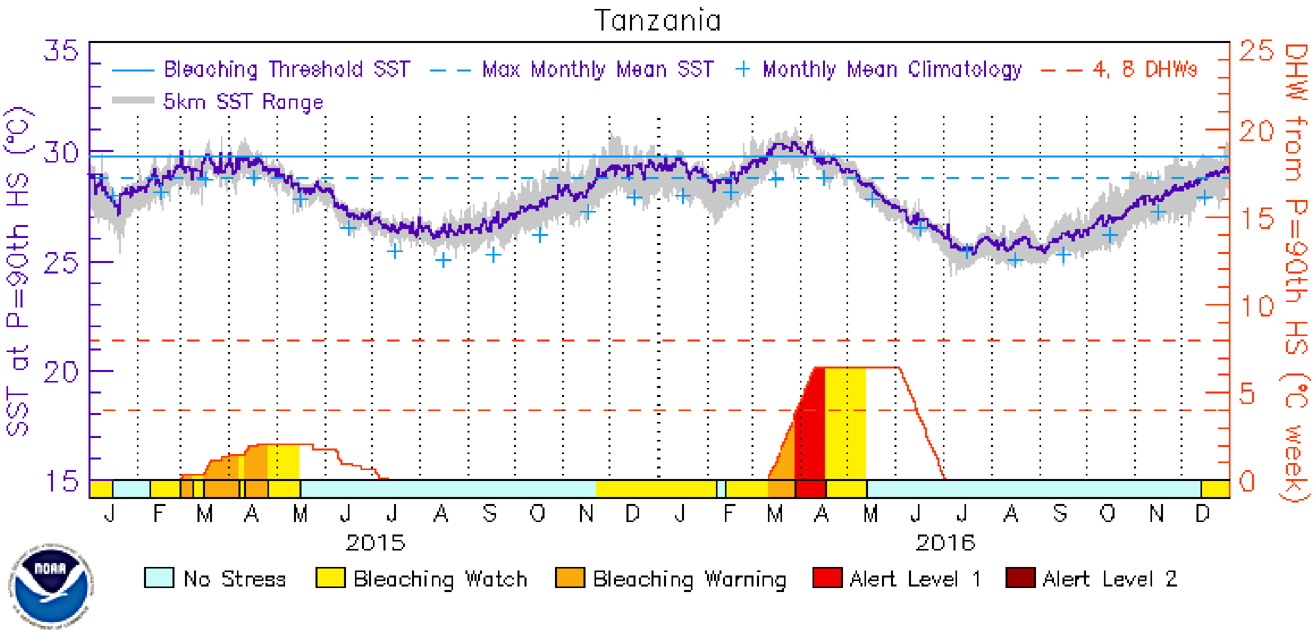

Figure 2.7.2. *National Oceanic and Atmospheric Administration (NOAA) Coral Reef Watch satellite bleaching products, showing the bleaching related climatic conditions present at a remote satellite monitoring station in Tanzania.*

In 2016, thermal stress began to accumulate relatively late, in mid-March, and peaked in early April at 6 degree-heating-weeks and alert level 1 (fig. 2.7.2). In mid-March to early April 2016, at the peak of coral bleaching, water temperatures repeatedly reached 31°C. After the first week of May bleaching stress had subsided completely.

Coral bleaching started in February 2016 and increased through till June (fig.2.7.3b). Peak bleaching occurred during late March and into April. Bleaching of 80–90% was observed on some reefs, such as Sinda reef off Dar es Salaam and northern Chumbe reef, Zanzibar (Yahya et al., 2017).

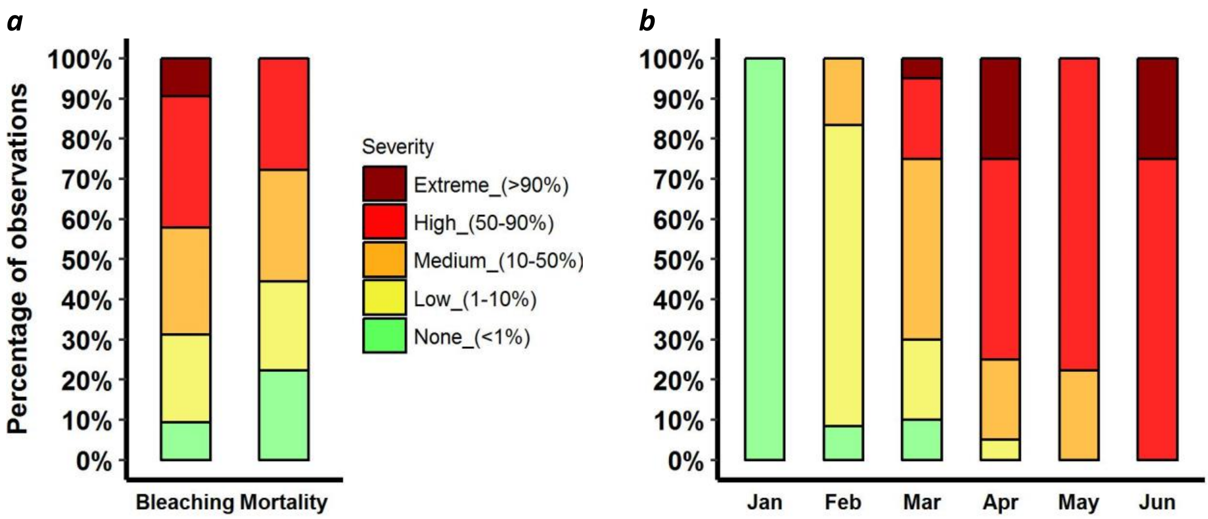

Figure 2.7.3. *Breakdown of observations collected in Tanzania in 2016 - a) coral bleaching (n=64) from Jan-May and mortality (n=18) from May-September 2016 and b) monthly breakdown of bleaching observations (Jan; n=3, Feb; n=12, Mar; n=20, Apr; n=20, May; n=9, Jun; n=4). Categories represent the severity of bleaching/mortality reported as percentage of coral cover bleached/dead at a site.*

Over 40% of reports from January to May indicated that there was severe bleaching (greater than 50% of coral cover bleached) (fig. 2.7.3a).

The effects of bleaching varied between species and growth forms, with the most affected corals at most sites being *Acropora*, *Fungia, Pocillopora, Porites* and the faviids. On Chumbe reef in Zanzibar, branching and table *Acropora* suffered significant mortality (Yahya et. al., 2017).

2.7.2 Results

In total, the analysis included data from 25 sites from 5 areas spread across the whole Tanzanian coast – Mtwara, Songo Songo, Mafia, Tanga and Zanzibar – between 1996 and 2017. Across all sites between 1992 and 2016, there is no long-term trend in hard coral cover, with mean cover varying between 30% and 55%, although temporary downward blips are shown in 1998/9 and 2010 corresponding to bleaching events (fig. 2.7.4).

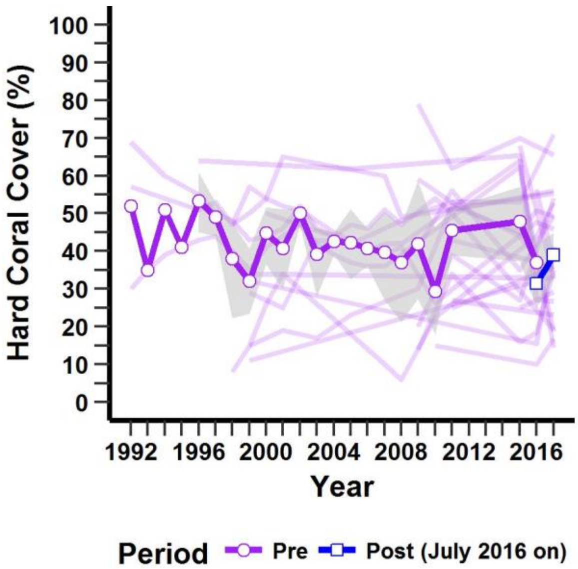

__Figure 2.7.4.__ Trends in hard coral cover on Tanzanian coral reef sites before and after the 2016 bleaching event (national mean (dark bold line) split into historical pre-bleaching data (purple line, open-circles) and post-bleaching data from July 2016 onwards (blue line, open-squares), 95% confidence limit (grey shaded area), individual monitoring stations (faded background lines)). Only stations with data for both periods were included in the analysis (n=25).

Even after the bleaching event in 2016, no major change in coral cover is clear, with coral cover remaining around 40% in 2017. The difference between 2016 post-bleaching and 2017 values (an apparent increase) is due to different sites represented rather than any actual recovery. For sites where both coral and fleshy algal cover were recorded, there has been an overall trend of increasing algal cover (and variability) from 1992 to 2017 (fig. 2.7.5). Levels of algal cover post-bleaching range between 15-20% and are significantly higher than the means in 2011 and 2015.

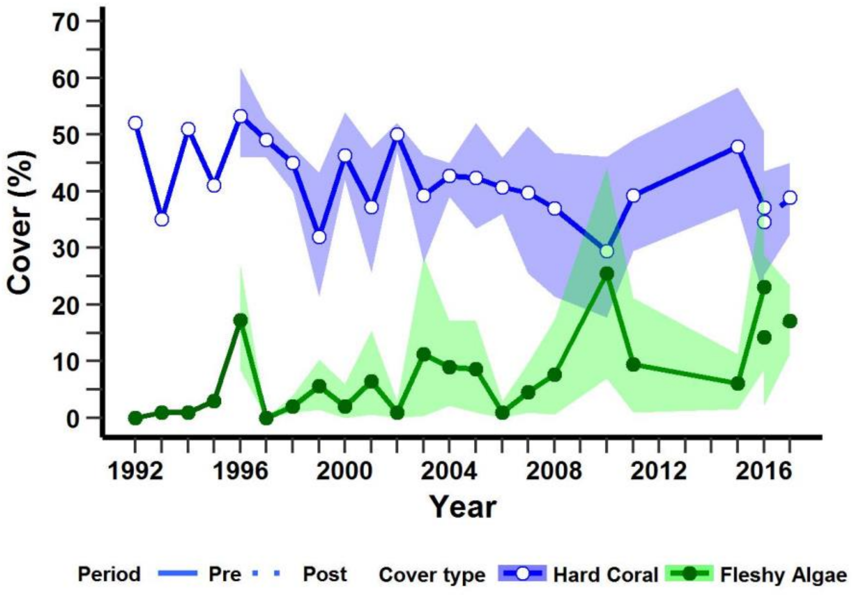

__Figure 2.7.5.__ Trends in fleshy algae (green line, closed circles) and hard coral cover (blue line, open-circles) in Tanzania before (solid line) and after (dotted line) the 2016 bleaching event. Shaded areas represent the 95% confidence limit. Only stations with data for both periods and with both fleshy-algae and hard coral cover were included in the analysis (n=24). The post-bleaching period is from July 2016 onwards.

Overall, from sites where pre- (2012 to June 2016) and post-bleaching (since July 2016) data for both coral and algal cover are available, there was an average decrease in live hard coral cover by almost 10% from 44 ± 4.7% (mean ± se) to 39 ± 4.2%, and a corresponding increase in fleshy algae cover, from 12 ± 4% to 15 ± 3.9% (fig. 2.7.6a).

a
b

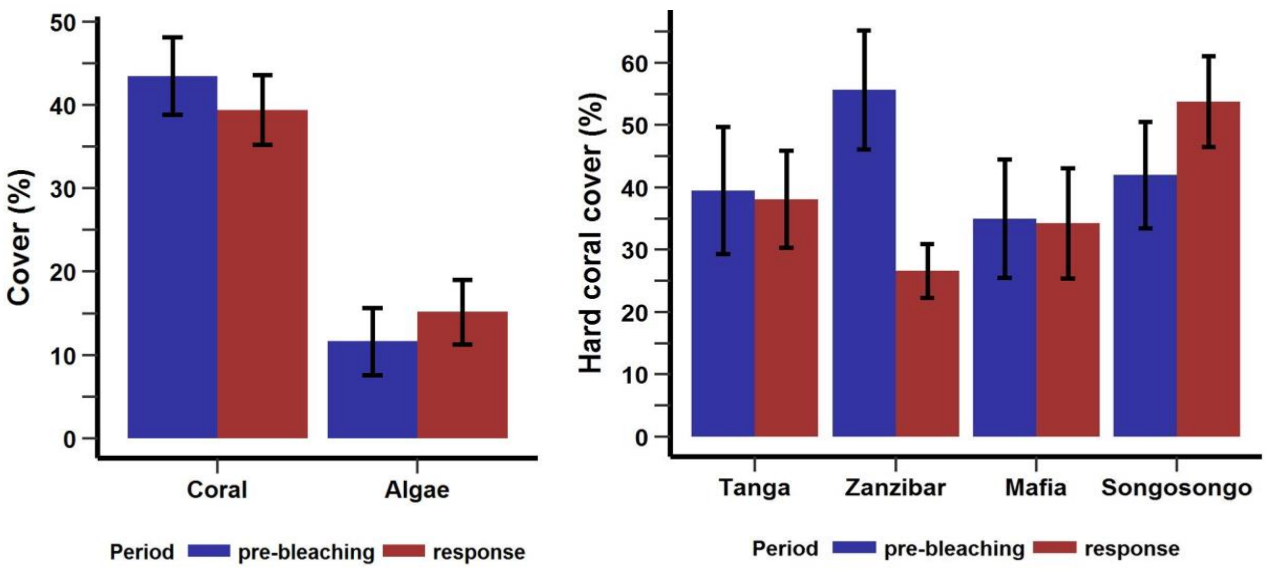

__Figure 2.7.6.__ Pre- and post-bleaching (response) mean (with standard error bars) __a)__ hard coral and fleshy algae cover of all Tanzanian reef sites with both fleshy-algae and hard coral cover data (n=16) __b)__ hard coral cover for the various regions in Tanzania arranged from North to South (Tanga; n=4, Zanzibar; n=4, Mafia; n=3, Songo Songo; n=5). Pre-bleaching data is from 2012-June 2016 and 'response' data is from July 2016 -2017. Only sites with data for both periods and were included in the analysis.

Comparing the change in coral cover at different areas in Tanzania after the bleaching event, we find that coral reefs in Zanzibar were the worst affected, with a 52% decrease in coral cover (56± 9.6%

pre-bleaching to 27 ± 4.3%, post-bleaching). Tanga recorded a minor decline (from 40 ± 10.1% to 38 ± 7.8%), as did Mafia Island (from 35 ± 9.5% to 34 ± 8.8%). Songo Songo showed an increase in coral cover (pre-bleaching 42 ± 8.6% to post-bleaching 54 ± 7.3%) (fig. 2.7.6b).

2.7.3 Discussion

The 2016 bleaching event had a lower than anticipated impact on Tanzania's reefs. Bleaching reports during January and May indicate that several sites experienced high levels of bleaching, but the lower levels of mortality points towards substantial recovery and survival of bleached corals. This may be due to resistance gained from surviving previous bleaching events, together with the early onset of the southeast monsoon that helped cool temperatures allowing bleached corals to recover. However, the lack of available data for a number of sites between 2011 and 2016 makes it difficult to make a precise assessment of the overall effect of the bleaching event on hard coral and algal cover. Nevertheless, some areas were significantly affected, particularly on the west coast of Unguja Island, Zanzibar. Once again, *Acropora* was the most susceptible to bleaching and mortality, especially on the shallow reefs of Chumbe. This could be important for any in-situ coral nurseries and restoration projects that plan to use this fast-growing genus. Interestingly, sites in Songo Songo were relatively unaffected by the bleaching, as occurred in 1998. The lack of bleaching and mortality from the 1998 event was attributed to screening by 'green water' from the Rufiji delta (Obura, 2005), which may provide stable protection for coral reefs in this area.

National hard coral cover remains at close to 40% even after the bleaching event, which is moderate relative to other countries in the region. Fleshy algae levels are moderate at under 20% but have shown an upward trend over several years. In the shallower reef flats, where most of the bleaching mortality occurred, there was a significant increase in turf algae. Unpublished data (S. Yahya 2017) shows a possible change in structure of fish assemblages, with an increase in herbivore species, likely due to the increase in turf algae. The abundance of these grazers may also explain the insignificant increase in fleshy algae, and the importance of herbivory in suppressing algal growth.

The long-term history of high coral mortality (in 1998), recovery to near pre-bleaching conditions for most sites and resistance of some sites to renewed bleaching is an indicator of some degree of resilience against climate change (e.g. McClanahan et al., 1999, 2009) and should be a priority for future conservation actions.

2.7.4 Recommendations

Based on the current state of the coral reefs in Tanzania, and their response to the coral bleaching of 2016, as well as long-term trends, the following recommendations are made:

Monitoring and understanding coral reef health

1) Coral reef monitoring should be continued, supported and expanded to include more sites and other parameters, particularly coral bleaching and disease.

2) Establish effective national coral bleaching response plans with the capacity, to include preparation, funding, monitoring and communications/awareness creation. Individual research programmes, NGOs and others can develop their own tailored coral bleaching response plans to help them prepare for future bleaching events.

3) Collate all historical coral reef health data into a central, safe database for secure storage and ease of access. To support this, a system to share metadata on coral reefs will make it easier to share information among organisations and foster greater collaboration.

Maintaining and improving the health of coral reefs

4) The role of herbivory in maintaining low cover of fleshy algae may be important on Tanzanian reefs and managing fisheries to protect herbivore populations should be considered.

Policy and research

5) Targeted research on the differential response of Tanzanian reefs to thermal stress and coral bleaching should be undertaken, to identify if there are resilient reefs (bleaching refuges), and what can be done to protect such sites and to promote seeding of other reefs.

2.7.5 References

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