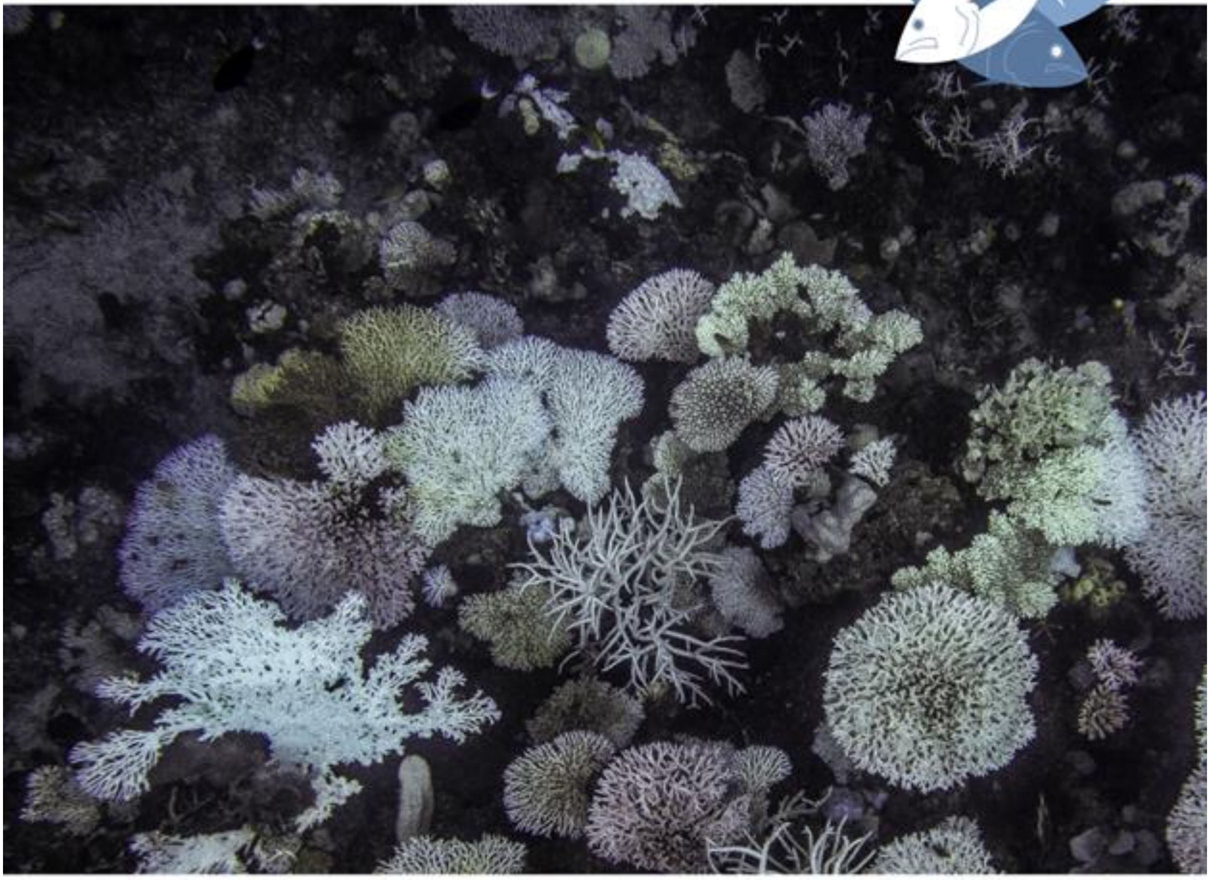
Status of Coral Bleaching in the Maldives 2016



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In collaboration with:

IUCN REGENERATE USAID

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EXECUTIVE SUMMARY

This report represents the most comprehensive effort to monitor coral bleaching in the Maldives to date, using a combination of citizen science and expert scientist (governmental, academic and non-governmental) data sets. The 2015-2016 El Niño weather phenomena and associated sea surface temperature anomalies in 2016 caused one of the largest recorded episodes of mass bleaching in the Maldives. The El Niño began in 2015 and caused sea surface temperature anomalies in the Pacific Ocean, first affecting Hawaii in August 2015. The 2016 El Niño is considered to be one of the strongest El Niño events recorded since 1950. In Maldives, sea surface temperatures and degree heating weeks peaked from late April to mid May 2016, precipitating the bleaching event, with high temperatures over 32°C recorded. Although the bleaching event was devastating in its impact on many Maldivian coral reefs, the event provided the opportunity to enhance our understanding of bleaching patterns in a way that was not possible in 1998. A much larger and more detailed data set for the Maldives was collected in 2016 due to the continued monitoring of the National Coral Reef Monitoring Sites (NCRMS) by the Marine Research Centre (MRC), collaborations with international partners such as the International Union for the Conservation of Nature (IUCN) and an expansion of data collection to additional sites around the Maldives in 11 atolls, with the help of citizen scientists and resort marine biologists. A total of 71 sites, consisting of sheltered (sheltered from oceanic wave actions) and exposed (exposed to oceanic wave actions) sites, across 11 atolls within 0 m to 13 m depth range were surveyed from March to June 2016 to understand the severity of the bleaching event.

The overall percentage of bleached corals recorded across all 71 sites in the Maldives is 73%, indicating a severe bleaching event. Analyses of the multiple monitoring efforts suggest that 66% of corals bleached at a depth of 0m to 7 m, and 77% of corals bleached in depth from 7m to 13 m. Furthermore, 72% corals in sheltered sites and 74% of corals in exposed sites bleached, with no significant difference in bleaching response detected between exposures.

The bleaching susceptibility index for coral genera shows free-living genera such as *Fungia, Herpolitha, Cycloseris* and *Halomitra* to be highly susceptible to bleaching. Other genera

found to be highly susceptible are *Pectinia, Merulina, Gardinoseris and Acropora*, which is the most dominant reef building coral genus in Maldives. On the other end of the spectrum corals from the more resistant Faviidae family, for example *Favites* and *Leptastrea,* and Poritidae family, for example *Porites* and *Goniopora*, were observed to be more resistant and less susceptible to bleaching. Assessments of post-bleaching coral mortality show a high decline in live coral cover in the sites surveyed. The highest levels of mortality occurred amongst corals of the *Acropora* genus, with low levels of mortality within the *Porites* genus.

Despite the high impact of the event, a number of sites (e.g. Drift Thelu Veliga House Reef in South Ari Atoll, Blue Cove and Coral Gardens at Magoodhoo island in Faafu Atoll, Reethi Beach West in Baa Atoll, Sonevafushi House Reef in Baa Atoll, and Emboodhoo Finolhu Inner Reef in South Malé Atoll) were reported to have less than 45% incidence of coral bleaching and more than 25% live coral cover. These sites have been defined as 'hope spots', and warrant further attention through follow up surveys and possible investment in management and protection.

CONTENTS

FOREWORD

Coral reefs are the physical basis of the Maldives, protecting the islands and nourishing its beaches. They also provide the resource base for tourism and fisheries – the two essential pillars of the Maldivian economy. Coral reefs are subjected to increasing stresses from developmental activities that are currently necessary for the Maldives but also from climate induced warming of the seas. The first known recorded mass bleaching event in 1998 is believed to have killed over 90% of the shallow coral in the Maldives. Like many other parts of the world, Maldives was not prepared at the time for monitoring reefs in advance of the event. As a response, the Marine Research Centre established a National Coral Reef Monitoring Programme in 1998, representing sites that span the entire length of the Maldives. The monitoring continues to this day and some of its results have been published.

The most recent mass-bleaching event of early 2016 was recorded relatively well in comparison to 1998. MRC, NGOs and tourists resorts conducted monitoring prior, during and after the event. This report summarizes the key findings of those activities following the event, providing a comprehensive overview of the status of the coral reefs. It is important to note that there are a number of parties in the Maldives, either based on tourist resorts or working collaboratively with the facilities, interested in coral reef monitoring and research. This work represents collaboration between the USAID-funded Project REGENERATE being implemented by the IUCN in the Maldives, with the MRC and the Ministry of Environment and Energy. We are grateful for the assistance from IUCN in this work.

It is hoped that the compilation will be useful for the scientific community in providing the status of the coral reefs following the bleaching event. Coral bleaching, caused by warming sea surface temperatures, is a clear and visible sign that climate change is already having impacts on our planet's ecosystems. It is a call to action for the global community to reduce carbon dioxide emissions, to move towards a decarbonized economy and to implement the Paris Agreement in order to give our valuable coral reef ecosystems an improved chance of survival.

M. Shiham Adam
Director General

ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
ARC	Australian Research Council
BC	Bleached Coral
CBRP	Coral Bleaching Response Plan
CCAP	Climate Change Adaptation Project
CoTS	Crown-of-Thorns Starfish
CRW	Coral Reef Watch
DHW	Degree Heating Weeks
EPA	Environmental Protection Agency
GBR	Great Barrier Reef
GCBE3	3rd Global Coral Bleaching Event
IUCN	International Union for Conservation of Nature
MAT	Maldivian Air Taxi
MNDF	Maldives National Defense Force
MoEE	Ministry of Environment and Energy
MoFA	Ministry of Fisheries and Agriculture
MoT	Ministry of Tourism
MRC	Marine Research Centre
NBC	Non-bleached Coral
NCRMP	National Coral Reef Monitoring Programme
NCRMS	National Coral Reef Monitoring Site
NOAA	National Oceanic and Atmospheric Administration
OT	Other benthic categories
PIT	Point Intercept Transect
REGENERATE	Reefs Generate Environmental and Economic Resilience in Atoll Ecosystems
RKC	Recently Killed Corals
SST	Sea Surface Temperature
TMA	Trans Maldivian Airways
USAID	United States Agency for International Development

INTRODUCTION

This report presents results of coral bleaching assessments conducted by MRC, IUCN, Project REGENERATE and other data submitted to MRC and IUCN during the coral bleaching period in 2016. Results are presented as bleaching assessments of the NCRMS; of the North Ari expedition of IUCN conducted in May 2016 and of bleaching data reported by marine biologists working in the resorts and other citizen scientists who submitted data during the coral bleaching in the Maldives. This report and other reports regarding the long term coral reef monitoring Programme can be downloaded from the MRC website.

BACKGROUND

After the mass bleaching event of 1997/1998, the Marine Research Centre (MRC) set up a National Coral Reef Monitoring Programme (NCRMP) in 1998. This Programme is based on sites which were surveyed directly after the 1998 coral bleaching and additional sites which were monitored to understand long term changes to coral reefs in Maldives. For brevity, these long-term coral reef monitoring sites are called National Coral Reef Monitoring Sites (NCRMS). In total 16 NCRMS were established across the Maldives, located in 5 atolls, to understand coral reef recovery from bleaching and long term changes due to natural and anthropogenic factors. NCRMP was designed to monitor these long term monitoring sites annually but due to lack of capacity and financial limitations, the goal of annual monitoring has been challenging.

The 2015-2016 El Niño and associated 2016 sea surface temperature anomalies (in the Maldives) caused the largest bleaching event recorded in the Maldives since 1998. Although devastating in its impact on corals, it did provide the opportunity to enhance our understanding of bleaching patterns in a way that was not possible in 1998. A more detailed data set for the Maldives was possible in 2016 than in 1998 due to the continued monitoring of the NCRMS, collaborations with international partners such as IUCN, and an expansion of data collection to additional sites around the Maldives with the help of citizen scientists and resort marine biologists. In 2016, more observers were available within the Maldives than in 1998 to record the coral bleaching event, with more marine biologists in resorts and a higher level of alertness by governmental and non-governmental institutions. Bleaching warnings and predictions based on satellite sea surface temperature (SST) data from NOAA (http://coralreefwatch.noaa.gov/vs/gauges/maldives.php[1]) also allowed a higher level of preparation than in 1998. Therefore the opportunity to record the mass coral bleaching event at an unprecedented scale (i.e. sites surveyed and data collected) was presented. Photo 1 and Photo 2 show bleached corals seen during the 2016 bleaching event. This report focuses on the impacts of the 2016 bleaching event, providing a summary of data from around the Maldives on the incidence and spatial variability of bleaching. A total of 71 sites in 11 atolls were surveyed either using Point Intercept Transect (PIT) and Belt Transect (BT) protocols to monitor the bleaching.

Following the 1998 bleaching event, around 80% of corals completely or partially bleached on the back reef (Wilkinson, 1998), where 60-100% coral mortality was reported depending on species and location (Bianchi *et al*, 2003; Wilkinson, 1998). Coral reefs of the Maldives displayed resilience and capacity for recovery, especially relative to continental coral reefs in the Indian Ocean and also to other Indian Ocean islands (with the notable exception of more remote islands with smaller human populations such as the Chagos Archipelago; Sheppard, et al, 2008). Morri *et al* (2015) note that in 1998, average live coral cover around the Maldives dropped from over 50% (Morri *et al*, 2015; Jaleel, 2013) to below 10% due to bleaching-induced mortality (McClanahan, 2000; Zahir, 2000; Edwards *et al*, 2001). *Acropora* cover declined, whilst massive (i.e. *Porites*) and encrusting (i.e. *Pavona*, *Leptastrea* etc.) coral species were the main survivors. However by 2004, large tabular *Acropora* coral colonies were already observed to be abundant on the reefs (Lasagna, 2010), and by 2009 reefs were observed to have returned from being dominated by massive and encrusting corals to *Acropora*-dominated reefs (Morri *et al*, 2015). Recovery to pre-1998 average live coral cover levels was observed by 2013 (Morri *et al*, 2015; Jaleel, 2013), despite a subsequent moderate bleaching event in 2010, the 2014 tsunami, which had comparatively little effect on coral cover (Zahir *et al* 2005), and episodes of *Acanthaster planci* (Crown-of-Thorns Starfish - COTS) outbreaks. Morri *et al* (2015) conclude that by 2014 the coral community was similar to pre-1998 conditions (Figure 1). However, some coral species did not recover, structural complexity on the reef has been reduced, the coral community composition has been observed to shift in many reefs (for example the loss of *Seriatopora*

[1] Accessed July 2016

hystrix or *Stylophora pistillata* and a higher abundance of more thermally tolerant species; McClanahan and Muthiga, 2014), and some reefs have become dominated by corallimorphs rather than scleractinian corals (Solandt *et al*, 2014).

A long-term and potentially irreversible phase shift to an algae-dominated reef was observed in many places throughout the Indian Ocean following the 1998 bleaching event (Graham *et al*, 2015), but was fortunately avoided in the Maldives with only short term shifts to algal-dominated communities observed, followed by recovery to coral-dominated ecosystems (Lasagna *et al*, 2008). On average, coral cover increased approximately 3% per year from 1998 to 2002 (Zahir, 2002). Important factors in ensuring the resilience of coral reefs and avoiding a permanent phase shift to an algal-dominated reef in the Maldives were the high biomass of herbivorous fish as these are not traditionally targeted for the tuna-based Maldivian diet (McClanahan, 2011; Tkachenko, 2012; Risk and Sluka, 2000); the large number of coral reefs in the Maldives (Naseer and Hatcher, 2004) connected in a vast system meaning a higher number of potential climate refuges that can reseed reefs following bleaching events; and the relatively small and dispersed human population in the country.

Photo 1: Tabular *Acropora* on reef top at 5m in Emboodhoo Finolhu Reef, South Male' Atoll

Photo 2: Non-bleached and bleached *Acropora* colony on reef slope at 10 metres in Rasdhoo House Reef, North Ari Atoll

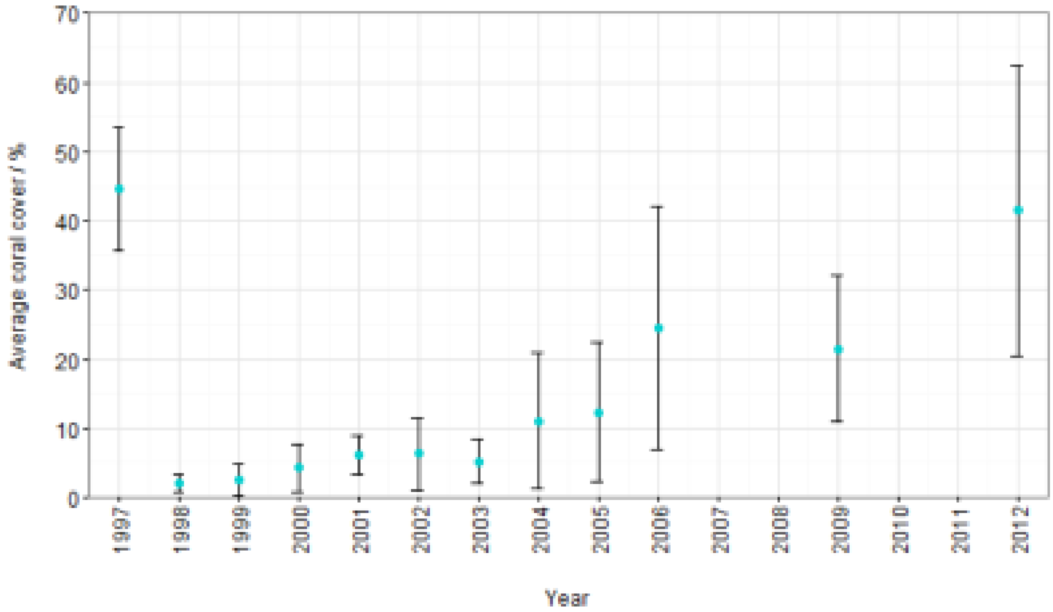

Figure 1: Average coral cover reported in the literature for Maldives from different sites, showing recovery from the 1998 bleaching event. Coral cover data were extracted from 15 peer reviewed or grey literature articles. The mass mortality of 1998 and subsequent recovery is clearly visible.

Sources: McClanahan (2000) Bleaching Damage and Recovery Potential of Maldivian Coral Reefs. Marine Pollution Bulletin.
Edwards et al (2001) Coral Bleaching and Mortality on Artificial and Natural Reefs in Maldives in 1998, Sea Surface Temperature Anomalies and Initial Recovery. Marine Pollution Bulletin.
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Jaleel (2013) The status of the coral reefs and the management approaches: The case of Maldives. Ocean and Coastal Management.
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EPA (2014) Rasdhoo Atoll marine survey. EPA.
McClanahan & Muthiga (2014) Community change and evidence for variable warm-water temperature adaptation of corals in Northern Male Atoll, Maldives. Marine Pollution Bulletin.
Morri et al (2015) Through bleaching and tsunami: Coral reef recovery in the Maldives. Marine Pollution Bulletin.
Solandt et al (2015) Little and large: surveying and safeguarding coral reefs & whale sharks in the Maldives. Marine Conservation Society

Pre-bleaching preparations

The main objective of the NCRMP is to monitor change and understand coral reef recovery from the 1997/1998 bleaching event. The El Niño began in 2015 in the Pacific Ocean, first affecting Hawaii in August and is considered to be among the strongest El Niño on record since 1950. Given the scale of the 2016 event, this report’s emphasis is to measure and understand the impacts of the mass coral bleaching which began in late April 2016 when thermal stress crossed the bleaching threshold (Figures 2 and 3). Sea temperatures in the tropics have increased by almost ~1°C over the past 100 years and are currently increasing at the rate of approximately ~1-2°C per century (Hoegh-Guldberg, 1999). Corals experience thermal stress, the main cause of bleaching, when sea surface temperatures exceed ~1°C above the maximum average that they are adapted to during warm months. This stress increases the longer the temperatures remain above average. Degree Heating Weeks (DHW), a product of NOAA Coral Reef Watch, show how much heat stress has accumulated in an area over the past 12 weeks by adding up any temperature exceeding the bleaching threshold during that time period. When an area reaches 4 DHWs, significant coral bleaching is likely, especially in more susceptible coral species. According to the DHWs product of NOAA published for the Maldives, thermal stress increased in mid-April and peaked at 5 DHWs during the month of May (Figure 2, Figure 3 and Figure 4).

MRC, with collaborating partners such as IUCN, started planning for the very likely bleaching event induced by El Niño in June 2015 based on the predictions by NOAA Coral Reef Watch, with training and capacity-building workshops to monitor the event. By the time heat waves reached the Maldivian coral reefs, MRC in collaboration with IUCN, had conducted three workshops to train marine biologists and marine enthusiasts on collecting data on coral bleaching. A total of 82 citizen scientists (27 women and 55 men) were trained (Photo 3a-d). The specific objectives of the coral bleaching assessments were:

- To understand bleaching severity (i.e., percentage corals bleached) and scale (how widespread the bleaching was).
- To provide scientific information to government and to the public for policy decision-making and awareness about the severity of the bleaching.
- To monitor and understand future changes to coral cover at long-term monitoring coral reef sites as well as additional sites monitored by resort marine biologists across the Maldives.

Two bleaching protocols were formulated 1) A simplified point intercept transect (PIT) benthic monitoring protocol which aims to record the benthic status (coral cover, composition and coral community etc.) according to the level and understanding of coral taxa of the observer. 2) Detailed benthic monitoring which is targeted to expert individuals who have detailed understanding of coral taxonomy using a belt transect method.

After data collection protocols were finalized, they were circulated to marine biologists and marine enthusiasts across the Maldives. Training programs were then conducted to further familiarize the citizen scientists with the protocols. Nationwide data collection was possible as many resorts employ trained marine biologists with the capacity to monitor the coral reef. It was focused on surveying long-term coral reef monitoring sites, as well as a joint expedition to assess coral bleaching in Alif Alif (North Ari) Atoll.

Photo 3(a): Nizam Ibrahim from MRC Picture providing training to marine biologists on monitoring coral bleaching; **(b)** Gabriel Grimsditch from IUCN Maldives providing training to marine biologists on monitoring coral bleaching; **(c)** Fathimath Nistharan from IUCN Maldives in a one day training workshop held in early April 2016 for marine biologists and government officials to prepare for the bleaching event; **(d)** Participants of the workshop

Aerial photos from seaplane pilots

Awareness sessions were conducted for the pilots of the largest seaplane operator in the Maldives, Trans Maldivian Airways (TMA) on 13th of April. The main aim of this awareness session was to explain to pilots what coral bleaching is and how to take aerial photographs (Photo 4 and Photo 5) if they observe coral bleaching. In this awareness session a total of 23 pilots from TMA participated. A second seaplane operator the Maldivian Air Taxi (MAT) was briefed regarding coral bleaching and how to contribute to aerial observations.

Photo 4: Non-bleached and bleached coral colonies on reef slope at 10 metres in Rasdhoo House Reef, North Ari Atoll

In response to the awareness sessions and the request by MRC to report coral bleaching in aerial observations, a total of 11 aerial coral bleaching observations were received by MRC. Two pilots from MAT and one from TMA reported these aerial observations. The majority of aerial coral bleaching observations were received with the photographs taken by seaplane pilots.

Photo 5: Aerial photograph of visible coral bleaching on a reef flat and slope near Kalhufahalafushi, Thaa Atoll from the 13th of April 2016. The white dots on the fore-reef in front of the wave break zone is evidence of bleached coral from a depth of approximately 3-7m. Image courtesy of Captain Mohamed (Maldivian Air Taxi)

Deployment of temperature loggers

Temperature loggers were deployed across the country to measure the *in situ* real time temperature reading in 10 m and 5 m (Photo 6).

NOAA Coral Reef Watch, predictions

Due to the strong El Niño signal and predicted thermal anomalies (https://coralreefwatch.noaa.gov/satellite/ssta.php), from mid-2015 the Coral Reef Watch, (CRW) of the National Oceanic and Atmospheric Administration (NOAA) of the United States already predicted coral bleaching for the Maldives region starting from April 2016. During May, the CRW alert level in Maldives reached 2, the highest possible alert level. The time series graphs below (Figure 2 and 3) show Sea Surface Temperature and Degree Heating Weeks by month, with comparisons between years. The figures also show alerts issued to the Maldivian region. Figure shows *in situ* temperature data collected at Bandos House Reef in North Malé Atoll, one of the long-term MRC monitoring sites.

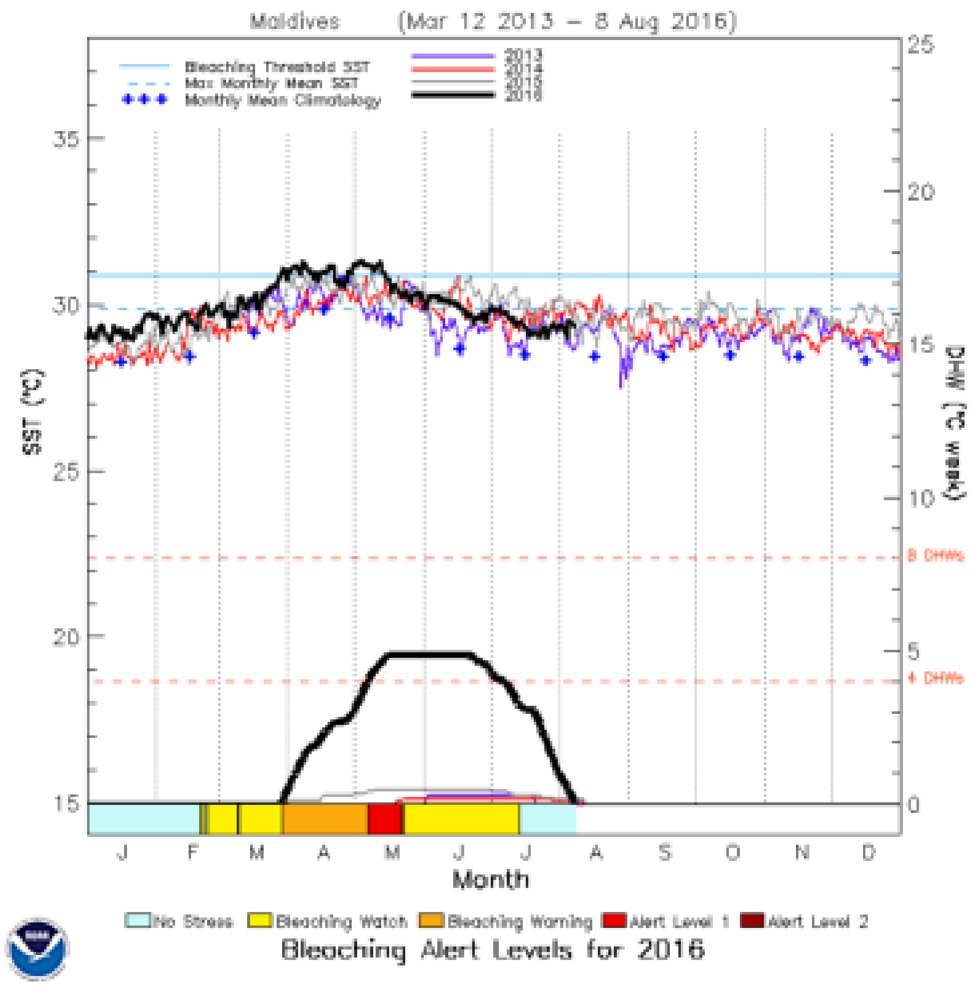

Figure 2: Degree heating weeks (secondary axis) and thermal stress anomalies for the Maldives for 2013 - 2016, with different years compared with different coloured lines. 2016 (dark bold color) displayed the highest thermal stress and the highest number of degree heating weeks, with peak DWHs in May and June 2016. The data were collected by NOAA satellites.

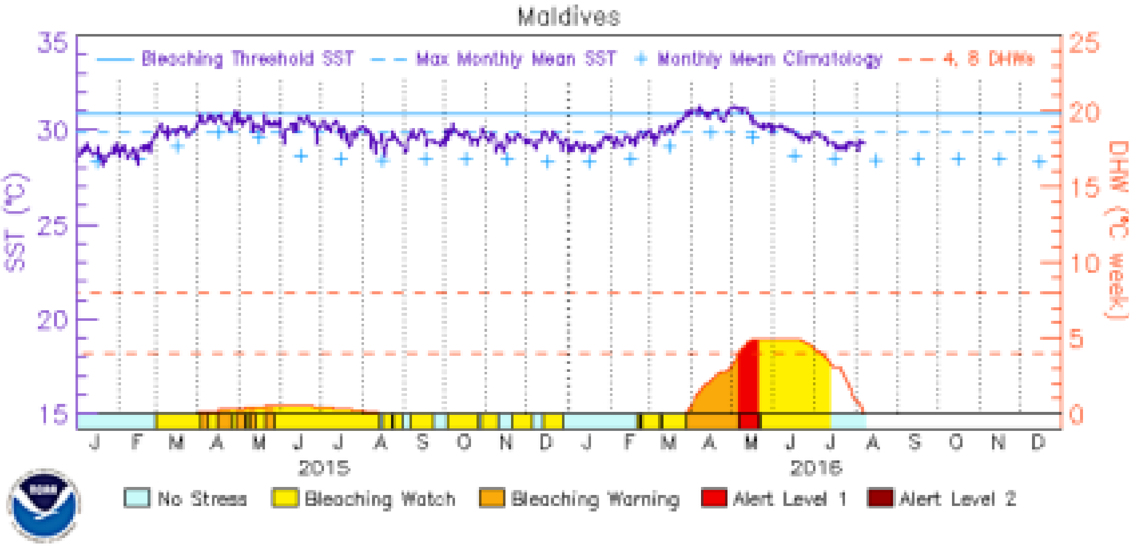

Figure 3: Daily temperatures in Maldives in 2015 and 2016, as well as the degree heating weeks (secondary axis) and thermal stress anomalies that led to the bleaching event. The data were collected by NOAA satellites.

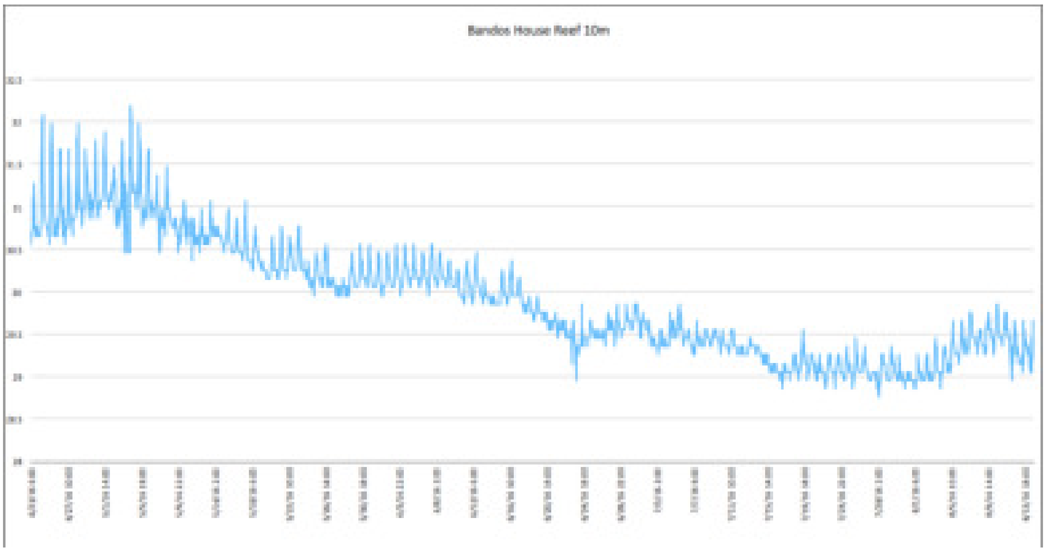

Figure 4: Daily temperatures for Bandos House Reef in North Malé, one of the long-term MRC monitoring sites. Temperatures were recorded in situ with a temperature logger from 23rd April 2016 to 14th August 2016. Highs of over 32 degrees Centigrade were recorded in late April and early May 2016. The logger was deployed in late April as the bleaching started, and removed in mid-August when most affected corals had already died or recovered.

Photo 6: Deploying temperature loggers to collect *in situ* data Scientists deploying a temperature logger at 10m in Baa Reethi Beach to collect in situ temperature data prior and during the bleaching event.

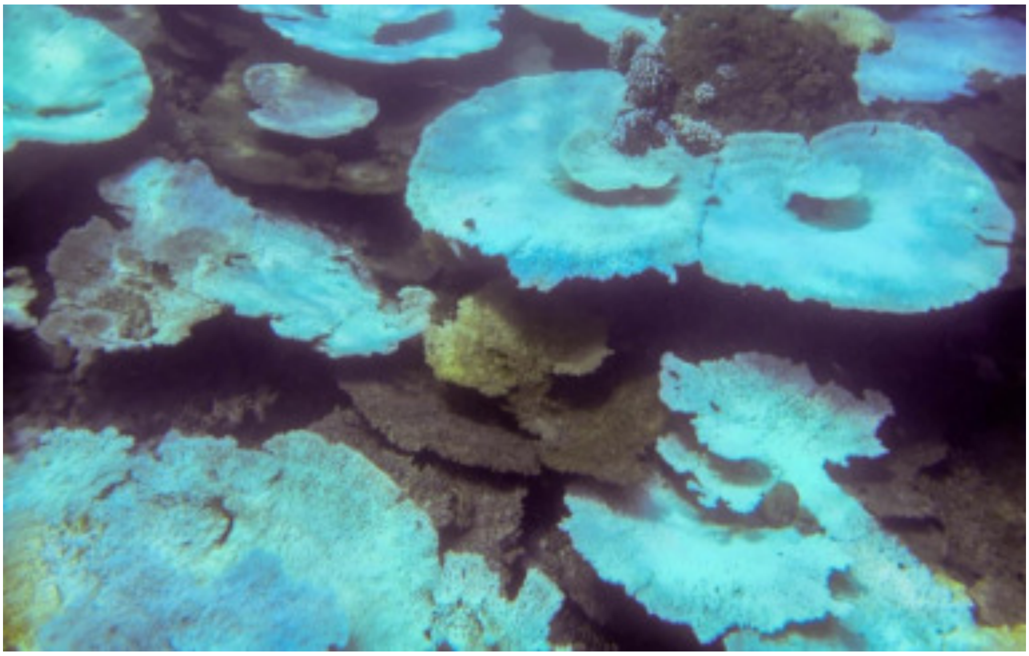

Photo 7: Bleached colonies of *Acropora* at a resort house reef at 10m in the reef slope in North Malé

Formation of inter-agency taskforce on coral bleaching

An Inter-Agency Task Force on Coral Bleaching was formed with direct guidance from Minister of Fisheries and Agriculture, Dr. Mohamed Shainee, due to the urgency and the need for a well-coordinated effort amongst stakeholders to monitor coral bleaching event. The task force was constituted with representatives from the Ministry of Fisheries and Agriculture (MoFA), Marine Research Centre (MRC), Ministry of Environment and Energy (MoEE), Environment Protection Agency (EPA), Ministry of Tourism (MoT) and Coast Guard of the Maldives National Defense Force (MNDF).

The main task of the Inter-Agency Task Force is to centralize and guide the nationwide data collection effort by coordinating with MRC, other government institutions, and non-governmental organizations (NGOs) researching coral reefs in the Maldives. The Task Force did provide advice to resorts on halting activities that put additional stress like beach replenishment, dredging and land reclamation on coral reefs during the bleaching period from May to end of June.

As of June 2016 a total of five sittings of the task force were completed, held at the Marine Research Centre.

METHODS

Two methods were employed to conduct benthic coral surveys. In the first method, three replicate detailed (coral colonies identified to the genus level) belt transects of 10 m x 1 m were surveyed and the bleaching status of coral genera or species as recorded depending on understanding of coral taxonomy by the observer (more details below). In the second method, three 50 m transects were surveyed and the benthic category (including the bleaching status of any coral observed) which intercepts transect every 0.5 m was recorded. Surveys were conducted at either <7 m or >7-13 m depth.

Belt transect:

A transect tape was laid at the selected depth parallel to the beach and all the corals present in three consecutive 10 m x 1 m linear transects were surveyed. A gap of at least ~3 m was left between each 10 m x 1 m transect. Figure 3 illustrates how to conduct belt.

All the coral colonies above 5 cm in diameter were counted in each transect, identified to genus and the extent of bleaching per colony was recorded using these six categories (Gleason, 1993).

Table 1: Bleaching severity categories identified in belt transect

Category	Description
1	No bleaching
2	1-10% of the colony is bleached
3	11-50% of the colony is bleached
4	51-99% of the colony is bleached
5	100% of the colony is bleached
6	Recently Dead

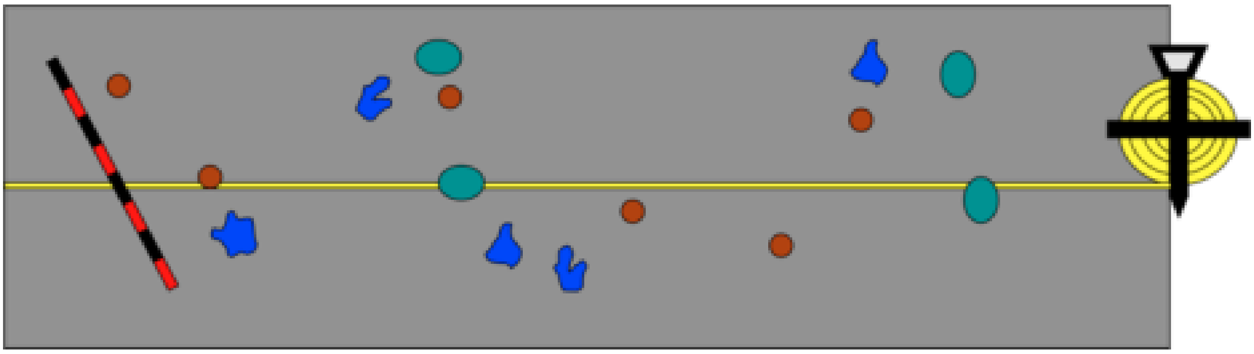

Figure 3: Visual representation of the belt transect method showing the transect, a marker stick to show the distance from the transect, and all the corals in the transect.

Point intercept transect (PIT) method:

Three consecutive 50 m transect tapes were laid within each site parallel to the beach. The following benthic categories that intercepted with the transect tape were identified every 50 cm along each 50 m transect tape: This method was employed to quantify the proportion of bleached versus Non-bleached Corals (Photos 8a and b).

Table 2:Main four benthic catagories identified during PIT assessments.

CODE	DESCRIPTION
BC	All fully or partially bleached, living hard corals
NBC	All not bleached, living hard corals
RKC	Recently killed coral (disease, predation, algal overgrowth)
OT	Anything other than living hard corals (categories were added to identify different benthic types depending on the level of knowledge of the observer)

Data collection on the benthic intercept transect began at 0.5 m on the transect tape and was repeated every 0.5 m. A minimum of 5 m gap was left between each 50 m transect. At each site and depth, 3 transects (3 x 50 m) were completed.

A one-way ANOVA was conducted comparing bleaching severity in shallower (<7 m) and deeper (7-13 m) corals. The same test was conducted to compare sheltered and exposed sites. A bleaching index was calculated for each coral genus identified based on the percentage of colonies bleached within each genus.

Photos 8 (a) and (b): Scientists from MRC and IUCN Maldives collecting data from the reef slope using the protocol in Malé Atoll at 10 m

Crown-of-Thorns starfish (COTS) reporting

Information regarding Crown-of-Thorns starfish (COTS) outbreaks reported to MRC is included in the results as some reefs were severely impacted due to combine impact of bleaching and COTS infestation.

Information presented in this report regarding Crown-of-Thorns starfish (COTS) were collected using an online Google form. It was designed with the essential COTS information to be submitted after a dive or snorkelling session in the area where COTS infestations were observed. Findings of these data are presented in results under a separate heading.

Sites surveyed

National Coral Reef Monitoring Sites

Bleaching surveys were completed at 12 sites out of 16 NCRMS sites located across the Maldives. In Malé atoll pre-bleaching and bleaching surveys were conducted in Bandos, Udhafushi and Emboodhoo Finolhu (Photo 9 and Photo 10).

Photo 10: Emboodhoo finolhu reef slope South Male' before bleaching at 10 m

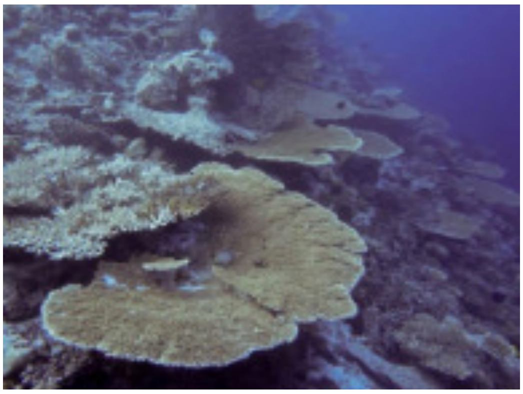

Photo 9: A Reef slope North Male' before bleaching at 10 m

North Ari (Alif Alif) Atoll

Detailed bleaching assessments were conducted at 12 islands located in North Ari (Alif Alif) atoll. Three sites per island were surveyed (a total 36 sites) during the annual MRC-IUCN Expedition 2016. These surveys were specifically conducted in North Ari (Alif Alif), where IUCN implements a coral reefs and climate change research and management project called REGENERATE with funding from USAID.

Photo 12: A reef in North Ari at 10 m in 2015

Photo 11: A reef in North Ari at 10 m in 2015

Sites surveyed by resorts marine biologists in the Maldives

From June 2015, a major focus of MRC was to train marine biologists and marine enthusiasts to collect data on the predicted bleaching event. This training provided resort marine biologists with the capacity to conduct bleaching assessments before, during and after expected coral bleaching in 2016. Up to the bleaching window in 2016, MRC, with the support of IUCN, completed 3 training workshops in which more than 75 resident marine biologists and marine enthusiasts were trained. A total of 25 marine biologists submitted data sets from 30 sites on 11 islands in 8 atolls. Figure 4 and Figure 5 show reef locations on which the coral bleaching assessments were conducted.

Photo 13: Resident Marine Biologist Anna-Sara collecting data using PIT Method from Reethi Beach Resort in Baa Atoll

Photo 14: MRC senior research officer, Nizam Ibrahim conducting PIT survey at a resort in Vaavu Atoll during the bleaching on May 2016

RESULTS

Spatial distribution of bleaching

Comparing the three regions of the Maldives, North, Centre and South (refer to Figure 4 and Figure 5), bleaching severity according to the data was recorded to be highest in the central region of the Maldives. However, these results should be understood within the context of the variation in observations across the Maldives. The majority of the data were collected from the central part of the Maldives and greater surveying effort was made in the central region due to a higher number of tourist establishments such as resorts and dive centres, as well as easy access from the capital Malé. Fewer data points were recorded from the Northern and Southern regions of Maldives.

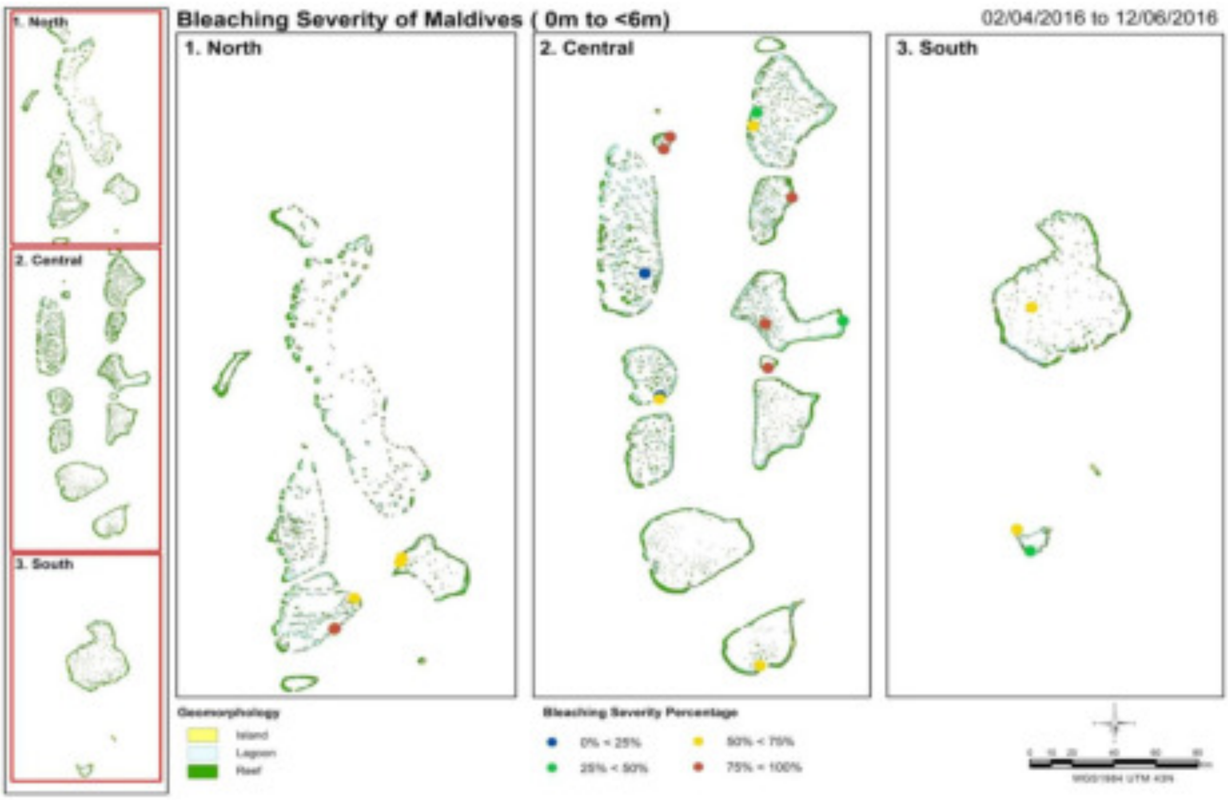

Figure 4: Bleaching severity from sites surveyed at depths between 0m and 6m throughout the North (1), Central (2) and Southern (3) Maldives. Sites are colour-coded according to bleaching severity among the sites recorded during the survey

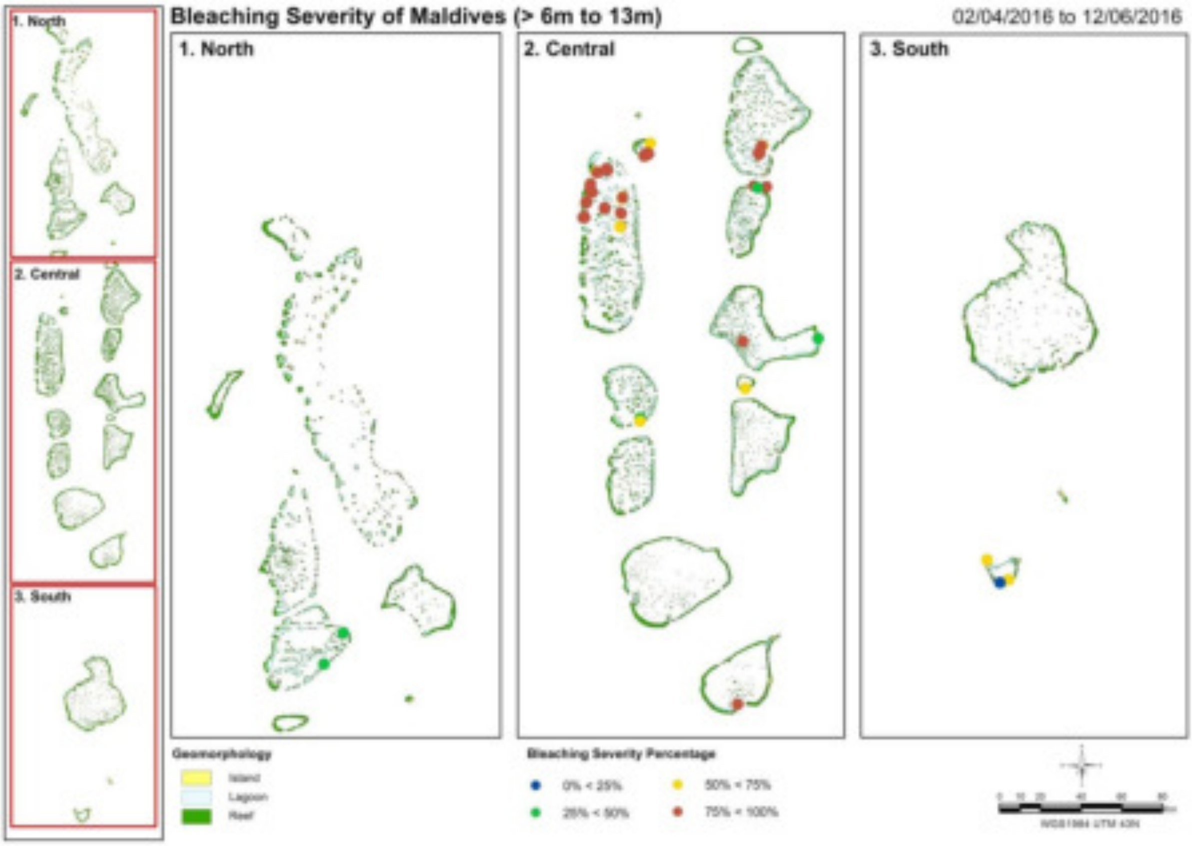

Figure 5: The sites that were surveyed at depths greater than 6 m down to 13 m throughout the Maldives. Sites are colour-coded according to the severity among the sites recorded during the survey.

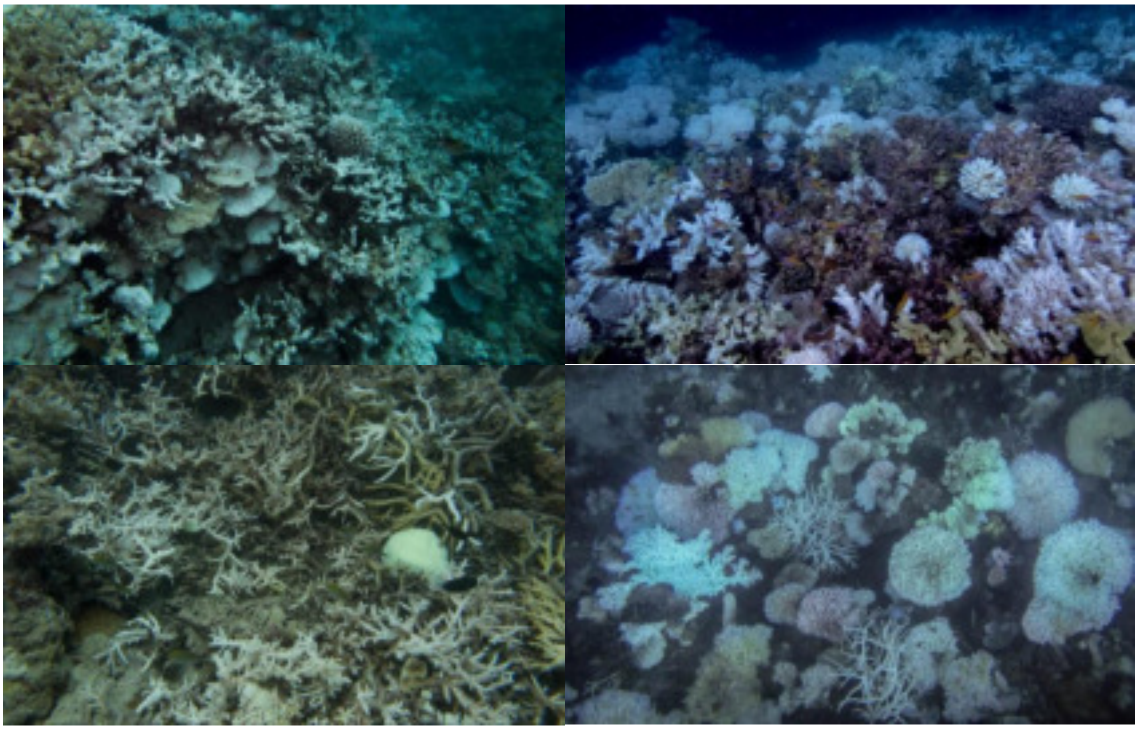

Photo 15 (a): Rasdhoo (North Ari); **(b)** Addu Kottey Reef; **(c)** Madoogali (North Ari); **(d)** Vaavu Atoll during a survey by MRC in peak coral bleaching period

Bleaching severity

The overall percentage of bleached corals recorded across all 71 sites in the Maldives is 73.1% (±21.2%). Below are results of bleaching severity by depth, by exposure, by over time, and by region. (Photo 15a-d & Photo 16a-g taken from various locations in the Maldives during bleaching assessments).

Bleaching severity by depth

A one-way ANOVA test showed that bleaching severity at 7-13 m depth was significantly higher than bleaching severity at <7 m depth ($p<0.05$). 65.53% of corals were bleached in <7 m while 76.89% corals suffered bleaching in 7-13 m (Figure 6).

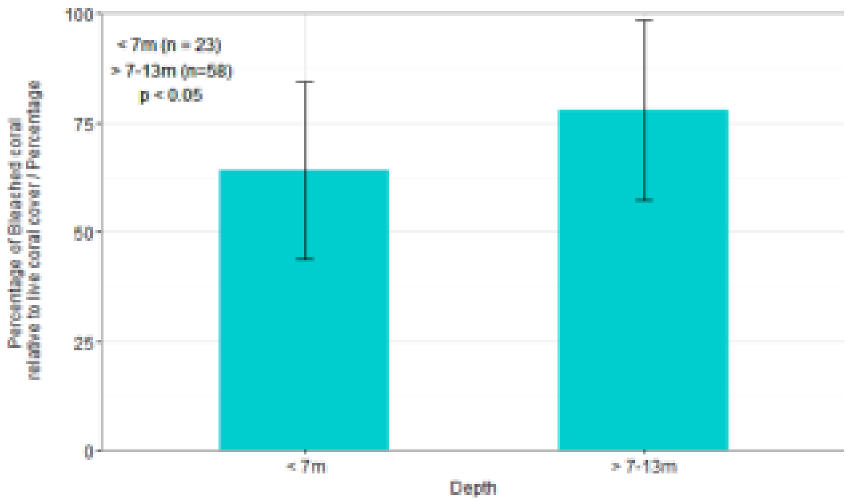

Figure 6: Average bleaching severity at 2 different depths in all sites surveyed in the Maldives during the peak of bleaching from the third week of April to the end of May. Error bars represent standard deviation

Bleaching severity by exposure

The data show that sheltered reefs (sites which are found inside the atoll) showed no significant difference in bleaching response to exposed sites (sites which are found on the ocean ward rim of the atoll and exposed to oceanic currents and wave action) (Figure 7).

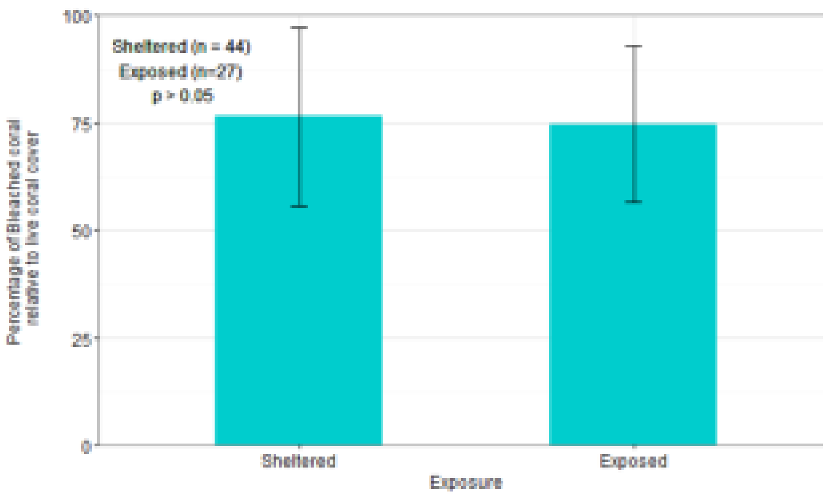

Figure 7: Average bleaching severity exposed versus sheltered sites surveyed in the Maldives during the peak of bleaching from the third week of April to the end of May. No significant difference was found in bleaching responses between exposed and sheltered site

Bleaching over time in <7 m depth

Bleaching severity in corals shallower than 7 m peaked in early May, with some sites even exhibiting close to 100% bleaching, and then most bleached corals either died or recovered by mid-July, although a small percentage remained in a bleached state several months after the peak of the event (Figure 8).

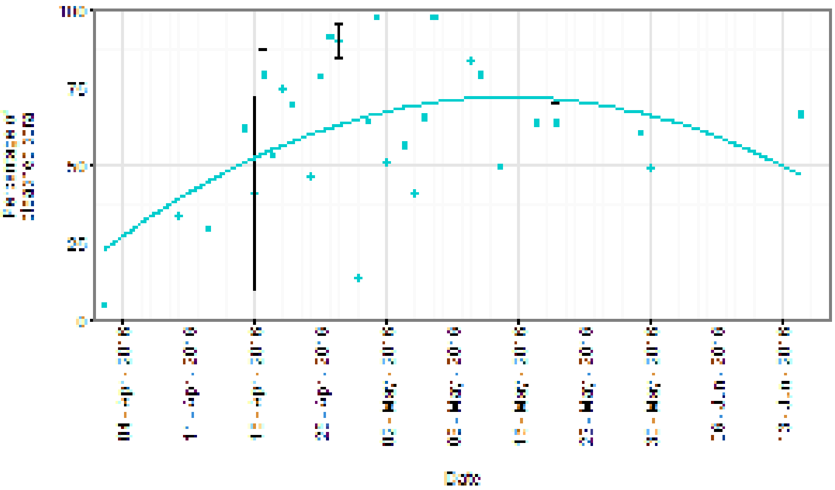

Figure 8: Average bleaching severity (% of bleached corals) recorded from 0 to 6 m depth around the Maldives from 20th March to the mid-July 2016. Where data permits 95% CI is given as vertical lines.

Bleaching over time in 7-13 m depth

Bleaching severity in corals 7-13 m deep peaked in early May, with some sites exhibiting up to 95% bleaching incidence, and then most bleached corals either died or recovered by mid-July. A small percentage remained in a bleached state several months after the peak of the event (Figure 9).

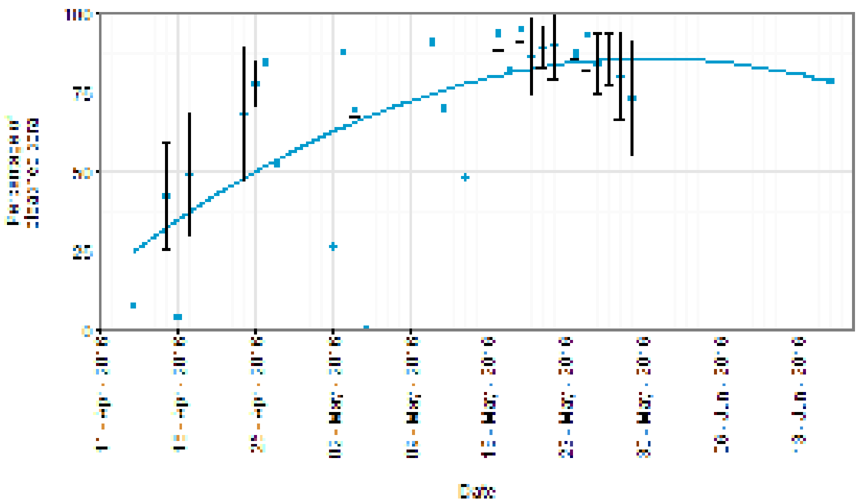

Figure 9: Average bleaching severity (% of bleached corals) recorded from 7 to 13 m depth around the Maldives from the first week of April to the last week of May 2016. Where data permits 95% CI is given as vertical lines.

Bleaching index for coral genera

Free-living corals such as *Halomitra*, *Cycloseris*, *Fungia* and *Herpolitha* exhibited the highest bleaching index, in addition to other genera such as *Pectinia*, *Gardinoseris*, *Merulina* and the fast-growing and common reef builder *Acropora*. Genera such as *Porites*, *Favites*, *Coscinarea*, *Acanthastrea*, *Leptastrea, Goniopora, Alveopora* and *Pavona* showed the highest resistance to bleaching. Photo 16a-g show bleached coral colonies of a variety of genera (Figure 10).

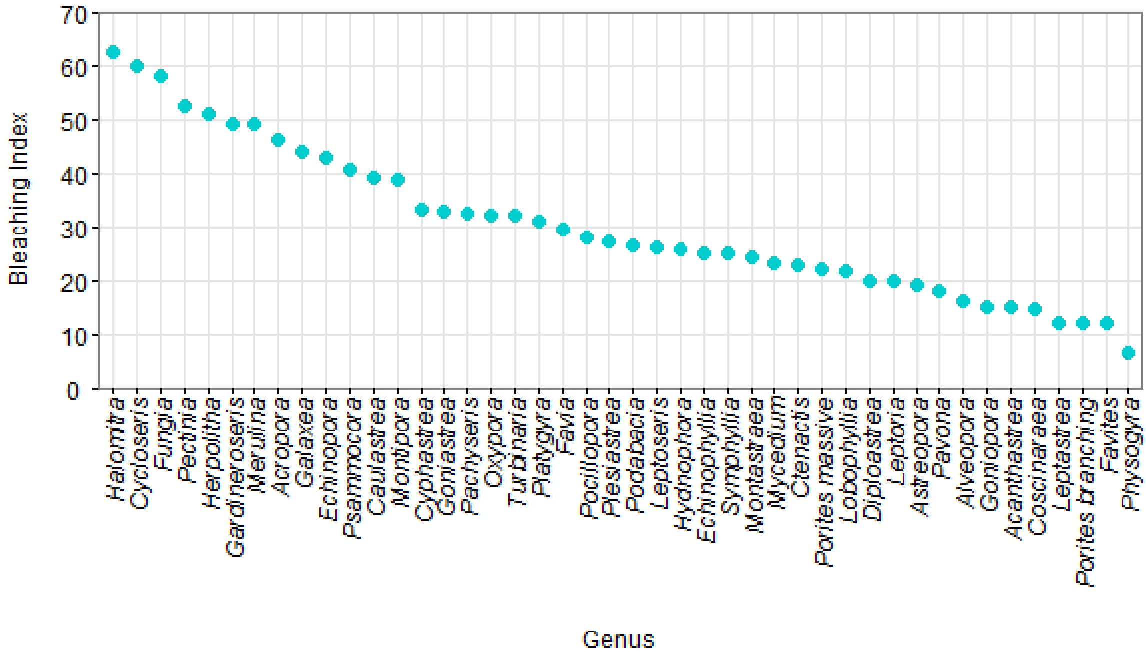

Figure 10: Coral bleaching index indicating the susceptibility of different genera to bleaching in 36 sites of North Ari (Alif Alif) atoll. This index reflects the severity of bleaching recorded for coral colonies of different genera. These data were collected during peak bleaching in May 2016.

Photo **16** **(a)** *Echinopora* sp. bleached in Velidhu (North Ari) May 2016; **(b)** *Merulina* sp. bleached in Bodufolhudhoo (North Ari) May 2016; **(c)** *Porites* sp. Branching bleached Rasdhoo (North Ari) May 2016; **(d)** *Physogyra* sp. bleached in Gaathafushi (North Ari) May 2016; **(e)** Anemone bleached in Madivaru (North Ari) May 2016; **(f)** *Turbinaria* sp. bleached in Maalhos (North Ari) May 2016; **(g)** *Acropora* sp. bleached in Bodufolhudhoo (North Ari) May 2016

Hope Spots

Of the 71 sites across Maldives for which data were submitted, 8 sites were identified as 'hope spots', due to the relatively low bleaching incidence and relatively high live coral cover. Hope spots were identified as those sites with less than 45% bleaching incidence, and higher than 25% live coral cover (Table 3 & Figure 11).

Table 3: Hope spots (reefs with high potential of surviving the coral bleaching event) identified by analysing all the coral bleaching data obtained

Island name	Site name	Atoll	Bleached coral %	Total live coral %
Thelu Veliga	Drift Thelu Veliga House Reef	South Ari	13.8	24.2
Magoodhoo	Blue Cove 4 m	Faafu	18.8	50.5
Reethi Beach	Reethi Beach House Reef West	Baa	26.3	38.0
Sonevafushi	Sonevafushi House Reef	Baa	28.1	31.2
Magoodhoo	Coral Gardens 12 m	Faafu	30.7	68.5
Magoodhoo	Coral Gardens 4 m	Faafu	42.2	80.5
Emboodhoo finolhu	Emboodhoo finolhu inner reef	South Male'	43.7	39.7
Magoodhoo	Blue Cove 8 m	Faafu	45.0	50.0

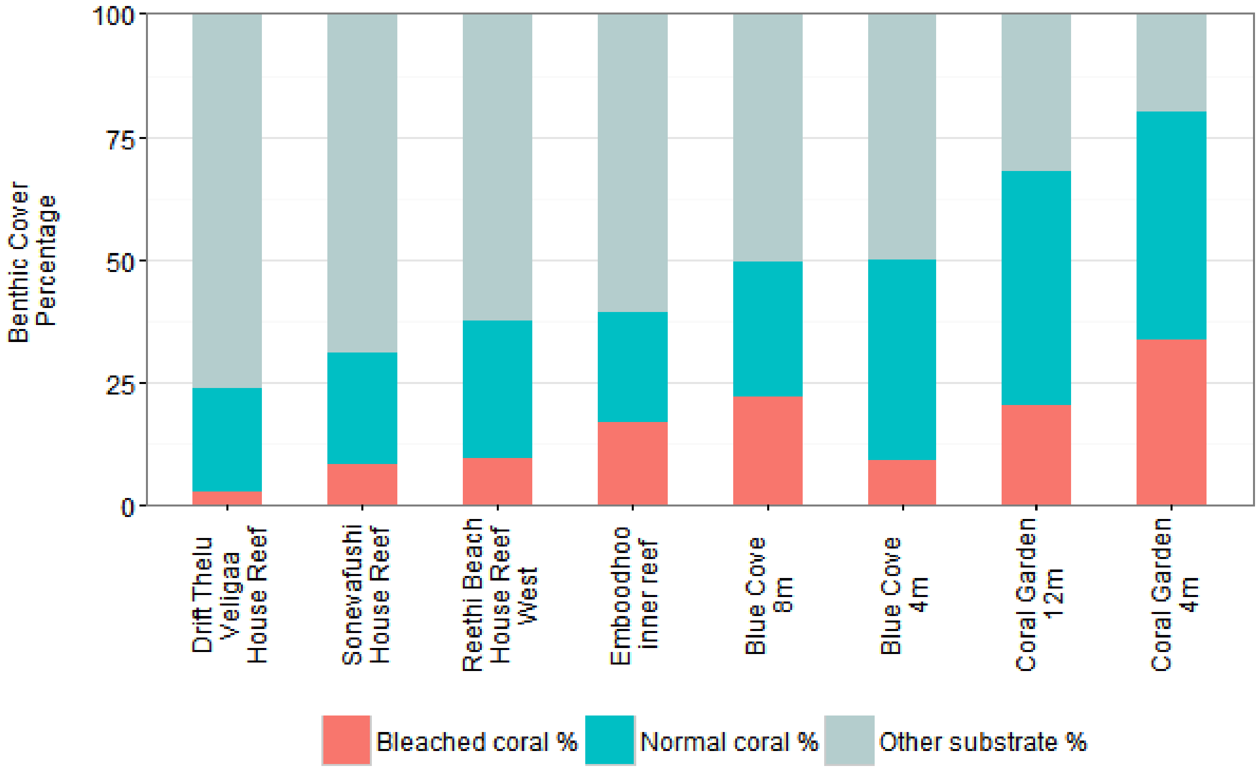

Figure 11: Live coral cover percentage at each of the hope spots where bleaching severity lower than 45% and live coral cover over 25% was recorded. Coral cover of corals in a normal state is indicated in orange, and the bleaching severity (as a percentage of the live coral cover) is indicated in blue. The total live coral cover is the sum of both parts. Drift Thelu Veligaa has the lowest percentage of bleached coral, but also the lowest total coral cover. Emboodhoo finolhu inner reef has the highest percentage of bleached coral compared to the total coral cover. Coral Gardens 4 m has the highest live coral cover, but also a relatively high percentage of bleached coral.

Mortality and survival of *Acropora* in North Malé (Kaafu) Atoll

Post-bleaching surveys allowed us to measure the mortality of important genera in North Malé (Kaafu) Atoll at the NCRMS sites. Here results for bleaching and mortality are presented for the important reef building genus *Acropora*. Mortality of *Acropora* spp. corals were very high, with over 80% of corals recorded as dead after the event, and about 20% remaining in normal state. When bleaching was recorded in late April, over 50% of *Acropora* spp. colonies were recorded as showing some signs of bleaching, and the bleaching severity increased as the event progressed into May and June (Figure 12).

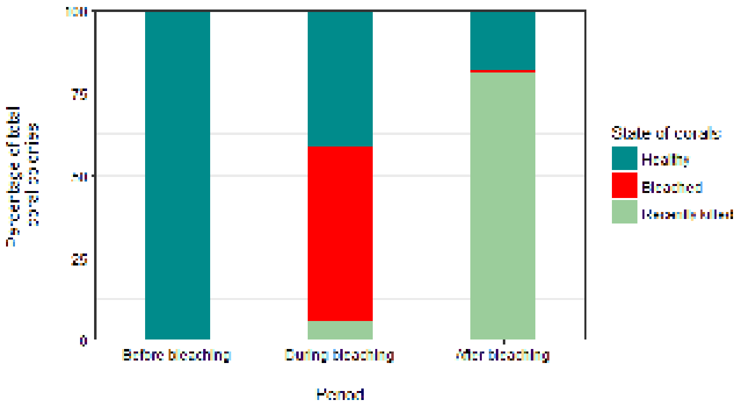

Figure 12: Bleaching and mortality of *Acropora* spp. corals in North Malé (Kaafu) Atoll before, during and after the bleaching event.

Mortality and survival of *Porites* in North Malé (Kaafu) Atoll

In comparison to *Acropora*, mortality of *Porites* spp. corals was very low, with less than 10% of corals recorded as dead after the event, and over 90% recovered from the bleaching, despite over 60% of the colonies showing some signs of bleaching at the peak of the event. *Porites* spp. were observed to bleach and then recover without dying (Figure 13).

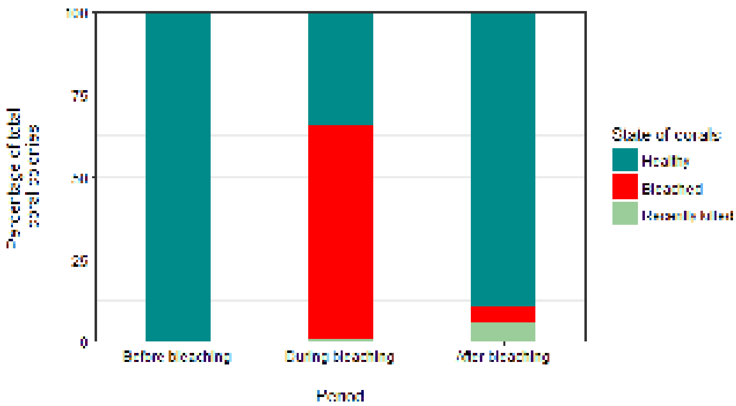

Figure 13: Bleaching and mortality of Porites spp. corals in North Malé (Kaafu) Atoll before, during and after the bleaching event

Coral bleaching relative to live coral cover in all the atolls surveyed

The data show spatial variation in bleaching patterns across atolls. However, the number of sites monitored per atoll varied from 1 to 36, as did the depth of surveys, and these discrepancies in sampling methodology makes it difficult to make robust conclusions about spatial variation in bleaching patterns at the atoll scale. North Ari was the atoll with the highest number of monitoring sites and the most consistent measurements in depth, and it exhibited an extremely high percentage of bleached coral (Figure 14).

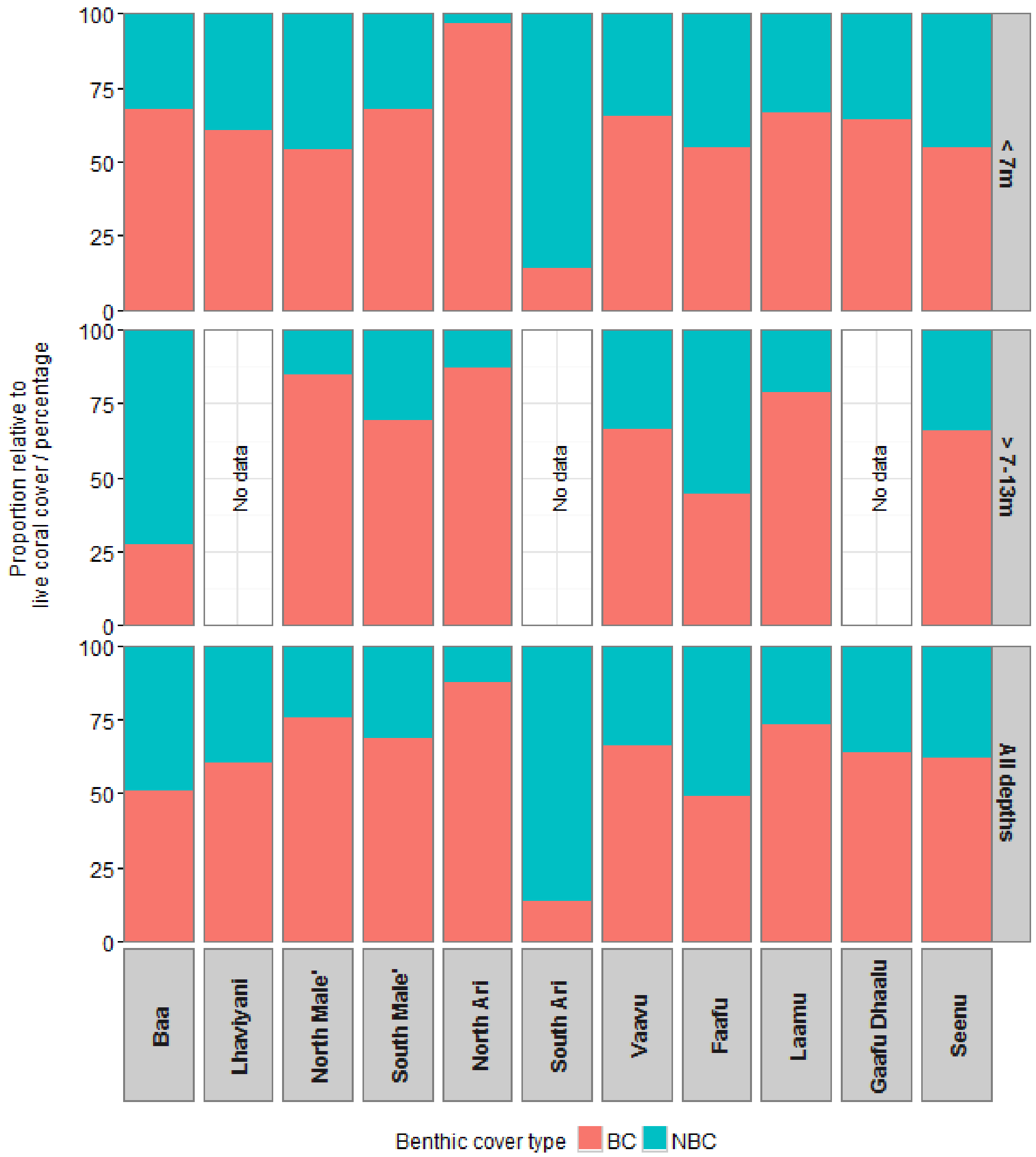

Figure 14: Coral bleaching relative to live coral cover in all atolls from which data is obtained in shallow, top portion (shallow <7 m), centre (>7 m to 13 m) and Bottom (Both depths combined). No data available for deep of Lhaviyani, South Ari and Gaaf Dhaalu. BC= Bleached Coral. NBC= Non-Bleached Coral.

Crown-of-Thorns starfish (COTS) outbreaks

From December 2014, MRC started receiving reports of COTS outbreaks from the central parts of the Maldives. MRC requested outbreaks of COTS to be reported if COTS outbreak conditions at a site were met (i.e. 15 COTS per hectare) according to the COTS outbreaks guideline by Great Barrier Reef Marine Park Authority (GBRMPA). Upon this request, MRC received a total of 58 unique reports of COTS outbreaks. Locations where COTS outbreaks were reported can be found in Figure 15. It is worth emphasising that some reefs surveyed in North Ari Atoll lagoon (e.g. Alikoirah and Meerufenfushi) suffered a synergistic impact of COTS outbreak and coral bleaching which resulted in total degradation of the coral reefs (Photo 17).

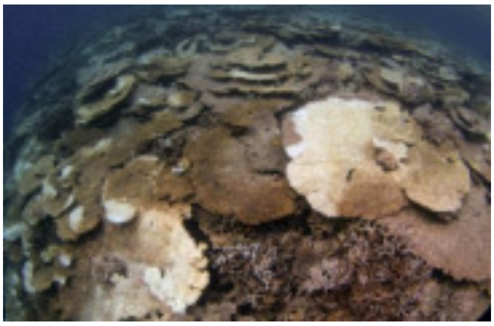

Photo 17: Mortality by COTs (North Ari)

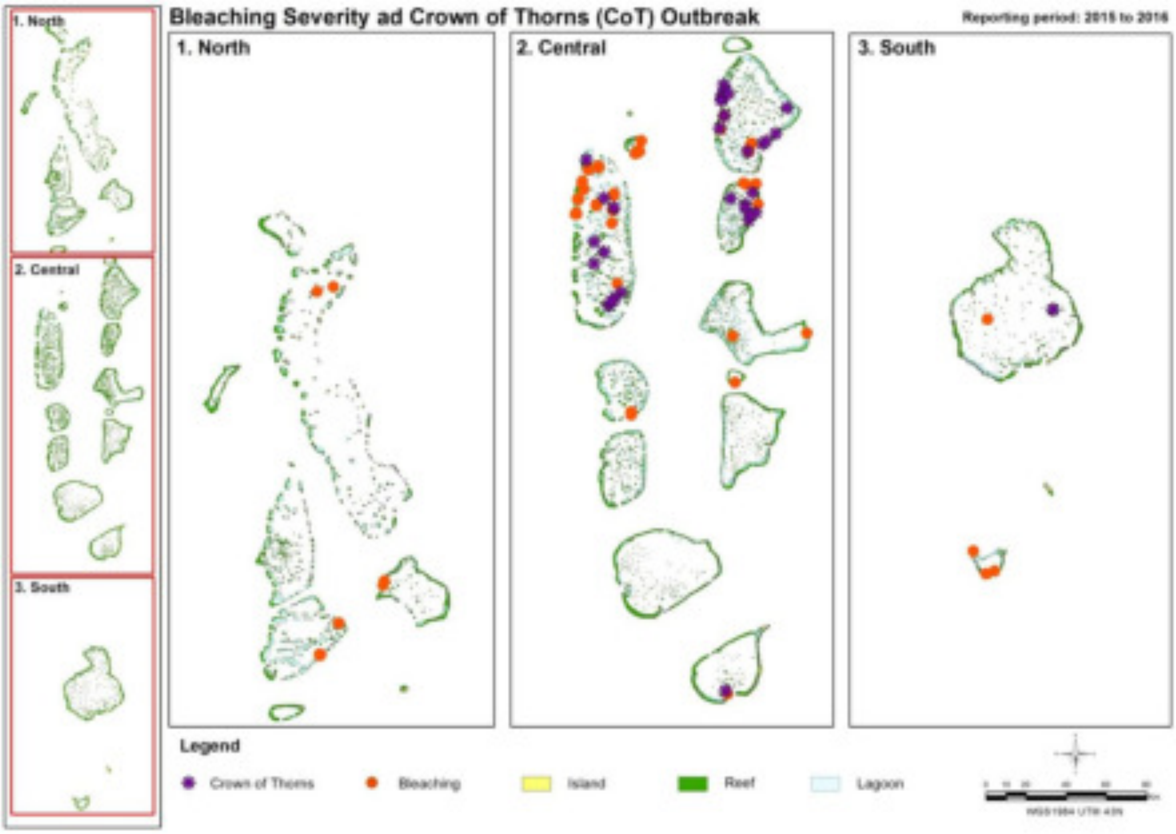

Figure 15: Coral bleaching and *Acanthaster planci* reports to the MRC in the 1) North, 2) Central and 3) Southern Maldives from December 2014 to October 2016

DISCUSSION

This report presents the largest and most comprehensive effort to monitor coral bleaching in the Maldives to date through a combination of citizen scientists, government experts, academic researchers and non-governmental scientists. A total of 71 sites across 11 atolls were surveyed from March to June 2016, and 82 citizen scientists were mobilized to monitor the event.

The 2015-2016 El Niño and associated mass bleaching event was the largest bleaching event recorded in the Maldives since 1998. Sea surface temperatures and Degree Heating Weeks (DHWs) peaked in late April through to the end of May, precipitating the bleaching event, with a high temperature of 32.2 degrees Centigrade recorded at Bandos on 4th May 2016. Five DHWs, a measure of the total heat energy accumulated in the ocean, were recorded in May and June, well over the threshold for a bleaching event.

Although devastating in its impact on corals, the event did provide the opportunity to enhance our understanding of bleaching patterns in a way that was not possible in 1998. A much larger and more detailed data set for the Maldives was collected in 2016 due to the continued monitoring of NCRMS, collaborations with international and local partners.

An analysis of the data shows that overall, the average percentage of bleached corals measured around the Maldives in late April to May, regardless of depth or exposure, was 73% (±21.2%) of total coral cover. Further analysis shows that 66% (±21.0%) of corals bleached in depths from 0 to 6 m, and 77% (±21.0%) of corals bleached in depths from 6 to 13 m Furthermore, 72% ((±23.5%) corals in sheltered sites and 74% (±18.8%) of corals in exposed sites bleached, but with no significant difference in bleaching response detected between exposures. These findings, and any significant differences, need to be discussed within the context of a highly variable data set.

One hypothesis as to why higher levels of bleaching were recorded in deeper corals is that coral communities in the shallow sites surveyed may consist of more resistant corals due to adaptation to bleaching conditions over time. However, it is difficult to reach this conclusion with the current data set, and more research would be necessary to confirm or reject this hypothesis. In North Ari atoll, which has the most detailed data set of any atoll for the bleaching event, shallower corals suffered higher bleaching incidence potentially due to the higher cover of susceptible *Acropora* corals in shallower areas as well as higher Ultraviolet radiation (UV). Again, it is difficult to confirm or reject this hypothesis with the current data set, and more research is required.

The data presents great spatial and temporal variation, with the majority of the data being from one-off measurements taken during the bleaching event by a large diversity of observers on reefs spread across the Maldives. Only a few sites were monitored repeatedly over time and at consistent depths, so this presents a patchwork of bleaching observations distributed around the Maldives over space, depth and time (about six weeks). Due to the temporal and spatial variation of the data, as well as the large number of observers, it is not possible to make fine scale and robust conclusions about the influence of habitat, exposure or depth on bleaching severity and incidence in the Maldives. Furthermore, these data only give an indication of the severity of the bleaching event based on total coral cover, but cannot be used to explore coral diversity and community assemblages at each site and how this could drive responses to coral bleaching.

However, the data collected using the Point Intercept Transect method are of high enough quality to provide us with an overview of the general severity and temporal progression of the bleaching event across the country. The data are useful for drawing large-scale conclusions about the severity, temporal progression and scale of the event, in a way that was not possible in 1998 due to the lack of observers, and the data are also useful for analysing single sites where observations were recorded. In this way, the data are useful for making management decisions, as well as for communicating the impacts of the bleaching event to the public and to important stakeholders in the tourism and fishing industries. This report shows that citizen science data, collected by trained individuals and coordinated by a centralized authority such as the Maldives Marine Research Centre, can be a useful tool for tracking and understanding bleaching events at large scale, as well as for collecting data that are useful for making management decisions.

Hope spots

Sites that suffered from less than 45% bleaching incidence and had a live coral cover of over 25% during the peak of the bleaching event were listed here as ‘hope spots’ that may have undergone less impact and mortality and could thus be considered as important for the recovery of surrounding coral reef ecosystems. Eight sites have been identified as having lower bleaching severity and high live coral cover. Resurveying the 'hope spots' post-bleaching will indicate whether they have indeed recovered more than other sites around Maldives.

By analysing data collected at the site level, although based on one-off measurements, it is possible to identify 'hope spots' where bleaching severity was found to be lower than average and live coral cover was found to be relatively intact. Despite the high overall impact of the event, some sites were less impacted than others, and these 'hope spots' warrant further attention, follow-up surveys and possible investment in management and protection. 'Hope spots' that were identified as having less than 45% bleaching impact and higher than 25% live coral cover are Thelu Veliga House Reef in South Ari, Blue Cove and Coral Gardens in Magoodhoo in Faafu, Reethi Beach West in Baa, Sonevafushi House Reef in Baa, and Emboodhoo finolhu Inner Reef in South Malé. It is recommended that these sites are re-surveyed in more detail post-bleaching, including surveying corals to genus level identification, to confirm whether they indeed escaped mortality. It is possible for sites to escape bleaching due to localised environmental conditions such as higher water flow, localised upwelling, turbidity that screens corals from sunlight, or the composition of coral reef communities (Grimsditch and Salm, 2006). Resurveying sites to understand why different sites may have bleached less can provide insights into managing bleaching events in the future.

A bleaching susceptibility index for coral genera developed from the data set collected by the belt transect method shows free-living genera such as *Fungia, Herpolitha, Cycloseris* and *Halomitra* to be highly susceptible to bleaching, although not necessarily to mortality. Other genera found to be highly susceptible are *Pectinia, Merulina, Acropora* and *Gardinoseris*. *Acropora* is of particular importance due to its dominance, its fast growth rates, and the structural complexity it provides as habitat to reef organisms including many fish (Floros and Schleyer, 2016). On the other end of the spectrum can be found corals from the more resistant Faviidae family, for example *Favites* and *Leptastrea,* and Poritidae family, for example *Porites* and *Goniopora*. Assessments of mortality post-bleaching show high levels of mortality in *Acropora* species but low levels of mortality in *Porites* species, with an overall reduction in live coral cover. *Acropora* was particularly abundant and dominant on

Maldivian coral reefs until the bleaching event (Morri *et al*. 2015), and the large-scale loss of *Acropora* frees up large areas of substrate for colonisation by other benthic organisms. As *Acropora* is a major reef building coral that provides significant structural complexity and habitat, the large-scale loss of *Acropora* can have significant impacts on the ecosystem, including potential cascading effects on reef fish populations and other commercially important species (Graham *et al*. 2007).

Following the 1998 bleaching event, where 60-100% mortality was recorded at sites around the Maldives, coral reefs took about a decade to recover to pre-1998 levels of coral cover and although some reefs changed in composition or did not recover to a coral-dominated state, coral recovery was generally high across the country (Morri *et al*. 2015). Current literature suggests the recovery of coral reefs in the Maldives following 1998 (especially relative to other sites around the Indian Ocean) was mainly due to the high biomass of herbivorous fish on the reefs as these are not traditionally targeted for the tuna-based Maldivian diet (McClanahan, 2011; Tkachenko, 2012; Risk and Sluka, 2000); the large number of coral reefs in the Maldives connected in a vast system (Naseer and Hatcher, 2004), meaning the existence of a higher number of potential and varied climate refuges that can reseed reefs following bleaching events; and the relatively small human population in the country.

Given that mass mortality of corals has occurred on some reefs of the Maldives, and that the substrate has again been freed up in those reefs for colonisation by benthic organisms, we hypothesise that the highly impacted reefs of Maldives will again go through a recovery process. Although past research suggests coral reef recovery from this year's bleaching event might occur (Morri *et al*. 2015) and that long-term and permanent phase shifts to algal-dominated states may be avoided given that water quality is good, herbivore biomass is still high and reservoirs for supplies of coral juveniles are still intact (Grimsditch and Salm, 2006); the reefs must be continually monitored in order to assess the rates of recovery and whether any impediments to recovery can be identified and managed. In the short term, many reefs will most likely be dominated by benthic organisms other than corals, for example potentially by macroalgae (McManus and Polsenberg, 2004), and over time the recovery potential will depend on the overall health of the system, including water quality and fish biomass (Grimsditch and Salm, 2006). It is also important to understand whether changes in coral composition (for example a potential reorganization of dominant coral species) and losses of rugosity or structural complexity occur on the reefs, and whether these have long-term effects on fish populations and other ecosystem services (Graham *et al*. 2007). It is especially important to understand the impacts of large-scale loss of the important reef-building *Acropora* corals that have been most affected by bleaching.

It must also be taken into account that conditions have changed in Maldives since 1998, and that human pressures on the reefs have increased. The human population of the country has increased (from 271,000 in 1998 to 409,000 in 2014), the number of expatriates have increased (from 80,839 in 1998 to > 100,000 in 2014), the number of tourists have increased > 3-fold (from 396,000 in 1998 to 1,210,000 in 2014) and the number of resorts excluding guest houses and other tourism establishments have increased (from 97 in 2009 to 111 in 2014), (World Bank, National Bureau of Statistics & Ministry of Tourism). These increases in human populations lead to increasing demand for reef fish for consumption, as well as to an increase in the number of development projects that require dredging (e.g. landfill and harbour dredging), and an increase in the nutrient load on coral reefs from land-based sources of pollution (e.g wastewater effluent from local and resort islands). The growing impacts of these activities on coral reefs have not been well documented or measured, but it is plausible that the resilience of the reefs could become eroded over time as reef fish populations decrease due to higher demand from tourism, and damage from coastal development projects, wastewater effluent and other pollution (i.e. marine debris) increase (Grimsditch and Salm, 2006).

Healthy coral-dominated reef ecosystems are crucial for the long-term well-being of the people of the Maldives, given the multitude of ecosystem services provided by coral reefs to the nation (Emerton *et al*. 2009). Monitoring of coral reefs in the years to come will be important for understanding whether phase shifts from coral-dominated states to other states occur, or whether reefs can recover to a healthy coral-dominated community, which provide valuable ecosystem services to coral reef organisms (i.e. refuge from predators and food) and the human population of the Maldives (i.e. habitat for major fisheries, barrier from storms and flooding events, tourism from diving and snorkeling; Emerton *et al*. 2009). It also important to understand whether there are shifts in coral communities and dominant genera, and whether changes have impacts on ecosystem services provided. Managing the impacts of human activities on coral reefs is important in determining the recovery trajectories that the coral reefs of the Maldives follow over the next years. The coral bleaching of 2016 highlights and brings the importance of managing human activities such as fishing, construction, waste production and tourism into focus. Overfishing and reduced water quality due to land-based sources of pollution can lead to the complete degradation of coral reefs following bleaching events, and reduce their potential for recovery (Hughes *et al*. 2007). This is especially true in the context of growing human populations and development, where there is a need to increase the resilience potential and the outlook for coral reefs, and the ecosystem services they provide, in the coming decade.

RECOMMENDATIONS

Developing a national coral bleaching response plan (CBRP)

A coral bleaching response plan lays out the details of responding to future coral bleaching events, including what measures can be taken by government, civil society and private institutions. It includes communications strategies for policy-makers and the general public. It also includes management responses available to coral reef managers for minimizing the impacts of the bleaching event on coral reefs and people, as well as a plan for monitoring bleaching effectively. A well-developed CBRP with inclusive involvement of stakeholders will allow coral reef managers to reduce the impacts of future events by reducing additional stressors on the coral reefs, and it will reduce any miscommunication and misinformation disseminated to the public during a bleaching event. A national coral bleaching response plan will be developed in 2017, in preparation for future bleaching events.

Strengthening National Coral Reef Monitoring Programme (NCRMP) at MRC

The NCRMP is the only long-term effort to monitor the status of the coral reefs in the Maldives by a government institution. Unfortunately, high staff turnover and funding limitations in the past have presented a challenge for this monitoring programme to carry out monitoring consistently on an annual basis. It is important to strengthen the coral reef unit of MRC by increasing the number of full time staff working in the unit and by building their capacity regarding coral reef ecology and taxonomy.

Expanding monitoring sites under the NCRMP

From 1998 until 2012 a total of 17 sites across the Maldives were monitored for coral reef health (i.e. coral cover percentage, algae cover and coral community composition). An additional 12 sites were added to this long term monitoring effort from 2012 to collect more representative data across the Maldives. More sites need to be added to get a better representative data set from across the Maldives as there are still some atolls where there are no permanent MRC monitoring sites.

This report is based on the changes to hard live coral cover due to coral bleaching. It is also important to conduct studies of the impacts of bleaching and the loss of habitat complexity on other marine life such as reef fish, bait fish and other mobile organisms. The long-term impact of bleaching on baitfish populations is especially important to the pole and line fishery in the Maldives. Fish surveys are essential to be included in future reports regarding coral bleaching.

Promote citizen science monitoring throughout the Maldives

This report shows the value of collecting data with the help of citizen scientists with central coordination by MRC, given the dispersed nature of the Maldives and the cost associated with travel and logistics. Citizen science also promotes collaboration with the private sector, especially resorts and dive centers. It is recommended that marine biologists, dive guides and marine enthusiasts are continually trained and refreshed on citizen science methods by MRC. It is also recommended that citizen scientists should use the methods to monitor the health of reef and submit data via coral database of National Coral Reef Monitoring Framework (coraldatabase.gov.mv).

Identify and resurvey 'hope spots' to measure mortality of corals and consider special protection or management

Sites which showed resilience to coral bleaching need to be studied to understand why they did not suffer as much compared to the majority of the sites. If they show features of a rich diversity of marine organisms or high coral cover with a high diversity of corals they could be worth considering for special protection or management. If the studies show these areas are indeed unique and rich in terms of coral cover and marine life, establishing no take areas in these hope spots will help in larval distribution to areas highly impacted by coral bleaching nearby and can facilitate overall ecosystem recovery.

Develop a plan for aerial bleaching surveys

Aerial surveys can effectively collect data on bleaching over large areas if they are conducted in a systematic manner. The largest fleet of seaplanes globally is currently operational in the Maldives, and this presents a great opportunity to develop a systematic monitoring plan for aerial surveys of future bleaching events.

Limitations

It must be noted that due to the haphazard sampling across time and space by multiple observers, the data might not be robust enough to make strong conclusions about detailed bleaching patterns, but that rather that these data are useful in gaining an overall understanding the severity and scale of the event.

LESSONS LEARNED

Unlike the 1997/1998 mass coral bleaching event, 2016 presented a unique opportunity to involve citizen scientists in the data collection effort. As this led to the collection of a large data set for bleaching across the Maldives, the consistency in the data collected is not the same, although the area covered is much larger. Consistency of the data set in future efforts can be improved giving more focused training to the interested observer or the citizen scientist.

Limitation of staff and other resources within the MRC presented another challenge for coordination and communication regarding the bleaching. Only one full time staff for the coral reef unit of MRC and additional staff from CCAP were available to work on the bleaching event, and it was a challenge for MRC during the peak bleaching window to attend to queries from concerned stakeholders, carry out secretarial commitments and conduct field surveys.

Aerial surveys for coral bleaching can be an effective tool to monitor large areas and gain a quick understanding of the impact of bleaching across a large number of reefs. In 2016, seaplane pilots were approached to submit photos of bleaching on their trajectories across the Maldives. The aerial photos submitted by seaplane pilots provided anecdotal evidence of bleaching across the Maldives, but they were not collected in a systematic manner and were not of high enough quality to make scientific conclusions about the scale of impact. Systematic aerial surveys were proven to be an effective tool for monitoring and understanding bleaching events in other countries in 2016, particularly in Australia, and it is recommended that for future bleaching events a plan is put in place for systematic national aerial surveys of coral bleaching.

OTHER CASUALTIES OF THE 2016 GLOBAL CORAL BLEACHING EVENT

Great Barrier Reef (GBR), Australia

The Great Barrier Reef of Australia is one of the most iconic reefs impacted by the 2015/2016 global coral bleaching event. As the largest coral reef system on Earth, it is also one of the most widely studied reef systems. According to the academic and scientific bodies monitoring the GBR, it was severely impacted in 2016. Figures released by ARC Centre of Excellence for Coral Reef Studies show that in the northern sector of the GBR, out of 522 reefs surveyed, 81% of the reefs were severely bleached and only <1% of the reefs escaped bleaching. In the central sector of the GBR, out of 226 reefs surveyed, 33% of reefs were severely bleached while 10% escaped bleaching. In the southern sector of the GBR, out of 163 reefs surveyed, 1% were severely bleached and 25% escaped bleaching. The extent and severity of bleaching in Maldives and the Great Barrier Reef put into context how much sea surface temperature anomalies experienced in 2016 have damaged coral reefs globally.

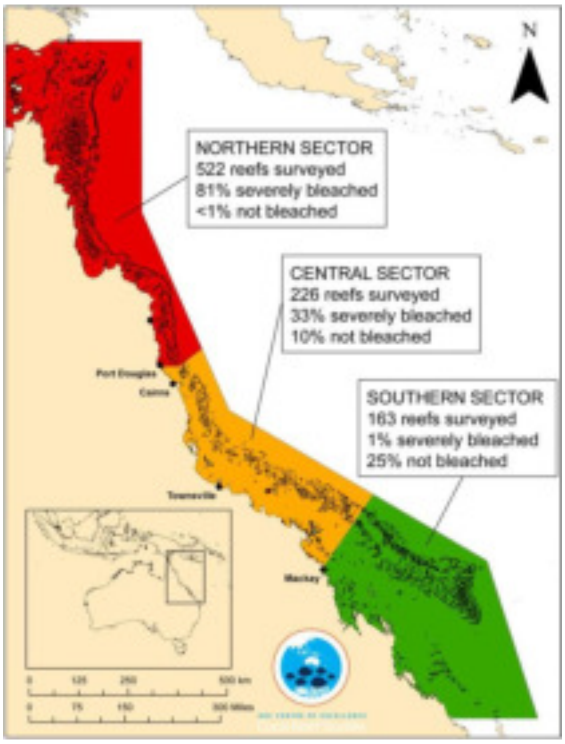

Photo 18: Coral bleaching observed from the GBR by ARC Centre of Excellence for Reef Studies.

Other areas of the world

According to citizen science initiatives such as Reefcheck, reefs in Samoa and American Samoa, Florida and Hawaii were some of the first reefs affected by the global bleaching event.

At the time of drafting this report, countries which reported coral bleaching include Japan, New Caledonia, Guam, Eastern Micronesia, Northern Mariana Islands, Taiwan, Fiji, Palau, Philippines, Mexico, Kiribati, Sri Lanka, Zanzibar, Brazil, India, Indonesia, Seychelles, French Polynesia, Madagascar, Comoros, Kenya, Mauritius and Tanzania among others. The global nature of this event presents the opportunity for nations to share knowledge and work together to develop best practices for monitoring bleaching and managing coral reef recovery.

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