CLIMATE COUNCIL

AUSTRALIA'S CORAL REEFS UNDER THREAT FROM CLIMATE CHANGE

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Preface

A disaster is unfolding in one of the world's most precious natural icons, the Great Barrier Reef. Rapidly warming oceans, driven by climate change from the burning of fossil fuels and an El Niño event, has led to a global bleaching event.

The latest surveys indicate that 93% of the individual reefs in the GBR have suffered some degree of bleaching, with reefs in the north the most severely affected. Australia's marine biodiversity, and the jobs and economic prosperity that the reef supports, is under grave threat.

This report presents a brief overview of the latest observations, and our current understanding of the causes and consequences of the event we are witnessing. The risks of climate change have never been more starkly illustrated. The need for action is more urgent than ever.

The Climate Council is extremely grateful to our team of reviewers whose comments and suggestions improved the report. The reviewers were: Dr Mark Eakin (US National Oceanic and Atmospheric Administration, NOAA), Professor Ove Hoegh-Guldberg (University of Queensland), Dr Gang Liu (NOAA and Global Science and Technology, Inc.), and Dr Janice Lough (Australian Institute of Marine Science).

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Key Findings

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The longest global coral bleaching event on record is underway due to record breaking ocean temperatures driven by climate change and El Niño.

- Australia's iconic reefs, particularly the northern part of the Great Barrier Reef, are experiencing severe bleaching.
- Climate change - driven mainly by the burning of coal, oil and gas – has caused extreme ocean temperatures, making the bleaching on the GBR this year at least 175 times more likely. At present rates of climate change, this level of bleaching could occur every two years by the 2030s.
- An estimated 36% of the world's coral reefs have been affected by major bleaching and nearly all reefs have experienced some thermal stress.
- Climate change also threatens fish, crustaceans and other species that rely on the reefs as habitat.

2

Coral reefs are among the most biologically diverse and economically valuable ecosystems on Earth, but they are under threat from climate change.

- The Great Barrier Reef is a multi-billion dollar economic asset. Its value-added economic contribution to the Australian economy was $5.7 billion in 2011-12, supporting 69,000 jobs.
- About 500 million people worldwide rely on coral reefs for their food and livelihoods, which represent an economic asset worth an astounding $1 trillion.
- Recovery could be impossible for many of the reefs currently affected by severe bleaching if climate change is not arrested.

3

The future of coral reefs around the world depends on how much and how fast we reduce greenhouse gas emissions now and in the coming years and decades.

- At the Paris UNFCCC conference on climate change (COP21) in December 2015, the world's nations pledged ambitious emission cuts in order to limit global warming to well below 2°C with a target of 1.5°C in the long-term.
- The pledges from COP21 need to be much more ambitious as the full implementation of current commitments would still see average global temperatures rise above 3°C.
- Australia has a critical role to play in the global effort to reduce fossil fuel emissions and protect reefs like the Great Barrier Reef.

1. A Disaster on the Great Barrier Reef

The Great Barrier Reef (GBR) is the largest single living marine structure on Earth and one of the world's natural wonders (Figure 1).

It stretches 2,300 kilometres along Australia's northeast coast and is so large it can be seen from space. Yet the GBR is now likely to suffer severe damage in the pristine northern sector from a mass coral bleaching event driven by climate change.

Figure 1: The Great Barrier Reef, a World Heritage-listed Australian icon.

The current, ongoing mass bleaching event is the worst in the GBR's history (GBRMPA 2016a; Hughes 2016; Figure 3). Extensive aerial and underwater surveys reveal that 93% of the individual reefs have been affected. Bleaching is extreme in the 1,000 km region north of Port Douglas all the way up to the northern Torres Strait between Australia and Papua New Guinea. Initial estimates indicate, on average, 50% mortality of bleached corals north of Port Douglas, and the final death toll is likely to exceed 90% on some reefs (CoE 2016a). The extent and intensity of observed bleaching decreases southwards along the 2,300 km length of the GBR from very severe in the north to moderate or minor in the central band of the reef to minor in the south. Although only about 1% of the reefs are severely bleached in the south, only a quarter have escaped bleaching entirely (Coral CoE 2016; GBRMPA 2016a, 2016b).

The current, ongoing mass bleaching event is the worst in the GBR's history.

Figure 2: Coral bleaching at Lizard Island, Great Barrier Reef.

MAP OF THE GREAT BARRIER REEF SHOWING RESULTS OF AERIAL SURVEYS FOR 911 REEFS

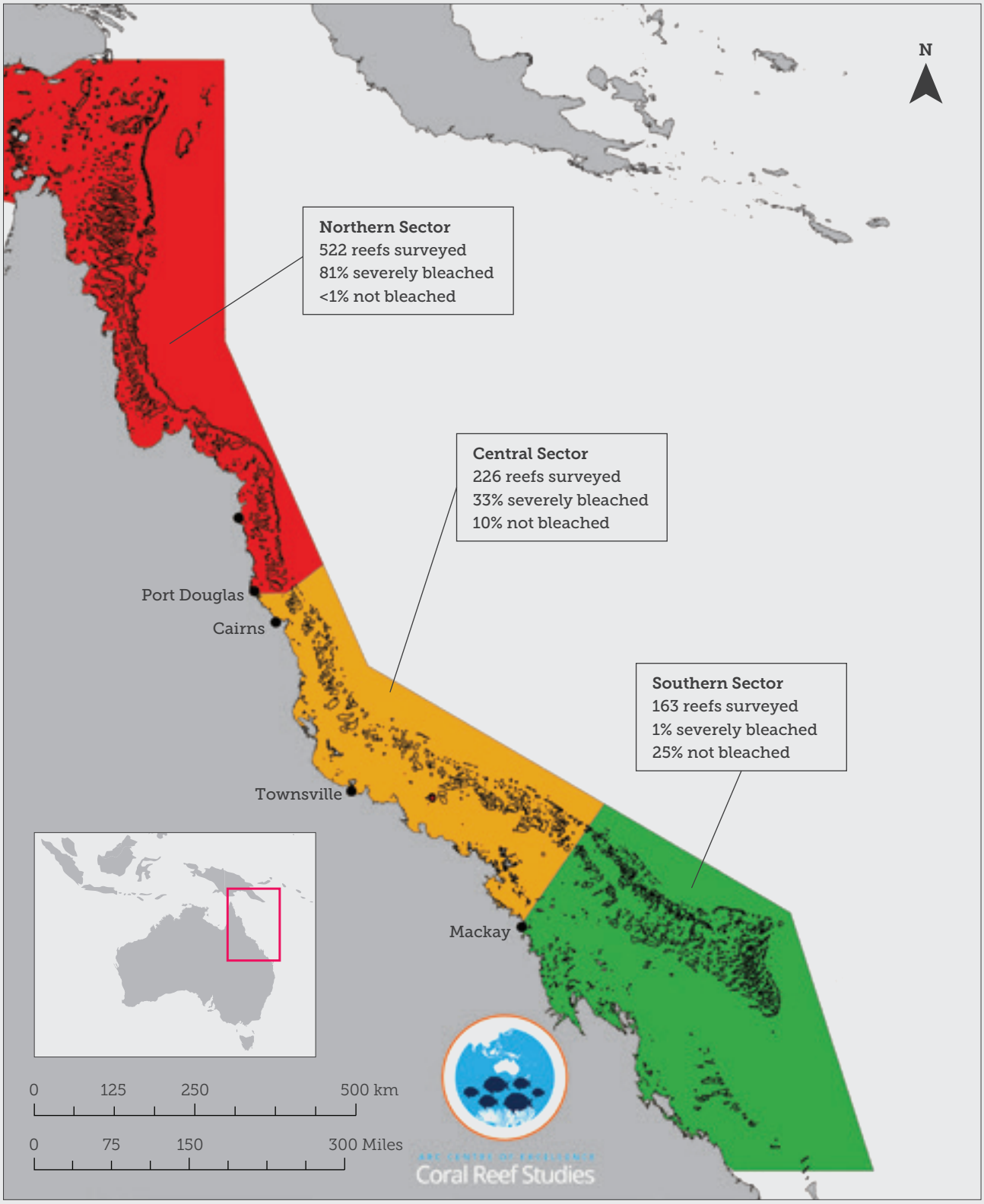


Figure 3: Map of the Great Barrier Reef showing results of aerial surveys for 911 reefs. **Source**: Adapted from ARC Centre of Excellence for Coral Reef Studies / Tom Bridge and James Kerry.

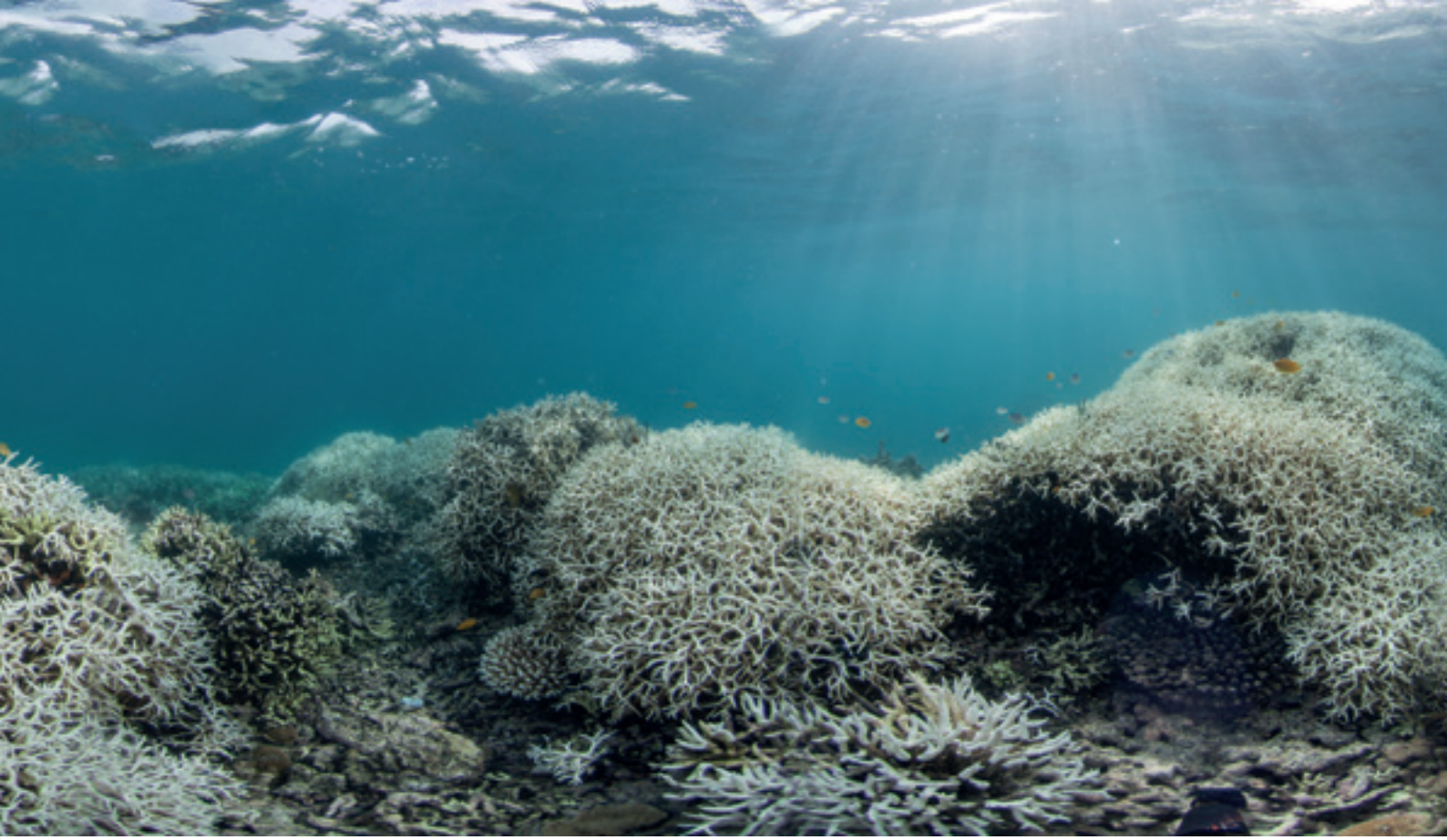


Figure 4: Coral bleaching at Lizard Island, Great Barrier Reef.

The majority of reefs north of Port Douglas have been severely bleached.

From late February through March 2016, the sea surface temperature over the northern Great Barrier Reef has been around 1 to 1.5°C above the recent long-term average (2002-2011) for this time of year (see BoM 2016a; Figure 5), and 1.5 to 2°C above the average of the period 1971-2000, with even higher temperatures in some areas (see NOAA 2016a). The increased temperature has resulted in coral bleaching across large areas, particularly on the most pristine and isolated reefs of the far north. Whilst the full extent of the damage to the GBR is still unfolding, the current bleaching is far worse than previously experienced in the region.

The current bleaching is far worse than previously experienced in the region.

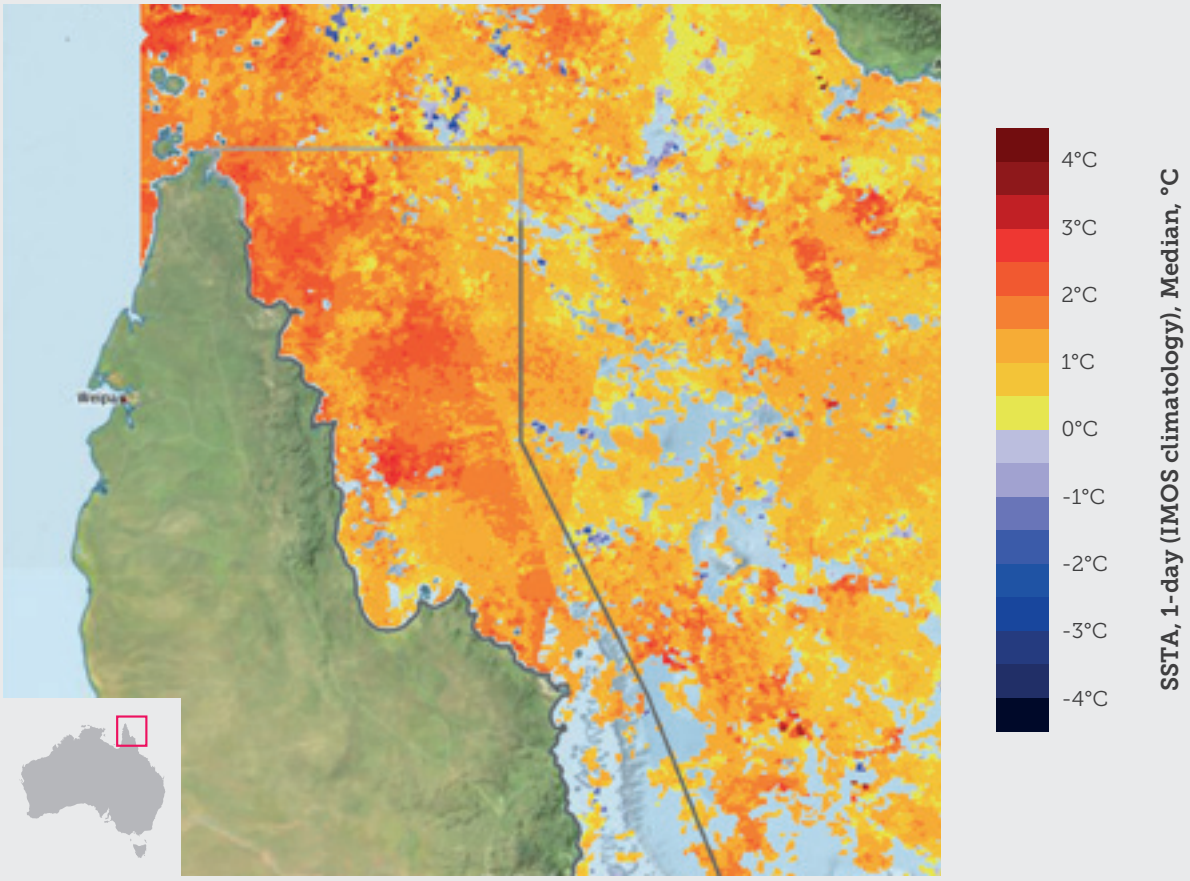
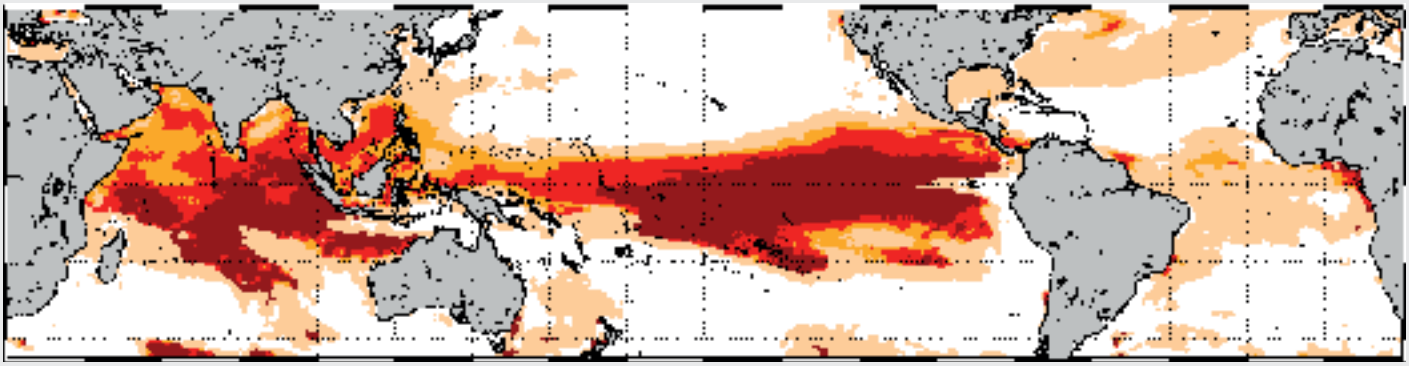


Figure 5: Image of the northern Great Barrier Reef (29 February to 6 March 2016), showing the sea surface temperature around 1 to 1.5°C above the recent long-term average (2002-2011) for this time of year, with higher temperatures in some areas. **Source:** Adapted from BoM 2016a.

The Great Barrier Reef is not the only Australian reef system to experience bleaching this year. The latest extended bleaching outlook shows that some reefs in Western Australia may suffer thermal stress and bleaching in April-May 2016, with possible mortality (Figure 6). Between 60-90% of corals on Scott Reef, off the northwest coast of Western Australia, have already bleached, and in some areas, more than half the corals have died. Varied levels of coral bleaching were observed mid-March in a number of reefs between Darwin and Broome. At time of writing, bleaching is occurring along the Kimberley coast as well as offshore locations such as Christmas Island, Cocos Islands, and Seringapatam Reef (AIMS 2016a). The only previous bleaching on record in Western Australia occurred in 2011, when extreme thermal stress caused major bleaching impacts in southerly reefs and ecosystems (Wernberg et al. 2013).

2016 APR 5 NOAA CORAL REEF WATCH
60% PROBABILITY CORAL BLEACHING THERMAL STRESS FOR APR-JUL 2016



Potential Stress Level: Watch Warning Alert Level 1 Alert Level 2

Figure 6: US National Oceanic and Atmospheric Administration's extended outlook issued on 5 April 2016 showing the global threat of bleaching for April to July 2016. The thermal stress along the northern coast of Western Australia may potentially increase during April to Alert Levels 1 and 2, including North Western Australia, Scott to Ashmore Reefs, Rowley Shoals, and Central Western Australia. The potential stress level categories are 'Warning' = possible bleaching, Alert Level 1 = bleaching likely, and Alert Level 2 = mortality likely. **Source**: adapted from NOAA 2016b.

BOX 1: WHAT CAUSES CORAL BLEACHING?

Corals have an interdependent relationship with tiny single celled plant-like organisms called *zooxanthellae* that live within their tissues, giving the corals their characteristic colour (NOAA 2015a, 2015b; Figure 7). The corals provide habitat for the *zooxanthellae,* while the algae provide the corals with food, producing as much as 90% of the energy the corals need to grow and reproduce (AIMS 2016b; GBRMPA 2016c).

When corals become stressed, they lose the *zooxanthellae*, revealing the white skeleton of the coral, hence the term "bleaching". Bleaching can occur when corals are subject to sea surface temperatures only 1 to 2°C above long-term average maximum temperatures (De'ath et al. 2012; Hoegh-Guldberg et al. 2014). If the thermal stress is mild or short-lived the corals may survive. If the stress is more severe, or over an extended period of time, the corals can die or partially die (Putnam and Edwards 2011; Sammarco and Strychar 2013; NOAA 2015b). Repeated, lower level bleaching events can also lead to a loss of corals over time (De'ath et al. 2012). Corals that survive the bleaching may have slower growth and decreased reproduction, and be more susceptible to disease. Coral reefs can take many years to recover after a major bleaching event (GBRMPA 2016c).

Coral reefs can take years or even decades to recover after a major bleaching event.

Figure 7 (opposite): What is coral bleaching? **Sources:** Adapted from NOAA 2015b; Underwater Earth 2015.

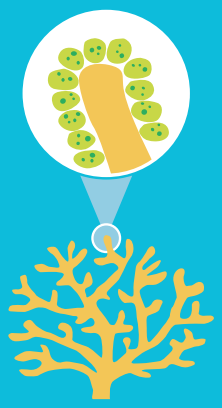
WHAT IS CORAL BLEACHING?

Coral reefs are highly vulnerable to a changing climate. Warmer ocean temperatures and other stressors cause coral bleaching events which can damage and destroy coral reefs and the ecosystems they support.

1 HEALTHY CORAL

Coral and algae depend on each other to survive.

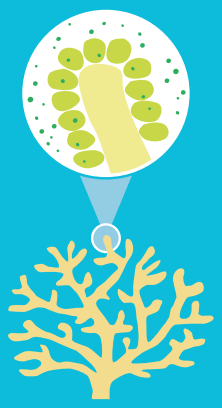
Corals have a symbiotic relationship with microscopic algae called zooxanthellae that live in their tissues. These algae provide their host coral with food and give them their colour.



2 STRESSED CORAL

If stressed, algae leave the coral.

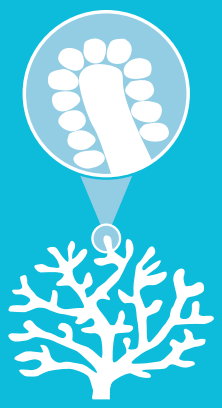
When the symbiotic relationship becomes stressed due to increased ocean temperature or pollution, the algae leave the coral's tissue.



3 BLEACHED CORAL

Coral is left bleached and vulnerable.

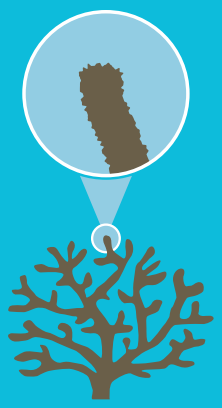
Without the algae, the coral loses its major source of food, turns white or very pale, and is more susceptible to disease.



4 DEAD CORAL

Coral is left bleached and vulnerable.

Without enough plant cells to provide the coral with the food it needs, the coral soon starves or becomes diseased. Soon afterwards, the tissues of the coral disappear and the exposed skeleton gets covered with algae.



CHANGE IN OCEAN TEMPERATURE

Increased ocean temperature caused by climate change is the leading cause of coral bleaching. Water temperature higher than the average summer maximum – just 1°C higher for four weeks can cause bleaching.

RUNOFF AND POLLUTION

Storm generated precipitation can rapidly dilute ocean water and runoff can carry pollutants - these can bleach near shore corals.

OVEREXPOSURE TO SUNLIGHT

When temperatures are high, high solar irradiance contributes to bleaching in shallow-water corals.

EXTREME LOW TIDES

Exposure to air during extreme low tides can cause bleaching in shallow corals.

Sources: Adapted from NOAA 2015b; Underwater Earth 2015.

2. Why is Bleaching Occurring Now?

Human activities, primarily the emission of greenhouse gases from the combustion of fossil fuels (coal, oil and gas), are driving climate change. The changing climate is putting the Earth's biodiversity and ecosystems at very high risk of serious impacts this century (Gattuso et al. 2015). We are already witnessing these impacts on some of the most diverse and important habitats on Earth.

Climate change is the most significant long-term threat to coral reefs (Hoegh-Guldberg et al. 2014; Wake 2016). As the atmospheric concentration of carbon dioxide (CO_2) and other greenhouse gases increase, ocean temperatures will continue to climb, increasing the likelihood of more frequent and destructive mass coral bleaching events (Figure 8). Future increases in sea temperature of as little as 0.5°C may lead to significant degradation of the Great Barrier Reef (Ainsworth et al. 2016).

Figure 8: The influence of climate change on coral bleaching. Climate change - driven mainly by the burning of coal, oil and gas - is causing ocean temperatures to rise and increasing the incidence and severity of coral bleaching.

The ten warmest years on record globally have all occurred since 1998.

The ability to recover from bleaching events varies among coral species. While corals can adapt to temperature over evolutionary time, there is little evidence thus far that corals will be able to adapt fast enough to the rapid rate of temperature rise currently being experienced (Hoegh-Guldberg et al. 2014). The Earth has already warmed about 0.9°C above pre-industrial levels, with much of that warming occurring since 1970 (IPCC 2013). Furthermore, despite the focus on air temperature, warming of the air accounts for only 1% of the additional energy stored in the climate system - more than 90% of the total energy accumulated between 1971 and 2010 has been absorbed by the oceans, and the upper 75 m - where most reef-building corals live - has warmed by 0.11°C per decade over the period 1992 to 2010 (IPCC 2013).

Global average temperature has been rising for over 50 years. Global heat records tumbled (yet again) last year, establishing 2015 as the hottest year on record, and breaking the previous record held by 2014 (NOAA 2016c). The ten warmest years on record globally have all occurred since 1998 (NASA 2015).

In 2015, the globally-averaged sea surface temperature was 0.74°C above the 20th century average, exceeding the 2014 record by +0.11°C (NOAA 2016c). This summer, the average sea surface temperature in the Coral Sea, off the northeast coast of Australia, was one of the hottest on record, reaching almost 0.7°C above the long-term average (1961-1990). With the weakening of the El Niño, March 2016 was easily the hottest March on record (BoM 2016b; Figure 9a,b). New analysis has revealed that human caused climate change made the extreme ocean temperatures that led to bleaching along the Great Barrier Reef this year at least 175 times more likely (CoECSS 2016). Moreover, climate change is very likely to make the extreme ocean temperatures that caused this year's event occur every two years during March by 2034. Extreme coral bleaching will become the new normal unless serious reductions in greenhouse gas emissions are achieved (CoECSS 2016).

Extreme coral bleaching will be the new normal by the 2030s unless serious reductions in greenhouse gas emissions are achieved.

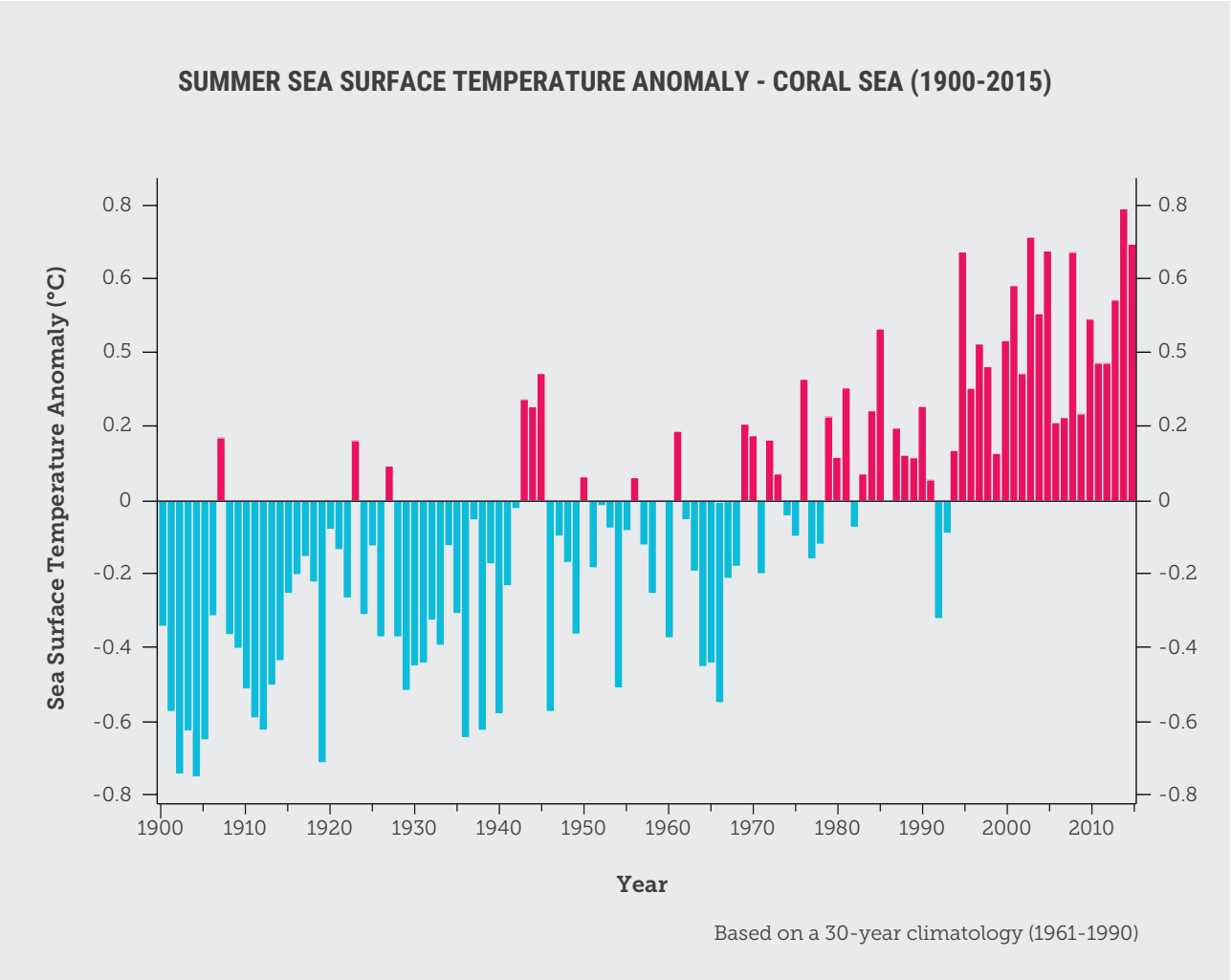


Figure 9a: Difference in summer sea surface temperatures for the Coral Sea, off the northeast coast of Australia, relative to the average period 1961-1990. **Source:** Adapted from BoM 2016b.

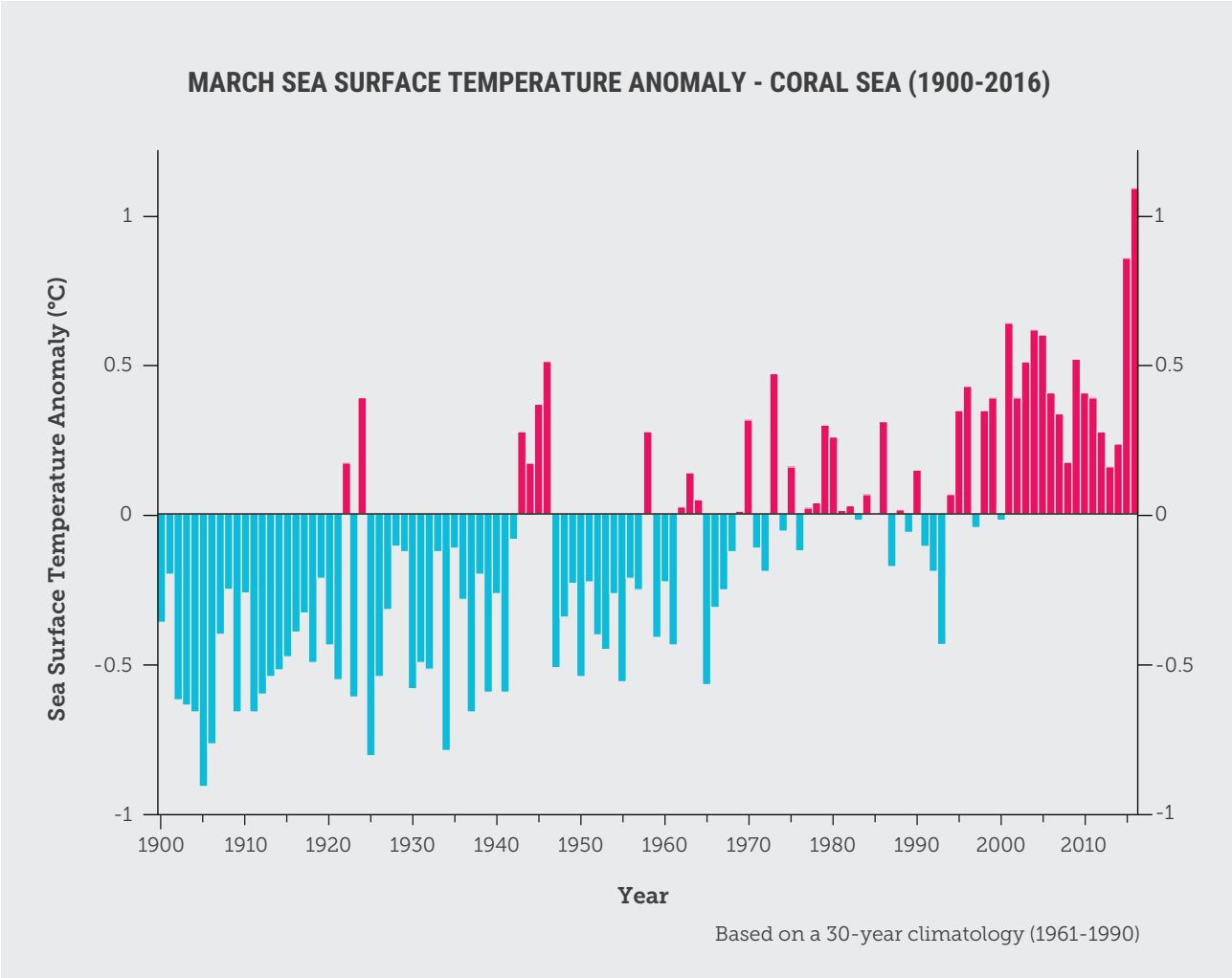


Figure 9b: Difference in March sea surface temperatures for the Coral Sea relative to the average period 1961-1990. **March 2016 was the hottest on record for this month. Source:** Adapted from BoM 2016b.

The current El Niño event is exacerbating the impact of climate change. As the El Niño phase begins to break down towards the end of summer, the warm waters in the central equatorial Pacific move towards Australia as normal wind and ocean current patterns are re-established. Ocean temperatures around northern Australia also warm substantially from December to March during El Niño events, in response to reduced cloud cover and weakened winds, because El Niño tends to suppress and delay the monsoon (BoM 2016b). While Australia has weathered El Niño events for centuries, the Great Barrier Reef only began to experience repeated coral bleaching events from the 1980s (see section below) (e.g., Hoegh-Guldberg 1999; Hoegh-Guldberg et al. 2014).

3. Has Bleaching on the GBR Occurred Before?

Bleaching events in Australian and other Southern Hemisphere reefs (Pacific and Indian Oceans) tend to occur in January-April, with a lag of up to a month in the response of corals following thermal stress (BoM 2011). Bleaching on the Great Barrier Reef was not known before the early 1980s (Hoegh-Guldberg et al. 2014).

Since that time, as climate change has become more severe, several bleaching events have occurred during periods of unusually warm sea surface temperatures, with the most severe events occurring in 1998, 2002 and 2006 (BoM 2011). In the 1998 event, for example, 42% of individual reefs on the GBR were affected, with severe bleaching on 18% (Berkelmans et al. 2004). Over the period 1985 and 2012, the GBR is estimated to have lost 50% of its hard coral cover. Most of this loss has been attributed to damage from tropical cyclones and crown-of-thorns starfish predation but bleaching accounted for about 10% (De'Ath et al. 2012). Long-term records show that this severe and sudden decline in coral growth is unprecedented in at least the last 400 years, and that 1990 may have been a 'tipping point' for coral calcification rates on the Reef (AIMS 2016c).

A survey conducted six months before the current bleaching event found that the Great Barrier Reef had recovered about 19% of its coral cover between 2012 and 2015 (AIMS 2016d). This positive trend, however, is now threatened by the current bleaching. Even those corals that may survive the current event are likely to have reduced reproduction and growth for several years, as well as increased vulnerability to further bleaching or other stressors.

The pattern of mass coral bleaching and mortality over the next nine months is very likely to follow the pattern and sequence seen in 1998 (see Hoegh-Guldberg 1999), although impacts are likely to be larger given the increased sea temperatures due to climate change. The current mass bleaching event is unprecedented in the GBR.

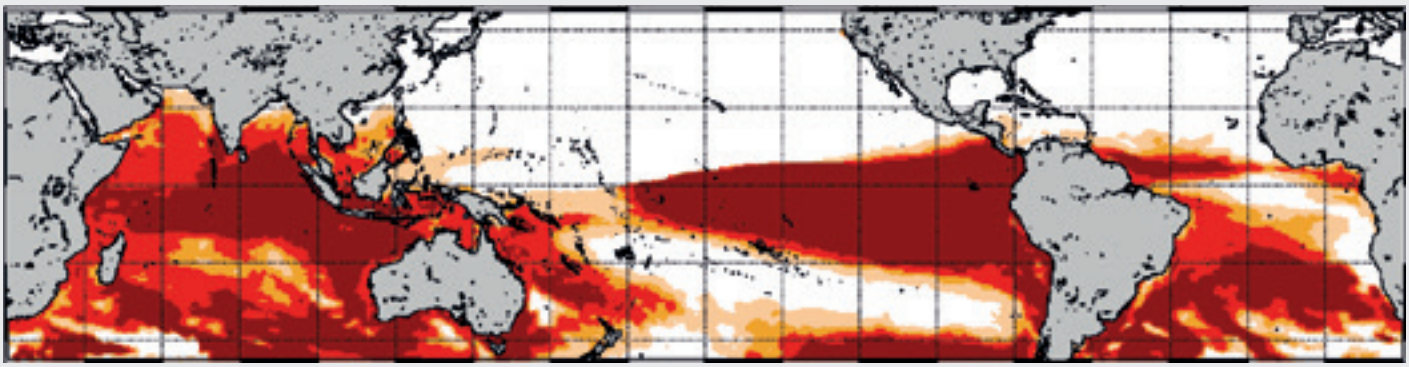
4. This is a Global Event

The Great Barrier Reef is not the only reef in trouble.

Record global ocean temperatures associated with a severe El Niño event, marked by up to 3°C warmer-than-average sea surface temperatures in the central and eastern equatorial Pacific Ocean over the past year or so, on top of the long-term warming trend, prompted NOAA to declare a global bleaching event (Figure 10) in October 2015, because the phenomenon was evident in all three ocean basins, the Indian, Pacific, and Atlantic/Caribbean (NOAA 2015a; Hoegh-Guldberg 2016). A global event such as this has only been declared twice before - in 1998 and 2010 (NOAA 2015a; Wake 2016).

Record breaking ocean temperatures driven by climate change has led to a mass global bleaching event.

2015 OCT 6 NOAA CORAL REEF WATCH
60% PROBABILITY CORAL BLEACHING THERMAL STRESS FOR FEB-MAY 2016



Potential Stress Level: Watch Warning Alert Level 1 Alert Level 2

Figure 10: Global mass bleaching event. This outlook issued by NOAA on 6 October 2015 predicted the likelihood of heat stress that causes coral bleaching. From February to May 2016 there was an estimated 60% chance of many of the world's reefs likely to be affected by a mass bleaching event. The potential stress level categories are 'Warning' = possible bleaching, Alert Level 1 = bleaching likely, and Alert Level 2 = mortality likely. **Source:** Adapted from NOAA 2015c.

This latest bleaching event, which began in the north Pacific in the 2014 Northern Hemisphere summer and expanded to the south Pacific, Atlantic and Indian Oceans in 2015, hit US Pacific coral reefs hard and extended into the Caribbean (NOAA 2015a). By early 2016, bleaching had affected Pacific Islands in the Southern Hemisphere and began to threaten the Great Barrier Reef (NOAA 2016d).

This mass global bleaching event is the longest ever recorded (NOAA 2016e). The event is still unfolding and we will not be able to gauge its full extent for at least a few months but initial reports on the impacts are extremely concerning:

"About 36% of the world's coral reefs – 72% of the U.S. reefs - are in such warm water they are under official death watch, and that could rise to up to 60% of the world's coral by July"

- Mark Eakin, NOAA
(Independent Mail, 6 April 2016).

US coral reefs have been hit hard, experiencing widespread bleaching for two years in a row, including record-breaking events in the Hawaiian Islands, American Samoa (Figure 11), Guam, the Commonwealth of the Northern Mariana Islands, and Florida. Satellite monitoring shows that all the US coral reef areas experienced some levels of bleaching or thermal stress in 2014-2015, with 30% of reefs placed on Alert Level 1 (typically associated with significant bleaching), and 41% placed on Alert Level 2 (typically associated with widespread coral bleaching and mortality) (NOAA 2016d).

Severe bleaching has also been reported for reefs across the Pacific, Caribbean and Indian Oceans. In the Pacific, severe bleaching has been reported in New Caledonia and Fiji and in Kiribati 80% of the corals have died (Eakin, 2016, pers comm, 8 April). Widespread coral mortality is likely in the western Indian Ocean in countries such as the Maldives, Kenya and the Seychelles, with severe impacts in southeast Asia and the Coral Triangle centred on Indonesia expected. As the northern summer develops, bleaching and coral deaths may occur in parts of the Middle East, Japan and the Caribbean by July and August (Hoegh-Guldberg and Ridgway 2016), again consistent with the pattern seen in 1998 (Hoegh-Guldberg 1999). NOAA scientists report that the current bleaching event could extend well into 2017 (NOAA 2016e).

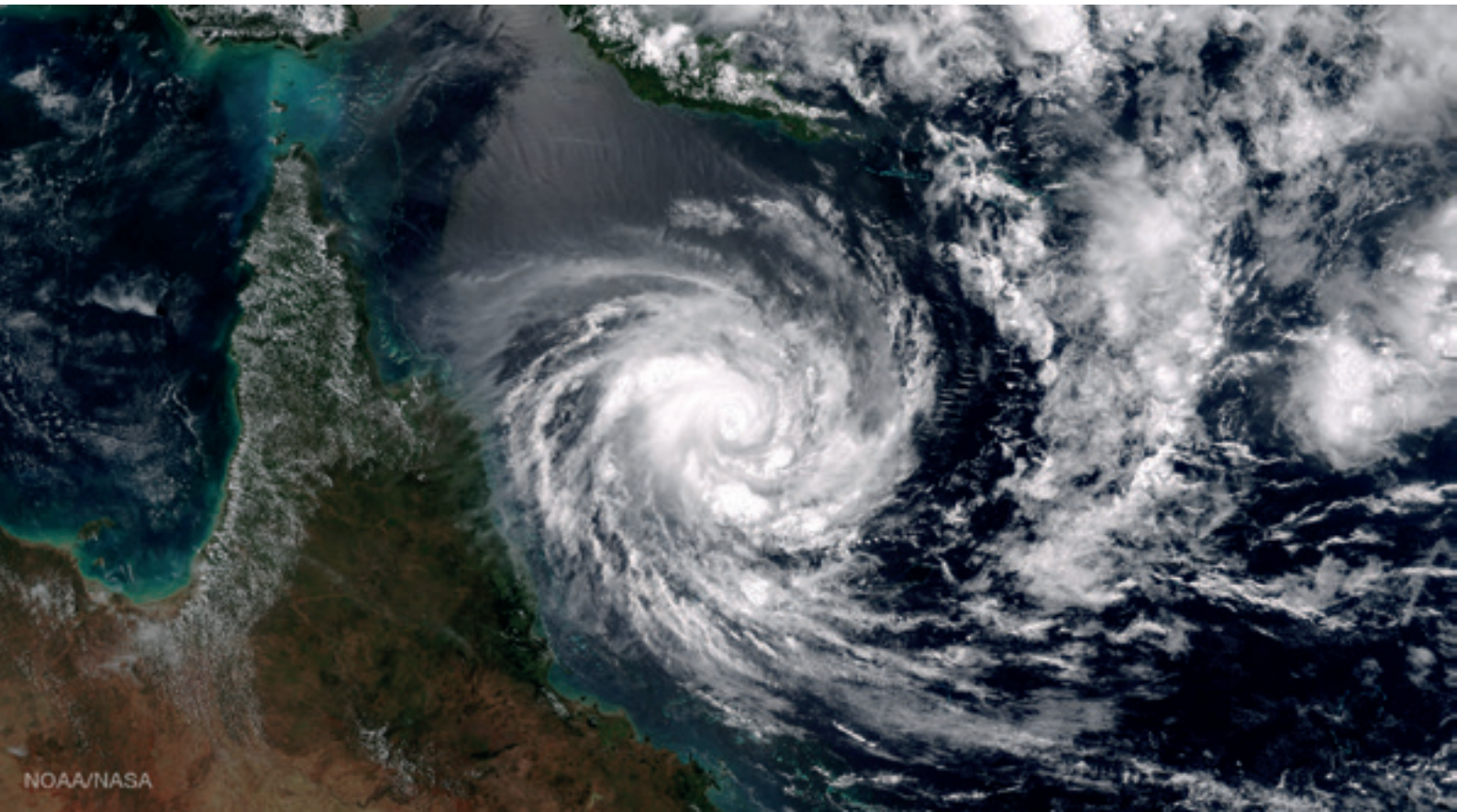
Figure 11: A marine biologist assessing the bleaching at Airport Reef in American Samoa in February 2015.

5. Can Our Reefs Recover?

Bleaching can be caused by many different stressors, including changes in water quality from pollution, freshwater inflows and increased sediment (BoM 2011; GBRMPA 2016c; Figure 7).

However, the most severe cases of bleaching are associated with unusually high seawater temperatures during the summer warm season (Hoegh-Guldberg 1999). There is some evidence that corals can acclimate (i.e. adjust their physiology to be more resilient). However, these increases in resilience are small in scale and are unlikely to play a significant role in future events as waters continue to warm (Ainsworth et al. 2016). The fact that bleaching is having greater and greater impacts (e.g. bleaching and mortality) over time is strong evidence that corals are not able to acclimatise adequately to the rate of increase in ocean temperature.

Figure 12: Tropical Cyclone Nathan in March 2015 circling the Great Barrier Reef. Climate change is likely to result in more intense cyclones which can cause physical damage to reefs.



Warming is not the only global change affecting coral reefs. Climate change is likely to result in more intense cyclones (Emanuel 2005; CSIRO and BoM 2015), increasing the risk of physical damage to reefs (Figure 12). Furthermore, corals will be increasingly affected by the additional stress of progressive ocean acidification. Roughly 25% of carbon dioxide released into the atmosphere each year from the burning of fossil fuels is absorbed by the oceans (Albright et al. 2016). As the carbon dioxide is absorbed, it reacts with seawater to form carbonic acid. As the acidity of seawater increases, the ability of corals, shellfish and other marine organisms to build their skeletons and shells from calcium carbonate declines (Orr et al. 2005; Doney et al. 2009).

An experiment conducted on a natural coral reef in the southern GBR altered the seawater chemistry to return the water's acidity to pre-industrial (pre-climate change) levels. The corals grew better under the pre-industrial conditions, indicating that ocean acidification linked to greenhouse gas emissions may already be slowing coral growth (Albright et al. 2016). Coupled with mesocosm experiments (outdoor experiments that examine the natural environment under controlled conditions) such as those of Dove et al. (2013), these experiments confirm that large-scale impacts are highly likely under warmer and more acidic oceans. Taken together, warming and acidification can interact (Anthony et al. 2008) and have devastating effects on coral reefs (Dove et al. 2013).

"The coral bleaching and disease, brought on by climate change and coupled with events like the current El Niño, are the largest and most pervasive threats to coral reefs around the world"

- Mark Eakin, NOAA Coral Reef Watch (NOAA 2015a).

6. How Can We Protect Our Coral Reefs?

Healthy coral reefs are among the most biologically diverse and economically valuable ecosystems on Earth.

These ecosystems protect coastlines from storms and erosion and provide habitat, spawning and nursery grounds for 25% of marine species, including many economically important fish. Coral ecosystems also provide jobs and income to local communities from fishing, recreation, and tourism, supporting livelihoods of 500 million people globally. Loss of coral reefs potentially puts an astounding $1 trillion at risk globally (Hoegh-Guldberg et al. 2015). The value-added economic contribution of the Great Barrier Reef World Heritage Area to the Australian economy in 2011-12 was $5.7 billion, and supported 69,000 jobs (Deloitte Access Economics 2013). Reefs are also of great cultural importance in many regions around the world, particularly in Polynesia (The Nature Conservancy 2016).

The survival of coral reefs worldwide is threatened if we continue to burn fossil fuels (coal, oil and gas) and warm the climate at current rates (Hoegh-Guldberg 1999; Lough 2008; Hoegh-Guldberg et al. 2014; Ainsworth et al. 2016; Hughes 2016).

We have a clear and urgent choice. The future of coral reefs depends on how much and how fast we reduce greenhouse gas emissions now, and in the coming years and decades (Hoegh-Guldberg 1999; Hoegh-Guldberg et al. 2007; De'ath et al. 2012). Global emissions must be trending downwards by 2020 at the latest. Renewable energy investment and implementation must therefore increase rapidly and most of the known fossil fuel reserves must remain in the ground (McGlade and Ekins 2015).

Australia joined the rest of the world at the Paris COP21 climate change conference in December 2015 to increase the level of commitment to limit climate change. Yet, the pledges from COP21 need to be much more ambitious as the full implementation of current commitments would still see average global temperatures rise above 3°C. Now is the time to turn ambition into action if we are to protect our coral reefs.

The future of coral reefs depends on how much and how fast we reduce greenhouse gas emissions now, and in the coming years and decades.

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