CLIMATE COUNCIL

CLIMATE CHANGE: A DEADLY THREAT TO CORAL REEFS

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Preface

The Great Barrier Reef is experiencing mass coral bleaching yet again, less than 12 months on from the most devastating bleaching event on record. Rapidly warming oceans, driven by climate change from the burning of coal, oil and gas has led to the world's longest ever global bleaching event, beginning in 2014 and ongoing in 2017, with repeated bleaching of the Great Barrier Reef and other reefs worldwide offering no reprieve.

In March 2017, the latest surveys of the Great Barrier Reef show severe bleaching has occurred already this year in inshore and offshore reefs between Palm Islands and Port Douglas - the central section of the reef which was largely spared last year. There is also bleaching (varying levels from minor to severe) over a much wider area to the north and south of this region. Generally, southern areas are faring better, especially offshore (GBRMPA 2017).

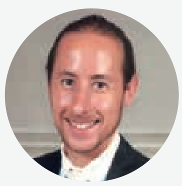
Climate change is the greatest threat to the Great Barrier Reef. The Reef supports a huge variety of marine biodiversity and an estimated 69,000 Australian jobs, and provides $7 billion to the Australian economy every year.

This report provides a brief overview of the 2016 bleaching event, initial survey results of the latest mass bleaching event on the Great Barrier Reef, and an outlook for reefs in Australia and around the world in the coming months and decades. We also describe how climate change is stacking the odds against coral reefs surviving unless drastic action is taken.

If we are to protect coral reefs we must rapidly and deeply reduce our greenhouse gas emissions by transitioning to renewables, improving energy efficiency and investing more in energy storage technologies.

The Climate Council is extremely grateful to Dr Janice Lough (Australian Institute of Marine Science) and an anonymous reviewer, whose comments and suggestions greatly improved the report. We would also like to thank Kylie Malone and Dylan Pursche for their assistance in preparing the report.



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Key Messages

1

The Great Barrier Reef is experiencing severe bleaching in 2017, following the worst bleaching event on record in 2016.

- Last year the Great Barrier Reef experienced its worst bleaching event ever. The pristine reefs in the north (Port Douglas to Papua New Guinea) were the most badly affected, with mortality of two-thirds of coral in this region.
- While the El Niño has waned, bleaching on the Great Barrier Reef appeared again in 2017, fuelled by climate change.
- In 2017 more bleaching is being observed in the central section of the GBR, which was spared last year.
- Cooler waters as a result of Tropical Cyclone Debbie that hit North Queensland in late March 2017, may bring some reprieve from further bleaching, especially in the central section of the GBR. But there could be significant physical damage to corals as Cyclone Debbie tore through the reef.
- Reefs bleached in both 2016 and 2017 have had no opportunity to recover and so high mortality rates can be expected.

2

Climate change is threatening our reefs and putting their future health at extreme risk.

- Rising sea surface temperatures, driven by climate change, are increasing the frequency and severity of mass coral bleaching events and reducing the opportunities for corals to recover.
- The longest global coral bleaching event on record, ongoing since 2014, has led to widespread bleaching and mortality of reefs as pools of unusually warm water move around the globe.
- It was virtually impossible for the extreme ocean temperatures that led to coral bleaching along the Great Barrier Reef in 2016 to have occurred without climate change.

3

Coral reefs are a huge economic asset, providing jobs and incomes to local communities.

- Loss of coral reefs potentially puts an astounding $1 trillion at risk globally.
- The World Heritage-listed Great Barrier Reef is a national economic asset worth $7 billion annually, supporting the livelihoods of 69,000 Australians employed in sectors such as tourism.
- If severe bleaching continues, regions adjacent to the Great Barrier Reef risk losing more than 1 million visitors annually - equivalent to at least $1 billion in tourism spending and 10,000 jobs.
- Over the next two to three decades, bleaching events are likely to become even more frequent and severe in Australia, with catastrophic impacts on reef health and the economy.

4

We must rapidly reduce greenhouse gas emissions now to protect our reefs.

- While carbon emissions flat-lined last year in China and declined in the United States and elsewhere, Australia's net emissions continue to rise, increasing by 0.8% in 2016.
- In the long term, protecting our coral reefs requires the rapid phasing out of fossil fuels globally, and the uptake of cheap, clean and efficient renewable energy and energy storage technologies. Australia must play its part.
- The commissioning of new coal mines such as that planned for the Galilee Basin, and the pursuit of polluting and expensive "clean coal" projects and new gas plants, is completely at odds with protecting the Great Barrier Reef and other reefs globally.

Contents

Introduction

One year on from the Great Barrier Reef's worst ever bleaching event, and with a new bleaching event unfolding, this briefing paper is an update of the Climate Council's report 'Australia's Coral Reefs Under Threat From Climate Change', published in May 2016. In the earlier report we described how rising global sea surface temperatures, driven by climate change, were the cause of the severe bleaching.

Climate change is the most significant long-term threat to coral reefs.

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 already affecting the Earth's biodiversity and ecosystems, and putting them at high risk of even more serious impacts over the next few decades (Gattuso et al. 2015).

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. Future increases in sea temperature of as little as 0.5°C from present are expected to lead to significant degradation of the Great Barrier Reef (GBR) (Ainsworth et al. 2016).

The Great Barrier Reef Marine Park Authority, after conducting initial aerial surveys with the Australian Institute of Marine Science, recently announced that mass coral bleaching is underway, yet again, following the GBR's worst bleaching event ever in 2016. The central region of the reef, which escaped the worst of the bleaching and mortality last year, is now experiencing widespread bleaching (GBRMPA 2017).

In 2016, record-breaking ocean temperatures occurred around Australia, with an annual mean sea surface temperature 0.73°C above the 1961-1990 average (BoM 2017a; Figure 1), and even higher above the pre-industrial baseline to which reefs are adapted. In 2016, the GBR recorded its hottest sea surface temperatures for February, March and April since records began in 1900. Sea surface temperatures were 29.1°C in February (1.1°C above the 1961-1990 average), 29.1°C (1.3°C

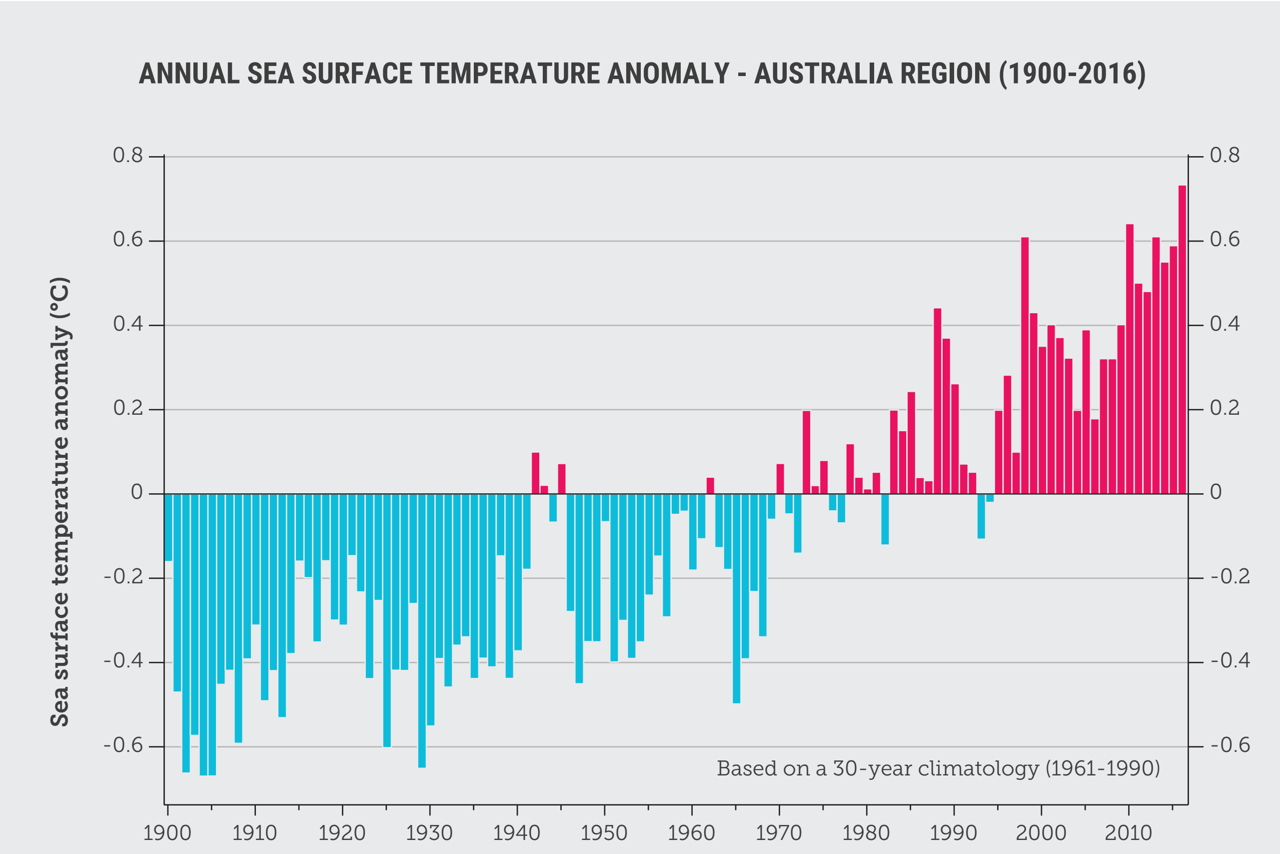


Figure 1: Long-term warming trend of ocean temperatures in the Australian region since 1900. Warm ocean temperatures around Australia were record-breaking in 2016, with an annual mean sea surface temperature 0.73°C above the 1961-1990 average, and even higher above the pre-industrial baseline. **Source:** BoM 2017c.

above average) in March and 27.8 °C (1.0°C above average) in April (BoM 2016a). This year, in March and April, sea surface temperatures were projected to be up to 0.8°C above average for the GBR region (BoM 2017d).

These high temperatures (Figure 2) resulted in coral bleaching and mortality across large areas, particularly in the pristine and isolated northern reefs. Surveys revealed that 91% of individual reefs across the GBR were affected in some way, with 67% coral mortality recorded in the 1,000 km northern section, stretching from north of Port Douglas up to the northern Torres Strait between Australia and Papua New Guinea (CoECSS 2016b; Hughes et al. 2017). Analysis by King et al. (2016) emphasised that the extreme March ocean temperatures (Figure 3) were virtually impossible without climate change. More specifically, conservative estimates show that the observed warm conditions in the Coral Sea were at least 175 times more likely to occur because of climate change (King et al. 2016).

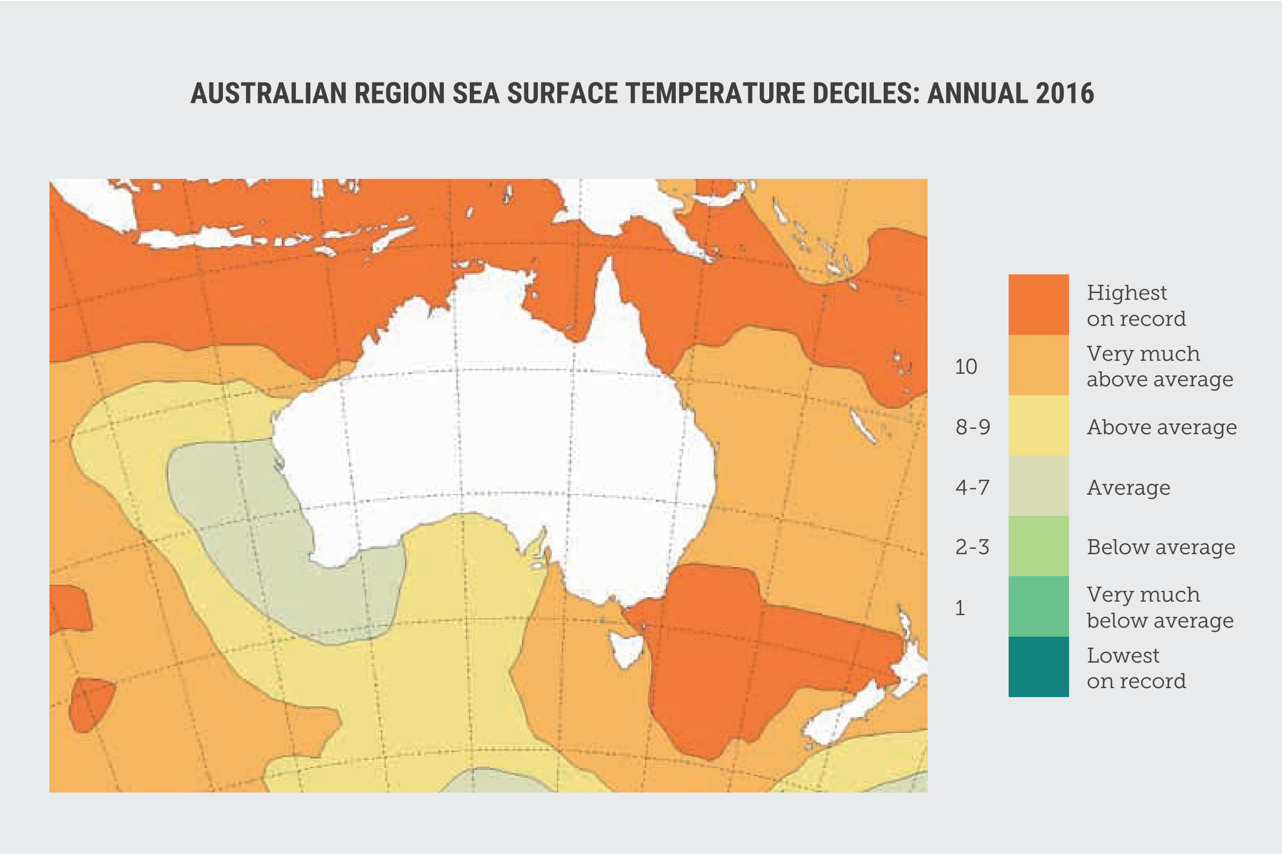


Figure 2: 2016 sea surface temperatures compared to historical records stretching back to 1900. Record warm ocean temperatures driven by climate change caused extensive coral bleaching in the northern section of the Great Barrier Reef (from the NOAA Extended Reconstructed Sea Surface Temperature dataset, ERSST v4). **Source:** BoM 2017a.

The devastating 2016 GBR bleaching was at least 175 times more likely due to climate change.

Figure 3: Bleached coral at Lizard Island in March 2016, north of Cooktown in the northern section of the Great Barrier Reef.

The GBR is not the only reef affected by unprecedented coral bleaching in recent times. The longest global bleaching event on record began in 2014 due to record breaking ocean temperatures and continues into 2017. While bleaching in 2016 was driven by both climate change and an El Niño event, bleaching is still occurring after the El Niño has waned (NOAA 2017). Up to 3°C warmer-than-average sea surface temperatures in the central and eastern equatorial Pacific Ocean, on top of the long-term warming trend, prompted NOAA to declare a global bleaching event in October 2015. The phenomenon was considered global because it was evident in all three ocean basins, the Indian, Pacific, and Atlantic/Caribbean (NOAA 2015a; Hoegh-Guldberg 2016). Such a global event has only been declared twice before – in 1998 and 2010 (NOAA 2015a; Wake 2016).

Unfortunately, the bleaching catastrophe experienced by the GBR in 2016 is not over and a new event is now underway. The purpose of this report is to summarise the new data available from aerial and underwater surveys of the GBR and other reefs around the world. We find that the GBR in particular was badly affected by bleaching in 2016, and a new bleaching event in 2017 threatens its long-term survival as repeated bleaching events reduce the opportunity for corals to survive. Over the next two to three decades, bleaching events are likely to become more frequent and severe in Australia, with catastrophic impacts on reef health and the economy.

For more details about the cause of the recent mass global bleaching event, please refer to our report, 'Australia's Coral Reefs Under Threat From Climate Change' (www.climatecouncil.org.au/reefreport).

1. What Causes Coral Bleaching?

Bleaching can occur when corals are subject to sea surface temperatures only 1 to 1.5°C above the seasonal maximum mean temperature (Baker et al. 2008).

Tropical reef-building corals have a mutually beneficial, symbiotic relationship with tiny single celled plant-like organisms called zooxanthellae that live within their tissues, giving the corals their characteristic colour (NOAA 2015b; Figure 4). Healthy corals have between one and two million zooxanthellae per square centimetre (CoECSS 2016a). The corals provide habitat and protection 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 2016a). When corals become stressed they lose the zooxanthellae, revealing the white skeleton of the coral - hence the term "bleaching". During the very severe bleaching event on the Great Barrier Reef in 2016, some corals had no zooxanthellae remaining in their tissues at all (CoECSS 2016a).

If the thermal stress to which corals are subjected is mild or short-lived, the corals may recover and survive. If the stress is more severe, or over an extended period, 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. Most worryingly, coral reefs can take many years to recover after a major bleaching event (GBRMPA 2016a).

During relatively mild bleaching, different coral species display great variability in their susceptibility – there are "winners and losers" (Hughes et al 2017). But during an extreme bleaching event all coral species on a reef may suffer – there are no winners. As a result, even if some areas regain corals during a subsequent period of recovery, the structure and composition of the reef community may be permanently changed (Hughes et al. 2017).

Coral reefs can take many years to recover after a major bleaching event.

Figure 4 (following page): Different states of coral. In a warming climate, coral reefs are highly vulnerable to bleaching and death.

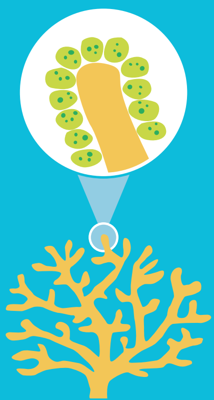
WHAT IS CORAL BLEACHING?

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.

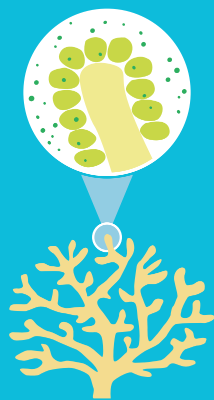
Corals have a symbiotic relationship with microscopic algae called zooxanthellae that live in their tissues. These algae provide their host coral with food and give them their colour.



2 STRESSED CORAL

If stressed, algae leave the coral.

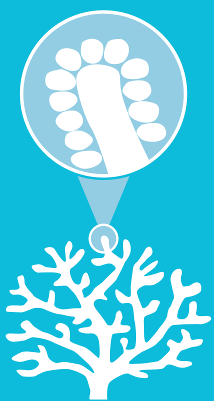
When the symbiotic relationship becomes stressed due to increased ocean temperature or pollution, the algae leave the coral's tissue.



3 BLEACHED CORAL

Coral is left bleached and vulnerable.

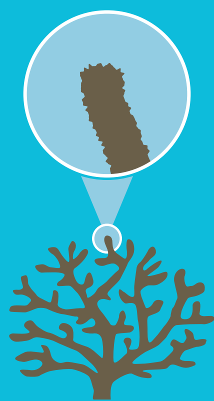
Without the algae, the coral loses its major source of food, turns white or very pale, and is more susceptible to disease.



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. Current Status of Australia's Reefs

Australia's reefs were hit hard by bleaching in early 2016. Of most concern was the impact that warm sea temperatures had on the iconic Great Barrier Reef.

The GBR is the largest single living marine structure on Earth and one of the world's natural wonders (Figure 5). It stretches 2,300 kilometres along Australia's northeast coast and is so large it can be seen from space. The most severe bleaching event on record in 2016 caused severe damage, particularly in the pristine northern sector.

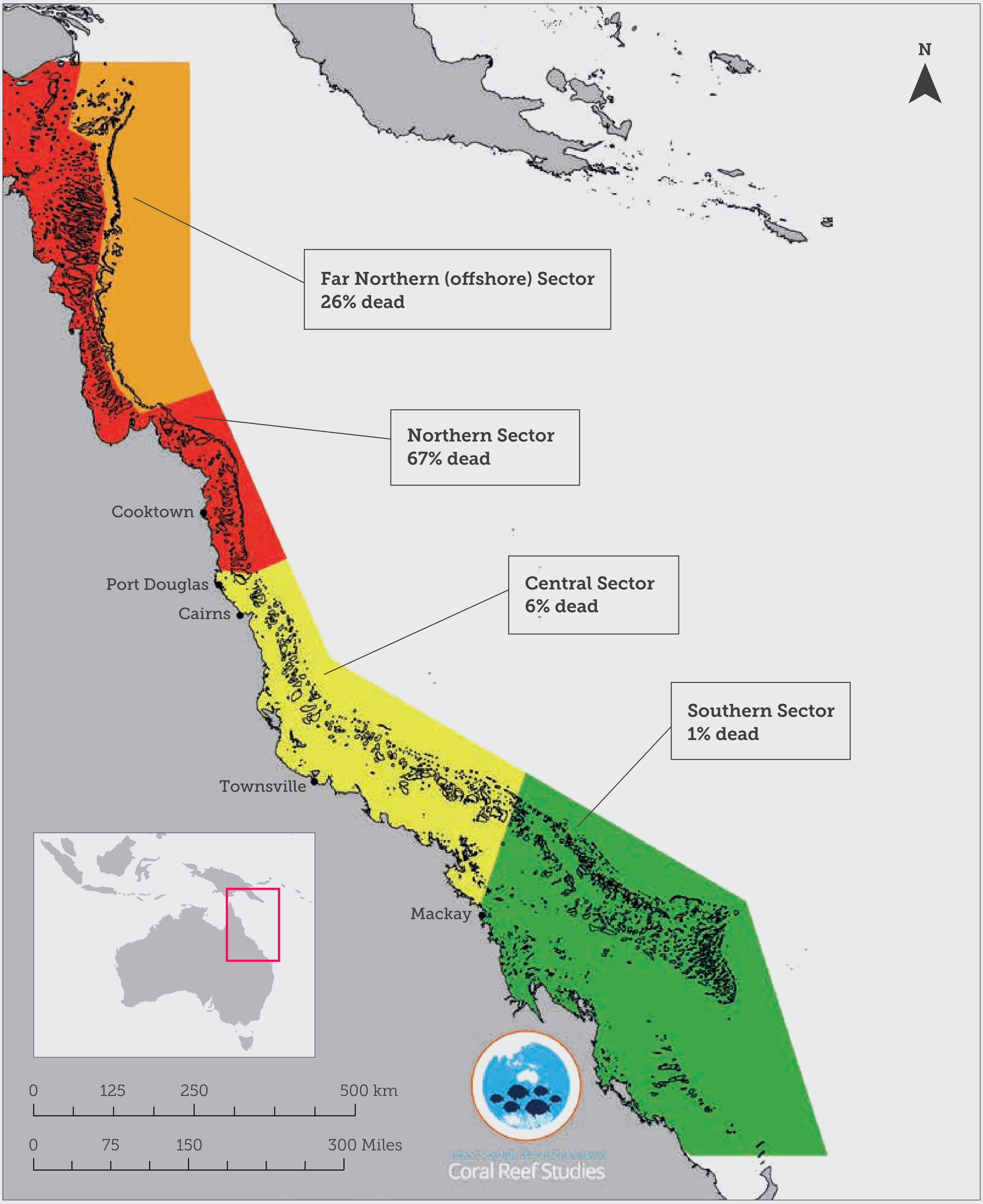
Figure 5: The Great Barrier Reef, a World Heritage-listed Australian icon.

Aerial and underwater surveys revealed that 91% of the individual reefs in the GBR had experienced bleaching (Hughes et al. 2017). While the more southerly sections appeared to have escaped the worst impacts, bleaching of the more pristine northern reefs led to extensive mortality (GBRMPA 2016b). Median coral cover loss in the section of the GBR from Port Douglas to Papua New Guinea was estimated to be 67%, while in the central section between Port Douglas and Mackay it was 6%, and in the southern section south of Mackay, it was only 1% (Figure 6; CoECCS 2016b). The lower mortality rates in the south are consistent with observations that this region did not experience the severe heat stress in February and March (Hughes et al. 2016), primarily due to the late summer cooling of sea temperatures from ex-Tropical Cyclones Winston and Tatiana (GBRMPA 2016c), bringing wind, cloud and rain.

A recently published analysis has compared the spatial extent and severity of the 2016 event to that of the two most severe previous events, in 2002 and 1998 (Hughes et al. 2017). In 2016, the proportion of reefs experiencing extreme bleaching (defined as >60% corals bleached) was more than four times that of 2002 and 1998. In 2016, just under 9% of surveyed reefs escaped bleaching, compared to ~42% of surveyed reefs in 2002 and ~45% in 1998. The combined "footprint" of the three bleaching events now covers virtually the whole of the Great Barrier Reef Marine Park, with only a few southern offshore reefs unaffected (Hughes et al. 2017).

The proportion of reefs at the GBR that suffered extreme bleaching was four times greater in 2016 than 1998 and 2002.

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



*upper and lower quantities

Figure 6: Coral mortality at the Great Barrier Reef from surveys conducted in October and November 2016 (CoECSS 2016c).

Another important result from the Hughes et al (2017) analysis is that water quality and fishing pressure had minimal effect on the severity of bleaching in 2016 – that is, local protection did not provide resilience in the face of severe heat stress.

The tragic aftermath of the severe bleaching that occurred in the northern GBR is illustrated in Figure 6. A photograph taken in March 2016 of a coral outcrop at Lizard Island, north of Cooktown, shows serious bleaching. A photo of the same outcrop taken two months later shows that the coral has died and become covered in algae (Figure 7).

Figure 7: A before and after image showing bleached coral (left, March 2016) and dead coral (right, May 2016) at Lizard Island on the Great Barrier Reef.

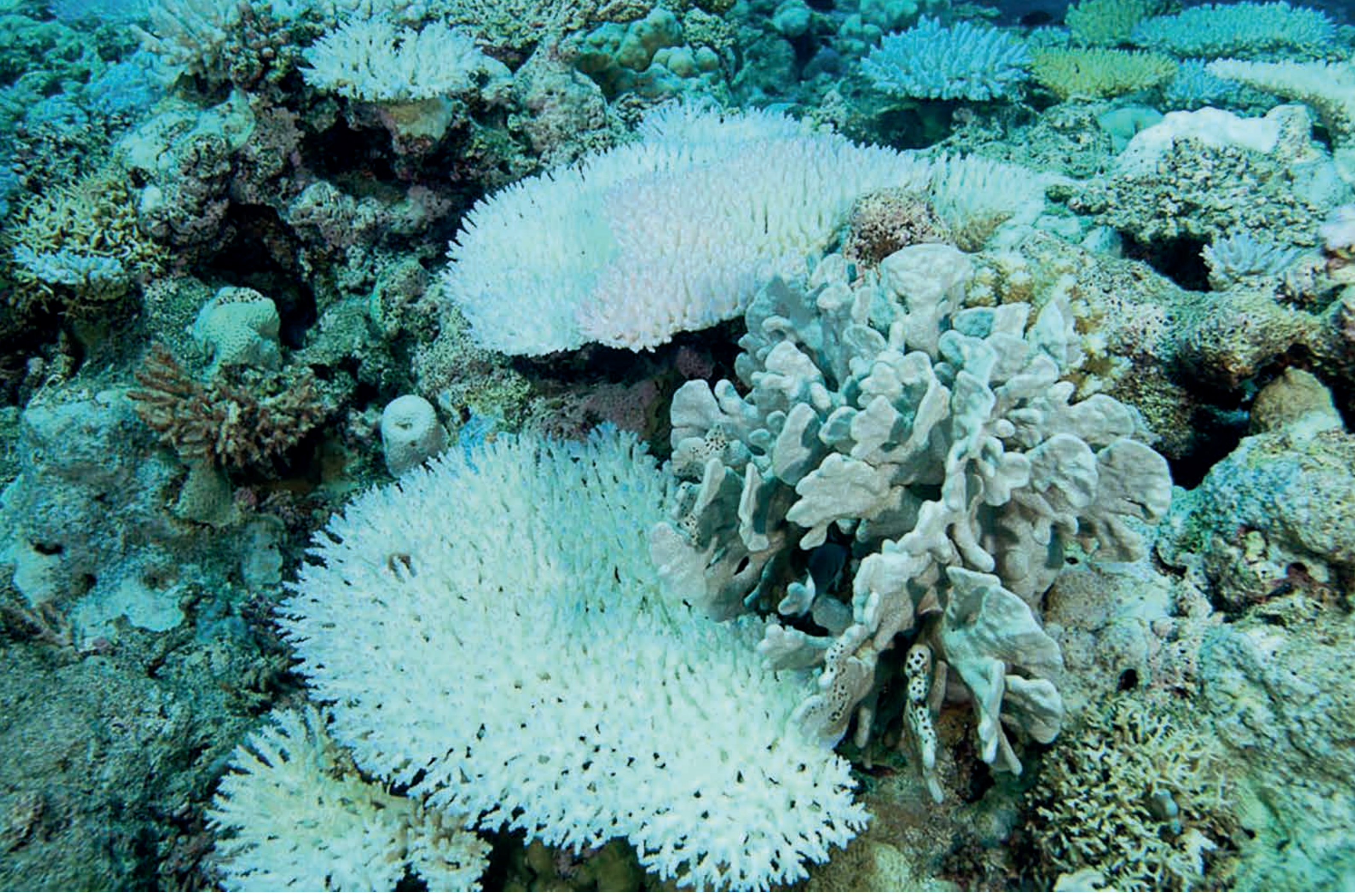


Figure 8: The Great Barrier Reef was not the only Australian reef to experience severe bleaching, Western Australian reefs were also affected. Scott Reef (image shown) suffered over 60% bleaching in shallow lagoon waters (AIMS 2016c).

The GBR was not the only Australian reef to suffer. Reefs in northwestern Australia, including those near the Kimberley coast, Christmas Island, Scott (Figure 8) and Seringapatam Reefs were severely bleached by record breaking ocean temperatures in early 2016. Bleaching was most severe (>60%) at Christmas Island, Scott and Seringapatam Reefs, and widespread (30-60%) on the inshore Kimberley reefs. Low levels (<10%) of bleaching were observed at several other reefs and submerged shoals in northwestern Australia. Reefs further south escaped bleaching due to the cooling effects of Tropical Cyclone Stan (AIMS 2016c).

The Scott Reef was also severely affected during the global bleaching event of 1998. While the coral cover recovered well after 12 years (Gilmour et al. 2013), the recurrence intervals of bleaching events are decreasing in length, which is providing less recovery between events (see Section 7). Consequently, the frequency of bleaching on Western Australian reefs has increased in recent years. Between 2010 and 2016, several Western Australian reefs have bleached more than once. The most severe and widespread bleaching of the southern reefs, including those at Ningaloo and the Abrolhos Islands, occurred during the 'marine heatwave' and La Niña conditions in 2011 (Moore et al. 2012; Box 1).

BOX 1: MARINE HEATWAVES, BLEACHING AND EL NIÑO SOUTHERN OSCILLATION

Marine heatwaves can be described as anomalously warm water events over a sustained period (Hobday et al. 2016). The formation of marine heatwaves, and in turn, coral bleaching events, can be influenced by either phase of the El Niño Southern Oscillation (ENSO) climatic pattern. The El Niño phase of the ENSO cycle is generally associated with unusually warm sea surface temperatures in late summer (Lough 2007). The sea surface temperature anomalies along the length of the GBR are more pronounced during El Niño events (Lough 2001).

In the summer of 2011, a stronger than normal La Niña forced warmer water, due to a strengthened Leeuwin Current, from Indonesia down the West Australian coastline (Depczynski et al. 2013; Benthuysen et al. 2014; Hobday et al. 2016). The resulting marine heatwave caused severe bleaching at Bundegi in the Ninagloo Marine Park (Doropoulos et al. 2016), and a subsequent 79-92% decline in coral cover (Depczynski et al. 2013), as well as widespread fish and invertebrate mortality, habitat range changes of seaweeds, whale sharks and mantra rays, and tropical fish occupying more southern waters (Pearce and Feng 2013). Conversely, in early 2016, unprecedented bleaching occurred on the Great Barrier Reef, driven by climate change and enhanced by an El Niño. One of the impacts of El Niño is a weakening of the monsoon trough, leading to fewer cloudy days. When combined with one of the lowest number of tropical cyclone years in Australia on record (BoM 2016b), ocean mixing was reduced and surface water temperatures increased.

Climate change is increasing the prevalence of marine heatwaves as ocean waters warm (CSIRO and BoM 2016; Figure 9). With projected warming (relative to 1986-2005) in sea surface temperatures of up to 1.22°C by 2050 under a high-emissions scenario, the likelihood of intense marine heatwaves will increase (Perkins-Kirkpatrick et al. 2016). This means there is an increased risk of coral bleaching around the Australian coastline.

ANNUAL SEA SURFACE TEMPERATURE ANOMALY - GREAT BARRIER REEF (1900-2016)

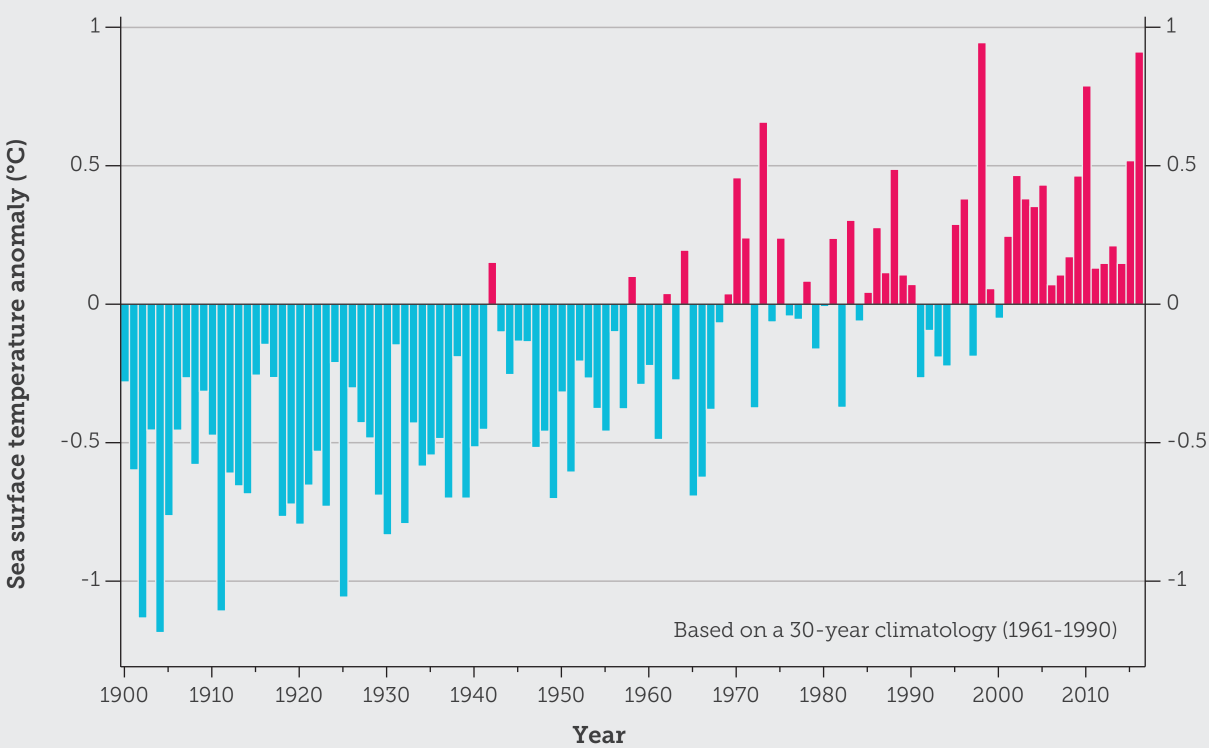


Figure 9: The annual sea surface temperature anomaly along the Great Barrier Reef, showing a warming trend since the 1970s, as climate change becomes more pronounced. **Source:** BoM 2017c.

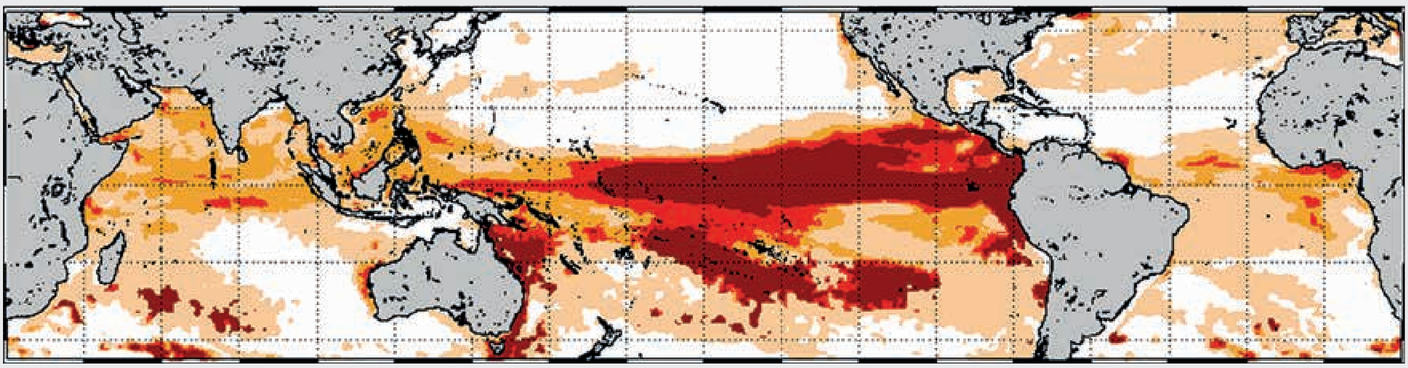
3. Coral Bleaching Outlook 2017

Coral reefs in many parts of the Pacific, including Australia, are at high risk of experiencing further bleaching and mortality in the coming months.

Globally, the areas most at risk in the period April to July 2017 are in the central Pacific (NOAA CRW 2017; Figure 10). Widespread bleaching and potentially significant mortality is expected in the Cook Islands, American Samoa and Kiribati, with bleaching also likely in Papua New Guinea.

Figure 10: NOAA Coral Reef Watch's Coral Bleaching Alert Area for April to July 2017, issued on 21 March (NOAA CRW 2017). This figure shows the regions that are projected to experience high levels of thermal stress that cause coral bleaching. The thermal stress along Australia's eastern coastline, including the Great Barrier Reef, may potentially reach Alert Level 2, while the central Western Australia coast, including the Ningaloo Reef, may potentially reach Alert Level 1. The potential stress level categories are 'Warning' = possible bleaching, 'Alert Level 1' = bleaching likely, and 'Alert Level 2' = mortality likely.

21 MARCH 2017 NOAA CORAL REEF WATCH
60% PROBABILITY CORAL BLEACHING THERMAL STRESS FOR APRIL TO JULY 2017



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

In Australia, there is potential for widespread bleaching and mortality along the entire length of the GBR (Alert Level 2 – mortality likely), as well as for coral communities in New South Wales (Figure 10). In March and April this year, sea surface temperatures were projected to be above average for the GBR region by up to 0.8°C (BoM 2017d) – too soon for the reef to have recovered after the devastating 2016 event. In Western Australia, the bleaching outlook is also serious for Ningaloo (Alert Level 1 – bleaching likely), but with warnings present for most other Western Australian reefs (Warning – possible bleaching).

The Great Barrier Reef Marine Park Authority, after conducting initial aerial surveys with the Australian Institute of Marine Science, recently announced that mass coral bleaching is underway, yet again, after the GBR's worst bleaching event ever last year. There are now reports of severe bleaching in inshore and offshore reefs between Palm Islands and Port Douglas - the central section of the reef which was largely spared last year. There is also bleaching (varying levels from minor to severe) over a much wider area to the north and south of this region. Generally, southern areas are faring better, especially offshore (GBRMPA 2017).

Cooler waters, as a result of the strong winds from Tropical Cyclone Debbie may bring some reprieve from further bleaching in 2017, especially in the central section of the GBR. While, in this case, it is fortunate that the tropical cyclone may temporarily reduce ocean temperatures in this section, they can also cause significant damage to reefs. For example, Tropical Cyclone Yasi caused extensive physical damage to coral in 2011 when it passed over large areas of the GBR. Coral damage was reported across almost 90,000 km^2, with 15% of the park sustaining some damage and 6% sustaining severe damage (GBRMPA 2011). Recovery from the ecological impact of this tropical cyclone is likely to take several decades (GBRMPA 2011). The extent of Tropical Cyclone Debbie's impact of the GBR has yet to be determined and may take several weeks to fully comprehend.

Figure 11: Bleached coral (white) and dead coral covered in algae (brown) at the Great Barrier Reef (Port Douglas) in March 2017.

4. Mass Coral Bleaching: a Global Event

The widespread bleaching across Australian reefs is part of the longest global coral bleaching event on record, an event continuing into 2017. It began in 2014, associated with record breaking ocean temperatures largely driven by climate change (NOAA 2017).

Coral bleaching was reported for reefs across the Pacific, Caribbean and Indian Oceans (Figure 12). Some US coral reefs were hit hard, experiencing widespread bleaching for two years in a row, including record-breaking events in the Hawaiian Islands and American Samoa. Guam has been one of the worst hit countries, with some reefs experiencing bleaching for four consecutive years (The Washington Post 2016). Widespread coral mortality occurred in the western Indian Ocean in countries such as the Maldives (Figure 13), Kenya and the Seychelles. Coral bleaching and coral mortality was also experienced in Asia, including Thailand and Japan. In Thailand, a country which heavily depends on tourism, ten popular diving spots were closed in order to protect coral from further damage (The Guardian 2016).

The current bleaching is part of the longest global coral bleaching event on record.

CORAL BLEACHING ACROSS THE WORLD

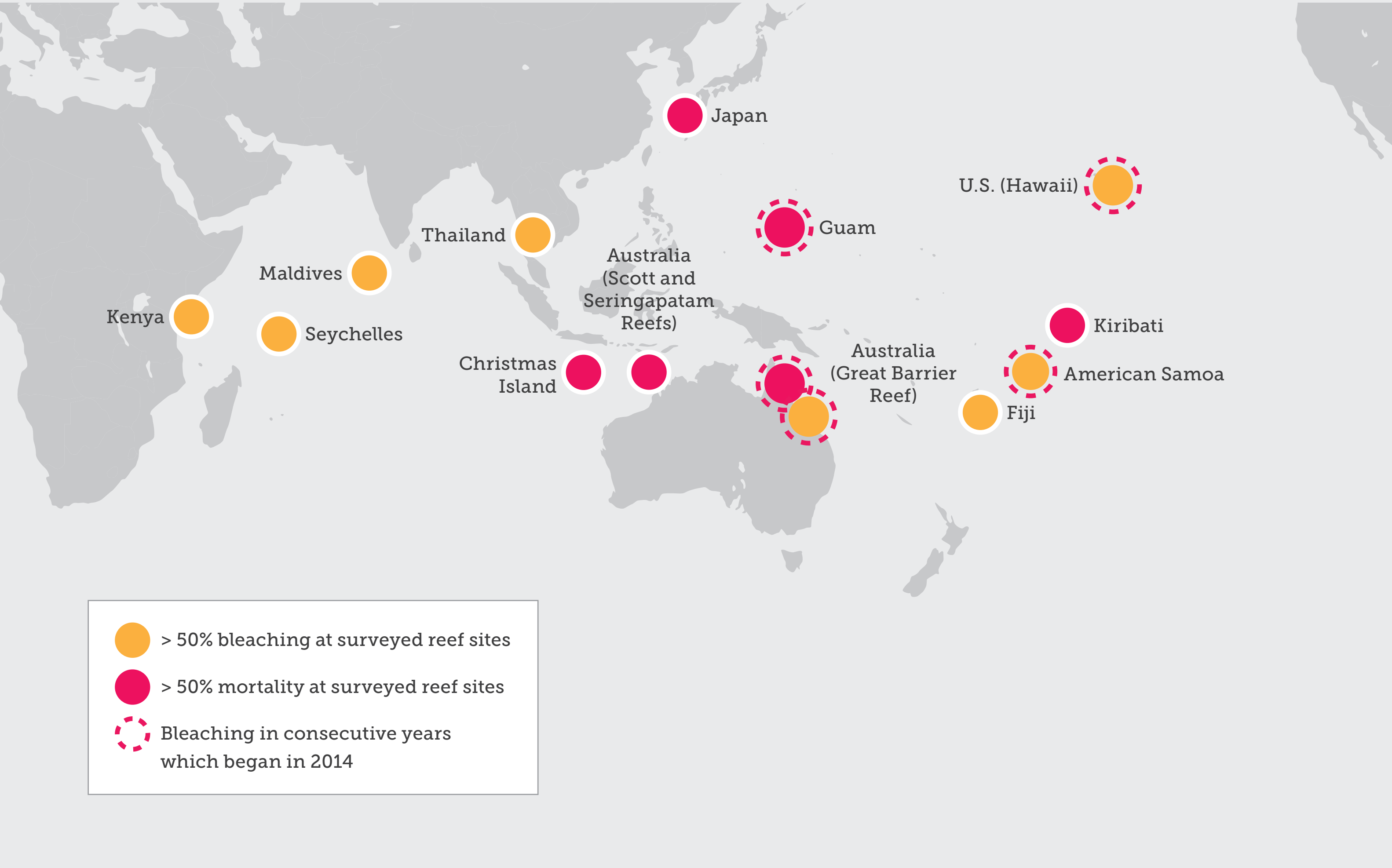


Figure 12: Bleaching and mortality observed at a number of coral reefs around the world during the global bleaching event which began in 2014 and is ongoing at time of publication. **Sources:** NOAA Coral Reef Conservation Program 2015; ABC 2016a; Bailey et al. 2016; CoECSS 2016b,c; CORDIO 2016; Financial Times 2016; NOAA CRW 2016; Phys 2016; Rice University 2016; The Guardian 2016a,b; The Washington Post 2016a,b; The Guardian 2017a.

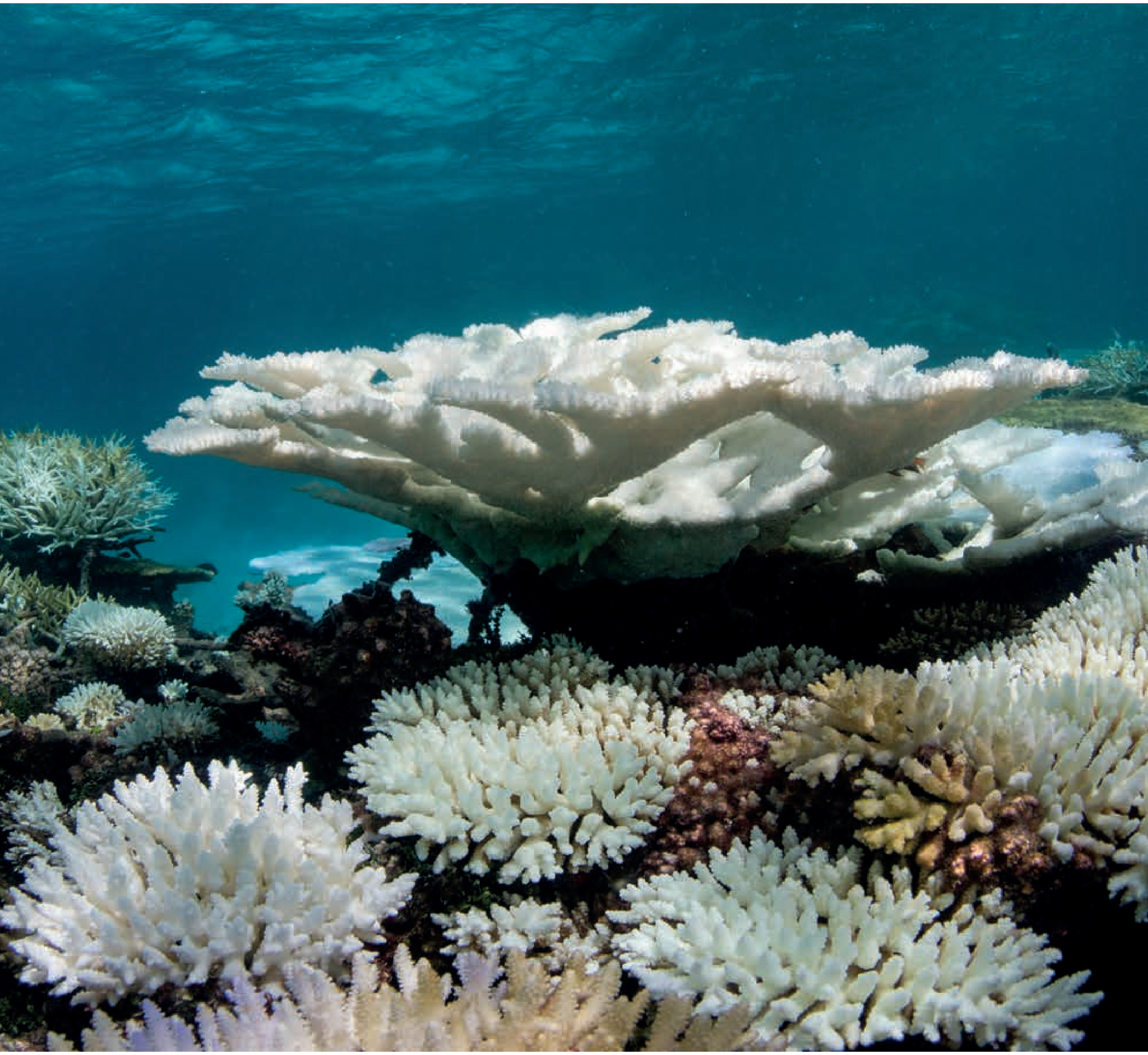


Figure 13: Coral bleaching in the Maldives in May 2016. Recent survey results estimate at least 60% of individual reefs were affected (The Guardian 2016a; Financial Times 2016).

5. Economic Impacts of Coral Bleaching

Healthy tropical coral ecosystems provide jobs and income to local communities from fishing, recreation, and tourism, supporting the livelihoods of 500 million people globally. Loss of coral reefs potentially puts an astounding $1 trillion at risk globally (Hoegh-Guldberg et al. 2015).

Australia's reefs are incredibly valuable economic and environmental assets. For example, an estimated 69,000 jobs in the 2011-12 period were reliant on the GBR (Deloitte Access Economics 2013). The GBR contributes around $7 billion to the national economy annually, mainly via tourism (Jacobs 2016; Figure 14). This is particularly the case for the northern sector where over $4 billion from tourism is generated (Jacobs 2016).

A recent study by The Australia Institute (2016) showed that if coral bleaching persists, tourism areas adjacent to the Great Barrier Reef risk declines in visitors from 2.8 million visitors (2015 figures) to around 1.7 million per year. This the equivalent of more than $1 billion in tourism expenditure, which supports around 10,000 tourism jobs in regional Queensland (The Australia Institute 2016).

The GBR is an economic asset worth about $7 billion annually to the economy.

A survey conducted before the latest coral bleaching event in three major tourism hotspots in Queensland (Port Douglas, Cairns and Airlie Beach) found that 69% of tourists said they wanted to visit the reef "before it was gone" (Piggott-McKellar and McNamara 2016). This "last chance" tourism, which in the short-term may contribute to the local economy, is likely to be unsustainable in the long-term.

Figure 14: Tourists snorkelling on the Great Barrier Reef. Loss of tourism as a result of coral bleaching and mortality is likely to have a significant impact on the local and Australian economy.

6. Will the Great Barrier Reef Recover?

Three major bleaching events in just 19 years (1998, 2002, 2016), will test the resilience of the GBR. These three events have all occurred while global temperatures have risen to almost 1°C above the 20th century average (NOAA 2017).

Climate change will drive more frequent and severe coral bleaching in the future.

The recovery of bleached coral can take at least a decade (e.g. Scott Reef in Western Australia; Gilmour et al. 2013), but much longer periods are required to regain the largest and oldest corals that have died (CoECSS 2016d). As the oceans around Australia continue to warm (CSIRO and BoM 2016), the frequency of bleaching is increasing (Ainsworth et al. 2016), and this trend is likely to continue. With more bleaching events, and shorter times between events, the chances that the corals will recover are diminishing. Climate projections for the future indicate that the extreme ocean temperatures that caused the most recent bleaching could occur every two years by the mid-2030s (CoECCS 2016e).

Coral mortality is not the only impact of bleaching. Those corals that manage to survive can suffer slower growth rates and reduced reproduction in later years (CoECSS 2016d; Keith et al. 2016). The spawning season on the northern reef did not occur in 2016 due to the stress corals had experienced. Scientists have struggled to find coral colonies with eggs (ABC 2016b). Spawning in the southern part of the reef in November 2016 appeared normal. Lower reproduction reduces the resilience of the reef to future stresses and further increases the time to recover after bleaching (Graham et al. 2016). A reduction in spawning can persist for multiple years following a bleaching event, with both bleached and unbleached coral being affected (Levitan et al. 2014).

7. How Can We Protect Our Coral Reefs?

The burning of coal, oil, and gas is putting Australia's iconic reefs at risk of further bleaching and death. The rate of surface ocean warming in the 21st century is seven times faster than during the 20th century and the frequency of extreme sea surface temperature events has increased (Evans et al. 2017). Extreme coral bleaching and the death of reefs will become the new normal unless serious and rapid reductions in greenhouse gas emissions are achieved.

Australia joined the rest of the world in Paris at the 21st United Nations Conference of the Parties (COP21) in December 2015, pledging to increase the level of commitment to limit dangerous climate change. While carbon emissions have flat-lined in China and declined in the United States and many other OECD (Organisation for Economic Co-operation and Development) countries (Le Quéré et al. 2016), Australia's net emissions have risen 0.8% in the last year (Commonwealth of Australia 2016a). Based on this result, there must be serious doubt as to whether even Australia's very weak target of reducing emissions 26-28% (relative to 2005) by 2030 can be achieved. This has been highlighted even further by an independent review of the Australian and Queensland government's Reef 2050 Plan, which finds that the government is failing to address the continuing threat of climate change because it is not doing its fair share of reducing emissions (Hart et al. 2017).

Coral bleaching will become the new normal unless serious reductions in greenhouse gas emissions are achieved.

Given fossil fuels are driving global warming, they must be rapidly phased out. One key solution is renewable energy sources, like solar and wind (e.g., Figure 16), coupled with energy storage technology. Recent promotion by the Federal Government of so-called "clean coal" is incompatible with tackling climate change and protecting coral reefs. "Clean coal" plants are simply more efficient coal plants and still emit significant amounts of greenhouse gases (see the Climate Council's Clean Coal fact sheet, https://www.climatecouncil.org.au/clean-coal-fact-sheet). For example, a new high-efficiency coal plant run on black coal would produce about 80% of the emissions of an equivalent old plant (Commonwealth of Australia 2016b), while renewables (e.g. wind and solar) have zero emissions. Further, it makes no economic sense to build new coal plants because new wind and solar plants both in Australia and overseas are more cost competitive (Jotzo 2017).

Similarly, the development of the Carmichael coal mine and the Galilee Basin, located to the west of Rockhampton in the GBR catchment area, is fundamentally at odds with tackling climate change and protecting the GBR (see Box 2).

BOX 2: NEW COAL MINES ARE INCOMPATIBLE WITH PROTECTING THE REEF

The burning of coal, oil and gas is driving climate change, including warmer ocean water temperatures. Tackling climate change effectively means that existing coal mines will need to be retired before they are fully exploited and new mines simply cannot be built (Climate Council 2015a,b). The development of the Carmichael mine in the Galilee Basin, located to the west of Rockhampton in the GBR catchment area, is fundamentally at odds with protecting not just the reef, but the rest of Australia's environment, economy and communities from the impacts of climate change.

Once completed, the Carmichael mine will be Australia's largest coal mine and would have a potential lifetime of 25 to 60 years (ABC 2016c) (e.g., Figure 15). Burning all of the coal in the Galilee Basin would release an estimated 705 million tonnes of carbon dioxide each year (Greenpeace 2012) – more than 1.3 times Australia's current annual emissions from all sources (Climate Council 2015a; Commonwealth of Australia 2016a). Put another way, if the Galilee Basin were a country on its own, it would rank in the top 15 emitting countries in the world.

If the Galilee Basin was a country and all its coal reserves were burned, it would rank in the top 15 world's worst polluters.

BOX 2: CONTINUED

Potential export markets for coal are rapidly dwindling as the world moves away from fossil fuels toward renewable energy. Global investment in new renewable capacity is now greater than investment in fossil fuels, and the gap is expected to widen. Coal mined at Carmichael is intended for export to India.

However, India is experiencing extremely rapid growth in renewables, and is reducing coal imports overall; raising doubts about the projected, long-term market for coal (Climate Action Tracker 2016). To protect the Great Barrier Reef and Australian's way of life, rather than opening new coal mines, Australia's focus should be to phase out existing coal mines well before their reserves are exhausted.

Figure 15: An open-cut coal mine in the Hunter Valley, New South Wales. The Carmichael mine in Queensland is planned to have six open-cut pits and up to five underground mines (ABC 2016c).

Figure 16: Wind turbines on the hills surrounding Lake George, near Canberra. The Australian Capital Territory's reverse auction process has delivered some of Australia's cheapest prices for wind power (Climate Council 2016).

We have a clear and urgent choice. The future of the world's coral reefs depends on how much and how fast we reduce greenhouse gas emissions now, and in the next few years (Hoegh-Guldberg 1999; Hoegh-Guldberg et al. 2007). Limiting temperature rise to no more than 1.5°C above pre-industrial levels is critical for reef survival (Frieler et al. 2012; Schleussner et al. 2016). Schleussner et al. (2016) show that the fraction of coral reefs globally at risk of long-term degradation is 70% by the end of the century with temperature rise limited to 1.5°C, while a 2°C temperature rise would put 99% of the world's coral reefs at risk by the end of the century (Schleussner et al. 2016).

Global emissions must be trending strongly downwards by 2020 at the latest to have a chance of limiting warming to 1.5°C above pre-industrial levels. Renewable energy and energy storage investment and implementation must therefore increase rapidly and most of the known fossil fuel reserves must remain in the ground, in Australia and elsewhere (McGlade and Ekins 2015). Any proposal to open new fossil fuel projects or expand existing ones is fundamentally at odds with the 1.5°C target and very likely to doom our most precious natural assets.

To protect our precious reefs, Australia must deeply and rapidly reduce its emissions.

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