

Interconnected Disaster Risks
2020/2021

Coral Bleaching in the Great Barrier Reef

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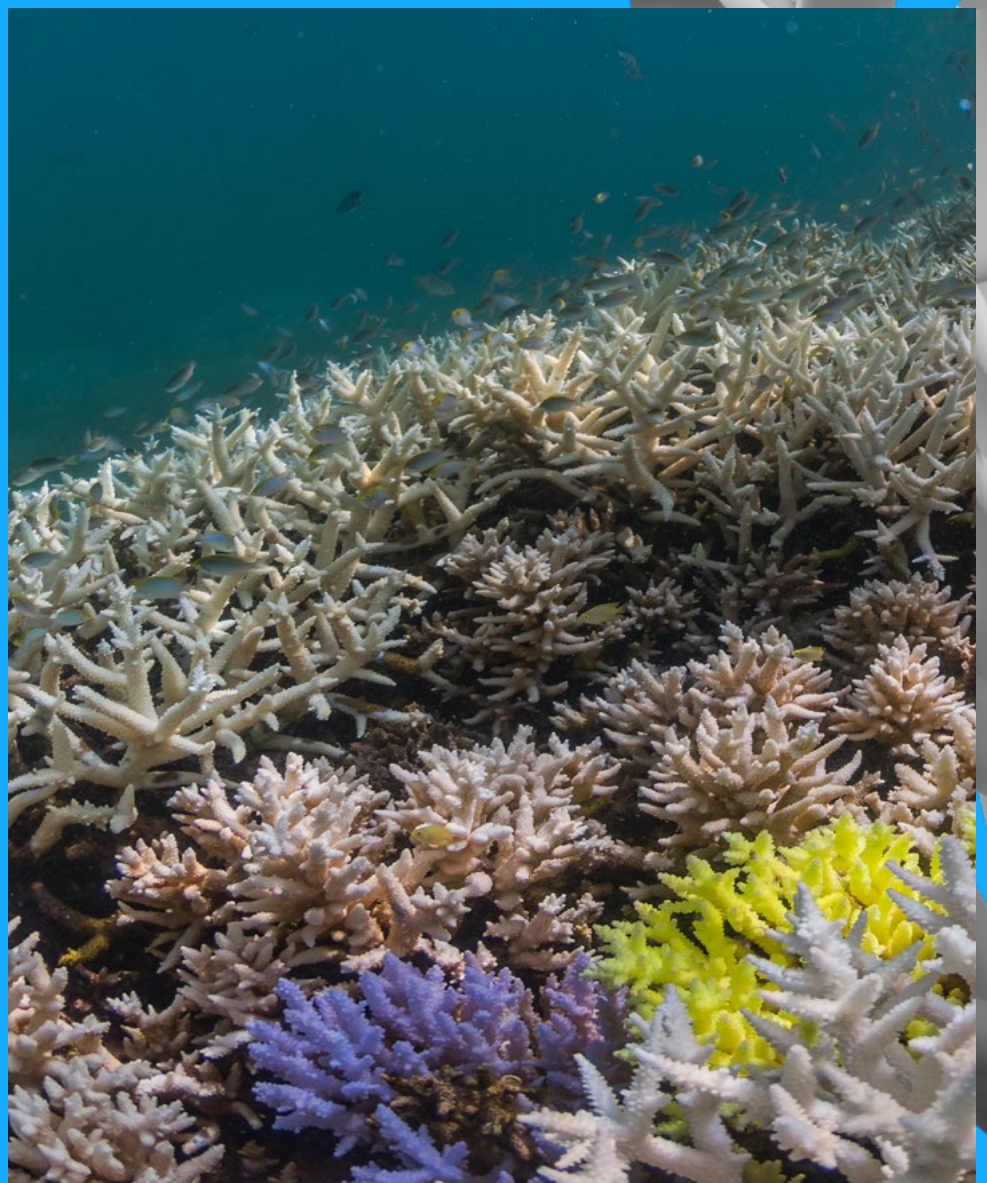
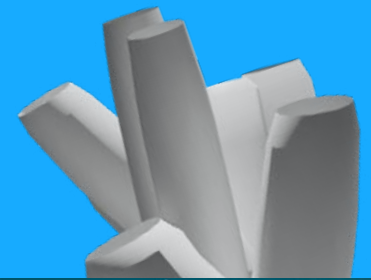


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1. Event

In February 2020, the Great Barrier Reef (GBR) experienced the highest monthly sea temperatures since Australia began keeping records, in 1900, with temperatures 1.2 degrees Celsius above the long-term February average (1961–1990) (GBRMPA, 2021). As heat built across the reef, the sea surface temperature exceeded the maximum summertime mean, causing stress in the corals as they were pushed to the limits of their physiological tolerances. This type of stress typically worsens the longer the heat anomaly persists. The heat stress accumulated in an area over a 12-week period is often expressed in Degree Heating Weeks (DHW), with significant coral bleaching being likely with four consecutive DHW (Kayanne, 2017). By early March vast swaths of GBR had accumulated more than eight DHW (Stone, 2020; NOAA, 2021b), triggering the Great Barrier Reef’s most widespread coral bleaching event on record (Tsarkisian, 2018; India Today, 2020a; Readfearn, 2020b).

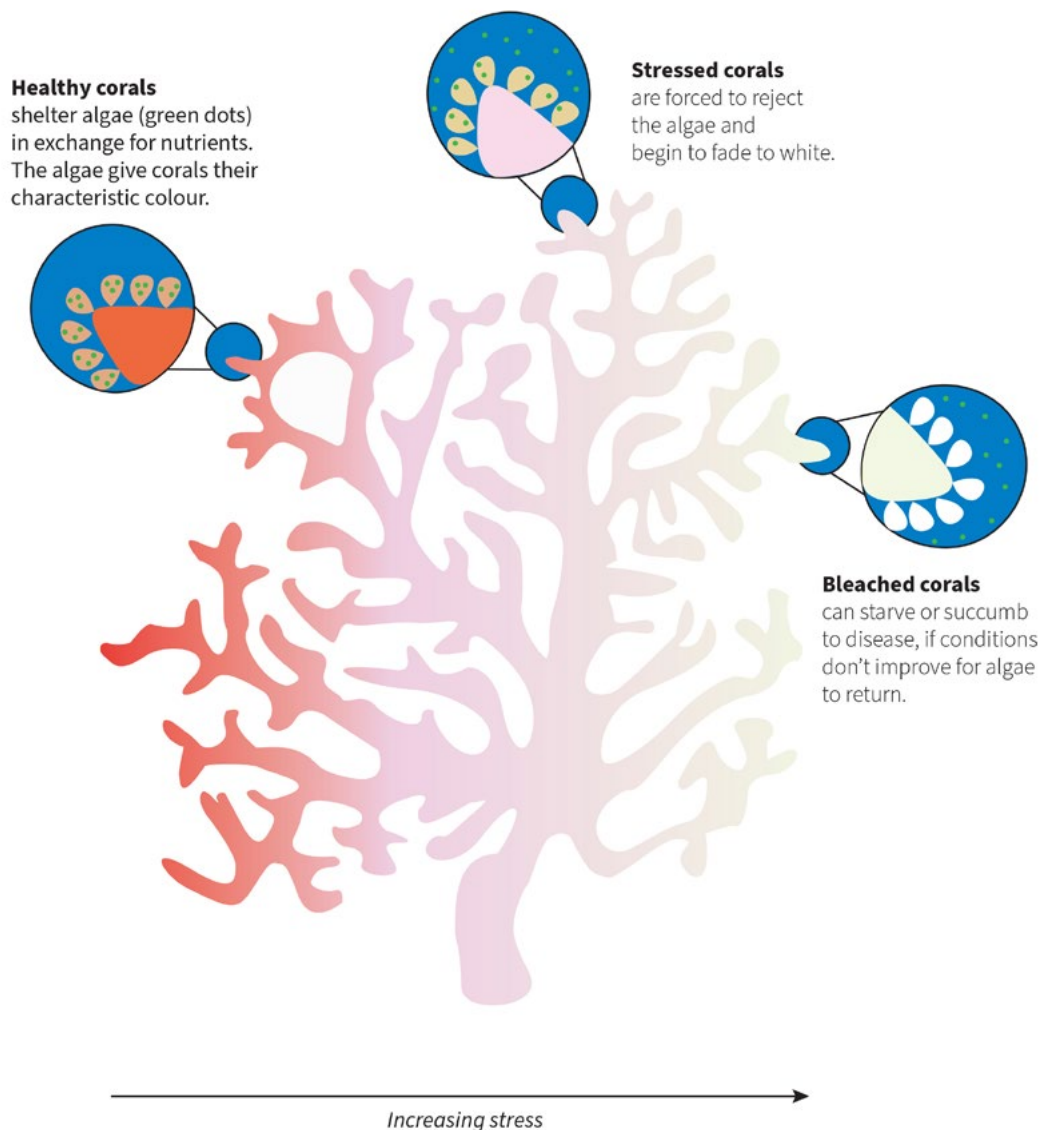


Figure 1: Schematic representation of bleaching process.



Coral reef bleaching is a physiological response to environmental stressors, which results in the release of their colourful symbiotic algae, leaving the white coral structure (Gibbens, 2020; Stone, 2020) (Figure 1). Under warmer conditions these algae, called zooxanthellae, release compounds toxic to corals and even become parasitic as a result of increased photosynthesis (Roth, 2014; Baker and others, 2018), forcing corals to expel them into the water column. It is the algae that give corals their beautiful colours and that allow them to survive (NOAA, 2021a). In fact, corals shelter the symbiotic zooxanthellae in exchange for food (Stone, 2020). The algae produces sugars from sunlight, which are mostly passed to the coral in exchange for carbon for photosynthesis in the host's waste (McDermott, 2020).

2. Impacts

Despite restrictions on research and monitoring due to the COVID-19 pandemic (Goreau, 2020), researchers documented (through aerial surveys) the most widespread coral bleaching ever, with bleaching events being recorded in all three sections of the reef – northern, central and southern – for the first time ever (Readfearn, 2020b). As illustrated in the map (Figure 2), bleaching occurred along the 2,300-kilometre reef system (Stone, 2020), with one quarter of the GBR suffering severe bleaching (Readfearn, 2020b) and some 35 per cent of the surveyed area experiencing moderate bleaching (Stone, 2020). The bleaching of 2020 hit the southern section of the reef most severely, as this area had never previously been affected by bleaching and corals there are less adapted to high temperatures, and thus are more heat-sensitive than in the northern parts.

Prolonged periods of elevated temperatures pose a high risk to coral reef ecosystems. Unless temperature conditions normalize and the symbiotic relationship is re-established, bleaching can kill a coral (Mies and others, 2020; McDermott, 2020; Alberts, 2020). Coral mortality in turn disrupts all the services provided by the reef (IPCC, 2019; IPCC, 2014). Coral mortality has impacts on coral-dependent livelihoods and industries, such as fisheries and tourism; it has impacts on food provision; it reduces coastal protection and results in a biodiversity loss, as coral species die and affect also coral-dependent species populations (Ferrario and others, 2014; Gibbs, 2020; Loria, 2018; Mace and others, 2014).

Unprecedented global warming and climate change, combined with growing local pressures such as

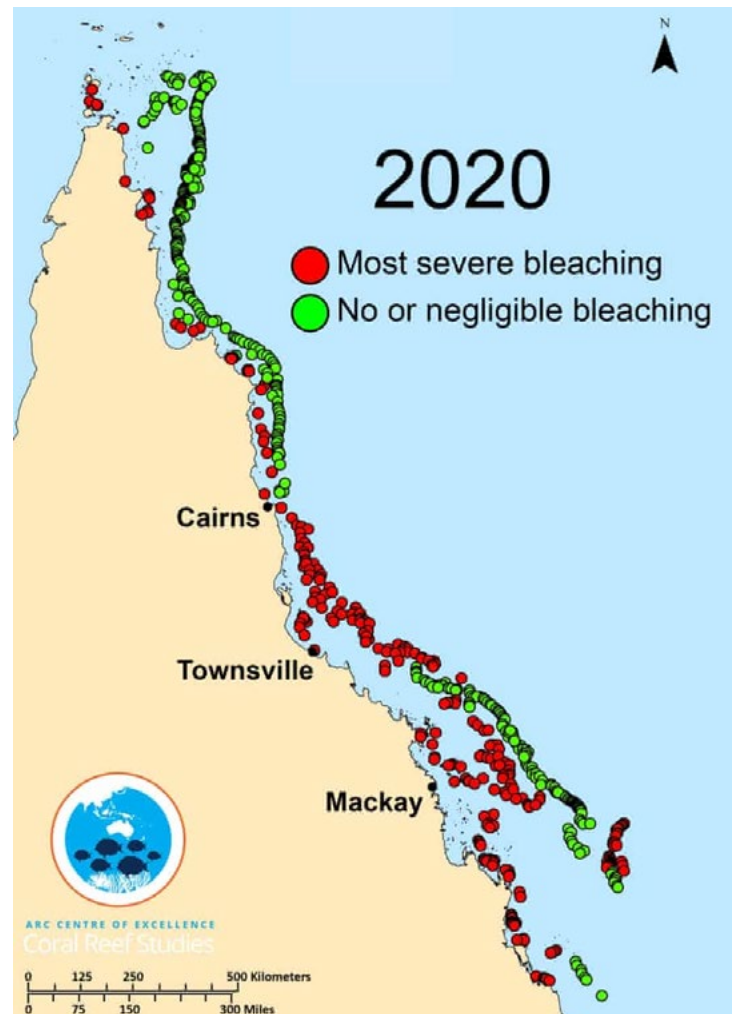


Figure 2: Extent and degree of the 2020 bleaching event along GBR, taken from ARC Centre of Excellence for Coral Reef Studies



overfishing and pollution (see sections 3, Drivers and 4, Root causes) have resulted in corals being among the most threatened ecosystems on Earth (IUCN, 2017). The increasing frequency and intensity of bleaching events has in fact impacted coral reefs worldwide (Mies and others, 2020). The increasing bleaching event frequency (Williams and others, 2019) means reefs have less time to recover between each bleaching event, compromising their ability to recover (Readfearn, 2020a). It is estimated that corals take about 10 years to recover fully from bleaching events (Chow, 2020; Wright & Watson, 2018); yet corals have experienced three bleaching events in the last five years only.

More frequent bleaching events furthermore limit the recruitment of corals. The number of corals on GBR have already declined by more than 50 per cent since the 1990s (Coral Reef Studies, 2020). This demographic change complicates coral survival over time, as the distance between coral formations increases, limiting their ability to reproduce (Fears, 2020; IPCC, 2019).

With the drastic reduction in coral fitness and the many threats they are facing, the future of coral reefs looks grim. Coral reefs are at high risk already and even if global warming is limited to 1.5°C, reefs are projected to suffer significant losses of area (IPCC, 2019). UNESCO has recommended listing the world's biggest coral reef system as a world heritage site 'in danger' (Readfearn, 2021), as the long-term outlook of GBR has deteriorated to 'very poor' in the past several years (Albeck-Ripka, 2021). Overheated by climate change, coral reefs in GBR and worldwide are indeed being pushed over a tipping point (Readfearn, 2020a; Duong, 2020) and will likely shift to a much less productive, much less biodiverse algae-based ecosystem that looks nothing like it did before (Hance, 2018; IPCC, 2019).

Because they are the very foundation of reef ecosystems, the crossing of tipping points not only has cascading effects on community composition and ecosystem functioning (Foley, 2020), but may potentially also lead to the collapse of the ecosystem. Considering that coral reefs provide important ecological, economic and societal benefits (see Figure 3) valued globally at about US\$ 9.8 trillion each year (de Groot and others, 2012; Costanza and others, 2014), their new state will have knock-on effects on society as a whole and will be particularly devastating for developing countries. Approximately 850 million people live within 100 km of and derive some benefits from coral reefs, with over 30 per cent of those depending directly on reefs for livelihoods and sustenance. Reef-dependence, and consequently vulnerability to reef loss, is particularly high in small-island states, as well as in many countries along the coral triangle, and among coastal populations in developing countries (UNEP, undated).

Reef loss entails a number of cascading impacts, as we stand to lose their benefits (see Figure 3), and contributes to emerging risks.

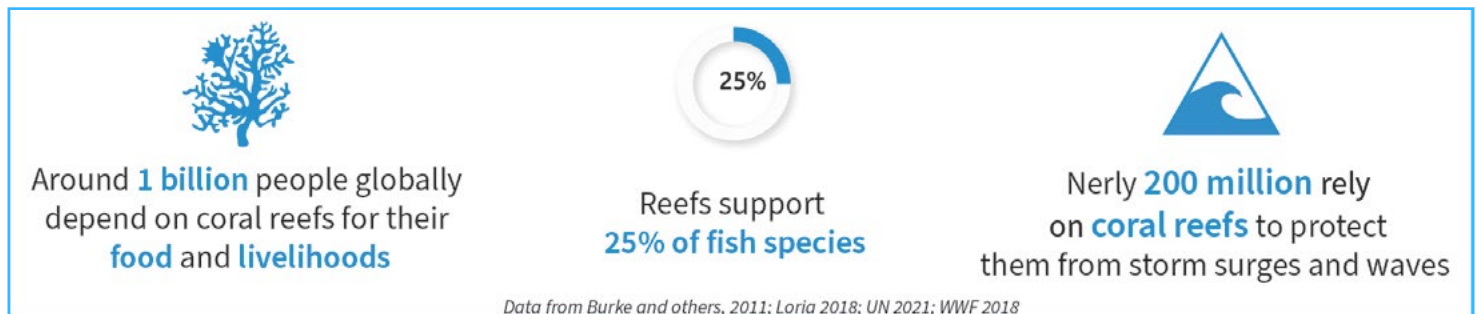


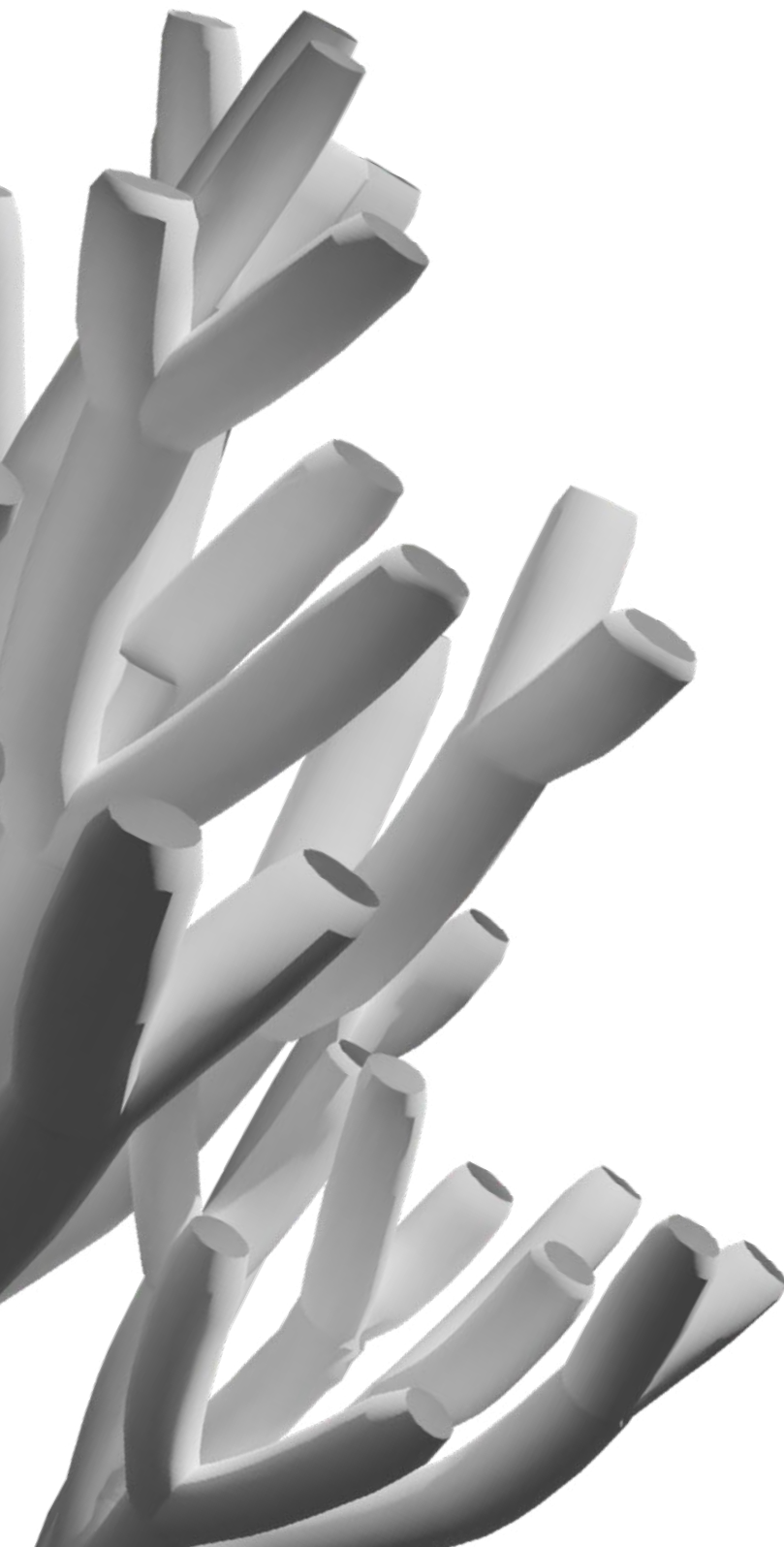
Figure 3. What we stand to lose if corals disappear.

Nearly a billion people depend on corals for their food security (Australian Marine Conservation Society, 2021). Considering that a healthy, well-managed reef can yield between 0.2 tons and 40 tons of seafood per square kilometre annually globally (Reef Resilience Network, 2021b), the collapse of reef ecosystems would significantly affect food security. Between a quarter and a third of all marine species have part of their life cycle in coral reefs (Loria, 2018). The loss of coral reefs and resulting ecological collapse (Wright & Watson, 2018) has severe implications for marine biodiversity and related ecosystem functions, such as fisheries productivity (Mace and others, 2014). Loss of marine biodiversity will

affect tens of millions of people who depend on living marine resources for their survival (MEA, 2005; Galaz and others, 2012). Furthermore, the depletion of fish stocks in one region due to ocean temperature rise could drive the price of fish up everywhere (IPCC, 2014), making it harder to afford and potentially increasing inequalities. Projections also show a fall in fish catch potential (IPCC, 2014). Increases in the risks for seafood security together with decreases in seafood availability may increase the risk to nutritional health (IPCC, 2014). In combination with increasing freshwater fish extinctions (see Technical Report, Chinese Paddlefish Extinction), this is worrisome. Some scientists in fact worry the loss of food supply could become a humanitarian crisis (Cave, 2020).

In addition to food insecurity, the degradation and loss of coral reefs as we know them can result in environmental and economic factors that may induce migration. The loss of coral reefs, for instance, is projected to greatly compromise their capacity to provide coastal protection (IPCC, 2014; IPCC, 2019). Reefs dampen waves, reduce current velocities and trap sediment (Spalding and others, 2014) and thereby provide protection to coastlines. The combination of reef crest and reef flat in fact reduces some 97 per cent of the wave energy that would otherwise impact the shorelines (Ferrario and others, 2014). GBR's present coastal protection benefit is estimated to be worth at least A\$10 billion (Gibbs, 2020), while globally some 200 million people are estimated to depend on coral reefs for protection (WWF, 2018). Losing the coral reef would thus expose people, assets and infrastructure to storms, cyclones and sea level rise, etc. In the Marshall Islands, the reduction in protection against floods and storms was found to significantly correlate with migration propensities at household level (van der Geest and others, 2020). In some cases, the loss of corals can reduce the habitability of coastal environments and contribute to the intensity and frequency of displacement events (Kälin & Schrepfer, 2012). Even in less extreme cases, the collapse of reef ecosystems may induce migration due to compromised livelihood security. Over 275 million people live in close proximity to coral reefs and have their livelihoods depend on reefs (Reef Resilience Network, 2021b; UNEP, undated).

Reduction in the tourism or fishery industries dependent upon a healthy coral environment, for instance, endangers the livelihoods of unique human communities and causes economic damage (IPCC, 2014), which may force people to migrate. Considering that coral reef fisheries employ over 6 million fishers globally (Reef Resilience Network, 2021b), the severe decline of coral reefs is expected to cause a widespread loss of income for fishers and households and may become a push factor in their migration considerations.



Furthermore, the loss of corals as we know them may impact on culture and sense of place, which needs to be considered in terms of potential reasons for migration. Migration decisions, particularly in the context of islands, are partly conditioned by culture and place attachment (Oakes, 2019). However, losing coral ecosystems and related activities, such as fishing, puts key cultural dimensions of lives and livelihoods at risk and may therefore reduce the place attachment pull. In fact, losing coral reefs and related activities could lead to potentially irreversible loss of culture and local knowledge, with negative impacts on traditions also in terms of diets (IPCC, 2019).

Finally, losing corals will result in biodiversity loss, not only of the diverse coral species themselves, but also of the ecosystem, since corals are the very foundation of reef ecosystems. The loss of coral reefs and resulting ecological collapse (Wright & Watson, 2018) will have substantial impacts on regional, and also distant, social and ecological systems and further escalate the biodiversity crisis (see main report, Chapter 3.3 Emerging risks – Escalating biodiversity crisis). Biodiversity loss is linked to the disruption of ecosystem structure, function and services (IPCC, 2014) and can interfere with biosphere processes (Mace and others, 2014). It will certainly dramatically change marine ecosystems (Barnosky and others, 2012; Monroe, 2021) and translate into a key risk of large-scale loss of ecosystem services (IPCC, 2014).

The continuous degradation of the ecosystem and its biodiversity likely further erodes the provision of ecosystem services on which human societies depend and, in turn, further exacerbates the above-listed emerging risks (Monroe, 2021). Changes may even be large enough to compromise the Earth's ability to sustain human societies as we know them (Mace and others, 2014)

3. Drivers

Coral reef bleaching is long known to be a general response to environmental stresses (Tsarkisian, 2018). Warming waters are certainly the most direct and main driver of bleaching, since corals release their symbiotic algae and turn white as a response to heat stress (Stone, 2020; Gibbens, 2020) (Figure 1). Additionally, though to a lesser extent, bleaching is driven by ocean acidification, pollution, overfishing and diseases (Gibbens, 2020).

Ocean warming

According to the Intergovernmental Panel on Climate Change (IPCC), the global ocean has warmed and taken up more than 90 per cent of the excess heat in the climate system, with the rate of ocean warming more than doubling since 1993 (IPCC, 2019). Since 1910, GBR's sea surface temperatures have increased by 0.8° C (GBRMPA, 2021). Marine heatwaves have also doubled in frequency since 1982 and are increasing in intensity (IPCC, 2019). In February 2020, GBR recorded its highest monthly sea temperatures since Australia began keeping records, in 1900 (India Today, 2020b; GBRMPA, 2021).

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1 When the daily sea surface temperature exceeds the local 99th percentile over the period 1982 to 2016 (IPCC, 2019).

In addition to disrupting the symbiotic relationship of corals and algae by causing the algae to be expelled into the water column, warm water temperatures can also turn the algae from symbionts into parasites, which may also lead to bleaching (Baker and others, 2018).

Furthermore, sea-surface temperatures impact the coral microbiome, making corals vulnerable to opportunistic bacteria. Heat-stressed corals release an organic compound known as dimethylsulfoniopropionate, along which many of these opportunistic bacteria chemotax, i.e. move in response to the chemical stimulus, allowing them to target thermally stressed corals (Zaneveld and others, 2016).

Ocean acidification

Rising levels of carbon dioxide (CO₂) in the ocean, due to increased human-related emissions to the atmosphere, are altering ocean chemistry. As CO₂ increases in the atmosphere, it is increasingly absorbed also by the oceans, through photosynthesis by phytoplankton and dissolution (Riebeek, 2008). The absorption of CO₂ has increased the acidity of ocean water beyond natural variability (IPCC, 2019). Since the 1980s, the ocean has taken up 20–30 per cent of total anthropogenic CO₂ emissions, causing a decline in ocean surface pH range of 0.017–0.027 pH units per decade (IPCC, 2019).

Ocean acidification induces bleaching through processes that are not yet fully understood. Experiments show that high CO₂ and lowered pH disrupt the photoprotective mechanisms of coral symbionts or algal chloroplasts by lowering rates of photorespiration and the capacity for thermal dissipation (Anthony and others, 2008). High CO₂ and irradiance thus affect the symbiotic relationship and trigger bleaching. An older study on the symbiotic relationships of dinoflagellates algae and the giant clam suggest that carbon-concentrating mechanisms alter the relationship (Leggat and others, 1999).

In addition to inducing bleaching, high CO₂ levels reduce the saturation level of aragonite, a compound corals need to build their skeletons, therefore impeding their growth (Burke and others, 2011). This in turn reduces the resilience of corals to disturbances, including bleaching events. Predicted acidification will have a dramatic effect on the reefs in Australia and much of the Pacific, pushing many reefs from 'low' to 'threatened' categories in the 2030s (Burke and others, 2011). Threats from warming waters and acidification will in fact be apparent by 2030 across all regions of the world.

Pollution

Much of the land-based pollution enters waterways and is transported to the coast, threatening coral reefs. Studies estimate that watershed-based pollution threatens about 4 per cent of Australia's reefs, including 2 per cent at high threat (Burke and others, 2011). Watershed-based pollution is linked to the increasing coastal development, land use and industrialization linked to mining.

As Queensland continues to grow, with a population growth above the Australian average, so does development along the coast and islands adjacent to the GBR region (Great Barrier Reef Foundation, 2021). Mining, industry (fueling growth in ports and shipping) and intensification of agriculture (which quadrupled over 150 years) have significantly increased coastal development along GBR, reducing connectivity between habitats along with the water quality (Baker and others, 2018). The expansion of cities in coastal south-east Queensland coincided with the clearing of vegetation from 1972 to 2010. Extensive clearing of riparian vegetation also resulted in catchments of the area having generally poor conditions (SOE, 2016). As populations steadily increase along coastlines near coral reefs, threats to coral reef ecosystems accumulate (Reef Resilience Network, 2021b). Most land in the GBR catchment is used for grazing, crops, dairy and horticulture (Great Barrier Reef Foundation, 2021). Along GBR, watershed-based pollution from forest clearance and adjacent agriculture has been widely recorded. Forest clearing and grazing has exposed the soil surface, and increased the sediments entering the waters (Brodie & Mitchell, 2005; Smeed, 2018; Queensland Audit Office, 2018). Watersheds are covered by ~95 per cent agriculture, from which dissolved nutrients and pesticides/herbicides run off into GBR (Carlson and others, 2019).



Industrialization along the eastern coast of Australia also contributes to pollution and sedimentation on reefs close to the mainland (Encounter Edu, 2021). The controversial project of the thermal coal mine Carmichael in the Galilee Basin in Central Queensland is now under construction. In addition to threatening GBR in terms of pollution entering the waters, the mining project poses a threat, as burning coal contributes to climate change, acidifying and heating the oceans (Bradley, 2019; Goodell, 2019; Thornhill, 2020).

Watershed-based pollution results in an excess in nutrients in the ocean. Dissolved nutrients can travel up to 200 km north from the river mouth over primarily inner shelf reefs <20 km from the coast (Carlson and others, 2019). Over the last century, nutrient discharges from rivers have increased at least four-fold in the central GBR (Brodie & Mitchell, 2005). Waters with excess nutrients promote the growth of algae. Enhanced dissolved inorganic nutrients promote the excessive growth of the coral's symbiotic zooxanthellae, ultimately disrupting the stability and functioning of the symbiotic relationship (Wooldridge, 2009). The development of zooxanthellae densities additionally limits corals to build tissue energy reserves needed to combat periods of stress (Wooldridge, 2020). Indeed, it has been demonstrated that corals regularly experiencing nutrient-polluted waters display higher bleaching sensitivity (Wooldridge, 2009).

In addition to inducing bleaching, pollution also compromises the resilience of reefs (Zaneveld and others, 2016; Tisthammer and others, 2020). The growth of algae can kill corals by smothering them, blocking their access to sunlight and promoting the growth of harmful bacteria (Coral Reef Alliance, 2021). Algae-dominated substrates also affect coral settlement, as rocky, bare substrates are needed for the coral larvae to begin a new coral colony (Encounter Edu, 2021), thereby affecting recruitment. The nutrient excess additionally encourages blooms of phytoplankton in the water, which block light from reaching the corals. In severe cases, eutrophication can lead to hypoxia, where decomposition of algae and other organisms consumes the oxygen in the water, leading to 'dead zones' (Wooldridge, 2020). These stressors affect survivorship (Zaneveld and others, 2016) of sensitive coral genotypes, compromising biodiversity and therefore the overall reef resilience (Tisthammer and others, 2020).

Plastic pollution, too, threatens the health of coral reefs. Plastics can affect the feeding and cleaning mechanisms of certain corals (Reichert and others, 2018).

Some corals are found to consume such high volumes of microplastics that the synthetic particles in the coral's gut outnumber their natural foodstuff. Additionally, plastic pollution in coral reefs has been associated with increased rates of disease (Carrington, 2018; Shukla, 2019). Plastic debris stresses corals through light deprivation, toxin release, and anoxia, making them more susceptible to diseases. Diseases in turn increase susceptibility of corals to bleaching (see 'Coral Disease', below). A study found a 20-fold increase in disease likelihood in plastic-wrapped corals (Lamb and others, 2018).

Overfishing

Coral reefs, even many of the world's most remote ones, are heavily fished (Burke and others, 2011; Reef Resilience Network, 2021b). Coral reefs are essential habitats that support coral reef fisheries. Yet overfishing is the most pertinent local threat to corals, affecting over half of all reefs worldwide (Reef Resilience Network, 2021a; Reef Resilience Network, 2021b).

Fishing is strongly enshrined in Australian culture, with approximately 3.4 million being regular fishers and Australians eating an annual 140 serves of seafood (Department of Agriculture, Water and the Environment, 2019). The excessive fishing pressure in Australia has contributed to the decline of many Australian fish species, like bream and snapper (Casben, 2018), with a 33 per cent fall in exploited populations between 2005 and 2015 (Graham & Ward, 2021).

As fish are being overfished and removed from the coral reefs, the ecosystem balance is affected (Encounter Edu, 2021). By removing herbivorous fishes, such as parrotfish and surgeonfish, overfishing induces algal growth. Herbivorous fishes play an important role in keeping algal growth in check. As their numbers decline, and algal growth is no longer regulated by their grazing activity, reefs become overgrown with algae (see section 3, Drivers > Pollution, for impacts of algal growth and bleaching). Removing predatory fishes from the system furthermore leads to outbreaks of sea urchins (Encounter Edu, 2021). Despite sea urchins being essential for grazing and controlling the growth of kelp and algae that can overtake the corals (Coyer and others, 1993), the abundance of sea urchins is negatively correlated with coral cover (McClanahan & Shafir, 1990).

Coral Disease

Coral disease outbreaks have emerged as the most recent threat to corals, becoming more frequent, severe and widespread around the globe (AIMS, 2021b; Talbot, 2019; Willis and others, 2004). These diseases challenge the resilience of reefs and can exacerbate the impact of other threats to coral health, such as bleaching (Willis and others, 2004). Diseases are often linked to other coral stresses, such as declining water quality, overfishing and heat stress mentioned above. In GBR, evidence of coral disease was recorded in the 1990s, with the most common diseases including white syndrome, black band and brown band disease (AIMS, 2021a).



4. Root causes

Human-induced greenhouse gas (GHG) emissions

With some 85 per cent of marine heatwaves that occurred between 2006 and 2015 being attributable to the anthropogenic temperature increase (IPCC, 2019), human-induced GHG emissions (including emissions of carbon dioxide, methane, nitrous oxide and trace gases) represent a significant cause of bleaching.

GHGs are a primary cause of climate change. As their concentration increases in the atmosphere, more heat radiated from the Earth's surface is trapped, leading to warming. The majority of excess atmospheric heat caused by increased GHG emissions is absorbed by the oceans (US EPA, 2021), with more than 93 per cent having been absorbed by them since the 1970s (IPCC, 2014).

This warming in turn leads to corals being thermally stressed and bleaching. As GHG concentrations and the resulting warming have been increasing, more bleaching is induced. Warmer waters are pushing coral reefs towards nearly annual bleaching (Duong, 2020; Readfearn, 2020a), giving them no time to recover. Depending on the climate change projections, it is estimated that GBR will experience annual bleaching by 2044 or 2051 (Heron & Eakin, 2018). Similarly, marine heatwaves are projected to increase by up to 50 times by 2081–2100, compared to 1850–1900 (IPCC, 2019).

Globally, most emissions are linked to the energy sector (see main report, Chapter 3.2 Root cause 1). To date, Australia's energy needs have been largely met by fossil fuels, which result in GHG emissions when used. Coal resources generate three-quarters of domestic electricity, followed by gas (16 per cent), hydro (5 per cent) and wind (2 per cent) (Geoscience Australia, 2021). Australia is the world's third largest exporter of coal (Green and others, 2020), mainly to Japan, India, the European Union, Republic of Korea and Taiwan, and it is worth more than \$40 billion (Swann, 2019).

An aspect that is directly linked to the emission of GHG and climate change is governance. Although it needs global cooperation to avert a global climate catastrophe (Castro Pereira, 2021), every nation needs to do its bit through strong governance. Yet, Australia ranks last for climate action among United Nations member countries (Cox, 2021). The government is actually planning to increase fossil fuel production (Green and others, 2020) and a 'gas-fired recovery' was announced to re-establish the COVID-19-hit economy, which would lock the country in fossil fuel dependence for another generation (Beatty, 2020).

Global demand pressures

Over one billion people rely on fish as their basic source of protein and as the global population increases, so does the demand for fish. In 2018, the total fish catch reached 96 million tonnes (105.8 million tons) globally, with 84 million tonnes (92.6 million tons) coming from marine catch (WWF, 2020). Compounded by a shift in eating habits, the consumption for seafood has been increasing, encouraging widespread overfishing (also illegal, unregulated and unreported fishing) around the world and in Australia (Navy, 2013).

Australia covers some nine million square kilometres and is the third largest fishing zone in the world (Pincock, 2021). Its largest export markets for seafood are Japan, Hong Kong and the United States (Navy, 2013).

In addition to the global pressure for fish consumption, encouraging overfishing, the land adjacent to GBR is under strong pressure from different land uses. Population growth, which has been particularly rapid in Queensland, has increased the need for both agriculture and housing (SOE, 2016). There has been high demand for the use of coastal land by the community (QLD, 2018).

Demand for resources is another important pressure that has been encouraging the mining industry in Australia. Queensland supplies a broad range of elements, energy, minerals and metals (historically especially to Japan and Republic of Korea, and nowadays also rapidly emerging economies like India, China and Viet Nam). With a growing world population, demand for energy and construction materials has driven Queensland's energy fuels exports, like thermal coal and gas, as well as materials like copper, zinc, aluminum and metallurgical coal (QRC, 2021). Employment in the Queensland mining sector has in fact steadily increased (despite the recent pandemic) and currently employs more than 60,000 people (more than during the 2012 boom) (Mcghee, 2020). Australia is the world's largest coal exporter, and will potentially become the world's largest liquefied natural gas exporter by 2030 (QRC, 2021).

5. Solutions

There is still hope. Coral reefs in GBR and across the world can be saved by increasing their resilience and, most importantly, addressing the root causes (see main report, Chapter 4 Solutions) that lead to bleaching.

Increasing resilience

Researchers across the world are working on solutions to help increase the resilience of reefs to the impacts of climate change. The conservation of the ecosystem contributes to reef health. Marine Protected Areas support good coral reef conditions to maintain healthy reefs (Gibbens, 2020), particularly by managing direct threats such as overfishing (Marshall and others, 2006). Additionally, reducing pollution, and improving water quality and fish harvests on reefs can help maintain a healthy reef (Fears, 2020; Readfearn, 2020b). In collaboration with HSBC, the Queensland Government is considering buying 'Reef Credits', a tradable unit that quantifies and values the work undertaken to improve water quality flowing on to the reef (India Today, 2020b).

Scientists are also exploring the option to repopulate coral reefs, assisting or accelerating natural recovery processes, through restoration which can take many forms (Marshall and others, 2006); in addition to coral transplantation and coral seeding, micro-fragmentation and fusion has been implemented to restore reefs (McDermott, 2016). Restoration can furthermore be targeted, breeding hardiest and more stress-tolerant corals in the lab. For instance, the fast-growing *Montipora capitata* has been identified as a strong individual that stayed brown, even in hot water, and showed recovery when bleached (McDermott, 2016).

Addressing the root causes

To tackle the issue at its root, we must get people to value nature, rather than treat it as a commodity, and therefore stop our rampant overconsumption and waste to reduce global demand pressures (Harvey, 2021). Most importantly, we need to drastically reduce our GHG emissions, recognizing that without sharp GHG emission cuts corals will cease to exist in the near future (Parker & Welch, 2017).

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