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Submerged Conscience

The Impact of Climate Change on the Great Barrier Reef

Photographs by Giacomo D’Orlando

Text by Dr. Gina D’Angelo, Ph.D.
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In an era of rapid environmental shifts, social changes and unprecedented economic development, worldwide demand and the need for relevant research about the effect of climate change on the environment has never been more urgent.

Globally, more than 300 million people depend on the ecosystem services that coral reefs provide for their livelihoods and food security. The Great Barrier Reef (GBR) extends over 2000 km along the Northeastern coastline of Australia and is the only living thing on Earth visible from space. The GBR is composed of over 2600 individual reefs and about 300 islands, and it boasts over 1500 species of fish, 400 species of coral, 4000 species of mollusks and uncountable species of worms, crustaceans, and echinoderms (Briney, 2020). All these characteristics make the GBR the largest complex of coral reefs and the most distinctive ecosystem on the planet. The GBR is considered one of the seven natural wonders of the world, with its importance underscored by the fact that it was registered on the World Heritage List in 1981.

Coral reefs are rapidly degrading due to multiple pressures such as climate change, overfishing, and pollution. The Australian government has repeatedly identified climate change as the greatest threat to the Great Barrier Reef. According to the Commonwealth's Great Barrier Reef Climate Change Action Plan 2007-2012, "The fate of coral reefs will ultimately depend on the rate and extent of climate change. As climate change is driven by global greenhouse gas emission, this issue must be addressed." United States government scientists launched the alarm in 2017 in their assessment on climate change, which explained that the average global temperature has increased by 1°C since the pre-industrial era, and that the past 115 years include the warmest period "in the history of modern civilization." The analysis warns that temperatures could increase by another 4°C by the end of the century, with dramatic consequences for people and ecosystems.

An aerial view shows the Blue Canal located in proximity of Hardy Reef.

A stressed portion of corals in the Agincourt Reef along the coast of Port Douglas.

A couple of *Zebrasoma flavescen*, commonly called Yellow Surgeon fish, in a healthy reef section.

The principal risk to the Great Barrier Reef posed by ocean warming is the phenomenon of coral bleaching. To better understand coral bleaching, we have to comprehend the details of the physical composition of coral. Coral is the result of a symbiotic partnership between a marine cnidarian (Class Anthozoa) and algae (*Symbiodinium* species). The coral polyps live in colonies and secrete calcium carbonate to produce a hard outer "skeleton." The structure of the coral reef forms from the remnants of the skeletons of thousands of coral polyps (Pezner, 2020).

The Crown-of-Thorns starfish can have up to 21 arms, more than 600 ovaries, and hundreds of 4 cm-long toxin-tipped thorns. It grows to 80 cm across, eats 10 square meters of coral a year, and can produce up to 50 million eggs annually. An adult female is a formidable predator.

For the coral colony to survive, the skeleton needs to grow at a rate faster than that at which the ocean water erodes it. This increased growth rate requires that the coral obtain additional energy. Establishment of a symbiotic relationship with photosynthetic algae enables the coral to power rapid growth of the skeleton (Muscatine, 1980, 1990). The coral takes up algae from the surrounding water, and instead of digesting it, incorporates the microscopic algae into its tissues, developing a symbiotic partnership.

The algae require sunlight to carry out photosynthesis, and the sugars produced support the growth of the algae and provide 95% of the coral's energy requirement. In addition, the algae produce lipids and oxygen, both of which can be utilized by the coral. The photosynthetic pigments of the algae also provide color to the normally clear bodies of the coral polyps (Pezner, 2020). Increased ocean temperatures create conditions that may exceed the thermal tolerance of both the coral and the algae. This may occur by a mechanism whereby damage to the photosynthetic machinery contained in the thylakoid membrane occurs, causing the release of toxic substances including reactive oxygen species (ROS) into the coral. More current research hypothesizes that the algae may become parasitic to the coral under warming conditions, causing the coral to expel the symbionts. Because the color of the coral arises from the photosynthetic pigments of the endosymbiotic algae, expulsion results in the loss of color, or "bleaching" of the coral (Downs, 2002). A recent study on the relationship between Symbiodinium and the coral *Orbicella faveolata* indicated that rising water temperatures leads to a progression from mutualism to parasitism as the symbiotic algae hoards carbon and nitrogen at the expense of the host (Baker, et al. 2018).

A stressed coral belonging to the Agincourt ribbon Reef. The stress period for a coral can range from two weeks to two months, depending on the species.

After expelling the symbiotic algae, the coral can survive from one week to two months (depending on the species), if it has some reserve of nutrients in its tissues. Once the nutrient reserve expires, the coral will not survive unless it establishes a symbiotic relationship with another algae (Downs, 2002). An additional concern is raised by evidence that the surviving corals may experience reduced reproduction, lowering the rate at which bleached populations can be re-established (Hoegh-Guldberg, 1999).

Since the 1980s, global warming and the resulting rising sea temperatures have triggered unprecedented mass bleaching of corals.

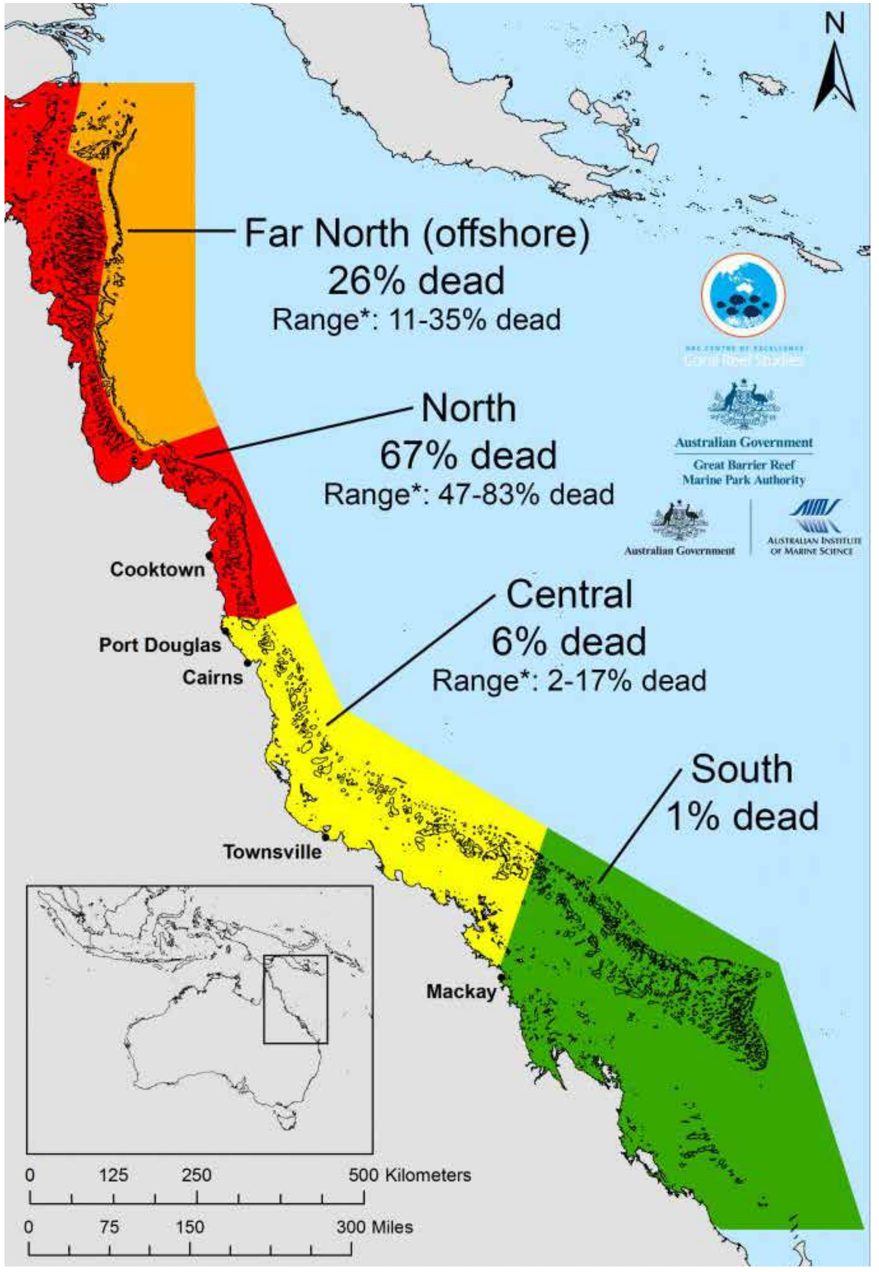
Physiological damage and prolonged bleaching leads to high levels of coral mortality. Increasingly, individual reefs are experiencing multiple bouts of bleaching, as well as the effects of more chronic local stressors such as pollution and overfishing. The geographic footprints of mass coral bleaching on the GBR varied markedly during three major events in 1998, 2002 and 2016 (Hughes, Kerry, et al., 2017).

In 1998, bleaching was primarily coastal and most severe in the central and southern regions of the GBR. In 2002, bleaching was more widespread, and affected offshore reefs in the central region that had escaped in 1998 (AIMS, 2020).

In 2016, bleaching was more extensive and increased in severity, especially in the northern regions, and to a lesser extent in the central regions, where many coastal, mid-shelf, and offshore reefs were affected (AIMS, 2020).

In 2016, the proportion of reefs experiencing extreme bleaching (more than 60% of corals) was over four times higher compared to 1998 or 2002. Conversely, in 2016, only 8.9% of 1156 surveyed reefs escaped with no bleaching, compared to 42.4% of 631 in 2002 and 44.7% of 638 in 1998 (AIMS, 2020).

The cumulative, combined footprint of all three major bleaching events now covers almost the entire Great Barrier Reef Marine Park.



Map detailing coral loss on Great barrier Reef, showing how mortality varies enormously from north to south. (ARC Centre of Excellence for Coral Reef Studies)

A portion of a dead reef on the ocean floor after the combined action of a bleaching event and cyclone damage. When the reef is in this condition, recovery is almost impossible.

The recovery time for coral species that are good colonizers and fast growers are 10-15 years, but when long-lived corals die from bleaching, their replacement will take many decades. Recovery for long-lived species requires the sustained absence of another severe bleaching event, an unrealistic prospect while global temperatures continue to rise (Hughes, Kerry, et al., 2017).

Douglas Baird, environment and compliance manager of Quicksilver Group. He works closely with the scientists carrying out the mesh experiments in the Agincourt ribbon reef.

Water contaminated with sediment moves outward along the coast of Airlie Beach. Decreasing water quality is one of the factors threatening the health of the Great Barrier Reef.

The goal of the COP21 (2015 United Nations Climate Change Conference in Paris) was to keep global average temperature increases to a level well below 2 degrees Celsius above pre-industrial levels, and to ultimately limit temperature increase to 1.5 degrees Celsius (Hughes, Barnes et al. 2017).

Summer tropical sea surface temperatures average 27-30 degrees Celsius or higher, rendering the global average of 14 degrees Celsius largely irrelevant because of differences in land and sea warming, latitude-dependent temperature gradients, and variation in regional rates of temperature increase. Dating from the late nineteenth century, regional and local-scale increases in tropical and subtropical sea surface temperatures have varied substantially, with 71% of reefs worldwide warming by 0.25 - 0.75 degrees Celsius . This global variation suggests that no one level of emissions is safe for all coral reefs. Therefore, the COP21 targets of 1.5 degrees Celsius and 2 degrees Celsius yield an incomplete solution to the future effects of global warming on coral reefs. If achieved, it will still lead to a level of warming having severe consequences on these delicate ecosystems (Hughes, Barnes, et al. 2017).

Global warming is not the only factor that threatens the future of coral reefs. According to studies conducted by the Australian Institute of Marine Science (AIMS), James Cook University (JCU), and the Centre of Excellence for Coral Reef Studies (ARC), the Great Barrier Reef has lost half its coral cover since 1985 due to diverse threats including ocean acidification, water quality, sedimentation, and loss of biodiversity. (AIMS, 2020, Hughes, Barnes, et al. 2017).

From the ocean surface, an operator of Tusa6 observes tourists diving through the Hamilton Reef.

A tourist is jumping off the boat in order to start his immersion tour in the Hamilton Reef.

A group of researchers undergo depressurization while rising from the ocean floor after checking the status of corals on Michaelmas Reef.

Quicksilver Group's scientifically innovative Reef Restoration Research Project aims to preserve the significant ecological, social, and economic value of the GBR World Heritage Area by transplanting corals onto low-voltage metallic mesh to facilitate the deposit of calcium carbonate and stimulate the growth of coral skeletons.

Ocean acidification is a major factor affecting the health of coral reef ecosystems. The ocean is a major sink for carbon dioxide, having absorbed close to one-third of atmospheric CO_2 in the last 200 years. Much of the CO_2 absorbed by the ocean results from human activities, reflecting the ocean's importance in regulating levels of atmospheric gases. When carbon dioxide dissolves in water, it forms carbonic acid, lowering the pH of the water and reducing the availability of the calcium carbonate that corals need to form their skeletons. This calcification is essential for coral recovery and for the reef to repair after physical and biological erosion (Morrison, Hughes et al. 2016).

Water quality is another important factor influencing coral health. Evidence for the negative effects of declining water quality on the GBR is extensive. Torrential rains occurring during Northern Australia's wet season cause erosion of woodland and agricultural landscapes, emptying an estimated 17 million tons of sediment into rivers that flow to waters of the GBR. The lagoon receives three to five times the suspended solids, at least double the total nitrogen, and between two and nine times the total phosphorus compared to pre-settlement amounts of 200 years ago (Great Barrier Reef Pollution, 2020).

Andrew Baird, a marine biologist working in collaboration with James Cook University, collects a coral sample from the reef around Magnetic Island in order to bring it to the laboratories in Townsville.

A researcher checks the condition of the corals in the Hemingway Reef before the beginning of the summer. In recent years, global warming caused by climate change extended the duration of the warm season from two weeks to approximately two months, during which time the water temperature can reach 31 degrees Celsius, leading to coral bleaching.

Andrew Baird, a marine biologist who collaborates with the James Cook University collects data about the reefs around Magnetic Island.

Excess sediment increased ocean turbidity in the vicinity of the GBR, causing a significant drop in light intensity and creating a problem for photosynthetic organisms such as the symbiotic algae in the corals. Increased nutrient availability from eroded soils and fertilizers favors the exponential growth of microalgae that can outcompete and displace corals on inshore reefs (Morrison, Hughes et al. 2016).

Sedimentation and nutrient runoff have been linked to the increasing frequency of outbreaks of the predatory Crown-of-Thorns starfish (Birkeland, 1982). The Crown-of-Thorns starfish feed voraciously on the coral, wiping out entire hard coral communities they encounter on their path.

Although a modest level of oceanic acidification undoubtedly will have discernible effects, mass bleaching events due to global warming and water pollution are likely to remain the most pressing challenges for reef biodiversity throughout the 21st Century. If acidification and pollution were eliminated, the coral cover on the reef could recover at a rate of nearly 3% per year.

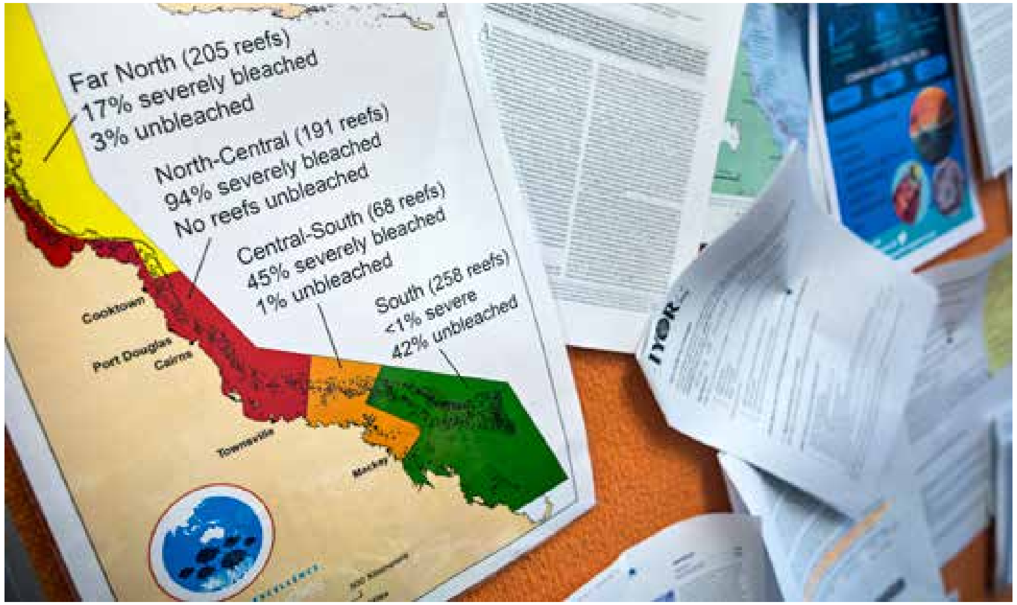
Reef naturalist Paul O'Dowd warns that 2019 could bring another massive bleaching event due to the warm waters accompanying "El Nino" weather patterns.

The GBR functions as a wall physically separating a lagoon from the Coral Sea. During the cyclone season, waves bring an influx of cold water from the ocean bottom into the Western Pacific Ocean and Coral Sea. This alters regional weather patterns, delaying summer storms occurring over the reef until late in the season. This leads to reduced mixing of GBR lagoon waters with those of the surrounding ocean and increased surface temperatures, setting the stage for future bleaching events (Haines, 2020, Smith, 2019).

The laptop screen shows the results of an experiment conducted by a Ph.D. student of James Cook University on the impact of changing ocean temperatures on marine wildlife (right).

Alexia Graba-Landry, a Ph.D. student at ARC, Centre of Excellence for Coral Reef studies, is conducting an experiment about the impact of increasing water temperature on the wildlife of the GBR. She is monitoring the effect of water temperature (26,28,30 and 32°C) on rabbit fish behavior, representing possible future scenarios (above).

The main experimental room of the National Sea Simulator in Townsville. Here, climate and ocean scientists and biologists have the opportunity to conduct more complex experiments on corals utilizing the state-of-the-art facility.



ARC results show how the different sections of the Great Barrier Reef have been damaged during the last years by bleaching events (top left). An AIMS researcher checks the growth status of the hybrid corals in the National Sea Simulator (bottom left).

A researcher takes pictures to track the growth of coral samples as part of the assisted evolution experiment (top). In the laboratories and aquariums of the Australian Institute of Marine Science near Townsville, researchers are working on coral hybrids - genetically novel species created by interbreeding. It is hoped that these cultured corals will have better chances of survival in warmer and more acidic waters (bottom).

A Ph.D. student in marine biology checks the acidity of the water in the different tanks used for experiments modeling possible future ocean conditions.

Lee Bastin, a Sea Simulator technician, checks the settled corals in the coral nursery. In this section of the Sea Simulator, experiments are conducted on different hybrid coral families belonging to different years, from 2014 to 2017, in order to compare the viability of each hybrid strain under various ocean conditions.

The experimental room of the Sea Simulator of the Australian Institute of Marine Science (AIMS), where scientists conduct the main hybridization experiments on the corals.

Inside the AIMS laboratories, a scientist applies an acidic solution to a microscope slide containing a small portion of hybrid coral. This experiment will allow the scientist to assess the effect of acidity on the structural integrity of the coral.

The challenge worldwide is therefore to steer reefs through this period of continued warming. In order to fight the effects of climate change on the GBR, different marine authorities are conducting experimental research with the aim of finding solutions for the protection and safeguarding of the reefs of the world.

One of the most trusted scientific agencies in Australia is AIMS, which has spent more than 40 years documenting unprecedented knowledge of tropical marine environments. Since 1972, AIMS has investigated marine ecosystems and processes across Australia's tropical north to support the protection and sustainable use of Australia's marine resources. They have developed long-term data sets to help industry, government, and scientists differentiate between natural cycles in the marine environment and the impact of development and climate change.

AIMS' flagship program is its National Sea Simulator, a huge laboratory where in-depth and controlled research about the reef is conducted. Opened in August 2013, the AIMS Sea Simulator is the most sophisticated marine research aquarium in the world, offering precise control over variables including water quality, temperature, and pH.

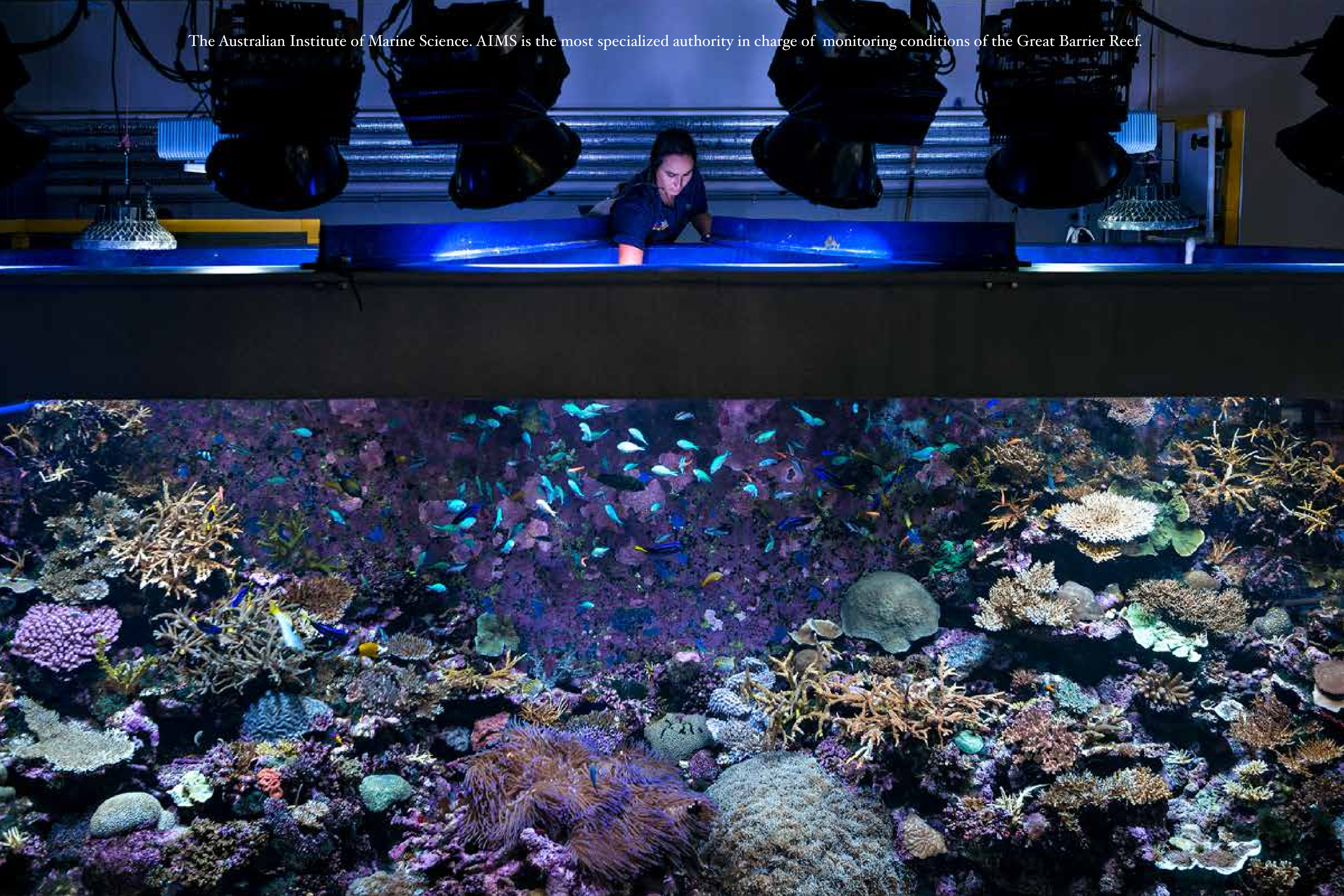
In recent years, researchers at AIMS have joined forces with those from JCU and ARC in the development of an assisted evolution project. This project seeks to accelerate the rate of natural selection with the goal of identifying hybrid strains of coral able to withstand increased ocean temperature and acidification.

The scientists are studying a heat-resistant strain of "Super-Coral" that has the potential to withstand rising ocean temperatures. This breakthrough research raises hopes that the effects of coral bleaching currently ravaging large parts of the reef could one day be counteracted (Shukla, 2020).

A tray with several samples of baby corals that are part of the assisted evolution experiment aiming to create the "Super Coral" which hopefully will possess the ability to survive global warming.

A James Cook University researcher collects samples of water containing the coral sperm and eggs in order to analyze their reproductive process.

Another authority involved in the "Super-Coral" project is the Great Barrier Reef Legacy (GBRL), an NGO that raises funds from private philanthropists and corporate donors with the goal of providing free access to "super-corals" for leading scientists, in hopes of discovering the characteristics that make them capable of surviving changing ocean conditions. The GBRL operates independently, boasting a 35-year history of leading collaborative coral reef expeditions and working to promote education and stewardship of the GBR. Working with AIMS, the GBRL



The Australian Institute of Marine Science. AIMS is the most specialized authority in charge of monitoring conditions of the Great Barrier Reef.

Several specimens of hybrid corals belonging to the 2016 assisted evolution experiment. This experiment aims to find a "Super Coral" which will be more resilient to the future bleaching events.

identified and collected samples from 12 living coral colonies from among the far northern "super stock" group of species known to have survived all recent bleaching events. Larvae from the spawning of nine of these super coral colonies were successfully settled onto special plates at AIMS National Sea Simulator (Search for Super Corals - Reef Legacy, 2020).

Dean Miller, director of science and media of Great Barrier Reef Legacy, says: "Given that we are a private organization with independent funding, we know that we can help the GBR a lot quicker than the government and universities, and this makes us proud of our work."

The GBR has an economic, social, and iconic asset value of $56 billion. It supports 64,000 jobs (mostly related to tourism) and contributes $6.4 billion to the Australian economy. The unique tourism experience offered by the GBR attracts millions of visitors each year. Tourism is the major business along the GBR coastline, boosting regional, state, and national income. Awareness of the importance of GBR health for the Australian tourism economy has led even tour operators to become involved in conducting experiments on the reef towards the goal of its restoration from bleaching events. For example, Quicksilver Group, a tour operator offering pontoon-based snorkeling and diving tourist packages in the reefs around Port Douglas, decided to undertake a novel experiment to address the loss of corals in the area of high visibility surrounding their pontoon, where tourists begin their immersions in the Agincourt ribbon reef.

This groundbreaking project involves the installation of electrically powered underwater mesh structures on which corals are grown. These structures consist of three steel mesh panels of 1.5 x 3 meters each, constructed over an area of coral rubble. These structures stabilize the rubble and allow small "recruit colonies" of coral to begin growing. The mesh is then attached to a power source which supplies it with constant and very low voltage electricity. The very low voltage stimulates coral growth on the metal frames by allowing the deposition of calcium carbonate into coral skeletons at a rate of up to three

The Australian Institute of Marine Science: In this room of the Sea Simulator, researchers are studying the impact of sediments in the water using different spectrums of artificial light. The complex light system of this room is constructed using 840 individual LED lights with 22 different colors.

The Reef HQ in Townsville is the world's largest living-coral reef aquarium. For the Australian government, the tourism related to the Great Barrier Reef ecosystem is worth more than six billion dollars every year.

A group of tourists view the corals of Agincourt Reef from a glass-bottom boat during a tour departing from Cape Tribulation.

to five times greater than normal ("Reef Restoration Research Project Quicksilver Cruises", 2020).

Douglas Baird, the environment and compliance manager of Quicksilver Group says: "Most tourists will not go further than the visual area of the pontoon and we don't want to give the idea that the reef is dying. We want to show people reefs in good condition in order to explain to them what we need to protect."

These interventions taken by the global and local authorities might not be enough to secure a future for the GBR coral reefs. The risk of extinction of the world's reefs is more real than ever and thus requires urgent and rapid action to reduce global warming. New approaches to ecosystem management through updated models of government oversight will be required to guarantee the survival of ecosystem biodiversity for future generations. Urgent action is required to address the multifactorial causes of climate change if the global reef crisis is to be averted. Immediate measures must be undertaken to curtail the emission of greenhouse gases and gain more accurate comprehension of ecosystem responses in the face of accelerated global climate crises.

Human-induced factors, both direct and indirect, drive ecosystem changes. These factors are increasingly diverse in their impact and scale. Globalization means that coral reefs have become more accessible, leading in a negative sense to their increased vulnerability, and in a positive aspect, to greater understanding and motivation towards local and international policy-driven protections.

Hope remains for the survival of Earth's coral reefs; however, governance must take human nature into account. As with all climate change legislation, governments must leverage the gravity of the situation to generate motivation for positive change while avoiding messages of doom and blame. Globally and locally, bold calls to action are necessary to inspire a vested and personal interest in the importance of coral reef protection and to empower us as human beings in our ability to save these delicate ecosystems.

This bleached staghorn coral faces an uncertain future. Its chance for survival is very small, and if recovery does occur, it will be slow and unlikely to bring the coral back to its original state.

Aerial view of the Hewitt Reef in the North-Central section of the Great Barrier Reef.

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Giacomo D’Orlando

Giacomo D’Orlando began his career as professional photographer in 2011 working in the advertising industry in Verona, Italy. In 2015 he moved to Nepal where he began to focus on documentary photographer subject matter for an NGO which helps women victims of violence. Several years later, he moved to Peru concentrating on social issues and other personal projects. After South America he moved first to Australia and then to New Zealand, where he focused more on environmental stories and issues related to climate change. During the few last years he has collaborated with international magazines worldwide and won awards in several international photo competitions such as PX3 (2017), State of the World (2019), International Photography Awards (2018 & 2019), MIFA (2017 & 2019), TIFA (2018) and Chromatic Photography Award (2017 & 2019).

Dr. Gina D’Angelo, Ph.D.

Gina D’Angelo received her Ph.D. in the Medical Sciences with a focus on Molecular Virology in 1996. After receiving her doctorate, she conducted postdoctoral research on tumor suppressor genes at Harvard University in Boston, MA and Fox Chase Cancer Center in Philadelphia, PA. She held the position of Research Fellow in Developmental Biology at Medical College of Georgia before making the transition to teaching. Dr. D’Angelo currently serves as Science Department Chair and teacher at Hamden Hall Country Day School in Hamden, Connecticut.

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Vision Project is an organization dedicated to the development of investigative journalism, documentary photography, multimedia, film, and education.

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