



TWENTY
20
ANNUAL REPORT



ARC CENTRE OF EXCELLENCE
Coral Reef Studies

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Vision

Providing scientific knowledge that fosters sustainable use, adaptive governance and effective management of the world's coral reefs to enhance human wellbeing.

Mission

To lead the global research effort in the provision of scientific knowledge necessary for sustaining the ecosystem goods and services of the world's coral reefs during a period of unprecedented environmental change.

Aims

The aims of the Australian Research Council (ARC) Centre of Excellence for Coral Reef Studies are:

- 1. Research**
Produce research that is world-best, innovative, collaborative, multi-disciplinary and highly relevant to coral reef management, adaptive governance and policy development.
- 1. Research Training and Professional Education**
Build human capacity and expertise in coral reef science worldwide.
- 3. National and International Linkages**
Create a global hub for integrated coral reef research collaborations.
- 4. Impacts and end-user engagement**
Exchange and transfer knowledge, technologies and research outcomes with end-users and partners.
- 5. Governance**
Continuously evolve Centre leadership and management to ensure it is co-operative, multi-institutional and communicative.

Overview

The ARC Centre of Excellence for Coral Reef Studies commenced operations in 2014 following the award of \$28 million from the Australian Research Council to fund the Centre for seven years. Headquartered at James Cook University (JCU), the Centre's additional nodes are The Australian National University (ANU), The University of Queensland (UQ) and The University of Western Australia (UWA). Our national and international partner institutions are the Australian Institute of Marine Science (AIMS), the Center for Ocean Solutions at Stanford University (COS, USA), Centre National de la Recherche Scientifique (CNRS, France), the Great Barrier Reef Marine Park Authority (GBRMPA), and WorldFish (Malaysia). In 2020, the Centre had collaborative links and co-authorships with 558 institutions in 74 countries.

The major objective of the Centre is to achieve a better understanding of the science, both social and natural, that underpins the dynamic changes currently occurring on coral reefs worldwide. The Centre's research is multifaceted and transdisciplinary. Improving the governance and management of natural systems and enhancing the capacity to sustain both human and natural capital is an overarching goal of our research.

DIRECTOR'S Report

PHOTO PETER MUMBY



It is a pleasure to introduce the 2020 annual report of the Australian Research Council (ARC) Centre of Excellence for Coral Reef Studies.

In 2020, the Centre's multi-nodal membership included 65 Chief Investigators, Research Fellows, and Associates; 26 Partner Investigators, resident international scholars, and adjunct researchers; and 156 research students (p79). Eight of our researchers this year are ARC fellows (Australian Laureate, Future and DECRA). The Centre also welcomed nine new research fellows and associates and 36 new graduate students from 14 countries. Terry Hughes stepped down as Director in July, but remains a Chief Investigator at the Centre.

2020 stands out as an unusual and challenging year. The third round of mass coral bleaching in five years began on the Great Barrier Reef in February (p33). Just as research began to document its extent, Australia entered a national lockdown (23 March) in an effort to contain the spread of COVID-19. State borders were closed, opened, and

closed again; international travel was limited; and field research plans for many of our researchers were severely disrupted. These impacts were particularly hard on our early career researchers and students, many of whom lost a field season and had to 'shelter in place' wherever they happened to be at the time, and on those who worked from home while caring for younger children.

I am happy to say that despite the challenges of 2020, it was another productive and high impact year for the Centre. Our researchers provided 77 public briefings or presentations and 109 presentations to end users throughout Australia and abroad (p77). They engaged with 194 new organisations, and the Centre's achievements were featured in more than 7,500 different commentaries. The Centre's website received over 10 million hits. Significant media attention

was generated by a series of 32 high-impact publications and press releases focusing on the state of ecosystems (p28), long-term shifts in coral colony size structure (p38), and pathways to improvement for marine management (p29).

The Centre's scientific impact in 2020 was high. Centre researchers published 421 publications, more than one every day (p82). Of these, 167 were in journals with Impact Factors over four, 38 were in prestige journals such as *Nature*, *Science* and *PNAS*, and Centre researchers collectively were cited over 70,000 times during the year. Our three research program summaries (pp 14-43) provide an overview of activities in 2020 and highlight some of the outstanding achievements of our researchers and partners.

The Centre has also continued to play an important role in training and mentoring across all four University nodes (p49). In 2020, we offered 33 training courses and professional development activities covering a wide range of topics, and 23 PhD students completed their degrees at JCU, UQ, UWA and ANU. A particular highlight was the highly successful Virtual Symposium that the Centre ran in

July, with presentations from four keynote speakers and 24 Centre graduate students to over 500 attendees (p58).

I would like to thank all of our partners and collaborators from around the world for their ongoing interest and engagement in the Centre. Many thanks are also due to the Centre's Advisory Board for their continued support. I am happy to announce that Hugh Possingham has agreed to take on the role of Chair of the Advisory Board (p75) following Brian Walker's retirement in 2019. We look forward to working with Hugh to continue to position the Centre for current and future success.

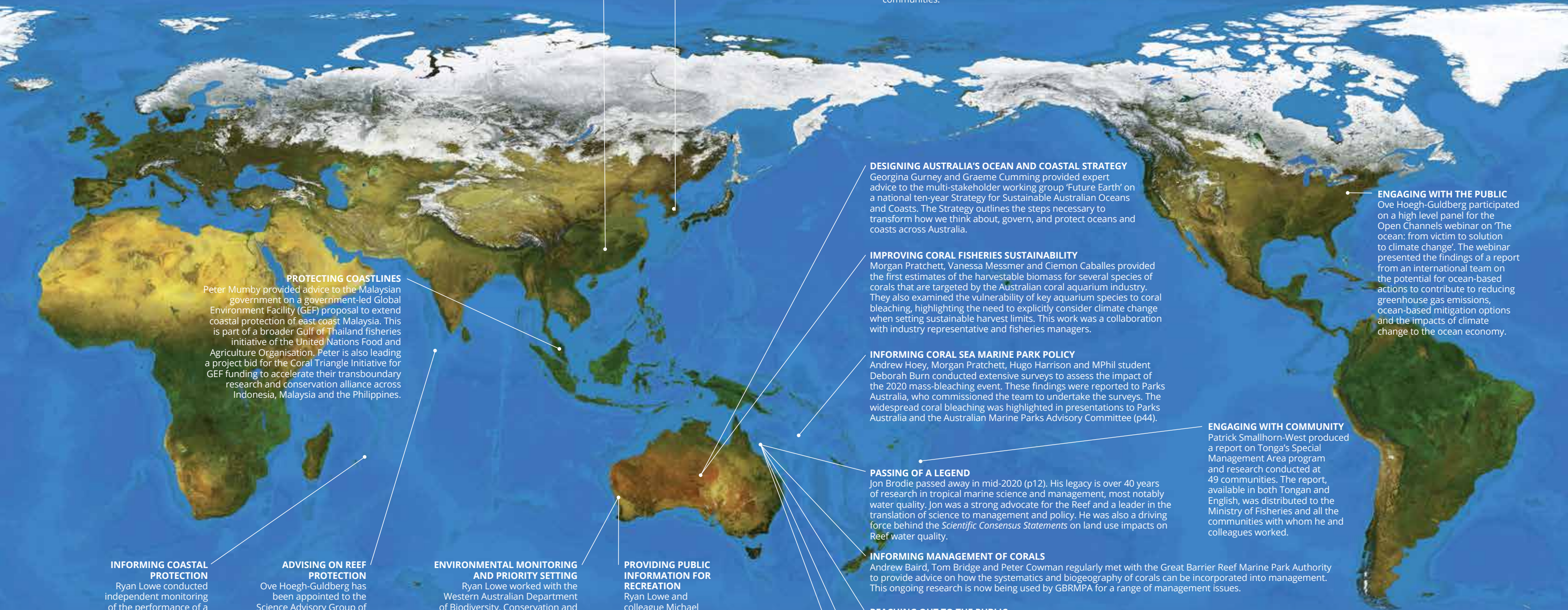
Last, but by no means least, I would like to express my profound thanks to the Centre's previous Director, Terry Hughes, for what he has achieved in creating and building the Centre in its current form. We have offered an overview of his achievements on p78. I wish Terry all the best for the future and look forward to further benefiting from his knowledge and experience in the years ahead.

Graeme Cumming
Director

PHOTO NICK EVENSEN



Impact & Engagement



INFLUENCING NATIONAL POLICY
Sun Kim (p30) co-authored the Global Coral Reef Monitoring Network National Chapter Report for South Korea. The report describes the current status of coral assemblages in South Korea, trends of tropicalisation, and bleaching patterns during the recent heat stress events.

ENGAGING GLOBALLY
Terry Hughes' video on the 2020 bleaching of the Great Barrier Reef, produced by the Australian Academy of Science, was translated into Chinese and viewed more than 200,000 times.

UNDERSTANDING AND COMMUNICATING IMPACTS OF COVID-19
Jacqueline Lau and Sarah Sutcliffe initiated a collaborative research project on impacts of COVID-19 in Papua New Guinea. In 2020, they communicated early findings in a report for policy-makers and an article in *The Conversation* (p12). In Kenya, they are collaborating with Kenyan Fisheries and Marine Research Institute and Wildlife Conservation Society on similar research in small scale fishing communities.

DEVELOPING INTERNATIONAL RESOURCES
Jorge Álvarez Romero led a group of conservation scientists and practitioners to update the Global Database on Conservation Planning (database.conservationplanning.org) which provides a platform to compile and provide access to key information about conservation planning initiatives and contributes to exchanging information about methods, tools, and best practice.

INTERNATIONAL ENVIRONMENTAL POLICY
Ove Hoegh-Guldberg participated as the review editor for Chapter 11 (Australia & New Zealand) of the *Intergovernmental Panel on Climate Change (IPCC) Assessment Report 6*. Ove is also a scientific adviser to the high-level panel for a sustainable ocean economy, which is a 14-nation initiative led by Norway to find solutions to climate change using ocean systems.

COMMUNICATING THE VALUE OF MARINE RESERVES
Hugo Harrison engaged with the International Union for Conservation of Nature (IUCN) on communicating the value of marine reserves. A product of this engagement was translating an infographic into French for an upcoming report on marine protection and seascape connectivity in the South Pacific.

PROTECTING COASTLINES
Peter Mumby provided advice to the Malaysian government on a government-led Global Environment Facility (GEF) proposal to extend coastal protection of east coast Malaysia. This is part of a broader Gulf of Thailand fisheries initiative of the United Nations Food and Agriculture Organisation. Peter is also leading a project bid for the Coral Triangle Initiative for GEF funding to accelerate their transboundary research and conservation alliance across Indonesia, Malaysia and the Philippines.

DESIGNING AUSTRALIA'S OCEAN AND COASTAL STRATEGY
Georgina Gurney and Graeme Cumming provided expert advice to the multi-stakeholder working group 'Future Earth' on a national ten-year Strategy for Sustainable Australian Oceans and Coasts. The Strategy outlines the steps necessary to transform how we think about, govern, and protect oceans and coasts across Australia.

IMPROVING CORAL FISHERIES SUSTAINABILITY
Morgan Pratchett, Vanessa Messmer and Ciemon Caballes provided the first estimates of the harvestable biomass for several species of corals that are targeted by the Australian coral aquarium industry. They also examined the vulnerability of key aquarium species to coral bleaching, highlighting the need to explicitly consider climate change when setting sustainable harvest limits. This work was a collaboration with industry representative and fisheries managers.

INFORMING CORAL SEA MARINE PARK POLICY
Andrew Hoey, Morgan Pratchett, Hugo Harrison and MPhil student Deborah Burn conducted extensive surveys to assess the impact of the 2020 mass-bleaching event. These findings were reported to Parks Australia, who commissioned the team to undertake the surveys. The widespread coral bleaching was highlighted in presentations to Parks Australia and the Australian Marine Parks Advisory Committee (p44).

PASSING OF A LEGEND
Jon Brodie passed away in mid-2020 (p12). His legacy is over 40 years of research in tropical marine science and management, most notably water quality. Jon was a strong advocate for the Reef and a leader in the translation of science to management and policy. He was also a driving force behind the *Scientific Consensus Statements* on land use impacts on Reef water quality.

INFORMING MANAGEMENT OF CORALS
Andrew Baird, Tom Bridge and Peter Cowman regularly met with the Great Barrier Reef Marine Park Authority to provide advice on how the systematics and biogeography of corals can be incorporated into management. This ongoing research is now being used by GBRMPA for a range of management issues.

REACHING OUT TO THE PUBLIC
Sue-Ann Watson worked with the Queensland Museum to develop an exhibition on Redmap (Range Extension Database & Mapping project). REDMAP enables the Australian community to spot, log and map marine species that are uncommon to their local seas. This information is used to track where species may be moving because of global warming and ocean heating events.

2020 CORAL BLEACHING EVENT
Terry Hughes provided daily briefings to GBRMPA, while undertaking aerial surveys of 1036 reefs during the 2020 coral bleaching event. Terry, Ove Hoegh-Guldberg and Peter Mumby also participated as members of the GBRMPA's Scientific Advisory Group, which informs Reef management on potential bleaching events.

EXPERT INPUT
Alana Grech provided expert review for applications to the Whitsunday Reef Islands Initiative, and the East Coast Inshore Fin Fish Fishery Level 2 Ecological Risk Assessment Large Mesh Nets (Gillnets & Ring nets) for the Queensland Department of Agriculture and Fisheries. Peter Mumby also provided advice to the GBRMPA compliance team on how compliance can be prioritised in areas of high ecological value.

ENGAGING WITH THE PUBLIC
Ove Hoegh-Guldberg participated on a high level panel for the Open Channels webinar on 'The ocean: from victim to solution to climate change'. The webinar presented the findings of a report from an international team on the potential for ocean-based actions to contribute to reducing greenhouse gas emissions, ocean-based mitigation options and the impacts of climate change to the ocean economy.

ENGAGING WITH COMMUNITY
Patrick Smallhorn-West produced a report on Tonga's Special Management Area program and research conducted at 49 communities. The report, available in both Tongan and English, was distributed to the Ministry of Fisheries and all the communities with whom he and colleagues worked.

INFORMING COASTAL PROTECTION
Ryan Lowe conducted independent monitoring of the performance of a new artificial reef designed for coastal protection in Mauritius, in collaboration with Subcon Blue Solutions with United Nations Development Programme (UNDP) funding.

ADVISING ON REEF PROTECTION
Ove Hoegh-Guldberg has been appointed to the Science Advisory Group of the 'Maldives Coral Institute' to provide advice on research and conservation activities within the Maldives. Ove and Institute founder Mohamed Nasheed, the Maldives' first democratically elected president, gave the opening plenary and welcome at the Coral Festival which launched the Institute.

ENVIRONMENTAL MONITORING AND PRIORITY SETTING
Ryan Lowe worked with the Western Australian Department of Biodiversity, Conservation and Attractions to establish a 5-year environmental monitoring program for reefs in the Dampier Archipelago. He also led a steering group with Perth Natural Resource Management to identify coastal research priorities for Western Australia. The steering group included State and Local Government, non-government organisations and community groups responsible for coastal management and planning

PROVIDING PUBLIC INFORMATION FOR RECREATION
Ryan Lowe and colleague Michael Cuttler created a publicly-available website for viewing real-time data on waves, sea surface temperature and wind along the coast of Western Australia, providing invaluable information for boating, fishing and recreational activities (wawaves.org).

Recognition of Excellence

OF CENTRE RESEARCHERS

Highlights of 45 awards, prizes and recognition of ARC Centre of Excellence researchers in 2020.

Eleven ARC Centre researchers, **Andrew Baird**, **David Bellwood**, **Sean Connolly**, **Ove Hoegh-Guldberg**, **Terry Hughes**, **Geoffrey Jones**, **Peter Mumby**, **Philip Munday**, **John Pandolfi**, **Morgan Pratchett**, and **Greg Torda** were identified as 2020 *Highly Cited Researchers* by Clarivate Analytics. Centre research affiliates **Nicholas Graham** (Lancaster University) and **David Mouillot** (University of Montpellier) were also listed. Highly cited researchers are those in the top 1% of researchers worldwide for their citations. Their research has demonstrated significant influence through publication of multiple highly cited papers during the past decade.

Andrew Baird was awarded the International Coral Reef Society (ICRS) *Mid-Career Scientist Award* in recognition of his outstanding body of research over an extended period of time.

Michele Barnes and **Peter Cowman** received Queensland *Young Tall Poppy* awards (p10).

Joshua Cinner led the Social-Ecological Research Frontiers team who were the winners of the 2020 Eureka Prize for *Excellence in Interdisciplinary Scientific Research*. The international team included Centre researchers **Michele Barnes**, **Georgina Gurney**, **Andrew Hoey**, **Jacqueline Lau**, and PhD candidate **Jessica Zamborain Mason**.

Joshua Cinner was honoured with the title *Distinguished Professor* by JCU, a highly prestigious university award bestowed upon Professors who have made an exceptional scholarly contribution to their discipline.

Graeme Cumming, **Andrew Hoey**, **Victor Huertas**, **Carrie Sims**, **Greg Torda** and **Kennedy Wolfe** were elected as Councillors to the Australian Coral Reef Society for 2020-2021.

Jennifer Donelson (p40) was awarded an Australian Coral Reef Society (ACRS) Fellowship in recognition of the strength of her research track record and her service to the coral reef science community. Jenni also received a scholarship from Women and Leadership Australia to participate in their leadership training programme.

Andrew Hoey was awarded the 2020 ACRS *Mid-Career Researcher Medal* in recognition of his high achievement in research and outstanding contribution to the conservation of Australian coral reefs.

Ove Hoegh-Guldberg and **Terry Hughes** were reappointed for an additional five-year term to the *Reef 2050 Plan Independent Expert Panel* which provides scientific and expert advice to the Australian and Queensland governments on the implementation and review of the Reef 2050 Plan and on funding priorities for the Reef Trust.

Terry Hughes received a number of accolades in 2020. He won the highly prestigious 2020 *BBVA Frontiers of Knowledge Award*, in the category of Ecology and Conservation Biology, for his contribution to marine conservation. Terry also received the Bob Brown Foundation's *Deni Greene Award* for showing 'outstanding courage' in his work for sustainability in documenting the largest coral bleaching on the Great Barrier Reef on record. The Irish Times recognised him as a 2020 *Climate Change Influencer*. Terry was also a co-author on *Nature* paper 'Rebuilding marine life' that was fifth on Carbon Brief's *climate papers most featured in the media in 2020*. In September, *The Australian* newspaper named Terry as Australia's leading researcher in the field of Life Sciences and Earth Sciences in their *Top 250 Researchers*.

Janice Lough was selected as an *ICRS Fellow* in recognition of her scientific achievement and service to the International Coral Reef Society.

Tiffany Morrison was appointed as Fellow of the Regional Studies Association.

Jodie Rummer was appointed to the Intergovernmental Oceanographic Commission Expert Group, the UN's Global Ocean Oxygen Network (GO2NE) which offers scientific advice to policy makers to preserve marine resources in the presence of deoxygenation.

Eugenia Sampayo attracted an Australian Biological Resources Study research fellowship (2020-2023) for her project 'Systematic and taxonomic analyses of eastern Australian Symbiodiniaceae: the unification of research on coral-algal mutualisms'.

Greg Torda was granted an ARC *Discovery Early Career Researcher Award (DECRA)* for his project 'Exploring eco-evolutionary dynamics to predict the future of coral reefs'.

Centre students also received wide recognition in 2020 (p49).



Joshua Cinner (far left) led an international group of over 40 social scientists, ecologists, engineers, and practitioners to win the 2020 Eureka prize for *Excellence in Interdisciplinary Scientific Research*. Research for this prize included fieldwork spanning 16 years in Papua New Guinean coastal communities. PHOTO JOSHUA CINNER

Young Tall Poppy

SCIENCE AWARDS

The ARC Centre's 14 Young Tall Poppies exemplify our commitment to world-best science, communication and mentoring.

The **Tall Poppy Campaign** was created in 1998 by the Australian Institute of Policy and Science (AIPS) to celebrate scientific excellence and encourage young people to explore opportunities in research. A focus of the Campaign is the prestigious annual Young Tall Poppy Science Awards.

The Young Tall Poppy Science Awards recognise Australian early career researchers (ECRs) for their excellence in research, community engagement and

communication. 'Tall Poppies' are widely considered to be Australia's future research leaders, with a strong focus on public policy and science translation.

Since its national launch just over ten years ago, Centre researchers have achieved incredible success in the Young Tall Poppy Science Awards. Fourteen ECRs have been recognised as 'Tall Poppies', and four were given the honour of Queensland Young Tall Poppy of the Year: Nicholas Graham (2012), Sue-Ann

Watson (2014), Alana Grech (2018) and Jodie Rummer (2019). The Centre's commitment to excellence in research training is also demonstrated by the award of 'Tall Poppies' to four of our PhD alumni: Morena Mills (2012), Jean-Paul Hobbs (2013), Ian McLeod (2017) and Christopher Doropoulos (2017).

The range of disciplines of our 'Tall Poppies' illustrates the breadth of the Centre's research. We are particularly proud of our social scientists, who have been awarded three 'Tall Poppies' despite the Campaign's focus on STEM disciplines: Pip Cohen (2014), Georgina Gurney (2018) and Michele Barnes (2020).

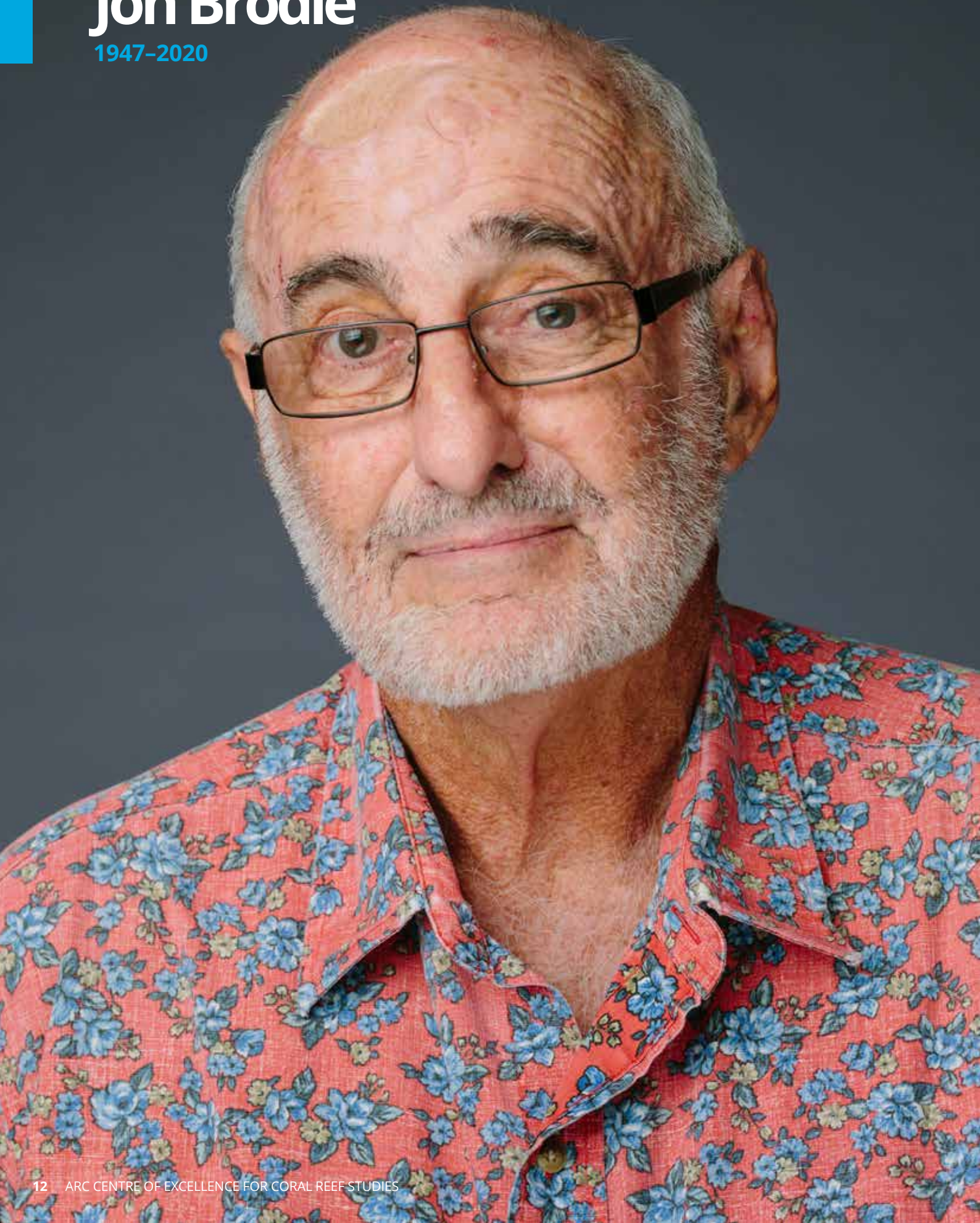
Winners of the Young Tall Poppy Science Awards are encouraged to promote interest in science among school students and teachers, as well as an understanding and appreciation of science in the broader community. Several ARC Centre 'Tall Poppies' have gone on to join the Wonder of Science programme as 'Flying Scientists', helping to promote a STEM culture in Queensland schools. Others have demonstrated excellence in research communication and community engagement through regular contributions to popular media, science outreach and participation in the Superstars of STEM programme.



TRIBUTE

Jon Brodie

1947–2020



Farewell to a great protector of the Reef

In June 2020, sadly, our dear friend and colleague Dr Jon Brodie passed away. He was one of the world's finest water quality scientists. The crucial work to which he dedicated his life — which included protecting the Great Barrier Reef — will benefit generations to come.

Jon was a Professorial Fellow at the ARC Centre of Excellence at James Cook University, ever present even on his days off.

He made significant contributions to protecting the Great Barrier Reef, leading many research programs that broadened the public knowledge and scientific understanding of the Australian icon. In doing so, Jon was fearless. He often spoke out forcefully and truthfully about environmental issues.

Jon's passion for science led him to complete a BSc in inorganic chemistry in 1968. He was then an analytical chemist and technical teacher at Newcastle Technical College for many years.

Following the completion of his post-graduate studies Jon held many roles including: Chief Research Scientist for the Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER); Director of the Water Quality and Coastal Development Section at the Great Barrier Reef Marine Park Authority; and Director of the Institute of Natural Resources at the University of the South Pacific in Fiji.

Jon was a world authority on water quality: the sources of pollutants in catchments; the transport of pollutants to the marine environment; the dispersal of land-based pollutants in coastal and marine environments; and the effects of terrestrial pollutants on marine ecosystems. He established the still-active TropWATER water quality laboratory.

Jon regularly advised Australian governments on policies regarding the management of water quality issues on the Great Barrier Reef.

The Director-General of the Queensland Department of Environment and Science recently thanked Jon for his "leadership in investigating land use impacts on the Reef, and your dedication to water pollution research in the tropical north." Both efforts produced crucial scientific evidence to support government actions to protect the Great Barrier Reef.

Jon's work was fundamental in the development of the Reef Water Quality Protection Plans and the Reef 2050 Water Quality Improvement Plan. The water quality targets he detailed within these publications guide today's local land management.

Throughout his career, Jon published more than 100 peer reviewed articles and more than 300 technical reports, books and book chapters.

He was a giant in his field, widely acknowledged as irreplaceable. His work leaves a deep and enduring impact not only on the thousands of people who had contact with him, but on water quality and reef management all over the world. He was also a generous and caring mentor and advisor to many graduate students and early career researchers with whom he worked tirelessly.

Jon remained central to his field right to his final days, when, in typical fashion, he was working fruitfully on a range of research and policy outputs.

Though Jon's valuable legacy remains, his meticulous science, fierce spirit and no nonsense straight-talking will be sorely missed by his colleagues. More deeply, his loss will be felt by his family, especially his sons Tim and Paul, daughter Nicola, and grandson Charlie.

RESEARCH PROGRAM 1

People and Ecosystems



Professor Joshua Cinner *FASSA*

Professor Joshua Cinner is a co-leader of Research Program 1. He received his PhD in 2006 from James Cook University. Joshua is a human geographer with broad research interests, including collective action, compliance, social-ecological linkages, fisheries management, behaviour change and adaptation. Joshua regularly leads large, interdisciplinary research teams comprising social scientists, ecologists, statisticians, engineers and practitioners. He works closely with non-government organisations, government agencies and local communities to enable his research to have greater impact. He has published more than 150 peer-reviewed articles, including 12 in *Science*, *Nature*, and *PNAS*. In 2018, Joshua was elected a Fellow of the Academy of Social Sciences in Australia. He is an ARC Future Fellow, and has received two other prestigious fellowships from the ARC and the Pew Fellowship in marine conservation. Joshua has received many additional prizes, including the 2020 Eureka Prize for *Excellence in Interdisciplinary Research*, the 2017 *Elinor Ostrom Prize for the Governance of Collective Action* and the 2018 *Mid-Career Award* from the International Coral Reef Society. Joshua was a Clarivate 2019 *Highly Cited Researcher*.



Professor Tiffany Morrison

Professor Tiffany Morrison is a co-leader of Research Program 1. She is an expert in environmental governance who combines theory and methods from geography, policy science and ecology to address complex environmental problems, such as climate adaptation. Tiffany received her PhD in 2004 from The University of Queensland. From 2004-2008 she taught in the School of Political and International Studies at Flinders University. In 2008, Tiffany joined The University of Queensland where she co-led an interdisciplinary team of ecologists, geographers, planners, economists and lawyers working on an ARC Super Science funded program of research on sea level rise. Since joining the Centre, she has developed and led a major new research program on the governance of climate adaptation and conflict in large-scale marine systems. Her research on environmental governance in Australia and the Pacific has been instrumental to a range of government policy and reports. Tiffany is a Fellow of the Regional Studies Association and serves on the Editorial Boards of *Global Environmental Change*, *Earth System Governance* and *Frontiers in Climate*. Her recent studies of the complex governance of tropical ecosystems have been published in *Nature*, *PNAS*, *Nature Climate Change*, *Global Environmental Change* and *Nature Sustainability*.



Professor Bob Pressey *FAA*

Professor Bob Pressey is a co-leader of Research Program 1. Bob's research includes studies of biodiversity, geographic information systems, spatial modelling of species and human activities, software development, explicit frameworks for deciding on the location and timing of conservation investments, and the socio-economic considerations involved in implementing conservation. Prior to moving to James Cook University and the Centre, he was a research scientist for the New South Wales National Parks and Wildlife Service for almost 20 years. During that time, Bob developed and applied leading-edge techniques in conservation planning, influencing policy and conservation practice. He has served on the editorial boards of leading conservation biology journals. Bob's awards include the Royal Botanic Gardens' Eureka Prize for *Biodiversity Research* in 2002 and the inaugural *Australian Ecology Research Award* from the Ecological Society of Australia in 2008. In 2010, he was elected a Fellow of the Australian Academy of Science for his contributions to the field of systematic conservation planning. His understanding of conservation applications has been recognised by appointment to national and international committees and working groups.

Researchers

Jorge Álvarez-Romero, Michele Barnes, David Bellwood, Brock Bergseth, Jon Brodie, Iain Caldwell, Pip Cohen, Graeme Cumming, Alana Grech, Georgina Gurney, Terry Hughes, Danika Kleiber, Jacqueline Lau, Laurence McCook, David Mills, John Pandolfi, Cristian Rojas, Garry Russ and Patrick Smallhorn-West.

PROGRAM 1

Report

Research in Program 1 focusses on understanding the linkages between coral reef ecosystems, the goods and services they provide to people, and the governance of those systems. The overarching objective is to improve the stewardship of coral reefs and the wellbeing of reef-dependent populations worldwide, while simultaneously providing lessons and insights for other ecosystems. Program 1 provides decision-support tools, guidelines for using information and rigorous assessments of the adequacy of existing conservation measures. Key research questions include how economic development, social networks, local history and political drivers influence resource use and governance. Program 1 places a high value on engagement with communities, managers and policy makers, government agencies and with non-government organisations.

Researchers in Program 1 rapidly responded to the COVID-19 pandemic in 2020 by changing their focus to remotely-led research projects and virtual workshops. Jacqueline Lau, Michele Barnes, Joshua Cinner and Sarah Sutcliffe worked with in-country partners, such as the Wildlife Conservation Society, to conduct regular phone interviews with fishers and fish traders in six local villages in Papua New Guinea and Kenya. Their goal was to understand the impact of the global pandemic on the wellbeing of coastal communities and ways of developing policies to improve food security (p22). Georgina Gurney and Michele Barnes co-chaired a special session on 'Power, equity, and justice in marine social-ecological systems undergoing rapid change' at the virtual *International Symposium on Society and Resource Management*, with speakers Tiffany Morrison and Jacqueline Lau. Tiffany Morrison also led an international virtual workshop on *Radical Interventions for the Anthropocene* with colleagues across four universities and time zones. Graeme Cumming and Tiffany Morrison spoke on a special invited panel for early career researchers on 'What is the future research agenda on governing natural resources?' at the *First Global International Association for the Study of the Commons Early Career Researcher Meeting*.

In *Science*, Joshua Cinner, Georgina Gurney, Michele Barnes, Cindy Huchery, Andrew Hoey and PhD student Jessica Zamborain-Mason published a **high-profile article** on coral reefs that 'have it all'. They assessed nearly 1800 tropical coral reefs around the world to find those with plentiful fish stocks, highly diverse fish communities and high levels of key ecosystem functions. The team found that marine reserves could make the biggest difference in locations with low human pressure. Joshua Cinner also led a collaborative interdisciplinary **essay** in *Conservation Biology* on how the presence of markets can change people's behaviour in ways that can have negative impacts on the environment. This research was part of a series of publications in *Science*, *Nature*, and *PNAS* that won the Social-Ecological Research Frontiers team the 2020 Eureka Prize for *Excellence in Interdisciplinary Scientific Research*.

In 2020, Program 1 continued to advance the science and application of conservation planning. Bob Pressey, with PhD students Jeremy Raynal and Me'ira Mizrahi and Masters of Science student Brayden Cockerell, published research on **livelihoods of small-scale fishers in Myanmar** and the **downgrading of marine protected areas in Australia's Commonwealth waters**, both in *Biological Conservation*. Their research on the untapped potential for recreational fishers to contribute to conservation of coastal marine ecosystems was published in *Global Ecology and Conservation*. Alana Grech published articles in *Biodiversity and Conservation* and *Conservation Biology* on long-term trends in cetacean bycatch and cost-effective mitigation strategies in Australian waters. Jorge Álvarez-Romero, in collaboration with colleagues at the World Conservation Monitoring Centre and Imperial College London, is extending the global database on conservation planning that he helped to establish. Joshua Cinner and PhD student Jessica Cramp published a paper in *Nature* on the first global analysis using a standard methodology to assess the abundance of reef sharks globally. The study revealed the profound impact that fishing has had on reef shark populations, but also highlighted where the best opportunities remain for



PHOTO ALEJANDRO USOBIAGA

conservation. PhD student Patrick Smallhorn-West led a series of publications in *Conservation Letters*, *Biodiversity and Conservation* and *PLoS ONE* on the status and conservation of coral reefs in Tonga. In early 2020, Patrick joined Program 1 as the fifth jointly-funded postdoctoral fellow in our ongoing WorldFish collaboration (p62).

Contributions to ecosystem service science and climate change adaptation were also important components of Program 1 research in 2020. Jacqueline Lau and PhD students Marie Lapointe and Ruby Grantham led a series of papers in *Ecology and Society*, *Ecosystem Services*, *Maritime Studies* and *World Development* on access to marine ecosystem services. Michele Barnes led a publication in *Nature Climate Change* with Jacqueline Lau, Joshua Cinner, and PhD students Sarah Sutcliffe and Jessica Zamborain Mason on social determinants of adaptive and transformative action (p18). The study uncovered key conditions that enable or constrain response to climate change. Importantly, they found that people were more likely to take action if they were socially connected to other people who already had.

Program 1 continued building research excellence in environmental governance in 2020. Tiffany Morrison, Terry Hughes and Cindy Huchery published a multi-disciplinary study in *Nature Sustainability* on navigating the politics of World Heritage (p19). The research was based on an analysis of interactions between the United Nations Educational, Scientific and Cultural Organization and the 102 national governments responsible for implementing ecosystem protection under the World Heritage Convention between 1972 and 2019. Tiffany Morrison also led a high profile perspective in *One Earth's* Special Issue on Ocean Health on new ideas for advancing coral reef governance into the Anthropocene. Graeme Cumming, Tiffany Morrison, Georgina Gurney and PhD student Sivee Chawla led a multi-disciplinary paper in *Current Opinion in Environmental Sustainability* on advances in natural resource governance. The paper arose from a workshop held at the National Socio-Environmental Synthesis Center in Annapolis, with funding from the US National Science Foundation and involving researchers from Canada, USA, Germany, Sweden, South Africa, the UK, India and Spain.

The study found people are more empowered to respond to the devastating impacts of climate change when they see others doing the same.

Personal connections key to climate adaptation

PHOTO DEAN MILLER

Connections with friends and family are key to helping communities adapt to the devastating impact of climate change on their homes and livelihoods, a **new study** shows.

The research found people are more empowered to respond when they see others doing the same.

Scientists analysed how an island community in Papua New Guinea of around 700 people coped with the impact of encroaching sea-levels and dwindling fish stocks. The study, published in the journal *Nature Climate Change*, examined the actions households took to deal with these impacts.

Lead author Dr Michele Barnes, from the ARC Centre of Excellence for Coral Reef Studies at James Cook University, said: "We found their actions were related to their social networks, the ways they are connected to other people within the community."

"To cope with the impacts of climate change, existing practices or behaviours can be tweaked—this is adaptation. However, in some cases this won't be enough, and people need to enact more fundamental changes—transformation."

"In our case, adaptation included things like building sea walls to protect existing land use," said co-author Dr Jacqueline Lau, from the Centre and WorldFish. "And transformation involved developing alternative food and income sources away from fish and fishing-related activities."

Essentially both sets of actions are necessary to combat the impacts of climate change.

Dr Barnes says influence within social networks encouraged both sets of actions. The team found that the households more socially connected to others taking action

were more likely to do the same.

"It may be a situation of 'like-attracts-like' where households with particular mindsets are more socially connected to similar households," Dr Barnes said. "Another explanation is that households were influencing each other's actions. It's likely a combination of the two," she said.

The authors also found that household connections with the marine environment played an important role in determining the responses to climate impacts.

"Climate change and other human impacts rapidly degrade coral reef ecosystems and alter the composition of reef fish communities," said co-author Professor Nick Graham, of Lancaster University in the United Kingdom.

"The adaptation of coastal communities is becoming essential. Our research highlights that interacting with and learning from the marine environment is one mechanism through which this adaptation can be achieved," he said.

Dr Barnes says the policies and programs seeking to reduce vulnerability to climate change often focus on building up material assets or creating infrastructure.

"Our research emphasises that a broader set of factors can play an important part in the actions communities end up taking," she said.

Barnes, ML, Wang, P, Cinner, JE, Graham, NAJ, Guerrero, AM, Jasny, L, Lau, J, Sutcliffe, SR and Zamborain-Mason, J (2020). *Social determinants of adaptive and transformative responses to climate change*. *Nature Climate Change* 10(9): 823-828.

The Great Barrier Reef is just one highly threatened ecosystem that successive Australian governments continue to shield from an In Danger listing.

How governments resist World Heritage 'in Danger' listings

PHOTO TERRY HUGHES

A **study** published today found national governments repeatedly resisted the placement of 41 UNESCO World Heritage sites—including the Great Barrier Reef—on the World Heritage in Danger list. This resistance is despite the sites being just as threatened, or more threatened, than those already on the in Danger list.

World Heritage sites represent both natural and cultural heritage for global humanity. Their protection sits within the jurisdiction of individual countries. An in Danger listing is intended to raise awareness of threats to these sites and encourage investment in mitigation measures, such as extra protection.

Lead author Professor Tiffany Morrison from the ARC Centre of Excellence for Coral Reef Studies at James Cook University says national governments responsible for these World Heritage sites use political strategies of rhetoric and resistance to avoid a World Heritage in Danger listing.

"Avoiding an in Danger listing happens through partial compliance and by exerting diplomatic pressure on countries that are members of the World Heritage Committee," Professor Morrison said.

She says World Heritage in Danger listings are increasingly politicised. However, until now, little was known about what that politicisation entailed, and what to do about it.

The study found the net number of in Danger listings plateaued since the year 2000. At the same time, low visibility political strategies—such as industrial lobbying and political trade-offs associated with the listings—intensified.

"Our results also challenge the assumption that poor governance only happens in less technologically advanced economies. Rich countries often have poor governance too," Professor Morrison said.

"We show that the influence of powerful industries in blocking environmental governance is prevalent in many regions and systems."

The Great Barrier Reef, under the custodianship of the Australian Government, is just one of the

threatened sites that continues to evade the World Heritage in Danger list.

Professor Terry Hughes, also from the Centre, says there is no doubt that coral reefs are in danger from man-made climate change.

"The study makes no recommendation on which World Heritage sites should be formally recognised as in Danger but points out that virtually all sites are increasingly impacted by anthropogenic climate change," Professor Hughes said.

World Heritage in Danger listings are frowned upon by high-value natural resource industries such as mining, forestry and environmental tourism. Professor Morrison says the in Danger listings restrict the social license of fossil fuel industries to operate.

"Industry coalitions therefore often lobby governments, UNESCO and World Heritage Committee member countries," she said.

"They claim an in Danger listing diminishes their nation's international reputation and restricts foreign investment, national productivity, and local employment. Some also challenge the World Heritage system itself and undermine reports by scientists, non-governmental organisations and the media."

These lobbying efforts heighten a government's sense of political threat by linking the listings to national economic performance, as well as to the individual reputations of politicians and senior bureaucrats.

The study provides new evidence for how interactions, from 1972 until 2019, between UNESCO and 102 national governments, have shaped the environmental governance and outcomes for 238 World Heritage ecosystems. It also provides examples of how concerned stakeholders experiment with countervailing strategies that harness these politics.

Morrison, TH, Adger, WN, Brown, K, Hettiarachchi, M, Huchery, C, Lemos, MC and Hughes, TP (2020). *Political dynamics and governance of World Heritage ecosystems*. *Nature Sustainability* 3(9): 769-769.

RESEARCHER PROFILE

Pip Cohen



"I want to build understanding of governance and resilience of coastal and inland communities and their fisheries"

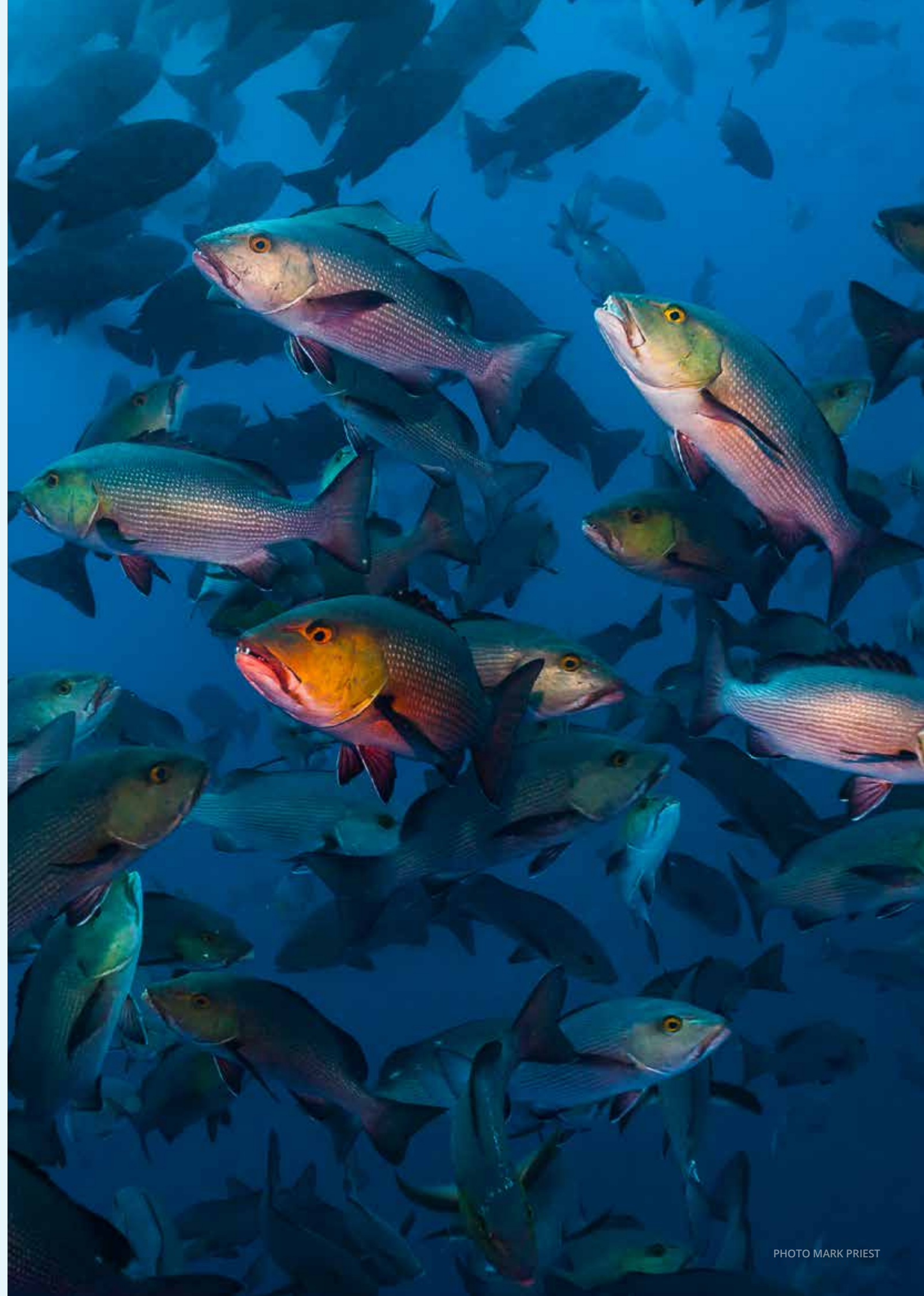
Pip Cohen is a Partner Investigator (WorldFish p62) and Board Member of the ARC Centre of Excellence for Coral Reef Studies. Pip's career started in the colder climate of Tasmania before moving to the much warmer islands of Tonga, Fiji, Solomon Islands and Penang, Malaysia. In Penang, where WorldFish is headquartered, Pip leads the CGIAR's Research Flagship Program on Resilient Small-scale Fisheries. Pip says she feels "incredibly lucky to work with such a diverse and dynamic team of researchers from across the Pacific, Asia and Africa".

Pip's undergraduate degree in Marine, Freshwater and Antarctic Biology at the University of Tasmania was followed by three years as a technical officer with the Rock Lobster Research team at the Tasmanian Aquaculture and Fisheries Institute. Pip recalls, "There was a lot of diving, boats and coasts, which was balanced out with an awful lot of boat cleaning and washing the wee out of other peoples' wetsuits. But honestly, it was the best job ever".

Pip had her one and only break from island life during her PhD at the Centre's headquarters at James Cook University (JCU). At this point, her career pivoted to the environmental social sciences, specifically the equitable governance of fisheries and aquatic resources in lower and middle income countries. Her PhD involved research with Solomon Islanders to understand the contribution of locally managed marine areas to small-scale fisheries and food security. Pip has fond memories of her time as a student at the Centre. "I have never experienced such fierce support for quality research, and for women in science. I continue to work with the professional networks I developed at the Centre. And I am so lucky to continue to work with and learn from the new cohorts of PhD scholars." Her collaborative and interdisciplinary PhD research was recognised with a Queensland Young Tall Poppy Science Award in 2014.

Learning from her experiences at the Centre, Pip exhibits a strong commitment to building the capacity and recognition of early career researchers, particularly women and those from lower and middle income countries. She believes, "it is the early career researchers at my organisation and around the world that keep my energy levels and optimism up". Pip is a co-advisor of five PhD students at JCU, and has been a key enabler in the development of collaborations between Centre students, WorldFish and local communities in the Asia-Pacific. Pip is also a mentor with the Women's Leadership Initiative run by Australian Awards.

Pip's career reflects a dedication to research for development, particularly in countries most vulnerable to the impacts of food insecurity and climate change. She says, "I want to build understanding of governance and resilience of coastal and inland communities and their fisheries". As a Partner Investigator with the Centre, Pip has published her research in a diverse range of journals, including *Nature*, *Nature Climate Change*, *Global Environmental Change*, *World Development*, *Food Security* and *Fish and Fisheries*. Her interdisciplinary and impact-driven research has been funded by the Oak and Minderoo Foundations, CGIAR, Australian Centre for International Agricultural Research and others. Pip is currently collaborating on a new data layer on FishBase to bring the world of human nutrition to what she describes as the "fishy folks". Pip engages closely with organisations like the United Nations Food and Agriculture Organisation, for example presenting a keynote at their 2019 event focussed on the science policy nexus. "I am continually excited to work with the Centre as they share my strong focus on pathways to impact, which relies on engagement and communication with a range of actors and research needs."



'We didn't have money or enough food': how COVID-19 affected Papua New Guinean fishing families

By Jacqueline Lau and Sarah Ruth Sutcliffe

In March 2020, Papua New Guinea went into a state of emergency to contain the spread of COVID-19. For Ahus Island — a small atoll community of around 600 people off the north coast of Manus Island — the state of emergency had far-reaching consequences.

In July and August, we interviewed Ahus islanders about their experience of COVID-19, and what they did to cope.

Their stories from the first six months of COVID-19 offer insight into the impacts of the pandemic on small-scale fishing communities and isolated islands.

As the new normal unfolds, the COVID-19 pandemic will continue to reverberate across fishing communities. The stories from Ahus Island reflect the experiences of other fishing communities across the Pacific. Other Papua New Guinean coastal communities struggled with food shortages, and needed external support for basic foods and services. Getting cut-off from markets and food can affect people's livelihoods and well being in unforeseen ways.

Globally, there is a need to coordinate short and long-term responses to support small-scale fisheries, especially across the Indo-Pacific, where food insecurity is already a concern.

Fishing pressure on island's reefs decreased, but at the cost of people's livelihoods

In Ahus, most people earn a livelihood selling fish — almost no food is grown on the island itself, and there are almost no other jobs.

During the state of emergency, fishers and fish sellers struggled to get to markets and to sell fish, which put stress on fishing families.

Normally, fishers sell fish at the town market, a 40-minute boat ride from the island. During the state of emergency, the market was deserted and there was almost no demand for fish. With no customers, people stopped earning income and were unable to buy food:

We found it hard because you go to the market and there's not one person who'll buy fish from you.

If you have money, you get food, if you don't have money you can't get food. And the way we get money is from the sea alone.

Passenger restrictions meant fewer passengers could get to town. And trips took three times as long because boat owners switched to smaller motors to save petrol.

One man explained:

For us on this island, it is hard ... We travel by sea. We go by boat. Now, if only limited people can get on a boat, then that affects us.

The island's market also closed briefly at the beginning of the pandemic, and travel to the mainland was restricted, leaving some people with no way to access food. Some people secretly bartered fish with relatives on the mainland, but others had to wait for markets to reopen.

When they did reopen, there was limited cash in the community, and many returned to a traditional system of bartering fish for vegetables.

The combination of disruptions of markets and transport restrictions impacted fishing. People explained that it was hard to get fuel from town to troll for ocean fish. Others fished less because they were afraid to leave the house for too long.

The town hospital was only accepting emergency patients. One woman said:

So I told our family, you can't go to the sea, because if you get sick then how can we go to the hospital? So during that time no one went fishing, and we didn't have money or enough food.

Fishing pressure on island's reefs decreased, but at the cost of people's livelihoods.

'Little, little for each child and each adult'

To cope with lack of income and difficulty getting food, most households started reducing what they ate. One woman said:

Before, we'd all eat rice often. Not now. I've cooked sago over and over, and everyone complains ... but there's nothing else.

Many families rationed food. As one person said:

There was limited food ... we'd serve just a little, little for each child and each adult. It doesn't matter if you're full up or only just full, that was your share.

Restricting food comes with risk. Diets of fish, sago and rice alone don't contain enough essential nutrients to maintain health. Children's physical and mental development can be permanently impaired if they are undernourished.

As families struggled to support themselves, some stopped sharing and helping others in the community. Several people mentioned that

they'd received government support during past emergencies in the form of food and basic services. Others had heard other provinces were receiving support and were frustrated that their community had been left out.

The road ahead

Since these interviews, we have spoken again with people in the community. Their situation has improved since the state of emergency lifted.

The sea cucumber season opened in September, bringing a quick cash injection to the community. Markets have returned to business as usual, food is accessible and people have started sharing again.

But the last year has shown many communities are ill-prepared for the economic disruption that comes with a pandemic. Pandemic responses that do not account for impacts on food and nutrition security may lead to non-compliance and foster distrust in the legitimacy of future directives.

Decision-makers, locally and globally, must balance management of pandemics with a recognition that fish and fishing communities are essential to local well being.

Our research report can be found [here](#).

Wilda Hungito, a PNG-based private research consultant and co-author on the report, contributed to this article.

PHOTO DEAN MILLER

THE CONVERSATION

Original article: 'We didn't have money or enough food': how COVID-19 affected Papua New Guinean fishing families 16 December 2020

RESEARCH PROGRAM 2

Ecosystem Dynamics: Past, Present and Future



Professor Graeme Cumming

Professor Graeme Cumming, from James Cook University, is the Director of the Centre and a co-leader of Research Program 2. Graeme has diverse interests in ecology, biodiversity conservation and social-ecological systems, with a particular focus on the relevance of spatial heterogeneity for sustainability and resilience in natural resource management. Graeme has published more than 200 peer-reviewed journal articles and book chapters, including many in leading journals, and is currently an Associate Editor for *Biological Conservation*, *Landscape Ecology* and *Ecology & Society*. He has supervised 40 postgraduate students to completion, including 14 PhD students. His contributions to science have been recognised by a range of awards, such as the *Meiring Naude Medal* of the Royal Society of South Africa; the *British Association Medal* of the Southern African Association for the Advancement of Science; and a T.W. Kambule National Research Foundation-National Science and Technology Forum Award from the South African National Research Foundation. He is currently a James S. McDonnell Foundation complexity scholar. Graeme is happiest outdoors and likes to spend his free time hiking, swimming or snorkelling in wild places with his wife and three children.



Associate Professor Alana Grech

Associate Professor Alana Grech, from James Cook University, is the Assistant Director of the Centre and co-leader of Research Program 2. She is an expert in conservation biogeography of coastal ecosystems, cumulative impact assessment (CIA) and environmental decision-making. Alana was previously employed as a Senior Lecturer in Spatial Information Science at Macquarie University and as a Postdoctoral Research Fellow at the Centre. She has authored more than 80 publications and reports, including publications in leading international journals including *Science*, *Global Change Biology*, *Conservation Letters* and *Frontiers in Ecology and the Environment*, and is Associate Editor of the journal *Diversity and Distributions*. Her research on coastal ecosystems and species of the Great Barrier Reef and Torres Strait has been instrumental to a range of Australian government policy and reports, with Alana regularly invited to provide technical and policy advice. In 2018, Alana received the *Queensland Young Tall Poppy Scientist of the Year Award* for her leadership in science and communication. Her contributions to research education at James Cook University were recognised in 2019 with an *Award for Excellence in Graduate Research Leadership*.



Professor John Pandolfi

Professor John Pandolfi, from the School of Biological Sciences and Centre for Marine Science, at The University of Queensland, is co-leader of Research Program 2. John is the world's leading expert on coral reef palaeoecology. He has broad research interests in marine palaeoecology, with emphasis on the effects of anthropogenic impacts and climate change on the recent past history of modern coral reefs. His research on coral reef ecosystems asks fundamental ecological questions that are best answered by acquiring and using long-term data. John has published more than 200 papers, including 25 contributions to *Science* and *Nature*. He has served as President of the Australian Coral Reef Society, Co-Chief Editor of *Paleobiology*, and Associate Editor for *Proceedings of the Royal Society B* and *Global Ecology and Biogeography*. John has provided frequent briefings on coral reef management and policy (e.g. to the US Congress and Australian Senate) and has been invited to serve on numerous international working groups. In 2001, John received the Discovery Magazine *Science Story of the Year* award. In 2013, he was awarded a prestigious *Discovery Outstanding Researcher Award* from the ARC. He is an elected Fellow of both the International Coral Reef Society and The Paleontological Society and is a 2020 *Highly Cited Researcher*.

Researchers: Kristen Anderson, Andrew Baird, David Bellwood, Yves-Marie Bozec, Tom Bridge, Jon Brodie, Jamie Caldwell, Carolina Castro-Sanguino, Severine Choukroun, Peter Cowman, April Hall, Vanessa Haller-Bull, Hugo Harrison, Karlo Hock, Andrew Hoey, Terry Hughes, Geoff Jones, Sun Kim, Michael Kingsford, Ryan Lowe, Robert Mason, Laurence McCook, Vanessa Messmer, Renato Morais, Peter Mumby, Philip Munday, Stephen Palumbi, Serge Planes, Morgan Pratchett, George Roff, Garry Russ, Eugenia Sampayo, Jodie Schlaefer, Patrick Smallhorn-West, Tim Staples, Greg Torda, Sue-Ann Watson, Sharon Wismer and Kennedy Wolfe.

PROGRAM 2

Report

Research in Program 2 focuses on the multi-scale past, present and future dynamics of reefs, ranging from population dynamics to macroevolution. Program 2 researchers focus particularly on four key research areas. First, they examine the historical transition from pristine ecosystems to the linked social-ecological systems of today, improving knowledge of how the resilience of coral reefs evolves and responds to human impacts. Second, they aim to increase understanding of the dynamics and resilience of ecosystems over multiple spatial and temporal scales and in response to environmental change, and to use those findings to inform and improve the management of coral reefs. Third, Program 2 examines how populations of organisms living on different reefs are connected to each other through the dispersal of their offspring, which promotes understanding of how reefs can recover from disturbances such as bleaching events. Finally, they study the roles of functional diversity and redundancy in coral reef assemblages, modelling and assessing the effects of changes in biodiversity on ecosystem function at regional to global scales, as well as investigating the effects of management on the dynamics of reef ecosystems.

Program 2 researchers made important contributions to global understanding of novel communities and species biodiversity in 2020. In *Science*, John Pandolfi and Tim Staples examined communities of plankton species over the past 66 million years and found that when novel communities formed, subsequent communities were more likely to develop into yet other novel states (p28). Our understanding of evolutionary units was also turned on its head by the *Molecular Phylogenetics and Evolution* publication led by Peter Cowman, Thomas Bridge, Andrew Baird, David Miller and PhD student Mila Grinblat. Their phylogenomic analysis found up to 3-times more *Acropora* species than currently accepted. This research has significant implications for all fields of coral reef science, from understanding the evolutionary history and biogeography of corals through to assessing extinction risk and informing conservation interventions.

In April, Terry Hughes co-authored a major paper in *Nature* that documented recovery rates of marine ecosystems following conservation actions. The study suggests that substantial re-building of the abundance, structure and function of marine life could be achieved by 2050, if major pressures, including climate change, are mitigated. As part of an international team, Terry Hughes and Graeme Cumming contributed to a paper in *Philosophical Transactions of the Royal Society B* on abrupt changes and regime shifts in ecological systems. The synthesis paper summarises a wide range of examples of ecosystems that have experienced or are currently experiencing rapid transitions and discusses priority research areas for improved approaches to both science and management. In November, PhD student Andreas Dietzel, Terry Hughes and Sean Connolly published a paper in *Proceedings of the Royal Society B* on shifts in the colony size structure of coral populations along the 2300 km length of the Great Barrier Reef, relative to historical baselines in the 1990s. The research, which received national and international media exposure, showed that coral abundances on reef crests and slopes have declined sharply across all colony size classes, and in all coral species, compared to historical baselines.

In another exciting new research initiative, David Bellwood is leading a new team of researchers that is exploring the resilience of coral reef functions to species change. With breakthrough papers in *Nature Communications* and *Ecology and Evolution*, they presented an alternative view of coral reef systems based on an evaluation of reef processes and productivity, rather than traditional metrics such as abundance or biodiversity. In *Bioscience*, David Bellwood also identified our tendency, as scientists, to select study species that are attractive and colourful rather than important for the future of reefs. Many members of Program 2 were also involved in a comprehensive review of coral reef ecosystem functioning in *Oceanography and Marine Biology: An Annual Review*. Kennedy Wolfe, Peter Mumby, David Wachenfeld, Sue-Ann Watson, Mia Hoogenboom, Andrew Hoey and others identified taxa of greatest conservation priority on the grounds of being highly important, threatened and manageable.



PHOTO TOM BRIDGE

Research in Program 2 informed the science underpinning the management of coral reefs in several breakthrough studies. Hugo Harrison and Geoff Jones revealed large fluctuations in the contribution of no-take marine reserves to the replenishment of local fish populations in the Great Barrier Reef Marine Park in *Proceedings of the National Academy of Science (PNAS)* (p29). They found connected networks of no-take marine reserves can yield important larval subsidies and minimise uncertainty in the replenishment of exploited fish stocks. Also in *PNAS*, Peter Mumby and colleagues found the greatest benefits to marine ecosystem productivity in Indonesia occurred when policies subsidised harvest and increased enforcement.

The connections between different marine habitats are increasingly being recognised as critical for coral reef resilience. In *PLoS Biology*, Alice Rogers and Peter Mumby used novel size-based food web models to reveal that mangrove nursery habitats can help offset some of the impacts of declining reef health on fisheries productivity. Andrew Hoey, Garry Russ and PhD students Eva McClure, Laura Richardson, Katie Sievers and Alexia Graba-Landry, published a series of papers in *Proceedings of the Royal Society B*, *Conservation Biology* and *Functional Ecology* that showed habitat has a greater effect on coral reef

fish assemblages than fishing, and that habitat condition and coral composition were important drivers of key processes on coral reefs.

Program 2 researchers continued to make important contributions to policy and management. Andrew Hoey was appointed to the Coral Sea Marine Park Advisory Committee and, with Morgan Pratchett, participated in multiple briefings to Parks Australia on Coral Sea reef health (p44). Alana Grech provided an expert review of the *East Coast Inshore Fin Fish Fishery - Level 2 Ecological Risk Assessment* for the Queensland Department of Agriculture and Fisheries. Peter Mumby was invited to lead a Global Environmental Facility proposal to assist in the Malaysian Government's expansion of coastal protection. Peter is also leading a Global Environmental Facility project for the Coral Triangle Initiative to accelerate their transboundary research and conservation alliance across Indonesia, Malaysia and the Philippines. In March, Terry Hughes led aerial surveys of mass bleaching throughout the Great Barrier Reef, for the third time in the past five years, which received global media attention (p32). He provided many briefings during and after the surveys, to the Great Barrier Reef Marine Park Authority, the Commonwealth government and UNESCO.

A huge pile of dead branching *Acropora* corals dominates the foreground of this seascape, where a few remaining massive Porites are the only live corals (centre and far right in photo). This reef in the Pacific has transformed from a branching coral-dominated to a massive coral-dominated 'novel community'.

Extinctions linked to new assemblages of species

PHOTO GEORGE ROFF

Scientists have found that as the world undergoes profound environmental change, identifying and protecting 'novel' communities of species can help prevent extinctions within vulnerable ecosystems.

Professor John Pandolfi and Dr Timothy Staples from the ARC Centre of Excellence for Coral Reef Studies at The University of Queensland are the lead authors of a **new study** in *Science* that looked at how combinations of plankton species changed across the world's marine ecosystems in the past 66 million years. From this, their team developed a world first method to detect 'novel' communities of species across all ecosystems.

"A novel ecological community is one with combinations of species that are different to any past observations from that site," Professor Pandolfi said. "These different species combinations can be due to new species arriving in the community, existing species leaving, or species becoming rarer or more common."

"We found that when novel communities formed, existing species were twice as likely to disappear from the community permanently, representing a 'local' extinction."

"Species in the novel community were also more likely to be new arrivals that had never been observed in the community before."

An example of a modern novel community comes from the coral reefs of the Caribbean, where the two once dominant species of branching coral are now rare. Those reefs are now home to novel communities of corals. The loss of the branching corals is due to the impacts of overfishing, changes in water quality, and climate change—resulting in new configurations of coral species within the Caribbean reef communities. And the shift means the benefits of the reef are now different: different species mean different inhabitants and functions.

"The challenge is to manage at risk or vulnerable areas like this where novel communities exist, or where they're in the process of forming," Professor Pandolfi said.

"To do this we need to understand the changes in species composition we see in novel communities, as well as what is driving these changes. To achieve these goals, we need to be able to reliably identify when a novel community has emerged."

The study outlines the first standardised, quantitative methodology for determining the existence of novel ecological communities. The researchers used a database of marine plankton over millions of years, but the methodology was designed to be applied more generally.

The researchers examined the marine plankton record using a global set of microfossil data from deep sea drilling cores - the NSB marine microfossil database, created and run by the Museum für Naturkunde in Berlin. By incorporating updated taxonomy and age models they built community data for species across geological time.

Professor Pandolfi said while novelty was rare, extinction was an important component. And after novel communities emerged, subsequent communities were more likely to develop into yet other novel states.

"Novelty begets novelty," Professor Pandolfi said. "And the likelihood of extinction was higher when novel communities emerged."

He said the pressures that cause communities to become novel in the first place need to be relieved. "Otherwise we may end up with cascading novelty, where the emergence of novel communities drives further novelty, including the loss of existing, native, species."

Prof Pandolfi says this means when a novel community is identified it needs attention and effective preventive management.

Pandolfi, JM, Staples, TL and Kiessling, W (2020). **Increased extinction in the emergence of novel ecological communities.** *Science* 370(6513): 220-222.

The study focused on coral groupers (*Plectropomus* spp.), which are a valuable fisheries species throughout the Indo-Pacific region. The total annual harvest on the Great Barrier Reef.

'Portfolio' of marine reserves enhances fish populations

PHOTO TANE SINCLAIR TAYLOR

Scientists say a 'portfolio' of protected areas within marine parks such as the Great Barrier Reef can help secure sustainable fish populations.

Dr Hugo Harrison from the ARC Centre of Excellence for Coral Reef Studies at James Cook University led a **study** on the effects of marine reserves, or no-take zones, on fish populations.

"The Great Barrier Reef Marine Park has established networks of no-take zones," Dr Harrison said. "A 'portfolio' of these protected areas can help connect reefs and ultimately provide more reliable quantities of fish across an ecosystem."

Dr Harrison says no-take zones—areas closed to fishing—on their own act as valuable sources of fish for neighbouring reefs. These areas support more fish, which then produce even greater numbers of baby fish. But, just how many babies survive and where they end up varies greatly from year to year. These fluctuations can be volatile and uncertain.

"Our findings are comparable to investing your resources wisely," said Professor Michael Bode, a co-author on the study from the Queensland University of Technology. "If you put all your money into one type of stock and then the value of that entire industry crashes, then all of your investment will crash too."

"By investing in a variety of stocks you can buffer or dampen market volatility and still maintain a valuable portfolio. Our study proves that marine protected areas are like financial stocks: if you invest in multiple smaller reserves instead of putting all your effort into one large reserve, you ensure a stable supply of fish to both recreational and commercial fishers."

The authors tracked more than 1,500 baby fish using DNA 'fingerprinting' techniques. The baby fish were traced back to their parents inside a network of four reserves.

The researchers found that each reserve was an important but variable source of baby fish.

However, together, the network of reserves generated a reliable source of offspring to replenish exploited fish stocks in surrounding reefs.

The study coincides with two significant international reports illustrating the stark decline of the natural world: the **Living Planet Report 2020** and the **Global Biodiversity Outlook 5**.

"Governments all around the world failed to meet any of the UN Sustainable Development Goals on Biodiversity Conservation," Dr Harrison said. "To stem the loss of natural habitats, they had committed in 2010 to expand the world's nature reserves across ten percent of coastal and marine areas by 2020."

The IUCN also recently released **guidelines** on protecting connectivity and 'corridors' within ecosystems, which are essential for healthy natural habitats—for conservation and for climate change adaptation.

Professor Bode says maintaining corridors between protected areas is easy to picture in a terrestrial realm—for example, in a forest setting where animals can move freely between areas.

"But it's a lot harder in the marine realm, where connectivity pathways between habitats are difficult to predict," Prof Bode said.

Dr Harrison said there is an urgent need for further discussions on the value of marine reserve networks—both locally and internationally.

"Our research is a timely reminder of the value of marine networks in protecting not only biodiversity but also, industries including tourism and the millions of people globally whose livelihoods depend on healthy ecosystems."

Harrison, HB, Bode, M, Williamson, DH, Berumen, ML and Jones, GP (2020). **A connectivity portfolio effect stabilizes marine reserve performance.** *Proceedings of the National Academy of Sciences* 117(41): 25595-25600.

RESEARCHER PROFILE

Sun Kim

"... amazed by the tropical biodiversity and seascape ... [it] primed me for my long-term interest in biogeography."



Sun Kim spent his childhood in Jeju Island, South Korea. It was here in the rock pools and kelp forests that Sun developed a fondness for marine ecosystems. He moved to the USA in 2002 to study a Bachelor of Science at Seattle University, and then to the University of Guam in 2007 to study a Master of Science under the supervision of Professor Alexander Kerr. Sun travelled throughout Micronesia to collect marine invertebrates during his Masters. Sun recalls that he was "amazed by the tropical biodiversity and seascape. But what excited me more than species rich coral reefs were the differences in the species composition among islands. This experience primed me for my long-term interest in biogeography."

After completing his Master's degree in 2010, Sun returned to South Korea to work at the Korea Institute of Ocean Science and Technology (KIOST). His position involved maintaining voucher specimen collections and conducting fieldwork across the western and central Pacific to document marine biodiversity. Sun had several opportunities to visit Jeju Island during his time at KIOST. He was shocked by the dramatic difference in seascape caused by climate change. "Tropicalisation had become obvious in the decade since I had left Jeju Island. Subtropical and tropical organisms were far more common than before and were invading the northern part of the island where kelp forests previously dominated."

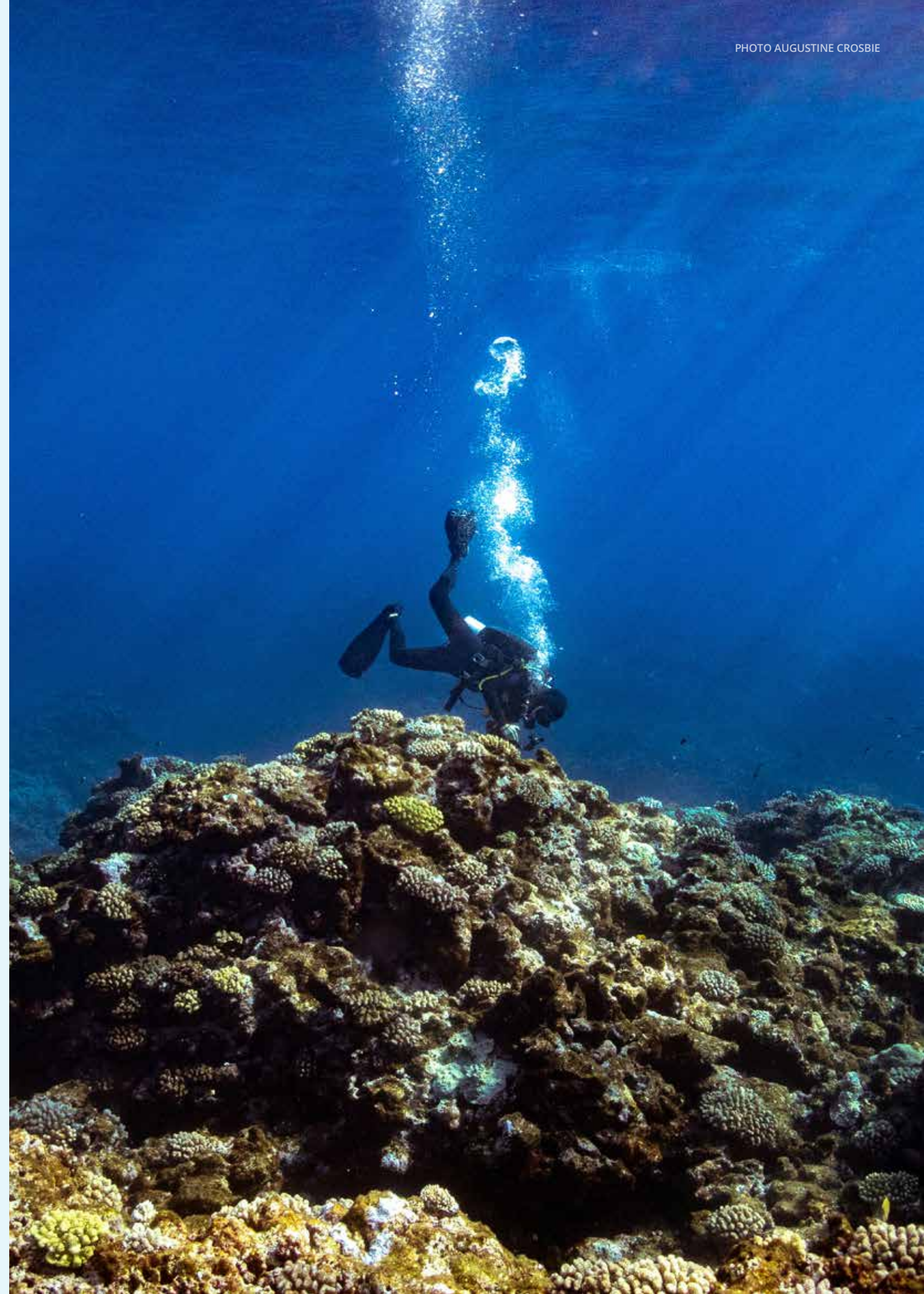
Sun's role at KIOST allowed him access to leaders and community members across the Pacific. He vividly remembers an exchange with the former President of Kiribati, Anote Tong. "The President told me that his long fight against climate change wasn't for the sake of politics, but was because it is an issue that impacts the daily lives of his people and others. I couldn't help but echo his frustration as I had also witnessed the dramatic change in Jeju Island's marine ecosystems. These experiences fostered my passion for studying impacts of climate change on marine ecosystems."

Sun moved to The University of Queensland in 2015 to work with Professor John Pandolfi on the effects

of long-term warming and short-term stress events on marine ecosystems. A large component of Sun's PhD was also focused on the functional diversity of scleractinian (stony or hard) corals. He compiled a large trait dataset for scleractinian corals using the literature and public databases. During this process, Sun found numerous data gaps which are also prevalent in trait databases of other taxonomic groups. Sun assessed the effect of data gaps in trait databases on downstream analyses and found that using incomplete trait datasets produces erroneous outcomes in ecological analyses. This work was published in 2018 in *Ecology Letters*.

The 2016 global bleaching event provided Sun with an opportunity to examine the bleaching response and mortality of corals in high-latitude eastern Australia. In his 2019 publication in *Global Change Biology*, Sun reported that local differences in species abundance and taxon-specific bleaching responses affected the severity of assemblage-scale bleaching. His work indicated that climate change could result in simplification of coral assemblage structures and homogenisation of reef functions at high-latitude locations. Sun also used global species occurrence data and climate model ensembles to quantify the change in environmental suitability of shallow-water reefs for all zooxanthellate scleractinian corals. He found a large taxonomic disparity in the magnitude of changes in habitat suitability. "My research predicts that ocean warming will impair the environmental suitability of most corals that live in eastern Australia."

Sun continues his research as a Postdoctoral Research Fellow in Program 2. His current project informs conservation by predicting the species-specific adaptive responses required for persistence under climate change. Sun is also examining how progressive warming could change current global patterns of biodiversity by comparing spatial patterns of evolutionary rates using phylogenetic and molecular tools.



We just spent two weeks surveying the Great Barrier Reef. What we saw was an utter tragedy.

Terry Hughes and Morgan Pratchett

PHOTO TERRY HUGHES

The Australian summer just gone will be remembered as the moment when human-caused climate change struck hard. First came drought, then deadly bushfires, and now a bout of coral bleaching on the Great Barrier Reef – the third in just five years. Tragically, the 2020 bleaching is severe and the most widespread we have ever recorded.

Coral bleaching at regional scales is caused by spikes in sea temperatures during unusually hot summers. The first recorded mass bleaching event along Great Barrier Reef occurred in 1998, then the hottest year on record.

Since then we've seen four more mass bleaching events – and more temperature records broken – in 2002, 2016, 2017, and again in 2020.

This year, February had the highest monthly sea surface temperatures ever recorded on the Great Barrier Reef since the Bureau of Meteorology's records began in 1900.

Not a pretty picture

We surveyed 1,036 reefs from the air during the last two weeks in March, to measure the extent and severity of coral bleaching throughout the Great Barrier Reef region. Two observers, from the ARC Centre of Excellence for Coral Reef Studies and the Great Barrier

Reef Marine Park Authority, scored each reef visually, repeating the same procedures developed during early bleaching events.

The accuracy of the aerial scores is verified by underwater surveys on reefs that are lightly and heavily bleached. While underwater, we also measure how bleaching changes between shallow and deeper reefs.

Of the reefs we surveyed from the air, 39.8% had little or no bleaching (the green reefs in the map). However, 25.1% of reefs were severely affected (red reefs) – that is, on each reef more than 60% of corals were bleached. A further 35% had more modest levels of bleaching.

Bleaching isn't necessarily fatal for coral, and it affects some species more than others. A pale or lightly bleached coral typically regains its colour within a few weeks or months and survives.

But when bleaching is severe, many corals die. In 2016, half of the shallow water corals died on the northern region of the Great Barrier Reef between March and November. Later this year, we'll go underwater to assess the losses of corals during this most recent event.

Compared to the four previous bleaching events, there are fewer unbleached or lightly bleached reefs in 2020 than in 1998, 2002 and 2017, but

more than in 2016. Similarly, the proportion of severely bleached reefs in 2020 is exceeded only by 2016. By both of these metrics, 2020 is the second-worst mass bleaching event of the five experienced by the Great Barrier Reef since 1998.

The unbleached and lightly bleached (green) reefs in 2020 are predominantly offshore, mostly close to the edge of the continental shelf in the northern and southern Great Barrier Reef. However, offshore reefs in the central region were severely bleached again. Coastal reefs are also badly bleached at almost all locations, stretching from the Torres Strait in the north to the southern boundary of the Great Barrier Reef Marine Park.

For the first time, severe bleaching has struck all three regions of the Great Barrier Reef – the northern, central and now large parts of the southern sectors. The north was the worst affected region in 2016, followed by the centre in 2017.

In 2020, the cumulative footprint of bleaching has expanded further, to include the south. The distinctive footprint of each bleaching event closely matches the location of hotter and cooler conditions in different years.

Poor prognosis

Of the five mass bleaching events we've seen so far, only 1998 and 2016 occurred during an El Niño – a weather pattern that spurs warmer air temperatures in Australia.

But as summers grow hotter under climate change, we no longer need an El Niño to trigger mass bleaching at the scale of the Great Barrier Reef. We've already seen the first example of back-to-back bleaching, in the consecutive summers of 2016 and 2017. The gap between recurrent bleaching events is shrinking, hindering a full recovery.

After five bleaching events, the number of reefs that have escaped severe bleaching continues to dwindle. Those reefs are located offshore, in the far north and in remote parts of the south.

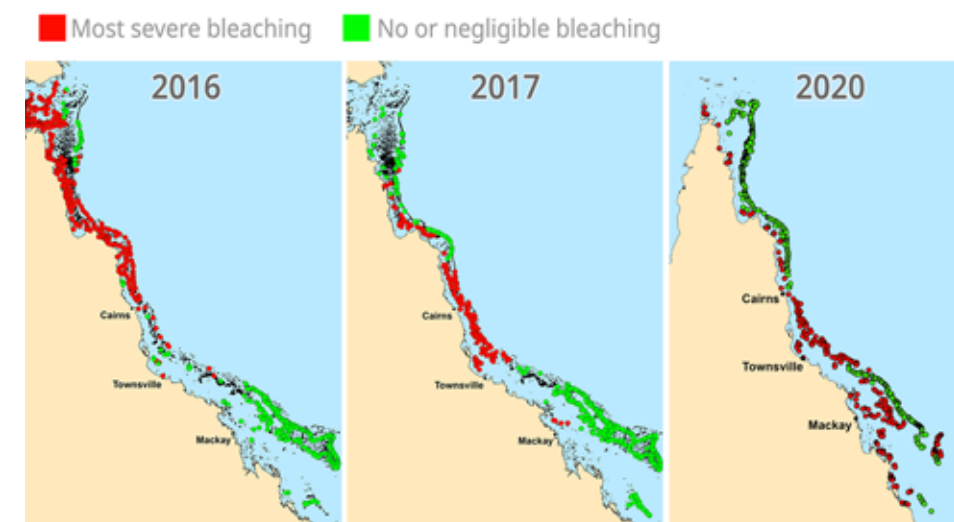
The Great Barrier Reef will continue to lose corals from heat stress, until global emissions of greenhouse gases are reduced to net zero, and sea temperatures stabilise. Without urgent action to achieve this outcome, it's clear our coral reefs will not survive business-as-usual emissions.

THE CONVERSATION

<https://theconversation.com/we-just-spent-two-weeks-surveying-the-great-barrier-reef-what-we-saw-was-an-utter-tragedy-135197>

The last three mass bleaching events

The severity of the last three mass bleaching events on the Great Barrier Reef



Source: ARC Centre of Excellence for Coral Reef Studies

PHOTO KRISTEN BROWN

RESEARCH PROGRAM 3

Responding to a Changing World



Associate Professor Maja Adamska

Associate Professor Maja Adamska, from The Australian National University, is co-leader of Research Program 3. Her graduate and first postdoctoral projects addressed interactions between signalling pathways and transcription factors during vertebrate development. To pursue her interests in the evolutionary origin of animal developmental regulatory genes, Maja moved to The University of Queensland to study them in the first sponge to have its genome sequenced, *Amphimedon queenslandica*. From 2007 to 2015, Maja was a group leader at the Sars International Centre for Marine Molecular Biology, in Bergen, Norway and in 2015 she established a laboratory at the Research School of Biology at The Australian National University. Maja was awarded an ARC Future Fellowship in 2017, and she continues to investigate evolutionary origin of key developmental processes, such as cell type specification, segregation of germ layers and axial patterning of embryos and adults. Recent major research themes in her laboratory include regeneration of sponges and corals, in particular mechanisms regulating gene expression during this process, as well as sponge-bacterial symbiosis. Maja is also deeply interested in the emergence of complex multicellularity and its genomic background.



Associate Professor Mia Hoogenboom

Associate Professor Mia Hoogenboom, from James Cook University, is co-leader of Research Program 3. Mia is an expert on coral reef ecophysiology. She received her PhD in 2008 from JCU. From 2008 to 2011, Mia was a Research Fellow at the Centre Scientifique de Monaco and later at the University of Glasgow. Mia has broad research interests in physiology and ecology, and her research establishes mechanistic links between environmental change, physiology, and population and community dynamics. Her ecotoxicology research informs strategies for managing the impacts of environmental contaminants on coastal marine ecosystems. Mia's research is multi-disciplinary and collaborative, bridging the fields of molecular biology, physiology, ecology and global change biology. Mia has published more than 80 papers in leading international journals, including *Trends in Ecology and Evolution*, *Nature*, *Science*, *PNAS* and *Current Biology*. She also actively participates in educational outreach programs that provide exciting marine biology field and laboratory experiences for secondary school students.



Professor Ryan Lowe

Professor Ryan Lowe, from the UWA Oceans Institute at The University of Western Australia (UWA), is co-leader of Research Program 3. Ryan's research examines how oceanic and atmospheric forcing drives the circulation, distribution of wave energy, and water level variability within the coastal zone, with a particular focus on processes that occur along coral reef coastlines. Major areas of his multidisciplinary research focus on improving predictions of coastal flooding and erosion risk along reef coastlines, identifying how ocean dynamics drive environmental variability within coral reefs, and how oceanographic processes shape reef ecosystems. Ryan received his PhD in Civil and Environmental Engineering in 2005 from Stanford University, USA and has been based at UWA since 2007. He has authored more than 130 papers in leading international journals, as well as numerous technical reports for government and industry. Ryan serves on the Expert Group in Physical Oceanography for the Australian Meteorological and Oceanography Society and on Australia's Surface Waves Working Group. Ryan received an ARC Future Fellowship in 2012, and in 2014 he was the recipient of the UWA Vice Chancellor's Mid-Career Researcher Award.

Researchers

Kristen Anderson, Natalia Andrade Rodriguez, Andrew Baird, Tom Bridge, Sean Connolly, Peter Cowman, Jennifer Donelson, Sophie Dove, Gal Eyal, Rebecca Green, Hugo Harrison, Ove Hoegh-Guldberg, Björn Illing, Michael Kingsford, Caitie Kuempel, Janice Lough, Ryan Lowe, David Miller, Philip Munday, Stephen Palumbi, John Pandolfi, Serge Planes, Morgan Pratchett, Veronica Radice, Jodie Rummer, Aleksey Sadekov, Eugenia Sampayo, Greg Torda, Arnold van Rooijen, and Sue-Ann Watson.

PROGRAM 3 Report

Program 3 aims to understand and predict the responses of coral reef organisms and ecosystems to environmental change, particularly climate change and declining water quality. Biological responses of reefs to changing conditions are investigated from three interlinked perspectives: the dynamics of the complex associations between corals and their symbiotic dinoflagellates and microbes; the physiological plasticity and capacity for adaptation of organisms, populations and species; and the stability of reef carbonate frameworks that are synthesised and maintained by corals and other organisms.

Program 3 researchers in 2020 made major advances in our understanding of how coral reef organisms acclimatise or adapt to stressors, and how management can incorporate this information into decision-making. In *Nature Climate Change*, Christopher Cornwall and Malcom McCulloch showed that a species of coralline algae develops tolerance to ocean acidification over multiple generations of exposure. Their results indicate that it is likely that some species could still maintain their critical ecological role in reef formation under climate change (p39). David Miller and colleagues in *Science Advances* found differences in the timing of coral and symbiont genome adaptation across multiple locations on the central Great Barrier Reef, suggesting adaptation to post-glacial climate change in *Acropora tenuis* has involved selection on many genes. Jenni Donelson co-organised a virtual workshop on 'Ecological Adaptation and Plasticity into Practice' to design a framework for how biological plasticity can be better incorporated in adaptive management and conservation practice.

A central theme of Program 3 research this year was understanding the responses of organisms to increasing ocean temperature. In *Science Advances*, Jodie Rummer and Philip Munday showed that changes in the way genes were expressed differed among species of reef fishes during the 2016 marine heatwave. In *Global Change Biology*, Sophie Dove and Ove Hoegh-Guldberg found negative effects of increased temperature and CO₂ concentration on coral growth and recovery from bleaching. Philip

Munday and Jenni Donelson revealed an epigenetic signature associated with changes in the phenotypes of a species of coral reef fish in response to ocean warming in *Frontiers in Marine Science*. Focusing on oceanic currents as contributors to between-ecosystem flows, Thomas DeCarlo and John Pandolfi showed in *Science Advances* that nutrients can aggravate the already negative effects of climate change on corals to trigger mass coral bleaching.

Program 3's postgraduate students made numerous contributions to coral reef research. Examples include a paper in *Marine Biology* led by PhD student Shannon McMahon, Jenni Donelson and Phillip Munday, which demonstrated that elevated seawater CO₂ and heatwave conditions affect swimming performance of baby snapper fish. In *Coral Reefs*, PhD student Ian Bouyoucos, Serge Planes and Jodie Rummer measured the home range of newborn blacktip reef sharks. PhD student Scott Morrissey, Jodie Schlaefer and Michael Kingsford linked the chemistry of jellyfish sensory tissues to seawater salinity and temperature in the *Journal of Experimental Marine Biology and Ecology*, to help identify movement patterns of jellyfish in the natural environment. In *Marine Ecology Progress Series*, PhD student Saskia Jurriaans and Mia Hoogenboom, showed how the responses of corals to temperature differs seasonally. In *Science of The Total Environment*, PhD student Christopher Brunner, Mia Hoogenboom and colleagues from the Australian Institute of Marine Science, quantified how the response of tiny coral recruits to sedimentation changes in seawater that has different CO₂ concentrations and water temperature.

Early in 2020, field-based studies conducted by Program 3 researchers provided new insight into environmental drivers of coral growth, abundance and diversity. Greg Torda participated in an international collaborative project on reefs in New Caledonia, led by colleagues at the Institut de Recherche pour le Développement. Malcolm McCulloch and collaborators conducted extensive deep-sea Remotely Operated Vehicle (ROV) surveys of unexplored coral habitats within submarine canyons off South Western Australia aboard the Schmidt



PHOTO AUGUSTINE CROSBIE

Oceans Institute R/V Falkor (p71). The surveys revealed spectacular coral gardens, extensive subfossil coral deposits and the occurrence of solitary scleractinian corals living considerably deeper than conditions considered suitable for coral calcification. Ongoing research by Malcolm McCulloch, funded by a new ARC Discovery Project, will assess climate change and nutrient dynamics in these canyons using deep sea coral samples as long-term environmental records.

In 2020, Program 3 researchers collaborated with multiple organisations around the world to translate research findings into policy outcomes and management actions. Ove Hoegh-Guldberg gave keynote presentations at the Ocean Digital Conference and the World Resources Institute about the key role of the ocean in climate change. Ove also participated in establishing the new Maldives Coral Institute, and Ryan Lowe contributed to designing new marine monitoring

activities in collaboration with the Munderoo Exmouth Research Laboratory. Researchers in Program 3 also synthesised new knowledge relevant to the management of reefs and coastlines. For example, in *Global Change Biology*, Ryan Lowe and collaborators at the Australian Institute of Marine Science conducted a global analysis of coral reef risk to tropical cyclone wave damage, and identified ecoregions that are most vulnerable to projected future changes in cyclone activity. Ryan Lowe's ongoing research on this topic is funded by a new ARC Discovery Project to develop improved models of how ecosystems such as coral reefs and mangroves reduce hazards to coastlines around the world. In 2020, Program 3 members also shared results of their research with audiences beyond the scientific community. For example, Maja Adamska provided insights into science careers within a STEM festival at Hedland Senior High School (Western Australia).

Impacts of the current trajectory of warming and ocean acidification by the end of the century include 'insidious and accelerated loss of coastal protection under unmitigated CO₂ emissions.

Coasts drown as coral reefs collapse under warming and acidification

PHOTO KRISTEN BROWN

A new study shows the coastal protection coral reefs currently provide will start eroding by the end of the century, as the world continues to warm and the oceans acidify.

A team of researchers led by Associate Professor Sophie Dove from the ARC Centre of Excellence for Coral Reef Studies at The University of Queensland investigated the ability of coral reef ecosystems to retain deposits of calcium carbonate under current projections of warming and ocean acidification.

Calcium carbonate is what skeletons are made of—and it dissolves under hot, acidic conditions. Marine animals that need calcium carbonate for their skeletons or shells are called 'calcifiers'. Hard corals have skeletons, which give reefs much of their three-dimensional (3D) structure. It's this structure that helps protect coasts—and those living on the coasts—from the brunt of waves, floods and storms. Without coral reefs the coasts 'drown'.

Associate Professor Dove says the amount of calcium carbonate within a coral reef ecosystem depends on the biomass of hard corals. But it also depends on the combined impact of warming and acidification on previously deposited calcium carbonate frameworks. She says the results of the study indicate the rate of erosion will overtake the rate of accretion on the majority of present-day reefs.

"Today's Great Barrier Reef has a 30% calcifier cover," Associate Professor Dove said.

"If CO₂ emissions aren't curbed, by the end-of-century a 50% calcifier cover is required to counter the physical erosion they face from storms and wave impacts," she said.

"In addition, more than 110% calcifier cover is needed to keep up with the minimal levels of sea-level rise."

However, Associate Professor Dove says both of

these scenarios are unlikely because high amounts of hard corals perish with intense underwater heatwaves. Previous studies show marine heatwaves will become chronic in the warmer months of an average year under unmitigated CO₂ emissions.

The study was published in today's *Communications Earth & Environment*, just after the IUCN World Heritage Outlook 3 rated the Great Barrier Reef as 'critical'.

A/Prof Dove and her team built experimental reefs closely resembling those of shallow reef slopes at Heron Island on the southern Great Barrier Reef. For 18 months, they studied the effects of future climate scenarios on the ecosystem.

"What we saw was the insidious and accelerated loss of coastal protection under unmitigated CO₂ emissions," said co-author Professor Ove Hoegh-Guldberg, also from the Centre.

"Under current projections, reefs will not simply adapt. Chronic exposure to the combined impacts of ocean warming and acidification will weaken reefs. They won't be able to re-build after disturbances such as cyclones, nor will they keep up with sea-level rise—possibly for thousands of years," said co-author Dr Kristen Brown, also from the Centre.

This means many coastal areas currently protected by calcareous coral reefs will no longer be so, impacting coastal infrastructure and communities.

"The combined impact of warming with the acidification of our oceans will see more than the collapse of ecosystems," Associate Professor Dove said.

Dove, SG, Brown, KT, Van Den Heuvel, A, Chai, A and Hoegh-Guldberg, O (2020). *Ocean warming and acidification uncouple calcification from calcifier biomass which accelerates coral reef decline. Communications Earth & Environment* 1(1): 55.

Coral 'helper' stays robust under ocean acidification

PHOTO CHRIS CORNWALL

Scientists say a type of algae crucial to the survival of coral reefs may be able to resist the impacts of ocean acidification caused by climate change.

In a world-first, the team—including researchers from the ARC Centre of Excellence for Coral Reef Studies at The University of Western Australia—found that coralline algae are able to build tolerance to ocean acidification over multiple generations.

"Coralline algae go through a natural process of calcification, where they build a crustose-like calcium carbonate skeleton," said lead author Dr Christopher Cornwall.

"Skeletons like this provide structure, allowing them to grow, as well as providing a substrate for other organisms such as corals to grow upon," he said.

"We show, for the first time, that while growth of these skeletons is initially susceptible to the effects of ocean acidification caused by increased CO₂, over multiple generations they develop resistance."

Coralline algae are vital not only to the survival of coral reefs but many ocean species.

"Crustose coralline algae bind coral reefs together," said Professor McCulloch, Centre Deputy Director, who led the research group. "Without them, coral reefs as we know them today wouldn't exist," he said.

"These species limit erosion in reefs that are often made up of mainly coral fragments, act as

a nursery for many marine species, and are the main player in temperate reef formation along the Australian and New Zealand coastlines."

The experiments took more than 18 months to complete. On average, the algae took six generations of about six to eight weeks each to develop resistance to ocean acidification.

The findings of the study are important in understanding how longer-lived species, such as tropical corals, could respond over multiple generations to ocean acidification.

"Coralline algae are a useful model species to test hypotheses about adaptation or acclimation over time as they grow to maturity in six weeks as opposed to several years for many coral species," Dr Cornwall said.

The next step is to test a wider range of coralline algae species.

"This research focused on tropical coralline algae species from northern Australia, so the next step is to study temperate species—like those in southern Australian and New Zealand waters—that grow a lot slower and may not acclimatise to climate change as quickly."

Cornwall, CE, Comeau, S, DeCarlo, TM, Lacombe, E, Moore, B, Giltrow, K, Puerzer, F, D'Alexis, Q and McCulloch, MT (2020). *A coralline alga gains tolerance to ocean acidification over multiple generations of exposure. Nature Climate Change* 10(2): 143-146.

RESEARCHER PROFILE

Jennifer Donelson



A career in marine ecology was always on the cards. Jenni recalls *“snorkelling and investigating rock pools whenever I had the chance”*.

Jennifer (Jenni) Donelson is an ARC Future Fellow in Program 3 at James Cook University. Growing up in Victoria, she spent her youth in the bush where she enjoyed swimming, fishing and spotting native animals. A career in marine ecology was always on the cards. Jenni recalls *“snorkelling and investigating rock pools whenever I had the chance”*.

Jenni moved from Melbourne to Townsville in 2002 to complete a Bachelor of Marine Biology at James Cook University (JCU). Her research career began with an Honours project on the parental effects of food consumption on the quality of offspring produced by fish. *“I found that it didn’t matter whether parents had access to ample food when their offspring ended up in good environmental conditions themselves. But if offspring developed in poor conditions those with well-fed parents survived and grew better.”* In 2008, Jenni enrolled in a PhD with the ARC Centre of Excellence for Coral Reef Studies and shifted her research focus to the effects of ocean warming on coral reef fish and the capacity for acclimation and adaptation.

During her PhD, Jenni reared 3 generations of a coral reef damselfish in complex aquarium systems that simulated different climate change scenarios. She discovered that while fish are sensitive to ocean warming, thermal performance is improved when fish are raised in warmer water. *“I also found that even greater improvement occurs as more generations experience warm conditions. However, the rate of warming experienced is critical in whether fish can cope: too rapid warming results in an inability to reproduce.”* Directly following her PhD, Jenni travelled to the United Arab Emirates on a Winston Churchill Fellowship to investigate how coral reef fish persist in the Arabian Gulf, the hottest ocean on the planet.

In 2013, Jenni moved to the University of Technology Sydney (UTS) where she was awarded a Chancellor’s Postdoctoral Fellow to expand her research into range-shifting tropical species in temperate Australia. Jenni reports that *“tropical marine larvae make their way down the east-coast of Australia every summer and settle on the rocky shores of New South Wales, but they currently don’t survive the cold winters”*. She found that winters only need to be a few degrees warmer for tropical fish juveniles to survive. Another interesting discovery was that tropical fish survive better when they join a school with local temperate species. *“It’s always best to hang out with the locals when traveling.”*

Jenni returned to the Centre at JCU in 2016 as a part of a collaborative project with the King Abdullah University of Science & Technology (KAUST), Saudi Arabia. The project was designed to utilise her multigenerational experiments to improve understanding of the genomic mechanisms that allow developmental and transgenerational acclimation to warming. This collaborative program with researchers from the Centre and KAUST revealed genes that play a key role in fish thermal acclimation. In 2019, Jenni was awarded an ARC Future Fellowship to continue her work on phenotypic and adaptive responses of coral reef fish to environmental change. Her fellowship will determine why acclimation to ocean warming differs in populations that have experienced diverse thermal history.



A difficult time to be a reef shark

By Natalie Parletta

PHOTO VICTOR HUERTAS

Reef sharks are having a challenging time as they confront threats from fishing, denser human populations and climate change.

An extensive survey has found that adults have effectively become extinct in nearly a fifth of the world's tropical oceans, while a separate study reveals that, even when protected, shallow shark nurseries are affected by warming water and diminishing oxygen levels.

Removing such predators from ecosystems can fundamentally change energy flows and nutrient recycling and allow growth of smaller predators with flow-on effects down the food chain, says co-author of the survey, Mark Meekan from the University of Western Australia.

The international study, [published by Global FinPrint](#) in the journal *Nature*, involved hundreds of scientists and conservationists.

It reveals a fall in reef shark numbers that, until now, has been undocumented – even though coastal sharks comprise two thirds of species traded globally, according to lead author Aaron MacNeil from Dalhousie University, Canada.

The survey included 371 reefs in 58 countries, using observations from more than 15,000 baited video stations (BRUVS) over four years. At each reef, they conducted 30 to 50 BRUVS and analysed the maximum number of sharks seen at

any one time on hour-long videos.

Using a statistical model, the researchers used these data to estimate the numbers of sharks expected to be seen on any given reef, along with factors that could explain why their numbers vary.

They found no sharks at 63% of the stations and 19% of reefs. More than half the nations had abundance scores 50% less than would be expected, which the authors say suggests “loss of reef sharks is pervasive among reefs globally”.

Nations with the lowest rank included Qatar, the Dominican Republic, Colombia, Sri Lanka, Jamaica, Kenya, Vietnam, India, French West Indies and Guam.

On the positive side, they found several countries where shark conservation is working. Those with robust populations compared to their region's average included Australia, the Bahamas, the Solomon Islands, New Zealand, French Polynesia, the Maldives, and the US.

Successful conservation strategies include strong shark fisheries management and low human pressure. Regions with depleted populations, on the other hand, had poor governance, are close to markets and use destructive gillnets and longlines.

While the results are sobering, MacNeil says they

also give hope that reef shark populations can be successfully conserved, even where people are present and fishing them.

Shark sanctuaries were associated with 50% higher abundance of sharks compared to nations without them, for instance, while introducing limits on catches could increase numbers by 15%, on average. Other successful strategies include catch limits and banning certain equipment.

Conservation measures would need to address local fishery operations, social norms and cultures. “By engaging with local communities,” says MacNeil, “we have a chance to make shark fishing sustainable across a wide range of contexts.”

The study also gives a baseline of shark numbers for future evaluation of conservation initiatives.

But we can't ignore the effects of climate change, says Jodie Rummer from [the ARC Centre of Excellence for Coral Reef Studies] James Cook University in Australia, lead author of the other study [published in the *Journal of Experimental Biology*](#).

Tackling overfishing and exploitation, their number one threats, is critical, she says. “But then, we need to address the fact that no matter what dotted lines we put around these countries to declare marine protected areas or shark sanctuaries, climate change crosses those lines.”

This is particularly important for baby sharks that rely on shallow coastal waters for protection and food while they grow, learn to hunt and stay clear of predators.

With lead author Ian Bouyoucos, her team investigated the impact of temperature and

oxygen levels on baby blacktip reef sharks (*Carcharhinus melanopterus*) in the world's largest shark sanctuary, spanning 4.8 million square kilometres in French Polynesia.

They found the pups are faring well, so far. “[W]e found the growth rate and metabolism of baby sharks is resilient to the temperature changes they currently face in these shallow habitat,” Bouyoucos says.

“We also found the sharks with a greater tolerance for higher temperatures had a greater tolerance for low oxygen levels, which is really promising.”

But the team is concerned the pups are reaching their biological limits, which would pose a dilemma.

“If they choose less harsh habitats, they lose their food and protection,” says Rummer. “If they remain within the safe, shallow nurseries, they suffer the effects of warming waters and decreasing oxygen levels.”

She says that despite token gestures to save reefs, such as [culling](#) crown-of-thorns starfishes or putting fans or shade cloth over them, they don't really get to the heart of the problem – human activities that are warming the planet.

MacNeil, MA, Chapman, DD, Heupel, M, Simpfendorfer, CA, [...] and Cinner, JE (2020). [Global status and conservation potential of reef sharks](#). *Nature* 583(7818): 801-806.

Bouyoucos, IA, Morrison, PR, Weideli, OC, Jacquesson, E, Planes, S, Simpfendorfer, CA, Brauner, CJ and Rummer, JL (2020). [Thermal tolerance and hypoxia tolerance are associated in blacktip reef shark \(*Carcharhinus melanopterus*\) neonates](#). *Journal of Experimental Biology* 223: jeb221937.

PHOTO TOM VIERUS



COSMOS (permission granted): <https://cosmosmagazine.com/nature/marine-life/a-difficult-time-to-be-a-reef-shark>

NATIONAL PRIORITY CASE STUDY

Partnerships to conserve the Coral Sea Marine Park

The ARC Centre is the principal knowledge provider to the Australian Government on the unique species and habitats of the Coral Sea Marine Park. Working in close partnership with the Director of National Parks and Parks Australia, our researchers deliver innovative science and rigorous monitoring of the health and resilience of coral reefs across the region.

The Coral Sea off the northeast coast of Australia is a unique biogeographic province that encompasses a diverse array of habitats, including coral reefs, sandy cays, deep sea plains and canyons. Its marine and terrestrial flora and fauna are distinctive, supporting some species that are unique, and others of international significance. The region supports six of the world's seven species of marine turtles, more than 28 species of whales and dolphins, as well as large predators such as marlin, swordfish, tuna and sharks.

A management plan for the Coral Sea Marine Park¹ (CSMP) was implemented by the Australian Government in mid-2018. The CSMP covers an area of about 990,000 km² making it Australia's largest single marine park and one of the world's largest marine protected areas. The Coral Sea has a long history of conservation management, with Lihou Reef benefiting from the strictest level of protection since 1982, making it one of the earliest no-take marine reserves in Australia. The isolation and protection of areas such as Lihou Reef has meant that many Coral Sea habitats have remained largely unaffected by direct anthropogenic pressures. However, recent destructive storms and marine heatwaves in 2016, 2017 and 2020 have left a visible footprint on the health of the Coral Sea.

The ARC Centre of Excellence for Coral Reef Studies works in close partnership with Parks Australia, the

Australian Government agency managing the CSMP, to deliver critical knowledge on the status and health of the coral reefs within the CSMP. The partnership has led to a seven year research programme encompassing multiple projects and collaborations with over 60 researchers and postgraduate students from ten partner organisations, including the Australian Institute of Marine Science and the Australian Museum. Director of National Parks, Dr James Findlay, said in a [joint press release with the ARC Centre](#) "it is very important that we monitor the health of these isolated coral reef ecosystems and increase our understanding of these amazing places".

Since 2016, the Centre has conducted 15 voyages to all 22 major reef complexes in the CSMP, resulting in the first comprehensive assessment of the regions biodiversity and reef health (Hoey *et al.* 2020). The Centre developed survey practices to facilitate comparisons across marine environments and monitor the status and trends of coral reef ecosystems through major disturbance events, such as cyclones and coral bleaching. After the 2016 and 2017 coral bleaching events that affected reefs in both the Great Barrier Reef Marine Park and CSMP, Parks Australia awarded Centre researchers a 3-year research contract to conduct annual assessments of coral reef health across the CSMP.

The Centre has led a wide range of research in the CSMP, including the assessment of taxonomic



PHOTO EMMA KENNEDY

diversity and regional patterns of marine fauna and flora, impacts from marine heatwaves and major storms, reef connectivity and oceanography, and marine plastic dispersal. Among our significant findings are the strong distinction in the community composition of fish and corals between the CSMP and adjacent Great Barrier Reef, demonstrating how unique the two environments are (Harrison *et al.* 2020; Payet *et al.* 2020). Regular monitoring and dedicated research by the Centre has also been integral to understanding the impact of coral bleaching events on the unique and isolated reefs (Harrison *et al.* 2018).

Research in the CSMP continued in 2020, with Andrew Hoey, Morgan Pratchett, and Hugo Harrison leading two expeditions across the region. Our partnership with Parks Australia was also reinforced through an Australian Government 'Our Marine Parks Grant' to Andrew Hoey and colleagues for two additional projects in the CSMP for 2021-2. The funding will support an investigation of the ecology of deeper coral reef habitats and the comprehensive monitoring of shallow reef habitats to assess the impacts

of the 2020 bleaching event. The strong collaborative relationship between the Centre, Parks Australia and the Director of National Parks will ensure that the conservation and management of the CSMP is informed by world-leading research into the future.

References

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- Payet, SD, Lowe, JR, Mapstone, BD, Pratchett, MS, Sinclair-Taylor, TH, Taylor, BM, Waldie, PA and Harrison, HB (2020). [Comparative demography of commercially important species of coral grouper, *Plectropomus leopardus* and *P. laevis*, from Australia's Great Barrier Reef and Coral Sea Marine Parks](#). *Journal of Fish Biology* 97(4): 1165-1176.

¹ <https://parksaustralia.gov.au/marine/pub/plans/coral-sea-management-plan-2018.pdf>

Rising tides, troubled waters: the future of our ocean

By Jeff Goodell

PHOTO VICTOR HUERTAS

Marine heat waves are also inflicting massive damage on coral reefs (where they are often called “bleaching events”). Reefs are the most biodiverse ecosystems on the planet — they occupy less than one percent of the ocean floor, but are home to more than 25 percent of marine life. Reefs are created by millions of coral colonies that build calcium carbonate skeletons. For the past 100 million years or so, corals have thrived in a happy marriage with microscopic plants called zooxanthellae that live embedded in their tissues. Zooxanthellae produce 85 to 95 percent of corals’ food through photosynthesis. In return, corals give the plants protection, nutrients, and carbon dioxide, one of the ingredients for photosynthetic food production. This marriage, however, is exquisitely sensitive to changes in ocean temperature. One or two degrees of warming, and the zooxanthellae become toxic to the corals. The corals spit them out like an abusive spouse and eventually starve to death, leaving only their bleached skeletons behind.

Australia’s Great Barrier Reef, a UNESCO World Heritage site and one of the crown jewels of the natural world, has been hit hard by warming. The reef stretches about 1,400 miles along the east coast of Australia — it’s the largest structure built by living organisms on the planet, so big it’s visible from space. Since 1998, the Great Barrier Reef has suffered four bleaching events, including devastating back-to-back heat waves in 2016 and 2017. Further bleaching in 2020 has scientists worried it will be a near-annual event.

According to Terry Hughes, a marine scientist at James Cook University in Queensland, Australia, 93 percent of the corals in the Great Barrier Reef have been impacted by some level of bleaching. “We’ve now added enough greenhouse gases to the atmosphere that mass bleaching of the reef is at risk every summer,” Hughes says. “It’s like Russian roulette.”

If you look at a few drops of ocean water under a microscope, you’ll see a wild world of bizarre-looking creatures swimming around, fighting and devouring each other. Many of these animals — forams, pteropods — have thin shells made of calcium carbonate. And thanks to the rising acidity of ocean waters, their shells — like the shells and skeletons of many other creatures in the sea — are slowly dissolving.

Acidification is primarily a consequence of rapidly rising CO₂ levels in the atmosphere. The IPCC report notes that carbon pollution so far has decreased the average ocean pH, which is based on a logarithmic scale, from 8.2 to 8.1, meaning the ocean is 25 percent more acidic today than before the Industrial Revolution. If we manage to hold global warming to 2 C, we could limit ocean acidification to 40 percent by 2100. But in a high-emissions scenario, the ocean could become 150 percent more acidic than it was before we began burning fossil fuels. In effect, we’re running a giant chemistry experiment in the ocean, and nobody has a clear understanding of how it will turn out.

The increasingly acidic waters in the Pacific are already impacting the shells of Dungeness crabs, jeopardizing the \$200 million crabbing industry on the West Coast. To prevent the acidic waters from dissolving those shells, oyster farmers in Oregon and Washington have to raise baby oysters in incubators before planting them on the beach to grow to adulthood.

In lab experiments, scientists have found acidification can do strange things to a fish’s mind. Clown fish, for example, normally stay close to home in coral reefs. But as the water becomes increasingly acidic, they wander farther and farther away, making them more likely to be eaten. Greater acidity also “impairs their ability to discriminate between the smell of kin and not, and of predators and not,” according to Philip Munday, a professor at the Coral Reef Studies center at James Cook University in Australia.

Over time, the biggest threat from acidification is the impact it could have on the food chain. Pteropods, a.k.a. “the potato chips of the sea,” are a food source for everything from seabirds to whales. Their thin shells are extremely sensitive to changes in ocean pH. A collapse of the pteropod population would have a domino effect on the entire ocean food chain, especially in the Southern Ocean.

On coral reefs, most of which are already weakened by bleaching events, acidification attacks the calcium skeletons that they build to support themselves. “By midcentury, pretty much every reef in the world will be eroding away,” says [Ken] Caldeira [a climate scientist at the Carnegie Institution for Science in Palo Alto]. That’s astonishing. Coral reefs have been around for about 250 million years, evolving into some of the most complex, diverse, and beautiful living structures on Earth. And yet if nothing changes, within 40 or 50 years, they will be crumbling ruins. “I think if we stopped emitting CO₂ tomorrow, some reefs would probably survive,” Caldeira says. “But if we go on a few more decades, I think the reefs are gone. Over geological time scales, they will come back, depending how long it takes the ocean chemistry to recover. But it’s likely to be at least 10,000 years before anyone sees a reef again.”

Please note that the following is an excerpt from the Rolling Stone article, to read in full please visit:

RollingStone

<https://www.rollingstone.com/culture/culture-features/oceans-and-climate-change-2020-report-jeff-goodell-967980/>

PHOTO VICTOR HUERTAS

GRADUATE AND EARLY CAREER Training

The ARC Centre of Excellence for Coral Reef Studies is the global leader in building human capacity and expertise in coral reef science. Students and early career researchers (ECRs) are an essential component of the Centre and contribute to our culture, research excellence and outreach. During 2020, the Centre provided supervision and research funding to 156 graduate students across our four nodes. More than 80% of students are enrolled in PhDs, with the remainder pursuing Honours or Masters degrees. Thirty-six students graduated in 2020, while 36 new students enrolled in graduate research degrees. The Centre also supports 23 ECRs, who are within 5 years of completing their PhD.

The Centre attracts students and ECRs to Australia from around the world. In 2020, 114 international students came from 33 countries, representing 73% of our cohort. Almost 70% of our ECRs were from overseas.

The Centre provides an exciting and multi-disciplinary intellectual environment, with a strong focus on training and mentoring the next generation of coral reef researchers. In response to COVID-19, the Centre adapted its professional development programme so that it could continue to support students and researchers meet their training goals. The Centre also provided funding for PhD scholarship extensions and a student *Working from Home Bursary*, to compensate for costs incurred when transitioning to working from home.

One of the early development opportunities provided by the Centre in 2020 was a virtual workshop on *Navigating Rapid Change and Resilience in Turbulent Times*, hosted by Linda Betts. The workshop provided evidence-based models to foster resilience and approach COVID-19 as a major change period, including discussion of what that means for staff and students in relation to adjusting, navigating and identifying opportunities. Sixty licences of the *Calm* meditation app were also made available

to postgraduate students to support those experiencing stress and anxiety.

In 2020, the Centre continued to advance the quantitative and modelling skills of its students and researchers. Every year the Centre funds a two-week intensive course on statistics in R, hosted by Murray Logan, biostatistician with our Centre Partner, the Australian Institute of Marine Science. In 2020, the course was converted to a hybrid learning model with an in-classroom or online option, to support participation of students and ECRs across the four nodes. The September workshop trained 34 postgraduate students and 6 researchers in reproducible research, data wrangling, graphics, multivariate analyses, and frequentist and Bayesian modelling.

A recurring focus of the Centre's 2020 training activities was grant development. In October, Chuck Fox, Executive Director of Oceans 5, presented a seminar on private philanthropy and marine conservation. Centre researchers Michele Barnes, Peter Cowman, Jenni Donelson, Ryan Lowe and Philip Munday participated in a Q&A session on project descriptions for ARC and non-ARC funding applications. In November, Peter Cowman and Alana Grech hosted an interactive session on ARC Research Opportunity and Performance Evidence (ROPE).

In October, the Centre hosted a *Diversity and Inclusion* training session with Polykala. The session featured strategies for cultivating inclusive workplaces through conversation, reflection and compassion. Seventeen students and researchers attended the event and follow-up discussions resulted in the development of the Centre's **Justice, Equity, Diversity and Inclusion Committee**, which will be integrated into the Centre's governance (p74).

Prior to the introduction of international travel restrictions, the Centre continued its commitment to building capacity and expertise in coral identification with a training workshop in Bolinao, Philippines. The workshop, hosted by Centre researchers Thomas Bridge and Andrew Baird and

students Jeremy Horowitz and Augustine Crosby, trained 10 members of the Marine Science Institute, University of the Philippines in coral taxonomy, systematics and classification.

The Centre sponsors two committees in support of research students and ECRs, respectively. Each committee is allocated funds to support training, mentoring and leadership activities during the year. In 2020, the student committee was chaired by Shannon McMahon and Katie Sievers. Other members were Kevin Bairos-Novak, Chloe Boote, Deborah Burns, Amy Coppock, Chris Hemingson, Mike Mihalitsis, and Rachel Spinks (JCU), and Carolina Chong Montenegro, Katie Lee and Karin Zwiép (UQ). The student and ECR committees are supported by Graduate Co-ordinator Olga Bazaka, Chief Operations Officer Jennifer Lappin and Assistant Director Alana Grech.

The student and ECR committees organised multiple social events across the four nodes during 2020, enhancing the Centre's collaborative and supportive culture. For example, the student committee organised an in-person social function at each of the four nodes to celebrate the *Coral Reef Virtual Symposium* (p58). During the lockdown period between April and June, the student committee hosted a weekly *Zoom Trivia Night*. At our JCU node, the committee hosted a *Student Forum* with Centre management to provide information support on COVID-19 to JCU Centre-affiliated students. An informal *Graduation and Award Ceremony* was held in November to celebrate our 2020 PhD graduates and to bring our students and researchers together in a relaxed atmosphere to build relationships and a sense of community.

Students supported by the Centre achieved many prizes and accolades in 2020, for example:

Jessica Cramp was recognised as an American Association for the Advancement of Science IF/THEN ambassador as one of six statues exhibited in Central Park Zoo, New York (image p68). IF/THEN seeks to advance women in STEM and inspire the next generation of pioneers (#IfThenSheCan).

Andreas Dietzel's PhD thesis was awarded *Cum Laude* and Mariana Alvarez-Noriega and Jacqueline Lau received the Dean's Award for Excellence in Higher Degree Research at JCU.

Justin Geldard received a *Keiran McNamara World Heritage Scholarship* and the *Robson and Robertson*

Award to develop innovative approaches to predict storm damage to corals of different morphologies.

Lucy Holmes-McHugh was awarded a *Fulbright Scholarship* by the Australian-American Fulbright Commission.

Jeremy Horowitz received the *Danielle Simmons Award* from the Australian Coral Reef Society, a *Morris Family Trust Student Research Grant* from the Orpheus Island Research Station and a *Visiting Collections Fellowship* from the Australian Museum Foundation.

Jacqueline Lau and Ruby Grantham received the *International Engagement Award* from the Crawford Fund to bring together Timor Leste, Solomon Island and Australian researchers to illuminate the values of gleaning.

Marta Panero won the Australian Society for Fish Biology's *Video Competition*.

Ruby Grantham received the 2020 Glenn Almany Memorial Prize for her research on the seasonal value of gleaning to women in coastal communities of Timor-Leste. This prize is awarded to graduate students whose coral reef research required them to work with people beyond traditional academic boundaries, to make a difference, or which has the potential to influence policy, management or practice.

Grantham, R, Lau, J and Kleiber, D (2020). Gleaning: beyond the subsistence narrative. *Maritime Studies* 19: 509 – 524.

The Centre recognises outstanding research students for their first-authored publications each year, through our annual Virginia Chadwick Awards. In 2020, they were won by students at JCU, UWA and UQ:

Bonesso, J, Cuttler, M, Browne, N, Hacker, J and O'Leary, M (2020). Assessing reef island sensitivity based on LiDAR-derived morphometric indicators. *Remote Sensing* 12(18): 3033.

Dietzel, A, Bode, M, Connolly, S and Hughes, T (2020). Long-term shifts in the colony size structure of coral populations along the Great Barrier Reef. *Proceedings of the Royal Society B* 287(1936):1-9.

Kenyon, T, Doropoulos, C, Dove, S, Webb, GE, Newman, S, Sim, C, Arzan, M and Mumby, P (2020). The effects of rubble mobilisation on coral fragment survival, partial mortality and growth. *Journal of Experimental Marine Biology and Ecology* 533: 151467.

Morais, R, Depczynski, M, Fulton, C, Marnane, M, Narvaez, P, Huertas, V, Brandl, S and Bellwood, D (2020). Severe coral loss shifts energetic dynamics on a coral reef. *Functional Ecology* 34 (7): 1507-1518.

Tebbett, S, Streit, R and Bellwood, D (2020). A 3D perspective on sediment accumulation in algal turfs: implications of coral reef flattening. *Journal of Ecology* 108:70-80.

2020 PhD STUDENTS IN THE ARC CENTRE

Student Name	University	Country	Thesis Title	ARC Centre Advisers
Samantha Aird	JCU	Australia	Socio-ecological dynamics in archaeological shellfish fisheries: a case from the Keppel Islands, Great Barrier Reef, Australia. (PhD awarded)	A Hoey
Cinzia Alessi	JCU, AIMS	Italy	Dynamics of coral recruitment and juvenile survival.	M Hoogenboom
Danielle Asson-Batzel	JCU, AIMS, CSIRO, STRI	USA	Multi-scale patterns of benthic species composition in the Great Barrier Reef region and implications for spatial management.	B Pressey, S Connolly, T Bridge
Eoghan Aston	JCU	United Kingdom	Spatial dynamics of tropical shallow marine habitats and their related mobile marine faunal communities.	A Hoey
Kevin Bairos Novak	JCU, STRI	Canada	Metapopulation dynamics of coral polyp dispersal and juvenile fish recruitment after severe bleaching events.	S Connolly, M Hoogenboom
Henry Bartelet	JCU	Netherlands	The resilience of ecologically-dependent human communities to disturbances within volatile social-ecological systems.	G Cumming, M Barnes
Anne Bauer-Civiello	JCU	USA	From people to reef, marine debris and plastic pollution in north Queensland. (PhD awarded)	M Hoogenboom
Makeely Blandford	JCU	Australia	Interactions between fish and coral reefs: the influence of habitat degradation on fish communities.	A Hoey, M Pratchett
Joshua Bonesso	UWA, Curtin University	Australia	Underpinning reef-island resilience to climate driven changes in metocean states in the Pilbara Archipelago, North West, Western Australia.	R Lowe
Chloë Boote	JCU	United Kingdom	The larval development, microbiome, and stress response of the mushroom coral <i>Heliofunga actiniformis</i> .	D Miller
Ian Bouyoucos	JCU, CRIOBE	USA	Ecological energetics of climate change for tropical sharks. (PhD awarded)	J Rummer
Christopher Brunner	JCU, AIMS	Germany	Cumulative impacts of water quality and climate change (sea surface temperature warming and ocean acidification) on important reef species.	M Hoogenboom
Ramona Brunner	JCU	Germany	The function and ligands of G-protein coupled receptors (GPCRs) in coral larvae settlement.	D Miller
Cüneyt Caglar	ANU	Germany	Sponge and coral regeneration: cellular and molecular characterisation of regeneration in reef-building invertebrates.	M Adamska
Paula Joy Cartwright	UWA, U. Curtin	Australia	Metocean drivers of turbidity in the Exmouth Gulf: implications for benthic habitats under climate change.	R Lowe
Sivee Chawla	JCU	India	Understanding ecosystem service choices made by individual actors and their implications for social ecological interactions.	G Cumming, T Morrison
Carolina Chong-Montenegro	UQ, U. Exeter	Ecuador	Examining trajectories of decline of megafauna in our coastal seas.	J Pandolfi
Vanessa Clark	UQ	Australia	Coral growth dynamics and climate change.	S Dove
Harry Clarke	UWA	Australia	Resolving the impacts of ocean warming and dredging in coral cores collected from the North West shelf of Australia. (PhD awarded)	M McCulloch
Mia Theresa Bullecer Comeros	JCU	Philippines	Strengthening catchment to sea connections by evaluating the impacts of water quality on parrotfishes and surgeonfish assemblages in American Samoa.	A Hoey, G Russ
Mario Conde-Frias	UWA	Colombia	Investigating the sediment dynamics within submerged canopies for unidirectional and oscillatory flows.	R Lowe
Amy Coppock	JCU	United Kingdom	Climate change and disturbance events: the role of settlement behaviour and larval connectivity in changes to coral reef fish communities.	G Jones
Jessica Cramp	JCU	USA	Evaluating the effectiveness of policy, fisheries management tools and large-scale marine protected areas on wide-ranging sharks.	B Pressey

Student Name	University	Country	Thesis Title	ARC Centre Advisers
Benjamin Cresswell	JCU	United Kingdom	The ecology of mesopredator fishes in reef networks: considerations for conservation and fisheries management.	G Jones, H Harrison
Augustine Crosbie	JCU, MTQ	Australia	Integrating physiological and environmental drivers of depth zonation patterns on coral reefs.	A Baird, T Bridge
Amber Datta	JCU, U. Montana	USA	Untapped capacity for adaptation and transformation in coral reef social-ecological systems: exploring governance and discourse in the Great Barrier Reef and Hawaiian Islands.	M Barnes, T Morrison
Jonathan Day	JCU	Australia	Ensuring effective and transformative policy reform: lessons from rezoning Australia's Great Barrier Reef, 1999-2004.	B Pressey, T Morrison
Amelia Desbiens	UQ, CSIRO	Australia	Superstars and outbreaks: exploring population dynamics of the pervasive crown-of-thorns starfish.	P Mumby
Stephanie Di Perna	JCU, AIMS	Canada	Coastal acidification in the benthic boundary layer on inshore reefs: implications on water chemistry and benthic communities.	M Hoogenboom
Beatriz Diazguizarro	JCU	Spain	A comparison of the regeneration stages with developmental stages of corals including those in the family <i>Heliofungia</i> .	D Miller
Andreas Dietzel	JCU, STRI	Germany	The viability of coral populations in the Anthropocene. (PhD awarded <i>Cum laude</i>)	T Hughes, S Connolly
Peter Doll	JCU, AIMS	Germany	Habitat suitability and patterns of larval settlement for crown-of-thorns starfish (<i>Acanthaster cf. solaris</i>) in the Western Pacific.	M Pratchett, A Hoey
Adam Downie	JCU	Canada	How do coral reef fish develop into athletes?	J Rummer, P Cowman
Ameer Ebrahim	UQ, U. Sunshine Coast	Seychelles	The role of rabbitfish in a marine environment, and their contribution towards the resilience of tropical coral reefs. (PhD awarded)	P Mumby
Eric Fakan	JCU	USA	The effects of habitat degradation on live coral associated reef fishes.	A Hoey, G Jones
Legana Fingerhut	JCU	Netherlands	Genome wide detection and evolutionary analysis of antimicrobial peptide repertoires in corals.	D Miller
Fikri Firmansyah	UQ	Indonesia	Optimizing fisheries management tools implementation to sustain tropical reef fisheries.	P Mumby
Eric Fisher	JCU, AIMS	Australia	Spawning aggregation sites on tropical reefs.	M Kingsford
Renan Fonseca da Silva	UWA	Brazil	Understanding and predicting the impact of submerged structures on coastal processes with application to wave energy converters.	R Lowe
Gemma Galbraith	JCU	United Kingdom	Submerged pinnacle coral reefs: reef fish ecology and functional connectivity.	G Jones, T Bridge
Justin Geldard	UWA	Australia	Hydrodynamic forces on coral reefs: colony to canopy scale.	R Lowe
Bettina Glasl	JCU, AIMS	Austria	Microbial indicators for environmental stress and ecosystem health assessment. (PhD awarded)	B Willis
Saul Gonzalez Murcia	JCU	El Salvador	The impact of parrotfishes on the coral new recruits.	G Jones, G Russ
Alexia Graba-Landry	JCU	Canada	The effect of increasing temperature on algae-fish interactions on coral reefs. (PhD awarded)	A Hoey, M Pratchett
Ruby Grantham	JCU, WordFish	United Kingdom	The temporal dynamics of reef fisheries as part of diversified coastal livelihoods.	G Cumming, D Mills
Erika Gress Hernandez	JCU, MTQ	Mexico	Drivers of biodiversity on coral reefs - the role of antipatharians supporting species richness and abundance on shallow and mesophotic reefs.	T Bridge, P Cowman
Camille Mathilde Grimaldi	UWA, AIMS	France	Oceanography drivers of coral reef connectivity of North Western Australia.	R Lowe
Mila Grinblat	JCU	Israel	Sex change and gene expression in <i>Fungia fungites</i> coral.	D Miller, P Cowman
Rodrigo Gurdek	JCU, AIMS	Uruguay	Spatial and temporal connectivity dynamics on the Great Barrier Reef Marine Park using genomics and biophysical modelling.	H Harrison

Student Name	University	Country	Thesis Title	ARC Centre Advisers
Nataly Gutierrez Isaza	UQ	Colombia	Latitudinal patterns of maternal investment, maternal provisioning, and performance of coral offspring.	J Pandolfi, E Sampayo
Nicholas Hammerman	UQ	USA	Assessing temporal change and persistence in coral communities from the Red Sea, Saudi Arabia and Moreton Bay, Southeast Queensland.	J Pandolfi, G. Roff
Kelly Hannan	JCU	USA	The mechanisms underpinning maintained or enhanced performance of coral reef fishes under elevated carbon dioxide conditions.	J Rummer, P Munday
Kynan Hartog-Burnett	JCU	Australia	Population ecology of common baitfish species in the Indo-Pacific.	M Kingsford
Christopher Hemingson	JCU	USA	The evolution, biogeography and ecological significance of colour in coral reef fishes.	D Bellwood, P Cowman
Tessa Hill	JCU, MTQ	United Kingdom	Direct and indirect effects of ocean acidification on reef corals.	M Hoogenboom, S-A Watson
Kyle Hillcoat	JCU	Australia	Latitudinal variations in age-based demography of three large predatory reef fishes (<i>Lutjanus sebae</i> , <i>Lutjanus malabaricus</i> and <i>Lutjanus erythropterus</i>) in Queensland, Australia.	G Russ, G Jones
Lucy Holmes McHugh	JCU	Australia	Power and participation in seascape conservation in the anthropocene: how are new governance models turning the tide?	T Morrison, P Cohen
Jeremy Horowitz	JCU	USA	Predicting 'the unknown unknowns' in the global oceans: increasing certainty of species distributions to inform conservation in marine ecosystems.	T Bridge, B Pressey, P Cowman
Victor Huertas Martin	JCU, CNRS, STRI	Spain	Feeding ecology of corallivorous reef fishes.	D Bellwood, S Connolly
Nicholas James	JCU	Australia	Australian responses of seabirds to environmental change.	G Cumming
Dharini Jha	JCU, AIMS	India	Investigation into artificial intelligence methods for hyperspectral image analysis in coral reef science applications.	M Hoogenboom
Kaylan Kemink	JCU	USA	Conservation targeting and prioritization in the prairie pothole region.	B Pressey
Tania Kenyon	UQ	Australia	Physical and biological dynamics of post-disturbance coral reef rubble fields.	P Mumby, S Dove
Felicity Kuek	JCU, AIMS	Malaysia	Dimethylsulfoniopropionate (DMSP) metabolism within the coral holobiont.	D Miller
Bethan Lang	JCU	United Kingdom	The effect of ocean warming on the behaviour and fitness of post-settlement crown-of-thorns starfish (<i>Acanthaster cf. solaris</i>).	M Pratchett, A Hoey, C Caballes
Marie Lapointe	JCU	Canada	Urbanization and human-nature relationships: a comparison of urban and rural dwellers' perceptions of ecosystem services in the Solomon Islands.	G Cumming, G Gurney
Sarah Lawless	JCU, WorldFish	Australia	The diffusion of meta-norms in natural resource governance.	T Morrison, P Cohen
Morane Le Nohaic	UQ, CSIRO	France	Climate change undermines connectivity of the Great Barrier Reef.	P Mumby
Jake Lowe	JCU	Australia	Effects of no-take marine reserve protection on abundance and demography of tropical wrasses.	G Russ
Magen Marzoni	JCU, AIMS	USA	Genome wide assessments of heat tolerance in corals.	H Harrison
Madeline McKenzie	JCU	USA	Upside-down jellyfish (<i>Cassiopea spp.</i>) as a model organism under changing climate conditions.	M Kingsford
Shannon McMahon	JCU	Australia	Effects of rising water temperature and food availability on predatory reef fish.	J Donelson, P Munday
Jennifer McWhorter	UQ, U. Exeter	United Kingdom	Coral reef futures under climate change and ocean acidification.	P Mumby
Matheus Antonio Mello Athayde	UQ	Brazil	<i>Porites cylindrica</i> (Dana, 1846), a resilient coral found on the Great Barrier Reef: present and future coral physiology.	S Dove
Hanaka Mera	JCU	USA	Role of hybridisation in evolutionary history of scleractinian corals.	A Baird, P Cowman, D Miller

Student Name	University	Country	Thesis Title	ARC Centre Advisers
Michalis Mihalitsis	JCU, STRI	Greece	Predator-prey interactions in coral reef fishes: ecology and Function.	D Bellwood, S Connolly
Rebecca Millington	UQ, U. Exeter	United Kingdom	Modelling the role of biodiversity in ecosystem resilience to climate change.	P Mumby
Meira Mizrahi	JCU	Australia	Maximizing potential impact of marine protected area (MPA) placement: an integrated socio-economic perspective. (PhD awarded)	B Pressey
Jose Montalvo Proano	JCU, AIMS	Ecuador	Acclimation responses of corals to future environmental conditions.	P Munday
Juliano Morais	JCU	Brazil	Coral – fish interactions on coral reefs.	D Bellwood
Renato Morais Araujo	JCU, STRI	Brazil	The productivity of coral reef fishes. (PhD awarded)	D Bellwood, S Connolly
Scott Morrissey	JCU	Australia	Finding the missing link of jellyfish life history.	M Kingsford
Katie Motson	JCU	United Kingdom	The impacts of coral reef health on fish-parasite interactions.	A Hoey
Pauline Narvaez	JCU	France	Food preferences of cleaner organisms and the impact of cleaning interactions on pathogen transmission.	J Donelson
Tiffany Nay	JCU	USA	Temperature preferences of tropical fishes and the influence of local abiotic and biotic factors. (PhD awarded)	A Hoey, M Pratchett
Nery Contti Neto	UWA	Brazil	Field observations of sediment dynamics within coastal benthic ecosystems.	R Lowe
Sekondeko Ronnie Noga	JCU, WorldFish	Botswana	Territorial use rights in small-scale fisheries management and the role of collective governance for sustainable fisheries in Botswana.	T Morrison
Sam Noonan	JCU, AIMS	Australia	Responses of corals and coral reef ecosystems to ocean acidification under variable temperature and light.	M Hoogenboom
Jaepeel Oh	UWA	South Korea	Wave attenuation by flexible vegetation.	R Lowe
Kai Pacey	JCU	Australia	Biology and ecology of Australian aquarium corals: information needed to secure the sustainability of ongoing wild harvest of scleractinian corals.	M Pratchett
Samuel Payet	JCU	Australia	The role of hybridisation in the evolution of coral reef fishes.	H Harrison, G Jones, M Pratchett
Katie Peterson	JCU, QUT	USA	Applying ecological coexistence theory to improve management. (PhD awarded)	T Hughes, S Connolly
Saishri Prabakaran	UWA	India	Influence of Leeuwin currents on the biogeochemical dynamics of the South West Australian waters.	R Lowe
Mark Priest	UQ, Palau ICRC	United Kingdom	A multi-disciplinary approach to predictive management of coral reef fisheries. (PhD awarded)	P Mumby
Abdi Priyanto	UQ, MMAF, Indonesia	Indonesia	Marine spatial planning in Indonesia: options for improved efficiency. (PhD awarded)	P Mumby
Laura Puk	UQ	Germany	Population dynamics of the brown <i>Macroalga Lobophora sp.</i> and its control by herbivorous fish. (PhD awarded)	P Mumby
Jeremy Raynal	JCU	USA	Assessing the potential for recreational fishing to contribute to conservation of coastal marine species and habitats.	B Pressey
Johan Risandi	UWA	Indonesia	Assessing the hydrodynamics and morphodynamics of a reef-fringed pocket beach.	R Lowe
Cristina Ruano Chamorro	JCU	Spain	Equity in fisheries co-management: social-ecological determinants and trade-offs.	J Cinner, G Gurney
Alfonso Ruiz Moreno	JCU, STRI	Spain	Spatial and temporal dynamics of reef fish diversity: combining community ecology and phylogenetics.	S Connolly, D Bellwood
Netramani (Netra) Sagar	UWA	India	Reconstructing climate and anthropogenic signals on the Indian Ocean Margins using geochemistry of marine calcifiers.	M McCulloch, A Sadekov
Katie Sambrook	JCU	United Kingdom	Beyond the reef: the influence of seascape structure on fish communities and ecological processes on reefs.	A Hoey, G Cumming

Student Name	University	Country	Thesis Title	ARC Centre Advisers
Jodie Schlaefer	JCU	Australia	Determining the population structures of cubozoan jellyfishes with biophysical modelling. (PhD awarded)	M Kingsford
Elliott Schmidt	JCU	Canada	Investigation of the capacity for thermal plasticity to future warming across a species range.	J Donelson, G Torda, M Hoogenboom
Katherine Sievers	JCU	USA	The influence of multiple habitat types on no take marine reserve performance, fish community structure, and demographics of important fishery species.	G Russ, G Jones
Carrie Sims	UQ	Australia	The influence of biotic interactions on settlement and post-settlement processes in corals, and the role of early life history dynamics in driving coral community structure and diversity maintenance. (PhD awarded)	J Pandolfi
Alexandre Siqueira Correa	JCU	Brazil	The evolution, macroecology and biogeography of coral reef fishes: a trophic perspective.	P Cowman, D Bellwood
Patrick Smallhorn-West	JCU, MTQ	Canada	Assessing the impact of coral reef community management in the Kingdom of Tonga. (PhD awarded)	G Jones, T Bridge, B Pressey, G Gurney
Jessica Spijkers	JCU, U. Stockholm	Sweden	Global patterns of international fisheries conflict. (PhD awarded)	T Morrison, G Cumming
Rachel Spinks (p56)	JCU	Australia	Keeping up with climate change: the evolutionary potential of coral reef fishes to rising sea temperature.	P Munday, J Donelson
Robert Streit	JCU	Kenya	Space use by fishes on coral reefs: establishment, fidelity and reef resilience. (PhD awarded)	D Bellwood, G Cumming
Sarah Sutcliffe	JCU, WorldFish	Australia	Macro and micro level determinants of the contribution of fish to nutritional security.	J Cinner, M Barnes, J Lau
Sterling Tebbett	JCU, STRI	Australia	The functioning of future coral reefs: fishes, sediments and productivity.	D Bellwood, S Connolly
Tullia Isotta Terraneo	JCU, KAUST	Italy	Species boundaries in the coral genus <i>Porites</i> : an integrated approach. (PhD awarded)	A Baird, D Miller
Jodi Thomas	JCU, MTQ	New Zealand	The neurobiological mechanisms through which ocean acidification effects invertebrate behaviours.	P Munday, S-A Watson
Damian Thomson	JCU	Australia	Resilience of coral assemblages in North West Australia.	A Hoey, M Pratchett
Cheng-Han Tsai	JCU, AIMS, STRI	Taiwan	Variation in relative species abundance of reef fishes: drivers and ecosystem impacts. (PhD awarded)	S Connolly, D Bellwood
Laura Velasquez Jimenez	JCU	Colombia	Effects of boat noise on parental contributions to the dynamics of coral reef fishes.	G Jones, J Donelson
Casey Whalen	JCU	USA	Coral mediation of associated microbial community.	D Miller
Carolyn Wheeler	JCU, U. Mass	USA	Quantifying life history energetics of an oviparous elasmobranch subject to future warming waters.	J Rummer
Adam Wilkinson	JCU	United Kingdom	Investigating potential co-factors of fibropapillomatosis development in <i>Chelonia mydas</i> of the Great Barrier Reef.	J Brodie
Jennifer Wilmes	JCU	Belgium	Spatial variation in the density and demography of newly settled crown-of-thorns starfish (<i>Acanthaster cf. solaris</i>). (PhD awarded)	M Pratchett, A Hoey
Jessica Zamborain Mason	JCU, STRI	Spain	Towards the sustainability of coral reef fisheries: a functional approach.	S Connolly, J Cinner
Jia Zhang	JCU	China	Genome wide analysis of natural selection in thermally tolerant coral communities from North Western Australia.	D Miller
Kim Zoeller	JCU	South Africa	Understanding the production of cultural ecosystem services and benefits.	G Cumming, G Gurney
Karin Zwiep	UQ	Netherlands	Using DNA to reconstruct past coral reef ecosystems.	J Pandolfi

GRADUATE PROFILE

Rachel Spinks

"It was exciting because at that point most people weren't aware fishes use sound to communicate."



Rachel grew up on the outskirts of north-west Sydney and spent most weekends with her family at the beach. She had a passion for animals and started breeding fish at age ten. Rachel volunteered as a wildlife rescuer and for a local reptile breeder. She also worked in the ornamental aquarium industry. By 18, there was a "fish tank or reptile enclosure along every wall in the house".

Rachel was the first in her family to attend university. Her studies commenced with a Bachelor of Marine Science at Macquarie University, after which she studied a Master of Science at the University of Basel, Switzerland. Her research with evolutionary biologist Professor Walter Salzburger focused on freshwater African cichlid fishes. She conducted experiments in the laboratory and in the field at Lake Tanganyika, Zambia. From an evolutionary perspective, Rachel tried to understand how and why African cichlid fishes produce sound. "It was exciting because at that point most people weren't aware fishes use sound to communicate." She was the first to document several species sounds, including a novel high pitch sound made by the Princess cichlid fish. From here Rachel knew that fish evolution would be the major theme of her future research.

After Zambia, Rachel travelled to South Africa where she worked as a dive master and marine ecologist for an international non-government organisation. Her time there was cut short after she suffered decompression sickness on a scuba dive as a result of an undiagnosed congenital heart defect. Similar to a stroke, it left Rachel with left sided weakness and speech problems. She spent months in rehabilitation learning how to walk and talk normally again.

Rachel moved to Townsville in 2016 to study a PhD at James Cook University under the supervision of Philip Munday and Jennifer Donelson. Her research focuses on how coral reef fishes evolve under climate change. To support her project, she cared for a mammoth 5000 fishes over 3 years. Her previous experience in the aquarium industry and her love of fish luckily meant that Rachel didn't mind being covered in salt water in a laboratory with 30°C air temperature

and 95% humidity! Breeding fishes across multiple generations in future climate change scenarios allowed Rachel to examine long-term effects and to test if coral reef fishes have the ability to rapidly adjust to changing environments. This type of research allowed Rachel to build strong programming and statistical as well as experimental skills.

Rachel faced multiple health challenges during her PhD. Before her confirmation, Rachel underwent surgery to repair her heart defect but it was unsuccessful (and sadly means she can no longer scuba dive). Rachel was then diagnosed with two autoimmune conditions. One was a type of arthritis that affected her capacity to walk, dress herself or open a door. Rachel also developed a neurological condition and had a very close call with cancer. With much perseverance, Rachel can manage her conditions but they still impact day-to-day activities.

Rachel is a strong advocate for improving support for students with disabilities, especially postgraduate research students. She joined *Chronically Academic*, an international support network of disabled academics, as the Australian representative. "My goals are to improve support for students with disabilities in higher education. I also want disability to be normalised within academia and not seen as less productive or too difficult. We have valuable skills and perspectives to offer but taking us on requires flexibility and support." Rachel has generously provided the Centre with action-orientated recommendations so that we can improve disability support for, and the wellbeing of our graduate students.

Her incredible research journey will see Rachel submit her thesis for examination in 2021. She planned to spend most of the year at Nord University, Norway as a visiting research fellow but COVID-19 has put that on hold for the moment. Instead, Rachel will conduct a data analytics internship with BHP in Perth. The internship was organised through the Australian Network on Disability *Stepping Into Program* that connects higher education students with disability aware companies.

Our goal is to build human capacity and expertise in coral reef science worldwide. In 2020, over 70% of our 156 graduate students and 23 ECRs were from overseas.



PHOTO THOMAS VIGNAUD

RESPONDING TO COVID-19

The COVID-19 pandemic has caused major social and economic devastation across the world. In Australia, we had to quickly adapt to new restrictions especially in the workplace. The Centre's swift response and flexibility empowered our members to continue their world-leading research, resulting in sustained outputs that exceeded virtually all key performance indicators (p106). We initiated multiple programmes to assist in the transition to a new working environment and support our members' health and wellbeing (p49). Among our most successful COVID-19 response initiatives were the conversion of our annual symposium and weekly seminar series to a virtual format.

Coral Reef Virtual Symposium 2020

The goal of the Centre's annual symposium is to showcase its research and foster collaborations amongst researchers and stakeholders. It is the most important event in the Centre's calendar and is held at locations across Australia to maximise exposure and stimulate new partnerships. In response to COVID-19 restrictions, the annual symposium was held using a Zoom Webinar format in 2020.

The focus of the symposium, *Coral Reef Virtual Symposium 2020*, pivoted to the Centre's post-graduate students in order to provide a professional development opportunity and to celebrate the outstanding achievements of the group most disenfranchised by the COVID-19 crisis. Prior to the event, the Centre's business team worked closely with James Cook University's Technology Solutions Directorate to implement the best technology set-up for the symposium and provide one-on-one training for the 30 presenters. Centre researcher Michele Barnes also provided virtual training to students on 'How to wow a crowd'.

The *Coral Reef Virtual Symposium 2020* was held on Tuesday 7th and Wednesday 8th July. The event featured four plenaries (JCU's David Bellwood and Georgina Gurney, UQ's Ove Hoegh-Guldberg and Wildlife Conservation Society's Emily Darling) and 24 presentations from postgraduate students

from across the Centre's four nodes. A Welcome to Country was provided by Bindal Elder Jeanette Wyles and the symposium was moderated by Assistant Director Alana Grech.

The symposium was a huge success. More than 530 people from 39 countries in 6 continents (North America, South America, Asia, Africa, Europe and Australia/Oceania) attended the event. Many members of the Centre's Partner Institutions, including the Great Barrier Reef Marine Park Authority and Australian Institute of Marine Science, were in attendance. Over 120 questions were lodged by viewers. The postgraduate students and Centre members were thrilled with the outcome. Most importantly, the symposium was able to bring us together as a community and to celebrate our students during an incredibly stressful and isolated period.

The things that we learned throughout the implementation of the *Coral Reef Virtual Symposium 2020* have informed subsequent events at the Centre, including virtual workshops, meetings and the Centre's weekly seminar series. In 2021, our improved understanding of how to run virtual events will be applied in the hybrid version of the Centre's annual symposium, to be held at the JCU Townsville campus in September.

Virtual Seminar Series

The Centre hosts a weekly seminar series to share the latest research of Centre members as well as leading researchers and environmental managers from across the world. The seminar series is co-ordinated by a group of early career researchers to support the development of professional skills in networking, conference technology and leadership. In 2020, the seminar series coordinators were Natalia Andrade Rodriguez, Brock Bergseth, Iain Caldwell and Jacqueline Lau.

The Centre's seminar series has used Zoom technology for several years to ensure that all nodes had access to seminars regardless of where they were hosted. However, 2020 presented a unique

challenge to the seminar coordinators as travel restrictions and campus closures cut-off a major source of presenters - national and international visitors. In April, the seminar coordinators responded to this challenge by earnestly seeking out volunteers for virtual presentations from global leaders in coral reef science and management.

The hard work of the seminar coordinators resulted in the most successful series in the Centre's history. It featured more than 30 presentations from researchers in 20 institutions and 4 countries. A special highlight were the presentations by Centre alumni who have transitioned to prestigious roles at overseas institutions. The virtual format enabled the participation of researchers, students and managers from across the world. The average number of

people in attendance at each seminar was more than 40, with some seminars exceeding 100.

The 2020 seminar series was a critical feature in our COVID-19 response that ensured we continued to feel and operate as a community of researchers and students despite our physical isolation. It also provided an opportunity for a more inclusive approach to science communication as the series was open to the broader community rather than Centre members only. The open format allowed the seminar series to become a focal point for coral reef researchers across the globe, exceeding our expectations. A very special thanks to our seminar coordinators and Digital Communications Officer Maria Nayfa for their ingenuity and dedication.

2020 Virtual Seminar Series Presenters

Shankar Aswani Canela Rhodes University (South Africa)	Arizona State University (USA)	Justin Rizzari Deakin University
Keisha Bahr Texas A&M University-Corpus Christi (USA)	Caroline Dubé University Laval and Academy of Sciences (USA)	Steven Robin University of Queensland
Natalie Ban University of Victoria (Canada)	Katharina Fabricius Australian Institute of Marine Science	Chris Roelfsema University of Queensland
Claudia Benham James Cook University	Manuel Gonzalez-Rivero Australian Institute of Marine Science	Stuart Sandin Scripps Institution of Oceanography (USA)
Simon Brandl University of Texas (USA)	Nicholas Graham University of Lancaster (UK)	Jennifer Selgrath Channel Islands National Marine Sanctuary's (CINMS) Science Team (UK)
Thomas Bridge Queensland Museum and James Cook University	Quentin Hanich University of Wollongong	Nyssa Silbiger Florida State University (USA)
Joshua Cinner James Cook University	Terry Hughes James Cook University	Eric Tremblay Deakin University
Danny Coffey Texas A&M University-Corpus Christi (USA)	Phillip Levin The Nature Conservancy and University of Washington (USA)	Felecia Watkin Lui James Cook University
Peter Cowman James Cook University	Zoë Lieb Allen Coral Atlas (USA)	Damian Weekers Great Barrier Reef Marine Park Authority
Patrick Crist PlanIt Forward and NatureServe (USA)	Aaron MacNeil Dalhousie University (Canada)	Charlie Wiener Schmidt Ocean Institute (USA)
Graeme Cumming James Cook University	Philip Munday James Cook University	Erika Woolsey The Hydrous (USA)
Brooke Deak James Cook University	Nicholas Murray James Cook University	Fernando A Zapata Universidad del Valle in Cali (Colombia)
Mary Donovan	Kirsty Nash University of Tasmania	

NATIONAL & INTERNATIONAL Linkages

In 2020, in response to the global COVID-19 pandemic, Australia entered a national lockdown and international and state borders were closed. Travel for collaborative visits, working group meetings, field work, and conference travel were not possible. The ARC Centre of Excellence for Coral Reef Studies responded decisively, innovatively and flexibly to these restrictions, leading the way in collaborating virtually, increasing its publication

output and achieving or exceeding nearly all of its performance targets. The Centre's aim to continuously expand its collaborations with national and international researchers was achieved with Centre researchers generating publications with 1712 co-authors from 558 institutions in 74 countries, a substantial increase from 2019. Other examples from 2020 include:

<p>322</p> <p>PUBLICATIONS WITH CROSS-INSTITUTIONAL CO-AUTHORSHIP</p>	<p>194</p> <p>NEW ORGANISATIONS COLLABORATING OR ENGAGING WITH THE CENTRE</p>	<p>24</p> <p>WORKING GROUPS AND WRITING RETREATS CONVENED BY CENTRE RESEARCHERS INVOLVING >300 EXTERNAL RESEARCHERS AND STAKEHOLDERS</p>
<p>>530</p> <p>ATTENDEES AT THE CENTRE'S CORAL REEF VIRTUAL SYMPOSIUM 2020 (p58)</p>	<p>30</p> <p>INVITED TALKS AT INTERNATIONAL MEETINGS</p>	<p>234</p> <p>INTERNATIONAL GRADUATE STUDENTS ATTRACTED TO AUSTRALIA FROM 46 COUNTRIES SINCE 2014, INCLUDING 22 NEW GRADUATE ENROLMENTS FROM 14 COUNTRIES IN 2020 (p49).</p>

In the 2020 travel-restricted environment, Centre researchers reached out to their colleagues in 21 countries across the world to establish agreements to engage with local scientists to facilitate sample and data collection and ensure continuity of research programs. The resulting outputs, media uptake, public outreach, and impact was global (p66). The ARC Centre's researchers are major contributors to intergovernmental organisations such as the Intergovernmental Panel on Climate Change (IPCC), the World Bank, United Nations expert groups, International Union for Conservation of Nature (IUCN) and the International Council for Science (ICSU). Centre personnel are also appointed to many editorial boards of international journals. Five Centre research leaders are Fellows of the Australian Academy of Science: David Bellwood, Ove Hoegh-Guldberg, Terry Hughes, Malcolm McCulloch and Bob

Pressey. Joshua Cinner is a Fellow of the Australian Academy of Social Sciences in Australia and Malcolm McCulloch is a Fellow of The Royal Society (UK).

The Centre has formal international partnership agreements with the Center for Ocean Solutions at Stanford University, France's Centre National de la Recherche Scientifique (CNRS), and WorldFish in Malaysia. Centre researchers also collaborate extensively with colleagues at a number of international non-government organisations (NGOs) including the Wildlife Conservation Society (WCS), The Nature Conservancy (TNC), the Worldwide Fund for Nature (WWF) and Conservation International (CI).

The ARC Centre's national and international collaborations result in quality research outputs and tangible impacts, including the development of trans-disciplinary research projects, multi-institutional



PHOTO AUGUSTINE CROSBIE

supervision of PhD students, recruitment of co-funded postdoctoral fellows, and enhanced engagement and uptake of our research by end-users. The Centre's governance structure strengthens these links (p74).

Examples of the Centre's national and international collaborators in 2020 are highlighted below.

Australian Institute of Marine Science

The Australian Institute of Marine Science (AIMS) is the Centre's major Australian research partner outside of the University sector. AIMS undertakes a range of research on tropical marine environments and aquaculture, is responsible for the long-term monitoring of the Great Barrier Reef, and provides research services to industry, including oil and gas companies, government agencies, port authorities and other clients and partners, particularly in Queensland, Western Australia and the Northern Territory. Dr Paul Hardisty, the AIMS Chief Executive Officer is a member of the Centre's Advisory Board with Dr Britta Schaffelke, leader of 'A Healthy and Sustainable Great Barrier Reef Research Program' delegated to this role in 2020. AIMS' senior principal research scientist, Janice Lough is a very active Partner Investigator in the Centre whose scientific achievements were recognised in 2020 with an International Coral Reef Society (ICRS) Fellow award. Centre and AIMS researchers have close, longstanding and productive collaborations. AIMS and the Centre

share valuable infrastructure, co-supervise graduate students (16 in 2020) and co-fund two research fellows: Kristen Anderson and Hugo Harrison. AIMS and Centre researchers co-authored 47 papers in 2020, including high profile publications in *PNAS* (p29), *Science of the Total Environment* (p36), *Nature*, and *Science Advances*. AIMS also contributes annually to the professional development of graduate students with AIMS biostatistician, Murray Logan, running an intensive statistics course, funded by the Centre (p49).

Great Barrier Reef Marine Park Authority

The Great Barrier Reef Marine Park Authority (GBRMPA) is a Centre partner and our most important end-user in Australia. GBRMPA is the Australian government agency with the primary responsibility of protecting and managing the Great Barrier Reef. Their role is to assess, inform, and implement government policies to maintain the environmental quality of the Great Barrier Reef. GBRMPA's partnership with the Centre provides them with direct access to the research expertise of Centre scientists, whose research goals are strongly aligned with the scientific information needs of GBRMPA. GBRMPA is a key component of the Centre's governance structure (p74) to facilitate research planning and the exchange of information and data. Josh Thomas, GBRMPA's Chief Executive Officer, sits on the Centre's Advisory Board, and the Authority's Chief Scientist, Dr David Wachenfeld is a member of the Centre's



PHOTO SAMANTHA AIRD

Scientific Management Committee. Ove Hoegh-Guldberg and Terry Hughes are members of the *Reef 2050 Independent Expert Panel*, which provides expert advice to GBRMPA and the Queensland and Australian governments on the Great Barrier Reef. GBRMPA managers receive regular updates, advice and frequent briefings on the Reef from Centre researchers. For example, Terry Hughes provided daily briefings to GBRMPA leaders, while undertaking aerial surveys during the 2020 coral bleaching event. Terry, Ove-Hoegh-Guldberg, Peter Mumby and Scott Heron also participated as members of the GBRMPA's Scientific Advisory Group, which provided advice to help guide GBRMPA'S response to potential bleaching events and coordinate impact assessment activities. Social scientist, Michele Barnes, and PhD student Amber Datta briefed GBRMPA on the results of their work to improve governance responses to coral bleaching. Jamie Caldwell met with GBRMPA management on a number of occasions and provided regular updates on the progress of a coral disease forecasting product which is under development. Jamie and Terry also joined GBRMPA managers for presentations, information exchange and discussions in GBRMPA's *Pre-Summer Reef Health Workshop*, a forum for planning and coordinating upcoming monitoring and research activities. April Hall continues to work in collaboration with GBRMPA on her Advance Queensland fellowship on evaluating the value of Conservation Park (yellow zones) to biodiversity in the Great Barrier

Reef Marine Park. Brock Bergseth discussed illegal fishing inside no-fishing zones with GBRMPA's Field Management Compliance Unit (FMCU). Peter Mumby also provided advice to the FMCU on how compliance can be prioritised in areas of high ecological value. Andrew Baird, Tom Bridge and Peter Cowman gave a series of presentations to GBRMPA on Project Phoenix, an international multidisciplinary collaboration among researchers in the taxonomy, systematics and evolution of corals, an area identified by GBRMPA as a research priority.

WorldFish

WorldFish is one of the Centre's longest standing and productive international research partners. WorldFish is an international non-profit scientific agency headquartered in Malaysia, undertaking research projects in developing nations with the aim of improving food and nutrition security, reduce poverty and improve management of natural resources for the 800 million people globally who depend on aquatic foods. The Centre and WorldFish share a common research interest in the dynamics and sustainable interaction between human societies and coral reef-associated fisheries. We have a strong, longstanding and productive partnership, which in 2020 generated 19 co-authored publications. Michele Barnes, Jacqueline Lau and others published a high profile paper in *Nature Climate Change* on how an island community in Papua New Guinea (PNG) coped with the impact of encroaching sea-levels and dwindling fish stocks (p18).

Jacqueline also led a paper in *Conservation Biology* that will contribute to more inclusive and equitable collaborative management of fisheries and marine resources. In addition to peer-reviewed papers, Danika Kleiber's contribution as an author on the Blue Paper '*Toward Ocean Equity*' is notable globally. Jaqueline is one of two research fellows jointly funded by the Centre and WorldFish. The other is Patrick Smallhorn-West who joined the small-scale fisheries Pathways Project in May 2020 following Danika Kleiber's move to a federal social scientist position with NOAA at the Pacific Island Fisheries Science Center, Hawaii.

Research fellows liaise closely with David Mills, a senior WorldFish senior scientist based at the JCU node of the Centre. Pip Cohen, Research Leader of the global program on resilient small-scale fisheries for WorldFish, co-leads the FISH CGIAR Research Program with the Centre's Joshua Cinner and Tiffany Morrison. Pip is also a member of the Centre's Advisory Board. In March 2020, Dr Gareth Johnstone, Director General of WorldFish visited the ARC Centre in Townsville to explore ways to strengthen our collaboration and meet with co-supervised PhD students. The partnership continues to invest in co-supervisory arrangements for four PhD students, Ruby Grantham, Sarah Lawless, Ronnie Noga and Sarah Sutcliffe. Ruby received the Centre's 2020

Glenn Almany Memorial Prize for her paper in *Maritime Studies* on the seasonal value of gleaning to women in coastal communities of Timor-Leste. Jacqueline and Sarah Sutcliffe are undertaking collaborative research projects in both PNG and Kenya on the impacts of COVID-19 (p22). Sarah Sutcliffe benefitted greatly from a three-week study period in February in Penang at the WorldFish headquarters. Danika also travelled to Penang during this time to work with WorldFish colleagues to finalise papers and reports on Community Based Resource Management and the development of a **network of gender advisors**, which spans almost two dozen countries. During this time, Danika also delivered Gender training and Pathways Project training in Port Vila, Vanuatu. We bid farewell to Danika in April and thank her for her enormous contribution to both WorldFish and the Centre. The Centre's ongoing collaboration with WorldFish creates strong links to end-users, including many inter-governmental organisations and NGOs, as well as local communities and the governments of many developing countries, particularly in the Coral Triangle.

Okinawa Institute of Science and Technology
The Okinawa Institute of Science and Technology Graduate University (OIST) is a pioneering graduate university in Japan that bridges disciplines to explore new frontiers of scientific

PHOTO SAMANTHA AIRD



knowledge and serves as a catalyst for breakthrough innovation locally and globally. The Centre and OIST share a strong and growing research interest in molecular genetics, genomics and the neurobiology of marine organisms.

Centre researchers collaborate closely with several OIST researchers including Professors Vincent Laudet, Noriyuki (Nori) Satoh and Timothy Ravasi. In 2020, Tim was appointed as an Adjunct Professor at the Centre at JCU to formalise these strong links and to foster and support collaborative research projects between our organisations. These ongoing collaborations enable groundbreaking discoveries on molecular processes in coral reef organisms, due to OIST's unrivaled capacity to undertake ultramodern high-throughput molecular research with state-of-the-art DNA/RNA sequencing.

David Miller has been involved with OIST since its origins in 2009 and in 2020 was awarded Visiting Researcher status. Dr Chuya Shinzato, Centre alumnus, joined OIST as a research fellow in 2009, and the resulting Shinzato *et al.* (2011) paper in *Nature* described the first whole genome sequence for a coral. Since then, David, Nori Satoh and colleagues have published a series of papers on various aspects of coral biology in high profile journals. In 2019, the OIST Marine Center was opened, and at OIST's invitation, five Centre researchers carried out fieldwork during the Okinawa coral spawning event. Travel restrictions associated with the COVID-19 pandemic meant this collaborative undertaking could not proceed in 2020. The coral spawning collaboration was a great opportunity to make use of OIST's unique combination of a well-equipped marine lab close to

coral reefs and state-of-the-art molecular facilities. Whilst the results of this work are still under analysis, it is clear that they will yield a series of publications and thesis chapters for Centre PhD students, Mila Grinblat and Ramona Brunner.

Jodie Rummer and Philip Munday's collaboration with Tim Ravasi, who moved from the King Abdullah University of Science and Technology to OIST in 2019, has led to a number of high profile publications on molecular acclimation and adaptation to climate change. Their 2020 *Science Advances* article determined the molecular responses of coral reef fish to the marine heatwave experienced on the Great Barrier Reef in 2016. In 2020, Centre PhD student, Jodi Thomas, became a Visiting Research Student at OIST to work with Tim and his team to determine the molecular response of the central and peripheral nervous system in cephalopods to elevated CO₂. Jenni Donelson is the external adviser for OIST graduate student Billy Moore. The collaboration will be strengthened in 2021 with the appointment of graduating Centre PhD student Shannon McMahon to a postdoctoral research fellowship position at OIST.

Overseas visiting researchers

One of the consequences of the COVID-19 pandemic disruptions was a significant reduction in the number of international visitors who could travel to, and be hosted by, the Centre, reduced to just 26 visitors in 2020. To maintain Centre researchers access to the latest research and opportunities for discussion and exchange, the Centre's seminar series moved to a virtual format attracting presentations from more than 30 coral reef research leaders from across the world (p58).

2020 INTERNATIONAL VISITORS

Name	Overseas institution	Country
Gintare Bielkinaitė	University of Amsterdam	Netherlands
Prof John Bruno	University of North Carolina	United States
Dr Jamie Caldwell	Stanford University	United States
Dr Patrick Crist	NatureServe and PlanIt Forward	United States
Flore Emonnot	IFREMER-UPPA	France
Lucy Fitzgerald	King Abdullah University of Science and Technology	Saudi Arabia
Dr Federica Fogliani	Marine Science Institute (ISMAR-CNR)	Israel
Andrea Graiani	University of Modena and Reggio Emilia (UNIMORE)	Italy
Ariel Greiner	University of Toronto	Canada
Dr Gareth Johnstone	WorldFish	Malaysia
Erina Kawai	Okinawa Institute for Science and Technology	Japan
Dr Naoki Kumagai	Ministry of Environment	Japan
Dr Kimiko Matsumura	Asia Pacific Biodiversity Observation Network	Japan
Prof Claudio Mazzoli	University of Padua	Italy
Dr Paolo Montagna	Marine Science Institute (ISMAR-CNR)	Italy
Rachael Penman	University of British Columbia	Canada
Dr Bruna Pereira Luz	Universidade Federal do Paraná	Brazil
Dr Alessandro Remia	Marine Science Institute (ISMAR-CNR)	Italy
Amy Shurety	University of KwaZulu-Natal	South Africa
Mayara Silveira	Federal University of Rio Grande do Norte	Brazil
Dr Marco Taviani	Marine Science Institute (ISMAR-CNR)	Italy
A/Prof Yoshi Tomayasu	Miami University	United States
Walter Torres	Duke University	United States
Prof Gert Woerheide	University of Munich	Germany

COMMUNICATION, MEDIA AND PUBLIC Outreach

The ARC Centre of Excellence for Coral Reef Studies has a highly successful and varied strategy for communicating research findings to a wide audience. For example, the Centre's communication programme actively promotes research outcomes through both traditional news sources and digital platforms. The Centre's comprehensive website recorded 10.2 million hits from over 162,400 visitors from 211 countries in 2020. The Centre's international seminar series, which was publicly accessible through Zoom and the Centre's [YouTube channel](#), hosted 47 online presentations in 2020 (p58).

Due to COVID-19 restrictions, the ARC Centre's annual symposium went virtual this year as the [Coral Reef Virtual Symposium](#) (p58). This highly successful event was hosted over Zoom and attracted over 530 individuals from 39 countries with all continents (bar Antarctica) in attendance. Talks were also made available on the Centre's [YouTube channel](#).

Social Media

The Centre's digital engagement continued to flourish and grow during 2020. The Centre's Twitter account [@CoralCoE](#) increased to over 10,500 followers. Followers registered more than 1.4 million impressions in Twitter feeds throughout the year.

The number of followers of the Centre's [Facebook page](#) grew by 36%, and it now has over 4,250 followers. In 2020, the Centre also created an [Instagram account](#) that attracted over 2,850 likes. These posts were also made available through the [Centre website](#). Expanding the Centre's video library and online presence was a priority during 2020 as a response to COVID-19, resulting in our [YouTube Channel](#) growing by over 24% and garnering over 20,500 views and over 1,300 watch time hours.

In 2020, COVID-19 highlighted the importance of digital networking for our members. Subsequently, the Centre created a [LinkedIn page](#) to provide a way

for our current members, alumni, collaborators and other interested parties to both connect and remain up to date on Centre research and opportunities.

Briefings

Even in the midst of COVID-19 restrictions in 2020, Centre researchers continued to provide timely and informative advice to key stakeholders on relevant coral reef science issues both locally and internationally. In total, Centre researchers engaged in 109 briefings across both the public and private sectors.

Centre researchers continued to deliver frequent briefings to government agencies. This included more than 25 briefings to the Great Barrier Reef Marine Park Authority by Michele Barnes, Brock Bergseth, Jamie Caldwell, Severine Choukroun, Joshua Cinner, Graeme Cumming, Alana Grech, April Hall, Ove Hoegh-Guldberg, Andrew Hoey, Terry Hughes, Mike Kingsford and Greg Torda. Briefing topics included climate change, coral bleaching, coral disease, reef management, and governance. Andrew Hoey and Morgan Pratchett briefed Parks Australia on the 2020 Coral Sea bleaching event and Coral Sea reef health (p44). Ove Hoegh-Guldberg and Terry Hughes participated in the Reef 2050 Plan Independent Expert Panel, providing advice to the Australian and Queensland Government on evidenced-based management of the Great Barrier Reef.

Peter Mumby advised the Government of the Philippines on managing marine transboundary resources shared with Malaysia and Indonesia. Rene Abesamis gave a series of briefings to the Government of the Philippines on marine protected areas. Jacqueline Lau reported to WorldFish and multiple stakeholders on preliminary findings from the 'Two Degree Initiative' (2DI). 2DI is an international initiative geared towards preparing the global food system for climate change.



PHOTO ASHWA FAHEEM, ANWAR AHMED & MALDIVES CORAL INSTITUTE

Briefings were also delivered across the industry sector. For example, Ryan Lowe gave briefings to the Mars Foundation, Minderoo Foundation, and Subcon Blue Solutions on assessing artificial reefs and their benefits. Georgina Gurney briefed Pew Charitable Trusts on other effective area based conservation measures.

Community briefings also continued in 2020 with the help of Zoom. Tiffany Morrison gave a briefing in Sweden on 'Governing through complexity, conflict and crisis'. Jorge Álvarez-Romero delivered information and spatial data to Madjulla Inc. and the Fitzroy Martuwarra River Council to assist Traditional Owners of the Fitzroy River catchment, Western Australia plan for future development and conservation of their countries.

Public engagement and school outreach

Public engagement and outreach were a vital activity for the Centre in 2020. In the midst of COVID-19 restrictions, Centre researchers delivered 77 outreach events and public talks.

For example, Ove Hoegh-Guldberg spoke and participated in the Coral Festival on Thulusdhoo Island in the Maldives in February 2020. Malcolm McCulloch participated in nine public outreach programs and talks throughout 2020: including, the Schmid's Ocean Institute's Ship to Shore program which afforded students the opportunity to speak to researchers about their work on board the Research Vessel Falkor (p71).

In 2020, Jodie Rummer gave several talks to students in Moorea, French Polynesia and through [Sharks4Kids](#) on the importance of sharks. In February, before COVID-19 restrictions were in place, Mia Hoogenboom and Alison Paley engaged with visiting high-school guidance counsellors from Canada and challenged them with hands on coral dissections. Brock Bergseth provided advice to students from James Cook University on careers in fisheries.

Michele Barnes was interviewed for her socio-economic expertise on [Saving Jaws](#), a television documentary. Malcolm McCulloch participated in a Japanese NHK wildlife TV program in September. Maja Adamska also gave a live interview on the Polish TV station TVN and on Polish radio TOK FM in January. Andrew Baird was interviewed on [Radio National Breakfast](#) in Townsville about the dozens of new coral species he and collaborators had discovered on the Great Barrier Reef.

For World Oceans Day, Alana Grech joined a panel organised by the United States Consulate General Sydney discussing innovation for a sustainable ocean. Morgan Pratchett provided expert advice to Queensland locals at a state election candidate forum on protecting our Great Barrier Reef and local livelihoods. Peter Mumby presented a talk to the Queensland Gold Coast Library on 'How to keep the Great Barrier Reef great'.

Plenary talks

In 2020, Centre researchers delivered 30 keynote addresses, with the majority presented virtually as a result of the COVID-19 pandemic. John Pandolfi and Timothy Staples were invited speakers at the 5th World Conference on Marine Biodiversity and spoke on 'Detecting novelty, and its causes and consequences, in ecological communities'. Michele Barnes and Jacqueline Lau delivered plenaries at the 2020 International Symposium for Society & Resource Management Virtual Conferences hosted by The International Association for Society and Natural Resources on 'How social networks and power interact to shape responses to climate change: Evidence from Papua New Guinea' and 'The environmental justice in coastal systems: perspectives from communities confronting change', respectively.

Peter Mumby was invited to speak at the International Symposium held by the Indonesian Institute of Sciences in collaboration with the Ministry of Science and the Indonesian Technology National Research and Innovation Agency on Coastal and Marine Biodiversity in 2020. Joshua Cinner presented a plenary at the International Conference on Marine Science on 'Locating and learning from bright spots among the world's coral

reefs'. Maja Adamska spoke at the Lorne Genome Conference on sponge genomes.

In 2020, Jorge Álvarez-Romero was invited to be a keynote speaker by both Food and Agriculture Organization Colombia and the United States National Oceanic and Atmospheric Administration on designing networks of marine reserves that consider ecological connectivity and the effects of ocean warming. Ryan Lowe spoke at China's Coastlab 2020 Conference on 'Experimental testing of ecosystem-flow interactions'.

Tiffany Morrison and Graeme Cumming were both panelists at 'What is the future research agenda on governing natural resources?' during the First Global International Association for the Study of the Commons Early Career Researcher Meeting on Institutional and Social-Ecological Systems. Ove Hoegh-Guldberg served on a high level panel for A Sustainable Ocean Economy Webinar and spoke about "The ocean: from victim to solution to climate change".

The Conversation

The Centre regularly publishes original research-based articles and commentaries in *The Conversation*, a popular online media resource.

PhD candidate Jessica Cramp was recognised as an American Association for the Advancement of Science IF/THEN ambassador as one of six statues exhibited in Central Park Zoo, New York, USA (p. 50).

AMERICAN ASSOCIATION FOR THE
ADVANCEMENT OF SCIENCE IF/THEN 2021

Throughout 2020, a total of 15 Centre researchers published 10 articles (including p23, p32). Other examples include:

Thomas Bridge, Andrea Quattrini, Andrew Baird, and Peter Cowman. *The first step to conserving the Great Barrier Reef is understanding what lives there*. 15 September 2020. https://theconversation.com/the-first-step-to-conserving-the-great-barrier-reef-is-understanding-what-lives-there-146097?utm_source=twitter&utm_medium=bylinetwitterbutton

Jon Day and Scott Heron. *'Severely threatened and deteriorating': global authority on nature lists the Great Barrier Reef as critical*. 3 December 2020. <https://theconversation.com/severely-threatened-and-deteriorating-global-authority-on-nature-lists-the-great-barrier-reef-as-critical-151275>

David Blair, David Franklin Treagust and Malcolm McCulloch. *We must fight climate change like it's World War III – here are 4 potent weapons to deploy*. 16 March 2020. <https://theconversation.com/we-must-fight-climate-change-like-its-world-war-iii-here-are-4-potent-weapons-to-deploy-131052>

Tiffany Morrison, Katrina Brown, Maria Lemos and Neil Adger. *New research reveals how Australia and other nations play politics with World Heritage sites*. 22 July 2020. <https://theconversation.com/new-research-reveals-how-australia-and-other-nations-play-politics-with-world-heritage-sites-142918>

Jodie Rummer, Bridie Allan, Charitha Pattiaratchi, Ian Bouyoucos, Irfan Yulianto and Mirjam van der Mheen. *It might be the world's biggest ocean, but the mighty Pacific is in peril*. 6 December 2020. <https://theconversation.com/it-might-be-the-worlds-biggest-ocean-but-the-mighty-pacific-is-in-peril-150745>

Media and Altmetrics

In 2020, the Centre developed and distributed 32 media releases, generating more than 7,650 news items and commentaries across the world. Centre researchers and/or their research were referenced in the media on average 21 times per day. The Centre's research was featured across multiple platforms - digital, TV, radio, and print in many of the world's most prominent news outlets, such as the *New York Times*, *Forbes*, *Rolling Stone*, *CNN*, *Washington Post* and *Scientific American*.

From February 2020, the Great Barrier Reef faced its third mass bleaching event in five years. During this time Centre researchers appeared in over 1,760 news items with a reach of >3.3. billion. Social media was also very active during this time, with the Centre's Facebook post being shared over 550 times, and included Greta Thunberg tweeting about our work.

Altmetric scores provide a metric of the attention paid to a scientific publication by tracking the media, Twitter, Facebook, blogs, and other online sources. Three Centre papers garnered Altmetric scores of over 1,200 (p82). One of those papers, co-authored by Terry Hughes, 'Rebuilding marine life' was

published in *Nature* and named Carbon Brief's 5th most featured climate paper in the media in 2020.

In 2020, eleven Centre researchers and two associates were identified as *Highly Cited Researchers* by Clarivate's Web of Science. In total, they published over 2,100 articles and received over 219,650 citations from 2016-2020.

Additional media highlights throughout 2020 include:

IFLScience (p72) – David Attenborough's "A life on our planet" carves a path out of Earth's biodiversity crisis, A Dietzel, 19 October 2020. <https://www.iflscience.com/environment/david-attenboroughs-a-life-on-our-planet-carves-a-path-out-of-earths-biodiversity-crisis>

The New York Times – *Great Barrier Reef is bleaching again. It's getting more widespread*, T. Hughes, 6 April 2020. <https://www.nytimes.com/2020/04/06/world/australia/great-barrier-reefs-bleaching-dying.html>

Forbes – *Great Barrier Reef bleaching: climate change tragedy for world natural wonder*, M. Pratchett, 7 April 2020. <https://www.forbes.com/sites/tamarathiessen/2020/04/07/great-barrier-reef-bleaching-climate-change-tragedy-natural-wonder/#52665d852472>

Brisbane Times – *Climate change 'threat multiplier' ignored in national environment laws*, A. Grech, 14 June 2020. <https://www.brisbanetimes.com.au/environment/climate-change/climate-change-threat-multiplier-ignored-in-national-environment-laws-20200612-p55213.html>

CNN – *The Great Barrier Reef has lost half its corals within 3 decades*, A. Dietzel, T. Hughes, 15 October 2020. https://edition.cnn.com/travel/article/great-barrier-reef-coral-loss-intl-scli-climate-scn/index.html?utm_content=2020-10-13T23%3A59%3A26&utm_term=link&utm_source=twCNNi&utm_medium=social

Scientific American – *Australia floats plan to better protect Great Barrier Reef*, G. Cumming, 25 August 2020. <https://www.scientificamerican.com/article/australia-floats-plan-to-better-protect-great-barrier-reef/>

Washington Post – *The Energy 202: How carbon levels hit a record high even as emissions fell during coronavirus pandemic*, T. Hughes, 5 June 2020. <https://www.washingtonpost.com/news/powerpost/paloma/the-energy-202/2020/06/05/the-energy-202-how-carbon-levels-hit-a-record-high-even-as-emissions-fell-during-coronavirus-pandemic/5ed91ba688e0fa32f82327d2/>

Finding Sustainability Podcast – *Comparative social-ecological fisheries research with Emily Darling and Georgina Gurney*, G. Gurney, 9 February 2020. <https://ici.radio-canada.ca/nouvelle/1537415/grande-barriere-de-coral-australie-rechauffement-changements-climatiques>

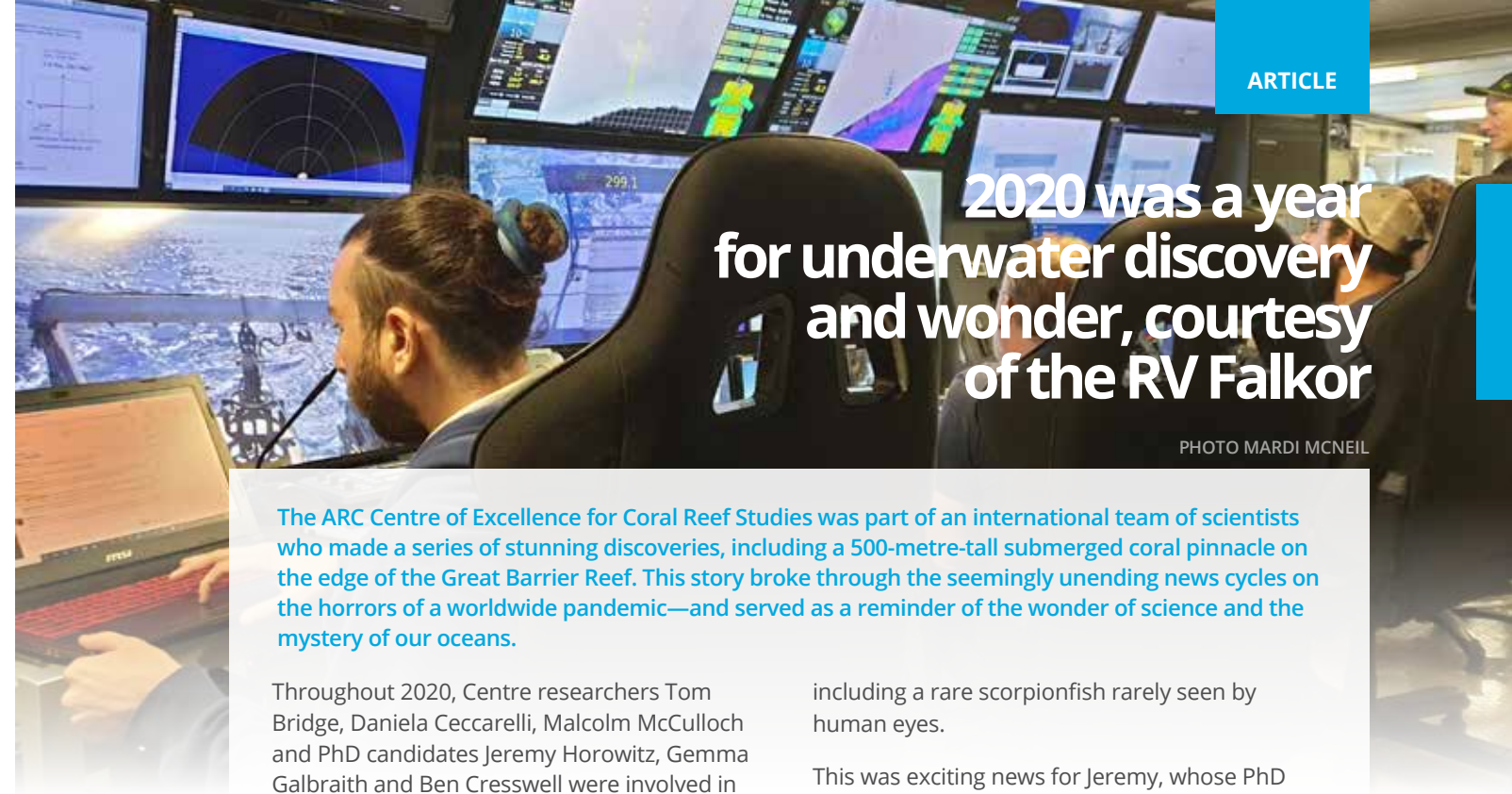
New York Post – *Great Barrier Reef enters crucial period in coral bleaching*, O. Hoegh-Guldberg, 6 March 2020. <https://nypost.com/2020/03/06/great-barrier-reef-enters-crucial-period-in-coral-bleaching/>

Radio National RN Breakfast – *Scientists discover new coral along Great Barrier Reef*, A. Baird, 22 January 2020. <https://www.abc.net.au/radionational/programs/breakfast/scientists-discover-new-coral-along-great-barrier-reef/11888552>

The Medical News – *Study: personal connections can help communities adapt to climate change*, M Barnes, 11 August 2020. <https://www.news-medical.net/news/20200811/Study-Personal-connections-can-help-communities-adapt-to-climate-change.aspx>

2020 was a year for underwater discovery and wonder, courtesy of the RV Falkor

PHOTO MARDI MCNEIL



The ARC Centre of Excellence for Coral Reef Studies was part of an international team of scientists who made a series of stunning discoveries, including a 500-metre-tall submerged coral pinnacle on the edge of the Great Barrier Reef. This story broke through the seemingly unending news cycles on the horrors of a worldwide pandemic—and served as a reminder of the wonder of science and the mystery of our oceans.

Throughout 2020, Centre researchers Tom Bridge, Daniela Ceccarelli, Malcolm McCulloch and PhD candidates Jeremy Horowitz, Gemma Galbraith and Ben Cresswell were involved in expeditions of discovery off both the **west and east coasts of Australia**.

They partnered with the Schmidt Ocean Institute (SOI), a private non-for-profit foundation advancing oceanographic research, discovery and collaborations that explore the deep sea. SOI's 83-metre research vessel, the *RV Falkor*, is a state-of-the-art research vessel fully equipped with the latest cutting-edge technology. Among the most important tools is a 3,500 kg remotely operated vehicle, the *SuBastian*, which allows scientists to explore depths up 4,500 metres. As part of SOI's mission to make ocean science accessible around the world, each dive of the *SuBastian* is live-streamed on SOI's Youtube and Facebook channels.

The first discovery of the *SuBastian* was in February 2020: deep-sea coral gardens and graveyards in the Bremer Canyon Marine Park, Western Australia. Then, in April, the team found the longest recorded sea creature—a 45m siphonophore in Ningaloo Canyon—plus 30 species new to science.

As the pandemic intensified, the SOI's *RV Falkor* left the Western Australian waters, moving east to explore and map the Coral Sea and Great Barrier Reef.

Here, the discoveries continued. In August, researchers including Jeremy, Gemma and Ben collected specimens of a range of different marine invertebrates including corals and sponges, many of which are likely to be undescribed. They also observed numerous fish species previously unknown from the region,

including a rare scorpionfish rarely seen by human eyes.

This was exciting news for Jeremy, whose PhD project uses black corals as a model system to investigate how drivers of speciation change in both vertical and horizontal dimensions.

It was October 2020 when the researchers discovered a massive detached **500-metre-tall coral reef** just off the Cape York Peninsula. They found the reef as they were mapping the northern Great Barrier Reef seabed.

"The base of the blade-like reef is 1.5km wide, then rises 500m to its shallowest depth of only 40m below the sea surface," Tom said.

And it was the first detached reef found in more than 120 years—adding to the seven other tall, detached reefs in the area, all mapped in the late 1800s. Unlike the others, this reef does not break the surface and had remained hidden, but was shown to support a huge diversity of life from corals and sponges to sharks.

Another important dimension to the expeditions was public outreach. The SOI and our Centre's researchers provided livestream commentary of the *SuBastian's* trips to the deep, participated in the SOI's *Ship to Shore* program for schools, wrote blogs, created videos, delivered presentations and engaged with social media. Centre researchers led live video streams, answering questions from people across the world, capturing imaginations at a time when COVID-19 was triggering mass lockdowns.

These collaboration and engagements highlight how much remains hidden in the depths of the oceans—and how these mysteries continue to intrigue humanity.

The Sydney Morning Herald – *There is no time to lose: Great Barrier Reef has lost half its coral*, A. Dietzel, T. Hughes, 14 October 2020. <https://www.smh.com.au/environment/climate-change/there-is-no-time-to-lose-great-barrier-reef-has-lost-half-its-corals-20201013-p564tx.html>

International Business Times Singapore – *Nutrients can worsen coral bleaching, finds study*, J. Pandolfi, 23 August 2020. <https://www.ibtimes.sg/nutrients-can-worsen-coral-bleaching-finds-study-50533>

The New York Times – *A bit surreal: the lonely plight of the Great Barrier Reef*, T. Hughes, 23 August 2020. <https://www.nytimes.com/2020/08/22/world/australia/great-barrier-reef-coronavirus.html>

Newsweek – *Deep-sea coral gardens discovered by researchers in mysterious underwater canyons*, M. McCulloch, 28 February 2020. <https://www.newsweek.com/deep-sea-coral-gardens-researchers-never-before-seen-underwater-canyons-1489758>

Phys.org – *How governments resist World Heritage 'in Danger' listings*, T. Morrison, 20 July 2020. <https://phys.org/news/2020-07-resist-world-heritage-danger.html>

Fox News – *Gardens and graveyards of coral discovered in hidden canyons off Australia's coast*, M. McCulloch, 3 March 2020. <https://www.foxnews.com/science/gardens-and-graveyards-of-coral-discovered-in-hidden-canyons-off-australias-coast>

The Economist – *Big parts of the Great Barrier Reef are dying*, T. Hughes, 18 April 2020. <https://www.economist.com/asia/2020/04/18/big-parts-of-the-great-barrier-reef-are-dying>

Gizmodo – *8 Wild examples of evolution copying itself*, D. Bellwood, 16 June 2020. <https://www.gizmodo.co.uk/2020/06/8-wild-examples-of-evolution-copying-itself/>

Radio National AM – *Widespread coral bleaching event hits the Great Barrier Reef*, O. Hoegh-Guldberg, 3 June 2020. <https://www.abc.net.au/radio/programs/am/widespread-coral-bleaching-event-hits-the-great-barrier-reef/12031916>

Radio Canada – *Le corail, victime parfaite du réchauffement planétaire*, H. Harrison, 25 February 2020. <https://ici.radio-canada.ca/nouvelle/1537415/grande-barriere-de-corail-australie-rechauffement-changements-climatiques>

MSN – *Hope in the dark for the world's coral reefs*, J. Cinner, 17 April 2020. <https://www.msn.com/en-us/news/environment/hope-in-the-dark-for-the-worlds-coral-reefs/ar-BB12Kk1M>

Hydro International – *Amazing discoveries in the submarine canyons off South-western Australia*, M. McCulloch, 10 March 2020. <https://www.hydro-international.com/content/news/deep-sea-coral-gardens-and-graveyards-discovered-in-the-submarine-canyons-off-south-western-australia>

ABC – *Great Barrier Reef bleaching concerns after hottest month of sea temperatures on record*, V. Huertas, T. Hughes, 15 March 2020. <https://www.abc.net.au/news/2020-03-15/cyclone-great-barrier-reef-bleaching-record-seas-temperatures/12050102>

Newsweek – *Enormous coral reef taller than Empire State Building discovered on Great Barrier Reef*, A. Dietzel, 26 October 2020. <https://www.newsweek.com/great-barrier-reef-coral-empire-state-building-1542066>

China Daily – *When ecosystems fail to recover*, M. McWilliam, M. Pratchett, 3 February 2020. <http://www.chinadaily.com.cn/a/202002/03/WS5e377b34a3101282172744e8.html>

Latest Nigerian News – *Great Barrier Reef may never recover from warming*, A. Dietzel, T. Hughes, 14 October 2020. <https://www.latestnigeriannews.com/news/9031991/great-barrier-reef-may-never-recover-from-warming.html>

London Evening Standard – *Great Barrier Reef experiences third bleaching event in five years*, T. Hughes, M. Pratchett, 5 May 2020. <https://www.standard.co.uk/news/world/great-barrier-reef-third-bleaching-event-five-years-a4430991.html>

The Weekend Australian – *Raised from depths, a feast for the eyes*, M. McCulloch, A. Sadekov, 6 June 2020. <https://www.theaustralian.com.au/weekend-australian-magazine/schmidt-ocean-institute-explores-vast-undersea-world-off-wa-coast/news-story/04e8a52bb91b351c5842072caa3709a3?btr=225c6b767daab2e91b66928264891166>

The Huffington Post – *Australia's Great Barrier Reef suffers its most extensive coral bleaching event*, T. Hughes, 4 June 2020. https://www.huffpost.com/entry/great-barrier-reef-coral-bleaching_n_5ed8aecc5b6ea15610b8a17

Atlas Obscura – *Turning on the lights in the ocean's twilight zone*, T. Bridge, 7 July 2020. <https://www.atlasobscura.com/articles/what-lives-in-the-twilight-zone>

The Edition – *Maldives Coral Institute successfully wraps up first 'Coral Festival'*, O. Hoegh-Guldberg, 26 February 2020. <https://edition.mv/news/15189>

The Sydney Morning Herald – *Record February heat pushes reef corals closer to big bleaching event*, T. Hughes, 5 March 2020. <https://www.smh.com.au/environment/climate-change/record-february-heat-pushes-reef-corals-closer-to-big-bleaching-event-20200305-p547bc.html>

The News – *Scientists find chink in coral-eating starfish armour*, M. Pratchett, 9 November 2020. <https://www.thenews.com.pk/print/739138-scientists-find-chink-in-coral-eating-starfish-armour>

David Attenborough's "A life on our planet" carves a path out of earth's biodiversity crisis

Rachel Funnel

PHOTO ANDREAS DIETZEL

In the poignant documentary *David Attenborough: A Life On Our Planet*, which recently aired on Netflix, the planet's favorite naturalist drew harrowing comparisons between the 1986 Chernobyl disaster and the ongoing crisis of biodiversity loss on Earth. Speaking from the condemned city, Attenborough describes how, without proper intervention, the climatic and ecological consequences of biodiversity loss could one day parallel the destruction caused by the rupture of Chernobyl's radioactive core and recent research indicates that we are already reaching a critical point.

New research published in the journal *Proceedings of the Royal Society B* has reported that populations of coral of all sizes have seen a 50 percent reduction on the Great Barrier Reef in the last 30 years. The study looked at corals across the length of the Great Barrier Reef, gathering data on their populations between 1995 and 2017. Analyses of the results revealed a sharp depreciation in corals since the 1990s in both shallow and deep-water species. The losses were most pronounced among the coral species that suffered from mass bleaching events triggered by record-breaking ocean temperatures in 2016 and 2017.

Since the close of the study's data capture in 2017, there have been further records smashed in the waters surrounding the Great Barrier Reef, as a spike in ocean temperature kicked off its **third and most widespread bleaching event** to date earlier this year.

"We measured changes in colony sizes because population studies are important for understanding demography and the corals' capacity to breed," said lead author Dr Andy Dietzel, from the ARC Centre of Excellence for Coral Reef Studies in a **statement**. "A vibrant coral population has millions of small baby corals, as well as many large ones — the big mamas who produce most of the larvae."

These findings tie in with the overarching message of Attenborough's latest release, which is that if climate-driven biodiversity loss is left to run rampant we may lose the critical ingredients required to restore ecosystems such as the Great Barrier Reef to a healthy and functional condition. With fewer large breeding adults and fewer baby corals to take their place, the resilience and capacity to recover even the world's largest reef is thrown into question.

The documentary is accented with chronological updates regarding population, **biodiversity loss**, and **atmospheric carbon**, the latter of which climbs throughout Attenborough's life starting at just 280 parts per million (ppm) in 1937 and eventually reaching a grim crescendo in 2020 of 415ppm. He explains how the fossil record reveals that a spike in this air pollutant has "always been incompatible with a stable Earth," with peaks featuring in all the mass extinction events. In the past, it took volcanic activity a million years to reach tipping point, but by dredging up and burning millions of years' worth of living organisms in the form of fossil fuels like oil and coal, we've managed to achieve the same

damage in less than 200 years. So, is the next mass extinction event on the horizon?

Climate scientists warned that **increasing atmospheric carbon** would push up global temperatures, which remained stable until around 1990. It was later discovered however that this was due to the ocean's ability to absorb the carbon we were churning out, a safety clause that ended when both air and ocean temperatures began to climb before the millennium. We know that coral bleaching happens in response to rising ocean temperatures, as the heat triggers the corals to expel the algae that live symbiotically on their surface, leaving only white, bone-like structures.

"When you first see it you think, "perhaps it's beautiful," and suddenly you realize it's tragic because what you're looking at is skeletons," Attenborough says. "Skeletons of dead creatures."

As well as losing the protection of the ocean as an effective carbon sink for our emissions, we're increasingly at risk of a drastic increase in global temperature as a result of the **ever-decreasing ice caps** in both the North and South poles. These enormous **ice sheets** act as a reflective surface sending much of the Sun's energy back into space. Without them, our already warming planet will take in that extra heat, and our sea levels will rise to an extent that threatens both human and wildlife populations. The effects of melting ice caps are already being seen among animals such as polar bears, which currently **face extinction by 2100** due to melting sea ice.

Furthermore, as long-frozen landscapes thaw they release copious amounts of **methane**, the disastrous greenhouse gas that is associated with **cattle farming** and has the potential to trigger a huge spike in global temperature. In the documentary, Attenborough explains how average temperatures have increased by 1°C (1.8°F) in his lifetime alone, and makes grim projections for where the planet could see itself in 10, 20, and 30 years as well as at the turn of the century if more isn't done to prevent climate change.

But, he grants us, there is hope. In order to turn the tide on rising global temperatures, drastic changes need to be made regarding both our use

of and occupation in the natural world. For starters, rewilding spaces now occupied by cities, farms, and suburbia could increase available plant life that can absorb harmful carbon dioxide and pump it back out as oxygen. Rewilding in farms has seen success in examples such as **Knepp Wildland** in the UK, and recent research published in the journal *Nature* has described how restoring just 30 percent of ecosystems could prevent 70 percent of predicted extinctions, protecting Earth's biodiversity.

Eating a more plant-based diet will also have great **environmental benefits**, reducing harmful emissions from livestock, which are a big source of methane, and freeing up farmland that left to return to a wilder state could both transform carbon dioxide and support more diverse ecosystems. *A Life on Our Planet* highlights how the Netherlands is paving the way for more sustainable agricultural practices, using **hydroponic farms** to increase yield while reducing demands for land, water, and harmful pesticides. And, of course, the integration of greener energy sources also earns a special mention in the documentary, with sunlight, wind, water, and geothermal energy each getting a shout out.

The issue of returning Earth to a sustainable state of being is as complex as it is pressing. While it's upon each of us to do our part in redressing the balance on climate change there still remain big barriers regarding the reluctance of industry and governments worldwide in tackling the few who constitute the greatest contributors to greenhouse gas emissions.

However, as Attenborough concludes in the documentary, this shouldn't distract us from the opportunity we still have to turn the tide on the climate crisis, support biodiversity and in turn save our own species by creating a sustainable planet enriched with plant, animal, and human life.

To use the icon's own words, "Just imagine that."



(permission granted): <https://www.iflscience.com/environment/david-attenboroughs-a-life-on-our-planet-carves-a-path-out-of-earths-biodiversity-crisis/>

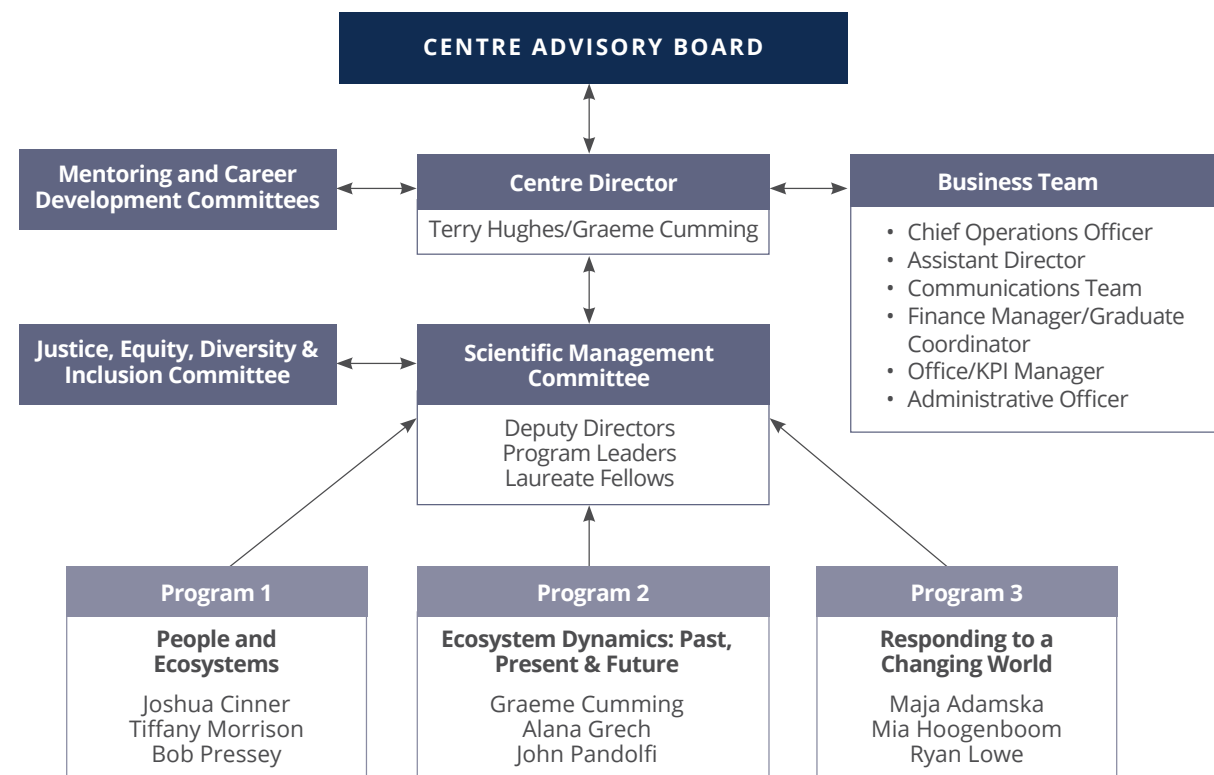
Governance

A key objective of the Centre is to foster sustainable use, adaptive governance and effective management of the world's coral reefs. The governance structures of the Centre reflect this objective and engage stakeholders in planning, research program development and knowledge exchange. Responsibilities and terms of reference at each level of governance are clearly defined.

James Cook University is the Administering Organisation with the Centre Director, reporting directly to the Provost, Professor Chris Cocklin. In July 2020, Terry Hughes retired as Director and Graeme Cumming was appointed as the new Centre Director (p78). Operations are managed by the Chief Operations Officer, Jennifer Lappin, in consultation with the Centre Director and Assistant Director, Alana Grech, supported by an effective business team. Further support is provided by administrative staff at

The Australian National University, The University of Queensland and The University of Western Australia.

The diagram below illustrates the Centre's governance structure and relationships. The Centre Director oversees the Centre's research programs and liaises regularly with the two Deputy Directors, Ove Hoegh-Guldberg (UQ) and Malcolm McCulloch (UWA). Chief Investigators, research fellows and students are located across three Divisions of James Cook University, and at the Centre's other university nodes. Partner Investigators are based at the Australian Institute of Marine Science, the Great Barrier Reef Marine Park Authority and in leading international research institutions (p60). Adjunct researchers based in institutions across the world make a significant contribution to the Centre's research.



The Centre Advisory Board and the Scientific Management Committee comprise the Centre's two principal governance committees. Eminent international researchers chair both committees and are provided with the support of the Chief Operations Officer, Jennifer Lappin, as Secretary.

The Centre also supports two career development committees, which are run by Centre graduate students and early career researchers, integral components of the Centre's research culture and operations. In consultation with the Assistant Director, Alana Grech, Chief Operations Officer, Jennifer Lappin and the Graduate Coordinator,

Olga Bazaka, these committees develop the annual professional development and mentoring plan for early career researchers. They are responsible for the organisation of annual retreats, training workshops and other career development activities (p49). In 2020, a group of Centre researchers, comprising staff and students established the **Justice, Equity Diversity and Inclusion (JEDI) Committee**, inviting all Centre people to join. The Committee's vision is for the Centre to be a leader in addressing systemic inequalities that exist in academia, including in the workplace and in research practice. The Committee meets regularly and will report to the Centre's Scientific Management Committee.



Professor Hugh Possingham FAA

Centre Advisory Board

The Centre Advisory Board provides high-level strategic advice to the Centre Director, and facilitates and advises on strengthening linkages between the Centre, stakeholders, government and industry. The Centre Director and Chief Operations Officer provide the link between the Centre Advisory Board, the Scientific Management Committee and Centre operations.

Membership of the Centre's Board reflects the Centre's strong multi-disciplinary research activities and includes a distinguished international researcher as Chair, the Chief Executive Officer of the Great Barrier Reef Marine Park Authority, the Chief Executive Officer of the Australian Institute of Marine Science, a senior representative from an international non-government organisation, WorldFish.

In 2019 we said farewell to our long-standing and highly distinguished Chair, Professor Brian Walker FAA. We are pleased to report that in 2020, Professor Hugh Possingham FAA accepted our invitation to be the new Chair of the Centre's Advisory Board. Hugh is Queensland's Chief Scientist and is an internationally acclaimed scientist in the field of conservation biology. Hugh brings a wealth of leadership experience at both a national and international level.

Hugh is a conservation scientist and mathematician who has held positions in the university, public and not-for-profit sectors. He is a Foreign Associate of the US National Academy of Sciences and a Fellow of the Australian Academy of Science. Hugh completed his PhD at Oxford University in 1987 as a Rhodes Scholar and was most recently the Chief Scientist at The Nature Conservancy, a global conservation



PHOTO TOM BRIDGE

organisation operating in 79 countries. A winner of two Eureka Prizes, his most significant contribution to conservation was the co-development of Marxa, software first used to rezone the Great Barrier Reef, and now used in almost every country in the world to inform the expansion of their marine and terrestrial protected area systems. Hugh has worked with all levels of government and many not-for-profit organisations, pro bono, to improve the state of Australia's threatened species and habitats. He has supervised over 200 honours students, doctoral candidates and postdoctoral fellows. He has published >650 peer-reviewed publications, with >30 in *Nature* and *Science*.

Given the COVID-19 pandemic and associated travel restrictions, and the delays in the recruitment of a new Chair, Board discussions in 2020 were largely informal. A key focus of these discussions during 2020 was providing advice on preparing the Centre for longer term business continuity in 2021 to 2023, and in establishing associated governance arrangements.

Membership of the Centre Advisory Board:

Professor Hugh Possingham *FAA* (Chair)
Queensland Chief Scientist

Dr Philippa Cohen
Research Program Leader
Resilient Small-Scale Fisheries
WorldFish
Malaysia

Professor Graeme Cumming
(from July 2020)/
Distinguished Professor Terry Hughes *FAA*
(to July 2020)
Centre Director
ARC Centre of Excellence for Coral Reef Studies

Dr Britta Schaffelke
Research Program Leader, A Healthy and Sustainable Great Barrier Reef
Australian Institute of Marine Science
(Delegate of Dr Paul Hardisty, Chief Executive Officer)

Josh Thomas
Chief Executive Officer
Great Barrier Reef Marine Park Authority

Scientific Management Committee

The Centre's Scientific Management Committee (SMC) is responsible for stewardship of the Centre's scientific research and high-level operational decisions. The Committee is chaired by distinguished social scientist and pioneer of interdisciplinary research, Professor Katrina Brown, from the University of Exeter, United Kingdom. Other members are the Centre's Director and Deputy Directors, leaders of each of the Centre's Research Programs, the Centre's current Australian Laureate Fellows and the Chief Scientist of the Great Barrier Reef Marine Park Authority. Membership of the SMC is continuously evolving. In 2020, we welcomed Distinguished Professor Joshua Cinner as a new program leader, replacing Terry Hughes, who stood down at the end of 2019. Graeme Cumming was appointed as a Program 2 leader following Sean Connolly's move to the Smithsonian Tropical Research Institution (STRI). Distinguished Professor David Bellwood *FAA* joined the Committee following the award of his Australian Laureate Fellowship. Kate Brown announced her retirement from the University of Exeter during 2020. We are delighted that Kate will continue as Professor Emerita and remain Chair of the Scientific Management Committee.

In 2020, SMC meetings were conducted in Zoom format on 1st April, 8th July, and 14th October. A key focus of discussions in 2020 was the COVID-19 pandemic and its implications for Centre researchers, particularly students and providing the necessary support for them to continue their research. Continuing priorities were research planning, business continuity, legacy activities and continuing to produce high quality research outputs and maintain engagement with key stakeholders. Members of the SMC continued to take a key role in providing advice to the Queensland and Australian Governments on the *Reef 2050 Plan*.

Membership of the Scientific Management Committee:

Professor Katrina Brown (Chair)
Chair in Social Science
University of Exeter
United Kingdom

Associate Professor Maja Adamska
Leader, Research Program 3
Australian National University

Professor David Bellwood *FAA*
Australian Laureate Fellow
James Cook University

Distinguished Professor Joshua Cinner *FASSA*
Leader, Research Program 1
James Cook University

Professor Graeme Cumming
Centre Director (from July 2020) and Leader,
Research Program 2
James Cook University

Associate Professor Alana Grech
Leader, Research Program 2
James Cook University

Professor Ove Hoegh-Guldberg *FAA*
Deputy Director
University of Queensland

Associate Professor Mia Hoogenboom
Leader, Research Program 3
James Cook University

Distinguished Professor Terry Hughes *FAA*
Centre Director (to July 2020)
James Cook University

Professor Ryan Lowe
Leader, Research Program 3
University of Western Australia

Professor Malcolm McCulloch *FAA FRS*
Deputy Director
University of Western Australia

Professor Tiffany Morrison
Leader, Research Program 1
James Cook University

Professor John Pandolfi
Leader, Research Program 2
University of Queensland

Distinguished Professor Bob Pressey *FAA*
Leader, Research Program 1
James Cook University

Dr David Wachenfeld
Chief Scientist
Great Barrier Reef Marine Park Authority

PROFESSOR
Terry Hughes
 RETIRES AS CENTRE DIRECTOR



“... cited more than 70,000 times—he has led contributions to transformative and transdisciplinary research on tropical reefs in the past three decades.”

In July 2020, Professor Terry Hughes retired from his 15-year role as the Director of the ARC Centre of Excellence for Coral Reef Studies.

Since establishing the Centre in 2005, Terry nurtured and transformed it into a world-leading “mecca for coral reef research”. He oversaw its enormous growth and huge success in every aspect of its operations, including more than a doubling of graduate student numbers, a quadrupling of publication output and doubling of income.

A distinguished researcher himself, Terry’s scientific publications are cited more than 70,000 times—he has led contributions to transformative and transdisciplinary research on tropical reefs in the past three decades.

Terry is internationally regarded as the foremost expert on the Great Barrier Reef—and he is a fearless voice for its future. He anticipated, witnessed and studied in real-time at the cellular, individual, population and community levels the bleaching events of 2016, 2017 and 2020, as well as the resulting impacts.

No other research group in the world has advanced the knowledge of the global challenge of climate change for marine ecosystems to the extent achieved by Terry and the team he led throughout the bleaching events.

Terry also pioneered the concept of no-take zones (marine reserves) as tools for managing the resilience of coral reefs to climate change. To this day, his concept of building resilience to unwanted regime-shifts continues to guide reef management across the globe. He also played an important scientific and political role in the radical re-zoning of the Great Barrier Reef in 2004.

He has received an innumerable national and international honours throughout his career, recognising him as an outstanding researcher,

a committed mentor and research leader. Most recently, in February 2020, Terry was awarded a *Frontiers of Knowledge Award* from the BBVA Foundation, “for cutting-edge work that is cross-disciplinary and cross border, and... goes beyond research to seek and propose solutions”.

He will remain a Chief Investigator in the Centre, keen to concentrate entirely on his research which plays a key role in international efforts towards sustainable marine ecosystems.

We sincerely thank Terry for his years of commitment to the Centre—which includes perhaps not blood but most certainly his sweat and tears—and for his clear and compelling vision, wisdom, integrity and generosity.

Looking forward, the Centre is delighted the leadership has transferred to the strong and capable hands of Professor Graeme Cumming.

Since his appointment to the Centre in 2015 as a Professorial Coral Reef Research leader, Graeme has strongly influenced the research direction of the Centre by introducing new approaches and interdisciplinary thinking. His background is in ecology, biodiversity, and conservation—not just in the marine realm. Graeme’s work has already won many highly competitive international awards. His unique vision and the application of skills and insights to ground-breaking research has demonstrably benefited the research of numerous postgraduate students, as well as early and mid-career researchers across the Centre’s three research programs.

We look forward to Graeme’s guidance and expert navigation of a new direction, pushing existing boundaries in both ecology and sustainability science, which will expand the influence of the Centre at the interface between ecology and social science.

Membership

In 2020, the ARC Centre’s membership comprised 65 Chief Investigators, Research Fellows and Associates; 26 Partner Investigators, resident international scholars and adjunct researchers; and 156 research students (p49). Eight of the Centre’s Research Fellows were funded by ARC Fellowships (Australian Laureate, Future and DECRA), one by an Advance Queensland Fellowship and one by an Australian Biological Resources Study Fellowship.

In 2020, the ARC Centre welcomed nine new Research Fellows and Associates: Carolina Castro-Sanguino, Jennifer Donelson, Caitie Kuempel, Renato Morais, Eugenia Sampayo, Jodie Schlaefer, Patrick

Smallhorn-West, Greg Torda and Arnold van Rooijen. Five of these new recruits are women and the Centre has exceeded its target of 50:50 gender equity in research fellow recruitment.

We also said farewell to ten researchers who have taken up new positions around the globe, extending the ARC Centre’s network of alumni collaborators: Natalia Andrade Rodriguez, Kristen Brown, Carolina Castro-Sanguino, Sean Connolly, Rebecca Green, Björn Illing, Danika Kleiber, Vanessa Messmer, Veronica Radice and Cristian Rojas. We wish them well in their future research careers!

Chief Investigators and Research Fellows

Professor Graeme Cumming
 Centre Director (from July 2020)
 Chief Investigator
 James Cook University

Professor Terry Hughes
 Centre Director (to July 2020)
 Chief Investigator
 James Cook University

Associate Professor Maja Adamska
 ARC Future Fellow
 Chief Investigator
 Australian National University

Dr Jorge Álvarez-Romero
 Research Fellow
 James Cook University

Dr Kristen Anderson
 Research Fellow
 James Cook University and Australian
 Institute of Marine Science

Dr Natalia Andrade Rodriguez
 Research Associate
 James Cook University

Professor Andrew Baird
 Chief Investigator
 James Cook University

Dr Michele Barnes
 Discovery Early Career Researcher
 Award (DECRA)
 James Cook University

Professor David Bellwood
 ARC Australian Laureate Fellow
 Chief Investigator
 James Cook University

Dr Brock Bergseth
 Research Fellow
 James Cook University

Dr Yves-Marie Bozec
 Research Fellow
 University of Queensland

Dr Tom Bridge
 Discovery Early Career Researcher
 Award (DECRA)
 James Cook University and
 Queensland Museum

Professor Jon Brodie
 Research Fellow
 James Cook University

Dr Kristen Brown
 Research Associate
 University of Queensland

Dr Iain Caldwell
 Research Associate
 James Cook University

Dr Carolina Castro-Sanguino
 Research Associate
 University of Queensland

Dr Severine Choukroun
 Research Associate
 James Cook University

Professor Joshua Cinner
 ARC Future Fellow
 Chief Investigator
 James Cook University

Professor Sean Connolly
 Chief Investigator
 James Cook University

Dr Peter Cowman
 Discovery Early Career Researcher
 Award (DECRA)
 James Cook University

Dr Jennifer Donelson
 ARC Future Fellow
 James Cook University

Associate Professor Sophie Dove
 Chief Investigator
 University of Queensland

Associate Professor Alana Grech
 Research Fellow
 James Cook University

Dr Rebecca Green
Research Associate
University of Western Australia

Dr Georgina Gurney
Research Fellow
James Cook University

Dr April Hall
Advance Queensland Research Fellow
James Cook University

Dr Vanessa Haller-Bull
Research Associate
University of Queensland

Dr Hugo Harrison
Research Fellow
James Cook University and Australian
Institute of Marine Science

Associate Professor Scott Heron
Research Associate
James Cook University

Dr Karlo Hock
Research Associate
University of Queensland

Professor Ove Hoegh-Guldberg
Deputy Director
Chief Investigator
University of Queensland

Professor Andrew Hoey
Research Fellow
James Cook University

Associate Professor Mia Hoogenboom
Chief Investigator
James Cook University

Professor Geoffrey Jones
Chief Investigator
James Cook University

Dr Sun Kim
Research Fellow
University of Queensland

Professor Michael Kingsford
Chief Investigator
James Cook University

Dr Danika Kleiber
Research Fellow
James Cook University and WorldFish,
Malaysia

Dr Caitie Kuempel
Research Fellow
University of Queensland

Dr Jacqueline Lau
Research Fellow
James Cook University and WorldFish,
Malaysia

Professor Ryan Lowe
Chief Investigator
University of Western Australia

Dr Robert Mason
Research Associate
University of Queensland

Professor Malcolm McCulloch
Deputy Director
Chief Investigator
University of Western Australia

Dr Vanessa Messmer
Research Associate
James Cook University

Professor David Miller
Chief Investigator
James Cook University

Dr Renato Morais
Research Associate
James Cook University

Professor Tiffany Morrison
Chief Investigator
James Cook University

Professor Peter Mumby
Chief Investigator
University of Queensland

Professor Philip Munday
Chief Investigator
James Cook University

Professor John Pandolfi
Chief Investigator
University of Queensland

Professor Morgan Pratchett
Chief Investigator
James Cook University

Professor Bob Pressey
Chief Investigator
James Cook University

Dr Veronica Radice
Research Associate
University of Queensland

Dr George Roff
Research Fellow
University of Queensland

Dr Cristian Rojas
Research Fellow
James Cook University

Associate Professor Jodie Rummer
Research Fellow
James Cook University

Professor Garry Russ
Chief Investigator
James Cook University

Dr Aleksey Sadekov
Research Fellow
University of Western Australia

Dr Eugenia Sampayo
Australian Biological Resources Study
Research Fellow
University of Queensland

Dr Jodie Schlaefer
Research Associate
James Cook University

Dr Patrick Smallhorn-West
Research Associate
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Malaysia

Dr Tim Staples
Research Fellow
University of Queensland

Dr Greg Torda
Discovery Early Career Researcher
Award (DECRA)
James Cook University

Dr Arnold van Rooijen
Research Associate
University of Western Australia

Dr Sue-Ann Watson
Research Fellow
James Cook University and Queensland
Museum

Dr Kennedy Wolfe
Research Associate
University of Queensland

Resident International Scholars

Dr Jamie Caldwell
Research Fellow
NASA/NOAA/University of Hawai'i, USA

Dr Gal Eyal
Marie Skłodowska-Curie Fellow
Israel

Dr Björn Illing
Deutsche Forschungsgemeinschaft (DFG)
Fellow
Germany

Dr Bruna Luz
Federal University of Paraná
Brazil

Dr David Mills
Senior Research Fellow
WorldFish, Malaysia

Dr Sharon Wismer
Swiss National Science Foundation
Postdoctoral Fellow
Switzerland

Partner Investigators and Adjunct Researchers

Dr Vanessa Adams
University of Tasmania

Dr Philippa Cohen
WorldFish, Malaysia

Professor Nick Graham
Lancaster University, United Kingdom

Dr Alison Green
King Abdullah University of Science
and Technology

Dr Richard Hamilton
The Nature Conservancy

Dr Tessa Hempson
Oceans Without Borders

Professor Christina Hicks
Lancaster University, United Kingdom

Dr Anne Hoggett
Lizard Island Research Station

Dr James Kerry
Great Barrier Reef Marine Park
Authority

Professor Janice Lough
Australian Institute of Marine Science

Professor Tim McClanahan
Wildlife Conservation Society, Kenya

Dr Laurence McCook
World Wide Fund for Nature, China

Dr Aurélie Moya
University of Konstanz, Germany

Professor Stephen Palumbi
Stanford University, USA

Dr Serge Planes
University of Perpignan, France

Professor Timothy Ravasi
Okinawa Institute of Science and
Technology, Japan

Dr David Wachenfeld
Great Barrier Reef Marine Park
Authority

Dr Peter Waldie
The Nature Conservancy

Dr Rebecca Weeks
ARC Centre of Excellence alumni

Professor David Yellowlees
Emeritus Professor

Graduate Students (see page 51)

Research Support Staff

Dr Rene Abesamis
James Cook University

Stacy Bierwagen
James Cook University

Casey Bowden
James Cook University

Carlin Bowyer
University of Western Australia

Dr Ciemon Caballes
James Cook University

Adriana Campili
University of Queensland

Aaron Chai
University of Queensland

Sage Fitzgerald
James Cook University

Dr Carrie Sims
University of Queensland

Joanne Moneghetti
James Cook University

Dr Allison Paley
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Pete Scott
University of Western Australia

Dr Annamieke Van Den Heuvel
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Jennifer Lappin
Chief Operations Officer
James Cook University

Associate Professor Alana Grech
Assistant Director
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Olga Bazaka
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Coordinator
James Cook University

Dr Rose Berdin
Administrative Officer
University of Western Australia

Vivian Doherty
Events Co-ordinator and KPI Officer
James Cook University

Rosanna Griffith-Mumby
Administrative Officer
University of Queensland

Melissa Lyne
Media Manager
Sydney

Dr Maria Nayfa
Digital Communications Officer
James Cook University

Janet Swanson
Administrative Officer
James Cook University

Hayley Ware
Project Officer
University of Queensland

Publications

In 2020, researchers from the ARC Centre of Excellence for Coral Reef Studies produced 421 publications, comprising 375 journal articles, 10 book chapters, 14 conference proceedings and 22 reports. Since 2014, publications have increased >36%.

Centre researchers published 167 articles in journals with an Impact Factor greater than four, including 38 in prestige journals – *Nature* and other *Nature* journals, *Science*, *Science Advances*, *Communication Biology*, *Microbiome*, *ISME J*, *Proceedings of the National Academy of Sciences (PNAS)* and *Global Environmental Change*. The average Impact Factor for all 375 journal articles in 2020 was 5.5. The Centre's research outputs were published this year in a total of 150 journal titles, spanning many fields of research and reflecting the multidisciplinary breadth of the Centre's activities.

According to *Scopus*, Centre researchers were collectively cited 70,065 times in 2020, 35 researchers were cited more than 500 times each and 22 had more than 1000 citations during the year.

The seven articles published in 2020 that received the highest Altmetric scores for ARC Centre publications were:

Duarte, CM, Agusti, S, Barbier, E, Britten, GL, Castilla, JC, Gattuso, JP, Fulweiler, RW, Hughes, TP, Knowlton, N, Lovelock, CE and Lotze, HK (2020). Rebuilding marine life. *Nature* 580(7801): 39-51.

Altmetric: 2,854 (referenced by 3 policy sources, 190 news outlets, tweeted by 1,816 individuals)

Dietzel, A, Bode, M, Connolly, SR and Hughes, TP (2020). Long-term shifts in the colony size structure of coral populations along the Great Barrier Reef. *Proceedings of the Royal Society B* 287(1936): 20201432.

Altmetric: 1,706 (picked up by 94 news outlets, tweeted by 1,336 individuals, referenced by 16 blogs)

MacNeil, MA, Chapman, DD, Heupel, M, Simpfendorfer, CA, Heithaus, M, Meekan, M, Harvey, E, Goetze, J, Kiszka, J, Bond, ME, Currey-Randall, LM... and Cinner, JE (2020). Global status and conservation potential of reef sharks. *Nature* 583(7818): 801-806.

Altmetric: 1,241 (picked up by 82 news outlets, tweeted by 737 individuals, referenced in 12 blogs)

Corlett, RT, Primack, RB, Devictor, V, Maas, B, Goswami, VR, Bates, AE, Koh, LP, Regan, TJ, Loyola, R, Pakeman, RJ, Cumming, GS, Pidgeon, A, Johns, D and Roth, R (2020). Impacts of the coronavirus pandemic on biodiversity conservation. *Biological Conservation* 246: 108571.

Altmetric: 705 (picked up by 47 news outlets, tweeted by 451 individuals, referenced in 8 blogs)

Bollati, E, D'Angelo, C, Alderdice, R, Pratchett, M, Ziegler, M and Wiedenmann, J (2020). Optical feedback loop involving dinoflagellate symbiont and scleractinian host drives colorful coral bleaching. *Current Biology* 30(13): 2433-2445.

Altmetric: 554 (picked up by 51 news outlets, tweeted by 135 individuals, referenced in 10 blogs)

Cinner, JE, Zamborain-Mason, J, Gurney, GG, Graham, NA, MacNeil, MA, Hoey, AS, Mora, C, Villéger, S, Maire, E, McClanahan, TR, Maina, JM...and Mouillot, D (2020). Meeting fisheries, ecosystem function, and biodiversity goals in a human-dominated world. *Science* 368(6488): 307-311.

Altmetric: 498 (referenced by 1 policy source, picked up by 26 news outlets, tweeted by 430 individuals)

França, FM, Benkwitt, CE, Peralta, G, Robinson, JP, Graham, NA, Tylianakis, JM, Berenguer, E, Lees, AC, Ferreira, J, Louzada, J and Barlow, J (2020). Climatic and local stressor interactions threaten tropical forests and coral reefs. *Philosophical Transactions of the Royal Society B* 375(1794): 20190116.

Altmetric: 460 (picked up by 43 news outlets, tweeted by 96 individuals, mentioned in 9 blogs)

2020 Publications

Book Section (10)

- Bouyoucos, IA and Rummer, JL (2020). Improving "Shark Park" protections under threat from climate change using the Conservation Physiology Tool Box. In: Cooke, SJ, Madliger, CL, Love, O.P., and Franklin, CE. (eds). *Conservation Physiology*, Oxford University Press, 185-204 pp.
- Cooke, SJ, Madliger, CL, Bergman, J, Nguyen, VM, Landsaman, SJ, Love, OP, Rummer, JL and Franklin, CE (2020). Optimism and opportunities for conservation physiology in the anthropocene: a synthesis and conclusions. In: Cooke, SJ, Madliger, CL, Love, O.P., and Franklin, CE. (eds). *Conservation Physiology*, Oxford University Press, 319-329 pp.
- Cumming, DHM and Cumming, GS (2020). One Health: une perspective écologique et de conservation. In: Zinsstag, J, Schelling, E, Waltner-Toews, D, Whittaker, MA and Tanner, M. (eds). *One Health, Une Seule Santé*, Routledge, 69-83 pp.
- Johnson, JE, Allain, V, Basel, B, Bell, JD, Chin, A, Dutra, LXC, Hooper, E, Loubser, D, Lough, J, Moore, BR and Nicol, S (2020). Impacts of climate change on marine resources in the Pacific Island region. In: L., K. (ed). *Climate Change and Impacts in the Pacific*, Springer Climate, Springer, Cham, 359-402 pp.
- Laubenstein, TD and Rummer, JL (2020). Communication in conservation physiology: linking diverse stakeholders, promoting public engagement, and encouraging application. In: Cooke, SJ, Madliger, CL, Love, O.P., and Franklin, CE. (eds). *Conservation Physiology*, Oxford University Press, 303-317 pp.
- Morrison, TH (2020). Polycentricity. In: Morin, J-F and Orsini, A. (eds). *Essential Concepts of Global Environmental Governance*, Routledge, 188-190pp.

- Rummer, JL and Brauner, CJ (2020). Gas Exchange. In: Currie, S and Evans, DH. (eds). *The Physiology of Fishes*, CRC Press/Taylor and Francis Group, 33-45pp.
- Shocket, MS, Anderson, CB, Caldwell, JM, Childs, ML, Couper, LI, Han, S, Harris, MJ, Howard, ME, Kain, MP, MacDonald, AJ, Nova, N and Mordecai, EA (2020). Environmental drivers of vector-borne diseases. In: Drake, JM, Bonsall, M and Strand, M. (eds). *Population biology of vector-borne diseases*, Oxford University Press, Oxford, United Kingdom, 85-119pp.
- Wolfe, K, Anthony, K, Babcock, RC, Bay, L, Bourne, DG, Burrows, D, Byrne, M, Deaker, DJ, Diaz-Pulido, G, Frade, PR, Gonzalez-Rivero, M, Hoey, A, Hoogenboom, M, McCormick, MI, Ortiz, J, Razak, T, Richardson, AJ, Roff, G, Sheppard-Brennand, H, Stella, J, Thompson, A, Watson, SA, Webster, N, Audas, D, Beeden, R, Carver, J, Cowlishaw, M, Dyer, M, Groves, P, Horne, D, Thiault, L, Vains, J, Wachenfeld, D, Weekers, D, Williams, GJ and Mumby, PJ (2020). Priority species to support the functional integrity of coral reefs. In: Hawkins, SJ, Allcock, AL, Bates, AE, Evans, AJ, Firth, LB, McQuaid, CD, Russell, BD, Smith, IP, Swearer, SE and Todd, PA. (eds). *Oceanography and Marine Biology*, Taylor & Francis, CRC Press, 79-318 pp.
- Yelenik, S, D'Antonio, C, Rehm, E and Caldwell, I (2020). Multiple feedbacks due to biotic interactions across trophic levels can lead to persistent novel conditions that hinder restoration. In: Traveset A and DM, R. (eds). *Plant invasions: the role of biotic interactions*, CAB International, Wallingford, UK, 402-420 pp.

Conference Proceedings (14)

- Bainbridge, ZT, Brodie, JE, Lewis, SE, Waterhouse, J and Wilkinson, SN (2020). Utilising catchment modelling as a tool

for monitoring reef rescue outcomes in the Great Barrier Reef catchment area. In *18th World IMACS Congress and MODSIM 2009 - International Congress on Modelling and Simulation: Interfacing Modelling and Simulation with Mathematical and Computational Sciences, Proceedings*. Cairns Convention Centre, Cairns, Australia.

- Cuttler, MW, Branson, P, Vos, K, O'Leary, M, Hansen, JE, Browne, N and Lowe, R (2020). Drivers of reef island morphodynamics revealed through high temporal resolution satellite imagery. In *Ocean Science Meeting San Diego, CA, USA, AGU*.
- Cyronak, T, Takeshita, Y, Schulz, K, Albright, R, Caldeira, K, Eyre, B, Griffin, AJ, Koweeck, D, de Orte, MR and Wolfe, K (2020). Re-evaluating total alkalinity (TA) and dissolved inorganic carbon (DIC) relationships in dynamic coral reef systems. In *Ocean Science Meeting San Diego, CA, USA, AGU*.
- de Orte, MR, Koweeck, D, Griffin, AJ, Wolfe, K, Takeshita, Y, Cyronak, T, Albright, R, Szmant, AM, Whitehead, RF and Caldeira, K (2020). Turf algae on dead corals: daytime calcification and nighttime dissolution. In *Ocean Science Meeting San Diego, CA, USA, AGU*.
- DeCarlo, TM, Harrison, HB, Ellis, J, Gajdzik, L, Coker, DJ and Berumen, ML (2020). The role of ocean currents in modulating coral bleaching susceptibility. In *Ocean Science Meeting San Diego, CA, USA, AGU*.
- Fitzgerald, L, Harrison, HB, Gatins, R, Saenz-Agudelo, P and Jones, GP (2020). Habitat turnover of host anemones *Stichodactyla gigantea* and *Heteractis magnifica* affect the *Amphiprion percula* population. In *Ocean Science Meeting San Diego, CA, USA, AGU*.
- Grimaldi, C, Lowe, R, Benthuyesen, J and Green, R (2020). Non linear interactions between waves

- and tides on a coral reef atoll. In *Ocean Science Meeting* San Diego, CA, USA, AGU.
8. Gruber, R, Lowe, R and Falter, J (2020). Tidal forcing of nutrient uptake on coral reefs: field and modelling study from a tide-dominated system. In *Ocean Science Meeting* San Diego, CA, USA, AGU.
 9. Lewis, SE, Sherman, BS, Bainbridge, ZT, Brodie, JE and Cooper, M (2020). Modelling and monitoring the sediment trapping efficiency and sediment dynamics of the Burdekin Falls Dam, Queensland, Australia. In *18th World IMACS Congress and MODSIM 2009 - International Congress on Modelling and Simulation: Interfacing Modelling and Simulation with Mathematical and Computational Sciences, Proceedings*. Cairns Convention Centre, Cairns, Australia.
 10. Lowe, R, Buckley, ML, Altomare, C, Rijnsdorp, DP, Yao, Y, Suzuki, T and Bricker, J (2020). A detailed investigation of surf zone hydrodynamics using smoothed particle hydrodynamics simulations. In *Ocean Science Meeting* San Diego, CA, USA, AGU.
 11. Neto, N, Pomeroy, A, Reidenbach, MA, Ghisalberti, M and Lowe, R (2020). Measuring hydrodynamics and sediment resuspension in seagrass meadows. In *Ocean Science Meeting* San Diego, CA, USA, AGU.
 12. Rahman, MJ, Wahab, MA, Nahiduzzaman, M, Haque, ABMM and Cohen, P (2020). Hilsa fishery management in Bangladesh. In *IOP Conf. Series: Earth and Environmental Science*.
 13. Schoepf, V, D'Olivo, J, Rigal, C, Jung, M and McCulloch, M (2020). Impacts of heat stress on the calcifying fluid chemistry and trace element composition of corals from thermally variable reefs. In *22nd EGU General Assembly* Online.
 14. Thomas, C, Hart, B, Nicholson, A, Grace, M, Brodie, J and Pollino, C (2020). Development of criteria for simplifying ecological risk models. In *MODSIM 2005 - International Congress on Modelling and Simulation: Advances and Applications for Management and Decision Making, Proceedings*. Melbourne University, Melbourne, Australia.
- Journal Article (375)**
1. Abesamis, RA, Utzurrum, JAT, Raterta, LJJ and Russ, GR (2020). Shore-fish assemblage structure in the central Philippines from shallow coral reefs to the mesophotic zone. *Marine Biology* 167: 185.
 2. Adams, H, Adger, WN, Ahmad, S, Ahmed, A, Begum, D, Matthews, Z, Rahman, MM, Nilsen, K, Gurney, GG and Streatfield, PK (2020). Multi-dimensional well-being associated with economic dependence on ecosystem services in deltaic social-ecological systems of Bangladesh. *Regional Environmental Change* 20(2): 42.
 3. Aeby, GS, Howells, E, Work, T, Abrego, D, Williams, GJ, Wedding, LM, Caldwell, JM, Moritsch, M and Burt, JA (2020). Localized outbreaks of coral disease on Arabian reefs are linked to extreme temperatures and environmental stressors. *Coral Reefs* 39: 829-846.
 4. Albouy, C, Delattre, V, Donati, G, Frolicher, TL, Albouy-Boyer, S, Rufino, M, Pellissier, L, Mouillot, D and Leprieux, F (2020). Global vulnerability of marine mammals to global warming. *Scientific Reports* 10(1): 4257.
 5. Allan, BJM, Illing, B, Fakan, EP, Narvaez, P, Grutter, AS, Sikkell, PC, McClure, EC, Rummer, JL and McCormick, MI (2020). Parasite infection directly impacts escape response and stress levels in fish. *Journal of Experimental Biology* 223(16): 1-8.
 6. Alsharif, NA, Aleisa, FA, Liu, G, Ooi, BS, Patel, N, Ravasi, T, Merzaban, JS and Kosel, J (2020). Functionalization of magnetic nanowires for active targeting and enhanced cell-killing efficacy. *ACS Applied Bio Materials* 3(8): 4789-4797.
 7. Anthony, KRN, Helmstedt, KJ, Bay, LK, Fidelman, P, Hussey, KE, Lundgren, P, Mead, D, McLeod, IM, Mumby, PJ, Newlands, M, Schaffelke, B, Wilson, KA and Hardisty, PE (2020). Interventions to help coral reefs under global change-a complex decision challenge. *PLoS One* 15(8): e0236399.
 8. Anton, A, Geraldi, NR, Lovelock, CE, Apostolaki, ET, Bennett, S, Cebrian, J, Krause-Jensen, D, Marbà, N, Martinetto, P, Pandolfi, JM, Santana-Garcon, J and Duarte, CM (2020). Reply to: Indiscriminate data aggregation in ecological meta-analysis underestimates impacts of invasive species. *Nature Ecology and Evolution* 4(3): 315-317.
 9. Archibald, CL, Barnes, MD, Tulloch, AIT, Fitzsimons, JA, Morrison, TH, Mills, M and Rhodes, JR (2020). Differences among protected area governance types matter for conserving vegetation communities at-risk of loss and fragmentation. *Biological Conservation* 247: 1-9.
 10. Arrigoni, R, Berumen, ML, Mariappan, KG, Beck, PSA, Hulver, AM, Montano, S, Pichon, M, Strona, G, Terraneo, TI and Benzoni, F (2020). Towards a rigorous species delimitation framework for scleractinian corals based on RAD sequencing: the case study of *Leptastrea* from the Indo-Pacific. *Coral Reefs* 39(4): 1001-1025.
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Activity Plan

1 Research

- a. Continue to conduct world-leading, innovative, transdisciplinary research that increases the Centre's international profile.
- b. Grow focus on research that emphasises an interdisciplinary approach to governance, resilience and adaptation that informs effective coral reef management worldwide.
- c. Deliver a high-profile Centre symposium '*Coral Reefs: Past, Present and Future*', highlighting the Centre's research, in a hybrid format in Townsville, Queensland on 29th and 30th September 2021.
- d. Submit an Expression of Interest for a new ARC Centre of Excellence.
- e. Consolidate research workforce and research program directions for business growth and continuity 2022-2024.

2 Research Training and Professional Development

- a. Deliver professional development workshops on statistics, altmetrics, media communication, diversity and inclusion, cultural awareness, pathways to impact and career preparation; and provide opportunities for Centre student internships with government and industry.
- b. Collaborate with student and postdoc committees to deliver programs for student and early career researcher retreats, writing workshops and attendance at the Centre's symposium in September.
- c. Deliver an adaptive leadership development program for established and mid-career researchers in the Centre.
- d. Provide mentoring and coaching in development of research proposals and award applications.
- e. Support Centre graduate students who are based internationally due to COVID-19 to complete their research projects and participate in Centre experiences, professional development and culture.

3 National and International Linkages

- a. Consolidate and further strengthen strategic, value-adding, international collaborations and partnerships.
- b. Strengthen the Centre's research partnership with WorldFish on small-scale fisheries and the FISH CGIAR Research Program.
- c. Pursue additional contract research with government, NGOs, funding bodies, foundations and philanthropic groups nationally and internationally to provide high quality, impactful research.
- d. Extend multi-institutional and/or multi-disciplinary supervisory arrangements for Centre students.

4 Impacts and End User Engagement

- a. Develop 'legacy' products to showcase the Centre's achievement over two ARC funding cycles.
- b. Continue to engage with government and stakeholders to provide the science that underpins the *Reef 2050 Long-Term Sustainability Plan*.
- c. Facilitate and increase use of 'Research insights' to extend the Centre's media outreach.
- d. Build the Centre's social media engagement strategies with an aim of exceeding 11,500 followers on Twitter.
- e. Extend the Centre's social media outreach through the establishment of a TikTok account, aiming for 10,000 views in 2021.

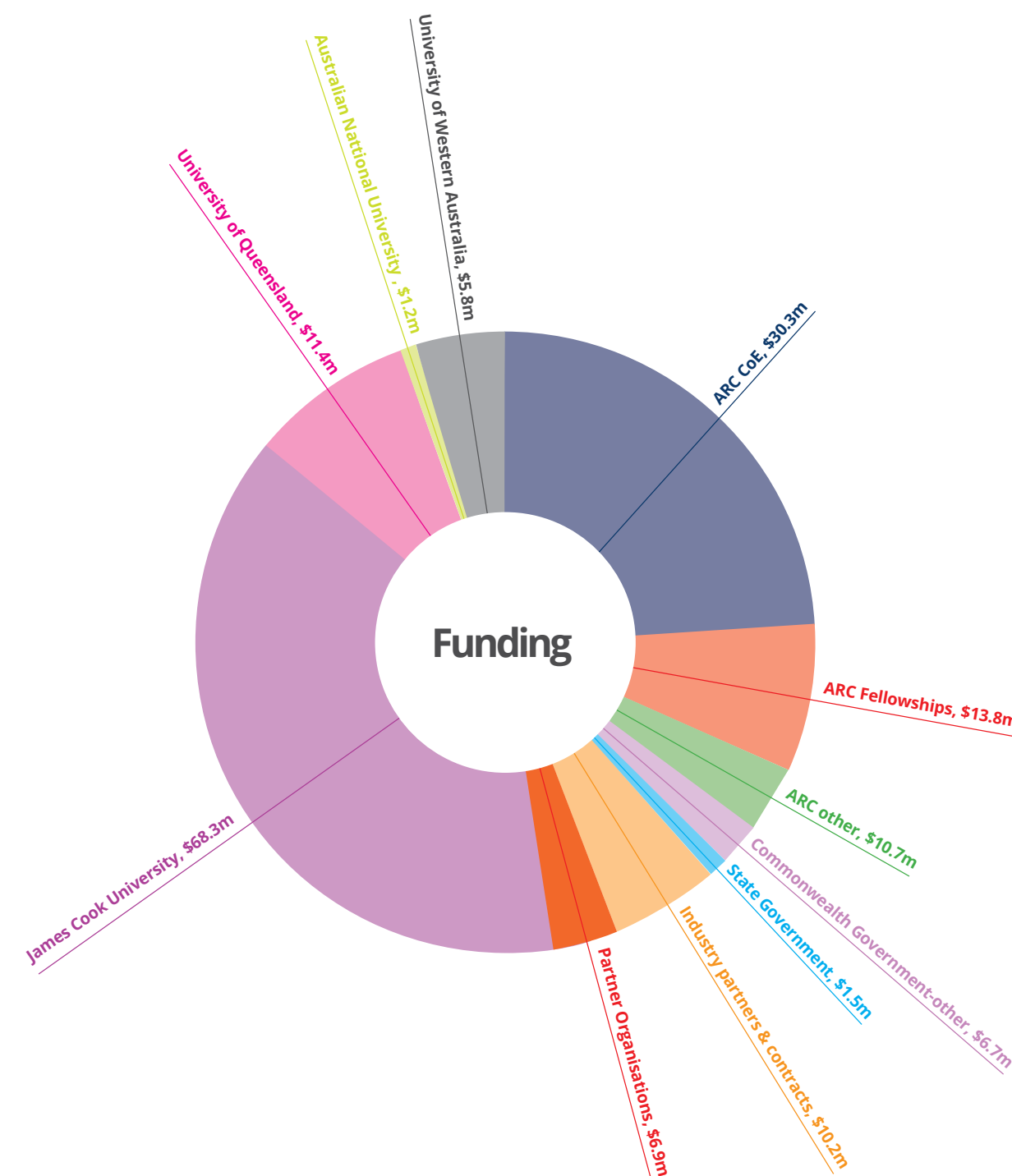
5 Governance

- a. Expand membership of the Centre's Advisory Board to reflect the Centre's changing research directions and to inform strategic planning for the future of the Centre.
- b. Increase participation in the *Scientific Management Committee* to facilitate diversity, inclusion and succession planning for the Centre.
- c. Renew the Centre's Strategic Plan for business continuity post ARC Centre of Excellence funding to strengthen and diversify income sources.
- d. Mentor female researchers and mid-career researchers into leadership roles in the Centre and their university nodes.
- e. Continue developing a Centre culture that values justice, equity, diversity and inclusion.

ARC Centre of Excellence for Coral Reef Studies
Statement of Operating Income and Expenditure for year ended 31 December 2020

	2019	2020	2021 forecast
	\$	\$	\$
INCOME			
ARC Centre Grant	\$4,478,439	\$4,559,049	
ARC Fellowships	735,407	758,115	772,394
ARC Other	135,812		
Host Institutions cash support	4,037,115	3,907,459	2,468,190
State Government	49,469	58,277	55,562
Commonwealth Government other grants	553,978	598,029	600,000
International and other contracts	938,311	708,117	900,000
Total Income	\$10,928,532	\$10,589,046	\$4,796,147
EXPENDITURE			
Salaries	\$7,763,010	7,472,119	6,276,580
Equipment	410,628	246,870	312,725
Travel	1,395,438	449,602	611,806
Research maintenance and consumables	1,301,775	1,331,360	1,123,462
Scholarships and prizes	190,504	175,697	177,454
Public outreach and administration	122,046	65,882	127,774
Total Expenditure	\$11,183,402	\$9,741,531	8,629,802
Surplus (Deficit)	\$(254,870)	\$847,515	\$(3,833,655)

As at December 2020, the total cash and in-kind contributions for the ARC Centre of Excellence for Coral Reef Studies for 1 January 2014 to 31 December 2021 totalled \$166.9m, 37% higher than when the Centre was established in 2014.



KEY PERFORMANCE Indicators

Standard Key Performance Indicators for ARC Centres of Excellence

Performance Measure	Target 2020	Outcome 2020
Number of research outputs		
• Journal articles/books/book chapters (p82)	350	421
• Published Data sets	40	52
Quality of research outputs (p82)		
• Publications in journals with Impact Factor >4	105	167
• Mean Impact Factor for journals published	4.7	5.5
• Citations: total by Centre researchers	35,000	70,065
• Centre researchers with >500 annual citations	24	35
• Awards and prizes (p8)	32	45
Number of training courses held/offered by the Centre (p49) (over and above the standard courses offered by institutions)	28	33
Number of workshops/conferences held/offered by the Centre (p66)	15	24
Number of additional researchers working on Centre research (p79)		
• Postdoctoral researchers	8	9
• PhD students	25	17
• Masters by research/coursework students	8	13
• Honours students	4	6
Number of postgraduate completions (p49)		
• PhD students	25	23
• Masters by research/coursework students	8	6
• Honours students	4	7
Number of mentoring programs offered by the Centre (p49)	12	23
Number of presentations/briefings (p66)		
• To the public	42	77
• To government/agencies/industry/business/end-users/NGOs (national and international)	80	109
(in addition to workshops/conferences above)		
Number of new organisations collaborating with, or involved in, the Centre	50	194

Centre-specific Key Performance Indicators

Performance Measure	Target 2020	Outcome 2020
Publications (p82)	110 over life of Centre	38 (206 to date)
• Prestige publications (e.g. <i>Nature</i> , <i>Science</i> , <i>PNAS</i>)		
Interdisciplinarity of research		
• No. of journal titles in which Centre of Excellence research published (p82)	110	150
• No. of students with multi-disciplinary supervisory arrangements (p49)	54	57
Centre integration		
• No. of publications with cross-institutional co-authorship	200	322
Global reach:		
• No. of countries where Centre undertakes field research	26	21
• No. of international co-authors	340	1712
• No. of invited talks/papers/keynotes at international meetings	28	30
Media (p66)		
• Commentaries about the Centre's achievements	4,400	7,655
• Articles	26	32
• Centre of Excellence Website hits	8.0m	10.2m
International visitors (p60)	80	26 (plus 18 international Zoom seminars (p58))
Gender equity		
• Research Fellow appointments (p79)	50:50	5f:4m
• Gender equity and diversity mentoring, and training activities: no. of participants and attendances (p49)	30	32

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- Australian Government: Department of the Environment and Energy
- Australian Institute of Marine Science (AIMS)
- Australian Coral Reef Society
- Australian Marine Sciences Association
- Australian Museum
- Australian Society for Fish Biology
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- Beijing Genomics Institute Australia
- Bob Brown Foundation, Hobart
- Center for Ocean Solutions, Stanford University, USA
- Centre de Recherches Insulaires et Observatoire de l'Environnement (CRIOBE), French Polynesia
- Centre National de la Recherche Scientifique (CNRS), France
- Charles Darwin University, Australia
- Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia
- Company of Biologists, UK
- Conservation International
- Coral Reef Research Foundation, Palau
- Deutsche Forschungsgemeinschaft, Germany
- Evolution Mining, Australia
- Federal University of Goiás, Brazil
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- Great Barrier Reef Marine Park Authority, Australia
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- Marine Parks Authority, Lord Howe Island Marine Park, Australia
- Marine Science Institute, University of the Philippines
- Ministry of Fisheries, Tonga
- Muséum national d'Histoire naturelle, France
- Musée Zoologique, France
- Museum für Naturkunde, Germany
- National Environmental Science Program, Australia
- National Geographic Society
- National Institute for Environmental Studies (NIES), Japan
- National Institute of Water and Atmospheric Research (NIWA), New Zealand
- National Oceanic and Atmospheric Administration (NOAA), USA
- National Research Foundation of South Africa
- National Science Foundation, USA
- National Socio-Environmental Synthesis Center (SESYNC), University of Maryland, USA
- National University of Singapore
- Natural History Museum, United Kingdom
- Naturhistorisches Museum, Austria
- Northern Territory Department of Primary Industries and Resources
- Okinawa Institute of Science and Technology Graduate University, Japan
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- Parks Australia
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- Queensland Department of Environment and Science
- Queensland Department of Natural Resources, Mines and Energy
- Queensland Museum Network
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- WorldFish, Malaysia
- World Wildlife Fund, International
- Yale Peabody Museum, USA



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