

Report



**Australian Museum
Lizard Island
Research Station**

2021



Lizard Island Research Station 2021 Report

Lizard Island Research Station
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The Lizard Island Research Station acknowledges the Traditional Owners of Jigurrū, the Dingaal and Ngurrumungu people, on whose land the research station is situated.

The Lizard Island Research Station respects elders past and present, and welcomes all who visit the research station.



Kim McKay AO
Director & CEO, Australian Museum

The marine conservation work at the Australian Museum's (AM) Lizard Island Research Station (LIRS) has never been more critical. With news of another mass bleaching event impacting the Great Barrier Reef (GBR), I am relieved to hear from LIRS Directors Lyle Vail AM and Anne Hoggett AM that the low-level bleaching reported around Lizard Island in early 2022 is not as severe as other locations on the GBR and that they expect most corals will recover.

Despite border closures and lockdowns experienced last year, LIRS researchers certainly made the most of this time, with 84 new scientific research papers published in 2021. With travel restrictions eased, it's great to see bookings at LIRS for 2022 are already picking up and we're starting to get back to a pre-pandemic level of activity.

I'm very proud of the solar upgrades made at LIRS in 2021, building on the ground-breaking work completed in 2011 that was led by the late, great Ken Coles AM, former Chairman of the Lizard Island Reef Research Foundation (LIRRF). Showing leadership in sustainability sets an example for others to follow, and solutions like solar power are vital to preserving the extraordinary natural environment of places like LIRS.

As part of the AM's commitment to transforming the conversation around climate change, we launched the inaugural Talbot Oration in 2021. Named after Prof Frank Talbot AM, founder of LIRS and former AM Director, it will be an annual event held at the AM to celebrate Talbot's achievements in marine research and environmental studies.

I'm so proud of the resilience the LIRS has displayed again in 2021 and I would like to thank our dedicated LIRS Directors Anne Hoggett AM and Lyle Vail AM for their continued leadership. I would also like to thank the Australian Museum Research Institute staff, and the AM Trust for their unwavering support of the AM's LIRS.

In closing, I'd like to recognise the extraordinary efforts of the LIRRF, led by Chair Kate Hayward, for its work to support the world-leading science and sustainability practices at LIRS. Thank you to the donors – without your support, LIRS' work to preserve our precious reef environment would not be possible.



Kate Hayward
Chair, Lizard Island Reef Research Foundation

Was it 2020 or 2021? We can all be forgiven for this blurring as, for many of us, our schedules remained disrupted and many interactions stayed virtual over this period. Yet despite border restrictions, the Lizard Island Research Station (LIRS) was open for much of 2021 although accessible, for the most part, to Queensland based researchers only. As detailed in this annual LIRS report, important research still continued, including three time-sensitive projects worked on by teams supported by our Foundation's grant program.

Pleasingly, the Fellowships program resumed in 2021 with seven new fellowships awarded for work commencing in 2022. This program is fully supported by the Foundation and over the past decade, \$1.5 million has been awarded for fellowships and grants. It's hard to overstate how important these programs are. Not only do they fund critical work, helping us better understand reef ecology, but they also support the careers of young, talented scientists. David Bellwood, Australian Research Council Laureate Fellow & Distinguished Professor of Marine Biology, James Cook University, has mentored many emerging marine scientists, including supervising a number of Lizard Island Doctoral Fellowship recipients. He recently wrote:

"I would like to thank the LIRRF for their generous contribution to reef research. Without such funds independent reef research would be in peril. The LIRRF and LIRS stand as beacons of hope. The value of these LIRRF contributions goes far beyond the immediate benefits. They lay the foundations for thoughtful, quality, future science".

It's now the 44th year that the Foundation has supported the Station, which next year celebrates its 50th anniversary. The success of the Station is due to a number of factors. These include the fact that it is a field station, located on the Great Barrier Reef, providing an in-situ work place for scientists; a highly capable and stable management team in Directors Anne Hoggett and Lyle Vail who for three decades have shaped the facility and created a supportive environment for researchers; and not least of all the generous support of our Foundation donors. I'd like to extend a heartfelt thank you to all our donors, each of whom recognize how critical it is to advance our knowledge to help preserve precious reef ecosystems which now face an increasing number of disturbances.

2021 in review



The pandemic continued to impact activities at Lizard Island Research Station (LIRS) during 2021, even though it remained COVID-19 free. LIRS was open all year, apart from short periods for staff leave, but usage was very low for the second consecutive year due to COVID-related travel restrictions. International visitors could not enter the country at all and interstate travel was hampered for much of the year. Overall, usage was only about 39% of that in 2019, the last non-COVID year. Scientific output from LIRS remains high at 84 new publications this year (page 19), but not as high as in some recent years.

Most visitors were researchers from Queensland-based institutions and a few interstate research teams also managed to get to LIRS. Some of the latter had to go to extraordinary lengths to meet border requirements. Student groups were also affected. LIRS normally hosts about 10 per year but in 2021, only one was able to make the trip - and that was at short notice and on its third attempt.

Encouragingly, we fielded a steady stream of inquiries from researchers and educational groups throughout the year. They ramped up markedly after announcements were made late in the year that both the Queensland and international borders would open for quarantine-free travel in December 2021 and February 2022, respectively.

After a year's hiatus due to COVID, the fellowships and grants program restarted in 2021 for research to commence in 2022. For the first - and hopefully only - time, applications were restricted to people based in Australia to mitigate the risk of travel complications. This valuable program is fully funded by the Lizard Island Reef Research Foundation (LIRRF). Seven new fellowships and grants and one new critical research grant have been awarded for 2022 (page 5). They join six ongoing awards that had to be delayed due to travel restrictions and which will commence or restart in 2022.

The inaugural Coral Reef Study Tour was originally planned for April 2020 and proposed for revival twice in 2021, but COVID-19 did not allow it. It is now planned for April 2022.

Left Corals bleaching after prolonged exposure to air during extreme low tides in winter. This is a normal process, unrelated to climate change.

This educational program is an initiative of the LIRRF and is funded by three of its generous donors. The trip is intended to immerse high-performing Year 11 biology students and teachers from NSW Government schools in coral reef science. In 2019, 16 students and two teachers were selected in a competitive process. In 2022, we hope that these people will finally be able to take part in this experience, even though the students have now left school.

As outlined in this report (page 12), an upgrade to the solar power system carried out this year is exceeding expectations. Modelling predicted that the upgraded system would meet 95 percent of electrical power needs at LIRS but in practice, the outcome so far is even better. Since the work was completed in April, the backup generator was only needed for six hours in total to the end of the year. While usage and hence power needs were lower than usual during those eight months, it was also cloudier and rainier than usual. We are confident that the system will provide excellent service when usage returns to normal and we thank the donors for enabling this important development.

Coral recovery in the vicinity of Lizard Island continued after the devastation caused by cyclones (2014, 2015), mass bleaching events (2016, 2017), and more minor, localised heat stress events (2020, 2021). Although the recovery is patchy, the reef now looks amazing in some places. Much of the resurgence is due to a single family, Acroporidae, which includes plate and staghorn corals. These corals are sometimes affectionately known as the weeds of the reef, due to their ability to recolonize an area quickly after a disturbance. Unfortunately, they are also highly susceptible to heat stress so the magnificent stands of coral now present in the area are the ones most likely to be wiped out during the next major bleaching event.

We look forward to welcoming many more researchers and student groups in 2022 to study this amazing ecosystem.

Lyle Vail AM and Anne Hoggett AM
Directors, Lizard Island Research Station



Fellowships and grants



The fellowships and grants program provides funding for field-intensive research at LIRS. It is fully supported by the Lizard Island Reef Research Foundation (LIRRF) and its donors. The program now awards up to ten fellowships and two grants per year. From inception of the program in 1982 to June 2021, \$2,151,530 has been spent on fellowships and grants. More than 70 percent of that (\$1,566,430) was in the past ten years.

The program was paused for a year in 2020 due to travel and other logistical difficulties caused by COVID-19. It restarted in 2021 for research that will commence in 2022. However, it was restricted to applicants who are based in Australia due to uncertainty about international travel. The program will again be open to international researchers as soon as practical.

Donors who support specific awards are listed below. We sincerely thank them for their generous support.

- LIRRF members and friends
- The Ian Potter Foundation
- The Charles Warman Foundation
- The Gough family
- The Banyer family
- The Nell and Hermon Slade Trust
- The Maple-Brown Family Foundation
- The estate of Sir John and Lady Proud
- The estate of Zoltan Florian
- The estate of Chris Joscelyne
- The Rossi Foundation
- Ian and Min Darling
- Sally White OAM

Details of the conditions and selection criteria for these awards can be found in the LIRS section of the Australian Museum's website. Applications for Fellowships are advertised in August or September for funding that becomes available in March of the following year.

Fellowships

Fellowships are for field-intensive coral reef research carried out by PhD students and recent postdoctoral researchers. The scope is intentionally broad to allow applicants to seek support for research within their existing commitments and areas of interest. By providing rare support for field work by researchers at these early stages, fellowships produce excellent research and provide a valuable contribution to research training. For the first time this year, fellowships were awarded for archaeological research.

Seven new fellows will commence work in 2022: four PhD students and three recent post-docs. Outlines of their projects can be found on pages 6-9.

Grants

The strategic objective of our grants program is to support coral reef research that is important on a broad scale and has a time-critical element. Reflecting that objective, these grants are now known as Critical Research Grants. The program is flexible so that we can support research where the need is greatest. This year, for the first time, we sought input from scientists themselves by requesting expressions of interest for work in areas that they view as both important and urgent.

One new grant has been awarded to start in 2022 as outlined on page 9. The 2022 Critical Research Grant is funded by Ian and Min Darling and Sally White.

Field work continued in 2021 for three grants awarded earlier:

- **Prof. Morgan Pratchett** (James Cook University) and collaborators, 2020 grant for "Effective sampling of *Acanthaster cf. solaris* to improve understanding and management of population irruptions." This is the last of 20 grants funded by The Ian Potter Foundation, aimed at reducing the impact of Crown-of-Thorns Starfish.
- **Dr Fredereike Kroon and Dr Mark Meekan** (Australian Institute of Marine Science), 2020 grant for "The effects of microplastic pollution on mesozooplankton: a unique threat?" This grant was funded by the Banyer family and the Rossi Foundation.
- **Dr Maria Dornelas** (University of St Andrews) and Dr Joshua Madin (University of Hawaii), 2020 grant for "Understanding coral reef recovery from extreme disturbances using 3D maps." This grant is funded by the Charles Warman Foundation.

Opposite Extraordinary recovery of corals at MacGillivray Reef in December 2021. Five years earlier, it was bare reef pavement.



Joshua Connelly

2022 Lizard Island Doctoral Fellowship
James Cook University

Investigating constructed seascapes in the Lizard Island Group, Far North Queensland

Joshua's research focusses on the extraordinary Aboriginal stone arrangements of Jiigurru (Lizard Island Group). Joshua and his PhD supervisor (Professor Sean Ulm) are partnering with Dingaal and Ngurramungu peoples to study the First Nations cultural landscapes and seascapes of the islands.

Indigenous stone constructions are known to have a number of functions including as houses and as ceremonial sites where engagement with spirits, ancestors, or totemic animals and forces took place. Joshua has already recorded hundreds of stone arrangements built by Aboriginal people across the islands of Jiigurru. Many are in the form of marine animals including crocodiles, turtles, dugongs, whales, manta rays, stingrays and fish. Other shapes include cairns, lines and single stones placed in an upright position.

Joshua's fellowship will support archaeological surveys of South and Palfrey Islands with some of his fellowship funding enabling the participation of Traditional Owners in on-Country fieldwork. Joshua says, "The sheer number and diversity of stone arrangements on Jiigurru is unparalleled elsewhere in Australia, making it an ideal place to study the social and spiritual landscapes and seascapes created by the Old People of Dingaal and Ngurramungu Traditional Owners."



Turtle stone arrangement on Lizard Island (head on the left, tail on the right).
Photo: Sean Ulm.



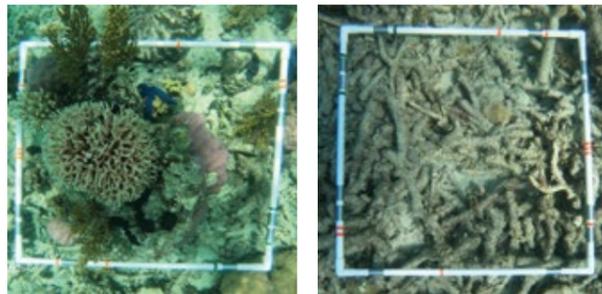
Eric Fakan

2022 Gough Family Doctoral Fellowship
James Cook University

The influence of habitat-degradation induced stress on population regulation of coral reef fishes

Coral reefs are one of the most threatened ecosystems. The combined effects of climate change and local anthropogenic stressors have resulted in regional declines in coral cover and increases in algal cover. While the effects of changes in benthic composition on fish assemblages are well documented, the underlying mechanisms and potential sub-lethal effects (such as declines in fitness) are lacking.

Eric's study will use a combination of field surveys and laboratory experiments to examine how the transition from live coral- to algal-dominated habitats affect regulation of reef fish populations. It seeks to understand the consequences of living in degraded habitat in terms of stress levels (measured by cortisol) and subsequent changes that may occur in important traits such as growth rates, fat content, and other body condition indexes which may be of evolutionary importance.



Example of Eric's study locations: more complex and healthier reef (L) compared to less complex, more degraded site (R). Photos: Eric Fakan.



Juliano Morais

2022 Ian Potter Doctoral Fellowship
James Cook University

Coral recovery dynamics on post-bleach coral reefs

Coral mortality induced by climate change is reconfiguring the dynamics and functions of coral reefs. On the Great Barrier Reef, extreme coral mortality occurred due to unprecedented back-to-back bleaching events in 2016 and 2017. This resulted in a noticeable and, in many cases, severe reduction in coral cover leading to a collapse in coral recruitment compared to historical baselines on the GBR. Encouragingly, some reefs around Lizard Island are now in a state of recovery with a considerable number of new coral colonies showing fast growth, particularly since 2020. The factors shaping recruitment and juvenile coral survival remain poorly known. If we wish to understand the future of coral populations, it is critical to quantify long-term, species-specific juvenile survival rates, as well as the habitat features influencing their survival.

To study the survivorship of corals, Juliano will add to an existing dataset of 451 photo-quadrats spread over 19 transects from around the Island which will enable him to follow the fate of all recruits recorded since 2018. The first of the historical photos were taken immediately prior to the 2016 bleaching event. By the completion of Juliano's fellowship, the dataset will have been censused eight times over eight years enabling him to track the fate and growth of existing corals and new recruits. He will also deploy 40 current meters that will provide fine-scale hydrodynamic data to help determine if currents can explain the distribution of coral recruits around the island. This project will increase our understanding of the dynamics of coral recruitment/survival, and the effect of environmental factors in shaping recovery trajectories.



Valerio Tettamanti

2022 Zoltan Florian Doctoral Fellowship
University of Queensland

Damsels in colour: adaptations of the visual system and colouration during the development of coral reef damselfishes

Vision is crucial for the survival of many animals and is required by most for feeding, sexual selection, and navigation. Damselfishes are a highly abundant and speciose reef fish family that varies in ecology, colouration, and shapes. These differences in their life history are also reflected in their visual systems which have been found to adapt for a specific diet, colouration, and depth (light environment).

Adaptation of the visual system of damselfishes includes differences in visual gene (opsin) expression which tends to correlate with species-specific ecologies. Specifically, the ultraviolet (UV) sensitive opsin is thought to play an important role in damselfishes: UV vision benefits feeding on zooplankton and allows for communication within and between species through UV signalling. While some progress has been made in describing the visual systems of adult damselfishes, little is known about how larval and juvenile damselfishes see their world. Many damselfishes show dramatic changes in colouration during development but how these might be linked to vision, especially in the UV, remains untested.

Valerio's research will provide a better understanding of the interplay between vision and colour in different developmental stages of damselfish found on the reefs around Lizard Island. Using a high-definition camera system that was recently developed in Professor Justin Marshall's lab at the University of Queensland, he will be able to identify ontogenetic changes in both visible and UV colour patterns with the latter being invisible to humans and to most coral reef predatory fish. Valerio plans to assess his findings within a phylogenetic framework which will enable insights into the visual adaptations of damselfish that underlies their successful settlement and growth on the reef.



Dr Fabio Cortesi

2022 Chris Joscelyne Postdoctoral Fellowship
University of Queensland

Anemonefish hotels: Restoring Nemo's home and its community for the future

The severe cyclone seasons of 2014 and 2015 followed by back-to-back mass bleaching events in 2016 and 2017 caused widespread damage and mass coral mortality to the Great Barrier Reef (GBR) including the reefs surrounding Lizard Island. In the past, coral reef habitats would likely recover naturally. However, the increasing frequency and severity of disturbances is outpacing recovery times. Consequently, there has been a recent shift in management strategies towards aiding coral reef recovery. One intervention is to use artificial structures to restore critical habitats that are relied upon by some species. The success of the intervention is dependent, in part, on identifying the optimal design of artificial structure.

Anemonefishes are an iconic and diverse group of damselfishes that are reliant on a critical habitat (anemones), which has declined significantly in recent years, primarily due to mass bleaching events. They form mutualistic relationships with a variety of anemone species.

Fabio's research proposes to determine the best approach for restoring anemonefish populations and their host anemones. He will trial 'anemonefish hotels' which are 3D artificial structures that can be seeded with the optimal combination of anemones and anemonefish to aid recovery. The hotel design attempts to replicate the underlying habitat that is required by the anemone and will initially be created using 3D printing. Fabio will test various surfaces and matrices to find the best structure for anemone attachment and survival. He will then test if the formation of new colonies can be accelerated by seeding the hotels with both anemones and anemonefishes in the LIRS aquarium, then transplanting them back into the field. While it is not feasible to place anemonefish hotels over a large scale (e.g., the entire GBR), it is anticipated that by increasing the reproductive output of anemone and anemonefishes in particular locations, they will help re-seed other nearby areas through asexual reproduction and larval dispersal.



Dr Ariana Lambrides

2022 John and Laurine Proud Postdoctoral Fellowship
James Cook University

Understanding long-term First Nations uses of the Great Barrier Reef: Re-excavating the Freshwater Bay Midden, Lizard Island

It is known that Aboriginal and Torres Strait Islander people actively exploited and interacted with the GBR during the whole timespan of the modern evolution of the system. Other studies have previously demonstrated the significant role of First Nations Peoples in influencing the size, abundance, distribution, and resilience of marine fish, mollusc and mammal populations over thousands of years.

Considerable debate surrounds the timing and use of Great Barrier Reef offshore islands by Aboriginal and Torres Strait Islander peoples, particularly how peoples' relationships with islands may have transformed over the past few thousand years. Archaeological evidence from Jiigurru (Lizard Island) indicates that Aboriginal occupation from ~4000 years ago was periodic, likely short term and perhaps seasonal by people with connections to the mainland or elsewhere. However, over the past 2000 years the frequency or length of visits appears to have increased. This pattern of use contrasts with other Great Barrier Reef islands where a hiatus or reduction in use has been reported between 2000 and 1000 years ago. Jiigurru thus provides an undocumented occupation pattern associated with GBR islands which likely relates to its place within the Coral Sea Cultural Interaction Sphere—a network that connected people from the Gulf of Papua and northern Queensland. As such, it provides a unique record of past marine resource use and coral reef interaction on the GBR.

With her collaborators, and in partnership with Dingaal and Ngurrumungu Traditional Owners, Ariana will spend a month on Country excavating the Freshwater Bay shell midden which is thought to be at least 3500 years old. Her team will undertake high-resolution analyses of recovered archaeological assemblages from the shell midden with a particular focus on the marine faunal remains. Results from this research will enable us to better understand the role Indigenous people played in shaping pre-European marine faunal biodiversity.



Dr Eva McClure

2022 Maple-Brown Family Foundation Postdoctoral Fellowship
James Cook University

Effects of recurrent disturbances on coral reefs across the continental shelf

Although the GBR is often perceived as a single large ecosystem, communities of both reef fishes and bottom-dwelling organisms, such as corals and algae, can be very different at different locations across the continental shelf. This variation is due to gradients in prevailing environmental conditions, such as higher levels of sediment and nutrients in inshore areas and higher wave action on outer reefs. Lizard Island is located about midway across the shelf, which is about 25 nautical miles wide in that area, and the research station provides access to its entire width. Previous research by Eva has shown that herbivorous fish assemblages at each shelf position respond differently to disturbance, at least in the short term.

The fellowship will enable Eva to investigate the long-term responses of reef fishes and their habitats to sequential severe disturbances. She will compare cross-shelf coral reef benthic composition and herbivorous fish biomass, structure, taxonomic and trait characteristics of the present day, to those five years prior to and six months after widespread damage from cyclone events (2014, 2015) and mass coral bleaching (2016, 2017). She will also compare contemporary cross-shelf browsing intensity of herbivorous fish to that of pre-disturbance levels using macroalgal bioassays, video cameras, and direct observations of the feeding frequency of herbivorous fish. This research will help us to understand if the unique species assemblages observed at each shelf position maintain or regain their characteristics with time from disturbance and what this means for key ecological processes like herbivory.



Prof. Andrew Baird¹

and co-investigators Dr Tom Bridge², Dr Peter Cowman² and Dr Joshua Madin³

2022 Critical Research Grant

(1) James Cook University (2) Museum of Tropical Queensland (3) University of Hawaii at Manoa

Taxonomy of the reef-building corals of Lizard Island

Coral taxonomy is currently based largely on morphology (form, shape) but it is becoming clear that there is much more genetic diversity – and species – among corals than is revealed by their appearance. This matters because different species interact with the environment in different ways. Knowing the number and identity of species is central to understanding ecologies and to managing and conserving natural resources.

The team already has a global project underway – Project Phoenix (coralprojectphoenix.org) – to resolve this problem in reef-building corals. They are sampling corals from around the world, mostly opportunistically, for molecular analysis that is conducted as funding allows. This provides a much deeper insight into genetic and species diversity than the outward appearance of corals. They are finding that some well-known coral 'species' that are currently considered to be widespread in the Indian and Pacific Oceans are in fact several distinct species that look alike and have much more restricted distributions. Even within a small area, some 'species' contain different genetic lineages that each merit species status.

This grant will bring Lizard Island corals into the project. The team will sample as many forms as possible for molecular analysis. In the short term, this will show which 'species' in the area are in fact multiple species. That will inform other research in this heavily studied area and improve outcomes. In the longer term, the Lizard Island material will form an important part of a worldwide revision of the taxonomy of reef-building corals. The number of coral species is likely to increase by a substantial proportion as a result. It is important to do this now, while much of the coral diversity remains intact but has an increasingly poor outlook for the future due to climate change and other human-induced stressors.

Lizard Island Reef Research Foundation (LIRRF)

The LIRRF is an independent trust established in 1978 to conduct and support scientific research at LIRS and elsewhere on the Great Barrier Reef.

Go to lirrf.org for information about the Foundation and the research it supports and to donate to its worthy causes. All donations of \$2 or more are tax deductible in Australia.

Members donate \$1,000 or more in a 12-month period and Friends give a lower amount. Life Members donate at least \$100,000 which may be spread over several years. LIRS would not be the place that it is without the support of the LIRRF. Members in 2021 are listed on page 24.

FOUNDER

The late Sir John Proud

PATRONS

Mr Andrew Green
 Dr Des Griffin AM
 Mr Raymond Kirby AO
 Mrs Jacqueline Loomis
 The Ian Potter Foundation
 Mr Robert Purves AM
 Thyne Reid Foundation
 Prof Frank Talbot AM

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 Mr Charlie Shuetrim AM (Chair, Appeal Committee)
 Mr David Armstrong
 Mrs Greer Banyer
 Dr Penny Berents
 Ms Allison Haworth-West
 Dr Rod Kefford AM
 Mrs Wendy King
 Mr James Kirby
 Mrs Anna Le Deux
 Prof Lynne Madden

TRUSTEES (cont.)

Ms Kim McKay AO
 Mrs Heather Power
 Mr Robert Purves AM
 Mr David Shannon¹
 Dr Geoff Shuetrim
 Ms Helen Wellings
¹ Retired during 2021

SCIENCE COMMITTEE

Dr Penny Berents (Chair)
 Mr Charlie Shuetrim AM
 Prof Kristofer Helgen
 Dr Lyle Vail AM
 Dr Anne Hoggett AM
 Prof Lynne Madden

We thank Australian Museum staff Dr Shane Ahyong and Dr Joey DiBattista for being part of the selection committee in 2021 for LIRRF Fellowships and Grants, joining Science Committee members Penny Berents, Kris Helgen, Anne Hoggett and Lyle Vail (Chair of Selection Committee).

Vale Ken Coles

Ken Coles AM was a Trustee of LIRRF from 1991 to 2015 and Chairman from 1994 to 2012. During his long tenure, Ken transformed the Foundation and the Research Station. Ken died peacefully at the age of 95 on 18 January 2022 with his wife Rowena Danziger AM at his side. His many achievements are outlined in a tribute by fellow Trustee, Charlie Shuetrim, on the LIRRF website (lirrf.org/a-tribute-to-ken-coles-am).

Projects and equipment funded by LIRRF in 2021

LIRRF supported research to the extent of \$405,090:

- \$79,009 for ongoing fellowships and grants awarded prior to 2021.
- \$231,741 for capital works to support research at LIRS, including initial payments for an upgrade to solar power system and for replacing outboard motors.
- \$94,340 for other research operations.



Coral Reef Study Tour

Following a rigorous selection process in 2019, sixteen high-achieving students of biology at NSW Government schools and two biology teachers were selected for a nine-night trip to LIRS to immerse themselves in coral reef studies. The inaugural Lizard Island Coral Reef Study Tour was due to begin on 10 April 2020 but had to be cancelled due to the pandemic. It was tentatively rescheduled twice in 2021 but could not go ahead due to the uncertainty of opening the NSW/Queensland border. The tour is now planned for 2022 for the same group of participants. It is funded by three generous donors to the LIRRF: the James N. Kirby Foundation, the Corella Fund and the Coles Danziger Foundation.

Solar power upgrade

Since 2011, LIRS has produced at least 60 percent of its power from solar power. Efficiency of the original system decreased to that level over the years due to inevitable degradation of the lead-acid batteries. Specifications for an upgraded system were developed with expert advice and modelling from Robert Thomas and Jay Banyer. The new system was installed in April 2021 and included the following upgrades:

- replaced the 10-year-old lead-acid battery bank with lithium ferrophosphate batteries that provide three times the usable energy storage (210 kWh compared to 70 kWh);
- replaced all inverters with new technology that deliver enhanced performance, and;
- added 33.4 kWp of solar collection, an increase of 50 percent that brings the total to 99 kWp from 384 solar panels.

Modelling predicted LIRS would produce about 95 percent of its electrical energy from solar after the upgrade. Early indications suggest the system will easily meet model predictions. This critical infrastructure upgrade was funded by generous donations from the Charles Warman Foundation, the Minderoo Foundation, Angela Rossi & Tim Whitbread, and Ian Learmonth & Julia Pincus. It was also supported by GenZ Energy who donated 15 kWh of lithium batteries.

Electrical switchboard upgrade

The LIRS electrical switchboard is a critical piece of infrastructure that distributes power and provides circuit protection. Although showing its age, the 46-year-old switchboard had served LIRS well, especially given the corrosive environment. It was replaced in 2021 to ensure reliable and safe supply of electrical power in compliance with current Australian Standards. The project was funded by the LIRRF in the 2021/22 financial year.

Events

For a second year, COVID-19 precluded large physical gatherings throughout 2021. Instead, the LIRRF provided online information sessions to engage with its supporters and hosted a smaller gathering at the Australian Museum (AM).

Two webinars were hosted by LIRRF with more than a hundred people attending each one. In October, Distinguished Professor Lesley Hughes (Macquarie University; lead author of the 4th and 5th Assessment Reports by the Intergovernmental Panel on Climate Change [IPCC]) shared her insights into the workings of the IPCC and interpreted the results of its most recent report, with emphasis on consequences of climate change for coral reefs. In November, Distinguished Professor Terry Hughes (former Director of the ARC Centre of Excellence for Coral Reef Studies) outlined findings from recent research which reviewed the scale and impacts of coral bleaching along the GBR. He was joined by policy expert Kate Mackenzie (Fellow at the Centre for Policy Development). Foundation Chair Kate Hayward, Trustee Geoff Shuetrim, and Australian Museum Research Institute (AMRI) Director and Australian Museum Chief Scientist Professor Kris Helgen were moderators for the webinars and, along with LIRS Director Anne Hoggett, helped field questions from the audience.

A back-of-house tour of the AM's Ichthyology collection was held in May for a small group of supporters. Some additional people joined them for lunch, where Professor Helgen and Ichthyology researcher Dr Joey DiBattista spoke about their work.

Staying in touch

The LIRRF's website (lirrf.org) was extensively overhauled during the year. Visit the new site to learn about the Foundation's work, the Research Station, and how to become a supporter.

Quarterly newsletters about LIRRF and LIRS activities are distributed by email to keep supporters and other interested people up-to-date. You can join the mailing list from the website.

Information about the Foundation's work is also disseminated through various AM digital platforms including a monthly post from LIRS on the AM blog featured in monthly AMRI e-newsletters.

Lizard Island Resort

In 2021, the head lease on which Lizard Island Resort operates was purchased by Tattarang, the holding company for the Forrest family's private interests. Andrew and Nicola Forrest visited LIRS in early 2020 and subsequently became generous donors to the solar upgrade project through their Mindaroo Foundation.

Delaware North, operator of the Lizard Island Resort, is a long-term supporter of the Research Station and the Foundation. The Resort provides an exceptional base from which to experience the GBR. A new General Manager, Leon Pink, started at the Resort in August 2021.

Each year, Delaware North donates to LIRRF a generous three-night stay at the Resort for two people that includes return transfers by light aircraft from Cairns, accommodation, meals, beverages and more. This wonderful package is used to raise funds.

In addition, current LIRRF Members qualify for a 20 percent discount on any stay of 3 or more nights at the Resort, except in the last week of October and in the Christmas-New Year period. See lirrf.org for information about making a booking.

When you are on the island, please be sure to visit the Research Station to see how your donation is being put to good use. For more information about the Resort, visit lizardisland.com.

Donations

LIRRF operates with very low overhead costs, and it provides a highly efficient channel for donations to support science on the GBR. LIRS would not exist and could not continue without donor support. Various options for donating are available online at lirrf.org/donate. All donations of \$2 or more are tax deductible in Australia.

For the record

Usage and COVID impacts

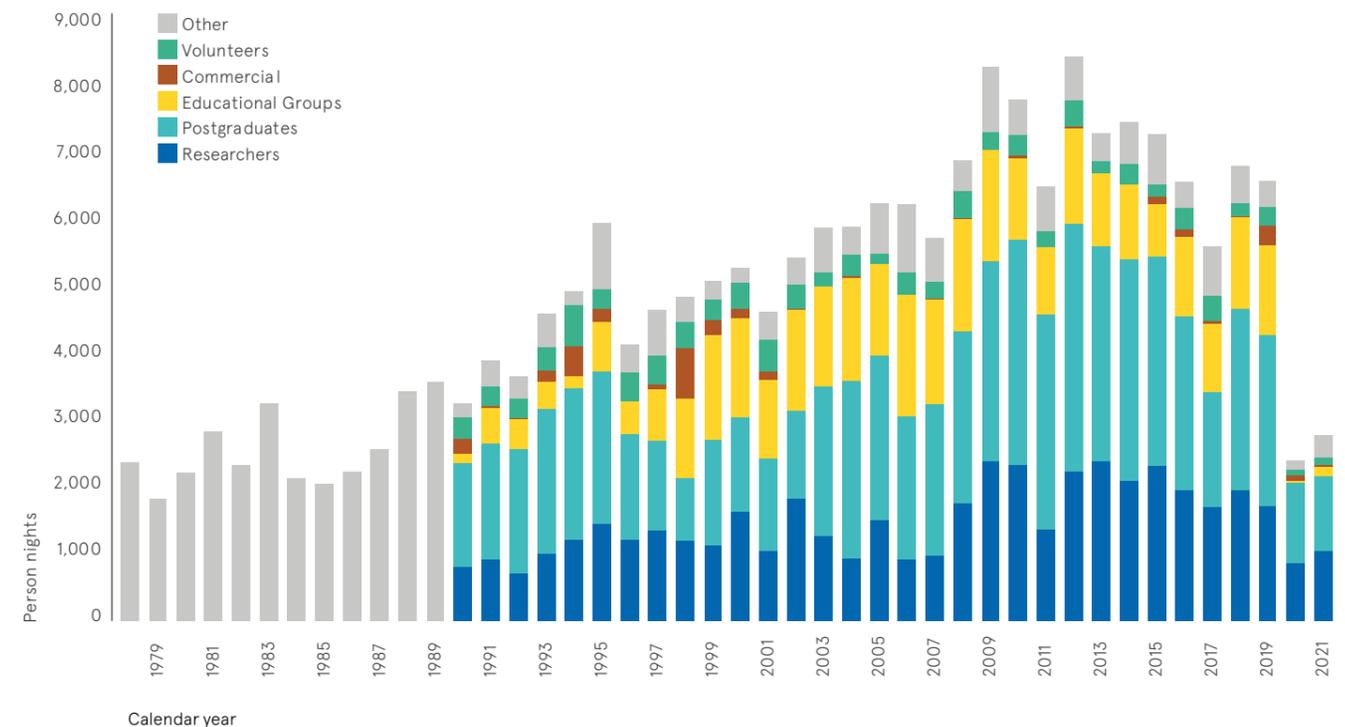
Usage of LIRS in 2021 was 2745 visitor nights, a small improvement on the previous year (2364), but still only 39 percent of optimal (7000). This was due to COVID-related travel restrictions. Usage will not improve markedly until quarantine-free international travel becomes reliable. Some international teams have tentative bookings for the first quarter of 2022, but their visits will depend on their institutions' acceptance of the financial and health risks involved, and on being able to make suitable travel arrangements in time.

Even interstate researchers found it difficult to get to LIRS due to border closures and other uncertainties. More than one such group made up to three attempts before either succeeding or postponing until travel becomes more reliable.

In late May 2021, Queensland Government health directions relaxed enough to allow resumption of tours of LIRS for Resort guests and other island visitors. As of December 2021, there have been no cases of COVID-19 at LIRS.



Above Floating robots are being developed to assist with reef management and regeneration.



Reef health

After almost five years without a major disturbance, reefs in many places around Lizard Island are looking wonderful again. That is despite minor coral bleaching events early this year and in early 2020. Both were ameliorated by changes in the weather that dropped the water temperature before heat stress accumulated enough to cause large-scale death of corals – and they demonstrate how close-to-the-edge corals live in this era of climate change. With the two major bleaching events in 2016 and 2017 that did cause mass coral death, there have now been four warm-water bleaching events in the past six years, an extraordinary increase from none recorded in this area prior to 2002.

The annual coral spawning took place in November 2021. Over the past few years there has been a pronounced increase in the number of coral larvae in the water compared to years just after devastating cyclones (2014 and 2015) and bleaching-associated mass coral mortality (2016 and 2017).

Staff

Dr Lyle Vail AM and Dr Anne Hoggett AM completed 31 years as joint Directors in August 2021.

Arthur Davie and Ruth Carr took on the roles of Maintenance Officer and Accommodation Officer, respectively, on a temporary but long-term basis, starting in January 2021. We sincerely thank them for their service during the year, for their flexibility, and for quickly becoming valued members of the LIRS community.

Volunteers

Volunteers provide indispensable help with maintenance and development of LIRS. As in 2020, far fewer than the normal number of volunteers could be accepted in 2021 due to travel restrictions. We welcomed the assistance of those who were able to get to LIRS: Renie and Snow Amos, Elliot Connor, Keesha Millar, Jason Peters, Annalucia Pacati and Skye Rowe. Thank you all!



Above Corals that have regenerated naturally since 2018 suffered low-level bleaching in early 2021. Bright pastel colours are an initial stage.

Scientific diving and boating

LIRS Director Lyle Vail AM represented the AM on a working group of experienced scientific divers that were upgrading the two Australian Standards that govern scientific diving work. Disappointingly, the process of improving these standards was cancelled after four years of development, due to insurmountable differences between committee members (scientific divers versus a commercial diver organization and some unions). An application has been made to Australian Standards to restart the process with committee members who have a genuine interest in developing appropriate Standards for scientific divers.

Boating regulations are in flux as well. Along with other members of the marine science community, the Australian Museum is working with the Australian Maritime Safety Authority to achieve a safe and sensible outcome.

Lizard Island Field Guide

Lizard Island Field Guide (LIFG) is an online guide to the life of Lizard Island, terrestrial and marine. At year's end, it included 3300 species with photographs and much other information. The background database of species known from the area – drawn from the scientific literature and scientists' collections and observations – contained just over 7800 names.

The online guide, (<http://lifg.australianmuseum.net.au/Hierarchy.html>) is updated continuously and free mobile applications for both major platforms are updated about twice each year. We thank the LIRRF for providing the funds to maintain these sites, to Geoff Shuetrim and the Gaia Guide Association for developing them, to Marianne Pearce who enters much of the background data, and to the many contributors. Anne Hoggett oversees the quality and development of content.

Bench fees

Per person per night, Including GST	2021	2022
Researcher	\$ 151.50	\$ 154.00
Researcher's assistant	\$ 135.00	\$ 138.00
Postgrad student (own project)	\$ 59.00	\$ 59.50
Postgrad's assistant	\$ 54.00	\$ 54.50
School or university group	\$ 97.00	\$ 98.00
Media	\$228.00	\$ 231.00
Commercial	\$285.00	\$ 289.00



Above Researchers from Southern Cross University and CSIRO are trialling reef regeneration using coral larvae.

Visitors in 2021

Scientists from 10 Australian institutions conducted 42 research projects in 2021. Three ongoing projects were continued thanks to Australia-based colleagues who conducted the work on behalf of international and interstate researchers who were unable to take part in person due to travel restrictions.

Project leaders are listed here with project titles and institutional affiliations.

Institutions

Australian

- 1 Australian Institute of Marine Science
- 2 CSIRO
- 3 Griffith University
- 4 James Cook University
- 5 Queensland University of Technology
- 5 Southern Cross University
- 7 University of New South Wales
- 8 University of Sydney
- 9 University of Queensland
- 10 University of Wollongong



Senior scientists and postdoctoral researchers

Ciemon Caballes⁴

Effective sampling of Crown-of-Thorns Starfish to provide early warning of new and renewed outbreaks

Neal Cantin¹

Bleaching processes

Wen-Sung Chung⁹

Circadian rhythms of reef octopus

Fabio Cortesi⁹ and Pauline Narvaez⁴

as field leaders for **Will Feeney³** (based overseas)

Long-term cleanerfish removal experiment

Fabio Cortesi⁹

Comparative reef fish brain anatomy

Guillermo Diaz Pulido⁵ and Soyoung Jeong³

Australian reef-building coralline algae: ABRs study

Sophie Dove⁹ and Annamieke Van Den Heuvel⁹

In field metabolism of the carbonate components of reefs

Matthew Dunbabin⁵

CoralBots for benthos classification, impact and restoration assessment

Oscar Pizarro⁸ with Mariana Alvarez Noriega, Luisa Fontoura, Andrew Hoey⁴, Rachael Woods and Kyle Zawada as field leaders for Maria Dornelas (University of St Andrews) and Joshua Madin (University of Hawaii)

Understanding coral reef recovery from extreme disturbances using 3D maps

Stephanie Gardner⁷

Rise of the turfs: unlocking the secrets of our changing reefs

Peter Harrison⁶ and Christopher Doropoulos²

Coral reef restoration using larvae

Andrew Hoey⁴

Resilience of coral- and macroalgal-dominated habitats to multiple disturbances

Ariana Lambrides⁴

10,000 years of First Nations fisheries informs future Great Barrier Reef

Justin Marshall⁹

1) Colour vision and communication
2) Navigation in the marine environment

Renato Morais Araujo⁴

Trophic pathways of fish productivity from inshore to outer shelf reefs

Samuel Powell⁹

Underwater navigation using in-water light patterns

Marina Santana¹ as field leader for Fredereike Kroon¹ and Mark Meekan¹

The effects of microplastic contamination on mesozooplankton: a unique threat?

Jodie Schlaefer⁴

Benthic pelagic coupling at a mid-shelf reef

Robert Streit⁴

Assessing feeding density of herbivorous fishes using underwater video and 3D habitat mapping

Sean Ulm⁴

Lizard Island archaeological project

Sven Uthicke¹

Testing eDNA as a new monitoring tool for early detection of Crown-of-Thorns Starfish outbreaks

Research students

Makeely Blandford⁴

The influence of habitat degradation and fragmentation on coral reef fish communities (PhD)

Casey Bowden⁴

To determine the role of Blenniidae in sediment transport on the Great Barrier Reef (Hons)

William Collins⁴

Monitoring the movement and feeding habits of nocturnal fishes on the Great Barrier Reef (Hons)

Joshua Connelly⁴

Investigating constructed seascapes in the Lizard Island Group (PhD)

Peter Doll⁴

Settlement rates and patterns for Crown-of-Thorns Starfish and early detection of renewed population irruptions (PhD)

Eric Fakan⁴

Impact of habitat quality on the survival and fitness of coral reef fishes (PhD)

Lily Fogg⁹

The role of habitat and lifestyle in the visual development of reef and deep-sea fishes (PhD)

Catheline Froehlich¹⁰

Investigating the advantages of sociality in challenging environments using coral-dwelling gobies (PhD)

Alison Hammond⁴

Age, growth and movement of the flowerfish, *Pearsonothuria graeffei* (Hons)

Christina Langley⁶

Larval treatments during early development to enhance survival and growth of mass larval cultures from wild-coral spawn (PhD)

Serena (Ya) Mou⁵

Few shot learning of fauna and flora (PhD)

Sophie Rallings⁶

Growth and year-long movement of elephant trunkfish, *Holothuria fuscopunctata* (Holothuroidea) (Undergraduate)

Colleen Rodd⁶

Feeding coral larvae: a novel larval restoration rearing protocol to enhance settlement and post-settlement survival (PhD)

Carl Santiago⁹

Restoration ecology of anemonefishes and their host anemones (PhD)

Abigail Shaughnessy⁹

Seasonal and phenotypic plasticity in colour vision of surgeonfish and damselfish (PhD)

Katie Sievers⁴

Microhabitat selectivity of juvenile fishes in variable reef conditions (PhD)

Sterling Tebbett⁴

1) An assessment of coral recovery after repetitive coral bleaching events (PhD)

2) Sediments and surgeonfishes across the Great Barrier Reef (PhD)

Valerio Tettamanti⁹

Development of the visual system and colouration in damselfishes (PhD)

Research students continued

Ching Wen (Judy) Wang⁹

Spectral and polarisation information processing in the stomatopod visual system (PhD)

Chelsea Waters⁶

Developing and scaling deployment, settlement and monitoring of wild cultured larvae for reef restoration (PhD)

Education groups

Emmanuel Anglican College

· Led by Justine Jacobs, Tom Papworth, Daniela Payne, and Paul Pryor

Special interest groups

· Two groups of Coral Sea Foundation citizen scientists recording coral recovery, led by Andy Lewis

· Author Anna Krien with family, research for a book about the Great Barrier Reef

Other visitors

Lizard Island Reef Research Foundation

· Life members Greer and Jay Banyer with daughters Eve and Erin; Greer is also a LIRRF Trustee

Media

· Southern Cross University media team filming coral larvae seeding project, led by Sharlene King

Australian Institute of Marine Science

· GBROOS maintenance team, Scott Gardner, Shaun Hahn, John Mahoney and Myles Gandy

First aid training

· Charlie Makray

Queensland Parks and Wildlife Service

· National Park maintenance, Kurt Zeitlow and Jack Hargreaves

Contractors

· Tropical Energy Solutions, upgrade solar power system and replace main switchboard

· VAE Group, install air conditioners

· Edge Marine, install outboard motors

· TWT Electrical, general electrical works



Publications

In 2021, 84 scientific publications based on work carried out at LIRS were received into the collection, as listed below. There are now more than 2500 LIRS publications.

1. Arvizu, B., B.J.M. Allan, J.R. Rizzari, 2021. Indirect predator effects influence behaviour but not morphology of juvenile coral reef Ambon Damselfish *Pomacentrus amboinensis*. *Journal of Fish Biology*, 99(2): 679–683.

2. Booth, D.J. and G.A. Beretta, 2021. Long-term demographics of a coral-reef fish: growth, survival and abundance at several spatial scales. *Coral Reefs*, 40: 1257–1266.

3. Bouwmeester, J., A.J. Edwards, J.R. Guest, A.G. Bauman, M.L. Berumen and A.H. Baird, 2021. Latitudinal variation in monthly-scale reproductive synchrony among *Acropora* coral assemblages in the Indo-Pacific. *Coral Reefs*, 40: 1411–1418.

4. Bresnahan, P.J., Y. Takeshita, T. Wirth, T.R. Martz, T. Cyronak, R. Albright, K. Wolfe, J.K. Warren and K. Mertz, 2021. Autonomous *in situ* calibration of ion-sensitive field effect transistor pH sensors. *Limnology and Oceanography: Methods*, 19: 132–144.

5. Caballes, C.F., M. Byrne, V. Messmer and M.S. Pratchett, 2021. Temporal variability in gametogenesis and spawning patterns of crown-of-thorns starfish within the outbreak initiation zone in the northern Great Barrier Reef. *Marine Biology*, 168: 13 pages.

6. Capa, M., E. Kupriyana, J.M. de Matos Nogueira, A. Bick, and M.A.

Tovar-Hernández, 2021. Fanworms: yesterday, today and tomorrow. *Diversity*, 13: 130.

7. Chapuis, L., B. Williams, T.A.C. Gordon and S.D. Simpson, 2021. Low-cost action cameras offer potential for widespread acoustic monitoring of marine ecosystems. *Ecological Indicators*, 129: 107957.

8. Chartrand, K.M., 2021. Growth dynamics and drivers of deep-water seagrasses from the Great Barrier Reef lagoon. PhD thesis, University of Technology Sydney.

9. Chivers, D.P., M.I. McCormick, E.P. Fakan, J.W. Edmiston and M.C.O. Ferrari, 2021. Coral degradation impairs learning of non-predators by Whitetail Damselfish. *Functional Ecology*, 35: 1268–1276.

10. Chivers, D.P., M.I. McCormick, E.P. Fakan, R.P. Barry and M.C.O. Ferrari, 2021. Living in mixed species groups promotes predator learning in degraded habitats. *Scientific Reports*, 11: 19335.

11. Chou, A., 2021. A neurobiological study of the stomatopod central complex. PhD thesis, University of Maryland Baltimore County.

12. Chow, C.F.Y., E. Wassenius, M. Dornelas and A.S. Hoey, 2021. Species differences drive spatial scaling of foraging patterns in herbivorous reef fishes. *Oikos*, 130: 2217–2230.

13. Cornwall, C.E., S. Comeau, N.A. Kornder, C.T. Perry, R. van Hooijdonk, T.M. DeCarlo, M.S. Pratchett, K.D. Anderson, N. Browne, R. Carpenter, G. Diaz-Pulido, J.P. D’Olivo, S.S. Doo, J. Figueiredo, S.A.V. Fortunato, E. Kennedy, C.A. Lantz and others, 2021.

Global declines in coral reef calcium carbonate production under ocean

acidification and warming. *PNAS*, 118(21): e2015265118.

14. Cowman, P.F., A.M. Quattrini, T.C.L. Bridge, G.J. Watkins-Colwell, N. Fadli, M. Grinblat, T.E. Roberts, C.S. McFadden, D.J. Miller and A.H. Baird, 2020. An enhanced target-enrichment bait set for Hexacorallia provides phylogenomic resolution of the staghorn corals (Acroporidae) and close relatives. *Molecular Phylogenetics and Evolution*, 153: 106944.

15. Cronin, T.W., N.J. Marshall, R.L. Caldwell and D. Pales, 2021. Compound eyes and ocular pigments of crustacean larvae (Stomatopoda and Decapoda, Brachyura). In: "Zooplankton: sensory ecology and physiology", P.H. Lenz (ed.), Routledge.

16. Cutmore, S.C. and T.H. Cribb, 2021. A new order of fishes as hosts of blood flukes (Aporocotylidae): description of a new genus and three new species infecting squirrelfishes (Holocentridae, Holocentridae) on the Great Barrier Reef. *Parasite*, 28: 76.

17. Cutmore, S.C., R., Q.-Y. Yong, J. D. Reimer, S. Shirakashi, M.J. Nolan and T. H. Cribb, 2021. Two new species of threadlike blood flukes (Aporocotylidae), with a molecular revision of the genera *Ankistromece* Nolan & Cribb, 2004 and *Phthinomita* Nolan & Cribb, 2006. *Systematic Parasitology*, 98: 641–664.

18. de Busseroles, F., F. Cortesi, L. Fogg, S.M. Stieb, M. Luehrmann and N.J. Marshall, 2021. The visual ecology of Holocentridae, a nocturnal coral reef fish family with a deep-sea-like multibank retina. *Journal of Experimental Biology*, 224: 1–16.

- 19. Deaker, D.J., R. Balogh, S.A. Dworjanyn, B. Mos and M. Byrne, 2021.** Echidnas of the sea: the defensive behavior of juvenile and adult Crown-of-Thorns Sea Stars. *Biological Bulletin*, 241(3): 12 pages.
- 20. Doll, P.C., V. Messmer, S. Uthicke, J.R. Doyle, C.F. Caballes and M.S. Pratchett, 2021.** DNA-based detection and patterns of larval settlement of the corallivorous Crown-of-Thorns Sea Star (*Acanthaster* sp.). *Biological Bulletin*, 241(3): 15 pages.
- 21. Downie, A.T., 2021.** How do coral reef fishes develop into athletes? PhD thesis, James Cook University.
- 22. Downie, A.T., C.M. Phelps, R. Jones, J.L. Rummer, D.P. Chivers, M.C.O. Ferrari and M.I. McCormick, 2021.** Exposure to degraded coral habitat depresses oxygen uptake rate during exercise of a juvenile reef fish. *Coral Reefs*, 40: 1361-1367.
- 23. Downie, A.T., J.M. Leis, P.F. Cowman, M.I. McCormick and J.L. Rummer, 2021.** The influence of habitat association on swimming performance in marine teleost fish larvae. *Fish and Fisheries*, 22: 1187-1212.
- 24. Fraser, K.M., 2020.** From temperate to tropical seas: drivers of variation in reef-associated epifaunal invertebrate communities. PhD thesis, University of Tasmania.
- 25. Fraser, K.M., R.D. Stuart-Smith, S.D. Ling and G.J. Edgar, 2021.** High biomass and productivity of epifaunal invertebrates living amongst dead coral. *Marine Biology*, 168: 102.
- 26. Froehlich, C.Y.M., O.S. Klanten, M.L. Hing, M. Dowton and M.Y.L. Wong, 2021.** Uneven declines between corals and cryptobenthic fish symbionts from multiple disturbances. *Scientific Reports*, 11, 16420.
- 27. Gao, B.-C. and R.-R. Li, 2021.** Correction of sunglint effects in high spatial resolution hyperspectral imagery using SWIR or NIR bands and taking account of spectral variation of refractive index of water. *Advances in Environmental and Engineering Research*, 2(3): 16.
- 28. Gibson, R. and P. Sundberg, 2001.** Some Nemertean (Nemertea) from Queensland and the Great Barrier Reef, Australia. *Zoological Science*, 18: 1259-1273.
- 29. Greenfield, D.W. and S.L. Jewett, 2016.** *Eviota melanosphena*, a new dwarfgoby from Australia (Teleostei: Gobiidae). *Journal of the Ocean Science Foundation*, 21: 71-77.
- 30. Grinblat, M., I. Cooke, T. Schlesinger, O. Ben-Zvi, D.J. Miller and P.F. Cowman, 2021.** Biogeography, reproductive biology and phylogenetic divergence within the Fungiidae (mushroom corals). *Molecular Phylogenetics and Evolution*, 164: 107265.
- 31. Hannan, K.D., 2021.** Effects of diel pCO₂ fluctuations on coral reef fishes now and into the future. PhD thesis, James Cook University.
- 32. Hannan, K.D., S.J. McMahon, P.L. Munday and J.L. Rummer, 2021.** Contrasting effects of constant and fluctuating pCO₂ conditions on the exercise physiology of coral reef fishes. *Marine Environmental Research*, 163: 105224.
- 33. Heather, F., R. Stuart-Smith, J. Blanchard, K. Fraser and G. Edgar, 2021.** Reef communities show predictable undulations in linear abundance size spectra from copepods to sharks. *Ecology Letters*, 24(10): 2146.
- 34. Huertas Martin, V., 2021.** The trophic ecology of reef fishes: the cnidarian challenge. PhD thesis, James Cook University.
- 35. Huertas, V., R.A. Morais, R.M. Bonaldo and D.R. Bellwood, 2021.** Parrotfish corallivory on stress-tolerant corals in the Anthropocene. *PLoS ONE*, 16(9): e0250725.
- 36. Huston, D.C., S.C. Cutmore, T.L. Miller, P. Sasal, N.J. SMIT and T.H. Cribb, 2021.** Gorgocephalidae (Digenea: Lepocreadioidea) in the Indo-West Pacific: new species, life-cycle data and perspectives on species delineation over geographic range. *Zoological Journal of the Linnean Society*, 193(4): 1416-1455.
- 37. Johansen, J.L., L.E. Nadler, A. Habary, A.J. Bowden and J. Rummer, 2021.** Thermal acclimation of tropical coral reef fishes to global heat waves. *eLife*, 10: e59162.
- 38. Killen, S.S., L.E. Nadler, K. Grazioso, A. Cox and M.I. McCormick, 2021.** The effect of metabolic phenotype on sociability and social group size preference in a coral reef fish. *Ecology and Evolution*, 11: 8585-8594.
- 39. Lester, E. 2021.** Investigating the influence of reef sharks on the behaviour of mesopredators in dynamic coral reef seascapes. PhD thesis, University of Western Australia.
- 40. Lin, C., H.-J.T. Hoving, T.W. Cronin and K.J. Osborn, 2021.** Strange eyes, stranger brains: exceptional diversity of optic lobe organization in midwater crustaceans. *Proceedings of the Royal Society B*, 288: 20210216.
- 41. Maggioni, D., A. Garese, D. Huang, B.W. Hoeksema, R. Arrigoni, D. Seveso, P. Galli, M.L. Berumen, E. Montalbetti, D. Pica, F. Torsani and S. Montano, 2021.** Diversity, host specificity and biogeography in the Cladocorynidae (Hydrozoa, Capitata), with description of a new genus. *Cladistics*, 2021: 1-25.
- 42. Maggioni, D., R. Arrigoni, D. Seveso, P. Galli, M.L. Berumen, V. Denis, B.W. Hoeksema, D. Huang, F. Manca, D. Pica, S. Puce, J.D. Reimer and S. Montano, 2021.** Evolution and biogeography of the Zanclea-Scleractinia symbiosis. *Coral Reefs*, doi.org/10.1007/s00338-020-02010-9.
- 43. McCormack, J.J. and D.D. Cotoras, 2021.** Beetle diversity across micro-habitats on Lizard Island Group (Great Barrier Reef, Australia). *Zoological Studies*, 60: 12 pages.
- 44. McNeil, M., J. Firn, L.D. Northdurft, A.R. Pearse, J.M. Webster and C.R. Pitcher, 2021.** Inter-reef *Halimeda* algal habitats within the Great Barrier Reef support a distinct biotic community and high biodiversity. *Nature Ecology and Evolution*, 5: 647-655.
- 45. McNeil, M.A., L.D. Nothdurft, N.J. Dyriw, J.M. Webster and R.J. Beaman, 2021.** Morphotype differentiation in the Great Barrier Reef *Halimeda* bioherm carbonate factory: Internal architecture and surface geomorphometrics. *Depositional Record*, 7: 176-199.
- 46. Meyer, D., M. Veitch, C.G. Messing and A. Stevenson, 2021.** Crinoid feeding strategies: new insights from subsea video and time-lapse. *Elements of Paleontology*, doi.org/10.1017/9781108893534.
- 47. Mihalitsis, M., C.R. Hemingson, C.H.R. Goatley and D.R. Bellwood, 2021.** The role of fishes as food: a functional perspective on predator-prey interactions. *Functional Ecology*, 35: 1109-1119.
- 48. Morais Araujo, R., 2020.** The productivity of coral reef fishes. PhD thesis, James Cook University.
- 49. Morais, J., R.A. Morais, S.B. Tebbett, M.S. Pratchett and D.R. Bellwood, 2021.** Dangerous demographics in post-bleach corals reveal boom-bust versus protracted declines. *Scientific Reports*, 11: 18787.
- 50. Morais, R.A., A.C. Siqueira, P.F. Smallhorn-West and D.R. Bellwood, 2021.** Spatial subsidies drive sweet spots of tropical marine biomass production. *PLoS Biology*, doi.org/10.1371/journal.pbio.3001435.
- 51. Mucciarone, D.A., H.B. DeJong, R.B. Dunbar, Y. Takeshita, R. Albright and K. Mertz, 2021.** Autonomous submersible multiport water sampler. *HardwareX*, 9: e00197.
- 52. Nadler, L.E., M.I. McCormick, J.L. Johansen and P. Domenici, 2021.** Social familiarity improves fast-start escape performance in schooling fish. *Communications Biology*, doi.org/10.1038/s42003-021-02407-4.
- 53. Narvaez, P., D.B. Vaughan, A.S. Grutter and K.S. Hutson, 2021.** New perspectives on the role of cleaning symbiosis in the possible transmission of fish diseases. *Reviews in Fish Biology and Fisheries*, 31: 233-251.
- 54. Narvaez, P., R. Q.-Y. Yong, A.S. Grutter and K.S. Hutson, 2021.** Are cleaner fish clean? *Marine Biology*, 168: 59.
- 55. Narvaez, P., R.A. Morais, K.S. Hutson, M.I. McCormick and A.S. Grutter, 2021.** Habitat degradation drives increased gnathiid isopod ectoparasite infection rate on juvenile but not adult fish. *Coral Reefs*, 40: 1867-1877.
- 56. Nicholson, G.M and K.D. Clements, 2021.** Ecomorphological divergence and trophic resource partitioning in 15 syntopic Indo-Pacific parrotfishes (Labridae: Scarini). *Biological Journal of the Linnean Society*, 132: 590-611.
- 57. Page, T.M., E. Bergstrom and G. Diaz-Pulido, 2021.** Acclimation history of elevated temperature reduces the tolerance of coralline algae to additional acute thermal stress. *Frontiers in Marine Science*, 8: 660196.
- 58. Paula, J.R., D. Sun, V. Pissarra, P. Narvaez, R. Rosa, A.S. Grutter and P.C. Sikkel, 2021.** The role of corals on the abundance of a fish ectoparasite in the Great Barrier Reef. *Coral Reefs*, 40: 535-542.
- 59. Pisapia, C., E.J. Hochberg and R. Carpenter, 2021.** Modes of metabolic performance of Pacific reefs. *Geophysical Research Letters*, 48: e2021GL092930.
- 60. Pollock, M.S., Z. Hoyle, M.I. McCormick, D.P. Chivers and M.C.O. Ferrari, 2021.** Disturbance cues facilitate associative learning of predators in a coral reef fish. *Behavioral Ecology and Sociobiology*, 75: 149.
- 61. Pratchett, M.S., C.F. Caballes, C. Cvitanovic, M.L. Raymundo, R.C. Babcock, M.C. Bonin, Y.-M. Bozec, D. Burn, M. Byrne and many others, 2021.** Knowledge gaps in the biology, ecology, and management of the Pacific Crown-of-Thorns Sea Star, *Acanthaster* sp., on Australia's Great Barrier Reef. *Biological Bulletin*, 241(3): doi.org/10.1086/717026.
- 62. Pratchett, M.S., L.E. Nadler, D. Burn, B.J. Lang, V. Messmer and C.F. Caballes, 2021.** Reproductive investment and fecundity of Pacific crown-of-thorns starfish (*Acanthaster cf. solaris*) on the Great Barrier Reef. *Marine Biology*, 168: 87.
- 63. Puskic, P.S. and A.R. Coghlan, 2021.** Minimal meso-plastics detected in Australian coastal reef fish. *Marine Pollution Bulletin*, 173: 113074.
- 64. Richards, Z.T., D.J. Juskiewicz and A. Hoggett, 2021.** Spatio-temporal persistence of scleractinian coral species at Lizard Island, Great Barrier Reef. *Coral Reefs*, 40: 1369-1378.
- 65. Roche, D.G., 2021.** Effects of wave-driven water flow on the fast-start escape response of juvenile coral reef damselfishes. *Journal of Experimental Biology*, 224(6): jeb234351.
- 66. Roche, D.G., M. Jornod, V. Douet, A.S. Grutter and R. Bshary, 2021.** Client fish traits underlying variation in service quality in a marine cleaning mutualism. *Animal Behaviour*, 175: 137-151.
- 67. Romanó de Orte, M., D.A. Koweek, T. Cyronak, Y. Takeshita, A. Griffin, K. Wolfe, A. Szmant, R. Whitehead, R. Albright and K. Caldeira, 2021.** Unexpected role of communities colonizing dead coral substrate in the calcification of coral reefs. *Limnology and Oceanography*, 66: 1793-1803 2021.
- 68. Santana, M.F.M, A.L. Dawson, C.A. Motti, L. van Herwerden, C. Lefevre and F.J. Kroon, 2021.** Ingestion and depuration of microplastics by a planktivorous coral reef fish, *Pomacentrus amboinensis*. *Frontiers in Environmental Science*, 9: 641135.
- 69. Semmler, R.F., 2021.** Identifying critical foraging thresholds for coral reef fishes. PhD thesis, Lancaster University.
- 70. Semmler, R.F., S.J. Brandl, S.A. Keith and D.R. Bellwood, 2021.** Fine-scale foraging behavior reveals differences in the functional roles of herbivorous reef fishes. *Ecology and Evolution*, 11: 4898-4908.
- 71. Sobonova, A. and Z. Duris, 2021.** Unexpected diversity in the sponge-associated shrimps *Onycozoidella* Bruce, 1981 (Crustacea: Decapoda: Palaemonidae) revealed by bulk collecting techniques and molecular tools. *Invertebrate Systematics*, 35: 361-393.

72. Streets, A., 2021. Structure and function of the optic lamina in stomatopods. PhD thesis, University of Queensland.

73. Streit, R.P., 2020. Space use by fishes on coral reefs: establishment, fidelity and reef resilience. PhD thesis, James Cook University.

74. Streit, R.P., C.R. Hemingson, G.S. Cumming and D.R. Bellwood, 2021. How flexible are habitat specialists? Short-term space use in obligate coral-dwelling damselfishes. *Reviews in Fish Biology and Fisheries*, 31: 381–398.

75. Tebbett, S.B., 2020. Functioning of a coral reef transformed by climate change. *Reef Encounter*, 35: 49–53.

76. Temple, S.E., M.J. How, S.B. Powell, V. Gruev, N.J. Marshall and N.W. Roberts, 2021. Thresholds of polarization vision in octopuses. *Journal of Experimental Biology*, 224: jeb240812.

77. Thompson, C.A., A.S. Hoey, S.R. Montanari, V. Messmer, P.C. Doll and M.S. Pratchett, 2021. Territoriality and condition of chevron butterflyfish (*Chaetodon trifascialis*) with varying coral cover on the Great Barrier Reef, Australia. *Environmental Biology of Fishes*, 104: 53–69.

78. Triki, Z. and R. Bshary, 2021. Sex differences in the cognitive abilities of a sex-changing fish species *Labroides dimidiatus*. *Royal Society Open Science*, 8: 210239.

79. Truskanov, N., Y. Emery, S. Porta and R. Bshary, 2021. Configural learning by cleaner fish in a complex biological market task. *Animal Behaviour*, 181: 51–60.

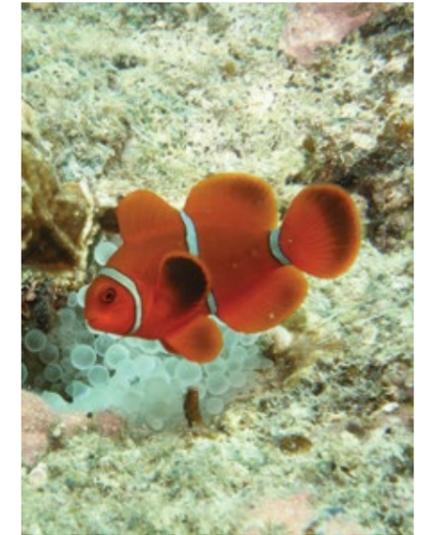
80. Valenzuela, J., D.R. Bellwood and R. Morais, 2021. Ontogenetic habitat shifts in fusiliers (Lutjanidae): evidence from *Caesio cuning* at Lizard Island, Great Barrier Reef. *Coral reefs*, 40(6): 1687.

81. Vishnyakov, A.E., N.P. Karagodina, G. Lim-Fong, P.A. Ivanov, T. F. Schwaha, A.V. Letarov and A.N. Ostrovsky, 2021. First evidence of virus-like particles in the bacterial symbionts of Bryozoa. *Scientific Reports*, 11: 4.

82. Wibowo, K. and H. Motomura, 2021. First records of the bandfin scorpionfish, *Scorpaenopsis vittapinna* (Actinopterygii, Scorpaeniformes, Scorpaenidae), from Australia. *Acta Ichthyologica et Piscatoria* 51(1): 53–57.

83. Xu, J., J. Zhao, F. Wang, Y. Chen and Z. Lee, 2021. Detection of coral reef bleaching based on Sentinel-2 multi-temporal imagery: simulation and case study. *Frontiers in Marine Science*, 8: 584263.

84. Yarlett, R.T., C.T. Perry and R.W. Wilson, 2021. Quantifying production rates and size fractions of parrotfish derived sediment: a key functional role on Maldivian coral reefs. *Ecology and Evolution*, 11: 16250–16265.



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