REEF RESTORATION & ADAPTATION PROGRAM

IMPACT REPORT 2020–2024

Australian Government | Reef Trust

Great Barrier Reef Foundation

Australian Government | Australian Institute of Marine Science

CSIRO

James Cook University Australia

QUT

Southern Cross University

The University of Queensland Australia

The Reef Restoration and Adaptation Program (RRAP) acknowledges Aboriginal and Torres Strait Islander Peoples as the first reef scientists and carers of Country. We acknowledge the Traditional Owners of the places where RRAP works, both on land and in sea Country. We pay our respects to elders; past, present, and future; and their continuing culture, knowledge, beliefs, and spiritual connections to land and sea Country.

Cover photo: Reef biodiversity detail on the Great Barrier Reef.
Credit: Gary Cranitch, Queensland Museum

Inside cover: Coral spawn collected during conservation aquaculture processes.
Credit: Marie Roman, Australian Institute of Marine Science

FOREWORD

Global warming is accelerating, and marine heatwaves are becoming more frequent and acute, threatening coral reef ecosystems across the world. Although nations are committed to reducing carbon emissions to net zero in the second half of this century, further ocean warming is inevitable over the next few decades. It is thus vital that we develop strategies to assist coral reefs to survive through this transitional period.

This report summarises progress made by the Reef Restoration and Adaptation Program (RRAP) in developing such strategies, with a particular focus on the Great Barrier Reef (GBR).

Our modelling of the future state of the GBR demonstrates that interventions will be needed to assist coral reefs in coming decades, under all realistic carbon emissions trajectories the world could follow. Without interventions, coral reef cover and diversity in the GBR will decline significantly and critical ecological, social, cultural and economic values will be lost.

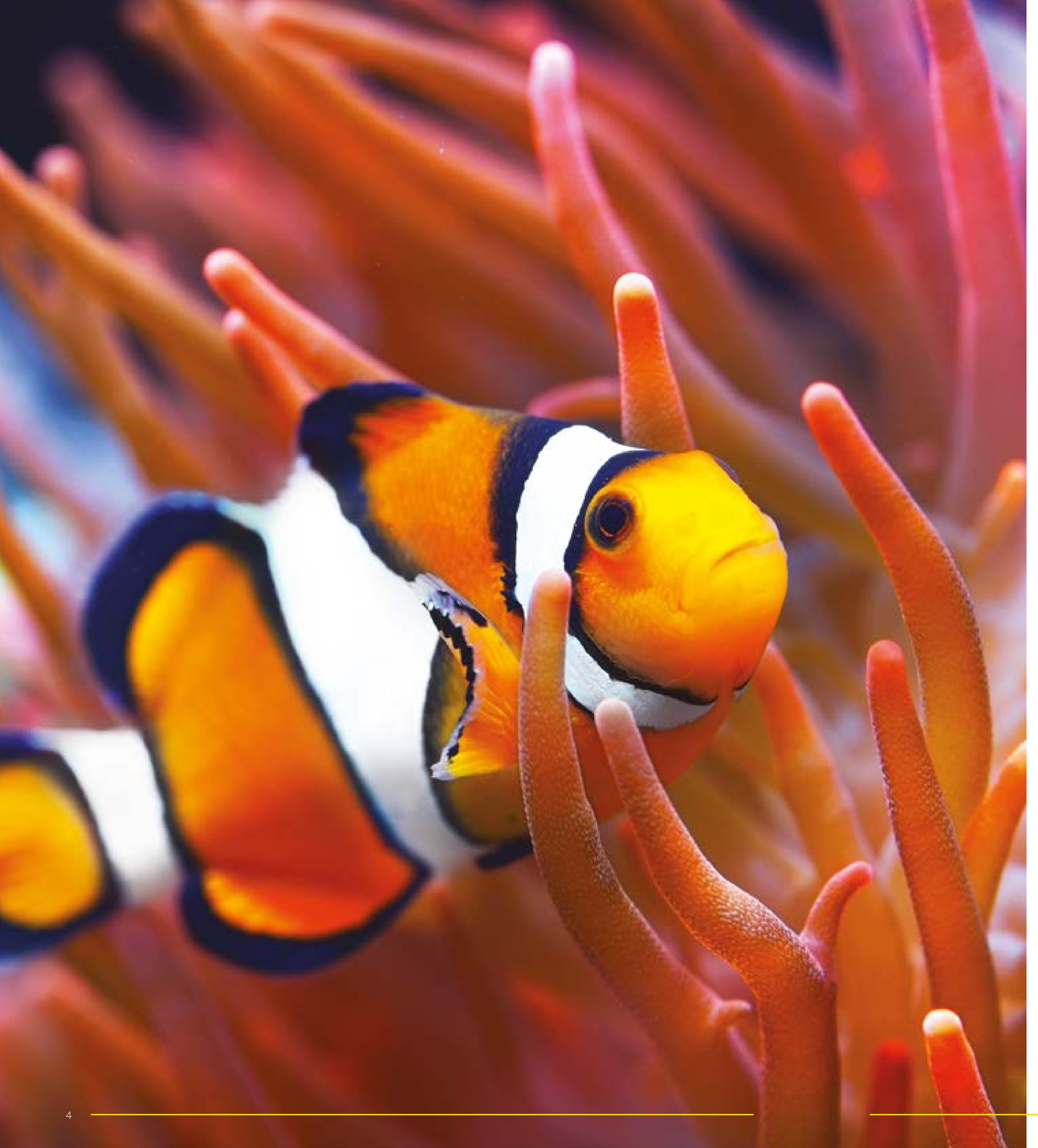
Over the last five years RRAP has been researching interventions that could give coral reefs a chance to survive as the global climate system stabilises. We have made excellent progress and we have growing confidence that at least some of the interventions we have been examining can be implemented at scale to benefit high priority assets on the Great Barrier Reef.

Other than the interventions investigated by RRAP, we are not aware of any other management levers that could directly protect the reef from the further ocean warming that lies ahead. Efforts to improve catchment water quality, arrest crown-of-thorns starfish incursions and protect fisheries are also vital management actions, but these efforts in themselves cannot protect the GBR from worsening marine heatwaves.

We have just commenced the final year of the first phase of RRAP research and are establishing a five-year program of trial deployments to test the efficacy and practicality of RRAP interventions at scale. More research is necessary, as are strengthened partnerships with traditional custodians of sea Country, other reef communities and businesses operating in the GBR. In the coming months we will be working with government and reef stakeholders to develop the next phase of partnership research that will ensure that reef managers have options to protect the GBR in the years ahead.

Professor Rob Vertessy,
Board Chair

Dr Cédric Robillot,
Executive Director



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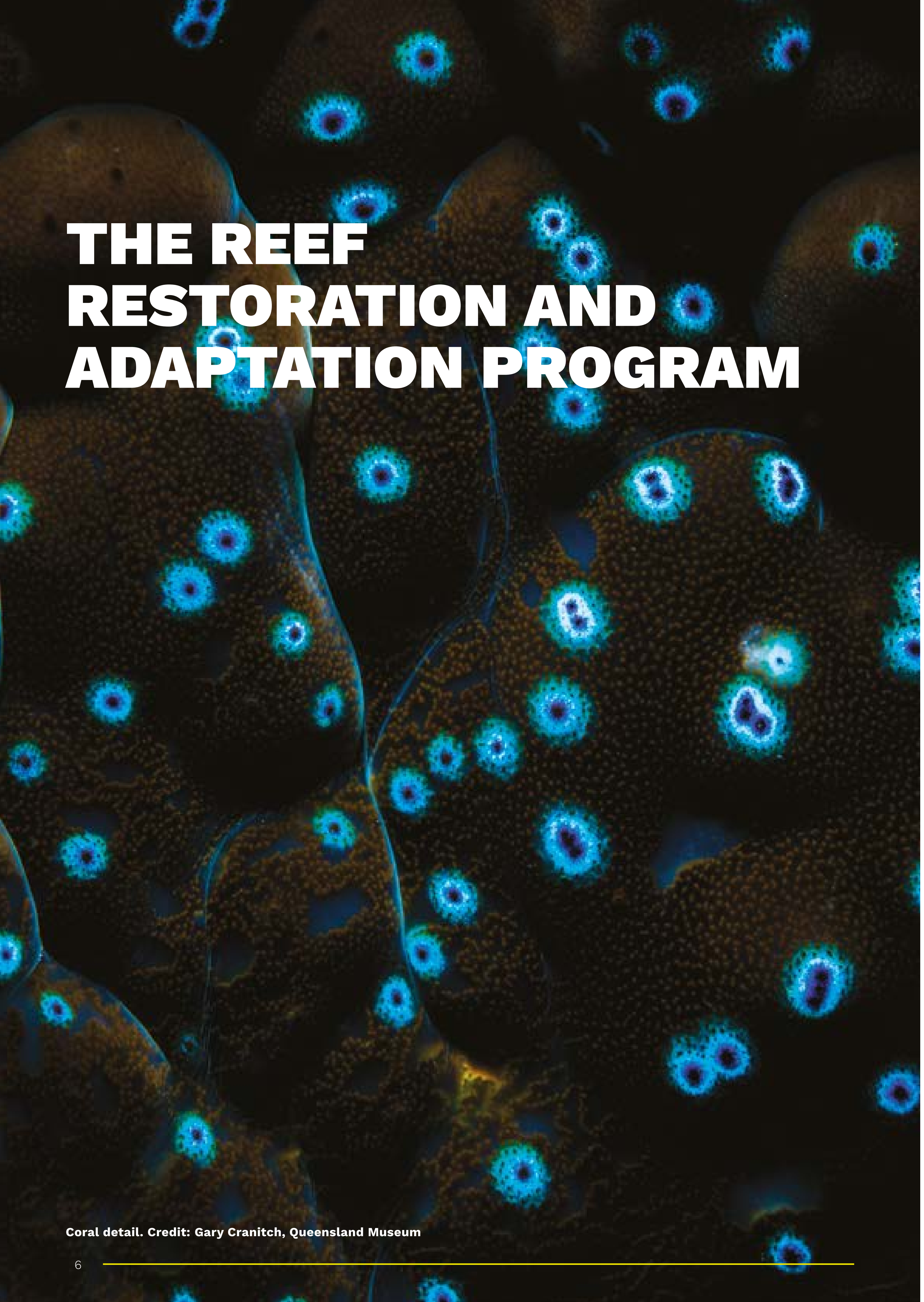
THE REEF RESTORATION AND ADAPTATION PROGRAM



Coral detail. Credit: Gary Cranitch, Queensland Museum

Since 2018, RRAP's mission has been to develop innovative solutions that can support the resilience of the Great Barrier Reef to the impacts of climate change, and to share our knowledge for the benefit of coral reefs globally.

RRAP's mission is to develop and test novel scientific solutions, and make those available to managers, to help the Great Barrier Reef (GBR) and other coral reefs survive in the decades ahead, as emissions reductions targets are reached. These solutions are developed and delivered in partnership with Traditional Owners, recognising their ancestral knowledge and the benefits of seeing the Great Barrier Reef as a cultural landscape beyond its biophysical features.

RRAP supports the consensus that addressing climate change and drastically reducing greenhouse gas emissions is the absolute priority for the long-term survival of coral reefs. This is alongside context-specific management activities which are essential to support reef resilience and recovery, such as actions to improve water quality, prevent overfishing and contain coral predator outbreaks.

Yet emissions reductions and current management actions alone will not safeguard the Great Barrier Reef and coral reefs around the globe. Based on coral declines already attributed to climate change and further ocean temperature warming locked in, our modelling of the future state of coral reefs clearly shows that new solutions will be needed to assist the Great Barrier Reef in coming decades.

The increased urgency to prepare for and respond to the impact of marine heatwaves on coral reefs was highlighted in 2024. The recent record ocean temperatures and the declaration of a fourth global mass bleaching event highlight the increased urgency to prepare and respond to the impact of marine heatwaves. The speed at which climate change impacts are unfolding is alarming. We are literally in a race against time to save our coral reefs.

A landmark investment from the Australian Government has enabled us to get off to a great start. We are propagating corals with enhanced thermal tolerance and developing methods to deploy them at scale. We are designing world-first cooling and shading technologies that could protect priority reefs during marine heatwaves. We are also identifying how to introduce interventions such as these to the Great Barrier Reef in ways that are acceptable to environmental regulators, Traditional Owners of sea Country and the broader Australian community.

This impact report highlights the advancements made by the program since its inception and how some of the interventions we have been examining are now ready to be tested at scale to benefit high priority assets on the Great Barrier Reef.

To give our reefs a fighting chance, we must act collectively at a speed and scale never before attempted. This is our mission.

WHY INTERVENE?

Projected coral futures in the absence of new interventions are stories of decline.

Modelling Great Barrier Reef change in the face of complexity

The GBR coral reef ecosystem is among the most complex in the world, in part due to its size (spanning 2300km), its interconnected reefs and habitats, its multitude of bioregions, and steep environmental gradients from coastal to oceanic influences. Models are simplified representations of processes and patterns in nature and are critical tools to understand how ecosystems might respond to environmental change and to management actions.

For reef ecosystems, corals take centre stage in ecological models. Like trees that support the bidoversity of a forest, corals provide critical three-dimensional habitats, food and protection for thousands of species of reef fish and invertebrates.

To generate forecasts for the GBR requires suites of interconnected models, describing global and regional environmental dynamics, drivers and pressures, and how corals respond to those. Additional models can also capture the socio-economic consequences of predicted changes for this ecosystem.

RRAP's Modelling and Decision Support has developed such capability, integrating and continuously improving environmental, ecological and economic models hosted across multiple institutions. This now accounts for all reefs on the GBR and determines their future ecological states under a range of possible climate scenarios.

Models do not predict the future but offer a series of possible futures tied to global greenhouse gas emissions trajectories. For each of these possible futures, they provide a picture of what the GBR will look like if no additional action is taken to help it adapt to the impacts of climate change. This is often referred to as a counterfactual baseline for GBR future health.

The impact of existing management interventions is accounted for in our baseline. This includes interventions targeting water quality improvements and crown-of-thorns starfish control. The benefits of new management interventions such as those developed by RRAP can then be considered relative to this baseline, asking the question "how much better would GBR reefs function if RRAP interventions are included in management actions?"

All complex ecosystem models are subject to uncertainty and limitations, yet they are powerful tools for interrogating possible futures, and the decisions and policy settings that might shape those futures.

What do the models tell us?

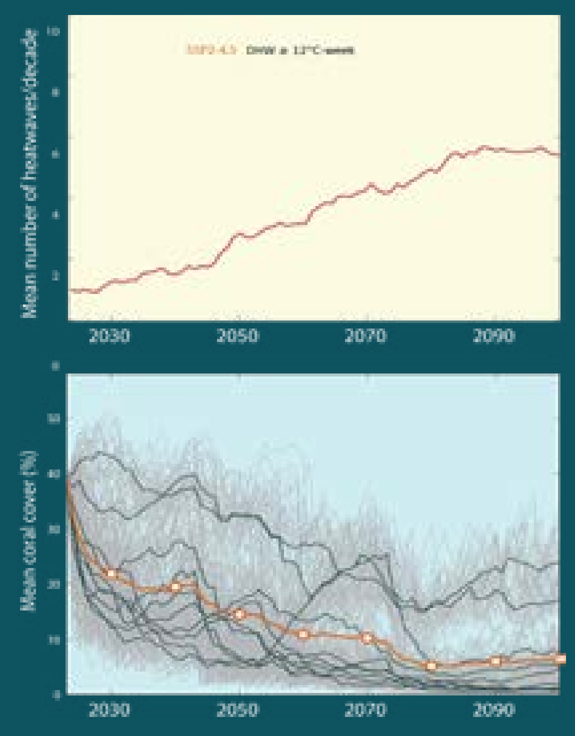
Climate change scenarios are identified by the Intergovernmental Panel on Climate Change (IPCC) as Shared Socioeconomic Pathways or SSPs.

Keeping warming below 1.5°C (IPCC high aspiration SSP1-1.9) is the best-case future for GBR corals.

Under this best-case scenario, which has only has 1% chance of unfolding, a decline in sea surface temperatures in the second half of the century could provide scope for well-adapted and surviving corals to recover. However, the average trajectory still sees a decline to about 15% coral cover by 2050.

The most likely climate future (up to 2.7°C increase) could drive coral cover below 5% by the end of the century.

A continued rise in sea surface temperatures after 2050 would expose corals to repeated and severe mass bleaching events, likely exceeding the natural adaptive capacity of corals to recover. This would lead to a precipitous decline in coral cover to around 5% by end of the century, with coral loss accelerating markedly after 2050. A coral cover of less than 5% is considered unsustainable from the perspectives of ecosystem function, reproductive capacity, resilience and likely support of biodiversity.

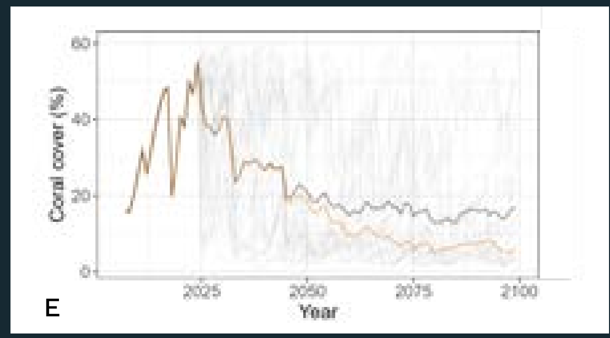


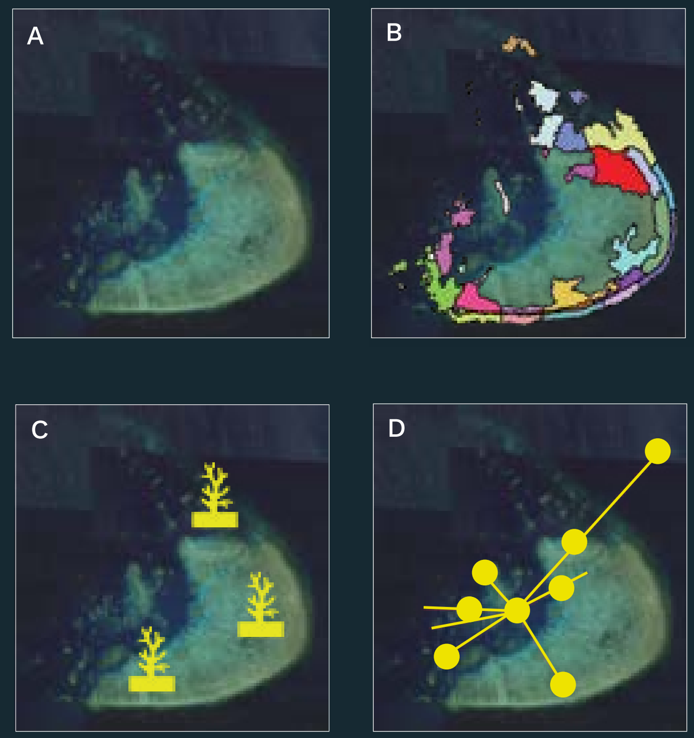
With each marine heatwave, corals experience significant heat stress. The degree heating weeks (DHW) is a measure of the accumulated heat stress over a twelve week period. An intensity of 12 DHW is linked to widespread and multi-species coral bleaching and mortality. This figure shows how many times per decade GBR coral reefs, on average, are predicted to experience such damaging intensity.

This figure shows predicted GBR coral cover trends under the most likely climate change trajectory (SSP2-4.5) over the course of this century. Grey lines correspond to individual model runs and black lines represent the average run for each of 10 global climate models. The orange line indicates the global mean across all individual runs and is our best estimate of the future state of the reef under this scenario.

Projected coral futures with new interventions are stories of hope.

Our modelling indicates a narrow window to act if we are to sustain coral reef resilience and function while climate change is arrested. Modelling intervention efficacy is a critical component of RRAP. Through this we determine the ecological benefits, above the baseline, of deploying new interventions at different scales on the reef.





Figures A-E illustrate the modelling process for coral seeding interventions. Representative local groups of reefs (A) are divided into sites (B) that have various ecological characteristics like wave exposure, depth, and thermal stress. Models can project coral deployment onto a site (C) and factor propagation of coral larvae after spawning through connectivity between sites (D).

Changes in average coral cover over time (E) are predicted without intervention (counterfactual – red line) and with intervention (black line).

As summarised in the graph (E) above, the difference represents the predicted benefit of the intervention.

A REEF RESILIENCE TOOLKIT

Five years into our Program journey, our goal remains to accelerate the translation of scientific discovery and technology innovation to real-world applications with a focus on scale, efficacy, and cost. To achieve this goal, RRAP has systematically considered the range of possible technology solutions, and pursued the development and testing of those that have the highest potential to deliver impact at scale and within the window of time available.

PROPAGATING CLIMATE RESILIENT CORALS

We identify corals and symbionts that can deal with warmer temperatures, for conservation aquaculture systems.

SPAWNING SLICK CAPTURE AND LARVAL RESETTLEMENT

We scale up the capture of wild coral spawn, before rearing and resettling larvae on priority target reefs, assisting natural reef recovery processes.

SECURING GENETIC DIVERSITY OF CORALS

We research and apply new cryopreservation techniques to bank coral sperm and larvae, securing genetic diversity and supporting coral conservation aquaculture.

LARGE SCALE CORAL PROPAGATION AND DEPLOYMENT

We design and automate innovative processes and deployment strategies to produce and seed corals at low cost and high survival.

STABILISING REEFS

We study the mechanism of rubble formation in order to predict the risk, characterise the impact and design strategies to stabilise damaged reef substrates prior to restoration.

PROTECTING REEFS FROM HEAT STRESS

We develop and trial innovative seawater spraying techniques to reduce coral UV and thermal stress from solar radiation, on a large scale (marine cloud brightening) or local scale (fogging).

ESSENTIAL FUNDAMENTAL ECOLOGICAL KNOWLEDGE

We develop and apply innovative monitoring techniques, to study corals in the field and build the fundamental knowledge as to the 'how, where, and when' of natural reef recovery and future interventions.

MODELLING AND DECISION SUPPORT

To guide investment and action, we assess the condition of the Reef with or without interventions using comprehensive physical, ecological, value and risk modelling.

A RRAP feasibility study completed in 2019, by 150 experts from 20 international science organisations, concluded that new coral reef protection, restoration and adaptation solutions are technically feasible and could provide benefits at a meaningful scale.

The study recommended a ten-year research and development program be implemented to test, validate and make these innovative solutions available to reef managers.

Translation to practice

INDUSTRY PATHWAYS

Scaling up restoration and adaptation will involve uptake of interventions by reef managers, industry operators and Traditional Owners. We actively invest in translating science to practice, working with government and industry to create new opportunities, build capacity and develop a pathway for adoption of new interventions on a large scale.

COMMUNITY AND TRADITIONAL OWNER ENGAGEMENT

We work to ensure Traditional Owners and stakeholders, including Reef communities, are better able to benefit from and adapt to the outcomes of interventions, by developing foundational social science and exploring engagement and partnership models. We co-design and pilot a biocultural value framework alongside targeted investment in Traditional Owner training and capacity building.

Coral broodstock collected for spawning in the 'autospawner' at the Australian Institute of Marine Science. Credit: SkyReef Photos

2000+
coral colonies tested for thermal tolerance to map resilience along the length of the Reef

100 MILLION+
coral larvae delivered using prototype spawn slick capture and culture equipment and techniques

60+
long-term integrated monitoring sites established within 18 reefs to study coral recovery and ecology

20,000+
adult coral colonies mapped and digitised

WORLD-FIRST
reef cloud brightening experiment with potential to protect hectares of reef from solar radiation

9,500+
coral seeding devices delivered via low-cost diver-less deployment with increased survival to 50-80%

100-1000x
increase in coral production through world-first high-throughput semi-automated sexual reproduction of dozens of coral species

WORLD-FIRST
heat-evolved symbiont algae shown to increase coral thermal tolerance without growth trade off

4 TRILLION +
Coral sperm from across 33 species cryopreserved for future restoration efforts and new larvae cryopreservation technique demonstrated

We have addressed critical knowledge gaps and made significant scientific and engineering breakthroughs.

This paves the way for larger field trials and pilot deployments from 2025-2030, technological, process, and management breakthroughs to allow for restoration scaling.

35 PROJECTS across ecological, social and engineering

Contributors to **GLOBAL REEF INITIATIVES** **10**

7 CORE PARTNERS Australian Universities and research Institutes

20+ COLLABORATING organisations and universities

130 field trips across all Reef regions

300 SCIENTISTS

40 STUDENTS

2000 days at sea

140 PUBLICATIONS

180 PRESENTATIONS

160 in depth interviews with reef community members

40 people involved in regional community panels and advisory groups

8000 AUSTRALIANS surveyed about RRAP interventions

40 TRADITIONAL OWNER GROUPS engaged for field research and biocultural framework

Co-investment from RRAP Partners and private sector

$55M DIRECT CASH

$110M IN KIND & PLEDGES

ACTIVATION PARTNERS
L'Oréal, Garnier, Life-Space Probiotics, Qantas, McLaren, Paul G. Allen Family Foundation and more

A UNIQUE PARTNERSHIP

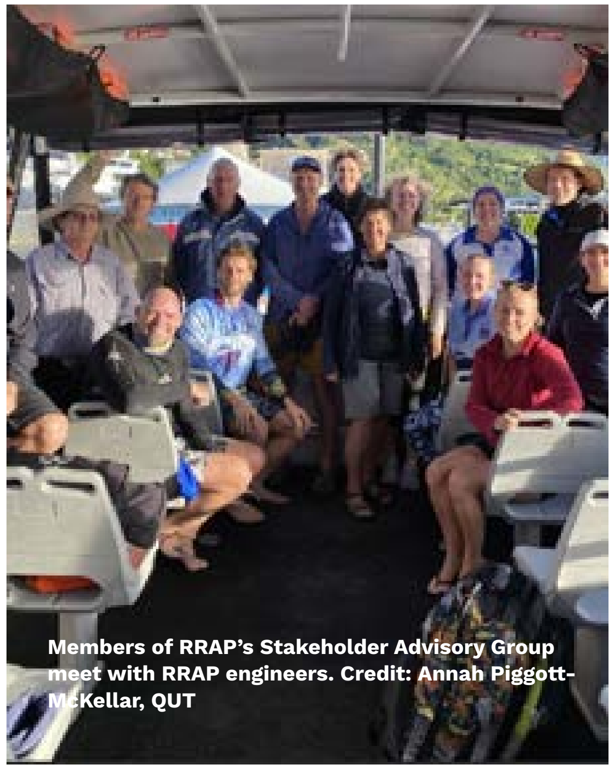
A BIOCULTURAL APPROACH

Since launching in 2020, our intention has been to embed co-design and knowledge sharing with Traditional Owners and reef communities from systematic Program design to how we do business every day. In an Australian-first, whenever RRAP is planning to work on sea Country where there may be Traditional Owner rights or interests in place, research teams must seek and obtain free prior and informed consent from Traditional Owners.

Under the RRAP Indigenous Engagement Framework, on-ground engagement has occurred with more than 40 Traditional Owner groups (24 FPICs).

The Program is implementing a Traditional Owner training and capacity building program to enable growing participation in intervention delivery.

RRAP has also supported the development of a unique Biocultural Assessment Framework, that can be used by Traditional Owners of the Great Barrier Reef, and possibly others, to assess the potential risks and opportunity pathways related to new RRAP interventions. This framework could also provide a platform for Traditional Owners and others to consider and plan risk mitigation and management and enterprise or other development pathways, as appropriate.



Members of RRAP's Stakeholder Advisory Group meet with RRAP engineers. Credit: Annah Piggott-McKellar, QUT

Our approach extends beyond a concept of social licence and is exploring how local actors can drive and benefit from this new reef restoration and adaptation industry.

Through targeted social research, we have advanced our understanding of public perceptions of RRAP interventions (including risks and benefits of research and development (R&D) and implementation), and opportunities to deliver community and stakeholder co-benefits. It has led the design and evaluation of best-practice, place-based, engagement opportunities for reef communities and the general public that are informed by global leading practice for regional ecosystem adaptation.

One such initiative was the RRAP Stakeholder Engagement Advisory Group. Formed in 2022, the group comprised of representatives from across the Great Barrier Reef community, including tourism operators and Traditional Owners.

The group subsequently provided advice to RRAP social scientists as to engagement strategy and effective deliberative process in the context of potential risks and benefits of RRAP intervention.

79%	**Australians are concerned about the health of the Reef**
74%	**Accept novel interventions to help reefs adapt to climate change**
83%	**Trust science to provide solutions to help repair the Reef**

RRAP recognises that interventions will only be successful if delivered in partnership with Traditional Owners, acknowledging their ancestral knowledge and the benefits of seeing the Great Barrier Reef as a cultural landscape beyond its biophysical features, and if local communities and industry are involved in their implementation, under the guidance of reef managers.

RRAP sought input from over 8000 Australians (including >750 Aboriginal and Torres Strait Islander respondents) through national and reef resident surveys (2018 & 2022). This provided a unique understanding of their views of reef health, climate impacts, risks, benefits and acceptability of RRAP and non-RRAP interventions. It also assessed perceptions of the role of science organisations in large scale restoration and adaptation efforts.

This was complemented by over 160 deep-dive interviews with regional Reef community members.

Traditional Owners, tourism operators and researchers work together to set up floating pools to collect coral spawn, as part of Boats4Corals, a Reef Islands Inititiative Project. Credit: Jodi Salmond, Reef Check Australia

OUR GOVERNANCE

Based on recommendations from the feasibility study and engagement with key stakeholders, RRAP established a governance framework. This has proven effective and adaptive in delivering a complex and integrated program of research and development (R&D), generating significant breakthroughs in record time and making clear progress towards achieving our goals.

The Board has oversight of the overall strategy and direction of the Collaboration, and management of the Collaboration's delivery of the R&D program.

Prof Robert Vertessy is the independent Chair of the Board.

12 MEMBERS
4 INDEPENDENTS
1 FIRST-NATION
2 OBSERVERS (DCCEEW AND GBRMPA*)

BOARD

The Steering Committee reports to the Board, recommending R&D plans and expenditure, and managing the working relationship and appropriate allocation of resources among Partners.

Dr Cedric Robillot (Executive Director) is the Chair of the Steering Committee.

10 MEMBERS
2 INDEPENDENT TRADITIONAL OWNER MEMBERS
1 OBSERVER (GBRMPA)

STEERING COMMITTEE

The Managing Entity (the Australian Institute of Marine Science) provides administrative and program management support to the Collaboration. It is responsible for financial management, performance tracking and progress reporting, data management and coordinates whole-of-program risk management functions.

Jim Higgs (Program Director) leads the Managing Entity.

MANAGING ENTITY

The Program Management Team delivers the integrated program of R&D activities and field work, ensures linkages and synergies are identified and maintained, and directly supports communication, stakeholder engagement and risk activities. It is composed of science leaders within Partner institutions.

SCIENCE LEADERSHIP

** Department of Climate Change, Energy, the Environment and Water. Great Barrier Reef Marine Park Authority.*

RRAP is delivered through a collaboration with the Great Barrier Reef Foundation, the Australian Institute of Marine Science, CSIRO, James Cook University, Queensland University of Technology, Southern Cross University and the University of Queensland as core partners.

TRADITIONAL OWNER CO-DESIGN GROUP

The program is guided on the implementation of it's Indigenous Engagement Framework by Traditional Owner representatives on the Board and Steering Committee but also by the Restoration and Adaptation Science - Crown-of-thorns starfish (RRAS-COTS) Traditional Owner Co-Design Group (established under the Reef Trust Partnership).

This has led to the development of a Biocultural Framework, reflecting aspirations of Traditional Owners and their unique role in caring for sea Country.


The RRAS-COTS Traditional Owner Co-Design Group (in 2023). Credit: Heather Miller Photography

INTERVENTION RISK REVIEW GROUP


Members of RRAP's Intervention Risk Review Group gather to workshop intervention risk. Credit: BlueClick Photography

The Intervention Risk Review Group was established to provide independent advice on the assessment and management of intervention risk, at a range of scales. Led by an Independent chair, Sue Barrell AO FTSE, its members are Australian and international experts highly recognised in their field.

The Reef Authority is represented in an observer capacity at its meetings, acknowledging that this group can provide uniquely independent assurance to regulators that risks associated with RRAP interventions are being adequately identified and addressed. This model has relevance for the design and implementation of coral reef restoration and adaptation globally.

OUR IMPACT

CONSERVATION AQUACULTURE

Automated high-volume coral production systems

RRAP has demonstrated an innovative, highly efficient and low-cost coral conservation aquaculture system to produce and deploy the number of healthy corals needed to help reefs recover and adapt. Rather than collecting and fertilising coral eggs by hand, an 'autospawner' has been developed to automate and control gamete collection, counting and fertilisation, generating millions of healthy larvae without human intervention.

After settling on specially designed tabs, corals then grow for a few weeks before being inserted into low-cost 'seeding' devices that can be released directly from a boat. Each seeding device carries 20 to 30 coral spats, with the target for at least one of these to survive to become an adult coral. This has now been applied to multiple coral species, demonstrating high survival rates with 50-90% of devices now able to grow a one-year-old coral.

The system to be used in 2025 has a production capacity 2-3 times orders of magnitude above current systems and with full automation 4-5 times orders of magnitude, however the scale of sustainable deployments will be dependent on investment.

RRAP researcher with broodstock coral in conservation aquaculture. Credit: SkyReef Photo

We are on track to build the capacity to **produce up to 100s of millions of corals per year,** measured as individual corals reaching 12 months of age post deployment.

Robotics for Aquaculture Accuracy

During the process of coral propagation in aquaculture, monitoring of fertilisation and early life stage survival has previously been done by a trained operator, which is time-consuming and labour intensive.

For the first time, our new robotic camera uses computer vision and learning algorithms to count individual settled corals and track their health and growth, including fragile day-old corals. This provides unprecedented levels of control in mass producing corals.

Additionally, the low-cost and modular nature of this technology will facilitate adoption of new restoration solutions by a wide range of reef communities around the world.

HARNESSING ADAPTATION

To ensure that restored corals have adaptive capacity under future climate scenarios, RRAP has focused on building the fundamental knowledge of variation in temperature tolerance across the length and breadth of the Great Barrier Reef.

Testing has now revealed that corals have a large existing variation in tolerance across species, population and habitat.

From this data, coral biologists and mathematicians have, together, designed new models to identify and map reefs containing high numbers of heat tolerant corals.

Tools were also developed to select target species for restoration and identify tolerant corals, allowing the phenotyping and genotyping of corals to understand markers of tolerance.

Heat evolved symbionts

The survival of reef-building corals depends on the mutually beneficial relationship between the coral host and microscopic algae residing in their tissues. When corals are under stress, they lose these algae or symbionts, a phenomenon known as coral bleaching.

RRAP has focused not only on understanding the biology of this symbiotic relationship, but methods to improve symbiont heat tolerance and boost coral resilience.

Professor Madeleine van Oppen with corals inoculated with heat tolerant symbionts. Credit: Marie Roman, Australian Institute of Marine Science

Coral fragments inoculated with heat tolerant symbionts. Credit: Wing Chan, Australian Institute of Marine Science

In a world-first, algal symbionts have been evolved in the laboratory to achieve increased heat tolerance and introduced in juvenile and adult coral hosts.

This led to an enhanced thermal tolerance for the corals without compromised growth at ambient temperatures, both in the laboratory and in the field.

Collaborative monitoring field work.
Credit: Matt Curnock, CSIRO

OUR IMPACT

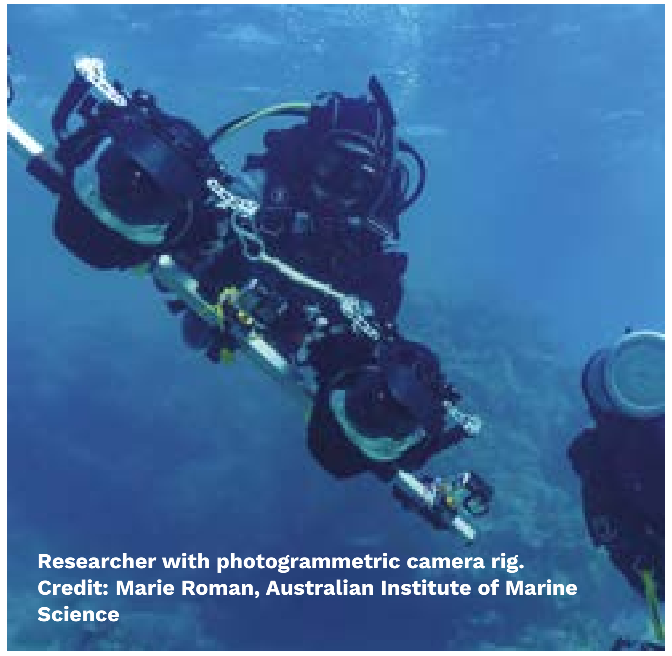
ADDRESSING KNOWLEDGE GAPS

Data-driven decision making

Smart and efficient decision-making is critical as we plan for future deployments. Our integrated monitoring and ecological intelligence efforts provide the backbone for the how, when, and why of effective restoration and adaptation. Customised monitoring tools like 3D photogrammetry are now able to capture and track over time ecological information at a wide range of spatial scales – from millimeters to kilometers. This data feeds into new or improved predictive models to understand the potential benefits, costs, risks, and uncertainties of our interventions.

We are addressing critical knowledge gaps, such as understanding coral growth and survival, especially during vulnerable early life stages, studying coral interactions with algae and fish, temperature tolerance, and improving our estimates of larval production from reefs and connectivity to neighbouring reefs.

We are working to **prioritise reefs for future restoration and adaptation** based on the benefits they can provide to the whole system, and ultimately measure the success of these interventions over time.



Researcher with photogrammetric camera rig.
Credit: Marie Roman, Australian Institute of Marine Science

Collaborative monitoring

RRAP teamed with the Cairns-Port Douglas Reef Hub to design and trial a collaborative monitoring program for coral seeding devices deployed in the field. RRAP scientists worked alongside local partners, investigating how to best deploy and monitor the devices, including in rubble habitats, and deepen understanding of coral recruitment patterns.

Alongside advancing scientific knowledge, the monitoring program aimed to improve visibility and transparency of RRAP amongst local partners.

A social science based evaluation framework has been developed and is being implemented to capture lessons, measure impact, and further inform decision-making and planning for future intervention deployment.

OUR IMPACT

PROTECTING AND ASSISTING RECOVERY

Protecting reefs from sunlight

As the Reef experiences increasing pressure from climate change, protecting corals currently in the system, and the biodiversity they harbour, remains an absolute priority.

In a world first, we are engineering methods that have the potential to protect reefs from solar radiation, thereby reducing heat accumulation in the system during times of heat stress. Our in situ experiments on the reef have demonstrated the capacity of innovative marine 'cloud brightening' equipment to successfully modify the microphysical properties of low-lying clouds, enhancing their reflectivity or shading capacity.

Modelling of cloud brightening indicates that this additional shade could be generated over very large areas and protect corals from excessive heat and light during the most intense summer periods. Another version of this technology has been developed, referred to as fogging, which could be deployed on a much smaller scale at priority reefs.

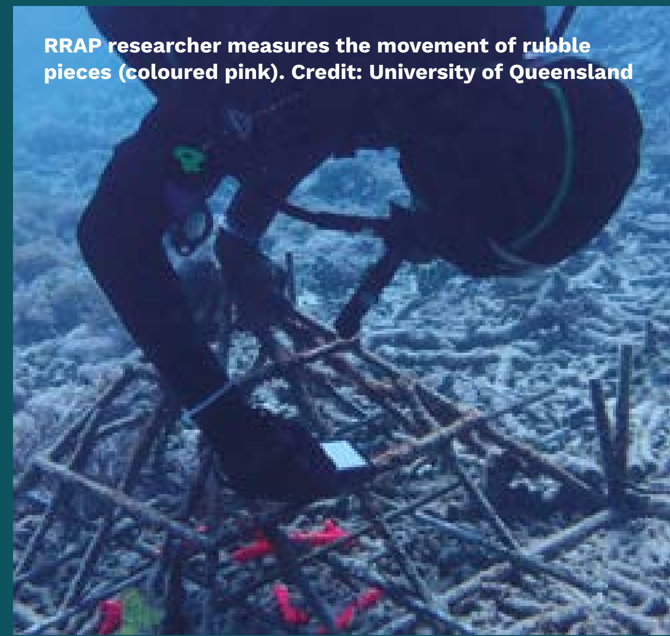
This work has not only addressed critical knowledge gaps in science and engineering but also established a robust atmospheric and aerosol monitoring program to better understand weather and cloud properties on the GBR under different seasonal conditions.

Sea water plume generated from aerosol sprayers during cooling and shading field trials. Credit: Southern Cross University

Assisting recovery of damaged reefs

Natural and anthropogenic disturbances (for example, cyclones, ship groundings, crown-of-thorns starfish outbreaks or coral bleaching) can reduce functional and diverse coral reefs to fields of rubble, with an unstable and mobile surface. This lack of stability and frequent motion inhibits recruitment of young corals back onto reefs and hampers recovery.

Laboratory simulations and data from field experiments have led to the development of models to predict rubble generation and persistence. Leadership by RRAP in engagement with practitioners and reef managers has enabled knowledge sharing and the development of a tool for management of rubble generation (such as in response to a ship grounding event).



RRAP researcher measures the movement of rubble pieces (coloured pink). Credit: University of Queensland

Universal Solutions for larval seeding

We have progressed coral spawn capture, larval rearing and reseeding methods towards larger scales of routine production. Performance improvements have been achieved across a range of process areas, including the optimisation of collection from diverse coral spawn slicks to 100s of millions of embryos, enhanced larval cultivation to tens of millions of diverse coral larvae, larval deployment methods to cover areas of reef >1 ha, integration with aquaculture device-based strategies to settle hundreds of thousands of diverse coral larvae at sea, and development of in situ macro-photogrammetric techniques to monitor deployment effectiveness.

We have also explored how local reef communities can drive and benefit from this new reef restoration and adaptation industry, with the design and testing of rugged and easily transportable larval rearing pools that can be used by non-scientists all over the world. Boats4Corals a Reef Islands Initiative project in the Whitsundays, is one such example where local tourism operators and Traditional Owners are trained in the use of the pools each spawning season.

Securing genetic diversity

Our efforts to restore damaged coral populations and enhance resilience and adaptation through coral seeding techniques relies on the genetic diversity of source populations. We recognise that securing biodiversity is a critical component of ensuring the continued function of coral reef ecosystems, and in a unique partnership with Taronga Conservation Society we have already preserved material from high-value coral species across the Great Barrier Reef, with almost a trillion gametes now biobanked.

One challenge has been cryopreserving the successfully fertilised coral larvae. Due to their size and structure, they are difficult to preserve but a prototype has solved the problem. The lightweight and cheap-to-manufacture 'Cryomesh' has been used to successfully freeze and then re-animate coral larvae, without the need for sophisticated cryopreservation equipment like laser warming.

Our dedicated coral cryopreservation teams are focused on not only ensuring a diverse representation of coral species is biobanked but that cryopreserved material is able to supply viable broodstock for conservation aquaculture efforts.

OUR DISCOVERIES

Precision imaging and machine learning for high-resolution dataset generation

- Precision 3D coral models to map rubble generation
- Macro-imaging to monitor early stage of life of settled corals
- Underwater photogrammetric 3D mapping to follow individual corals.

Integrated approach to map and model coral reef ecology and optimise interventions

- C-scape – New models integrating data and processes within a reef
- New coral phenotyping and genotyping methods to identify promising corals
- Ideal proximity ratio identified for the successful reproduction of corals
- Mapping coral recovery under different habitats and future climate scenarios.

Cameras use AI to monitor coral larvae. Credit: Dorian Tsai, QUT. Transporting photogrammetry tools to reef sites. Credit: Marie Roman, Australian Institute of Marine Science. 'LarvalBot' delivers coral larvae. Credit: Gary Cranitch.

RRAP is contributing scientific discoveries which have application opportunity beyond coral reefs, furthering Australia's leadership and contributing to economic productivity.

New automation systems to increase safety, productivity and lower costs

- Robotic AI cameras to monitor coral settlement and growth
- ReefScan to map coral reefs faster and at higher resolution
- Autonomous surface vehicles to collect spawn and deliver larvae
- 'Auto-spawner' delivering millions of coral larvae.

Advanced engineering solutions with applications beyond reef restoration

- Eco-friendly marine antifouling technology
- Predator protection in coral deployment devices
- Cryomesh for coral larvae cryopreservation
- New nozzle designs for amplified aerosol production
- Next-gen drones 3D map aerosol plumes
- Biodegradable underwater adhesive.

Drone fitted with atmospheric measuring instruments. Credit: SCU. Researcher monitors fertilisation in the 'autospawner' Credit: Marie Roman, Australian Institute of Marine Science. Researchers operate aerosol sprayers. Credit: SCU.

IMPLEMENTATION ON THE REEF

Over the last four years, RRAP has been actively maturing several types of interventions. Maturity is assessed by considering a range of criteria which include feasibility, efficacy, cost, scalability, safety and acceptability. Our readiness assessments led to a recommendation that interventions based on coral seeding be considered for on-water pilot deployment from 2025, as an integral step in the translation of R&D to operational restoration and adaptation.

The two specific interventions recommended for at-scale piloting are the seeding of aquaculture-propagated corals and reef-based larval restoration, alongside a fit-for-purpose monitoring program to measure benefits and continue to improve our knowledge.

Larval seeding

Reef-based larval restoration uses natural sexual reproductive processes of reef-building corals to produce large numbers of genetically diverse larvae, harvested from spawn slicks and reared at sea, for transfer and seeding onto reefs with low coral cover. The intent is to catalyse rapid recovery of reef areas with reduced coral cover and diversity.

Seeding corals from conservation aquaculture

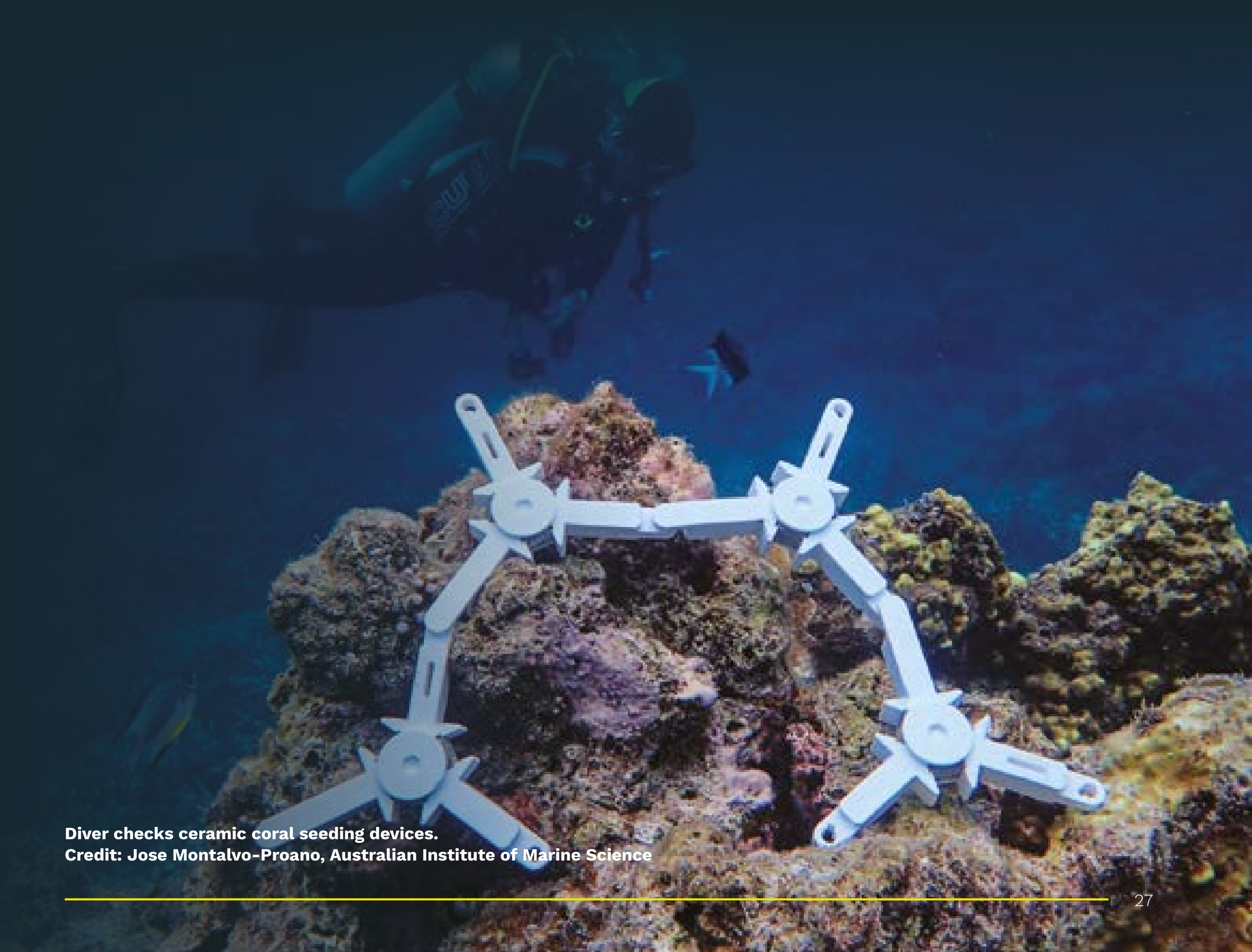
This intervention aims to seed large numbers of heat tolerant corals grown in conservation aquaculture onto the Great Barrier Reef using human-assisted delivery methods. The methodology has been developed so that it can be delivered using fixed land-based aquaculture facilities or integrated as a 'containerised' unit able to be deployed on location, including in remote areas, or within the facilities of industry partners as a capacity building strategy.

Researcher holds a rack of coral seeding devices ready for deployment. Credit: Marie Roman, AIMS

Vessel with floating larval pool to collect coral spawn. Credit: Southern Cross University

The Pilot Deployment Program is a platform to build on RRAP's social science research findings, and operationalise those through **open, respectful, and constructive engagement and co-design** with Traditional Owners and local actors.

This will lay the foundations for **long-term ownership of and support for new interventions.**



Diver checks ceramic coral seeding devices.
Credit: Jose Montalvo-Proano, Australian Institute of Marine Science

LOOKING AHEAD

Sharing our learnings and furthering Australia's leadership

Over the last four years, we have demonstrated the value of collaborative, integrated and multidisciplinary R&D, leading to a suite of technical innovations and advancing our fundamental understanding of coral reefs.

RRAP as a public good program is committed to sharing knowledge widely. Now at the end of our first R&D phase, we will systematically publishing results in high quality peer-reviewed journals, and release targeted technical reports and standard operating procedures that will support a growing global community of practice.

Taking interventions to the Reef and its communities

Pilot deployments of our coral centric interventions, which are scheduled to start in late 2025, represent a critical step on the pathway to adoption and scaling of these solutions.

The next twelve months will involve significant planning, on-ground engagement and capacity building. RRAP will continue to work with regulators and Traditional Owners, with guidance from the independent Intervention Risk Review Group, to ensure risk is adequately managed and opportunities realised.

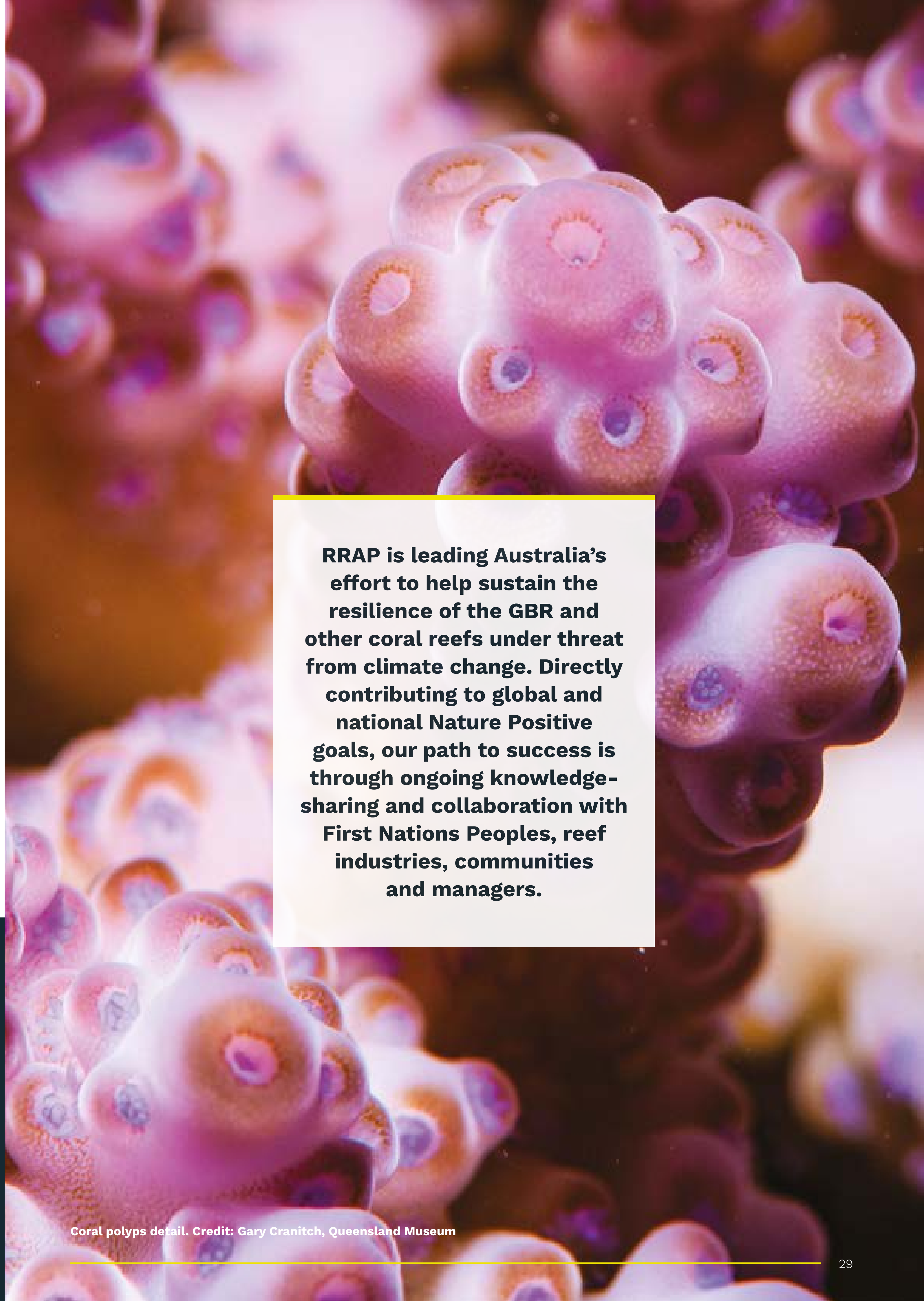
Designing the next phase of research

Acknowledging the multi-decadal challenge faced by coral reefs and building on our learnings to date, we are actively planning the next phase of R&D.

RRAP Partners remain committed to an integrated, multi-disciplinary and mission-focused program, albeit with additional emphasis on ecosystem planning and decision making, technology scale-up, and a greater involvement of First Nations Peoples and local industries. This next phase of R&D and the benefits it will generate will be presented in an RRAP 2.0 Investment Case.

Timeline

October 2024	May 2025	July 2025	December 2025
Investment case	Final reports on RRAP 1.0	Targeted start of RRAP 2.0	Pilot Deployments



RRAP is leading Australia's effort to help sustain the resilience of the GBR and other coral reefs under threat from climate change. Directly contributing to global and national Nature Positive goals, our path to success is through ongoing knowledge-sharing and collaboration with First Nations Peoples, reef industries, communities and managers.

Coral polyps detail. Credit: Gary Cranitch, Queensland Museum

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This work was undertaken for the Reef Restoration and Adaptation Program (RRAP). Funded by the partnership between the Australian Governments Reef Trust and the Great Barrier Reef Foundation.

RRAP Partners are the Australian Institute of Marine Science, CSIRO, the Great Barrier Reef Foundation, Southern Cross University, the University of Queensland, Queensland University of Technology and James Cook University.

Marine turtle swimming above reef.
Credit: Great Barrier Reef Foundation

Back Cover: Research vessel with floating pool to collect coral larvae during spawning.
Credit: Southern Cross University

RRAP

REEF RESTORATION & ADAPTATION PROGRAM

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