

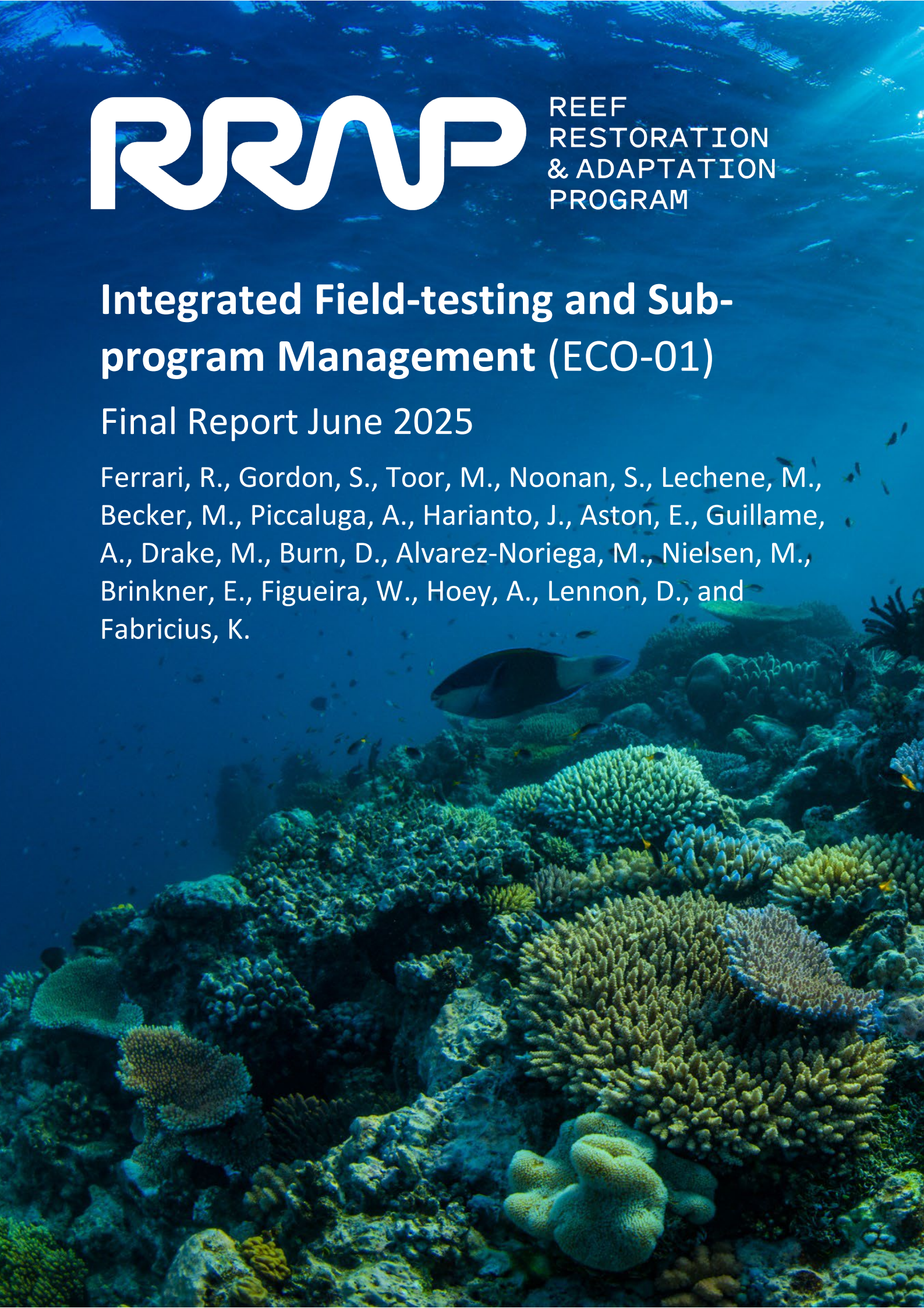


REEF
RESTORATION
& ADAPTATION
PROGRAM

Integrated Field-testing and Sub-program Management (ECO-01)

Final Report June 2025

Ferrari, R., Gordon, S., Toor, M., Noonan, S., Lechene, M., Becker, M., Piccaluga, A., Harianto, J., Aston, E., Guillame, A., Drake, M., Burn, D., Alvarez-Noriega, M., Nielsen, M., Brinkner, E., Figueira, W., Hoey, A., Lennon, D., and Fabricius, K.



RRAP Integrated Field-testing and Sub-program Management (ECO-01) Final Report June 2025

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Cover Page: Coral reef, Credit: Gary Cranitch, Queensland Museum

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This Report summarises work undertaken under *Integrated Field-testing and Sub-Program Management (ECO-01)* in accordance with the Reef Restoration and Adaptation Program's *Ecological Intelligence for Reef Restoration (EcoRRAP)* Project Agreements. It provides a summarised, point-in-time synopsis of activities, methods, findings and outcomes completed in accordance with the approved project scope up to 30 June 2025.

All information reflects project scope and outcomes as of May-June 2025. Subsequent updates, analyses, or scientific developments are not included. This report should be read alongside any associated and publicly available technical reports, datasets, and publications for full detail. This report does not provide scientific inferences, policy guidance or operational instructions beyond the project's defined scope and duration.

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The RRAP partners acknowledge Aboriginal and Torres Strait Islander Peoples as the first marine 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.

We specifically acknowledge and thank the following Traditional Owners of sea Country that this report relates to:

Location	Traditional Owner Group
Torres Strait	Masigalgal, Porumalgal, Warraberalgal
Northern GBR	Gunggandji, Ngurruumungu, Dingaal
Central GBR	Manbarra, Bindal
Southern GBR	Woppaburra, Bailai, Gurang, Gooreng Gooreng, Taribelang Bunda

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1 Executive Summary

EcoRRAP is a sub-program of the Reef Restoration and Adaptation Program (RRAP) focused on filling key ecological knowledge gaps to inform effective interventions for the Great Barrier Reef (GBR) and Torres Strait (TS). Its multidisciplinary research supports decisions around “what, where, when, and how” to implement reef restoration and protection strategies.

Now in its fifth year, EcoRRAP has significantly enhanced understanding of reef dynamics through a strong collaboration involving the Australian Institute of Marine Science (AIMS), Commonwealth Scientific and Industrial Research Organisation (CSIRO), James Cook University (JCU), the Queensland University of Technology (QUT), Southern Cross University (SCU), the University of Sydney, and the University of Queensland (UQ). Outputs include 38 peer-reviewed publications, 26 awards, six SOPs, 17 postgraduate student theses (completed or in progress), and broad engagement with Traditional Owners and reef practitioners. It has supported the training of over 30 higher degree students and early-career researchers, building a robust scientific capacity for reef management in Australia and beyond.

The RRAP Project Integrated Field-testing and Sub-program Management (ECO-01) has delivered a broad suite of outputs and impacts:

- **Program Coordination and Traditional Owner Engagement:** ECO-01 coordinated the EcoRRAP Sub-program, established and maintained engagement with Traditional Owners and stakeholders, and successfully obtained original and extensions for required Great Barrier Reef Marine Park Authority (GBRMPA) permits.
- **Reference Sites and Monitoring:** A network of over 100 RRAP Reference Sites was established through more than 20 ecological field campaigns.
- **Advanced Monitoring Techniques:** Innovations in photogrammetry and artificial intelligence (AI)-supported image analyses enabled high-resolution, non-invasive monitoring of coral colonies at scale, overcoming the limitations of traditional methods. These include assessing coral bleaching severity, extent, and vital rates, and are shaping global best practices and capacity building (e.g. National Oceanic and Atmospheric Administration (NOAA), Large-Area Imaging (LAI) Network).
- **Open Data and Tools:** ECO-01 provided open-access to the world’s largest photogrammetry-derived coral datasets, ensuring discoverability and reproducibility under [FAIR](#) and [CARE](#) principles.
- **Recruitment Bottlenecks and Ecological Interactions:** Water quality and macroalgal presence are key factors limiting coral recruitment. Coral-macroalgae interactions, fish community dynamics, and habitat complexity were studied to understand recovery processes and potential bottlenecks.
- **Biophysical and Oceanographic Data:** Empirical data supported eReefs and RECOM model validation. These inputs helped investigate the relevance of environmental thresholds for coral growth, survival, and bleaching severity across gradients of temperature, sedimentation, and water flow.
- **Genetic Sampling and Cryptic Species:** ECO-01 supported sample collection for studies on cryptic species and their physiological diversity, with important implications for population connectivity and thermal tolerance (analysed under RRAP Project Ecological and Genetic Adaptation (ECO-03)).
- **Decision Support Tools:** ECO-01 developed ecological heuristics for outplanting decisions, leading to tools that are now integral to RRAP’s Pilot Deployments Program (PDP) and site selection frameworks.

Program Integration and Impact

EcoRRAP's scientific and technical outputs directly inform RRAP going forward, the Pilot Deployments Program, and biodiversity accounting initiatives. The program has created a strong foundation for evaluating restoration outcomes and ensuring ecological soundness.

2 Background and Justification for the Research

The Reef Restoration and Adaptation Program (RRAP) is a collaboration of Australia’s leading experts to create a suite of innovative and targeted measures to help preserve and restore the coral reefs globally. These interventions must have strong potential for positive impact, be ecologically sound, socially and culturally acceptable, ethical, and financially responsible.



Figure 1: A diagram showing how EcoRRAP (red box) provides input across all RRAP sub-programs.

The problem, previous research, and rationale

Key ecological and evolutionary knowledge gaps, essential for the success and cost-effectiveness of reef restoration, were identified in 2020, leading to the creation of the RRAP EcoRRAP Sub-program (Figure 1). Within EcoRRAP, three projects were created: (1) Integrated Field-testing and Sub-program Management (ECO-01), (2) Limits to Early Recovery (ECO-02), and (3) Ecological and Genetic Adaptation (ECO-03). This report refers to the ECO-01 project, whose overarching goal is to produce unprecedented datasets to address key ecological and evolutionary knowledge gaps, inform restoration practitioners, and increase the likelihood of restoration success in reefs of the GBR and TS.

Previous research and monitoring datasets (e.g. The Australian Institute of Marine Science’s Long Term Monitoring Program - LTMP, Marine Monitoring Program - MMP, Reef Life Survey) were considered, but were limited in their spatial, temporal, or environmental representation. Datasets on coral vital rates, early life stages, and genetic-environmental associations were extremely limited to a handful of reefs, habitats, or species, with cryptic species being an important consideration. ECO-01 rationale was to not only produce datasets but also integrating datasets to maximise their value (Figure 2).

Many of the limitations of existing datasets could also be resolved through novel monitoring technologies. ECO-01 developed, tested, and operationalised novel technologies such as photogrammetry to map and monitor coral reefs at scales matching large-scale restoration efforts. Photogrammetry offers a standardised, non-invasive, and efficient method for quantifying attributes of thousands of coral colonies across large, environmentally diverse reef areas. This approach circumvents the limitations of traditional survey methods, where detailed tracking of individual colonies comes at the expense of large sampling areas and sizes. ECO-01 fine-tuned photogrammetry methods to meet RRAP requirements and aspirations, and, in collaboration with ECO-03, also developed AI semi-automated pipelines for data processing and extraction, achieving unparalleled efficiency, precision, and accuracy. ECO-01 produced several Standard Operating Procedures (SOPs) and has trained many next-generation scientists in the application of these technologies.

EcoRRAP Integrated Field-testing Program research questions

Establish and monitor a network of Reference Reef sites, to investigate reef dynamics, coral vital rates, recovery, and natural adaptation processes of reef communities. ECO-01 successfully established ongoing monitoring sites across 19 reefs and six regions on the GBR and TS. The biology, ecology, region-specific temperature and acidification tolerance, and the environmental constraints of common corals need to be well understood to prioritise coral species and sites for interventions.

The ECO-01 datasets are used to prioritise locations and taxa for intervention by quantifying contemporary stress exposure, the resilience and sensitivity to stress across taxonomic and life-history stages, and their natural ecological functions, including life histories of population, reef dynamics, and recovery ability. These datasets are also helping prioritise coral species based on their functional traits for region-specific RRAP intervention. Thus, restored communities will be more likely to maintain key ecosystem properties as diverse communities, structural complexity, and reef accretion rates, while minimising vulnerability to disturbances.

While ECO-01 **integrates these datasets**, much of the research to synthesise them happens within ECO-02 and ECO-03. The empirical datasets produced by ECO-01 have **enabled novel research and empirically validated key modelling and decision support tools** beyond EcoRRAP and RRAP. Key knowledge gaps and associated research covered by EcoRRAP include, but are not limited to:

- **Support RRAP models and decisions with data** to optimise the deployment of corals for long-term and large-scale effectiveness in returning and maintaining reef function.
- **Inform RRAP on reef recovery processes, thresholds of recovery limitation and facilitation**, and recovery trajectories at within-reef to GBR-wide scales, with an emphasis on the role of demographic rates, recovery and adaptation bottlenecks, cryptic species, and thermal growth curves.
- **Identify critical ecological requirements** to maintain and enhance reef recovery across multiple spatial scales, environmental and biophysical gradients.
- **Investigate processes and drivers of ecological and evolutionary adaptation** to a changing climate and acute disturbances across taxonomic resolutions (i.e. species, population, community).
- **Produce high-quality monitoring technologies, standard operation procedures, open-access data, and peer-reviewed publications** critical for informing ecologically-sound restoration and adaptation.
- **Train the next generation** in reef ecology, monitoring, AI for monitoring, and conservation science.
- Conduct all work in consultation, participation, and with free and informed prior consent of Traditional Owners.

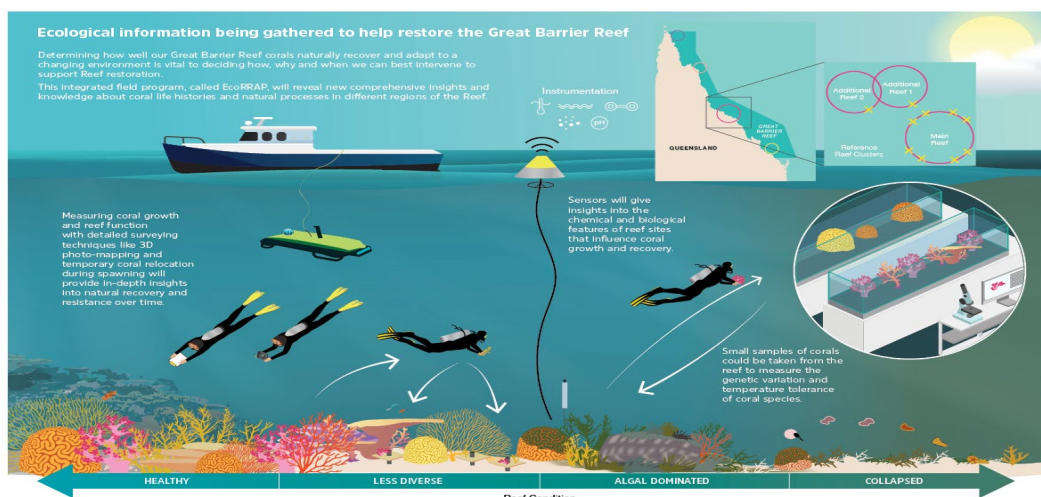


Figure 2: Infographic of EcoRRAP's Integrated Field-testing Project (ECO-01).

3 Research Objectives and Key Findings

A current list of project outputs are listed on the RRAP website: gbrrestoration.org. Key research objectives and findings are detailed below.

Table 1: Key findings of the Project aligned to the overarching and specific research questions for each sub-project.

Objective	Key Findings and/or Outcomes
<p>1 Establish permanent sites on reef clusters (referred to ‘Reference Reefs’ hereafter) that will be studied at fine within-reef scale and across regions.</p>	<ul style="list-style-type: none"> • 88 permanent sites (1500 - 2000 m²) across 19 reference reefs were established from the Capricorn Bunkers in the south of the Great Barrier Reef (GBR) to Masig Island in the north in Torres Strait, spanning a distance of ~1,600km (15 degrees in latitude), and providing coverage of nearshore and offshore reefs (Figure 3). <ul style="list-style-type: none"> ○ Reefs or islands where sites were established include Heron Island, Lady Musgrave Island, Keppel Islands, Davies Reef, Little Broadhurst Reef, Chicken Reef, Palm Islands, Moore Reef, Lizard Island, One-Tree Island, Aukane Reef, Dungeness Island, Masig Island. • At each reef, four survey plots (72 m² each) as shown in Figure 3 were established in each of four common reef habitat types (front, flank, back, lagoon) at: shallow (three to eight metres) and deep (9 – 17 metres) depths, and surveyed over five years (2021 – 2025). A total of 416 plots across 88 sites were established.

Objective

Key Findings and/or Outcomes

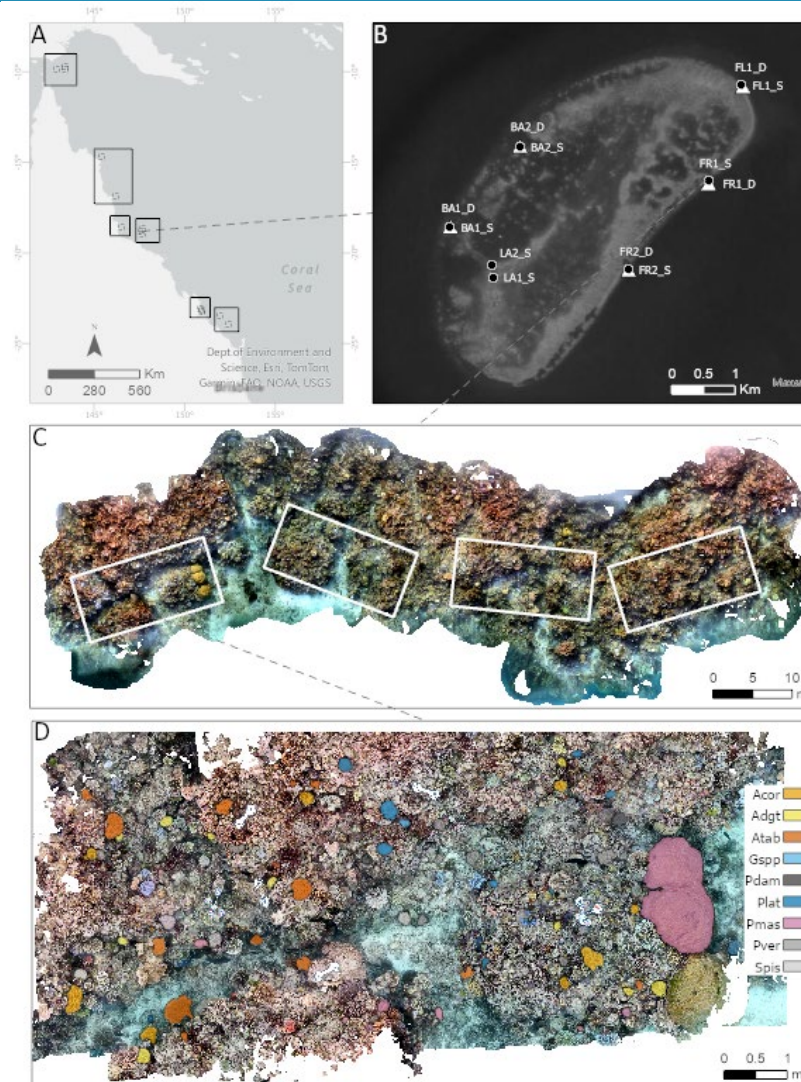


Figure 3: The hierarchical study design used by ECO-01 to address key knowledge gaps on the GBR and TS, Australia, across four spatial scales. (A) map of reefs (circles) surveyed (rectangles show

Objective	Key Findings and/or Outcomes
	<p>reef clusters), (B) example study design across Davies reef stratified across habitats and depths (FR = exposed slope, FL = moderately exposed slope, BA = sheltered slope, LA – lagoon, D = deep, S = shallow, and numbers denote replicates for the same habitat by depth combination), (C) example orthomosaic produced using photogrammetry of a surveyed reef site (~1500 sq. m at cm resolution), with four sub-mm resolution 72 sq. m plots marked by the embedded rectangles, and (D) example of a 72 sq. m. orthomosaic with digitised colonies identified in situ and tracked over five years (<i>Acor</i> = <i>Acropora corymbose</i>, <i>Adgt</i> = <i>Acropora digitate</i>, <i>Atab</i> = <i>Acropora tabular</i>, <i>Gsp</i> = <i>Goniastrea spp.</i>, <i>Pdam</i> = <i>Pocillopora damicornis</i>, <i>Plat</i> = <i>Platygyra spp.</i>, <i>Pmas</i> = <i>Porites massive</i>, <i>Pver</i> = <i>Pocillopora verrucosa</i>, <i>Spis</i> = <i>Stylophora pistillata</i>).</p>
<p>2 Collect high-resolution environmental, biological and ecological time series data, including oceanographic data, benthic imagery and the derived three-dimensional (3D) maps, macroalgal dynamics, rates of fish corallivory and herbivory, and rates of reef accretion/dissolution and photosynthesis/ heterotrophy, to quantify natural inter- and intra-reefal variation in recovery rates.</p>	<p>Using the hierarchical study design in Figure 3 for permanent sites, data was collected along the latitudinal gradient, from inshore to offshore reefs, including reef slopes and reef lagoons, across gradients of wave exposure and depth.</p> <p>At the Reference Reefs, critical environmental, genetic, population vital rates, community composition and structure, fish behaviour (corallivory and herbivory), diversity, and generic data were collected using traditional and cutting-edge tools, including 3D-photogrammetry.</p> <p>All sites were visited and surveyed annually, and when massive bleaching events occurred, further surveys were conducted to improve our understanding of coral reef adaptation and recovery potential from acute disturbances, especially those driven by climate change.</p> <p>In 2024, due to the massive bleaching event, EcoRRAP collaborated with the University of Sydney to additionally survey 10 permanent plots before, during, and after bleaching, bringing the total number of EcoRRAP plots to 362 at the time.</p> <p>In 2025, the RRAP Enhanced Corals and Treatments (ECT) Sub-program collaborated with EcoRRAP to extend EcoRRAP areas in the northern and Central GBR clusters for monitoring, virtual tagging, and identification of heat-tolerant resistant colonies for broodstock collection. Resulting in the establishment of two new EcoRRAP-ECT sites on North Direction Reef, 54 new plots for potential broodstock harvesting, and a total number of 416 permanent plots for monitoring (~ 31,400 m² of high-resolution data).</p> <p>All ECO-01 and ECO-03 data can be discovered and accessed through the Australian Institute of Marine Science metadata records (https://apps.aims.gov.au/metadata/view/fe9659f1-12d6-4acf-ab89-67acdd37efe5).</p>
<p>3 Collect high-resolution physico-chemical environmental time series data across a gradient of environments (i.e. shallow to deep, exposed to sheltered). These data are used to assess environmental conditions</p>	<p>Oceanographic loggers, recording at specified intervals for temperature, salinity, light, and currents, have been deployed continuously at our EcoRRAP monitoring sites since their inception in 2021. Deployments are typically for 12 months, with loggers exchanged and data retrieved during the</p>

Objective	Key Findings and/or Outcomes
<p>linked to reef dynamics. These data provide a reference of the natural recovery potential of reef habitats, against which the effectiveness of interventions can be tested by Pilot Deployments Program interventions. They will help predict <i>where</i> RRAP interventions will be most successful.</p>	<p>annual monitoring expeditions. Data have been collected to provide explanatory information for ecological and genetic datasets, and for model parameterisation.</p> <p>Topographic (depth, slope, surface area, surface rugosity, fractal dimensions, etc.) data across multiple spatial resolutions and extents have also been collected, created, and quality checked and quality assured (QCQA) for the entire GBR and some sections of the TS (EcoRRAP reef sites). These data were generated to explore the role of seabed topography as a surrogate of species distributions and densities, and as potential explanatory variables for other key recovery and adaptation processes. Several high-impact publications have arisen from these datasets (Alvarez-Noriega et al. 2025, Guillame et al. 2025, Aston et al. 2023).</p> <p>Use this link for further details and to access the data: https://apps.aims.gov.au/metadata/view/778cc4e3-7979-4601-8fdf-772f345d8956</p>
<p>4 Provide the biological baseline data, to be processed in collaboration with RRAP-ECO-02 and ECO-03, against which the effectiveness of RRAP interventions can be tested by the intervention sub-programs (e.g. region- and depth-specific <i>in situ</i> coral demographic rates of native corals will form a baseline for comparison of demographic rates of corals originating from husbandry (coordinated with RRAP Project Coral propagation and deployment (CAD-01)).</p>	<p>Biological baseline data from the surveys specified above and across all EcoRRAP reference reefs have been processed and analysed from 2021 – 2025. Several publications have been produced, and data have been made publicly accessible through AIMS metadata records and other platforms. A summary of the biological baseline data discovery platforms is below (for a list of all data, please see the metadata records):</p> <ol style="list-style-type: none"> 1) EcoRRAP 3D models can be visualised here (please note these are low resolution to facilitate web-viewing, for high resolution equivalents, please refer to the metadata record). SketchFab is the world’s 3D model online viewer and enables the user to easily discover and explore 3D models online: https://sketchfab.com/AIMSEcoRRAP.

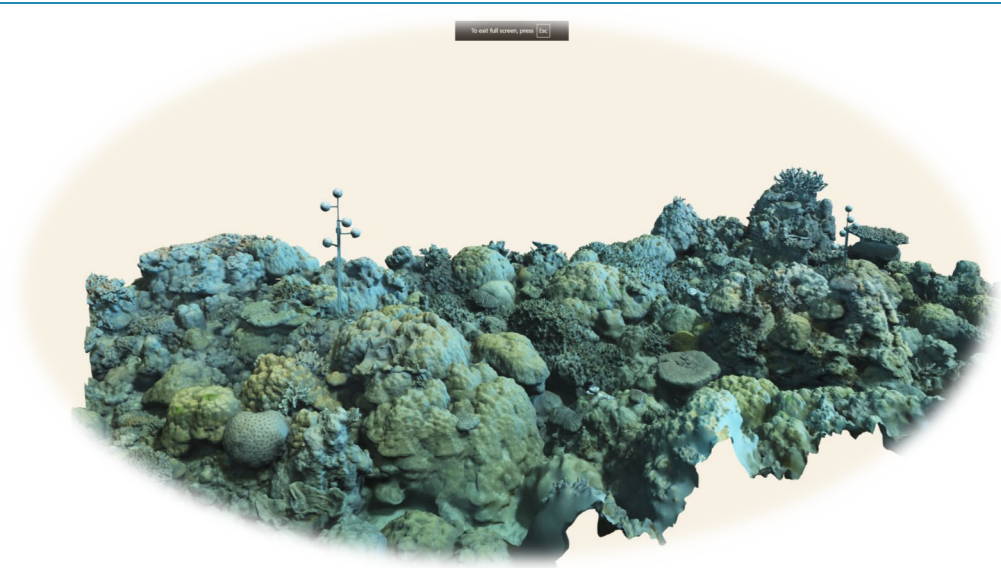


Figure 4: Example 3D model from EcoRRAP reference plot (72 m²) from Masig back reef in the Torres Strait, imaged in 2022.

- 2) Large area maps (orthomosaics) can be visualised and explored in this spatial website (please note these are low-resolution to facilitate web-viewing, for high-resolution equivalents, please refer to the metadata record). The StoryMap website integrates coordinates and geolocates each plot, enabling the exploration of the same plot over time, during massive bleaching events, and summarising the research that is related to this dataset.

<https://storymaps.arcgis.com/collections/f0c4a3ef3bda426195326a3e9b096024?item=1>

Objective

Key Findings and/or Outcomes

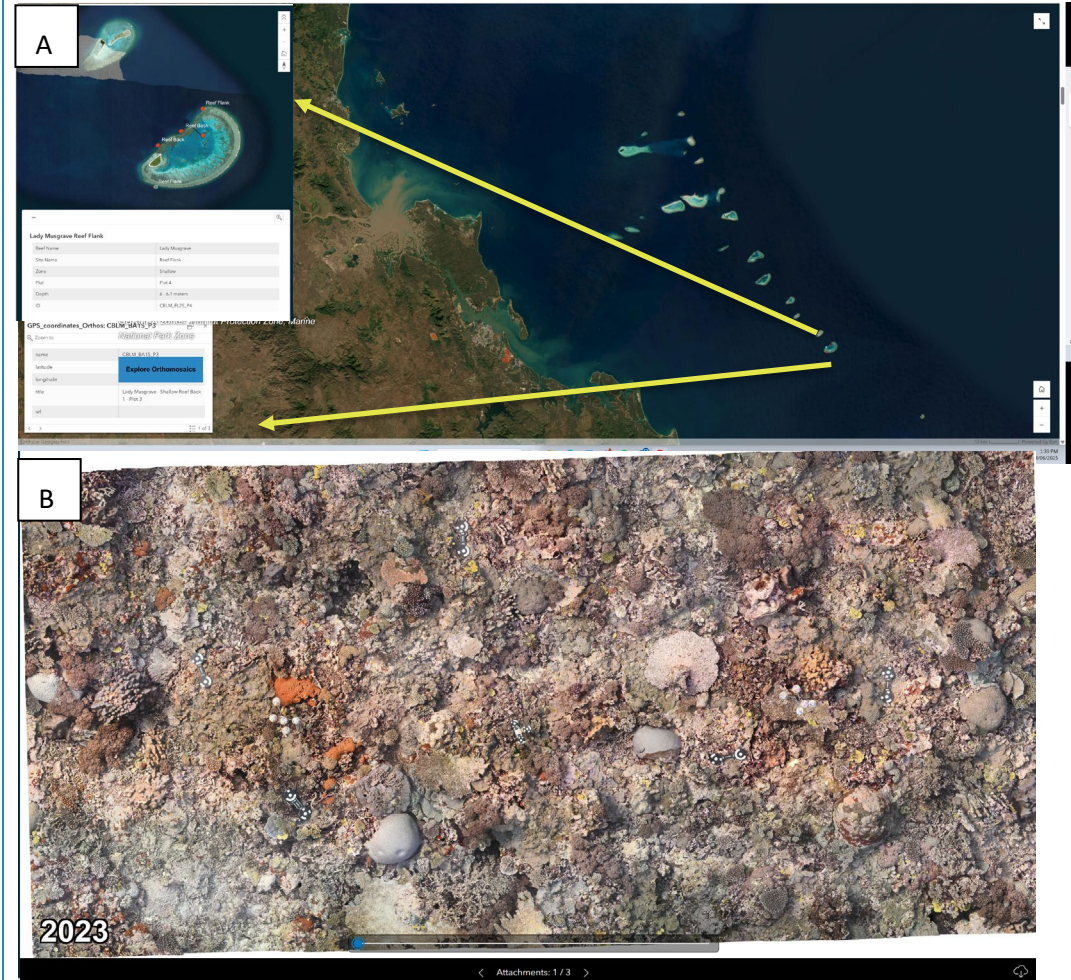


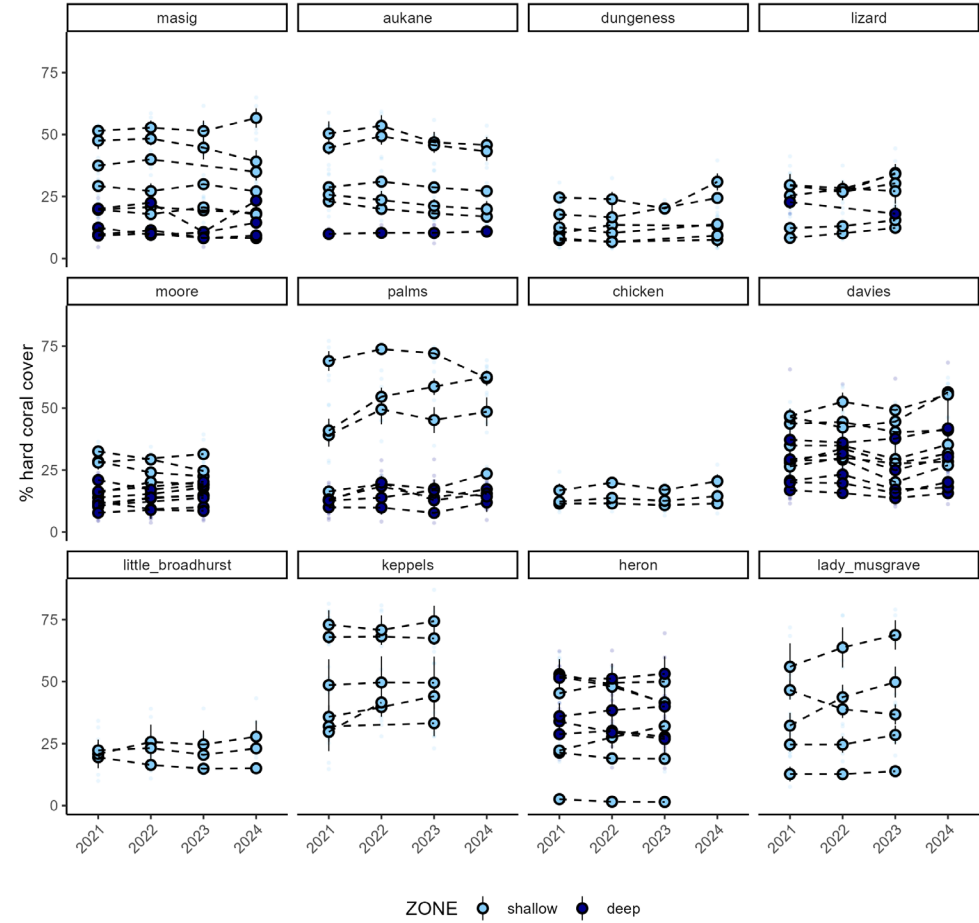
Figure 5: EcoRRAP StoryMap spatial website showing: (A) the spatial interactive map showing the southern GBR, and (B) an example orthomosaic of an EcoRRAP permanent plot on the front reef of Lady Musgrave Island, imaged in 2023.

Objective	Key Findings and/or Outcomes
	<p>To discover more orthomosaics across time go to the link above. The spatial extent is 72 m², each black and white dumbbell in the image measures 40 cm long (30 cm between bullseyes).</p> <p>3) Statistical and visualisation summary of sample sizes from photogrammetry surveys, including benthic cover, coral colony survival, growth, and community composition and structure: https://api.aims.gov.au/data-v2.0/48de2e3c-52a9-42f0-84ac-eb13baab0b07/files/summary_stats_ecorrap_2021-2023.html</p>

Objective

Key Findings and/or Outcomes

42 Image Dataset



% cover of 13 coral taxa from 2021-2024, 42 image dataset

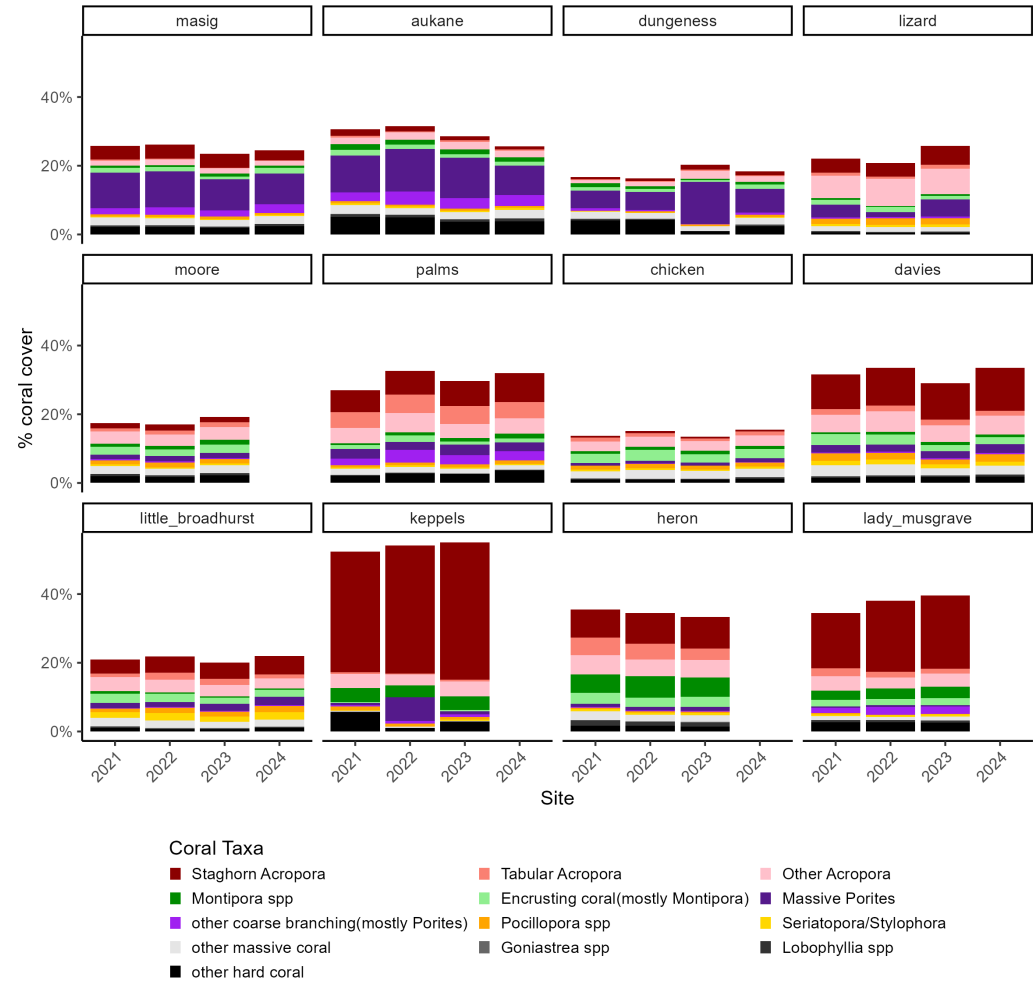


Figure 6: Change in total coral cover, community composition, and structure on EcoRRAP reference reefs from 2021 to 2024, data is pooled for all plots and sites per reef in each year. Reefs without data for 2024 suffer bleaching, and data will be processed for those and all 2025 surveys between 2025- 2026. More detailed data can be accessed via the link above the figure.

Objective	Key Findings and/or Outcomes
<p>5 Supply EcoRRAP data for improving model parametrisation at different ecological levels (from colony rates to population rates). This will increase the accuracy of the models when validated against independent datasets (e.g. LTMP). Jointly we will help identify the criteria to assess where and when restoration is needed and which type of interventions would likely be most beneficial. We will house and disseminate open access to the quality assured and quality controlled environmental and biological data. This includes data required for parameterising intervention risk assessments and decision support models.</p>	<p>EcoRRAP data has been widely used to provide the necessary parameters that models require at different ecological levels (from genomes to communities).</p> <p>EcoRRAP data has increased accuracy and reduced the uncertainty of ecosystem and population model predictions produced by RRAP modelling and intervention sub-programs and beyond.</p> <p>These models and other tools incorporating EcoRRAP data are routinely used to identify the criteria to assess where and when restoration is needed, and which type of intervention would likely be more beneficial.</p> <p>As per the above milestones, EcoRRAP has produced, housed, and disseminated unprecedented and essential empirical datasets.</p> <p>These include essential data required for parametrising intervention risk assessments and decision support models. Some of the key examples of how EcoRRAP data has been incorporated into essential RRAP modelling are below:</p> <ol style="list-style-type: none"> 1) C~scape: EcoRRAP data have been incorporated into the C~scape modelling framework, one of the main ecosystem models being used by the RRAP Modelling and Decision Support Sub-program. Data on annual growth and survival from almost 10,000 coral colonies, from ECO-01, were used to build Integral Projection Models (IPMs) for six distinct coral types. These IPMs are the 'engine' for the C~scape modelling framework, allowing the projection of coral population dynamics across space and over time. <p>The uptake of the EcoRRAP data was a major improvement on the previous demographic parameterisation used in the C~scape framework, which was only for two coral types, using data from non-GBR locations.</p> <p>The C~scape and EcoRRAP teams are working collaboratively to apply these IPMs to assess the sensitivity of coral population growth to different stages of the coral life cycle, which can help inform what size or life stages of coral may be most successful in restoration efforts.</p> <p>These models are also assessing variation between reef habitats and environmental variables to better inform site selection for restoration.</p> <ol style="list-style-type: none"> 2) CoralBlox: EcoRRAP data is also used to inform model parameterisation and calibration processes for CoralBlox to improve confidence in modelled projections of reef state. CoralBlox is a coral ecosystem model developed by the AIMS Decision Support team to assist in scenario modelling and exploration of management outcomes.

Objective	Key Findings and/or Outcomes
	<ul style="list-style-type: none"> 3) Spatial layers: The AIMS Decision Support team has also used EcoRRAP site location data to contextualise the reef scape (on printed maps) for local stakeholders involved in PDP workshops, and to guide PDP deployments by Traditional Owners on the southern GBR. 4) ReefGuide: In the near-to-mid-term, ReefGuide - a spatial assessment platform - may incorporate data from coral habitat and species distribution models empirically tuned with EcoRRAP observations. 5) Ecological Heuristics: EcoRRAP data have been combined with grey and white literature in a review to produce a conceptual model using quantitative tools to guide reef site prioritisation to maximise the survivorship and growth of out-planted corals. 6) eReefs and Relocatable Coastal Model (RECOM): ECO-01 oceanographic data have been used to benchmark and empirically validate several oceanographic variables and improve hindcasts made by both eReefs and RECOM models on the GBR and the Torres Strait. 7) Selection of broodstock for coral aquaculture: Information on cryptic species as defined by genetic analyses (e.g. <i>Acropora hyacinthus</i>) is being considered a factor for broodstock selection for coral aquaculture in PDP. 8) Biodiversity Credit Accounting framework: EcoRRAP data, specifically structural complexity, benthic and fish data, were used to inform the selection of relevant metrics for the Reef Condition Index recommended by the Reef Biodiversity accounting methodology, currently being developed by the Great Barrier Reef Foundation. 9) Statistical models in publications: EcoRRAP data has informed many statistical models used in 34 publications (10 additional papers submitted and pending review) generating significant knowledge to inform restoration interventions.
<p>6 Effectively communicate the findings with other RRAP parties and end users including policy makers, Traditional Owners, tourism operators and the wider community, in collaboration with the RRAP Communications and RRAP Stakeholder and Traditional Owner Engagement teams.</p>	<p>Presentations at reef symposiums/conferences/government/universities (Australia and International): 102</p> <p>Internal Online presentations/talks: EcoRRAP has conducted 25 online talks covering findings and research questions for the RRAP community to help maintain effective collaboration between programs.</p> <p>YouTube videos: three, https://youtu.be/fwwDWIn7lvk, https://youtu.be/bGLS8H9BNf0, https://youtu.be/WWtNaxsONCE</p> <p>Traditional Owners: numerous factsheets, talks, workshops, and field reports have been produced and distributed for relevant groups whose sea Country we have been conducting work in. If</p>

Objective	Key Findings and/or Outcomes
	<p>EcoRRAP secures future funding, we will be following up with a concise report on key findings from the research within their sea Country.</p> <p>Websites making available EcoRRAP resources:</p> <ul style="list-style-type: none"> - Sketchfab has 387 3D reef models from EcoRRAP, publicly available, 5000+ views: Sketchfab - The best 3D viewer on the web. - Global Coral Reef Monitoring Network has two EcoRRAP Standard Operational Procedures (SOPs) for Photogrammetry listed as a monitoring resource: Advancing Coral Reef Monitoring: The Power of 4D Photogrammetry – GCRMN. - Large Area Imaging Network has two EcoRRAP Standard Operational Procedures (SOPs) for Photogrammetry listed as a monitoring resource. - StoryMap of large area images from over 1000 EcoRRAP benthic orthomosaics, including during bleaching, to facilitate data discovery and exploration. - AIMS Standard Operations Procedures: has 3 EcoRRAP Standard Operational Procedures (SOPs) for Photogrammetry https://www.aims.gov.au/research-topics/monitoring-and-discovery/monitoring-great-barrier-reef/reef-monitoring-sampling-methods. <p>Factsheets: numerous factsheets have been prepared for restoration practitioners and Traditional Owners.</p> <p>Awards: A total of 26 awards have been won by EcoRRAP graduate students, PhD candidates, and graduates.</p>

Adjustments to key research objectives

Table 2: Variation in the Project over time.

Initial Research Question	Explain when, how and why the research question changed
No adjustments to report	

4 Future Research Recommendations

4.1 Future research in coral reef state and trajectory, and population dynamics

The RRAP Integrated Field-testing and Sub-program Management (ECO-01) Project (photogrammetric, genetic, environmental, ecological and biophysical) data collected from 2021 – 2025 on 416 permanent plots, are a treasure trove of information on the dynamics of important coral populations and reef structures, unlike any other dataset available globally, and will support numerous new analyses and publications that will advance biological, evolutionary and ecological understanding across multiple fields of research. In turn, this new knowledge will inform conservation and restoration of Pacific reefs, boosting the probability of success of restoration interventions.

For example, Burn et al. (in preparation) have integrated seven datasets to identify the contribution of different demographic processes in different environmental settings to reef recovery (or the lack of). By integrating EcoRRAP datasets into a population model, we can identify the type of intervention that is most likely to promote recovery on a reef, answering questions like – **where a specific intervention (i.e. one increasing coral recruits) would make the biggest difference to reef recovery post-disturbance?** Future research should continue to **integrate multiple datasets** to ask applied research questions that inform conservation and restoration decisions.

The 2024-25 transition is of extreme value to understand the **legacy effects on coral populations of the worst bleaching event the GBR and the world has suffered to date** (2024 summer). **Future research** should focus on integrating community composition and structure, vital rates, and environmental datasets across 2021-2025 to shed light on mid-term reef dynamics driving reef trajectories in a warming ocean. The data covers three very informative years of background values (free of large-scale disturbances), followed by a mass bleaching event in 2024, and a post-bleaching recovery survey in 2025. As a result, the routine background data on rates of colony growth and survival can be contrasted against rates during and after the 2024 bleaching event, identifying the most heat-tolerant corals, protective and cumulative environmental factors that co-determine bleaching outcomes, and habitat/region-specific pockets of resilience. Desktop work is planned for 2025/26, processing, extracting, and sharing the 2025 datasets (the last field trip finished in May 2025).

The RRAP Integrated Field-testing and Sub-program Management (ECO-01) Project has produced unprecedented demographic datasets for dominant coral morpho-taxa on the GBR and the TS. EcoRRAP has worked with other RRAP researchers to produce a species priority list, and the photogrammetry data already collected can be used to quantify vital rates of many more taxa. To date, EcoRRAP has produced and curated datasets for 13 of these 22 morpho-taxa, and developed AI-classifiers to automatically extract data from new reef areas. **Future research should produce the vital rates datasets and associated AI-classifiers for the remaining nine priority morpho-taxa (including key species)** to inform future phases of RRAP.

Water quality has been confirmed as a key determinant of reef dynamic processes. Reef restoration is informed not only by coral population dynamics but also by complex interactions between reef intervention activities and water quality, which need to be investigated in further work.

Importantly, the **Reference Reefs, and reference sites within reefs, should continue to be maintained and monitored**, since their value will continue to increase during the next five to ten years. Importantly, having five years of data allows us to interrogate our datasets to optimise the sampling effort and survey-design to: (1) inform PDP monitoring designs so that they are as statistically robust and as powerful as possible within the existing logistical constraints, and (2) inform future Reference Reefs monitoring to cut cost and optimise future learnings. Maintaining the existing Reference Reefs will save significant costs for PDP and other research in the future.

Coral population, benthic community composition and structure, and structural complexity datasets have now been obtained for three annual transitions (2021-2024), and we have the data for a fourth transition (2024-2025). **Future work on population dynamics** on the Reference Reefs will capture the effects of other forms of disturbance, as well as bleaching events with different intensities, and their effects can be compared against increasingly solid baseline values during non-disturbance years, but in a warmer-than-ever ocean. Importantly, longer-term time-series data, capturing the responses of the same corals to additional bleaching events with varying intensities, **will inform on potential natural rates of adaptation to increasing heat stress**, a crucial **missing link in our prognosis of reef futures** in the context of global warming.

4.2 Scientific underpinning of the Pilot Deployments Program (PDP); also responding to extreme events

In the coming years, the lessons from EcoRRAP will be applied to the 2025 - 2028 Pilot Deployments Program. On the GBR, we will re-purpose the RRAP Reference Reefs on reefs where PDP occur to become control sites for restoration interventions on adjacent sites. We will also use the EcoRRAP knowledge to establish realistic expectations across different environmental gradients and interventions.

For example, we now understand that growth rates and upper limits play a crucial role in the speed at which a community can recover from an acute disturbance. Reefs with higher upper limits (more available suitable space) recover up to 36% faster than those with half that upper limit (Alvarez-Noriega et al. 2024). This knowledge informs restoration by setting realistic expectations for assessing the success of interventions based on the characteristics of the sites where these actions take place. It also aids in allocating adequate control areas that possess similar upper limits to those where restoration occurs.

Future research should continue to integrate EcoRRAP knowledge and continue monitoring Reference Reefs to inform future restoration interventions and ecosystem models.

One lesson from EcoRRAP was that rapid responses to extreme events occurring at Reference Reefs provided indispensable ecological information to improve predictions and inform site selection. For example, we can now use size frequency distributions across similar reef areas to inform which areas are more resilient to future bleaching events, and which may benefit the most from interventions capable of increasing the heat tolerance of a population. Such **rapid response surveys** will need to be factored into the design of future population time series studies on both control and intervention sites.

ECO-01 produced GBR-wide datasets of 3D structural complexity at 10+ meter resolution and used these datasets in combination with environmental models and benthic datasets to develop species distribution models (SDM). These SDMs are currently being incorporated into ReefGuide and are essential to inform site selection for target species. **Future research will extend the existing SDMs** to include new species, including cryptic species, and new reefs.

The coral community and performance data will also inform the analyses under RRAP and PDP to choose the most suitable coral species and habitats for deployment, and eventually to compare the performance of newly deployed colonies (i.e. survival and growth) against those observed in the wild before and during a climate disturbance. Future research in this direction will maximise learnings from PDP and speed the development of ecologically successful restoration interventions at scale.

4.3 Monitoring tool development and operationalisation: Improve automation of data acquisition (corals, bleaching, fish)

We recommend the development of **new monitoring methods and technologies** under ECO-01 to support the monitoring design and methods for future restoration efforts. Future research should continue developing:

1. Automated pipelines and AI-assisted tools to automate data extraction from large area images and fish video footage (e.g. RapidBenthos, see link: [More information, faster, with new AI monitoring tool | AIMS](#)).
2. The use of AI to produce accurate and precise large area images in 3D and 2D more efficiently.
3. Simplified monitoring methods compatible with current state-of-the-art approaches and allow for data standardisation and application of FAIR and CARE principles (e.g. Federated Reefs idea).

Efficient and standardised field data collection methods (Gordon et al. 2023, SOP14) and large-area imaging processing pipelines (Gordon et al. 2024, SOP16, Toor et al. 2025, SOP17) have been developed by the RRAP EcoRRAP Sub-program.

AI-assisted tools (e.g. TagLab, ReefCloud and RapidBenthos) exist and are operational, but require expertise that is unlikely to be found among most restoration practitioners, stakeholders, and Traditional Owners. Current AI tools are still under development and not yet operational for automated detection of bleaching severity, colour correction across space and time (e.g. SeaThru), and fish diversity and biomass data extraction. **Future research should continue developing and ultimately operationalise such AI tools to allow for large-scale data production, with low-cost and across a wide range of stakeholders and restoration practitioners (Figure 7).**

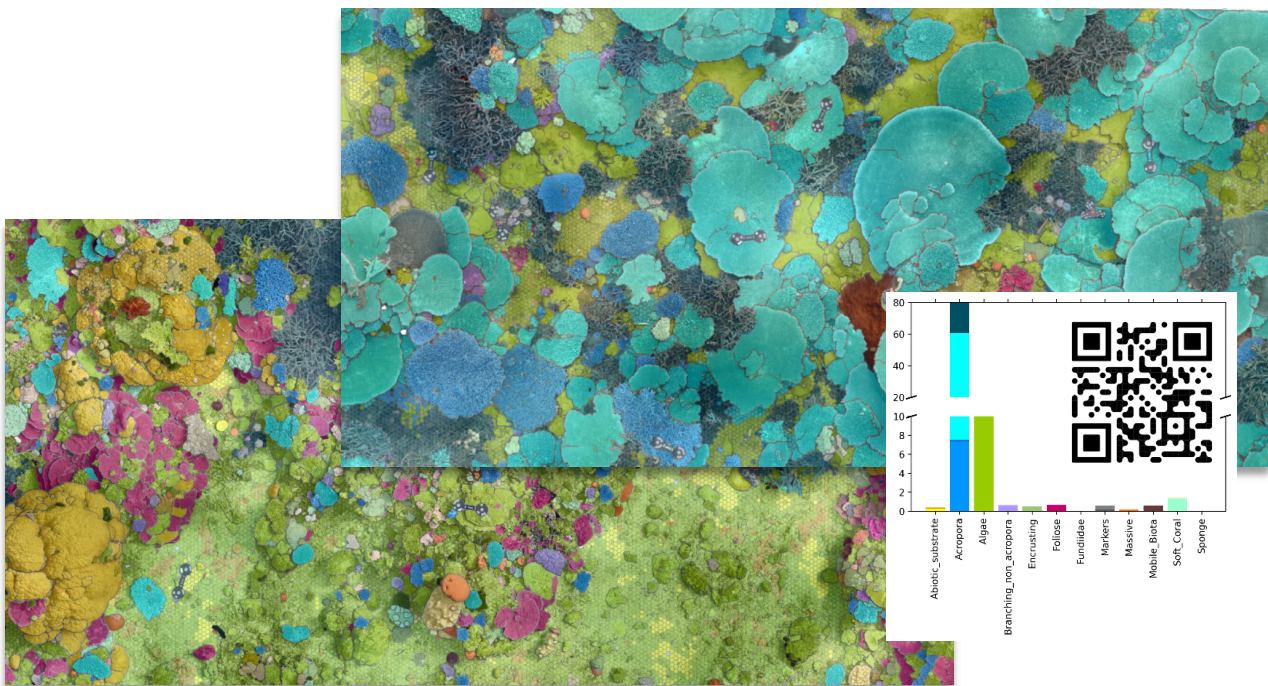


Figure 7: EcoRRAP developed RapidBenthos, an AI tool capable to segment and classify every component in a coral reef large-area-image (orthomosaic). Figures from Remmers et al. 2025.

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