REEF RESTORATION & ADAPTATION PROGRAM

Translation to Deployment (T2D-01)

Final Report June 2025

Davis, P., Corry, P., Jez, J., Dendle, N., Moshirian, B., Jackel, K., Fischer, T., Raine, S., Tsai, D., Samvedi, G., Lamont, R., Tutin, A., Morris, T., Lui, A., Esplin, J., Morris, A., Sim, L., and Hu, J.

RRAP Translation to Deployment (T2D-01) Final Report June 2025

Enquiries should be addressed to:

QUT – Paul Corry p.corry@qut.edu.au

AIMS – Jakub Jez j.jez@aims.gov.au

QUT – Tobias Fischer tobias.fischer@qut.edu.au

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

This report should be cited as

Davis, P., Corry, P., Jez, J., Dendle, N., Moshirian, B., Jackel, K., Fischer, T., Raine, S., Tsai, D., Samvedi, G., Lamont, R., Tutin, A., Morris, T., Lui, A., Esplin, J., Morris, A., Sim, L., and Hu, J. (2025) Reef Restoration and Adaptation Program – Translation to Deployment (T2D-01) Final Report 2025. (22 pp).

Copyright and Disclaimer

Acknowledgement

This work was undertaken for the Reef Restoration and Adaptation Program (RRAP). Funded by the partnership between the Australian Government's Reef Trust and the Great Barrier Reef Foundation, partners include: 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.

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**
Brisbane	Turrbal, Yugara
Townsville	Gugu-Badhun, Nyawaygi, Bindal, Wulgurukaba

Table of Contents

1 Executive Summary **1**

2 Background and Justification for the Research **4**

2.1 Coral Spawn and Larvae Imaging and Camera System (CSLICS) 4

2.2 Coral Growout Robotic Assessment System (CGRAS) 4

2.3 Coral tab breakage and Device Assembly 5

2.4 Deployment Guidance System (DGS) 6

2.5 Logistics modelling 6

3 Research Objectives and Key Findings **9**

4 Future Research Recommendations **12**

5.1 Coral Spawn and Larvae Imaging and Camera system (CSLICS) 12

5.2 CSLICS Desktop 12

5.3 Coral Growout Robotic Assessment System (CGRAS) 12

5.4 Coral tab breakage and Device Assembly 13

5.5 Deployment Guidance System (DGS) 13

5.6 Logistics modelling 13

5 References **14**

List of Figures

Figure 1: Six CSLICS deployed at AIMS during coral spawning season 2024. 1

Figure 2: CGRAS tested at AIMS, 2023. 2

Figure 3: Jig Cutter prototype (left) and Jig Press prototype (right). 2

Figure 4: Deployment guidance system – render of motors and vessel control hardware. 2

Figure 5: Global positioning system (GPS) tracks collected during 2024 Boats 4 Corals (B4C) project in the Whitsundays. 3

Figure 6: (left) earlier version of CSLICS prototype with vertical mounted camera focused on data capture; (right) updated version with side-mounted camera and lighting to address coral adhesion issue observed in the spawning of 2023. 4

Figure 7: CSLICS Desktop version being tested during coral spawning in 2024. 4

Figure 8: Coral Growout Robotic Assessment System tested at AIMS in 2023. 5

Figure 9: Coral tab breakage and device assembly process (left to right: wet concrete tile; tile broken into tabs; devices loaded with tabs). 5

Figure 10: Deployment guidance workflow and acknowledgements. 6

Figure 11: Scenario analysis example - Assembly of coral deployment devices on land versus assembly at sea. 6

Figure 12: Example of summary page for slick capture cost modelling for a small-scale deployment scenario. 7

Figure 13: Output of logistics and cost modelling to explore an emergency response scenario for fogging. 7

Figure 14: Example mother ship and small deployment vessel routing optimisation. 8

List of Tables

Table 1: Key findings of the Project aligned to the overarching and specific research questions for each sub-project. 9

Table 2: Variation in the Project over time. 11

1 Executive Summary

During the first phase, RRAP has achieved significant breakthroughs in developing and advancing a suite of coral restoration and intervention methods. These include, but are not limited to, the “coral aquaculture intervention” and the “Slick Capture/Release intervention” methods. While these approaches have been scientifically and ecologically validated as feasible, large-scale deployment still requires meeting a range of prerequisites. These span across several domains, including technology readiness, logistical frameworks, social licence, regulatory approvals, and financing mechanisms.

Building upon the strong collaboration between the Queensland University of Technology (QUT) and the Australian Institute of Marine Science (AIMS) established during the former RRAP “Integrated Logistics and Automation” Sub-program at the start of RRAP, the RRAP “Translation to Deployment” (T2D) Sub-program was launched in 2022. The purpose of the T2D Sub-program is to facilitate critical enabling activities necessary for transitioning priority interventions into viable, large-scale reef management solutions beginning in 2025–2026.

Initially, the T2D Sub-program encompassed a broad scope of activities, including deployment planning, regulatory pathway development, supply chain readiness, and technological advancements aimed at improving the efficiency of coral aquaculture, deployment, and monitoring. In 2023, following the separation of the Pilot Deployments Program (PDP) from the RRAP T2D Sub-program, T2D’s focus was refined. It shifted towards the development of a suite of core enabling technologies critical for success across the entire coral aquaculture pipeline—from grow-out and settlement to large-scale deployment and post-deployment monitoring.

Over the past two years, several of these enabling technologies (outlined below) have progressed to either the prototyping stage or are nearing finalisation. The research context, current development status and future recommendation of each technology are detailed in the following section: *2. Background and Justification for the Research* and *5. Future Research Recommendations*.

- **Coral Spawn and Larvae Imaging and Camera system (CSLICS) -** Machine vision and software-systems for counting and tracking coral larvae through the rearing phase of coral aquaculture process.

Figure 1: Six CSLICS deployed at AIMS during coral spawning season 2024.

- **Coral Grow-out Robotic Assessment System (CGRAS) -** Robotic, machine vision and software systems for counting, mapping and tracking coral recruits on concrete settlement tiles throughout grow-out phase of coral aquaculture process.

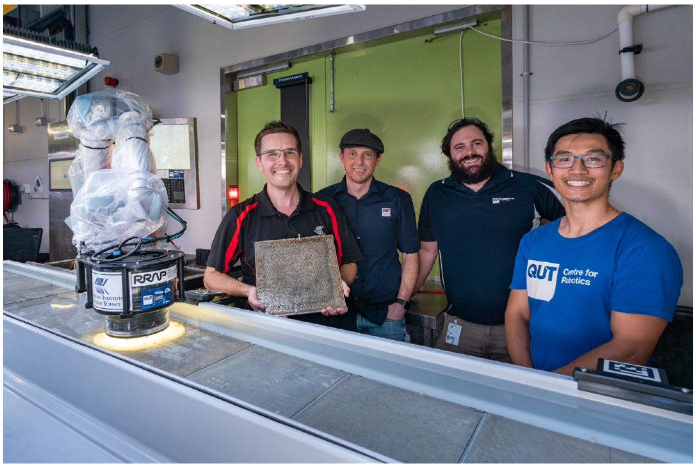

Figure 2: CGRAS tested at AIMS, 2023.

- **Coral Device Assembly system (JIGS) -** Mechanical augmentation of processes involved in cutting concrete settlement tiles and assembly of deployment devices.

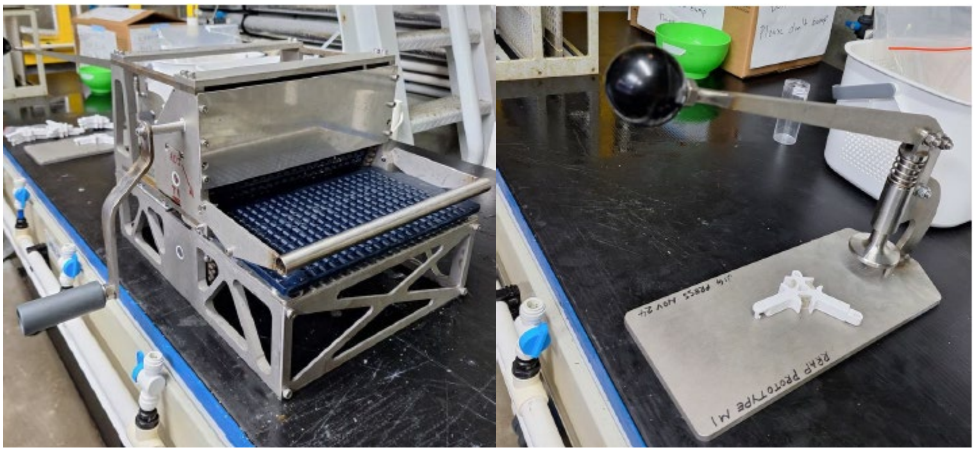

Figure 3: Jig Cutter prototype (left) and Jig Press prototype (right).

- **Deployment Guidance System (DGS)** – A vessel guidance system (set up for small vessel) to control path of boat and guide coral deployments with artificial intelligence (AI) capability.

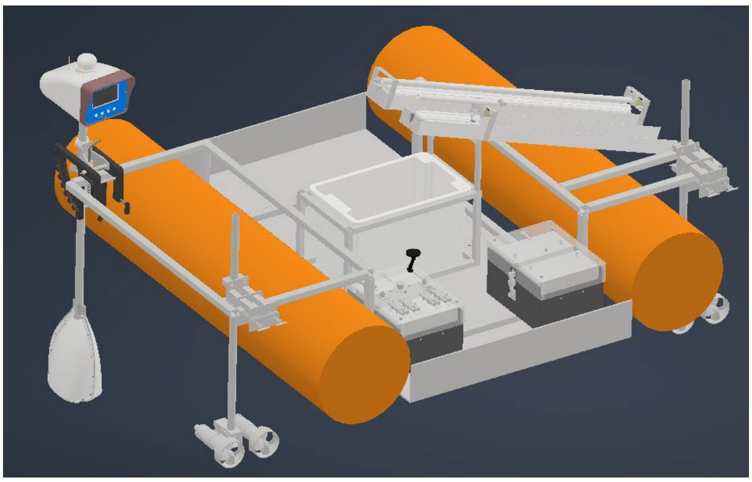

Figure 4: Deployment guidance system – render of motors and vessel control hardware.

In addition, the RRAP T2D Sub-program has maintained a strong collaborative relationship with the Pilot Deployments Program, providing ongoing support through logistics modelling to optimise deployment planning. This collaboration includes refining the Slick Capture/Release intervention methods and coral aquaculture techniques, ensuring these innovative approaches are implemented in a cost-effective and efficient manner.

Figure 5: Global positioning system (GPS) tracks collected during 2024 Boats 4 Corals (B4C) project in the Whitsundays.

2 Background and Justification for the Research

2.1 Coral Spawn and Larvae Imaging and Camera System (CSLICS)

High-density coral larvae rearing is essential to the success of the RRAP aquaculture pipeline, during which coral embryos develop into larvae over five to seven days. However, larval cultures can crash within a matter of hours, and so frequent counting is required. Due to the previously low scale of operations, this process is a time-consuming and manual process that risks damaging the delicate corals in the process and has since become a significant bottleneck in future large-scale operations. Additionally, accurate counts are required for quality and control purposes. To address this bottleneck, a QUT robotics and engineering team developed CSLICS to automatically count coral spawn using images and machine learning (ML) with a network of cameras at the scale required for pilot deployment operation.

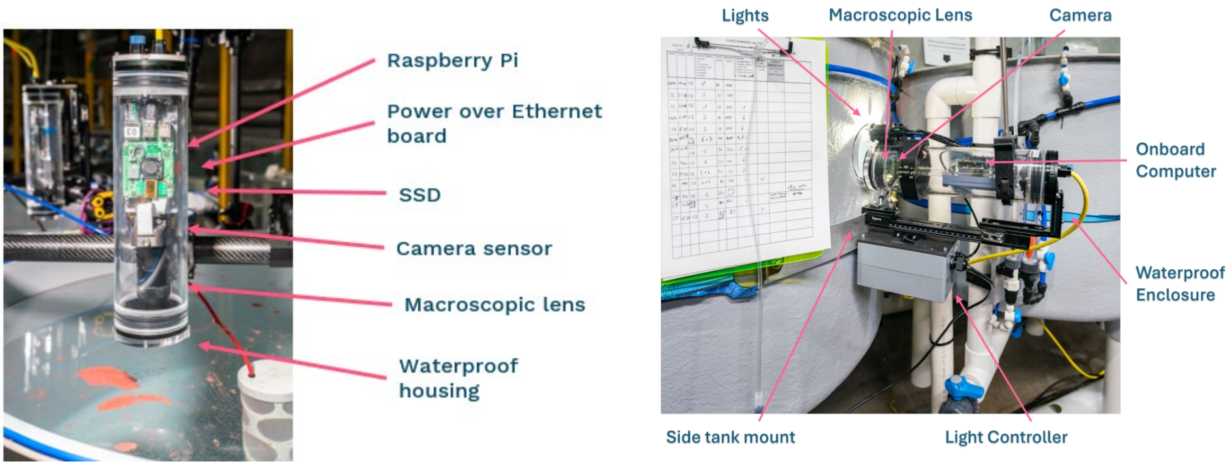

Figure 6: (left) earlier version of CSLICS prototype with vertical mounted camera focused on data capture; (right) updated version with side-mounted camera and lighting to address coral adhesion issue observed in the spawning of 2023.

In parallel, the CSLICS Desktop prototype was developed to provide initial stocking density counts and fertilisation success measures, and general larvae counting capability. It is a more accessible, flexible, computerised imaging system with integrated lights and coral counting models.

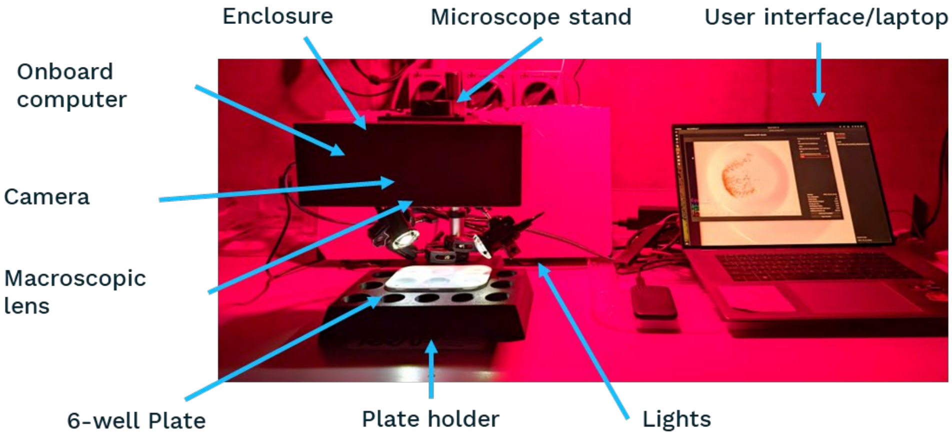

Figure 7: CSLICS Desktop version being tested during coral spawning in 2024.

2.2 Coral Growout Robotic Assessment System (CGRAS)

Accurate and regular monitoring of the health and status of the coral recruits in the growout tanks is paramount for the success of the coral aquaculture process. Coral caretakers have traditionally required a significant amount of time to examine the coral tiles (over one to two hours per tile), especially during the early stages of development. The required expertly-trained labour and resources would grow substantially to meet the target number of survival corals for the Pilot Deployments Program (over 10,000 tiles measured every week). Clearly, automation technology is essential to reliably track the health and deployment-readiness of the coral recruits. The team at QUT has since developed CGRAS, a semi-automated platform aimed at imaging the coral tiles at a macroscopic scale to automatically count and assess recruits' health and understand recruit distribution on tiles to achieve better yields during the coral grow-out phases. It significantly reduces the manual labour costs to scale up coral aquaculture production.

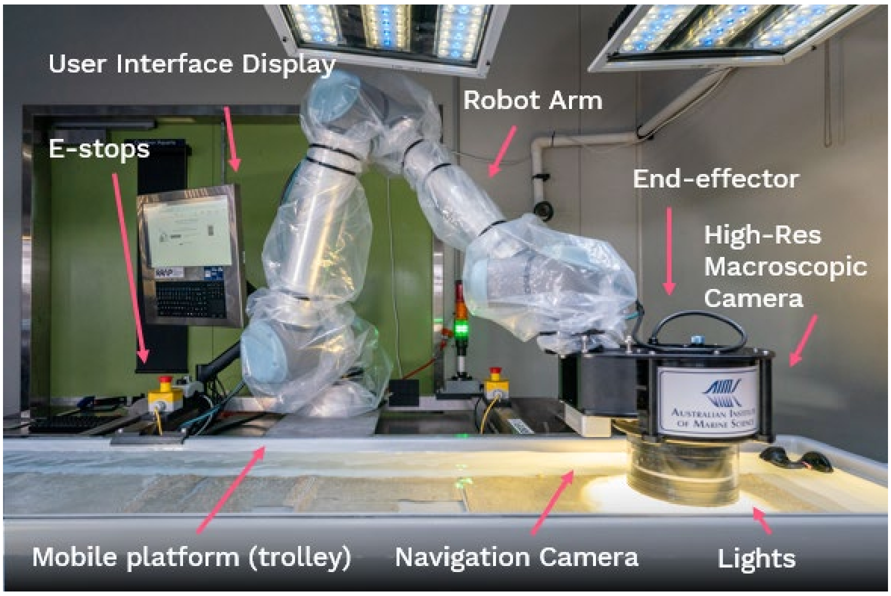

Figure 8: Coral Growout Robotic Assessment System tested at AIMS in 2023.

2.3 Coral tab breakage and Device Assembly

As part of the coral aquaculture pipeline, baby corals are cultivated for up to 12 weeks on 28cm x 28cm concrete tiles. To maintain high survival rates, these tiles must be broken safely and accurately into smaller tabs without contacting the surface where the corals grow. Precise tile breakage not only protects the corals but also ensures the tabs can be efficiently loaded into deployment devices. Consistent and accurate loading improves both coral and operator safety while significantly reducing processing time. Originally, the manual processes—cutting each tile took around 15 minutes, and loading devices could take up to 3 minutes per device (longer if fit issues occurred)—were too time-consuming to meet the scalability demands of the Pilot Deployments Program (PDP), highlighting the need for process improvements.

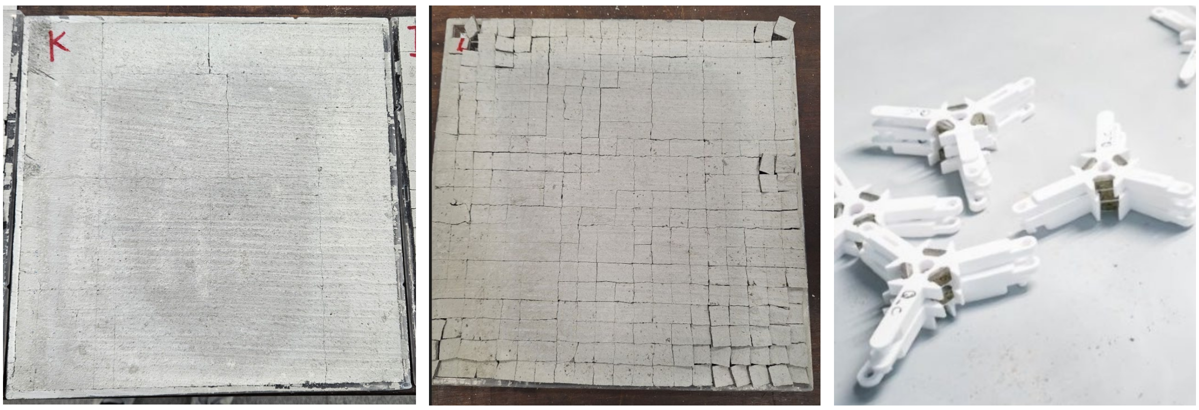

Figure 9: Coral tab breakage and device assembly process (left to right: wet concrete tile; tile broken into tabs; devices loaded with tabs).

The Jig Cutter and Jig Press were developed as the essential tools for pilot deployments, designed to improve efficiency and coral and operator safety. The Jig Cutter breaks coral tiles into tabs using a bending method that avoids contact with the coral surface except along the breaklines, while the Jig Press mechanically aids in accurately loading tabs into deployment devices.

2.4 Deployment Guidance System (DGS)

. Informed decision-making to guide design, implementation and evaluation is essential at every stage - from selecting appropriate interventions to determining quantities, timing, deployment locations, and monitoring their impact. It is a time-consuming and labour-intensive exercise particularly for large scale deployment. To tackle this challenge, RRAP invested in the development of the deployment guidance system with an on-boat vessel guidance system and device dispenser to guide the on-water deployment. It is also equipped with ReefScan (underwater camera) and an in-house AI system for suitable substrate detection to support on-vessel deployment decisions.

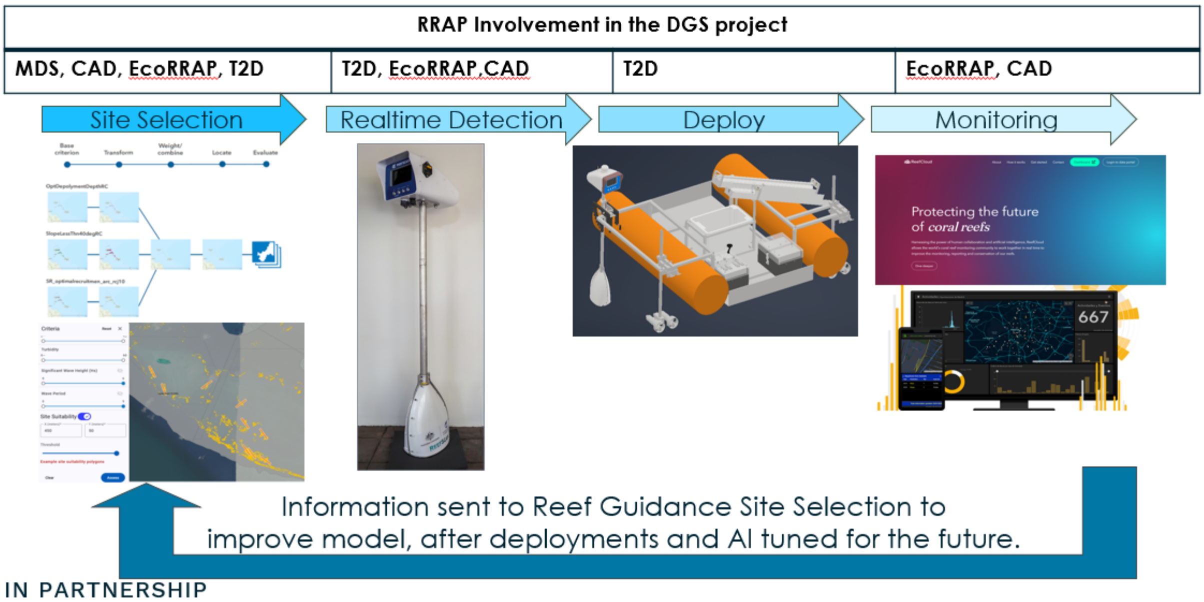

Figure 10: Deployment guidance workflow and acknowledgements.

2.5 Logistics modelling

As RRAP is moving towards large scale deployments, it is critical for the program to maintain an oversight of the up-to-date cost and logistics models for various intervention methods at scale. Over the duration of the project, the Translation to Deployment (T2D) team has been constantly conducting scenario analyses to support sub-programs and PDP decision making on deployment operating processes and developing methods for logistics planning optimisation.

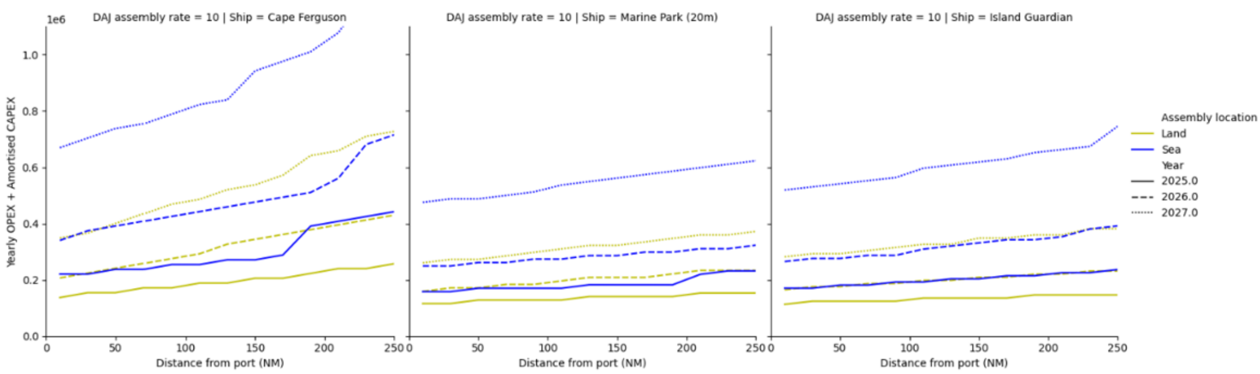

Figure 11: Scenario analysis example - Assembly of coral deployment devices on land versus assembly at sea.

Examples of logistics and cost modelling that has been conducted to support other RRAP Sub-programs follow below. This has included working with the slick capture and larval rearing team (from the RRAP Moving Corals Sub-program) to estimate deployment costs and cost per one-year old coral at different deployment scales (see example in Figure 12).

Inputs					Key results		
Quantity	Value	Unit	Comment		Quantity	Value	Unit
Device deployment size	15000	devices			Total cost	$ 1,770,676.50	$
Larval release pools	5	pools	Must be viable for a single barg		OPEX	$ 1,554,176.50	$
					CAPEX	$ 216,500.00	$
New domain	FALSE	switch			Amortised CAPEX	$ 21,650.00	$
Pre-spawning vessel	Large Tourism A	type					1YOEC
Spawning-block mothership	Large Tourism A	type			Projected free-release area covere	0.25	ha
Setup support ship	Oversized Tender (Day)	type			Expected free-release 1YOEC/pool	14800	1YOEC/pool
Spawning support ship	Oversized Tender (Night)	type			Expected coverage per pool	0.296	ha
					Expected coverage per pool	0.246666667	ha
Passive spawn catcher proportion	0%	switch	Chance of complete failure, due to mispositioning or unexpected winds.				
					Projected device 1YOEC	9000	
					Projected free-release 1YOEC	74000	
					Total 1YOEC	83000	
					OPEX/coral	$ 18.73	
					A-CAPEX/coral	$ 0.26	
					Cost/coral	$ 18.99	

Figure 12: Example of summary page for slick capture cost modelling for a small-scale deployment scenario. Costs for this intervention may be as low as $2.07 per 1YOEC.

Other analysis undertaken considered an emergency response scenario whereby fogging could be deployed at short notice for rapid response to unfavourable bleaching conditions.

	Per day	one off cost	30 Days	90days	Existing infastructure 30 days	Existing infastructure 90 days
Dumb barge x3 rent	$3,000		$90,000	$270,000	$90,000	$270,000
Dumb barge x3 purchase -Alloy full survey		$105,000				
Tug/live aboard	$8,000		$240,000	$720,000	$240,000	$720,000
Service boat depending on site and requireme	$6,000		$180,000	$540,000	$180,000	$540,000
Fuel (60ltr/hr @ 6hr/day)@ $2/ltr	$720		$21,600	$64,800	$21,600	$64,800
Water						
6 x technicans	$4,800		$144,000	$432,000	$144,000	$432,000
Victualling	$200		$6,000	$18,000	$6,000	$18,000
Change over personel. Travel		$15,000			$15,000	$15,000
Equipment service x 3@ $1000/service		$9,000			$9,000	$9,000
Consumables	$500		$15,000	$45,000	$15,000	$45,000
Nozzles @ $45/n X 1080		$48,600			$24,300	$24,300
Vessel workshop set up		$20,000			$20,000	$20,000
Generator x 3		$60,000			$60,000	$60,000
IBC x 10 @ 500		$5,000			$5,000	$5,000
Fuelling systems- marine safe		$20,000			$20,000	$20,000
Vessel fuel @ 2/ltr 500lt/day	$1,000		$30,000	$90,000	$30,000	$90,000
Fogging system modification		$80,000			$240,000	$240,000
Fogging system purchase x 3 @ 290000 each		$870,000				
Monitror equipment (flame or similar, weatherstation, camera, water quality,		$150,000			$150,000	$150,000
Researcher to crunch numbers x 2 @ 350/day. 20 days		$7,000			$7,000	$14,000
Barge equipment rope anchors, saftey, survey etc @ 10		$30,000			$30,000	$30,000
Tender vessel @ $250/day	$250		$7,500	$22,500	$7,500	$22,500
Operations management	$1,000		$90,000	$90,000	$90,000	$90,000
SUB TOTAL		$1,419,600	$824,100	$2,292,300	$1,404,400	$2,879,600
30% CONTINGENCY		$425,880	$247,230	$687,690	$421,320	$863,880
GRAND TOTAL		$2,916,810		$4,825,470	$1,825,720	$3,743,480

Figure 13: Output of logistics and cost modelling to explore an emergency response scenario for fogging.

Other aspects of logistics modelling with a more long-term view, and a focus on optimisation research, have been considered as part of a PhD project. This work has considered the optimal locations of multiple coral aquaculture facilities under different deployment scenarios, and computational optimisation for routing of motherships supporting a fleet of small vessels during deployment optimisation (see Figure 14).

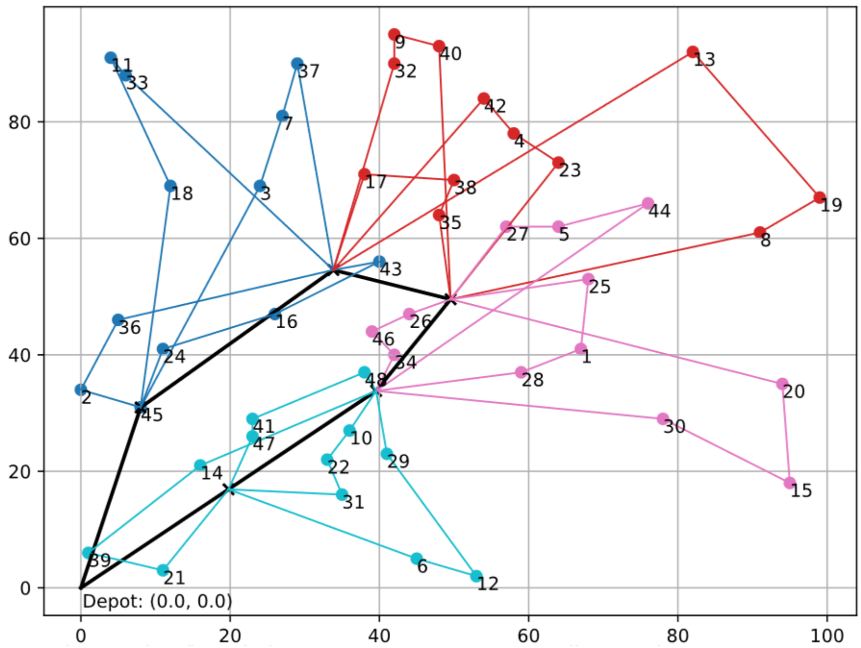

Figure 14: Example mother ship and small deployment vessel routing optimisation.

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
1.	Production (by aquaculture), deployment, and monitoring of temperature-tolerant corals (up to 1-2 million per year).	**Coral Spawn and Larvae Imaging and Camera System (CSLICS)** – The prototype system of networked cameras for real-time, non-invasive coral spawn monitoring was developed. The six-camera networked system was successfully deployed during 2024 December spawning. For the surface interval, the coral spawn detector for Acropora corals provides consistent surface fertilisation success measures comparable to manual counts. For the sub-surface interval, results showcased observable larval settlement behaviour and was useful as a trend-monitoring tool. **CSLICS Desktop** – Two functional prototypes have been developed and deployed during the 2024 spawning and have provided initial stocking density counts and fertilisation success measures, and general larvae counts, comparable to a trained expert. It is a more accessible, flexible, computerised imaging system with integrated lights and coral counting models. **Coral Growout Robotic Assessment System (CGRAS)** – the semi-automatic image capture system has been designed and built on a robotic platform. An earlier version of the prototype was deployed during 2023 spawning on two tanks, successfully used by AIMS researchers for data capture. The complete image processing pipeline has been developed for the system from tile reconstruction, alignment, coral detection, per-tab counts to trend visualisation. **Jig Cutter** - Testing revealed that an initial cookie cutter concept, which attempted to cut a 28×28 cm concrete tile in a single action required excessive force, rendering the method impractical. While the original grid design was successful on small samples, it failed under full-scale testing. As a result, the Jig Cutter was developed using a "bend and snap" technique, which proved much more effective, requiring significantly less force and producing cleaner, more consistent breaks. **Jig Press** – the prototype was developed to press fit three coral tabs into each coral device with minimal operator effort, using a single press motion. The prototype was tested at the 2024 spawning season with well received user feedback. **Deployment Guidance system (DGS)** – The system prototype equipped with vessel control system, ReefScan and dispensers have been developed and is currently being field tested. Extensive labelled data from mid-shelf and inshore reefs has supported the development of a

Objective		Key Findings and/or Outcomes
		patch-based AI classifier, enabling effective model interpretation and threshold tuning. Preliminary field trials in the Whitsundays and at Heron Island showed the AI system performed comparably to human ecologists and responded conservatively under uncertainty. The model runs in real time on ReefScan hardware, processing each image in approximately 0.7 seconds. **Logistic modelling** – a logistics simulation model was developed as a configurable dynamic model in Python for simulating and visualising intervention campaigns.
2.	Production (by spawning slick capture and larval rearing), resettlement and monitoring of corals (up to 1-2 million per year).	Logistics and cost models have been developed for slick capture and larval rearing. Working with the RRAP Sub-program Leads, the modelling team have maintained up to date models, and have incorporated slick capture, rearing and cloud release into the dynamic logistics simulation model for intervention campaigns. These models are used to assist PDP in planning for pilot deployments.
3.	Fogging deployment and monitoring, as a local coral reef protection intervention, if deemed viable (based on technical feasibility, effectiveness and cost).	Logistics and cost models were developed for fogging in cooperation with the RRAP Cooling and Shading (C&S) Sub-program. These models were used to provide cost estimates for emergency fogging response scenarios, which was under consideration for future pilot deployments.

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
Design and engineering iterations	There have been numerous design and engineering iterations across the suite of the technologies being developed within T2D to meet the user requirements for supporting pilot deployment operations. The majority of the iterations and changes have been as a result of changes to the coral aquaculture process itself during the design and build process. It is challenging to automate a process when the underlying process is constantly evolving. However, these changes have been mostly variations at a technical level with only minor project delays and minimal impact on project milestones.
PDP and T2D separation	With the separation of the Pilot Deployments Program from the RRAP Translation to Deployment (T2D) Sub-program, a substantial portion of responsibilities—such as deployment planning, regulatory pathway development, and supply chain preparedness—were transferred to the Pilot Deployments Program. This shift was made to better support the coral production targets associated with both the "spawning slick capture and larval rearing" method and the "coral aquaculture" method.

4 Future Research Recommendations

The Reef Restoration and Adaptation Program (RRAP) aims to equip reef managers and policy makers with a cutting-edge portfolio of interventions that are not only innovative and effective but also safe, socially acceptable, and economically viable. These interventions are designed to support the long-term protection and resilience of the Great Barrier Reef in the face of increasing climate change pressures.

Within RRAP, the Translation to Deployment (T2D) Sub-program plays a critical role to facilitate the transition of emerging technologies from research and development into real-world application. The sub-program ensures that these technologies can be implemented safely, at scale, and in ways that are publicly acceptable and financially sustainable—core criteria essential to achieving RRAP's overarching mission.

While the Sub-program has already made significant progress and delivered important breakthroughs, the landscape of coral restoration is rapidly evolving. As such, continued and sustained investment is vital. Ongoing funding will enable the adaptation of technologies to meet emerging challenges and to scale up interventions effectively, ensuring they have a meaningful and lasting impact on reef restoration outcomes.

In light of these dynamics, a set of targeted research recommendations has been developed for each of the technologies currently under development. These recommendations are intended to guide future work and ensure that each solution is aligned with RRAP's goals of safe, effective, and scalable reef restoration.

5.1 Coral Spawn and Larvae Imaging and Camera system (CSLICS)

To date, the project has successfully developed a consistent, rapid, non-invasive, and scalable prototype method for monitoring coral larvae as part of the coral aquaculture process. Continued refinement of this system is essential. First, improving the machine learning (ML) pipelines to provide more reliable coral spawn detection models and iterate on other coral genera, such as *Porites* and *Goniastrea*, will greatly improve the applicability of the CSLICS systems across the Pilot Deployments Program (PDP) target species for large scale deployment. Second, improving the robustness of the CSLICS alarm system to be able to handle a wider variety of alert scenarios would allow for more responsive control for the aquaculture facility operators. Third, developing a more advanced calibration method for CSLICS will improve the systems' consistency across camera units for more reliable tank estimates. Finally, a large-scale study across the different tanks and coral species using CSLICS is of strong interest to researchers and operators to better understand high-density larval culture mortality in aquaculture facilities, which could ultimately lead to improved survival of coral larvae. These improvements should be informed by feedback from large-scale coral rearing operations to ensure the system is ready to support deployment at significantly greater scales.

5.2 CSLICS Desktop

The current CSLICS Desktop prototype supports stock density estimation, fertilisation success measurements, and larvae counting. However, several key improvements are planned. First, upgrading to a more compact industrial camera setup—drawing on advancements from CSLICS—could deliver significantly faster detections and a smoother user experience. This will also require enhanced integrated lighting to ensure uniform illumination, addressing the limitations of the current overhead setup for top-down imaging. Second, further development of the coral detection models is needed to improve robustness across a wider range of coral species and genera, enhancing overall detection accuracy.

5.3 Coral Growout Robotic Assessment System (CGRAS)

The project is on track in developing the robotic imaging system for in-tank coral tile monitoring with in-house software for supporting the automated image reconstruction and per-tab coral detection. The system is estimated to reduce tile processing times from ~140 min manually to ~10 min automatically. However, the project does not have sufficient time or resources to further expand the work along several interesting and valuable directions. First, is improving the richness of the coral health metrics that can be extracted from the CGRAS datasets, such as classifying partial mortality, clustering and symbiosis status and integrating this into the Coral Counting and Visualisation System's data export process. Second is exploring the broader benthic community for pests, grazers and algae identification. Third is improving the ML pipelines to more efficiently develop new coral recruit detection models to reduce the manual labelling load and allow faster and easier development of detection models to other coral species. Fourth is investigating alternative methods for imaging from vertical growout tiles. And finally, fifth is identifying additional robot arm applications, such as phenotyping, coral manipulation and tank cleaning. These potential project improvements could greatly increase the usefulness and utilisation of the CGRAS system to further support large scale reef restoration.

5.4 Coral tab breakage and Device Assembly

The current Jig cutter prototype allows an operator to cut a 28 cm x 28 cm cement tile in just two minutes—making the process nearly seven times faster than the original method. Similarly, the Jig press has halved the time required to assemble a coral device. Both tools have significantly improved the safety of the coral assembly process, reducing physical strain and operational risks for workers.

Looking ahead, it is essential that the insights and designs developed through this project be further tested and validated in larger-scale field operations. This will help enhance both efficiency and safety as deployment scales up. Strategic collaboration, such as part of the McLaren-Great Barrier Reef Foundation partnership with AIMS and QUT which is focused on developing a machine for automated device assembly, will be key to accelerating progress and ensuring that these innovations are effectively integrated into high-volume restoration workflows.

5.5 Deployment Guidance System (DGS)

Significant progress has been achieved in the development of the deployment guidance system. An integrated solution—combining vessel control, underwater camera, a GPS system, and an AI-driven pipeline—has been successfully developed and tested in the field.

To build on this strong foundation, further investment in both time and funding is needed. Efforts should focus on reducing the manual effort required for data labelling when fine-tuning the AI model for new locations. Additionally, developing automated methods for identifying when and where model retraining is needed would enhance system adaptability and efficiency.

From a deployment perspective, it is also essential to explore strategies for scaling and distributing deployment activities in collaboration with operational partners. This will ensure that the system can be effectively integrated into large-scale restoration efforts and managed efficiently across multiple sites.

5.6 Logistics modelling

The logistics and cost modelling work is an ongoing effort designed to support informed decision-making for operational processes involved in pilot deployments. This includes detailed analysis of coral deployment device assembly workflows, viability inspection procedures, cost-distance trade-offs, and site survey operations.

This modelling has already contributed to, and will continue to inform, RRAP's proposal submissions to the Department of Climate Change, Energy, the Environment and Water (DCCEEW). To enhance its accuracy and usefulness, the work will require continued data collection, ground-truth validation, and the development of interactive dashboards to support real-time planning and scenario analysis.

Work is continuing on the mothership and deployment vessel routing optimisation, in collaboration with the RRAP Modelling and Decision Support (M&DS) Sub-program, incorporating bathymetry (depth) constraints on vessel movements, along with disruptions relating to locally unfavourable wind and wave conditions.

5 References

Gold S, Seuring S. Supply chain and logistics issues of bio-energy production. Journal of Cleaner Production. 2011;19(1):32-42. doi: 10.1016/j.jclepro.2010.08.009

Marx DH, Bryan WC, Cordell CE. Survival and growth of pine seedlings with Pisolithus ectomycorrhizae after two years on reforestation sites in North Carolina and Florida. Forest Science. 1977;23(3):363-73. doi:

Duryea M, McClain K. Altering seedling physiology to improve reforestation success. Seedling physiology and reforestation success. 1984:77-114. doi:

Mexal JG, Cuevas Rangel RA, Negreros-Castillo P, Paraguirre Lezama C. Nursery production practices affect survival and growth of tropical hardwoods in Quintana Roo, Mexico. Forest Ecology and Management. 2002;168(1):125-33. doi: 10.1016/S0378-1127(01)00735-6

Forsman ZH, Rinkevich B, Hunter CL. Investigating fragment size for culturing reef-building corals (Porites lobata and P. compressa) in ex situ nurseries. Aquaculture. 2006;261(1):89-97. doi: 10.1016/j.aquaculture.2006.06.040

Villanueva RD, Baria MVB, dela Cruz DW. Growth and survivorship of juvenile corals outplanted to degraded reef areas in Bolinao-Anda Reef Complex, Philippines. Marine Biology Research. 2012;8(9):877-84. doi: 10.1080/17451000.2012.682582

Helmstedt KJ, Possingham HP. Costs are key when reintroducing threatened species to multiple release sites. Animal Conservation. 2017;20(4):331-40. doi: 10.1111/acv.12319

Henry JA, O'Neil KL, Pilnick AR, Patterson JT. Strategies for integrating sexually propagated corals into Caribbean reef restoration: experimental results and considerations. Coral Reefs. 2021;40(5):1667-77. doi:

South DB, Mexal JG. Growing the" best" seedling for reforestation success. 1984. doi:

Owen SH, Daskin MS. Strategic facility location: A review. European journal of operational research. 1998;111(3):423-47. doi: 10.1016/S0377-2217(98)00186-6

Conceição S, Pedrosa L, Neto A, Vinagre M, Wolff E. The facility location problem in the steel industry: a case study in Latin America. Production Planning & Control. 2012;23(1):26-46. doi:

Medrano-Gómez XD, Ferreira D, Toso EAV, Ibarra-Rojas OJ. Using the maximal covering location problem to design a sustainable recycling network. Journal of Cleaner Production. 2020;275:124020. doi: 10.1016/j.jclepro.2020.124020

Cornuéjols G, Nemhauser G, Wolsey L. The Uncapacitated Facility Location Problem. Cornell University Operations Research and Industrial Engineering: Cornell University Operations Research and Industrial Engineering; 1983.

Fazel Zarandi MH, Davari S, Haddad Sisakht SA. The large scale maximal covering location problem. Scientia Iranica. 2011;18(6):1564-70. doi: 10.1016/j.scient.2011.11.008

Silva A, Aloise D, Coelho LC, Rocha C. Heuristics for the dynamic facility location problem with modular capacities. European Journal of Operational Research. 2021;290(2):435-52. doi: 10.1016/j.ejor.2020.08.018

Jena SD, Cordeau J-F, Gendron B. Dynamic Facility Location with Generalized Modular Capacities. Transportation Science. 2015;49(3):484-99. doi: 10.1287/trsc.2014.0575

Verter V, Dincer MC. Facility location and capacity acquisition: an integrated approach. Naval Research Logistics (NRL). 1995;42(8):1141-60. doi: 10.1002/1520-6750(199512)42:8<1141::Aid-Nav3220420803>3.0.Co;2-B

Hughes TP, Day JC, Brodie J. Securing the future of the Great Barrier Reef. Nature Climate Change. 2015;5(6):508. doi: 10.1038/nclimate2604

Pandolfi J, Bradbury R, Sala E, Hughes T, Bjorndal K, Cooke R, et al. Global Trajectories of the Long-Term Decline of Coral Reef Ecosystems. Science (New York, NY). 2003;301(5635):955-8. doi: 10.1126/science.1085706

Spalding M, Brown B. Warm-water coral reefs and climate change. Science. 2015;350(6262):769-71. doi: 10.1126/science.aad0349

Cohen FPA, Cabral AE, Lillebø AI, Calado R. Relieving pressure from coral reefs: Artificial oyster rocks can replace reef rocks used for biological filtration in marine aquariums. Journal of Cleaner Production. 2021;325:129326. doi: 10.1016/j.jclepro.2021.129326

Bay LK, Severati A, Abrego D, Cleves PA, Heyward A, Hoj L, et al. Reef Restoration and Adaptation Program - strategies, plans and costings: aquaculture and treatments. A report provided to the Australian Government from the Reef Restoration and Adaptation Program. A report provided to the Australian Government from the Reef Restoration and Adaptation Program; 2019.

Samuel-Fitwi B, Wuertz S, Schroeder JP, Schulz C. Sustainability assessment tools to support aquaculture development. Journal of Cleaner Production. 2012;32:183-92. doi: 10.1016/j.jclepro.2012.03.037

Jegatheesan V, Zeng C, Shu L, Manicom C, Steicke C. Technological advances in aquaculture farms for minimal effluent discharge to oceans. Journal of Cleaner Production. 2007;15(16):1535-44. doi: 10.1016/j.jclepro.2006.07.043

Leal MC, Ferrier-Pagès C, Petersen D, Osinga R. Coral aquaculture: applying scientific knowledge to ex situ production. Reviews in Aquaculture. 2016;8(2):136-53. doi: 10.1111/raq.12087

McLeod IM, Hein MY, Babcock R, Bay L, Bourne DG, Cook N, et al. Coral restoration and adaptation in Australia: The first five years. Plos one. 2022;17(11):e0273325. doi:

Morrison TH, Adger WN, Agrawal A, Brown K, Hornsey MJ, Hughes TP, et al. Radical interventions for climate-impacted systems. Nature Climate Change. 2022:1-7. doi:

Okubo N, Motokawa T, Omori M. When fragmented coral spawn? Effect of size and timing on survivorship and fecundity of fragmentation in Acropora formosa. Marine Biology. 2007;151(1):353-63. doi:

Bruno JF. Fragmentation in Madracis mirabilis (Duchassaing and Michelotti): how common is size-specific fragment survivorship in corals? Journal of Experimental Marine Biology and Ecology. 1998;230(2):169-81. doi:

Madin JS, Baird AH, Dornelas M, Connolly SR. Mechanical vulnerability explains size-dependent mortality of reef corals. Ecology letters. 2014;17(8):1008-15. doi: 10.1111/ele.12306

Barton JA, Willis BL, Hutson KS. Coral propagation: a review of techniques for ornamental trade and reef restoration. Reviews in aquaculture. 2017;9(3):238-56. doi: 10.1111/raq.12135

Doropoulos C, Roff G, Bozec YM, Zupan M, Werminghausen J, Mumby PJ. Characterizing the ecological trade-offs throughout the early ontogeny of coral recruitment. Ecological Monographs. 2016;86(1):20-44. doi: 10.1890/15-0668.1

Forrester GE, Ferguson MA, O'Connell-Rodwell CE, Jarecki LL. Long-term survival and colony growth of Acropora palmata fragments transplanted by volunteers for restoration. Aquatic Conservation: Marine and Freshwater Ecosystems. 2014;24(1):81-91. doi: 10.1002/aqc.2374

Doropoulos C, Stephenson B, Giuliano C, Koukoumaftsis L, Humphrey C, Randall C. Part 4: Preliminary Data on the Utility of Micro-Fragments in Reef Restoration. 2020. In: Fast-tracking knowledge to breed, settle and field deploy corals required for restoration at scale [Internet]. Report prepared for Great Barrier Reef Foundation. Australian Institute of Marine Science; [21-8].

Smith L, Hughes T. An experimental assessment of survival, re-attachment and fecundity of coral fragments. Journal of Experimental Marine Biology and Ecology. 1999;235(1):147-64. doi: 10.1016/S0022-0981(98)00178-6

Purcell SW, Agudo NS. Optimisation of mesh enclosures for nursery rearing of juvenile sea cucumbers. PloS one. 2013;8(5):e64103. doi: 10.1371/journal.pone.0064103

Little JD. A proof for the queuing formula: L= λ W. Operations research. 1961;9(3):383-7. doi:

Croarkin C, Tobias P. e-Handbook of Statistical Methods 2012 [cited 2021 9/12/21]. Available from: http://www.itl.nist.gov/div898/handbook/.

Perron L, Furnon V. OR-Tools. 9.3 ed: Google; 2022. doi:

Li G, Liu J, Giordano A. Robust optimization of construction waste disposal facility location considering uncertain factors. Journal of Cleaner Production. 2022;353:131455. doi: 10.1016/j.jclepro.2022.131455

Kulkarni R, Mohanty R. A temporal decomposition approach for solving a multilocation plant sizing and timing problem. Production Planning & Control. 1996;7(1):27-37. doi: 10.1080/09537289608930322

Vlachos I, Malindretos G. Supply chain redesign in the aquaculture supply chain: a longitudinal case study. Production Planning & Control. 2021:1-17. doi: 10.1080/09537287.2021.1959663

Jia D, Li X, Shen Z. Robust optimization model of waste transfer station location considering existing facility adjustment. Journal of Cleaner Production. 2022;340:130827. doi: 10.1016/j.jclepro.2022.130827

Raine, S., Marchant, R., Kusy, B., Maire, F., & Fischer, T. (2024). Image labels are all you need for coarse seagrass segmentation. In Proceedings of the IEEE/CVF Winter Conference on Applications of Computer Vision (pp. 5943-5952).

Banaszak, A. T., Marhaver, K. L., Miller, M. W., Hartmann, A. C., Albright, R., Hagedorn, M., ... & Chamberland, V. F. (2023). Applying coral breeding to reef restoration: best practices, knowledge gaps, and priority actions in a rapidly-evolving field. *Restoration ecology*, *31*(7), e13913.

REEF RESTORATION & ADAPTATION PROGRAM

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