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PROGRAM

Larval Collection, Culture, Deployment, Translocation (MC-01)

Final Report June 2025

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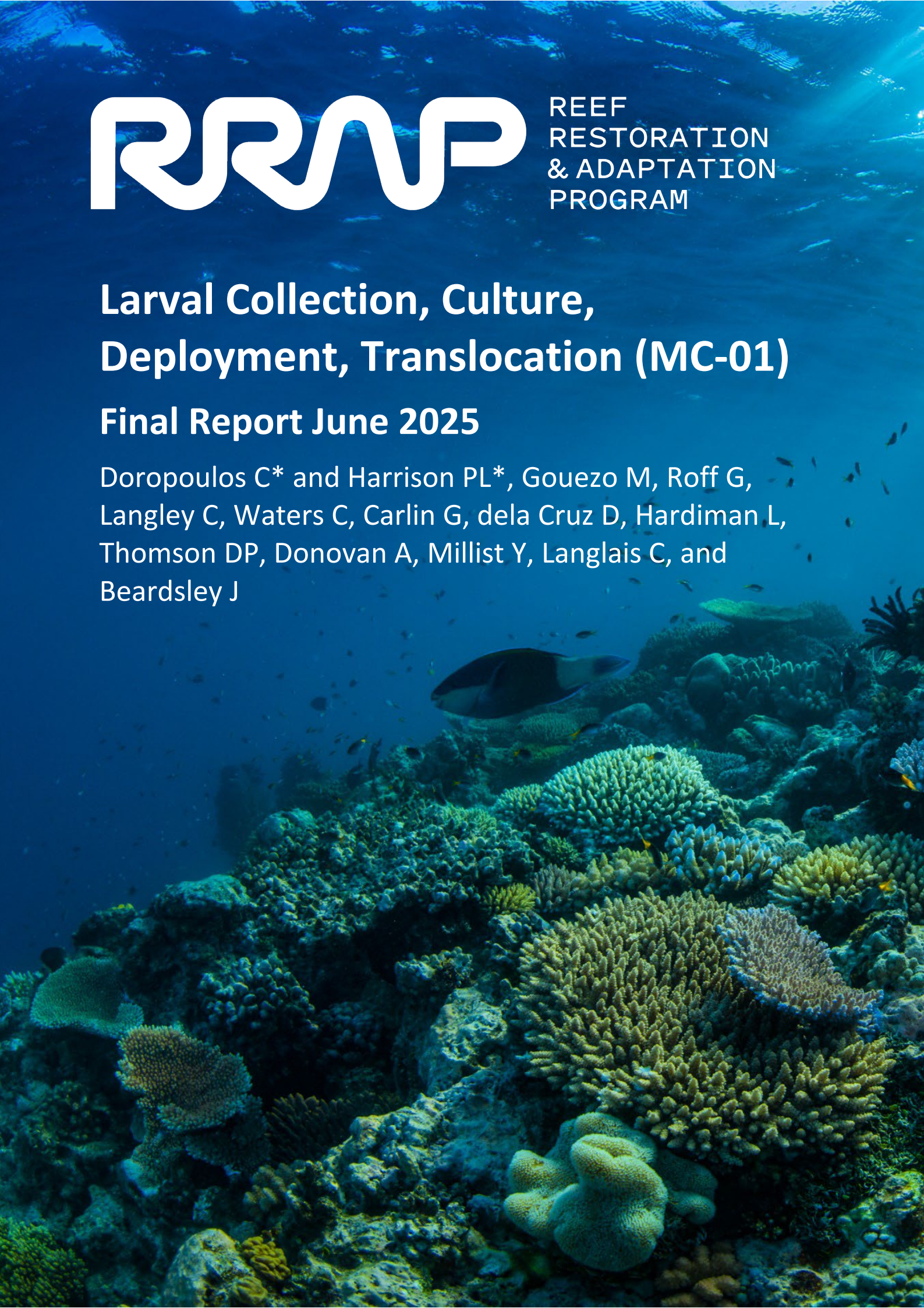

RRAP Larval Collection, Culture, Deployment, Translocation (MC-01) Final Report June 2025

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

This report should be cited as

Doropoulos, C.*, Harrison, P. L.*, Gouezo, M., Roff, G., Langley, C., Waters, C., Carlin, G., dela Cruz, D., Hardiman, L., Thomson, D. P., Donovan, A., Millist, Y., Langlais, C., and Beardsley, J. (2025) Reef Restoration and Adaptation Program – Larval Collection, Culture, Deployment, Translocation (MC-01) Final Report 2025. (36 pp).

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This report summarises work undertaken under *Larval Collection, Culture, Deployment, Translocation (MC-01)* in accordance with the Reef Restoration and Adaptation Program's *Moving Corals* 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.

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**
Heron Island, One Tree Island	Bailai, Gurang, Gooreng Gooreng, Taribelang Bunda
Palm Islands, Townsville	Manbarra, Bindal
Lizard Island	Ngurruumungu, Dingaal

Table of Contents

List of Figures

List of Tables

1 Executive Summary

The Moving Corals Sub-program of the Reef Restoration and Adaptation Program (RRAP) was established to address a key issue in coral reef restoration: enabling reef-based larval restoration interventions to scale from localised trials to ecologically meaningful deployments. The Sub-program focused on harnessing the immense restoration potential of coral spawn slicks—vast surface aggregations of embryos from mass spawning events—by developing, testing, and refining methods to collect spawn, and culture and deploy larvae at scale.

Coral spawn slicks contain billions of genetically diverse embryos, most of which are lost to the open ocean or predation. The RRAP Moving Corals Sub-program aimed to collect and convert samples of eggs and embryos from these slicks into high-value restoration opportunities by developing and optimising tools to:

1. Efficiently collect large quantities of embryos in open reef systems.
2. Culture larvae at high densities to maximise survival and readiness to settle.
3. Deploy larvae at scale using cost-effective, field-ready free-release approaches.
4. Integrate thermally tolerant larvae to boost restored populations' adaptation potential.

High-Volume Embryo Collection. Scalable collection tools—such as floating spawn catchers, vessel-based harvesting using surface nets and skimmers, and vessel-mounted pumps — enabled efficient harvesting from wild slicks. For example, in 2023, over 405 million eggs and embryos were collected in a single night, demonstrating capacity to collect spawn, and culture and mobilise larval stock on reefs at massive scales.

Reliable, High-Density Larval Culture. Reef-based larval culture pool systems supported survival rates over 60% at densities up to 15 million larvae per pool. These systems were robust to environmental variability and produced many millions of settlement-ready competent larvae in just three to five days.

Free Larval-Release Success with Seedboxes and Slow-Release Methods. The program developed and tested scalable, low-complexity larval-release technologies, including seedboxes and passive slow-release methods, to deliver larvae directly onto reef substrates without containment. Seedbox deployments achieved settlement across >1,000 m² at 24-times natural densities, marking a major advance in larval-based restoration. Further gains were made by pre-settling larvae on tiles and devices in pools before reef transfer.

Deployment of Thermally Tolerant Larval Cohorts. Gametes from thermally tolerant corals in the far northern Great Barrier Reef (GBR) were used to culture and deploy larvae onto nearby reef areas, laying the foundation for climate-adaptive restoration to support long-term reef resilience.

Cost-Effectiveness. Modelling based on empirical data indicates that free coral larval releases could deliver highly cost-effective outcomes—as low as $2.07 per one-year-old equivalent coral by 2027, even without further optimisation. In contrast, larval settlement onto devices appears less efficient due to higher investment and operational costs.

Key Outputs. To date, the project has produced seven published scientific papers, five under review (two pre-prints), three in final stages, two book chapters, one standard operating procedure, and supported the completion of two PhDs.

The Moving Corals Sub-Program has produced a highly cost-effective and scalable process for converting the natural phenomenon of coral spawn slicks into a restoration-ready intervention pathway directly on reefs. Through high-volume embryo collection, robust larval culture, and scalable free-release methods, it has delivered a viable model for large-scale coral larval restoration. The consistent detection of enhanced settlement across large reef areas underscores the ecological relevance and scalability of this approach. To advance large-scale, climate-resilient coral restoration, research should focus on thermally tolerant broodstock, scaling larval culture and deployment, enhancing genetic and functional diversity, enabling assisted gene flow, and integrating real-time monitoring and predictive tools to improve ecological outcomes

across the GBR. With these innovations, larval-based restoration is ready to play a central role in global reef recovery strategies.

2 Background and Justification for the Research

Propagule-based restoration is a proven method for large-scale recovery of coastal ecosystems (Vanderklift et al. 2020), especially in plant-dominated habitats like mangroves and seagrasses (Lewis III 2005, Orth et al. 2020). However, this approach has seen limited success with invertebrates, whose complex life histories and dispersal patterns hinder large-scale recruitment through simple propagule release (Strathmann 1985, Marshall and Morgan 2011). As a result, restoration efforts for invertebrates with planktonic larvae such as oysters and corals have remained small in scale–0.015 km^2 for oyster reefs and 0.010 km^2 for coral reefs (Bayraktarov et al. 2016, Boström-Einarsson et al. 2020) due to the use of settlement nets, cages, or artificial substrates required to retain and enhance larval retention and survival in smaller scale trials (Heyward et al. 2002, Rinkevich 2005, Baggett et al. 2015). These challenges highlight the need to develop strategies for corals that can increase the spatial scale and effectiveness of restoration on coral reefs, beginning at collection and continuing during culturing and then transfer to degraded reefs.

Mass larval-based coral restoration has emerged as a scalable alternative to traditional, smaller-scale reef restoration methods (Harrison 2024b). Mass spawning on the Great Barrier Reef typically occurs over a few nights at each reef following the October, November, or December full moons (Harrison et al. 1984, Babcock et al. 1986). During these events, vast quantities of coral embryos and larvae aggregate as buoyant slicks that drift on surface currents, which often concentrate into coral spawn slicks depending on local weather conditions and hydrodynamics of the area (Oliver and Willis 1987, Wolanski et al. 1989). However, many larvae disperse away from suitable settlement areas, leading to extensive loss of potential recruits (Harrison and Wallace 1990, Jones et al. 2009). Harvesting these wild spawn slicks for restoration provides an opportunity to capture naturally produced, genetically diverse larvae and redirect them onto degraded reefs. If conditions are windy slicks may not form, as eggs and sperm are dispersed by waves and strong surface currents. In some years, coral spawning is 'split' across multiple months (Willis et al. 1985), which reduces the volumes of eggs and sperm available after some mass spawning events and reduces the likelihood of dense spawn slicks forming. Similarly, following large disturbance events such as coral bleaching, dense spawn slicks may not form due to a reduction in reproductive adult corals and fecundity (Hughes et al. 2019). Collection of wild coral spawn slicks for culturing has occurred in high convergence or retention zones such as channels, lagoonal and fringing reefs, and harbours (Heyward et al. 2002, Omori et al. 2007, Doropoulos et al. 2019b). Therefore, efficient and reliable harvesting methods require developing collection and modelling tools that utilise different techniques for different environmental conditions.

Once collected, embryos are cultured in tanks on vessels (Doropoulos et al. 2019b) or ocean-based larval pools (Heyward et al. 2002, Omori et al. 2007, Harrison et al. 2021) until larvae reach settlement competency. Experimental larval treatments, such as microbial conditioning, nutrient supplementation, and co-culturing with crustose coralline algae (CCA), have shown potential to enhance larval survival and growth during this stage (Harrington et al. 2004, Damjanovic et al. 2017, Rodd et al. 2022). Maintaining a diverse, thermally tolerant larval pool is especially critical, as wild spawn slicks contain naturally adapted genotypes from surviving colonies in increasingly warm ocean environments (Doropoulos et al. 2019a, Banaszak et al. 2023). While previous work has produced up to approximately six million competent larvae using such approaches on vessels (Doropoulos et al. 2019b), approximately two million larvae in small floating cages (Heyward et al. 2002), and tens of millions of larvae in larger reef culture pools (Harrison 2024b), increasing the scale of coral larval production to hundreds of millions of larvae is essential for restoring degraded coral reefs at larger scales.

Larval deployment strategies vary, from direct release under mesh sheets and tents that restrict dispersal (Heyward et al. 2002, Edwards et al. 2015, dela Cruz and Harrison 2017, dela Cruz and Harrison 2020, Harrison et al. 2021) to free larval releases onto reefs (Doropoulos et al. 2019a), or settlement onto devices that are later transplanted to the reef benthos (Petersen et al. 2005, Chamberland et al. 2017, Randall et al. 2022). Directly releasing coral larvae under tents and nets has shown enhanced settlement of coral larvae in all cases (Heyward et al. 2002, Edwards et al. 2015, dela Cruz and Harrison 2017, dela Cruz and Harrison 2020, Harrison et al. 2021), with restoration of local breeding corals within 2-3 years and enhanced

ecosystem benefits in some of those studies (dela Cruz and Harrison 2017, Harrison et al. 2021). For coral deployed on devices, high rates of settlement and post-settlement survival can lead to high near-term yield (Chamberland et al. 2017, Randall et al. 2022), yet tracking devices until recruits become large enough and reproduce is rarely conducted (but see Baria et al. 2012, Guest et al. 2023). Due to the challenges working with tents and nets underwater, the spatial scale of the initial deployments of larvae using these methods has thus far been limited to <100 m^2, and for devices spatial scales have not been reported and are likely much smaller. To scale up these efforts, unrestrained larval releases using real-time biophysical models could guide the placement and timing of releases to increase local retention and settlement success (Doropoulos et al. 2019a), yet remain untested.

Transport of larvae sourced from heat-tolerant corals or reefs regularly exposed to warmer conditions offers a promising means to enhance recovery on degraded reefs with reduced adaptive capacity, especially in response to climate-related bleaching events (van Oppen et al. 2017, Quigley and van Oppen 2022). Isolating individual colonies for selective breeding is one successful approach that can be conducted (Humanes et al. 2024). Collecting spawn from reefs that have naturally resilient populations or have recovered from recent bleaching events offers another, more scalable approach working with wild coral assemblages.

The Moving Corals Sub-program of the Reef Restoration and Adaptation Program (RRAP) is a reef-based research and development (R&D) initiative designed to enhance, scale, and mechanise larval-based coral restoration by refining spawn collection, mass larval culture, and deployment strategies of larvae (Figure 1). Specifically, this project developed:

1. Collection and transfer techniques that efficiently capture wild coral-spawn slicks in common reef- and weather-dependent scenarios. This work focuses on harvesting naturally drifting coral spawn slicks using passive and active collection systems adapted for various reef conditions. It also evaluates methods for transferring slicks into rearing environments to maximise larval yield and viability.

2. Treatments of larvae during mass culturing for enhanced survival and production, and tracking. The project optimised reef-based larval culture systems using a range of pool designs and water quality control. Experimental treatments, including staining, will be developed and scaled up, and validated through field trials.

3. Deployment and monitoring techniques that provide scalable targeted transfer of larvae onto reefs through direct application or via settlement on devices. Larval deployment methods—both direct and device-based—will be tested for precision, scalability, and post-transfer larval integrity. Monitoring tools and dispersal models will assess settlement success under varying environmental conditions.

4. Transfer and delivery methods of naturally more thermally-tolerant larvae to combat inhibited reef recovery from climate-related stress events. Larvae sourced from coral populations with potentially higher thermal stress tolerance will be compared to larvae sourced from ‘normal’ populations. This will test their survival and inform strategies for long-term, climate-resilient reef restoration.

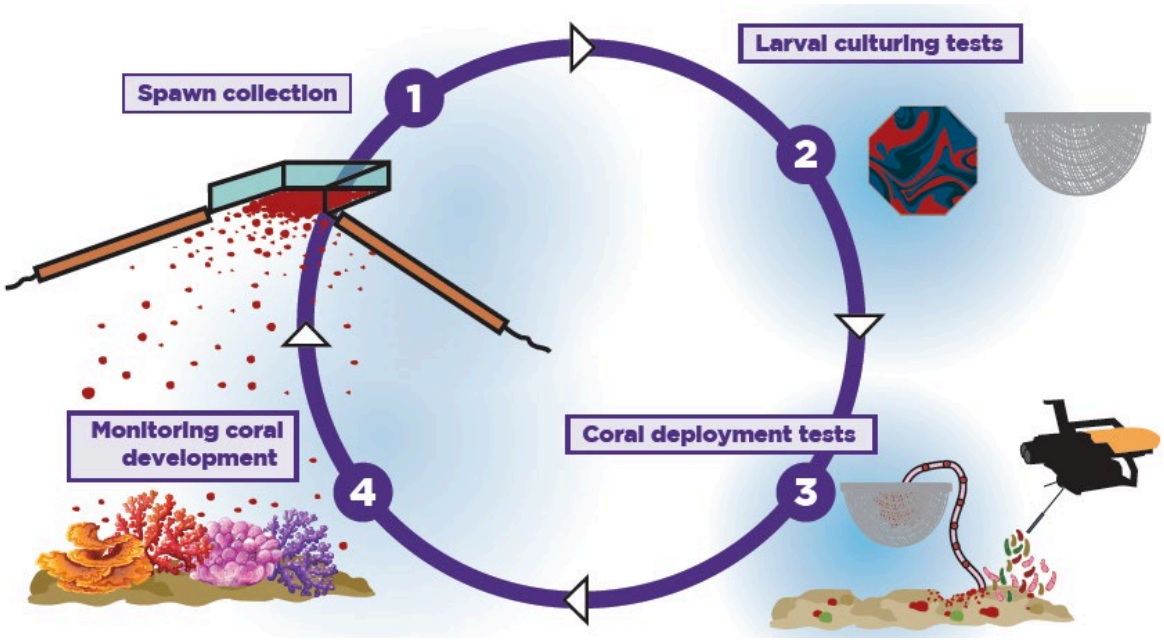


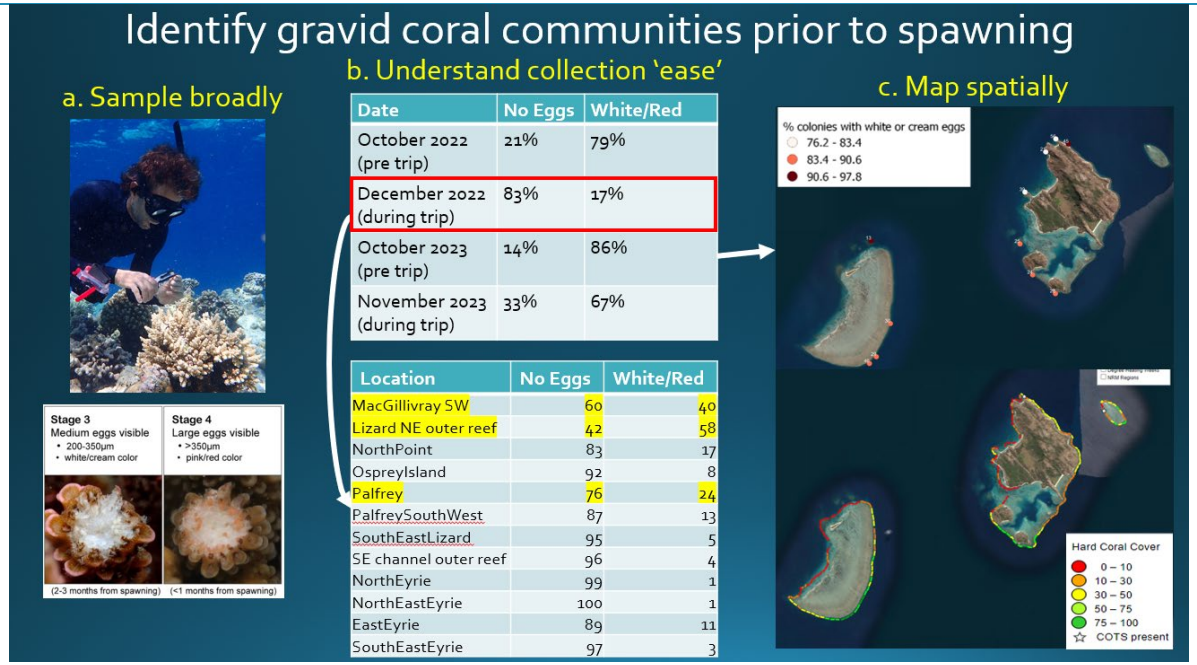
Figure 1: Major processes being assessed by the RRAP Moving Corals Sub-program to scale the use of wild coral spawn slicks for scaling reef restoration.

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. Developing and scaling collection and transfer techniques of coral spawn-slicks		
1 (a)	Develop, test, and adapt coral spawn and slick collection equipment and transfer methods on different reef habitats and under different environmental conditions to maximise efficiency and operational handling for mass larval production.	We developed multiple approaches for harvesting wild coral spawn slicks to routinely collect 10s-100s millions of gametes for upscaling the production of diverse coral larvae assemblages to deployment onto reefs. During our project, we collected >18 million fertilised eggs in our first trial during the pilot year (2020); >50 million in our second year (2021); >30 million in our third year (2022), despite our trip being conducted on the second 'minor' lunar cycle of a split spawning event; >405 million in our fourth year (2023); and >115 million in our final year (2024), despite being conducted follow major mass bleaching and mortality at our study location. To routinely collect 10-100s millions of gametes for culturing in a variety of environmental settings, reef states (healthy versus post-bleaching), and timings of mass spawning events (major versus split), we have developed operational workflows and multiple collection techniques. Once on site, we sample the existing coral communities broadly to understand where coral densities are high and where high proportions of corals are gravid. This informs the production potential of given areas (Figure 2). We utilise high resolution particle tracking, coupled with oceanographic instrumentation, to target convergence zones downstream from zones of high production potential (Figure 3). We position and deploy passive spawn catchers for efficient collections in those zones, and our team members work in small groups on collection vessels to actively target different areas for spawn collection each night.



Date	No Eggs	White/Red
October 2022 (pre trip)	21%	79%
December 2022 (during trip)	83%	17%
October 2023 (pre trip)	14%	86%
November 2023 (during trip)	33%	67%

Location	No Eggs	White/Red
MacGillivray SW	60	40
Lizard NE outer reef	42	58
NorthPoint	83	17
OspreyIsland	92	8
Palfrey	76	24
PalfreySouthWest	87	13
SouthEastLizard	95	5
SE channel outer reef	96	4
NorthEyrie	99	1
NorthEastEyrie	100	1
EastEyrie	89	11
SouthEastEyrie	97	3

Figure 2: Example workflow for identifying gravid coral communities for prioritising collection areas prior to spawning.

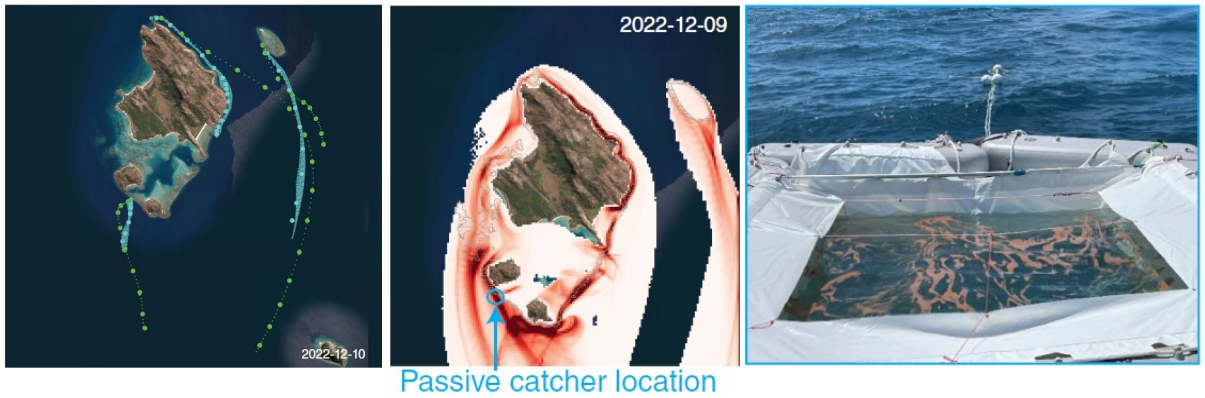


Figure 3: Example modelling and comparisons with instruments for predicting high convergence zones of wild coral spawn slicks for placing passive spawn catcher (Harrison 2024a) collecting devices (Gouezo et al. 2025b).

Multiple collecting techniques are utilised depending on the reef environment whether formation of dense slicks occurs, and development of automated and upscaled approaches for different scaling approaches. The use of hand scoops that

Objective	Key Findings and/or Outcomes
	are a modified pool scoop and net system has been the most successful collecting technique due to its simplicity, ease of use, and ability for multiple teams of people to be operating with them (Figure 4). Typically, three people utilise a small tender – one driving, with two scooping the coral spawn slicks. On board the tender is a large fertilisation tub (250 litres (L)) and the coral spawn samples are then transferred into the tub. Once full, the concentrated gametes are transferred to culture pools or vessel tanks.  *Figure 4: Simple low-cost coral spawn scoop net systems deployed to collect egg-sperm bundles and early embryos during mass coral spawning nights with different slick densities (Harrison 2024a).* Remotely operated automated surface vessels (ASVs) are an effective method for efficiently collecting coral spawn from the sea surface in very shallow environments or other areas where small vessels with people cannot access (Figure 5). ASVs can efficiently cover large areas, pre-programmed or operated manually by a user interface. For example, eight runs of approximately 100 metres in length can collect enough coral spawn to fill two 65 L nally bins and two 20 L buckets of larvae. Total collection time of transects and transfer from the ASVs to the boat is approximately 50 minutes with two people. This time included repositioning the boat three times due to being blown off station by wind.

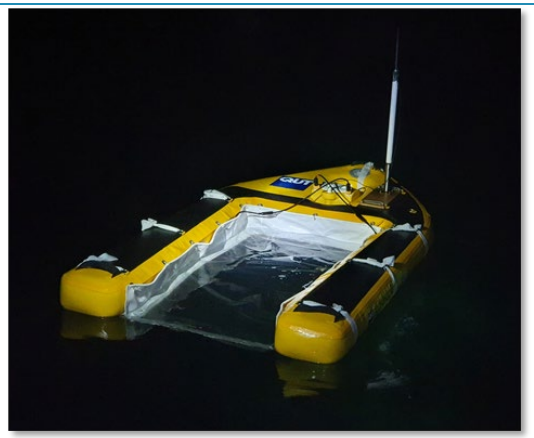


Figure 5: An ASV fitted with the spawn catching net during operation (Mou et al. 2022).

Pumping coral spawn slicks directly from the water surface to large containers for culturing, or for transfer to other culture pools or tanks, was developed in our sub-program (Figure 6). We built a system on a small barge that utilised a customised intake concentrating mouth, with two intakes that fed through two diaphragm pumps to two 1,500 L rainwater tanks. The system worked extremely well, with one skipper, one coordinator, and one assistant on board, collecting >35 million embryos in a single run.

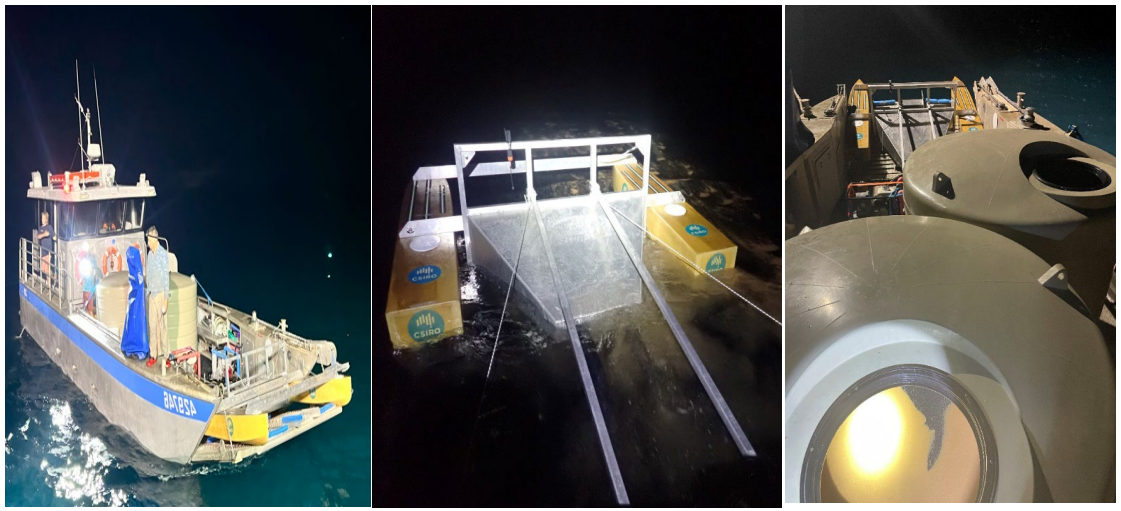


Figure 6: Collections of wild coral spawn slicks directly from the water surface to two 1,500 L tanks onboard a barge using diaphragm pumps and a floating intake mouth. Far right image shows direct transfer into a larval pool for culturing.

Objective		Key Findings and/or Outcomes
		Mechanistic work shows that pumping has minimal effects on embryo fragmentation if conducted within the first hour following spawning prior to first cleavage, but high fragmentation at 5five to eleven hours following fertilisation (Langley et al. *Under Review-b*). There are no effects on larval settlement from pumping when it occurs at three to six days following spawning (Waters et al. *Under Review*).
2. Mass larval culture and experimentally treating larvae from wild coral-spawn for enhanced survival and growth		
2 (a)	Develop, test and adapt mass larval culture in reef pools and apply experimental treatments during larger-scale larval culturing to enhance production, survival and growth.	We conducted larval culturing in larval pools primarily and also using an on-board vessel-based aquaculture system. We are now routinely producing up to >15 million competent larvae per coral larval pool (Harrison 2024a) with an average survival rate of 54% from initial stocking to competent larvae, increasing the initial stocking densities (Langley et al. 2024), as well as testing shading and ultraviolet (UV) effects (Langley et al. *Under Review-a*) during the project. Across our project, we cultured >5 million competent larvae with a 30% survival rate from initial stocking in our first trial during the pilot year (2020); >16 million competent larvae across five-culture pools with a 32% survival rate in our second year (2021); >22 million across three-culture pools and one-spawn catcher with a 60% survival rate in our third year (2022); >78 million across nine-culture pools with a 68% survival rate in our fourth year (2023); and >59 million across six-culture pools with a 65% survival rate in our final year (2024). We experimentally trialled different stocking densities in a lab-based experiment to determine if we could stock culture pools at higher concentrations than previously thought. Findings show that densities of around five embryos per millilitre (mL), which is around 40-50% coral spawn slick coverage on a pool, is an optimal amount for producing competent coral larvae (Figure 7).

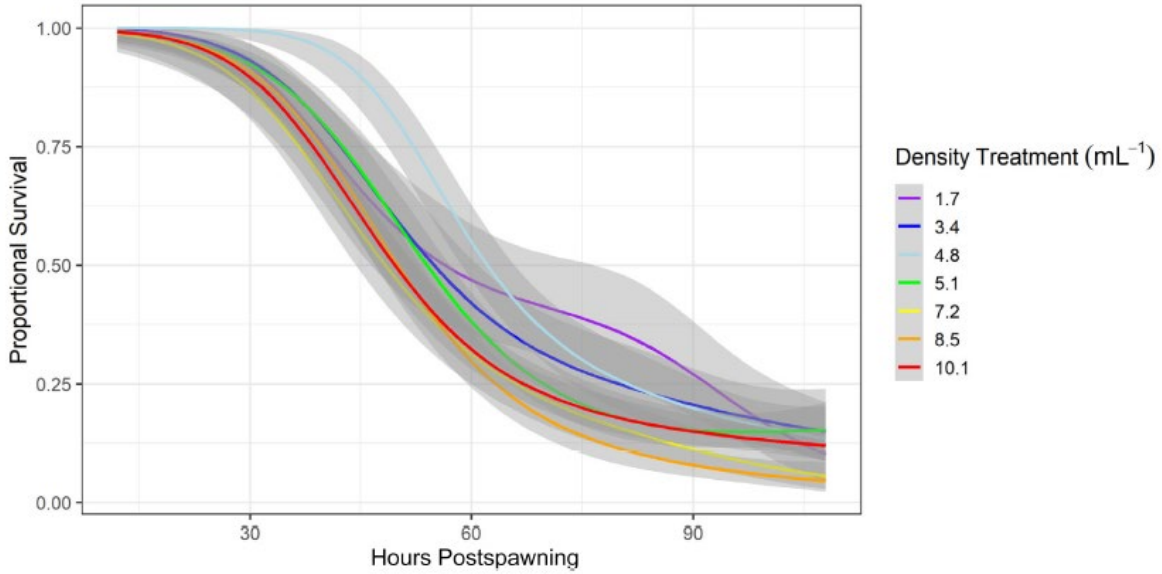
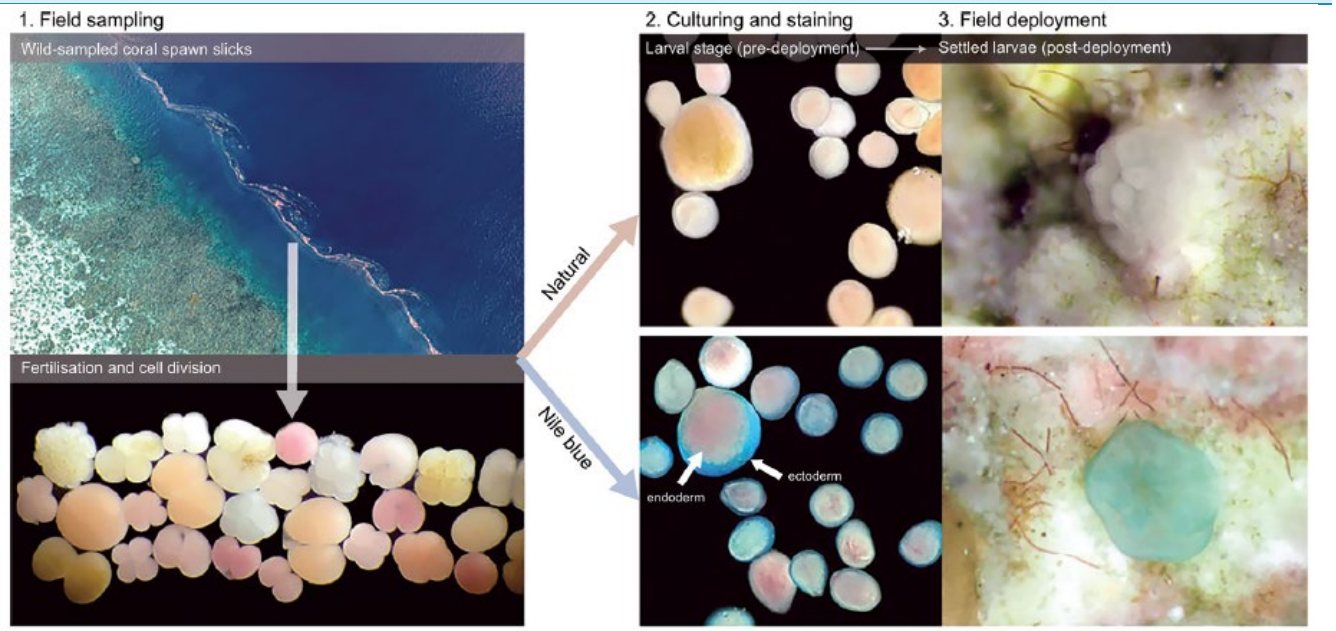


Figure 7: Proportional survival in laboratory trials from the embryo to the larval phase for each density treatment from 12 hours post-spawning until larvae were competent (Langley et al. 2024).

We developed a rapid, cheap, and easy coral larval staining technique in the laboratory and then field validated it for tracking the dispersal and settlement of larvae that we release in our field trials (Figure 8). The technique is fully described in an open access publication for researchers and practitioners to utilise. We utilised the technique at scale in 2022 and 2023 during the free release delivery of larvae to directly detect stained larvae on settlement tiles across the ha areas of reef (described in the next section).

Objective		Key Findings and/or Outcomes
		 *Figure 8: Field validation of larval staining: capture of wild-sampled coral spawn slicks showing high diversity of developing coral embryos, staining using Nile blue (1,000 mg l−1 concentration for 60 minutes), and field deployment of competent stained and natural (unstained) larvae for detection on the reef (Doropoulos and Roff 2022).*
3. Developing and scaling deployment, settlement and monitoring of cultured wild larvae for reef restoration		
3 (a)	Design, test and refine equipment and methods for increasing scales of bulk transfer of larvae to the reef using direct and indirect approaches onto target areas.	**Site Selection and Larval Dispersal Modelling** Fine-scale (~30 m resolution) hydrodynamic modelling effectively predicted larval dispersal pathways in both surface slicks and benthic environments. At the surface, models accurately identified slick convergence zones—prime locations for larval aggregation and collection. At the seafloor, modelled current velocities matched observed conditions at 58% of test sites, with 15 out of 25 sites exhibiting periods of low flow (lasting 5–15 hours) likely to support successful larval retention and localised mass settlement. These insights support the use of predictive modelling for spatial and temporal targeting of larval releases.

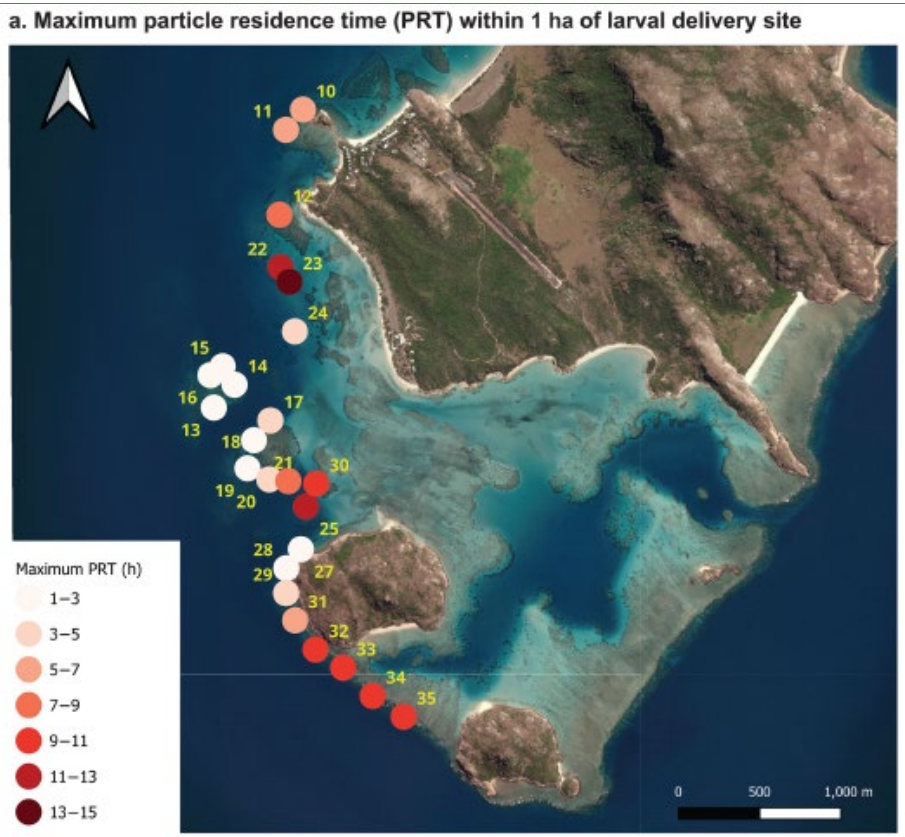
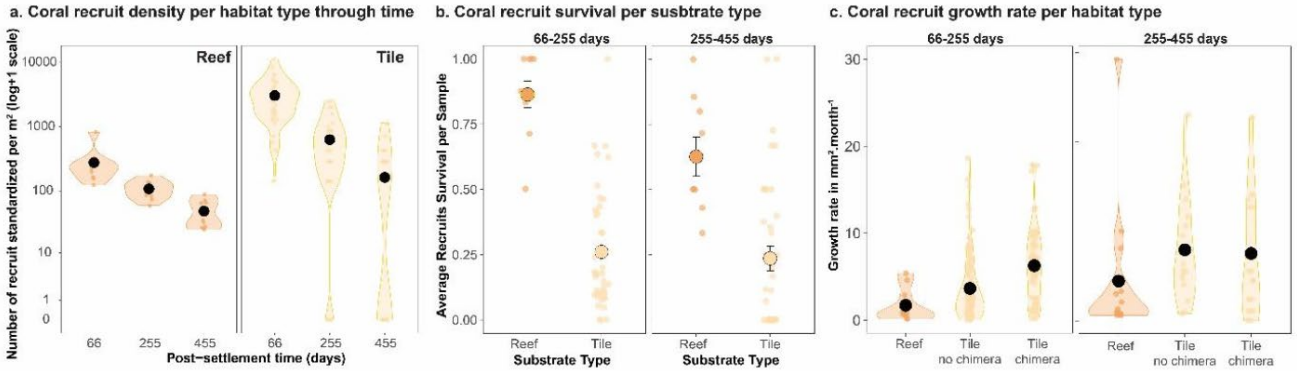


Figure 9 Modelled maximum particle residency time (hours) within one hectare (ha) of the 20 delivery sites to help optimise larval release delivery locations.

Larval Retention and Settlement Dynamics

Short periods of larval retention (as little as two to three hours) significantly enhanced settlement success, increasing rates up to 40-fold compared to ambient reef conditions. Retention via larval tents (2.5–24 hours) yielded four to seven times more settlers than free-release methods, and up to 300 times more than untreated controls. However, initial gains in settlement did not always persist; by three months, differences in recruit densities had diminished due to high post-settlement mortality. Moreover, when the reef provides optimal microhabitats for settlement and survival, the ratio of surviving recruits per competent larvae is much higher than on settlement tiles (Figure 10). This highlights how vital rates derived from settlement tiles may be inaccurate and skew the assessment of coral colonisation dynamics. Overall, these

Objective	Key Findings and/or Outcomes
	results suggest strong density dependence and highlight the need to optimise not just larvae density at delivery, but also post-settlement survival conditions.  *Figure 10: Acroporidae coral density (a) survival (b) and growth rate (c) between the reef and tile substrate (Gouezo et al. 2025a).* **Free-Release Trials from vessel tanks and reef pools** Large-scale larval releases using both tank-reared and semi-natural pool-reared larvae were trialled (Figure 11). Pool-reared larvae showed higher competency and overall abundance, though both sources experienced mortality. While free-release approaches resulted in low absolute settlement, recruit densities were still elevated compared to background controls. Over time, survival patterns again revealed convergence across treatments. The reef trials helped refine protocols for larval release timing, placement, and post-release monitoring.

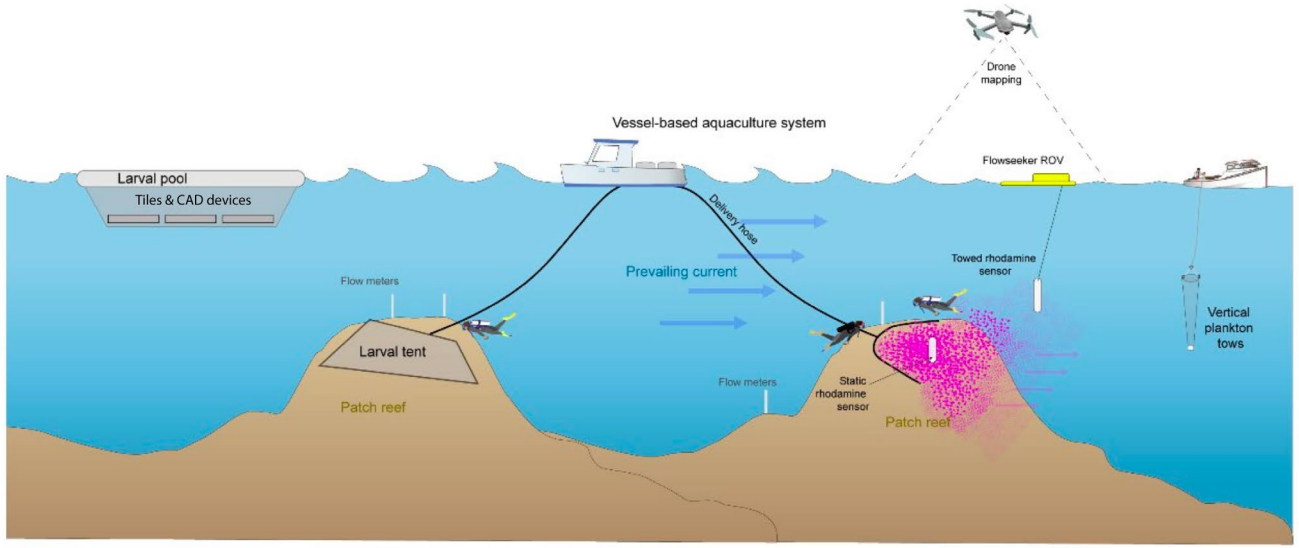


Figure 11: Schematic representation of release trials from culture pools and vessel tanks.

Slow-Release Pipe System Trials

Two scalable slow-release systems—"hose" and "octopus pipe system" (Harrison 2024b)—were tested, delivering over 24 million larvae to reef areas. Both systems were successful in producing measurable settlement above background levels. Settlement efficiency per million larvae was comparable between the systems (7.2–10 settlers per million), indicating both larval delivery methods are viable depending on the logistical and environmental context. Their modularity allows for deployment aligned with peak larval competency and favourable hydrodynamic conditions in sheltered reef habitats.

Larval Seedboxes

Seedboxes functioned as passive, modular larval delivery units that retained larvae locally and enhanced settlement across a ~10 m radius (Figure 12). In field trials, seedboxes led to enhanced larval settlement on 84% of tiles that exceeding background rates by an order of magnitude of 24-times on average. Some tiles had over 1,000 settlers per tile. Each unit was deployable in under five minutes, and the method scaled efficiently—one operation seeded ~14 million larvae over 3,000 m². Seedboxes offer a compelling balance of simplicity, scalability, and performance. They can be deployed in a variety of habitats, including semi-exposed to exposed reef habitats.

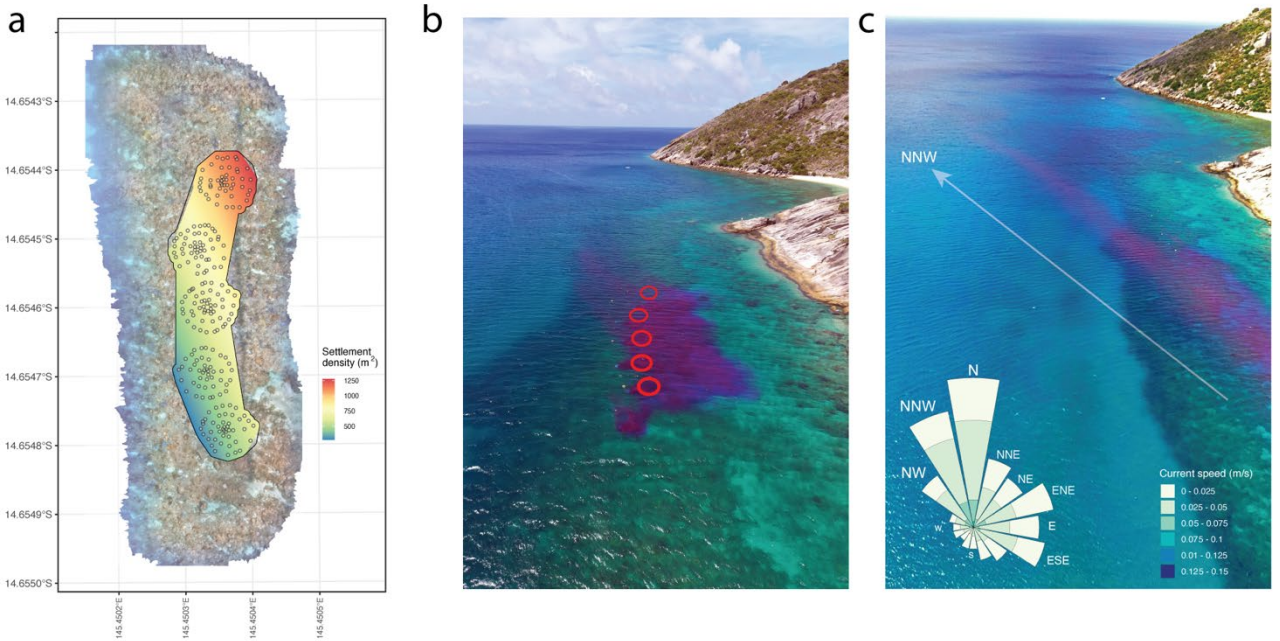
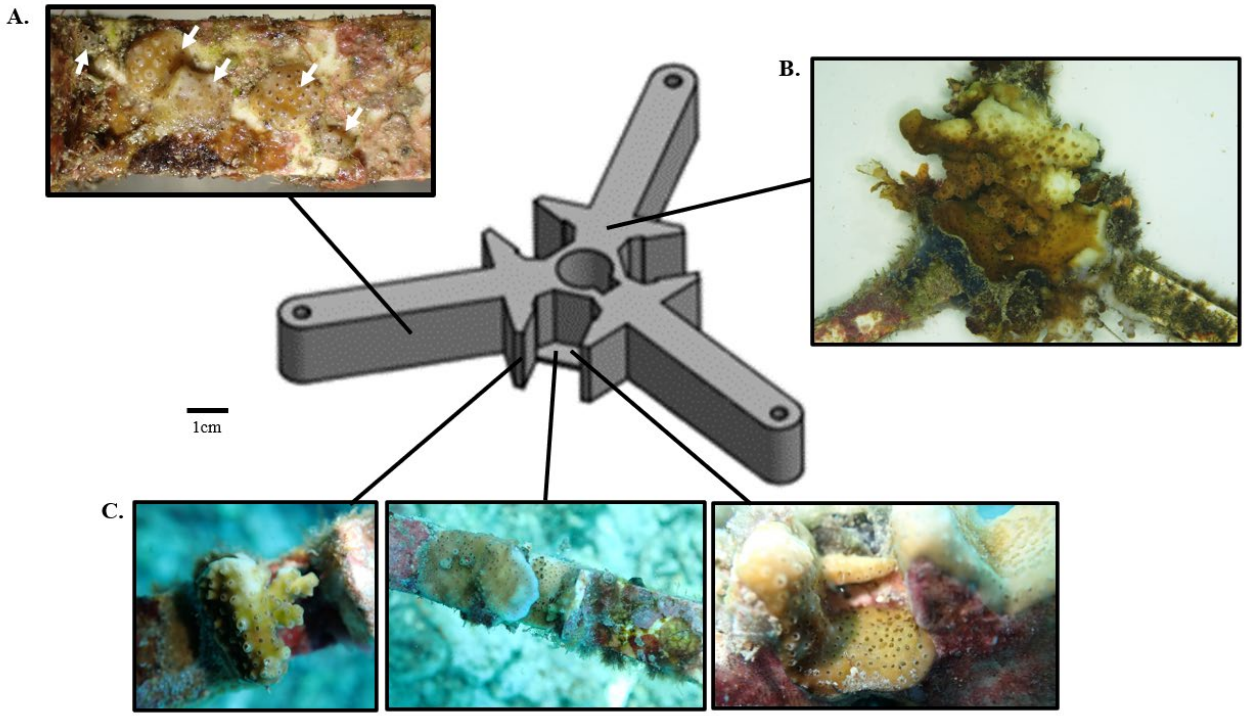


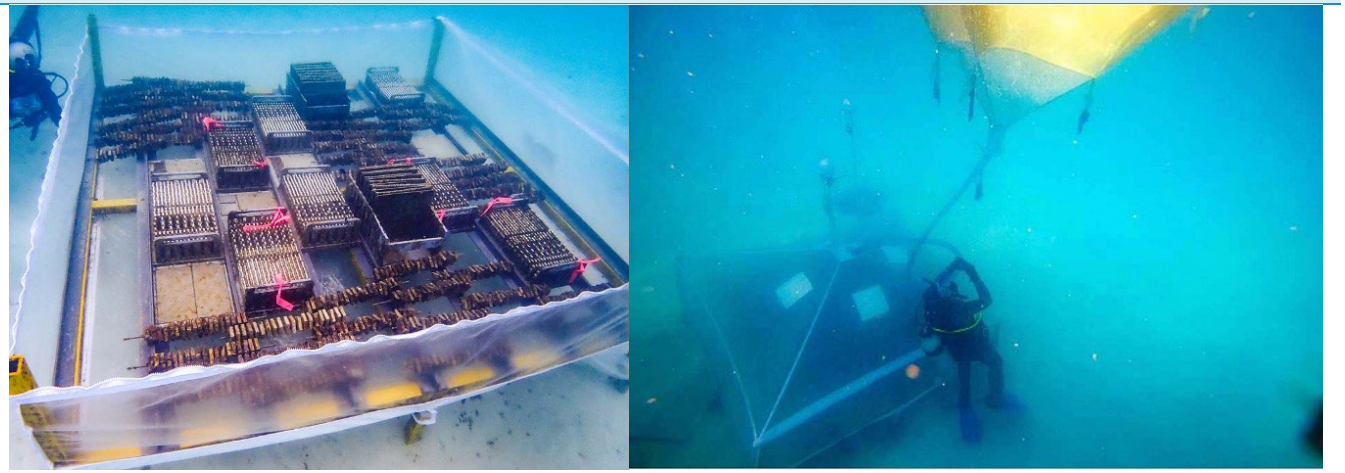
Figure 12: Performance outcomes of larval seedbox releases showing highly effective larval seeding of 3,000 m^2 of coral reef (Doropoulos et al. 2025).

Settlement on Tiles and Coral Attachment Devices (CAD) settlement devices

Settlement substrates—5 x 5 cm natural limestone settlement tiles (Harrison 2024b), and ceramic Coral Attachment Devices (CADs) developed by the Australian Institute of Marine Science (AIMS)—played a key role in quantifying and enhancing larval settlement. Standard 5 x 5 cm limestone tiles were used as reference metrics and revealed clear spatial gradients in settlement relative to larval sources, supporting their continued use for quantifying deployment effectiveness. Tiles were also used for increasing larval settlement within reef-based settlement pools (Harrison 2024b) prior to deployment. CADs were also used in settlement pools and supported dense larval settlement, often with hundreds of settlers per device, and allowed for direct out-planting of structured habitat units and testing fixed versus unattached CAD deployments. These findings reinforce the importance of optimised microhabitat structure and material properties in promoting larval attachment and early survival.

Testing different immersion times and substratum types for larval settlement revealed important findings for scalable restoration (Waters et al. 2025). A 24-hour immersion of limestone tiles and ceramic CADs in larval pools was sufficient to achieve high settlement from diverse larval assemblages. However, after 21 months, survival and yield were low

Objective	Key Findings and/or Outcomes
	across three sites, largely due to smothering by sand, unstable rubble, and low structural complexity. Interestingly, unattached devices had higher survival than attached ones, supporting the potential for free-release deployment. These results highlight the need to assess local reef conditions before placing seeded substrates to enhance juvenile coral success.  *Figure 13: Photos showing juvenile coral survivors on CAD devices at 21 months post-deployment on a) side, b) upper and c) groove habitats (Waters et al. 2025).* A total of 300 limestone tiles and 1,000 CADs were also used in a larger-scale larval settlement trial on a settlement table enclosed in a fine mesh net that was deployed on sand in Lizard Island lagoon. One million competent larvae cultured from wild spawn slick collections were released from the base of the larval culture pool net system via a pipe into the mesh enclosure resulting in very high larval settlement rates on tiles and CADs (Figure 14).

Objective	Key Findings and/or Outcomes
	 *Figure 14: Photos showing the arrangement of large numbers of tiles and CADs on the settlement table (left) and a million larvae being released from a larval pool via a pipe into the mesh enclosure to increase larval settlement rates.* **Monitoring and Detection via Macrophotogrammetry** During the project, we developed and applied an innovative macrophotogrammetry technique (Gouezo et al. 2023). The approach proved highly effective for early detection of very small and cryptic coral recruits, capturing 10–20 times more individuals than diver-based surveys, particularly in the <15 mm size range (Figure 15). The method enables high-resolution mapping of settlers in three dimensions (3D) and supports long-term monitoring of individual colony growth and survival. Its integration into monitoring protocols enhances the accuracy and interpretability of restoration outcomes, especially in the critical months following larval release.

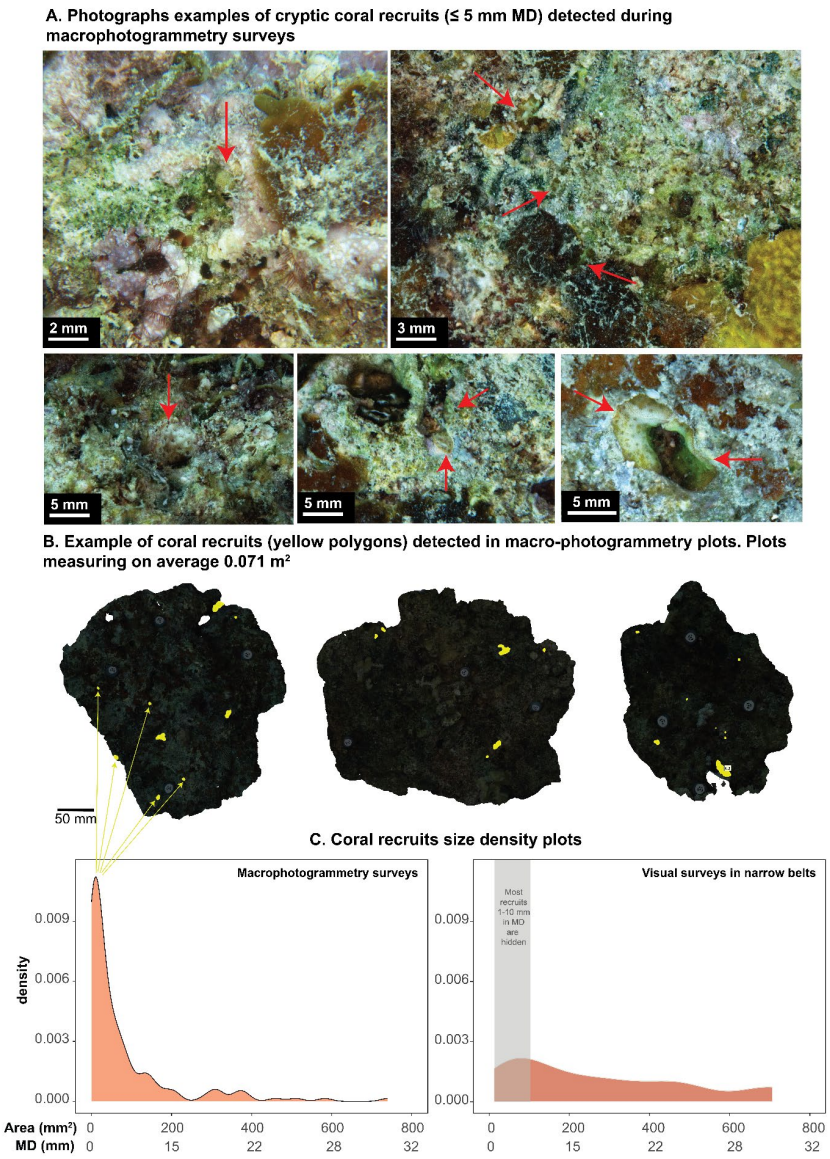
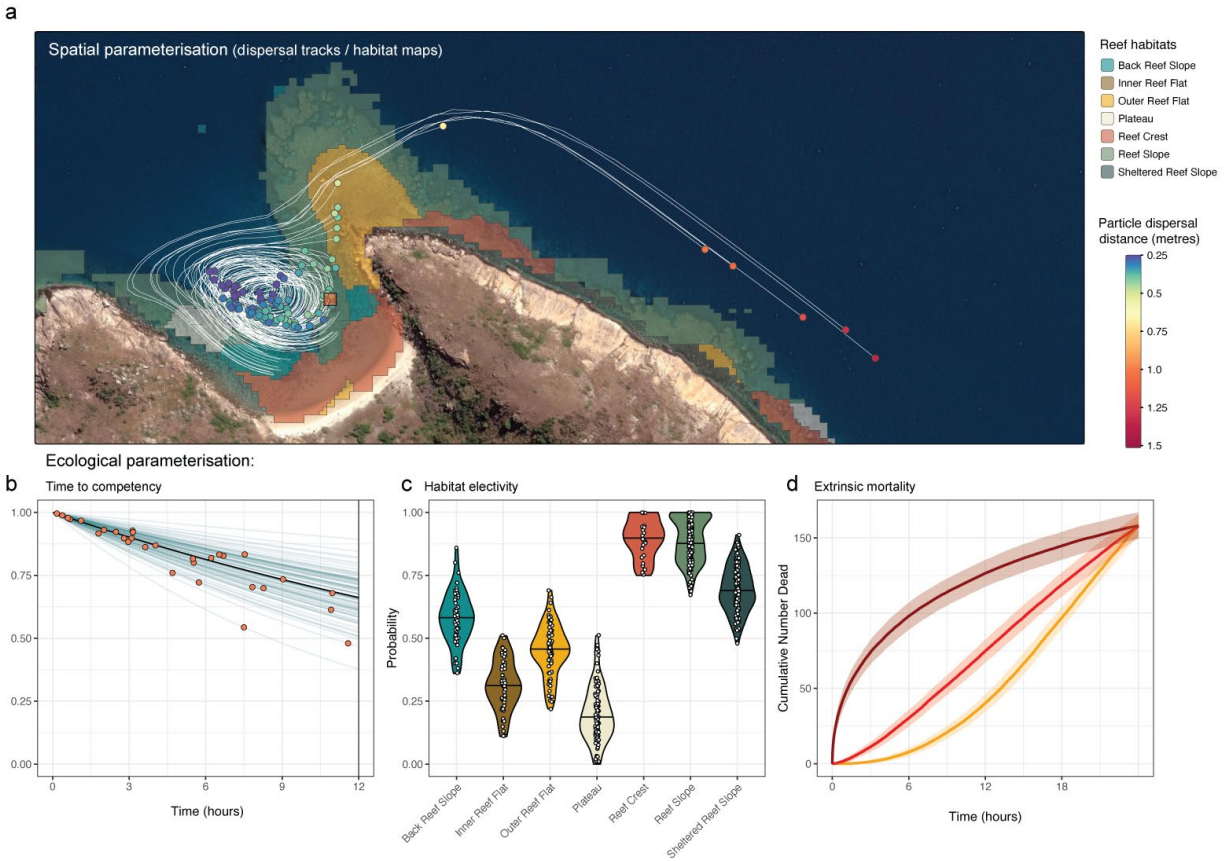


Figure 15: Comparisons between traditional and with macrophotogrammetry techniques in detecting coral recruits on the reef (Gouezo et al. In Prep).

Objective	Key Findings and/or Outcomes
	Development of *CoralSeed*: A Spatially Explicit Larval Seeding Model The *CoralSeed* model integrates empirical larval data, mortality rates, and hydrodynamic flows to simulate dispersal and settlement across reef environments (Figure 16). By producing spatially explicit predictions of larval delivery footprints and expected settler densities, it serves as a decision-support tool for operational planning. The model enables users to virtually test alternative deployment scenarios before committing field resources, helping align seeding strategies with biological and environmental realities.  *Figure 16: Spatially explicit map of simulated larval dispersal and settlement at Mermaid Bay, Lizard Island (November 2022) and ecological parameterisation of the CoralSeed model (Roff et al. In Prep).*

Objective		Key Findings and/or Outcomes
		Modelling indicates extremely efficient cost per coral from the RRAP Moving Corals Sub-program data Cost per coral modelling shows that the RRAP Moving Corals Sub-program reef-based slick collection, culturing, and deployment approach is extremely cost efficient. Over the past two to three years, we have been improving the efficiencies of our operations across all the stages of larval based coral restoration, and the outcomes of the modelling show that this has made an enormous impact. Utilising our team's data from our 2022 and 2023 coral spawning and larval restoration campaigns at Lizard Island, and the costs of labour and operating with a large vessel during our 2023 campaign, the modelling indicates that the cost per surviving one-year old coral grown from free larval releases could be as low as $2.07/1YOEC in 2027, and that's without improving on current approaches and using lower cost vessels. Moreover, not only is the production cost extremely efficient, but the scales of production are huge, where we routinely produce >50 million competent larvae with small teams of experienced personnel (e.g. eight personnel and six pools in 2024).
4. Larger scale translocation and settlement of thermally tolerant coral larvae to restore damaged reefs		
4 (a)	Develop and assess the efficacy of vessel translocation and settlement methods for transfer of larvae from more thermally-tolerant corals from warmer, more northern parts of the GBR to cooler, more southern target reefs of the GBR.	**Translocation Capacity – Key Outcomes from Vessel-Based Larval Culture System** A mobile, vessel-based larval culture system was successfully developed and tested that will enable long-distance translocation of coral larvae across the Great Barrier Reef (Figure 17). The system consisted of four 10,000 L tanks designed for operational efficiency and vessel stability. Key design features—such as wide, low-profile tanks and adjustable flow systems—supported high-density larval culture and stable marine operations. *Key Findings and Outcomes* • **Operational Readiness**: The system maintained continuous, high-volume (>4,000 L/hr per tank) flow-through seawater filtration, ensuring optimal water quality for larval development during transit. • **Scalable Design**: Tank dimensions (3 m diameter × 1.6 m height) maximised surface area for buoyant gamete capture and offered ergonomic access for in-tank maintenance. • **Custom Flow Control**: Each tank featured adjustable flow via manifolds and down pipes, promoting consistent water circulation and larval health. • **Larval Delivery**: The integrated outflow system enabled direct transfer of larvae from tanks to reef sites using 3-inch hoses, supporting efficient, on-site seeding of patch reefs. This system represents a major step forward in enabling larger-scale vessel based, flexible coral larval restoration efforts for transfer of larvae across remote reef locations.

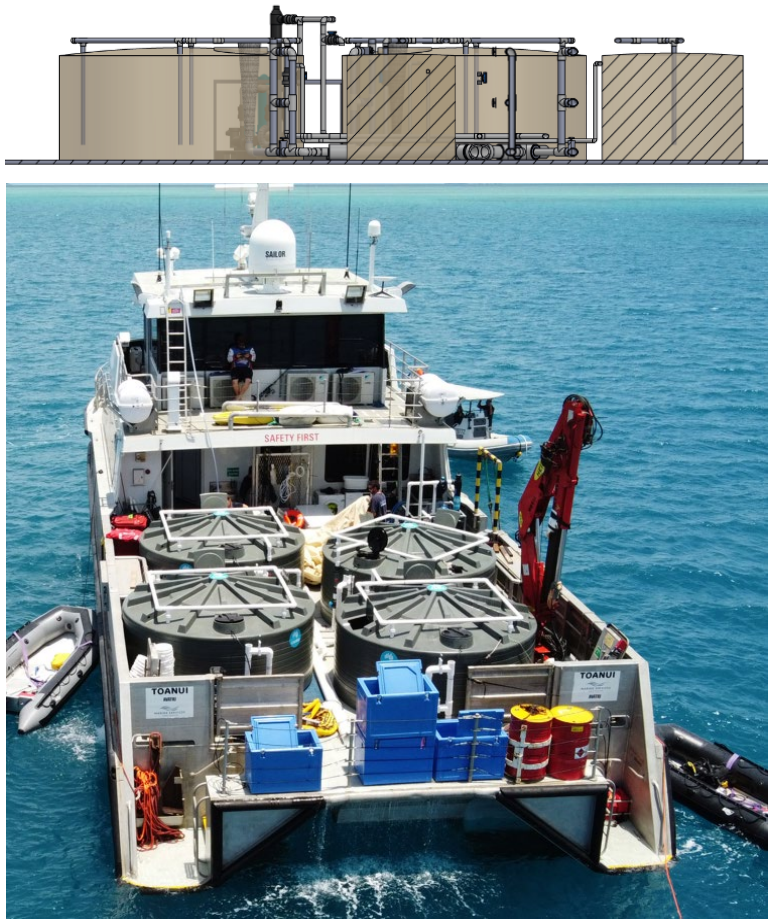


Figure 17: Computer-aided design drawing and image of the flow-through vessel-based aquaculture system. Each tank holds 10,000 L of seawater.

Assessing Reproductive Capacity and Larval Performance of Bleaching Survivors

In early 2024, severe thermal stress caused over 75% coral mortality at North Point, Lizard Island—a site previously dominated by high-cover *Acropora* species. This experiment aimed to understand the reproductive resilience and larval performance of coral colonies that survived and recovered from this acute thermal event, compared to conspecifics from unimpacted reefs nearby (i.e. Ribbon Reefs). The goal was to assess whether broodstock from heat-impacted reefs can retain or enhance reproductive and settlement success, potentially supporting thermal adaptation.

Objective		Key Findings and/or Outcomes
		Key Objectives 1. Identify and compare gravid survivor and unimpacted coral colonies of *Acropora hyacinthus and A. spathulata*. 2. Evaluate reproductive output and fertilisation success. 3. Assess larval development and competency during culture. 4. Measure larval settlement success under controlled reef conditions. 5. Monitor post-settlement survival and potential thermal resistance over time. *Key Findings and Outcomes* • **Reproductive Output**: Both survivor and unimpacted colonies were gravid and spawned synchronously, even though they were sourced from different locations. Highly successful gamete collection (>7 million) and fertilisation rates (>80%) were achieved from both groups. • **Larval Development**: Larvae from both survivor and unimpacted colonies developed at similar rates, with comparable numbers of competent larvae after five days of culture (>4 million, 55% survival), indicating no apparent developmental disadvantage from prior bleaching. • **Settlement Success**: Settlement was significantly higher in larvae from bleaching survivors—157 settlers per tile, compared to 71 settlers per tile from unimpacted colonies. It is unknown why settlement was two-times higher in the bleaching survivor progeny, but it may be related to the settlement substrates being preconditioned in the same environment from where the adults were collected. • **Post-Settlement Survival**: At 107 days post-settlement, survival rates were similar across both treatments, indicating no short-term fitness trade-offs in larvae from bleaching survivors. This experiment provides early evidence that thermally stressed but surviving coral colonies can retain strong reproductive and settlement potential, offering a promising avenue for adaptive restoration strategies that harness naturally resilient broodstock.

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

To support the continued development of larger-scale, climate-resilient coral restoration, future research should focus on refining larval-based interventions to enhance resilience, cost-efficiency, and ecological outcomes. Building on the achievements of the RRAP Moving Corals Sub-program, five key areas are recommended:

1. Strategic Use of Thermally Tolerant Broodstock

Expanding the use of thermally tolerant corals is essential to enhance restoration success under warming conditions. Future research should utilise satellite-derived sea surface temperature data and long-term in-situ datasets to identify areas with high temperature variability and recent bleaching across the GBR. These areas can serve as broodstock sources, with larvae reared and compared to wild slick-derived controls to assess differences in culture performance, settlement success, and early survival. This work will help quantify the potential of locally adapted broodstock to confer increased heat tolerance—targeting gains of up to five Degree Heating Weeks (DHW) initially, and potentially up to 10 DHW with assisted gene flow approaches.

2. Scaling Up Larval Culture and Deployment

To meet restoration targets at the hectare and reef-cluster scales, larval production and delivery methods need to be further optimised. Improving reef-based and vessel-based culture systems to reliably produce hundreds of millions of competent larvae per spawning event is required. Investigations into larval density thresholds, competency timing, and water quality optimisation will support this goal. For deployment, novel engineering solutions should be further tested to increase local settlement rates. These methods, coupled with high-resolution larval dispersal models and real-time hydrodynamic data, will improve spatial targeting and settlement efficiency, contributing to the objective of greater than five one-year-old corals per square meter across hectare scales at a cost of less than $2 per colony.

3. Enhancing Diversity and Functional Outcomes

To build long-term ecological resilience, maintaining high levels of genetic and taxonomic diversity is essential. Advanced barcoding and genomic tools should be employed to characterise larval slick composition, track diversity through the culture process, and assess post-settlement assemblages. This will provide valuable insights into potential winnowing of species during intervention processes and support the identification of rare but functionally important coral taxa. These data will help inform broodstock selection and ensure restoration outcomes align with broader ecosystem recovery goals.

4. Assisted Gene Flow and Cross-Regional Translocations

Assisted gene flow and population-scale translocations offer promising strategies to increase genetic diversity and thermal tolerance across reef systems. Future research should prioritise cross-breeding trials, reciprocal larval transplants, and post-settlement assessments to evaluate compatibility, survival, and adaptive potential across diverse reef environments. These approaches will generate critical knowledge to inform GBR-wide deployment strategies under projected climate scenarios and support the development of climate-adaptive coral populations.

5. Integration with Monitoring and Predictive Tools

Research should advance the development of monitoring systems and predictive models to support adaptive management. Technologies such as autonomous tile-imaging systems, real-time local-scale flow sensors, and reef-deployed instrumentation will improve detection of larval settlement and track dispersal success. These tools, in combination with updated predictive models such as *CoralSeed*, will provide a feedback mechanism for refining deployment strategies and improving the precision of large-scale restoration activities.

Together, these research priorities will underpin the next phase of coral restoration innovation, delivering scalable, cost-effective, and climate-resilient outcomes for the GBR.

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