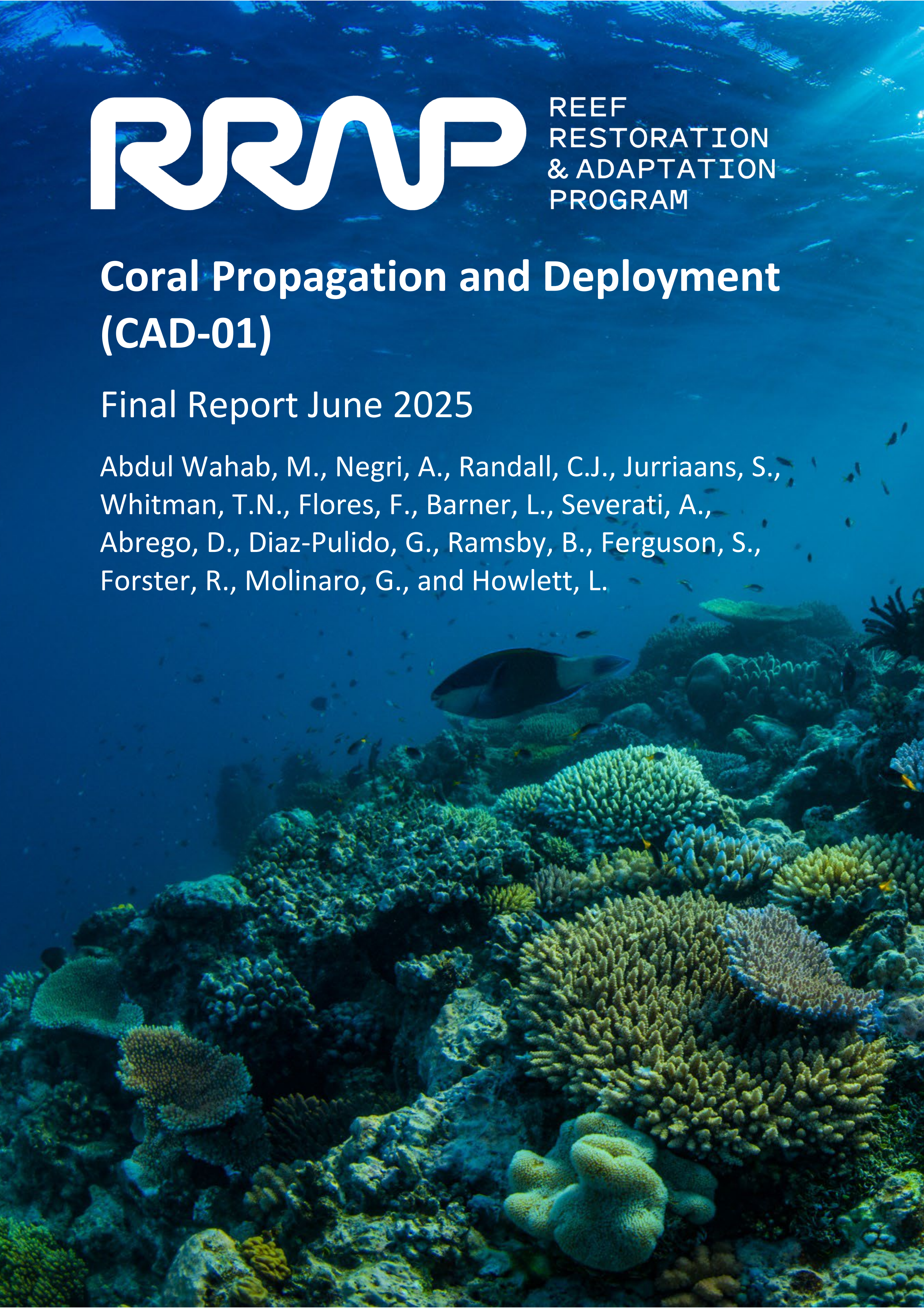

REEF
RESTORATION
& ADAPTATION
PROGRAM

Coral Propagation and Deployment (CAD-01)

Final Report June 2025

Abdul Wahab, M., Negri, A., Randall, C.J., Jurriaans, S., Whitman, T.N., Flores, F., Barner, L., Severati, A., Abrego, D., Diaz-Pulido, G., Ramsby, B., Ferguson, S., Forster, R., Molinaro, G., and Howlett, L.

RRAP Coral Propagation and Deployment (CAD-01) Final Report June2025

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

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This report summarises work undertaken under *Coral Propagation and Deployment (CAD-01)* in accordance with the Reef Restoration and Adaptation Program's *Coral Aquaculture and Deployment* 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**
Davies Reef and SeaSim facility	Bindal
Magnetic Island	Wulgurukaba
Palm Island Group	Manbarra
Keppel Islands	Woppaburra
Heron Island	Gooreng Gooreng, Gurang, Bailai, and Taribelang Bunda
Moore Reef	Gunggandji

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1 Executive Summary

The RRAP Coral Propagation and Deployment (CAD-01) Project, under the Coral Aquaculture and Deployment Sup-program, focused on optimising processes around the propagation (sexual and asexual), settlement, symbiont infection, and post-settlement survival in early life-history stages of core Great Barrier Reef (GBR) coral species. Three sub-projects were contracted to align with key components of the coral propagation pipeline. Firstly, sexual and asexual propagation methods were developed in aquaria at the Australian National Sea Simulator (SeaSim) at the Australian Institute of Marine Science (AIMS) in Townsville as part of sub-project CAD-01.1. Secondly, coral deployment devices were designed and developed and material science research performed in CAD-01.2 to optimise the settlement, survival and growth of juvenile corals in facility and in the field, and the survival of recruits on deployment devices. Finally, the ecological processes that affected survival, were assessed in the field via CAD-01.3.

Throughout the first phase of the Reef Restoration and Adaptation Program (RRAP), sub-project CAD-01.1 examined the sexual and asexual propagation of 56 coral species across nine taxonomic families, with successful ex situ spawning achieved for many Acroporidae, Poritidae, Merulinidae, and Lobophyllidae species. High-density larval culture systems were trialled, with tank size and larval density optimised for different coral taxa. Innovations in larval culture tank design, including improved water flow and harvesting mechanisms, allowed for successful rearing of up to 500,000 larvae per square metre of facility space. Settlement cues, such as crustose coralline algae (CCA) and coral rubble, were tested for up to 25 species, revealing species-specific preferences and timing for optimal settlement. *Titanoderma tessellatum* emerged as a broadly effective settlement inducer, prompting further efforts to culture this CCA under aquaculture conditions.

Asexual propagation efforts focused on tissue sheet development for coral microfragments, particularly for *Porites, Acropora, Platygyra* and *Montipora*, which demonstrated high growth rates and viability. Growth performance was strongly influenced by substrate material and angling, with flat orientations prone to fouling and steeper angles causing uneven growth. Feeding trials indicated that night-time heterotrophic feeding enhanced growth, although optimal feeding regimes remain to be established. *Acropora* species were deemed less suitable for this propagation method due to tissue necrosis and high mortality rates in aquaculture conditions, which would require further optimisation of rearing condition for this genus.

Deployment device trials highlighted concrete as the most effective substrate for balancing high larval settlement and post-settlement survival, despite fouling by CCA and macroalgae. Low light intensity was critical for increasing spat survival by limiting algal competition, particularly from aggressive CCA species like *Lithophyllum* and *Crustaphytum*. Foul release coatings applied selectively to device cores substantially increased coral spat survival during the vulnerable early stages of development post-deployment, with benefits persisting for up to a year in the field.

Further innovations for deployment devices included the use of dense alumina-based materials enabling device stability without seabed attachment, and bioadhesives derived from biodegradable polymers for reef applications. These bioadhesives showed no negative effects on coral health and offered reliable fixation of deployment units and fragments. Novel neuropeptide settlement inducers and microtopographic features also demonstrated potential to improve settlement precision while reducing spatial and material requirements.

Post-deployment coral survival was found to be highly variable and driven by fine-scale environmental conditions, with greater variability observed between individual devices than between sites. Species, life stage, and deployment timing significantly influenced survival and growth outcomes, highlighting the importance of species-environment matching. Key survival determinants include benthic community composition (particularly CCA), protective device features, and optimal deployment depth (four to ten metres). Habitat quality, fish community composition, and microhabitat conditions (e.g. sedimentation, rubble) were also found to critically influence outcomes, thus highlighting that species-specific and site-specific strategies are essential for successful coral deployments. Collectively, these integrated approaches are advancing coral settlement methods in aquaria and deployment techniques in the field to support future scalable reef restoration interventions.

Future research should focus on optimising coral aquaculture methods to enhance the performance and efficiency of propagation processes. A priority area is the development of buffering methods that enable step-changes in the production and availability of sexually produced propagules, with the goal of supporting year-round deployment by removing seasonal constraints associated with larval supply. Simultaneously, continued research into low-cost and efficient strategies for the year-round production of asexually produced propagules is recommended to support broader restoration objectives.

To improve the success of restoration outcomes, research should also prioritise the upscaling of sustainable, environmentally acceptable, and high-throughput treatments such as symbiont inoculation and antifoulant application that have been shown to improve the survival and growth of young corals in the facility and once they are deployed onto the reef. Investigations into the direct and indirect effects of environmental conditions on coral survival post-deployment will be critical to informing deployment strategies and site selection. Further refinement of deployment engineering is also needed to reduce costs and increase environmental and social acceptability, particularly through innovations in device design (e.g. size, retention, degradability, and ease of assembly). Together, these research directions will strengthen the effectiveness and scalability of coral restoration interventions.

2 Background and Justification for the Research

2.1 CAD-01.1: Optimising coral propagation

The reliable production of sexually and asexually propagated coral individuals is fundamental to the success of reef restoration and adaptation interventions. Achieving this requires a comprehensive understanding of key biological processes throughout coral life-stages, including fragmentation, reproduction, spawning, fertilisation, larval culture, symbiont acquisition, settlement and early post-settlement. These processes must be examined across a diverse suite of coral species representing multiple taxonomic groups and reproductive strategies to support the development of robust, scalable restoration methods. Therefore, as part of the Reef Restoration and Adaptation Program (RRAP), the CAD-01.1 team aimed to address these knowledge gaps, optimise coral propagation methods, and facilitate the reliable and upscaled production, of sexually (as spat) and asexually produced corals (as tissue sheets). To improve scalability, the team also sought to develop, test and assess high density, large scale larval culture systems for the six core GBR coral species selected as representative model organisms by the broader RRAP program. CAD-01.1 also worked to develop and assess methods to optimise post-settlement survival and growth in the aquaculture facility through controlling substrate biofilm and algal communities and succession in the first 12 weeks.

Prior to the commencement of RRAP, a substantial body of research had been conducted on coral settlement cues; however, the vast majority of these studies focused on *Acropora* spp. For example, crustose coralline algae (CCA), CCA extracts, and peptide-based inducers had been established as reliable settlement cues for *Acropora* larvae, but their effectiveness for larvae from other coral families remained poorly understood. Similarly, much of the research on artificial substrates and micro-crevice designs was also limited to *Acropora*, with minimal investigation of other coral genera. Therefore, this project sought to address these knowledge gaps by developing and testing methods to control and optimise the settlement of three core non-acroporid GBR coral species.

Symbiotic algae from the family *Symbiodiniaceae* are essential for coral survival and reef accretion. Extensive research over the past three decades has demonstrated the critical influence of algal physiology on the performance of the coral-algal holobiont, particularly in relation to growth and thermal tolerance. Prior to 2021, most investigations into enhancing coral fitness via inoculation with adaptive symbiont strains had been restricted to *Acropora*, *Orbicella*, and certain octocorals. While the potential of targeted symbiont manipulation has been explored in depth under the RRAP Project Enhanced Corals and Treatments - Assisted Evolution (ECT-02), sub-project CAD-01.1 focused specifically on optimising and scaling symbiont infection protocols to support medium- to large-scale interventions.

In addition, this sub-project addressed significant knowledge gaps in asexual coral propagation, particularly the technique of microfragmentation. First developed independently at Mote Marine Laboratory (Florida) and in Hawaii approximately a decade ago, this method involves cutting small fragments (3–10 polyps) from the leading edge of coral colonies, which are then affixed to new substrates. These edge-derived fragments exhibit faster growth rates than those taken from colony cores. While this technique had been adopted in several restoration programs – particularly in the Caribbean and the Philippines – prior to RRAP, the scientific basis for its efficacy remained limited, and critical uncertainties persisted, especially regarding its scalability for broader application. Research in CAD-01.1 made advancements in this area.

2.2 CAD-01.2: Deployment devices

Maximising the early survival of coral recruits is critical to the viability of large-scale reef restoration initiatives that utilise sexually propagated corals (Randall et al. 2020). The first few months following settlement represent a particularly vulnerable life stage, during which survival is influenced by a complex interplay of biological and physical factors. These include competition with benthic algae and sessile invertebrates, predation, grazing pressure, sedimentation, and suboptimal light conditions. Of these, competition for space, particularly from algal overgrowth, has been identified as a leading cause of post-settlement mortality within the first-year.

Despite the importance of these early survival dynamics, limited research prior to this sub-project had focused on developing targeted treatments or designs to mitigate competitive fouling and support recruit survival and growth during this critical period. The use of non-biocidal antifouling surface coatings on coral deployment devices emerged as a promising strategy to reduce fouling pressure while avoiding the environmental risks associated with chemical biocides. In parallel, earlier studies indicated that the material composition and structural design of deployment devices, such as surface complexity, crevice size, and texture, could significantly affect coral recruit survival and growth. Structural features that mimic natural reef microhabitats, including appropriately sized crevices, may offer protection from grazers and space competitors, enhancing survival prospects.

Furthermore, for restoration methods involving sexually produced corals to be scalable, the logistics of device deployment must also be optimised. Among various approaches, surface deployment (where devices are placed directly onto the reef substrate and rely on passive self-attachment) has emerged as the most scalable and operationally efficient method.

Given these challenges and opportunities, research within this sub-project focused on the design, material selection, and functional treatments of coral deployment devices to enhance early recruit survival and support effective, scalable reef restoration. This foundational knowledge will be critical to ensuring that sexually propagated corals can not only be produced at scale but also survive and thrive once deployed onto degraded reef habitats.

2.3 CAD-01.3: Drivers of survival

Survival and growth of coral spat vary considerably across environments, communities and species, and can have significant consequences for the success or failure of a restoration intervention. Yet, understanding why recruits or juveniles perform well on one reef and perform poorly on a similar reef 100 metres away constitutes a critical knowledge gap (Randall et al. 2020). Worldwide attempts to deploy coral recruits propagated in captivity have, to date, relied on dive operations to manually anchor the artificial substrate bearing the coral to the reef, and have typically achieved poor survivorship (<10%) over the first-year post-deployment (e.g. Chamberland et al. 2017). Therefore, the aims of this research sub-project were three-fold: (1) to describe the relationships between environmental and biological conditions and juvenile coral mortality across species and sites, and identify any context-specific dependencies in coral survival; (2) investigate the mechanistic relationships that drive mortality; and (3) inform the design of deployment devices (developed in collaboration with CAD-01.2), and test their ability to improve post-deployment survival. Ultimately, the team aimed to optimise the deployment process by understanding *what* we should deploy *where*, and *when*, to maximise the success of seeded corals used in restoration.

3 Research Objectives and Key Findings

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. CAD-01.1: Optimising coral propagation		
1 (a)	Optimise the propagation, and facilitate the reliable and upscaled production, of sexually and asexually produced coral recruits	• 56 species of corals across nine taxonomic families (Acroporidae, Poritidae, Merulinidae, Diploastreidae, Lobophyllidae, Fungidae, Dendeophyllidae, Pocilloporidae and Euphyliidae) were studied either for sexual or asexual propagation research. • *Ex situ* spawning (at SeaSim) has been successful for many Acroporidae species (several species within *Acropora* and *Montipora*), Poritidae (three species of *Porites*), Merulinidae (several species within *Dipsastrea*, *Platygyra*, *Goniastrea*, *Caulastrea* and *Mycedium*), *Diploastrea heliopora*, Lobophyllidae (species within *Lobophyllia*, *Echinophyllia* and *Oxypora*), *Fungia* and *Galaxea*; with large scale spawning and culturing successful for many of the Acroporidae, Poritidae, Merulinidae and Lobophyllidae species (Abdul Wahab et al. 2022). *Ex situ* spawning behaviours for all species were documented. • Asexual propagation, for the development of tissue sheets, in facility were completed for *Acropora*, *Montipora*, *Platygyra* and *Porites* (see 1(f) below).
1 (b)	Develop, test and assess high density, large scale larval culture systems for the six core GBR coral species selected as representative model organisms by the broader RRAP program.	• High density culture tanks of two sizes were tested: 70 litre fiberglass tanks for coral species that release small volumes of gamete (e.g. non-Acroporidae) and 500 litre fiberglass tanks for coral species releasing large volumes of gamete (i.e. several species within the Acroporidae, and a species of Merulinidae; *Mycedium*) (Abdul Wahab et al. 2022a - SOP). • The 70 litre tanks worked well for larval culturing, with densities of up to 2-3 larvae/mL successfully cultured for corals with small sized larvae (e.g. *Porites*, *Mycedium, Platygyra* and *Fungia*). For large-sized coral larvae (e.g. *Acropora*, *Dipsastrea*, *Lobophyllia*, *Echinophyllia*, and *Montipora*) culture densities of up to 1-2 larvae/mL could be supported. Culture density of 0.3 larva/mL was typically used prior to RRAP. • Modifications to the 500 litre tanks were made to allow for better water movement in the tank (new water in-flow design), better water out-flow (larger central mesh standpipe that reduced the occurrence of clogging with an accompanying air curtain system) and tank features to facilitate efficient concentration of larvae for harvesting. Two experiments were completed to assess culture conditions (i.e. water exchange rates, ultraviolet (UV) filtration methods, recirculation systems, and culture densities), which

Objective		Key Findings and/or Outcomes
		found that Acropora species could be cultured at a density of up to one larva/mL, at a water exchange rate of 0.3x/hour and no UV filtration in the new culture tanks. Culture density of 0.3 larva/mL was typically used prior to RRAP (Ramsby et al. 2026). Larval culture in recirculating systems is also possible provided flow-through water is provided to the cultures within 24-48 of embryo introduction to the culture tanks, prior to switching to recirculating. 500,000 larvae could be cultured per 1 m^2 footprint of facility (Abdul Wahab et al. 2024).
1 (c)	Develop and assess methods to control and optimise the settlement of three core non-acroporid GBR coral species	• Larval pre-competency and settlement behaviour of 25 species of corals (including 12 non-Acroporidae species) were tested against settlement inducers including crustose coralline algae (CCA), coral rubble and biofilm discs, and across time, to identify the start and peak of competency during ontogeny (Randall et al. 2024). This work identified effective inducers for each species and provided a timeline for when to settle which species. • The settlement of 15 coral species across five taxonomic families (including 11 non-Acroporidae species) were tested against 15 species of CCA. Through this work, species-specific settlement patterns of corals to CCA were found which could be used to optimise their settlement. In particular, the CCA species *Titanoderma tessellatum* was an effective inducer broadly across the corals tested inducing 50% settlement in 14 of the coral species (81% mean settlement) (Abdul Wahab et al. 2023). The metabolomes of these CCA species were characterised to identify chemistry that may be responsible for larval settlement (Diaz-Pulido et al. 2025) A workshop on CCA identification and handling was completed, which trained 19 participants across the RRAP Coral Aquaculture and Deployment (CAD) and Enhanced Corals and Treatments (ECT) Sub-programs (Diaz-Pulido et al. 2021).
1 (d)	Develop and assess methods to optimise the production and performance of coral larvae and recruits through symbiont infection at scale	• Demonstrated that survival of early life stage corals is enhanced by inoculation with microalgal symbionts. • Established juvenile stage as the optimal early life stage to inoculate corals with symbionts at scale. • Established optimal symbiont densities to inoculate coral juveniles at scale.
1 (e)	Develop and assess methods to optimise post-settlement survival and growth through controlling substrate biofilm and algal communities and succession in the first 12 weeks	• The community composition of the CCA was explored under different light regimes (irradiance intensity and spectra) and preliminary findings indicate that two species of coralline algae, *Crustaphytum* and *Lithophyllym* sp. (identified using DNA sequencing) are dominant in the *ex situ* facility systems and can be highly aggressive to the spat. Irradiance intensity rather than spectra is a key determinant of CCA community structure.

Objective		Key Findings and/or Outcomes
		- One factor that limits post-settlement survival of coral spat is competition for space. In aquaria, the crustose coralline algae used to induce larval settlement subsequently can overgrow the developing spat. To control algal growth, we tried several methods of preserving settlement tiles, including freezing, that killed benthic competitors while preserving cues for settlement. Growth of spat on preserved tiles frees them from competition (for weeks to months) and enables faster growth at higher irradiance than when competitors are present. For example, growing spat (*A.* aff. *kenti*) on tiles with live CCA led to 20% survival whereas growth (*A. spathulata*) on tiles that had been frozen led to 80% survival at the same irradiance level (at 50-60 micromoles (µmol)). When competition is reduced, spat can grow four times larger when reared at 50 µmol compared to 5 µmol prior to deployment, and lead to two times higher yield one-year after deployment (Ramsby et al. in prep).
1 (f)	Develop and assess methods to optimise asexual propagation of six core GBR coral species through the production of "coral tissue sheets"	- Material type and texture is an essential aspect of coral sheets; material and surface roughness can be conducive to increased fouling and thus direct competition with coral fragments inhibiting growth and potential mortality. Testing indicated growth rates of coral microfragments are highest on non- textured/low porosity materials including alumina and smoothed concrete. Microfragments of *P. lutea* doubled in size after 12 weeks, covering 40% of a 90x90cm sheet (Abdul Wahab et al. 2026). - The angling position for grow-out is also a critical component for growing coral sheets. Coral sheets can be positioned at a 38° angle to maximise holding capacity without limiting growth and maintaining uniform growth patterns across the sheet. Sheets grown flat (0°) are subject to increased fouling displacement due to water movement. Sheets grown on a steeper angle (65°) do not grow homogenous and instead grow unidirectional (Ferguson et al. in prep). - Feeding of microfragments to accelerate growth needs to be optimised, continuous feeding during nighttime hours where heterotrophic feeding is assumed to be more active showed a positive effect on growth rates compared to those fed during daylight hours. More research is needed to determine optimal feeding concentrations and nutritional profiles for species-specific feeding. - *Acropora* species may not be suitable candidates for coral sheets. Despite rapid tissue growth, they are subject to tissue necrosis and have high rates of mortality as microfragments in an aquaculture environment. - *Montipora* and *Porites* species are good candidates for coral sheets.

Objective		Key Findings and/or Outcomes
		• The production of secondary fragments from complete coral sheets onto new sheets is achievable, however, the re-growth of these secondary fragments is much slower likely due to the decline in energetic reserves from long-term holding in aquaculture. More research is needed into sustaining corals to promote continued growth and promote the production of new sheets. • Other parameters including optimal temperature and light conditions have not yet been optimised for production of asexual fragments and should be a consideration for the future.
2. CAD-01.2: Deployment devices		
2 (a)	Improve the survival and growth of coral recruits of a core set of species by optimising the physical characteristics of deployment devices and minimising competition for space on the devices using antifoulants.	All aspects of Objective 2(a) are captured in 2(c and f) in this report.
2 (b)	Identify deployment device materials for optimal design flexibility and recruit survival	• Three tile materials (alumina-based ceramic, calcium carbonate ($CaCO_3$), and concrete) with varying surface roughness were tested for their effects on coral larval settlement and post-settlement survival in macroalgae-conditioned mesocosm tanks (Fong et al. 2024a; Antunes et al. 2024). • Surface roughness did not significantly influence larval settlement success or spat survivorship. Macroalgal community composition differed significantly among substrate materials but not by surface texture and was strongly influenced by tank-specific conditions. • Concrete tiles supported the highest larval settlement density, while $CaCO_3$ tiles resulted in the highest post-settlement spat survival. Spat mortality was primarily due to overgrowth by *Crustaphytum* (CCA) and *Lobophora* (brown algae). Considering both settlement and survival, concrete was the most effective substrate overall. • Substrate material plays a greater role than surface roughness in determining coral spat settlement and survival. Concrete offers a practical balance between high larval settlement and acceptable post-settlement survival and is well-suited for restoration deployment. • The CCA *Titanoderma sp.* is a key species for settling a diversity of species in coral aquaculture. Fragments of the *Titanoderma sp.* were cultured under combinations of temperature (27.5°C and 30°C) and light (10 and 40 µmol photons m^{-2} s^{-1}) on $CaCO_3$,

Objective		Key Findings and/or Outcomes
		concrete, and PVC substrates. Optimal growth of adult fragments occurred under 27.5°C and higher light (40 µmol photons m^{-2} s^{-1}) (Fong et al. 2024b). • Conceptacle (reproductive structure) development was stimulated by high light conditions but unaffected by temperature. Sporeling settlement and growth into juveniles only occurred under high irradiance conditions. Concrete substrates supported the highest recruitment of juvenile *Titanoderma*. • High light conditions are critical for both growth and reproduction of *Titanoderma*, with concrete being the most suitable substrate for recruitment. Cultivation of *Titanoderma* under optimised aquaculture conditions could improve larval settlement success in coral restoration applications.
2 (c)	Test a range of treatments based on eco-friendly chemical antifoulants (compatible with coral growth) to reduce competition and improve survival rates of corals post-settlement.	• Five commercial Foul Release Coatings (FRCs) were successfully tested for their ability to protect seeding devices from aggressive fouling and improve spat survival on mid shelf and inshore reefs (Röepke et al. 2022a, 2022b; Montalvo-Proano et al. 2025a, b, c). • The coating of device cores, but not the arms of devices, ensured fouling protection close to the coral, while still allowing rapid colonisation of the device to promote stability on the reef. • All FRCs performed well in field trials, especially within the first 20 weeks of deployment, when coral spat were at their most vulnerable. The best performing FRCs reduced fouling by approximately 75% over almost a year in the field. • The FRCs tested were not harmful to corals, with coral tissue overgrowing the coatings. • FRC treatments of device cores increased spat survival by 10 – 100% in long-term field trials until spat reached critical size threshold grater than one centimetre. The greatest protection was at inshore algae-dominated sites. • This project provided the first mechanistic evidence that FRCs indirectly enhance coral spat survival in the field by mitigating competitive fouling pressure during the critical early growth period. • The greatest benefits for spat survival occur in the first six months, and fouling protection persisted throughout year-long the deployments, suggesting that FRCs could provide a scalable solution to improve restoration outcomes.
2 (d)	Explore the potential of regulating light spectral quality to control fouling and enhance recruit survival.	• Low light intensity leads to increased survival of coral spat (*Acropora* aff. *kenti*) in aquaculture by limiting the growth of competitors, principally crustose coralline algae (CCA) (Ramsby et al. 2024)

Objective		Key Findings and/or Outcomes
		• Spat were overwhelmed by CCA on live substratum when photosynthetic active radiation (PAR) exceeded 50 µmol, highlighting the need to minimise competition for coral spat. • Spectral quality did not affect the outcome of competition, as spat survival and growth was similar to under full spectrum irradiance. • Low irradiance natural light is also beneficial for the minimisation of algal competition in outdoor aquaria. These low light conditions are being applied in vertical spat grow-out trials aiming to substantially increase the holding capacity prior to deployment (Benyon et al. in prep).
2 (e)	Develop and test deployment device designs to optimise retention on a range of seafloor rugosities	• Alumina has a high density and specific gravity, enabling seeding devices to sink rapidly, remain in place, and resist damage. These properties allow for deployment without attachment to the seabed – a novel approach in coral restoration. • Retention of devices (% recovered after one-year) ranged from 61 to 89%, varying by reef and deployment site. Device yield (% with surviving coral) was also high, up to 80%, depending primarily on site and coral species (Ramsby et al. in 2026b). • Device shape had minimal influence on device retention compared to the large variation observed among sites. Sites with high rugosity (~3) tended to have lower retention, although this was partially offset at locations with steep slopes (~15°) or shallower depths (three metres). • Deployment method had little effect on retention, with similar outcomes whether devices were deployed by divers or released from surface vessels. Surface deployment offers significant potential to scale up restoration efforts and reduce the labour requirements.
2 (f)	Engineer selective access of coral propagules to deployment device (shapes, complexities, and topographies) to maximise survival through controlling irradiance and grazing.	• An experiment testing combinations of coral larval settlement inducers and microtopography of three-dimensional (3D) printed ceramic inserts on settlement substrate was performed (Briggs et al. 2026). • Neuropeptide Hym-248 was the most active neuropeptide, settling eight of the 13 species tested. • Larval settlement can be directed by immobilisation of chemical inducers and conditioned microtopographies. • Conditioned protrusions with microtopographic features directed larval settlement with all spat settling on the protrusion.

Objective		Key Findings and/or Outcomes
		- There is a nine-fold decrease in tank space needed to condition protrusions over traditional concrete tabs. - Assessments of light manipulations for controlling fouling and maximising survival of spat were performed in 2(d).
2 (g)	Develop and test biomimetic glues to retain deployment devices among a range of coral reef habitats.	- A range of bioadhesives made from natural, biodegradable materials (i.e. biobased polyphenols) and bioadhesive hybrid material were evaluated for their potential use across multiple coral reef restoration applications, i.e. coral deployment and rubble stabilisation (Baker et al. 2024; Moghaddam et al. 2024). - The bioadhesives were effective in securing concrete settlement tabs to deployment devices, providing a practical alternative to conventional attachment methods (Barner et al. 2025). The bioadhesives showed no negative impact on the survival and growth of *Acropora loripes* during a nine-month trial in Davies Reef. - Cotton filaments coated with bioadhesive were used to connect individual deployment devices with each other and showed no observable negative impacts on *Montipora digitata* coral fragments during the assessment period. - When applied to stabilise deployment devices, the bioadhesive filaments successfully anchored them to surrounding reef rubble for up to three months post-deployment. Alternative materials such as untreated cotton and PLA (polylactic acid) filaments were too weak or degraded quickly.
3. CAD-01.3: Drivers of survival		
3 (a)	Improve understanding of post-deployment survival probabilities to support decisions regarding what, when and how many corals to deploy in a given location to achieve a target outcome, and to improve the design of deployment devices to maximise survival	- Survival is highly variable and driven by fine-scale environmental conditions not captured at the site level. Variability between devices is greater than variability between sites. (Jurriaans et al. 2025). - Survival probabilities, and growth, differ substantially by species, life-history stages (microfragmentation versus spat) and timing of deployment (Jurriaans et al. 2025, 2026). Matching the right species with their preferred environment is crucial for deployment/restoration success (Jurriaans et al. in prep). - Predictive models remain limited due to environmental stochasticity and confounding factors, like year and cohort, which require caution when making direct comparisons (Jurriaans et al. 2025). - Benthic community (in particular, CCA) at tab level is likely an important determinant for survival (Page et al. 2024). Tab-level benthic communities are also likely to determine the level of grazing-related coral mortality from parrotfishes (Whitman et al. 2024).

Objective		Key Findings and/or Outcomes
		• Based on current knowledge, seeding devices should be populated with tabs at a spat density between five to ten individuals to optimise survivorship. Further testing is underway to validate and refine these recommendations (Jurriaans et al. (meta-analysis, in prep). • Based on current knowledge, deployment sites should target depths between four to ten meters. Shallow reef crest habitats should be avoided unless devices can be securely fixed or wedged into the substrate due to the high-energy environment. Similarly, highly sloped reef habitats (i.e. >45°) are not recommended, although further testing is underway to define acceptable slope gradients. Lagoonal environments may be suitable for certain species, although high sedimentation can limit success. To avoid contact with sediments or other abrasive materials like reef rubble and foliose macroalgae, devices could be fixed and raised above the reef substrata (Whitman et al. 2026; Page et al. 2024; Smith et al. 2025). Highly dynamic environments can reduce survival, potentially due to increased competition with crustose coralline algae or physical dislodgement. • Scraping parrotfishes (*Scarus* spp.) can cause significant coral mortality (that is presumably accidental or indirect) when corals are seeded without protection from fish grazing. Up to 95% of corals can be lost to grazing within 24 hours. (Whitman et al. 2024).
3 (b)	Determine the environmental and biological drivers of survival and growth of juvenile corals across a range of environments at four core study sites	• Wave exposure (nominal wave energy and bottom stress) and sedimentation on turf were among the strongest predictors of early post-settlement survival, although effects weakened over time and varied by reef and species. • Survival varied more within than between sites (meaning that there was greater variance between devices than between sites), suggesting that small-scale (within-site) environmental variation rather than site-level predictors plays a stronger role in shaping post-settlement outcomes. • Current flow data is insufficient to capture micro-scale hydrodynamics relevant to recruits. • Species-specific responses highlight the need for tailored, fine-scale deployment strategies. • Parrotfish-related coral mortality post seeding is site specific and is related to adequate food sources for fishes (Whitman et al. 2024) and reef hydrodynamics (Whitman et al. 2025), with the negative effects of some fishes exacerbated in degraded (e.g. rubble, sediment, sand, macroalgal dominated) and branching *Acropora* dominated habitats (Whitman et al. 2025; Whitman et al. in submission). • Post-seeding survival of *Acropora* corals (species: *A. digitifera* and *A. millepora*) appears to be higher when devices are deployed to plots (< 1m^2) with crustose coralline algae,

Objective		Key Findings and/or Outcomes
		ascidians, non-*Acropora* corals (encrusting corals, branching *Pocillopora*), and cyanobacterial foods for fishes (Whitman et al. 2024, 2025, in submission). • Sites abundant with small fishes (herbivores, detritivores, invertivores) such as wrasse, blennies, and damselfishes can support seeded coral survival (*A. digitifera*, *A. millepora*) likely through algal, sediment, and parasite removal (Whitman et al. 2025; Whitman et al. in submission). • Sites with mobile, unconsolidated rubble, sediments, and macroalgae are detrimental to seeded coral survival (Whitman et al. 2025; Whitman et al. in submission) and may require pre-seeding interventions (rubble stabilisation, macroalgal removal, catchment management) prior to device deployments (Page et al. 2026).

3 (c)	Evaluate the optimal design(s) of deployment devices that maximise survival and growth across environments and for six to nine species.	• Coral survival is higher on devices that include protective features, such as structural protrusions that shield recruits from fish grazing. Protection is critical as 100% mortality can occur within the first 48 hours on unprotected devices. Incorporating protective features significantly improves survival outcomes (Whitman et al. 2024). Devices with larger protection features (i.e. longer protrusion/wall lengths) yield more corals and perform more consistently across sites than devices with shorter features (Whitman et al. in submission). Devices with arms may promote better stability on rubble reefs, minimising device loss in complex rubble matrices and reducing coral abrasion from sediments/rubble, in comparison to devices without arms (Whitman et al. in submission).
		• Survival is higher when corals are oriented in vertical (side facing) positions of the device rather than horizontal (top facing) positions; this will limit grazing mortality, sediment abrasion, and harmful exposure to light (Whitman et al. 2024). Survival is also higher when corals are oriented in vertical than bottom-facing positions (Page et al. 2024) which are likely light limited.
		• Survival outcomes vary by species, reef, and deployment method. Below is a summary of device-level survival (percentage of devices with at least one surviving coral) and/or tab-level survival (percentage of individual settlement tabs with at least one survival coral).
		• Davies Reef (Whitman et al. 2024, Jurriaans et al. 2026, in prep (a)):
		  • *Mycedium elephantus* had 0% survival after nine months.
		  • Microfragments outperformed spat in *Montipora turtelensis* (67% vs. 17%) and *Galaxea fascicularis* (75% vs. 10%) after 15 and nine months, respectively.

Objective		Key Findings and/or Outcomes
		• *Acropora loripes* showed higher survival for spat (57% at nine months) than microfragments (34% at 15 months), although this difference was not evident when both life stages were compared at the same nine-month time point. • *Goniastrea retiformis* was only deployed as microfragments at Davies Reef, with 55% survival after 15 months (higher than *A. loripes* at the same site and time). • *Acropora hyacinthus* survival averaged 24% (device yield), or 9% (tab yield) after 17 months deployment. • *Acropora digitifera:* On average, 10% (tab yield) for coral spat and 83% (tab yield) for microfragments after an eight-month deployment. For spat, the side position of the exclusion device had the highest survival (23%) while the top position of the control had 0% survival; caged devices were not tested for spat. For microfragments, the side facing position of the caged device had the highest survival (97%) while the top-facing position of the featureless control devices had the lowest survival (61%). • Heron Reef (Jurriaans et al, in review): • *Acropora cf. kenti* device-level survival averaged 23 ± 4% after 27 months. • *A. hyacinthus* device-level survival averaged 13 ± 1% after 27 months. • Moore Reef (Whitman et al. 2025, Jurriaans et al. in review): • *Acropora digitifera* after one-year, tab-level survival for spat was 61%, ranging from eight to 96% across sites. The exclusion device had 65% tab-level survival while the featureless control device had 58% survival. • *Acropora millepora* device-level survival averaged 32% ± 7% s.e.m (***standard error of the mean***),(range: 8–76%), while tab-level survival was 14% ± 4% after 18 months of deployment. • Keppel Islands (Whitman et al. in submission) • *Acropora millepora:* On average, 50% device yield, ranging from 26-64% across sites. Exclusion devices outperformed controls, with 41-63% and 12-52% (device yield), respectively. On average, 25% tab yield, ranging from 12-33% across sites. The exclusion device showed the least site-related variation in tab yield (29–39%), while the control device had the most (14–34%).

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**
2. CAD-01.2: Deployment devices: Objective 2(a)	This objective – Improve the survival and growth of coral recruits of a core set of species by optimising the physical characteristics of deployment devices and minimising competition for space on the devices using antifoulants – duplicates aspects of both Objective 2 (c) Test a range of treatments based on eco-friendly chemical antifoulants (compatible with coral growth) to reduce competition and improve survival rates of corals post-settlement and Objective 2 (f) Engineer selective access of coral propagules to deployment device (shapes, complexities, and topographies) to maximise survival through controlling irradiance and grazing. 2(a) was not in the original Project Agreement. All aspects of Objective 2(a) are captured in 2(c and f) in this report.

4 Future Research Recommendations

Several key residual knowledge gaps and challenges, to further optimise and scale the production of corals in an *ex situ* facility for restoration were identified and are detailed below.

4.1 Optimising methods to improve the performance of the conservation aquaculture processes

Methods to settle, inoculate (Symbiodiniaceae and probiotics), and feed young corals have been successfully developed for several coral species in the families *Acroporidae* and *Merulinidae*. To achieve better production efficiency in the future, and thus higher returns on investments (better cost efficiency), we identified key future research and development pathways to improve the settlement, survival, growth and health of young corals in the facility, including across a broader species range with different larval behaviours, symbiotic relationships and feeding strategies. Further improvements could be achieved by engaging in the following activities:

1) Investigate the chemistry (metabolomes) of CCA and microbes that induce larval settlement and explore pathways for synthesis of those chemical inducers (for upscaled and universal substrate treatments).
    a. **Potential future gains:** The identification, isolation and syntheses of chemistry from CCA and microbial taxa that have been shown to induce coral larval settlement across key coral species would eliminate the need to condition substate in seawater. Currently, the substrate conditioning step, which is aimed at developing live communities of inductive CCA and microbial biofilm, requires facility footprint to be dedicated for up to eight weeks leading up to the spawning and production period. Eliminating this step, by having synthetic chemical inductive coatings that could be applied onto the substrate ahead of time at scale and stored in dry storage, thus reducing the labour and resources associated to this process step.
2) Investigate novel microtopographic features/inserts that couple chemical and microtopographic inducers for challenging coral larvae (non-Acroporids).
    a. **Potential future gains:** Non-acroporid coral species have been found to settle onto more complex substrate surface comprising of nooks, crannies and pores, rather than surfaces that are smooth and featureless, even when they are well conditioned. The incorporation of microtopographic features on the surfaces of settlement substrates, in conjunction with the application of inductive chemical inducers as described above, could improve the total settlement of non-acroporid species. In addition, these microtopographic features could also be used to direct the settlement of coral larvae more broadly to where there they should ideally be positioned to improve the yield of substrate units with viable coral spat, e.g. centre of each tabs.
3) Optimise feeding strategies and symbiont provisioning (Symbiodiniaceae and microbes) to improve survival, health and growth of young corals in facility and track their performance in the field once deployed.
    a. **Potential for future gains:** Feeding of coral spat with live feeds such as microalgae, rotifers and Artemia have been found to improve the survival and growth of some coral taxa when held mid- to long-term in facility (e.g. while awaiting deployment, up to 12 weeks holding), in particular for coral species with higher reliance on heterotrophic feeding to meet their nutritional needs. Likewise, a similar trend has been demonstrated for spat provided with

cultured photosymbionts across most coral taxa tested, and it has been shown that the microbiome of newly settled spat is amenable to manipulation. While the benefits of feeding and symbiont provisioning have been shown for spat grown in the facility, the assessment on whether these benefits extend to after the spat are deployed in the field is less understood. Understanding if one type of feed or symbiont taxa provides better survival or growth to deployed corals would further optimise these processes during production.

4) Optimise holding conditions, and maximise growing space, while in facility to improve survival and growth across a range of species.

    a. **Potential for future gains:** Facility space is valuable and its optimisation through the development of high density holding and grow-out aquaculture systems, which do not compromise on the survival and health of the resulting spat would be required to upscale production. Through the current RRAP, we have developed methods to increase the density of holding and grow-out of spat, for example through vertical tile growing conditions – however, this has not been tested at the full-scale capacity. The upscaled production of coral seeding units in facility for the Pilot Deployments Program (PDP) would provide an opportunity for assessing the performance of high density grow-out conditions at a scale that is realistic. Maintaining linkages with the scope of work currently in CAD 2-1 – Upscaling coral propagation will be crucial.

4.2 Developing buffering methods for step-change in production of sexual propagules and year-round deployment by removing time constraint of larval supply

The production of coral recruits through sexual propagation, at scale, is currently limited to the summer spawning, and thus comes under a batch production model. If we are able to expand /buffer the production of sexual recruits year-round, this will 1) allow for year-round deployment of corals, 2) utilise the facility year-round. This activity is aimed at developing buffering strategies for year-round coral production and deployment by:

1) Developing novel methods for bulk cryopreservation of excess larvae that are generated during the peak spawning season.

    a. **Potential for future gains**: Typically, more larvae are being generated during the coral spawning season than could be work flowed in a timely manner through downstream processes, including larval settlement and device assembly, without impacting on the quality of the larval cultures. Preservation methods, such as cryopreservation of larvae – even for a subset of species having smaller larvae (whereby the method would have better success) – would allow for the buffering and spreading of these downstream processes over the course of the year. If the process of cryopreservation and thawing of larvae is successful and has minimal impact on larval performance, such as survival, settlement and post-settlement survival and growth, then additional research should also investigate the effects of deploying these coral spat in the field outside of their natural planktonic and recruitment window.

2) Developing novel space and water efficient technologies for maximising facility production throughput.

    a. **Potential for future gains**: Novel methods for the holding of larvae and spat that reduces the use of *ex situ* facility footprint and resources, e.g. water and electricity, would make the production of coral seeding units more cost effective. Novel engineered substrate that could store larvae or spat in closed pods (e.g. <2x2 cm dimensions), with formulated seawater that contains provisions for nutrition and symbionts, and with gas exchange facilitated by bespoke environmentally suitable polymer-film, could eliminate the need of costly facilities for larval culturing, settlement and nursery grow-out, and serve as a buffering mechanism for protracted deployment. If these pods could also be utilised directly for deployment, then this would eliminate the need for seeding devices. Maintaining linkages with the scope of work currently in RRAP Sub-project CAD-02.1 – Upscaling coral propagation, will be crucial.

3) Upscaling out-of-season spawning for the supply of larvae throughout the year.
    a. **Potential for future gains**: Out-of-season spawning has successfully been performed at AIMS and elsewhere globally, by offsetting the spawning cycle of corals through the manipulation of temperature, photoperiod and lunar profiles. To date, the AIMS SeaSim team has been able to mass spawn and produce larvae of coral species in the Acroporidae and Merulinidae, that typically spawn in the summer months, in autumn and during the daylight hours in controlled room settings, albeit at small- to medium-scale. There is potential for upscaling this process, which needs to be balanced with the cost of production and also needs to consider the implications of deploying spat outside of their natural, temporal recruitment window. Maintaining linkages with the scope of work currently in RRAP Sub-project CAD-02.1 – Upscaling coral propagation, will be crucial.

4.3 Upscaling of sustainable, environmentally acceptable and high-throughput treatments that improve in-field survival (symbionts, antifoulants)

We have gained further insight into how the provision of symbionts (Symbiodiniaceae) and the reduction of biofouling can enhance the survival and growth of coral spat deployed in the field. Improving coral growth and heat-tolerance increases the return on investment and contributes to the overall success of restoration efforts. This recommended activity is aimed at improving the survival of deployed corals by:

1) Developing aquaculture systems to upscale the production of relevant beneficial Symbiodiniaceae in facility, across several source locations, species/strains and genotypes.
    a. **Potential for future gains**: As restoration initiatives expand across geographic scales, it will be important to diversify the culture lines of Symbiodiniaceae in facility to include those from the location of restoration application and deployments, and across several taxa to ensure taxonomic diversity of photosymbionts that are available for inoculation across the diversity of coral taxa. In addition, desirable phenotypic traits, e.g. for holobiont heat-tolerance, across these photosymbiont taxa need to be further developed – either from collections from habitats and environments they are naturally occurring or through selective evolution. Also, to ensure fitness genetic diversity within each of these symbiont taxa and strains, along with the genetic diversity of the coral host needs to be maximised. Aquaculture systems and strategies that allows for scaling the culture of symbionts, while also facilitating taxonomic and genetic diversity, would facilitate the supply of cultured symbionts for spat inoculation in facility.

2) Developing methods to upscale the application of environmentally safe antifoulant coatings/technologies on the seeding devices.
    a. **Potential for future gains**: Overgrowth by aggressive benthic competitors in the initial months after deploying seeding devices poses a major threat to spat survival in restoration

programs. Biocide-free antifoulant coatings, known as foul release coatings (FRCs), can reduce fouling by up to 70% in the first year, decreasing competitive pressure until spat reach a size-escape threshold of approximately 10 mm in diameter, beyond which mortality significantly declines. Our research has shown that applying FRCs to the cores of seeding devices can double spat survival at both the tab and device level. Consequently, development and application of ecologically sustainable FRCs could halve the number of deployment devices needed to effectively seed degraded reefs, particularly those dominated by macroalgae.

4.4 Understanding direct and indirect effects of environmental conditions on the survival of deployed corals

Survival dynamics of early corals deployed into the field is complex, species-specific, and varies among sites that are in relatively close proximity. Future large-scale deployment strategies will need to deploy to sites selected based on models, and the effectiveness of these modelled selections have not yet been field-validated. More knowledge is required to understand how predictions apply to a range of species, and how processes affect early coral survival at various spatial scales. Targeted experiments to further inform and optimise the survival dynamics of deployed spat include:

1. Previous deployments have limited extrapolating results to broader contexts, due to cohort-specific testing and inter-annual variability. Field experiments to validate the effectiveness of modelled site selection need to be performed, along with targeted testing of deployments across environmental gradients over a range of spatial scales.
    a. **Potential for future gains**: Future experiments should utilise high temporal censusing frequency out of field hubs (field stations) to maximise, and expedite, learnings while reducing large resourcing needs that are typically associated to vessel based, remote and offshore field studies. The approach of developing an integrated field program for the collection of coral broodstock, initial deployments of seeding devices, censusing of offshore/remote reefs, and the use of the same larval cohorts to test across a broader range of sites, and the same parental broodstock over multiple years would increase confidence in data interpretation through the repeatability and transferability of results. This future work would inform species-environment interaction to better predict the survival of deployed corals and would guide deployment strategies to improve post-settlement survival.

4.5 Refining the engineering of deployment processes to reduce costs and increase enviro-socio acceptability (device size and retention, degradability, and assembly)

We have improved the efficiency and scale of coral production in aquaculture which would be further optimised through advancements in system designs across more species, with an aim to further improving survival and growth. A significant cost reduction will require refinement of device designs (including size reduction and biodegradability) and automation to assist with production monitoring and device assembly, maintaining efficient and safe work processes and operations. This activity will:

1) Design and test smaller devices that are equally effective or have better retention post-deployment (assisted by novel biopolymers), promoting better survival of corals in the field.
    a. **Potential for future gains**: The development of smaller device designs, which do not compromise their retention on the reef (e.g. via advancing auto-adhesion strategies), and that would maintain or improved the survival of the deployed corals could reduce the cost of

production of each seeding unit which would in turn improve the returns on investment. Assessment of alternative materials that are accessible to bioeroders and facilitate degradation over decadal periods may further improve environmental acceptance of the device material(s) when future large-scale deployments are being performed, e.g. millions of corals to be deployed per year. An industry scan for relevant device manufacturers would be beneficial to identify groups of suppliers that could deliver the volume of devices that are required, and to establish production of these devices at a fraction of their current costs.

2) Improve durability of bioadhesive coated filaments for retention of deployment devices on reef substrate, upscale the production of bioadhesives and coated filaments, develop automation of filament attachment to deployment devices.
    a. **Potential for future gains:** Future experiments should focus on the coated filaments that performed best in reef trials, i.e. based on extended durability and that supported the retention of deployment devices on the reef substrate. The upscaling of bioadhesive production would support the provision of sufficient materials (i.e. filaments) for large-scale coral spat deployment. Automation of filament attachment to deployment devices would also support large-scale deployment of corals with improved retention, survival and growth.
3) Further develop automated and machine learning processes, and device assembly platforms, that could be adopted by industry.
    a. **Potential for future gains**: To achieve the scale and operationalisation to support any future reef restoration initiatives for the Great Barrier Reef, the processes and technologies that have been developed in the RRAP Coral Aquaculture and Deployment (CAD) Sub-program will need to be transferable to industries and communities. To facilitate this, the production pipeline would need to be easily adaptable and adopted and be cost-effective. Currently, production bottlenecks exists, for the assessment of tabs that are useable (i.e. with live corals) and the assembly of devices – both of which are manual processes. The development and application of processes such as computer vision and machine learning processes for screening tabs and automation for the assembly of devices would facilitate the sustainability of these future upscaled operations.

5.6 Continue developing low-cost solutions for year-round production of asexual propagules

Taking advantage of the rapid asexual growth of coral microfragments to form tissue sheets that could be utilised as material for coral seeding would reduce the reliance of new materials (i.e. wild colonies and fragments) for propagation. However, experiments for tissue sheet generation yielded variable results, depending on the taxa used. For example, while *Montipora* and *Porites* microfragments showed promising results to produce tissue sheets in *ex situ* conditions, *Platygyra* showed limited horizontal growth while *Acropora* fragments displayed significant mortality from the procedure. While treatments of growing angles and feeding treatments resulted in better growth for *Montipora* and *Porites*, these treatments did not improve the asexual performance of *Acropora* in aquaria, and other factors including lighting optimisation and alternative nutritional options could be investigated. As maintaining coral fragments in facility long-term can be expensive (six months to achieve full substrate coverage for *Montipora*), future scaling of asexual propagation methods should consider low-cost options, such as in field nursery with research to further optimise fragment survival and growth across more coral taxa.

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