RRAP Intervention Risk Assessment of the Pilot Deployments Program

2025

REEF RESTORATION & ADAPTATION PROGRAM

PEARS, R.J.
DRYDEN, J.
DUNGAN, A.
SMITH, R.

Reef Restoration and Adaptation Program
Intervention risk assessment of the Pilot Deployments Program

Enquiries should be addressed to: Dr Rachel Pears (AIMS), r.pears@aims.gov.au

[Cover Page: Corals on John Brewer Reef, Credit: Matt Curnock, Ocean Image Bank]

This report should be cited as

Pears, R., Dryden, J., Dungan, A., and Smith, R. (2025) *Reef Restoration and Adaptation Program – Intervention risk assessment of the Pilot Deployments Program.* Australian Institute of Marine Science, Townsville (pp93).

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 authors acknowledge and thank the many subject-matter experts from these and other organisations who reviewed and improved content and causal maps in this report and participated in processes. Special thanks for feedback that improved the report go to Corinne Allen, Line Bay, Chris Doropoulos, Annika Lamb, David Mead, Bob Muir, Matthew Nitschke, Juan Ortiz, Cynthia Riginos, George Roff, Yui Sato, Elliott Schmidt, Madeleine van Oppen and Muhammad Abdul Wahab. The Intervention Risk Review Group provided valuable guidance (e.g., on the approach) and input (e.g., to risk identification), and conducted an independent review of the near-final report. Risk identification and understanding benefited from inputs from many additional people (e.g., community panel members, workshops under an RRAP Biocultural Project with Reef Traditional Owners).

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.

Contents


Anthias fish and coral reef. Credit: Gary Cranitch, Queensland Museum

1 Executive summary

The Reef Restoration and Adaptation Program (RRAP) is a long-term research and development (R&D) program that develops, tests and risk-assesses novel interventions to help keep the Reef resilient and sustain critical functions and values.

> *This intervention risk assessment evaluates the potential ecological risks associated with the RRAP Pilot Deployments Program (PDP), proposed for implementation between 2025 and 2030.*

The assessment focuses on risks to the environment and biodiversity values of the Great Barrier Reef Marine Park from two coral-based intervention methods: (1) larval Slick Collection and Release (SCR), and (2) Conservation Aquaculture (CA). Both methods are already undergoing field trials and refinement on coral reefs. Large field trials—or pilot deployments—are an integral next step in translating this R&D into operational reef interventions.

The proposed interventions aim to deliver large numbers of young corals onto the reef, with the goal of supporting positive outcomes for Marine Park values, now and in the future. As part of a precautionary and due diligence approach, this assessment focuses on evaluating the risk of potential harmful outcomes to Marine Park values that the Program seeks to avoid.

The assessment evaluates the ecological risks associated with a defined deployment configuration involving deployments at selected reefs in up to three regions of the Great Barrier Reef (GBR or the Reef). All deployments will use native coral and symbiont material sourced from the same reef region or cluster, and no experimental manipulation (e.g., heat-evolved strains) is included. Deployment will occur under robust protocols developed through RRAP.

The process captures diverse perspectives in identifying and understanding risk. A structured risk assessment method was followed, incorporating expert elicitation, qualitative analysis of mapped causal pathways, published literature, RRAP research and monitoring data, and expert judgement. The assessment focused on ecological dimensions; social, cultural, and heritage considerations are addressed through separate processes.

RISK FINDINGS

> *The overall risk to the environment and biodiversity values of the Marine Park from the pilot deployments was assessed as **Low**.*

This includes risks associated with both SCR and CA methods, and applies to:

- Corals (target and non-target)
- Plankton and microbes, including algal symbionts and coral-algal symbiosis
- Coral reefs at and beyond deployment sites
- Other ecological values (e.g. fish, invertebrates, marine turtles, sharks, rays, marine mammals).

All identified risk pathways were rated as **Low**, with a high level of agreement among the expert panels. These findings reflect the proposed scale of deployments, characteristics of the interventions, current and projected reef conditions, and embedded safeguards.

Knowledge gaps remain, such as in the genetic structure of coral and symbiont populations, but these were not considered limiting to assessment or management of ecological risk of the Pilot Deployments. Several of these gaps are being actively addressed through ongoing research and development.

The assessment process was overseen by the Intervention Risk Review Group (IRRG), an independent, interdisciplinary expert body that ensured integrity, transparency, and technical rigour. The IRRG's role included independent input, review of draft outputs, observation of expert elicitation sessions, and endorsement of the final assessment findings. The IRRG have issued a formal Statement providing its full endorsement of this assessment and its findings.

CONCLUSION

This risk assessment provides a strong evidence base for ensuring ecological risks associated with the PDP are well managed. It concludes that the proposed RRAP Pilot Deployments Program presents **Low risk** to the environment and biodiversity values of the Marine Park when implemented with current practices and existing safeguards. The PDP activities are assessed as consistent with management objectives for the Great Barrier Reef. These findings support the continued, carefully managed progression of coral restoration and adaptation efforts under RRAP.

If additional intervention options are proposed, the assessment will be updated accordingly and further risk management measures applied as needed. The PDP's implementation will continue to be supported through existing RRAP governance and adaptive management processes.

1.1 Risk profile summary

The key results from the intervention risk assessment of the Pilot Deployments (as detailed in the intervention proposal) are summarised below (Figure 1). All ecological value groups assessed were rated as **Low** risk for both methods (SCR and CA).

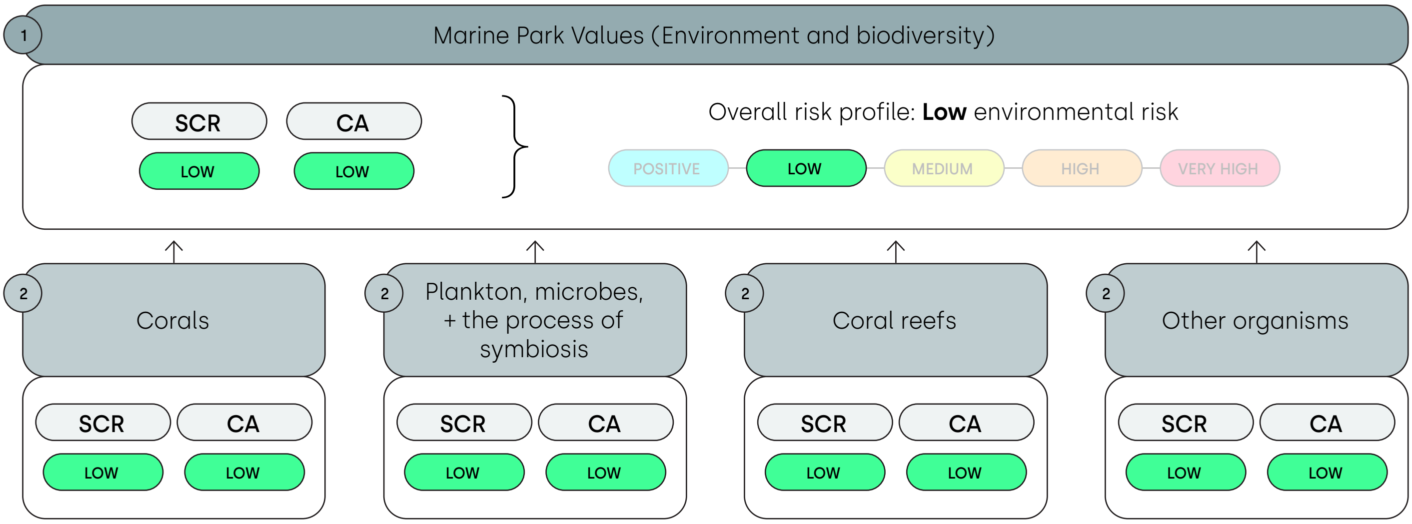


Figure 1 Overall risk profile of the RRAP Pilot Deployments Program 2025-2030 activities.

LEGEND

INTERVENTION METHOD:

SCR = *Slick Collection & Release* CA = *Conservation Aquaculture*

OVERALL RISK LEVEL:

POSITIVE – LOW – MEDIUM – HIGH – VERY HIGH

ASSESSMENT PURPOSE

To assess the potential intervention risks associated with the 2025–2030 RRAP Pilot Deployments Program (PDP) in the Great Barrier Reef Marine Park (the Marine Park or Marine Park).

SCOPE OF THE ASSESSMENT

This assessment addresses risks to the environment and biodiversity values of the Marine Park. Risks to social, cultural and heritage dimensions are addressed through separate processes.

INTERVENTION DEPLOYMENT METHODS ASSESSED

SCR = Slick Collection and Release
CA = Conservation Aquaculture.

SCR: Coral larval-based seeding via spawn slick collection and delivery

CA: Coral production and seeding via *ex situ* breeding and rearing and deployment of juvenile corals

INTERVENTION PROPOSAL ASSUMPTIONS – SUMMARY

The deployment configuration is defined in the intervention proposal. The current configuration that was assessed is sometimes known as the 'base case'.

- Deployments at selected reefs in up to three regions of the Reef
- Regionally sourced coral material returned to the same reef region or cluster
- Use of native coral and symbionts only
- No experimental manipulation (e.g., heat-evolved strains) included
- All deployments conducted under defined supervision and risk mitigation protocols

CONFIDENCE AND KNOWLEDGE BASE

- Strong agreement in risk estimates among expert panels
- Risk ratings supported by multiple lines of evidence
- Knowledge gaps and uncertainties acknowledged but not considered limiting under the current intervention proposal

RISK MANAGEMENT AND INTENDED BENEFITS

Risk mitigation is embedded through deployment design (scale, site selection, sourcing), quality assurance protocols, and scientific oversight. This assessment will be updated if additional intervention options are proposed for use. Risk management will continue to be supported by RRAP's adaptive governance processes.

These findings should be interpreted alongside broader information on intervention benefits and opportunities. While this report focuses on identifying and mitigating potential harms, the intended outcomes of PDP—such as enhanced coral cover and resilience, knowledge generation and development of supply chains and local capacity—are also important considerations for decision-makers evaluating the balance of risks and benefits.


Reef aerial. Credit: GBRF

Coral fragment collection for heat tolerance assays. Credit: Ian McLeod

2 The Reef Restoration and Adaptation Program (RRAP)

The Reef Restoration and Adaptation Program (RRAP) is a long-term R&D program to develop, test and risk-assess novel interventions to help keep the Reef resilient and sustain critical functions and values.

> *The goal of RRAP is to provide reef managers and decision-makers with an innovative suite of safe, acceptable and cost-effective interventions to help the Reef survive the impacts of climate change, in conjunction with best-practice reef management and reducing carbon emissions.*

While RRAP is initially focused on developing technology and solutions to help the Reef, these solutions could potentially be considered for use on other reefs in Australia and around the world.

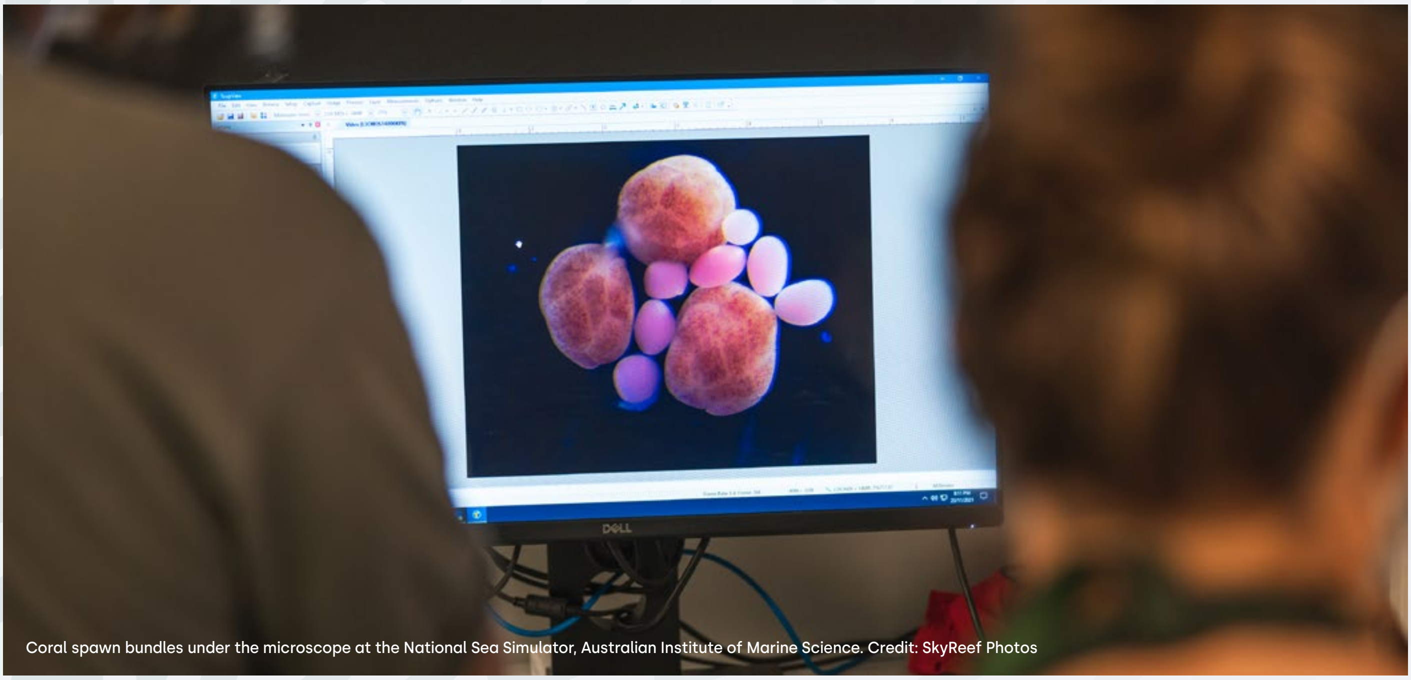
The Reef is the world's largest living structure and an Australian icon. While it remains a vibrant ecosystem of great natural resilience and beauty, warming oceans are causing more frequent and serious bleaching events, which can kill coral. Reducing global greenhouse gas emissions is the most important action to minimise the impact of climate change on the Reef. Yet the science is clear; warming ocean temperatures are locked in, with emissions reductions no longer the only action needed to safeguard coral reefs. Projections for coral futures on the Reef highlight the critical need for restoration and adaptation solutions that can be deployed at scale within the next ten years.

The suite of coral reef interventions being researched and developed by RRAP vary in their intended outcomes and associated risks. An improved understanding and evaluation of intervention benefits and risks is a key component of RRAP, including from ecological, social, economic, cultural, heritage and regulatory perspectives. Making decisions around managing and adapting to climate change requires information. Uncertainty and risk are inherent parts of this decision-making process. This work aims to support active decision-making to protect the Reef by providing decision makers with an understanding of the risks and uncertainty associated with reef intervention methods.

The RRAP R&D program has a focus on addressing the scientific and engineering bottlenecks and knowledge gaps that limit the size and scale of reef restoration efforts.

> *Large field trials – or pilot deployments – are an integral next step in translating this research and development into scalable restoration efforts.*

The RRAP Pilot Deployments Program (PDP) is designed to create knowledge and develop supply chains that can only be derived from larger deployments and enable practical engagement with Traditional Owners and the breadth of stakeholders and industries required to establish operational programs. The first interventions to be progressed by the PDP include Slick Collection and Release and Conservation Aquaculture. These Pilot Deployment interventions are assessed in this report.



Coral spawn bundles under the microscope at the National Sea Simulator, Australian Institute of Marine Science. Credit: SkyReef Photos

Coral spawn collection under red light at the National Sea Simulator, Australian Institute of Marine Science. Credit: Dorian Tsai, QUT

3 Intervention risk assessment approach and methods

3.1 Overview

RRAP uses the Intervention Risk Assessment process to specifically identify and assess the potential risks of proposed reef interventions and how they would be implemented on the Reef.

> *The process is framed around Great Barrier Reef management objectives and assesses the risks posed to the condition and trend of the Marine Park values.*

This includes ecological, social, economic, cultural and heritage values. It is a science-rich process, incorporating broad knowledge, experience and evidence. Additionally, insights and knowledge from across RRAP's suite of work, from engagement and partnerships to science and engineering projects, are integrated into the process. The risk assessment findings should be interpreted alongside broader information on intervention benefits and opportunities.

The 'no-new intervention' case is a key consideration in the RRAP Intervention Risk Assessment process, providing a contextual baseline against which intervention risks are assessed. It draws on current climate models and knowledge of coral responses to climate change impacts (such as marine heatwaves and cyclones) to project future reef conditions in the absence of new interventions.

Where relevant to a particular risk (e.g. risks to corals), the absolute risk posed by the proposed intervention is assessed in the context of the existing risk from inaction. In such cases, the assessment focuses on the additional contribution to risk—if any—that could plausibly arise from the intervention activities, beyond those which could arise from climate change alone. The risks that are only due to climate change impacts are not to be included in the scoring of likelihood and severity, or in risk estimates, since they are not intervention risks. Consideration of the reference case also provides an understanding of how the potential risks of reef intervention deployments compare to a future where no new interventions are deployed.

In assessing the risks from the PDP, current and projected reef conditions under climate change were taken into account, informed by briefings on the research of the RRAP Modelling and Decision Support Subprogram. This no new interventions reference case is being published by RRAP researchers (Bozec *et al.*, In Review). Under the most likely warming scenarios it indicates there will be a generalised decline in coral cover, with all coral groups affected, and warming exceeds coral adaptive capacities (Figure 2).

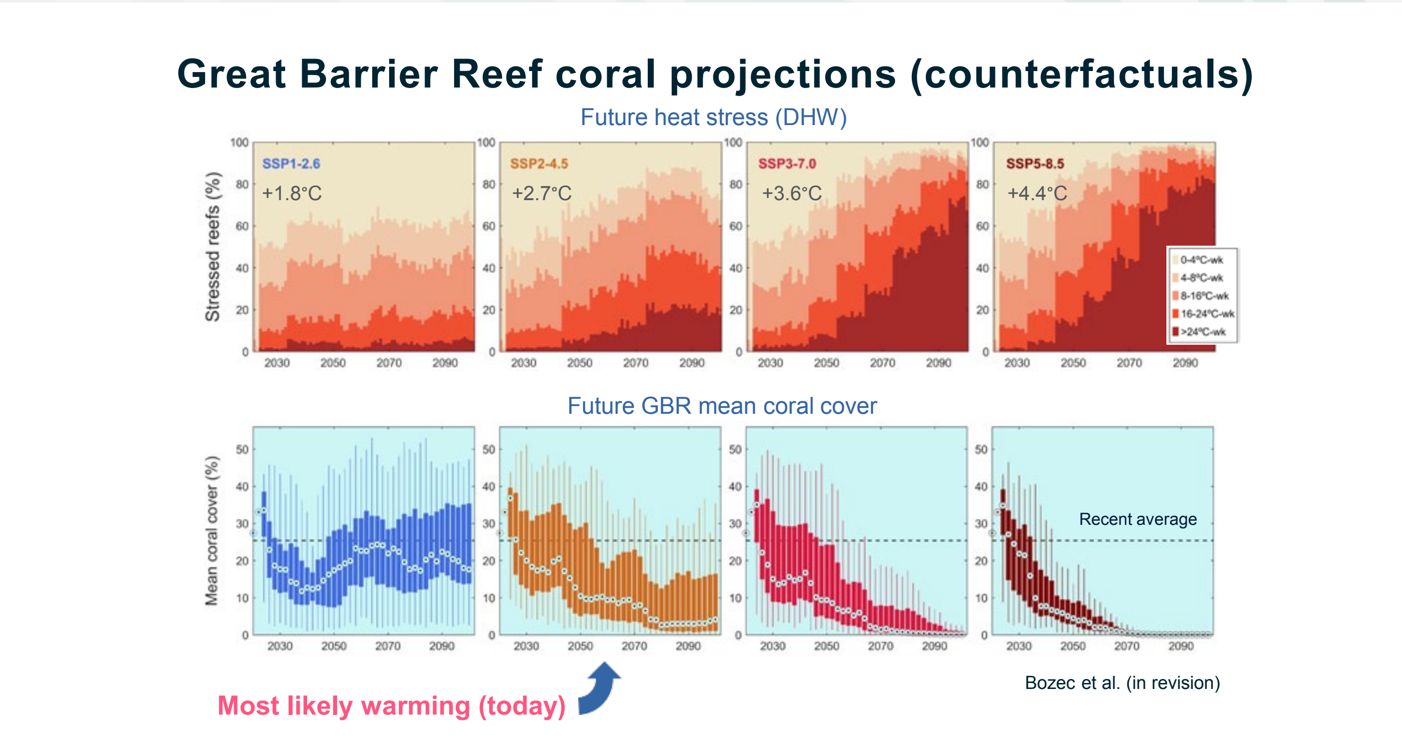


Figure 2 Summary information on the no new interventions reference case: projections of coral cover on the Great Barrier Reef under a range of climate change scenarios. Source: RRAP Modelling and Decision Support Subprogram.

The Intervention Risk Assessment process (detailed in *RRAP Intervention Risk Assessment: Approach and methods*) starts with gaining an understanding of the intervention to be assessed and determines the framing for the risk assessment (see Appendix 1 for descriptions of key terms). It then follows a series of stages to undertake risk identification, risk pathway mapping, risk analysis, risk characterisation and the preparation of risk management advice and reports, as illustrated in Figure 3.

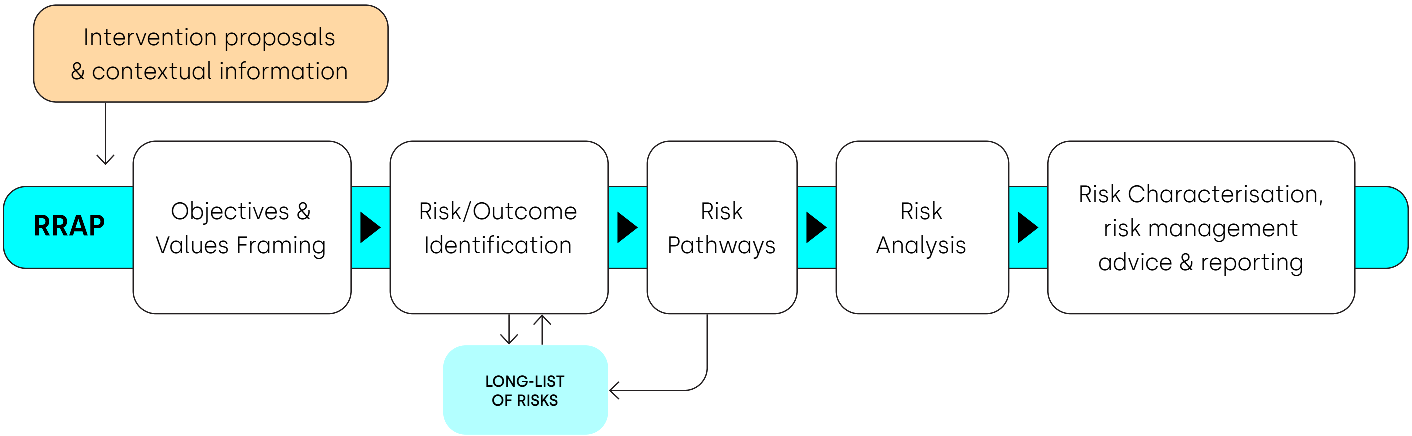


Figure 3 RRAP Intervention Risk Assessment process (Pears et al. 2025)

IN SUMMARY:

Understanding the intervention deployment proposal: The first stage of the RRAP Intervention Risk Assessment process involves gaining a comprehensive understanding of the reef intervention deployment proposal and relevant contextual information. The intervention deployment proposal (along with relevant contextual and supporting information) is reviewed to inform risk identification and pathway mapping as well as identify factors that may influence the likelihood and severity of any risks. Experts in the risk analysis expert elicitation process also use the proposal and relevant contextual information to understand the proposed intervention activities that they are assessing.

Objectives and values framing: Given the GBR is managed based on an overarching set of objectives and a comprehensive framework of Marine Park values, achievement of the relevant GBR management objectives and protection of Marine Park values are then considered in relation to the proposed reef interventions. A process is undertaken to determine whether the proposed activities may interact with any Marine Park values (directly and/or indirectly), which of these values require assessment, and whether further information is needed. Where a possible interaction is identified, these values are considered in the risk assessment process.

Risk/outcome identification: Several approaches are undertaken that together provide a comprehensive approach to identifying all risks potentially associated with the proposed intervention deployment(s) and incorporate diverse inputs. These approaches include expert elicitation, discussions and projects/activities/forums with Traditional Owners, stakeholders and community members, literature reviews, modelling, experiments and field research. The identified potential risks and outcomes are captured in the long-list of risks. The potential risks are organised into a structure that allows for analysis.

Risk pathway mapping: A series of causal maps (along with supporting information) are developed to capture the risk pathways and ensure there is a sound understanding of how the intervention activities may possibly lead to potential consequences for Marine Park values, including the relevant mechanisms, conditions and sequence of events. Risk pathway mapping can also contribute to further risk identification.

Risk analysis: An analysis is undertaken of the likelihood, severity and risk of the potential consequences of the proposed intervention deployment(s). Where areas of uncertainty and knowledge gaps are identified during the assessment, these are taken into account during the assessment, captured in this report (Section 7) and provided back to the research teams for planning of future research. The findings of the risk analysis, along with the supporting information, are considered to understand the nature of the potential risks and any broader risks, and whether further action or analysis is required prior to proceeding to risk characterisation.

Risk characterisation and risk management advice: The understanding gained about the risks of proposed intervention deployment(s) in the previous stages is brought together to characterise the potential risks to Marine Park values. This includes any risk management advice arising from the assessment.

Overall processes including risk management: For RRAP research and development and the Pilot Deployments Program, risk management is via established program and governance processes. These processes apply a risk management framework that includes Intervention Risk (the subject of this report).

A Risk Review process is in place, with the Intervention Risk Review Group (IRRG) providing independent input, oversight, and review functions. The IRRG had visibility of each stage of this Intervention Risk Assessment conducted by RRAP, and the IRRG reviewed the detailed findings and the report. Further information on the IRRG is provided in Section 3.4. The combined approach for Intervention Risk Assessment by RRAP and Risk Review by the IRRG is illustrated in Figure 4. These processes are carefully managed to uphold the independence of the IRRG.

RRAP INTERVENTION RISK ASSESSMENT AND IRRG RISK REVIEW APPROACH

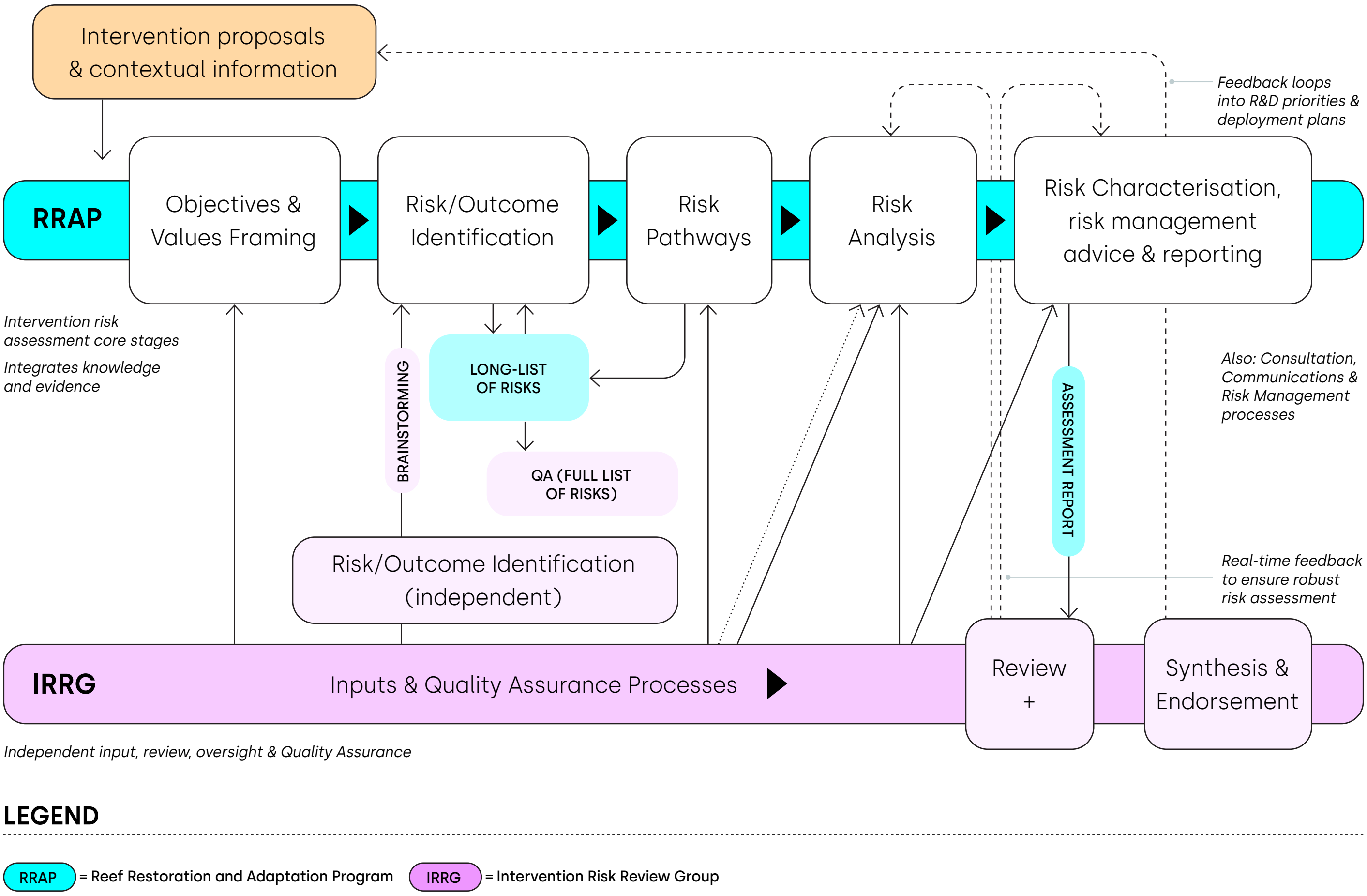


Figure 4 Schematic of the combined RRAP Intervention Risk Assessment and IRRG Risk Review Process.

3.2 Scope of this report

This report documents the findings from RRAP's assessment of the risks of the Pilot Deployments activities (current configuration of activities, or 'base case') to the environment and biodiversity values of the Marine Park. Risk assessment for the social, economic, cultural and heritage values of the Marine Park will be documented in a subsequent report. Evaluating any risk of harm to Marine Park values (which we seek to avoid) is part of a due diligence approach to ensure intervention risks are considered and understood, both by RRAP and by Marine Park managers and other decisions-makers. Where any additional intervention option(s) beyond the base case are proposed for use in the Pilot Deployments Program, such as the use of heat evolved symbionts aiming to improve heat tolerance of corals, further risk assessment would be completed on those options.

3.3 Approach and methods applied to the intervention risk assessment of the Pilot Deployments

A companion report covers the approach and methods used for this assessment: *RRAP Intervention Risk Assessment: Approach and methods* (Pears et al. 2025).

An intervention risk assessment of the proposed Pilot Deployments was undertaken to ensure intervention risks were identified and assessed to support decision-making in relation to the Pilot Deployments on the Reef.

The intervention risk assessment of the proposed Pilot Deployments also served as a trial of the intervention risk assessment process. The learnings from this trial led to the modification and refinement of some elements of the methods. Therefore, while the methods applied to intervention risk assessment of the proposed Pilot Deployments largely follow those described in *RRAP Intervention Risk Assessment: Approach and methods*, the methods do differ to some degree for some of the risk assessment stages. Where there are differences, the methods used instead are briefly summarised in the individual methods descriptions for each relevant section of this report, and in detail in Appendix 6 of *RRAP Intervention Risk Assessment: Approach and methods*. In sections where the methods were in line with the Approach and methods document (with no exceptions), the text indicates that this stage/step in the process was undertaken as per the *RRAP Intervention Risk Assessment: Approach and methods*.

3.4 Quality control and assurance

QUALITY CONTROL

The Intervention Risk Assessment approach and methods were applied to the assessment of the Pilot Deployments proposals, ensuring that for each stage in the assessment, the purpose was met and set standards were adhered to, as outlined in *RRAP Intervention Risk Assessment: Approach and methods*. Quality control processes were embedded throughout and included checks to verify the appropriate application of methods, the quality of inputs (e.g. evidence), and the completeness and accuracy of outputs. Processes used include ensuring all steps were thoroughly documented, version-control of documents, and application of the Quality Management System described in the Approach and methods to ensure consistency, transparency, and defensibility.

QUALITY ASSURANCE

The work completed under the RRAP Intervention Risk Assessment process is quality assured both internally by RRAP and independently through a unique arrangement established by the Board of RRAP, which has oversight of risk management. In 2022, the Board established the Intervention Risk Review Group (IRRG) – an independent, inter-disciplinary expert group whose key role is to consider the risk of coral reef interventions and provide guidance and advice on risk assessment and management.

The IRRG has developed rigorous quality assurance processes. Further information on the IRRG is available on its webpage.

IRRG STATEMENT

The IRRG looked at whether this assessment process met agreed standards and was implemented with integrity and transparency. The quality assurance aspects of their role included discussing and reviewing draft outputs and the near final version of this report, observing processes including expert elicitation discussions, and providing advice on the rigour and completeness of the risk assessment.

After the IRRG completed their review of RRAP's findings and a draft of this final report, they issued an independent statement. This confirms the IRRG fully endorses this report and concurs with the ***Low*** *risk profile for PDP.*

Causal maps review session at IRRG Workshop

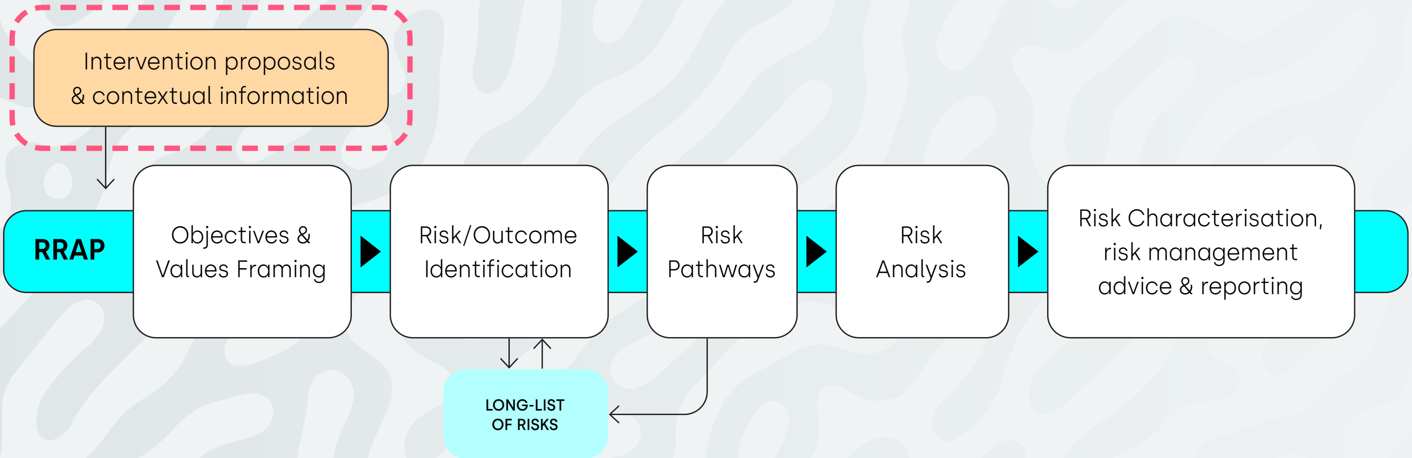
Review of images captured using 3D photogrammetry. Credit: Marie Roman, AIMS

Pilot Deployments Program field activities. Credit: Great Barrier Reef Foundation

4 Understanding the intervention deployment proposal

4.1 Methods

The first stage of the RRAP Intervention Risk Assessment process involves gaining a comprehensive understanding of the proposed reef intervention and relevant contextual information. This stage is detailed in *RRAP Intervention Risk Assessment: Approach and methods*. In summary, the intervention deployment proposal (along with relevant contextual and supporting information) was reviewed to inform risk identification and pathway mapping as well as identify factors that may influence the severity and likelihood of any risks.



4.1.1 APPLICATION OF THE METHODS TO THE PROPOSED PILOT DEPLOYMENTS

Understanding the intervention deployment proposal for the Pilot Deployments Program was undertaken as per the *RRAP Intervention Risk Assessment: Approach and methods*.

4.2 Overview of Pilot Deployments proposal

The *Pilot Deployments Program Intervention Ecological Plan* (*PDP Ecological Plan*) sets out the plans and details of the proposed reef intervention deployments in the Marine Park. It should be noted that this plan focuses on the ecological aspects of the proposed Pilot Deployments, while other aspects of the proposed Pilot Deployments are being covered by separate plans. The *PDP Ecological Plan* notes that regulatory approvals and Free, Prior, Informed Consent from Traditional Owner groups would need to be in place before field activities occur.

The interventions planned for deployment are outlined, and the objectives and intended benefits described. The plan describes the intervention deployment activities that are part of current plans (i.e. the base case) and mentions the additional optional activities which could be considered for future inclusion in the Pilot Deployments Program. Any additional optional activities would be subject to separate risk assessments and are not considered further in this document.

In terms of scale, it is anticipated that Pilot Deployment activities will occur on approximately nine or so reefs, with several reefs to be selected from up to three regions (the northern, central and southern regions) of the Marine Park. As an example, the spatial scale that the term 'region' is being applied here is 'northern region' refers to reefs in the vicinity of Cairns and Port Douglas (i.e., where these would be the usual port for accessing those reefs). At each reef, the Pilot Deployment activities will take place at several discrete sites within that reef, rather than at the scale of the whole reef.

The proposed Pilot Deployments involve two key methods – Slick Collection and Release and Conservation Aquaculture:

Slick Collection and Release (SCR): Using the natural reproductive processes of reef-building corals, genetically diverse coral spawn slicks will be harvested from collection reefs, cultured into larvae *en masse*, and deployed to target reefs to catalyse rapid recovery of areas with reduced coral cover and diversity. This will include a combination of larval cloud releases as well as seeding larvae onto devices at sea, aboard vessels or in pop-up shore-based facilities.

Conservation Aquaculture (CA): Thermally tolerant (bleaching resistant) coral broodstock are selected for breeding based on phenotype, with the aim of creating coral offspring with potentially enhanced thermal tolerance using stationary and mobile aquaculture facilities. These coral offspring are provided with algal symbionts and then introduced onto target reefs, increasing the abundance of potentially heat-tolerant corals within those populations.

On the Reef, investigation, testing and small-scale field trials of SCR have been underway for nearly a decade, and there have also been several years of research and development and small-scale field testing of CA. This work is further supported by decades of research and restoration from other areas such as Florida and the Caribbean. The scaled-up Pilot Deployments are the next step in RRAP's strategy and will generate critical field data on the scalability, risk and benefits of interventions.

SCR and CA focus on the direct deployment of corals (either at larval and juvenile life stages) and are expected to have conservation benefits through supplementing rates of natural coral replenishment, leading to an increase in coral density and cover. These corals will contribute to local ecosystem services as they grow. Once deployed colonies reach sexual maturity and reproduce (sexually) with existing corals, desirable phenotypic traits may be passed on to future generations (depending on the strength of heritability), providing a broader restoration benefit (increased coral abundance) and facilitating the spread of beneficial traits (e.g., thermal tolerance), resulting in increased fitness within targeted populations.

This report focuses on risk assessment of the current proposed activities (as opposed to the additional optional activities) for SCR and CA as part of the proposed Pilot Deployments Program. The current proposed activities for SCR and CA are illustrated in Figure 5.

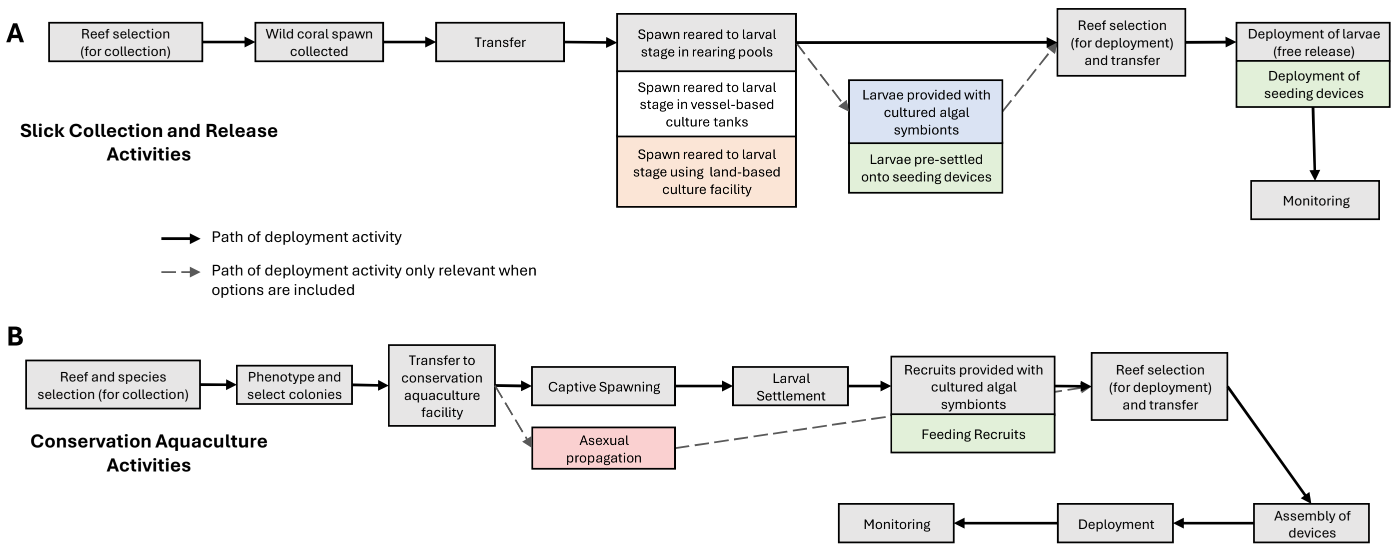


Figure 5 Pilot Deployments activities. Pipeline illustrating the stepwise activities of the proposed Pilot Deployments for A) Slick Collection and Release B) Conservation Aquaculture. The order of activities is indicated by solid black arrows. Coloured boxes and dashed arrows indicate an optional activity (i.e. only a subset of the corals in the pipeline will be involved in that activity). All activities shown are assessed in this report as part of the current intervention proposal.

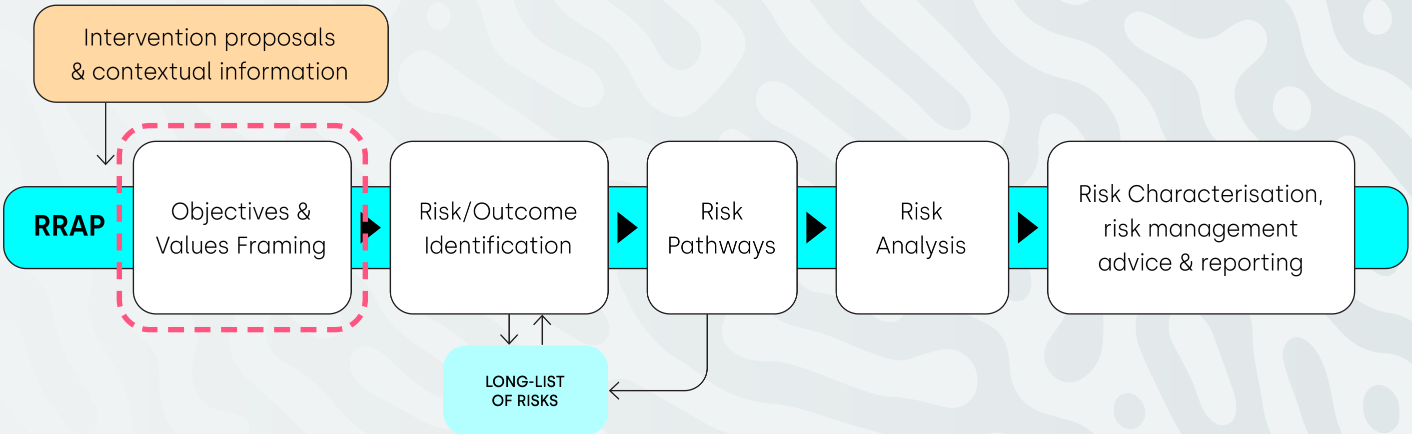
Figure 6 top) Coral seeding devices used in Slick Collection and Release and Conservation Aquaculture. This image represents devices immediately after deployment. Bottom) Larval pools used in Slick Collection and Release

Data collection for RRAP's Ecological Intelligence Subprogram. Credit: Ian McLeod

5 Objectives and values framing

5.1 Methods

The Reef is managed based on an overarching set of objectives and a comprehensive framework of Marine Park values. The objectives and values framing stage is designed to ensure all relevant Great Barrier Reef management objectives and Marine Park values are considered in relation to the proposed reef interventions. This stage also provides the foundation for the entire Intervention Risk Assessment by defining the scope and frame of reference for risk analysis—ensuring alignment with legislative and policy objectives, particularly those of the Reef Authority, and incorporating broader perspectives. The methods for objectives and values framing are detailed in *RRAP Intervention Risk Assessment: Approach and methods*.
For this assessment, a process was undertaken to determine whether the Pilot Deployment activities may interact with any Marine Park values (directly, indirectly or both), and hence which values needed to be assessed, or whether further information was needed. Where a possible interaction was identified, these values were considered in the initial assessment process. Where any interaction was considered unlikely, those values were excluded from consideration in the initial assessment process. However, the process allows for additional relevant values to be added into the assessment where additional information and feedback is received.



5.1.1 APPLICATION OF THE METHODS TO THE PROPOSED PILOT DEPLOYMENTS

Objectives and values framing for the proposed Pilot Deployments was undertaken as per the *RRAP Intervention Risk Assessment: Approach and methods*.

5.2 Findings

Risk assessment findings should be considered in the context of important and relevant Great Barrier Reef management objectives, particularly:

- The long-term protection and conservation of the environment, biodiversity and heritage values of the Great Barrier Reef Region
- Ensure consistency with World Heritage obligations
- Ensure the proposed intervention deployment is an ecologically sustainable use of the Great Barrier Reef Region or its natural resources that is consistent with the primary objective
- Ensure consistency with other legislative requirements, including duties to prevent environmental harm, general biosecurity obligations and the protection of Matters of National Environmental Significance protected under the national environmental law.

The objectives and values framing work identified that the Pilot Deployment activities (including associated equipment and any plausible unintended activities) might have direct and indirect interactions with several Marine Park values in each of the value dimensions being assessed (ecological, social, economic, cultural and heritage).

In the ecological dimension (the focus of this report), the objectives and values framing work identified that the Pilot Deployment activities may have a combination of direct and/or indirect interactions with corals (target and non-target), plankton and microbes (symbionts) and the process of symbiosis, coral reefs (intervention reefs and those beyond the intervention reefs) and other organisms including bony fish, dolphins, whales, marine turtles, other invertebrates, sea snakes, sharks and rays. Direct or flow-on indirect interactions of Pilot Deployment activities with corals or coral reefs could also in turn lead to indirect interactions with the continental slope within the Marine Park. Direct or indirect harm to environment and biodiversity values may in turn cause direct or indirect harm to connected social, economic, cultural and heritage values of the Marine Park. No additional environment and biodiversity values were identified for inclusion during the assessment.

The Pilot Deployment activities could also lead to direct and indirect interactions with social and economic dimension values (independent of the ecological pathways), as well as values specifically important to Traditional Owners. Interactions with the social, economic, cultural and heritage values are currently being risk assessed by RRAP, and this includes consideration of the *Strong Peoples – Strong Country Framework*.

Several Marine Park values were found unlikely to interact either directly or indirectly with the activities of the Pilot Deployments due to the coral-centric nature of the proposed interventions and the proposed location of the collection and deployment sites i.e. coral reefs. For example, the activities of the proposed Pilot Deployments on coral reefs are very unlikely to interact either directly or indirectly with seagrass meadows or the key species dependent on seagrass meadow habitat, such as dugongs.

These findings are summarised in Table 1 below.

Table 1 The environment and biodiversity Marine Park values that could interact with the intervention deployment activities and whether these interactions could be direct/indirect.

2 TYPE OF INTERACTION	VALUES	
Direct and/or indirect interactions	✓ Corals (target and non-target) ✓ Plankton and microbes (symbionts) ✓ Symbiosis ✓ Coral reefs (intervention reefs and beyond intervention reefs) ✓ Bony fish ✓ Dolphins	✓ Whales ✓ Marine turtles ✓ Other invertebrates ✓ Sea snakes ✓ Sharks and rays ✓ Continental slope
No interactions	× Halimeda banks × Islands × Lagoon floor × Mainland beach and coastlines × Mangrove forests × Seagrass meadows × Shoals × Water columns/ Open water	× Dugongs × Estuarine crocodiles × Mangroves × Seagrasses × Shorebirds × Channels and canyons × River deltas × Terrestrial ecosystems that support the region

Following Table 1, the list of key environment and biodiversity values assessed in this report are listed below (see also Figure 7). Note that Section 8 of this report applies the findings of the risk assessment to characterise the nature and level of risk to these key values.

- Corals (target and non-target),
- Plankton and microbes (particularly algal symbionts and the process of symbiosis),
- Coral reefs (both intervention reefs and those beyond the intervention footprint), and
- Other ecological values (other organisms) e.g. bony fish, dolphins, whales, marine turtles, other invertebrates, sea snakes, sharks, and rays.

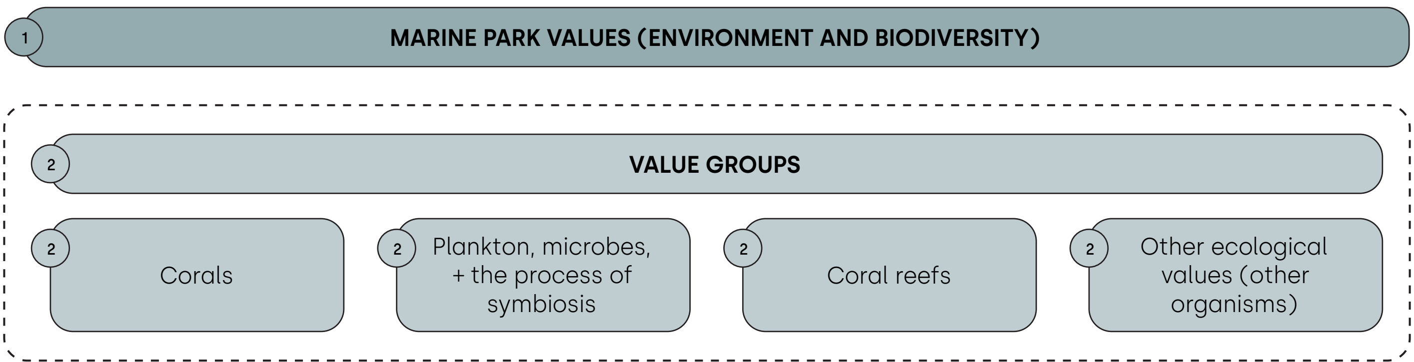


Figure 7 Summary of the four Marine Park Value Groups to be assessed. This is the second level in the assessment structure.

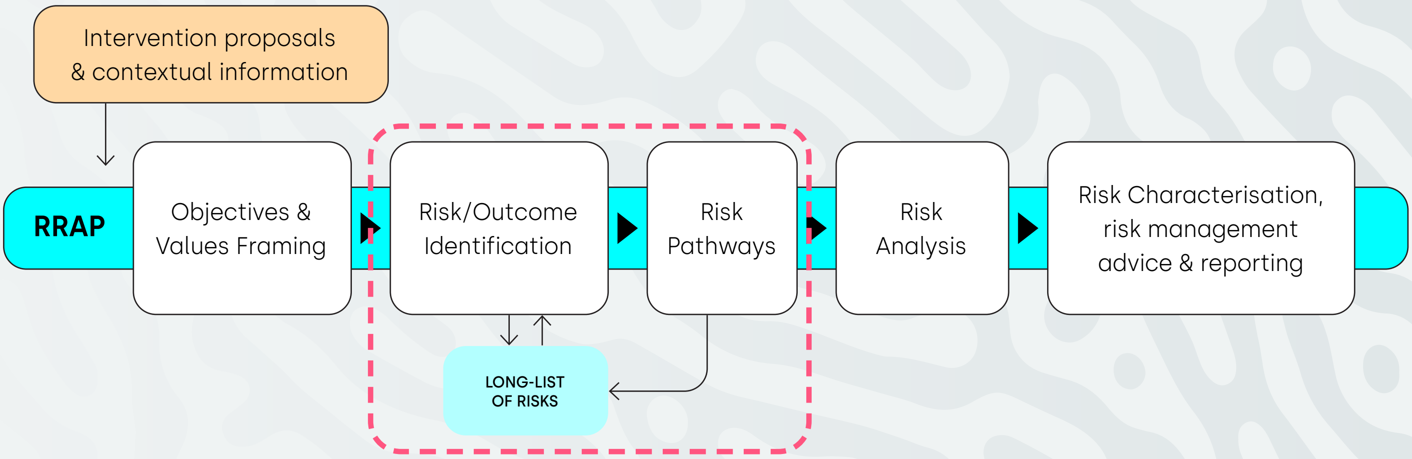
John Brewer Reef. Credit: Matt Curnock, Ocean Image Bank


Coral spawning. Credit: Gary Cranitch, Queensland Museum

6 Risk identification and risk pathway mapping

6.1 Methods

The methods for the risk/outcome identification and risk pathways stages are detailed in *RRAP Intervention Risk Assessment: Approach and methods.* The purpose of the identification stage is to ensure a comprehensive process is undertaken to identify all risks potentially associated with reef intervention deployments. Approaches to risk identification included expert elicitation (RRAP and non-RRAP), discussions and projects/activities/forums with Traditional Owners, stakeholders and community members, literature reviews, modelling, experiments and field research. The identified risks and outcomes are captured in the long-list of risks/outcomes. The purpose of the risk pathways mapping stage is to ensure there is a sound understanding of how the intervention activities may possibly lead to potential consequences for Marine Park values, including the relevant mechanisms, conditions and sequence of events. Risk pathways mapping may also contribute to further risk identification. A series of causal maps were developed to capture the risk pathways for the ecological dimensions of the Pilot Deployments base case assessment, and the supporting evidence base was documented. The IRRG Risk Review Process (Section 3.1) provided real-time feedback on this assessment, and input to these stages.



6.1.1 APPLICATION OF THE METHODS TO THE PROPOSED PILOT DEPLOYMENTS

RISK IDENTIFICATION

Risk identification for the proposed Pilot Deployments was undertaken as per the *RRAP Intervention Risk Assessment: Approach and methods*, with some exceptions (detailed in Appendix 6 of *RRAP Intervention Risk Assessment: Approach and methods*). The exceptions included:

Under the *RRAP Intervention Risk Assessment: Approach and methods*, the risk identification stage is undertaken once the intervention deployment proposal has been received. However, in this case, risk identification for SCR and CA methods initially drew upon findings from RRAP intervention risk identification work conducted prior to the development of the Pilot Deployments proposal. This previous work included (but is not limited to) literature reviews, research, modelling, expert elicitation, community panels, a biocultural risk project, discussions with Reef managers and surveys and interviews with Traditional Owners, stakeholders and community members. Upon development of the Pilot Deployments proposal, risk identification work also drew upon individual and group work directly in response to those proposals, as described in the *RRAP Intervention Risk Assessment: Approach and methods*. Across the risk assessment of the Pilot Deployments Program, over 80 people internal and external to RRAP contributed to risk identification and understanding of potential intervention risks, capturing diverse perspectives.

RISK PATHWAYS

Risk pathway mapping for the proposed Pilot Deployments was undertaken as per the *RRAP Intervention Risk Assessment: Approach and methods.*

6.2 Findings

Through the risk identification stage and preparatory work for the risk analysis, a set of potential consequences to Marine Park values was identified for inclusion in the assessment (refer to Table 2), as well as the mechanisms by and conditions under which consequences might occur (Appendix 1 for descriptions of key terms).

Causal maps were developed based on these findings and were also informed by a large body of scientific knowledge and theoretical understanding on relevant risk pathways, summarised in this report. During the risk identification and risk pathways development stages, areas of uncertainty were also identified.

These results are presented for each of the two Pilot Deployment methods (Slick Collection and Release, and Conservation Aquaculture) within the overarching theme of Environment and Biodiversity.

6.2.1 ENVIRONMENT AND BIODIVERSITY

The Objectives and values framing indicated the Pilot Deployment activities could have direct and/or indirect interactions with corals, plankton and microbes (symbionts) and the process of symbiosis, coral reefs and other organisms. To address the complexity of assessing the risks to these key environment and biodiversity values, the assessment was structured around several logical sub-themes (Figure 8).

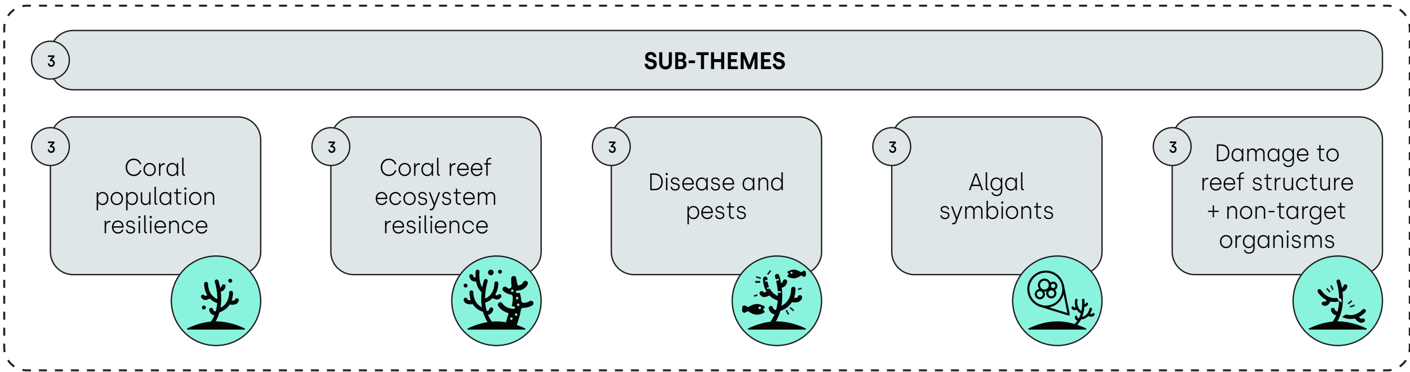


Figure 8 The five Sub-themes used to structure the assessment. This is the third level in the assessment structure.

THESE SUB-THEMES ARE:

1. Coral population resilience
2. Coral reef ecosystem resilience
3. Disease and pests
4. Algal symbionts
5. Damage to reef structure or non-target organisms

These sub-themes are included in Table 2 in relation to the relevant identified potential consequences (direct and indirect) to Marine Park values.

The sub-themes introduced in this section and included in Table 2 are presented and discussed in the following sub-sections of the report, each with background information and causal maps for each of the Pilot Deployment methods. The causal maps illustrate the Pilot Deployment activities and the potential consequences to Marine Park values which required assessment - along with the mechanisms and risk pathways by which these might occur. Further supporting information on mechanisms is provided in Appendix 2. The overall structure of the assessment has four levels and is summarised in Figure 9.

An example causal map is provided in Figure 10, and risk analysis is conducted for each risk pathway. Importantly, when estimating the risk associated with a particular risk pathway, it is the whole pathway that needs to be considered. For the pathway to eventuate, the pathway could occur via any relevant mechanism, and the whole pathway would need to occur and lead to the potential consequence.

Table 2 The list of potential consequences identified for assessment in relation to the current configuration of the proposed Pilot Deployments. Each potential consequence is described in terms of the assigned assessment sub-theme, the Marine Park value(s) it may directly or indirectly affect and the associated risk pathways (in terms of specific potential impacts, further defined in Table 3).

3

SUB-THEME	TYPES OF POTENTIAL CONSEQUENCE(S)	DIRECT EFFECT OF POTENTIAL CONSEQUENCE ON MARINE PARK VALUE(S)	INDIRECT EFFECT OF POTENTIAL CONSEQUENCE ON MARINE PARK VALUE(S)	TYPES OF POTENTIAL IMPACT(S) (VIA ASSOCIATED RISK PATHWAYS)
Coral population resilience	Detrimental effect on overall adaptive potential	Harm to coral population resilience, making coral populations less resistant to, or slowing recovery rates from, stressors and reef health impacts, including the impacts of climate change.	Flow on effects of harm to coral populations could in turn lead to harm to bony fish, other invertebrates and the continental slope of the Marine Park. Flow on effects to social and heritage dimensions (separately assessed).	• Future generations have reduced fitness
	Detrimental effect on overall adaptive potential And/or Detrimental effect on genetics of a coral species		Flow on effects of harm to coral populations could in turn lead to harm to bony fish, other invertebrates and the continental slope of the Marine Park. Flow on effects to social and heritage dimensions (separately assessed).	• Inbreeding depression • Loss of genetic diversity • Metapopulation connectivity is disrupted • Outbreeding depression
Coral reef ecosystem resilience	Detrimental effect on ecosystem structure or function	Harm to coral reef ecosystem resilience, making coral reefs less resistant to, or slowing recovery rates from, stressors and reef health impacts, including the impacts of climate change.	Flow on effects of harm to coral populations could in turn lead to harm to bony fish, other invertebrates and the continental slope of the Marine Park. Flow on effects to social and heritage dimensions (separately assessed).	• Metacommunity connectivity is disrupted • Shifting coral composition
Disease and pests	Detrimental effect on coral or reef organism health that causes the species to decline	Harm to corals or reef organisms from disease or pests results in a decline in the population of that species, leading in turn to the loss of ecosystem services or flow on effects within the reef food web.	Flow on effects of harm to coral populations could in turn lead to harm to bony fish, other invertebrates and the continental slope of the Marine Park. Flow on effects to social and heritage dimensions (separately assessed).	• Increased prevalence of parasites and pests • Increased prevalence of disease of biotic origin

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3

SUB-THEME	TYPES OF POTENTIAL CONSEQUENCE(S)	DIRECT EFFECT OF POTENTIAL CONSEQUENCE ON MARINE PARK VALUE(S)	INDIRECT EFFECT OF POTENTIAL CONSEQUENCE ON MARINE PARK VALUE(S)	TYPES OF POTENTIAL IMPACT(S) (VIA ASSOCIATED RISK PATHWAYS)
Algal symbionts	Detrimental effect on genetics of local algal symbiont populations	Harm to genetic diversity/ adaptive potential of local algal symbiont population means local algal symbiont populations are less resilient to stressors and reef health impacts, including the impacts of climate change.		• Loss of genetic diversity/ adaptive potential of local algal symbiont population
	Detrimental effect on coral-algal symbiosis	Harm to coral-algal symbiosis in non-target areas/non-target corals results in reduced coral health and resilience, making the non-target corals less resilient to stressors and reef health impacts, including the impacts of climate change.	Flow on effects of harm to coral populations could in turn lead to harm to bony fish, other invertebrates and the continental slope of the Marine Park. Flow on effects to social and heritage dimensions (separately assessed).	• Uncontained spread of provided symbionts to non-target areas/ corals
Damage to reef structure + non-target organisms	Detrimental effect on non-target coral or reef organism health that causes the species to decline or prevents recovery	Harm to non-target corals or reef organisms at intervention sites results in a decline in the populations of those species at target sites, leading to loss of ecosystem services or flow on effects within the food web.	Flow on effects of harm to coral populations could in turn lead to harm to bony fish, other invertebrates and the continental slope of the Marine Park. Flow on effects to social and heritage dimensions (separately assessed).	• Damage or disturbance to reef structure or other living things at target sites • Damage or disturbance to reef restructure or other living things at non-target site • Harm to species of conservation concern • Unsustainable depletion of other species from the ecosystem

Table 3 The list of potential impacts identified for assessment in relation to the current configuration of the proposed Pilot Deployments. A definition is provided for each potential impact.

4

TYPES OF POTENTIAL IMPACT	DEFINITION
Future generations have reduced fitness	A decrease in the ability of future generations to survive and reproduce in the environment in which they find themselves, and thus contribute genes to the next generation.
Inbreeding depression	The reduced biological fitness that has the potential to result from inbreeding (the breeding of related individuals).
Loss of genetic diversity	A reduction in the total number of genetic characteristics in the genetic make-up of a species.
Metapopulation connectivity is disrupted	Disruption of the connections between discrete local populations of coral species
Outbreeding depression	The reduced biological fitness that has the potential to result from crosses between two genetically different groups or populations.
Metacommunity connectivity is disrupted	Disruption of the connections between local communities of corals
Shifting coral composition	Changes in the types and relative proportions of coral species which make up a coral reef.
Increased prevalence of parasites and pests	Increased prevalence of parasites (organisms that live on or in a host organism and derives its food from or at the expense of the host) and pests (organisms which are harmful to human concerns).
Increased prevalence of disease of biotic origin	Increased prevalence of diseases caused by living things.
Loss of genetic diversity/ adaptive potential of local algal symbiont population	A reduction in the total number of genetic characteristics in the genetic make-up of a local algal symbiont population/ reduction in the capacity of the local algal symbiont population to respond to environmental changes through genetic variation.
Uncontained spread of provided symbionts to non-target areas/corals	Algal symbionts provided to target corals spread to non-target areas/ corals when deployed in the Marine Park.
Damage or disturbance to reef structure or other living things at target sites	Damage or disturbance to the ridge of material at or near the surface of the ocean that comprises the reef structure at target sites, or to other non-target organisms at the target sites e.g. fish.
Damage or disturbance to reef structure or other living things at non-target sites	Damage or disturbance to the ridge of material at or near the surface of the ocean that comprises the reef structure at non-target sites, or to other non-target organisms at non-target sites e.g. fish.
Harm to species of conservation concern	Harm to a plant or animal species that is protected by law or requires special conservation management within the Great Barrier Reef Marine Park.
Unsustainable depletion of other species from the ecosystem	Depletion of a species from the ecosystem at a rate or level that is not able to be maintained.

THE OVERAL STRUCTURE OF THE RISK ASSESSMENT

LEVEL	LEVEL NAME	EXAMPLE
1	Theme	Environment and biodiversity, social and economic
2	Value Groups	Corals, coral reefs
3	Sub-themes	Coral population resilience, coral reef ecosystem resilience
4	Risk pathways (via specific potential impacts)	Reduced connectivity within metapopulations

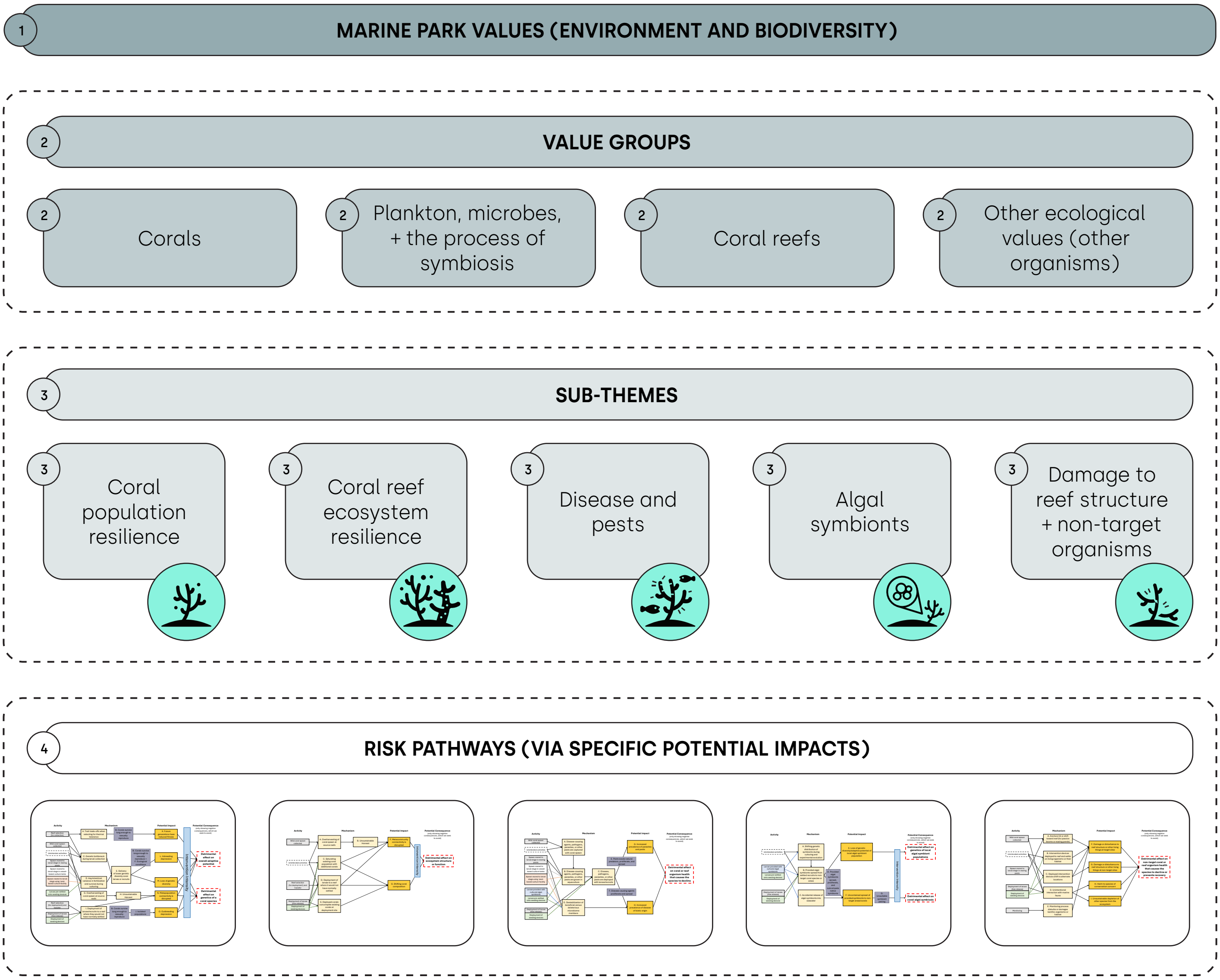


Figure 9 Overview of the risk assessment structure, showing the four levels.

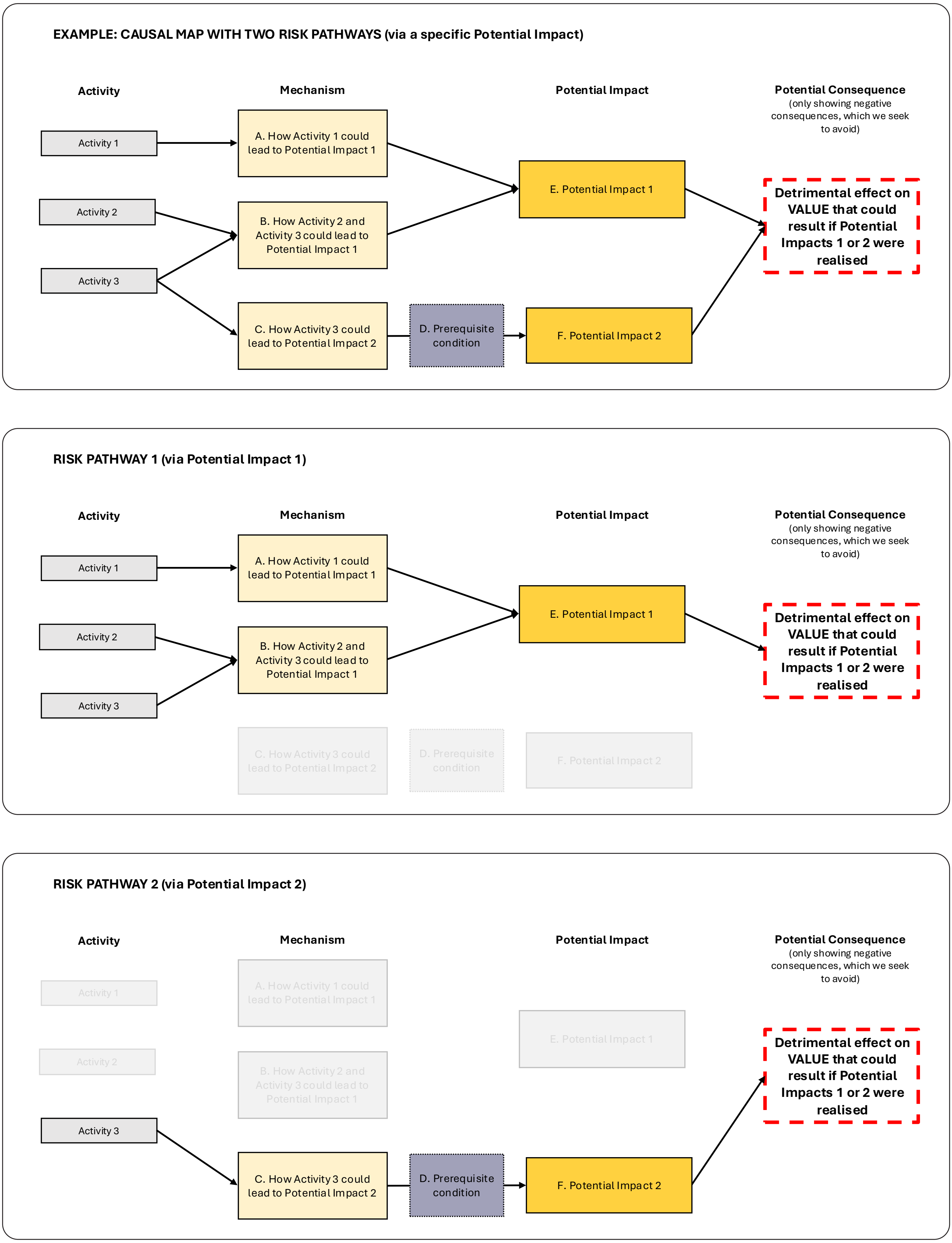


Figure 10 How to read the causal maps. This shows an example causal map with two risk pathways.

BACKGROUND

This part of the assessment addresses risks to coral population resilience of the specific coral larvae, juveniles, and adults involved in the interventions (termed 'target corals'). It also identifies direct or indirect risks to the resilience of other populations of corals (if any) that might interact with the proposed Pilot Deployments. These latter corals have been termed 'non-target corals'.

Resilience describes the stability of populations, communities or ecosystems and their responses to external perturbation (Ives & Carpenter, 2007). While various definitions of the term 'resilience' exist, two distinct components of resilience relevant to coral populations are: 1) the capacity for recovery, and more specifically, the rate at which coral populations retain former structure and abundance after an acute disturbance event has caused population declines, and 2) the resistance of the system to a changing environment (Nyström *et al*., 2008, Maynard *et al*., 2015). These two components of resilience, that is, recovery rate and resistance, can be considered at the coral population level (discussed in this section) and at the coral reef ecosystem level (discussed in the next section).

At the coral population level, thermal resistance (or thermal tolerance) is often used to describe the ability of individual corals to resist bleaching or to recover and survive after they have bleached, which is made possible by both species-specific and environmental factors (Done, 1999, West & Salm, 2003). The current configuration of the proposed Pilot Deployments includes the implementation of interventions that have some potential to increase coral thermal tolerance. Heat-tolerant corals (colonies with high resistance to thermal-induced bleaching) have been identified throughout the Reef and, if this trait is heritable, may have the potential to produce offspring with increased heat tolerance (Quigley & van Oppen, 2022).

POTENTIAL CONSEQUENCES AND RISK PATHWAYS

Two main potential consequences (Detrimental effect on overall adaptive potential, and Detrimental effect on genetics of coral species) were identified for assessment. The risk pathways by which the activities undertaken as part of SCR and CA might lead to these potential consequences are illustrated in the figures below.

Specifically, the risk analysis addresses risks associated with future generations of corals having reduced fitness (Figure 11 K and Figure 12 L), inbreeding depression (Figure 11 L and Figure 12 M), a loss of genetic diversity (Figure 11 M and Figure 12 N), a disruption of metapopulation connectivity (Figure 11 N and Figure 12 O), and outbreeding depression (Figure 11 O and Figure 12 P), leading to a detrimental effect on overall coral adaptive potential and/or genetics of a given coral species. An assessment is made of the risk of detrimental effects on overall coral adaptive potential and/or genetics of a given coral species on the Marine Park value 'Coral' and its attributes, should one (or more) of these potential impacts (e.g., reduced fitness, inbreeding depression) be realised because of the proposed intervention activities.

The potential consequence of a detrimental effect on overall adaptive potential addresses the possibility of harm to coral that alters their ability to adapt and survive in the environment over time. Genetic diversity is a Marine Park value and the potential consequence of a detrimental effect on genetics of a coral species addresses the possibility of harming this value during the proposed activities.

Current scientific understanding indicates that adaptive potential is closely linked to genetic diversity because greater standing genetic variation increases the likelihood that some individuals within populations will have the capacity to withstand environmental changes and other stressors (Boulding 2008; Carr *et al.* 2025; Chhina *et al.* 2024; Eizaguirre & Baltazar & Soares 2014; Torda & Quigley 2022). When genetic diversity is low and population sizes are small, the effects of drift (stochastic changes in genetic variation) can overwhelm adaptation in response to selection (Allendorf *et al.* 2022). Outbreeding depression (Figure 11 O, Figure 12 P) can manifest as the F1 generation of intermediate genotypes, produced by genetically distinct and often locally adapted parents that are less fit than either parental genotypes or the breakdown of biochemical or physiological compatibility (Frankham *et al.* 2011; Van Oppen *et al.* 2014). During inbreeding depression (Figure 11 L, Figure 12 M), individuals have an increased likelihood of the accumulation of deleterious genes resulting in phenotypes with low levels of fitness (Baums 2008). Both outbreeding and inbreeding depression can result in a reduction in genetic diversity, as well as overall adaptive potential. Details for each mechanism presented in Figure 11 and Figure 12 are outlined in Appendix 2. Of the potential impacts identified in Figure 11 and Figure 12, most would require two or more generations of coral due to many of the mechanisms relating to breeding and future generations and would likely take even longer to lead to a detrimental effect (potential consequence). The assessment considers and addresses any such slow-acting risks that could potentially occur over future coral generations.

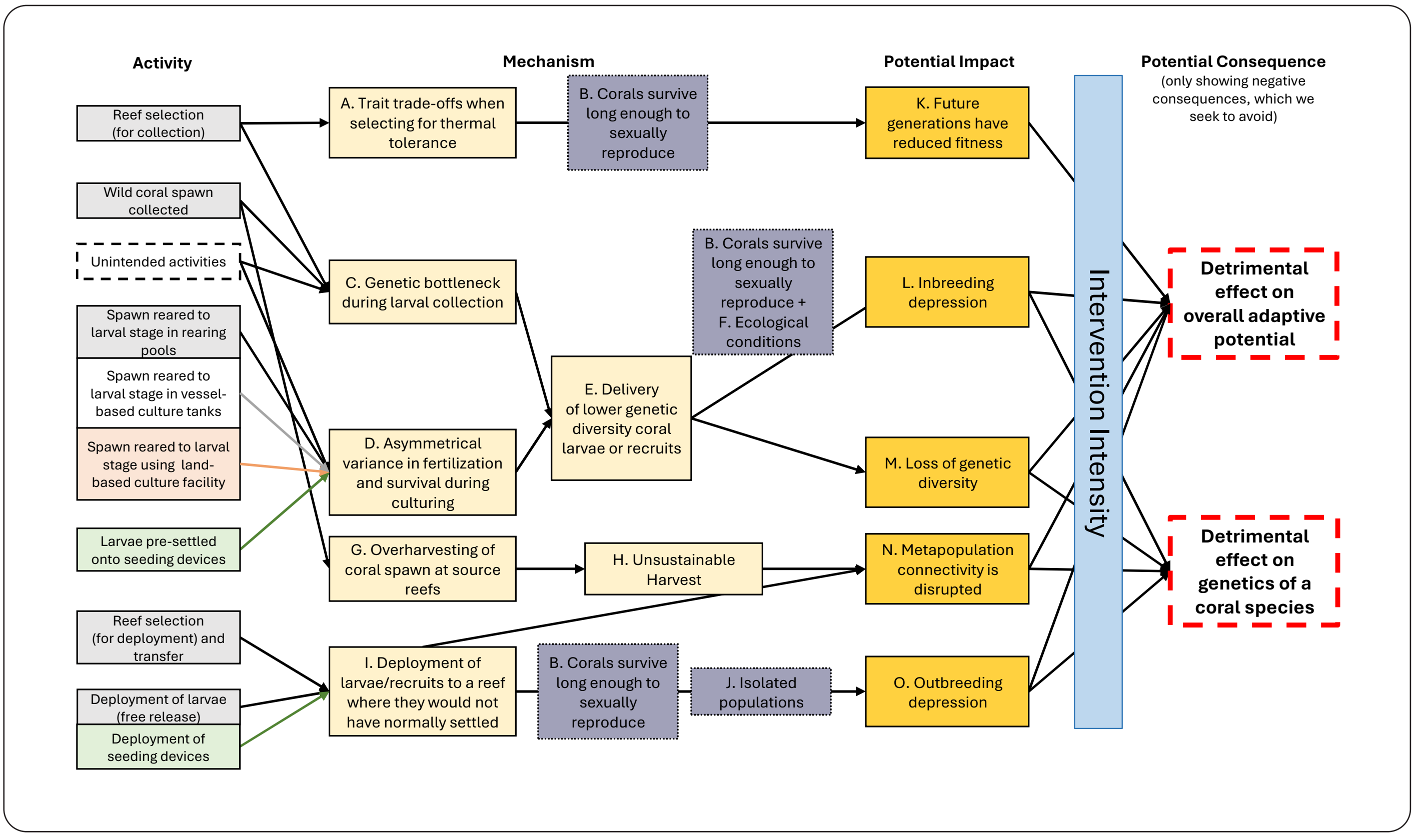


Figure 11 Causal map showing pathways to detrimental effects on coral population resilience based on activities from SCR. Arrows indicate stepwise mechanisms (A-J) that, if they eventuate, could lead to negative impacts (K-O) which could then manifest as detrimental effects on genetics or overall adaptive potential of a coral species on the Reef.

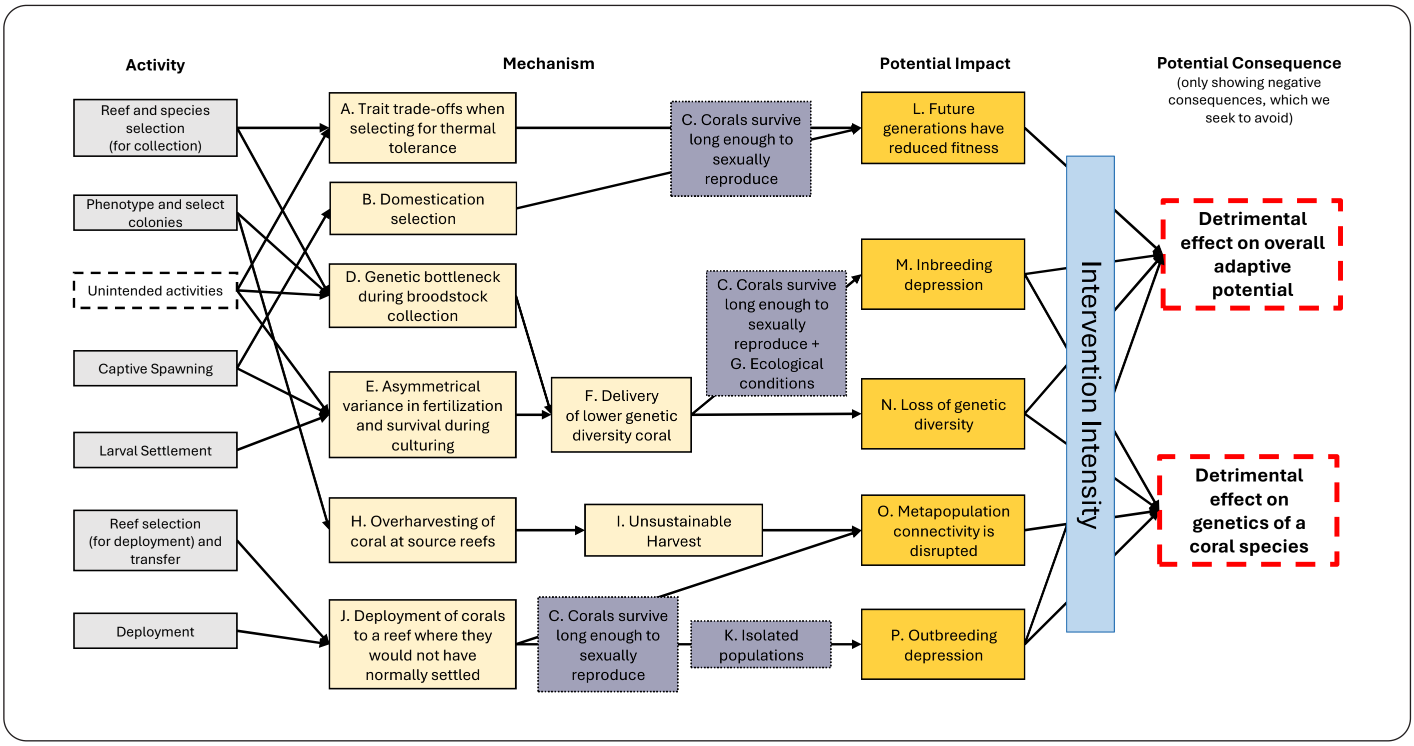


Figure 12 Causal map showing pathways to potential impacts on coral population resilience based on activities from CA. Arrows indicate stepwise mechanisms (A-K) that, if they eventuate, could lead to negative impacts (L-P) which, could then manifest as detrimental effects on genetics or overall adaptive potential of a coral species on the Reef.

Factors that may influence the likelihood and severity of a given potential impact leading to detrimental effects on coral genetic diversity or overall adaptive potential:

Factors that influence the estimate of likelihood, severity and risk were identified and considered during the risk assessment process. The influencing factors are further considered in terms of building knowledge and understanding the potential risks, how the risks might arise and opportunities for risk management.

- **Reef connectivity.** Spawning corals produce planktonic larvae that are capable of dispersing long distances (van Oppen *et al.*, 2008, Nunes *et al.*, 2011, Torda *et al.*, 2013, Wood *et al.*, 2014), facilitating high connectivity among distinct reefs and leading to low levels of genetic differentiation (Selkoe *et al.*, 2016). Marine larvae can disperse great distances (Kinlan & Gaines, 2003), with coral larval dispersal estimated to range from 1-100+ kilometres (van Oppen *et al.*, 2008, Underwood *et al.*, 2009). Despite the potential for long range dispersal, there is a genetic subdivision between the northern and central Great Barrier Reef regions (which are panmictic) and the southern offshore Great Barrier Reef (which has a higher level of genetic diversity and population structure (Lukoschek *et al.*, 2016, van Oppen *et al.*, 2011)). At the population level, the importance of regional connectivity of coral larvae is widely recognised to contribute to resilience via improved capacity for recovery (Jones *et al.* 2009b). Under natural conditions dispersal is dependent on the duration of larval competency. The presence of suitable surfaces for settlement, release timing of larvae, larval "behaviour" (e.g., chemotaxis and changes in buoyancy over time), and hydrodynamics have further influence on coral settlement, and thus, gene flow between populations (Botsford *et al.* 2009). Given the long potential range of natural dispersal of coral larvae and the relatively short distances of PDP larval transfers, the SCR intervention will maintain a safe operating (within region or subdivision) space that avoids moving corals beyond their natural distributions and ecological boundaries (such as the offshore southern to central and northern biogeographic divide).
- **Relative genetic diversity of collected broodstock/gametes compared to overall population diversity.** At the time of the assessment, the locations of the deployment sites and the coral species to be used were not yet confirmed, therefore the relative genetic diversity of collected broodstock/gametes compared to overall population diversity was unknown. This uncertainty was taken into account by the experts participating in the elicitation process (below). It is expected that, in the case of trait-selected breeding for CA, genetic diversity within deployed corals would be reduced but the background population genetic diversity will remain similar if sufficient genotypes contribute to the parental pool. As the scale of the interventions increases (considering the number of coral species and genotypes of each species included), this would decrease the likelihood of harm to coral genetic diversity by incorporating additional diversity into the deployment. Future research includes capturing population genomic information for corals at source reefs to estimate the numbers of broodstock required (for CA) to scale the genetic diversity to natural standing variation. For SCR, broodstock are collected from wild coral spawn slicks, so initial collections would likely represent relatively high genetic diversity. However, heterogeneity in spawning times of different taxa and potential selective loss of genotypes during culturing means that the entire genetic diversity of corals on the reef would not be represented. Understanding the genetic structure of corals on the Reef has been a key research focus over the past decade. Genetic analyses of common broadcast spawning *Acropora* (van Oppen *et al.*, 2011, Lukoschek *et al.*, 2016, Riginos & Beger, 2022) identify two distinct populations: a well-mixed northern/central cluster (from 9° to ~19°S), and a well-mixed southern cluster (from ~19° to ~24°S). Models of larval dispersal indicate that while many larvae may settle close to natal reefs (Thomas *et al.*, 2014), long-distance dispersal by larvae can allow for genetic mixing between populations (van Oppen *et al.* 2008). The aim is to mitigate risk associated with moving corals between genetically distinct populations by limiting larval transfer activities to include movement only between reefs within a cluster or nearby reefs (within a reef region).
- **Ecological processes.** Disturbance events after deployment (storms, bleaching, Crown-of-thorns starfish (COTS) predation), baseline levels of mortality (independent of any major disturbance events), fecundity of deployed corals, larval dispersal, and environmental filtering could impact genetic diversity and adaptive potential of deployed corals. Should there be any loss in genetic diversity attributed to CA and SCR activities, it would be managed by natural variation and tolerance of the system and would not lead to a reduction in overall coral genetic diversity for a given population of corals. Furthermore, low genetic diversity in small, fragmented populations can be reversed by crossing between genetically diverse populations (e.g., genetic rescue) (Clarke et al. 2024; Hoffmann et al. 2021).
- **Heritability and impact of trade-offs.** Where trade-offs with the selection of thermally tolerant corals have been documented, the most common is reduced growth (Bay & Palumbi, 2017, Cornwell *et al.*, 2021). Depending on the extent of growth suppression, it is possible for reduced growth to constrain recovery capacity and further increase the risk of declines in the face of recurrent disturbances. However, 1) adding slower growing, heat-tolerant corals to a reef may be considered better than adding none, and 2) given community-level dynamics on the Reef, the ecological cost of a reduced growth rate is low (Ortiz *et al.*, 2013).

- **Temporal factors.** For potential impacts identified in Figure 11 and Figure 12, most require 2+ generations of coral for any consequence to be observed and would likely take even longer for these consequences to lead to a detrimental effect. Changes in coral genetics from the potential impact of 'metapopulation connectivity is disrupted' (Figure 11 N and Figure 12 O) could be possible from a single coral generation (this has been observed in other marine taxa, e.g., Le Corre *et al.* 2015; Taboun *et al.* 2021). The length of a coral generation, that is, the duration from larval settlement to sexual maturity, varies from species to species (Rapuano *et al.*, 2023). At a minimum, one coral generation is 2-3 years, but is typically >5 years and as long as 10-20 years (Babcock 1991).
- **Varying dispersal capacity of different coral taxa.** Corals have a range of reproductive strategies, and most corals have a broadcast spawning or brooding mode of reproduction (reviewed by Harrison 2011, see also for example Gilmour *et al.*, 2016). The mode of reproduction is one of the factors that can affect dispersal capacity, especially brooding corals compared to spawning corals.

Existing avoidance/mitigation measures:

Existing or planned measures to avoid or mitigate any risks from the proposed Pilot Deployments were identified and considered during the risk assessment process. These measures were further considered in terms of building knowledge and understanding the potential risks, how the risks might arise and opportunities for risk management.

- **Careful intervention design, methods and appropriate intensity.** The combination of the abundance and density of corals deployed in relation to the receiving population size with the magnitude of thermal enhancement (if any, in relation to the thermal tolerance of the wild population). These will affect the likelihood of potential short- and long-term impacts being realised and the severity of impacts and hence risk levels.
- **Brief *ex situ* and *in situ* holding times for adult corals and larvae, respectively.** In CA, adult corals are typically selected and carefully removed from their natal reef, transported in aerated seawater to aquaria facilities, held until gametes are released, and then returned to their original locations. This is typically a 1-4-week process, depending on the location of the facility in relation to where corals are collected. Furthermore, the newly produced corals are held in the facility for as short a duration as possible, which is typically 1-5 weeks and up to a few months at most (much less than one generation). In SCR, it typically takes 5-8 days from spawn slick collection to development into competent larvae (the time until they reach peak competency to settle) prior to deployment directly onto the reef or settlement onto devices.
- **Selection criteria for source and deployment reefs.** Genetic management tools are being developed by RRAP to maximise genetic diversity, while avoiding reefs that are isolated with low gene flow (low connectivity), which can increase the risk of inbreeding depression. When selecting for source and deployment reefs, in terms of biological criteria, RRAP considers coral cover and diversity, connectivity with other reefs, biophysical properties, and history of bleaching (resilience). Non-biological criteria are also considered in the selection process, such as high value sites for Traditional Owners and/or tourism.
- **Selection criteria for broodstock species.** CA considers the availability of population genetics data, colony morphology, reproductive mechanisms, thermal tolerance, and suitability for aquaculture. An annual planning process will carefully select species across functional traits and will adopt a strategy that allows for the rotation of species and genotypes across intervention deployment years to minimise risk and maximise genetic diversity. SCR typically collects spawn slicks from a variety of locations and across multiple nights to maximise diversity. Ideally, selection criteria will also incorporate areas of reef with broodstock that are likely to have higher thermal tolerances, by collecting from areas that have high temperature ranges, higher mean temperatures, and increased number of prior mild bleaching events.
- **Deployment patterns.** The number of corals being deployed on a given reef are substantially smaller compared to the overall numbers of conspecific corals on that same reef and the numbers of corals from adjacent sites whose genetic material will contribute to future generations. Given coral deployment capacity, more deployment sites with fewer corals could reduce the likelihood and severity of any detrimental effects on local genetics because it avoids swamping and reduces the likelihood of deploying a saturated density of corals at an isolated site.

Ecosystem resilience has been defined as "the capacity of a system to absorb disturbance and reorganise while undergoing change to still retain essentially the same function, structure, identity, and feedbacks" (Walker *et al.*, 2004). Genetic diversity of foundation species, such as corals, can be a major driver of community structure and ecosystem function (Crutsinger, 2016). The delivery of corals to the selected deployment sites is intended to help chosen local reefs continue to be dominated by coral. A system that is dominated by corals offers more structure and will harbour more non-coral species diversity and higher species abundance (McClanahan *et al.*, 2012). Importantly, while SCR and CA interventions may shift coral community composition, if ecosystem function is unaffected or improves, there is no detrimental consequence on coral reef resilience.

POTENTIAL CONSEQUENCES AND RISK PATHWAYS

For coral reef ecosystem resilience, the risk analysis addresses the likelihood of a disruption to metacommunity connectivity (Figure 13 F and Figure 14 F) or shifting coral composition (Figure 13 G and Figure 14 G), leading to a detrimental effect on ecosystem structure and function. When considering the potential impact of a disruption to metacommunity connectivity, it is key to address how RRAP activities may influence spatiotemporal variation in magnitude and direction of connectivity among distinct reefs and the resultant dispersal of coral communities. Dispersal (i.e., gene flow) not only contributes to coral reef persistence through demographic rescue but can also hinder or facilitate evolutionary (local) adaptation (Kawecki & Ebert 2004). This section addresses the potential severity of a detrimental effect on Reef ecosystem structure and function should one of these potential impacts be realised. This potential consequence addresses harm to Marine Park values that can result from an alteration in ecosystem structure (the abundance of species or variation in community composition among spatial units) or function (energy and material fluxes) (Brandl *et al.*, 2019). Details for each mechanism presented in Figure 13 and Figure 14 are outlined in Appendix 2.

Factors that may influence the likelihood and severity of a given potential impact causing harm to coral reef ecosystem structure or function:

The influencing factors for risks to coral genetic diversity or overall adaptive potential also apply to the risk of harm to ecosystem structure and/or function. These include reef connectivity, species diversity of collected broodstock/gametes, and ecological processes such as competition.

Existing avoidance/mitigation measures (same as above for coral population resilience):

- **Selection criteria for source and deployment reefs.** Genetic management tools are being developed by RRAP to maximise species diversity, while avoiding reefs that are isolated with low gene flow. Low connectivity could, over time, lead to species divergence and the formation of cryptic species. When selecting for source and deployment reefs, RRAP considers coral cover and diversity, connectivity with other reefs, biophysical properties, and history of bleaching. These selection parameters will reduce the likelihood of a potential impact being realised and the severity of the potential consequence.
- **Selection criteria for source broodstock.** For CA, coral species can be selected across a range of reproductive strategies (e.g., brooding, spawning), and across a range of colony morphologies (e.g., branching, massive, etc.) and thermal tolerances, although species that are thermally tolerant are preferred. A combination of criteria will be used to ensure a diversity of coral species across functional traits, reproductive strategies and ecological responses are captured to minimise risk. For SCR, collection is from the wild community so covers a broad space for multiple traits (morphologies, tolerances, vital rates, diversity). Species that have previously been the focus of extensive ecological and genetic analysis will be prioritised in early deployments.
- **Sustainable collection of broodstock.** For CA, a very small proportion of adult corals are collected from the donor reef for transfer to aquarium facilities for, collection of gametes following spawning, or microfragmentation (asexual production). When utilised for gamete collection, adult colonies are returned to collection locations. For SCR, a very small proportion of spawned gametes is collected from the wild coral spawn slicks that are released (<0.001%; Doropoulos *et al.*, 2019).

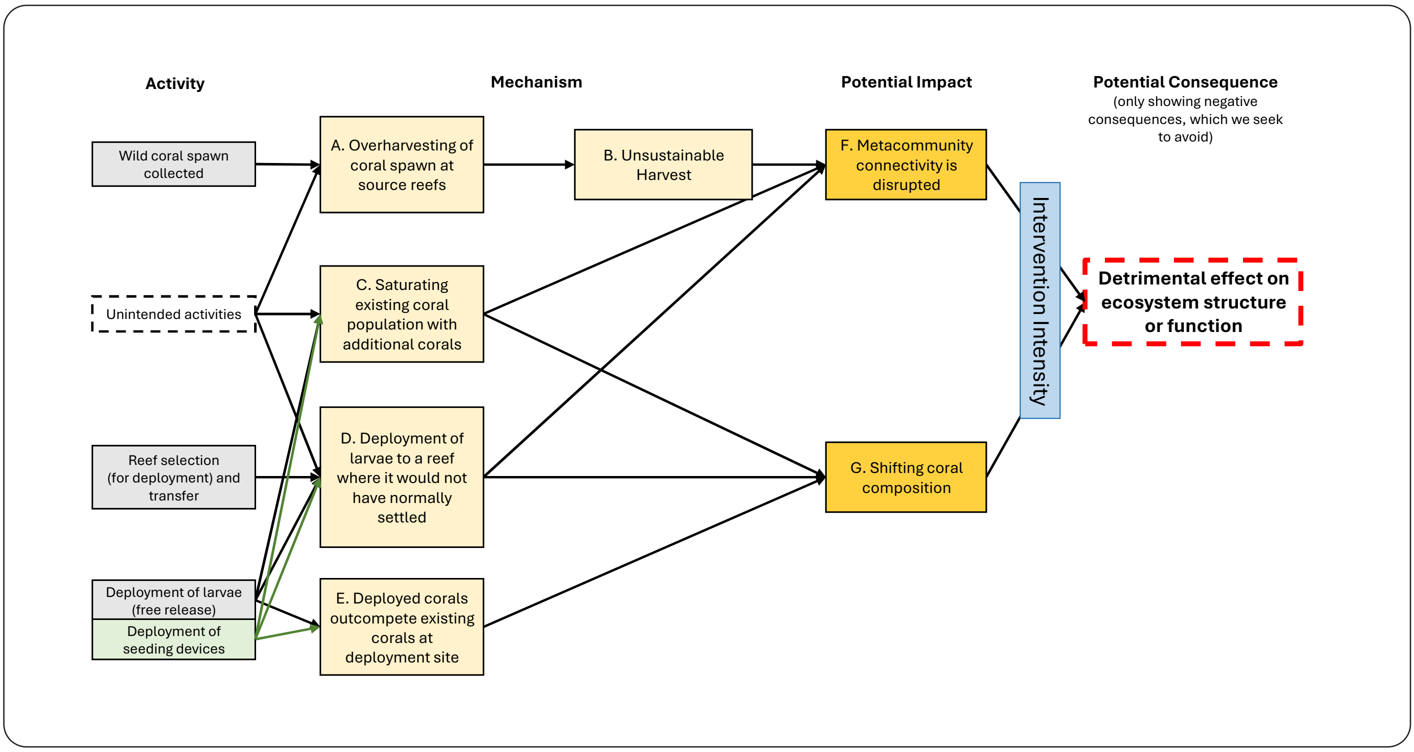


Figure 13 Causal map showing pathways to a detrimental effect on coral ecosystem structure or function based on activities from SCR. Arrows indicate stepwise mechanisms (A-E) that, if they eventuate, could lead to negative impacts (F-G) which could then manifest as detrimental effects on ecosystem structure or function for the Reef.

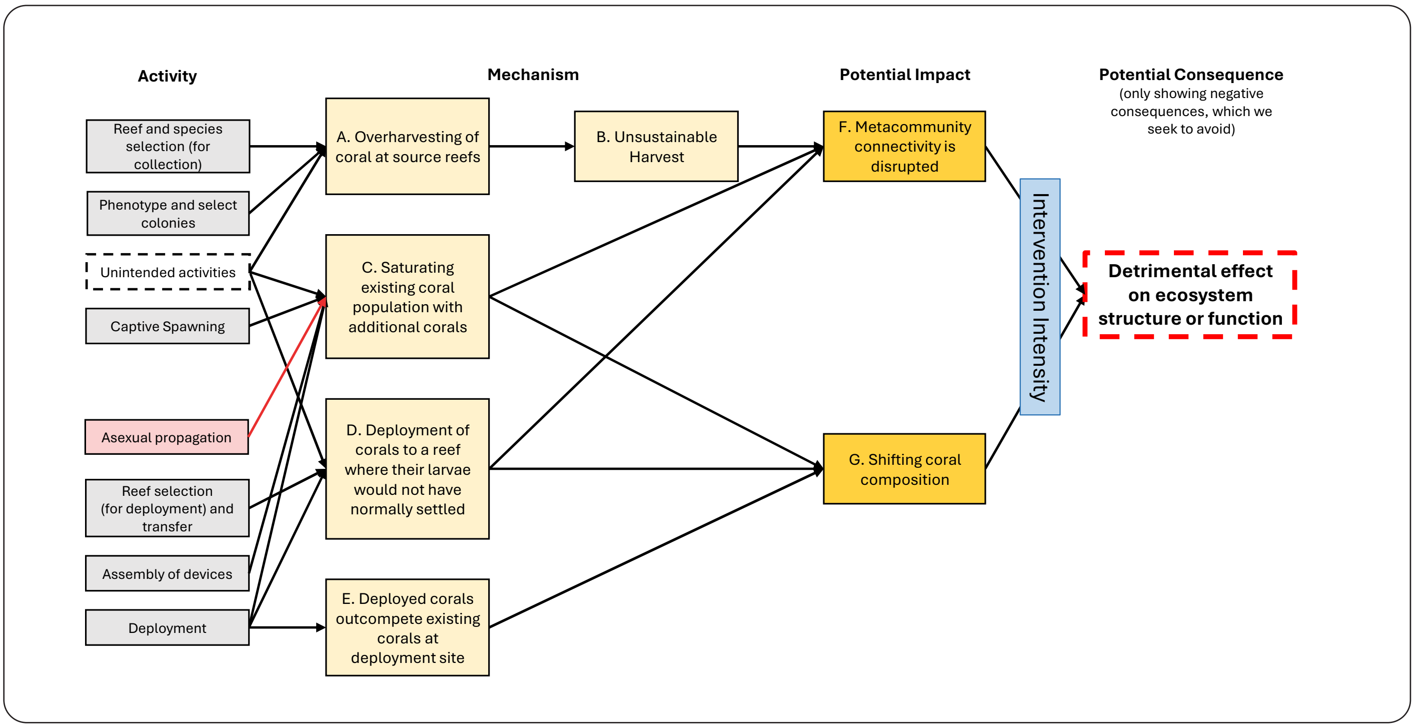


Figure 14 Causal map showing pathways to a detrimental effect on coral reef ecosystem structure or function based on activities from CA. Arrows indicate stepwise mechanisms (A-E) that, if they eventuate, could lead to negative impacts (F-G) which could then manifest as detrimental effects on ecosystem structure or function for the Reef.

3 6.2.1.3 DISEASE AND PESTS

Generally, when deploying coral interventions on the Great Barrier Reef, it is essential to consider the risk of exacerbating coral diseases, such as black band disease, white syndromes, skeletal eroding band and emerging diseases, or introducing new disease and pest issues. Restoration activities must also account for factors that influence disease dynamics, including coral handling, thermal stress, water quality, and microbial community disruption, to ensure interventions do not inadvertently increase coral vulnerability or compromise reef health. Similarly, pests such as the crown-of-thorns starfish (*Acanthaster cf. solaris*) can significantly impact coral cover and may be inadvertently introduced, attracted, or spread through the movement of materials or changes to local environmental conditions. Restoration deployments must therefore consider the potential for interventions to alter disease or pest dynamics and implement biosecurity and monitoring measures to minimise these risks.

During the collection, maintenance, and deployment of corals used by the SCR and CA interventions, there is potential for a risk of spread or increased prevalence of coral disease, pathogens, parasites, and pests. The mechanisms detailing this path to harm are shown in Figure 15 and Figure 16 and described in Appendix 2.

POTENTIAL CONSEQUENCES AND RISK PATHWAYS

The risk analysis addresses the likelihood and severity of an increased prevalence of parasites and pests (Figure 15 G and Figure 16 G) or an increased prevalence of disease of biotic origin (Figure 15 H and Figure 16 H) leading to a detrimental effect on coral or reef organism health that causes the species to decline. This potential consequence specifically addresses the mortality of coral or reef organisms because of pests, parasites, or disease that are enriched in the ecosystem because of intervention activities. For there to be harm to Marine Park values, there would have to be sufficient mortality that leads to a reduction in species abundance and thus influences downstream ecological processes.

For the Reef to experience a reduction in coral or reef organism health that is substantial enough to cause a species to decline, disease causing agents or pests would have to be collected with larval slicks (Figure 15 A) or selected broodstock (Figure 16 A) and then propagated during the aquaculture phase (Figure 15 B and Figure 16 B) before being introduced back to the Reef via deployed corals (Figure 15 C and Figure 16 C). From there, disease-causing agents must find a host organism or other medium to grow and spread to other hosts (Figure 15 F and Figure 16 F). Pests would have to evade their natural predators on the reef, proliferate, and spread (Figure 15 E and Figure 16 E). Alternatively, culturing conditions, optional treatments, and/or deployment could result in a shift in the coral-associated microbial community and an increase in coral disease-associated pathogens (Casey *et al.*, 2015) (Figure 15 D and Figure 16 D).

AIMS scientist watches over the Autospawner - designed to harvest and aid in the fertilisation of coral eggs and sperm, producing millions of coral larvae. Credit: Marine Roman, AIMS

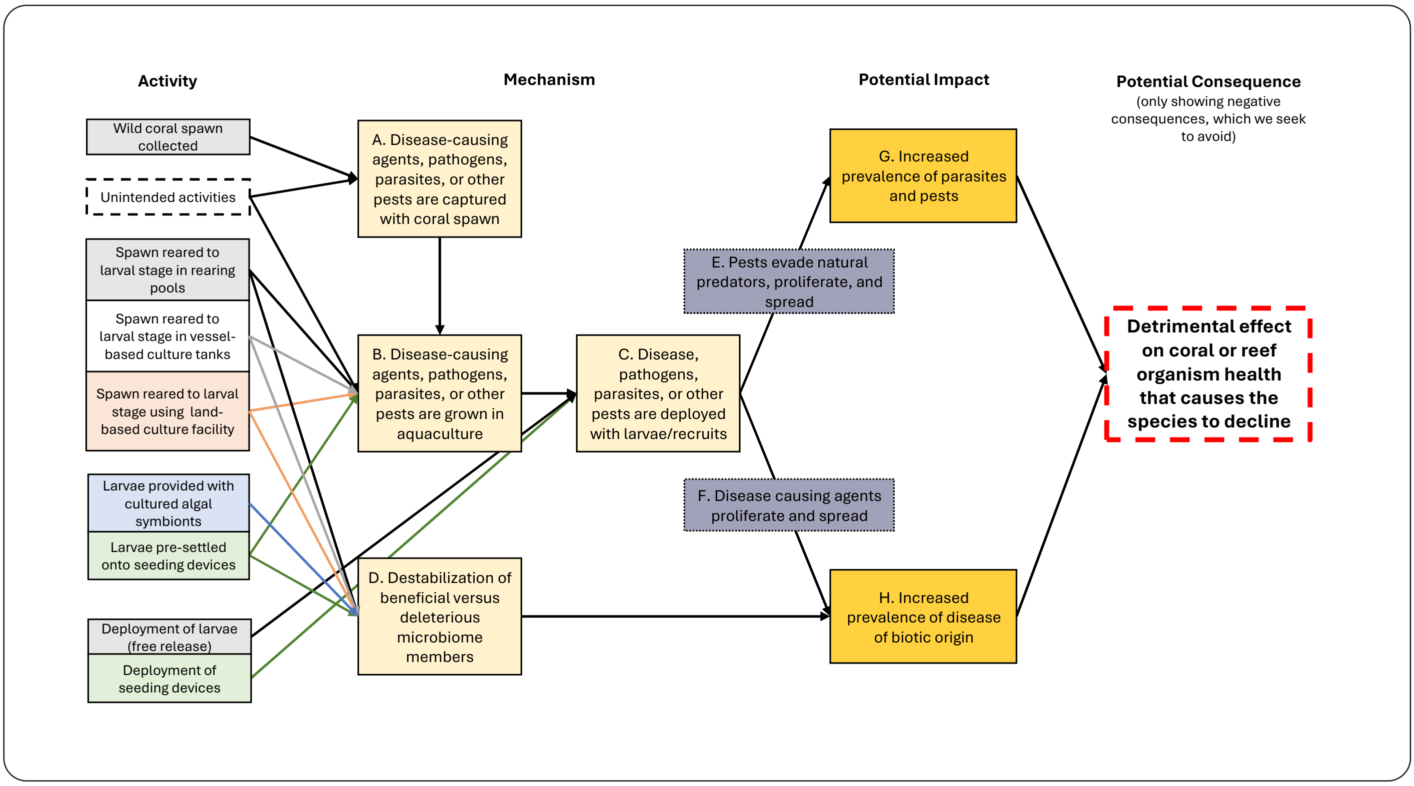


Figure 15 Causal map showing pathways to a detrimental effect on coral or reef organism health based on activities from SCR. Arrows indicate stepwise mechanisms (A-F) that, if they eventuate, could lead to negative impacts (G-H) which could then manifest as detrimental effects on coral or reef organism health that may cause the species to decline.

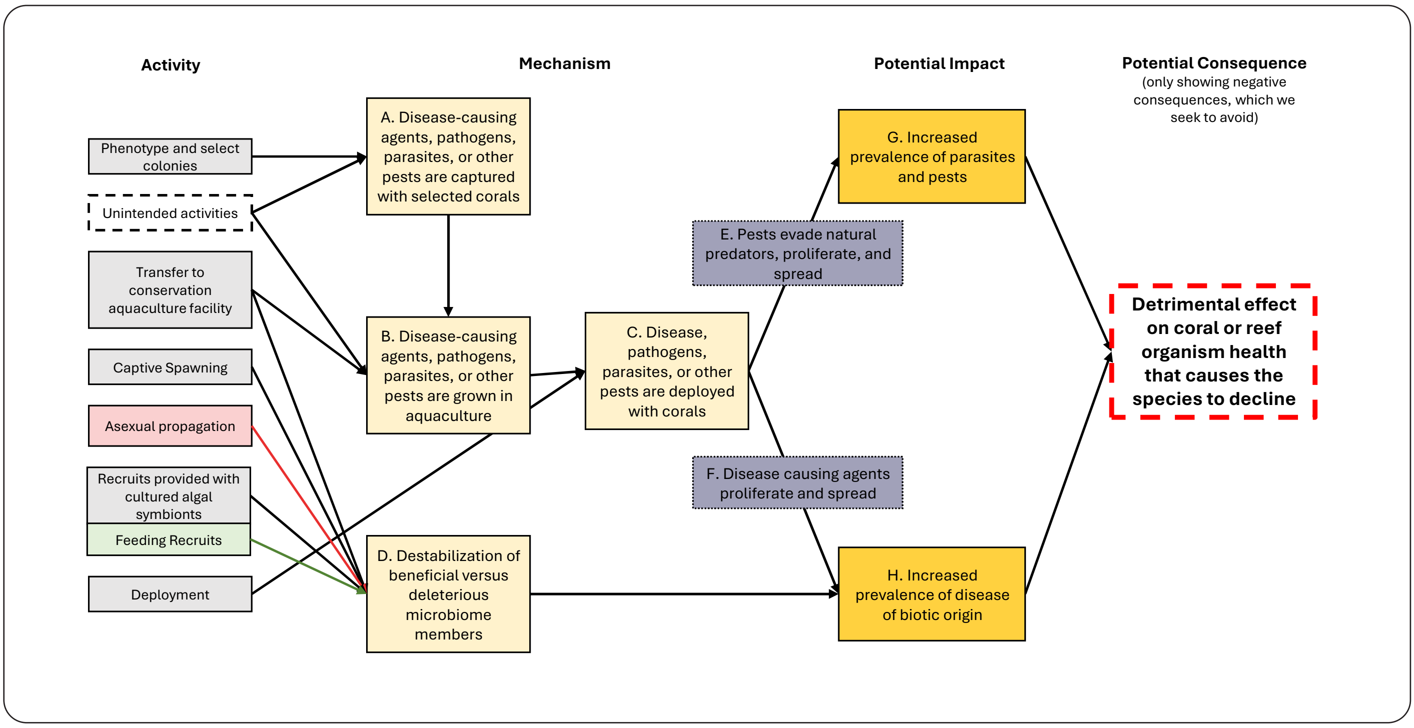


Figure 16 Causal map showing pathways to a detrimental effect on coral or reef organism health based on activities from CA. Arrows indicate stepwise mechanisms (A-F) that, if they eventuate, could lead to negative impacts (G-H) which could then manifest as detrimental effects on coral or reef organism health that may cause the species to decline.

Factors that may influence the likelihood and severity of a given impact causing harm to coral or reef organism health:

- **Duration.** For corals deployed as part of SCR, the larvae will be held for a short period in either rearing pools in the ocean or on-board culture tanks; coral gametes/larvae/recruits will not be exposed to corals from other collections (e.g. different spawning trips) and reef systems (as specified in the *PDP Ecological Plan*). Conversely, CA corals will spend significantly more time in aquaculture facilities and may be exposed to potential pathogens or pests brought in with different coral cohorts. However, corals from the SeaSim have been deployed for the past decade and there have been no known cases of the spread or increased prevalence of disease picked up in the post-deployment monitoring that has occurred. Dedicated disease monitoring has generally not been part of those projects.
- **Prevalence of disease-causing agents.** Prevalence of disease-causing agents in deployed corals is considered likely to be comparable to background ecosystem levels. Most corals typically harbour low abundances of microbes that can be disease-causing at high density (Pratte 2013; Work *et al.* 2008). When this relative abundance shifts and the prevalence of disease-causing agents is greater than that of the background ecosystem, this increases the likelihood of disease (Littman *et al.*, 2011, McDevitt-Irwin *et al.*, 2017)
- **Transmission of disease/pests from one host to another.** The spatial distribution of coral disease on the Reef is typically patchy (Haapkylä *et al.*, 2010) with some diseases not transmitting to a neighbour colony even with direct contact (Roff *et al.*, 2011), indicating that disease outbreaks are usually restricted to the local scale. For the spreading or increased prevalence of pests, pests have natural predators on the Reef that would tend to reduce or eliminate this threat in the wild. The density of host corals in the target reef could also influence the transmission of disease/pests (Beeden *et al.* 2012).
- **Ecological conditions.** Environmental conditions (high temperature, nutrient and sediment load) that are conducive to the proliferation of some disease-causing agents or pests would increase the likelihood of the potential impact of an increased prevalence of disease of biotic origin (Beeden *et al.* 2012).
- **Recovery rates.** The natural ability of corals to recover from disease, as well as the time required for natural microbiomes to re-establish and stabilise, will influence the likelihood and severity of the intervention activities leading to a detrimental effect on coral or reef organism health.
- **Coral cover/composition.** Sites with higher *Acropora* and *Montipora* cover might be more susceptible to disease as there may be selective impacts of disease on coral communities and acroporid corals are known to be susceptible (Haapkylä *et al.* 2010; Hobbs *et al.* 2015). However, sites with high coral cover are unlikely to be targeted for coral restoration activities.

Existing avoidance/mitigation measures:

- **No corals or material from outside of the Great Barrier Reef.** Corals and coral spawn will be locally sourced from the Reef (i.e., coral animals and associated pests/microbiota are native to the Reef) and therefore no foreign novel pathogens/pests will be introduced by RRAP interventions.
- **QA/QC protocols.** QA/QC measures will focus on the production processes to screen against harmful microbial infestations and outbreaks of targeted eukaryotic pests. The CA protocols and the SCR protocols (where relevant) implement water sterilisation techniques (filter seawater through a series of 5-50 μm filters and sterilised seawater using UV filters) that minimise potential pathogen/pest build-up. Visual checks are performed on the broodstock corals and larval cultures during CA. Only visually healthy corals will be deployed to intervention sites. CA QA/QC will be further facilitated by using DNA-based techniques to detect and quantify targeted pests (e.g., flatworms) and bacteria (total bacterial load and relative abundance of specific taxa commonly associated with disease in aquatic animals, e.g., *Vibrio* spp.) where practical. Because corals are maintained in aquaculture facilities for only short periods (typically weeks to a few months), it is not expected that pests or microorganism would evolve to become more virulent during this period. Based on the same reasoning, it is also not expected that culture conditions will favour the differential proliferation of rare types of pests or microorganisms that might become problematic.
- **Site selection.** Visual surveys will be used to select SCR sites and will avoid collections from sites with evidence of abundant crown-of-thorns starfish (COTS) to avoid capturing and propagating COTS larvae. COTS on the Reef typically spawn in Jan-Mar (Caballes *et al.*, 2021), which is later than the mass coral spawning events of corals (Oct-Dec), making it unlikely that COTS larvae would be co-collected with coral spawn slicks. Molecular approaches, such as monitoring environmental deoxyribonucleic acid (eDNA), can also be used to detect COTS (Kwong *et al.* 2021; Uthicke *et al.* 2022; Wei *et al.* 2024) in larval rearing pools.

3 **6.2.1.4 ALGAL SYMBIONTS**

Corals live in symbiotic association with other organisms, including bacteria, protists, fungi, archaea, and viruses (Blackall *et al.*, 2015, Ainsworth *et al.*, 2017, Huggett & Apprill, 2019, Ricci *et al.*, 2019). These microbial associates contribute to the overall health of this complex host-microbe association, or holobiont (Rohwer *et al.*, 2002). A noted eukaryote in the coral holobiont are the algal endosymbionts, which are dinoflagellates in the Family Symbiodiniaceae. In this obligate, mutualistic relationship, corals provide a safe haven and inorganic nutrients, while the Symbiodiniaceae meet most of the corals' energy needs through the transfer of photosynthate (Tremblay *et al.* 2012; Yellowlees *et al.* 2008) in an otherwise nutrient-poor environment (Falkowski *et al.* 1984; Muscatine & Porter 1977). The relationship between the coral host and Symbiodiniaceae breaks down during the biological process of coral bleaching. The dominance of certain Symbiodiniaceae genera, particularly *Durusdinium*, within the coral host can promote resilience under environmental stressors such as increased sea surface temperatures (Baker *et al.* 2004; Berkelmans & van Oppen 2006; Fabricius *et al.* 2024; Jones *et al.* 2008).

Furthermore, it is understood that the provisioning of Symbiodiniaceae to coral larvae and recruits can improve the survival of these juvenile corals in aquaculture facilities and post-deployment (Suzuki *et al.*, 2013). To achieve these benefits, SCR (Figure 17) and CA (Figure 18) will provide larvae or recently settled recruits with cultured symbionts that are sourced from the same region of the Reef (and, where possible, the same Traditional Owner sea Country) as the deployment site. There has been recent CA research and trials by RRAP on the Reef including provisioning corals with cultured algal symbionts.

POTENTIAL CONSEQUENCES AND RISK PATHWAYS

The risk analysis addresses the likelihood and severity of a loss of genetic diversity/adaptive potential of local algal symbiont populations (Figure 17 E and Figure 18 D) leading to a detrimental effect on the genetics of local algal symbiont populations. Here, the potential consequence addresses a change in genetic diversity of existing algal symbionts on the Reef, noting that these symbionts could be currently in symbiosis with other organisms as well as free-living in the sediments or seawater. Genetic diversity in and of itself is a value of interest and is a driver of adaptation.

For the likelihood and severity of an uncontained spread of provided symbionts to non-target areas/corals (Figure 17 F and Figure 18 E) leading to a detrimental effect on coral-algal symbiosis, this potential consequence addresses potential changes to the coral-algal relationship that cause harm to non-target corals. This includes incompatibilities between symbionts and corals that lead to a failure to establish or maintain a healthy symbiosis or where the relationship shifts from a mutualistic to parasitic, leading to coral death. Note that trait trade-offs are covered in 'coral population resilience' above. Details for each mechanism presented in Figure 17 and Figure 18 are outlined in Appendix 2.

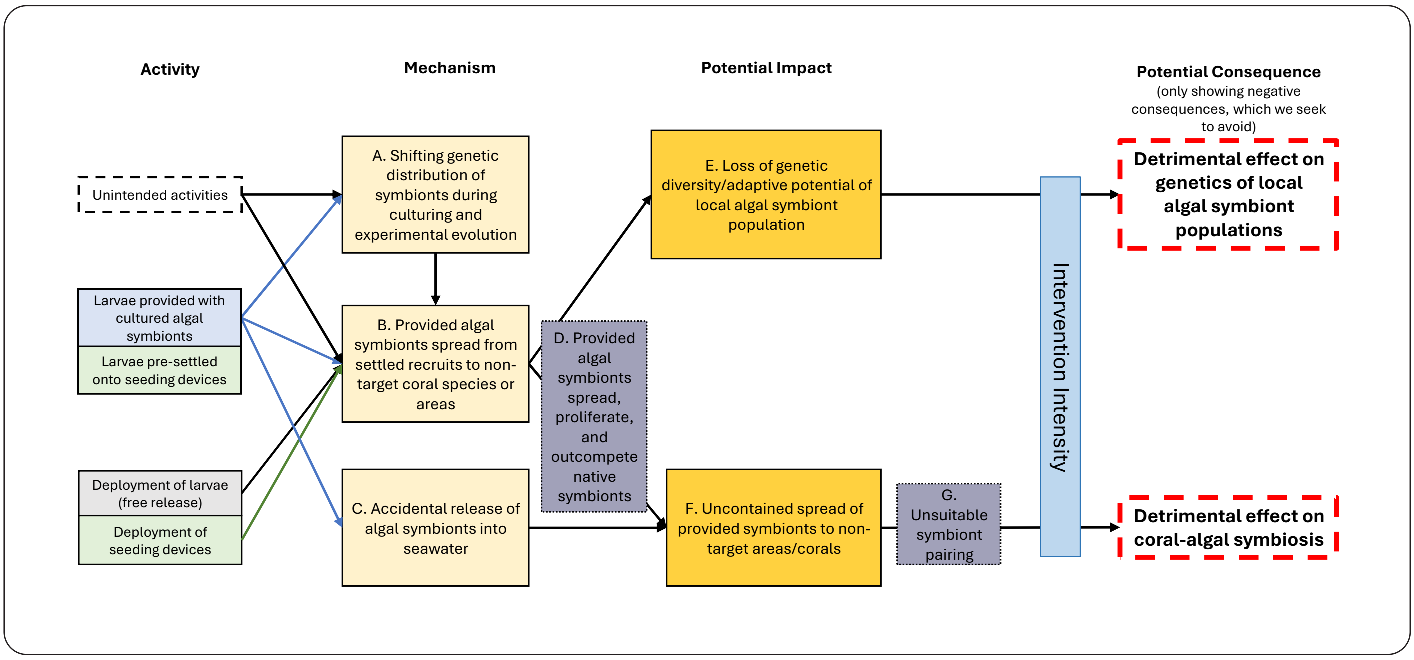


Figure 17 Causal map showing pathways to harm when applying algal symbionts to corals based on activities from SCR. Arrows indicate stepwise mechanisms (A-D, G) that, if they eventuate, could lead to negative impacts (E-F) which could then manifest as detrimental effects on the genetics of local algal symbiont populations and coral-algal symbiosis, respectively.

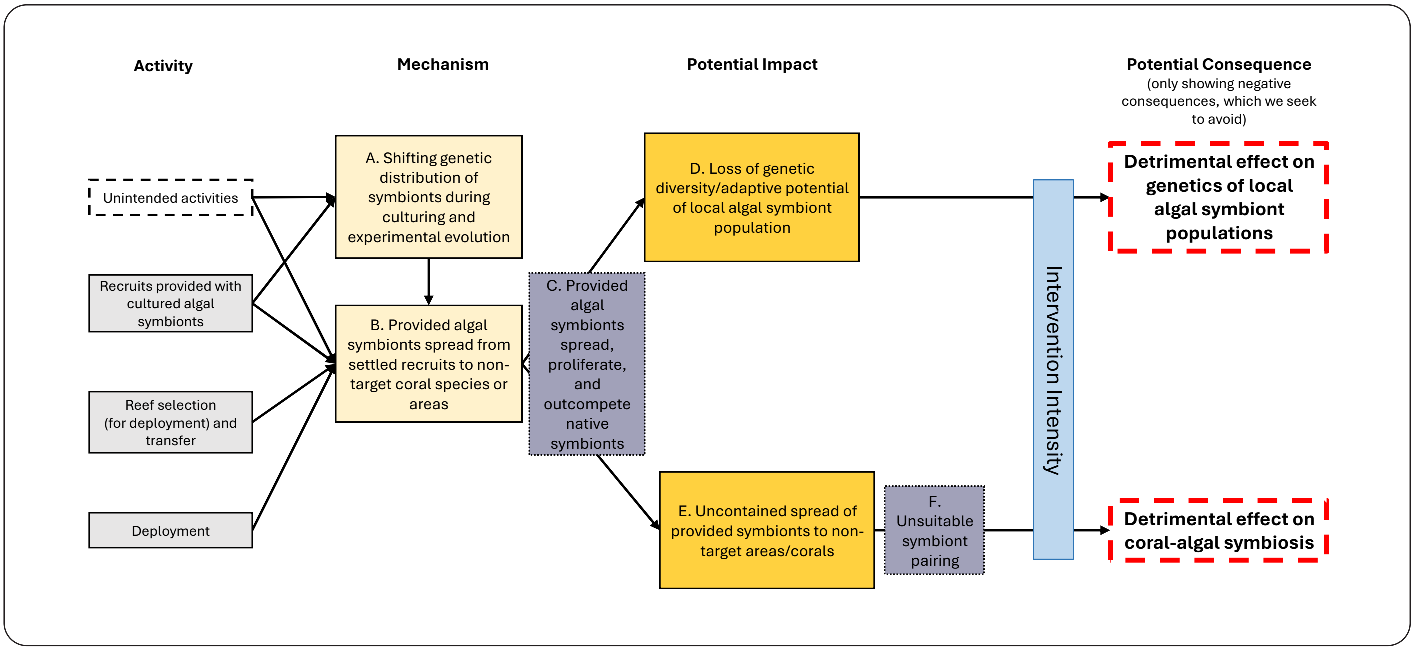


Figure 18 Causal map showing pathways to harm when applying algal symbionts to corals based on activities from CA. Arrows indicate stepwise mechanisms (A-C, F) that, if they eventuate, could lead to negative impacts (D-E) which could then manifest as detrimental effects on the genetics of local algal symbiont populations and coral-algal symbiosis, respectively.

Factors that may influence a potential impact causing harm to coral-algal symbiosis or genetics of local symbiont populations:

- **Source of algal symbionts.** Source location and host for cultured algal symbionts versus source and deployment reefs for corals they are provided to. For the proposed deployments, cultured symbionts will be sourced from the same Reef region (and, where possible, the same Traditional Owner sea Country) as the deployment site. The symbiont species most likely to be used will be generalist species that are compatible with multiple coral species, such as the species *Cladocopium proliferum* which is highly prevalent and ecologically widespread in nearly all ocean basins and reef habitats where photosymbiotic animals occur (LaJeunesse *et al.*, 2010, LaJeunesse *et al.*, 2018). This species associates with a broad range of invertebrate host taxa including numerous species of reef-building corals, sea anemones, jellyfish, clams, and various soft corals (LaJeunesse *et al.*, 2018, Lee *et al.*, 2020).
- **Time from establishment of cultures to provisioning of symbionts.** There is evidence of sexual reproduction in algal symbionts (Figueroa *et al.*, 2021). Long-term maintenance of cultures could result in genetic changes in the culture as the result of genetic drift and/or selection for culture conditions, which could result in cultures that are not as suitable for reef environments as symbionts that have been freshly isolated from those environments.
- **Culturability of different symbionts.** The diversity of Symbiodiniaceae on the Reef is high, particularly among certain genera, such as *Cladocopium* (LaJeunesse *et al.,* 2004; Quigley *et al.,* 2022; Fujise *et al.,* 2021; Marzonie *et al.,* 2024) and many symbionts are not yet established in culture. Different symbionts vary in the ease with which they can be cultured, leading to culture bias in favour of common taxa that are easily cultured. Some coral species might not do as well if provisioned with these 'generalist' taxa compared to 'specialist' symbiont taxa and would have to acquire these separately once out-planted.
- The establishment of algal cultures is an ongoing area of research; however, it is not expected there would be a change in coral phenotype (ability to form symbiosis, *in hospite* symbiont photo physiology, coral growth and survival) when corals are provided with symbionts that have been in culture (Quigley *et al.*, 2021).
- **Ability and preference of corals or other organisms to form symbioses.** The ability and preference of corals or other organisms to form symbioses with RRAP-provided algal symbionts. This also includes physiological state of non-target corals as bleached corals are more likely to acquire exogenous symbionts (Cunning *et al.,* 2015; Lewis & Coffroth, 2004) with repercussions for ecosystem persistence in some cases. On coral reefs, increases in heat-tolerant symbionts after thermal bleaching can reduce coral susceptibility to future stress. However, the relevance of this adaptive response is equivocal owing to conflicting reports of symbiont stability and change. We help reconcile this conflict by showing that change in symbiont community composition (symbiont shuffling). The Pilot Deployments are most likely to provision corals with generalist species of algal symbionts that are compatible with multiple coral species, such as the species *Cladocopium proliferum* which is highly prevalent and ecologically widespread in nearly all ocean basins and reef habitats where photosymbiotic animals occur (LaJeunesse *et al.*, 2010, LaJeunesse *et al.*, 2018). There may be specificity of symbionts for a particular coral species, and *Cladocopium proliferum* is not necessarily the preferred symbiont for at least some of the coral species on the long-list for use in the PDP. However, expert discussions confirmed any mismatch in preferred symbionts is not an ecological risk to Marine Park values. Such symbionts would likely be replaced over time if suboptimal.
- **Existing population dynamics and biomass of local algal symbionts.** The existing population dynamics and biomass of local algal symbionts, including those in symbiosis with other corals and sediment/seawater reservoirs. There is substantial evidence that corals can shift their symbiont communities (Baker 2003, Berkelmans & van Oppen 2006, Stat & Gates 2011, Cunning 2021, Elder *et al.*, 2023), particularly after bleaching (Baker 2001, Baker *et al.,* 2004, Jones *et al.,* 2008, LaJeunesse *et al.,* 2009, Cunning *et al.,* 2015, Quigley *et al.,* 2022, Palacio-Castro *et al.,* 2023). There is a need to consider any effects on coral-algal symbiosis (using evidence and reasoning), such as on establishing or maintaining symbiosis or any effects on the nature of the relationship between host and symbiont and lifetime host fitness (e.g., Baker *et al.*, 2004, McIlroy *et al.*, 2019, Palacio-Castro *et al.*, 2023).
- **Spread.** The spread of provisioned symbionts to other areas and corals is an intended outcome of some coral reef interventions and speaks to the scale at which this intervention can be deployed and self-sustained. Corals naturally expel symbionts as part of their population control mechanisms, some of which may be viable (Fujise *et al.* 2013). Thus, there is potential that these symbionts can spread to neighbour corals (Williamson *et al.,* 2021, Figure 17 B and Figure 18 B).
- **Ecological conditions.** These include currents and connectivity of deployment site with nearby reefs.

Existing avoidance/mitigation measures:

- **Source of algal symbionts.** Current practice is to provide coral larvae/recruits with algal symbionts that are sourced from the same source/deployment region (North/Central/South).
- **Culturing of algal symbiont.** There is a natural reservoir of resident symbionts in the sediment and seawater, but they cannot be harnessed in an applied way. RRAP interventions mitigate risk by creating and using algal symbiont cultures which allows researchers to increase survival of early-stage coral recruits during the restoration process by provisioning algal symbionts while including QA/QC practices.

POTENTIAL CONSEQUENCES AND RISK PATHWAYS

The risk analysis addresses the likelihood and severity of damage or disturbance to reef structure or other living things at target (Figure 19 F and Figure 20 D) or non-target (Figure 19 G and Figure 20 E) sites, harm to species of conservation concern (Figure 19 H), or an unsustainable depletion of other species from the ecosystem (Figure 19 I), leading to a detrimental effect on non-target coral or reef organism health that causes the species to decline or prevents recovery. This potential consequence encompasses scenarios where a substantial number of corals or other reef organisms are killed, or their habitat destroyed because of intervention activities. Species considered include bony fish, dolphins, whales, marine turtles, other invertebrates, sea snakes, sharks and rays—including a number of species protected under conservation laws. For species with healthy populations, this potential consequence is of concern when the numbers of individuals impacted is sufficient to cause the species to decline or prevent recovery from a disturbance. For species with heavily depleted populations, such as some species of conservation concern, this potential consequence may be of concern when even small numbers of individuals are impacted. This includes considerations to ensure ecological sustainability, as well as broader considerations such as community acceptability of interactions for iconic or threatened species. Details for each mechanism presented in Figure 19 and Figure 20 are outlined in Appendix 2.

Factors that may influence a potential impact causing harm to reef structure or non-target organisms:

- **Environmental conditions.** Inclement weather conditions and major storms would contribute to the likelihood of a given impact causing harm to reef structure or non-target organisms. However, as part of standard operating procedures, RRAP would delay intervention field work to avoid storms and poor weather conditions as these not only increase potential ecological harm but are also a safety concern to the staff operating the boats/equipment. The strength of currents at intervention sites could also influence divers disturbing or damaging benthic organisms or habitat in the locality where they are working during the collection/monitoring process.
- **Diver experience.** The less experienced a SCUBA diver is, the more likely they are to disturb/damage the benthos during collection (CA) or monitoring (CA and SCR) activities. All RRAP divers are certified scientific divers. There is limited diving required.
- **Quantity of deployment devices.** The more devices deployed, the more likely some will settle on living organisms (Figure 19 B and Figure 20 B) or shift to non-target micro-habitats or sites (Figure 19 C and Figure 20 C) leading to damage or disturbance to intervention sites and non-intervention sites, respectively. The number of coral seeding devices considered in the assessment is detailed in the *PDP Ecological Plan*, and is at the high-end of possible deployment numbers for PDP (as later years of the proposal are not yet funded).

Existing avoidance/mitigation measures:

- **Proof of concept and testing has already been undertaken on the GBR.** A key risk avoidance measure has been the staged approach taken to the research and investigations of these intervention techniques and the comprehensive research program underpinning the intervention methods. This includes over four years of research and staged field trials/ experiments on coral seeding devices without harm to the Reef – this proof of concept, along with the testing results, has informed the *PDP Ecological Plan*. During the program of research by RRAP on the SCR and CA methods proposed for use in the Pilot Deployments, there has been associated monitoring for effects on corals, other living things and deployment sites.
- **Collection and culturing site selection.** Some of the collection (booms) and culturing (rearing ponds) apparatuses for SCR require heavy chains and anchors to keep them in place in case of strong currents or windy conditions. Culture pools are typically deployed over sandy areas to avoid anchor or chain damage to any hard substrate but also to protect the culture pool plankton mesh from damage by snagging on coral/rock. Collection booms are often deployed in sandy bottom channels just off the reef where currents are high to increase the likelihood of high concentration collections and avoid damage to hard substrate from anchors and chains, or the boom net.
- **AI/ML system for deployment.** AI/ML systems are being utilised for deployment to instantaneously classify optimal areas within sites for deployment of devices. Areas of abundant live corals and other live organisms are avoided, so the feedback to the deployment operator (whether a human or machine) decreases the likelihood of deploying onto live coral or other fragile benthic organisms.
- **Diver training.** All RRAP divers maintain, at a minimum, scientific diver certification and training is provided in the techniques to be used where required. There is limited diving required.
- **Maintenance.** Proper maintenance of all equipment, including boats, could reduce or fully eliminate risks associated with boating activities.

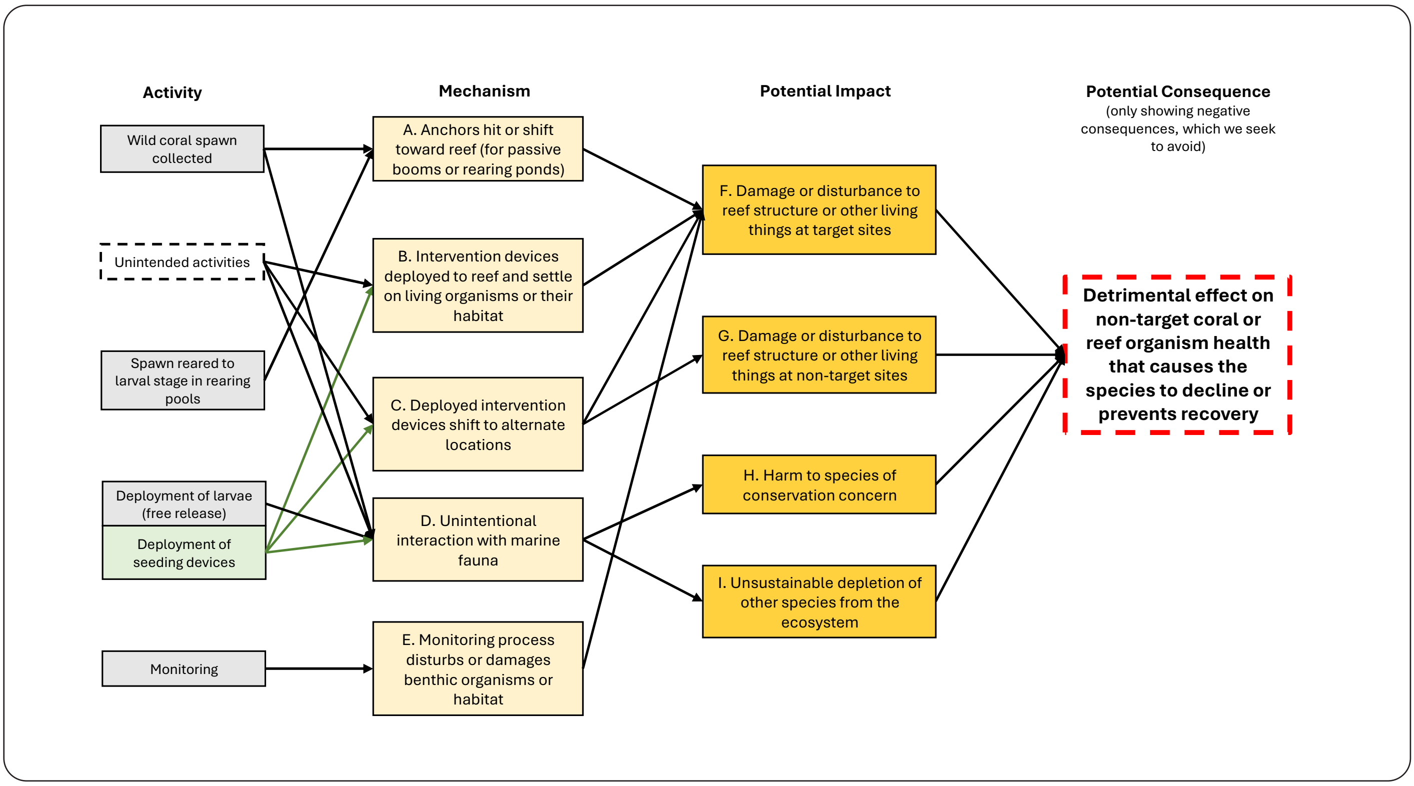


Figure 19 Causal map showing pathways to a detrimental effect on coral or reef organism health based on activities from SCR. Arrows indicate stepwise mechanisms (A-E) that, if they eventuate, could lead to negative impacts (F-I) which could then manifest as detrimental effects on coral or reef organism health that cause the species to decline or prevents recovery.

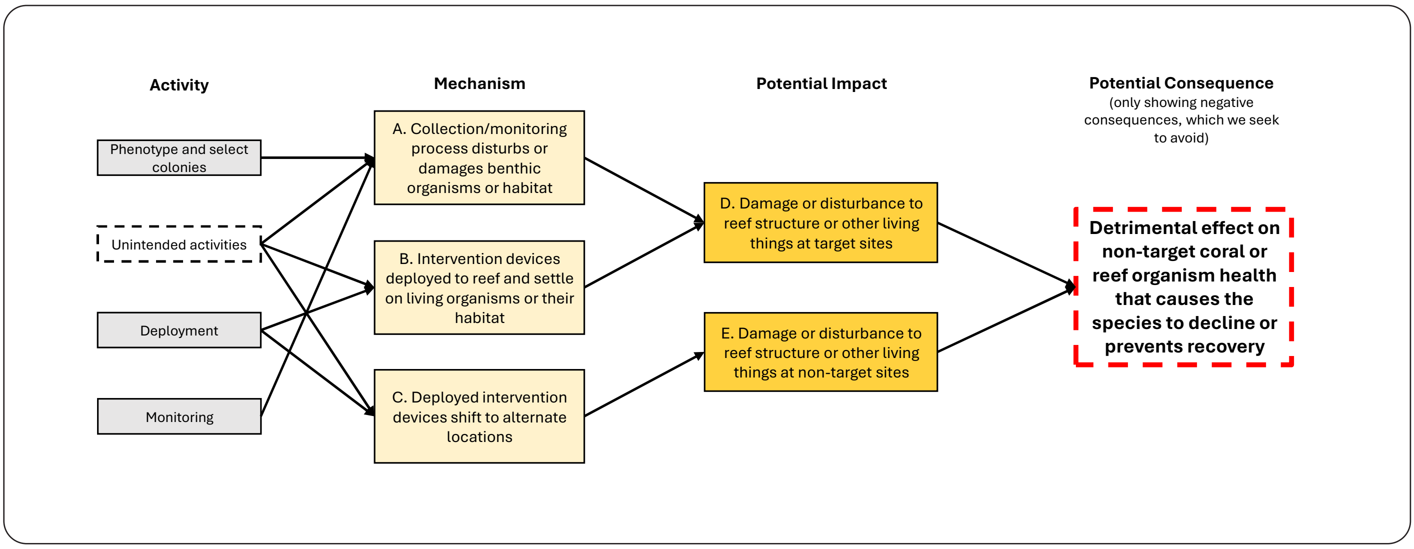


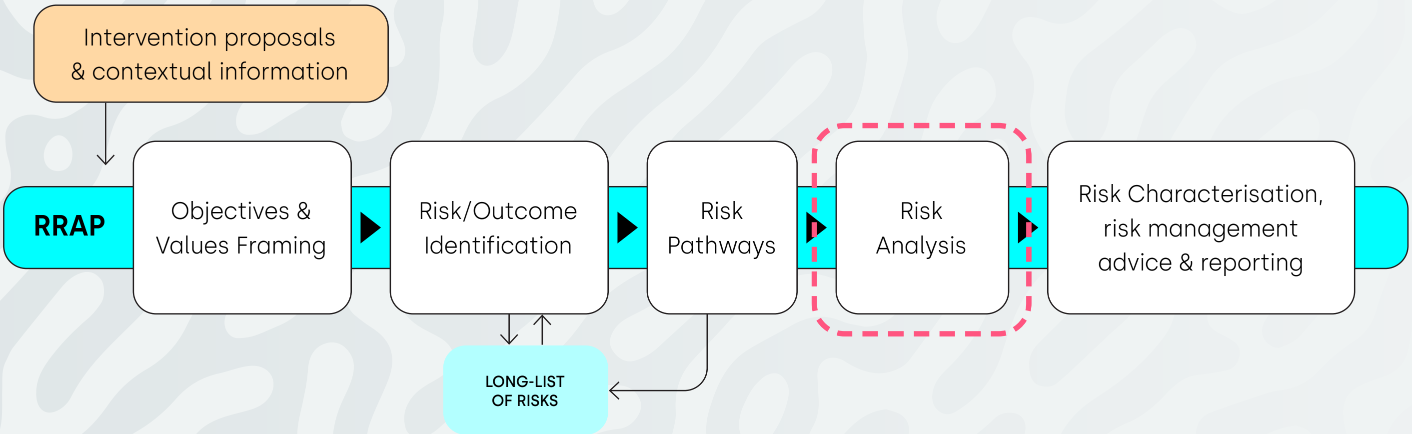
Figure 20 Causal map showing pathways to a detrimental effect on coral or reef organism health based on activities from CA. Arrows indicate stepwise mechanisms (A-C) that, if they eventuate, could lead to negative impacts (D-E) which could then manifest as detrimental effects on coral or reef organism health that cause the species to decline or prevents recovery.

Preparing settlement tiles for spawning research, for RRAP's Moving Corals Subprogram. Credit: Southern Cross University

7 Risk analysis

7.1 Methods

The purpose of the risk analysis stage is to ensure a comprehensive analysis is undertaken of the likelihood, severity and overall risk level of the potential consequences of reef intervention deployments. The overarching process and methods are detailed in *RRAP Intervention Risk Assessment: Approach and methods.* In summary, an initial risk analysis process was undertaken, using expert elicitation to populate a risk analysis template. As part of this, each identified risk pathway is considered and assessed in detail, including any plausible pathways that could lead to harm Marine Park values. The risk analysis findings and supporting information were considered to understand the nature of the potential risks, and whether these might interact or combine and lead to any different or amplified risks, or lead to any significant flow on secondary effects on other environment and biodiversity values. An evaluation for further action or analysis was undertaken prior to proceeding to risk characterisation.



7.1.1 APPLICATION OF THE METHODS TO THE PROPOSED PILOT DEPLOYMENTS

Risk analysis of the proposed Pilot Deployments was undertaken as per the *RRAP Intervention Risk Assessment: Approach and methods*, with some exceptions (detailed in Appendix 6 of *RRAP Intervention Risk Assessment: Approach and methods*). These exceptions included:

EXPERT ELICITATION – INVESTIGATE

Uncertainty: As per the *RRAP Intervention Risk Assessment: Approach and methods*, experts were asked to think about uncertainty prior to estimating the likelihood and severity of potential consequences occurring (through specific risk pathways) because of the Pilot Deployment activities. However, during this trial of the methods in mid-2024, the approach and reporting metrics on individual expert certainty/uncertainty had not been resolved in the Approach and methods. Areas of uncertainty that were identified have been documented later in this Section. Likelihood was considered before severity.

Confidence: As per the *RRAP Intervention Risk Assessment: Approach and methods*, an understanding of the level of confidence in the risk estimate was sought. However, during this trial of the methods, experts were not directly asked for their level of confidence in their risk estimates. Instead, the focus was on understanding the level of agreement between experts. Rules were used to classify the level of agreement as Strong agreement, Partial agreement or Disagreement (further details are provided in the RRAP Intervention Risk Assessment – Approach and methods).

The risk matrix (Table 4) is provided below for reference and an illustration is provided (Figure 21) to introduce how the findings are presented in this section.

Table 4 Risk matrix for determining risk levels to Marine Park Values (adopted from GBRMA, 2019a)

	DEGREES OF SEVERITY					
LIKELIHOOD	**POSITIVE**	**NEGLIGIBLE**	**MINOR**	**MODERATE**	**MAJOR**	**EXTREME**
Almost Certain	Positive	Low	Medium	High	Very High	Very High
Likely	Positive	Low	Medium	High	High	Very High
Possible	Positive	Low	Low	Medium	High	Very High
Unlikely	Positive	Low	Low	Low	Medium	High
Rare	Positive	Low	Low	Low	Medium	High

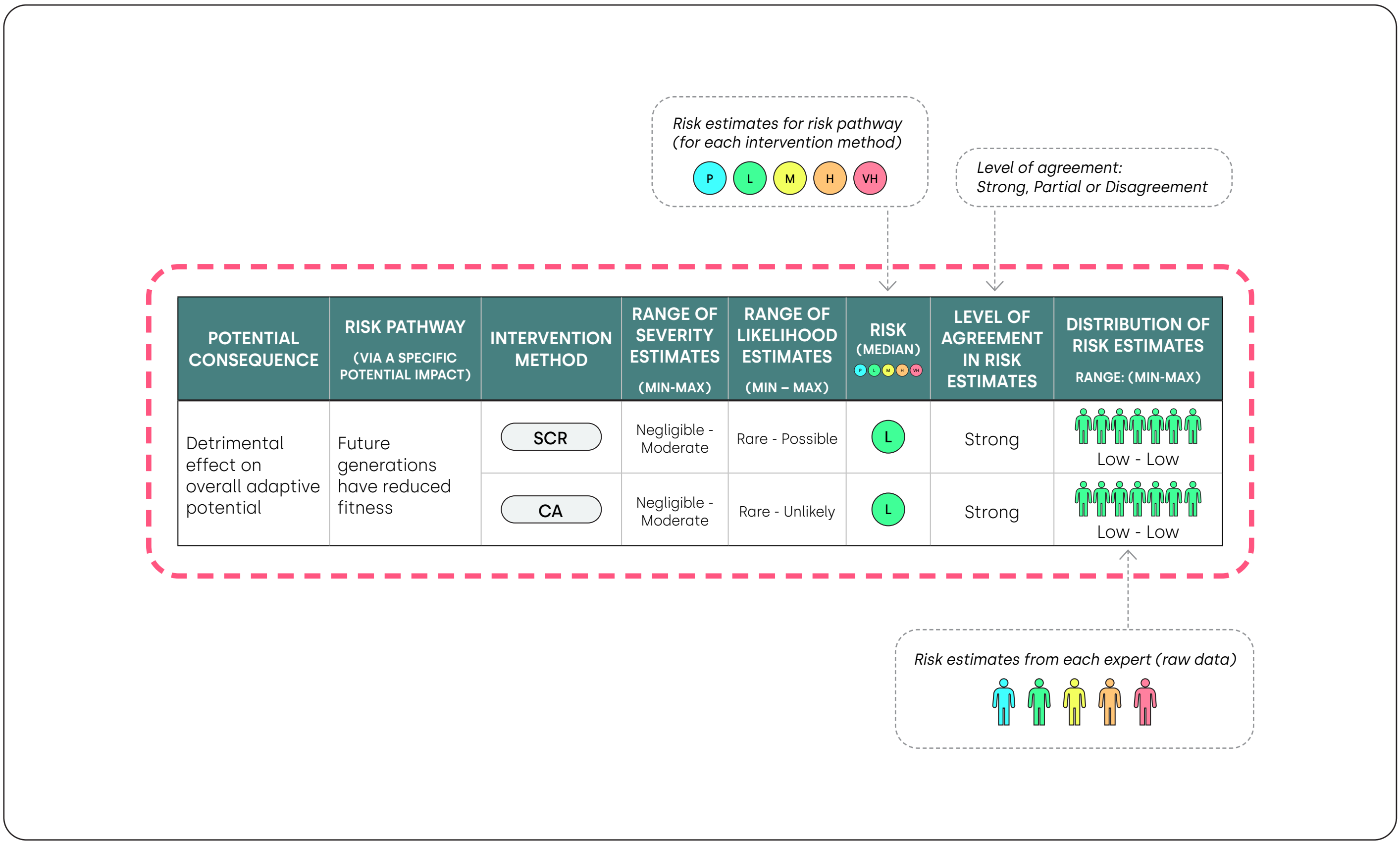


Figure 21 How the risk analysis findings are presented for each Sub-theme and risk pathway.

The ranges of severity, likelihood and risk estimates columns represent the between expert range of the best estimates for those values.
The 'Risk (median)' column represents the median level of risk derived from the experts' estimates of risk.
The 'Level of agreement in risk estimates' column represents the between experts' level of agreement around the risk estimates.
The 'Distribution of risk estimates' column shows the raw data (i.e., the risk estimates from each expert, noting for each expert the level of risk is determined from the expert's best estimates of severity and likelihood).

7.1.2 Findings

7.1.2 ENVIRONMENT AND BIODIVERSITY

The findings from the risk analysis of the proposed Pilot Deployments are presented below for each of the two Pilot Deployment methods (Slick Collection and Release [SCR], and Conservation Aquaculture [CA]) within the overarching theme of Environment and Biodiversity. Detailed justifications of the findings are provided and these stem from the evidence already cited and presented in this report, as well as from the expert elicitation process and other discussions with domain experts – as per the *RRAP Intervention Risk Assessment: Approach and methods.* Results are presented by sub-themes:

- Coral population resilience
- Coral reef ecosystem resilience
- Disease and pests
- Algal symbionts
- Damage to reef structure or non-target organisms

3 7.2.1.1 CORAL POPULATION RESILIENCE

The results of the risk analysis for the coral population resilience sub-theme are presented below, supported by justifications for the findings. Strength of the supporting evidence base, areas of uncertainty, relevant influencing factors, avoidance/ mitigation measures and potential broader impacts on other values are described.

RESULTS SUMMARY

Detrimental effect on overall coral adaptive potential

The estimated risk for both SCR and CA was **Low**. There was consistent agreement on the risk level among the experts. For the one relevant risk pathway, the severity estimates ranged from Negligible to Moderate, and the likelihood estimates ranged from Rare to Possible (*Table 5*).

Table 5 Expert elicitation risk analysis results. Shows the estimated severity, likelihood and risk of the Pilot Deployment activities (Slick Collection and Release (SCR) and Conservation Aquaculture (CA)) leading to detrimental effects on overall coral adaptive potential because of the potential impact that future generations of corals have reduced fitness. (n=7)

POTENTIAL CONSEQUENCE	RISK PATHWAY (VIA A SPECIFIC POTENTIAL IMPACT)	INTERVENTION METHOD	RANGE OF SEVERITY ESTIMATES (MIN-MAX)	RANGE OF LIKELIHOOD ESTIMATES (MIN – MAX)	RISK (MEDIAN)	LEVEL OF AGREEMENT IN RISK ESTIMATES	DISTRIBUTION OF RISK ESTIMATES RANGE: (MIN-MAX)
Detrimental effect on overall adaptive potential	Future generations have reduced fitness	SCR	Negligible - Moderate	Rare - Possible	L	Strong	Low - Low
		CA	Negligible - Moderate	Rare - Unlikely	L	Strong	Low - Low

Detrimental effect on adaptive potential and genetics of a given coral species

The estimated risk for both SCR and CA was **Low**. There was generally very consistent agreement on risk level among the experts. Across these four risk pathways, the severity estimates ranged from Negligible to Moderate, and the likelihood estimates ranged from Rare to Possible (Table 6).

Table 6 Expert elicitation risk analysis results. Shows the estimated severity, likelihood and risk of the Pilot Deployment activities (Slick Collection and Release (SCR) and Conservation Aquaculture (CA)) leading to detrimental effects on adaptive potential and genetics of a given coral species because of specific potential impacts. (n= 7)

POTENTIAL CONSEQUENCE	RISK PATHWAY (VIA A SPECIFIC POTENTIAL IMPACT)	INTERVENTION METHOD	RANGE OF SEVERITY ESTIMATES (MIN-MAX)	RANGE OF LIKELIHOOD ESTIMATES (MIN – MAX)	RISK (MEDIAN)	LEVEL OF AGREEMENT IN RISK ESTIMATES	DISTRIBUTION OF RISK ESTIMATES RANGE: (MIN-MAX)
Detrimental effect on overall coral adaptive potential and Detrimental effect on genetics of a coral species	Inbreeding depression	SCR	Negligible - Minor	Rare - Unlikely	L	Strong	Low - Low
		CA	Negligible - Minor	Rare - Possible	L	Strong	Low - Low
	Loss of genetic diversity	SCR	Negligible - Minor	Rare - Unlikely	L	Strong	Low - Low
		CA	Negligible – Minor	Rare - Possible	L	Strong	Low - Low
	Outbreeding depression	SCR	Negligible - Minor	Rare - Unlikely	L	Strong	Low - Low
		CA	Negligible – Minor	Rare - Unlikely	L	Strong	Low - Low
	Metapopulation connectivity is disrupted	SCR	Negligible - Moderate	Rare - Possible	L	Strong	Low - Medium
		CA	Negligible - Moderate	Rare - Possible	L	Strong	Low - Low

JUSTIFICATIONS FOR RISK ESTIMATES

General justifications for the risk estimate results (which apply to all the risk pathways leading to these potential consequences on adaptive potential and coral genetics) include:

1. The number of corals proposed for deployment though the proposed Pilot Deployments represents a relatively low proportion of the overall rates of coral replenishment (e.g., 5 coral seeding devices per square metre).
2. Since deployments will be in the same reef cluster or reef region from which corals were sourced, connectivity between recipient populations is likely high. Any reductions in genetic diversity of the stock (CA) are likely to be mitigated by the high standing genetic diversity of the recipient populations and high levels of gene flow.
3. For SCR, many different individuals from within and across many different species contribute to spawn slicks. This means that genetic diversity increases with every collection from any slick.
4. Selection criteria for source and deployment reefs will consider factors that influence the likelihood and severity of impacting coral population resilience to mitigate these risks (see Section 6). These selection criteria include:
    a. Coral abundance on the destination reef, including abundances of target species for CA, and target densities for CA and SCR
    b. Larval connectivity
    c. Coral community diversity (for SCR)
5. Selection criteria for broodstock (CA) includes, where data are available, mitigation options to manage the likelihood and severity of potential impacts causing harm to coral population resilience. These selection criteria include:
    a. Population genetics data including individual genotyping to avoid breeding between closely related parents.
    b. Numbers of genotypes collected and bred per species in relation to the diversity of wild populations on source and deployment reefs.
    c. Regular rotation and/or addition of species and genotypes across years.

Specific justifications for the risk estimate results relevant to the risk pathway for future generations have reduced fitness leading to detrimental effect on overall adaptive coral potential include:

- In the Pilot Deployments, time in captivity is too short to expect domestication selection significant enough to lead to reduced fitness.
- The intensity of these interventions (numbers of corals deployed) is too small to genetically swamp natural populations at recipient reefs to substantially reduce fitness even if there were trade-offs or domestication selection.
- Future rounds of reproduction would tend to dilute reductions in fitness rather than amplify them.
- The benefits of increased heat tolerance likely outweigh the costs of potential trade-off, e.g., slow growth.

Specific justifications for the other risk estimate results (relevant to specific risk pathways to one or both potential consequences) include:

POTENTIAL CONSEQUENCE	RISK PATHWAY (VIA A SPECIFIC POTENTIAL IMPACT)	JUSTIFICATION(S)
Detrimental effect on overall coral adaptive potential and/or Detrimental effect on genetics of a given coral species	Inbreeding depression	• For both proposed deployments (CA and SCR), inbreeding depression can only occur when a substantial number of low-diversity corals are deployed in close proximity AND there are extensive barriers to sexual reproduction between deployed and native corals. Reproductive barriers are expected to be unlikely due to the high connectivity in many Great Barrier Reef corals. However, if such reproductive barriers were to exist, they would tend to limit the impact and spread of any intervention effects to a greater area of the Reef; the spatial extent of potential negative impact (if any) would be local. • Given that the target spawning populations (SCR) will differ over time/ deployments and the conversion rate is low, it is highly unlikely that siblings will come to dominate the larval pool and co-recruit in a way that would result in inbreeding in subsequent generations.
	Loss of genetic diversity	• Any reductions in genetic diversity in stock (CA) are likely to be mitigated by standing genetic diversity of recipient population and gene flow. This tends to reduce likelihood and severity. • Combinations of both CA and SCR interventions are used in each region (as per *PDP Ecological Plan*). These methods involve different source corals and genetic diversity, and this will tend to minimise the loss of genetic diversity of corals deployed into each region and the deployment sites. • If thermal tolerance is enhanced at a cost of reduced genetic diversity (and genetics and thermotolerance are strongly linked), this may not represent additional severe selection than what would occur via natural selection. If genetic diversity were to become a problem in and around the deployment sites, such losses of local genetic diversity could be reversed with management options (such as genetic rescue). • It is possible that coral genetic diversity is improved by the interventions, since standing genetic diversity is expected to decrease in the future to some extent due to climate change. This intervention could proactively enhance the frequency of tolerance-conferring alleles, preserving some amount of total diversity through future bottlenecks.
	Outbreeding depression	• Coral population genetics data from the Reef do not support strong signatures of local adaptation that would result in outbreeding depression. The Reef has a low divergence time and high connectivity between reefs, which both lead to low population differentiation and reduce the likelihood of outbreeding depression. Should outbreeding depression occur, the corresponding reduced fitness means that these corals are likely to have low rates of survivorship and not impact recipient population gene pool given the short time scale of the 2025-2030 deployments relative to coral generation times.
	Disruption of metapopulation connectivity	• Importantly, the slick (SCR) and coral (CA) collection volumes are very low compared to levels that are available in nature. • Loss of metapopulation-level diversity is a multi-generational process; Pilot Deployments are too short-term to have an impact. • On a local scale, a disruption to metapopulation connectivity can be reversed with management options (such as artificial gene flow).

STRENGTH OF SUPPORTING EVIDENCE BASE

As documented earlier in this report, there is a strong evidence base supporting the assessment of the risks of the Pilot Deployment activities to Marine Park values related to coral population resilience. The scientific theory and understanding around the concept of coral population resilience (and the mechanisms and factors which may influence it) is well established, including relevant work from the Reef and internationally. There is currently limited population genetics data available for comprehensive modelling, however recent work has been increasing this knowledge base (Fuller *et al*. 2020; Quigley *et al*. 2020a) and this has also been a focus of RRAP research.

Among the experts involved in the risk assessment process there was strong level of agreement around the theory underpinning the risk pathways/causal maps developed for coral population resilience, and there was no requirement to create alternative maps to accommodate divergent viewpoints.

On the Reef, investigation, testing and field trials of SCR have been underway for nearly a decade, and there have also been several years of research and development and field testing of CA. This work is further supported by decades of research and restoration from other areas such as Florida and the Caribbean. This body of knowledge has informed the assessment, and key information is summarised here or in the *PDP Ecological Plan.*

AREAS OF UNCERTAINTY FOR EXPERTS

This (and similar) sub-sections list knowledge gaps and areas of uncertainty that were identified in the risk assessment including during the expert elicitation process. The points have not been prioritised.

Knowledge gaps

- Limited data on population genetics data for many coral species across the Reef.
- Limited understanding of any trade-offs and their genetic underpinnings.
- Local connectivity strengths <50 km and realised self-retention rates are poorly understood for the Reef.

Other

- There is uncertainty surrounding the temporal extent of potential impacts (e.g. inbreeding depression etc.) associated with coral population resilience with ranges from 3-20+ years. Experts tend to agree that these potential impacts would take multiple coral generations for any potential consequences to manifest. The length of a coral generation, that is the duration from larval settlement to sexual maturity, varies from species to species (Rapuano *et al*., 2023). At a minimum, one coral generation is 2-3 years, but is typically 5-years and up to 10-20 years or longer depending on coral species and state of health.
- Specific reefs for source and deployment sites have not yet been selected. Until these decisions are made specific details on these coral populations (population structure, genetic diversity, connectivity) are unavailable.
- Although a long list of 20 potential species for CA has been selected, the number of individual genotypes being used per species and their genetic variation have not yet been identified.
- While there can be negative consequences of outbreeding depression, there are also potential benefits:
  - Higher genetic diversity that confers resilience to future conditions may outweigh the loss of locally adapted alleles.
  - Positive impacts could occur if the crossing of population/species boundaries facilitates the production of hybrid species or interbred populations with resilient phenotypes that could enhance genetic diversity and adaptive capacity.
  - By definition, outbreeding depression is negative. However, a changing fitness landscape means population genetics must change to compensate if there is genetic basis to performance. Pre-empting this change may be beneficial.

INFLUENCING FACTORS

Factors that influence the estimate of likelihood, severity and risk were identified and considered during the risk assessment process. The influencing factors are further considered in terms of building knowledge and understanding the potential risks, how the risks might arise and opportunities for risk management. Relevant factors which may influence the severity and likelihood of intervention risks to coral population resilience include reef connectivity, the relative genetic diversity of collected broodstock/gametes compared to the overall population diversity, disturbance from reef health events (e.g. cyclones, coral bleaching), the fecundity of the deployed corals, heritability and impact of trait trade-offs and the coral species involved, depending on the length of their generation times. Further information on influencing factors for coral population resilience is available in Section 6.

AVOIDANCE AND MITIGATION MEASURES

Relevant avoidance and mitigation measures in the *PDP Ecological Plan* for the Pilot Deployments base case include applying biological criteria (e.g., reproduction strategies) to the selection of broodstock species and source/deployment reefs, careful design and planning around intervention methods and intensity and reducing the *ex-situ* holding times for corals as much as possible. Given these existing avoidance and mitigation measures and the estimated Low risk to coral population resilience, no additional avoidance and mitigation measures are considered necessary. Further information on avoidance and mitigation measures is available in Section 6.

POTENTIAL BROADER IMPACTS ON MARINE PARK VALUES

Consideration was given to whether the identified potential impacts relevant to coral population resilience might interact or combine to lead to different or amplified risks to corals, or in turn lead to significant flow on secondary effects on other environment and biodiversity Marine Park values. The assessment concluded that there was a Low risk of interacting or combined potential impacts detrimentally affecting coral population resilience. Given the risks of the proposed Pilot Deployments to coral population resilience (through either individual potential impacts or interacting/combined potential impacts) are estimated to be Low, it is unlikely that any effects on coral population resilience will be significant enough to lead to significant secondary risks to other environment and biodiversity Marine Park values.

CONCLUDING STATEMENT

Based on the *PDP Ecological Plan* for the Pilot Deployments base case, the risks to coral population resilience are estimated to be **Low**, with generally very consistent agreement among the experts. The only exception was in the assessment of Slick Collection and Release activities leading to the potential impact "Metapopulation connectivity is disrupted." Of the seven experts, six estimated the risk of this was Low, while one expert estimated it as Medium. In that case, the expert considered it possible that slick collection could impact 'destination reefs' (e.g. if the collection of larvae was sufficient to reduce natural supply of larvae to those destination reefs), leading to moderate consequences. Discussions indicated any potential risk can be managed via existing protocols to ensure that collection levels are sustainable.

There were strong justifications for the risk estimates and a strong supporting evidence base (including sufficient existing scientific literature and information from research and development). While knowledge gaps were identified that will be of use in determining future research priorities for RRAP or others, they are not barriers to the assessment or management of any potential risks for the proposed configuration of the Pilot Deployments. The intervention proposal proposes the deployment of corals back to the regions from which they were sourced, therefore, a complete understanding of population genetic structure and connectivity across the Reef is not immediately necessary. Gene flow likely already occurs between neighbour reefs (Jones *et al.* 2009a; Kininmonth 2024), which means the deployment of coral originating from neighbouring reefs will strictly include individual genotypes that have the opportunity to naturally occur. Additionally, the proportion of individuals introduced to deployment reefs via the Pilot Deployments Program will represent a fraction of the total population. This strategy will provide corals to selected sites with little or no risk of genetic swamping. The proposed localised approach (i.e., deployments within the same region as the sources of corals and symbionts) for the Pilot Deployments Program base case serves as a logical initial step for piloting these methods as it minimises risk such as outbreeding depression from distant populations.

Influencing factors that tend to reduce the risk of these risk pathways leading to potential consequences include high reef connectivity in the deployment regions, intact natural ecological processes which support coral population resilience, the use of practices to avoid collecting broodstock with very low genetic diversity and the combined use of broodstock and slick collection of gametes from diverse corals. Avoidance and mitigation measures are in place to manage the risks to coral population resilience, and the risk assessment did not identify any additional measures as necessary.

The Low risk to the target value (coral) suggests that there will also be a Low direct or indirect risk to other environment and biodiversity values. Given the Low risk levels and the strong agreement in risk estimates between experts, using the criteria in the *RRAP Intervention Risk Assessment: Approach and methods*, it was concluded that no further analysis or action is required. The results from assessment of coral population resilience were therefore progressed to the Risk Characterisation stage.

3 7.2.1.2 CORAL REEF ECOSYSTEM RESILIENCE

The results of the risk analysis for the coral reef ecosystem resilience sub-theme are presented below, supported by justifications for the findings. Strength of supporting evidence base, areas of uncertainty, relevant influencing factors, avoidance/mitigation measures and potential broader impacts on other values are described.

RESULTS SUMMARY

Detrimental effect on ecosystem structure or function

The estimated risks for both SCR and CA were **Low**. There was generally consistent agreement on risk level among the experts. Across these two risk pathways, the severity estimates ranged from Positive to Minor, and the likelihood estimates ranged from Rare to Possible (Table 7).

Table 7 Expert elicitation risk analysis results. Shows the estimated severity, likelihood and risk of the Pilot Deployment activities (Slick Collection and Release (SCR) and Conservation Aquaculture (CA)) leading to detrimental effects on ecosystem structure or function because of specific potential impacts. (n= 7)

POTENTIAL CONSEQUENCE	RISK PATHWAY (VIA A SPECIFIC POTENTIAL IMPACT)	INTERVENTION METHOD	RANGE OF SEVERITY ESTIMATES (MIN-MAX)	RANGE OF LIKELIHOOD ESTIMATES (MIN – MAX)	RISK (MEDIAN) P L M H VH	LEVEL OF AGREEMENT IN RISK ESTIMATES	DISTRIBUTION OF RISK ESTIMATES RANGE: (MIN-MAX)
Detrimental effect on ecosystem structure or function	Disruption of metacommunity connectivity	SCR	Negligible – Minor	Rare - Unlikely	L	Strong	Low - Low
		CA	Negligible – Minor	Rare - Unlikely	L	Strong	Low - Low
	Shifting coral composition	SCR	Positive - Minor	Rare - Possible	L	Strong	Low - Low
		CA	Positive - Minor	Rare - Possible	L	Strong	Low - Low

JUSTIFICATIONS FOR RISK ESTIMATES

General justifications for the risk estimate results (which apply to both risk pathways leading to the potential consequence) include:

1. Selection criteria for source and deployment reefs will consider factors that influence the likelihood and severity of impacting coral reef ecosystem resilience to mitigate these risks.
2. The focused deployment of a subset of the total species (CA) or larvae derived from a coral slick (SCR) alters the ecosystem structure, however, 'detrimental' must be considered relative to the reference case of 'no new interventions', which is a decreasing number of species and functional collapse.
3. The slick (SCR) and coral (CA) collection volumes are very low compared to natural levels and therefore an unsustainable harvest will not occur.

Specific justifications for the risk estimate results (relevant to specific risk pathways to the potential consequence), include:

POTENTIAL CONSEQUENCE	RISK PATHWAY (VIA A SPECIFIC POTENTIAL IMPACT)	JUSTIFICATION(S)
Detrimental effect on ecosystem structure or function	Disruption of metacommunity connectivity	• Unlikely that strong isolation-by-distance occurs at the scale of a reef cluster and connectivity would be maintained during deployment activities.
	Shifting coral composition	• The spatial extent for the impact of 'shifting coral composition' will be restricted to the local area that corals are deployed in. • For 'shifting coral composition' to lead to a 'detrimental effect on ecosystem structure or function,' juvenile corals would have to be deployed at a high enough concentration to overwhelm the system ('intervention intensity') AND survive long enough to grow to a size and/or reproduce sufficiently that could change ecosystem function. This is unlikely based on the number of corals reported for deployment in the *PDP Ecological Plan*, which represent a relatively low proportion of the overall rates of replenishment (e.g., 5 devices per square meter). • The selection of up to ~20 species for restoration out of the >400 species on the reef could possibly shift coral community composition at the local scale in the short to medium term but could attract more diverse species in the longer term by promoting natural successional recruitment.

STRENGTH OF SUPPORTING EVIDENCE BASE

As documented earlier in this report, there is a strong evidence base supporting the assessment of the risks of the Pilot Deployment activities to Marine Park values related to coral reef ecosystem resilience. The scientific theory and understanding around the concept of coral reef ecosystem resilience (and the mechanisms and factors which may influence it) is well established, including relevant work from the Reef and internationally.

Among the experts involved in the risk assessment process there was a strong level of agreement around the theory underpinning the risk pathways/causal maps developed for coral reef ecosystem resilience, and there was no requirement to create alternative maps to accommodate divergent viewpoints.

On the Reef, investigation, testing and field trials of SCR have been underway for nearly a decade, and there have also been several years of research and development and field testing of CA. This work is further supported by decades of research and restoration from other areas such as Florida and the Caribbean. This body of knowledge has informed the assessment, and key information is summarised here or in the *PDP Ecological Plan*.

AREAS OF UNCERTAINTY FOR EXPERTS

Knowledge gaps

There were no specific knowledge gaps identified for the sub-theme of coral reef ecosystem resilience.

Other

Specific reefs for source and deployment sites have not yet been selected. Until these decisions are made specific details on community dynamics for each site (species diversity, connectivity) are unavailable.

INFLUENCING FACTORS

Factors that influence the estimate of likelihood, severity and risk were identified and considered during the risk assessment process. The influencing factors are further considered in terms of building knowledge and understanding the potential risks, how the risks might arise and opportunities for risk management. Relevant factors which may influence the severity and likelihood of intervention risks to coral reef ecosystem resilience are similar to, or the same as, those identified for coral population resilience. Any harm to coral genetic diversity or overall adaptive potential will also influence the likelihood and severity of harm to ecosystem structure and/or function. These factors include reef connectivity, species diversity of collected broodstock/gametes compared to the overall population diversity, and ecological processes.

AVOIDANCE AND MITIGATION MEASURES

Relevant avoidance and mitigation measures in the *PDP Ecological Plan* for the Pilot Deployments base case include developing and following selection criteria for source/deployment reefs and (for the purposes of CA) source coral species. Further information on avoidance and mitigation measures is available in Section 6.

POTENTIAL BROADER IMPACTS ON MARINE PARK VALUES

Consideration was given to whether the identified potential impacts relevant to coral reef ecosystem resilience might interact or combine to lead to different or amplified risks to coral reefs, or in turn lead to significant flow on secondary effects to other environment and biodiversity Marine Park values. The assessment concluded that there was a Low risk of interacting or combined potential impacts detrimentally affecting coral reef ecosystem resilience. Given the risks of the proposed Pilot Deployments to coral reef ecosystem resilience (through either individual potential impacts or interacting/combined potential impacts) are estimated to be Low, it is unlikely that any effects on coral reef ecosystem resilience will be significant enough to lead to significant secondary risks to other environment and biodiversity Marine Park values.

CONCLUDING STATEMENT

Based on the *PDP Ecological Plan* for the Pilot Deployments base case, the risks to coral reef ecosystem resilience are estimated to be **Low**, with generally consistent agreement among the experts. The only exception was the assessment of risk of Conservation Aquaculture activities leading to shifting coral composition. Of the seven experts, one estimated the level of risk as Positive while the remaining experts estimated it as Low. In this case, the expert concluded that a net positive effect would be expected in the long-term with the coral cover possibly enhancing natural succession of other corals and diversity.

There were strong justifications for these estimates, a strong supporting evidence base (including sufficient existing scientific literature and information from research and development). No major scientific knowledge gaps were identified, however the specific locations for the Pilot Deployment activities are yet to be determined and this remained a source of some uncertainty for the experts. Until decisions are made on collection and deployment locations, the specific details on community dynamics for each site (species diversity, connectivity etc) are unavailable for consideration in the risk assessment process.

Influencing factors which tend to reduce these potential impacts are similar to those for coral population resilience and include high reef connectivity in the deployment regions, intact natural ecological processes which support coral population resilience, the use of practices to avoid collecting broodstock with very low genetic diversity and the combined use of broodstock and slick collection of gametes from diverse corals. Avoidance and mitigation measures are in place to manage the risks to coral reef ecosystem resilience, and the risk assessment did not identify any additional measures as necessary.

The Low risk to coral reef ecosystem resilience suggests that there will also be a Low direct or indirect risk to other environment and biodiversity Marine Park values associated with coral reef habitats, associated species and ecosystem processes (as relevant to this sub-theme). Given the Low risk levels and the strong agreement in risk estimates between experts, using the criteria in the *RRAP Intervention Risk Assessment: Approach and methods*, it was concluded that no further analysis or action is required. The results from assessment of coral reef ecosystem resilience were therefore progressed to the Risk Characterisation stage.

3 7.2.1.3 DISEASE AND PESTS

The results of the risk analysis for the disease and pests sub-theme are presented below, supported by justifications for the findings. Strength of supporting evidence base, areas of uncertainty, relevant influencing factors, avoidance/mitigation measures and potential broader impacts on other values are described.

RESULTS SUMMARY

Detrimental effect on coral or reef organism health

The estimated risk for both SCR and CA was **Low**. There was consistent agreement on risk level among the experts. Across these two risk pathways, the severity estimates ranged from Negligible to Minor, and the likelihood estimates ranged from Rare to Possible (Table 8).

Table 8 Expert elicitation risk analysis results. Showing the estimate severity, likelihood and risk of the Pilot Deployment activities (Slick Collection and Release (SCR) and Conservation Aquaculture (CA)) leading to detrimental effects on coral or reef organism health that causes the species to decline because of specific potential impacts. (n=4)

POTENTIAL CONSEQUENCE	RISK PATHWAY (VIA A SPECIFIC POTENTIAL IMPACT)	INTERVENTION METHOD	RANGE OF SEVERITY ESTIMATES (MIN-MAX)	RANGE OF LIKELIHOOD ESTIMATES (MIN – MAX)	RISK (MEDIAN)	LEVEL OF AGREEMENT IN RISK ESTIMATES	DISTRIBUTION OF RISK ESTIMATES RANGE: (MIN-MAX)
Detrimental effect on coral or reef organism health	Increased prevalence of disease of biotic origin	SCR	Minor - Minor	Rare - Possible	L	Strong	Low - Low
		CA	Minor - Minor	Rare - Possible	L	Strong	Low - Low
	Increased prevalence of parasites and pests	SCR	Negligible - Minor	Rare - Possible	L	Strong	Low - Low
		CA	Negligible - Minor	Rare - Possible	L	Strong	Low - Low

JUSTIFICATIONS FOR RISK ESTIMATES

General justifications for the risk estimate results (which apply to both risk pathways leading to the potential consequence) include:

1. Based on general routine monitoring of coral experiments and trial deployments, an increased prevalence of disease or pests/parasites has never been observed from corals taken from the SeaSim and deployed on to the reef.
2. Corals will be locally sourced from the Reef (i.e., coral animals and associated microbiota are native to the Reef). Undetected pathogens/pests, if any, would have originated from the Reef. There will be no foreign or novel pathogens/pests introduced by PDP interventions.

Specific justifications for the risk estimate results (relevant to specific risk pathways to the potential consequence) include:

POTENTIAL CONSEQUENCE	RISK PATHWAY (VIA A SPECIFIC POTENTIAL IMPACT)	JUSTIFICATION(S)
Detrimental effect on coral or reef organism health	Increased prevalence of disease of biotic origin	• In the cases where there has been incidence of disease on the Reef, the spatial distribution is patchy (Haapkylä *et al.*, 2010) with some diseases not transmitting to a neighbour colony even with direct contact (Roff *et al.*, 2011), indicating that disease outbreaks are likely to be restricted to a local scale. • Microbial disease agents transmitting from coral spats to wild corals will be unlikely to occur, given the short life span of infected coral spats to serve as infectious source.
	Increased prevalence of parasites and pests	• In the event a release of undetected pests occurs, natural predators will likely control their proliferation in the wild.

STRENGTH OF SUPPORTING EVIDENCE BASE

As documented earlier in this report, there is a moderate evidence base supporting the assessment of risks that may be posed by the Pilot Deployment activities in relation to disease and pests in the Marine Park. The scientific theory and understanding around disease and pests (and the mechanisms and factors which may influence them) is growing, including relevant work from the Reef and internationally.

Among the experts involved in the risk assessment process there was strong level of agreement around the theory underpinning the risk pathways/causal maps developed for disease and pests, and there was no requirement to create alternative maps to accommodate divergent viewpoints.

On the Reef, investigation, testing and field trials of SCR have been underway for nearly a decade, and there have also been several years of research and development and field testing of CA. This work is further supported by decades of research and restoration from other areas such as Florida and the Caribbean. This body of knowledge has informed the assessment, and key information is summarised here or in the *PDP Ecological Plan.*

AREAS OF UNCERTAINTY FOR EXPERTS

Knowledge gaps

- Although 40 coral diseases have now been identified affecting a wide variety of corals across the globe (Moriarty *et al.*, 2020, Morais *et al.*, 2022), little is known about the causative agents of coral diseases (Pollock *et al.*, 2011), transmission dynamics (Shore & Caldwell, 2019), and how to prevent, control or mitigate disease impacts (Beeden *et al.*, 2012).

Other

- If intervention activities lead to an increased prevalence of disease of biotic origin (i.e. infectious disease) or pests and parasites on the Reef, this could become apparent either immediately following the deployments or be delayed and remain undetected until environmental conditions (e.g. warm temperatures) are more conducive to proliferation of disease-causing agents or pests.

INFLUENCING FACTORS

Factors that influence the estimate of likelihood, severity and risk were identified and considered during the risk assessment process. The influencing factors are further considered in terms of building knowledge and understanding the potential risks, how the risks might arise and opportunities for risk management. Relevant factors that may influence the severity and likelihood of intervention risks around disease and pests include the amount of time that corals spend in production or aquaculture facilities, the prevalence of disease-causing agents, transmission of disease/pests from one host to another, ecological conditions, recovery rates and coral cover/composition. Further information on influencing factors for risks associated with disease and pests is available in Section 6.

AVOIDANCE AND MITIGATION MEASURES

Relevant avoidance and mitigation measures in the *PDP Ecological Plan* for the Pilot Deployments base case include site selection to avoid collecting from sites with pests, the use of QA/QC protocols to screen against harmful microbes and outbreaks of targeted pests among broodstock corals and larval cultures, and visual checks to ensure only healthy corals are deployed back onto the Reef. Further information on avoidance and mitigation measures is available in Section 6.

POTENTIAL BROADER IMPACTS ON MARINE PARK VALUES

Consideration was given to whether the identified potential impacts relating to disease and pests might interact or combine to lead to different or amplified risks to corals, or in turn leads to significant flow on secondary effects on other environment and biodiversity Marine Park values. The assessment concluded there was a Low risk of interacting or combined potential impacts associated with disease and pests detrimentally affecting corals. Given the risks of the proposed Pilot Deployments affecting disease and pests (through either individual potential impacts or interacting/combined potential impacts) are estimated to be Low, it is unlikely that any effects on disease and pests will be significant enough to pose secondary risks to other environment and biodiversity Marine Park values.

CONCLUDING STATEMENT

Based on the *PDP Ecological Plan* for the Pilot Deployment base case, the risks associated with disease and pests are estimated to be **Low**, with consistent agreement among the experts.

There were strong justifications for these risk estimates, and a moderate supporting evidence base (including growing scientific literature and information on research and development). Experts identified existing knowledge gaps around the causative agents of coral disease, transmission dynamics and how to prevent, control or mitigate coral diseases on the Reef. Experts also noted that increased prevalence of coral disease or pests because of the intervention activities may either be apparent immediately or not become apparent until environmental conditions (e.g. warm temperatures) area conducive to proliferation. However, these knowledge gaps do not present significant barriers to the assessment or management of potential risks for the proposed Pilot Deployments base case. Corals will be locally sourced from the Reef, minimising the risk of introducing foreign pathogens or pests.

Influencing factors that tend to reduce the risk of these potential impacts include practices within aquaculture facilities to eliminate or reduce disease-causing agents and the transmission of disease/pests from one host to another, as well as limiting (where possible) the overall amount of time that corals spend in aquaculture facilities. Beyond the aquaculture facilities, influencing factors which tend to reduce the risks of disease and pests include beneficial ecological conditions, high coral recovery rates and robust coral cover and composition. Avoidance and mitigation measures are in place to manage the risks of disease and pests, and the risk assessment did not identify any additional measures as necessary. As future interventions expand or scale, the potential risks around disease and pests should continue to be pro-actively managed and risks re-assessed. Likewise, if procedural details for PDP operations are refined, then some additional risk assessment may be required.

The Low risk to the target value (coral) suggests that there will also be a Low direct or indirect risk to other environment and biodiversity Marine Park values. Given the Low risk levels and strong agreement in risk estimates between experts, using the criteria in the *RRAP Intervention Risk Assessment: Approach and methods*, it was concluded that no further analysis or action is required. The results from assessment of disease and pests were therefore progressed to the Risk Characterisation stage.

3 7.2.1.4 ALGAL SYMBIONTS

The results of the risk analysis for the algal symbionts sub-theme are presented below, supported by justifications for the findings. Strength of supporting evidence base, areas of uncertainty, relevant influencing factors, avoidance/mitigation measures and potential broader impacts on other values are described.

RESULTS SUMMARY

Detrimental effect on genetics of local algal symbiont populations

The estimated risk for both SCR and CA was **Low**. There was generally consistent agreement on risk level among the experts. For this risk pathway, the severity estimates ranged from Negligible to Minor, and the likelihood estimates ranged from Rare to Possible (Table 9).

Table 9 Expert elicitation risk analysis results. Showing the estimated severity, likelihood and risk of the Pilot Deployment activities (Slick Collection and Release (SCR) and Conservation Aquaculture (CA)) leading to detrimental effects on the genetics of local algal symbiont populations because of specific potential impacts. (n= 5)

POTENTIAL CONSEQUENCE	RISK PATHWAY (VIA A SPECIFIC POTENTIAL IMPACT)	INTERVENTION METHOD	RANGE OF SEVERITY ESTIMATES (MIN-MAX)	RANGE OF LIKELIHOOD ESTIMATES (MIN – MAX)	RISK (MEDIAN)	LEVEL OF AGREEMENT IN RISK ESTIMATES	DISTRIBUTION OF RISK ESTIMATES RANGE: (MIN-MAX)
Detrimental effect on genetics of local algal symbiont populations	Loss of genetic diversity/ adaptive potential of local algal symbiont populations	SCR	Negligible – Minor	Rare - Possible	L	Strong	Low - Low
		CA	Negligible – Minor	Rare - Possible	L	Strong	Low - Low

Detrimental effect on coral-algal symbiosis

The estimated risk for both SCR and CA was **Low**. There was partial agreement on risk level among the experts. For this risk pathway, the severity estimates ranged from Positive to Minor, and the likelihood estimates ranged from Rare to Possible (Table 10).

Table 10 Expert elicitation risk analysis results. Showing the estimated severity, likelihood and risk of the Pilot Deployment activities (Slick Collection and Release (SCR) and Conservation Aquaculture (CA)) leading to detrimental effects on coral-algal symbiosis because of specific potential impacts. (n = 5)

POTENTIAL CONSEQUENCE	RISK PATHWAY (VIA A SPECIFIC POTENTIAL IMPACT)	INTERVENTION METHOD	RANGE OF SEVERITY ESTIMATES (MIN-MAX)	RANGE OF LIKELIHOOD ESTIMATES (MIN – MAX)	RISK (MEDIAN)	LEVEL OF AGREEMENT IN RISK ESTIMATES	DISTRIBUTION OF RISK ESTIMATES RANGE: (MIN-MAX)
Detrimental effect on coral-algal symbiosis	Uncontained spread of provided symbionts to non-target areas/corals	SCR	Positive - Minor	Rare - Possible	L	Partial	Low - Low
		CA	Positive - Minor	Rare - Possible	L	Partial	Low - Low

JUSTIFICATIONS FOR RISK ESTIMATES

General justifications for the risk estimate results (which apply to both the potential impact pathways leading to their respective potential consequences) include:

1. The cultured algal symbionts will be native to the source/deployment reefs. The symbiont species most likely to be used will be generalist species that are compatible with multiple coral species, such as the species *Cladocopium proliferum,* which is highly prevalent and ecologically widespread in nearly all ocean basins and reef habitats where photosymbiotic animals occur. The supporting evidence indicates this species associates with a broad range of invertebrate host taxa including numerous species of reef-building corals, sea anemones, jellyfish, clams and various soft corals. Therefore, the deployment of corals provisioned with these cultured algal symbionts would be highly unlikely to shift the existing symbiont community composition.
2. To effect local algal symbiont populations or non-target coral-algal symbiosis, provided symbionts would not only have to survive and proliferate in the free-living state (Figure 17 D and Figure 18 C), but they would also have to outcompete the very large existing community of suitable symbionts (Figure 17 G and Figure 18 F) and infect other corals, and available evidence indicates this would not be likely given priority effects (initial algal symbionts/communities can become dominant and have a competitive advantage over later arriving symbionts).

Specific justifications for the risk estimate results (relevant to specific risk pathways to each of the potential consequences), include:

POTENTIAL CONSEQUENCE	RISK PATHWAY (VIA A SPECIFIC POTENTIAL IMPACT)	JUSTIFICATION(S)
Detrimental effect on genetics of local algal symbiont populations	Loss of genetic diversity/ adaptive potential of local algal symbiont populations	• Should minor genetic changes occur during the culturing process, by providing these symbionts to deployed corals there is the possible benefit of increasing genetic adaptive diversity/potential. (addresses Figure 17 A and Figure 18 A) • The establishment of algal cultures is an ongoing area of research; however, it is not expected there would be a change in coral phenotype (ability to form symbiosis, *in hospite* symbiont photo physiology, coral growth and survival) when corals are provided with symbionts that have been in culture. • There is evidence of sexual reproduction in algal symbionts; increased genetic variation in Symbiodiniaceae could arise via sexual recombination, which may mitigate any potential reduction in genetic variation because of RRAP activities. • Although corals will be inoculated with algal cultures, they will also likely acquire additional symbionts from the preconditioned choco-blocks or deployment sites, increasing diversity of symbionts in each coral and potentially mitigating any trade-offs.
Detrimental effect on coral-algal symbiosis	Uncontained spread of provided symbionts to non-target areas/corals	• Corals naturally expel symbionts as part of their population control mechanisms, some of which may be viable . Thus, there is potential that these symbionts can spread to neighbour corals (Figure 17 B and Figure 18 B). There is substantial evidence (detailed earlier in the report) that corals can shift their symbiont communities, particularly after bleaching. However, there is no evidence that this uncontained spread of symbionts leads to harm to coral-algal symbiosis, which is defined above as incompatibilities between algal symbionts and corals that lead to a failure to establish or maintain symbiosis or a shift in the nature of the relationship from a mutualistic to parasitic, leading to harm to one or more coral species. In fact, an advantage is most often reported where this symbiont shuffling may improve lifetime host fitness (additional references include Baker *et al.*, 2004, McIlroy *et al.*, 2019, Palacio-Castro *et al.*, 2023).

STRENGTH OF SUPPORTING EVIDENCE BASE

As documented earlier in this report, the available evidence and knowledge base around algal symbionts was sufficient to support the risk assessment process, including an understanding of the mechanisms and factors that influence algal symbionts. While there are knowledge gaps (described below), this evidence base is continuing to improve, with current research underway to address knowledge gaps including research into the uptake of cultured symbionts by non-target corals (RRAP) and the rate of genetic change in Symbiodiniaceae during culture (Macquarie University/AIMS). RRAP has also trialled deploying corals with cultured symbionts in the Marine Park in 2024.

Among the experts involved in the risk assessment process there was a strong level of agreement around the theory underpinning the risk pathways/causal maps developed for algal symbionts, and there was no requirement to create alternative maps to accommodate divergent viewpoints.

On the Reef, investigation, testing and field trials of SCR have been underway for nearly a decade, and there have also been several years of research and development and field testing of CA. This work is further supported by decades of research and restoration from other areas such as Florida and the Caribbean. This body of knowledge has informed the assessment, and key information is summarised here or in the *PDP Ecological Plan.*

AREAS OF UNCERTAINTY FOR EXPERTS

Knowledge gaps

- An absence of data on existing algal symbiont community structure in the target coral species at the proposed intervention sites for the proposed Pilot Deployments.
- An absence of data on the uptake of cultured symbionts by non-target corals and corresponding physiology data. This research is currently in progress, led by Dr Matt Nitschke (AIMS/RRAP scientist).
- An absence of data on the population genetics of algal symbionts on the Reef. There are limited genomic resources across Symbiodiniaceae taxa, which have a challenging genome structure. This makes tracking genetic changes that may result from culturing difficult. Further, there is a lack of consensus regarding best practices for interpreting Symbiodiniaceae genomic data where available (Davies *et al.*, 2023).
- The rate of genetic change in Symbiodiniaceae during culturing. This research is currently in progress, led by Patrick Buerger (Macquarie University/AIMS scientist)

Other

- Uncertainty regarding the randomness and rate of mutation that could occur in culture conditions and how these might impact host fitness or algal population genetics and, if an impact is experienced, the spatial extent of that impact.
- Once symbionts are introduced, there is no way to contain them, and they will be subject to natural processes of competition and grazing/predation.

INFLUENCING FACTORS

Factors that influence the estimate of likelihood, severity and risk were identified and considered during the risk assessment process. The influencing factors are further considered in terms of building knowledge and understanding the potential risks, how the risks might arise and opportunities for risk management. Relevant factors which may influence the severity and likelihood of intervention risks related to algal symbionts include the source of the algal symbionts, the amount of time between when the symbiont cultures are established and when they are provided to the corals, the ability and preference of the corals (or other organisms) to form a symbiosis with the symbionts being provisioned, the existing population dynamics and biomass of local algal symbionts, and the spread of symbionts. Further information on influencing factors for risks associated with disease and pests is available in Section 6.

AVOIDANCE AND MITIGATION MEASURES

Relevant avoidance and mitigation measures in the *PDP Ecological Plan* for the Pilot Deployments base case include ensuring that the algal symbionts provided to coral larvae/recruits are sourced from the same region as those larvae/recruits, as well as QC protocols for the production steps involved in the intervention methods. Further information on avoidance and mitigation measures is available in Section 6.

POTENTIAL BROADER IMPACTS ON MARINE PARK VALUES

Consideration was given to whether the identified potential impacts relevant to algal symbionts might interact or combine to lead to different or amplified risks to algal symbionts and symbiosis, or in turn lead to significant flow on secondary effects on other environment and biodiversity Marine Park values. The assessment concluded that there was a Low risk of interacting or combined potential impacts detrimentally affecting algal symbionts and symbiosis. Given the risks of the proposed Pilot Deployments to algal symbionts (through either individual potential impacts or interacting/combined potential impacts) are estimated to be Low, it is unlikely that any effects on algal symbionts will be significant enough to lead to significant secondary risks to other environment and biodiversity Marine Park values.

CONCLUDING STATEMENT

Based on the *PDP Ecological Plan* for the Pilot Deployments base case, the risks associated with algal symbionts are estimated to be **Low**, with generally consistent agreement among the experts. The only exception was the assessment of risk of Slick Collection and Release and Conservation Aquaculture activities leading to uncontained spread of provided symbionts to non-target areas/corals. Of the five experts, two indicated that the level of risk was Positive while the remainder estimated it as Low. In this case, the two experts estimating the risk as Positive concluded that if a symbiont reaches a density in the environment where it is readily acquired by non-target corals, it is likely that the symbiosis has been a success and is therefore a positive outcome.

There were strong justifications for these estimates, and the available evidence and knowledge base was sufficient to support a conclusive risk estimate. While knowledge gaps around algal symbionts were identified that will be of use in determining future phases of RRAP, they are not barriers to the assessment or management of any potential risks for the proposed Pilot Deployments base case. For instance, the base case involves the deployment of corals with cultured algal symbionts that are native to the source/deployment reefs. The localised nature of this intervention reduces the risk of significant disruptions to the existing ecosystem or genetic structure of algal symbionts. Additionally, while the spread of symbionts to non-target corals remains a consideration, experts considered there is no basis to suggest that this uncontained spread would result in harm to coral-algal symbiosis. The ongoing research in this field will further enhance our understanding of the further development of this intervention, such as implementation of heat-evolved symbionts.

Influencing factors which tend to reduce the risks associated with algal symbionts include sourcing the symbionts from the same Reef region as the planned deployment site, following protocols to minimise the time from establishment to provisioning of algal cultures, and working with those algal species that have been tested in pilot deployment studies which establish long-term symbioses with the corals used in the interventions. Avoidance and mitigation measures are in place to manage the risks associated with algal symbionts, and the risk assessment did not identify any additional measures as necessary.

The Low risk associated with algal symbionts suggests that there will also be Low direct or indirect risks to other environment and biodiversity values. Given the Low risk levels and strong agreement in risk estimates between experts, using the criteria in the *RRAP Intervention Risk Assessment: Approach and methods*, it was concluded that no further analysis or action is required. The results from assessment of algal symbionts were therefore progressed to the Risk Characterisation stage.

3 7.2.1.5 DAMAGE TO REEF STRUCTURE + NON-TARGET ORGANISMS

The results of the risk analysis for the damage to reef structure or non-target organisms sub-theme are presented below, supported by justifications for the findings. Strength of supporting evidence base, areas of uncertainty, relevant influencing factors, avoidance/mitigation measures and potential broader impacts on other values are described.

RESULTS SUMMARY

Detrimental effect on non-target coral or reef organism health that causes the species to decline or prevents recovery

The estimated risks for both SCR and CA were **Low**. There was consistent agreement on risk level among the experts. Across these risk pathways, the severity estimates ranged from Negligible to Minor, and the likelihood estimates ranged from Rare to Possible. For CA, the risk pathways "Harm to species of conservation concern" and "Unsustainable depletion of other species from the ecosystem" were not risk analysed as there are no evident pathways by which these potential impacts could occur from CA activities (Table 11).

Table 11 Expert elicitation risk analysis results. Showing the estimate severity, likelihood and risk of the Pilot Deployment activities (Slick Collection and Release (SCR) and Conservation Aquaculture (CA)) leading to detrimental effects on non-target coral or reef organism health that cause the species to decline or prevents recovery because of specific potential impacts. (n = 5)

POTENTIAL CONSEQUENCE	RISK PATHWAY (VIA A SPECIFIC POTENTIAL IMPACT)	INTERVENTION METHOD	RANGE OF SEVERITY ESTIMATES (MIN-MAX)	RANGE OF LIKELIHOOD ESTIMATES (MIN – MAX)	RISK (MEDIAN)	LEVEL OF AGREEMENT IN RISK ESTIMATES	DISTRIBUTION OF RISK ESTIMATES RANGE: (MIN-MAX)
Detrimental effect on non-target coral or reef organism health that causes the species to decline or prevents recovery	Damage or disturbance to reef structure or other living things at intervention sites	SCR	Negligible - Minor	Low - Low	L	Strong	Low - Low
		CA	Negligible - Minor	Low - Low	L	Strong	Low - Low
	Damage or disturbance to reef structure or other living things at other (non-intervention) sites	SCR	Negligible - Minor	Low - Low	L	Strong	Low - Low
		CA	Negligible - Minor	Low - Low	L	Strong	Low - Low
	Harm to species of conservation concern	SCR	Negligible - Minor	Low - Low	L	Strong	Low - Low
		CA	N/A	N/A	N/A	N/A	N/A
	Unsustainable depletion of other species from the ecosystem	SCR	Negligible - Negligible	Low - Low	L	Strong	Low - Low
		CA	N/A	N/A	N/A	N/A	N/A

JUSTIFICATIONS FOR RISK ESTIMATES

General justifications for risk estimate results (which apply to all the risk pathways leading to the potential consequence) include:

1. If damage or disturbance does occur via collections or deployment it will be unlikely to have an impact significant enough to cause a species to decline or prevent recovery of a reef.

Specific justifications for the risk estimate results (relevant to specific risk pathways to the potential consequence) include:

POTENTIAL CONSEQUENCE	RISK PATHWAY (VIA A SPECIFIC POTENTIAL IMPACT)	JUSTIFICATION(S)
Detrimental effect on non-target coral or reef organism health that causes the species to decline or prevents recovery	Damage or disturbance to reef structure or other living things at intervention sites & Damage or disturbance to reef structure or other living things at other (non-intervention) sites	• Most potential impacts associated with damage to reef structure can be avoided through proper mitigation measures (e.g., maintenance of boats and equipment, AIMS boating and diving qualifications, etc.). • Automated deployment system will be implemented to maximise success of deployed corals while minimising local damage. • Inert devices (alumina) currently used have been shown to be overgrown by natural benthic organisms with no observable detrimental effects. • Deployment devices have high field retention rates (90% after 10 months) and quick integration into reef structure. • Monitoring has shown that ~60% of devices did not shift during an extreme weather event (Cyclone Kirrily) in 2024. For those devices that do shift, they typically move <1m from landing site (fall into crevices at target site rather than away from the targeted intervention site) even in severe weather due to the high-density material used. • On unstable substrate the devices can be linked together (5+) to reduce movement.

STRENGTH OF SUPPORTING EVIDENCE BASE

As documented earlier in this report, the available evidence and knowledge base around damage to reef structure or non-target organisms was sufficient to support the risk assessment process, including an understanding of the mechanisms and factors that influence damage.

Among the experts involved in the risk assessment process there was a strong level of agreement around the theory underpinning the risk pathways/causal maps developed for damage to reef structure or non-target organisms, and there was no requirement to create alternative maps to accommodate divergent viewpoints.

On the Reef, investigation, testing and field trials of SCR have been underway for nearly a decade, and there have also been several years of research and development and field testing of CA. This work is further supported by decades of research and restoration from other areas such as Florida and the Caribbean. This body of knowledge has informed the assessment, and key information is summarised here or in the *PDP Ecological Plan*.

AREAS OF UNCERTAINTY FOR EXPERTS

Knowledge gaps

- An absence of data on the longer-term effects of devices on the integrity of the reef matrix
- Limited data on the movement of devices when subjected to extreme weather events e.g. cyclones

Other

- Limited understanding around some details of the intervention deployment proposal (including activities associated with coral collections), particularly whether these would be sufficient to lead to a detrimental effect on non-target coral or reef organism health that could then lead to local population decline or prevent recovery.

INFLUENCING FACTORS

Factors that influence the estimate of likelihood, severity and risk were identified and considered during the risk assessment process. The influencing factors are further considered in terms of building knowledge and understanding the potential risks, how the risks might arise and opportunities for risk management. Relevant factors which may influence the severity and likelihood of risks associated with damage to reef structure or non-target organisms include the quantity of deployment devices, the level of experience of the divers conducting the collection and monitoring activities, and environmental conditions, i.e., weather, storms and currents.

AVOIDANCE AND MITIGATION MEASURES

Relevant avoidance and mitigation measures in the *PDP Ecological Plan* for the Pilot Deployments base case include careful design of the intervention activities and protocols, as well as ensuring proper maintenance of all intervention equipment and proper certification and training of divers. Further information on avoidance and mitigation measures is available in Section 6.

POTENTIAL BROADER IMPACTS ON MARINE PARK VALUES

Consideration was given to whether the identified potential impacts relevant to damage to reef structure or non-target organisms might interact or combine to lead to different or amplified risks to these values, or in turn lead to significant flow on secondary effects on other environment and biodiversity Marine Park values. The assessment concluded that there was a Low risk of interacting or combined potential impacts detrimentally affecting reef structure or non-target organisms. Given the risks of the proposed Pilot Deployments relating to damage to reef structure or non-target organisms (through either individual potential impacts or interacting/combined potential impacts) are estimated to be Low, it is unlikely that any damage to reef structure or non-target organisms will be significant enough to lead to significant secondary risks to other environment and biodiversity Marine Park values.

CONCLUDING STATEMENT

Based on the *PDP Ecological Plan* for the Pilot Deployments base case, the risks associated with damage to reef structure and other non-target organisms are estimated to be **Low**, with consistent agreement among the experts.

There were strong justifications for these estimates, and the available evidence and knowledge base was sufficient to support a conclusive risk estimate. While knowledge gaps around the use of devices were identified that will be of use in determining future phases of RRAP, they are not barriers to the assessment or management of any potential risks for the Pilot Deployments base case.

Influencing factors which tend to reduce the risks associate with damage to reef structure or non-target organisms include using a highly experienced divers to conduct collection and monitoring activities, and conducting the collection, deployment and monitoring activities at times and in locations where environmental conditions are most favourable i.e. least exposed to storms, strong winds and strong currents. Avoidance and mitigation measures are in place to manage the risks of damage to reef structure and other non-target organisms, and the risk assessment did not identify any additional measures as necessary.

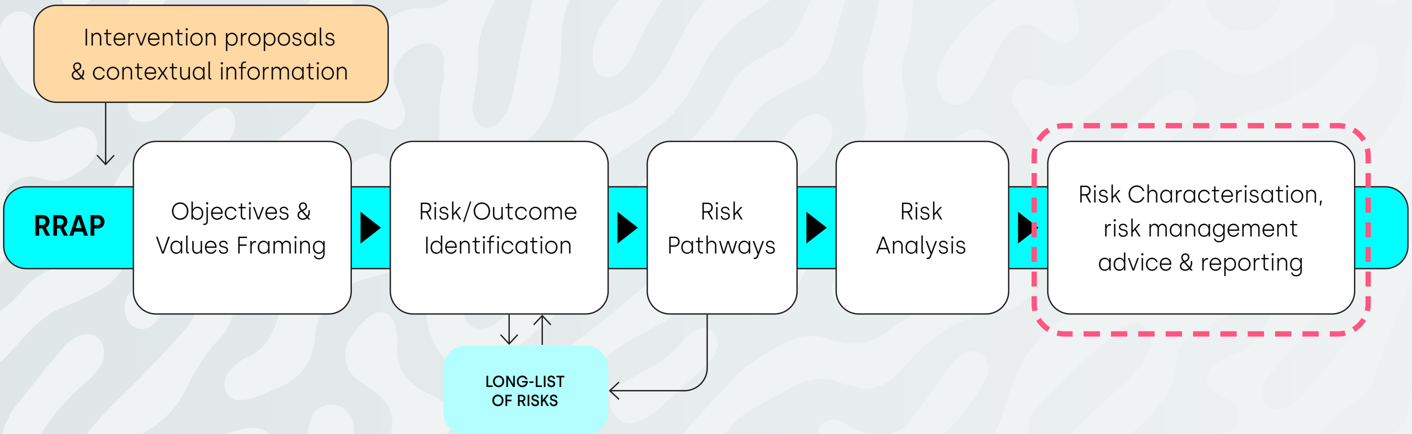
The Low risk associated with damage to reef structure or non-target organisms suggests that there will also be Low direct or indirect risks to other reef environment and biodiversity values. Given the Low risk levels and strong agreement in risk estimates between experts, using the criteria in the *RRAP Intervention Risk Assessment: Approach and methods*, it was concluded that no further analysis or action is required. The results from assessment of damage to reef structure or non-target organisms were therefore progressed to the Risk Characterisation stage.

Wave flume tanks to measure coral rubble movement. Credit: University of Queensland

8 Risk characterisation and risk management advice

8.1 Methods

The purpose of the risk characterisation stage is to bring together the understanding gained about the reef intervention deployments to characterise the potential risks to Marine Park values. The overarching process and methods are detailed in *RRAP Intervention Risk Assessment: Approach and methods*. Information on potential risks and outcomes across the different Marine Park value groups and intervention types was synthesised and presented holistically.



8.1.1 APPLICATION OF THE METHODS TO THE PROPOSED PILOT DEPLOYMENTS

Risk characterisation of the proposed Pilot Deployments was undertaken as per the *RRAP Intervention Risk Assessment: Approach and methods*.

For the theme Environment and Biodiversity, a thorough initial risk analysis (using expert elicitation) was undertaken of the risks identified under the five sub-themes Coral population resilience, Coral reef ecosystem resilience, Disease and pests, Algal symbionts and Damage to reef structure or non-target organisms. This risk analysis was detailed in the previous section. Following this initial risk analysis and consideration of the potential for additional or broader ecological risks, it was determined that the risk analysis stage was complete, and all identified risks could proceed to the risk characterisation stage, without the need for further review or additional analysis.

This risk characterisation section draws upon the findings from assessment of these five sub-themes. Understanding from these findings is applied back to characterise the nature and level of risk to the key values that could have direct and/or indirect interactions with the activities of the proposed Pilot Deployments.

8.2 Findings

The interventions being discussed here aim to provide positive outcomes for Marine Park values, now and in the future. However, as part of a due diligence approach to ensure intervention risks are considered and understood, both by RRAP and by Marine Park managers and decision-makers, the focus of this document has been on any risk of harmful outcomes to Marine Park values (which the Program seeks to avoid). Consequently, the findings of this report should be considered alongside the broader information available on each intervention and the Pilot Deployments Program, including their intended benefits, to achieve a balanced understanding of the potential risks and benefits of undertaking these activities within the Marine Park.

8.2.1 ENVIRONMENT AND BIODIVERSITY

The findings under each sub-theme will now be discussed in terms of the key values that could have direct and/or indirect interactions with the activities of the proposed Pilot Deployments. Table 12 indicates which of the five sub-themes were assessed in relation to each key value.

Table 12 Summary of which sub-themes were assessed in relation to each key value.

VALUE		INTERVENTION METHOD	SUB-THEME				
			CORAL POPULATION RESILIENCE	CORAL REEF ECOSYSTEM RESILIENCE	DISEASE AND PESTS	ALGAL SYMBIONTS	DAMAGE TO REEF STRUCTURE AND NON-TARGET ORGANISMS
Corals	(target)	SCR	✓		✓	✓	✓
		CA	✓		✓	✓	✓
	(non-target)	SCR	✓		✓	✓	✓
		CA	✓		✓	✓	✓
Plankton and microbes	(algal symbionts) and process of symbiosis)	SCR				✓	
		CA				✓	
Coral reefs	(intervention reefs)	SCR	✓	✓	✓	✓	✓
		CA	✓	✓	✓	✓	✓
	(beyond the intervention reefs)	SCR	✓	✓	✓	✓	
		CA	✓	✓	✓	✓	
Other ecological values	(e.g. bony fish, dolphins, whales, marine turtles, other invertebrates, sea snakes, sharks and rays)	SCR			✓	✓	✓
		CA			✓	✓	✓

LEGEND

✓ *sub-theme was assessed in relation to the value*

☐ *blank indicates the sub-theme was not assessed in relation to the value.*

The nature and level of risks to these key values are informed by the risk levels for risk pathways (Figure 22) and summarised below, including the rationale for ratings.

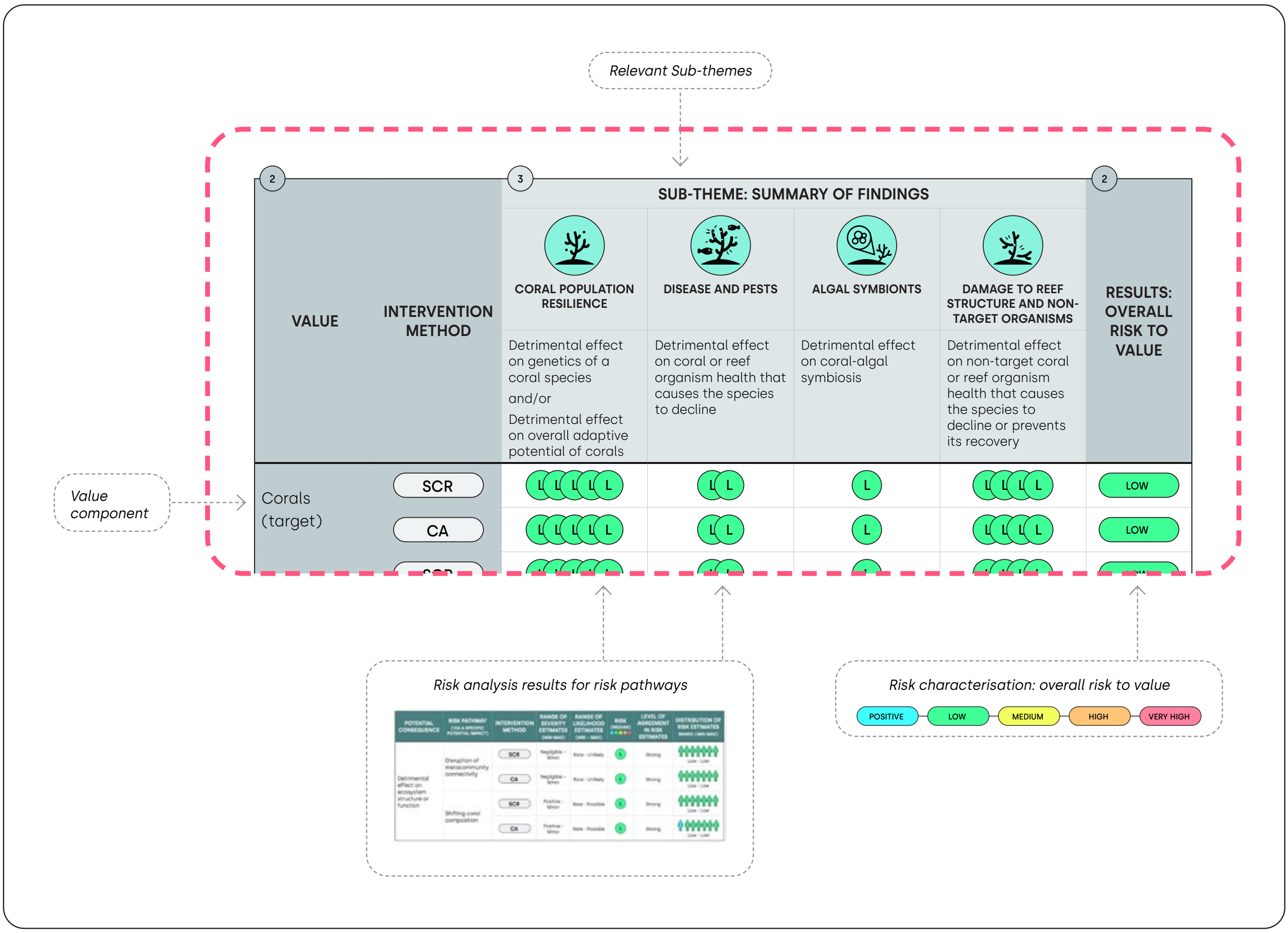


Figure 22 Results for the risk characterisation for each Value Group are informed by the risk levels for risk pathways. The figure shows an example extract from a risk characterisation table.

2 8.2.1.1 CORALS

RISK LEVEL

The overall risk to corals (both target and non-target) in the Marine Park from the Pilot Deployment activities (both SCR and CA) was assessed as **Low**.

The risk level of each risk pathway to each relevant potential consequence for Corals (target and non-target) is shown in Table 13 below, and further explanation is provided in this section.

Table 13 Summary of risk levels of the Pilot Deployment activities on corals (both target and non-target). For each of the two intervention methods (SCR and CA) the estimated risk level is shown for each potential risk pathway. The number of potential risk pathways varies from 1 to 5 pathways depending on the sub-theme and intervention method.

VALUE	INTERVENTION METHOD	SUB-THEME: SUMMARY OF FINDINGS CORAL POPULATION RESILIENCE Detrimental effect on genetics of a coral species and/or Detrimental effect on overall adaptive potential of corals	DISEASE AND PESTS Detrimental effect on coral or reef organism health that causes the species to decline	ALGAL SYMBIONTS Detrimental effect on coral-algal symbiosis	DAMAGE TO REEF STRUCTURE AND NON-TARGET ORGANISMS Detrimental effect on non-target coral or reef organism health that causes the species to decline or prevents its recovery	RESULTS: OVERALL RISK TO VALUE
Corals (target)	SCR	L L L L L	L L	L	L L L L	LOW
	CA	L L L L L	L L	L	L L L L	LOW
Corals (non-target)	SCR	L L L L L	L L	L	L L L L	LOW
	CA	L L L L L	L L	L	L L L L	LOW

LEGEND

INTERVENTION METHOD:

SCR = *Slick Collection & Release* CA = *Conservation Aquaculture*

OVERALL RISK LEVEL:

POSITIVE – LOW – MEDIUM – HIGH – VERY HIGH

EXPLANATION OF RISKS TO CORALS

The relevant pathways by which the Pilot Deployment activities might cause detrimental effects to corals have been comprehensively assessed. This included all risk pathways related to corals across the causal maps for coral population resilience, disease and pests, algal symbionts, and damage to reef structure or non-target organisms. Based on risk analysis by expert panels, each of these risks to corals in the Marine Park was rated as Low (see Table 13).

It is considered unlikely that two or more Low risks across these sub-themes would combine or interact in a way that elevates overall risk to corals. Potential indirect flow-on effects to other environment and biodiversity values were also considered. However, given the Low individual and combined risk ratings for corals, significant secondary effects were assessed as unlikely. Accordingly, the overall risk of detrimental effects on corals was assessed as Low.

These findings reflect the type of interventions proposed for deployment (SCR and CA) and the design of the deployment proposal, i.e. scale, intervention intensity, use of a selection process for source reefs and broodstock, existing avoidance and mitigation measures and QA/QC protocols, and location of deployment reefs in relation to source reefs (within the same reef region). Coral material will be regionally sourced, ensuring that deployed larvae or juveniles are returned to the same reef region or cluster from which they originated. This approach minimises the risk of outbreeding depression and disruption to population genetic structure, even though finer-scale genetic structure across the GBR remains incompletely understood.

The risk of inbreeding depression or reduced genetic diversity is also Low. Both SCR and CA use multiple broodstock sources and natural spawn slicks to maximise diversity, and genetic management principles are informing the detailed plans for the Pilot Deployments Program. Deployment volumes are small relative to background coral populations, and expert elicitation confirmed that genetic and demographic risks are not significant under this scale and intensity of intervention.

Disease transmission risks are mitigated through practices such as health screening of coral material and recruits, sterilisation techniques for water and culture systems, and short holding times in coral production facilities. No foreign species or materials are used in the interventions, thus avoiding the introduction of novel pests or diseases.

The assessment also found that there is a Low risk of detrimental effects on coral-algal symbiosis, and a Low risk of damage to reef structure, including to target and non-target corals. These findings are discussed in earlier sections and supported further below. All assessments took current and projected reef conditions into account.

LEVEL OF AGREEMENT, STRENGTH OF SUPPORTING INFORMATION AND KNOWLEDGE GAPS

The risk analysis panel experts were aligned as to the nature and level of any risks to corals from the Pilot Deployment activities.

Multiple lines of evidence and studies (documented earlier in the report) were available to sufficiently support the risk assessment process for risk pathways that relate to corals. The assessment also benefited from the learnings and knowledge base being generated from ongoing research and development into the intervention methods being assessed.

As with the assessment findings at the sub-theme level, some uncertainties and knowledge gaps were noted. However, these were not considered to limit the assessment or the ability to manage risks to the coral value group.

CONCLUSION

The Pilot Deployments are assessed as **Low** risk to target and non-target corals on the Great Barrier Reef.

RISK LEVEL

The overall risk to plankton and microbes in the Marine Park from the Pilot Deployment activities (both SCR and CA) was assessed as **Low**. This includes any risks to algal symbiont population genetics and to coral-symbiont relationships.

The risk level of each risk pathway to each relevant potential consequence for plankton and microbes (symbionts) and symbiosis is shown in Table 14 below, and further explanation is provided later in this section.

Table 14 Summary of risk levels of the Pilot Deployment activities on plankton and microbes (symbionts and symbiosis). For each of the two intervention methods (SCR and CA) the estimated risk level is shown for each potential risk pathway. For this sub-theme, for each intervention method there is 1 potential risk pathway to each of the potential consequences.

2 VALUE	INTERVENTION METHOD	3 SUB-THEME: SUMMARY OF FINDINGS		2 RESULTS: OVERALL RISK TO VALUE
		ALGAL SYMBIONTS		
		Detrimental effect on genetics of local algal symbiont populations	Detrimental effect on coral-algal symbiosis	
Plankton and microbes (symbionts) and symbiosis	SCR	L	L	LOW
	CA	L	L	LOW

LEGEND

INTERVENTION METHOD:

SCR = *Slick Collection & Release* CA = *Conservation Aquaculture*

OVERALL RISK LEVEL:

POSITIVE – LOW – MEDIUM – HIGH – VERY HIGH

EXPLANATION OF RISKS TO PLANKTON AND MICROBES (SYMBIONTS AND SYMBIOSIS)

The relevant pathways by which the Pilot Deployment activities might cause detrimental effects to algal symbionts and coral-algal symbiosis have been comprehensively assessed. This included all risk pathways related to algal symbionts and symbiosis as mapped in the risk pathways for the algal symbionts sub-theme. Based on risk analysis by an expert panel, each of these risks to plankton and microbes was rated as Low risk (see Table 14).

It is considered unlikely that two or more of the different Low risks within this sub-theme would combine or interact in a way that elevates overall risk to plankton and microbes. Potential indirect flow-on effects to other environment and biodiversity values were also considered. However, given the Low individual and combined risk ratings for plankton and microbes, significant secondary effects were assessed as unlikely. Accordingly, the overall risk of detrimental effects on plankton and microbes (symbionts and symbiosis) was assessed as Low.

These findings reflect the scale and design of the proposed interventions, the within-region sourcing strategy, the tiny deployment volumes of symbionts compared to natural background symbiont populations, and the quality control measures in symbiont culturing and provisioning. There is also evidence that this provisioning with symbionts may provide a survival benefit to the juvenile corals.

All algal symbionts used in provisioning the proposed Pilot Deployments will originally be sourced from the same region as the deployment reefs, reducing the likelihood of ecological mismatch or disruption to local symbiont populations and natural processes. Symbionts will be cultured to the required volumes for provisioning the early-stage corals; their use in these coral intervention methods has already been field-tested on the Reef. No experimental manipulation (e.g., heat evolution) is proposed for symbionts as part of the intervention proposal covered in this report.

The cultured symbionts are expected to remain compatible with local coral hosts (likewise for non-coral hosts, if any). Any spread beyond intervention sites/reefs is expected to be limited in scale and harmful ecological consequence are not considered likely. Some expert views considered successful symbiosis by the provisioned symbionts to be potentially positive rather than harmful; no experts considered it to be more than a Low risk.

While some knowledge gaps remain—for example, regarding symbiont community structures and long-term population dynamics—the risk of meaningful negative impacts under the base case was assessed as Low. To significantly affect local symbiont populations or coral-algal symbiosis, the symbionts that are used in the intervention would need to outcompete an already dense and diverse existing community and infect other corals or organisms. This was considered unlikely. The high natural abundance and diversity of free-living symbionts in reef environments further buffer against potential disruption.

LEVEL OF AGREEMENT, STRENGTH OF SUPPORTING INFORMATION AND KNOWLEDGE GAPS

The risk analysis panel experts were aligned as to the nature and level of any risks to plankton and microbes from the Pilot Deployment activities.

As documented earlier in this report, multiple lines of evidence and studies were available to sufficiently support the risk assessment process. The assessment also benefited from the learnings and knowledge base being generated from ongoing research and development into the intervention methods being assessed.

While some knowledge gaps remain—such as limited data on algal symbiont community structure in the target coral species, the potential uptake of cultured symbionts by non-target corals, and the population genetics of algal symbionts in the Reef—these uncertainties were not considered to limit the assessment or the ability to manage risks to plankton and microbes.

CONCLUSION

The Pilot Deployments are assessed as **Low** risk to plankton and microbes (symbionts) and the process of symbiosis on the Great Barrier Reef.

8.2.1.3 CORAL REEFS

RISK LEVEL

The overall risk to coral reefs in the Marine Park from the Pilot Deployment activities (both SCR and CA) was assessed as **Low**. This applies to intervention reefs and reefs beyond those.

The risk level of each risk pathway to each relevant potential consequence for coral reefs is shown in Table 15 below, and further explanation is provided later in this section.

Table 15 Summary of risk levels of the Pilot Deployment activities on coral reefs (both intervention reefs and those beyond the intervention reefs). For each of the two intervention methods (SCR and CA) the estimate risk level is shown for each potential risk pathway. The number of potential risk pathways varies from 0 (represented by an empty box) to 5 pathways depending on the sub-theme and intervention method.

VALUE	INTER-VENTION METHOD	SUB-THEME: SUMMARY OF FINDINGS						RESULTS: OVERALL RISK TO VALUE
		CORAL POPULATION RESILIENCE		CORAL REEF ECOSYSTEM RESILIENCE	DISEASE AND PESTS	ALGAL SYMBIONTS	DAMAGE TO REEF STRUCTURE AND NON-TARGET ORGANISMS	
		Detrimental effect on overall adaptive potential of corals	Detrimental effect on genetics of a coral species	Detrimental effect on ecosystem structure or function	Detrimental effect on coral or reef organism health that causes the species to decline	Detrimental effect on coral-algal symbiosis	Detrimental effect on non-target coral or reef organism health that causes the species to decline or prevents its recovery	
Coral reefs (intervention reefs)	SCR	L L L L L	L L L L	L L	L L	L	L L L L	LOW
	CA	L L L L L	L L L L	L L	L L	L	L L	LOW
Coral reefs (beyond the intervention reefs)	SCR	L L L L L	L L L L	L L	L L	L		LOW
	CA	L L L L L	L L L L	L L	L L	L		LOW

LEGEND

INTERVENTION METHOD:

SCR = *Slick Collection & Release* CA = *Conservation Aquaculture*

OVERALL RISK LEVEL:

POSITIVE – LOW – MEDIUM – HIGH – VERY HIGH

EXPLANATION OF RISKS TO CORAL REEFS

The relevant pathways by which the Pilot Deployment activities might cause detrimental effects to coral reef ecosystems have been comprehensively assessed. This included all risk pathways related to coral reefs across the causal maps for coral population resilience, coral reef ecosystem resilience, disease and pests, algal symbionts and symbiosis, and damage to reef structure or non-target organisms. These assessments also reflect detailed consideration of risks to corals, plankton and microbes (including symbionts and symbiosis), and non-target organisms. Based on risk analysis by an expert panel, each of these risks to coral reefs was rated as Low (Table 15).

This conclusion applies to intervention reefs (receiving deployments) and nearby reefs. Reefs located further afield are expected to be at even lower risk from the proposed Pilot Deployments. The assessment determined that such distant reefs would face negligible risk. This conclusion was supported by review of the mapped risk pathways, consideration of the ecosystem processes underpinning coral reef function (as described in the Great Barrier Reef Outlook Report series: outlookreport.gbrmpa.gov.au), and expert input obtained through the comprehensive discussions undertaken during this assessment process.

It is considered unlikely that two or more Low risks across these sub-themes would combine or interact in a way that elevates overall risk to coral reefs. Potential indirect flow-on effects to other environment and biodiversity values were also considered. However, given the Low individual and combined risk ratings for coral reefs, significant secondary effects were assessed as unlikely. Accordingly, the overall risk of detrimental effects on coral reefs was assessed as Low.

These findings reflect the type of interventions proposed for deployment (SCR and CA) and the design of the Pilot Deployments Program, including its modest scale and low intervention intensity relative to the size and ecological complexity of coral reef habitats. The intervention design includes site selection criteria and deployment guidance that account for reef condition, existing community structure, and proximity to source reefs. Deployment activities will occur within reef regions—and often within reef clusters—which helps ensure ecological compatibility and reduces the likelihood of cumulative or ecosystem-scale changes. Risk pathways related to ecosystem structure, coral composition, and non-target organisms were systematically mapped and assessed, with no pathway rated above Low.

The risk of disruption to coral reef ecosystem structure or function is Low. The use of multiple coral species across a range of ecological traits, along with within-region sourcing and site-specific deployment, minimises the risk of shifting coral composition or disrupted metacommunity connectivity. While this report does not assess potential ecological benefits, one expert noted that any changes in coral composition that may occur could be ecologically beneficial under future climate scenarios.

The interventions are intended to support local reef resilience by supplementing coral cover and restoring structural complexity. They are designed to reinforce coral dominance, which is an essential component of reef biodiversity and ecosystem services, while avoiding harm to ecological processes. The proposed deployment footprint is modest in scale and intensity and has been informed by prior experimental work. Several years of careful coral seeding device design and testing have been undertaken, and field activities will be implemented by trained and experienced operators, further minimising the risk of reef disturbance.

LEVEL OF AGREEMENT, STRENGTH OF SUPPORTING INFORMATION AND KNOWLEDGE GAPS

The risk analysis panel experts were aligned as to the nature and level of any risks to coral reefs from the Pilot Deployment activities.

As documented earlier in this report, multiple lines of evidence and studies were available to sufficiently support the risk assessment process. The assessment also benefited from the learnings and knowledge base being generated from ongoing research and development into the intervention methods being assessed. Uncertainties or knowledge gaps were not considered limitations to managing the risk to corals reefs.

CONCLUSION

The Pilot Deployments activities are assessed as **Low** risk to intervention reefs and other coral reefs within the Marine Park.

8.2.1.4 OTHER ECOLOGICAL VALUES (OTHER ORGANISMS)

RISK LEVEL

The overall risk to other organisms in the Marine Park (including bony fish, dolphins, whales, marine turtles, other invertebrates, sea snakes, sharks and rays) from the Pilot Deployment activities (both SCR and CA) was assessed as **Low**. The risk level of each risk pathway to each relevant potential consequence for these "Other" values is shown in Table 16 below, and further explanation is provided later in this section.

Table 16 Summary of risk levels of the Pilot Deployment activities on other ecological values (other organisms). For each of the two intervention methods (SCR and CA) the estimated risk level is shown for each potential risk pathway. The number of potential risk pathways varies from 1 to 4 pathways depending on the sub-theme and intervention method.

VALUE	INTERVENTION METHOD	SUB-THEME: SUMMARY OF FINDINGS			RESULTS: OVERALL RISK TO VALUE
		DISEASE AND PESTS Detrimental effect on coral or reef organism health that causes the species to decline	ALGAL SYMBIONTS Detrimental effect on genetics of local algal symbiont populations	DAMAGE TO REEF STRUCTURE AND NON-TARGET ORGANISMS Detrimental effect on non-target coral or reef organism health that causes the species to decline or prevents its recovery	
Other ecological values (other organisms) e.g. bony fish, dolphins, whales, marine turtles, other invertebrates, sea snakes, sharks and rays	SCR	L L	L	L L L L	LOW
	CA	L L	L	L L	LOW

LEGEND

INTERVENTION METHOD:

SCR = *Slick Collection & Release* CA = *Conservation Aquaculture*

OVERALL RISK LEVEL:

POSITIVE – LOW – MEDIUM – HIGH – VERY HIGH

EXPLANATION OF RISKS TO OTHER ORGANISMS

The relevant pathways by which the Pilot Deployment activities might cause detrimental effects to other ecological values (i.e., other organisms) —such as bony fish, marine turtles, sea snakes, invertebrates, sharks, rays, and marine mammals—have been comprehensively assessed. This included all risk pathways relevant to these non-target organisms across the causal maps for disease and pests, algal symbionts and symbiosis, and damage to reef structure or non-target organisms. Based on risk analysis by an expert panel, each of these risks to other ecological values was rated as Low (Table 16).

Given the nature of the Pilot Deployment activities, species that occur outside the deployment sites are expected to be at even lower risk, as such distant or incidental exposures would result in negligible risk. This conclusion was supported by review of mapped risk pathways, expert discussions, and consideration of habitat usage by at-risk species (e.g., listed threatened species protected by law) and ecosystem interactions among trophic groups and reef-dependent species.

It is considered unlikely that two or more Low risks across these sub-themes would combine or interact in a way that elevates overall risk to other ecological values. Potential indirect flow-on effects to other environment and biodiversity values were also considered. However, given the Low individual and combined risk ratings for these non-target organisms, significant secondary effects were assessed as unlikely. Accordingly, the overall risk of detrimental effects on other ecological values in the Marine Park was assessed as Low.

These findings reflect the nature and scale of the proposed interventions, the design of the Pilot Deployments Program, and the safeguards in place to avoid harm to non-target organisms. No direct interactions between marine mammals, turtles, fish, invertebrates, sharks, or rays and the proposed deployment methods were identified that would plausibly result in harmful outcomes affecting their conservation status or ecological sustainability. All identified indirect risk pathways—such as those relating to unintended reef degradation or physical disturbance at localised sites, or pathogen transmission—were assessed as Low, and are effectively mitigated through existing quality assurance procedures, the use of reef-compatible deployment methods, careful supervision of the field-based activities and the use of experienced personnel, and the application of non-toxic and inert coral seeding device materials.

The PDP does not involve the use of any foreign biological material. All biological components—corals, larvae, and symbionts—are native to the deployment regions and sourced locally. This helps to minimise ecological disruption and avoids the introduction of novel pests or pathogens. Quality assurance and quality control (QA/QC) protocols include health screening, further reducing any risk of disease transmission to reef organisms.

In addition, the coral seeding devices have been tested through multiple years of field experiments and trials, with evidence showing high retention rates and minimal movement under normal and more extreme weather conditions. These devices are deployed with ecologically informed guidance, and deployment densities are low relative to natural habitat complexity. Accordingly, the risk of mechanical disturbance to other organisms is Low. Over time, increases in coral cover and structural complexity associated with the interventions may provide indirect benefits to other reef-dependent species by enhancing available habitat and ecosystem services.

LEVEL OF AGREEMENT, STRENGTH OF SUPPORTING INFORMATION AND KNOWLEDGE GAPS

The risk analysis panel experts were aligned as to the nature and level of any risks to other non-target values from the Pilot Deployment activities.

As with the assessment findings at the sub-theme level, while some uncertainties and knowledge gaps were noted, these were not considered to limit the assessment or ability to manage risks to other ecological values. This conclusion was supported by the availability of multiple lines of evidence and the growing knowledge base generated through ongoing research and development of the intervention methods.

CONCLUSION

The Pilot Deployments activities are assessed as **Low** risk to other ecological values within the Marine Park.

RISK LEVEL

*The overall risk of the RRAP Pilot Deployments base case to environment and biodiversity values of the Marine Park was assessed as **Low**. The risk level for large-scale piloting of each of the Pilot Deployments methods—Slick Collection and Release (SCR) and Conservation Aquaculture (CA), as proposed for use in the Program—was also assessed as **Low** and reflects consistent findings across all key value groups.*

The risk assessment for environment and biodiversity values provides a well-supported understanding of the nature and level of ecological risk associated with the proposed Pilot Deployments. This includes consideration of potential direct and indirect risks to key ecological values, interactions between risks and cumulative consequences.

The assessed risk level for each environment and biodiversity value is summarised in *Table 17* below. For all values (as detailed in Sections 8.2.1.1 to 8.2.1.4), the assessed risk was rated as Low across both deployment methods. No Medium or higher risks were identified. It is considered unlikely that two or more Low risks across these value groups would combine or interact in a way that elevates the overall risk to the environment and biodiversity values in the Marine Park, given the findings discussed earlier in this report.

Looking ahead, if additional intervention options or deployment scenarios (beyond those that are part of the *PDP Ecological Plan*) are proposed for inclusion in the Pilot Deployments Program, this ecological risk assessment can be updated to reflect the expanded scope. Any new activities would be carefully evaluated using the same RRAP Intervention Risk Assessment framework and quality assurance process applied in this report. Risk management will remain an integral part of PDP planning and implementation, tailored to the characteristics and scale of each intervention. This ensures that risks to Marine Park values continue to be identified, assessed, and managed in a transparent and adaptive manner.

CONCLUSION

The Pilot Deployments activities, as currently proposed and configured, are assessed as posing **Low** risk to the environment and biodiversity values of the Great Barrier Reef Marine Park. This finding reflects the scale and intensity of the proposed interventions, the incorporation of existing risk avoidance and mitigation measures, and factors such as the use of corals and symbionts sourced from within reef regions and the incorporation of tested, reef-compatible technologies. Current and projected reef conditions were taken into account. Based on these findings, implementation of the Pilot Deployments Program is consistent with the management objectives for the Great Barrier Reef and supports continued progress through carefully managed testing and development of reef interventions.

Coral seeding device with settlement tile. Credit: Australian Institute of Marine Science.

Table 17 Summary of overall risk ratings to key value groups (e.g. corals) and to the environment and biodiversity values in the Marine Park from each Pilot Deployment method, and the program as a whole.

VALUE	INTERVENTION METHOD		SUMMARY OF FINDINGS: OVERALL RISK TO VALUE
Corals (target)	SCR	LOW	2 Corals SCR: LOW CA: LOW
	CA	LOW	
Corals (non-target)	SCR	LOW	
	CA	LOW	
Plankton and microbes (symbionts) and symbiosis	SCR	LOW	2 Plankton, microbes, + the process of symbiosis SCR: LOW CA: LOW
	CA	LOW	
Coral reefs (intervention reefs)	SCR	LOW	2 Coral reefs SCR: LOW CA: LOW
	CA	LOW	
Coral reefs (beyond the intervention reefs)	SCR	LOW	
	CA	LOW	
Other ecological values (other organisms) e.g. bony fish, dolphins, whales, marine turtles, other invertebrates, sea snakes, sharks and rays	SCR	LOW	2 Other organisms SCR: LOW CA: LOW
	CA	LOW	
RESULTS: OVERALL RISK PROFILE	SCR		LOW
	CA		LOW
RRAP Pilot Deployments Program			
1 Marine Park Values (Environment and biodiversity) Overall risk profile: Low environmental risk POSITIVE – **LOW** – MEDIUM – HIGH – VERY HIGH			

Measuring coral larvae settlement during RRAP Moving Corals Subprogram field work. Credit: Southern Cross University

Larval culturing tanks used for RRAP's Coral Aquaculture and Deployment systems. Credit: Dorian Tsai, QUT

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Coral spawning under red light in the National Sea Simulator, Australian Institute of Marine Science. Credit: Dorian Tsai, QUT

Appendix 1 – Key terms

TERM	DEFINITION/EXPLANATION
Activity	A task in a workflow that is completed in series to achieve the desired outcome
Hazard Alternative terms: Stressors Risk sources	A source of potential harm; a situation, action or behaviour that may negatively impact a Marine Park value, whether intentionally or unintentionally. In ecological risk assessment, hazards are sometimes referred to as 'stressors' or 'risk sources'.
Intervention intensity	Combination of the number of corals of a given species deployed in relation to the receiving population size and the magnitude of thermal enhancement (in relation to the natural population thermal tolerance).
Mechanism	A natural or established process by which something takes place or is brought about.
No new interventions	This is the name of the reference case – see Section 3
Non-target coral/organism	Where non-target is specified, this indicates existing communities of corals or other organisms at the source or deployment sites that were NOT directly involved in the intervention activities.
Non-target area	Where non-target is specified, this indicates regions of the Reef that are NOT the source or deployment sites. These non-target areas may be directly adjacent to the source or deployment sites but also include regions further away.
Potential consequence	To what degree a potential impact may affect a value of the Marine Parks. Consequences may be certain or uncertain and can have positive or negative effects on values.
Potential impact	The response from a value due to effects of a hazard/activity on the value
Prerequisites	A condition (or set of conditions) that must exist for the path from intervention activity to potential consequence to be realised
Unintended activity	Activities which are not intended or foreseen as part of a workflow
Value	Aspects or attributes of an environment that make it of significance.

Appendix 2 - Supporting information on risk pathway mechanisms

The following tables contain information on mechanisms (the steps that must occur for an activity to create a hazard leading to a potential impact and a potential consequence on Marine Park values) relevant to each sub-theme under the Environment and biodiversity theme. The figure references refer to the risk pathway causal map figures for Slick Collection and Release and Conservation Aquaculture, under each sub-theme.

Table 18 Information on Mechanisms relevant to coral population resilience

CORAL POPULATION RESILIENCE **MECHANISMS FROM FIGURE 11 AND FIGURE 12**	**FACTS/INFORMATION**
Figure 11 *A* and Figure 12 *A - Trait trade-offs when selecting for thermal tolerance*	Due to the limited data collected from corals as part of the Pilot Deployments base case, the corals used in the interventions will not be chosen purely based on thermal tolerance (or any other trait). However, this mechanism was still included in the risk pathways for thoroughness. Trait trade-offs are a normal part of evolution; it is understood that corals with different life history strategies vary in colony morphology, growth rate, and reproductive mode, with trade-offs affecting their response to disturbances (Darling *et al.*, 2012, Grime & Pierce, 2012, Darling *et al.*, 2013). Selecting for thermal tolerance, which is planned to a limited degree for both SCR and CA intervention activities, can potentially have consequences for growth (Bay & Palumbi, 2017, Cornwell *et al.*, 2021) and disease susceptibility (Shore-Maggio *et al.*, 2018). However, selective breeding to enhance one trait does not necessarily imply that there will be trade-offs – in some cases, selecting for a specific coral phenotype did not result in detectable trade-offs (Muller *et al.*, 2018, Koch *et al.*, 2022, Lachs *et al.*, 2023, Turnham *et al.*, 2023).
Figure 12 *B - Domestication selection*	Domestication can be defined as the adaptation of an animal to the human environment and its specific conditions (Milla *et al.*, 2020). There are many striking differences in the conditions experienced by wild corals in their natural habitat and corals reared in aquaculture facilities. Cultured corals experience altered water quality, may be stocked in unusually high densities, typically have abundant and predictable supply of food and are protected from predation and exposure to wild pathogens. Such differences could cause the phenotypic traits of coral recruits reared in culture, including their behavioural responses, to deviate from those of wild individuals. To date, domestication selection has not been reported in coral aquaculture, though it has been well described for salmon hatcheries (Araki *et al.*, 2008), which are analogous to corals in that they are reared for only part of their lifecycle. Even a single generation in captivity can result in a substantial selection for traits that are beneficial in captivity but severely maladaptive in the wild (Christie *et al.*, 2012). Domestication is an inadvertent mechanism that can lead to greater genetic divergence and future generations having reduced fitness under field conditions (National Academies of Sciences & Medicine, 2019).
Figure 11 *B* and Figure 12 *C - Corals survive long enough to sexually reproduce*	Should trait trade-offs lead to the death of deployed corals, these traits will not be incorporated into the local population and the pathway to harm for coral resilience ends. However, if the corals with detrimental traits survive through to sexual reproduction, those traits could be passed on to future generations (noting that alleles will be reshuffled during sexual reproduction and not all offspring may show the trade-off). Such trade-offs can constrain the manner in which selection can optimise traits (*Østman et al.*, 2014) and thus lead to future generations having reduced fitness.

Figure 11 *C - Genetic bottleneck during larval collection;* Figure 12 *D - Genetic bottleneck during broodstock collection*	SCR: Collecting gametes from slicks necessarily leads to a subsampling of the total community and population diversity. If source reefs for slick collections have experienced recent disturbance events (e.g. coral bleaching or crown-of-thorns starfish outbreaks) or have patchy population genetics over the scale of harvest, larval collection could result in a lower genetic diversity of broodstock. Slick collection plans include both spatial and temporal variation for collections to mitigate this. CA: Subsampling from the population, through both source reef selection and selection of individuals based on phenotype, may cause a genetic bottleneck. This depends on the sample size, population size, and genetic variation in the broodstock corals compared to the natural standing variation in the source population. Genetic management principles are being developed by RRAP to provide guidance on selecting broodstock.
Figure 11 *D and* Figure 12 *E - Asymmetrical variance in fertilization and survival during culturing*	Fertilisation and settlement success is not evenly distributed across coral genotypes; there is a magnified competitive advantage of larvae of certain species (SCR) and genotypes (CA and SCR) when maintained at high densities (Lamb, 2022). These and other stochastic processes (readiness of a given coral to spawn, quality and quantity of gametes, etc.) can affect population dynamics and resultant genomics in deployed larvae or recruits leading to unintended selection of particular genotypes or species. While sexual reproduction of the thermally resilient corals in CA could result in less genetic diversity for the selected feature, the variance in reproductive success will affect genome wide diversity, effectively reducing the number of breeding parents.
Figure 11 *E- Delivery of lower genetic diversity coral larvae or recruits;* Figure 12 *F - Delivery of lower genetic diversity coral*	Certain mechanisms are required for detrimental effects to occur on either the genetics of a coral species or overall adaptive potential. Genetic bottlenecks must occur prior to larval collection (SCR, Figure 11 C) or during broodstock collection (CA, Figure 12 D). Stochastic effects during fertilisation and larval settlement (leading to asymmetrical variance in fertilisation and survival during culture) (Figure 11 D and Figure 12 E) must result in the delivery of lower genetic diversity coral (Figure 11 E and Figure 12 F). If these less diverse corals are delivered at high density and survive to reproduce maturity (Figure 11 B and Figure 12 C), there is a risk of inbreeding depression (Figure 11 L and Figure 12 M) if there are no reproductive barriers that prevent these corals from reproducing with native corals (ecological conditions; Figure 11 F and Figure 12 G). This risk is higher the smaller the native population becomes. Even in the absence of these ecological conditions, the loss of genetic diversity (Figure 11 M and Figure 12 N) is possible if lower genetic diversity corals saturate existing populations.
Figure 11 *F* and Figure 12 *G – Ecological conditions*	Deploying less diverse corals that are unable to breed with native corals may lead to inbreeding in the offspring of the deployed population. The ecological conditions that must be present for inbreeding depression to occur are: 1) a severely reduced local population size, and 2) reproductive barriers (i.e., isolated reefs, reduced gene flow, etc.) which cause deployed corals to only breed among themselves (Riginos *et al.*, 2024).
Figure 11 *G - Overharvesting of coral spawn at source reefs;* Figure 12 *H - Overharvesting of coral at source reefs*	SCR: During mass coral spawning, trillions of eggs can be released into the water column, forming visible coral slicks that drift across the Reef. During SCR activities, larvae will be collected from the surface of the slick, either by nets or by pumping larvae into filtered holding tanks on board vessels. Harvesting wild coral spawn slicks to produce 500 million competent larvae would require less than 0.03% of eggs produced during a single mass spawning event on a typical reef with 30% *Acropora* cover (Doropoulos *et al.*, 2019). By collecting only a small fraction of coral slicks, SCR activities will minimise the amount of eggs removed from an individual population to ensure the potential for continued genetic mixing of broodstock populations within regions. CA: The CA activities include the phenotypic selection and collection of relatively few individuals at a time (e.g., a few dozen). Furthermore, when possible, corals used as broodstock will be returned to the reef after spawning. These corals are likely to have already contributed to coral spawning on the Reef prior to their collection and are therefore considered to already be contributing as parents to local, wild populations.

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Figure 11 *H* and Figure 12 *I - Unsustainable Harvest*	At a metapopulation-level, the harvesting of gametes or adults becomes unsustainable when the result is detrimental impacts on reef connectivity. This impact can result in a loss of metapopulation diversity because augmentation of particular genotypes in one population may spill over into adjacent populations.
Figure 11 *I* and Figure 12 *J - Deployment of larvae/ recruits/coral to a reef where they would not have normally settled*	If corals at any developmental stage are deployed on a reef where they would not ordinarily have settled because of natural larval dispersal, there is the possibility of introducing maladaptive alleles (suboptimal alleles for the new environment), which could lead to outbreeding depression. This could also disrupt metapopulation connectivity by homogenising genotypes across populations, which in turn could reduce ecosystem-wide diversity and adaptive the capacity to adapt to changing environmental conditions. Most corals on the Reef are broadcast spawners and reproduce annually during mass spawning events (Baird *et al.*, 2009, Harrison, 2011). Under natural conditions, coral larvae drift with the currents until they encounter suitable conditions to settle (typically 4-40 days, but as high as 120 days (Graham *et al.*, 2008, Graham *et al.*, 2013)). In a 40-day window following spawning, coral larvae can travel between 25 to 250 km depending on currents (Matz *et al.*, 2018, Hock *et al.*, 2019, Figueiredo *et al.*, 2021). If larvae do not find a reef to settle between 4-40 days, they can persist as larvae for upwards of 120 days and travel >1000 km before settling. For the SCR in the PDP base case, larvae will be released in the same region (e.g. Cairns area) they were collected (well within a maximum distance of 1000 km between collection and deployment locations).
Figure 11 *J* and Figure 12 *K - Isolated populations*	Outbreeding depression can occur if corals are deployed on isolated reefs, where deployed and local populations are genetically distant and reproductive incompatibility between taxa lead to low fitness offspring. These isolated populations typically have a low larval supply and high divergence times. The latter is particularly unlikely given the relatively young age of the Reef. Outbreeding depression is also possible where deployed corals have different locally adapted gene complexes compared to the local population; recombination could lead to a loss of fitness when those co-adapted alleles are broken up.

Table 19 Information on Mechanisms relevant to coral reef ecosystem resilience

CORAL REEF ECOSYSTEM RESILIENCE **MECHANISMS FROM FIGURE 13 AND FIGURE 14**	**FACTS/INFORMATION**
Figure 13 *A* and Figure 14 *A - Overharvesting of coral at source reefs*	SCR: During mass coral spawning, trillions of eggs are released into the water column, often forming visible coral slicks that drift across the Reef. During SCR activities, larvae will be collected from the surface of the slick either by nets or by filtering larvae into holding tanks. Harvesting wild coral spawn slicks to produce 500 million competent larvae would require less than 0.03% of eggs produced during a single mass spawning event on a typical reef with 30% *Acropora* cover (Doropoulos *et al.*, 2019). By extracting a small fraction of coral slicks, SCR activities will minimise the amount eggs extracted from an individual population and ensure the potential for continued genetic mixing of brood-stock populations within regions. CA: The CA activities include the phenotypic selection and collection of relatively few individuals at a time. Further, where possible, corals used as broodstock will be placed back on the reef after spawning.
Figure 13 *B* and Figure 14 *B - Unsustainable Harvest*	At a metacommunity-level, the harvesting of gametes or adults becomes unsustainable when there are resultant detrimental impacts on reef connectivity. This impact could result in a reduction to metacommunity connectivity. This is detrimental as ecosystem connectivity may enhance indirectly the resilience of coral populations to disturbance (Mumby & Hastings, 2008).
Figure 13 *C* and Figure 14 *C - Saturating existing coral population with additional corals*	If sites selected for deployment have low diversity (richness or evenness) of species and low coral cover AND the interventions deploy a substantial number of corals that saturate existing coral populations with additional corals, RRAP interventions could shift coral composition.

Figure 13 *D* and Figure 14 *D - Deployment of corals to a reef where their larvae would not have normally settled*	If corals are deployed to a reef where their larvae would not have normally settled, a composition more reflective of the source site could occur (i.e., if species introduced from the source site start to dominate more in target location compared to their previous composition). This in turn could reduce the overall regional diversity (gamma diversity), where gamma diversity might plan a role in overall system function (including response capacity to disturbance as a part of that function) (Chase, 2003).
Figure 13 *E* and Figure 14 *E - Deployed corals outcompete existing corals at deployment site*	An invasive species is an organism that is not indigenous to a particular area, spreads across the ecosystem with high population growth, and produces impact (Pereyra, 2016). Because the corals deployed as part of SCR and CA interventions are native to the Reef, there is no possibility of introducing invasive species. They could, however, have 'invasive-like' behaviours or be considered native invaders if they outcompete existing corals at the deployment site.

Table 20 Information on Mechanisms relevant to disease and pests

DISEASE AND PESTS **MECHANISMS FROM FIGURE 15 AND FIGURE 16**	**FACTS/INFORMATION**
Figure 15 *A – Disease-causing agents, pathogens, parasites, or other pests are captured with coral spawn;* Figure 16 *A - Disease-causing agents, pathogens, parasites, or other pests are captured with selected corals*	The first step in the pathway is the capture of disease-causing agents or pests with selected corals (CA) or spawn slicks (SCR). As all interventions are only getting coral stock from the Great Barrier Reef, foreign and novel pests/pathogens would not be collected and therefore cannot be introduced here and later. Effort will be taken to collect only visually healthy corals; any individuals with signs of disease will not be brought back to aquaculture facilities.
Figure 15 *B – Disease-causing agents, pathogens, parasites, or other pests are grown in larval culture;* Figure 16 *B - Disease-causing agents, pathogens, parasites, or other pests are grown in aquaculture*	Both interventions seek to maximise the number of corals deployed on reefs by reducing mortality and increasing survival during the aquaculture process. Water quality issues and load of problematic bacteria could impact coral survival during operations. The CA and SCR protocols implement water sterilisation techniques (filter seawater through a series of 5-50 μm filters and sterilised seawater using UV filters) that minimise potential pathogen/pest build-up. Further CA QA/QC consists of using DNA based techniques to detect and quantify pests (e.g. flatworms) and bacteria (total bacterial load and targeted taxa associated with disease). If pest/pathogens are present on corals collected from the Reef, they will be pests/pathogens that are already native to the Reef. These pests/pathogens will only survive and proliferate during the aquaculture process if they have access to their food resources (i.e. host tissue).
Figure 15 *C - Disease, pathogens, parasites, or other pests are deployed with larvae/ recruits;* Figure 16 *C - Disease, pathogens, parasites, or other pests are deployed with corals*	Any potential pathogens or pests that are retained within the coral tissue, their substrate, or the deployment devices can end up back on the reef upon deployment. Only visibly healthy corals will be deployed to sites in the Marine Park. Additional checks including molecular detection of pests and quantification of bacterial load can be implemented to ensure coral cultures are sufficiently clean for deployment.
Figure 15 *D* and Figure 16 *D - Destabilisation of beneficial versus deleterious microbiome members*	It is normal for corals to have background abundances of potentially pathogenic bacteria in their microbiome. When the relative abundance of these microbes shifts, natural compositions may breakdown (dysbiosis) and could conceivably lead to disease pathogenesis (Zimmer *et al.*, 2014, Certner & Vollmer, 2018, Sun *et al.*, 2023).

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Figure 15 *E* and Figure 16 *E - Pests evade natural predators, proliferate, and spread*	In an aquaculture setting, pests and parasites can proliferate due to the absence of natural predators. Only visually healthy corals will be released to reefs, and additional molecular detection of pests can be applied. If reintroduced to deployment sites, pests will be subject to biological control by existing reef organisms (Barton *et al.*, 2020).
Figure 15 *F* and Figure 16 *F - Disease causing agents proliferate and spread*	To cause a spread or increased prevalence of disease, disease causing agents or pathogens must find a host organism or substrate to infect, proliferate above natural levels, and spread to other hosts.

Table 21 Information on Mechanisms relevant to algal symbionts

ALGAL SYMBIONTS MECHANISMS FROM FIGURE 17 AND FIGURE 18	**FACTS/INFORMATION**
Figure 17 *A* and Figure 18 *A - Shifting genetic distribution of symbionts during culturing and experimental evolution*	While it is feasible that there is a loss of genetic diversity due to the culturing process (symbiont cultures begin with a single cell as to prevent the accumulation of uncharacterised microorganisms that could compromise the integrity of the culture), the interventions will attempt to utilise multiple cultures, initiated from distinct cells where available, to provide genetic diversity to coral recruits.
Figure 17 *B* and Figure 18 *B - Provided algal symbionts spread from settled recruits to non-target coral species or areas*	Corals are constantly shedding their algal symbionts so it is expected that deployed corals with provided symbionts will release some Symbiodiniaceae into the water column. However, corals exhibit strong priority effects indicating that the symbiont community of adjacent corals will be unlikely to shift. Experimentally, the only way scientists have been able to control symbiont community structure of the coral-algal symbiosis is to either provide symbionts to recently settled recruits that are aposymbiotic OR to use a chemical process to bleach corals (Scharfenstein *et al.*, 2022). Only the former is included in the PDP for both interventions.
Figure 17 *C - Accidental release of algal symbionts into seawater*	In the case of the SCR program, symbionts could be introduced into the marine park in the event of an accidental spill during transit on vessels.
Figure 17 *D* and Figure 18 *C - Provided algal symbionts spread, proliferate, and outcompete native symbionts*	For either potential impact (loss of genetic diversity/adaptive potential of local algal symbiont population or uncontained spread of provided symbionts to non-target areas/corals) to be realised, the provided symbionts would need to spread, proliferate, and outcompete native symbionts. Based on existing priority effects and coral-symbiont partner fidelity this is extremely unlikely. To effect local algal symbiont populations or non-target coral-algal symbiosis, provided symbionts would not only have to survive and proliferate in the free-living state (Figure 17 D and Figure 18 C), but they would also have to outcompete the very large existing community of suitable symbionts (Figure 17 G and Figure 18 F) and infect other corals, and the likelihood of this may be influenced by priority effects (initial algal communities generally exclude later arriving symbionts) (Fukami, 2015).
Figure 17 *G* and Figure 18 *F - Unsuitable symbiont pairing*	For the uncontained spread of provided symbionts to non-target areas/corals (Figure 17 F and Figure 18 E) to lead to a detrimental effect on coral-algal symbiosis, the pairing between host and symbiont must be unsuitable. This prerequisite is unlikely to occur as hosts can detect suitable symbionts to initiate symbiosis via sugar complexes on the algal cell wall (Tortorelli *et al.*, 2022). If a symbiont enters symbiosis and is not performing adequately, hosts can shuffle symbionts to keep those that are best contributing to the holobiont.

Table 22 Information on Mechanisms relevant to damage to reef structure and non-target organisms

DAMAGE TO REEF STRUCTURE AND NON-TARGET ORGANISMS **MECHANISMS FROM FIGURE 19 AND FIGURE 20**	**FACTS/INFORMATION**
Figure 19 *A - Anchors hit or shift toward reef (for passive booms or rearing ponds)*	SCR: Anchors for passive booms (gamete collection) and rearing ponds (larval culture) will be deployed in sandy areas adjacent to the collection sites. In the event of a major disturbance, these could shift to damage or disturb the reef structure or other living things at target sites (Figure 19 F)
Figure 19 *E* and Figure 20 *A - Collection/ monitoring process disturbs or damages benthic organisms or habitat*	During the collection (CA only) and monitoring process (CA and SCR), in water divers could disturb/damage the benthos at target sites (Figure 19 F and Figure 20 D) due to the suspension of sediment, contact with the reef, or their presence being a disruption to the organisms in the environment.
Figure 19 *B* and Figure 20 *B - Intervention devices deployed to reef and settle on living organisms or their habitat*	If intervention devices are deployed and land on living coral or other organisms, they could cause damage or be a disturbance to those local animals (Figure 19 F and Figure 20 D).
Figure 19 *C* and Figure 20 *C- Deployed intervention devices shift to alternate locations*	In the event of a cyclone or other major storm, deployed intervention devices could shift to local non-target areas and cause damage or disturb local communities of organisms (Figure 19 G and Figure 20 E). Preliminary data post Severe Tropical Cyclone Kirrily suggest that ~60% of deployment devices did not shift to other (non-intervention) sites. For those devices that do shift, they typically move <1m from landing site (fall into crevices at target site rather than away from the targeted intervention site) even in severe weather due to the high-density material used.
Figure 19 *D -Unintentional interaction with marine fauna*	The use of coral slick collection apparatus and rearing ponds for SCR activities presents the chance of unintentional interactions with marine fauna leading to harm to species of conservation concern (Figure 19 J) when interacting with protected organisms or unsustainable depletion of other species from the ecosystem (Figure 19 K). The latter can only occur when a substantial number of individuals are collected that would impact overall population densities thus preventing recovery or causing further decline.

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