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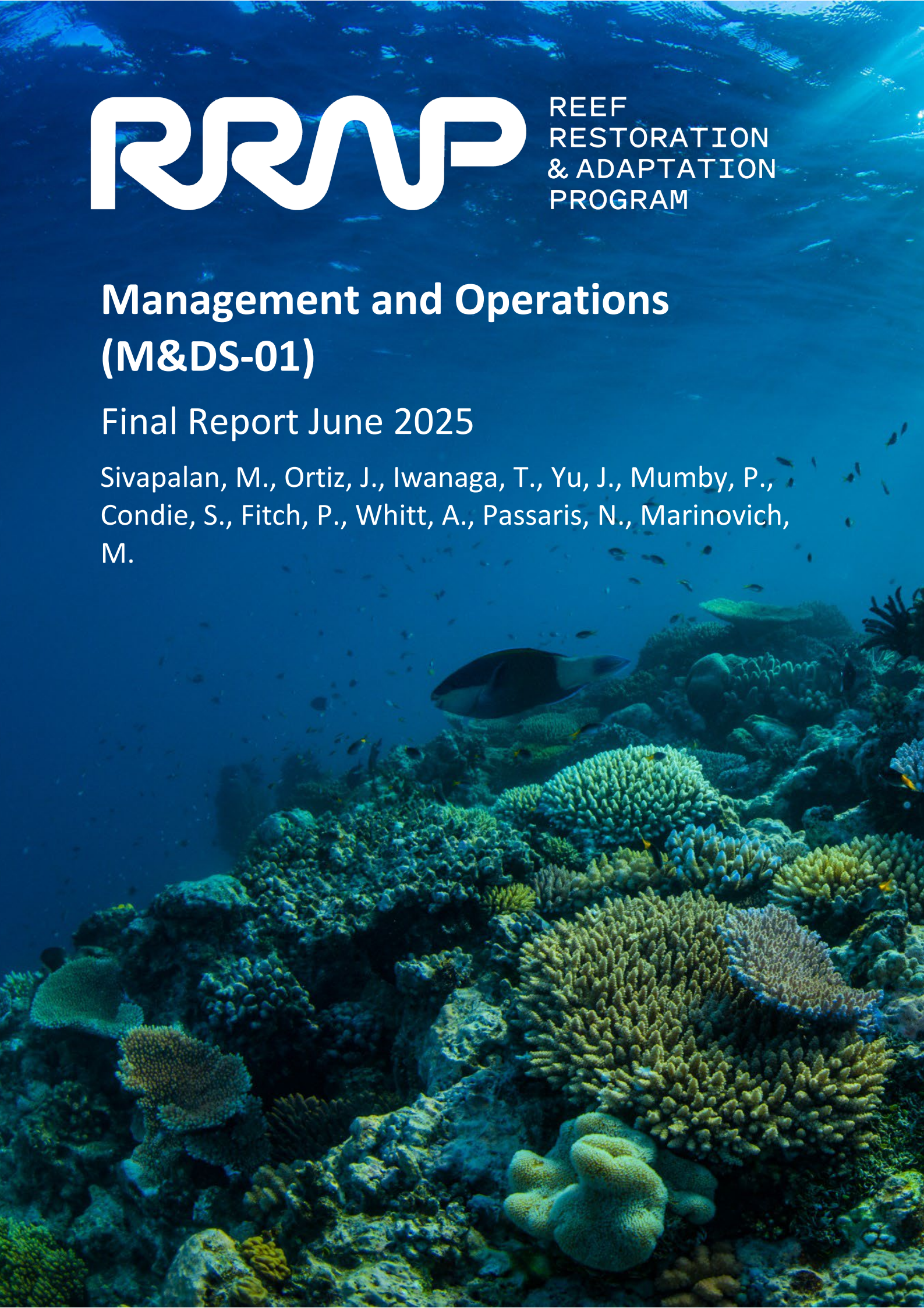
PROGRAM

Management and Operations (M&DS-01)

Final Report June 2025

Sivapalan, M., Ortiz, J., Iwanaga, T., Yu, J., Mumby, P., Condie, S., Fitch, P., Whitt, A., Passaris, N., Marinovich, M.



RRAP Management and Operations (M&DS-01) Final Report June 2025

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

This report should be cited as

Sivapalan, M., Ortiz, J., Iwanaga, T., Yu, J., Mumby, P., Condie, S., Fitch, P., Whitt, A., Passaris, N., Marinovich, M. (2025) Reef Restoration and Adaptation Program – Management and Operations (M&DS-01) Final Report 2025. (19pp).

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This report summarises work undertaken under *Management and Operations (M&DS-01)* in accordance with the Reef Restoration and Adaptation Program's *Modelling and Decision Support* Project Agreements. It provides a summarised, point-in-time synopsis of activities, methods, findings and outcomes completed in accordance with the approved project scope up to 30 June 2025.

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

Acknowledgement

This work was undertaken for the Reef Restoration and Adaptation Program (RRAP). Funded by the partnership between the Australian Government's Reef Trust and the Great Barrier Reef Foundation, partners include: the Australian Institute of Marine Science, CSIRO, the Great Barrier Reef Foundation, Southern Cross University, the University of Queensland, Queensland University of Technology and James Cook University.

The RRAP partners acknowledge Aboriginal and Torres Strait Islander Peoples as the first marine scientists and carers of Country. We acknowledge the Traditional Owners of the places where RRAP works, both on land and in sea Country. We pay our respects to elders; past, present, and future; and their continuing culture, knowledge, beliefs, and spiritual connections to land and sea Country.

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

Location	**Traditional Owner Group**
Moore Reef and surrounds	Gunggandiji, Yirrganydji
Brick Reef and surrounds	Ngaro
Whadjuk boodjar / Perth	Whadjuk Noongar
Brisbane	Tuurbal, Yuggera
Gold Coast	Yugambeh
Hobart	Muwinina Palawa
Melbourne	Wurundjeri Kulin
Townsville	Gurambilburra Wulgurukaba, Bindal, Nywaigi, and Gugu Badhun
Canberra	Ngunnawal

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1 Executive Summary

The RRAP Modelling and Decision Support (M&DS) Sub-program is tasked with developing, applying and operationalising a capability that enables the appropriate people and programs in making and communicating quality decisions, both in regard to RRAP research and development (R&D), RRAP interventions on the Great Barrier Reef (GBR), in support of a broader operational Australian restoration and adaptation industry, and global reef restoration and adaptation activities.

The sub-program has two main objectives:

1. Enable quality decisions for development and deployment of RRAP solutions at the appropriate time and scale that optimises net benefits to the program and to the GBR.
2. Systematically increase the breadth and maturity of modelling and decision support capability pertaining to RRAP interventions.

Delivered in alignment with principles of **Trust, Knowledge, and Partnership,** the RRAP Management and Operations (M&DS-01) Project serves as the sub-program's core operational component, coordinating modelling, decision support, and information systems to ensure readiness and integration across stakeholders and supporting research and deployment activities.

The RRAP Management and Operations (M&DS-01) has developed and operationalised three core capabilities to support quality decision-making:

- **Reef Counterfactuals:** Producing forecasts of reef conditions and values under different climate change scenarios and traditional management systems, establishing baselines for assessing RRAP intervention impacts.
- **Reef Interventions:** Enabling insights into intervention solutions that deliver robust outcomes against multiple objectives in space and time under uncertainty, constraints, and limited resources.
- **Reef Characterisation and Selection:** Supporting informed strategic and tactical intervention decision-making through integration of environmental, ecological, social and economic drivers to identify optimal intervention locations.

The RRAP Modelling and Decision Support (M&DS) Sub-program has achieved its objectives through the development and implementation of the following systems and processes and targeted engagements:

- **Studies Management and Decision Support:** A structured study management process introduced in 2022/2023 enabled the delivery of ~14 targeted studies, generating actionable insights for decision-makers.
- **Decision Simulation Framework:** Two simulations in 2023 refined decision pathways for RRAP Pilot Deployments Program (PDP) and informed Year One delivery through a co-designed process with the PDP Steering Group.
- **Programmatic Integration:** A cross-program integration effort in 2023 facilitated knowledge sharing and identified opportunities for collective impact through a series of collaborative workshops.
- **Capability Maturation**: Technical working groups and a 2022 Technology Strategy advanced sub-program maturity, evolving its role from RRAP-specific support to broader GBR decision-making, leveraging the RRAP Information System.
- **Stakeholder Engagement**: Engagement with the RRAP Independent Risk Review Group (IRRG) and the Reef Authority enhanced oversight, modelling rigour, achievement of stronger partnerships with external stakeholders.

The sub-program has produced impactful scientific and technical outputs, including high-profile publications, technical reports, and Standard Operating Procedures (SOPs), highlighting advances in synthetic data, climate refugia, coral dynamics, and reef connectivity modelling, contributing to the scientific community while driving operational outcomes.

To mature the RRAP Modelling and Decision Support (M&DS) Sub-program capability for industrial-scale reef restoration and adaptation, priority activities for future phases of RRAP include:

- **Monitoring Integration:** Developing modelling systems to inform monitoring strategies for intervention effectiveness as RRAP scales beyond pilot deployments.
- **Advanced Intervention Modelling**: Ongoing improvements for emerging techniques including cloud brightening, fogging, and coral translocation.
- **Operational Efficiency**: Implementing improved study management systems, models evaluation frameworks, and enhanced integration with non-RRAP information systems.
- **Expanded User Engagement**: Broadening the user group and developing web-based end-user interfaces based on stakeholder requirements.

Conclusions

The RRAP Management and Operations (M&DS-01) Project has successfully established the foundational capability for science-driven decision support in reef restoration and adaptation. The integration of Trust, Knowledge, and Partnership principles has enabled delivery of credible, defensible insights that support quality decision-making across scales. The systematic approach to capability maturation, stakeholder engagement, and programmatic integration positions the RRAP Modelling and Decision Support Sub-program to support the transition from pilot-scale interventions to industrial-scale reef restoration and adaptation operations, contributing to the preservation of the Great Barrier Reef under climate change.

2 Background and Justification for the Research

Despite being one of the best-managed coral reef ecosystems in the world; there is broad scientific consensus the long-term survival of the Great Barrier Reef (GBR or 'the Reef') is under threat from climate change. In addition to strong global action to reduce carbon emissions, and continued management of local pressures, bold action is needed. Important, quality decisions need to be made about priorities and acceptable risk and resulting actions must be understood and co-designed by Traditional Owners, Reef stakeholders and the broader community.

The Reef Restoration and Adaptation Program (RRAP) is a collaboration of Australia's leading experts to create a suite of innovative and targeted interventions to help preserve and restore the Reef. These interventions must have strong potential for positive impact, be scientifically-proven, ecologically-effective, socially-acceptable, technically-feasible and economically-viable. Decisions on where, when and how to intervene under climate uncertainty, varying degrees of risk and across different scales must be robust, transparent and inclusive to justify continued investment and build trust within the Reef community.

Much of the capability needed to support quality decision-making on the Reef already exists; however, many independent datasets, models, processes and systems—decision focused, environmental, economic and ecological—operate in isolation within scientific institutions, universities and government agencies. Greater integration and cross-collaboration can enhance collective impact and unlock the full potential for unified, science-driven outcomes on the Reef.

The RRAP Modelling and Decision Support (M&DS) Sub-program is a component of RRAP, tasked with enabling the appropriate people and programs in making and communicating quality decisions, both in regard to RRAP interventions on the Reef and in support of a broader operational Australian restoration and adaptation industry.

Executed through six projects, including Management and Operations (M&DS-01) and five R&D improvement projects (Information Systems R&D (M&DS-02), Decision Support R&D (M&DS-03), ReefMod R&D (M&DS-04), eReefs and CoCoNet R&D (M&DS-05), and Integrated Population Model Framework (IMPF) R&D (M&DS-06)), the sub-program brings together a consortium of partners including Adaptus, Commonwealth Scientific and Industrial Research Organisation (CSIRO), the Australian Institute of Marine Science (AIMS), the University of Queensland (UQ), the Queensland University of Technology (QUT) and James Cook University (JCU) and several other consultants.

The RRAP Modelling and Decision Support (M&DS) Sub-program has two main objectives:

1. Enable quality decisions for development and deployment of RRAP solutions at the appropriate time and scale that optimises net benefits to the program and to the GBR.
2. Systematically increase the breadth and maturity of modelling and decision support capability pertaining to RRAP interventions in the Reef industry.

In line with the sub-program's three guiding principles, M&DS-01 delivers the core operational decision-support, information, and modelling capability. It also provides the technical know-how to set priorities for the five R&D projects, ensuring that critical knowledge gaps are identified, prioritised through a robust studies management process and integrated to support the ongoing development and maturity of the capability (Figure 1).

Guiding principles:

- *Trust* - Our joint capability generates insights that are credible, defensible, and trusted by Reef stakeholders, rightsholders, and the scientific community.
- *Knowledge* – We work with decision-makers to generate, synthesise, and communicate knowledge as insights for reef management - building a stronger evidence base for action.

- *Partnership* – We operate as trusted partners in decision-making, co-developing, resourcing, and applying fit-for-purpose tools to support long-term Reef Management decisions.

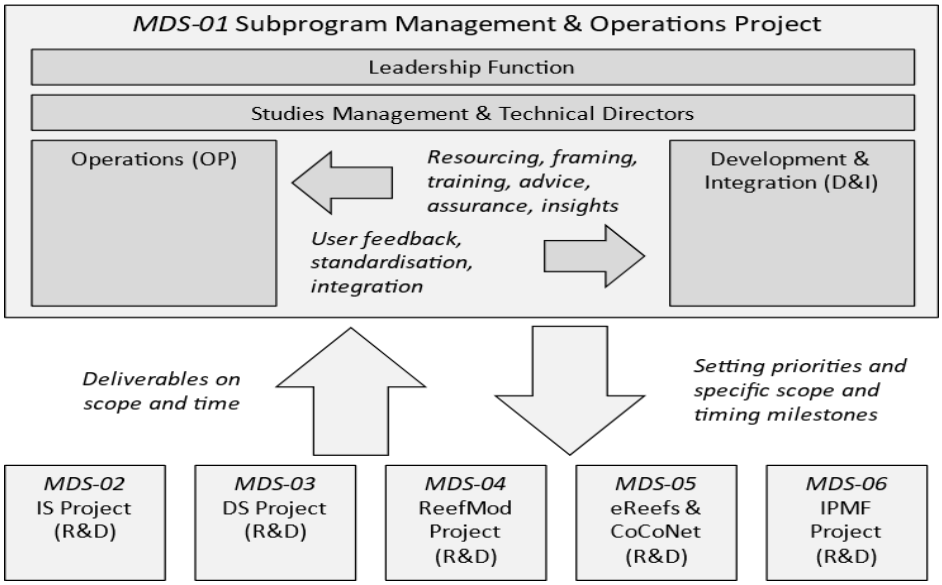

Figure 1: Schematic of the RRAP Modelling and Decision Support (M&DS) Sub-program structure and functions, including Management and Operations (M&DS-01) and five R&D improvement projects (M&DS-02, M&DS-03, M&DS-04, M&DS-05, M&DS-06).

To support the development of an operational capability, and scale it to deliver robust modelling and decision support for an Australian reef restoration and adaptation industry, the sub-program has integrated its collective expertise to develop and mature three core capabilities that drive its objectives:

1. **Reef Counterfactuals**: Produce forecast of reef conditions and values for the Reef under different climate change scenarios and traditional management systems,
2. **Reef Interventions:** Enable insights into intervention solutions that can deliver robust outcomes against multiple objectives in space and time under uncertainty, constraints, and limited resource, and
3. **Reef Characterisation and Selection**: Support informed strategic and tactical intervention decision-making and management planning for the Reef, people and industries.

Reef Counterfactuals

Counterfactuals are defined as the no-RRAP cases - projected trajectories of environmental, ecological, social and economic metrics in the absence of RRAP interventions under various climate change scenarios. Effective counterfactuals should represent best case outcomes under conventional management and serve as the baseline for assessing the impact of RRAP interventions.

Reef Interventions:

The modelling of RRAP interventions and their interaction with existing coral ecosystem dynamics is critical to enabling insights about better intervention solutions under climate uncertainty given specific objectives and under relevant constraints. Furthermore, a credible representation of interventions allows for meaningful inquiry into the potential risks at site and regional scale of different deployment scenarios.

Reef Characterisation and Selection:

A key element of the Decision Support value proposition is the ability to identify optimal locations for RRAP interventions, either to maximise the likelihood of success or to maximise the magnitude of benefit. This is achieved by integrating environmental, ecological, social, and economic drivers, in consultation with stakeholders, to develop selection criteria and objectives that guide intervention deployment planning and

strategic decision-making (i.e. region, cluster or reef selection) using the existing models, decision processes, systems and available data.

Before confidently selecting locations for RRAP intervention deployment, it is essential to appropriately characterise coral ecosystem dynamics. This ensures model outputs provide enough clarity and resolution for scientists and decision-makers to understand how the ecosystem may respond to interventions and environmental changes. The Modelling and Decision Support (M&DS) Sub-program is focused on delivering credible and defensible insights, underpinned by targeted R&D that strengthens how we characterise and model the Reef.

The following section outlines how the M&DS Sub-program has achieved its objectives in line with operationalising these three core capabilities.

3 Research Objectives and Key Findings

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

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

Objective		Key Findings and/or Outcomes
1.	Enable the appropriate people to make and communicate quality decisions for development and deployment of solutions at the appropriate time and scale that optimises net benefits to the program and to the GBR.	**Studies Management** Introduction of the study management process in 2022/2023 enabled the consistent coordination and execution of modelling systems and processes within RRAP Modelling and Decision Support (M&DS) Sub-program supporting the delivery of meaningful insights for decision makers. These studies generated actionable knowledge by leveraging existing datasets, models, processes and systems within the sub-program and the broader RRAP program. Studies were framed with the decision-maker to ensure insights generated and communicated were fit-for-purpose, building stronger evidence based for action. This work has strengthened our capability across Reef Selection, Counterfactuals and Intervention Modelling to better respond to Reef Management needs. Since its inception, the RRAP Modelling and Decision Support (M&DS) Sub-program has progressed approximately 14 studies, delivering insights across a range of critical research questions, including: • What is the ecological outlook for the GBR under possible climate futures? • What do we learn from counterfactual modelling at site-scale versus reef-scale versus region-scale versus GBR-scale? • What are the reefs and reef clusters that meet desired attributes for intervention deployment? • Which reefs have common characteristics to inform understanding of intervention value at scale? • How do reefs within a cluster interact and what are the implications for reef selection for deployment? • What are the impacts of site-scale deployment considerations on intervention efficacy and value? • How do different levels of coral enhancement influence outcomes? • What is the impact of enhanced coral deployment on native corals?

Objective		Key Findings and/or Outcomes
		Decision Simulations using Structured Decision-Making Processes Decision Simulations (DS) commenced in 2023 and were designed to test and refine the pathway to decision-making within the sub-program and across the broader RRAP program in relation to location selection for RRAP Intervention Pilot Deployments planned for November 2025. The objective was to ensure the right combination of people, processes, information, and technology within the sub-program and across RRAP were in place to support confident, timely decisions and identify any gaps requiring further refinement. DS1 focused on internal M&DS processes, using a range of potential deployment designs and scenarios to inform recommendations for a 2025 pilot deployments strategy within the available budget. DS2 broadened participation by involving representatives across RRAP sub-programs to simulate integrated, program-wide decision-making using shared expertise and available tools. Evolving from simulations to applied research, our work helped to refine the deployment reef and site selection decision-making process to support Year One of the Pilot Deployments Program (PDP). The process was co-designed with the PDP Decision Support Steering Group, which was chaired by M&DS and included members from the Managing Entity and PDP. It involved standard steps of structured decision-making processes, tailored specifically to the PDP's needs, and considered the regulator, stakeholders and Traditional Owner group engagement and timings. **Wider Programmatic Integration** As part of the RRAP Modelling and Decision Support (M&DS) Sub-program's mandate to bring together the right people to support high quality, transparent decision making that delivers net benefits for the Reef and the Australian economy, we initiated a broader programmatic integration effort – endorsed by RRAP - across RRAP, the Crown-of-thorns starfish (COTS) Control Innovation Program (CCIP), Integrated Monitoring and Reporting Program (IMR), Reef 2050 Plan Reef Integrated Monitoring and Reporting Program (RIMReP) and the Great Barrier Reef Marine Park Authority (GBRMPA or Reef Authority). The aim was to share current knowledge and capabilities in data management, modelling and decision support across the Reef Trust Partnership Programs, and to identify opportunities for further alignment and integration. Ultimately, this effort seeks to enhance collective impact and realise the full potential for unified, science-driven outcomes on the Reef through optimising the development and delivery of our joint capability for Reef Management. A series of workshops held between May and October 2023 facilitated rich knowledge exchange, strengthened connections, and identified clear actions for continued collaboration. While significant progress

Objective	Key Findings and/or Outcomes
	was made, ongoing coordination and governance will be essential to fully integrate joint capabilities and effectively and efficiently translate into operations to reef outcomes. **Engagements** Under guidance from a dedicated sub-program Communications Plan, the sub-program aims to ensure effective communication and collaboration across partner / participant entities that enable the identification of opportunities to deliver actionable knowledge and decision support that enables quality decision making for the development and deployment of reef interventions. <u>RRAP Intervention Risk Review Group (IRRG)</u> The RRAP Modelling and Decision Support (M&DS) team provided comprehensive briefings to the IRRG's Modelling Methods sub-committee through a structured questions and answers (Q&A) session in June 2024, building on three previous deep-dive sessions. This engagement ensured IRRG members understood M&DS capabilities and could make informed decisions about modelling approaches for reef interventions. In support of our Counterfactual Reporting to the Reef Authority, the IRRG provided feedback on the social implications of our modelling results, which helped maintain consistency in how social risks were assessed and communicated. These engagements demonstrate our approach to keeping the IRRG informed and equipped to fulfill their oversight role, while ensuring that decision-making processes for reef interventions are transparent, scientifically sound, and aligned with established risk management frameworks. <u>The Reef Authority</u> M&DS led a comprehensive stakeholder engagement process centred on the “GBR Coral Futures: Assessing Climate Risks and Implications for Australia” report. This process exemplified collaborative dialogue, resulting in significant improvements to the content and framing of the report. The engagement followed a structured approach beginning with the socialisation of the draft report with key stakeholders. This initial engagement identified areas requiring deeper scientific dialogue and clarification. The Reef Authority provided detailed feedback across 20 specific technical and methodological areas, ranging from overall context to specific queries about model assumptions and limitations, and about the interpretation of uncertainty in future projections. Key areas of focus included: • Model assumptions and parameterisation, particularly regarding degree heating week (DHW) projections and coral mortality relationships.

Objective		Key Findings and/or Outcomes
		• Uncertainty quantification and the communication of model limitations. • Regional variations in model projections and their implications. • Critical low states analysis and threshold interpretations. • Narrative balance to ensure findings were presented with appropriate scientific caveats. RRAP engaged in multiple technical and science-focussed discussions with the Reef Authority. This iterative and collaborative process resulted in the majority of concerns being resolved through inclusion of additional clarification in the final version of the report. The engagement process delivered several significant improvements to the scientific work: 1. **Enhanced Model Transparency**: More explicit articulation of model assumptions, limitations, and their potential implications for projections. 2. **Improved Uncertainty Communication**: Clearer presentation of the range of possible outcomes and the factors influencing projection reliability. 3. **Strengthened Scientific Rigor**: Better validation of model performance against observational data and more nuanced interpretation of results. 4. **Policy-Relevant Context**: Enhanced discussion of regional variations and management implications. This engagement demonstrated the value of collaborative science-policy dialogue in producing robust, policy-relevant research. Inclusion of technical expertise from the Reef Authority contributed to a more nuanced final product. RRAP's detailed responses to queries from key stakeholders enhanced understanding of model capabilities across the broader scientific and policy community. The process established a precedent for ongoing collaborative review of RRAP's modelling efforts, ensuring continued alignment between scientific enquiry and policy needs .
2.	Systematically increase the breadth and maturity of modelling and decision support capability within RRAP.	**Working Groups established to drive maturity** The RRAP Modelling and Decision Support (M&DS) Sub-program introduced working groups to drive critical programs of work that relied upon the coordination and collaboration across R&D teams to support the maturity and development of our internal capability, external reputation and impact. These included (1) Operational Delivery Improvement, (2) Decision Support Systems, (3) Model Evaluation and Validation and (4) Publications.

Objective		Key Findings and/or Outcomes
		The working groups focused on the integration of capabilities, validating models and enhancing operational processes, capturing and documenting standard ways of working within the RRAP Modelling and Decision Support (M&DS) Sub-program, ensuring quality consistency and continuous improvement in sub-program operations and enabling more efficient and effective delivery of M&DS product and services. **Technology Strategy** The Technology Strategy "the Strategy" was introduced in 2022 to set and the define the maturity levels and technical governance required to ensure the M&DS Sub-program capability aligns with RRAP's objectives, resource constraints and timelines. Given the importance of models and decision support systems in enabling quality decisions that advance program objectives, the inclusion of the Strategy into RRAP's governance structure was critical to guiding operational delivery and continuous improvement within M&DS. The Operational Delivery Improvement (ODI) working group, formally the Technical Readiness Group (TRG), has led the implementation of the Strategy, including the develop of a data management plan and maturity assessment framework. Since its inception, the ODI has played a key role in driving system integration, operational readiness, and model maturity. As a result, the M&DS capability has evolved from meeting the specific knowledge needs of RRAP to delivering broader GBR decision support, and providing transparent, traceable, and accessible insights through the application of the RRAP Information System.

Adjustments to key research objectives

Table 2: Variation in the Project over time.

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

4 Future Research Recommendations

An operational RRAP Modelling and Decision Support (M&DS) Sub-program is responsible for rapidly answering study questions by applying current operating versions of ecological, economic and environmental models within existing processes and using available data to deliver credible, traceable insights that support quality decision making for Reef Managers (Figure 2).

To mature the M&DS Sub-program capability for RRAP intervention decision-making and scale reef restoration and adaptation to an industrial level, targeted operational and capacity-building activities are required to develop a fit-for-purpose capability that earns the trust of Reef Managers and broader stakeholders

The following activities are prioritised for future phases of RRAP:

- **Modelling systems help to inform monitoring of intervention strategies** - As RRAP progresses towards larger-scale deployments beyond the Pilot Deployments Program (PDP), it becomes increasingly important to demonstrate the tangible benefits of intervening. A well-designed monitoring strategy is essential to assess intervention effectiveness and support transparent, evidence-based decision-making and M&DS can play a supporting role in helping to prioritise what and where to monitor.
- **Ongoing improvements in intervention modelling of emerging techniques** —As new RRAP interventions are introduced into the reef restoration and adaption portfolio, such as cloud brightening and fogging, robust modelling systems are needed to assess their potential impact on ecosystem value drivers (i.e. coral cover) at regional and site scale.
- **Intervention complementary for strategic planning** – Explore the complementarity of multi-intervention deployment strategies to optimise net benefits of restoration on the Reef.
- **Model Traditional Knowledge** – Incorporate Traditional Owner values and knowledge of the Reef in the M&DS suite to ensure that decision-making is inclusive, culturally respectful and aligned with custodianship of sea Country where restoration activities are planned.
- **Improving Connectivity** – Strengthen connectivity modelling across ecological systems to improve the representation of complex ecological processes on the Reef. Enhanced connectivity modelling is critical for forecasting the benefits of interventions.
- **Collaboration and integration with other sub-programs** – Enhance cross-program and sub-program knowledge sharing and capability integration to accelerate the maturity of the M&DS system and deliver greater coordinated impact on the Reef. Increased collaboration, including uptake of the RRAP Information System (RRAP IS) across R&D teams and other sub-programs, will enable faster data access, improve transparency of workflows, and unlock greater potential for coordinated, science-driven outcomes across RRAP and the broader Reef Trust Partnership.
- **Evolution of the study management process** – Continue to optimise and refine the study management process to ensure the efficient generation of actionable, credible, and traceable knowledge and decision support. Enhancing this process will improve the delivery of fit-for-purpose insights for Reef Managers, enabling timely and informed intervention planning.
- **Model evaluation framework** – Embed the model evaluation and validation framework to ensure M&DS insights are credible and trusted by Reef stakeholders.
- **Continuous operational delivery improvement** in the following areas:
    - *Model containerisation* - to enable the creation of operational model versions to generate insights for Reef Managers, while R&D continues in parallel to continuously improve the capability.

- *Efficient workflows* – streamline use case delivery by collaborating with modelling teams to identify bottlenecks, mitigate risks, and seize efficiency opportunities, reducing the time from a request to insights.
- *Integrate external data needs*– leveraging the RRAP IS and data sharing agreements with other program and sub-programs to ensure modelling systems and decision support processes use the best available data to inform insights and credible decision-making.
- *Continue to integrate economic modelling into M&DS* –to ensure intervention planning and strategic decisions consider the full costs of scaling reef restoration and adaptation, including multi-intervention deployment strategies, ongoing cost modelling developments and integration into M&DS is critical.

Proposed research study questions to improve the capability:

- How to facilitate natural adaptation through restoration and local adaptation effects?
- How to improve ecological modelling of in-shore reef interventions?
- How to incorporate risk modelling into the M&DS suite?
- What implications does light have on coral ecosystem processes under various climate scenarios?
- How to improve modelling of COTS dynamics at site scale?

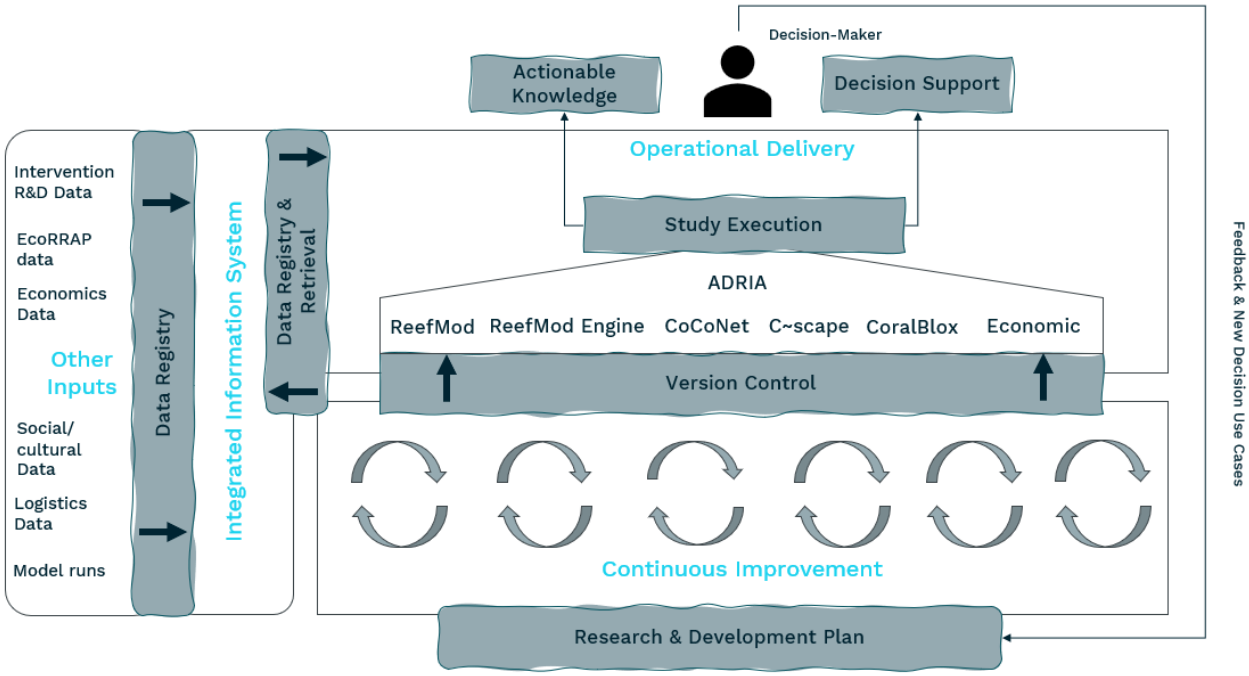

Figure 2: Operational M&DS Schematic.

RRAP REEF RESTORATION & ADAPTATION PROGRAM
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