REEF RESTORATION & ADAPTATION PROGRAM

Synthesis, Intervention Tool and Guidelines (RS-03)

Final Report June 2025

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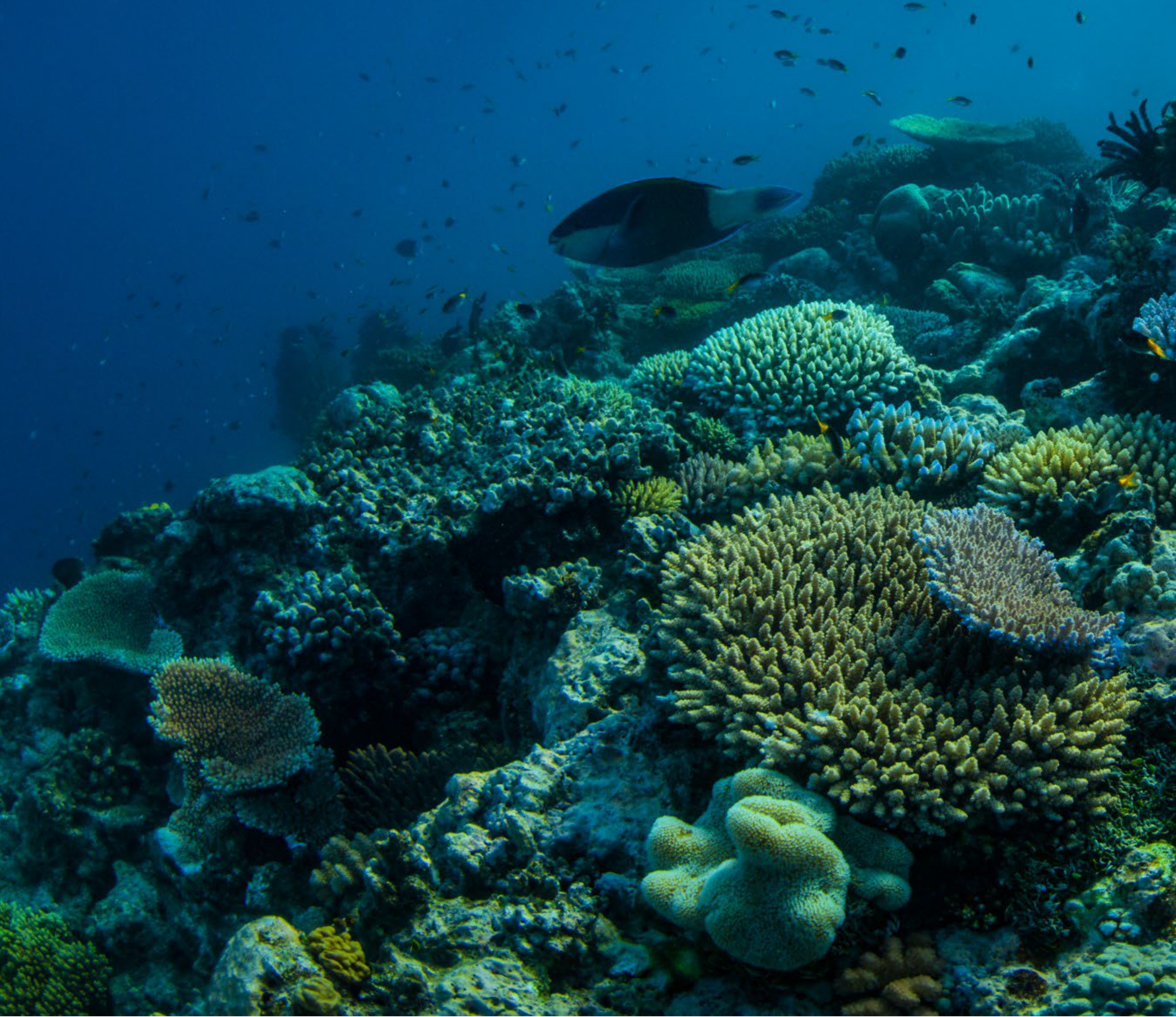

RRAP Synthesis, Intervention Tool and Guidelines (RS-03) Final Report June 2025

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

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

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1 Executive Summary

Disturbance-generated coral rubble can pose a substantial barrier to reef recovery when it remains loose and unstable over time. Rubble stabilisation interventions can help overcome this barrier and support reef resilience across the Great Barrier Reef (GBR). While existing research has advanced our understanding of the rubble problem, there has been a clear need to synthesise insights from across Rubble Stabilisation research under the Reef Restoration and Adaptation Program (Rubble location, prediction and sub-program management (RS-01) and Approaches to stabilisation (RS-02)), into practical, accessible outputs. The Synthesis, intervention tool and guidelines (RS-03) Project addressed this need by developing user-oriented tools and resources that support local decision-making and promote the effective application of rubble stabilisation as a coral reef restoration strategy.

The investigation activities in the Synthesis, Intervention Tool and Guidelines (RS-03) Project comprised three main areas: (1) synthesising the current knowledge on the impacts of rubble stabilisation; (2) developing rubble intervention tools to help users assess where and how rubble stabilisation could be applied; and (3) producing a comprehensive set of guidelines for rubble stabilisation interventions that also introduce the intervention tools. Key activities included convening an international workshop in November 2023; collaborating closely with stakeholders across sectors (academia, government, industry and tourism); and publishing the rubble intervention tools and rubble stabilisation guidelines.

The main outputs include (1) two expert-based Bayesian Belief Networks (BBN) that predict the effectiveness of different rubble stabilisation interventions across environmental gradients; (2) interactive maps that characterise areas of most to least concern in terms of natural rubble bed recovery potential across the GBR, to pinpoint sites where intervention is most necessary; and (3) a set of practitioner guidelines, "*A Practical Guide to Restoration and Rehabilitation of Rubble Fields on Coral Reefs*", which complements the intervention tools and offers detail guidance for all stages of a rubble stabilisation project (planning, implementation, monitoring and evaluation). Together, these outputs respond to the needs of multiple stakeholder groups and strengthen the case for rubble stabilisation as a feasible and effective intervention option.

This work has contributed to a growing recognition of rubble stabilisation's role in coral reef restoration frameworks, especially in the context of climate change and intensifying disturbance regimes. This research has also generated momentum for further investigation in this space. Future research could focus on expanding BBN datasets and refining rubble intervention tools to improve long-term predictions. Rubble stabilisation methods can also be improved upon as additional research is undertaken. Ongoing efforts include preparing publications that present insights drawn from the BBNs and recovery potential maps in more detail.

2 Background and Justification for the Research

The RS-03 Project aimed to synthesise existing knowledge on rubble stabilisation and translate it into practical outcomes. Substantial progress had been made in identifying areas on the GBR where rubble is likely to be generated and remain a persistent problem following disturbances (RS-01), and in evaluating the efficacy of existing rubble stabilisation methods (RS-02). With this growing body of knowledge, there was a clear opportunity and pressing need to consolidate these research outputs and drive real-world impacts. While some synthesis efforts were published in the literature, e.g. Ceccarelli et al. (2020); Kenyon et al. (2023), they were primarily designed for an academic audience and often not tailored to end users. What was needed to complement these review articles was a more accessible, comprehensive, and user-focused resource to guide practitioners and managers in decision-making.

Early stakeholder consultations highlighted a strong demand for a decision-support tool to guide rubble stabilisation methods in practice. The RS-03 team engaged government, industry, and tourism representatives to shape a framework and explore potential applications for the tool. Government representatives from the Great Barrier Reef Marine Park Authority (GBRMPA), who respond to over 20 ship groundings each year, noted that restoration decisions should be guided by robust, science-based evidence. As such, they expressed support for a tool that guides decision-making regarding rubble stabilisation. Industry stakeholders saw the potential for applying the tool to project sites in future, while tourism operators were interested in its development, particularly for use in areas affected by disturbances—such as the damage caused by Cyclone Debbie in 2017. They anticipated benefits such as enhanced community engagement, stronger environmental stewardship, improved hands-on training, and deeper partnerships across sectors.

Furthermore, the development of rubble intervention tools supported the broader needs of the RRAP Modelling and Decision-Support (M&DS) Sub-program. This project had to pinpoint not only where rubble will persist but also where intervention methods can be most effective. These spatial insights could then be integrated into the broader M&DS framework, along with other ecological dynamics and alternative restoration strategies to inform holistic decision-making.

Despite strong scientific progress and a recognised need for practical tools, several key challenges still impeded real-world application. First, there were no universally accepted metrics or consistent terminology for characterising and defining rubble beds, making it challenging to compare outcomes or evaluate success reliably across projects (Paewai-Huggins, in preparation; Dodgen, in preparation). Second, most stabilisation trials remained small-scale, short-term and reported only in grey literature or personal communications. Therefore, their effectiveness remains uncertain in the future under a changing climate. As such, it was important not only to gather existing information, but to generate new insights by critically examining that knowledge from diverse expert perspectives. By systematically bringing together these disparate data, developing clear, standardised measures, and translating lessons from past successes and failures into practical tools, RS-03 aimed to bridge the gap between science and on-the-ground action.

In response to these challenges and needs, RS-03 pursued three primary objectives. First, under **sub-project 3.1,** the team synthesised the results of RRAP rubble stabilisation research and sought international scrutiny of the findings and their application. Second, through **sub-project 3.2**, a rubble stabilisation intervention toolset was developed for local applications. Third, **sub-project 3.3** produced a set of comprehensive guidelines for practitioners. It outlines the nature of the rubble problem, approaches to assessing rubble beds, details of existing stabilisation methods and their effectiveness, and an introduction to the intervention toolset developed in sub-project 3.2. Research objectives of the sub-projects are outlined below.

Sub-project 3.1: Synthesis of Impact of Rubble Stabilisation

This sub-project addressed the lack of consolidation in rubble stabilisation knowledge by conducting an international workshop near the end of the project. The team brought together stakeholders from academia, industry, non-government organisations (NGOs), tourism, and government across multiple countries to synthesise the benefits and challenges of various rubble stabilisation methods used for reef management and ecosystem restoration. Experts scrutinised existing data and qualitative findings and translated them into actionable recommendations for practitioners.

Sub-project 3.2: Rubble Intervention Tools

The sub-project addressed end user demands and M&DS objectives by developing a rubble stabilisation intervention toolbox to support decision-making in the format of Bayesian Belief Networks (BBNs) and interactive maps.

BBNs were selected as the core framework due to their suitability for handling uncertainty and incomplete data in complex systems, which is a common issue in rubble stabilisation projects. BBNs had previously been used in reef-related applications - e.g. coastal protection modelling in Indonesia; Callaghan et al. (2018) - and were shown to be accessible to a wide range of users via free platforms like Netica.

Interactive maps were developed to visualise areas according to predicted recovery potential, from low to high. Key findings relating to rubble binding rates and strengths in different habitats, revealed in RS-01, were integrated into the underlying models for these maps.

Taken together, managers can use the information available in these tools to make decisions relating to intervention placement locations (maps of recovery potential) and the type of stabilisation effort to employ (BBNs, as well as Guidelines below).

Sub-project 3.3 Rubble Stabilisation Guidelines

This sub-project supported the broader application of RS-01 and RS-02 research, addressed the lack of practical synthesis of rubble stabilisation approaches, and improved communication across stakeholder groups, by developing a set of practitioner guidelines. The team produced a suite of materials available both online and in hard copy that provide essential information and guidance on the use of various rubble stabilisation methods, and of the BBN intervention tool developed in sub-project 3.2.

3 Research Objectives and Key Findings

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

Objective		Key Findings and/or Outcomes
3.1: Synthesis of Impact of Rubble Stabilisation		
3.1 (a)	Convene a workshop of all project personnel and key End-Users to synthesise the overall benefits of rubble stabilisation for reef management and ecosystem restoration.	The RRAP Rubble Stabilisation workshop convened from 17–21 November in Sanur, Bali at the Coral Triangle Center. It began with a series of presentations from academic researchers, industry practitioners, government representatives (GBRMPA) and tourism operators, each detailing their approaches to stabilising and restoring rubble-dominated reef areas. Key themes across presentations included the observation that, in high-energy, clear-water sites, restricting rubble movement alone often promoted recovery, whereas sheltered or high-sediment environments frequently required additional substrate elevated above the rubble. Steep, sloping beds were considered the most challenging to restore, although several participants shared successful case studies. A field excursion to Nusa Penida National Park, led by partner organisation, Blue Corner Marine Research, further unified understanding by allowing close observation of rebar A-frames and mesh stabilisation structures. Participants also contributed quantitative data cataloguing their stabilisation successes and failures via an online survey and broke into discussion groups to synthesise benefits, obstacles and anticipated outcomes across rubble stabilisation method categories. The workshop fostered cross-sector and international collaboration between experts from Australia, Indonesia, the Philippines, Malaysia, China, and the United States and built consensus around best practices. Attendees expressed strong enthusiasm for incorporating survey data and workshop insights into a BBN-based rubble intervention tool and practitioner guidelines. There was broad optimism that these efforts would accelerate knowledge transfer and advance reef restoration globally.
3.1 (b)	Scrutinise the results of the research to date and consider how this can be adapted to advise practitioners. This activity will build on research both within and beyond RRAP	In the early stages of RS-03, literature reviews, internal team workshops, and meetings coordinated between the rubble stabilisation field team and experts working in rubble stabilisation identified the key factors and available datasets to inform the BBN-based rubble intervention tool (sub-project 3.2b). At this stage, information was collected on the array of methods available, and the proportion of projects which had quantitative versus qualitative data, or no post-deployment observations at all. These preliminary concepts were used to feed into RS-02 in terms of field-testing stabilisation methods and were also built upon during the 2023 Rubble Stabilisation Workshop (3.1a).

Objective		Key Findings and/or Outcomes
		At the workshop, breakout groups critically reviewed the existing data and practical experience gained through the deployment of various rubble stabilisation methods to date (including from the project undertaken as part of RS-02). Guided by a set of focus questions, participants reached a consensus on each method's suitability in different environments, scalability, pros and cons, environmental, socio-political and financial constraints, and expected ecological and physical outcomes. Group findings were presented to the wider forum, and participants shared practical implementation tips. These collective insights were distilled into the background chapters and comparison matrix of the practitioner guidelines (3.3) and directly informed the key variables and structure of the BBNs (3.2). These tools were designed to support practitioner decision-making.
3.2: Rubble Intervention Tool		
3.2 (a)	Integrate results with findings and outputs from RRAP M&DS to assess not only where rubble will become a problem but where tools [interventions] offer an opportunity to stabilise rubble given other environmental constraints.	RS-01 and RS-03 findings were integrated into the rubble intervention tools. For the Bayesian Belief Networks (BBNs), this included expert survey data from the RS-03 3.1 sub-project (RRAP Rubble Stabilisation workshop 2023), which captured information on project site conditions, outcomes of different rubble stabilisation methods, and expectations of success as determined by experts. Key literature sources including Clark and Edwards (1994); Fox et al. (2019); Raymundo et al. (2007) were also used to fill remaining data gaps. For the maps of rubble bed recovery potential, hydrodynamic and geomorphological datasets (GBRMPA (2024); Roelfsema et al. (2021)) were used along with results from RS-01 on rubble binding rates, strength (Kenyon et al. 2025), and prevalence (Kenyon et al. 2024). The hydrodynamic data constituted a 70-year time series of daily maximum wave-driven bottom orbital velocity data estimated by Callaghan (2023). While the tools have not been directly integrated into the RRAP M&DS Sub-program products so far, outputs could be feasibly incorporated in future work.
3.2 (b)	Create a Rubble Stabilisation Intervention Tool, that: integrates the research from RS to identify where rubble can be stabilised; and provides stand-alone functionality to users seeking local advice on where to stabilise rubble.	While the original objective was to create only one rubble stabilisation intervention tool, two tools have been created which can be used independently or in tandem. These were created to support local decision-making and integrate research insights from the RRAP rubble stabilisation program. The first tool is a pair of expert-based, interactive Bayesian Belief Networks (BBNs) to predict stabilisation method efficacy, regardless of global position, while the second is an interactive map of the Great Barrier Reef (GBR) that predicts natural recovery potential. The latter is specific to the GBR, and can be used in tandem with the BBNs, which can be implemented by users worldwide. If an area on the GBR is identified as being of 'low

Objective		Key Findings and/or Outcomes
		recovery potential', the BBN can be used (in combination with reference to the Guidelines) to determine the most effective rubble stabilisation method to employ in that area. The BBNs were developed, using data from the 2023 workshop (3.1a). These tools were designed to help users identify where rubble stabilisation is likely to be effective and to compare the expected outcomes of different intervention methods under varying environmental conditions. The BBNs are available for download via the RRAP website: https://gbrrestoration.org/program/rubble-stabilisation/. The first BBN estimates the potential benefits of intervention, defined as the predicted increase in coral cover at a restored site compared to an unrestored control. The second BBN captures expert opinions on the likelihood of restoration success across different environmental conditions. Users can input environmental and methodological information to reflect local site conditions, and the BBNs dynamically update the conditional probabilities to display likely outcomes. Alternatively, users can specify desired outcomes (e.g. target coral cover or likelihood of success) to identify suitable combinations of site conditions and intervention types. The UQ team developed an interactive map to highlight locations on the GBR where rubble beds – if generated – are likely to have low natural recovery potential, making them strong candidates for rubble stabilisation interventions. Across the GBR, approximately 8 million reef points (at 50 × 50 metre resolution) were assessed using 70-year time series data of the wave environment (maximum bottom orbital flow velocity) and predicted rubble binding rates and strength over time based on the habitat type of each reef point. After running the function describing binding strength over time, against the time series wave data, the proportion of time that rubble at that point was expected to be i) stable and ii) binding successfully, was estimated. Using these estimates, each point was classified into one of four classes, corresponding to three levels of natural recovery potential: high, intermediate, and low. Class C represents sites with the lowest likelihood of recovery without intervention and may be of greatest interest to managers, while Class B sites are considered 'least concern' due to their high natural recovery potential. Under a pessimistic scenario (where rubble is positioned such that it is easily rolled), 21% of reef points fell into Class C and 75% fell into Class B. A publication detailing the findings of this tool is currently in preparation and nearing submission to Ecological Applications. Together, these two sets of tools provide an accessible decision-support platform to guide rubble stabilisation necessity and approaches.

Objective		Key Findings and/or Outcomes
3.2 (c)	Work with end-users to build a web-enabled tool (e.g. BBN), that links to GIS models so that rubble maps can be updated as the environment changes, and allow users to evaluate the degree to which current stabilisation methods are successful for rubble.	An interactive, web-enabled tool (3.2b) has been developed to allow users to explore GBR-wide and reef-specific rubble bed recovery potential. The maps are linked to spatial datasets and can be updated as new environmental data (e.g. hydrodynamics, rubble binding rates) become available. While currently hosted on GitHub and the UQ Research Data Manager (UQRDM) for internal use, efforts are underway to transition the tool to a publicly accessible platform. This tool enables end-users to identify sites with low to intermediate recovery potential and assess where rubble stabilisation efforts might be most needed. The BBNs, discussed above, allow users to evaluate the success of currently employed stabilisation methods, to the degree to which data are available to conduct adequate assessments.
3.3 Rubble Stabilisation Guidelines		
3.3 (a)	Communicate with a diverse set of users with different needs in consultation with other components of RRAP (e.g. the RRAP Stakeholder and Traditional Owner Engagement Sub-program, Science Communication).	Following the 2023 workshop, UQ research teams conducted additional interviews and informal consultations with participants to ensure the guidelines (3.3b) and rubble intervention tools (3.2b) reflected the diverse needs of different users. Experts from academia, industry, government, and tourism were invited to supplement their survey responses with additional detail in photos, diagrams, and written input. Many also reviewed the draft practitioner guidelines and provided feedback to ensure clarity, accuracy, and relevance, resulting in an extensive author list for the guidelines. Collaboration with both the RRAP internal team and external stakeholders helped ensure the final products were grounded in real-world practice and accessible to a broad audience. The set of intervention tools, as well as the rubble stabilisation guidelines, were shared with Traditional Owner groups in the Cairns and Port Douglas region, during a workshop held in November 2024. The Rapid Rubble Assessment, described in RS-01 in the context of rubble bed classification and binding, is a photo-based tool that was introduced to Traditional Owner groups during several engagement activities from 2023 to 2024. The Rapid Rubble Assessment introduces the concept of rubble bed recovery potential but is used in-water and thus at a small spatial scale. The 'recovery potential' maps can then be easily introduced to users as a method of scaling up these kinds of assessments, at a coarser scale. The intervention tools have also been shared with the Ship Grounding team at GBRMPA, and discussions are underway as to how their team can best utilise these tools within their current ship impact assessments.

Objective		Key Findings and/or Outcomes
3.3 (b)	Develop practitioner guidelines, manuals and web content, including for online BBN. Liaise with project researchers, as well as managers and restoration practitioners.	The development of "*A Practical Guide to Restoration and Rehabilitation of Rubble Fields on Coral Reefs*" was led by UQ in collaboration with researchers, managers, and practitioners to support decision-making across all stages of a rubble stabilisation project. The guidelines provide a comprehensive resource that captures a suite of knowledge on rubble stabilisation, drawing from sources including published papers, case studies, 2023 workshop insights (3.1a), RS-02 project findings, and expert data from around the globe. The guidelines are available for download, together with the BBN-based rubble intervention tool (3.2b), via the RRAP website: https://gbrrestoration.org/program/rubble-stabilisation/. Additional physical copies were printed for broader distribution.

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
3.2 (a) Integrate results with findings and outputs from RRAP M&DS	The original objective aimed to integrate results with findings and outputs from the RRAP M&DS Sub-program to identify where rubble is likely to become a problem and where interventions may be feasible under environmental constraints. However, as the project progressed (mid-late 2023), it became clear that the outputs from M&DS, particularly from ReefMod, were not yet suitable for direct integration into rubble intervention tools. A decision was made to use other data sources that were better suited to the development of a standalone decision-support tool. These included data from RS-01 on rubble binding and survey data from RS-03 sub-project 3.1. These datasets provided more targeted and relevant information to assess where rubble is likely to become a problem, as well as where and which interventions may be most viable, given environmental constraints. This change allowed the tool to be developed within project timeframes while remaining flexible for potential integration with M&DS in the future, should those models and outputs become available and aligned.

4 Future Research Recommendations

Future research could focus on expanding the dataset used to refine the BBN-based rubble intervention tool. While the current survey data has provided valuable insights, it remains sparse, particularly for some combinations of environmental conditions, which limits the accuracy and generalisability of the predictions. Expanding the dataset will improve the predictive power of the BBNs, allowing for more reliable decision-making in rubble stabilisation. If the BBN were to be expanded to all possible environments and methods, the recovery potential maps could then be successfully linked to the BBN, to not only provide recovery potential predictions, but also the most suitable method to employ if considered necessary based on the specified class.

Additionally, the current BBN models are limited in predicting outcomes beyond five years. To evaluate the long-term effectiveness of stabilisation methods, future research should aim to collect more longitudinal data. Continued multi-disciplinary collaboration among rubble stabilisation experts will be essential to refine the BBN tools.

The rubble stabilisation guidelines could also be updated in response to new research findings. As an online resource, the guidelines are easily accessible and managed by UQ, allowing for timely updates as new information emerges.

With additional future research, rubble bed recovery maps could be improved in terms of binding rates and strength estimates. Investigating binding strength monitoring in additional habitats (e.g. deeper inshore sites, not investigated in RS-01) and intermediate exposure areas, could improve binding predictions at a wider variety of habitats across the GBR. Additionally, there are several limitations underlying the maps that could be improved upon with future research. These are that: a) the binding rates and strengths are based on solidly stabilised rubble only; and b) the binding model assumes that binding is reset to 'zero' after a bound pair is broken apart. While the binding experiments under RS-01 were conducted with solidly stabilised rubble for important logistical and experimental reasons, there will be a combination of solidly stable rubble fragments (e.g. interlocked) and loose fragments (easily shifted) in an actual rubble bed. A pilot study conducted under RS-01 revealed that bind abundance and strength between loose fragments will be slightly lower than between solidly stabilised fragments. Thus, modelled estimations of binding potential may be partially inflated. However, this may be offset by the fact that the binding rate is likely to be underestimated after every breakage event (i.e. where the wave velocity goes above the binding break velocity and breaks apart a bound rubble pair). The binding experiment conducted under RS-01 used bleached, bare rubble fragments to standardise the starting point and represent rubble that had been formed immediately following a disturbance that has smashed up the coral and killed it (e.g. storm, dynamite fishing, ship grounding). Thus, the resulting function of binding strength over time begins with bare rubble. This is what is applied in the model when rubble is: i) first stable; and ii) just after a breakage event. In reality, bound rubble that has been broken apart will *not* be bare, and existing encrusting and binding organisms may be able to more rapidly rebind. These accelerated binding rates have not been investigated over long-time scales, but if conducted in future could be incorporated into the recovery potential modelling.

5 References

Callaghan, D. (2023). Great Barrier Reef non-cyclonic and on-reef wave model predictions. In: The University of Queensland.

Callaghan, D. P., Baldock, T. E., Shabani, B., & Mumby, P. J. (2018). Communicating physics-based wave model predictions of coral reefs using Bayesian belief networks. *Environmental Modelling & Software*, *108*, 123-132. https://doi.org/https://doi.org/10.1016/j.envsoft.2018.07.021

Ceccarelli, D. M., McLeod, I. M., Boström-Einarsson, L., Bryan, S. E., Chartrand, K. M., Emslie, M. J., Gibbs, M. T., Gonzalez Rivero, M., Hein, M. Y., Heyward, A., Kenyon, T. M., Lewis, B. M., Mattocks, N., Newlands, M., Schläppy, M.-L., Suggett, D. J., & Bay, L. K. (2020). Substrate stabilisation and small structures in coral restoration: State of knowledge, and considerations for management and implementation. *PLOS ONE*, *15*(10), e0240846. https://doi.org/10.1371/journal.pone.0240846

Clark, S., & Edwards, A. J. (1994). Use of artificial reef structures to rehabilitate reef flats degraded by coral mining in the Maldives. *Bulletin of Marine Science*, *55*(2-3), 724-744.

Fox, H. E., Harris, J. L., Darling, E. S., Ahmadia, G. N., Estradivari, & Razak, T. B. (2019). Rebuilding coral reefs: success (and failure) 16 years after low-cost, low-tech restoration. *Restoration Ecology*, *27*(4), 862-869. https://doi.org/10.1111/rec.12935

GBRMPA. (2024). *Reef Geohub: GBR10 GBRMP Geomorphic and Great Barrier Reef Features*. https://geohub-gbrmpa.hub.arcgis.com/maps/93fd689452e44e74801845b7935c54c4/about

Kenyon, T. M., Doropoulos, C., Wolfe, K., Webb, G. E., Dove, S., Harris, D., & Mumby, P. J. (2023). Coral rubble dynamics in the Anthropocene and implications for reef recovery. *Limnology and Oceanography*, *68*(1), 110-147. https://doi.org/10.1002/lno.12254

Kenyon, T. M., Eigeland, K., Wolfe, K., Paewai-Huggins, R., Rowell, D., Dodgen, T., & Mumby, P. J. (2024). Material Legacies on Coral Reefs: Rubble Length and Bed Thickness Are Key Drivers of Rubble Bed Recovery. *Global Change Biology*, *30*(11), e17574. https://doi.org/https://doi.org/10.1111/gcb.17574

Kenyon, T. M., Mumby, P. J., Webb, G. E., Dove, S., Newman, S. P., & Doropoulos, C. (2025). Trajectories and agents of binding in stabilized and unstabilized coral rubble across environmental gradients. *Ecosphere*, *16*(2), e70195. https://doi.org/https://doi.org/10.1002/ecs2.70195

Raymundo, L. J., Maypa, A. P., Gomez, E. D., & Cadiz, P. (2007). Can dynamite-blasted reefs recover? A novel, low-tech approach to stimulating natural recovery in fish and coral populations. *Marine Pollution Bulletin*, *54*(7), 1009-1019. https://doi.org/10.1016/j.marpolbul.2007.02.006

Roelfsema, C. M., Lyons, M. B., Castro-Sanguino, C., Kovacs, E. M., Callaghan, D., Wettle, M., Markey, K., Borrego-Acevedo, R., Tudman, P., Roe, M., Kennedy, E. V., Gonzalez-Rivero, M., Murray, N., & Phinn, S. R. (2021). How Much Shallow Coral Habitat Is There on the Great Barrier Reef? *Remote Sensing*, *13*(21), 4343. https://www.mdpi.com/2072-4292/13/21/4343

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