COTS Control Innovation Program Investment Plan

Mary Bonin, Cedric Robillot, Richard Brinkman, Bruce Taylor, Damien Burrows, Peter Mumby, Sheriden Morris, Roger Beeden, Eric Fisher, Malachi Johnson, Britta Schaffelke, Charlie Morgan

Australian Government | Reef Trust | Great Barrier Reef Foundation | Australian Institute of Marine Science | CSIRO | James Cook University Australia | The University of Queensland Australia

COTS Control Innovation Program Investment Plan

Mary C Bonin[1], Cedric Robillot[1], Richard Brinkman[2], Bruce Taylor[3], Damien Burrows[4], Peter Mumby[5], Sheriden Morris[6], Roger Beeden[7], Eric Fisher[8], Malachi Johnson[9], Britta Schaffelke[2], Charlie Morgan[1].

1. Great Barrier Reef Foundation
2. Australian Institute of Marine Science
3. Commonwealth Scientific and Industrial Research Organisation
4. James Cook University
5. University of Queensland
6. Reef and Rainforest Research Centre
7. Great Barrier Reef Marine Park Authority
8. Experience Co Ltd.
9. Gooreng Gooreng Nation

COTS Control Innovation Program | A research and development partnership to better predict, detect and respond to crown-of-thorns starfish outbreaks

Inquiries should be addressed to:

Mary C. Bonin
Great Barrier Reef Foundation
mbonin@barrierreef.org

This report should be cited as

Bonin MC, Robillot C, Brinkman R, Taylor B, Burrows D, Mumby P, Morris S, Beeden R, Fisher E, Johnson M, Schaffelke B, Morgan C (2022) *COTS Control Innovation Program Investment Plan*. A report to the Australian Government by the COTS Control Innovation Program (16 pp).

Funding Acknowledgement

The COTS Control Innovation Program aims to accelerate the development of innovative surveillance and control methods to manage outbreaks of coral-eating starfish on the Great Barrier Reef. The Program is a collaboration between the Great Barrier Reef Foundation, Australian Institute of Marine Science, Commonwealth Scientific and Industrial Research Organisation, James Cook University and The University of Queensland. The Program is funded by the partnership between the Australian Government's Reef Trust and the Great Barrier Reef Foundation.

Traditional Owner Acknowledgement

The COTS Control Innovation Program extends its deepest respect and recognition to all Traditional Owners of the Great Barrier Reef and its Catchments, as First Nations Peoples holding the hopes, dreams, traditions and cultures of the Reef.

Disclaimer

While reasonable efforts have been made to ensure that the contents of this document are factually correct, CCIP does not make any representation or give any warranty regarding the accuracy, completeness, currency or suitability for any particular purpose of the information or statements contained in this document. The views and opinions expressed in this publication are those of the authors and do not necessarily reflect those of the Australian Government.

Contents

List of Figures

List of Tables

Acroynms and Abreviations

AIMS	Australian Institute of Marine Science
CCIP	COTS Control Innovation Program
COTS	Pacific crown-of-thorns starfish (*Acanthaster* cf. *solaris*)
CSIRO	Commonwealth Scientific and Industrial Research Organisation
GBR	Great Barrier Reef
GBRF	Great Barrier Reef Foundation
GBRMPA	Great Barrier Reef Marine Park Authority
IPM	Integrated Pest Management
JCU	James Cook University
NESP	National Environmental Science Program
QUT	Queensland University of Technology
R&D	Research and development
RIMREP	Reef 2050 Integrated Monitoring and Reporting Program
RRAP	Reef Restoration and Adaptation Program
RRRC	Reef and Rainforest Research Centre
RTP	Reef Trust Partnership
SCU	Southern Cross University
SDM	Structured Decision-Making
TO	Traditional Owner
UQ	University of Queensland
USC	University of Sunshine Coast
USYD	University of Sydney
UTAS	University of Tasmania

1. INTRODUCTION

1.1 The Crown-of-thorns starfish Control Innovation Program

The Pacific crown-of-thorns starfish (COTS; *Acanthaster* cf. *solaris*) is a coral-eating starfish that is native to the Great Barrier Reef (GBR). Outbreaks of this starfish cause significant damage to coral reefs across large spatial scales and are a major threat to the long-term health of the GBR. Controlling these outbreaks is considered one of the most scalable and feasible direct management interventions available today to enhance the Reef's resilience in the face of climate change (GBRMPA 2017, GBRMPA 2020). Indeed, the COTS Control Program has demonstrated its ability to effectively reduce COTS densities and improve coral cover at a site scale (Westcott et al. 2020) and modelling suggests COTS control is one of the most effective interventions for reducing decline in coral cover at the scale of the GBR over the next 50 years under climate change (Condie et. al 2021). With a current outbreak still spreading across the central and southern regions of the Reef, and the next outbreak already developing in the northern region, there is an urgent need to invest in research that improves our ability to manage COTS outbreaks at the scale of the GBR.

To achieve this objective the Reef Trust Partnership (RTP) Investment Strategy includes a total of $9.8m to establish the COTS Control Innovation Program (CCIP). The overarching goal of this program is to create a step change and accelerate the development and uptake of innovative methods that improve the efficacy and efficiency of COTS surveillance and control. This program builds upon the Integrated Pest Management (IPM) strategy developed under the National Environmental Science Program (NESP) (Westcott et al. 2016) and intends to deliver innovations that can be integrated into the on-water COTS Control Program. The CCIP is being delivered across two phases:

- Phase 1 - Feasibility and Design (2020-2021, $1.5m), focused on assessing the feasibility (technical, social and regulatory) and benefit (impact) at scale of a broad range of possible improvements and interventions in order to recommend an integrated program of research;
- Phase 2 – Research and Development (R&D) (2021-2024, $8.3m), which will focus on implementing the recommendations of the Feasibility and Design Phase and identifying pathways for trialling and integration of research outcomes into the COTS Control Program.

1.2 Delivery model and governance

The CCIP is being delivered as scientific consortium of core research partners from the Australian Institute of Marine Science (AIMS), Commonwealth Scientific and Industrial Research Organisation (CSIRO), James Cook University (JCU), and The University of Queensland (UQ), and coordinated by the Great Barrier Reef Foundation (GBRF). These five partners have entered into a CCIP Collaboration Agreement, fostering a cooperative and outcome-focused approach where multidisciplinary teams work across institutional boundaries to maximise impact and ensure the program's findings are widely supported.

An open Expression of Interest process was also run from May to June 2020 to identify additional technical experts from beyond the core research partner institutions. This resulted in additional expertise from a range of institutions and organisations joining to design and/or deliver the research program (e.g., University of Sydney, Southern Cross University, University of the Sunshine Coast, Queensland University of Technology, Babel-sbf, Marenray).

The CCIP is governed by a Steering Committee chaired by GBRF and consisting of members from core partner research institutions, a Traditional Owner member, an independent member appointed by the Reef and Rainforest Research Centre (RRRC), as well as representatives from the Department of Climate Change, Energy, the Environment and Water (DCCEEW), the Great Barrier Reef Marine Park Authority (GBRMPA), and the tourism industry (**Figure 1.1**).

The CCIP Steering Committee oversees the design, progress and delivery of both phases of the research and innovation program, including endorsing strategic and operational plans, budget allocations, and reports. The Committee also provides strategic advice on risks and opportunities related to the program and ensures program funds are spent in accordance with the CCIP Collaboration Agreement. A Program Director reports to and acts under the direction of the Steering Committee, providing day-to-day oversight of program delivery by the technical teams.

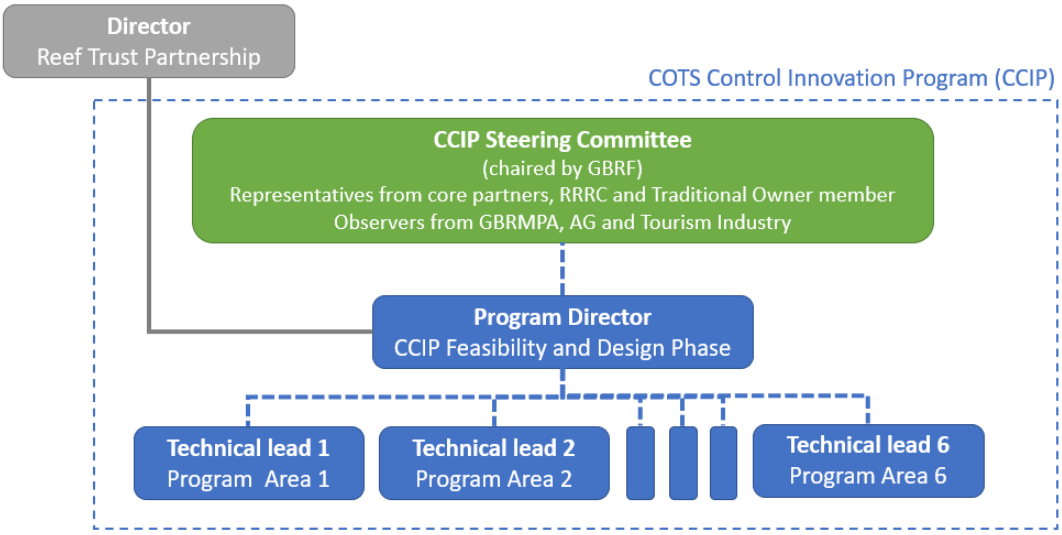

Figure 1.1 Governance structure for the COTS Control Innovation Program (CCIP)

2. CCIP FEASIBILITY AND DESIGN PHASE: OBJECTIVES AND PROCESS

2.1 Design phase objectives

Achieving the CCIP's overarching goal of delivering innovation in COTS surveillance and control requires targeted research that drives progress while also managing cost and risk. The problem at hand is that there are a wide range of Research Opportunities that could potentially achieve this goal, with no singular clear pathway for research investment. Moreover, the feasibility and benefit of many (arguably most) Research Opportunities in delivering innovative COTS management outcomes is not well understood. Consequently, decision-makers are faced with a complex problem in determining which Research Opportunities warrant investment through the CCIP.

In the Feasibility and Design Phase a structured decision-making (SDM) process was used to develop opportunities and prioritise research investment in the three-year R&D program (Phase 2). The intention of this process was to deliver insight to decision-makers about how well the objectives and vision of the CCIP will be met through a systematic assessment of the various investment options.

2.2 Design phase process

Prior to undertaking the Feasibility and Design Phase, six Program Areas were identified that represent key research themes for achieving CCIP goals:

- population control,
- monitoring and surveillance,
- decision support and modelling,
- proximal causes of outbreaks,
- COTS biology and ecology, and
- social acceptability, regulatory and institutional arrangements.

Teams of multidisciplinary technical experts were then assembled from across partner institutions and third-parties for each Program Area.

A total of 43 multidisciplinary experts were engaged across the six Program Areas in designing the research program. These teams worked together to identify, assess and recommend Research Opportunities for consideration as part of the R&D Phase (**Figure 2.1**), with strong emphasis on ensuring the synergies across Program Areas were identified. Additional input into program design was also provided by the Program Director, CCIP Steering Committee and four external assessors at later steps in the process.

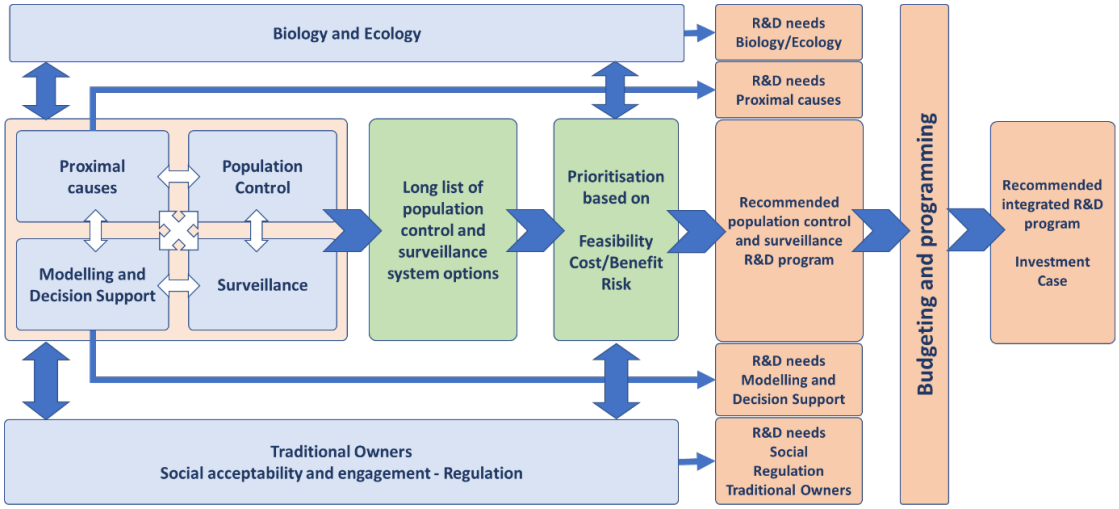

Figure 2.1 Overview of Program Areas and program design framework.

The broad steps involved in the CCIP Feasibility and Design Phase were as follows:

1. Gap analysis or literature review within each Program Area in order to systematically identify gaps in knowledge and capability within each research theme.

2. Identification and Scoping of Research Opportunities that fill the most critical knowledge and capability gaps within each Program Area, with experts collecting information on the benefits, costs, and risks of those opportunities.

3. Assessment of Research Opportunities through evaluation of their relative benefits, costs and risks by the experts within each Program Area using standard criteria.

4. Development and Assessment of alternative strategic R&D portfolio options using the Research Opportunities generated across Program Areas, in order to gain a directional view on the preferred R&D strategy and prioritised Opportunities to be included in final program design.

5. Final Program Design and Budgeting, including scope and cost rationalisation of prioritised Opportunities as part of an integrated R&D program.

This **Investment Plan** focusses on summarising the outcomes of the fifth and final step in the process. Several companion reports detail the process and outcomes of prior steps. The CCIP Feasibility & Design Phase Technical Report (Fletcher et al. 2021) covers the first three steps, which were delivered by the technical experts. The Investment Prioritisation Report (Sivapalan 2021) reports on step four in the process. A summary of the technical findings and recommendations of these two companion reports is provided in Section 3.

3. CCIP FEASIBILITY AND DESIGN PHASE: SUMMARY OF RECOMMENDATIONS

3.1 Research opportunity recommendations

The technical expert teams engaged in designing the research program collectively identified >300 knowledge and capability gaps relevant to advancing capability in COTS control and surveillance (**Table 3.1**). These experts then developed a total of 52 Research Opportunities to fill the most crucial knowledge and capability gaps and assessed their relative benefits, costs and risks through a structured evaluation process. Details on the process are provided in the CCIP Feasibility & Design Phase Technical Report (Fletcher et al. 2021) and are summarised in **Table 3.1**. In some cases, this assessment process enabled the technical teams to further prioritise amongst Research Opportunities to ultimately recommend a refined set of 'must have' Opportunities for investment. In other cases, the expert teams determined that all of the Research Opportunities that were developed and assessed were equally valuable and recommended that all be prioritised. This ultimately left the prioritisation decisions in the hands of the CCIP Program Director and Steering Committee, given that the available R&D program budget was not sufficient to fund all the Research Opportunities that were recommended by the technical experts.

Table 3.1 Overview of the number of knowledge and capability gaps that were identified, assessed, and recommended as 'must have' as part of a research portfolio by the technical expert teams.

Design Phase Program Area Expert Teams	Number of Knowledge Gaps Identified	Number of Research Opportunities Assessed	Number of Research Opportunities Recommended
Population Control	85	7	6
Monitoring and Surveillance	24	10	5
Decision Support and Modelling	86	10	10
Proximal Causes of Outbreaks	52	12	12
COTS Biology and Ecology	71	8	8
Social Science	6*	5	4
TOTAL	**324**	**52**	**44**

* Social Science Program Area used literature review process to identify broad themes rather than specific knowledge gaps.

3.2 Portfolio investment strategy recommendations

Following on from the work of the technical expert teams to identify, develop, assess and recommend Research Opportunities for potential investment in the CCIP R&D Phase, the next step in the design process was to take a portfolio view and consider alternative strategic R&D investment options using various combinations of the Research Opportunities developed by the technical teams. This step in the design process engaged a group of 21 key stakeholders (i.e. leading technical experts from each Program Area, the CCIP Program Director, Steering Committee members and four external assessors) to gain a directional

view on the preferred investment strategy to inform final program design (Sivapalan 2021). Alternative portfolio investment strategies were identified at a framing workshop with this group, and seven portfolios were then constructed by selecting combinations of Research Opportunities that closely aligned to delivering on that strategic intent until a total budget envelope of approximately $14m was reached (Sivapalan 2021). Each of the seven portfolios was then assessed across six evaluation criteria, and the relative weighs of the evaluation criteria were also assessed. Details of the process are provided in the Investment Prioritisation Report (Sivapalan 2021) and an overview of the outcomes is summarised in **Table 3.2**.

Table 3.2 Summary of assessment outcomes for seven potential R&D portfolio investment strategies. The percentage rankings are derived from monte-carlo analysis of the probabilistic performance of each portfolio given the range of scores and weights as assessed across 21 key stakeholders.

R&D Portfolio Strategy	Number of Research Opportunities included	Modelled % instances ranked 1st or 2nd across respondents
Emphasis on suppressing the 2025 outbreak (medium-term)	30	46%
Emphasis on preventing future primary outbreaks (long-term)	25	46%
Emphasis on managing the current outbreak (short-term)	23	36%
Emphasis on informing strategy for control and surveillance	28	31%
Emphasis on maximising synergies in CCIP and across other GBR programs	26	18%
Emphasis on improving system understanding	30	14%
Emphasis on creating new control approaches	26	9%

The clear outcome of the assessment was that stakeholders recommended a program design that focussed on both 1) suppressing the 2025 outbreak and 2) preventing future primary outbreaks (Sivapalan 2021). These two portfolio strategies were considered to offer greatest potential to have a beneficial impact on coral at scale and achieve a step-change in COTS surveillance and control. In contrast, a strategy that focussed primarily on investing in research that created new control approaches was the least preferred option. While stakeholders considered this investment approach to offer strong potential for step-change in control capability, they also considered it to have the least direct and immediate benefit to coral at scale (Sivapalan 2021). Investment in creating new control approaches was also considered to have the highest risk and uncertainty in its ability to deliver potential benefits to coral from both technical and regulatory perspectives. Ultimately, the assessors recommended prioritising investment in research that offered more certainty in delivering direct and immediate benefits to coral in the medium-term (i.e. the outbreak suppression

strategy), over those that, while innovative, were riskier and would take longer time-frames to realise benefits at scale.

4. CCIP R&D PROGRAM INVESTMENT PLAN

4.1 Final program design steps

In the final steps of program design, the CCIP Program Director and Steering Committee considered the insights and recommendations from the Research Opportunity and portfolio investment strategy assessments and provided guidance back to the technical teams to inform the development of full research project proposals and budgets. The following guidance was provided:

- a shortlist of 29 Research Opportunities prioritised based on their strategic alignment to a portfolio focused on 1) suppressing the 2025 outbreak and 2) preventing future primary outbreaks,
- scope refinement advice for each shortlisted Research Opportunity based on the insights gained through the Research Opportunity assessment process, which in some instances included suggestions to merge several Research Opportunities into a single project to promote collaboration and capitalise on synergies,
- cost rationalisation advice and a target budget for each shortlisted Research Opportunity, and
- the Program Director and Steering Committee's view on the relative priority of the 29 shortlisted Research Opportunities for inclusion in the final program design, should it not be feasible to include them all within the available program budget.

The CCIP Program Director and Steering Committee also identified three subprogram themes that were highly relevant to achieving effective suppression and prevention of outbreaks—***Prediction***, ***Detection*** and ***Response***—and the shortlisted Research opportunities were organised under these themes. These subprogram themes recognise that most effective pest management frameworks are centred around *early* prediction and detection of an impending pest outbreak to enable a rapid and *early* response (Hoey et al. 2016). This type of proactive approach to managing COTS outbreaks on the GBR is likely to be less costly and more effective than reactive approaches employed previously (Hoey et al. 2016, Babcock et al. 2020).

The technical experts considered this guidance and then prepared formal project proposals along with detailed budgets. In several instances the technical teams discussed budget constraints and agreed not to advance Research Opportunities that were considered lower priority so that funding could be reallocated to other higher priority Opportunities. In other cases, several Research Opportunities were merged and proposed as a single project.

Following these final adjustments, a total of 21 projects were approved by the CCIP Program Director and Steering Committee as part of the final R&D portfolio (**Figure 4.1**). Ultimately,

the portfolio primarily emphasised a suppression strategy, with some selected projects focused on prevention.

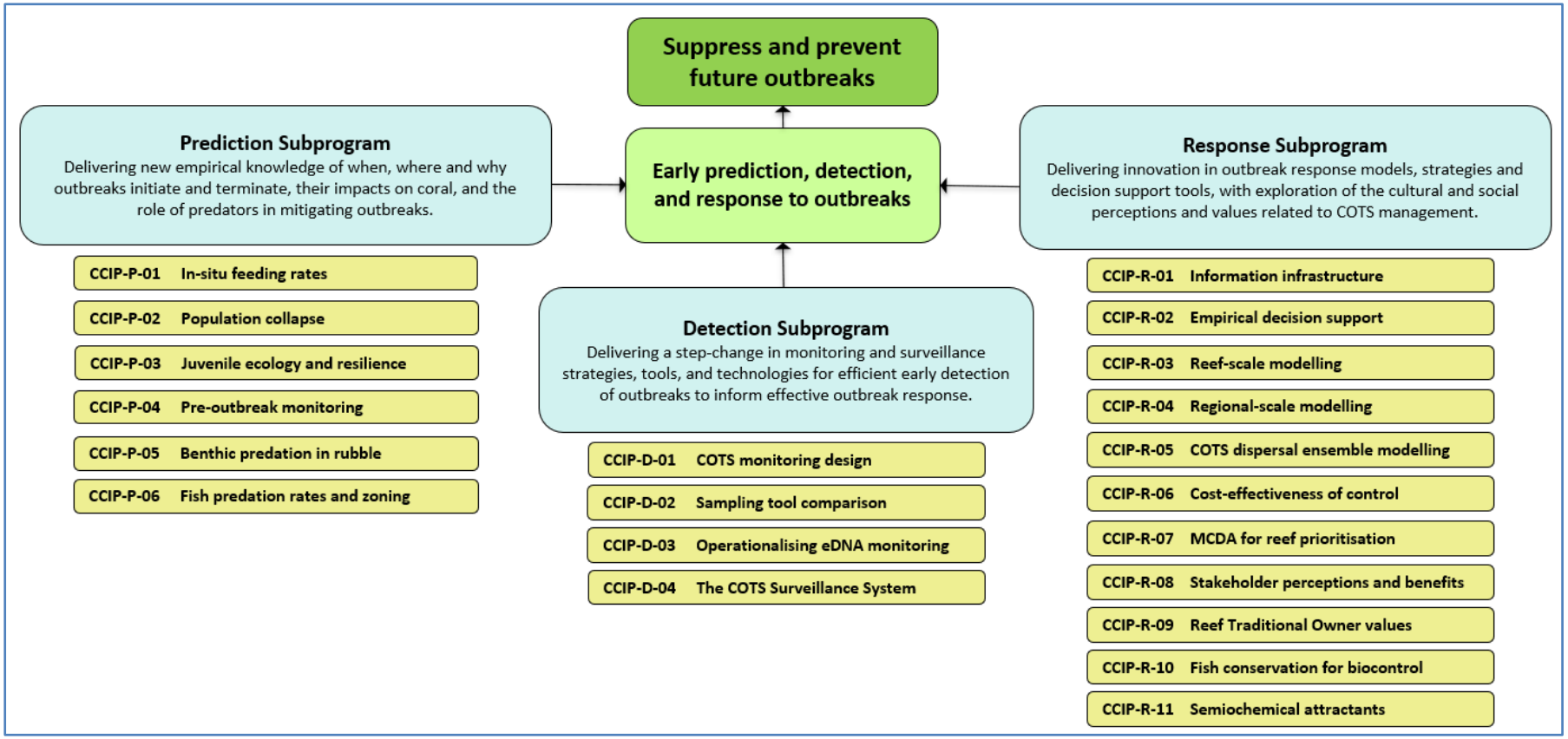

Figure 4.1 The 21 projects across three subprograms prioritised for investment as part of the CCIP R&D portfolio.

4.2 Subprogram overviews

4.2.1 Prediction

Integrated Pest Management (IPM) requires a thorough understanding of the biology, ecology, and population dynamics of the pest species being managed, and is fundamental to underpin accurate pest detection and effective management response. The ***Prediction Subprogram*** will deliver new empirical knowledge of when, where and how outbreaks develop to inform effective and efficient early detection and response across a total of **6 projects**. This subprogram focuses on understanding the role of predators in mitigating outbreaks, juvenile COTS ecology, factors influencing feeding rates, the causes of population collapse at the end of outbreaks, and the demography of pre-outbreak populations. An overview of each project in the subprogram is provided in **Table 4.1**.

Table 4.1 A summary of the six collaborative projects under the Prediction subprogram.

Project code	Title (short)	Project Summary	Project collaborators
CCIP-P-01	In-situ feeding rates	This project quantifies feeding rates of COTS in the field relative to the size and abundance of COTS, as well as changes in prey availability (coral cover and composition) and seasonal variation in seawater temperature. This empirical data is critical to modelling and decision support for effective outbreak response.	JCU (lead), USYD, UTAS
CCIP-P-02	Population collapse	This project uses field and laboratory experiments to determine the causes of abrupt population decline at the end of outbreaks, testing whether local depletion of prey resources results in subsequent starvation and reduced immunity against opportunistic pathogens.	JCU (lead), AIMS
CCIP-P-03	Juvenile ecology and resilience	This project uses laboratory experiments to understand juvenile COTS ecology, a major black box. It tests the juvenile resilience hypothesis, whereby reserves of juveniles build up in the reef infrastructure as a proximate contributor to outbreaks, potentially years after settlement.	USYD (lead), SCU
CCIP-P-04	Pre-outbreak monitoring	This project will conduct annual field surveys (diver-based scooter and eDNA) across reefs in the primary outbreak initiation region to reveal how the density, distribution and size-structure of COTS populations changes, providing field data to inform early warning and response in the lead up to the 2025 outbreak.	JCU (lead), AIMS
CCIP-P-05	Benthic predation in rubble	This project will use field surveys and laboratory experiments, including eDNA and metabarcoding analyses, to identify cryptic COTS predators and measure the mortality rates they inflict on early juvenile COTS in rubble habitats.	UQ (lead), AIMS, SCU
CCIP-P-06	Fish predation rates and zoning	This project uses field studies to quantify predation rates on COTS by mobile fish species across marine park management zones, to provide mechanistic insight and inform fisheries management measures in mitigating outbreaks.	JCU (lead), SCU, UTAS

4.2.2 Detection

The ***Detection Subprogram*** will deliver a step-change in monitoring and surveillance strategies, tools and technologies for efficient early detection of outbreaks, in order to inform effective outbreak response across a total of **4 projects**. Projects in this subprogram include developing underwater robotics and machine learning capability, and sensitive early warning tools through eDNA detection of adult COTS. An integrated monitoring strategy using an expanded toolbox for COTS detection will dramatically improve both the efficiency and safety of COTS monitoring and surveillance methods and provide rich data at greater temporal and spatial scales to inform strategic and targeted on-ground response. An overview of each project in the subprogram is provided in **Table 4.2**.

Table 4.2 A summary of the four collaborative projects under the Detection subprogram.

Project code	Title (short)	Project Summary	Project collaborators
CCIP-D-01	COTS monitoring design	This project will develop a monitoring strategy for COTS and coral that integrates information from a range of survey tools to guide decision-making in the COTS Control Program, with particular focus on early warning detection and response. It will develop decision rules for trading-off investment in monitoring versus control depending on outbreak phase.	CSIRO (lead), AIMS, JCU, GBRMPA
CCIP-D-02	Sampling tool comparison	This project uses a combination of desktop and fieldwork to characterise and measure the detection errors associated with various COTS survey tools (e.g. manta tow, towed platform, eDNA, scooter, cull dives) and will calibrate density estimates across these tools to enable integration of data from multiple sources and programs into COTS Control Program decision-making.	CSIRO (lead), AIMS, JCU
CCIP-D-03	Operationalising eDNA monitoring	This project will develop the methodology and sampling strategy to use eDNA for early detection of post-settlement COTS. It will further train COTS Control Program crew in sampling methodology so that it can be implemented as part of the program and will test the feasibility of using ships of opportunity to collect additional data.	AIMS (lead)
CCIP-D-04	The COTS Surveillance System	This project will develop an end-to-end system for COTS and coral surveillance across the GBR, including a towed survey platform, machine learning models, data workflows, and user interfaces. This system intends to deliver a major step-change in the accuracy, safety, and spatial scale of COTS outbreak surveillance.	AIMS (lead), CSIRO

4.2.3 Response

The ***Response Subprogram*** will deliver innovation in outbreak response models, strategies and decision support tools, with exploration of the technical, cultural, social and regulatory feasibility of selected novel control methods across **11 projects**. This subprogram includes both biophysical and social science research, including a significant investment in decision support and modelling aimed at improving the efficiency and effectiveness of the COTS Control Program in the years leading up to the next outbreak, as well as research to understand the cultural and socio-economic benefits of control. Moreover, the investment in genomic research under this subprogram will drive research progress in the development of

semiochemical attractants as a new biocontrol method and explore how predator conservation can be used to help mitigate outbreaks. An overview of each project in the subprogram is provided in **Table 4.3**.

Table 4.3 A summary of the 11 collaborative projects under the Response subprogram.

Project code	Title (short)	Project Summary	Project collaborators
CCIP-R-01	Information infrastructure	This project will create an Information Infrastructure to underpin the sharing and distribution of field, derived, and modelled data between CCIP researchers and the COTS Control Program. It will create a digital delivery mechanism to enable efficient, reliable sharing of data including metadata to guarantee provenance. This system will be designed to integrate with broader infrastructures being developed through RRAP and RIMREP.	CSIRO (lead), JCU, QUT, UQ, GBRMPA
CCIP-R-02	Empirical decision support	This project will deliver immediate and ongoing decision support for the COTS Control Program, including analysis of program data to enhance the efficiency of on-water operations and the development of a new Early Warning System that leverages field and modelled data from multiple sources to inform early response.	CSIRO (lead), JCU, GBRMPA
CCIP-R-03	Reef-scale modelling	This project will model COTS and coral dynamics at the reef scale to develop ecological thresholds that are responsive to variation in coral cover and community composition across reefs targeted by the COTS Control Program. It will leverage new empirical data collected through the Prediction subprogram and evaluate the efficacy of management interventions under different ecological conditions at the reef scale.	CSIRO (lead), UQ
CCIP-R-04	Regional-scale modelling	This project leverages and builds on the capabilities of two COTS-coral community models, CoCoNet and ReefMod, to identify control strategies that maximise the resilience of coral populations across the GBR. It will inform the optimal deployment of COTS Control Program vessels and evaluate the benefits of integrating other management interventions into control program strategy.	UQ (co-lead), CSIRO (co-lead), GBRMPA
CCIP-R-05	COTS dispersal ensemble modelling	This project will use an ensemble model approach to improve the COTS larval dispersal predictions that are critical to underpin regional-scale modelling of outbreak dynamics and the prioritisation of reefs for control. It will characterise uncertainty to enable robust predictions.	JCU (co-lead), QUT (co-lead), UQ, UCL
CCIP-R-06	Cost effectiveness of control	This project will evaluate the cost-effectiveness and economic efficiency of different control strategies, in order to inform strategic allocation of COTS Control Program resources for enhanced cost-effectiveness and assess the social net benefit generated by control in monetary terms.	CSIRO (lead), UQ, GBRMPA
CCIP-R-07	MCDA for reef prioritisation	This project will provide a formal and transparent methodology for considering multiple criteria to identify priority reefs for COTS control. Building on the current approach, it will provide a flexible framework and decision analysis tools for evaluating trade-offs amongst ecological and economic values that can be extended to incorporate additional values such as cultural importance.	QUT (lead), CSIRO, GBRMPA
CCIP-R-08	Stakeholder perceptions and co-benefits	This project will provide the first empirical examination of GBR stakeholder perspectives related to COTS and their management. It will leverage sociocultural research planned as part of RRAP, extending those stakeholder engagements and interviews to measure perceptions of acceptability, risks and benefits related to COTS control. It will also assess the	JCU (lead), UQ

		regulatory and policy implications of selected novel control methods.	
CCIP-R-09	Reef Traditional Owner values assessment	This project will use a Community of Practice model to build knowledge of Reef Traditional Owner perceptions and aspirations related to COTS research and management. It will develop guidelines for data sharing and integration of TO knowledge in COTS decision frameworks, and facilitate Reef TO involvement in CCIP research and implementation.	JCU (lead), CSIRO
CCIP-R-10	Fish predator conservation for biocontrol	This project will use regional-scale modelling to develop and assess the efficacy of scenarios for fish predator conservation (e.g. zoning, fisheries management) to control COTS outbreaks. It will identify and rank the scenarios that have strongest potential to prevent COTS outbreaks within the 20-30 years and engage with management agencies to communicate findings for consideration in planning/policy.	AIMS (lead), CSIRO
CCIP-R-11	Semiochemical attractants and genomics	This project will use genomics and proteomics to identify COTS pheromone attractants that modify conspecific behaviour and could be used as a future biocontrol method. It will assess the efficacy of identified attractants in laboratory trials and consider their suitability for deployment as part of an Integrated Pest Management strategy, with potential for field trials if strong candidate attractants are identified.	AIMS (lead), CSIRO, UQ, USC

4.3 Program Budget

The iterative design process described above has resulted in an R&D program with a total budget of approximately $15.6m. This includes $8.6m cash contribution from the RTP as well as an estimated $7m co-contribution from core research partners (**Table 4.4**). Focusing on the RTP contribution, approximately 19% is allocated to the Prediction subprogram, 29% to the Detection subprogram, and 39% to the Response subprogram. An additional 13% of the RTP funding is allocated to program management ($556k) and contingency ($580k) that will support emerging research opportunities that arise once the R&D program gets underway.

Table 4.4 Budget overview for the R&D Phase of the COTS Control Innovation Program.

Subprogram	RTP Contribution ($,000)	Co-contribution ($,000)	Total Budget ($,000)
Prediction	1,617	1,985	3,602
Detection	2,473	1,203	3,676
Response	3,374	3,743	7,117
Program Management & Contingency	1,136	98	1,234
	8,600	**7,029**	**15,629**

The breakdown of RTP and co-investment funding per subprogram is shown in **Figure 4.2**, highlighting the significant matching co-investment in the R&D program from core research partners. The annual budget for each subprogram across financial years is shown in **Figure 4.3**.

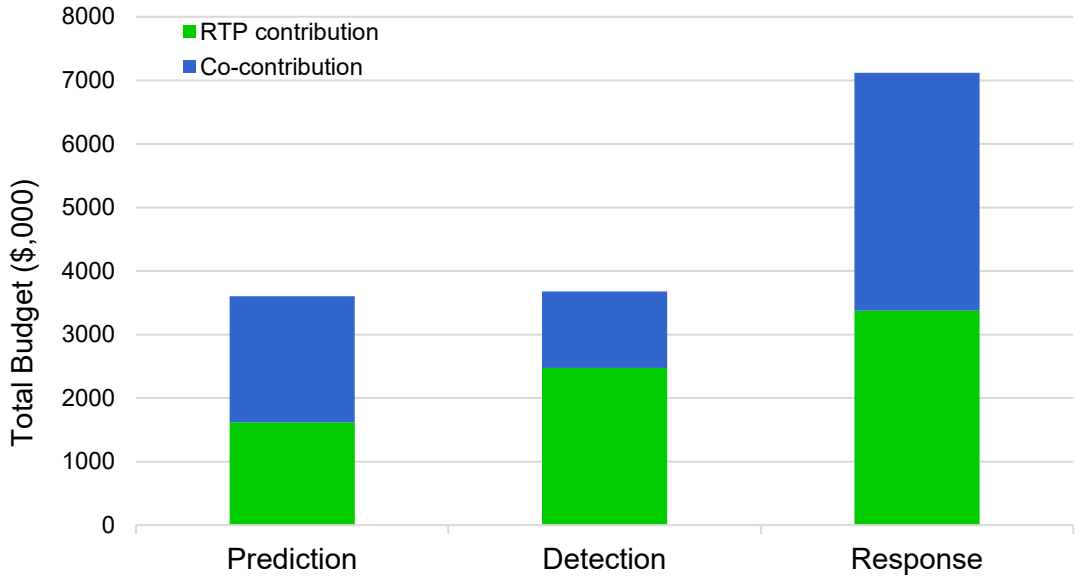

Figure 4.2 RTP funding and co-contribution by core research partners across CCIP subprograms.

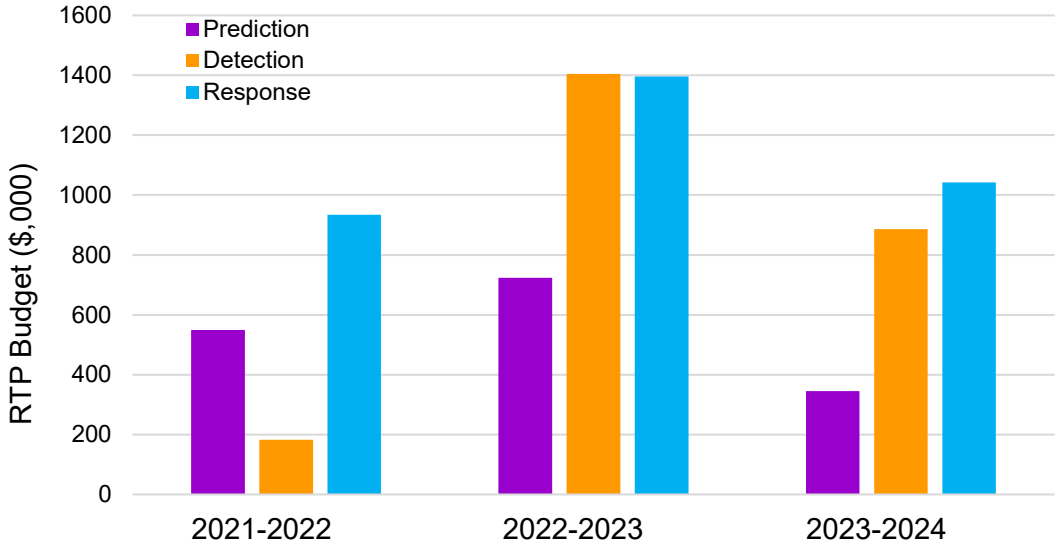

Figure 4.3 Budget per financial year across CCIP subprograms.

4.4 Conclusion

This CCIP Investment Plan draws upon the knowledge and recommendations of over 40 multidisciplinary experts, decision-makers and stakeholders who contributed to an iterative program design process. The collective insights gained through this process were critical in assessing the relative feasibility, risks and benefits of 52 research opportunities that experts developed to fill critical knowledge and capability gaps related to COTS surveillance and control (Fletcher et al. 2021), and in prioritising these opportunities to build an integrated research portfolio (Sivapalan 2021). Underpinned by recognition that the IPM approach implemented in the COTS Control Program in 2018 provided a solid foundation to build upon, and a sense of urgency to protect and boost Reef resilience in the face of climate change, the experts and decision-makers recommended investment in a portfolio that would primarily deliver benefits in the near to medium-term (e.g. within 3-10 years) rather than more 'blue-sky' research focused on the development of new control technologies.

Based on the insights gained from the design phase, the Reef Trust Partnership and core CCIP research partners from AIMS, CSIRO, JCU and UQ are investing approximately $15.6m in 21 projects across three subprograms of research. Investment is focussed primarily on suppressing future outbreaks through a portfolio that delivers new tools and technologies for enhanced prediction, detection and response that can be readily integrated into the COTS Control Program, while also filling targeted knowledge gaps related to the pest and the socio-ecological context in which our pest management takes place. Collectively, this research will deliver a step-change in the quality and scale of COTS surveillance that will drive major improvements in the efficiency and effectiveness of management decision-making and response.

REFERENCES

Babcock RC, Plagányi ÉE, Condie SA, Westcott DA, Fletcher SC, Bonin MC, Cameron D (2020) Suppressing the next crown-of-thorns outbreak on the Great Barrier Reef. *Coral Reefs* 39(5): 1233-1244

Condie SA, Anthony KR, Babcock CR, Baird ME, Beeden R, Fletcher SC, Gorton R, Harrison D, Hobday AJ, Plagányi ÉE, Westcott DA (2021) Large-scale interventions may delay decline of the Great Barrier Reef. *Royal Society Open Science* 8: 201296

Fletcher CS, Bonin MC, Caballes CF, Gómez-Cabrera MC, Kroon FJ, Mankad A, Pratchett MS, Uthicke S, Westcott DA (2021) Design of the COTS Control Innovation Program: a technical report and recommendations. A report to the Australian Government by the COTS Control Innovation Program (149 pp.).

Great Barrier Reef Marine Park Authority (2017) *Great Barrier Reef blueprint for resilience*. Great Barrier Reef Marine Park Authority, Townsville

Great Barrier Reef Marine Park Authority (2020) *Crown-of-thorns starfish Strategic Management Framework*. Great Barrier Reef Marine Park Authority, Townsville

Hoey J, Campbell ML, Hewitt CL, Gould B, Bird R (2016) *Acanthaster planci* invasions: applying biosecurity practices to manage a native boom and bust coral pest in Australia. *Management of Biological Invasions* 7(3): 213-220

Sivapalan M (2021) *CCIP Feasibility & Design Phase Investment Prioritisation: Application of Structured Decision Making to Inform Program Design*. A summary report prepared for the Great Barrier Reef Foundation, Adaptus, Perth

Westcott DA, Fletcher CS, Babcock R, Plaganyi-Lloyd E (2016) *A Strategy to Link Research and Management of Crown-of-Thorns Starfish on the Great Barrier Reef: An Integrated Pest Management Approach*. Report to the National Environmental Science Programme. Reef and Rainforest Research Centre Limited, Cairns, 80 pp

Westcott DA, Fletcher CS, Kroon FJ, Babcock RC, Plagányi ÉE, Pratchett MS, Bonin MC (2020) Relative efficacy of three approaches to mitigate Crown-of-Thorns Starfish outbreaks on Australia's Great Barrier Reef. *Scientific Reports* 10: 12594

COTS Control Innovation Program | A research and development partnership to better predict, detect and respond to crown-of-thorns starfish outbreaks

Australian Government

REEF TRUST

Great Barrier Reef Foundation

Australian Institute of Marine Science

CSIRO

James Cook University Australia

The University Of Queensland Australia