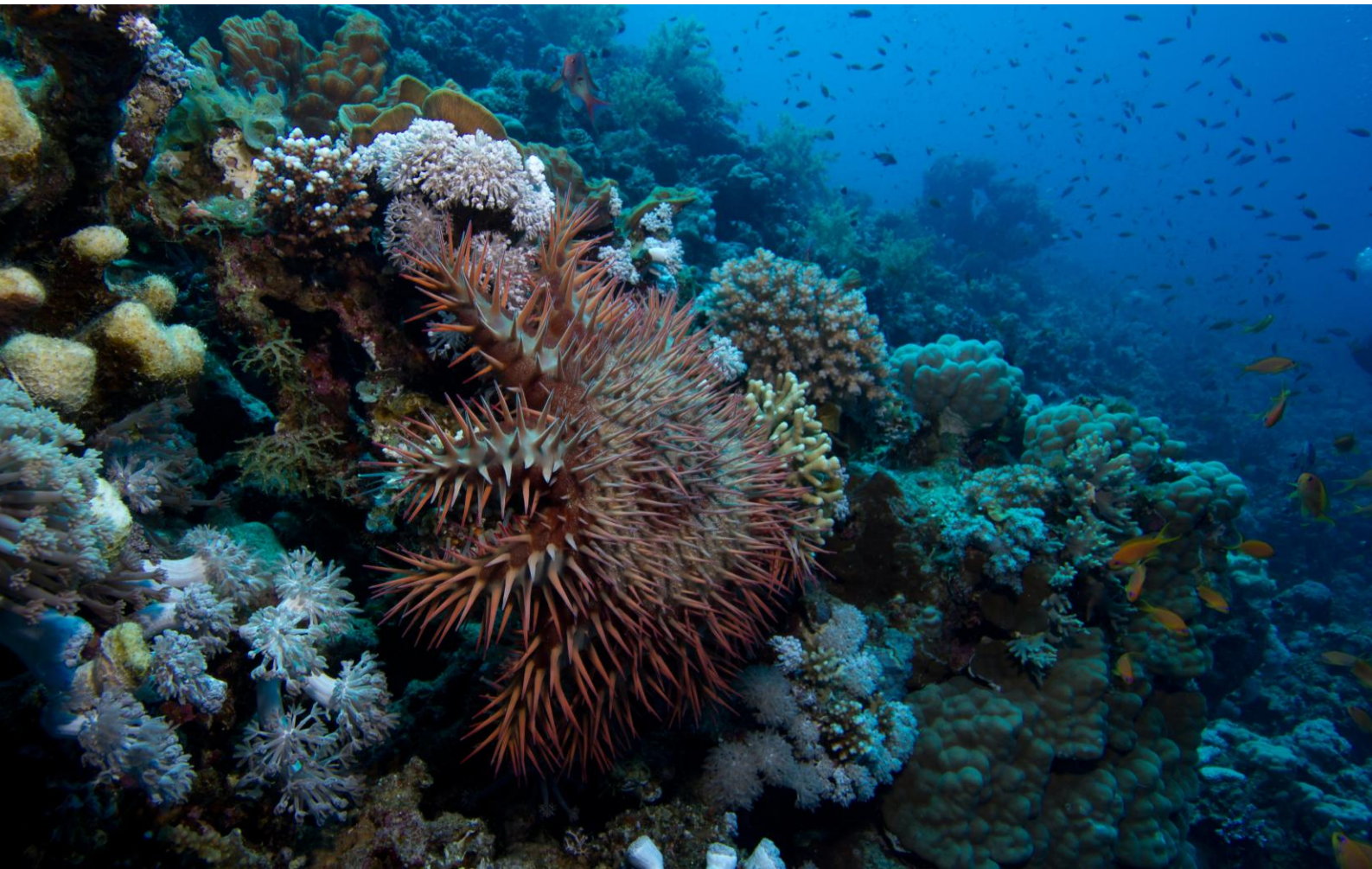


Perceptions of crown-of-thorns starfish (COTS) management in the Great Barrier Reef, economic and social co-benefits, and regulatory considerations

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Great Barrier
Reef Foundation



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



Great Barrier
Reef Foundation



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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.

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ACRONYMS AND ABBREVIATIONS

AMPTO	Association of Marine Park Tourism Operators
APVMA	Australian Pesticides and Veterinary Medicines Authority
CCIP	Crown-of-thorns starfish Control Innovation Program
COTS	Crown-of-thorns starfish
CQ	Central Queensland
Cth	Commonwealth
DCCEEW	Department of Climate Change, Energy, the Environment and Water (Australian government)
DETSI	Queensland Department of Environment, Tourism, Science and Innovation
DPI	Queensland Department of Primary Industries (previously called Department of Agriculture and Fisheries or DAF)
EPBC	Environment Protection and Biodiversity Conservation
FNQ	Far North Queensland
FTE	Full Time Equivalent
GBR	Great Barrier Reef
GBRWHA	Great Barrier Reef World Heritage Area
MNES	Matters of National Environmental Significance
NQ	North Queensland
OGBR	Office of the Great Barrier Reef (Queensland government)
QBFP	Queensland Boating and Fisheries Patrol
QPWS	Queensland Parks and Wildlife Service
Reef Authority	Great Barrier Reef Marine Park Authority
RRAP	Reef Restoration and Adaptation Program
SCUBA	Self-Contained Underwater Breathing Apparatus
SLO	Social Licence to Operate
TO	Traditional Owner
TORR	Traditional Owner Rights and Responsibilities
TUMRA	Traditional Use of Marine Resource Agreements

EXECUTIVE SUMMARY

The overarching aim of the Crown-of-thorns starfish (COTS) Control Innovation Program (CCIP) R-08 project was to support the development and deployment of COTS management options perceived by the public and stakeholders as socially responsible and acceptable. Its objectives addressed existing public and stakeholder perceptions of COTS and COTS management, the distribution of social, economic and cultural opportunities and risks associated with COTS control, and the regulatory and policy implications of a limited number of novel control strategies including the use of semiochemical attractants.

Public, community and stakeholder perceptions

This project has established a comprehensive knowledge base of public, stakeholder and community perceptions of COTS and COTS management using a combination of in-depth interview and broadscale survey methodologies.

- **Strong, but nuanced, support for COTS management**

National survey results from 2018 and 2022 showed public support for culling using manual, or conventional, control methods, which was best explained by respondents' views concerning the importance of the Reef to themselves, the threat posed by COTS to the Great Barrier Reef (GBR), confidence in management, trust in scientific solutions, the manageability of risks, and the social, environmental, and ethical responsibility of culling. The perceived threat of climate change had no impact on acceptance of culling despite the contribution COTS control makes to reef climate resilience.

National survey results from 2024 demonstrated that public support for both conventional and semiochemical-based COTS control was high across all stages of research and development from the provision of research funding to lab research and small-scale trials, while support for large-scale outdoor use was medium to strong.

Support for large-scale use of conventional and semiochemical-based COTS control was particularly high among Aboriginal and Torres Strait Islander respondents, those with high self-assessed knowledge of the technology, those convinced of its environmental and economic feasibility, and men. Support was lower among those who voted for independent political candidates and minor parties, those who know COTS are native to the GBR, and respondents over 50 years of age.

Poor respondent knowledge of COTS and inconsistent relationships between knowledge and support suggest public communication and engagement about the rationale for innovation in COTS control will be critical to successful implementation.

- **Foundations of 'social license' in COTS management**

Analysis of 117 interviews with 140 community members living and/or working in close proximity to the GBR has suggested that social license for (or societal acceptance of) COTS

control is dependent on how people perceive its: (1) ethical responsibility; (2) knowledge and rationale; (3) management effectiveness; and (4) socioeconomic benefits.

Accounts from both Indigenous and non-Indigenous participants clearly illustrate a widespread expectation that the unique rights of Reef Traditional Owners be honoured. For this reason, four further themes precede other social licence considerations, including: (1) free, prior and informed consent; (2) Indigenous knowledge; (3) early engagement; and (4) project involvement.

The distribution of opportunities, benefits and risks

A small subset of community interviews – with people employed in COTS management – has yielded rich insights regarding the range of vocational opportunities afforded by participation in COTS management, including access to training and qualifications, enhanced practical and project management skills, and enriched social and professional networks.

Analysis of Cairns-based COTS control operations has estimated a total economic output in financial year 2023–2024 of AU\$20.2 million. The total employment impact was estimated at up to 61.3 full-time equivalent jobs. More research is required to understand whether these impacts extend across the three regions in which control operations are based and, more importantly, the contribution of COTS control activities to economic and vocational equity within regions.

Regulatory and policy implications

Novel COTS control methods add to the regulatory complexity within the GBR permission system and beyond. Semiochemicals and the restocking of natural COTS predators are classified as high risk under the Reef Authority's assessment guidelines, requiring tailored evaluation, proof of concept, and often small-scale pilot studies before any operational deployment. In addition to GBR-specific permissions, semiochemicals must also comply with the Agricultural and Veterinary Chemicals framework administered by the Australian Pesticides and Veterinary Medicines Authority (APVMA), which was developed for terrestrial contexts. This dual regulatory pathway may create uncertainty, potential delays, and additional data requirements. Addressing these challenges will require early planning, robust scientific evidence, and strong interagency collaboration between the Reef Authority, APVMA, and other regulators.

1. INTRODUCTION

Crown-of-thorns starfish (COTS) (*Acanthaster* spp.) are highly effective predators that feed on scleractinian corals (including *Acropora* and *Montipora* spp.) across the Indo-Pacific. Although these animals typically occur in low densities and have negligible impacts on coral cover, populations can periodically surge causing significant damage to coral reefs. On the Great Barrier Reef (GBR), COTS outbreaks are recognised by scientists and managers as one of the leading causes of coral decline (see for example De'Ath et al. 2012; Bozec et al. 2022; Matthews et al. 2024), and COTS management is included as a strategic action under the Reef 2050 Long-term Sustainability Plan (Commonwealth of Australia, 2023). Programs to manage COTS densities have grown increasingly sophisticated, with coordinated population monitoring and modelling to inform management decisions and dedicated control vessels with skilled teams of divers to maintain populations at levels unlikely to cause significant ecological damage (Pratchett and Cumming 2019; Matthews et al. 2024; Rogers et al. 2024).

Improvements notwithstanding, COTS control is a labour intensive and potentially dangerous activity reliant on divers to undertake in-water monitoring and manual culling using a lethal injection of bile salts or vinegar, the effectiveness of which is hampered by the cryptic behaviour of COTS and consequent low detection rates (Harris et al. 2023). Researchers associated with the COTS Control Innovation Program (CCIP) are thus exploring a range of strategies to improve COTS management through three key subprograms: Prediction, Detection, and Response (**Figure 1**). Of particular relevance to this report is investigation – through the Response Subprogram – of two novel biocontrol methods including the conservation or augmentation of marine species that predate on COTS and on the use of semiochemicals to influence COTS behaviour.

Multiple species are known to predate on COTS, particularly during the early larval and settlement phases of the COTS lifecycle (Pratchett et al. 2021). Understanding how predation influences the population dynamics of COTS is key to understanding whether and how it can be used in COTS management (Pratchett et al. 2021).

Semiochemicals are compounds released by organisms that provoke changes in the behaviour of receiving organisms (Harris et al. 2025). They include compounds that influence other members of the same species (pheromones) and compounds that influence other species (allelochemicals). More specifically, semiochemicals may alert others to food sources or danger, discourage predators, attract mates, coordinate reproduction, etc. These chemical vocabularies are used in a variety of ways by humans to enhance pest management (mostly in agriculture) by attracting target species to defined areas for trapping and removal, pushing target species away from an area, attracting predators of the target species, disrupting reproduction, and so on (Harris et al. 2025).

According to Høj et al. (2020), the conservation or augmentation of native COTS predators present low ecological risks, but potentially high political risk, as a result of widespread public interest in fisheries management and access to recreational fisheries. Subject to confirmatory

research, they argue, semiochemical use is likely to present both low ecological and low political risk (Høj et al. 2020).

It is reasonable to speculate that semiochemical use in COTS management is likely to be less controversial than other biocontrol options given the toxicological inactivity of semiochemicals and their widespread use in agriculture (Harris et al. 2025). It is equally reasonable to speculate that manual COTS control enjoys broad public support given the absence of overt conflict despite steady growth in the Control Program. Neither possibility, however, can be taken for granted. Just as the absence of conflict over existing control measures does not necessarily signify active support, neither would support for manual control necessarily signify support for novel biocontrol methods. All control methods require research and engagement to understand and build social acceptability (Høj et al. 2020).

While the impacts of COTS outbreaks and the importance of management are well known within GBR research, management and policy, the ways in which local communities, stakeholders and the broader public perceive COTS and their management is less well understood. Some research indicates that members the Australian public underestimate the risks posed by COTS in the GBR, especially in comparison to those posed by climate change (Marshall and Curnock 2019; Thiault et al. 2021), while studies limited to New South Wales residents have found high variance in views regarding the threat posed by COTS (Fabian et al. 2020). A deeper understanding of the different perceptions and aspirations that local GBR communities, stakeholders and the broader Australian public hold regarding COTS and COTS management is an important component in the design and delivery of COTS control technologies and innovations, helping to ensure they are socially responsible, acceptable and beneficial.

This project, CCIP-R-08 Stakeholder perceptions of COTS management, socio-economic risks, opportunities and co-benefits, aimed to:

- Collect baseline data on sociocultural perceptions of COTS as a native species, as well as its role as a significant pest in the GBR and beliefs about the need for COTS management, from a diverse range of GBR stakeholder groups.
- Explore attitudes toward possible control scenarios (e.g. enhanced surveillance and monitoring, the release of semiochemical attractants), with a focus on stakeholder perceptions of acceptability and risk. Investigate regulatory and policy implications of these scenarios (with a focus on semiochemicals).
- Investigate the distribution of social, cultural and economic outcomes arising from COTS management and, where possible, quantify economic and social outcomes arising from COTS management.

These aims complemented three concurrent projects within the CCIP Response Subprogram: CCIP-R-09 which sought to enhance Reef Traditional Owners' partnerships with COTS researchers and managers (Backhaus et al. 2025), CCIP-R-10 which explored the potential value of enhanced fish predation in COTS management (Ceccarelli et al. 2025), and CCIP-R-11 which explored the potential use of pheromone or semiochemical attractants to aid in the detection, surveillance and control of COTS outbreaks (Motti et al. 2024).

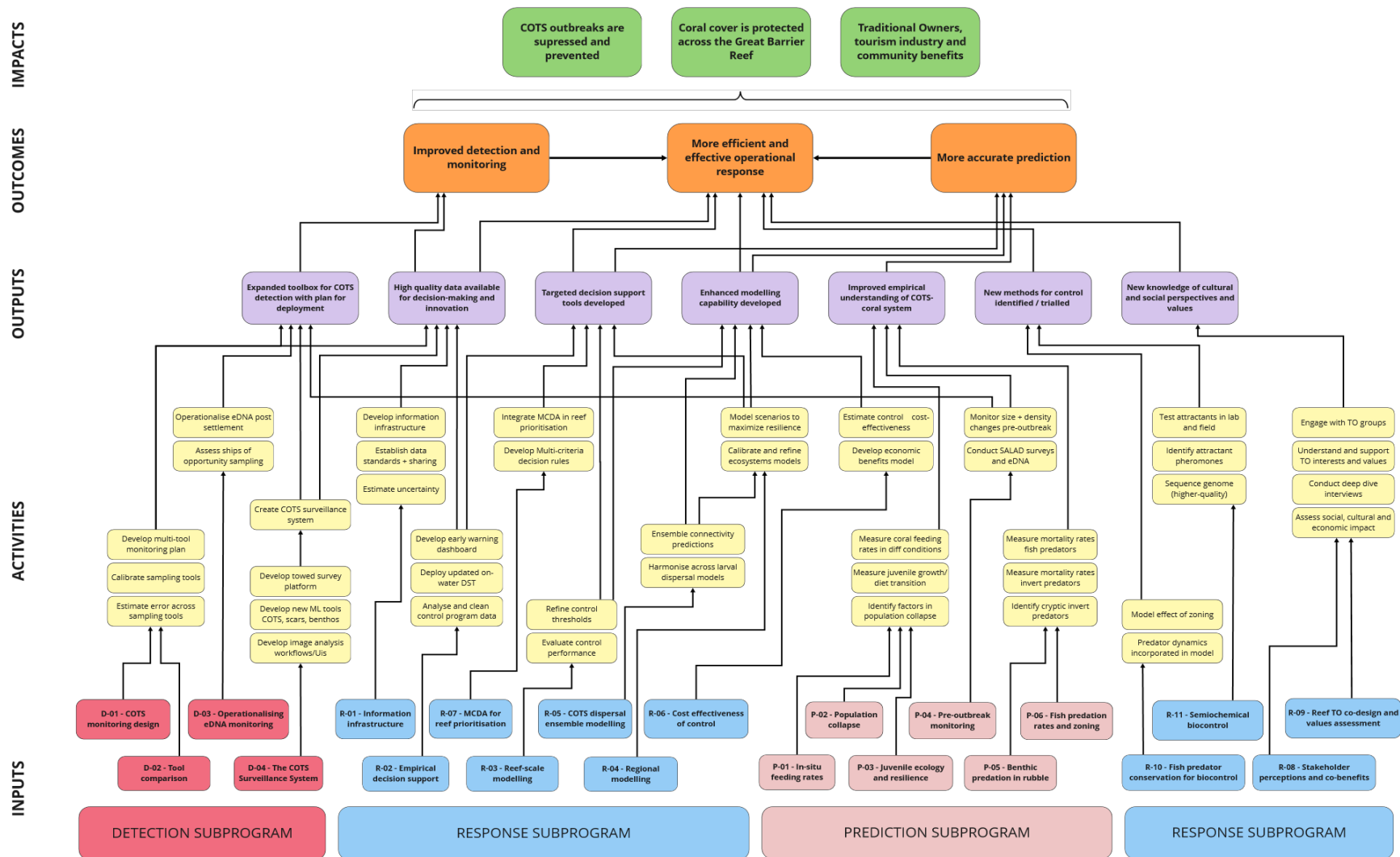


Figure 1. CCIP Program Logic including project CCIP-R-08 as part of the Response Subprogram.

2. METHODS

Research reported here was undertaken through four major activities described below. It is important to note that implementation of these activities leveraged research already under way through the Reef Restoration and Adaptation Program (RRAP).

Funded through the Reef Trust partnership, RRAP is a multi-institutional research and development program focused on development of socially acceptable, ecologically sound, and technically feasible measures to help the GBR and other coral reefs survive, recover and adapt to the impacts of climate change. As one of the largest, most comprehensive programs of its type, RRAP involves a wide range of experts and a diverse set of research activities. CCIP-R-08 has drawn on qualitative and quantitative social data collected through the RRAP Social Licence and Impact Monitoring project (within the Stakeholder and Traditional Owner Engagement Subprogram), and desktop regulatory reviews and consultations have been conducted through RRAP's Regulatory Subprogram (Fidelman et al. 2019).

2.1 RRAP National Survey

Data were collected through three large-scale national surveys conducted in 2018, 2022, and 2024, with a combined sample of n=12,635 Australian adults. Respondents were drawn from two key sampling frames: a national sample, representative of the broader Australian population, and a 50GBR sample, comprising individuals residing within 50 km of the GBR coastline. In each survey wave, data were gathered via online surveys administered by a market research company using online panels. Quota sampling ensured representativeness, with national quotas calibrated against Australian census data (incorporating gender, age, and geographic distribution across urban and rural areas), while the resident sample was guided by soft quotas aligned with Queensland's demographic composition.

Each survey was designed to capture a broad range of demographic indicators – including age, education, employment status, and Aboriginal and Torres Strait Islander identity – alongside public attitudes toward an expanding portfolio of reef intervention technologies including manual COTS control and (in 2024 only) semiochemical enhanced COTS control. A semi-experimental format was used in which each participant was presented with a detailed, plain-English description of one intervention strategy, outlining its purpose, mechanisms, and potential implications before being asked a series of questions about their support for the strategy and perceived risks and benefits.

The 2018 survey provided the following introduction:

One approach is controlling coral predators and pests through pest control. This includes controlling Crown of Thorns starfish populations which destroy coral when there are too many of them. Methods can include manual removal by divers with tools such as metal spears. Pest control is most effective when used in conjunction with other reef restoration approaches. Potential benefits include the repair of high value reefs. Potential risks could include damage to coral when the

pest is being removed. This method requires significant human labour and is already being deployed in many areas, including at important tourism sites.

The introduction was updated for the 2022 and 2024 surveys to better reflect current practice:

One approach is manual control of coral predators and pests such as the Crown of Thorns starfish. This involves divers killing Crown of Thorns starfish by injecting them with vinegar or saline water. Pest control is most effective when used in conjunction with other reef restoration approaches. Potential benefits include reduced damage to high value reefs. Potential risks could include damage to coral during control operations. This method requires significant human labour and is already being deployed in many areas, including at important tourism sites.

The slight differences in the description of the manual COTS control technology should be considered when evaluating results. COTS control using semiochemicals was added to the 2024 survey using the following description:

One approach is the use of non-toxic biological compounds (such as pheromones) in the management of coral predators such as the crown-of-thorns starfish (COTS). These compounds are naturally produced by coral predators to communicate with each other. The compounds could be made into baits and deployed by qualified teams of divers to influence coral predator behaviour. For example, they could help to attract COTS to sites for more efficient control or disrupt their mating/reproduction. Potential risks may include unforeseen effects on closely related marine species. Potential benefits include more effective predator management and coral protection.

Detailed information on survey variables and analytical techniques are provided in Appendix A. Results presented in this report are drawn primarily from the 2024 survey in order to reflect the incorporation of semiochemical-based control methods.

2.2 RRAP Regional Deep Dive

Between mid-2021 and early 2023, 117 interviews involving 140 participants were conducted as part of a larger investigation of how community members living and working in proximity to the GBR perceived its likely and potential future along with their perceptions of existing and novel strategies for helping the Reef resist, recover from, and adapt to climate change. Participants were recruited through a combination of purposive and snowball (referral) sampling. With few exceptions, interviews were conducted face-to-face at a location suggested by the participant. Researchers followed an interview protocol with a series of flexible, open-ended questions designed to elicit candid discussion of participants' lives and their connections with the Reef, their visions for its future, and their responses to the prospect of novel management strategies. Interviews were audio-recorded and transcribed verbatim.

The RRAP Regional Deep Dive interviews were conducted in two phases to allow researchers to review and adapt the interview protocol. The qualitative insights contained in this report are based on participants' accounts of COTS and COTS management across both these phases.

Of the 70 interviews conducted in the first phase of the Regional Deep Dive, 47 were conducted prior to the commencement of CCIP and contained no specific questions relating to COTS. However, 25 of these interviews contained spontaneous references to COTS and COTS management. Upon commencement of CCIP, deliberate prompts were used in the following 23 interviews to elicit views on COTS and COTS management in respect to the future of the Reef and the effectiveness of existing management.

In the second phase of the Regional Deep Dive, 47 interviews were conducted. These contained additional questions designed with input from CCIP researchers and program leaders. As well as being asked about their experiences and perceptions of COTS and COTS management and what role they thought it had in terms of the Reef's future, participants were invited to express their initial views on two prospective management strategies being explored under the CCIP Response subprogram: the use of semiochemicals and predator control strategies. Researchers used the following script to guide discussion, offering each participant a description of one or both technologies (dependent on time and other considerations):

"There are a number of new methods and technologies being explored to manage COTS on the Reef. These include:

- *The possible use of pheromone/scents to attract COTS to certain areas and aid detection and manual removal, or to repel them from high value areas*
- *Possible strategies to protect populations of animals that predate on juvenile COTS (such as Reef fish and invertebrates) or strategies to augment populations of predators*

When I talk about these sorts of interventions on the Reef, what thoughts come to mind?"

This qualitative phase of research complemented the RRAP National Survey, enabling development of a richer understanding of the ways GBR communities, stakeholders and Traditional Owners relate to and understand COTS and COTS management, and evaluate the acceptability of novel strategies and technologies (such as predator control and semiochemical use) being explored under CCIP. It also facilitated development of an inductive model of social licence and a preliminary, but nuanced, understanding of the social and vocational opportunities and outcomes created through COTS management.

2.3 Economic impact assessment

An input-output (I-O) model was used to quantify the economic impacts of COTS Control Program activities. The I-O approach, originally developed by Wassily Leontief (1936), captures the inter-industry relationships and ripple effects of project-induced spending through direct, indirect, and induced economic activities. This framework has been widely used in regional economic impact assessments (Miller & Blair 2009), and has been previously applied in environmental restoration projects (Spörri et al. 2007; Gao et al. 2024). The analysis was conducted for the Cairns Region in Far North Queensland, defined according to the local government area boundaries of the Cairns Regional Council. The timeframe considered was the financial year 2023–2024.

Regional input-output tables for May 2025 were obtained from the Australian Bureau of Statistics through REMPLAN software (REMPAN 2006). Detailed expenditure data related to COTS control, including labour, maintenance, operations, and others, were provided by the regional COTS Control operations company in Cairns.

Economic multipliers (output, employment, income) were derived from the regional I-O model to estimate broader economic effects. The analysis estimated changes in total output, employment, labour income, and value-added across the local economy. The model assumes fixed production coefficients and no supply constraints. All industries respond proportionally to demand changes without price effects. Induced effects were calculated using regional household income and consumption patterns. We assume a full-time equivalent (FTE) job entails of 35 hours of work per week.

2.4 Regulatory assessment

This component of the project consisted of a desktop review of relevant legislation and policy documents and consultation with relevant regulators, including the Reef Authority and the Australian Pesticides and Veterinary Medicines Authority (APVMA). The documents for the review were sourced from databases, such as the Queensland Legislation website and the Federal Register of Legislation, as well as websites of government agencies like the Reef Authority and APVMA. Scoping regulatory implications of novel COTS control methods, namely semiochemicals, was based on the envisioned use of semiochemicals in the context of existing policy and regulatory frameworks. It provided insights into potential permission requirements should semiochemicals become available as a control method. In addition to the document review, the scoping exercise included an online workshop with GBR regulators, including the Reef Authority, Queensland Department of Environment, Tourism, Science and Innovation (DETSI) and APVMA, which is responsible for regulating semiochemicals in Australia.

3. RESULTS

3.1 Baseline perceptions of COTS and COTS management

3.1.1 Support for large-scale deployment of COTS control across the GBR

As **Figure 2** shows, data from the 2024 RRAP National Survey demonstrate strong public support for research funding, indoor lab research, and small-scale outdoor trials of both conventional and semiochemical-based control methods. Support for scaled deployment of conventional and semiochemical-based control was lower but still moderately strong with 67% and 59% of respondents respectively offering some level of agreement.

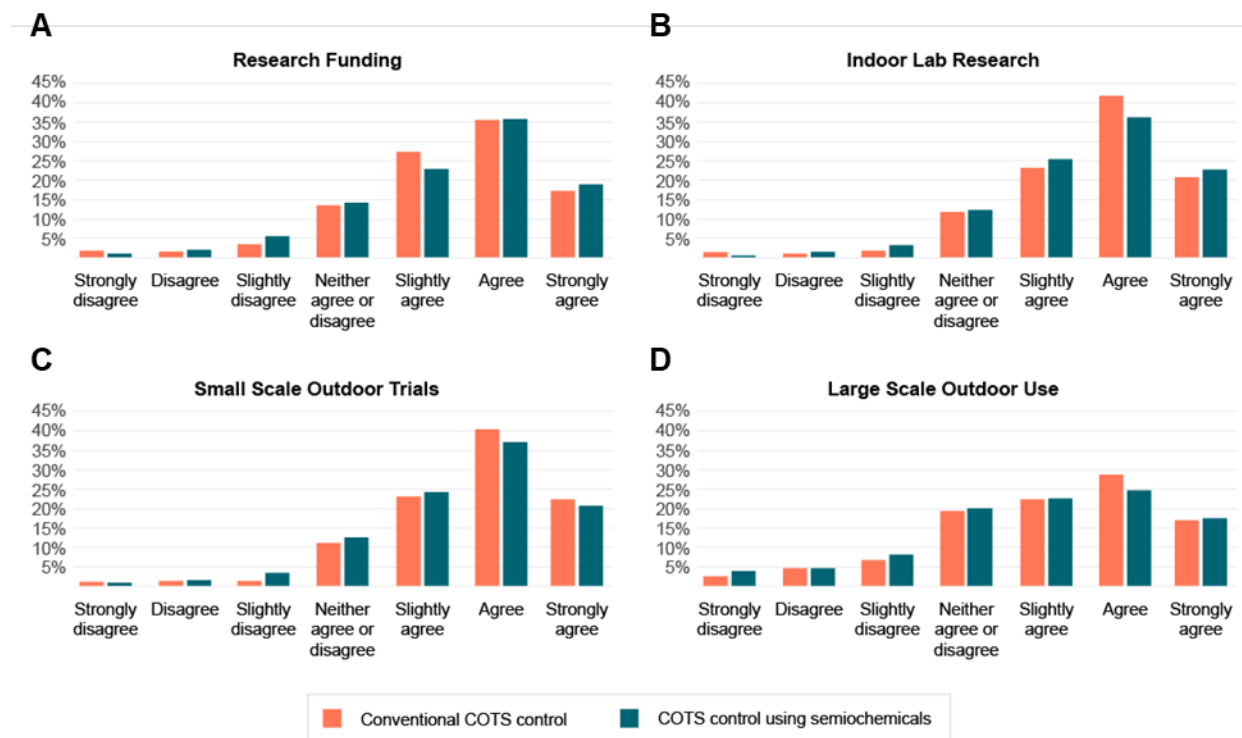


Figure 2. Support for manual and semiochemical-based COTS control including support for (A) research funding, (B) indoor lab research, (C) small scale outdoor trials in selected parts of the GBR, and (D) large-scale outdoor use across the GBR. Level of agreement measured on a 7-point Likert scale from: (1) strongly disagree; (2) disagree; (3) slightly disagree; (4) neither agree or disagree; (5) slightly agree; (6) agree; to (7) strongly agree. Survey results are based on independent samples with respectively 538 (conventional) and 523 (semiochemicals) Australian residents.

Importantly, there were no statistically significant differences in support for conventional and semiochemical-based control methods at any of the four stages of development. Neither was there any statistically significant variance in support for conventional COTS control across the three survey rounds from 2018 to 2024.

3.1.2 Perceived benefits and risks

As shown in **Figure 3**, COTS control using either conventional or semiochemical approaches was generally believed more likely to result in benefits than to cause harm. This was true in relation to the perceived feasibility (mean values of 4.71 for conventional and 4.64 for semiochemical, $p = 0.376$) and social impacts (mean values of 4.71 for conventional and 4.60 for semiochemical, $p = 0.208$) COTS control. Respondents did, however, perceive COTS control using semiochemicals to be slightly less ethical and safe than conventional COTS control (mean values of 4.84 for conventional and 4.55 for semiochemicals, $p = 0.001$).

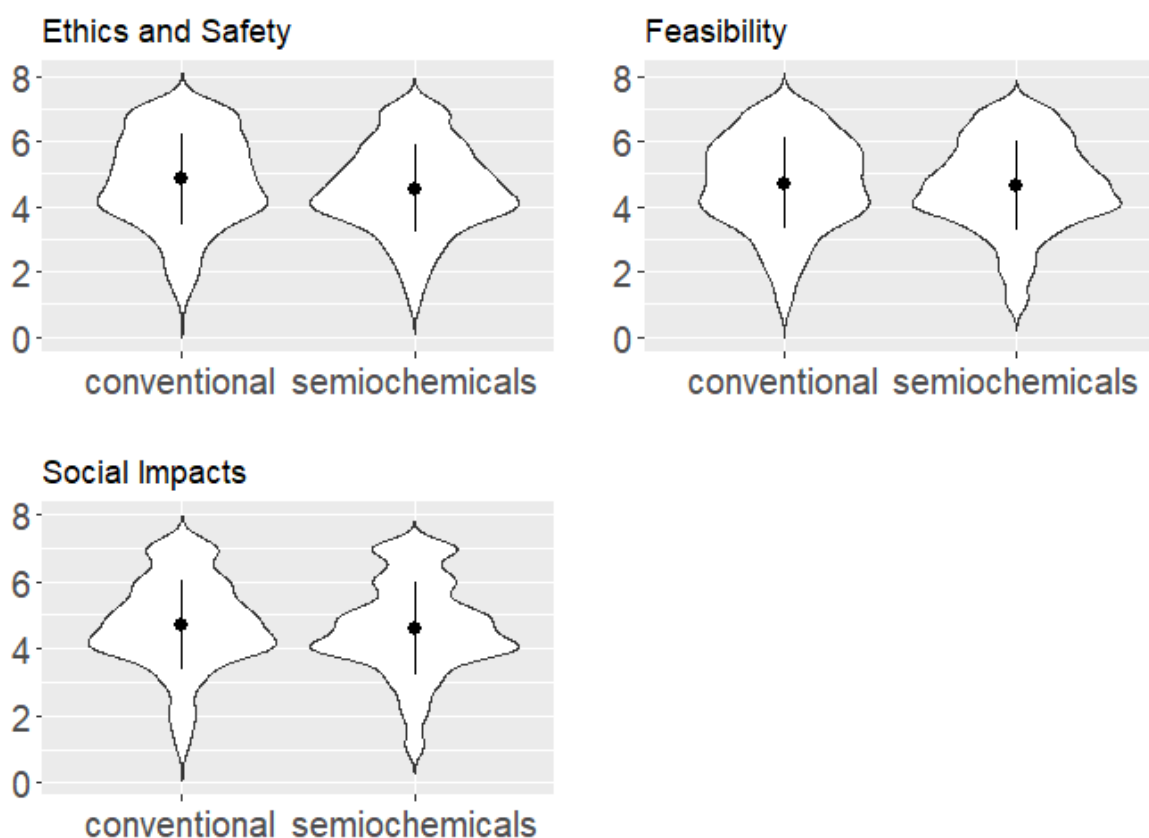


Figure 3. Differences in distribution and average perceived risks and benefits of conventional and semiochemical COTS control. Figure shows distribution of risk/benefit levels according to density curves, with the round dot showing the mean value and the vertical line showing the mean value plus or minus one standard deviation (i.e. the agreement level for approximately 68% of survey respondents).

3.1.3 Knowledge about the native status of COTS on the GBR

The 2024 survey introduced a question asking whether the statement, 'crown-of-thorns starfish are an introduced species now invasive on the Great Barrier Reef', was true or false. Some 82% of the total survey sample of 4,201 answered incorrectly that this statement is

true. Analysis shows that the odds of older and more educated respondents answering correctly were 49% (OR 95% CI 39–57%) and 18% (OR 95% CI 3–30%) respectively lower than younger and less educated respondents. The odds of male respondents answering correctly were 25% (OR 95% CI 6–46%) higher than female respondents. GBR residents were not significantly more likely to provide the correct answer than non-residents about the invasive status of COTS (Mean OR: 1.02, 95% CI 0.85–1.22%).

3.1.4 Predicting support for scaled deployment

Analysis of data from the 2018 and 2022 surveys showed that support for manual COTS control was best explained by six factors including the personal importance of the GBR, the perceived threat to the GBR from COTS, confidence in GBR management, trust in scientific solutions, the manageability of culling risks, and the perceived responsibility of culling (socially, environmentally, and ethically) (see Lockie et al. 2024).

Analysis of data from the 2024 survey, which was inclusive of both manual/conventional and semiochemical-enhanced control methods, showed that the perceived *feasibility* of control methods and the self-rated *understanding* of the respondent were the only variables with a positive influence on both conventional and semiochemical control methods (**Figure 4**). Perceived feasibility increased the odds of supporting conventional and semiochemical control by 52% (OR 95% CI 14–103%) and 68% (OR 95% CI 21–133%) respectively. Self-rated understanding meanwhile increased these odds by 63% (OR 95% CI 38–94%) and 69% (OR 95% CI 42–102%).

Age, conversely, was the only variable with a negative influence on support for both conventional and semiochemical control methods, with those over 50 years of age some 35% (OR 95% CI 9–54%) and 33% (OR 95% CI 5–53%) less likely than younger respondents to express support.

The only other variable associated with support for the scaled deployment of conventional COTS control was the perception of positive social impacts, increasing the odds of support by 40% (OR 95% CI 7–84%).

Support for the scaled deployment of semiochemical-based control was particularly high among Aboriginal and/or Torres Strait Islander respondents, who were 119% (OR 95% CI 26–284%) more likely to express support than non-Indigenous respondents. Men also were 44% (OR 95% CI 5–99%) more likely to express support than were women.

However, respondents who answered correctly that COTS are *not* an introduced species on the GBR were 44% (OR 95% CI 16–62%) less likely to support scaled deployment of semiochemical-based control. The implications of this finding for management and communications deserve careful consideration.

Respondents affiliated with Independents and other political parties were 56% (OR 95% CI 25–75%) and 61% (OR 95% CI 34–77%) respectively less likely to support semiochemical control than were respondents affiliated with the Labor party.

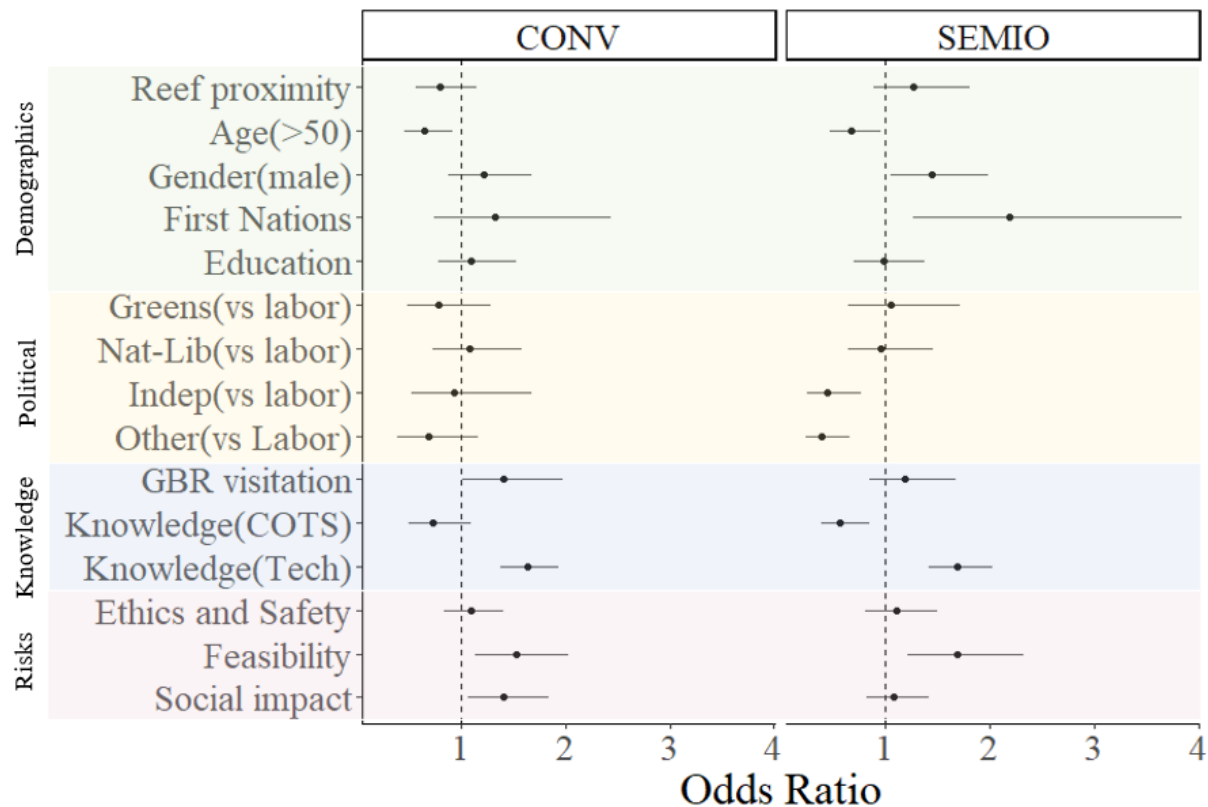


Figure 4. Regression statistics (odds ratios at 95% confidence intervals) for ordinal logistic regression model outcomes associated with support for large-scale outdoor deployment of conventional COTS control (CONV, n = 538) and COTS control using semiochemicals (SEMIO, n = 523) across the GBR. Outcomes are on a 7-point Likert scale (**Figure 1**). Significant predictors are those that do not cross the dotted '1' line. Non-binary predictors (all predictors below Knowledge COTS) were standardised using z-scores. Effect sizes shown in this Figure and discussed in the text can be de-standardised by multiplying with the standard deviation of the respective indicator.

Among these findings, one of the most compelling and concerning ones has been the widespread public misconception that COTS are an introduced species. This finding—affecting nearly 90% of survey respondents—sparked a sense of urgency among stakeholders, scientists and management, who were surprised that such a fundamental misunderstanding persists despite ongoing communication efforts. Several highlighted the need for renewed and creative messaging strategies, pointing to the challenge of conveying that COTS are both native and, under certain conditions, ecologically harmful. The limitations of binary language such as 'invasive' versus 'native' were noted as a key barrier to effective public understanding.

This concern was deepened by reflections on the basic visibility and accessibility of information. One participant noted that common online searches for 'crown-of-thorns' often fail to yield relevant ecological results, reinforcing the view that public awareness of the species remains limited. These insights connected directly to another key finding: many

respondents overestimated their knowledge of COTS, despite scoring poorly on factual questions. The gap between perceived and actual knowledge, particularly among certain demographic groups, was seen as a structural challenge for education and outreach.

The broader pattern of ‘conditional support’ for both COTS control and other reef interventions also sparked interest among various stakeholders. Survey data showing high levels of cautious approval—but lower enthusiasm for large-scale deployment—was interpreted as a sign of public prudence rather than resistance. This emphasis on careful, measured support suggests a public that is willing to endorse management actions, but only when they are perceived as safe, transparent, and scientifically justified.

3.2 Perceptions of COTS management: building on the baseline

Many of the baseline insights gained through the Regional Deep Dive related to the myriad ways people interact with the GBR, how they perceive COTS, and their perspectives on COTS management. This section presents a synthesis of themes as community members talked about and considered COTS management and Reef management more broadly. It then explores participants’ initial responses to two prospective COTS management strategies being explored under CCIP: predator control and the use of semiochemicals.

It is important to note when reading this section that Regional Deep Dive participants had varying levels of expertise and experience in COTS management and novel technologies. Their judgements on it were personal and subjective, formed using vernacular knowledge such as taken for granted heuristics (or ‘rules of thumb’), their own firsthand observation of COTS and the Reef, and tangential experiences with other organisations and other forms of Reef management. The views presented here should not be read as a statistically representative evaluation of broader levels of understanding and support for the COTS Control Program or CCIP technologies. The material presented here is intended to explore some of the things Regional Deep Dive participants weighed up as they talked about COTS management on the Reef, and the prospect of novel approaches.

3.2.1 Considering COTS management: Common themes

Dialogue across Regional Deep Dive interviews highlighted how participants consider a complex range of factors as they discuss their views on different forms of Reef management. In the case of COTS management, these considerations can be loosely grouped into those concerned with its pragmatic or practical aspects, and those concerned with its broader ethical implications.

Practical consideration 1. Does it materially help the Reef?

While accounts from the Regional Deep Dive highlighted complex and nuanced community perceptions of COTS, they also showed that COTS were frequently defined as problematic due to their predation on coral and the propensity of populations to periodically surge into ‘outbreaks’. COTS were regularly described alongside climate change, cyclones, and other human pressures as a threat to the Reef’s ongoing ecological health. Accordingly, discussion

of existing COTS management often centred on its effectiveness as a practical strategy for protecting coral and enhancing the Reef's ecological state.

Following the introduction of more specific questions about novel COTS control options in the second phase of Deep Dive interviews, 18 participants reiterated this theme. Some accounts framed COTS management as an effective way of addressing the problems created by COTS and protecting coral and coral reefs and included:

- firsthand accounts of visible effects of COTS and COTS management on coral and reefs;
- descriptions of COTS management as making a positive difference to the Reef; and
- accounts in which COTS management is described as a local practice that is, or could be, readily engaged in by Reef communities.

Some discussion involved uncertainty about whether COTS management effectively helped coral and the Reef, such as:

- concerns it might yield more benefits to tourism and regional livelihoods than to coral ecologies;
- fears COTS management might inadvertently interfere with the Reef's intrinsic ecological resilience and its natural capacity to recover from and adapt to change;
- questions about whether COTS management makes a meaningful impact within a context of complex and escalating ecological threats to the Reef; and,
- scepticism over whether COTS management is implemented at a scale or precision necessary to offer adequate levels of protection to the Reef.

Practical consideration 2. Does it benefit the community?

In the second phase, 17 interviews included accounts of COTS management and its impact on communities. These included discussion of:

- practical benefits to tourism, coral fisheries and other Reef-related industries;
- opportunities for regional marine-based employment and training; and
- opportunities for local community groups to enhance their connections to the Reef through practical Reef management and stewardship.

COTS management also evoked concerns and uncertainties, however, regarding:

- the resources (e.g. boats, equipment) required to participate in COTS management; and
- whether communities have equitable access to the opportunities and benefits yielded by COTS management.

Practical consideration 3. Is it sensible and well-informed?

The rationale and knowledge behind COTS management was a consideration observed in 16 second phase interviews. Positive accounts reflected a general satisfaction that COTS management:

- is undertaken in ways that seem logical or ‘make sense’ to participants;
- that it is based upon robust research and knowledge of COTS; and
- will solve the problem and not cause additional harm.

Accounts reflecting lower levels of confidence included:

- fears that a lack of knowledge about COTS outbreaks and the impacts of management will lead to perverse ecological outcomes as well as misguided and ineffective management decisions;
- observations that the scientific theories regarding COTS outbreaks (e.g. agricultural runoff, predator removal) have shifted;
- concerns that decisions regarding COTS management are unduly influenced by particular interests (e.g. economic interests);
- uncertainty that the resources used to manage COTS might be excessive compared to the ecological benefits gained;
- frustration that scientists do not consult with and draw on the knowledge of local communities regarding COTS and COTS management; and confusion about why COTS are managed on some reefs and not others.

Ethical consideration 1. Is it morally sound and socially fair?

The morality and fairness of COTS management was also a common consideration observed in 15 of the second phase interviews. Discussion included:

- whether it is right to harm species endemic to coral reefs with an ecological purpose and a right to ‘belong’;
- whether the benefits of COTS management to other species, the Reef, and humans justify the harm done to COTS;
- whether humans have a moral obligation to manage COTS; and
- whether humans should interfere in natural cycles and processes.

Ethical consideration 2. Does it help address systemic environmental problems?

While participants did not expect COTS management to solve all problems, its relation to broader social and political problems was a consideration and closely related to questions regarding its morality and fairness. This theme was observed in 15 second phase interviews, and included positive and negative accounts of the role COTS management plays in:

- building public awareness of and willingness to help the Reef;
- building (or distracting from) an ethic of human responsibility for the Reef;
- enhancing community stewardship of the Reef; and
- creating (or limiting) the broader change necessary to address the systemic social and political issues that create environmental problems.

3.2.2 Responses to novel COTS management strategies

As Regional Deep Dive participants discussed the Reef, its future and its management, researchers also sought their views on two novel COTS control strategies being explored under CCIP, specifically using predators to control COTS and semiochemical control.

Note that the key objective of the Regional Deep Dive was to engage Reef communities in candid and open discussion. While researchers made every effort to provoke discussion regarding novel management strategies being explored under CCIP, discussions were kept flexible to allow participants to raise topics and interests of importance to them. Of the 47 interviews conducted in the second phase of the Deep Dive, the issue of novel strategies to manage COTS was discussed in 27. Of these:

- 4 contained specific accounts of both predator control and semiochemical strategies;
- 12 contained accounts of predator control only;
- 16 contained accounts about semiochemical strategies only.

Discussion of semiochemical controls centred on three considerations: their sense and logic, their ecological outcomes, and their community impacts. Discussion of predator controls centred on sense and logic, ecological outcomes, and ethical and moral aspects.

Semiochemicals 1. Sense and logic

A sensible and logical rationale was central in discussions about the prospect of semiochemicals as a potential COTS management strategy, observed in 15 of the 20 interviews that discussed this novel approach. Discussion of this centred on three things about semiochemical-based control: its practicality, its benefits to the efficiency of manual control methods, and the robustness of the knowledge base underpinning it.

Practicality: given that the use of semiochemicals in COTS management is only in its developmental stages, the majority of participants who talked about them had limited understanding and experience of their actual applications. To grapple with this question, some drew on their experience of pheromones in more familiar settings, such as agricultural and urban pest management, to form nascent positive positions on semiochemical attractants as practical measures in COTS management. Others expressed difficulty making sense of the practical aspects of semiochemicals. As they draw on their experience and knowledge, the coral collector below expresses doubts and confusion regarding how semiochemicals might be effectively used in the marine environment:

And the main difficulty is just the practical application. How can they do it when you have so much water? Even on the weather we've got now with 20 knots south-east, it's just water movement. How do you actually utilise it in a practical manner? Commercial fisher, CQ, November 2022

Efficiency: despite difficulty imagining their practical implementation, participants could easily recognise the potential benefits of semiochemicals. As discussed in Section 3.2.1 above, the resources required to manually control COTS was a common concern observed across both phases of the Regional Deep Dive, and participants were particularly optimistic about the possibility that semiochemicals could reduce the time and labour required to manually remove COTS. This potential was discussed in 11 of the 20 accounts of semiochemicals in the second phase interviews:

Oh, I think it's a great idea. I mean, if you're going to attract them to a certain area and then deal with them, then I guess it makes your job a bit easier. Commercial fisher, FNQ, September 2022

As the quote above suggests, greater management efficiency was predominantly associated with using semiochemicals as attractants. This was typically considered to provide more control over outcomes, and could be combined with other technologies, such as robot and drone technology.

Knowledge-base: the robustness of the knowledge underpinning decisions to use semiochemicals in COTS management was also a consideration in participant accounts. For example, participants discussed the importance of robust risk assessments and scientific testing to avoid unforeseen errors:

So if something goes wrong, how do you remove all that intervention you did without leaving a trace of an impact? You know, look, we've done it with other species as well.....as long as it's robustly tested, I suppose, before [it had] deployment out into the natural world...which is probably [what] would I caution. Reef and catchment manager, CQ, February 2023

Participants emphasised the importance of drawing other forms of knowledge into decision-making around semiochemicals. In the quote below a coral collector discusses the wealth of knowledge they and other commercial fishers have of COTS, and how using this could improve management:

[it] could be very difficult and take a very long time, if you found a way to attract COTS to a certain area, for them to actually migrate there. Whereas if you spoke to somebody like myself, I'd be able to say "oh yeah, well I was just up at this reef the other week and there was dozens of them". You know? "You probably want to go try there. I can give you GPS coordinates if you like" You know [it would be] a lot quicker, a lot easier, [and you] wouldn't have to spend years of research trying to work out other techniques. Commercial fisher, FNQ, September 2022

Semiochemicals 2. Ecological outcomes

The practical ecological outcomes of semiochemicals were a consideration evident in 15 of 20 interviews in which this method was discussed. The main ecological benefits recognised in semiochemical technologies lay in their use as attractants, which (as already discussed) were imagined would streamline the manual removal of COTS and enable better outcomes for coral and reefs. Aside from this, accounts primarily centred on the potential for semiochemicals to have negative ecological outcomes. Concerns regarding this were present in eight interviews. In the account below a catchment manager describes the material aspects of chemicals and their ability to endure in environments and create unintended effects. They express misgivings about the use of semiochemicals and their preference for manual removal for this reason:

I feel more comfortable with something like a COTS bot [to manually remove COTS] than a pheromones bot the amount of toxicants and chemicals they detect in basically every single wetland in our region now from hormone controls and caffeine and things that people just consume and goes out to the natural environment, it has impact. Reef and catchment manager, CQ, February 2023

While there was some acknowledgement that using semiochemicals to deter COTS might help high value reefs, it was more frequently imagined to risk unforeseen ecological consequences including the potential for negative impacts on other marine life:

Those pheromones don't only affect corals. They also affect the other species of sea stars. And it could be affecting other species that they may not realise. So it actually could be – not scaring off the sea stars, but it might be doing the same with sea cucumbers or it might even do the same with fish species. And last thing you need is to scare off something like a grazing herbivore from that site because grazing herbivore is what keep the algae down for the coral [to] keep coming back. It is like taking away the maintenance crew just to get rid of a predator, yeah. Traditional Owner, FNQ, October 2022

Semiochemicals 3. Community impacts

Consideration of the community impacts of using semiochemicals in COTS management was evident in six interviews. However, five of these involved COTS managers discussing the impacts that semiochemical methods might have in a vocational context. The majority of these COTS managers did not imagine negative impacts to them from the potential introduction of semiochemicals. Instead, they highlighted the potential benefits it would have to the efficiency of manual removal, their enjoyment of their work, and their sense of efficacy as a reef manager.

Predator control 1. Sense and logic

Consideration of the rationale underlying predator control and whether it ‘made sense’ to participants was evident in 9 of the 16 Regional Deep Dive accounts containing discussion of this prospective COTS management strategy.

Overall, participants understood the connections between predators and COTS populations and generally agreed that strategies to boost populations of COTS predators seemed logical and reasonable. Many referred to instances in which they had witnessed the impacts of predator removal – including the impacts of overfishing on reef ecologies, imbalances between predators and coral in aquaculture, and the removal of predators on agricultural pests. The idea of targeting particular COTS predators was also generally considered sensible, and participants often mentioned the predators that they were most aware of – the triton and various predatory fish.

So your Māori wrasse, they'll eat them. Your Spangled Emperor, your Red Great Emperor.....the [practice I saw] was injecting with cow bile, which was like dissolving them on the inside out. It's a natural acid, but it can be diluted safely and stuff in the water. But then the Red Great Emperor and the Spangled Emperor, the wrasse were coming in; once they'd started to break down, they were cleaning them up pretty quick. Recreational fisher, NQ, October 2022

While the idea of using predators to manage COTS made sense to participants, uncertainty was expressed regarding the use of restocking to build populations of COTS predators. Several practical issues were raised, including how predator restocking could be deployed in ways that would target populations of juvenile COTS, how it would address the damage done by adult COTS, and the logistics of breeding, rearing and dispersing predator brood stock in sufficient numbers:

How many fish do you need to introduce to make a difference? How many crabs ...? I mean, it's unthinkable. We couldn't even do it at aquaculture levels. If we took all the aquaculture effort and transferred it into raising [COTS predators] or something like that ... it just wouldn't make enough difference. Science community, NQ, March 2023

Misgivings were also expressed regarding predator control through enhanced protection, with participants referring to problems observed in current fisheries management in the Reef – including community resistance to zoning and non-compliance with regulations:

Rezoning, obviously, would hopefully protect more reefs, and then they can rejuvenate themselves and get more sea life ... [but] you're going to upset quite a few people if you make the whole thing a Green Zone, so I'm not for making the whole thing Green, I'm just like, look, let's make a few more so reefs can help each other out. Reef and catchment manager, CQ, March 2023

And also the biggest thing is compliance. Compliance has been lacking in this area for a long time ... Not enough enforcement, not enough checking. Tourism operator, NQ, October 2022

Predator control 2. Ecological outcomes

Consideration of whether predator control would provide practical outcomes and help Reef ecologies was present in 8 of the 16 Regional Deep Dive accounts containing discussion of this prospective COTS management strategy. Predator control generally was described as a positive step to address the problem of human impacts and resource extraction in the Reef:

So I think my pick straight up would be let's control the fisheries around the predators because I think we've targeted species that are easy to target that used to eat all the COTS or used to eat a lot of the COTS ... I really like the idea of trying to get species back and get this biodiversity back where it should be. Local government, NQ, December 2022

Restocking was also seen as a potential means of addressing anthropogenic impacts on Reef ecologies with parallels drawn with land-based environmental restoration (Other government, CQ, October 2022):

If boosting those fish stocks to reduce the COTS numbers, then in turn brings the coral back and then brings other species back in.....if we have a goal to try and restore that balance, I think that's a good goal to work towards. Reef and catchment manager, CQ, February 2022

Concerns regarding restocking centred on its potential to have perverse ecological outcomes. In the quotes below, participants raise concerns regarding the impact of introduced predators on other species, and regarding the well-being of the stock introduced into reef ecologies.

And, again, what else are they going to eat? Are, they going to eat other things? They're going to influence other populations not just crown-of-thorns. Science community, NQ, March 2023

Predator control 3. Ethical and moral considerations

Participants discussed the ethical and moral considerations of predator control in seven of the 16 Regional Deep Dive accounts containing discussion of this prospective COTS management strategy. In the quote below, a participant discusses the enhanced protection of COTS predators as a positive step in making humans more responsible and accountable for the COTS problem:

By overfishing the predators of the crown-of-thorn, it comes back to the human again.... It all comes back to humans really, doesn't it? Other community, CQ, December 2022

In the quote below, a participant describes predator restocking as a troubling example of human interference and control:

Restocking, as in breed them and release them? I don't know how that... I'm like, wow, there's just so much interfering. Like, why don't we just let nature kind of do its thing? We just need to back off a little bit and let it just rejuvenate itself, because the reef is so resilient. We've seen firsthand how resilient the reef can be, and how it can come back so strongly from bleaching events, and how it can come back and literally rejuvenate itself. If we're sick and injured, we heal ourselves, it's just what we do.... Reef and catchment manager, CQ, March 2023

These findings on community perceptions and values prompted deep engagement among stakeholders, scientists and management. The majority welcomed the insight that support for COTS management is shaped not only by knowledge and risk perception, but also by ethical considerations, cultural relationships to sea Country, and visions of systemic change. Rather than holding fixed views, community members were found to navigate tensions between care, pragmatism, and responsibility. This complexity was seen as essential to acknowledge and integrate into future planning—underscoring the need for ongoing dialogue, rather than one-off engagement, in the pursuit of social license.

3.2.3 Social licence to operate

The concept of social licence to operate (SLO) refers to initial and ongoing acceptance of projects, programs, or policies by society and local communities (Moffat et al. 2016). The concept was first popularised in the mining industry where operators recognised the potential to reduce delays and cost blowouts arising from conflict over anticipated social and environmental impacts (Costanza 2016; Moffat et al. 2016). In this context, factors consistently associated with social licence include economic benefits, provision of social infrastructure, quality and quantity of contact between mining workers and community, consultation, distributional and procedural fairness, trust in governance, opportunities to participate in decision-making, well-defined and enforced property rights, interested media coverage, and the absence of public protest (Moffat & Zhang 2014; Dumbrell et al. 2021).

It is important to remember that support for a program or project can change over time and so it is equally important to consider how social licence can be maintained. This is likely to reflect not only the material outcomes of project decisions but the quality and inclusiveness of decision-making, the equity of outcomes, and the recognition of unique rights and responsibilities such as those of Indigenous peoples (Brueckner & Eabrasu 2018; Lyons et al. 2023).

An inductive theory of social licence was drawn from Regional Deep Dive interview data using the same process of thematic analysis used to explore perceptions of COTS and COTS management (Bartelet et al. 2025). The resulting framework (see **Figure 5**) distinguishes between four themes related to the rights and responsibilities of Reef Traditional Owners (Free, prior and informed consent, Indigenous knowledge, early engagement, and project involvement) that precede other social licence considerations

summed up in an additional four themes (ethical responsibility, knowledge and rationale, management effectiveness, and socioeconomic benefits).

This organisation of themes reflected the view among many interview participants, Indigenous and non-Indigenous, that public expectations about honouring the unique rights of Reef Traditional Owners is becoming increasingly important in social licence considerations. This was seen to offer multiple benefits including access to traditional knowledge, realising the aspiration of Traditional Owners for genuine involvement in Reef management, creating employment, business, and training opportunities, and improving environmental management. As one participant explained:

I really believe in providing that opportunity and developing those partnerships. I think it's our duty to do that as acknowledging and recognising Indigenous people, part of the land, part of the sea. But also, it's about increasing capacity within the communities which has ongoing, and a lot of downstream benefits for not only them but their families, their friends, their communities. So, it's about building that capacity and building those ideas and linkages with opportunities to improve their connection with the ocean and the land, and so I believe in it.
Livelihood stakeholder



Figure 5. High-level overview of TORR and SLO themes associated with crown-of-thorns starfish (COTS) management on the Great Barrier Reef. Themes were identified using Grounded Theory based on 117 semi-structured interviews with GBR community members. Derived from Bartelet et al. (2025).

Participants recognised the potential social and economic benefits of COTS control. In addition to the positive impact of COTS control on Reef tourism and employment, several participants discussed the development of skills and creation of jobs. For example:

...the COTS program that has the COTS boat up and down the Reef where they're employing at risk youth, they're teaching people, they take them on as cadetships; that is awesome, what a cool program in terms of reaching people... And there was a lot of Indigenous or Torres Strait Islander children, lots of other kids at risk and it trains them in the skills, they get their divemaster and sometimes their coxswain out of it and it just skills them in the maritime industry, so that's great, plus they're doing the surveying and the culling work. Institutional stakeholder

Participants also spoke to the importance of mitigating against negative social and economic impacts such as the maldistribution of benefits and the opportunity costs (in terms of investment, scientific effort, personnel, etc.) of focusing on COTS at the potential expense of other environmental and social risks.

In contrast with National Survey Results, drawn from a representative sample of Australian residents, the majority of Deep Dive participants understood COTS were naturally occurring predators on coral reefs. Many were uneasy about defining COTS as a problem and drew attention to human activities, particularly agriculture and fisheries, as underlying drivers of COTS outbreaks. This led to reflection on the ethics of lethal control and the need to ensure it was based on sound knowledge and reasoning along with evidence that management was proving effective.

Interview participants discussed uncertainty over the causes and consequences of COTS outbreaks, whether enough is known to justify and inform culling, and the risk of unintended consequences. They also, however, discussed the importance of acting despite uncertainty. For example:

Whether it's the crown-of-thorns, whether it's a cyclone or whether it's bleaching, they seem to be the three main ones, and then you have your recovery in between so, yeah, who knows...some reefs might take years to recover, and if we continue to have these events coming more frequently, they may never recover.... Livelihood stakeholder

Participants' reluctance to treat COTS in simple terms (as self-evidently problematic animals, for example) did not emerge as a barrier to social licence for their management. It did reinforce, however, the importance of treating social licence as an ongoing process and of ensuring rigorous and transparent evaluation of the data and understanding on which control strategies are based.

3.3 Economic co-benefits of COTS management

The local and regional economic benefits of the COTS Control Program operations based out of Cairns, Far North Queensland, were estimated using regional economic impact methodology. Data provided by the regional COTS Control operations company in Cairns and input-output tables (May 2025) obtained from the Australian Bureau of Statistics, accessed through REMPLAN software (REMPAN 2006), were used to examine direct, indirect, and induced economic activities in the Cairns Regional Council local government area resulting from project spending in financial year 2023–2024.

The regional input-output (I-O) model was used to estimate:

- Direct effects: immediate economic activity from project spending.
- Indirect effects: economic impacts from supply chain responses to increased demand.
- Induced (consumption) effects: additional economic activity generated by increased household spending from incomes earned due to the project.

Analysis estimated changes in total output, employment, labour income, and value-added across the local economy.

The COTS Control Program was estimated to have generated a direct output of approximately AU\$10.5 million. This output was associated with the creation of 34.4 full-time equivalent (FTE) jobs. The economic contributions spanned various industries, highlighting the program's broad impact on the local economy.

The total economic output, which includes direct, supply-chain, and consumption effects, was projected to reach AU\$20.2 million. This resulted in a Type 2 Output multiplier of 1.921, indicating that for every dollar spent on the program, an additional 92.1 cents were generated in the local economy.

The employment impact of the Program was significant. The total employment impact, combining direct and indirect effects, was estimated to increase by up to 61.3 FTE jobs. This resulted in a Type 2 Employment multiplier of 1.782, suggesting that for every job created directly by the program, an additional 0.782 jobs were generated in the local economy.

The Program was estimated to increase the total value-added by up to AU\$10 million. This reflected the program's substantial economic influence on the local economy, contributing to the overall economic well-being of the Cairns Region.

Care should be taken in extrapolating these results to the GBR region at large. While it might seem reasonable to assume that, with two of six vessels contracted to undertake control operations in 2023–2024 based in Cairns the total economic benefit of the Program would be approximately three times the results for Cairns, there are also good reasons to assume this might not be the case. COTS operations in Cairns, Townsville, and Gladstone are run by different contractors, each of whom have their own operating, employment, and expenditure models. Economic multipliers differ, further, across the three regions as a consequence of

different inter-industry relationships. More research is required to assess both variability across the regions and, perhaps more importantly, the extent to which the COTS Program addresses intra-regional inequalities in access to economic and vocational opportunities.

It is fair to conclude, however, that the COTS Control Program not only plays a crucial role in preserving the ecological health of the GBR but also provides significant economic benefits to the Cairns Region. By generating substantial economic output, creating jobs, and increasing value-added contributions, the Program demonstrates its importance as both an ecological and economic initiative.

3.4 Social and personal co-benefits of COTS management

A key focus of Regional Deep Dive interviews was exploring how participants articulated their relationships with the Reef. Accounts of COTS management in these narratives often centred on its potential to:

- **Protect** the benefits communities derived from the Reef by curbing the damage that COTS outbreaks can inflict on coral (including its physical integrity, its ecological functioning, its aesthetic beauty and the economic activities dependent on these).
- **Enhance** those benefits by creating employment and livelihoods, building Reef skills and knowledge, and enhancing local connections to the Reef (social bonds, teamwork).
- **Equitably** distribute the opportunities and benefits associated with COTS management.

During the second phase of the Regional Deep Dive, researchers conducted interviews with eight COTS managers conducting COTS detection and management work as part of the COTS Control Program. Alongside broader questions relating to the GBR and its future, researchers took the opportunity to explore participants' experiences of the COTS management program. Informal, open-ended questions were used to elicit discussion about participants' vocational histories, their current experiences in COTS management and their aspirations for the future.

While this section draws on a relatively small number of accounts, it contains firsthand insights into how, as it works to protect the Reef, the COTS management program leverages the skills, experiences and interests of an established Reef management community. It shows how the program builds this vocational capital by providing opportunities for:

- practical on-water experience, training and qualifications;
- enhanced reef, research and project management skills; and
- enriched social bonds and professional networks.

The sections below outline themes observed across participants' accounts, focusing on those common to their experience prior to involvement with the COTS Control Program, their experience during the COTS Control Program, and their intentions beyond the COTS Control Program. Due to the relatively small number of COTS managers currently working on the

Reef, additional care has been taken in this section to remove potentially identifying details. Quotes below are labelled 'COTS manager 1', 'COTS manager 2'.

3.4.1 Before COTS management

Many accounts from COTS managers contained discussion of their experiences prior to COTS management.

Values

As participants described their career histories, the factors influencing their vocational decisions, and their current experiences in COTS management, they described being driven by a strong desire to work in marine environments. Multiple COTS managers described their connection to the ocean as a core aspect of their identity often formed in childhood and in association with family and kin:

I find I'm definitely more comfortable under water, like freediving, just holding my breath, than I am on land walking down the street. Even if I can't see the bottom, and it's just blue abyss all around me, that's where I feel the most comfortable.

COTS manager 4

Early, immersive experiences in the marine environment (often using SCUBA technology) were also described as formative events in participants' career paths, catalysing further academic and vocational training. Alongside a desire to be in or near the ocean, the desire to care for the marine environment was also an influence, with encounters with marine animals and a growing awareness of environmental threats described as key factors in participants' career aspirations and decisions.

Experience

According to accounts from COTS managers, conducting on-water COTS management involves teams of around 10–15 people including the Project Manager, the vessel's captain, a voyage leader, a marine crew and a diving team. While team members have varied duties and levels of seniority, most typically have extensive experience working on water prior to being employed in COTS management.

To become a member of a COTS dive crew, candidates are expected to have completed a large number of dives (500 dives was described as the typical minimum) and hold advanced diving certifications (a Dive Master qualification was described by one participant as the standard expectation). Members of the marine crew are expected to have advanced vessel operation and navigation experience and qualifications.

Not surprisingly, gaining this experience requires significant time, access to significant resources (including access to vessels and dive equipment), and connections to expertise (including mentorship and training opportunities). When asked how they gained the necessary experience, participants described:

- previous employment on tourism, including on tourism vessels, on island resorts and in related businesses;
- participating in marine-based research and academic study; and
- previous employment in commercial fishing and coral collecting and commercial shipping.

Qualifications

As well as having extensive on-water experience and dive qualifications, five of the eight COTS managers interviewed also held academic qualifications in marine science and ecology. These managers described their academic experience with mixed feelings. While it offered them opportunities to gain knowledge of the marine environment and experience in diving and fieldwork, some admitted to feeling limited by its emphasis on theoretically focused and (in the words of one manager) ‘data heavy’ scientific research. This was felt to conflict with their inclination towards more practical on-water work:

I didn't really enjoy the lab work or the statistics and analysis of my degree. I very much more preferred the field work side of things. And I think that's why I got stuck in tourism diving for so long. [I wanted to be] out in the water and outside and actually seeing everything. COTS manager 3

Networks

While a strong desire to work on the water, extensive on-water experience and advanced diving certifications and qualifications were critical to participants' involvement in COTS management, participants still needed to access these opportunities. While the details regarding how participants came to be employed under the COTS management program were not explicitly discussed, some participants described learning of opportunities to work in COTS management through word-of-mouth and through colleagues and connections, and others used colloquial terms such as ‘falling into’ (COTS manager 1) it. This indicates that informal networks and social connections facilitate opportunities and participation in COTS management.

While this may seem a minor observation, it is noted here as it may warrant additional investigation to ensure that access to COTS management opportunities is equally distributed.

3.4.2 Participating in COTS management

As COTS managers discussed their current experiences under the COTS management program, researchers prompted them to describe the key challenges of their role, the things they loved or hated about their work, what they thought the qualities of an effective or ‘good’ colleague were, and what was unique about COTS management in comparison to other positions they had held.

These accounts illustrate the unique vocational challenges and opportunities involved in COTS management, and the skills, abilities and capacities participants draw upon to negotiate these. Four common themes were observed in accounts, and these can be understood as the fundamental vocational capacities in accounts of COTS management. These are the capacity to:

- work on and in water;
- detect and kill COTS;
- work in teams; and
- operate within a broader Reef management project.

Working on and in the water

Not surprisingly, operating within a marine environment featured highly in all eight accounts from COTS managers. Participants described how COTS management required work on the water, with extensive time spent on management vessels traveling to and around COTS-affected reefs. This required them to spend weeks away from home, share confined accommodation, work in remote conditions with no internet or mobile coverage, and contend with inclement weather.

Their work also demanded they spend many hours each day working under the water, detecting, monitoring and killing COTS. Compared to the underwater work involved in the tourism industry, COTS diving was described as physically exhausting and faster paced, with more underwater tasks, including detection, data collection and management, COTS killing, communicating and coordinating teams. COTS managers were also typically expected to dive in more challenging underwater conditions than would be expected of divers working with tourists:

The task loading underwater can be a lot to someone who's come from tourism diving, just leading dives. [With COTS management] they've got all this added equipment, they're looking for the starfish, as well as looking after their buddies and keeping an eye out for any dangers as well. We often dive in poor visibility and strong currents as well, and sometimes at depth, so there's always a lot going on.....In winter the water can get quite chilly out there. If you're only diving once it's fine, but after two weeks diving all day every day your body temperature doesn't have time to recover, so every dive's cold and miserable. On top of bad surface conditions, it can be quite exhausting sometimes. COTS manager 3

Being effective in these conditions required participants to exercise considerable physical stamina, drive and tenacity, and develop time management, multitasking and interpersonal skills. While it presented these challenges, COTS managers also described how this intensive work offered them significant rewards. Participants were not only able to gain an income and earn a living in connection with the marine environment, but they also gained significant experiential benefits as they dived, explored and engaged with the Reef:

Some days it's hard....but then once you get in the water, there's always something that reminds you of why you do it...It's like the ocean knows. It just tries to pull you back in. A tiger shark will come. Or [the ocean will] just be "Wait, don't go. Here's something cool" and make you obsessed with it again. COTS manager 7

Another key benefit described by COTS management was the opportunity to learn new things about the marine environment and further develop on-water experience and skills. The COTS managers interviewed were enthusiastic about the experience and training they had gained through their current role regarding the operation of marine vessels. They described this opportunity as more readily available through their work in COTS management compared to previous roles in tourism and other marine-based work:

Working here, I've gained an insane amount of knowledge from the boat perspective....It's such a great learning environment. All the skippers that we've had are pretty [supportive]. If you want to get down to the engine room, they'll get you down to the engine room... [marine vessel operation is] definitely a male-dominated industry, but this has been one of the workplaces I've got the most opportunity, for sure, to learn. Working in tourism, I was always trying to get opportunities [to learn and gain certifications in regard to vessel operation]... You've got to learn, right? And you can't learn unless someone's willing to teach you....I really pushed for it at a lot of places, but I never really got recognition. Whereas here, as soon as I kind of mentioned that that's what I wanted to do, it happened. COTS manager 2

Managing COTS

Another key capacity evident in all eight accounts from COTS managers was the ability to detect and kill COTS. While central to their role, exercising this capacity was not as straightforward as one might expect. Mirroring the baseline findings of the first phase of the Regional Deep Dive, participants expressed complicated perspectives about engaging in lethal control of COTS, and often struggled to find ways to situate this responsibility within their broader environmental values and the connection they felt to the marine environment. As a result, killing was often described as one of the less pleasurable aspects of COTS management, which participants reconciled themselves to by highlighting the ecological disruption that COTS outbreaks cause and framing it as a moral obligation and an act of human-environment reparation:

I personally don't like killing something, but once I saw an outbreak, an extreme outbreak, I think a little bit of that guilt got left behind. I could see what the result [would be] if that was left unchecked. COTS manager 3

In contrast to the act of killing, no discomfort was expressed about detecting and monitoring COTS. As also evident in the first phase of the Regional Deep Dive, this was described as a satisfying part of COTS management. Implicit in these accounts was the ability of COTS to hide and evade detection. This allowed them to be described, not as vulnerable and

defenceless victims, but as more equal agents in the management relationship. Unlike the ethical dilemma provoked by killing, participants could frame detection as an enjoyable pursuit, like a game or sport:

I don't get enjoyment out of the actual culling process. I do enjoy searching for them because they are quite cryptic creatures, so it's essentially like solving a puzzle when you find them. Especially when you find the juvenile ones because they're very difficult to find and more nocturnal than the adults, so that part is almost enjoyable. COTS manager 3

As also observed in the first phase of the Regional Deep Dive, participants often described the exceptional sensory skills they had gained through this 'sport' with pride. They described how sustained embodied interaction with reefs had made them keen observers of marine life. The quote below further illustrates the depth and intimacy of a manager's embodied knowledge of COTS:

You can see when they've travelled, obviously, from a long distance...they lose all their body mass. You'll see a large COTS, but it's really skinny and it's got lots of spines. They're just all spines, no juice to them. And you go "You've come from a long way my friend."...We joke about it, but...you just know what they like, what their preferences are. It's just you get to know them. So, like a big branching Acropora, like a big long one with long branches, not short little ones - they love to be deep in that. Not the blue ones, the brownie ones. Or a big plate in coral, they'll sit underneath it. And you might have no indication other than the coral looks a little bit discoloured... because they'll feed from underneath. COTS manager 6

Working in teams

Working in teams was another capacity evident in all eight accounts from COTS managers and was described as both a rewarding and challenging aspect of COTS work. It was rewarding when team members worked well together, understood, and trusted each other, when spirits and rapport was high. It was challenging when people did not work well together, when trust was low and when factors like the confined living spaces and adverse weather created additional obstacles to team functioning and morale.

Given that teamwork featured prominently in accounts of COTS work, participants were asked to describe what things they believed influenced the cohesion and functioning of COTS teams. Interpersonal skills were considered particularly important. This included an awareness and appreciation of different perspectives and a willingness to accommodate them:

I love people generally, and I love their potential, and I love seeing them work to their potential, but people are people and there's always drama...[An undesirable co-worker is] someone who isn't conscientious of dynamic personalities, or the dynamics of living and working [on a COTS vessel]. So, someone who's not

considerate....I'm not really talking about the skills per se.... It's all around the attitude. COTS manager 1

We have a lot of crew from a lot of different places in the dive team. We have crew from everywhere, and I don't find that to make much of a difference. Because like I said, we were working down here, regardless of background and history, we are all like-minded, ultimately and I think we just embrace getting to know people from different cultures. COTS manager 6

The value placed on workplace diversity was sometimes highlighted as a positive aspect of COTS management with some participants highlighting the vocational opportunities offered to women as a positive aspect of their experience (see section above). However, competitive cultures and exclusionary attitudes were seen as common in other marine-based workplaces and several accounts highlighted the potential impacts of this on COTS management teams:

When people come on new and really want to assert themselves rather than take onboard our knowledge, right off the bat, that can be frustrating.... the marine industry is rife with it [and] sexism, like, the women get underestimated all the time. COTS manager 6

We've had a few [problems] in the past. Quite often it's the people with big egos. They are often overqualified and from a commercial background as well where it's quite every man [sic] for himself. Everyone's a bit of a cowboy. We've also had a few people from like the slug diving industry. Their diving is very repetitive, and a lot of dive related injuries occur and that sort of thing, so they're quite lax on their rules. We're very safety orientated.... COTS manager 3

In line with a commitment to diversity and difference, many participants emphasised the importance of inclusion in team composition and management. While diving experience and academic qualifications are often desirable criteria in participation in COTS management, below a senior COTS manager discusses the importance of supporting promising individuals to gain experience and build capacities:

[A lack of science degree] doesn't close me off to [employing] people because I still believe in diversity as strength. Some of our best crew aren't science graduates. Some of our best crew weren't great divers....I've got a long history of a variety of different roles and all sorts of different industries... so I believe you can find great people in all sorts of areas and it's not that cookie cutter kind of thing. COTS manager 1

Alongside support from teammates and managers, accounts also indicate that shared values and motivations play an important role in the cohesiveness of COTS crews. As discussed above, operating within a small vessel in remote marine areas requires significant tenacity. Being intrinsically motivated by a love of, and care for, the ocean and the Reef was one of the key qualities in a good teammate:

I feel most of the time people come in and they want to be here, and they want to do the job and they're super passionate and keen and that really shows. I spend more time with [co-worker] than I do with my partner because we share a bunk. It's crazy! So, obviously, you want to be able to put trust in those people....But I we get people coming through now and then that just aren't....they're not bad divers, but [they just don't want] to be out on the water, to be honest....Yeah, some people just want a pay cheque at the end of the day. COTS manager 7

As the quote above suggests, trust and reciprocity were considered crucial to the smooth operation of a COTS management team.

I love everything about it. Well, I love being on the water, I love everyone that I work with, I love diving. I mean, it is hard work. I have trips where I get home and I am just absolutely exhausted.....It is more work when we have a lot of new people. Regardless of who they are, it is more work getting to know new people as opposed to when you already know each other. We get each other's routines and vibes and that thing. So yeah, when we have a lot of new crew, it can be just more tiring because you've got that added social aspect to work towards as well. COTS manager 6

Contributing to broader Reef management

The ability to effectively work within and contribute to the objectives and strategies of the COTS Control Program was another key capacity present in six interviews.

One of the ways this capacity became evident was through managers' accounts of collecting and sharing information relating to COTS management. Collected during COTS work, compiled on board COTS vessels, and shared with the organisations overseeing COTS control, participants considered this an important responsibility which often demanded diligence, accuracy, and the ability to multi-task on and under water. Despite these challenges, participants also expressed satisfaction about undertaking this work, recognising the skills it developed and its value for understanding COTS and making effective management decisions. Through data management, participants could connect their practical, day-to-day activities to the broader strategic objectives of the COTS Control Program. This not only built their interest in data collection but their ability to understand their work in terms of its unique contribution to the Reef's protection and management:

Well, I guess in uni... I just couldn't wrap my head around[the] vast amounts of data.... [but] in the field you understand what the data is and where it's coming from... Yeah, I find that I guess a lot more straightforward because I know exactly what it is and how we use that data as well. So yeah, it just makes a lot more sense to me and I guess it's more meaningful to me because I know what the data that we're collecting, I know how it's going to influence what we're going to be doing in the coming week... Obviously in tourism you have all these people to worry about, and I feel like you're not as engaged in the ocean side of things because you're so concerned with these people and making sure they get back

okay...but with [COTS management] the work seems a lot more meaningful. It's the conservation, and I guess you just get the time to appreciate it a little more.
COTS manager 8

Because we're not just doing COTS work. We're doing all the Reef Health Impact Surveys and things that as well. Which, I guess, is invaluable data for the reef that will show how it's changing over time, which will be the ultimate thing that will push to get something done.... I feel I've just learned so much...'cause not only all the COTS data, but we do water quality samples and plankton samples, and just how much there is to be done. And I'm just quite interested in learning more, I suppose. COTS manager 7

COTS managers also expressed satisfaction regarding the opportunities that COTS management created to engage in program activities, such as workshops and conferences, and connecting with a broader community of Reef managers.

3.4.3 Beyond COTS management

Although it was not an explicit question asked in the deep dive interviews, as participants discussed their experience in the COTS management program, several discussed their plans and aspirations for the future. While no participants discussed immediate plans to leave the COTS management program, one discussed the prospect of retirement, others discussed the possibility that changes to their living circumstances (e.g. having a family, starting a business, moving away from the reef etc.) may make the remote nature of COTS management work unviable, or the possibility that the COTS management program may change or end.

Valuable skills

Accounts from COTS managers highlight how participation in COTS management offers unique opportunities to practice connections with the ocean, extensively dive the Reef, have underwater encounters while simultaneously earning a living. It also allows managers to build crucial marine-based skills, credentials, and vocational capacities.

As they speculated about their careers beyond COTS management, participants were enthusiastic about the vocational benefits they had gained through their involvement in COTS management. This enthusiasm centred around the development of skills in research and data collection, teamwork, environmental management, and vessel operation. Valuable and unique, these skills allowed participants to imagine new career horizons:

This job is an amazing stepping stone for me [and] now I've got a lot more boating experience, a lot more research experience. I don't see [myself] doing [this job] for the rest of my life. It takes a big toll on your body and on relationships.When I finished uni, I applied for a few research assistant jobs and I had gotten very close. The feedback I was consistently getting was "we almost went with you, you need more boat experience". Now I've got that in spades. COTS manager 6

If you had told me when I started, or that I was even going to be in the position that I am in now, I just would have laughed, I wouldn't have believed you. It's something you can't even pay for or just ask for, like the experience that I've received from my co-workers and my boss and the boat itself. I've learned so much about safety, that's a really big one. COTS manager 4

Deepened connections

As well as building skills, some participants described how their interaction with, and observation of, Reef environments through COTS management had made them more curious and keener to learn about marine environments. The participant below describes how COTS management had built their desire to pursue further study and possibly a career in marine research:

The things that I observe on the dives, obviously I've got no data to back these things up, but I've got a lot of theories that I would love to actually prove or disprove. I think that would be a really cool next step. This job, it's not a lot of research [but] it's a lot of data collection and it's a lot of fieldwork. I would like probably in the future, something more balanced. I still really want to be in the field, but I would love to also see all that through into papers and results... and obviously that would probably involve doing a masters as well [and possibly a PhD]. COTS manager 6

3.5 Regulatory assessment

3.5.1 GBR regulatory environment

The regulatory environment under which COTS control is implemented comprises multiple regulations and entities involved in their development, implementation, and compliance. Here, 'regulations' or 'regulatory arrangements' are broadly defined to include laws, policies, plans, and agreements that are relevant to various aspects of GBR management. Entities involved in this process include government agencies, who primarily develop and implement these regulations. They also include industry, community, and environmental groups that may participate in the development and implementation of regulations, but they are also required to comply with them (Fidelman et al. 2019). This assessment focuses on the government agencies that regulate the range of activities undertaken in the GBR, including COTS control.

The overall GBR regulatory environment – that is directly or indirectly linked to COTS control – encompasses numerous regulatory arrangements and entities. These arrangements and entities pertain to four governance levels and have intersecting responsibilities in the protection and management of the GBR:

- International level: This involves Australia's commitment to various international treaties, especially the World Heritage Convention.

- Commonwealth government level: This includes departments and agencies of the Commonwealth Government, with a particular emphasis on the Great Barrier Reef Marine Park Authority (Reef Authority) and the Department of Climate Change, Energy, the Environment and Water (DCCEEW).
- State government level: This involves departments of the Queensland Government, notably the Department of Environment, Tourism, Science and Innovation (DETSI) and the Department of Primary Industries (DPI, previously the Department of Agriculture and Fisheries (DAF)).
- Local government level: This includes the 39 local governments within the GBR catchment area.

The Commonwealth and Queensland governments hold the most significant roles in regulating activities in the GBR, and are described in more detail, as follows:

Commonwealth government

The Reef Authority is the primary agency responsible for the GBR Marine Park. However, it shares the day-to-day planning and management responsibilities within the Marine Park with other Queensland government agencies. The Reef Authority administers the *Great Barrier Reef Marine Park Act 1975* (Cth) (GBRMP Act), which sets up a permit system for activities within the GBR. This system involves joint permit assessments and approvals by the Reef Authority and Queensland Parks and Wildlife Service (QPWS) when proposed activities involve both Commonwealth and Queensland jurisdictions.

The Reef Authority has implemented various plans of management, policies, strategies, position statements, and site-specific management arrangements. The most relevant regulatory arrangements for COTS control include the Great Barrier Reef Marine Park Zoning Plan 2003 (Reef Authority 2004), Crown-of-Thorns Starfish Control Guidelines (Reef Authority 2017a), Guidelines: Applications for Restoration/Adaptation Projects to Improve Resilience of Habitats in the Great Barrier Reef Marine Park (Reef Authority and Queensland Government 2018), and Policy on Great Barrier Reef Interventions (Reef Authority and Queensland Government 2020).

DCCEEW administers the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) (EPBC Act). This Act regulates activities both within and outside the GBR World Heritage Area (GBRWHA) likely to significantly impact the environment in the GBR, Outstanding Universal Values of the GBRWHA, or other Matters of National Environmental Significance (MNES), such as listed threatened species.

The Australian Pesticides and Veterinary Medicines Authority (APVMA) was established under the *Agricultural and Veterinary Chemicals (Administration) Act 1992* (Cth). It administers the *Agricultural and Veterinary Chemicals Code 1994*, which provides the framework for assessment, registration and control of agricultural and veterinary chemicals products, including semiochemicals. Any such products manufactured, imported, supplied, sold, or used in Australia must be registered with the APVMA.

Queensland government

DETSI is the key Queensland government agency responsible for the protection and management of the GBR. It administers the *Marine Parks Act 2004* (Qld), which establishes the GBR (Coastal) Marine Park – which runs the full length of the Commonwealth GBR Marine Park, protecting Queensland tidal lands and tidal waters. Within DETSI, QPWS is responsible for managing the GBR (Coastal) Marine Park. DETSI also plays an important role in implementing the Reef 2050 Plan and Reef 2050 Water Quality Improvement Plan.

DPI is tasked with the management of fisheries in the GBR, as per the *Fisheries Act 1994* (Qld). The Queensland Boating and Fisheries Patrol (QBFP), a division within DPI, is responsible for enforcement of fisheries and zoning regulations under the GBRMP Act and *Marine Park Act 2004* (Qld). QBFP collaborates with the Reef Authority and QPWS through a joint field management program, which focuses on surveillance, compliance and enforcement activities.

3.5.2 Regulatory considerations for COTs control

The GBRMP Act stipulates that certain activities including fishing, research and tourism require approval to be conducted in the Marine Park (**Table 1**). The activities pertinent to COTS control fall under the “Program to take animals or plants that pose a threat to marine ecosystems of the Marine Park”. This program regulates a broad range of actions concerning animals and plants in the Marine Park. The term “take”, as defined by the GBRMP Act in relation to an animal or plant, encompasses actions such as “remove, gather, catch, capture, kill, destroy, dredge for, raise, carry away, bring ashore, interfere with and obtain”.

Table 1. Summary of activities requiring approval within the GBR Marine Park.

-
- Harvest and development fisheries
 - Aquaculture operations
 - Educational programs (other than limited impact educational programs)
 - Tourism programs and developments
 - Research (other than limited impact research)
 - Operating a facility, including:
 - Navigating a managed vessel or aircraft
 - Vessel or aircraft charter operations
 - Discharging waste from a facility
 - Installation, operation and decommissioning of a facility
 - Moorings
 - Operating a landing area or a facility for aircraft
 - Carrying out works, including:
 - Dredging
-

-
- Dumping of spoil
 - Reclamation
 - Beach protection works
 - Harbour works
- Taking animals and plants that pose a threat to human life or safety, marine ecosystems of the Marine Park or use or amenity of a part of the zone or adjacent area
-

Source: Reef Authority (2004).

Furthermore, the *Great Barrier Reef Marine Park Zoning Plan 2003* (Cth), Special Management Areas, and Plans of Management may prohibit or regulate activities within the Marine Park differently across various zones (Reef Authority and Queensland Government 2020). The Crown-of-Thorns Starfish Control Guidelines 2017 (Reef Authority 2017a) specify that permits **are not necessary** for the currently approved methods of controlling COTS. These methods include the single-shot method using bile salts or household vinegar, and the multi-shot method using sodium bisulphate. The following zones are exempt from requiring permits:

- General Use Zone
- Habitat Protection Zone
- Conservation Park Zone

On the other hand, permits are **necessary** for using these methods to undertake COTS control in the following zones:

- Buffer Zone
- Scientific Research Zone
- Marine National Park Zone
- Preservation Zone

In zones where permits are not necessary, the Crown-of-thorns Starfish Control Guidelines 2017 (Reef Authority 2017a) offer instructions on how to carry out COTS control activities. In zones where a permit is necessary, the permission system employs a risk-based strategy to assess the likelihood and potential effects of impacts on the values of the Marine Parks. Permits are mandatory in all zones for any methods not currently approved in the Crown-of-thorns starfish Control Guidelines 2017.

As previously mentioned, numerous policies, agreements, position statements, strategies, and guidelines are in place related to the protection and management of the GBR. This includes Indigenous Land Use Agreements, and activities in areas where these agreements apply would be subject to their terms. Additionally, under the *Native Title Act 1993* (Cth), the Reef Authority is tasked with notifying native title holders or claimants about areas that will be impacted by proposed permissions (Reef Authority 2017b). Other key documents include the *Guidelines: Applications for Restoration/Adaptation Projects to Improve Resilience of Habitats in the Great Barrier Reef Marine Park* (Reef Authority and Queensland Government

2018) and the Policy on Great Barrier Reef Interventions (Reef Authority and Queensland Government 2020). These guidelines and policy outline the probable regulatory requirements and the assessment approach used for various reef interventions, including the control of COTS.

Permit applications are assessed on a case-by-case basis, with the appropriate assessment approach determined by the risks and impacts of the proposed activities. The assessment of risks, impacts, and risk management measures is based on the following information provided by the applicant:

- Type and scale of activity, duration, location, equipment, materials and methods used.
- Potential direct, indirect and cumulative impacts on the Marine Parks' values and benefits over time and space, encompassing the entire life of the proposal where relevant (this includes construction, operation and decommissioning or removal).
- The strategies for avoiding, mitigating, or offsetting impacts to the values of the Marine Parks.
- The methods for monitoring the impacts on the values of the Marine Parks to evaluate the effectiveness of the avoidance, mitigation, or offset measures.
- The compliance of the proposal with relevant plans, policies, guidelines, and standards (Reef Authority and Queensland Government 2017).

If the risk is assessed as high, additional information will be needed for the Reef Authority to decide on whether to grant or refuse a permit for the activity. Regardless, when deciding whether to grant a permit for an application, the Reef Authority must consider the factors specified in the *Great Barrier Reef Marine Park Regulations* 2019 (Cth), regulation 103. These encompass:

- a. the zone objectives;
- b. legislative instruments applicable to specific areas of the Park;
- c. the applicant's suitability;
- d. the requirement (s 37AA *Reef Authority* 1975 (Cth)) to take all reasonable steps to prevent or minimise harm to the environment in the Marine Park that might or will be caused by the user's use or entry;
- e. whether there are feasible and prudent alternatives to the proposed conduct;
- f. any written comments received in connection with the application;
- g. the relevant impacts of the proposed conduct;
- h. options for avoiding, mitigating and offsetting those relevant impacts;
- i. options for monitoring and managing those relevant impacts;
- j. relevant in-force laws of the Commonwealth or of Queensland, or a relevant plan, relating to management of the environment or an area of the Marine Park;

- k. (where applicable) the assessment documentation and approval (or otherwise) under the EPBC Act;
- l. (where applicable) approval or permission and conditions under other Queensland legislation;
- m. any recovery plan, wildlife conservation plan, threat abatement plan or approved conservation advice, where relevant;
- n. any international agreement to which Australia is a party, or any Commonwealth/State or Territory agreements, where relevant;
- o. any policies relevant to the proposed conduct and the management of the Marine Park or of its environment, biodiversity or heritage values, and published by the Reef Authority and adopted by the Department (administering the EPBC Act);
- p. any other matters relevant to the proposed conduct and either (i) achieving the objects of the Act or (ii) orderly and proper management of the Marine Park.

As noted previously, agricultural and veterinary chemical products manufactured, imported, supplied, sold, or used in Australia require registration with the APVMA. This involves assessment of the safety and effectiveness of a product to protect human, animal and environmental health and safety. Under the APVMA's Guideline for the Regulation of Biological Agricultural Products, semiochemicals fall under the classification of biological chemicals. The APVMA decides on the data requirements for semiochemicals on a case-by-case basis, considering various factors such as low application rates, high volatility, and potential for low toxicity (Australian Pesticides and Veterinary Medicines Authority 2022). The APVMA's website provides comprehensive information about the permit application process, types of permits and associated requirements (www.apvma.gov.au). However, such information refers to semiochemicals in the agricultural context, where they are used as pesticides. It is unclear how the existing regulatory requirements may be adapted for the use of semiochemicals in the context of COTS control.

Certain activities may require further permissions under different regulations. For example, activities that could significantly impact¹ the environment of the Marine Park or other matters of national environmental significance² need to be assessed under the EPBC Act. Current arrangements between the Reef Authority and DCCEEW allow for a referral under the EPBC Act to be incorporated as part of the permit application under the GBRMP Act. Activities that involve fishery resources (including corals), or those that interfere with fish habitats, marine plants, and algae would necessitate permission under the Fisheries Act 1994 (Qld).

¹ For the purposes of the EPBC Act, a significant impact is defined as "...an impact which is important, notable, or of consequence, having regard to its context or intensity. Whether or not an action is likely to have a significant impact depends upon the sensitivity, value, and quality of the environment which is impacted, and upon the intensity, duration, magnitude and geographic extent of the impacts".

² Matters of national environmental significance include world heritage property, listed threatened species and ecological communities and migratory species protected under international agreements.

Novel COTS control methods would trigger different regulations and policies depending on the nature and risk level of the method, as outlined in **Table 2**.

Table 2. Examples of relevant regulations and levels of risk for selected COTS control methods.

Control Methods	Relevant regulation						Risk*
	GBRMP Act 1975 Marine Parks Act 2004 (Qld)	Reef Authority/QLD Policy 2020	Reef Authority/QLD Guidelines 2018	EPBC Act 1999	Fisheries Act 1994 (Qld)	Agvet Code 1994	
Manual Control	◆	◆	◆				Low
Natural COTS predators	◆	◆	◆	◆	◆		High
Semiochemicals	◆	◆	◆	◆		◆	High

Note: Reef Authority/QLD Policy 2020: Policy on Great Barrier Reef Interventions (Reef Authority and Queensland Government 2020); Reef Authority/QLD Guidelines 2018: Guidelines – Applications for restoration/adaptation projects to improve resilience of habitats in the Great Barrier Reef (Reef Authority and Queensland Government 2018); Agvet Code: Agricultural and Veterinary Chemicals Code 1994. *Risk levels based on Reef Authority and Queensland Government (2018).

The Guidelines for Permit Applications for Restoration/Adaptation Projects to Improve Resilience of Habitats in the Great Barrier Reef Marine Park (Reef Authority and Queensland Government 2018) set forth various risk levels and assessment approaches for different reef interventions. Apart from manual COTS control, all novel methods in **Table 2** fall into the categories of high risk or very high risk.

The likely approach to permission based on risk levels is summarised as follows:

Low risk

Control methods that are considered low risk, such as manual control following the Crown-of-thorns starfish Control Guidelines are typically subject to standard assessment procedures. The Guidelines for Application for Restoration/Adaptation Projects to Enhance the Resilience of Habitats in the Great Barrier Reef Marine Park state that these activities usually do not necessitate a pilot study since the proof of concept is already established. As detailed in the Environmental Impact Management – Permission System Policy (Reef Authority and Queensland Government 2017), this is suitable for activities that have been assessed by the managing agencies (i.e. Reef Authority and QPWS) as low risk when undertaken in a standardised manner, and the information supplied in the application is adequate for the managing agencies to predict the risks of the activity with high confidence. This process does not require public comment, and standard mitigation measures include monitoring and reporting. It is also feasible for currently approved manual control methods to be classified as management activities or authorised as such by the Reef Authority under section 5.4 of the *Great Barrier Reef Marine Park Zoning Plan 2003* (Cth) or by QPWS under sections 145A and 145B of the *Marine Parks Act 2004* (Qld) in zones where a permit is required.

High risk

Semiochemicals and predators and restocking populations of natural COTS predators are deemed to be high risk. Accordingly, they would require tailored approaches to assessment and permit, incorporating joint risk assessment with CCIP researchers and the Reef Authority – and other relevant regulators, where applicable (e.g. APVMA in the case of semiochemicals). Such tailored approaches “...require the applicant to provide more information and require the authority to undertake a detailed assessment. These [...] are non-standard/non-routine in nature” (Reef Authority and Queensland Government 2018: 8).

High-risk control methods would necessitate:

- Proof of concept or supporting rationale for likely success in the Marine Park.
- Small-scale pilot study in the GBR, which is considered a research activity, that includes tailored assessment. If such a pilot study is regarded as successful, a non-research focused permit could then be sought.
- Depending on the scale and risk involved, the operational application may require a tailored or public information package assessment, deed/bond, public advertising and/or an environmental management plan (Reef Authority and Queensland Government 2018).

As outlined in the Environmental Impact Management – Permission System Policy (Reef Authority and Queensland Government 2017), this approach is appropriate where the application contains enough information for the managing agencies to confidently anticipate the risks of the activity. However, certain aspects of the application may require detailed consideration. A pre-application meeting is recommended to assist the Reef Authority to understand the proposal and to advise the applicant of any additional information requirements.

High risk control methods may also trigger the EPBC Act, depending on the scale, location, magnitude and intensity of their activities. As noted earlier, this Act regulates activities that may cause a significant impact on the environment of the Marine Park or other matters of national environmental significance.

4. DISCUSSION AND OUTPUTS

4.1 Baseline perceptions of COTS and COTS management

4.1.1 Support for COTS control across the GBR

Public support for further research and development of both conventional and semiochemical-based COTS control methods is strong, while support for scaled deployment is moderate to strong. While only about a tenth of our respondents had some level of disagreement with the deployment of manual COTS control, almost half provided neutral responses or only slight agreement. Australians might not perceive the coral predator as an iconic Australian native animal species (like koalas, kangaroos and dingoes), for which more resistance was expressed to lethal control (Mehmet and Simmons 2018; Drijfhout et al. 2020; Boulet et al. 2021; van Eeden et al. 2021). On the other hand, public support for COTS culling might not be as high as for invasive species like feral animals and lionfish (Kleitou et al. 2019; Zander et al. 2021), although results are not directly comparable because of different methods used to measure support.

The support levels for funding, researching, trialling, and deploying semiochemical-based COTS control are similar to those for conventional methods, despite the early stage of semiochemical research (Harris et al. 2025). The strongest predictor of support for semiochemical-based control was respondents' status as Aboriginal and/or Torres Strait Islander. However, this does not imply automatic consent by Reef Traditional Owners for pest control methods in specific locations and at specific times. Field deployment will occur on the Sea Country of around 70 First Nations with moral and legal rights in the GBR and well-documented aspirations for involvement in COTS monitoring and management.

We found no significant differences in support for COTS control methods between GBR region residents and other Australians (**Figure 4**). Older respondents were less likely to support either method, possibly due to lower knowledge about COTS native status (**Figure 4**). Male respondents were more supportive of lethal control interventions, consistent with prior research (Dunn et al. 2018; Boulet et al. 2021; Zander et al. 2021).

Political affiliation did not significantly affect support levels for pest management. Respondents affiliated with the Liberal-National Coalition, Australian Labor Party, or the Greens showed similar support levels, indicating widespread political support for semiochemical-based COTS control. However, those affiliated with small parties and independents were less accepting (**Figure 4**).

Respondents who correctly identified COTS as a native species were less likely to support semiochemical-based control, reflecting concerns about lethal control of native animals (Thresher et al. 2019; van Eeden et al. 2020; Straka et al. 2022). Taken at face value, this suggests that public education about COTS could undermine support for conventional and semiochemical-based control methods. However, respondents' understanding of COTS control technologies positively influenced support for scaled deployment of both conventional and semiochemical control as did the perceived feasibility of both control methods (**Figure**

4). Neither ethics nor safety, by contrast, had a statistically significant bearing on support for either method. By highlighting the complexity and fluidity of relationships between knowledge, risk perceptions, and support for lethal culling, these findings suggest value in communication and education focused on explaining COTS control methods, highlighting supporting scientific activities, and providing opportunities for public deliberation.

Communication should also consider analysis of 2018 and 2022 survey data (in relation to manual control only) showing that support was strongly associated with the immediate threat of COTS on the Reef but not with the longer term benefit of COTS control to Reef resilience. This is consistent with findings from research on koala and kangaroo culling (Boulet et al. 2021). Importantly, such findings do not necessarily reflect a lack of concern with the future but the escalating impact of uncertainty and potentially conflicting information on support for management interventions with temporally and/or spatially distant benefits (Platt and Huettel 2008; Sterman 2012; Moxnes 2023). Communication planning should, therefore, weigh the potential for messaging focused on immediate ecological and social benefits to promote support against the need to build understanding of longer term processes and options.

4.1.2 Tensions between pragmatic and ethical concerns for the Reef

Accounts from the Regional Deep Dive interviews suggest a level of ambivalence in Reef communities around defining COTS as a problem and a threat to the Reef. On one hand, participants formed relatively cohesive narratives around COTS being antithetical to the natural capital of the Reef, and many included COTS within the compounding set of issues they listed as threatening to the Reef's future. On the other hand, participants often moderated their definitions of COTS as problematic, using counter-narratives to frame COTS as endemic to the Reef and thus a 'natural' part of Reef ecologies, and COTS outbreaks as an anomaly to 'normal' reef functioning. When it came to considering the longer-term future of the Reef, the localised threats posed by COTS were differentiated from more broad-reaching pressures on the Reef. The relatively manageable threat of COTS was downplayed in comparison to more intractable problems requiring complex collective change and political action, such as climate change.

This suggests that a similar dilemma might be provoked among members of the public more generally when considering moral and ethical implications of COTS management. Emphasising the pragmatic importance of managing COTS may be insufficient to gain consensus over the acceptability of COTS management programs. Even though it has become relatively common for action to be taken to control native animals when they behave in ways that transgress human expectations for ecological functioning, well-being and economic productivity, an animal's native or endemic status remains an important cultural marker of an animal's value and right to 'belong' in Australian environments (Franklin 2006; Trigger and Head 2010; Head 2012). Actions against animals considered endemic can become controversial, especially when lethal measures are taken, when the methods used to manage animals carry risks to ecological or cultural values, when there are welfare concerns or disagreement around the problematic status of the animal, or when management is considered unjustified or ineffective (McKiernan and Instone 2016; McKinnon et al. 2018; Mo et al. 2020; Whisson and Ashman 2020).

These tensions are also likely to affect the ways in which Reef communities evaluate the desirability and effectiveness of novel COTS management strategies, and the use of various technologies to manage COTS. Participants evaluate COTS management methods against potential ecological risks or imbalances, perceptions of unnecessary persecution of COTS, moral uncertainties about the extent and nature of human interference in the Reef, and so on. The ways perceptions of these technologies are ethically and morally mediated requires further examination.

4.1.3 Community and vocational benefits of COTS management

As positive accounts of COTS management from the Regional Deep Dive interviews highlight its effectiveness in protecting the Reef's ecological, aesthetic and economic capital through curbing the damage that COTS can inflict on coral, they also highlight the social and vocational capital generated through COTS management programs. The local implementation of COTS management strategies help develop a range of Reef skills for participants and a sense of enjoyment, mastery and efficacy through its readily observable impacts. COTS management also brings teams together to implement management, enhancing collaboration, social bonds and a sense of citizenship and identity among Reef managers.

Accounts also indicate community awareness of the potential opportunities that participation in COTS management can have, especially when it comes to building the capacity and skills of Traditional Owner groups and other Indigenous communities. They also indicate the existence of scepticism regarding the fair distribution of the benefits gained through COTS management, and the importance of measures to ensure that capital does not accumulate in pockets of the Reef community. Resourcing and facilitating communities to participate in COTS management is a vital action for enhancing inclusion in COTS management programs, and further work needs to be done to engage with communities and Traditional Owners to build participation in COTS management.

These results suggest the need to consider the impacts that novel strategies and technologies might have on the development of vocational or social capital. Skills and knowledge are built through ongoing, bodily interaction with the Reef, and are mediated by a range of cultural beliefs, normative rules, and emotional factors, including an ethical connection to the Reef, a sense of efficacy, aesthetic enjoyment, the trust between team members and a belief in the importance of practical work. Further consideration of the ways that novel management strategies and technologies might disrupt the skills and knowledge created in interaction with the Reef, and jar with the expectations about what constitutes meaningful and ethical ways to work with the Reef, is warranted. This could be particularly relevant for the enduring forms of cultural knowledge, lore and custodial responsibilities that are practiced by Traditional Owner communities as they exercise rights over, and connections to, the Reef.

4.2 Co-benefits of COTS management

The COTS Control Program is responsible for meaningful economic benefits for local economies. From an annual direct expenditure of about AUD\$5.5 million in control operations in Cairns in 2023–2024, a total economic output of about AUD\$20 million was created. This was made up of direct effects (\$10.5 million), supply-chain effects (\$4.9 million), and consumption effects (\$4.8 million). The Program led, moreover, to the creation of 61 jobs, including 34 direct jobs, 13 supply-chain effect jobs, and 13 consumption-effect jobs.

Drawing on firsthand accounts from eight COTS managers, the Regional Deep Dive explored how vocational and social capital was enhanced through participation in the COTS management program. The accounts outlined in this report highlight how the COTS management program:

- draws on a community of workers with established on-water skills and certifications, deep connections with the marine environment, and a strong desire to engage in practical management work on the GBR.
- offers these participants the opportunity to build their on-water experience and qualifications and gain valuable underwater, research and project management skills.
- builds participants' sense of identity and efficacy as Reef managers through the creation of specialist skills, the formation of strong social bonds between teammates, and connections with the broader COTS Control Program.
- shapes COTS managers' plans for the future, including their continued involvement in marine research and management.

However, these accounts also indicate some potential issues when it comes to ensuring that the opportunities, benefits, and vocational capital created by the COTS management program is equitably distributed.

4.3 Evaluation of novel COTS management scenarios

4.3.1 Public and stakeholder perceptions

Synthesising the Regional Deep Dive accounts, this report has identified some common considerations that Regional Deep Dive participants make as they talk and think about existing and prospective COTS management. Loosely classified into pragmatic and moral/ethical concerns, this research has shown how these considerations shape initial responses to two prospective COTS management strategies being explored under CCIP: predator control and the use of semiochemicals.

In particular, it has highlighted how participants' responses of prospective COTS management approaches are connected to perceptions of:

- their practical outcomes for reef ecologies (whether they assist or harm the Reef);

- their impacts on the existing COTS management (whether it will become more efficient and effective);
- their underpinning knowledge base and rationale (whether these are judged to be robust and logical);
- their impacts on Reef communities (whether these will be positive or negative);
- whether or not they are considered morally right, socially just, and contribute to the systemic changes necessary to create better human-environment relationships.

4.3.2 Maintaining social licence

These findings have direct implications for the design, deployment, and communication of COTS management. The inductive social licence framework can help Reef managers strengthen public support for COTS management on the GBR. It treats social license for COTS control not as a box to be ticked but as a continually changing, individually determined, weighted evaluation of the positives and negatives of the intervention in terms of perceptions of ethical responsibility, knowledge and rationale, management effectiveness, and socioeconomic benefits.

Trust in underlying knowledge and rationale as well as trust in scientific solutions for the GBR are major determinants of support for COTS control. The relationship between support for culling and trust in scientific knowledge and solutions suggests management programs should draw on, contribute to, and communicate scientific understanding of COTS' ecology, social and environmental impacts. Reef managers could provide well-informed, continually updated, access to relevant information on COTS and COTS management for the public and GBR stakeholders based on the best science, but not necessarily in scientific language or format.

The importance of ethical considerations around COTS management highlights a need for more deliberate and active participation by society and communities. COTS are rightly considered by many GBR community members as an endemic GBR species, begging the question what gives humans the right to take it out of the Reef. On the other hand, people also care about the Reef and acknowledge we have the responsibilities to protect it from a species that is eating coral in pest proportions. Ethical responsibility to the Reef is also related to questions about the extent to which humans are responsible for COTS outbreaks through pollution, overfishing, and other impacts. There is a lot of ambiguity here and could be classified as a moral-ethical dilemma. Such dilemmas cannot be solved by scientific papers but likely require public involvement and negotiation.

National survey data suggest that evidence of direct and immediate impacts on GBR health may be a more powerful motivator of support for COTS control than messaging around indirect contributions to the management of complex and longer-term threats such as climate change (**Figure 3**). This important finding may be associated to the underlying social licence themes of ethics and knowledge. In other words, if people perceive knowledge gaps and uncertainties as high they may perceive non-intervention as the more ethical choice. While neither the interview nor survey data suggest that uncertainty, scepticism, or lack of

understanding about the long-term contribution of COTS control to climate resilience is fomenting opposition, they do suggest more immediate benefits are playing an important role in maintaining social licence.

4.3.3 Regulatory challenges

Using novel COTS control in the GBR presents a complex regulatory challenge, involving multiple agencies and a multifaceted permission system. The introduction of methods, such as semiochemicals and predator control, adds to this complexity. These methods are considered high-risk and can trigger a variety of regulations and policies. Ensuring compliance with these regulations will require careful navigation of the permission system to understand and meet the requirements for high-risk methods like semiochemicals and predator control.

The use of semiochemicals introduces additional challenges, as the regulatory framework of the APVMA is primarily designed for an agricultural context. Applying for permits to use semiochemicals in a marine environment like the GBR can be difficult, as the unique characteristics of the marine environment and the specific nature of COTS control methods may not be fully addressed within the existing framework. This could potentially lead to delays in permit approvals or additional requirements for demonstrating the safety and efficacy of the proposed methods.

Aligning the APVMA's regulatory process with the specific needs of COTS control in the GBR is a significant challenge. It requires careful planning, robust scientific evidence, and ongoing engagement with the APVMA and other stakeholders. This alignment is crucial to ensure that the proposed methods are effective, safe for the marine environment and compliant with all relevant regulations.

A key recommendation to address these challenges is fostering collaboration between the Reef Authority and the APVMA. As both agencies would be assessing applications for the use of semiochemicals in the GBR, their collaboration could streamline the approval process, reduce potential redundancies, and ensure a more coordinated and effective approach. This collaboration could also facilitate the sharing of knowledge and resources, leading to more informed decision-making and potentially accelerating the approval of safe and effective COTS control methods.

4.4 Research outputs

CCIP-R-08 has produced the following final outputs:

Published manuscripts

- Lockie S, Bartelet H, Ritchie B, Sie L, Paxton G (2024) Quantifying public support for culling crown-of-thorns starfish (*Acanthaster* spp.) on the Great Barrier Reef. *Conservation Science and Practice*, 6(11), e13252. <https://doi.org/10.1111/csp2.13252>
- Harris R, Barnard d'A, Paxton G, Lockie S, Craik D, Cummins S, Wang C, Motti C (2025) The future of utilising semiochemical pest control methods to manage the destructive crown-of-thorns starfish outbreaks on coral reefs. *Biological Conservation*, 302, 110984. <https://doi.org/10.1016/j.biocon.2025.110984>
- Bartelet H, Paxton G, Lockie S, Backhaus V, Brooksbank L (2025) A social license to operate theory for lethal control of crown-of-thorns starfish on the Great Barrier Reef. *People and Nature*, 7: 2838–2851.
- Bartelet HA, Lockie S, Demeter C, Ritchie BW (2025) Public support for novel crown-of-thorns starfish (*Acanthaster* spp.) control interventions using semiochemicals on the Great Barrier Reef. *Coral Reefs*, 1–17.

Manuscripts in preparation

- Bartelet HA, Lockie S, Paxton G, Ritchie BW, Demeter C (in preparation) Quantifying and qualifying public support for the use of semio-chemicals to control crown-of-thorns starfish populations on the Great Barrier Reef. *Ecology and Society*.
- Paxton G, Lockie S, Bartelet HA, Brooksbank L (in preparation) Exploring the vocational dimensions of environmental management: a case study on crown-of-thorns starfish culling on the Great Barrier Reef. *Qualitative Sociology*.

5. RESEARCH SYNERGIES AND NEXT STEPS

In principle, this project has provided a pathway for public and stakeholder perceptions to feed into all CCIP programs. Known synergies include:

- CCIP-R-09 (Backhaus et al. 2025): Reef Traditional Owner co-design, values and governance assessment. Overlap of objectives (specifically, documenting perceptions of COTS management and the distribution of social, cultural and economic outcomes) and opportunity for comparative analysis.
- CCIP-R-10 (Ceccarelli et al. 2025) and CCIP-R-11 (Motti et al. 2025). Public and stakeholder values information are useful for assessing the political and social sensitivities for reef fish predator management and semiochemical attractant scenarios.

Collaboration with the RRAP Engagement and Traditional Owner Engagement Subprogram, Social Licence and Monitoring project, has afforded the opportunity to:

- Share learning across programs.
- Integrate activities, where appropriate, to minimise demands on the public and stakeholders.
- Involve more Traditional Owners throughout the GBR catchment.

The following key priority areas for further R&D have emerged through this project:

- Exploring in more depth, through interviews and surveys, how the Australian public and GBR community members, evaluate the trade-offs between ethical considerations, practical outcomes, uncertainty/risks, and co-benefits, as related to COTS management.
- Focus on the Australian public and GBR communities' preferences for Reef prioritisation as related to COTS management. What should be the primary drivers to prioritise Reefs for COTS control, e.g. ecological, economics, and/or cultural values. Research here can provide people with different scenarios to elicit their preferences.

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7. HUMAN RESEARCH ETHICS

Ethics clearance to conduct the RRAP National Survey was obtained through the University of Queensland Human Research Ethics Committee (ref: 2018001183) with reciprocal approval granted by the James Cook University Human Research Ethics Committee (ref: H9172).

Ethics clearance for Regional Deep Dive interviews was obtained from James Cook University's Human Research Ethics Committee in June 2021 (ref: H8435).

8. DATA ACCESSIBILITY

The data that has been used for the research is confidential. Only researchers named under the ethics approval agreements are permitted to access the data.

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APPENDIX A – RRAP NATIONAL SURVEY

The RRAP National survey explored public and community attitudes toward existing and prospective management interventions in the Great Barrier Reef (GBR). Surveys were conducted in 2018, 2022 and 2024 involving over 12,000 Australian residents to explore support both for current management practices, and the potential introduction of novel management practices designed to accelerate coral adaptation to climate change and/or recovery from disturbance.

This report draws primarily on the 2024 survey ($n = 4,201$). In the quasi-experimental design, each respondent had the opportunity to respond to a specific approach/technology (scenario) rather than comparing the full suite of eight interventions that the research explored. This report uses a subsample of 1,061 surveys focused on two approaches to the management of COTS. The surveys requested information on deployment support rates for these approaches as well as on demographic and contextual information associated with the respondent. Ordinal logistic regression models were used to explore how different demographic, knowledge, and perceived risk indicators affected support for both small-scale outdoor trials and large-scale outdoor deployment across the GBR.

Sampling

Our main sampling strategy consisted of two primary sub-groups, comprising of:

- An Australia-wide study of residents across all states and territories (national sample).
- A specific sample of residents located within 50 kilometres of the GBR coastline (resident sample).

The surveys were distributed via a market research company, using online panels. A stratified sampling method was used, and representativeness was maintained by using Australian census data quotas (based on gender, age, and location) for the *national* sample and soft quotas for Queensland as a guide for the *resident* sample. A more detailed description of the sampling methodology is available elsewhere (Bartelet et al. 2025).

About a third of our survey respondents for both conventional and COTS control using semiochemicals consisted of survey participants that lived in closer proximity (<50 km) to the GBR, and a relatively even balance was achieved in terms of age, gender, and education. About a tenth of both samples consisted of participants that classified themselves as Aboriginal and/or Torres Strait Islander. Sixty percent of respondents had ever visited the Reef. Most respondents were politically affiliated with either the Australian Labor Party or the Liberal-National Coalition.

Public support for COTS control technologies

We used survey participants' stated support for different approaches/technologies with regards to four different scales of deployment (levels of development or possible use), using the respondents' level of agreement with the following statements:

- I support the funding of research into this approach/technology.

- I support indoor lab research into this approach/technology.
- I support small-scale outdoor trials of this approach/technology in selected parts of the GBR.
- I support large-scale outdoor use of this approach/technology across the GBR.

The level of agreement was measured using a 7-point Likert scale including (1) strongly disagree; (2) disagree; (3) slightly disagree; (4) neither agree or disagree; (5) slightly agree; (6) agree; and (7) strongly agree. Questions regarding support for COTS control were asked following a brief description of the COTS control approach/technologies and of risks and benefits associated with their use.

Perceived risks and benefits of COTS control technologies

Table A 1. Perceived risks and benefits of COTS control approaches¹.

Statement representing highest potential risk (value of 1)	Statement representing the most benefit (value of 7)
Ethics and Safety (Cronbach's $\alpha = 0.850$)	
Use of this technology is unethical	Use of this technology is ethical
This sort of technology will be unsafe for ecosystems	This sort of technology will be safe for ecosystems
This technology will be unsafe for people	This technology will be safe for people
Feasibility (Cronbach's $\alpha = 0.864$)	
This technology is not needed for long-term health of the Reef	This technology will be critical to the long-term health of the Reef
The benefits of this technology will be too small to justify the cost	Likely to be cost-effective when fully developed
The technology is unlikely to work	The technology looks like a promising option to help the Reef
The technology will only help small sections of the Reef	This technology should help large sections of the Reef
Social Impact (Cronbach's $\alpha = 0.897$)	
This technology will compromise cultural values associated with the Reef	This technology will enhance cultural values associated with the Reef
This technology will damage Reef industries such as tourism	This technology will provide new opportunities for Reef industries such as tourism
This technology will have negative impacts on communities living near the Reef	This technology will have positive impacts on communities living near the Reef

¹ Measured using a 7-point Likert scale in which 1 represents agreement with the statement representing the highest potential risk and 7 represents agreement with the statement representing the highest potential benefit.

Twelve additional questions were asked concerning potential risks and benefits of each COTS control approach (**Table A 1**). These questions consisted of two opposing statements, to which the respondent should indicate their level of support, using a 7-point Likert scale. A value of 4 indicated neutrality between the opposing statements. The potential risk and benefit variables were categorised under the higher-level constructs of Ethics and Safety, Feasibility, and Social Impact that were found based on a larger sample with novel interventions on the GBR (Demeter et al. in review). For each higher-level construct, we created a novel variable using a weighted average of the specific risk and benefit variables that were clustered under it. We tested the internal reliability of the scales by calculating the Cronbach's alpha (α) for the variables that were used within each scale. Cronbach tests were done on the combined sample ($n = 1,061$) including both surveys for conventional and COTS control using semiochemicals. All scales showed internal reliability with Cronbach's α above 0.70 (**Table A 1**). We also noted that the Cronbach α for the three scaled variables (Ethics and Safety, Feasibility, and Social Impacts) was 0.907, indicating significant overlap between different dimensions of risk as perceived by Australian residents. For example, respondents may perceive that technologies that are less ethical and safety may also be less feasibility or socially beneficial (Demeter et al. in review).

Predictors of support for scaled deployment of COTS control technologies

We used four different groups of predictors to test which determinants were most strongly associated with support for the scaled deployment across the GBR of conventional and COTS control using semiochemicals (**Table A 2**). The four groups of predictors included demographics, political affiliation, knowledge, and the risk and benefit scales shown in **Table A 1**.

Table A 2. Explanatory variables used to explain support for the large scale-scale deployment of conventional and COTS control using semiochemicals.

Variable	Description	Unit of measurement
Demographics		
Reef proximity	Distance of participant's residence from the GBR.	(0) >50 km from GBR (1) <50 km from the GBR
Age Group	Participant's age group; initially measured using six levels.	(0) <50 years (1) >50 years
Gender	Gender of participant.	(0) Female (1) Male
First Nations	Participant identified as Aboriginal and/or Torres Strait Islander.	(0) No (1) Yes
Education	Participant had an undergraduate and/or postgraduate degree; initially measured using five levels.	(0) No (1) Yes
Political		

Political affiliation	Political party to which participant considered themselves close, if any.	(0) Australian Labor Party (1) Australian Greens (2) Liberal-National Coalition (3) Independents (4) Other
Knowledge		
Reef visitation	Participant had ever visited the GBR.	(0) No (1) Yes
Knowledge (COTS) ¹	Whether participant was able to correctly answer that Crown-of-thorns starfish are <i>not</i> an introduced species now invasive on the Great Barrier Reef.	(0) No (1) Yes
Knowledge (Technology)	Respondent's self-rated knowledge about the approach/technology	From 1 'know very little' to 10 'know a lot'
Risk and benefits		
Ethics and Safety (Table A 1)	Weighted average of whether respondent perceives technology as (1) ethical in use; (2) safe for ecosystems; and (3) safe for people.	7-point Likert scale from statement representing highest potential risk (1) to highest potential benefit (7) [treated as continuous]
Feasibility (Table A 1)	Weighted average of whether respondent perceives technology as (1) critical for long-term health of the Reef; (2) likely to be cost-effective when fully developed; (3) a promising option to help the Reef; and (4) having benefits for large sections of the Reef.	
Social Impacts (Table A 1)	Weighted average of whether respondent perceives technology as (1) enhancing cultural values; (2) providing new opportunities for Reef industries; and (3) having positive impacts for Reef communities.	

¹ Please read the following statements and select one of the following options: true or false. **Crown-of-thorns starfish are an introduced species now invasive on the Great Barrier Reef.**

Analysis

Student's t-test, with a two-tailed distribution and assuming two-sample equal variance (homoscedastic), was used to test whether there were significant differences between the mean values of the four different scales of deployment of the two COTS control technologies, as well as for the mean scores on the risk and benefit scales (**Table A 1**). A binary logistic regression model was then used to test for differences in knowledge about COTS' non-introduced status across social demographics, including Reef proximity, age, gender, First Nations' status, education, and visitation as predictor variables.

Ordinal logistic regression was used to test which of the predictors described in **Table A 2** had the strongest association with support for scaled deployment of conventional and COTS control using semiochemicals across the GBR. Models were fit using R modelling software (R Core Team 2013), version 4.4.1, using the MASS package in R (Ripley et al. 2013). All non-binary predictors in the models were scaled using z-scores to reduce multicollinearity and to make effect sizes directly comparable (Abelson 1995). Testing for multicollinearity was undertaken through variance inflation factors using the performance package in R (Lüdtke et al. 2021). All predictors in the models had a variance inflation factor below 4, indicating low collinearity. Pseudo-R-squared values were derived by using the DescTools package, specifically the Nagelkerke (Cragg and Uhler) value, which represents the proportion of the total variability in the outcome variable that is accounted for by the model.

Overall, the models explained 25% and 28% respectively of the total variance (Nagelkerke R-squared) in support levels for the scaled deployment of conventional and COTS control using semiochemicals.

APPENDIX B – RRAP REGIONAL DEEP DIVE

The Regional Deep Dive is a comprehensive program of qualitative social research exploring the relations that local GBR communities (i.e. people living and working in proximity to the GBR) practice with the Reef, their aspirations for its future and their responses to the prospect of technologically assisted adaptation in the Reef. Between July 2021 and March 2023, 117 semi-structured interviews involving 140 participants were conducted.

The Regional Deep Dive used an open-ended, exploratory interview approach to allow participants to discuss their experiences in detail and raise issues important to them. The majority of interviews were conducted face to face and the average length of the interviews was one hour. The interviews covered four broad topics:

- Existing relationships to the Reef.
- Perceptions of the Reef's future, including ecological change and threats to it.
- Views on existing management and the prospect of technological interventions to support Reef protection.
- Views on community and stakeholder engagement to support Reef management and restoration.

Interviews were conducted in two phases to enable research protocols to be revised as needed. During the first, 70 interviews were conducted between July and December 2021, and in the second phase, an additional 47 interviews were conducted between November 2022 and March 2023.

Research participants

Researchers adopted a purposive sampling strategy, and Regional Deep Dive participants were recruited according to a typology of Reef communities and stakeholders used in the Reef 2050 Long-term Sustainability Plan (Commonwealth of Australia 2023). These included:

- **Reef Traditional Owners** with ongoing traditional connections to and rights over the GBR.
- **Livelihood communities** including individuals and businesses that gain income, profit or other financial benefits from the GBR.
- **Institutional stakeholders** representatives from scientific, government and community institutions.
- **Civil society communities** representing public interests in the GBR including reef management NGOs, wildlife advocates, conservationists and recreational users.

A summary of recruitment across these categories can be found in **Table A 3** below. Interviews were conducted across the GBR region, including Cairns, Townsville, Airlie Beach, Rockhampton, Gladstone and Bundaberg. A summary of recruitment by geographic region can be found in **Table A 4** below.

Table A 3. Summary of Regional Deep Dive recruitment by community category.

Participant category	1 st phase	2 nd phase	Total
Traditional Owners			
Reef Traditional Owners	6	4	10
Livelihood communities			
Commercial fishing (including coral collectors)	2	4	22
Tourism industry (e.g. reef tour operators, hotels, tourist attractions)	9	2	
Commercial transport and shipping	1	0	
Associated industries (e.g. agriculture)	1	1	
Other reef industries	2	0	
Institutional stakeholders			
Local government representatives	3	1	28
Other government bodies (State, Federal)	6	2	
Scientific organisations (universities, consultants)	5	4	
Community institutions (e.g. schools)	3	4	
Civil society communities			
Environmental and conservation advocates	12	3	57
Recreational fishers	3	3	
Reef restoration and catchment management organisations (including COTS managers)	7	10	
Broader Indigenous community	2	0	
Citizen scientists	1	1	
Other community (e.g. other recreational users – photographers, divers, boaters etc.)	7	8	
Total	70	47	117

Table A 4. Summary of Regional Deep Dive recruitment by geographic region.

Reef region (where interview was conducted)	1 st phase	2 nd phase	Total
Cairns and north of Cairns to Torres Strait islands (coded as FNQ or Far North Queensland)	41	10	51
South of Cairns to Airlie Beach (coded here as NQ or North Queensland)	24	7	31
South of Airlie Beach to southern-most tip of Reef (referred to here as Central)	1	30	31
Outside Reef region*/Encompassing whole of Reef region	4	0	4
Total	70	47	117

*these participants were interviewed outside the Reef region but worked extensively within it.

Integrating community perceptions of COTS into the RRAP Regional Deep Dive

The first phase of the Regional Deep Dive interviews commenced prior to the CCIP program, with 47 interviews completed before specific questions regarding COTS and COTS

management were included in the Regional Deep Dive interview protocol. Nevertheless, 25 of these interviews contained spontaneous accounts of COTS and COTS management. Upon commencement of the CCIP program, the scope of the Regional Deep Dive was expanded to include issues relating to COTS and COTS management. The interview protocol was updated to include specific prompts to encourage participants to share their perspectives on COTS, their impact and management as they discussed the GBR's future more broadly. A further 23 interviews were conducted in the first phase of interviews using this updated protocol, bringing the total number of first phase interviews that address COTS or COTS management to 48.

In the second phase of the Regional Deep Dive, the interview protocol was updated and additional questions designed with input from CCIP research and program leaders. Alongside views on questions about experiences and perceptions about COTS and COTS management, these sought to elicit participants' initial responses to two prospective management innovations being explored within the CCIP Response subprogram: the use of semiochemical attractants/ deterrents or the COTS predator control strategies. Researchers gave participants a brief explanation of one of these approaches and invited them to articulate their initial thoughts regarding these, with prompts used to encourage deeper consideration of the innovation (see Appendix C).

Researchers made every effort to provoke discussion regarding novel management strategies being explored under CCIP, with participants typically asked about one or both of these approaches. However, given the flexible nature of the interviews, discussion of novel COTS management was not always possible if Deep Dive participants focused on different topics and interests. Of the 47 interviews conducted in the second phase of the Deep Dive, 43 interviews included accounts of COTS and existing COTS management. In 27 of these interviews, participants were invited to consider novel COTS management strategies. Of these, 20 contain accounts of semiochemical approaches and 16 contain accounts of predator control.

Firsthand accounts of COTS management

Given the purposive nature of recruitment in the Regional Deep Dive, many participants described firsthand experience in GBR management and related industries. In the first phase of research, eight interviews contained some brief accounts of past involvement in COTS management through monitoring or control activities. In the second phase, researchers interviewed another eight participants involved in COTS detection and management under the COTS Control Program at the time of the interview. This enabled the opportunity to gain a deeper understanding of these participants' firsthand experiences of the COTS management program and understand the social and vocational co-benefits gained through participation in the Program. As well as the questions contained in the Regional Deep Dive protocol, researchers asked informal, open-ended questions to elicit discussion of participants' vocational histories, their current experiences in COTS management and their aspirations for the future.

Analysis

Regional Deep Dive interviews were transcribed verbatim and analysed using the qualitative analysis software NVivo. An interpretive process was used to analyse the data, drawing on the principles of thematic and narrative analysis (Babbie 2011). First, the researchers searched each interview for accounts of COTS and COTS management, classifying this material into high-level qualitative themes and categories (e.g. 'Encountering COTS', 'Descriptions of COTS', 'Descriptions of COTS management' etc.). Researchers then followed a process of 'open coding' under each category, paying attention not just to what was being said but patterns in participants' narrative strategies (i.e. the logics used to form accounts and express views) and use of rhetoric (language intended to persuade and influence). This allowed researchers to closely trace the processes whereby participants drew upon existing experiences and knowledge in order to imagine and articulate views about something new and unfamiliar. While the results described here are exploratory and descriptive, they provide rich insights regarding common areas of uncertainty, ambiguity and emotionality, which can form a valuable basis for more comprehensive risk and social impact assessments. They are not intended to be statistically representative of broader populations or to explain any causes relating to community perceptions.

An additional round of analysis was undertaken with the aim of exploring the key foundations in a 'social license to operate (SLO)' unique to COTS control. Following an inductive approach (Bryant & Charmaz 2007), researchers conducted a thematic analysis to identify higher-level themes emerging from the data related to participants' perceptions of COTS and COTS management. This progressively transitioned from open coding (trying to capture all relevant concepts) to selective coding focused on identifying how concepts were related and how they could be interpreted as elements of SLO. Themes represent concepts that reoccur frequently through the data and which are associated with other concepts identified through open coding (Bryant & Charmaz 2007). Further, this analysis acknowledged *a priori* that Aboriginal and Torres Strait Islander peoples (Reef Traditional Owners) have unique rights and responsibilities as recognised in the Reef 2050 Long-Term Sustainability Plan (Commonwealth of Australia 2023) and key mechanisms including Traditional Use of Marine Resource Agreements (TUMRA). This report consequently distinguishes between SLO and Traditional Owner rights and responsibilities (TORR) which is inclusive of four domains associated with Traditional Owner support for COTS management in addition to those associated with community-wide social license considerations. Reef Traditional Owners thus provided input into domains for both TORR and SLO, as neither their interests nor expertise are restricted to TORR.

APPENDIX C – REVISED REGIONAL DEEP DIVE INTERVIEW PROTOCOL

Preamble: Discussion of ethical issues, gaining informed signed consent, turning the recorder on.

Part 1: Background

First, I just get some background information about you and the work you do.

1a: Can you please tell me a bit about yourself and your history with the Great Barrier Reef?

Part 2: Likely and aspirational futures

Now, I want to explore how you imagine and anticipate the future of the Reef both up to 2050 and beyond.

2a: What do you think the most probable future for the Reef will be? What do you think the Reef will be like by 2050? What does its future look like?

Try to discuss:

- Causes and drivers (prompt for COTS and other threats)
- Implications/opportunities
- What observations/evidence/knowledge they base this scenario on
- Uncertainties

2b: What would be the best possible future for the Reef for 2050 and beyond. What would that look like? What does the best possible future look like?

Part 3: The prospect of intervention to help the Reef

Next, I want to ask you to consider a future in which human management of the Reef goes beyond the existing focus on protection and starts to include broadscale efforts to restore damaged Reef, and help it adapt to climate change.

3a: When you imagine this kind of future for the Reef, what things spring to mind?

Pay attention to and seek expansion on:

- perceived impacts to/opportunities for Reef, self, community or others
- Sources of discomfort, confusion or uncertainty
- Discordance with existing Reef values and practices

3b: How does this future feel in comparison to the other futures you described? Get more detail on dissonances/harmonies

Part 4: Specific RRAP technological interventions

Now, I'd like to focus in more detail on a few specific interventions being explored through RRAP which are:

- Enhancing the settlement of coral larvae on degraded reefs to speed up their recovery (also known as coral IVF).
- Selecting and breeding coral for heat-tolerance.
- Reproducing and growing coral in land-based aquaculture facilities for use in restoration projects.
- Reducing the exposure of reefs to solar radiation during extreme heat events using cloud brightening or fogging.

4a: When I talk about these interventions, what thoughts come to mind?

4b: What (if anything) would you need to know or see to feel confident that these interventions were being carried out for the right reasons and in the right way?

4c: Other technological options we haven't foreseen yet might become available. In your view, is technological intervention a viable option for the Reef? Why/Why not?

Part 5: Discussion of COTS, COTS management and COTS management technologies

Next, I want to talk about Crown of thorns starfish.

5a: Can you please describe your experience and knowledge of COTS on the Great Barrier Reef? Probe for connections between COTS, and what has already been said about Reef practices, values and imagined futures

5b: In your view, what role will COTS and its management play in terms of the Reef's future?

5c: There are a number of new methods and technologies being explored to manage COTS on the Reef....

These include:

- The use of pheromone/scents to attract COTS to certain areas to aid detection and manual removal (pull strategies)
- The use of pheromone/scents to repel COTS from high value areas (push strategies)
- OR
- Strategies to protect populations of animals that predate on juvenile COTS including Reef fish and invertebrates (think: various phases in the life stage)
- Strategies to augment populations of Reef predator – fish, tritons and invertebrates (predators at various stages of COTs life stage)

....When I talk about these sorts of interventions on the Reef, what thoughts come to mind?

Look for more detail on:

- Questions/uncertainties
- Imagined effect (positive and negative) to their own lives and the work they do, and their Reef practices (eg. connect it to what they have already said)
- Any effects (positive and negative) they see on other people's lives, their community, other communities

Part 6: Wrap up (5-10 mins)

6a: Is there any issue or point that you think is important that we haven't covered today?

6b: Is there anyone else who you think I should be talking to?

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