

## RESEARCH ARTICLE

# A social license to operate theory for lethal control of crown-of-thorns starfish on the Great Barrier Reef

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## Abstract

1. Outbreaks of crown-of-thorns starfish (COTS) have been recorded on the Great Barrier Reef (GBR) since 1962 and have considerable ecological and economic impact. Monitoring and control of COTS to predict, prevent and mitigate outbreaks is an important part of the ongoing protection of the GBR. We set out to develop an in-depth understanding of GBR community perceptions of COTS management and to synthesize these perceptions inductively into a social licence to operate (SLO) theory. Our study contributes to the nascent literature on factors that influence SLO in (marine) conservation contexts.
2. Informed by 1593 surveys with Australian residents and based on 117 semi-structured interviews with 140 community members living and/or working in close proximity to the Great Barrier Reef, we developed a grounded theory of the primary domains of SLO for COTS management on the GBR. These included community perceptions of (1) ethical responsibility; (2) knowledge and rationale; (3) management effectiveness; and (4) socioeconomic benefits. Our results also emphasize the need to distinguish between SLO and the unique rights and responsibilities of GBR Traditional Owners.
3. Except for the importance of socioeconomic benefits, the domains we identified differ from those found by previous studies of the mining and resource extraction industries, where SLO has been more established. Our grounded SLO Theory can be helpful for environmental managers to identify potential avenues to increase community support and social licence for environmental management programmes such as the culling of COTS.

## KEYWORDS

community perceptions, coral reef, culling, environmental management, Great Barrier Reef, marine conservation, social acceptance, Traditional Owners, wildlife management

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## 1 | INTRODUCTION

Australia has an extensive history of conflict over the culling of animals, both endemic and introduced, deemed problematic due to their impacts on ecosystem health and diversity, economic activity and/or public safety (Whisson & Ashman, 2020). While all culling programmes have the potential to evoke concern over animal welfare, cost-effectiveness and other issues, the culling of iconic, charismatic or familiar species can be particularly controversial. This is especially so with species understood as 'native' or 'endemic'—classifications that function as cultural markers of animals' right to belong in Australian environments (Franklin, 2006; Head, 2012; Trigger & Head, 2010). Actions to control locally or regionally overabundant endemic species such as kangaroos and koalas have provoked controversy over the ethics of lethal measures, their animal welfare implications, risks to other ecological or cultural values, the evidentiary base for defining the animal as problematic and the effectiveness of control programmes (McKiernan & Instone, 2016; McKinnon et al., 2018; Mo et al., 2020; Whisson & Ashman, 2020). Such conflict is not inevitable, however, and considerable research has been undertaken to understand public and stakeholder concerns and thus to inform control programme development and communication (Drijfhout et al., 2020, 2022).

Our focus in this paper is on community perceptions related to the culling of crown-of-thorns starfish (COTS) (*Acanthaster* spp.) on Australia's Great Barrier Reef (GBR). Although COTS are endemic to the GBR and other reefs across the Indo-Pacific, their predation on coral causes widespread ecosystem degradation during periodic population surges (De'ath et al., 2012; Kayal et al., 2012; Pratchett et al., 2014). For this reason, they have been actively culled in the GBR for more than 10 years and in increasingly larger numbers (Pratchett et al., 2019). Monitoring and control of COTS is a strategic action in the Reef 2050 Long-Term Sustainability Plan—Australia's overarching strategy for protecting and managing the health and resilience of the GBR (Commonwealth of Australia, 2021). This policy recognizes COTS outbreaks, alongside coral bleaching and cyclone damage, as one of three major causes of widespread coral cover decline, with COTS outbreaks the only one that can be directly mitigated through local management action (Great Barrier Reef Marine Park Authority, 2020).

The lethal control of COTS has not, to date, evoked widespread expressions of concern or debate in the public sphere. In fact, surveys of coastal residents and stakeholders in the GBR suggest that COTS are seen as a less serious threat than climate change, pollution, fishing, water quality, shipping and coastal development, leading Thiault et al. (2021) to speculate that the dominance of media discourses by debate over the relationships between climate change, coral bleaching and coal mining has served to limit public appreciation of the threat COTS outbreaks play to coral reef resilience. The absence of overt conflict should not be taken as evidence though that people are unconcerned or that conflict will not arise in the future. Community perceptions of COTS culling have not yet been explored and so understanding perceptions of the program currently in operation is a priority.

In this study, we explored community perceptions of Australia's COTS culling program using the concept of 'social license to operate' (SLO); an idea popularized in the resources industry to denote the critical role that support and acceptance from local communities or society at large play in the development and implementation of proposed and ongoing projects. Our goal is not to evaluate acceptance of the existing COTS Control Program in the GBR or to imply that its social licence is at risk. Rather, we aim to use firsthand accounts of COTS management to develop an inductive theory of SLO with potential applications for a spectrum of environmental management challenges. Drawing on both quantitative survey data and semi-structured, conversational interviews with 140 community members living and/or working in proximity to the Great Barrier Reef, we identify the key issues observed in participants' consideration of COTS control and discuss the implications of these issues for gaining and maintaining social licence. In the following section, we summarize the theoretical foundations for this concept, then detail our research approach and results.

## 2 | SOCIAL LICENCE THEORY

The idea of a social licence to operate originates in the mining industry where it is used to emphasize the importance of maintaining societal approval for the smooth running of operations and to avoid the delays and cost blowouts that can arise from conflict over a project's social and environmental impacts (Costanza, 2016; Moffat et al., 2016). SLO has since been adopted across a range of extractive industries including energy, agriculture, and forestry (Dumbrell et al., 2021) where it refers to initial and ongoing acceptance by society and local communities of certain activities (Moffat et al., 2016; Prno & Scott Slocombe, 2012).

While the SLO literature has surged in recent years, the ways it is defined and the factors considered important in its development often vary across contexts. As Brueckner and Eabrasu (2018) point out, social licence as an ongoing acceptance of a company's operations can be interpreted in myriad ways including the satisfaction of stakeholder demands, compliance with social norms, and relationship-building with communities. Understanding who holds a salient stake in a project or operation's social licence is also subject to multiple interpretations, with some focusing exclusively on stakeholders directly affected by, or with the capacity to effect, company activities while others focus on acceptance among regional and national publics (Brueckner & Eabrasu, 2018; Meesters et al., 2021).

The concept of SLO has increasingly found its way into the field of environmental management (Kelly et al., 2017; van Putten et al., 2018). A systematic review focused on the marine sector found that SLO was mostly applied to marine management and conservation, followed by aquaculture and fisheries (Kelly et al., 2017). Public expectations around environmental management and conservation generally relate to the protection and

preservation of natural landscapes and ecological processes and, in this context, SLO relates to whether society and local communities consider actions to protect the environment taken by governments, NGOs and other environmental actors necessary, effective and socially acceptable. For example, marine protected areas could affect marine livelihoods and local agency and they have thus been one of the conservation areas that has been studied using SLO (Kelly et al., 2020). According to Kelly et al. (2017) and von Essen and Redmalm (2023), however, research into the processes involved in obtaining and maintaining SLO for environmental management remains limited.

In response, Margeson et al. (2024) undertook a scoping review of the peer-reviewed marine conservation, restoration and adaptation planning literature to identify common factors in gaining or measuring public support. These included a strong sense of place that contributes to quality of life, the distribution of costs and benefits, perceived risk, trust and knowledge sharing. In the mining context, where SLO has a longer history, factors consistently associated with increased community support include economic benefits, positive impacts on social infrastructure, quality and quantity of contact between mining workers and the 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 (Dumbrell et al., 2021; Moffat & Zhang, 2014). While it is unlikely these SLO factors are directly transferable, they are suggestive of a more complex array of requirements for public support than that identified in Margeson et al.'s (2024) synthesis of early lessons from marine conservation planning.

While SLO holds promise as a concept for understanding societal responses to marine management and conservation, several aspects of its history and use warrant consideration. First, SLO became popular in the mining industry due to its pragmatic benefit to mining projects. As a concept, it not only encompasses the tacit and taken-for-granted ways that communities evaluate the legitimacy and potential harm of an operation or decision but the demonstrable dangers that proceeding without the necessary conditions of societal acceptance can have for projects (Meesters & Behagel, 2017; Ramírez-Monsalve et al., 2022). As a result, there is a risk of understanding SLO too instrumentally, and defining it only in terms of the necessary correlates that determine a project's acceptability (Dumbrell et al., 2021; Moffat & Zhang, 2014). This overlooks the social and political nuances underpinning social acceptability and the complex collective processes whereby decisions become considered legitimate. These can relate as much to the quality of decision-making processes as they do to material or social outcomes of those decisions (Brueckner & Eabrasu, 2018). Indeed, in many cases, SLO is not necessarily the ultimate or exclusive goal of marine management and conservation (Kendal & Ford, 2018). SLO can be combined with more socially inclusive approaches that prioritize co-design, co-management and local leadership. Second, there is need to recognize social heterogeneity, and the need for inclusivity, when considering SLO. Broad acceptance of a programme or project

should not be used as an excuse for ignoring minority views or for failures to address negative consequences for some communities. Third, SLO should be applied carefully in relation to Indigenous peoples, who have unique rights and responsibilities in addition to those shared with other community members (Lyons et al., 2023; Lyver et al., 2019); rights that the SLO review studies referred to above fail to acknowledge. Finally, in all cases, support for a programme or project can change over time, so it is important to consider how SLO can be maintained.

## 2.1 | Background and study sites

Comprising over 2500 individual reefs and stretching 2300 km along the coast of northeast Australia, the GBR is the world's largest reef system and recognized for its outstanding universal value as a site of extraordinary beauty, biodiversity, evolutionary significance and scale. As a biocultural landscape, it is home to over 70 Aboriginal and Torres Strait Islander peoples with Traditional Ownership rights and responsibilities (Jarvis et al., 2019). The economic, social and icon asset value of the GBR has been estimated at AUS\$56 billion with 64,000 jobs in industries such as fishing and tourism and an annual contribution to the Australian economy of AUS\$6.4 billion (Deloitte Access Economics, 2017). Population outbreaks of COTS have been recorded in the GBR since 1962 and have had considerable ecological and economic impact (Pratchett & Cumming, 2019). The first manual COTS control programmes were implemented in the Indo-Pacific in the 1960s (Birkeland & Lucas, 1990; Yamaguchi, 1986). Since then, programmes have become more efficient and effective, as in situ lethal chemical injections replaced physical removal and disposal, single-shot injection methods were developed, and new chemicals such as bovine derivatives, vinegar and lime juice reduced the risk of adverse ecological impacts (Boström-Einarsson & Rivera-Posada, 2016; Moutardier et al., 2015; Pratchett et al., 2019; Rivera-Posada et al., 2014).

Since 2012, the Australian Government has invested over \$100 million in a COTS Control Program delivered by the Great Barrier Reef Marine Park Authority (GBRMPA) in partnership with a range of stakeholders. The programme is guided by a Strategic Management Framework, with vessels and trained crews that undertake pest surveillance and culling across reefs of high economic and ecological value (Great Barrier Reef Marine Park Authority, 2022b). Currently, six vessels operate between Cooktown and Gladstone, managing COTS across more than 150 reefs every year. The goal of the program is not to eradicate the starfish, but to reduce and maintain COTS numbers below outbreak levels so that their environmental impact is minimized (Great Barrier Reef Marine Park Authority, 2020). Since 2018, the programme has implemented an Integrated Pest Management approach that combines single-shot injection methods with a structured decision process and ecologically informed culling targets, linked to monitoring and surveillance systems as well as to ongoing data collection and analysis (Fletcher et al., 2020; Plagányi et al., 2020; Westcott et al., 2016). This has

resulted in more effective deployment of control effort, with emerging evidence that this approach effectively reduces COTS numbers and improves coral cover (Castro-Sanguino et al., 2023; Westcott et al., 2020).

### 3 | METHOD

Our study draws on quantitative surveys and qualitative interview data that were collected as part of a broader study examining community perceptions of current and potential management interventions in the GBR as part of Australia's Reef Restoration and Adaptation Program (RRAP).

This study is informed by longitudinal data from surveys conducted in 2018, 2022 and 2024 with a combined sample size of 1593 respondents focused on public support for COTS management. Results from the 2018 and 2022 surveys have previously been reported by Lockie et al. (2024). A stratified sampling strategy was employed to target two key groups: (1) Australian residents across all states and territories (national sample); and (2) individuals residing within 50km 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. We measured each respondent's support for COTS management using their agreement with the following statement, *I support large-scale outdoor deployment 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 (see [Appendix A](#) in the [Supporting Information](#)). Here we present descriptive data on differences in public support levels across time and between our samples with GBR and national residents.

Our grounded theory of the primary domains of SLO for COTS management on the GBR was based on qualitative interview data gathered between late 2021 and early 2023. Specifically, 117 interviews involving 140 participants were conducted as part of a larger investigation of how community members living proximate to the Great Barrier Reef perceive 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. All were either living and/or working within the GBR catchment<sup>1</sup> and were identified through their membership of

four broad categories: (1) Reef Traditional Owners (10 participants); (2) livelihood stakeholders involved in commercial enterprises such as Reef tourism, fishing and coral collecting/aquariums (30 participants); (3) institutional stakeholders representative of public and community institutions with interests in the Reef (i.e. government, research and scientific institutions) (28 participants); and (4) civil society stakeholders including non-government advocacy, conservation and marine management organizations and recreational users such as anglers, snorkelers/SCUBA divers and photographers (49 participants). It should be noted these categories were only used for the purpose of ensuring diversity in the sample. They are of limited analytical use due to the qualitative nature of our study, the small sample size and the fact that many participants belonged to more than one category.

With few exceptions, interviews were conducted face-to-face at a location suggested by the participant. Questions were open-ended and encouraged 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, and the insights outlined in this paper draw from accounts in these interviews relating to COTS and COTS management. In some interviews, these insights came up spontaneously while in others they were prompted by asking, (1) *can you please tell me about your knowledge/experience of COTS in the Reef?* (2) *in terms of existing management arrangement, can you please tell me something about your perspectives on COTS management?*

All interviews were recorded, transcribed and imported to NVivo software. Analysis was informed by constructivist grounded theory (Bryant & Charmaz, 2007; Corbin & Strauss, 1942; Glaser & Strauss, 1967) and aimed to develop an SLO theory inductively rather than from prior theoretical frameworks. We used a thematic analysis in which we aimed to identify any higher-level theoretical constructs (domains) that emerged from the data as being related to participants' perceptions of COTS and COTS management. To do so, we progressively transitioned from open coding (trying to capture all relevant concepts) to selective coding, where we identified which concepts were related and how these related concepts could be interpreted integrally as a domain of SLO. Domains are those that reoccur frequently within the data and are increasingly associated with other concepts that have been identified through open coding (Bryant & Charmaz, 2007). A detailed schematic overview of our coding process (that is, of how open and selective coding informed identification of higher-order SLO constructs or domains) is provided in [Appendix B](#) in the [Supporting Information](#).

Our analysis of the data acknowledges a priori that Aboriginal and Torres Strait Islander peoples (Reef Traditional Owners) have unique rights and responsibilities (Ignace et al., 2023; Short, 2007; United Nations, 2007) as recognized in the Reef 2050 Long-Term Sustainability Plan (Commonwealth of Australia, 2021) and key mechanisms including Traditional Use of Marine Resource Agreements (TUMRA) (Great Barrier Reef Marine Park Authority, 2022a). We consequently distinguish between SLO and Traditional Owner rights and responsibilities (TORR) which is inclusive of four domains

<sup>1</sup>Face-to-face interviews were carried out in Cairns, Innisfail, Townsville, Airlie Beach/Proserpine, Mackay, Rockhampton, Gladstone and Bundaberg. A small number of online interviews were conducted with participants located in remote areas or outside the Reef regions.

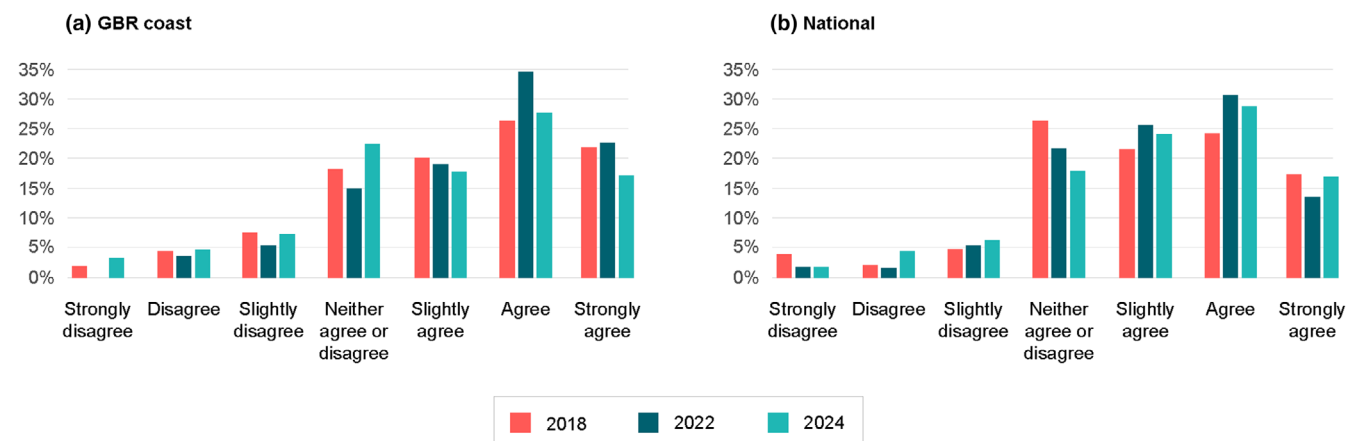
associated with Traditional Owner support for COTS management in addition to those associated with community-wide social licence considerations. Reef Traditional Owners thus provided input into domains for both TORR and SLO, as neither their interests nor expertise are restricted to TORR.

## 4 | RESULTS

### 4.1 | Tentative support for COTS management observed in surveys with GBR residents and the broader Australian public

We found consistent support across time for COTS management among both national and regional (GBR coast) respondents (Figure 1). Across all years, we found little outright opposition to the scaled deployment of COTS control across the GBR. Nevertheless, a meaningful fraction of both national and GBR coast residents were either neutral or in slight agreement, indicating more tentative than full support. The fraction of respondents that showed tentative support was, respectively, 38%, 34% and 40% across our survey years for the regional (GBR coast) sample and 48%, 47% and 42% for the national sample. Mean support levels were closely clustered around *slight agreement* (5 on a 7-scale Likert) in both surveys across all years. The regional survey showed respective mean support levels across the survey years of 5.2, 5.4 and 5.0, while the national sample showed mean support levels of 5.0, 5.1 and 5.1.

The ambiguities evident in the levels of support expressed by national and GBR coast residents invite additional exploration of the factors that influence perceptions of COTS management and its acceptability to communities. The following section outlines the primary themes evident in qualitative interviews with GBR community members and which form the basis of our grounded SLO theory.



**FIGURE 1** GBR and Australian residents' support for large-scale deployment of COTS control across the GBR by year of survey. A regional survey (GBR coast, panel a) was conducted with, respectively, 160, 168 and 152 GBR residents living within 50km from the Great Barrier Reef coastline across the years 2018, 2022 and 2024. A national sample survey (panel b) was conducted with, respectively, 335, 392 and 386 Australian residents living further than 50km from the Great Barrier Reef coastline across the years 2018, 2022 and 2024.

### 4.2 | TORR and SLO domains associated with COTS management on the GBR

The higher-order (theoretical) SLO constructs (domains) identified through thematic grounded theory analysis are shown in Figure 2. Each domain is substantiated in more detail below through a summary of topics discussed in relation to that domain and illustrated



**FIGURE 2** High-level overview of TORR and SLO domains associated with crown-of-thorns starfish (COTS) management on the Great Barrier Reef. Domains were derived using Grounded Theory based on 117 semi-structured interviews with 140 GBR community members. The arrow from TORR to SLO shows that acknowledging and honouring TORR was also identified as a domain of SLO.

with quotes from interview participants. This section provides inductive evidence of the character and importance of each TORR and SLO domain with discussion of relationships between the domains and their connections to the literature deferred to the following section (Section 5).

#### 4.2.1 | Traditional owner rights and responsibilities

Reef Traditional Owners talked about their aspirations to be more involved in the management of Sea Country including through participation in COTS management. Currently, Reef Traditional Owners are often limited to work on land, which could be partly explained by the lack of ownership of or access to boats. The incorporation of Indigenous knowledge within the COTS Control Program was also discussed and focused on holistic thinking, cultural focus and the inclusion of traditional management practices. In the quote below, a Reef Traditional Owner describes how Western and Traditional knowledge could complement each other:

Western and Traditional sciences are different. I think if we can combine the two, but not like with all our traditional knowledge they can gatekeep it, but let some of it out, and then with the Western science we can use that, but also put in our traditional practices and knowledge in a way we can act on the collaboration.

[Reef Traditional Owner]

Reef Traditional Owners emphasized that getting consent to enter their Sea Country for COTS management or other GBR activities should be a minimum requirement but one which is not yet honoured. It is also deemed necessary to engage Reef Traditional Owners early in the GBR management process, which would necessitate some form of co-management. In the quote below, frustration with the way in which Reef Traditional Owners are currently engaged is expressed:

I think the main issue making sure Reef Traditional Owners are involved at the start, not in the middle or just at the end just for photo opportunities.

[Reef Traditional Owner]

In Figure 2, we have drawn an arrow from the TORR domains to the SLO domains to show that the acknowledgement and honouring of TORR was also found to be an important dimensions of non-Traditional Owner support for COTS and broader GBR management. That is, the desire to involve Reef Traditional Owners more in COTS management was explicitly stated by two non-Indigenous interview participants representing local government bodies and livelihood communities, as exemplified by the quote below:

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]

Moreover, in terms of broader GBR management, participants across all community groups expressed the need for increased Traditional Owner leadership in GBR management, as reported in Lockie et al. (2025). This emphasizes that the Australian public's general awareness and expectations about honouring the unique rights of Reef Traditional Owners is becoming increasingly important in SLO considerations.

#### 4.2.2 | SLO for COTS control

Interview participants discussed a wide range of topics relating to COTS and COTS management. From these discussions, we were able to identify four domains around which participants considered COTS management and articulate their views on it. We understand these four domains as key factors in ongoing dialogue around the SLO of COTS management (Figure 2). Rather than instrumental objectives, these are better understood as primary points for engagement and building the quality of relationships and discussions around COTS management.

##### *Ethical responsibility*

Based largely on an understanding of COTS as naturally occurring predators on coral reefs, the ethical complexities of their lethal removal were a central consideration in participants' discussions of COTS management. Uneasiness around the definition of COTS as a problem in the GBR was expressed in 16 interviews, with participants often aware of the damage caused by COTS outbreaks but still moderating their language about the animals. In the quote below, for example, a participant draws a careful distinction between COTS and invasive lionfish:

I think we've been fairly fortunate that we haven't had, say like the Bahamas, the explosion of lionfish or whatever. We haven't had any of those examples, other than COTS, but they're not a pest species, we know they're a naturally occurring predator that's been here probably as long as the coral itself.

[Institutional stakeholder]

In 17 interviews, human activities, particularly agriculture and fisheries, were framed as underlying drivers of COTS outbreaks. As participants acknowledged both the endemic status of COTS and

human responsibility for their proliferation, they emphasized the obligation this necessitated on the part of humans and human social systems, as exemplified below:

...What do we do here as human beings? Mother Nature will take its course but we're helping Mother Nature along in regard to the struggle that it may be having thanks to global climate, chemicals from the farmers, people walking on the reef, all of the above.

[Civil society stakeholder]

While our results show that the Reef communities from which we sampled were relatively knowledgeable in relation to COTS, two participants (one from the tourism industry and one from a community institution) expressed concern about confusion they perceived among broader publics about the status of COTS. Specifically, they suspected, treatment of COTS as a pest may lead members of the public to conclude they are an invasive species.

#### *Knowledge and rationale*

The knowledge and rationale behind COTS management was a consideration observed in 39 interviews with community members. Interview participants discussed the limits to current understanding of the causes and consequences of COTS outbreaks and COTS management, sometimes discussed together with a level of doubt about whether there is sufficient understanding to justify and inform culling. Participants discussed four primary sources of uncertainty in relation to COTS control including the underlying causes of outbreaks, the GBR's ability to recover naturally, the potential for unintended ecological consequences and historical evidence of COTS proliferation.

The most common source of doubt concerning the knowledge and rationale behind COTS culling related to the underlying causes of COTS outbreaks, which was discussed in 25 interviews. Below, an interview participant from a scientific organization provides an overview of the three prevailing hypotheses:

And I guess there's...three prevailing hypotheses. This is natural phenomena, akin to what happens with sea urchin outbreaks, and now their reproductive biology suggests that that's definitely possible. And then there's the nutrient idea that has been the dominant one for a very long time and then there's the predator exclusion idea, which I think is starting to gain momentum again.

[Institutional stakeholder]

According to interview participants, it seems that scientific doubt about the role of nutrient runoff on COTS outbreaks has grown over time as it became clear that COTS outbreaks are occurring (e.g. The Swains), or even starting (around Lizard Island), in regions with limited to no exposure to agricultural runoff. In terms of predator exclusion, an interview with a participant from a scientific organization

brought up scientific evidence that shows COTS numbers are significantly higher on fished reefs versus protected reefs. Other participants also discussed uncertainty about the effect of predator fish on juvenile COTS, as well as about the role of the Giant Triton snail in predating on adult COTS. Finally, participants discussed uncertainty about the role of a warming ocean on COTS outbreaks and the limited scientific understanding we have about the larval phase of COTS, which they argued to be of critical importance for their overall proliferation.

Nine participants expressed doubts about the long-term impacts of COTS on coral reefs, given the GBR's natural ability to recover even from severe outbreaks. They acknowledged that reefs can be severely affected by COTS outbreaks but argued they are able to bounce back, with some participants mentioning a recovery time of around 5–7 years. Some participants also emphasized that while COTS outbreaks are severe, not all coral species are equally affected, as exemplified by the following quote:

I'm not too worried about crown-of-thorns...I've seen what they do. It's terrible. They literally strip the whole reef, but they leave some portions of the colonies remaining generally, and the reef can recover and they're not taking [all] of the species as well.

[Civil society stakeholder]

In contrast, other interviews described COTS as a '*massive issue*' and '*our number one biggest threat*' with the ability to undermine the GBR's resilience:

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]

Eleven participants discussed the potential for unintended consequences should COTS control affect natural ecosystem processes on the GBR. One of the primary topics of discussion related to the effect of culling on the natural outbreak dynamics of COTS and how intervention in outbreaks might impact this over time. In the quote below, a reef manager describes the effects of intervention on COTS populations following inherently balanced—but easily disrupted—'boom-and-bust' cycles:

...what it seems to be doing is keeping the levels of crown-of-thorns at a chronic level and not allowing them to do their normal acute thing and then their 'bust' thing, which is what we've observed over years. So, it has its aesthetic use doing that, but otherwise, I

think personally that the Reef has evolved in ways to cope with the crown-of-thorns....

[Institutional stakeholder]

Finally, four participants expressed uncertainty about whether there is evidence to support the view that COTS outbreaks have proliferated over time, or whether they are part of a natural cycle, as exemplified by the following quote:

COTS first arose back in the early '80s or '70s even... And, you know, it's been the—I don't know, maybe they increase populations, but the only evidence seems to be that bit of modelling work or work to clean the active. I don't know if there's other evidence now that—I've been out of that field a while.

[Institutional stakeholder]

### *Management effectiveness*

Thirty-one participants discussed topics associated with the effectiveness of COTS management on the GBR. The perceived effectiveness of culling was influenced by several factors, including the visibility of results (9 interviews), the availability of other solutions to reduce COTS populations (9 interviews), the level of innovation (6 interviews), the scale of the management programme (7 interviews) and the perception of COTS as a controllable threat through management (5 interviews).

Participants discussed how the lack of visibility of results was associated with the fact most people and community members are not regularly in GBR waters to experience the actual COTS problem and to see if it is improving, as exemplified by the following quote:

People don't know what it is and because people aren't divers, they don't know what it is. When you can see things every day in your face you go I can see that like introduced weeds, people can say I see it every day but stuck under the water you don't see it.

[Civil society stakeholder]

In contrast, a participant from the tourism industry expressed concerns regarding the potential for social media to exaggerate the severity and extent of COTS outbreaks.

Some interview participants were grappling with the question of how they should evaluate the effectiveness of control, whether just looking at the culling numbers is the right measure of success, as exemplified by the following quote:

I don't know how well it works, I just know that the numbers of COTS that are getting pulled out, it sounds better than if they weren't getting pulled out.

[Civil society stakeholder]

Interview participants expressed the view that the effectiveness of culling would be improved through parallel improvements in non-lethal measures including fisheries management and water quality programs. The importance of innovation in COTS control was also emphasized, participants discussing both improvements they have seen in the past and potential for continued innovation. For example:

It just means increasing the investment, increasing the way in which COTS control was carried out, you know, more boats, more people, different—more effective methodologies. And that's what's happened.

[Civil society stakeholder]

With respect to innovation, participants also discussed the potential for artificial intelligence, machine learning and underwater drones to contribute to more cost-effective COTS management.

Participants expressed a need to manage expectations regarding the effectiveness of COTS control at a large scale:

We're never going to be able to get on top of all of them and it's going to be an ongoing issue unless we address the real problem, which is climate change in my opinion I think in the meantime it's a really good way of reducing one of the pressures on the reef. But there's only six to seven boats out there at any one time across the whole Great Barrier Reef and we can't really expect to control all those populations.

[Livelihood stakeholder]

Finally, five interview participants discussed what they perceived as the effectiveness of COTS culling in having transformed the COTS problem into a manageable threat by controlling severe population outbreaks, as exemplified by the following quote:

Oh, I mean, well that program's been running for years, the COTs program. So, I mean, that seems to be reasonably successful, and I think they're probably running out of places to go and chase crown-of-Thorns. Obviously, you're going to get a little here and there, but that seems to be well and truly under control.

[Livelihood stakeholder]

### *Socioeconomic benefits*

In 25 interviews, there was at least some discussion of the socioeconomic dimensions of COTS control, often discussed as positively or negatively contributing to perceived support for culling. In terms of the scale of management, 12 interview participants discussed the positive impacts COTS control has in terms of protecting local tourism sites from reef degradation that could affect visitor numbers. Participants mentioned the impacts of COTS outbreaks on tourism, a key industry and livelihood in the region and the local benefits of management:

The people who own that business, they were sending divers out every day and getting the crown-of-thorns out physically, because they wanted to keep that reef looking good, so they can keep paying customers going there. So, if you didn't have customers going there, if it wasn't making revenue, and unfortunately that's the way our world works. It doesn't matter what country you're in, you need dollars. You need dollars spent on the reef. The way to get those dollars is to make it a valuable asset.

[Institutional stakeholder]

While many interview participants discussed the tourism benefits from COTS control in a positive way, one discussed COTS control from a more critical stance, arguing that COTS culling is done for political agendas to protect tourism sites rather than based on the actual ecological threat of COTS for the GBR.

Besides tourism benefits, four participants discussed the socioeconomic benefits of COTS control in terms of the development of skills and the creation of new jobs, in regional areas and for disadvantaged community members, as exemplified by the following quote:

...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]

In terms of negative socioeconomic impacts, interview participants discussed concerns about the distribution of benefits (6 interviews), opportunity costs (4 interviews), perverse academic interests (4 interviews) and negative impacts on the agricultural sector (3 interviews). Distributional concerns were related to several factors, including the choice of reefs that were protected by the program, the absence of COTS Control in the Torres Strait and the on-land allocation of government funding. Participants emphasized the significant cost of COTS control and that this investment could potentially crowd out other environmental and non-environmental community initiatives that are often not able to attract even a small fraction compared to COTS funding. Participants also discussed the potential for perverse incentives for researchers to exaggerate the COTS problem to help attract more research funding, as exemplified by the following quote:

And the more you say oh, the Reef needs research, oh we're going to need funding for that, you know, government can give us money, you know, it's another cycle.

[Livelihood stakeholder]

Finally, participants discussed the potential negative consequences that agricultural communities experience because they are being portrayed as being to blame for the COTS outbreaks and the impacts on the GBR, as exemplified by the following quote:

And that's really unfortunate because then all the money gets spent in the wrong direction and people get their nose out of joint because they're being blamed for something that they're not actually—what now is proven—they're not actually responsible for. So that was a bit unfortunate.

[Institutional stakeholder]

## 5 | DISCUSSION

Building upon the consistent, but tentative, support for COTS management observed in national and regional surveys (Figure 1), we set out to acquire an in-depth understanding of the ways GBR communities perceived COTS management and to synthesize these into an inductive social licence to operate theory that could potentially be used to inform a spectrum of environmental management challenges. Through our analysis, we produced three key findings. First, we distinguished between SLO and Traditional Owner rights and responsibilities because Traditional Owners have rights and responsibilities in addition to those that they share with other community members (Figure 2). Second, we found that our classification of SLO for COTS control had both overlap and differences with domains found to be important for the SLO of the mining industry and marine conservation. Specifically, the domain of socioeconomic benefits overlapped with both mining and marine conservation, while management effectiveness and knowledge/rationale were previously identified as relevant in the marine conservation sector only (Kelly et al., 2017; Kendal & Ford, 2018; Margeson et al., 2024). Our identified SLO domain 'ethical responsibility' is a novel contribution in a marine conservation context. Third, our findings indicate that SLO should not be considered a once-off or binary outcome. The SLO domains we found are interlinked, and participants are likely to have contrasting perceptions about different domains of the SLO, for example, having positive perceptions of socioeconomic benefits while having ethical reservations about our human responsibility to intervene in natural ecosystems. These three findings are discussed below.

### 5.1 | Traditional owner rights and responsibilities relative to SLO

Classifying Reef Traditional Owner support as one of several parallel domains of SLO would require the problematic categorization of Reef Traditional Owners as one stakeholder group among many rather than as a unique group of rightsholders (Moffat et al., 2016).

While social licence may be understood as an expression of *de facto* authority (in this case, the ability of stakeholders to influence project or programme implementation regardless of their legal standing), Traditional Owner rights and responsibilities are treated increasingly as a source of *de jure* authority (i.e., as legally inscribed property rights) (Costanza, 2016). Recognition and formalization of this *de jure* authority is incomplete. While over 40 percent of the GBR is managed in accordance with Traditional Use of Marine Resources Agreements (TUMRAs), there is not yet any formal requirement for agencies to attain consent from Reef Traditional Owners for management or research activities. Nonetheless, our study found that TORR is about more than consent and should focus on the inclusion of traditional knowledge and approaches to COTS control, for example, traditional knowledge could provide a framework for GBR intervention (Australian Academy of Science, 2023). The importance of early engagement of Reef Traditional Owners can help facilitate the integration of traditional and novel ways of management. Overall, our findings endorse other studies that have highlighted the aspirations of Reef Traditional Owners to become more involved in the management of Sea Country (Commonwealth of Australia, 2018).

Traditional Owners along the GBR acknowledge their own geographical, social, cultural and linguistic diversity (George et al., 2004). At the same time, Traditional Owners have an intimate understanding of shared heritage including the collective and intergenerational experience of dispossession (Ens et al., 2016; Hill et al., 2012; McLean et al., 2023). Integral to acknowledging Traditional Owner rights and responsibilities is thus supporting a collective process towards self-determination (Hill et al., 2012). This has been approached in recent times through various forms of co-management and agreement-making between Traditional Owners and government agencies in the marine and other sectors (Rist et al., 2019). These attempts to recognize the benefit, value and importance of traditional knowledge alongside the rights of knowledge holders who bring alternative understandings of marine ecologies and environmental change along the GBR (George et al., 2004). Through TUMRAs, for example, the Great Barrier Reef Marine Park Authority has been seeking since 2008 to connect Reef Traditional Owners with benefit-sharing mechanisms provided by the state. However, for some Traditional Owner groups, TUMRAs are treated with caution. Traditional Owners have experienced a legacy of previous iterations of co-management or joint management which have at times excluded Traditional Owners from participating meaningfully to exercise rights and responsibilities across various Sea Country management activities (George et al., 2004; Ross et al., 2009; Smyth, 2001). A potential Traditional Owner Rights and Responsibilities (TORR) model ought to ensure a level of respect, integrity and dignity is afforded to Sea Country governance and such a model could precede formalized state and federal management and agreement mechanisms within marine environments. The model would provide avenues for Traditional Owners to assess and evaluate the approach taken by state and federal bodies and allied stakeholders who envisage responsible environmental management.

## 5.2 | Specific aspects of social licence to operate in marine management

While SLO theory is increasingly applied within marine conservation (Kelly et al., 2017; van Putten et al., 2018), few studies have identified the main domains of SLO within a marine or conservation context (Kelly et al., 2017; Kendal & Ford, 2018; Margeson et al., 2024). Our results are consistent with major themes identified in Margeson et al.'s (2024) scoping review (i.e. sense of place, costs and benefits, perceived risk, trust and knowledge) but add important detail with respect to the relationships between knowledge, involvement in management and decision-making, and the rights of Indigenous peoples. Our results also raise additional questions about the ethics of lethal control in marine conservation we discuss in more depth in Section 5.3. In comparison to important domains within the mining sector, our grounded SLO theory identified *socioeconomic benefits* as the primary overlap, with other factors like the quantity and quality of contact between mining workers and local communities as well as impacts on social infrastructure being noticeably absent from our findings (Dumbrell et al., 2021; Moffat & Zhang, 2014). The fact that COTS control mostly plays out offshore and employs a relatively small number of people might make the social infrastructure and contact dimensions less relevant as compared to mining activities and associated impacts on labour and housing markets, social and health services, transport infrastructure, and so on. The perception that private and public benefits provided by COTS control were largely in sync (i.e. that protection of tourism assets was, for most participants, consistent with the conservation of biodiversity and natural heritage) may also be relevant. Further research is required to evaluate the transferability of our SLO domains to other (marine) conservation contexts.

Importantly, within our community interviews (except for those with Reef Traditional Owners), there was not much emphasis on the need for stakeholder involvement in COTS control decision-making processes. Within mining, prior studies identified stakeholder consultation and procedural fairness as important aspects of SLO (Dumbrell et al., 2021; Moffat et al., 2016). The lack of emphasis on stakeholder involvement could potentially be the result of our research design in which we embedded questions about COTS management in a larger study about reef restoration. It may also be the case, however, that GBR communities are relatively familiar with and accepting of current management arrangements as a consequence of GBRMPA's long history (since 1975) of managing the GBR (Day, 2022) in comparison to most mining projects. These possibilities warrant further investigation.

## 5.3 | SLO as a social process rather than a binary outcome

Accounts from the community interviews regarding the relative threat to the GBR posed by COTS reflect the ambivalence observed

in levels of support given to COTS management in national and regional public surveys (Figure 1). On the one hand, participants formed relatively cohesive narratives around COTS being antithetical to the natural capital of the GBR, and many included COTS within the compounding set of issues they believed were threatening the GBR's future. On the other, participants often moderated their definitions of COTS as problematic through counter-narratives which framed COTS as endemic to the GBR, a 'natural' part of coral reef ecologies, and COTS outbreaks as anomalies to 'normal' reef functioning. When it came to considering the longer-term future of the GBR, localized threats posed by COTS were differentiated from more broad-reaching pressures on the GBR, and the comparatively manageable threat of COTS was downplayed relative to intractable problems requiring collective and political action such as climate change. Survey results demonstrating that respondents typically rank COTS below other threats to the GBR (Thiault et al., 2021) may reflect a similar logic, with responsibility for coral mortality associated with COTS attributed not to the animals themselves but to anthropogenic pressures that stimulate ecological change and COTS outbreaks.

This logic carries over to consideration of the moral and ethical implications of COTS management. The pragmatic need to manage COTS outbreaks and limit coral damage was weighed by participants against the role humans play in provoking those outbreaks and the need for profound and urgent action to mitigate climate change, water quality deterioration, overfishing and other pressures on the GBR ecosystem. In participants' accounts, COTS were accorded with a 'right to belong' similar to that observed by scholars exploring the cultural significance of endemic and iconic Australian species (Franklin, 2006; Head, 2012; Trigger & Head, 2010). Similarly, while there was little overt concern expressed for the welfare of starfish, participants grappled with ethics as they carefully weighed the effectiveness and potential ecological impacts (both positive and negative) of lethal control. While ethical considerations may not yet stand out as a risk to social licence, it is thus a consistent factor in expectations of COTS management and evaluations of its ecological benefits. While conclusive research is required to evaluate the extent to which COTS is understood to be endemic, if an erroneous belief exists within the broader public that COTS is introduced and invasive (as suspected by some participants), this brings the possibility of additional ethical concerns raised through enhanced public communication and education regarding COTS.

Our grounded SLO Theory (Figure 2) can be helpful for environmental managers to identify potential avenues to increase community support and social licence for environmental management programmes such as the culling of COTS. For example, ethical dilemmas on more active kinds of environmental protection, such as COTS culling, could be addressed through more deliberative discussions with communities. Science communication could help to better inform the public on the latest state of knowledge regarding COTS outbreaks, while there also could be novel ways in which the actual and perceived effectiveness of COTS culling can be improved (Harris et al., 2025). In terms of socioeconomic benefits, the positive

local benefits of COTS management for tourism sites were widely acknowledged by participants, while other concerns, for example on the distribution of benefits, could be addressed by the design of the management programme.

## 6 | CONCLUSION

The aim of our research was to identify the main domains important for building SLO in the specific context of COTS management, and these can be used in further quantitative studies that explore trade-offs between the different domains and their contribution to overall public support. For example, it remains a question whether ethical concerns could be compensated for by higher socioeconomic benefits, and how much underlying knowledge of the environmental issue is required to gain community support for intervention in natural ecosystems. There is a chance there will be no permanent answer to the question of SLO because different community groups and members will make different trade-offs between the domains, while these domains are also likely to be dynamic (e.g. perceptions of *knowledge and rationale* might change based on novel scientific evidence). Moreover, it remains a question whether social licence can be addressed in a reductionist way, focused on individual GBR interventions, or whether perceptions on COTS management should be considered in a larger context of people's relationships with and perspectives on the GBR and its future. Thus, SLO is not a binary tick-off box but should be considered within a wider governance system with more deliberate and active participation by society and communities (Brueckner & Eabrasu, 2018).

## AUTHOR CONTRIBUTIONS

**Henry A. Bartelet:** Visualization, formal analysis, writing—original draft, writing—review and editing. **Gillian Paxton:** Conceptualization, investigation, methodology, data curation, project administration, formal analysis, writing—original draft, writing—review and editing. **Stewart Lockie:** Conceptualization, funding acquisition, methodology, supervision, visualization, writing—original draft, writing—review and editing. **Vincent Backhaus:** visualization, writing—review and editing. **Lokes Brooksbank:** Investigation, methodology, data curation, formal analysis, project administration.

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## CONFLICT OF INTEREST STATEMENT

On behalf of all authors, the corresponding author states that there is no conflict of interest.

## DATA AVAILABILITY STATEMENT

Data reported in this manuscript are archived in the James Cook University institutional repository. They are not available for free use under confidentiality requirements stipulated by the James Cook University Human Research Ethics Committee.

## ETHICS STATEMENT

Approval to conduct interviews associated with this research was obtained from James Cook University's Human Research Ethics Committee (ref: H8435). Interview participants were provided with written and verbal research information prior to interviews, and consent was given in writing or audio-recorded dependent on interview format. Approval to conduct the 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).

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## SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

**Appendix A.** Description of COTS management used in surveys.

**Appendix B.** SLO domains coding overview.

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