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Quantifying public support for culling crown-of-thorns starfish (*Acanthaster* spp.) on the Great Barrier Reef

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Abstract

Population surges of crown-of-thorns starfish (COTS) (*Acanthaster* spp.) are a leading cause of coral cover loss on Australia's Great Barrier Reef (GBR). While COTS culling has been undertaken since 2012 little is known about how the public perceive COTS culling or how perceptions vary among social groups. Drawing on survey data collected in 2018 and 2022 we test the relative influence of demographic variables, social and institutional variables, and beliefs concerning the risks and benefits of culling, on public acceptance for the culling of COTS on the GBR. In contrast with previous research suggesting a polarization of views, we found limited opposition to culling (12% in 2018 and 8% in 2022). Remaining respondents, however, were almost equally divided between those who agreed or strongly agreed with culling and those who were neutral or only slightly in agreement. The strongest predictors of support, in terms of standardized mean odds ratios, were the perceived social, environmental, and ethical responsibility of culling (1.57), the manageability of culling risks (1.46), the personal importance of the GBR to the respondent (1.33), trust in science to deliver solutions (1.30), confidence in management of the GBR (1.26), and how much of a threat respondents believed COTS posed to the Reef (1.25). These findings suggest public communications about COTS culling might usefully focus on how scientific understanding, ongoing research, ecosystem monitoring, and partnerships with Reef Traditional Owners and stakeholders guide operations.

KEYWORDS

coral reef, culling, ecosystem management, marine conservation, pest species, social license, wildlife management

1 | INTRODUCTION

Lethal control, or culling, of pest animals is widely used as an instrument of environmental management in both terrestrial and marine environments. While culling is undertaken to support a range of values important to people including food security, public health and safety, ecosystem health and diversity, and so on (Sagar, 1991;

Whisson & Ashman, 2020), culling can also be subject to contestation and disruption (von Essen & Redmalm, 2023). Despite its normalization in contemporary environmental management practice the acceptability of lethal control among stakeholders and broader publics is not something that can be taken for granted.

Existing research points toward a range of factors associated with community responses to culling. Demographic variables including age, gender, and profession (Boulet et al., 2021; Zander et al., 2021); awareness of the harm caused by pest species (Kleitou et al., 2019; Yin et al., 2023); scientific evidence of the effectiveness of culling (Enticott, 2015); the rationale for culling (e.g., animal welfare, ecological integrity, disease risk, and public safety) (Boulet et al., 2021; Koval & Mertig, 2004; Van et al., 2021); the extent and immediacy of pest animal impacts (Boulet et al., 2021; Kleitou et al., 2019); and awareness of species' native or endemic status (van Eeden et al., 2020), have all been identified as correlates of support.

Species' status as either endemic or exotic to particular environments is typically fundamental to their definition as environmental problems (van Eeden et al., 2020). However, the influence of endemicity on support for culling is not straightforward (Yin et al., 2023). Among endemic Australian species targeted for control due to local overabundance, approval for the culling of koalas has been found to be as low as 30% (Drijfhout et al., 2020, 2022), approval for dingo control has been measured as slightly negative (Van et al., 2021), and studies of kangaroo control reveal divided opinion and acrimony (Boulet et al., 2021; Mehmet & Simmons, 2018). Support for the culling of introduced invasive species in Australia is higher but still a focus in some cases (e.g., feral horses) of significant social and political conflict (Zander et al., 2021). While evidence suggests that approval for the culling of iconic and native species is generally lower than approval for species perceived as exotic, invasive and/or harmful, many species defy straightforward binary classification. People are not always sure whether animals are native or not (van Eeden et al., 2020) and some studies suggest that approval for the culling of individual species is not necessarily reflective of their biological class or native status in any case (Yin et al., 2023). Some may therefore argue that a species' charisma rather than its endemic status is more important as a determinant for culling approval (Crowley et al., 2019; Dawson et al., 2024; Drijfhout et al., 2020; Williams et al., 2019). The factors influencing public support for the culling of environmentally problematic but endemic species are thus likely to numerous and contextual.

In this paper we explore levels of public support for the lethal management of crown-of-thorns starfish (COTS) (*Acanthaster* spp.) on Australia's Great Barrier Reef (GBR). Although one of several coral-eating species endemic to the GBR and other reefs in the Indo-Pacific, periodic surges in COTS populations have singled it out as one of the leading causes of coral reef degradation along with bleaching events and cyclone damage (De'ath et al., 2012; Kayal et al., 2012; Pratchett et al., 2014). Control programs overseen by the Great Barrier Reef Marine Park Authority were consequently introduced in 2012 and expanded in 2018. Manual control operations undertaken by divers working from a fleet of vessels deployed across the GBR are informed by strategic monitoring, structured decision-making processes, and ongoing research. The aim is not eradication of COTS but maintenance of population densities below levels likely to cause significant degradation of hard coral cover and diversity (Pratchett & Cumming, 2019).

COTS management in the GBR has been subject to limited social research to date. Several studies suggest that members of the general public under-estimate COTS' impact on the Reef (Marshall & Curnock, 2019; Thiault et al., 2021), leading Thiault et al. (2021) to speculate that media coverage of conflict over climate change and the contribution of coal mining in Reef catchments may have a 'crowding out' effect on public awareness of other serious and persistent threats. Fabian et al.'s (2020) study, by contrast, found a polarization of opinion on COTS management, with half their sample believing COTS should be protected due to their role in maintaining coral reef biodiversity and half believing COTS should be controlled due to their destructive tendencies. Two important caveats, however, must be placed on this finding. First, the study was limited to a relatively small ($n = 312$) sample of New South Wales residents, meaning it did not include respondents living proximate to the Great Barrier Reef and nor did it have sufficient statistical power to investigate the effect of demographic or other variables on support for COTS control. Second, the study forced respondents to choose the one management objective they 'relate to the most' meaning the very real possibility of some people believing that COTS should be controlled despite having a right to exist was not investigated.

In this paper, we add to empirical literature focused on culling approval rates, and specifically on a marine species that is surrounded by some ambiguity regarding its pest classification. Besides contributing empirical evidence of COTS culling approval rates, we also answer recent calls for better understanding of differences among people in terms of approval for animal culling (von Essen & Redmalm, 2023). In doing so, we test the relative influence of demographic variables, social and institutional contextual variables, and beliefs concerning the risks and benefits of culling, on public acceptance for the manual control of COTS on the GBR.

2 | METHOD

Data reported in this manuscript were collected through a larger study of community attitudes toward existing and prospective management interventions in the Great Barrier Reef.[1] Surveys were conducted in 2018 and 2022 with over 8000 Australian residents in total to explore support both for current management practices, including COTS control, and the potential introduction of novel management practices designed to accelerate coral adaptation to climate change and/or recovery from disturbance. Ethics clearance to conduct this 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). This manuscript draws on a subsample of 1059 surveys focused on the manual control (culling) of crown-of-thorns starfish. The surveys requested information on support rates for different aspects of manual COTS control as well as on demographic and contextual information associated with the respondent. We used ordinal logistic regression models to explore different theories of public support to explain the observed levels of support for manual COTS control.

2.1 | Sampling

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

1. An Australia-wide study of residents across all states and territories (national sample).
2. A specific sample of residents located within 50 km of the Great Barrier Reef coastline (resident sample).

In both years, 2018 and 2022, online surveys were distributed via a market research company, using online panels.[2] 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. The 2018 survey amounted to a total of 499 surveys (339 from the *national* sample and 160 from the *resident* sample). The 2022 survey amounted to a total of 560 surveys (392 from the *national* sample and 168 from the *resident* sample).

2.2 | Public support for manual COTS control

We used survey participants' stated support for large-scale deployment of manual COTS control across the GBR as our response (outcome) variable. The outcome variable was measured using a 7-point Likert scale ranging from strongly disagree (1), neither agree nor disagree (4), to strongly agree (7). Questions regarding support for COTS control were asked following a brief description of manual control methods and of risks and benefits associated with their use. 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 survey 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 our results. In our statistical models we included the year of the survey as a predictor variable to evaluate whether the passage of time or changes to the survey instrument influenced our results.

Besides the question on overall support for manual COTS control, we asked 15 additional questions associated with potential benefits and risks of manual COTS control (Table 1). These specific outcome variables were measured using survey questions that consisted of two opposing statements, to which the respondent should indicate their level of support, using a 7-point Likert scale. A value of four indicated neutrality between the opposing statements. We first merged the ordinal levels into binary rates of *approval* for each beneficial side of the opposing statements, where we classified levels of five to seven as *higher* approval for the beneficial statement.

After evaluating individual risk and benefit statements in a binary way, we used principal component analysis (PCA) on the ordinal values to explore whether some risks and benefits were clustered together. PCA was undertaken using *R*'s in-built *stats* package, using the *princomp* function. We excluded the last three statements about the socioeconomic benefits of manual COTS control as described in Table 1 because they were not included in the 2018 survey.

2.3 | Testing theories of public support for manual COTS control across the GBR

We tested four different theories of public support for manual COTS control across the GBR using four separate regression models, and one integrated model in which we combined predictors from all four theoretical models (Table 2). We controlled for the year of the survey (2018 or 2022) in all models. First, we evaluated how much variation in public support could be explained by demographic factors. Second, we evaluated how much variation in public support could be explained by participants' perceived values and threats associated with the GBR and COTS specifically. Third, we evaluated how much variation in public support could be explained by participants' perceptions of existing GBR management. Fourth, we evaluated how much variation in public support could be explained by the perceived risks and benefits of manual COTS control. For this analysis, we used four clusters identified through PCA that will be explained in more detail in Section 3 and in Appendix S1. The four scale variables we used here were created by averaging the values of the specific risk/benefit questions that were included in each cluster (Table 2). We tested the internal reliability of the scales by calculating the Cronbach's Alpha for the variables that were used within each scale. All scales showed internal reliability with Cronbach's Alpha above 0.70 (0.72 for effectiveness, 0.87 for long-term benefits, 0.85 for manageable risks, and 0.85 for responsibility).

TABLE 1 Perceived risks and benefits of manual COTS control[a].

Statement representing highest potential risk (value of 1)	Statement representing the most benefit (value of 7)
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
This technology will be unsafe for people	This technology will be safe for people
The benefits of this technology will be too small to justify the cost	Likely to be cost-effective when fully developed
This sort of technology will be unsafe for ecosystems	This sort of technology will be safe for ecosystems
Use of this technology is unethical	Use of this technology is ethical
Turn the Reef into an artificial system	Protect the Reef's natural values
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
Likely to have unforeseen environmental impacts if implemented	Environmental impacts can be identified and tested
The costs outweigh the benefits	The benefits outweigh the costs
This approach will hinder more than it will help the Reef	This approach will help more than it will hinder the Reef
Any negative environmental impacts will be irreversible	Any negative environmental impacts can be reversed
This technology will compromise cultural values associated with the Reef[b]	This technology will enhance cultural values associated with the Reef[b]
This technology will damage Reef industries such as tourism[b]	This technology will provide new opportunities for Reef industries such as tourism[b]
This technology will have negative impacts on communities living near the Reef[b]	This technology will have positive impacts on communities living near the Reef[b]

[a]Specific outcomes are 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 most benefit.
[b]Question included in 2022 survey only.

TABLE 2 Theories of public support for manual COTS control across the GBR.

Variable	Description	Unit of measurement
Demographic factors		
Reef proximity	Distance of participant's residence from the GBR.	(0) >50 km from GBR (1) <50 km from the GBR
Gender	Gender of participant.	(0) Female (1) Male
Age group	Participant's age group; initially measured using six levels.	(0) <50 years (1) >50 years
Indigenous	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
Employment	Participant had a full-time employment status at the time of the survey.	(0) No (1) Yes
Reef visitation	Participant had ever visited the GBR.	(0) No (1) Yes
GBR knowledge	Self-rated knowledge about the GBR	10 levels from know very little (1) to know a lot (10) [treated as continuous]
Perceived values and threats		
Value (national asset)	Extent to which participants agreed with the statement that *the GBR is an important national asset.*	7 levels from strongly disagree (1) to strongly agree (7) [treated as continuous]
Value (personal)	Extent to which participants agreed with the statement that *the GBR is personally important to me.*	
GBR condition (concern)	Extent to which participants agreed with the statement that I am concerned about the environmental condition of the GBR.	
Future existence (worry)	Extent to which participants agreed with the statement that I worry that the GBR will cease to exist for future generations	
Perceived threat (COTS)	Extent to which participants agreed with the statement that environmental pests are negatively affecting the health of the GBR (i.e., crown of thorns star fish)	
Perceived threat (climate)	Extent to which participants agreed with the statement that climate change is negatively affecting the health of the GBR.	
Perceptions about management of the GBR		
Trust in GBRMPA	Extent to which participants agreed with the statement that the Great Barrier Reef Marine Park Authority (GBRMPA) does what is right (in the best interest of society)	7 levels from not at all (1) to very much so (7) [treated as continuous]
Confidence in GBR management	Extent to which participants agreed with the statement that *I feel confident that the GBR is well managed.*	7 levels from strongly disagree (1) to strongly agree (7) [treated as continuous]
More action needed	Extent to which participants agreed with the statement that considering the potential values and threats to the GBR, more should be done to save it.	
Trust in scientific solutions	Extent to which participants agreed with the statement that scientific research can provide solutions to help prevent damage to the GBR.	

(Continues)

TABLE 2 (Continued)

Variable	Description	Unit of measurement
Perceptions of specific risks and benefits		
Effectiveness	Averaged level of support for the statements that (1) manual COTS control is likely to be cost-effective when fully developed; and (2) should help large sections of the Reef (Table 1).	7-point Likert scale from statement representing highest potential risk (1) to most benefit (7) [treated as continuous]
Long-term benefits	Averaged level of support for the statements that (1) manual COTS control will be critical to the long-term health of the Reef; (2) has benefits that outweigh the costs; and (3) looks like a promising option to help the Reef (Table 1).	
Manageable risks	Averaged level of support for the statements that manual COTS control (1) has environmental impacts that can be identified and tested; (2) will help more than it will hinder the Reef; and (3) protects the Reef's natural values (Table 1).	
Responsibility	Averaged level of support for the statements that manual COTS control (1) will be safe for people; (2) will be safe for ecosystems; and (3) is ethical in use (Table 1).	

Note: Explanatory variables used to explain support for the large scale-scale deployment of manual COTS control across the GBR.

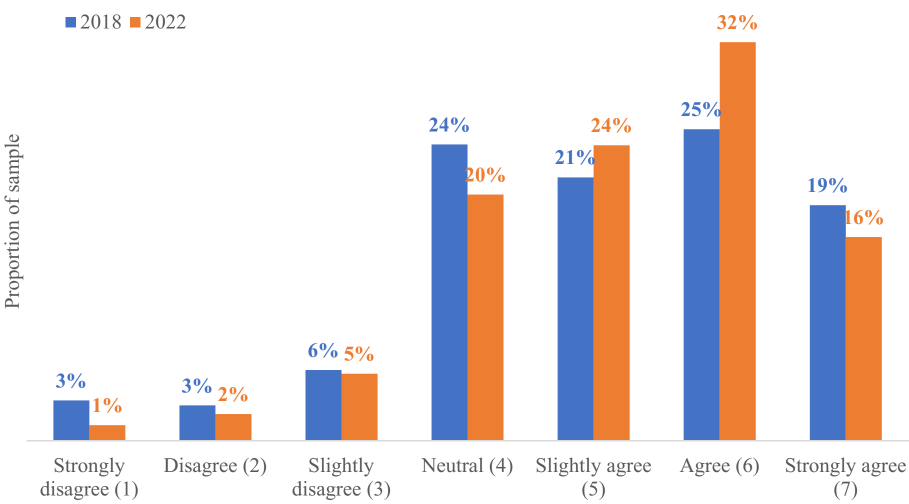

FIGURE 1 Level of support for large-scale deployment of manual COTS control across the GBR by year of survey, based on ($n = 1055$) surveys with Australian residents.

2.4 | Analysis

As alluded to above, we ran a total of five regression models, one for each theory of public support for the large-scale deployment of manual COTS control across the GBR, and one integrated model with all theories and variables combined. Models were fit using R modeling software (R Core Team, 2013), version 4.2.2. We compared theoretical models in terms of their ability to explain public support for manual COTS control, using pseudo-*R*-squared values that were derived by using the *DescTools* package. We reported 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. We also compared the models in terms of parsimony using Akaike information criterion (AIC). AIC weighs the benefit of increased model complexity against the cost of increased sampling variability, indicating whether more complex models contain significantly more information than simpler models (Akaike, 1974). The less information a model loses, the higher the quality of the model. The model with the lowest AIC value has best quality as measured by AIC.

Because our outcome variable was measured on a 7-point Likert scale, we used ordinal logistic regression models which were implemented using the *MASS* package in R (Ripley et al., 2013). Using a Brant Test (Brant, 1990; Schlegel & Steenbergen, 2020), we found that the proportional odds assumption did not hold for multiple predictors at a 95% confidence level.

Visualization of the data indicated that the violation of the proportional odds assumption was mainly caused by lower density of responses in the lower ordinal outcome levels (Figure 1). Because the data visualization did not indicate any nonlinear relationship between the non-proportional predictors and our outcome of interest, we decided to proceed with the ordinal logistic regression models. For the non-proportional predictors, the effect size represents an average (rather than a proportional) effect size over the different ordinal levels, and this could be more realistic as compared to transforming the ordinal outcome levels into an artificial binary variable (Harrell, 2020).

All non-binary predictors in the models were scaled using *z*-scores to reduce multicollinearity and to make effect sizes directly comparable. We tested for multicollinearity through variance inflation factors using the *performance* package in R (Lüdecke et al., 2021). All predictors in the models had a variance inflation factor below five, indicating low collinearity.

3 | RESULTS

3.1 | Sample description

About a third (31%) of our sample consisted of survey participants that lived in closer proximity (<50 km) to the Great Barrier Reef and we had a relatively even balance in terms of age, gender, and education (Table S1). Almost a tenth (8%) of our sample consisted of participants that classified themselves as Aboriginal and/or Torres Strait Islander. About two-thirds (62%) of the participants had ever visited the Reef and the average self-reported knowledge about the GBR was 5.3 on a 10-point scale.

3.2 | Public support for manual COTS control

In both the 2018 and 2022 surveys, the largest fraction of respondents agreed (scale 6) with the statement of support for the large-scale deployment of manual COTS control across the GBR (Figure 1). The fraction of the sampled respondents that at least slightly agreed (scale 5) increased from 65% in 2018 to 72% in 2022, while the average value increased from 5.06 in 2018 to 5.23 in 2022. We found low levels of disagreement with the large-scale deployment of manual COTS control across the GBR, with respectively 12% and 9% of respondents in the years 2018 and 2022 either slightly disagreeing, disagreeing, or strongly disagreeing. Almost half of the respondents in both years (45% in 2018 and 43% in 2022) were either neutral or indicated only slight agreement.

3.3 | Perceived risks and benefits of manual COTS control

Respondents generally believed that the benefits of manual COTS control outweighed risks in relation to protecting the Reef's natural values and the long-term health of the Reef (Figure 2). Perceptions of the ethics of manual culling were stable with 57% of participants agreeing COTS control is ethical in both years. Participants were less convinced, however, that manual COTS control offered more benefit than risk in relation to scalability (49%), cultural values (43%), cost-effectiveness (42%), and the reversibility of any negative environmental impacts of its use (35%).

Using PCA on the collected data on a 7-level scale (whereas Figure 2 is shown on a binary scale), we found that the first two principal component could explain about 60% of the total variance in the 12 potential risks and benefits that were included in both the 2018 and 2022 survey. The statement about the reversibility of impacts was an outlier in our analysis, which might have been caused by the framing of this question, in particular the use of "if any." We therefore decided not to include this statement in our further analysis. Clustering the risks and benefits based on these first two principal components identified roughly four clusters of risks and benefits in our dataset (Appendix S1):

1. Effectiveness (technology is likely to be cost-effective when fully developed and should help large sections of the Reef).
2. Long-term benefits (technology will be critical to the long-term health of the Reef, has benefits that outweigh the costs, and looks like a promising option to help the Reef).
3. Manageable risks (technology has environmental impacts that can be identified and tested, will help more than it will hinder the Reef, and protects the Reef's natural values).
4. Responsibility (technology will be safe for people, will be safe for ecosystems, and is ethical in use).

3.4 | Testing theories of public support for manual COTS control

We found only weak support for a demographic theory of public support for manual COTS control, with the model explaining 6% of the total variability in support levels

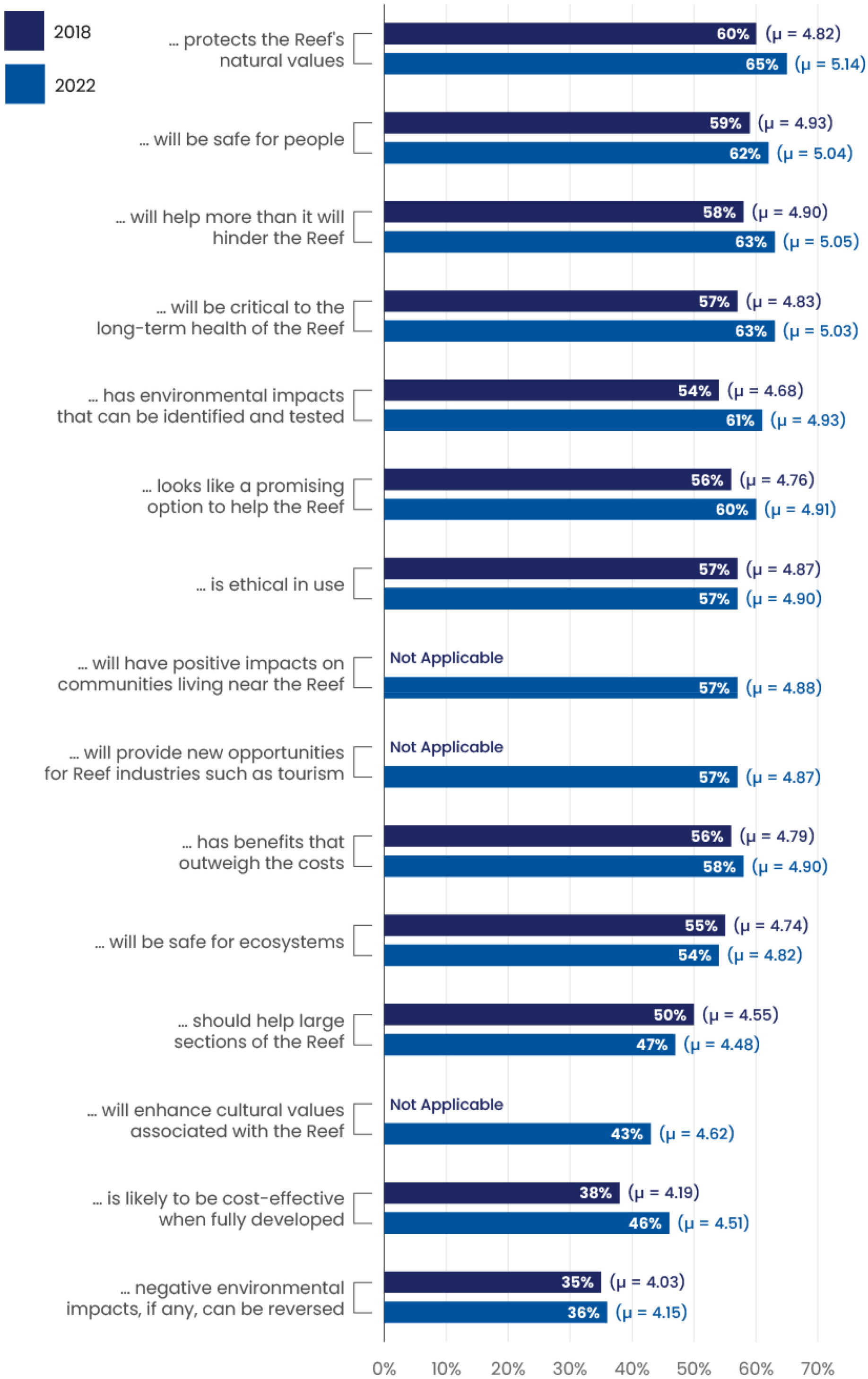

FIGURE 2 Approval rates for statements about the benefits and costs of manual COTS control. Sorted by highest approval rating as considered over the combined sample (2018 and 2022, not shown in figure). Approval reflects a survey score of 5–7 on a 7-scale survey question with opposing statements, on which four was considered neutral. Statements in first column should be read as starting with 'This technology…' Average (μ) values on a scale between 1 and 7 for each statement by year are provided between brackets.

(Table 3). Demographically, support levels for manual COTS control were most strongly affected by the *age of the respondent* (Figure 3), with older respondents (>50 years) having significantly higher support levels (mean odds ratio = 1.58, *p*-value = .000). *Reef proximity* (mean odds ratio = 1.29, *p*-value = .052) and *knowledge about the GBR* (standardized mean odds ratio = 1.34, *p*-value = .000) also had a positive effect on support levels for manual COTS control.

Stronger support was found for culling support theories based on values and threats, and perceptions of GBR management, both explaining about a fifth of the total variability in support levels (Table 3). In the values and threats model, support levels for manual COTS control were mostly strongly affected by the *perceived threat of COTS to the GBR* (Figure 3; standardized mean odds ratio = 1.52, *p*-value = .000). The respondent's *perceived value of the GBR to Australia* (standardized mean odds ratio = 1.44, *p*-value = .000) *and to their personal lives* (standardized mean odds ratio = 1.42, *p*-value = .000) also had a significantly positive effect on support levels. The *perceived threats of climate change to the GBR* did not have a significant effect on support level for manual COTS control (standardized mean odds ratio = 1.15, *p*-value = .098). In the management perceptions model, support levels for manual COTS control were most strongly affected by the level of *trust in science to provide solutions to prevent damage to the GBR* (Figure 3; standardized mean odds ratio = 1.69, *p*-value = .000). The other three predictors in this model also had a significantly positive effect on support levels for manual COTS control.

The model including the perceived costs and benefits of manual COTS control had the highest predictability, explaining about a quarter (27%) of the total variability in the outcome variable (Table 3). Support levels were most strongly affected by the respondent's perceptions about the *responsibility* (Figure 3; standardized mean odds ratio = 1.59, *p*-value = .000) and *manageability of risks* (standardized mean odds ratio = 1.54, *p*-value = .000) associated with manual COTS control. The other two benefit and risk predictors (effectiveness and long-term benefits) also had a positive, but less strong effect size.

The integrated model combining all three theories explained almost 40% of the total variability in the outcome variable, and this model also outperformed other models in terms of parsimony (Table 3). None of the demographic predictors were statistically significant in the combined model, while two predictors from each of

TABLE 3 Model comparison based on predictability (pseudo-*R*-squared, Nagelkerke) and parsimony (Akaike information criterion).

Theory of public support	Predictability (R^2)	Parsimony (AIC)
Demographic	0.06	3451 (df = 15)
Values and threats	0.20	3313 (df = 13)
Management perceptions	0.18	3313 (df = 11)
Benefits and risks of culling	0.27	3204 (df = 11)
Combined	0.38	3055 (df = 29)

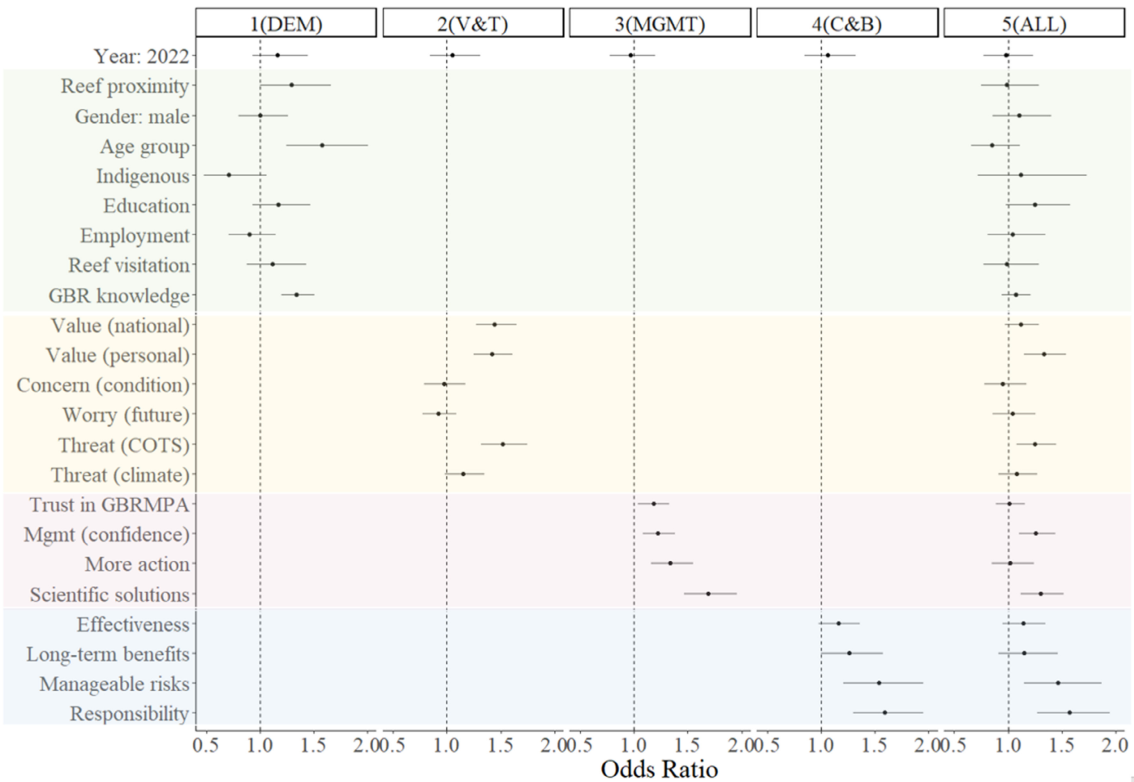

FIGURE 3 Regression statistics (odds ratios at 95% confidence intervals) for ordinal logistic regression model outcomes associated with support for large-scale outdoor deployment of manual COTS control across the GBR. Outcomes are on a 7-point Likert scale (Figure 1). Significant predictors are those that do not cross the dotted '1' line. Non-binary predictors (all predictors below *Reef visitation*) were standardized using *z*-scores. Effect sizes shown in this figure and discussed in the text can be de-standardized by multiplying with the standard deviation of the respective indicator (Appendix S1).

the other three theories (Table 3) had a significant effect on support levels. In the combined model, the significant predictors were, according to effect sizes, *responsibility* (standardized mean odds ratio = 1.57, *p*-value = .000), *manageability of risks* (standardized mean odds ratio = 1.46, *p*-value = .002), *personal importance of the GBR* (standardized mean odds ratio = 1.33, *p*-value = .000), *trust in science to provide solutions to prevent damage to the GBR* (standardized mean odds ratio = 1.30, *p*-value = .001), *confidence that the GBR is well-managed* (standardized mean odds ratio = 1.26, *p*-value = .001), and the *perceived threats of COTS* (standardized mean odds ratio = 1.25, *p*-value = .003).

4 | DISCUSSION

We set out to quantify public support for culling crown-of-thorns starfish in the Great Barrier Reef and to identify those factors most relevant to understanding variation in levels of support between people. Our analysis produced four key findings—namely, that:

1. Public support for large-scale deployment of manual COTS control is widespread but tentative (Figure 1).
2. Respondents generally believed that manual COTS control helped protect the Reef's natural values, that it was safe for people, and that negative impacts could be identified and managed. They were less convinced, however, that manual COTS control was scalable, cost-effective, protective of cultural values, and that any negative environmental impacts of its use are reversible (Figure 2).
3. Perceptions of risks and benefits associated with manual control explain more variance in public support than do perceived values and threats, perceptions on existing GBR management, and demographic factors (Table 3).
4. Support for manual COTS control can be best explained by six factors including personal importance of the GBR, perceived threat from COTS, confidence in GBR management, trust in scientific solutions, the manageability of culling risks, and perceived culling responsibility (social, environmental, and ethical) (Figure 3).

These findings are discussed in more detail below.

4.1 | Support for large-scale deployment of manual COTS control across the GBR

There is widespread but tentative support for the large-scale deployment of manual COTS control across the GBR (Figure 1). 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. The average level of support increased from 5.06 in 2018 to 5.23 in 2022 and indicated a slow transition from, on average, slight agreement to agreement. However, when we controlled for demographic differences in our samples between the years, we did not find a significant change in support levels over the four-year period from 2018 to 2022. The relatively constant support levels are surprising given that the years 2020 to 2022 were characterized by the impacts from the COVID-19 pandemic, which could have impacted perceptions of risk and government interventions.

Our results, showing that there is tentative support, and no strong opposition toward the culling of COTS, indicates that 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 (Boulet et al., 2021; Drijfhout et al., 2020; Mehmet & Simmons, 2018; Van 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 tentative rather than high support for COTS culling might also be explained by the effect of salience on the acceptance of lethal measures. Prior research has shown that the Australian public underestimates COTS' impact on the Reef (Marshall & Curnock, 2019; Thiault et al., 2021) and therefore people might not care that much about the COTS problem and existing control measures. Indeed, prior research has highlighted the importance of issue salience and public communication on support for pest species management (Ballari & Barrios-García, 2022; DeGolia et al., 2019; Miller et al., 2018).

4.2 | Risk and benefit perceptions associated with manual COTS control

We found that there are competing perceptions of risks and benefits associated with manual COTS control (Figure 2), indicating that survey respondents might balance their overall support based on several different inputs including potential Reef benefits, economic co-benefits, ethical considerations, and environmental safety. We found four distinctive clusters of risk/benefit perception in relation to manual COTS control associated with *effectiveness, long-term benefits*, *manageable risks*, and *responsibility* (Appendix S1). It was interesting to note that perceptions of ethics were associated with safety for both people and ecosystems. This indicated that in terms of ethics, respondents think about human and natural systems in an integrated way, rather than as separate subsystems (Aggestam, 2015; Piccolo et al., 2022).

While an increasing number of people (rising from 54% of respondents in 2018 to 61% in 2022) agreed that the environmental impacts of manual COTS control can be identified and tested, still only half (54% in 2018 and 55% in 2022) agreed that manual COTS control is safe for ecosystems. Further, only 35%–36% of people think that potential negative environmental impacts of COTS control, if they do occur, are reversible. Speculatively, these results could indicate that people feel uneasy about intervening in a system that is out of balance because of other things people have done. Some respondents might think that, pragmatically, we need to act while others worry that more intervention will make things worse. It would follow that ineffective intervention could, in peoples' minds, risk tipping ecosystems over the edge of irreversible change. The wording of the question on impact reversibility probably encourages answering this way even if respondents think negative impacts are unlikely.

Besides concerns about manageable risks, our results also indicate that more than half the respondents identified more risks than benefits in relation to scalability, the enhancement of cultural values, and cost-effectiveness. Cost-effectiveness and scalability could potentially be addressed by the development of more affordable, effective, and scalable solutions, such as those being explored under the Crown-of-Thorns Starfish Control Innovation Program (CCIP). Novel methods and technologies explored as part of CCIP include the potential use of semiochemicals to either attract or deter COTS, and predator control strategies in which predator species would be actively restocked or given greater protection through fisheries management. However, any novel innovations should consider the existing unease people feel about intervening in natural ecosystems and focus on the need to mitigate any potential risks for environmental harm. Novel COTS management approaches based on Indigenous knowledge could potentially contribute to risk management as well as the enhancement of cultural values (Yibarbuk et al., 2001).

4.3 | Testing theories of public support for manual COTS control

We explicitly focused on evaluating differences in support levels for manual COTS control between Reef residents (i.e. people living within 50 km of the GBR) and the wider population. Our demographic model indicated that Reef residents were more likely to support the large-scale deployment of manual COTS control across the GBR (Figure 3). However, in our integrated model using all theoretical predictors the effect size for Reef proximity became insignificant, indicating that the effect size was now partly explained by other factors. The same logic applied to older respondents, who were strongly more supportive of manual COTS control, but the effect of respondent age became insignificant in the integrated model. Similar to prior studies (Boulet et al., 2021; Enticott, 2015), the demographic model had limited predictability, explaining only 6% of the total variability in support levels (Table 3). Older respondents were more likely to support COTS culling, which was also found in prior studies on culling of other animals, but we did not find evidence for male respondents having higher support levels (Boulet et al., 2021; Zander et al., 2021).

We found that the public support theory focused on perceived risks and benefits had the best predictability, explaining 27% of the total variability, while the model that combined all theories was able to explain 38% of the total variability and scored best in terms of parsimony (Table 3). The most interesting finding from the combined model was that support was strongly associated with how much respondents perceived manual COTS control (1) to be responsible (ethically, environmentally, and socially); and (2) to have environmental risks that can be managed (Figure 3). To our knowledge, our study is one of the first to include such factors as predictors of support for the culling of pest animals. Confidence in existing GBR management, trust in scientific solutions to help prevent damage to the GBR, and personal importance of the ecosystem that is being protected from the pest were also important, and they are also novel contributions to the social acceptance of animal culling literature.

Another interesting finding was that support levels were strongly associated with the immediate threats of COTS to the Reef rather than with considerations about longer term benefits that COTS culling might provide for the Reef. The importance of immediate threats associated with the animal in question was also found to affect support for koala and kangaroo culling (Boulet et al., 2021). People are often biased toward short-term results because of uncertainty, delays, and potentially conflicting information associated with longer-term impacts and benefits (Moxnes, 2023; Platt & Huettel, 2008; Sterman, 2012). Another explanation could be that people might think we do not have the right to cull (native) animal species unless there is an immediate societal concern for it. This finding is important for environmental policymakers because it indicates that strategies to improve public support for environmental programs such as COTS culling might be more effective if they focus on highlighting immediate benefits or relief from threats, rather than emphasizing potential outcomes and benefits in the future.

4.4 | Future research avenues

Based on our findings, we suggest several avenues for future research. First, while our focus was on identifying the key variables that are important in explaining support for manual COTS control, further analysis could focus on identifying different groups of respondents based on their clustering on all variables. Identifying segments or groups of respondents could facilitate targeted communication and engagement based on socio-demographics, and perceived risks and benefits. For example, it would be beneficial to further explain why older people were more supportive of manual COTS control (Figure 3), whether they might see fewer risks and/or have more confidence in management. A latent class analysis might provide helpful. Second, while our combined predictive model explains a relatively high (for social sciences) amount of the total variance (38%; Table 3), our results beg the question of what other variables might be important to explain support for manual COTS control. One obvious exclusion was perceptions about the socioeconomic benefits of manual COTS control because we only had data on these benefits from the 2022 survey. It would also be helpful, in future surveys, to measure respondents' knowledge of the native status of COTS, to test if such knowledge affects support levels (van Eeden et al., 2020). Third, our finding that the urgency of the COTS problem is an important predictor for support levels could be further unpacked using Construal Level Theory (CLT), which looks at proximity to the issue based on temporal distance (current or future impact/action) and physical distance (physical proximity) (Trope & Liberman, 2010). The CLT theory may help further explain attitudes to COTS management and other proposed interventions toward reef management.

5 | CONCLUSION

Culling of crown-of-thorns starfish on the Great Barrier Reef is approved by most Australians. Ongoing approval, however, cannot be taken-for-granted. This research demonstrates that demographic variables are of less importance in explaining support for culling than are respondents' views on the importance of the Reef to themselves, how COTS impact the Reef, how well the GBR is managed, the ability of science to deliver solutions, and the riskiness, safety, and ethics of manual culling. Although these findings are not directly generalizable to all environmental management scenarios, they suggest important considerations for policymakers and managers in the GBR and elsewhere. These include, first, that evidence of direct and immediate impacts on ecosystem health may be a more powerful motivator of support for culling than messaging around indirect contributions to the management of complex and longer-term threats such as climate change. Belief among most participants that climate change threatens the Reef (Table S1) should be encouraging for proponents of long-term planning (e.g., Commonwealth of Australia, 2021), but it did not translate into any more or less support for COTS control. Second, the relationship between support for culling and trust in science to provide solutions suggests management programs should draw on, contribute to, and communicate scientific understanding of pest species' ecology, social and environmental impacts, and control. Third, and relatedly, doubts expressed by participants in the scalability and cost-effectiveness of manual culling suggests communication might usefully focus on how research and development, ecosystem monitoring, partnerships with Reef Traditional Owners and stakeholders, and so on, contribute to control program innovation and improvement.

AUTHOR CONTRIBUTIONS

Stewart Lockie: Conceptualization, Funding acquisition, Methodology, Supervision, Writing—original draft, Writing—review and editing. **Henry A. Bartelet:** Formal analysis, Visualization, Writing—original draft. Writing—review and editing. **Brent W. Ritchie:** Conceptualization, Funding acquisition, Methodology, Supervision, Writing—review and editing. **Lintje Sie:** Conceptualization, Investigation, Methodology, Project administration, Writing—review and editing. **Gillian Paxton:** Writing—review and editing.

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(CSIRO) to test public attitudes to novel reef interventions in 2018 as part of the Concept Feasibility Phase of RRAP. Dr. Lintje Sie, Professor Brent W. Ritchie, and Professor Stewart Lockie reviewed and updated the survey instrument for the 2022 survey, including through the revision and addition of scenarios and treatments.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that has been used is confidential. Regression statistics are available in Appendix S2.

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ENDNOTES

[1] The Reef Restoration and Adaptation Program (RRAP) is funded through a partnership between the Australian Government's Reef Trust and the Great Barrier Reef Foundation. Partners include the Australian Institute of Marine Science, CSIRO, James Cook University, Queensland University of Technology, the University of Queensland and Southern Cross University. The Program aims to provide Reef managers with a suite of scientifically proven, ecologically-effective, socially-acceptable, technically-feasible, and economically-viable options to intervene at scale on the Reef, to enhance its resilience and adaptation to climate change. The surveys on which this manuscript draw are embedded within RRAP's Stakeholder and Traditional Owner Engagement Subprogram. They aim to provide a longitudinal understanding of Australian attitudes toward the development and deployment of novel reef restoration and adaptation options, along with the factors that influence attitudes toward restoration and adaptation.

[2] The final survey in 2018 was launched on 7 August 2018 and remained open until 14 September 2018. The final survey in 2022 was launched on 14 February 2022 and remained open until 28 February 2022.

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SUPPORTING INFORMATION

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

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