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Current and emerging feral cat management practices in Australia

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ABSTRACT

Context. Feral cats are responsible for the decline and extinction of species globally. Predation by feral cats is identified in Australian legislation as a key threatening process. However, clear guidance to local land managers on feral cat management techniques and their impacts, limitations and potential costs can be difficult to find. **Aims.** In this study, feral cat management experts from around Australia identified available management techniques and their average environmental, social, and economic impact for different ecoregions and land-use types. **Methods.** We convened a 1-day structured elicitation workshop with 19 experts and five facilitators. Experts identified the techniques used for feral cat management; the effectiveness, impact, and cost of each method; and the key knowledge gaps associated with feral cat management. Facilitators aided in the design and format of the workshop, led the discussion at each stage and collated the results. **Key results.** Experts identified the following 10 techniques currently used in Australia: aerial baiting; ground baiting; leghold trapping; cage trapping; shooting; tracking with detector dogs; tracking by Indigenous Rangers; habitat modification; resource modification; and exclusion fencing. In general, experts highlighted that permits, legislation and scale of application constrained many of these techniques. Aerial baiting was considered the most effective technique for reducing feral cat populations in natural and production systems. Cage trapping, shooting, or tracking with detector dogs were considered more effective in residential areas. For all techniques, efficacy estimates varied according to the following three broad vegetation structural regions: (1) deserts and xeric shrublands; (2) forests and woodlands; and (3) grasslands, savannas and shrublands. Techniques considered to have the lowest social tolerance and highest impact to non-target native species included aerial baiting, ground baiting and leghold trapping. Techniques considered to have high social tolerance and low impact on non-target species included tracking by Rangers, tracking with detector dogs, and habitat and resource modification. **Conclusions.** Estimates of management action efficacy differ among land-use types and at least three vegetation structural regions. However, social licence, logistic and legislative constraints are the key drivers of the availability of methods for these areas. **Implications.** Feral cat management programs should consider how program strategy can be prioritised on the basis of technique availability, region of use and expected impact.

Keywords: animal trapping, conservation management, expert elicitation, feral cat, invasive species, pest management, shooting, toxic baiting.

Introduction

Invasive predators are considered instrumental in the decline and extinction of species globally (Salo *et al.* 2007). One of the most destructive invasive predators is the domestic cat (*Felis catus*) (Lowe *et al.* 2000). Humans have spread domestic cats to nearly every continent, resulting in self-sustaining feral cat populations (Long 2003). Globally, these introduced cats have contributed to at least 26% of bird, mammal, and reptile species extinctions in recent times (Doherty *et al.* 2016). These declines can be attributed to direct impacts, such as predation (Medina *et al.* 2011; Loss *et al.* 2013; Doherty *et al.* 2015), and indirect impacts including competition (Phillips *et al.* 2007), disease transmission (Nishimura *et al.* 1999; Dubey 2008), and hybridisation (Pierpaoli *et al.* 2003). Reducing the negative impacts of cats is a priority for global conservation efforts (Nogales *et al.* 2013).

Self-sustaining feral cat populations occur across Australia in every climate and habitat (Legge *et al.* 2017) and feral cats are the primary driver of the decline and extinction of many native species (Dickman 1996; Woinarski *et al.* 2015, 2018; Doherty *et al.* 2017). Indigenous Australians manage or co-manage 57% of the Australian landmass (Jacobsen *et al.* 2020), and some groups have been actively managing feral cats since their introduction (Paltridge *et al.* 2020). The Australian government has recognised the problem feral cats pose to conserving native species by listing feral cat predation as a key threatening process under the *Environment Protection and Biodiversity Conservation Act* (1999). Several key threatened species management policies also acknowledge the importance of managing feral cats, including the Australian Government's recent Threatened Species Strategy Action Plan 2022–2032, which includes targets focussed on reducing cat impacts (Department of Climate Change, Energy the Environment and Water 2022).

A range of management techniques has been employed in an effort to control feral cats. However, controlling populations remains challenging and the success of management programs has been highly variable (Algar *et al.* 2007; Denny and Dickman 2010; Moseby and Hill 2011; Fancourt *et al.* 2021). Several methods employed in Australian control programs include combinations of trapping, shooting, (Short *et al.* 2002; Nogales *et al.* 2004), poison baiting (Moseby and Hill 2011; Comer *et al.* 2020; Fancourt *et al.* 2021), and exclusion fencing (Bengsen 2015). Novel methods are also being developed, such as walk-past grooming traps (i.e. 'Felixers', Read *et al.* 2014) and automated sensor traps (e.g. Notz *et al.* 2017; Meek *et al.* 2020), which may provide alternative control options in future. Each technique varies in their scale of use, cost, required effort and overall efficacy, influencing the value and practicality of employing them. Clear guidance on the availability of management techniques, their impacts, limitations, and potential costs is vital, given that feral cat management is a high-priority conservation action.

Likely success of feral cat control depends on multiple external factors, including local population dynamics, environmental conditions, and land use. Higher-density feral cat populations are more common as vegetation productivity increases (Bengsen *et al.* 2016). However, higher-productivity areas are typically subject to greater or more frequent rainfall (Good and Caylor 2011; Guo *et al.* 2012), which can decrease the efficacy of control programs by reducing (1) bait uptake or trap success as prey availability increases (e.g. Christensen *et al.* 2013), (2) bait longevity (e.g. Gentle *et al.* 2007), or (3) road accessibility and management intervals (Algar *et al.* 2007; Fancourt *et al.* 2021). Control programs are also limited by legislation relating to different land-use types. For example, in natural or agricultural landscapes, different control techniques may be applied subject to jurisdiction-specific legislation (Johnston and Algar 2020). However, in residential areas lower-risk techniques (e.g. cage trapping) are preferred over higher-risk techniques that may injure or kill non-target domestic animals (e.g. leghold trapping, baiting; Sharp *et al.* 2022). Unintentional injury or poisoning of non-target native fauna is another consideration in the development of management programs (Fairbridge *et al.* 2003; Sharp *et al.* 2022). Understanding how management actions can be affected by external factors is crucial for evaluating the efficacy and impact of the management program on feral cat populations.

Currently, empirical data regarding the efficacy of different feral cat management techniques are patchy. Some data on the efficacy of cat control options in different environmental and land-use contexts have been published; however, many researchers and practitioners hold substantial experiential information that is not formally documented. Expert elicitation provides a means to gather this knowledge through facilitated discussion in a structured workshop setting (Hoffman and Lintern 2006). In this study, we worked with 19 experts to identify current and emerging feral cat management techniques being used around Australia and key factors influencing their success. We aimed to identify the average environmental, social, and economic impact of each identified management technique by ecoregion and land-use type. Further, through expert opinion, we sought to identify knowledge gaps and prioritise topics for future Australian feral cat management research.

Materials and methods

We convened a 1-day workshop with 19 experts in feral cat management in August 2022. Experts identified the techniques used for feral cat management, the effectiveness, impact, and cost of each method, and the key knowledge gaps associated with feral cat management. Five experienced facilitators from unrelated fields led the structured elicitation in feral cat management. Facilitators aided in the design and format of the workshop, led the discussion at each stage and collated the results. To prevent unconscious bias, we collaborated with all facilitators beforehand to review the workshop objectives and materials, confirm their understanding of biases and ensure strategies to prevent their introduction. Facilitators were instructed to not contribute to the discussion, but to primarily ensure that tasks were being completed in a timely fashion. If necessary, they also brought discussion back to the pertinent points. They did not provide opinions or data to discussions or quantitative elicitation. Furthermore, small group reporting was undertaken by participants, not facilitators, to further prevent any facilitator bias.

Workshop participants

Workshop participants were drawn from every Australian State and Territory and have substantial experience in research, management implementation and policy. Among the participants recruited, seven had experience as researchers, four had experience as feral cat management practitioners, three had both, and five had experience in relevant policy (Table 1). They came from 16 different institutions and their experience ranged from <10 years (11 participants) to >30 years (one participant) (Table 1). During the workshop, experts were divided into small groups of four to five individuals. These groups were allocated to maximise diversity in terms of research background and years of experience at each table.

Defining ecoregions

First, experts worked to define the Australian ecoregions in which feral cat management occurs. Ecoregion descriptions provided by the Department of Sustainability, Environment, Water, Population and Communities (2012) (retrieved from www.dcceew.gov.au) were utilised as a starting point. Following group discussions, all experts were asked to describe how well these ecoregion definitions equate to functional differences in feral cat management programs. Several caveats were identified during this discussion, including the influences that topography, human population density and the landscape complexity can have on management techniques and outcomes. Experts also noted that island systems probably do not suit the ecoregion definitions provided and should be considered separately when discussing feral cat management techniques.

Experts identified several ecoregions could be combined into 'vegetation megaregions' in which feral cat control approaches were similar. The vegetation megaregions that were considered by experts during the workshop were as follows: (1) 'deserts and xeric shrublands' (three responses); (2) 'Mediterranean forests, woodlands and scrub' (three responses); (3) 'temperate broadleaf and mixed forests' (seven responses); (4) 'temperate grasslands, savannas and shrublands'/'tropical and subtropical grasslands, savannas and shrublands'/'montane grasslands and shrublands' (henceforth 'srasslands') (two responses); and (5) 'tropical and subtropical moist broadleaf forests' (no responses). During the workshop, there was little or no discussion of feral cat management in 'tropical and subtropical moist broadleaf forests'. This is because the area covered by this megaregion is much smaller than the others and has fewer people working on feral cat management within it (i.e. expert recruitment unintentionally missed experts from this region). The grasslands megaregion (comprising 'temperate grasslands, savannas and shrublands', 'tropical and subtropical grasslands, savannas and shrubland' and 'montane grasslands and shrublands') were considered by experts to be functionally equivalent for management purposes because of the similarities in vegetation structure (Department of Climate Change, Energy the Environment and Water 2021).

Table 1. Demographics of workshop attendees (excluding facilitators) showing the number of participants in each category and this number as a percentage of the 19 experts who participated in the workshop.

Category	Number of participants	Percentage
Organisation		
University of New England/Department of Primary Industries [NSW]	1	5.3
Department of Planning and Environment [NSW]	1	5.3
NRM Regions Australia	1	5.3
Department of Environment, Parks, and Water Security [NT]	1	5.3
Charles Darwin University	1	5.3
Department of Defence [AUS]	1	5.3
University of Western Australia/WA Feral Cat Working Group	1	5.3
Department of Climate Change, Energy, the Environment and Water [AUS]	3	15.8
Centre for Invasive Species Solutions	2	10.5
Department of Agriculture and Fisheries [Qld]	1	5.3
Kangaroo Island Landscapes Board [SA]	1	5.3
Department of Environment, Land, Water and Planning [Vic.]	1	5.3
Department of Natural Resources and Environment [Tas.]	1	5.3
Australian National University	1	5.3
Department of Biodiversity, Conservation and Attractions [WA]	1	5.3
Department of Agriculture, Fisheries and Forestry [AUS]	1	5.3
State/territory		
New South Wales	4	21.0
Northern Territory	1	5.3
Queensland	1	5.3
South Australia	1	5.3
Tasmania	2	10.5
Victoria	2	10.5
Western Australia	3	15.8
Australian Capital Territory	5	26.3
Type of experience		
Researcher	7	36.8
Practitioners	4	21.0
Both	3	15.8
Policy	5	26.3
Years of experience		
1–10	11	57.9
11–20	5	26.3

(*Continued on next page*)

Table 1. (*Continued*).

Category	Number of participants	Percentage
21–30	2	10.5
30+	1	5.3
Gender		
Male	12	63.2
Female	7	36.8

For 'Organisation', the relevant State or Territory of the organisation is provided in square brackets.
ACT, Australian Capital Territory; NSW, New South Wales; NT, Northern Territory; Qld, Queensland; SA, South Australia; Tas., Tasmania; Vic., Victoria; WA, Western Australia; AUS, Federal government department.

Identifying current and emerging management techniques

Experts were asked to work in their groups to list and define feral cat management techniques for which they had the most experience. Workshop facilitators used the list of identified techniques to focus the ensuing conversation. Workshop participants were given 1.5 h to answer a series of questions about each management action, including (1) where it had been used, (2) the spatial scale of use, (3) the season of use, (4) the annual frequency of use, (5) whether the outcome was monitored and (6) any pros and cons associated with its use. All experts then participated in an all of workshop discussion around the management techniques to separate those that are commonly used from those that may be used in future. These discussions led to a final list of 10 current management techniques to be considered for the remainder of the workshop. Discussions around the definitions of each technique standardised the participants' understanding of the management techniques.

Estimating impacts of management techniques

Individuals were then asked to quantify the impact of each technique in the following six different land-use types: natural; production; agricultural; rural residential; urban residential; and wetlands (defined in Supplementary material Table S1). These land-use types were based on existing primary- and secondary-class definitions from the 'The Australian Land Use and Management Classification Version 8' (ABARES 2016). Via a self-response survey hosted on Qualtrics, an online survey platform, experts provided estimates for a 10,000 ha area in each of the land-use types related to the following: (1) the reduction in the feral cat population that would occur 1 month from the implementation of a management program; (2) the reduction in the population that would occur 12 months from the implementation of a program; and (3) the expected cost of implementing the management technique for a single round of management (e.g. one aerial bait deployment or one targeted trapping program). Additionally, the survey asked experts to consider the following: (4) the proportion of the budget in their region attributed to each management technique over a 12-month period; (5) to what degree the management technique negatively affects non-target native species over a 12-month period; and (6) the social acceptability of the technique. For all elements of the survey (except Point 4 above), experts were asked to consider the impact or cost of each technique by itself and not in relation to the impact or cost of other techniques. The questions asked during the online survey are provided in Supplementary material.

Experts considered many of the techniques as either not applicable in certain land-use types or they could not provide an estimate of the expected response. Therefore, we present results only for techniques for which more than 50% of the experts provided estimates of the reduction in the feral cat population (summarised in Table S2). Additionally, estimates on the impacts of fencing are not reported here because it is very site specific in its application and discussion around how it should be considered during the workshop was limited.

Experts' responses were aggregated and summarised using R (v4.1.0, R Core Team 2021), then presented to the group for discussion. The expected reductions in feral cat populations were summarised using equal-weight aggregation (Hemming *et al.* 2020), in which we took the arithmetic mean of the estimates provided for each technique within each land-use and vegetation megaregion. Best estimates were averaged to calculate the mean expected response in each group. Upper confidence limits were calculated by averaging expert estimates for the highest plausible reduction in feral cats following management. Lower confidence limits were calculated by averaging the estimates for the lowest plausible reduction. Equal-weight aggregation was used because it is considered a suitable aggregation method when calibration questions for expert accuracy are not used (Hemming *et al.* 2022).

Expert estimates of the expected cost of implementing each management technique over a 1-month period were aggregated in a boxplot. The boxplot was produced in R using the 'ggplot2' package (Wickham 2009). The boxes show the interquartile range (IQR) of the data illustrating the lower (Q1), median (Q2) and upper (Q3) quartiles of expert estimates. The whiskers of the boxplot show the estimate dispersion, spanning from $Q1 - 1.5 \times IQR$ to $Q3 - 1.5 \times IQR$.

The proportion of budget in each vegetation megaregion allocated to each technique was summarised by calculating the average of the proportion estimates provided by the experts. Finally, the proportion of responses in each category for impact by non-target species (no impact–high impact) and social acceptability (no tolerance–high tolerance) were calculated for each management technique. Summaries of all the experts' responses were plotted using the 'ggplot2' package (Wickham 2009) in R.

Identifying research priorities

The final workshop task was for individuals to write down three key knowledge gaps relating to feral cat management. These were compiled into a list and the experts participated in a facilitated group discussion to ensure that all the identified knowledge gaps were included and represented correctly. This refined list of knowledge gaps was provided to the experts via a second self-response survey, so they could arrange the list in order of research priority. The average ranking value for each knowledge gap was calculated to order the list from higher to lower research priority.

Ethics statement

This research has been approved by the Ethics, Grants and Research Integrity team at the University of New England (HREC Project Number: HE22-104, valid to 8 July 2023).

Results

Experts identified and defined the following 10 techniques currently used in feral cat management: aerial baiting; ground baiting; cage trapping; leghold trapping; shooting; tracking by Rangers; tracking with detector dogs; habitat modification through prescribed fire or grazing; resource modification through targeted control of non-native prey species (e.g. rabbits, *Oryctolagus cuniculus*); and exclusion fencing (see Table S3 for full definitions). A further five techniques for feral cat population reduction were identified that are either infrequently used or may be used in future; these were gene drive technology, Felixer grooming traps, immunocontraception, trap–neuter–release programs, and biocontrol (see Table S3 for definitions).

Estimated impacts of management techniques

In most vegetation megaregions after 1-month, on average, greater reductions in feral cat populations were predicted from baiting techniques than the other methods with sufficient responses for analysis (Fig. 1). The expected scale of reduction tended to change little after 12 months for all management techniques, except habitat modification where the average expected impact of the technique led to further population reductions 12 months after management (Fig. S1). There was considerable overlap in the estimates provided for feral cat population reduction among land-use types within each management technique (Figs 1, S1). However, on average, cage trapping was considered more effective in residential areas than in forested or agricultural areas, although large overlap in confidence limits indicated that this difference was only minor (Fig. 1). The average estimates for most other techniques considered indicated that the reverse was true, with higher expected efficacy in natural and production environments than in residential areas (Fig. 1).

Baiting and trapping techniques were identified as having a greater negative impact on non-target native species than were other methods (Fig. 2*a*). Tracking with detector dogs and tracking by Indigenous Rangers were considered least likely to have negative impacts on native, non-target fauna (Fig. 2*a*).

None of the techniques were described as having no social tolerance by the experts, but some considered there was 'low tolerance' for baiting techniques, leghold trapping and shooting (Fig. 2*b*). Conversely, 'high tolerance' was ascribed by some experts to techniques including cage trapping, tracking with detector dogs, tracking by Indigenous Rangers, habitat modification, and resource modification (Fig. 2*b*).

Experts identified aerial baiting and detector dogs as the most expensive techniques, followed by cage trapping, leghold trapping, shooting and habitat modification (Figs 3, S2). However, the experts generally agreed that most of the budget available for feral cat management went to aerial baiting in each megaregion except for Mediterranean forests (Fig. S3).

Research priorities

Many of the knowledge gaps identified by participants related to the requirement for effective monitoring of feral cat populations to implement successful management programs. The multiple knowledge gaps raised around this issue were summarised into a general knowledge gap pertaining to how we can improve monitoring to inform management. This was assigned the highest research priority ranking by most experts (Table 2). Other key research areas related to the implementation of management programs, the longevity of management and ethical considerations around management.

Discussion

Experts identified 10 feral cat management techniques, which varied in scale, season of application, return interval and legislative requirements. Of the techniques with estimates, aerial baiting was considered to cover the largest areas and, on average, to cause the greatest feral cat population reductions in both natural and production landscapes in the short term (~1 month). However, some experts noted that habitat modification through fire and grazing, or resource modification via the control of non-native prey, such as rabbits, may have an equivalent impact in some regions of Australia. Further research in this area is needed to understand the potential impacts and benefits of these techniques. In urban or rural residential areas, techniques such as cage trapping, shooting, or tracking with detector dogs were considered most effective. On average, this resulted in higher-than-expected reductions in feral cat populations compared with other techniques. The management techniques considered to have the largest impact on non-target native species included aerial and ground baiting, leghold trapping and cage trapping, whereas the techniques with the lowest social

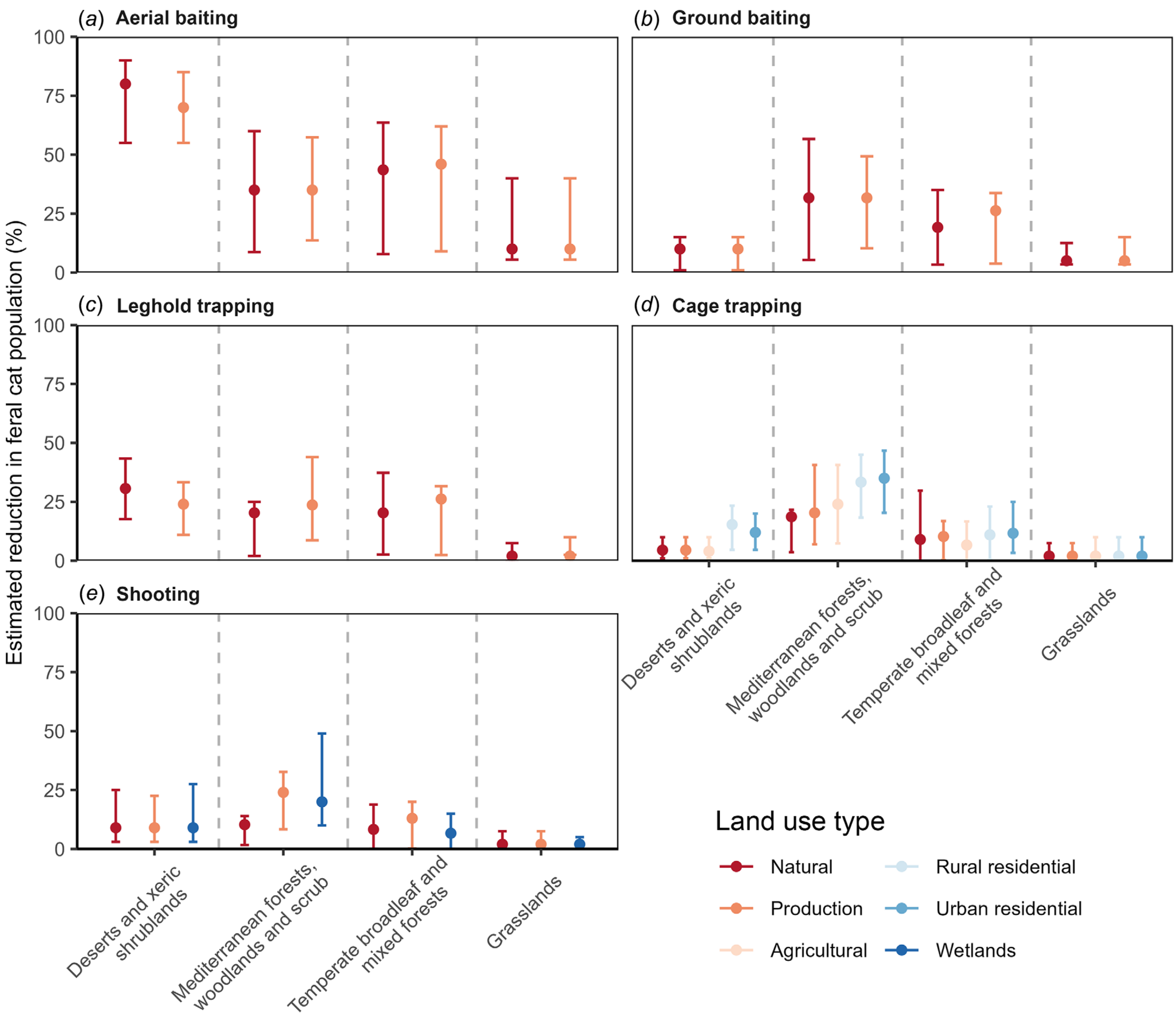

Fig. 1. Average best, lower and upper estimates from experts on the percentage reduction in feral cats 1 month from the beginning of a management program for the different land-use types and vegetation megaregions with estimates from more than 50% of experts (Table S2) for (*a*) Aerial baiting, (*b*) Ground baiting, (*c*) Leghold trapping, (*d*) Cage trapping, and (*e*) Shooting.

tolerance included aerial baiting, ground baiting, leghold trapping and shooting. Aerial baiting was considered the most expensive technique and experts indicated that it received the largest proportion of management budget.

Influence of vegetation megaregion

Experts agreed that five of seven pre-defined ecoregions were functionally different in how feral cats were managed or responded to management. Although experts considered the revised megaregions generally acceptable for delineating management approaches, they highlighted that land use, topography, population density and landscape complexity were more important for determining the impact of management actions. For this reason, large overlap in management efficacy estimates were detected for 'Mediterranean forests, woodlands and scrub' and 'temperate broadleaf and mixed forests' in natural and production land-use types. This suggests that, when examining management impact in natural systems at the broadest levels, only the following three functional groups for vegetation region may be required: (1) deserts and xeric shrublands; (2) forests and woodlands; and (3) grasslands, savannas and shrublands.

Identifying management techniques

Ten currently used management techniques were identified by experts, with an additional five techniques acknowledged for potential use in future feral cat management. Of the currently used techniques, only five have defined national

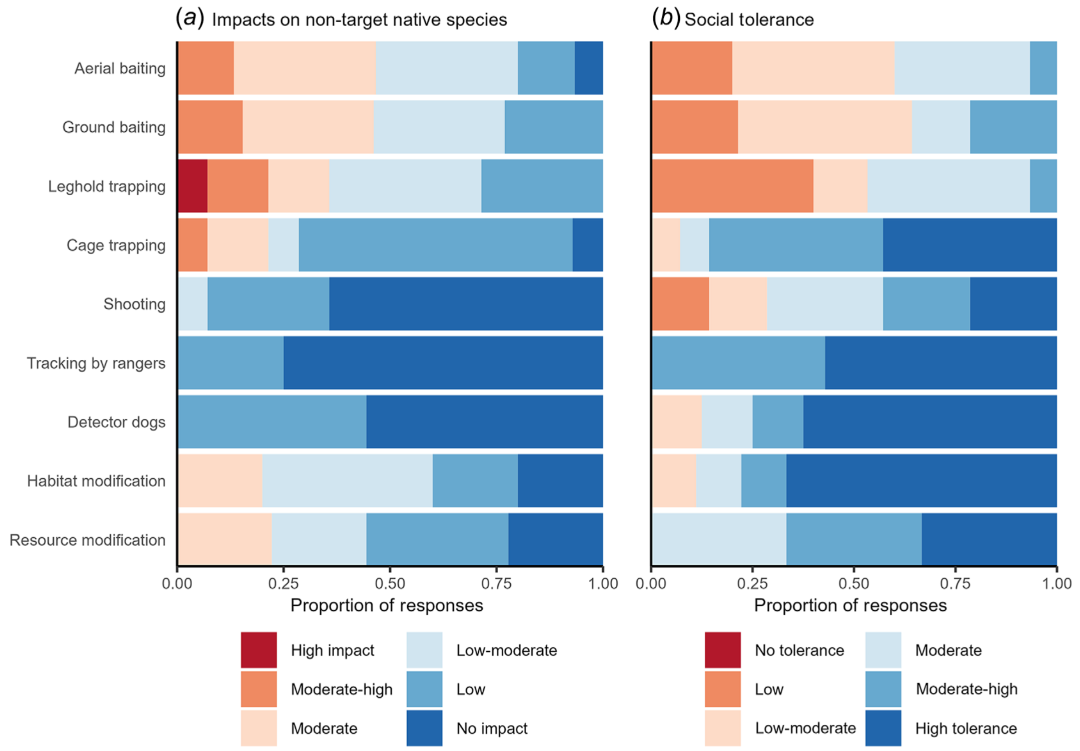

Fig. 2. Expert opinions for each technique on (*a*) ecological impact on non-target native species, where no or low impact indicates that the technique does not harm non-target native species, and high impact suggests potential harm or death, and (*b*) social tolerance, where no or low tolerance indicates strong resistance to use of the technique and high tolerance indicates acceptance or indifference.

standard operating procedures (SOPs), namely, leghold trapping (Sharp 2005*a*), cage trapping (Sharp 2005*b*), shooting (Sharp 2005*c*), and ground and aerial baiting (Sharp and Quinn 2020; Sharp *et al*. 2022). While these SOPs are accepted nationwide, there are differences in legislation among Australian states and territories, which limit the use of certain techniques. For example, leghold traps are currently permitted only under ministerial approval in Victoria and Tasmania, preventing their use in many management programs (Johnston and Algar 2020). As a result, there is great variability in where and how the identified management techniques can be applied in Australia, with little or inconsistent guidance on the best strategy for implementing these techniques.

Efficacy of control programs

In natural and production ecosystems, management techniques applied at larger spatial scales (i.e. >100,000 ha), such as aerial baiting, resource and habitat modification, were, on average, estimated to be the most effective management for feral cat control. In the month following management, aerial baiting was estimated to be the most effective technique, although the average impact of aerial baiting differed across megaregions. This was potentially due to interactions involving jurisdiction regulations, available bait types and differences in vegetation structure. Megaregions are unevenly distributed across Australian States and Territories; for example, 'Mediterranean, woodlands, and scrub' are found in the south and 'grasslands' in the north. Vegetation structural differences also influence the applicability and efficacy of techniques in different areas; for example, dense rainforest canopies may prevent effective application of aerial baits (Dorph and Ballard 2023). Further, although there are several meat baits available for feral cat baiting programs, they differ in their efficacy (e.g. Fancourt *et al*. 2019) and availability because each jurisdiction has distinct regulatory frameworks specifying whether they can be used (e.g. Queensland Health 2021; Department of Energy, Environment and Climate Action 2023). Legislative requirements, bait efficacy and megaregion may therefore influence our results, underscoring the need for further research on aerial baiting efficacy under different management scenarios to provide optimal guidance for program design. Indeed, in some megaregions, there is little research into the efficacy of different baits; for example, very little research on baiting efficacy in the 'grasslands' megaregion exists in the literature (but see Fancourt *et al*. 2022).

Over a 12-month period, resource and habitat modification were also estimated to be effective management techniques in natural and production ecosystems. Resource modification

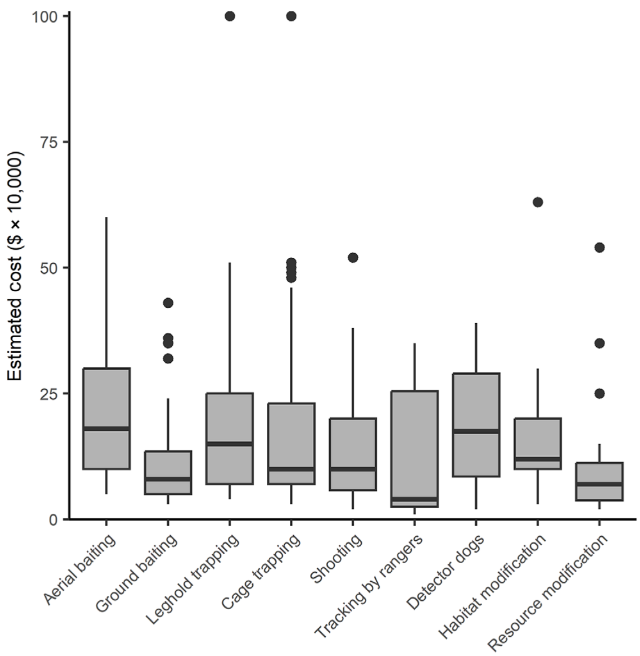

Fig. 3. Boxplot of all expert estimates for the cost of implementing each management technique for a 1-month period. The thick black line indicates the median value of the expert estimates. Lower and upper limits of the grey box indicate the first and third quartiles respectively. Lower and upper whiskers extend to the minimum and maximum of 1.5 times the interquartile range. Black dots indicate outlying estimates.

Table 2. Expert identified knowledge gaps ranked in order of research priority from highest to lowest.

Priority	Knowledge gap
1.	How do we best monitor to inform management (where cats occur, how they are using the landscape, cat density, juveniles and subadults, novel techniques e.g. eDNA)?
2.	What are the interacting impacts of feral cats (*Felis catus*)/European red foxes (*Vulpes vulpes*)/wild dogs and dingoes (*Canis familiaris*) on prey species with and without management?
3.	What is the longevity of a management program, including time to reinvasion?
4.	How much movement is there between urban/peri-urban environments and natural environments and how can we best manage this?
5.	Which areas do we prioritise for eradication?
6.	How to manage across multiple tenures over time to increase the time to reinvasion?
7.	In a cost–benefit framework, how can we optimise and prioritise resource expenditure in an adaptive manner?
8.	How do we achieve and maintain social licence, how can we best communicate this and how does it change over time?
9.	How far can we push ecological manipulation as a method for control (e.g. grazing, rabbits (*Oryctolagus cuniculus*), fire)?
10.	What is the fine-scale habitat use of feral cats/European red foxes/wild dogs and dingoes?
11.	How can indigenous practices contribute to cat management?
12.	How can we develop effective novel management practices (e.g. gene drive, new baits)?
13.	What is the appetite for the management of domestic cats and how does this vary across jurisdictions?
14.	How do we convert research into practice?
15.	How can we ethically kill cats in traps?
16.	How do we 'kill the last cat' in an area?
17.	How do we develop national data on cat management – what's working, where do we put future effort?
18.	How do we support private land holders to manage cats to deliver outcomes?

through the control of rabbit populations is expected to reduce feral cat populations because rabbits make up a significant proportion of feral cat diets (Doherty *et al.* 2015; Pedler *et al.* 2016; McGregor *et al.* 2020). However, experts cautioned that prey-switching following resource modification may negatively affect native fauna populations at the point when rabbit numbers are first reduced (e.g. McGregor *et al.* 2020). Habitat modification through fire and grazing management was also expected to cause reductions in feral cat populations over time. Fire and feral herbivores can contribute to the creation of more open habitat structure (Haslem *et al.* 2011; Reid *et al.* 2023). Studies have reported that feral cat activity initially increases in these disturbed areas for the resources they provide, but as vegetation recovers cat activity decreases again (e.g. Leahy *et al.* 2015; McGregor *et al.* 2016; Hradsky 2020). Therefore, controlling the impact of disturbance from fire and mega-herbivore activity may lead to lower feral cat activity and occupancy, as observed in less degraded areas of northern Australia (Davies *et al.* 2020; Stobo-Wilson *et al.* 2020). Increased research on these techniques under different scenarios is crucial for refining guidance on their optimal use for positive outcomes.

In rural and urban residential environments, management techniques used at localised or smaller scales (i.e. <20,000 ha) were estimated to be more effective for targeted feral cat control. Cage trapping, shooting and, in some megaregions, tracking by detector dogs were identified as most effective for reducing cat numbers. Estimates for these techniques were notably higher in 'Mediterranean, woodlands and scrub' potentially owing to greater success of these techniques in this megaregion. For example, in 'Mediterranean, woodlands and scrub' cage trapping for feral cats is more successful than in 'temperate, broadleaf and mixed forest' (Robley *et al.* 2019). The impacts of many other techniques were not estimated for rural and urban residential areas, likely owing to legislative requirements preventing the use of lethal or harmful methods, such as baiting and leghold trapping, in residential areas (e.g. toxic baits are prohibited within 150 m of residential areas; Sharp and Quinn 2020). Social perception and licence also have a greater impact in residential areas where accidental harm or killing of free-roaming pet cats may be more likely, underscoring the preference for non-lethal or targeted methods, such as cage trapping.

In addition to the limitations imposed by legislation and social licence, logistical constraints and cultural sensitivity were identified as potential barriers to the application and efficacy of the different management techniques. For example, the time and effort required to implement management techniques, such as shooting or cage trapping, can act as a barrier to their use, particularly at larger scales (Short *et al.* 2002; Fisher *et al.* 2015). Therefore, experts highlighted that some of the techniques applied at smaller or more localised scales were more suited to integrated management programs, supplementing larger-scale programs (e.g. aerial baiting). Cultural sensitivity can also limit the use of some management actions; for example, Aboriginal and Torres Strait Islander communities are opposed to aerial and ground baiting in parts of Australia (Koichi *et al.* 2013). These factors all need to be considered when making recommendations for management actions in different regions.

Non-target species impact and social tolerance

There was overlap between the techniques that had the lowest social tolerance and those that had the largest negative impact on non-target species. Aerial baiting, ground baiting and leghold trapping were all considered to have a high negative impact on non-target native species (e.g. Surtees *et al.* 2019) and were also considered to have low social tolerance (e.g. Subroy *et al.* 2018). In contrast, tracking by rangers, tracking with detector dogs, habitat and resource modification were all considered to have a low impact on non-target species and a higher social tolerance. However, the social tolerance and negative impact assessment of non-target native species for cage trapping and shooting were in conflict. Shooting was considered one of the more socially unacceptable methods, despite experts identifying it as a technique with low non-target species impact. Conversely, cage trapping had a high social tolerance, even though experts considered this method as having a greater impact on non-target species. When designing feral cat management programs, it will be important to balance the actual non-target impacts of any management techniques with the public perceptions.

Economic impact

Cost estimates provided by experts varied on the basis of their megaregion and the state or territory for which they had knowledge. On average, for a single management program, most techniques were estimated to cost <AU$250,000 to implement. Aerial and ground baiting were suggested to receive ~50% of the feral cat management budget in all megaregions except 'Mediterranean forests, woodlands and scrub' (Fig. S3). In this megaregion, there was higher attribution of funds to shooting, cage trapping and leghold trapping. Potentially, in this megaregion integrated control programs are considered more effective and so more funds are attributed to supplementary control techniques. In addition to potential higher returns for effort of techniques such as cage trapping in this megaregion (Robley *et al.* 2019), integrated control programs may also be preferable in this megaregion, which has many areas of high conservation concern and where potentially detrimental off-target impacts from baiting programs have been reported (e.g. Hohnen *et al.* 2020). These estimates should be considered with caution because there was high variability within states and megaregions regarding the expected costs of different management programs. More structured understanding of relative program costs is required to fully appreciate the expense required for these management programs.

The expert elicitation approach

The interacting factors influencing which feral cat management programs are available paired with complex feral cat populations dynamics, impedes our ability to understand the likely outcomes of different management scenarios. Expert elicitation is a valuable tool in this context, when data are either unavailable or involve high costs and difficulties in collection, but the process is not without its limitations. In particular, experts are not always able to produce accurate estimates relative to real-world outcomes. However, they are able to capture the real-world outcome between 49% and 63% of the time (McBride *et al.* 2012). When no other data are available, this information can still provide guidance on the best management action in decision-making scenarios. There is also potential subjectivity inherent in expert opinion, which can be overcome in elicitation procedures using facilitated discussion sessions, as was undertaken here. However, in future using a structured protocol for the workshop (e.g. the IDEA protocol) may further improve the reliability of expert estimates (Hemming *et al.* 2018). Finally, a limited pool of experts during an expert elicitation can lead to a narrow range of perspectives (Morgan 2014). To address this, during this workshop we included experts from a wide array of feral cat management roles including practitioners, researchers and policy makers, to ensure that a variety of concerns and opinions on various management techniques was raised. With these limitations in mind, we would not recommend using the results of this expert elicitation procedure to replace real-world data collection or guarantee accurate predictions of feral cat responses. Instead, we recommend using the outputs of this research as a guide, while additional reliable empirical data are collected. Future studies looking to provide guidance on the potential management options available for other vertebrate pests globally may consider using a similar approach.

Areas for future research

Whereas an approach different from the elicitation process described here may improve some of the estimates provided by experts, there were still clear knowledge gaps in relation to some of the management techniques. For example, there was no clear indication provided by experts that any of the management techniques discussed would be able to reduce feral cat populations in 'grasslands' megaregions. Fewer experts representing these areas, or fewer studies on the efficacy of management operations in 'grasslands', may have led to a reduced understanding of the efficacy of different feral cat management techniques for this megaregion. Similarly, many experts were unable to provide estimates for how feral cat populations would be affected by management in wetland environments. The lack of research in some areas was highlighted further when we asked experts to identify key knowledge gaps related to feral cat management. Many of the experts identified that we need improved monitoring techniques to understand where feral cats occur, how they use the landscape and their population dynamics to inform our management strategies in future. This knowledge gap can be emphasised by the fact that the experts acknowledged that many of the management techniques they defined were not monitored following implementation (Table S3). Our ability to successfully monitor and understand the impact of management programs underpins many of the remaining knowledge gaps identified by the experts during this exercise. For example, the longevity of management impacts cannot be determined without first having effective monitoring in place. Improving understanding and practice regarding monitoring is a requirement for understanding best-practice feral cat management. Short-term funding cycles often prevent long-term monitoring of feral cat populations from occurring, inhibiting our ability to improve monitoring practices. To address this gap and improve our understanding of best-practice management, more funding should be invested in longer-term monitoring programs.

Conclusions

The expert elicitation workshop provided an opportunity to review and collate information about feral cat management strategies currently used in Australia, their efficacy and impacts associated with them. Such an extensive assessment would be difficult to conduct solely from the literature because many researchers and practitioners hold substantial experiential information that has not been formally documented. On the basis of the information collected from experts, three key factors should be considered when developing feral cat management programs. First, the effectiveness of management actions will differ among at least three vegetation structural regions, namely (1) deserts and xeric shrublands, (2) forests and woodlands, and savannas (3) grasslands, savannas and shrublands. Second, management options will vary between two general land-use classifications, namely, residential areas or natural and fragmented systems. Finally, logistical, legislative, and social constraints apply to all the management techniques, limiting the scale at which techniques can be applied and where they can be used. Consequently, it is important when designing feral cat management programs to remember that not all management techniques in all landscapes are equal, and that for optimal feral cat management, we need to prioritise our strategy on the basis of the technique, region of use and expected impact.

Supplementary material

Supplementary material is available online.

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Data availability. The data that support this study cannot be publicly shared due to ethical or privacy reasons and may be shared upon reasonable request to the corresponding author if appropriate.

Conflicts of interest. Sarah Legge is an Editor of Wildlife Research. To mitigate this potential conflicts of interest they were blinded from the review process.

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