Assessing the effectiveness of cage trapping to manage feral cats for biodiversity conservation in Victoria

A Biodiversity Response Planning project

A. Robley, L. Cockman, S. Donald, M. Hoskins, A. Shiells and L. Stringer

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Front cover photo: feral cat (C*atus felis*) (DELWP).

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A Biodiversity Response Planning project

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Context:

The Victorian Government declared feral cats (*Felis catus*) an established pest on specified Crown Land in 2018. That declaration allows for a more practical application of currently available control tools (e.g., confinement traps, shooting), and provides for the use of emerging tools (baits, grooming traps) if they become available. On Parks Victoria estate and Department of Environment, Land, Water and Planning (DELWP) forested lands (where the declaration applies), land managers are now able to humanely destroy cats identified as feral that have been caught in cage traps.

As part of a state-wide investment to increase feral cat management effectiveness and capabilities, Biodiversity Response Planning (BRP) has funded several feral cat control projects. Four of these projects plan to use cage trapping as the initial control tool.

Currently, we have no clear understanding of the most effective approach for using the available tools for the control of feral cats in Victoria (in what combination, and for what duration, timing, etc.), the scale at which to apply these tools, or the level of reduction in feral cat populations to expect from the application of these tools.

Aims:

Year one (2019/20) of the overall feral cat BRP project, reported here, aimed to assess the efficacy of cage trapping to control feral cat populations by quantifying feral cat density before and after cage trapping operations across four sites at five locations around Victoria. The outcomes will contribute to improving management capabilities and provide standards for the control of feral cats in Victoria.

Methods:

At each location, cage trapping grids were established that consisted of between 40 and 50 wire cage traps spaced at an average of 1 km intervals along accessible roads and tracks across an area of approximately 40 km^2. Cage traps were wired open prior to being 'set', to allow resident feral cats to become accustomed to the presence of the traps. Once 'set', traps were baited with a range of food and scent-based lures that were refreshed at most, weekly. Traps were checked daily for 5–6 weeks in late autumn to early winter 2019.

Before and after cage trapping, we established grids of 60–100 heat-in-motion–activated digital cameras spaced at ~500–1000 m intervals, covering the same area as the cage traps. Cameras were lured with a mix of visual and olfactory scents, and generally operated for ~35–55 days before and after cage trapping.

Using images captured on cameras we constructed capture and recapture histories by identifying individual feral cats from their distinctive coat markings. This data was used to assess pre– and post–cage trapping feral cat densities using mark–resight models.

Results:

Cage trapping feral cats was generally unsuccessful. Fourteen feral cats were removed from the Mournpall Block at Hattah–Kulkyne National Park, three from the Isthmus area of Wilsons Promontory, two from Mount Clay State Forest, and none from Cobboboonee National Park.

Due to a lack of resighting's following cage trapping at Hattah–Kulkyne National Park, it was not possible to detect a change in density. However, of the 12 cats known to be alive during the cage trapping period, 5 (41%) were known to be caught as they were matched to pre–cage trapping camera images.

Feral cat density estimates ranged from 0.16 to 0.57 cats/km^2 across all locations; however, precision in these estimates was generally low and confidence limits were wide.

Conclusions and implications:

Cage trapping was found to be ineffective at population-level control of feral cats. The very low level of captures at most sites and the lack of a population-level effect at Hattah–Kulkyne National Park may have been due to several factors. The availability/abundance of live prey (which can make cage trap bait unattractive), the skill level of the operators in setting traps, the spacing of the trapping arrays (which can limit encounter opportunities) and weather, can all play a part in determining the success of cage trapping.

The uncertainty in the feral cat density estimates obtained in this study was the result of too few camera trap resighting's. This likely resulted from camera spacing being too sparse to ensure the required rate of

resighting's for performing the analysis, which in turn was due to limited knowledge of feral cat movement and home range size.

Cage trapping could be used to supplement more effective control strategies, such as landscape scale baiting or attempts at island eradication. There is some evidence to suggest that low-level culling (as would occur with cage trapping) can lead to *increased* abundance under some circumstances, and thus cage trapping should be avoided as a single control tool.

Increasing our understanding of feral cat movement and home range size in various habitats will be useful for the planning of any future control action, regardless of the control tool being employed. Determining the best time of year for attempting control in southern and mountainous areas of Victoria is also necessary for increasing management effectiveness.

1 Introduction

Australia’s endemic species are particularly susceptible to predation by introduced predators due to our long history of geological isolation (Short et al. 2002). Following the arrival of Europeans, the rate of mammal extinctions has been the highest on Earth in modern times, with the Red Fox (*Vulpes vulpes*) and feral cat (*Felis catus*) being implicated as key drivers in most of the extinctions (ICUN 1996; Short et al. 2002; Woinarski et al. 2011; Ziembicki et al. 2014; Fisher 2015). In Victoria, there are 43 species listed under the *Flora and Fauna Guarantee Act 1988* (FFG Act) or the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) as threatened by feral cat predation.

Over the past few decades, robust evidence has emerged that demonstrates the significant impact that feral cats have on native wildlife through direct predation (Nogales et al. 2004; Marlow et al. 2015; Jones et al. 2016). It has been shown that feral cats preferentially select small mammals as prey (Kutt 2012), and that some individual feral cats can be disproportionately responsible for predation on populations of native species (Moseby et al. 2015). Predation by feral cats has been identified as the main contributing factor in the failure of several reintroduction programs (Moseby et al. 2011; Moseby et al. 2015; Hardman et al. 2016). Feral cats have also been demonstrated to be the main predator of medium-sized mammals, at locations in which there has been sustained control of foxes (Marlow et al. 2015).

In Victoria, it is known that feral cats have become established in almost every terrestrial habitat type, although limited direct evidence is available of the specifics of feral cat habitat use or of their density, and how it varies throughout the various habitats in Victoria. Jones and Coman (1982) estimated feral cat density at Hattah–Kulkyne National Park in the Victorian Mallee as ranging from 0.74 cats/km^2 in the winter to 2.4 cats/km^2 in the summer. Robley et al. (2017) estimated feral cat density at the same location in 2015 as 0.24/km^2 in spring. M. Rees (University of Melbourne, 2018 unpublished data) estimated feral cat density in wet forests of the Otway Ranges at 0.98/km^2.

Feral cats are obligate carnivores and can obtain their water requirements almost entirely from their food (Duffy and Capece 2011). As a result, feral cats prefer eating live prey such as rabbits, small mammals and lizards (MacDonald et al. 1984; Holden and Mutze 2002) over the consumption of carrion, including baits deployed during control programs. In addition, feral cats tend to only consume baits when hungry, regardless of palatability (Algar et al. 2007).

The Strategic Management Prospects (SMP) project is a conservation planning tool developed by DELWP that seeks to identify cost-effective management interventions for biodiversity conservation across Victoria (Thomson et al. 2017). SMP integrates the information available on species distributions, threatening processes, and the effectiveness and costs of management actions. An output from this project is the identification of geographic locations at which biodiversity benefits would be gained from the control of feral cats.

The Victorian Government declared feral cats an established pest on public land in 2018. That declaration allows for a more practical application of currently available tools (confinement trapping, shooting) and provides for the use of emerging tools (baits, grooming traps) when they become available. On Parks Victoria estate and DELWP forested lands (where the declaration applies), land managers are now able to humanely destroy cats identified as feral and caught in cage traps. In addition, DELWP can undertake spotlight shooting without the need for demonstrating that all reasonable attempts have been made to first capture feral cats.

Compared with that of many other pest animals, the history of feral cat control for strategic management in Australia is short, and the suite of tools available is limited (Bengsen 2015). A survey of pest mammal control programs conducted in Australia between 1998 and 2003 found that most (59%) feral cat control programs used trapping to remove cats from the target population, followed by baiting (21%), shooting from the ground (18%), and other unspecified tools (2%) (Reddiex et al. 2006).

However, we currently have no clear understanding of the appropriate use of the available tools (in what combination, and for what duration, timing, etc.), the scale at which to apply these tools, or what level of reduction in feral cat populations to expect from the application of these tools. This project aimed to develop plausible management approaches and to test the use of cage trapping to reduce feral cat populations, as there is currently no feral cat bait product registered in Victoria. The overall objective of this work was to improve management capabilities and provide standards for the control of feral cats in Victoria.

To maximise the efficacy of trapping feral cats, we need to know how much effort is required (number of traps, number of trap nights, spatial configuration) in order to be confident that we have captured most feral cats in a given area and also the cost of doing so.

In April 2017, the Victorian Government released Biodiversity 2037 (*Protecting Victoria's Biodiversity: Biodiversity 2037*; DELWP 2017) to stop the decline of the state's native plants and animals, and to improve the natural environment so it is healthy, valued and actively cared for. Biodiversity 2037 contains 20-year management output targets across public and private land. This includes targets for the control of pest predators (e.g. foxes, and feral cats) in priority locations across 1.5 million hectares. Funding for the implementation of on-ground actions is through the Biodiversity Response Planning (BRP) process.

Three BRP feral cat projects (funded for 3 years) will implement on-ground management actions involving feral cat cage trapping over a total of 25,000 ha in 2018–2019 to 2019–2020, through an investment of $1.65 million dollars (Table 1).

Table 1. Biodiversity Response Planning feral cat projects monitored by this project

Locations	Agency	Project	BRP #	Proposed area (ha)	Budget ($)
Mallee	MCMA	Controlling feral cats in the Mallee	BRP047	10,000	735,000
Gippsland and Inlets/Islands	PV	Developing control options for feral cats at WPNP	BRP083	5,000	500,000
Barwon South West	DELWP	Glenelg Ark – next phase	BRP024	10,000	420,000
Total				**25,000**	**1,655,000**

BRP = Biodiversity Response Planning; MCMA = Mallee catchment Management Authority; PV = Parks Victoria; DELWP = Department of Environment, Land, Water and Planning.

To maximise the BRP projects' ability to build on-ground management capability, we investigated the efficacy of feral cat control with the following objectives:

- to quantify the probability of trapping feral cats under current practices
- to identify the number of feral cats in the trappable population
- to determine the density of feral cats in each site
- to identify factors that may influence the probability of capture occurring
- to provide recommendations to improve the management of feral cats in Victoria.

We also collaborated with external groups (e.g. universities) to:

- assess captured feral cat family relationships
- assess the prevalence of feline herpesvirus in feral cats as part of research into immunocontraception of feral cats.

To assess the effectiveness of the trapping operations and to be able to increase management capabilities, we needed to assess feral cat density before and after the control actions. Feral cat density was assessed using spatial mark–resight models following the methods of Ramsey et al. (2015) and (Efford 2019), using data collected from arrays of camera traps. Detections of individuals at multiple locations can produce spatially correlated detections, which are essential for obtaining unbiased estimates of population density when the population is totally or partially unmarked (Ramsey et al. 2015; Efford and Hunter 2018).

Information collected in this study should allow us to estimate the level of effort needed to remove a set proportion of the feral cats from a population and provide guidance for the development of future management strategies, thus increasing our capability to manage feral cats in Victoria.

This information is critical for future planning and management efforts and will feed directly into management decision systems such as Strategic Management Prospects. The approach implemented in this project can be used to assess other control tools as they become available (e.g. Curiosity® cat bait, and the Felixer spray trap).

2 Methods

2.1 BRP feral cat control projects

The BRP investment in feral cat projects covers five projects across seven sites. This project aims to utilise the implementation of three BRP projects controlling feral cats at five sites to assess the efficacy of cage trapping in year 1 (2018–2019 to 2019–2020). The three project locations and five sites are listed in Table 2. All sites contained native species known to be threatened by feral cat predation and were either determined by an existing management program to control introduced pests, or were areas identified as benefiting from control via SMP. The three BRP projects are briefly described below.

Table 2. The locations and sites used in this study to assess the effectiveness of cage tapping to reduce feral cat populations.

Location	Sites	Area (ha)
Barwon South West	Cobboboonee National Park	3200
	Mount Clay State Forest	3200
South Gippsland	Wilsons Promontory National Park	4500
Mallee	Hattah–Kulkyne National Park	5700
	Big Desert State Forest	5400

2.1.1 BRP024—Glenelg Ark: the next phase

This project aims to facilitate the recovery of native mammal populations at risk from predation by foxes and feral cats in far south-west Victoria by undertaking broad-scale fox baiting (using buried 1080 bait) and trialling feral cat management options within the project areas.

Cage trapping for feral cats was implemented for 6 weeks in areas of Cobboboonee National Park (3200 ha) and Mount Clay State Forest (3200 ha) in late autumn/early winter 2019. Both areas have been subject to fox control since 2005 as part of the Glenelg Ark project. Fox activity is significantly lower on these sites compared with comparable sites with no fox control (Robley et al. 2019).

2.1.2 BRP047—Controlling feral cats in the Mallee for improved management outcomes

Feral cat control was undertaken to reduce predation impacts within Hattah–Kulkyne National Park (Mournpall Block; 5700 ha). Feral cat density was assessed at Big Desert State Forest (5400 ha) in late autumn/early winter 2019. Delivery will also support the assessment of available feral cat control strategies and tools to support continuous improvement processes and improve management outcomes.

While the initial proposal indicated that feral cat control would be implemented in year 1 at Big Desert State Forest, this was altered to implementing control only at Hattah–Kulkyne National Park in year 1 and monitoring feral cat density at Big Desert State Forest with the view of implementing control in year 2 at Big Desert State Forest.

2.1.3 BRP083—Developing control options for feral cats at Wilsons Promontory to improve on-ground management capability

This project will develop and test strategies and control tools (trapping, shooting, baiting) to improve management capabilities and provide standards for the control of feral cats at Wilsons Promontory National Park. Cage trapping was implemented across the Yanakie Isthmus (4500 ha) in late autumn/early winter 2019 for 6 weeks, and alternatives explored in years 2 and 3.

2.2 Assessing efficacy of cage trapping

To explore factors that may influence the efficacy of cage trapping, we propose to standardise as far as possible the general approach taken to cage trapping across all four sites by the various land management agencies.

2.2.1 Feral cat cage trapping

Trapping was undertaken at all four sites in late autumn/early winter 2019. Within each site we placed 40–50 cage traps (40 cm × 40 cm × 70 cm; Wiretainers Pty Ltd, Melbourne) roughly spaced at 1 km intervals. Traps were located between 20 and 50 m off walking or vehicle tracks. Traps were covered with hessian and placed in shaded/sheltered positions to provide protection for captured animals from the elements (Figure 1).

Figure 1. Cage trap *in situ* at one of the four BRP project locations

Traps at Wilsons Promontory National Park, Cobboboonee National Park, and Mount Clay State Forest were wired open for a minimum of 2–3 weeks before ‘live’ trapping commenced to allow traps to ‘settle’ into the environment and for feral cats to become accustomed to their presence. Traps were not baited or lured during this time.

Live traps (not wired open and baited) were checked daily for 5–6 weeks, 7 days a week at Wilsons Promontory National Park. However, at Cobboboonee National Park, Mount Clay State Forest and Hattah–Kulkyne National Park, traps were operated for 5–6 weeks but closed each Friday after checking and re-opened on the following Monday.

Live traps were baited with a range of lures depending on operator preference. The dates on which traps were opened and closed and/or moved to new sites were recorded, along with their locations (eastings/northings). Details of feral cats captured (sex, weight, body and reproductive condition) as well as lure type were also recorded. A DNA sample was collected for later analysis to test for population structure and family relatedness of captured cats. A serum sample was also collected to determine the presence or absence of feline herpesvirus in feral cat populations.

A photograph of both the left and right side of each feral cat was taken to identify individuals captured by camera traps. These are to be used later for density estimations (section 2.2.3).

Feral cats were euthanised at the point of capture by project staff. If in the unlikely circumstance a domestic cat was captured, it was to be transported to either the local council pound or a veterinarian clinic where it was managed according to local Government regulations.

2.2.2 Data collection and management

Camera trapping

Camera trapping was used to generate pre- and post-cage trapping feral cat density estimates (Section 2.2.3) We set between 60 and 110 Reconyx cameras (Reconyx Inc., Holmen WI USA) in grids across each of the five sites. The planned distance between camera stations was 500 m. Every attempt was made to place the cameras in predefined locations on the grid to maximise data collection; however, in some cases this was not possible, and cameras were then placed as close to these locations as physically possible.

The protocol for setting camera traps was to set cameras 30 cm above the ground facing south and 1.5–2 m from an olfactory lure, with cameras programmed to take five images (with no delay) upon detection of movement. Lures were either tuna oil or commercially available feral cat lure (‘cats Me Dead’, Western Trapping Supplies, Toowoomba QLD). Lures were contained in either vented cowlings or tea infusers housed in wire cages. Lure containers were either mounted 1 m above the ground on stakes or pegged to the ground (Figure 2), and in some cases had brightly colour ‘feathers’ attached to act as a visual lure.

Figure 2. Lure holders used in camera traps were either a tea infuser or vented cowling.

Camera data management

We used artificial intelligence software to identify and sort feral cats from other animals. The software (ALFIE, OutofBox Solutions Pty Ltd, Melbourne) uses convoluted neural networking to scan individual images for a species' unique characteristics it has learnt from a training dataset. In this way, it can identify species and sort images into different folders. All the analysed data is stored in a database, and queries can be run to produce a range of data outputs from the data captured.

2.2.3 Pre- and post-control density assessment

To determine whether the management action was effective, and to increase land managers' ability to manage feral cats, we needed to assess changes in the underlying abundance/density of feral cats resulting from the cage trapping.

Few studies have estimated the density of feral cats in Australia, due (in part) to the wide-ranging and generally cryptic nature of feral cats. This cryptic nature means that monitoring designs that are usually suitable for density estimation may not be feasible or may be too costly to implement (e.g. mark–recapture, involving physical capture and marking of individuals). An alternative is to use images of feral cats collected by cameras placed in the landscape to 'capture' and 'recapture 'individuals identified from their unique coat markings (REF).

Instead, photos of individual feral cats collected from camera trapping were inspected, and if distinctive natural markings could be used to identify the individual, a unique ID and corresponding detection history was recorded for that individual. Two independent observers classified cats, with comparisons between observer groups made until consensus was reached or a feral cat could not be given an individual identity, in which case it was classed as unidentifiable. Figure 3 provides an example of features used to identify individual feral cats. For individuals that could not be identified, the number of detections of unmarked individuals per camera was recorded.

Figure 3. Features used to identify individual feral cats. These included (i) number and position of bands on the tail, (ii) number, shape and position of bands on the forelegs and the hind legs, and (iii) pattern of stripes and bands on the body, (iv) other unique identifiers included shape of ears, and colouring, e.g. white or tabby patterns.

When the feral cat population included several individuals that could be identified from natural markings, and a number that could not be identified, we were able to use the data obtained from spatial capture–resight (secr) methods (Ramsey et al. 2015, Efford and Hunter 2018) to obtain estimates of population density. The assumptions of secr models are that the marked individuals (i.e., those known individuals identified from camera trap images) are a random sample from the population, and that marking occurs throughout the defined sampling area. We can see no reason why feral cats with distinctive marks are more likely to be detected than feral cats without such markings, and feral cats with distinctive markings could be detected on any of the cameras throughout the defined sampling area, so both these assumptions should be reasonably valid. It was also assumed that all marked individuals could be correctly identified, and that no marked individuals were lost or emigrated from the area during the study. We used two observers to independently assess feral cat identity, to compare the results, and to resolve any anomalies to reach a final consensus on the identity of individual feral cats.

We attempted to fit the camera trap data to spatial mark–resight models (Efford and Hunter 2018) using the ‘secr’ library (v. 3.2; Efford and Hunter 2018) in R version 3.4.4 (R Development Core Team 2017). SECR methods are ideally suited for estimating population density in wide-ranging, cryptic predator species. Unlike conventional (non-spatial) capture–recapture methods, secr models explicitly incorporate a sampled area into the estimation process; hence, estimation of population density is straightforward. SECR methods also overcome other technical problems that cause bias in conventional capture–recapture methods, such as heterogeneity in detection, due to differential exposure of individuals with detection devices.

To ensure density was estimated over an area large enough to include the activity centres of all feral cats potentially exposed to trapping we buffered the outermost camera traps by a distance equivalent to the radius of the estimated home range size of feral cats.

2.3 Supplementary information

2.3.1 Feral cat genetics

Little is known about the genetic profile of feral cats in Victoria. We collected a small tissue biopsy from captured feral cats. Tissue samples were stored in 100% denatured alcohol, stored for later analysis when funds become available.

2.3.2 Feral cat fertility control

Blood samples were collected immediately after feral cats are euthanised. Samples were drawn directly from the heart, labelled, and stored on ice for transportation to a University of Melbourne PhD candidate. The samples will be used to develop an immunocontraceptive, whereby modification of the feline herpesvirus (FHV) to carry essential fertility genes may induce a host immune response against the natural activity of these genes, rendering the cat sterile.

3 Results

3.1 Feral cat cage trapping

3.1.1 Hattah–Kulkyne National Park

At this location, 45 cage traps were set between 23 April 2019 and 20 June 2019, with several days where traps were closed due to poor weather conditions. There was a total of 2115 potential trap nights, but adjustment for traps that were closed yielded 2039 effective trap nights. Fourteen feral cats were captured (0.68 captures / 100 trap nights): 11 males and 3 females. Males weighed 3.7–6.3 kg and females 3.3–3.8 kg, all were reported in ‘good’ condition. Figure 4 indicates where feral cats were captured, on three occasions feral cats were caught at the same location.

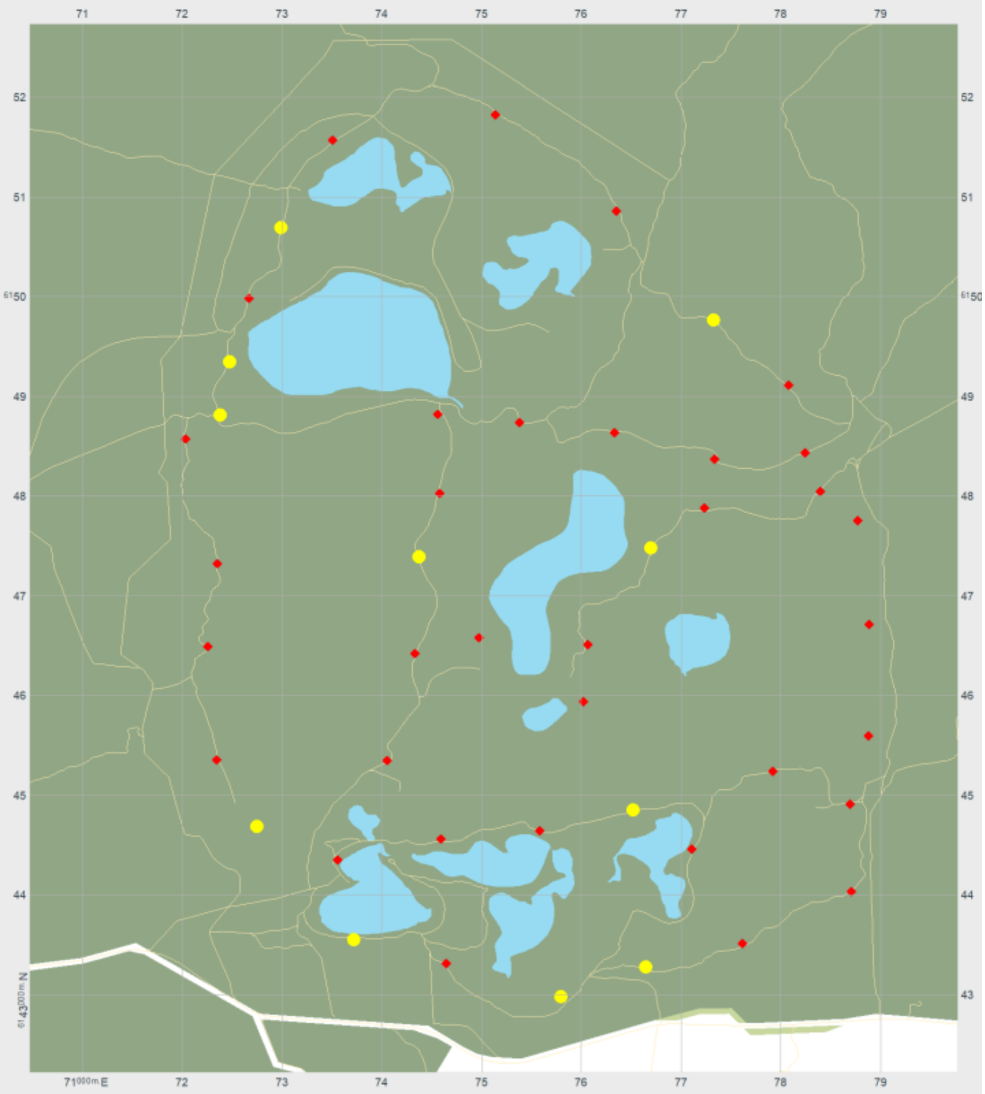

Figure 4. Location of feral cat captures in cage traps at Hattah–Kulkyne National Park
Yellow dots = location were feral cats were captured in cage traps; red dots locations of cage traps.

3.1.2 Barwon South West

Forty cage traps were set at each of Cobboboonee National Park and Mount Clay State Forest between 13 May 2019 and 14 June 2019, for a total of 759 and 800 potential trap nights, respectively. After adjustment for trap closures and missing bait, there were 743 and 751 effective trap nights, respectively.

One feral cat was captured across both sites, and this occurred at Mount Clay (0.13 captures / 100 trap nights): a male in good condition weighing 4.9 kg was caught on a lure of fresh rabbit.

3.1.3 Wilsons Promontory National Park

Fifty cage traps were set between 14 May 2019 and 15 June 2019, for a total of 2715 potential trap nights. After adjustment for traps that were closed, there were 2487 effective trap nights.

Three cats were captured (0.12 captures / 100 trap nights): two males (one 2.4 kg and the other 3.6 kg) and one female (3.2 kg). All three feral cats were described as in fair body condition.

There were 43 non-target captures: Common Wombat (*Vombatus ursinus*) (27); Short-beaked Echidna (*Tachyglossus aculeatus*) and Raven (*Corvus*) sp. (4 each); Common Ringtail Possum (3) Southern Brown Bandicoot and Common Brushtail Possum (2 each); Bush Rat (*Rattus fuscipes*) (1). All non-target species were unharmed and released at the point of capture.

3.1.4 Summary of feral cat cage trapping efficacy

The most feral cat captures occurred at Hattah–Kulkyne National Park, with a heavy male bias, and the least at Cobboboonee National Park (Table 3). Cage trapping removed on average approximately 20% of the estimated feral cats (see section 3.3), with an average of 0.23 feral cats trapped for every 100 trap nights.

All feral cats were reported to be in apparent fair to good body condition, with none reported as showing signs of emaciation.

Table 3. Summary of feral cat captures from the four sites

Site	Sex		Captures/100 trap nights	Estimated abundance/km^2 (95%CL)	Proportion removed
	Male	Female			
Hattah–Kulkyne NP	11	3	0.68	29 (16-50)	0.48
Cobboboonee NP	0	0	0	35 (17-74)	0.0
Mount Clay SF	1	0	0.13	6$^{\#}$	0.16
Wilsons Promontory NP	2	1	0.12	28 (15-54)	0.11
	14 (total)	**4 (total)**	**0.23 (average)**		**0.19 (average)**

insufficient data to estimate abundance, figure is the number of cats known to be alive prior to cage trapping; NP = National Park; SF = State Forest.

3.2 Camera trapping setup

The number of cameras set, and the number of camera trap days varied with site and are shown in Table 4. Camera traps operated before and after cage trapping at Wilsons Promontory National Park, Cobboboonee National Park, and Mount Clay State Forest. At Big Desert State Forest and Hattah–Kulkyne National Park, cameras also operated throughout the trapping period.

Table 4. Number of camera traps set and the number of camera trap days in parenthesis at each location before and after trapping. Traps were operated continuously from the beginning of trapping at Hattah–Kulkyne and Big Desert State Forest.

Location	Before cage trapping	After cage trapping	Total camera trap nights
Cobboboonee National Park	100 (4700)	100 (4400)	9100
Mount Clay State Forest	90 (3690)	100 (4300)	7990
Wilsons Promontory National Park	52 (2704)	51(2856)	5560
Hattah–Kulkyne National Park	78 (4212	78 (3588)	7800$^{\#}$
Big Desert State Forest	60 (3120)	60 (2880)	6000*

$^{\#}$Camera traps were operated through the 48 days of cage trapping; *No cage trapping was undertaken at Big Desert in year 1.

Camera spacing varied with site and was affected by access, and in some cases occupational health and safety concerns of local field crew due to the perceived presence of dangerous trees. Table 5 lists the actual minimum, maximum and mean distances to the nearest camera monitoring station on the grid achieved at each location.

Table 5. Summary of distance (m) to nearest camera monitoring station at each location

Location	Minimum	Maximum	Mean
Cobboboonee National Park	274	508	452
Mount Clay State Forest	212	667	446
Wilsons Promontory National Park	191	1111	568
Hattah–Kulkyne National Park	43	1546	745
Big Desert State Forest	800	1071	942

3.3 Effect of cage trapping on feral cats

3.3.1 Big Desert State Forest

A total of 12 individual feral cats were identified from the camera trapping, with feral cats recorded at 23% of sites (*n* = 14); in comparison, foxes were detected at 42% of sites.

Feral cats were detected at 14 different cameras on a total of 18 occasions over the 127 nights (7620 camera trap nights) of the study. The area of the state–space used for estimating the abundance and density of feral cats was 120 km^2, determined by buffering the outermost camera trap locations by 2 km in each direction. The feral cat abundance and density, as well as the parameters of the spatial detection process (g_0, σ), are given in Table 6 for the camera trapping surveys. The estimated abundance ($\hat{N}$) of feral cats within the state–space in the camera trapping survey was 36, with a corresponding density estimate of 0.30 cats/km^2 (Figure 5). However, the precision of these estimates was very low, with a 95% CI for feral cat density of 0.17–0.54/km^2 (Table 6). The daily probability of detection when a camera coincided with the centre of a feral cat home range was 0.01 (Table 6).

Table 6. Parameter estimates of feral cat population size $\hat{N}$ (and density) as well as parameters of the detection function (g_0, σ) from the secr model applied to detections in camera traps from Big Desert State Forest.

Parameter	Mode	SE	2.5%	97.5%
$\hat{N}$	36	11	20	64
Density (feral cats/km^2)	0.30	0.09	0.17	0.54
g_0	0.01	0.01	0.003	0.03
σ (km)	0.39	0.10	0.23	0.65

3.3.2 Hattah–Kulkyne National Park

A total of 17 individual feral cats were identified from analysis of the camera trapping images. Of these, five were known to have survived the cage trapping (29%) as they were recorded during the post–cage trapping camera monitoring. Five feral cats that were cage trapped (29%) were matched to images captured during the pre-trapping camera surveys. The remaining seven feral cats (41%) are assumed to have survived, despite not having their image captured post cage trapping.

During the pre–cage trapping period, feral cats were detected at 14 different cameras on 33 occasions over the 118 nights (9676 camera trap nights) of the study. The area of the state–space used for estimating the abundance and density of feral cats was 175 km^2, determined by buffering the outermost camera trap locations by 4 km in each direction. Feral cat abundance and density, as well as the parameters of the spatial detection process (g_0, σ) for the pre–cage trapping period, are given in Table 6. The estimated abundance ($\hat{N}$) of feral cats within the state–space in the pre–cage trapping survey was 29, with a corresponding density estimate of 0.16 cats/km^2 (Figure 5). However, the precision of these estimates was very low, with a 95% CI for feral cat density of 0.09–0.29/km^2 (Table 7). The daily probability of detection when a camera coincided with the centre of a feral cat home range was 0.008 (Table 7).

Insufficient feral cats were captured on cameras in the post-trapping period to undertake density estimates. Five feral cats were detected at five different camera traps on a total of six occasions over the 40 nights (3280 camera trap nights) of the study.

Table 7. Parameter estimates of feral cat population size $\hat{N}$ (and density) and the detection function (g_0, σ) from the secr model applied to detections from camera traps at Hattah–Kulkyne National Park

Parameter	Mode	SE	2.5%	97.5%
$\hat{N}$	29	8	16	50
Density (feral cats/km^2)	0.16	0.05	0.09	0.29
g_0	0.008	0.003	0.004	0.017
σ (km)	0.817	0.236	0.468	1.424

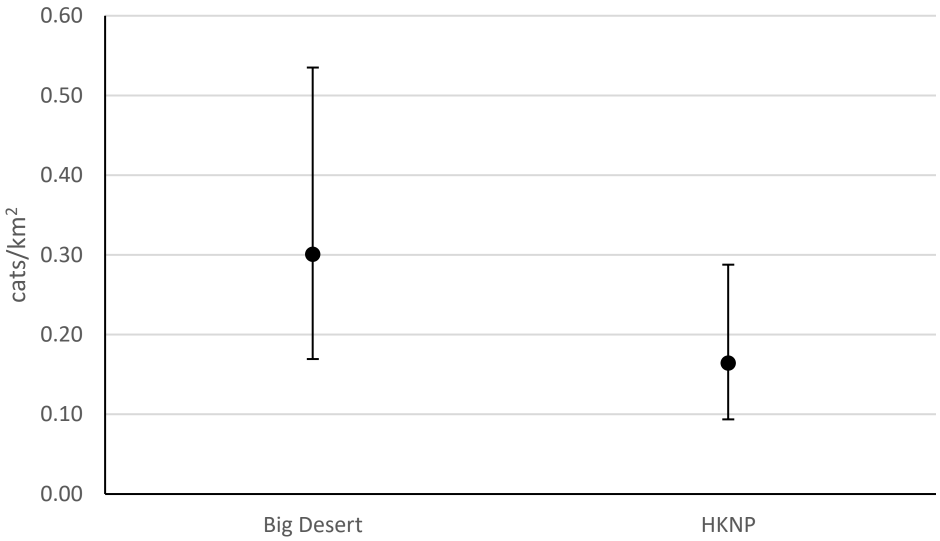

Figure 5. Feral cat density at and Big Desert State Forest (no control was undertaken at Big Desert SF) and Hattah–Kulkyne National Park (HKNP; pre-control only).
Bars are 95% CLs.

3.3.3 Barwon South West

Mount Clay State Forest

During the pre–cage trapping camera surveys, five feral cats were detected at 8% of sites ($n = 8$). None of the five cats were recaptured over multiple days at the same site, and only two feral cats were recaptured, once each at different sites in the pre–cage trapping camera survey. There were insufficient numbers of individual feral cats recaptured on camera to run the secr models to assess feral cat density in the pre–cage trapping surveys.

Post-trapping six feral cats were identified at 6% of sites ($n = 6$). One of these was recaptured at a different site once, the remainder were all captured only once on camera. There were insufficient numbers of individual feral cats re-captured on camera to run the secr models to assess feral cat density in the post-trapping surveys.

Cobboboonee National Park

Pre–cage trapping, feral cats were detected at 15 different camera sites on 14 occasions over the 44 nights (3608 camera trap nights) of the study. However, there was only one recorded movement of one feral cat; all other feral cats were detected only at one camera station. This meant it was not possible to undertake density analysis, because the model required resighting of individuals at multiple locations.

In the post–cage trapping period, feral cats were detected at 11 different cameras on 19 occasions over the 43 nights (4730 camera trap nights) of the study. The area of the state–space used for estimating the abundance and density of feral cats was 119 km^2, determined by buffering the outermost camera trap locations by 3 km in each direction. The feral cat abundance and density, as well as the parameters of the spatial detection process (g_0, σ), are given in Table 8 for the post–cage trapping surveys. The estimated abundance ($\hat{N}$) of feral cats within the state–space in the post–cage trapping survey was 35, with a corresponding density estimate of 0.29 cats/km^2. However, the precision of these estimates was very low, with a 95% CI for feral cat density of 0.14–0.61/km^2 (Table 8. The daily probability of detection when a camera coincided with the centre of a feral cat home range was 0.013 (Table 8).

Table 8. Post cage trapping parameter estimates of feral cat population size $\hat{N}$ (and density) and the detection function (g_0, σ) from the secr model applied to detections from camera traps at Cobboboonee National Park

Parameter	Mode	SE	2.5%	97.5%
$\hat{N}$	35	14	17	74
Density (feral cats/km^2)	0.29	0.11	0.14	0.61
g_0	0.013	0.007	0.004	0.039
σ (km)	0.39	0.11	0.23	0.67

3.3.4 Wilsons Promontory National Park

During the pre–cage trapping camera survey, 13 feral cats were detected at 14 different cameras on 23 occasions over the 39 nights (2028 camera trap nights) of the study. The area of the state–space used for estimating the abundance and density of feral cats was 66 km^2, determined by buffering the outermost camera trap locations by 2 km in each direction. The feral cat abundance and density as well as the parameters of the spatial detection process (g_0, σ), are given in Table 9 for the pre–cage trapping surveys.

The estimated abundance ($\hat{N}$) of feral cats within the state–space in the pre–cage trapping survey was 28, with a corresponding density estimate of 0.43 cats/km^2 (Figure 6). However, the precision of these estimates was very low, with a 95% CI for feral cat density of 0.23–0.84/km^2 (Table 9). The daily probability of detection when a camera coincided with the centre of a feral cat's home range was 0.03 (Table 9).

Table 9. Pre–cage trapping parameter estimates of feral cat population size $\hat{N}$ (and density) and the detection function (g_0, σ) from the *secr* model applied to detections from camera traps at Wilsons Promontory National Park

Parameter	Mode	SE	2.5%	97.5%
$\hat{N}$	28	10	15	54
Density (feral cats/km^2)	0.43	0.15	0.23	0.84
g_0	0.033	0.017	0.012	0.088
σ (km)	0.365	0.93	0.23	0.56

During the post–cage trapping camera survey, 11 feral cats were detected at 14 different cameras on 16 occasions over the 55 nights (2860 camera trap nights) of the study. The area of the state–space used for estimating the abundance and density of feral cats was 67 km^2, determined by buffering the outermost camera trap locations by 2 km in each direction.

The estimated abundance ($\hat{N}$) of feral cats within the state–space in the post–cage trapping survey was 38, with a corresponding density estimate of 0.57 cats/km^2 (Figure 6). However, the precision of these estimates was very low, with a 95% CI for feral cat density of 0.27–1.36/km^2 (Table 10). The daily probability of detection when a camera coincided with the centre of a feral cat's home range was 0.04 (Table 10).

Table 10. Post–cage trapping parameter estimates of feral cat population size $\hat{N}$ (and density) and the detection function (g_0, σ) from the secr model applied to detections from camera traps at Wilsons Promontory National Park

Parameter	Mode	SE	2.5%	97.5%
$\hat{N}$	38	18	16	91
Density (feral cats/km^2)	0.57	0.27	0.27	1.36
g_0	0.044	0.028	0.012	0.146
σ (km)	0.197	0.054	0.116	0.336

Figure 6 shows the feral cat density at Wilsons Promontory National Park before and after cage trapping.

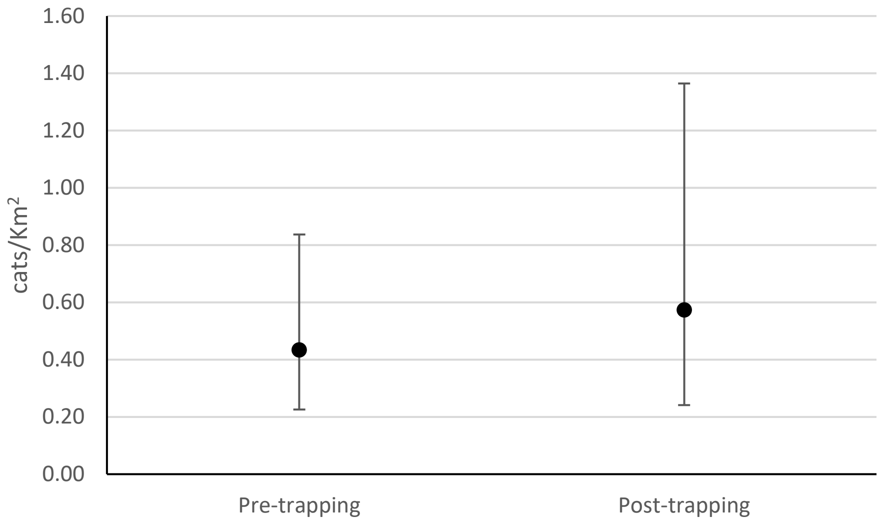

Figure 6. Feral cat density on the Isthmus at Wilsons Promontory National Park before and after cage trapping. Bars are 95% CLs.

3.4 Additional information

3.4.1 Feline immunocontraceptive study

This is work being undertaken by Ellen Cottingham (PhD candidate; University of Melbourne).

Traditional control methods have had some positive impacts on feral cat populations, but more effective long-term control methods are required. This project is attempting to develop an immunocontraceptive, whereby modification of the feline herpesvirus (FHV) can carry essential fertility genes that may induce a host immune response against the natural activity of these genes, rendering the cat sterile.

Concern exists, however, that any previous exposure to the naturally occurring FHV may reduce the effectiveness of this immunocontraceptive. Therefore, the project is assessing the likelihood of feral cats having had previous exposure to FHV.

Feral cat serum samples (*n* = 14) were collected from feral cats trapped at Hattah-Kulkyne National Park and sent to the University of Melbourne for analysis. Of the 14 samples, 2 were not deemed appropriate for the assay analysis. All 12 samples analysed were negative for anti-FHV antibody activity.

The presence of anti-FHV antibodies indicates either vaccination against FHV or previous exposure to FHV. This study did not detect any anti-FHV antibodies from this small sample but a lack of exposure to the virus may increase the effectiveness of the immunocontraceptive in feral cats. More sampling from a wider geographic location and greater number of feral cats is planned.

4 Discussion

We set out to quantify the changes in feral cat density as a result of removals due to cage trapping operations at four sites. At three of the four sites, cage trapping was unsuccessful at removing substantial numbers of feral cats; this plus the low resight rates of feral cats on camera traps before and after trapping resulted in uncertain density estimates at most sites.

The only site at which feral cats were removed in any number was Hattah–Kulkyne National Park (Mournpall Block). The reason for the difference in trapping success between this site and the other two trapped sites is uncertain but is likely related to several factors. First, underlying prey availability may have been significantly lower at Hattah–Kulkyne National Park, compared with the more mesic southern sites. Other possible factors, also not quantifiable in this study, include differences in operator experience, lure types, and weather.

In arid environments, studies have shown that the likelihood of feral cats consuming baits is related to the ratio of prey (small mammals) to feral cat abundance (Algar et al. 2007; Christensen et al. 2013; Read et al. 2015). These authors were able to predict the success or failure of feral cat control operations based on the relationship between pre-baiting feral cat abundance and the abundance of small mammals. In arid and semi-arid environments, small mammal abundance is known to fluctuate in response to environmental triggers, such as rainfall (Dickman et al. 1999). In wetter environments, such as in south-eastern Australia, the relationship between feral cat prey abundance and the likelihood of feral cats taking bait is unknown. It is possible that the underlying productivity of forest systems in southern Victoria is relatively more reliable than that of more arid north-west Victoria, and that feral cats may not experience the same degree of food stress in southern Victoria as is present in more arid habitats.

The most likely prey of feral cats at Hattah–Kulkyne National Park are rabbits, reptiles and waterbirds as the small mammal fauna is depauperate. By late autumn/early winter, most of this prey base would be at its lowest density. However, in the southern sites the range of prey that feral cats could potentially access (small rodents, small and medium-sized mammals, ground- and low-nesting birds, and reptiles) are likely to provide a relatively stable food source. For example, at Cobboboonee cameras detected 10 mammal and 10 bird species that feral cats would be able to prey on, whereas at Hattah–Kulkyne National Park cameras detected three mammal, one reptile and four bird species. While these are not abundance estimates, they do provide some insight into the relative differences in potential prey. We require more detailed information (on the temporal availability of prey and on what feral cats are preying upon) to be able to make better decisions about when to implement feral cat control, whether by trapping or baiting.

Density estimates based on the mark–resight data collected from the pre–cage trapping and post–cage trapping camera surveys had high levels of uncertainty, despite this method having been used in several studies around Australia in recent years (McGregory et al. 2015; Ramsey et al. 2015; Forsyth et al. 2019). As the name suggests, the method requires the resighting of known individuals at different times and places during the survey period. The probability of a feral cat encountering a camera trap is a primary assumption of the analytical approach and is related to the spatial arrangement (spacing and density) of camera traps relative to the feral cat home range size and movement rate. We used estimates from the literature as the basis for judging feral cat home range size (Jones and Coman 1982; Molsher et al. 2005; Buckmaster 2011; Johnston. 2012; Bengsen et al. 2015; McGregor et al. 2015). The high levels of uncertainty in our density estimates were influenced by the spacing of cameras which were likely too far apart, with smaller than expected home range size resulting in fewer opportunities for feral cats to be redetected on adjacent cameras. More information on feral cat home range and movement is required in order to be able to plan monitoring programs and make better decisions regarding approaches for assessing management effectiveness.

The limited knowledge about how feral cats use Victorian landscapes currently presents a challenge in developing efficient management strategies. Feral cats, like wild dogs (*Canis familiaris*) and foxes, can occupy large geographic areas, with home ranges estimated to be between 1.3 km^2 and 6.2 km^2 in Victoria (Jones and Coman 1982; Johnston 2012). We know relatively little about feral cat home range and territory size, habitat selection preferences, and what drives changes in feral cat abundance under Victorian conditions. An understanding of the ways in which feral cats occupy and move through the landscape is critical to the effective and efficient implementation of control programs (Bengsen et al. 2012). This information could help determine where control devices should be deployed for optimal efficiency (Recio et al. 2010), how large an area should be treated in a control program (Norbury et al. 1998), and at what density control or monitoring devices should be deployed (Moseby et al. 2009). On the basis of this and other insights, spatial information can also be used to predict the efficacy of different control tactics or strategies (Alterio et al. 1998; Molsher et al. 2005; Guttilla and Stapp 2010).

Estimates of feral cat home range size could be estimated for different landscapes using remotely sensed data. Home range size is generally related to the underlying productivity of the landscape. The higher the productivity, the smaller the home range size, and the greater the density of feral cats. In most cases, land managers will not have information on underlying productivity, although see Bengsen et al. (2015). These authors used the fraction of photosynthetically active radiation (fPAR) absorbed by vegetation to characterise landscape productivity from data collected by NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) sensors to derive a measure of landscape productivity, enabling them to predict feral cat home range sizes.

Cage trapping is a labour-intensive method that is unsuitable for population-level control and should only be used as a supplement to more appropriate landscape-scale tools, e.g. baiting. Feral cats have high reinvasion potential (Lazenby et al. 2014), so shooting and trapping are unlikely to be effective broad-scale control tools in isolation. These two techniques are most useful for removing 'problem' individual feral cats preying on threatened species (see Moseby et al. 2015), in the later stages of eradication programs (see Algar et al. 2002), or as adjuncts to large-scale baiting operations. Conventional trapping typically presents ethical and logistical challenges; non-target species (no non-target injuries or deaths were reported during this project) may be caught, and traps must be checked daily. Automated cat-specific grooming traps that spray a toxin onto passing individuals are currently in development and may help to circumvent some of these issues (Read et al. 2014).

Consideration needs to be given to the potentially adverse effects of low-level culling or harvesting of feral cats that often occurs with trapping-only programs. Lazenby et al. (2014) found that following low-level culling in two open sites in southern Tasmania, the relative abundance and activity of feral cats actually *increased* in the cull sites, even though the numbers of cats captured per unit effort during the culling period declined. They suggested this was due to immigration following the removal of dominant cats.

Feral cats are cryptic and elusive in their behaviour, making it difficult to detect them and to assess any changes in abundance resulting from control actions. However, recent advances in the application of tools (such as the use of camera traps and the development of statistical techniques) are making it possible to assess changes in density and abundance of feral cats (MacKenzie et al. 2006; Robley et al. 2010; Ramsey et al. 2015).

Developing landscape-scale control of feral cats in Victoria will ideally require an increased understanding of:

1. the optimal time, scale and frequency to undertake baiting, particularly in southern Victoria, including when cats are most food stressed. This is likely to vary with geographical location, because prey availability will fluctuate according to local conditions. This requires knowledge of seasonal changes in feral cat diet and the relative abundance of prey in feral cat diet.
2. feral cat home range and movement patterns, and bait uptake rates, (including foxes and wild dogs). This requires locational data collected from GPS collars and simultaneous information on the fate of known baits. This information can be incorporated into optimising control program designs.
3. how to integrate feral cat control with herbivore, fox and wild dog control to optimise cost-effectiveness. This requires cost: benefit information on the various current approaches and how these can be optimised through integrating control actions for multiple outcomes.
4. the methods for detecting changes in feral cat numbers under Victoria conditions. There are currently several existing methods for detecting changes in feral cats, a comprehensive review and guide to application, methods and outcomes of each method would be beneficial to land managers.

Now that feral cats have been declared an established pest animal, there is likely to be an increased investment by land managers in control actions. To ensure a maximum benefit from control actions it would be efficient to harness this effort in a coordinated manner to maximise learnings and to establish operational infrastructure, enabling acquisition of the required information in an adaptive learning framework.

We have shown that cage trapping is an ineffective and costly tool and not appropriate for the reduction of feral cat populations. Also, while we did not test factors likely to influence trapping success (e.g., underlying prey availability, time of year) these are likely to influence the success of cage trapping. Density estimation is important for being able to understand the effectiveness of any control action. While our estimates were uncertain, the general approach is sound and has been used successfully elsewhere, better understanding of feral cat home range and movement will improve the outcomes for this method.

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