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Response of feral cats to a track-based baiting programme using *Eradicat*® baits

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Summary **The feral Cat (*Felis catus*) is a significant threat to Australian fauna, and reducing their impacts is considered an essential action for threatened species conservation. Poison baiting is increasingly being used for the broad scale control of feral cats. In this study, we measured the population response of feral cats to a track-based baiting programme using *Eradicat*® baits in the semi-arid northern wheatbelt region of Western Australia. Over two years, 1500 baits were laid once annually and the response of feral cats was measured using remote cameras in a before–after, control–impact design. There was a significant reduction in feral cat activity in the second year, but not the first. During bait uptake trials, corvids removed the most number of baits, followed by cats and varanids. The lack of a response to baiting in the first year may be due to existing low cat numbers in the baited area and/or the timing of the baiting. We provide a list of key recommendations to help inform future cat baiting programmes and research.**

Key words: 1080, bait, control, *Felis catus*, feral cat, sodium monofluoroacetate.

Introduction

The feral Cat (*Felis catus*) preys on native fauna and is responsible for numerous extinctions globally (Medina *et al.* 2011; Doherty *et al.* 2015b; Woinarski *et al.* 2015). Predation by feral cats can jeopardise conservation programmes aiming to reintroduce native fauna into areas of their former range (Moseby *et al.* 2011b; Potts *et al.* 2012), and cats can have nonlethal impacts on susceptible populations through competition, disease transmission, induced predator avoidance behaviour and hybridisation (Daniels *et al.* 2001; Fancourt & Jackson 2014; Medina *et al.* 2014; Doherty *et al.* 2015a). Cats have been particularly damaging to Australian wildlife and, together with the introduced European Red Fox (*Vulpes vulpes*), have contributed to the extinction of 22 Australian mammals since European settlement (Johnson 2006; Woinarski *et al.* 2015). Cats are considered to be a contributing factor to recent declines in northern Australia's mammal fauna (Fisher *et al.* 2014a; Woinarski *et al.* 2015; Ziembicki *et al.* 2015) and are listed as a *Key Threatening Process* under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (Department of the Environment Water Heritage & the Arts 2008). Reducing their impact is considered an essential action for the conservation of Australian birds and mammals (Denny & Dickman 2010; Garnett *et al.* 2013; Woinarski *et al.* 2015).

Techniques for controlling populations of feral cats include shooting, trapping, poison baiting and exclusion fencing (Denny & Dickman 2010). Cats have successfully been eradicated from a number of islands (DIISE 2014) and fenced mainland reserves using different combinations of control methods. Unfenced mainland sites, on the other hand, require sustained control efforts because cats have a high reproductive output and an aptitude for reinvasion (Read & Bowen 2001; Short & Turner 2005). Both trapping and shooting are time- and labour-intensive methods of pest control, whereas baiting is comparatively more cost-effective when targeting larger areas (Fisher *et al.* 2014b). However, poison baiting of feral cats is notoriously challenging. While the Red Fox, Dingo (*Canis dingo*) and Dingo/Dog (*Canis lupus familiaris*) hybrids ('wild dogs' hereafter) will readily take carrion, inclusive of poison meat baits, inanimate baits are assumed to be less preferred food items relative to normal live prey for feral cats (Fisher *et al.* 2014b). However, feral cats are adaptable enough to scavenge, so where possible baiting should be timed to coincide with low availability of natural prey resources (Short *et al.* 1997; Algar *et al.* 2007; Moseby & Hill 2011; Christensen *et al.* 2013). Risbey *et al.* (1997) found that four different bait mediums (dried meat baits, a fishmeal-based bait, a bait coated in a flavour enhancer and baited European Rabbit [*Oryctolagus cuniculus*] carcasses) were all ineffective in controlling feral cats at Shark Bay in Western Australia. Other studies also found that dried meat baits were ineffective in controlling cats in arid and semi-arid Western Australia (Burrows *et al.* 2003; Algar & Burrows 2004). However, using fresh meat baits, Burrows *et al.* (2003) were able to reduce cat abundance in Western Australia's Gibson Desert by 75% and 100% during two years of below average rainfall.

The Western Australian Department of Parks and Wildlife (and its predecessors) has developed a bait medium and baiting technique that can effectively reduce feral cat populations, as well as fox and wild dog populations. The bait (*Eradicat*®) is similar to a chipolata sausage and is composed of 70% kangaroo meat mince, 20% chicken fat and 10% digest and flavour enhancers (Algar *et al.* 2007, 2013). It weighs ~20 g wet weight, is dried to 15 g, blanched and then frozen (Algar *et al.* 2013). The toxic baits contain 4.5 mg of sodium monofluoroacetate (compound 1080) per bait. Uptake of *Eradicat*® by cats was significantly greater than uptake of both a chicken sausage bait and a dead day-old cockerel at a semi-arid site (Algar *et al.* 2007). The Department of Parks and Wildlife currently bait a number of locations in Western Australia by deploying *Eradicat*® baits from an aircraft at a rate of 50 baits/km^2 during late autumn or early winter, when prey availability is lowest and cats are more likely to consume the baits (Algar *et al.* 2011, 2013; Christensen *et al.* 2013). Field trials have shown that annual aerial baiting using *Eradicat*® can achieve sustained control of feral cats at the landscape scale (Algar *et al.* 2013). However, the efficacy of track-based baiting – where baits are laid by hand along roads or tracks – has not been tested, despite its potential utility to smaller landholders, such as private conservation organisations, given that it is less costly than aerial baiting over smaller areas. In this study, we measured the population response of feral cats to a track-based baiting programme using *Eradicat*® baits in the semi-arid northern wheatbelt region of Western Australia. The study was operational in nature, rather than experimental, and hence did not involve replication of treatment and control areas.

Methods

Study site

We conducted this study at Charles Darwin Reserve (CDR), a ~68,000 ha pastoral lease 350 km north-east of Perth (29° 35′ S, 116° 58′ E), managed for conservation by Bush Heritage Australia and destocked of goats (*Capra hircus*) and sheep (*Ovis aries*) since 2003. The climate is semi-arid Mediterranean, with cool winters, hot summers and unreliable, low rainfall (mean 306 mm/year at the adjacent Wanarra pastoral station; Bureau of Meteorology 2014). Dense mixed-species shrublands on yellow sandplains comprise 50% of the reserve's area, and the remainder is a mixture of eucalypt woodlands and other vegetation types (Braun 2006).

Poison baiting

Prior to the start of this trial, dried meat 1080 poison baits were laid on the reserve biannually, primarily for the control of foxes, although wild dogs are also likely to have taken those baits. That baiting programme ceased in March 2012 and no data are available on its efficacy. Poison baiting for feral cats using *Eradicat*® baits was conducted at CDR by Bush Heritage Australia in 2013 and 2014 under an experimental permit (PER14102) issued by the Australian Pesticides and Veterinary Medicines Authority, which only allowed baits to be laid once per year. Prior to being laid, baits were thawed and placed in direct sunlight – a process termed 'sweating' – which causes the oils and lipid-soluble digest material to exude from the surface of the bait. During the sweating process, baits were sprayed with *Coopex*® insecticide at a concentration of 12.5 g/L to deter ants from consuming the bait, which can make them less attractive to cats.

Baits were laid by hand from the back of a slow-moving vehicle at a rate of one bait every 50 m along access tracks in the southern half of the reserve (Fig. 1). This interval was chosen to maximise the baiting density that could be achieved and increase the likelihood of individual cats encountering baits when hungry (Algar *et al.* 2007, 2014). Baits were laid on alternate sides of tracks. Baiting was conducted on two occasions: 8 September 2013 and 11 May 2014, with 1500 baits being laid on each occasion. Baiting in 2013 was planned to take place in May of that year, but delays in obtaining the research permit meant that the baiting was delayed until September. Baiting was only conducted when the local weather forecast predicted at least five consecutive

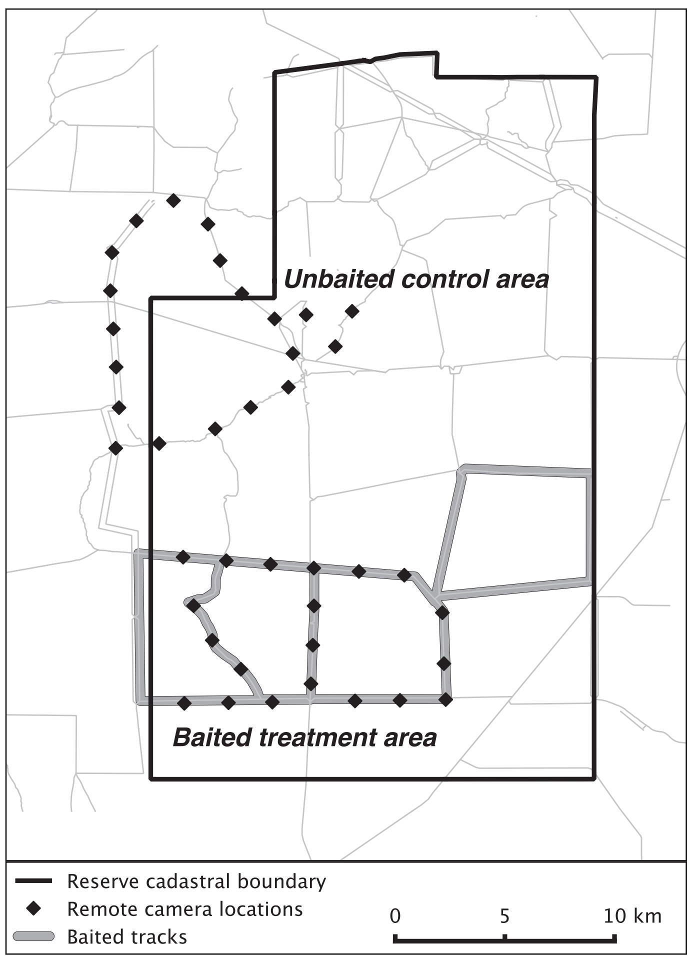

Figure 1. Location of the baited part of the reserve (grey shaded tracks) and the 40 remote camera locations (black diamonds).

days of dry weather because rain can make baits unpalatable to cats (Algar & Burrows 2004; Algar *et al.* 2013). Baiting density was ~11 baits/km^2 (if the baited area was taken as a minimum convex polygon around the baited tracks on the perimeter of the baiting envelope; Fig. 1).

Predator monitoring

We used remote cameras in an unreplicated BACI design (before–after, control–impact) to monitor the response of predator 'activity' to baiting. Predator activity was surveyed using 40 remote cameras positioned on vehicle tracks (20 Moultrie i60 and 20 Scoutguard 560PV; Fig. 1). Twenty cameras, each separated by ≥2 km, were positioned on a circuit in the southern, baited part of the reserve, and 20 cameras were positioned on a northern circuit that was not subject to baiting and acted as an experimental control (Fig. 1). In studies such as this one, it is recommended that a single model of remote camera be used to reduce variation in detectability between individual cameras (Meek *et al.* 2015); however, financial constraints meant that we had to use two different camera models. Nevertheless, our approach to deploy equal numbers of the two camera types in treatment and control areas and randomly assign cameras to locations minimised any potential bias. The minimum distance between the northern cameras and the baited area was 5.5 km, although most northern cameras (75%) were >9.5 km from the baited area. Mean feral cat home range estimates from similar environments in Australia were 2.48 km^2 (Molsher *et al.* 2005), 4.7 km^2 (Jones & Coman 1982), 5.11 km^2 (Bengsen *et al.* 2012), 9.8 km^2 (Hilmer 2010) and 22.1 km^2 (Edwards *et al.* 2001), which correspond to home range diameters between 1.8 and 5.3 km (if the home range is assumed to be a circle). The distance between our baited treatment and unbaited control areas is therefore sufficiently large enough for the two areas to be considered independent of each other for the purposes of this study, although we acknowledge that cats have occasionally been recorded moving larger distances in other parts of Australia (e.g. Moseby *et al.* 2009).

Cameras were fixed to a steel post so that the sensor was ~30 cm above the ground and were programmed to take a series of three photographs each time the sensor was triggered, with a minimum delay of one minute between triggers because this was the minimum delay possible for one of the camera models (Moultrie). At half of the cameras, a raw chicken wing encased in a PVC bait holder pegged to the ground was used as a scent lure, and at the remaining cameras, an electronic device that makes the sound of a bird tweeting was used as an audio lure (Lucky Duck, WI, USA). Lures were swapped between cameras halfway through each monitoring period. A fresh chicken wing was placed inside the bait holder each time the lures were swapped.

Cameras were operated for between 30 and 39 days immediately before each baiting event and again beginning 24 days after baiting in 2013 and 10 days after baiting in 2014 (Table 1). Cameras were also operated for 11 days in February 2013 and 28 days in May/June 2013, independent of any baiting events (Table 1).

Bait uptake trials

We also used the same remote cameras and settings to determine what animal species were responsible for removing baits. During laying of baits, we placed an *Eradicat*® bait in front of 18 cameras in September 2013 and 19 cameras in May 2014. Cameras were active for two weeks, and baits were not replaced if they were removed. No other lures were present at cameras during this time. Memory cards were collected from cameras after two weeks and photographs were inspected to determine whether baits were taken and what species were responsible. We classed a bait as 'not taken' if it was still present after the two-week period.

Statistical analyses

Remote camera photographs were stored in a database and tagged with the camera identification number, treatment (baited or unbaited), session, date, time and species using EXIFPro 2.0 (Kowalski & Kowalski 2012). Tags were written to the EXIF data of each file and then exported from EXIFPro as a text file. To ensure independence of repeat photographs of the same species caught on the same camera, we classified photographs that were captured within 15 min of each other as a single photograph 'event'. Inspection of frequency tables of the time elapsed between photographs indicated that this was a suitable breakpoint (Table S1). For each session, we summed the total number of independent photograph events of each species at each remote camera.

We used Poisson generalised linear mixed models to test the effect of baiting on feral cat activity. Foxes were rarely detected at the study site, and wild dogs were infrequently detected in the baited area (<6% of photographs), so we did not analyse that data due to the small sample sizes. We used the number of photographs of cats caught on each camera in

Table 1. Dates of remote camera monitoring sessions and baiting events

Session	Survey length (days)	Sampling effort (camera-nights)	Notes
February 2013	11	370	One control camera malfunctioned
May 2013	28	1070	–
August 2013	30	1111	Two treatment cameras stolen
Baiting	–		–
October 2013	38	1106	One treatment camera malfunctioned
April 2014	39	1347*	–
Baiting	–		–
May 2014	30	965*	One control malfunctioned

*NB: the difference between sampling effort pre- and post-baiting in 2014 is due to one control camera that malfunctioned for the entire postbaiting period and three other control cameras in which the batteries failed after between two and six days of operation also during the postbaiting period. These differences do not affect our interpretations of the effect of baiting because all of those cameras were in the unbaited control area.

each session as the response variable and used the number of nights cameras were active ('camera-nights') as an offset to account for variable sampling effort. We fitted models with fixed effects of time (before/after) and treatment (baited/unbaited), the interaction term, and random intercepts for camera ID and model. Fitting camera model as a random intercept accounts for any additional variation associated with the two types of cameras (Moultrie or Scoutguard). We fitted separate models for the 2013 and 2014 baiting. An effect of baiting on cat activity would be shown as a significant interaction between time and treatment in the models. We calculated 95% confidence intervals (CI) for each predictor variable and inferred 'significant' effects where the confidence intervals did not overlap zero. For graphical representation, we standardised remote camera data to a relative activity index by dividing the number of photograph events on each remote camera by the number of camera-nights and multiplied this by 100. Models were fitted using the lme4 package version 1.1-6 in R version 3.0.2 (R Core Team 2013; Bates *et al.* 2014).

Results

Across the six monitoring periods, we captured 128 independent photographs of feral cats, 51 of wild dogs and four of foxes. Cat activity in the baited treatment area declined between February and August 2013, before baiting began, whereas it was relatively constant in the unbaited control area during the same period (Fig. 2).

Effect of baiting

In 2013, there was a significant treatment effect (Table 2), with cat activity in the unbaited area being significantly higher than the baited area both before and after baiting (Table 3; Fig. 3a). There was no significant change in cat activity following baiting in either the baited or unbaited areas (Table 2). In the baited area, cats were detected on 5.6% of cameras prebaiting and 10.5% postbaiting, whereas cats were detected on 50% of cameras both before and after baiting in the unbaited control area (Table 4). In 2014, there was a significant interaction between time and treatment (Table 2), with an 85% decline in cat activity in the treatment area following baiting (Table 3, Fig 3b) and an 80% decline in the number of cameras detecting cats (Table 4). In the unbaited control area, there was a small nonsignificant increase in cat activity following baiting (Tables 2 and 3, Fig. 3b), although the number of cameras detecting cats decreased slightly (Table 4).

Bait uptake trials

During the bait uptake trials, three cameras malfunctioned and the bait was not visible in the field of view of four other cameras, so we have excluded these seven baits from the results below. Of the remaining baits (n = 30), animals removed two-thirds and the remaining one-third were not taken, as evidenced by baits remaining *in situ* when cameras were checked. Corvids (*Corvus* spp.) removed 12 baits (40%), cats removed six (20%) and varanids (*Varanus* spp.) removed two (6.7%). Cats removed one bait in 2013 and five in 2014. All removed baits were taken within five days of being laid.

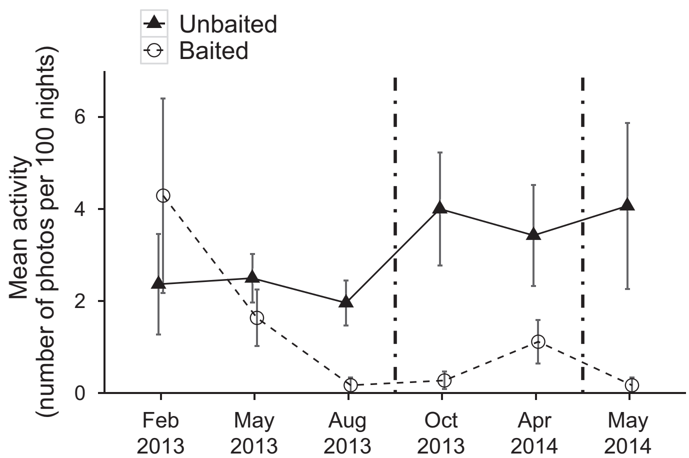

Figure 2. Mean cat activity (number of photographs per 100 nights) and standard error bars in the unbaited control (solid line and triangles) and baited treatment (dashed line and circles) areas during six sampling periods. The dashed vertical lines indicate the timing of baiting in September 2013 and May 2014.

Table 2. Mixed modelling results for the effect of time, treatment and the interaction term on cat activity at the September 2013 and May 2014 baiting events. Significant terms are indicated with bold text

	Model term	Estimate	95% CI
September 2013	Time	−0.59	−1.30, 0.12
	Treatment	**−2.26**	**−3.75, −0.77**
	Time × Treatment	−0.07	−2.58, 2.43
May 2014	Time	−0.12	−0.71, 0.47
	Treatment	**−3.05**	**−6.03, −1.22**
	Time × Treatment	**2.07**	**0.26, 5.04**

Discussion

We sought to determine whether track-based baiting using *Eradicat*® baits could effectively reduce feral cat activity at a semi-arid site in Western Australia. As this study took advantage of an operational baiting programme, there are certain limitations inherent in the study design and subsequent inferences. Specifically, baiting could only be conducted once per year, and control and treatment areas were not replicated. Nevertheless, the following findings are of value to future cat baiting trials.

The lack of a response to baiting in 2013 could be due to the existing low cat numbers in the baited area and/or

Table 3. Mean cat activity (number of photographs per 100 nights) in the baited treatment area and unbaited control area before and after baiting in September 2013 and May 2014. Standard errors are given in parentheses

	Treatment	Prebaiting	Postbaiting
September 2013	Baited	0.17 (0.17)	0.28 (0.19)
	Unbaited	1.96 (0.49)	4.00 (1.23)
May 2014	Baited	1.12 (0.47)	0.17 (0.17)
	Unbaited	3.43 (1.09)	4.07 (1.80)

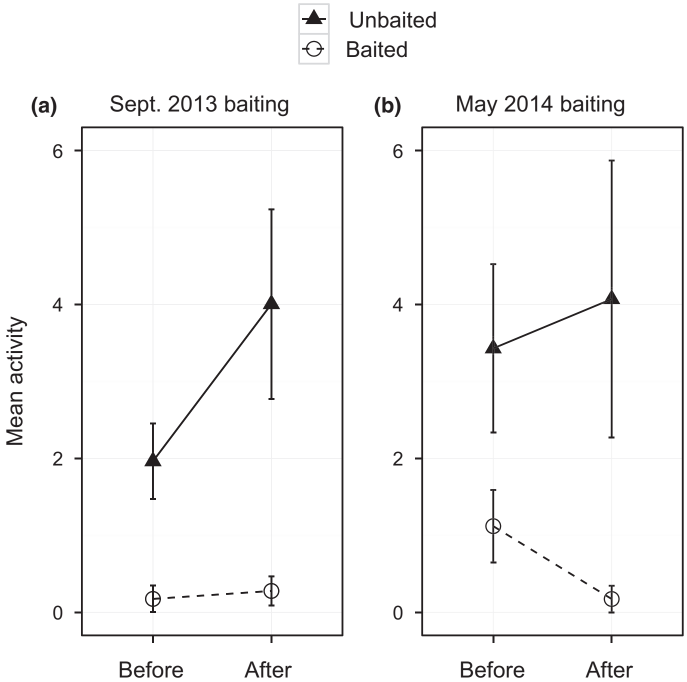

Figure 3. Response of cat activity (number of photographs per 100 nights) to time (before/after) and treatment (baited/unbaited) in (a) September 2013 and (b) May 2014. Standard error bars are shown.

Table 4. Percentage of remote cameras in the baited treatment area and unbaited control area that detected feral cats before and after baiting in September 2013 and May 2014. Raw number of cameras is given in parentheses

	Treatment	Prebaiting	Postbaiting
September 2013	Baited	5.6% (1)	10.5% (2)
	Unbaited	50% (10)	50% (10)
May 2014	Baited	25% (5)	5% (1)
	Unbaited	50% (10)	42.1% (8)

the timing of the baiting. During 2013, cat activity had already declined in the baited area prior to the baiting event. The reason for this decrease is unclear, especially given that cat activity in the unbaited control area remained relatively stable during the same period. Despite this, even if cat numbers were high enough to detect any effect of baiting, it may have been compromised by the inappropriate timing. Cat baiting in Western Australia is timed to periods of lowest prey availability and hence when cats are most hungry and more likely to consume the baits (Short *et al.* 1997; Algar *et al.* 2007). Christensen *et al.* (2013) found that the efficacy of aerial cat baiting operations was negatively correlated with a predator–prey index, that is baiting was most effective when the number of prey available to a single cat was lowest. The period of lowest prey availability in the study region is in late autumn, when temperatures are cooler, but before the winter rainfall. The 2013 baiting took place in September, a time when juvenile rabbits would be entering the population and reptiles are more active due to the higher daily temperatures – both of which are key prey species for cats at the study site (T. Doherty, unpublished data). The increased prey availability at this time would likely have made cats less likely to consume the baits. In contrast, the 2014 baiting appeared to be effective in reducing cat activity. Baiting in 2014 was undertaken in May when prey availability is expected to be at its lowest.

Future considerations

An issue with track-based baiting is that tracks represent only a small proportion of the home range of a cat, and hence, cats may access tracks for only a relatively small proportion of their daily activity (Algar *et al.* 2007). Algar *et al.* (2007) suggested that increasing baiting frequency at the time of lowest prey availability could improve the efficacy of track-based baiting because baits would be present at different times and thus increase the chances that cats are hungry when they encounter the baits. The experimental permit for this project allowed for only a single annual application of baits, but investigating the influence of increased baiting frequency on bait uptake by cats could be the focus of future track-based baiting work.

Additionally, the network of tracks at a site governs the potential baiting densities that can be achieved. Higher baiting densities can be achieved at sites with higher densities of tracks. We estimated our baiting density to be ~11 baits/km^2, whereas aerial baiting is conducted at 50 baits/km^2. However, our calculation did not include a buffer extending outside of the baiting envelope, nor did it consider the central areas of land that were up to 3.5 km from the nearest baited track. Although we do not have data on optimal baiting densities, track-based baiting may not be effective at sites that have a limited track network and consequently have large areas of land within which cats would be unlikely to encounter baits.

Nontarget bait uptake also has the potential to limit bait availability for cats. Corvids removed twice the number of baits than cats did in our bait uptake trials, and previous studies have also recorded relatively high rates of bait uptake by both corvids and varanids compared to cats (Algar *et al.* 2007; Denny 2009a,b; Moseby *et al.* 2011a). Although uncommon during our study, foxes and wild dogs also readily take *Eradicat*® baits (Burrows *et al.* 2003). We only recorded varanids removing two baits in our study and baiting during the cooler months when reptiles are less active is likely to reduce bait uptake by varanids. Additionally, placing baits under bushes rather than in the open may decrease uptake by corvids (Moseby *et al.* 2011a). Burying the baits is also likely to reduce nontarget uptake, as has been observed in canid baiting programmes (Allen *et al.* 1989; Thomson & Kok 2002; Glen & Dickman 2003), although this is also likely to reduce bait uptake by cats. Cats are less likely than canids to locate and excavate buried baits because they are primarily auditory and visual hunters (Bradshaw 1992; Fisher *et al.* 2014b) that lack the acute olfactory senses of canids. Surface laying of cat baits is standard practice is Western Australia (Algar *et al.* 2007, 2011, 2013) where the native fauna have a relatively high tolerance to 1080 poison because they have co-evolved with endemic plants containing a similar compound (Twigg & King 1991; Twigg *et al.* 2003). Alternative means of bait presentation that reduce nontarget risk but maximise uptake by cats, such as suspending baits above the ground (Algar & Brazell 2008), should be investigated for use in other parts of Australia. Additionally, a prototype cat bait (*Curiosity*®) is being tested elsewhere in Australia (Johnston *et al.* 2011, 2012, 2013, 2014), which encapsulates the poison in a pellet inside the bait and may reduce nontarget risks (Marks *et al.* 2006; Hetherington *et al.* 2007; Buckmaster *et al.* 2014).

Our results are based on two years of baiting trials, with one year potentially being compromised by seasonal effects. However, the significant reduction in cat activity following track-based baiting in the second year of the project is encouraging. As a result of this study, we make five key recommendations to help inform future cat baiting programmes and research: (i) baiting should be conducted during seasons of lowest prey availability; (ii) the effect of increased baiting frequency (during periods of low prey availability) should be investigated; (iii) the impact of nontarget uptake on bait availability to cats should be considered; (iv) innovative methods of bait presentation that minimise nontarget risks but maximise uptake by cats should be developed; and (v) spatially and temporally replicated experimental trials should be conducted.

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Supporting Information

Additional Supporting Information may be found in the online version of this article: **Table S1**. Percentage of feral cat photo events in time periods for the number of minutes between successive photos on the same camera within each session.

