CSIRO PUBLISHING

Wildlife Research, 2011, **38**, 338–349 www.publish.csiro.au/journals/wr

The use of poison baits to control feral cats and red foxes in arid South Australia I. Aerial baiting trials

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Abstract

Context. Feral cats and foxes pose a significant threat to native wildlife in the Australian arid zone and their broadscale control is required for the protection of threatened species.

Aims. The aim of this research was to trial aerial poison baiting as a means of controlling feral cats and foxes in northern South Australia.

Methods. Eradicat baits or dried meat baits containing 1080 poison were distributed by air over areas of 650 to 1800 km^2 in trials from 2002 to 2006. Different baiting density, frequency, bait type and area were trialled to determine the optimum baiting strategy. Baiting success was determined through mortality of radio-collared animals and differences in the track activity of cats and foxes in baited and unbaited areas.

Key results. Quarterly aerial baiting at a density of 10 baits per square km successfully controlled foxes over a 12-month period, while annual baiting led to reinvasion within four months. Despite the majority of radio-collared cats dying after baiting, a significant decline in cat activity was only recorded during one of the eight baiting events. This event coincided with extremely dry conditions and low rabbit abundance. Rabbit activity increased significantly in baited areas over the study period in comparison with control areas.

Conclusions. Despite trialling different baiting density, frequency and area over a five-year period, a successful long-term baiting strategy for feral cats could not be developed using Eradicat baits or dried meat baits.

Implications. Broadscale control of feral cats in the arid zone remains a significant challenge and may require a combination of control methods with flexible delivery times dependent on local conditions. However, it is doubtful that current methods, even used in combination, will enable cat numbers to be reduced to levels where successful reintroductions of many threatened wildlife species can occur.

Additional keywords: 1080, introduced, predators, rabbit, reduce, suppress.

Introduction

The introduced feral cat (*Felis catus*) and red fox (*Vulpes vulpes*) pose a significant threat to native wildlife in Australia and are responsible for the failure of many threatened species reintroduction programs (Short *et al*. 1992; Christensen and Burrows 1994; Gibson *et al*. 1994; Southgate and Possingham 1995; Priddel and Wheeler 1997; Priddel and Wheeler 2002). The introduced red fox is also considered a key threat to many threatened species in North America (Lewis *et al*. 1999) and feral cats have been implicated in the extinction of several species in Mexico (Wood *et al*. 2002). In Australia, feral cats are thought to cause the decline and extinction of many native animals on islands (Dickman 1996) and Priddel and Wheeler (2002) found cat predation responsible for the failure of brush-tailed bettong (*Bettongia pencillata*) re-establishment at Yathong Nature Reserve in western New South Wales. Control of these introduced predators is often the most important management action required for successful re-establishment of threatened mammal species in Australia (Kinnear *et al*. 2002).

A variety of methods have been used to control foxes including poison baiting (Thomson and Algar 2000), trapping and shooting. Most studies have found poison baiting to be highly effective both in Australia (Kinnear *et al*. 1998; Thomson and Algar 2000; Olsson *et al*. 2005) and overseas (Hegglin *et al*. 2004). Significant native fauna responses to fox baiting have been recorded including increases in abundance of threatened species (Kinnear *et al*. 2002) and other native fauna, such as goannas (*Varanus* spp.; Olsson *et al*. 2005). Poison baiting has a long history in Australia, with most practitioners now using the poison 1080 (sodium monofluoroacetate), a derivative of the naturally occurring fluoroacetate compound found in many *Gastrolobium* and *Oxylobium* plants in Western Australia (Eason 2002). The 1080 compound is odourless, tasteless and colourless and many native species have evolved a tolerance to it (King 1990). The poison is injected into a bait substrate, which is normally meat-based when used for introduced predator control.

 10.1071/WR10235 1035-3712/11/040338

Unfortunately, feral cat control through poison baiting has often been less effective due to poor bait uptake (Short *et al*. 1997*a*; Burrows *et al*. 2003; Algar and Burrows 2004; Hegglin *et al*. 2004; Olsson *et al*. 2005; Algar *et al*. 2007; Moseby *et al*. 2009*a*) and a cost-effective, large-scale control mechanism for feral cats is currently not available (Denny and Dickman 2010). Poison baiting for feral cats has been most successful in confined areas, such as islands (Twyford *et al*. 2000), or in areas where alternative live prey are in low abundance (Algar *et al*. 2007). Recent research into bait attractiveness has led to the development of a soft sausage bait, designed to be more attractive to feral cats (Algar and Burrows 2004). This Eradicat (WA Department of Environment and Conservation) bait has been successfully used to control cats in some areas of Western Australia; however, bait uptake has been found to be extremely variable, with a bait density of 10 baits per km^2 resulting in more than 75% reduction in cat activity in some years and only 25% reduction in others (Algar and Burrows 2004; Algar *et al*. 2007). Even at higher baiting densities of 50 baits per km^2, poor results have been recorded when prey species, such as rabbits (*Oryctolagus cunniculus*), are in high abundance (Algar and Burrows 2004). Although the Eradicat bait was developed to target feral cats, it is also highly effective against foxes (Algar and Burrows 2004).

The success of poison baiting may depend on factors such as bait palatability, timing, density, delivery, frequency and baiting area. If baited areas are too small, rapid reinvasion by animals living in peripheral non-baited areas may occur. Within arid Australia, the home range and movements of feral cats and foxes are significantly larger than in other environments (Edwards *et al*. 2001; Burrows *et al*. 2003; Moseby *et al*. 2009*a*), perhaps reflecting the lower productivity. Movements of more than 26 km and 45 km in three and two days respectively have been recorded, suggesting that reinvasion into baited areas may be rapid and large baited areas are required (Moseby *et al*. 2009*a*). Thomson *et al*. (2000) found that reinvasion of a baited area by foxes occurred faster in autumn, possibly due to dispersal of juveniles. Algar and Burrows (2004) suggested that bait uptake by cats in the arid zone is higher under cool, dry conditions in late autumn and winter. Rabbit densities in the region are typically lowest during this time (Bowen and Read 1998), and previous studies have shown that highest bait uptake is during periods of low rabbit abundance (Short *et al*. 1997*b*; Algar *et al*. 2007).

The Arid Recovery Reserve is a conservation reserve in northern South Australia where rabbits, feral cats and foxes have been eradicated and excluded from a large fenced exclosure for the protection of native species (Moseby *et al*. 2009*b*). Radio-tracking studies have shown that feral cats outside the reserve are wild and do not rely on human contact (Moseby *et al*. 2009*a*), the nearest town being more than 25 km away. The aim of this study was to determine whether a cost-effective baiting regime outside the Arid Recovery Reserve could reliably and significantly reduce the activity of feral cats and foxes. Reduced cat and fox activity was considered desirable to minimise the likelihood of foxes and feral cats breaching the fence and to increase the area of habitat available for threatened species. This study outlines the success of eight aerial poison baiting events for the feral cat and red fox over five years, 2002–06.

Materials and methods

Study area

The study was conducted between October 2001 and December 2006 within a 20 km radius of the Arid Recovery Reserve in northern South Australia (30°29′S, 136°53′E). The climate is hot and dry with a long-term average rainfall of 166 mm per annum. The mean annual summer maximum temperature exceeds 35°C, and the mean annual winter minimum is 4°C.

The study area supports a variety of habitats including dunes (*Acacia ligulata* and *Dodonaea viscosa*), sandplains (*A. aneura* and *Callitris glaucophylla*), chenopod swales (*Atriplex vesicaria* and *Maireana astrotricha*), ephemeral swamps (*Eragrostis australasica*), claypans and creek lines. Taller vegetation is present on dunes, whereas swales support more open, low vegetation (Finlayson and Moseby 2004). Feral cats, red foxes and European rabbits were present throughout the study area, which is primarily used for cattle (*Bos taurus*) grazing. Feral cat and fox densities in the study region fluctuate according to seasonal conditions but averaged ~0.8 and 0.6 per km^2 respectively over a 10-year period before the study (Read and Bowen 2001). Regional targeted control is limited to irregular shooting by amateur shooters and some irregular poison baiting to the north of the study area for dingo (*Canis lupus dingo*) control. Rabbit densities during the study period were estimated using spotlight counts, and averaged between 51 and 55 per km^2 (BHP Environmental Department, unpubl. data). Prior to the introduction of rabbit haemorrhagic disease in 1995, rabbit density averaged between 100 and 150 per km^2 (BHP Environmental Department, unpubl. data).

The Arid Recovery Reserve lies immediately south of the dingo fence, a man-made structure built to protect sheep from dingoes. Dingoes are present to the north of the dingo fence but are sometimes baited in a 30 km buffer zone north of the fence to minimise fence breaches. The baited and control track transects used in this study included areas to the north and south of the dingo fence. For this reason the locations of transects north and south of the dingo fence were included in the analysis as a covariate to determine whether the presence of dingoes influenced the baiting results.

Poison baiting

Two bait types were used in the aerial baiting trials, Eradicat baits and dried kangaroo (*Macropus* spp.) meat baits. Eradicat baits were developed by the Western Australian Department of Environment and Conservation and are a semi-dried meat product containing additives specifically attractive to cats. Eradicat baits weighed 20 g net (dried to 15 g) and contained 4.5 mg of 1080 (sodium monofluoroacetate). Baits were used under an experimental licence held by the Western Australian Department for Environment and Conservation and the South Australian Department of Water, Land and Biodiversity Conservation. The baits were frozen until the morning of the baiting when they were thawed on mesh racks and sprayed with a residual insecticide (Coopex, Bayer Environmental Science, Melbourne) mixed with water to reduce insect attack. Baits were then left for 1–2 h on the racks to 'sweat', where oils from within the sausages start to show on the surface and the outer skin becomes firm. In 2002 and 2003, baits contained red

Rhodamine B dye, a biomarker that fluoresces orange under UV light and can be used to assess bait consumption by feral animals (Fisher *et al*. 1999). In 2004, dried meat baits were used instead of Eradicat bait: ~80–120 g pieces of kangaroo meat injected with 3 mg of 1080. Baits were dried to 50% of their weight, frozen and thawed before use. Dried meat baits contained a lower concentration of 1080 than Eradicat baits as they were produced by the South Australian Department for Environment and Natural Resources for controlling foxes, which are more susceptible to 1080 poisoning than cats. However, the LD_{50} for foxes is 0.13 mg kg^{-1} (McIlroy and King 1990) compared with 0.28 mg kg^{-1} for cats (Eason *et al.* 1992) so both baits contained enough poison to potentially kill either species.

The density, frequency and area of baiting varied from year to year in an attempt to determine the optimum baiting strategy (Table 1). Random assignment and replication of treatments was not feasible due to the requirements that the baited area be located around the Arid Recovery Reserve to protect re-introduced species. Other reasons for lack of replication included funding constraints, the remote nature of the site and the large scale required for meaningful treatments. After discussions with the bait developer and manufacturer (Western Australian Department for Environment and Conservation) we decided to initially trial a bait density of 25 Eradicat baits per square kilometre. This rate was based on advice from the supplier that 25 baits per square kilometre was likely to be as effective as their trialled rate of 50 baits (D. Algar, pers. comm.). Subsequent published trials in Western Australia recorded baiting success at 10, 22, 50 and 100 baits per square kilometre depending on prey availability and seasonal conditions (Burrows *et al*. 2003; Algar and Burrows 2004). Algar and Burrows (2004) suggested that reducing bait intensity below 50 per square kilometre may not reduce baiting efficacy. Additionally, we felt that the cost of baits and potential risk to non-target species rendered 50 baits per square kilometre an unrealistic and unsustainable baiting density over our landscape scale study site. Baiting was conducted in autumn and winter when prey availability was lowest. After two years of trials at 25 baits per square kilometre, dried kangaroo baits were trialled due to results suggesting some cats would ingest buried dried meat baits. Finally, a bait density of 10 Eradicat baits per square kilometre was trialled at a higher baiting frequency in an attempt to combat high reinvasion rates and increase the chance of animals encountering baits during key times of low food availability.

During the first year of baiting, baits were laid in a 10 km buffer zone around the outside of the Arid Recovery Reserve fence line (Fig. 1). In subsequent years this was increased to 20 km. Baits were individually dropped from a helicopter or fixed wing aircraft along 1 km wide flight paths. Flight paths followed linear dunes as previous research had indicated that cats and foxes prefer dune habitat (Moseby *et al.* 2009*a*). An automated GPS recorded the location of all baits dropped during the program and ensured that no baits were dropped outside the baiting boundary. In 2002, 1400 dried kangaroo meat fox baits were buried using ground baiting two weeks before the aerial baiting to reduce the amount of Eradicat baits taken by foxes.

Change in activity

Mortality of radio-collared cats and changes in detection rates of cat and fox tracks were used to determine the success of baiting events. A series of track transects was established on vehicle tracks within the baited area and in nearby control areas. Transects established for the first baiting event in 2002 were altered for subsequent years due to an increase in the size of the baited area. In 2002, there were five transects within the baited area and six in the unbaited area (Fig. 1). In subsequent years the number of transects increased to six in the baited area and decreased to five in the unbaited area (Fig. 1). Transects in control areas were more than 10 km from the edge of the baited zone, baited transects were more than 5 km from the edge in 2002 and 10 km in subsequent years. Transects were a modified version of the monitoring technique established by Engeman and Allen (2000). Each transect consisted of a series of 200 m long segments on sand, separated by a distance of at least 500 m. Segments were longer that those suggested by Engeman and Allen (2000) due to subsequent research by Read and Eldridge (2010) regarding optimum segment lengths for monitoring cats. Where possible, segments intercepted sand dune crests as previous studies have found preferential use of this habitat by cats and foxes in Australian desert environments (Mahon *et al.* 1998; Moseby *et al*. 2009*a*). In 2002, the number of segments in each transect varied from 10 to 20, in subsequent years 15 segments were counted in all transects (Fig. 1).

Transects were driven over by a four-wheel drive vehicle in the late afternoon of the day preceding sampling. The tyre tread impressions obliterated older tracks and loosened the surface for increased detectability. Transects were monitored the following morning by a person walking along each segment of individual transects. The presence or absence of fresh cat, fox, rabbit, dingo and kangaroo tracks on the vehicle track was recorded for each segment. Although the number of intrusions into the plots over successive days is thought to be a more sensitive measure of population than a single binary measure (Engeman and Allen

Table 1. Details of the aerial baiting regime used each year around the Arid Recovery Reserve, 2002–06

* preceded by ground baiting three weeks prior, using 1400 buried dried kangaroo meat baits at an approximate density of two per km^2 to target foxes and thus maximise availability of Eradicat baits to feral cats

Year	Bait type	Frequency	Density (per km^2)	Total baits	Area (ha)	Timing
2002	Eradicat*	Annual	25	15 000	65 000	June
2003	Eradicat	Annual	25	45 000	180 000	May
2004	Dried meat	Annual	5	9000	180 000	May
2005	Eradicat	Quarterly	10	54 000	180 000	May, August, November
2006	Eradicat	Quarterly	10	36 000	180 000	February, May

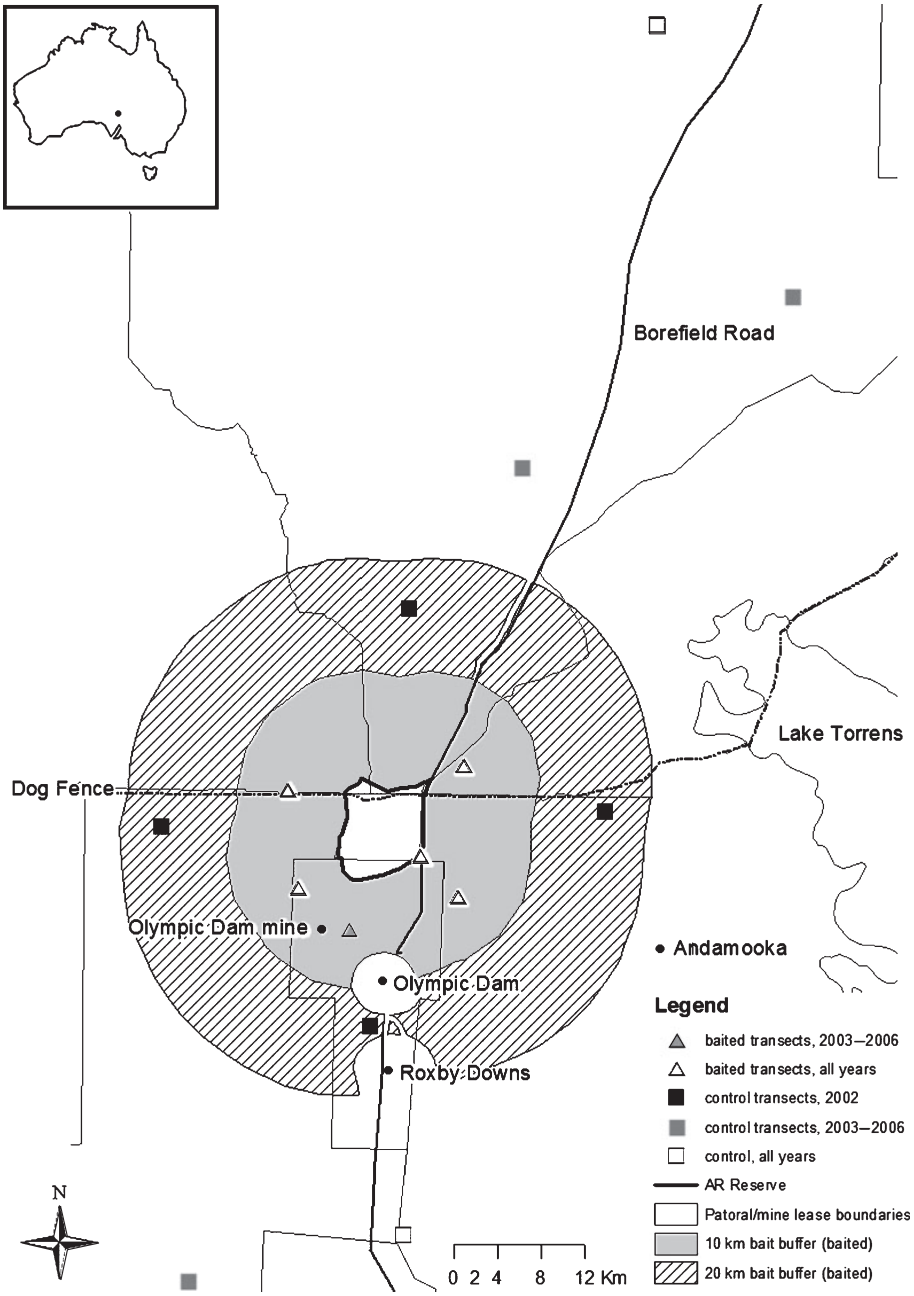

Fig. 1. The location of the Arid Recovery Reserve, monitoring transects and baited buffer zones from 2002–06. Transects symbols represent the midpoint of transects.

2000), the large size of the study area and logistical constraints prevented more than one night of monitoring. For rabbits, an additional record was made of the presence or absence of tracks within the first 20 m of the right-hand side tyre impression because short sections are more sensitive to fluctuations in rabbit numbers when rabbit densities are high (Read and Eldridge 2010). If strong winds or rain occurred before transects could be checked they were resampled. All transects were checked over a one-week period, occasionally this increased to two weeks when transects were affected by wind or rain. Transects were sampled a minimum of two times before and three times after each year's baiting event at intervals of 1–3 months. All transects were sampled within one month of each baiting event. Transects were sampled a total of 44 times between October 2001 and December 2006. Control transects were situated on surrounding pastoral stations and monitored using trained personnel including station managers. In most cases there was consistency of observers for each transect.

Feral cats within the baited area were captured and radio-collared before baiting trials in 2002, 2003 and 2006. Cats were also radio-collared in control areas more than 10 km from the baiting boundary in 2003 and 2006 and two foxes were radio-collared in the baited area in 2003. Feral cats were trapped using Victor Soft-Catch (No. 1.5) rubber jawed leg-hold traps (Coast to Coast Vermin Traps, Baldivis, WA) or wire cage traps baited with rabbit, chicken or other meat. Two lures were used in association with the leg-hold and sometimes cage traps: 'pongo' (cat urine) and, occasionally, a felid attracting phonic, 'FAP' (Westcare Electronics, Perth). Cat urine was collected from euthanised feral cats and occasionally from live domestic cats using stainless steel litter trays. During 2006, food was not used as a lure, to both minimise capture of non-target species and because food may attract hungry, inefficient hunters that were more likely to take poison baits during the subsequent baiting session.

Traps were checked early each morning, and captured feral cats and foxes were restrained using gloves and towels, and anaesthetised with a mixture of Metetomidine Hydrochloride and Ketamine administered intramuscularly. The anaesthetic was reversed using Atipamezole Hydrochloride. The cats and foxes were weighed and sexed and released at point of capture. The condition of their teeth, body and reproductive organs was also noted. During 2002 and 2003, simple 50–70 g VHF radio-collars with a short whip antenna and leather belting were used (Biotelemetry Australia, Adelaide). In 2006, 135 g SIRTRACK (Havelock North, New Zealand) GPS data logger collars with VHF were used. The units recorded GPS fixes every four hours and were housed in epoxy resin and contained two antennas: a micromouse GPS; and a 220 mm, 2NC gauge whip antenna. All collars were fitted with mortality sensors (40/80 ppm), triggered after 24 h without movement.

Animals were radio-tracked on foot and by fixed wing aircraft, both opportunistically as well as one to four days before and one to three days after baiting events. If a cat or fox was found dead, the location was recorded and the general area inspected for any evidence of predation or regurgitation of baits. The animal was then relocated to a laboratory where its mouth and stomach contents were inspected for the remains of baits. In 2002, the liver and stomach of four cats suspected to have died from 1080 poisoning were sent to the Alan Fletcher Research Station in Queensland for testing. In 2003, the stomachs of four dead animals were removed and sent to Dave Algar (Western Australian Department for Environment and Conservation) who inspected them for the presence of Rhodamine B.

Data analysis

We compared transect data on control and baited transects over time to determine if baiting had a significant effect on detection rates of cats, foxes and rabbits. Detection rates were calculated at each time for each transect by dividing the number of segments with a particular species track present by the total number of segments. This proportion provided a measure of track activity for each species for each transect. These data were transformed using empirical logit-transformation ($\log((x+0.5)/(\text{total} - (x+0.5)))$), where x is the total number of segments with track activity and total is the total number of segments in the transect. Generalised linear mixed models (Galwey 2006) were used to determine significant predictor variables explaining patterns in cat, fox and rabbit detection rates. Treatment (baited or control) and time were fixed effects and site (transect) was a random effect. The significance of fixed effects was determined using Wald's statistic (Kenward and Roger 1997). The presence of rabbit tracks in the first 20 m of the segments was used as the response variable for rabbits rather than counts from the whole transect.

Three different time scales were used for analysis. First, all monitoring sessions over the entire study period were compared between baited and control transects to determine long-term trends in rabbit, cat and fox detection rates and the effectiveness of baiting across all years. Second, the baiting events in 2002, 2003, 2004 and 2005–06 were analysed as separate baiting regimes. For each baiting regime, monthly monitoring sessions were grouped into monitoring periods and blocked into before or after baiting events (Table 2). In 2002, monitoring sessions were grouped into before, immediately after and long after the baiting event. In 2003 and 2004, monitoring sessions were grouped into before and after baiting events. For quarterly baiting in 2005 and 2006, sessions were combined and blocked into before the first baiting event, between each of the five quarterly baiting events and after the final baiting event. The interaction term between treatment and time was used to determine whether baited transects responded differently to control transects after baiting. Finally, individual track monitoring sessions were compared between baited and control transects for each baiting regime. The least significant difference term was used to identify months when significant differences occurred. This analysis allowed us to determine how long the poison baiting remained effective after each baiting event.

A factor for inside or outside the dingo fence was included as a fixed covariate in initial models to determine whether the presence or absence of dingoes influenced the effect of baiting. If the dingo fence factor was not significant it was removed from the model. Models were also run with rabbit detection as a fixed covariate to determine whether rabbit activity was influencing the effectiveness of baiting. Introduced predators are known to respond to rabbit activity in the arid zone and rabbits are a key prey item for local foxes and cats (Read and Bowen 2001).

There was some serial dependency within sites (transects), which was accounted for by using site (transect) as a random effect. We initially explored serial dependence as a decay in an exponential way. There was some very weak evidence of exponential decay in the serial dependence component; however, this did not change inferences. Predicted means derived from the models were plotted to show trends in the data. Least significant difference was used to indicate which means showed a significant difference. Bars representing least significant difference were added to graphical results.

Results

Rainfall

Annual rainfall was well below average in 2002 (43 mm, Fig. 2), around the average in 2003 (152 mm), 2004 (193 mm) and 2005 (160 mm), and below average again in 2006 (105 mm).

Cats

Despite eight baiting events, there was no significant difference in cat detection rates over time or between treatments over

Table 2. Track monitoring sessions used in the study including the grouped monitoring periods used for some data analysis

The dotted lines indicate baiting events and the solid lines separate different baiting regimes. 'Between' refers to the monthly track transects conducted between the quarterly baiting events in 2005 = –06. * denotes a significant difference in detection rates at the $P < 0.05$ level. Significant differences at the monitoring period time scale indicate a significant treatment by time interaction while significant differences at the monitoring session time scale indicate months when there was a difference in detection rates between baited and control transects

Baiting regime	Transect monitoring period	Cats	Foxes	Transect monitoring session	Cats	Foxes
2002				October 2001		*
2002				November 2001		
2002				January 2002		
2002	Before			February 2002		
2002				March 2002	*	
2002				April 2002		
2002				May 2002		
2002				Early June 2002		
2002		*	*	Late June 2002	*	*
2002	Immediately after	*	*	July 2002		*
2002		*	*	August 2002	*	*
2002				September 2002		
2002	After			October 2002		
2002				November 2002		
2003				February 2003		*
2003	Before			March 2003		
2003				April 2003		
2003			*	May 2003		*
2003	After		*	June 2003		*
2003			*	July 2003		*
2004	Before			February 2004		
2004				May 2004		
2004				June 2004		-
2004				July 2004		*
2004	After			September 2004		
2004				October 2004		
2005–06				January 2005		
2005–06	Before			March 2005		
2005–06				April 2005		
2005–06			*	May 2005		*
2005–06	Between 1			June 2005		*
2005–06				July 2005		*
2005–06			*	August 2005		*
2005–06	Between 2			September 2005		
2005–06				October 2005		
2005–06			*	November 2005	*	*
2005–06	Between 3			December 2005		
2005–06				January 2006		*
2005–06	Between 4		*	March 2006		
2005–06				May 2006	*	*
2005–06			*	June 2006		*
2005–06				August 2006	*	
2005–06	After			October 2006		
2005–06				December 2006		

the five-year period (Figs 3 and 4). However, a significant interaction term suggests that cat detection rates in baited and control treatments responded differently over time (Wald = 8.09, d.f. = 1, $P = 0.004$) with baited transects exhibiting considerably more variation than control transects. When baiting regimes were considered separately (2002, 2003, 2004 and 2005–06) the 2002 baiting was the only year when cat activity declined significantly after baiting. On a monthly scale (monitoring sessions) the detection of cats in 2002 was lower on the baited transects than the control for the first and third months after baiting (Wald = 25.47, d.f. = 13, $P = 0.02$; Fig. 3) but overall there was no significant interaction between treatment and time. In the first month after baiting, detection rates dropped from 17 to 3% on baited transects but increased from 18 to 23% on control transects. When the data were grouped into monitoring periods to reduce some of the variability within the monthly dataset, a significant baiting effect was observed (interaction term Wald = 11.31, d.f. = 2, $P < 0.05$; Fig. 3). However, this effect only lasted for the three-month monitoring period immediately after baiting.

Aerial baiting was ineffective at both scales for all other baiting regimes. Interestingly, during the 2005–06 baiting regime, significantly lower detection rates were recorded in control transects during three of the post-baiting monitoring sessions. However, a non-significant interaction term indicates that this result was not related to baiting events.

Radio-tracking results in 2002 were in accordance with the decline in track detection rates recorded in baited transects with all nine radio-collared cats in the baited area dying after fox or cat baiting (Table 3). Two cats were collared a month before the aerial baiting and just before the 1080 ground baiting for foxes, with the remaining seven collared in the three weeks between ground baiting and aerial baiting. Six cats were captured using leg-hold traps and three in cage traps. Weights ranged from 1.5 to 5.0 kg. Two of the leg-hold captures were incidentally recaptured in cage traps before aerial baiting. Interestingly, when the cats were checked two days before aerial baiting, seven of the nine cats were already dead, most or all apparently killed by the buried fox baits laid two weeks earlier. The remaining two cats died within 48 h of the aerial baiting. One of these cats had sausage remains around its mouth and in its stomach suggesting it had died from ingesting an Eradicat bait. Both of the cats that died after baiting tested positive to 1080 as did one of two cats tested that died between ground baiting and aerial cat baiting.

In 2003, four male and two female cats were radio-collared, with two captured in leg-hold traps and four in cage traps. Weights ranged from 1.8 to 5.5 kg. Although poison baiting in 2003 did not lead to any significant differences in cat detection rates between baited and control transects (Figs 3 and 4), five of the six radio-collared cats within the baited area died within three days of baiting (Table 3). One radio-collared cat and one additional uncollared cat were found dead next to regurgitated baits. However, of the remaining collared cats, only one of four stomachs tested positive to the marker Rhodamine B.

In 2006, two female and four male cats were radio-collared in the baited area and six male and one female in control areas. Cats ranged in weight from 2.7 to 5.4 kg and only one cat in the

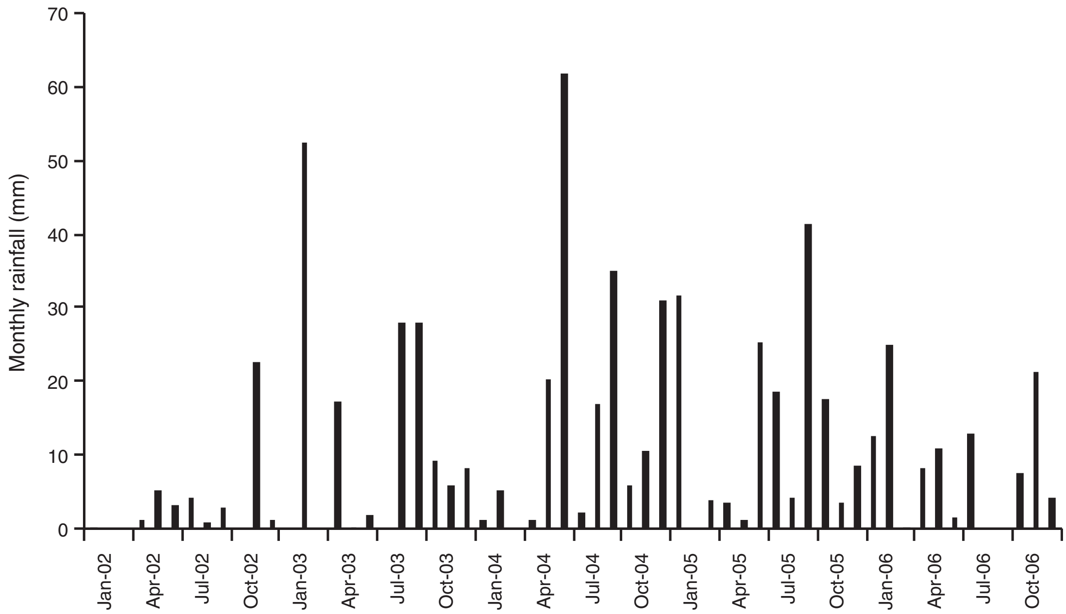

Fig. 2. Monthly rainfall recorded during the study.

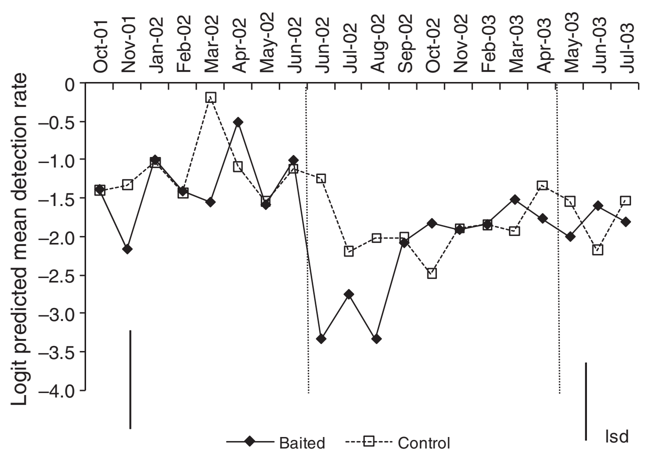

Fig. 3. Logit predicted mean detection rate of cats on track transects in baited and control areas before and after baiting in 2002 and 2003. Dotted vertical lines indicate baiting events. Least significant difference (l.s.d.) bars are shown for 2002 and 2003.

baited area died in the three weeks after baiting (12 days). Two control cats died, one within two days of baiting and the other (after moving 15 km into the baited area) died the next day, possibly after ingesting a bait (Table 3). Analysis of radio-collar GPS fixes indicated that this was the only control cat that entered the baiting area. High mortality was recorded in both baited and control areas, with seven of the 11 control cats and three of the six baited cats dying between two and 60 days after baiting (Moseby *et al*. 2009*a*).

Foxes

Poison baiting was highly effective in reducing fox activity in the baited area with a significant difference in fox detection rates between baited and control sites over the five-year study period (Wald = 12.19, d.f. = 1, $P < 0.001$; Figs 5 and 6). A non-significant interaction term suggested that fox activity was consistently lower on baited transects and the overall effect of baiting was greater than the effect of reinvasion between baiting events. Towards the end of the study when quarterly baiting was implemented, detection rates on baited transects were around one-third of those recorded on control transects and generally remained at less than 15% of pre-baiting rates.

When baiting regimes were analysed individually, fox detection in the baited areas consistently dropped below 10% after all baiting events (Figs 5 and 6). Significant interaction terms between treatment and time suggested that the decline in fox detection rates on baited transects in 2002, 2003 and 2005–06 was a response to the baiting regimes (interaction terms 2002: Wald = 53.62, d.f. = 13, $P < 0.001$; 2003: Wald = 11.50, d.f. = 5, $P < 0.05$; 2005–06: Wald = 31.26, d.f. = 17, $P < 0.05$) when monthly monitoring sessions were analysed. These differences were maintained, as expected, when data were grouped and modelled at the monitoring period time scale (interaction terms 2002: Wald = 32.3, d.f. = 2, $P < 0.001$; 2003: Wald = 6.64, d.f. = 1, $P < 0.01$; 2005–06: Wald = 20.45, d.f. = 5, $P < 0.001$).

During the 2004 baiting regime, wet conditions prevented control transects from being checked in the first month after baiting. However, detection rates fell dramatically from 38 to 9% at baited sites after baiting and there was a significant difference in fox detection rates between treatments (Wald = 6.3, d.f. = 1, $P = 0.012$). This difference was most pronounced in the first monitoring session after baiting (Fig. 6). The results from the model do not show a significant interaction between monitoring and treatment at a monthly or monitoring period time scale possibly due to the missing control data. A significant interaction may have been recorded if monitoring data were available immediately after baiting for control sites.

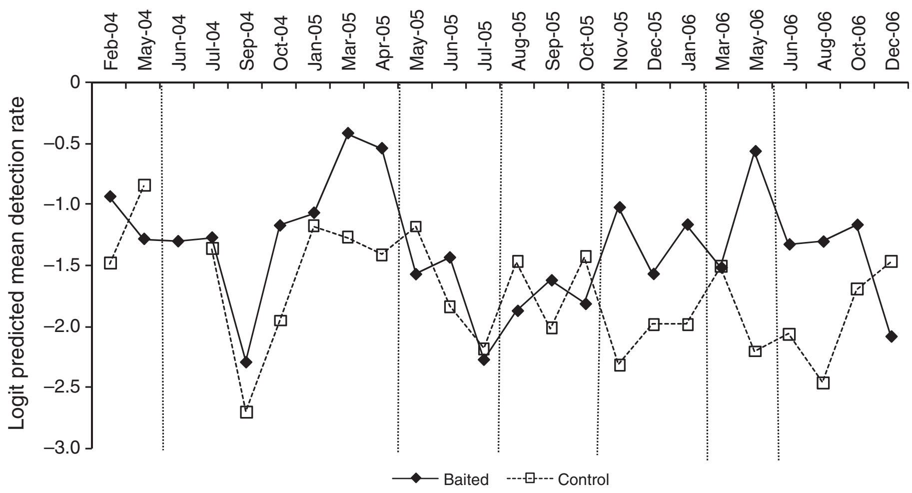

Fig. 4. Logit predicted mean detection rate of cats on track transects in baited and control areas before and after baiting in 2004 and 2005–06. Dotted vertical lines indicate baiting events.

Table 3. The fate of radio-collared cats in relation to baiting events
Data from 2005–06 is taken from Moseby et al. 2009*a*. The number of cats dying after baiting refers to deaths within 14 days of baiting. Deaths after this time are more likely to be due to natural causes. No cats were radio-collared in 2004 or 2005. * denotes cats likely killed by fox baits laid three weeks before aerial cat baiting

Year	Baited			Control	
	No. cats	Deaths prior	Deaths after	No. cats	Deaths after
2002	9	7*	2	–	–
2003	6	0	5	1	0
2006	6	0	1	7	2

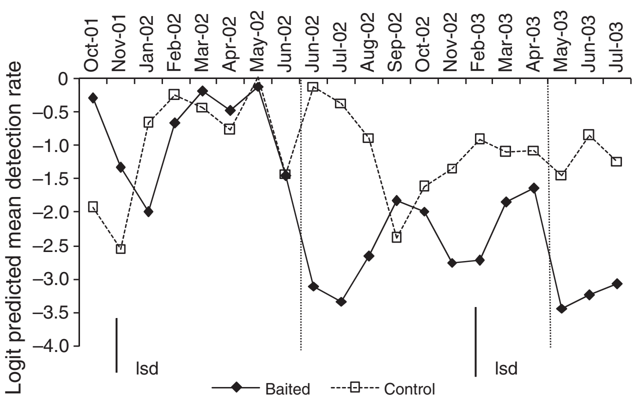

Fig. 5. Logit predicted mean detection rate of foxes on track transects in baited and control areas before and after baiting in 2002 and 2003. Dotted vertical lines indicate baiting events. Least significant difference (l.s.d.) bars are shown for 2002 and 2003.

Additionally, of the two foxes that were radio-collared in the baited area in 2004, one could not be located after baiting and the other died within two days of aerial baiting.

Baiting effects were short-lived with significant differences only recorded in the first few months after baiting. In 2002, fox detection rates in baited areas dropped from 47 to 4% but were no different from control areas four months after baiting (Table 2, Fig. 5). Baiting over a larger area in 2003 reduced fox detection rates from 16 to 3% and remained effective for three months. Monitoring ceased three months after baiting and was not reinstated until nine months after baiting, by which time there was no difference between fox detection on control and baited sites. In 2004, fox detection rates at baited sites were similar to control sites at four months after baiting (Table 2). Quarterly baiting in 2005 and 2006 produced a more sustained response but there was still some variability in fox detection on a monthly basis (Table 2).

In 2002, the only year when cat detection rates declined after baiting, there was a 91% reduction in fox detection rates on baited transects in the month after baiting, compared with an 82% reduction for cats. Fox detection rates on baited transects were 84% lower than control transects in the month after baiting in 2003, 82% lower in 2004 and 81, 58, 65, 56 and 87% lower in 2005–06. There was no apparent relationship between bait density and magnitude of response.

Rabbits

Over the five-year study there was a significant difference in rabbit detection rates over time (Wald = 66.17, d.f. = 1, $P < 0.001$) but no significant difference between baited and control treatments. However, a significant interaction term (Wald = 10.92, d.f. = 1, $P < 0.001$) indicates that rabbit detection in the baited and control areas responded differently over time due to rabbit detection increasing on baited transects but not control transects (Fig. 7). To investigate further, years at the beginning and end of the study period were analysed separately. There were significantly more rabbits detected at control sites than at baited sites in 2002 (Wald = 9.64, d.f. = 1, $P < 0.05$). By 2005–06 there was no significant difference between treatments due to the increase in rabbits at baited sites. Results suggest that rabbits increased in the baited area over time but not in the control area.

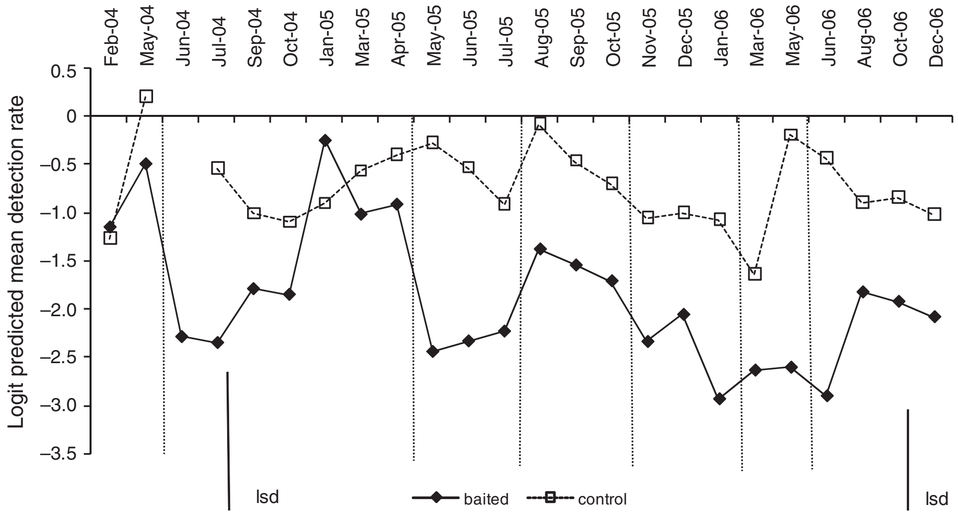

Fig. 6. Logit predicted mean detection rate of foxes on track transects in baited and control areas before and after baiting in 2004 and 2005–06. Dotted vertical lines indicate baiting events. Least significant difference (l.s.d.) bars are shown for 2004 and 2005–06.

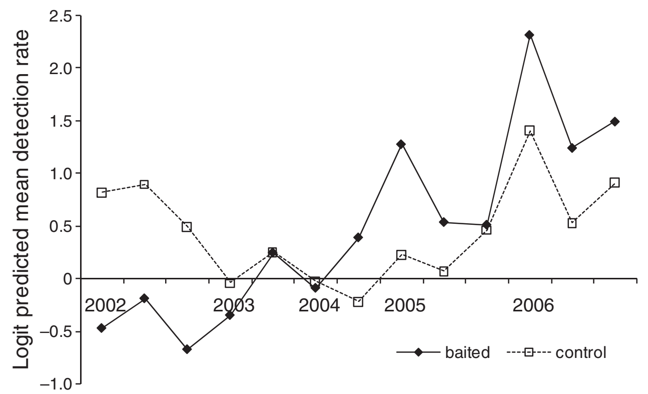

Fig. 7. Logit predicted mean detection rate for rabbits at baited and control sites over the five-year study period. Monitoring sessions (months) have been blocked into monitoring periods to show overall trends.

The detection rate of rabbits was run as a covariate across the entire study period for both cats and foxes. Rabbits were significant as a single factor variable for cats (Wald = 15.64, d.f. = 1, $P < 0.001$) suggesting that there is a relationship between detection rates of cats and rabbits. However, there was no significant interaction between treatment, monitoring session and rabbits, suggesting that the relationship between cats and rabbits did not influence the response of cats to baiting events. Despite this result, the only effective baiting event for cats occurred in 2002 when rabbits, their primary prey, were at their lowest for the study period. Rabbits were not significant as a covariate for foxes suggesting that baiting had a stronger influence on fox activity than rabbits.

The dingo fence was also initially run as a covariate for all of the models. Occasionally there were some minor significant effects between sites inside and outside the dingo fence. However, none of these effects were related to aerial baiting and were more often mirroring the experimental design, in which more control sites occurred outside the dingo fence than baited sites. The dingo fence covariate was subsequently removed from the model.

Discussion

Aerial baiting using the Eradicat bait was consistently effective at reducing fox but not cat activity outside the Arid Recovery Reserve. The effectiveness of cat baiting was not improved by changing the size of the baited area, baiting frequency, bait density or the seasonal timing of baiting. Statistical analysis suggested that cat activity was more strongly influenced by rabbit activity than by baiting events.

The activity of rabbits was not found to statistically influence the response of cats to baiting but this may have been at least partly related to the fact that only one baiting event occurred during a period of low rabbit activity. Cat detection rates only declined significantly after baiting in 2002, the driest year of the study and the year when rabbits were least abundant. Several other studies have found bait uptake by cats to be low, highly variable or effective only during times of low prey availability (Short *et al.* 1997*a*, 1997*b*; Algar and Burrows 2004; Algar *et al.* 2007). During the 2002 baiting, most of the radio-collared cats died in the two-week period between the fox baiting and aerial cat baiting and at least one death may have been directly attributed to a fox bait. The high mortality suggests that cats were under severe nutritional stress and either died from starvation or were hungry enough to locate and dig up buried fox baits, a behaviour not typically recorded in other fox baiting studies (Short *et al.* 1997*a*; Algar and Burrows 2004). Reduced effectiveness of baiting in subsequent trials could also be related to bait shyness by remaining cats. These cats could have received a sub-lethal dose of a decomposing bait in 2002 or naturally be more averse to consuming carrion.

Preference trials have shown that Eradicat baits are more palatable to cats than dried fox baits (Algar and Burrows 2004). However, although the Eradicat bait has been shown to be palatable at times to feral cats (Algar and Burrows 2004) it is not known whether dried fox baits would also successfully control cats if they were used during dry conditions at similarly high densities. Algar and Burrows (2004) compared fox bait and Eradicat uptake by cats in the Gibson Desert but the baits were used at different times and fox baits were only used at low densities. Direct comparisons of the two bait types are needed at landscape scales to determine their comparative effectiveness under different environmental conditions.

Successful control of feral cats using poison baiting requires that cats both find and ingest baits. We suggest that both of these may not have occurred effectively in our study and some other cat baiting trials. Apart from bait longevity and cat density, three main factors influence whether cats find baits in aerial baiting events: the number of baits distributed, the location of baits in the landscape and non-target uptake. A large number of baits may need to be distributed for a cat, normally an active hunter of live prey, to successfully locate an inert bait that neither moves nor emits a sound. Algar and Burrows (2004) recorded successful baiting events for cats at 22, 50 and 100 baits per square kilometre and Moseby *et al*. (2009*a*) used real fixes from radio-collared cats to model that 25 baits per square km were needed for a cat to approach one bait within three days. The lower bait density used during baiting events in 2004, 2005 and 2006 may have contributed to poor bait uptake. However, this does not explain the poor uptake in 2003 when a bait density of 25 per square km was used, nor the high mortality of radio-collared cats after the 2002 fox baiting at a density of two per square kilometre. Even at high bait densities, cats may not always effectively locate baits as they rely more on visual and audio stimuli than olfactory cues and use search images or sounds to locate prey in close proximity (K. M., pers. obs.). This suggestion is supported by Algar *et al*. (2007) and Moseby *et al*. (2011) who recorded cat tracks travelling past baits without deviating from their line of travel. Differential habitat use by feral cats may also mean that only a portion of randomly distributed baits are functionally available to cats. Our study targeted dunes, habitat known to be preferred by cats in the region. However, cats may not use dunes randomly or may hunt in areas that are not preferred habitat. Non-target uptake was also found to be significant during ground and aerial baiting trials (Moseby *et al*. 2011) with up to 80% of baits removed by non-target species, vastly reducing baits available to cats.

Low bait ingestion rates may also have contributed to poor baiting results for feral cats. Poor bait ingestion rates may be due to cats locating baits when they are not hungry, unpalatable baits or an aversion to scavenging. Algar *et al*. (2007) and Moseby *et al*. (2011) recorded uptake rates for cats in some instances to be as low as 14% despite cats passing within 0.5 m of an Eradicat bait. Higher bait uptake has been recorded by researchers when using familiar foods, such as birds, fish or mice (Short *et al*. 1997*b*; Twyford *et al*. 2000; Mitchell *et al*. 2002). Catling (1988) and Paltridge *et al*. (1997) found low levels of carrion in wild arid zone cat stomachs and usually only during dry winters or droughts, suggesting a preference for live prey.

Hungry cats, stray cats or cats found at town dumps are more likely to scavenge than feral cats (Risbey *et al*. 1999; Short *et al*. 2002) and are arguably easier to trap using food as lures. The high ingestion rates of baits by radio-collared cats in 2003, despite no significant drop in track detection rates, may have been partly due to the use of food-based lures and some cage traps for catching radio-collared cats. These cats may have been hungry inefficient hunters or younger inexperienced cats that were more likely to scavenge and be susceptible to baiting. Short *et al*. (2002) found cage traps caught younger cats and those that scavenged for food, while leg-hold traps caught more male cats and hunters. Thomson *et al*. (2000) also found differences in bait uptake of foxes with younger foxes taking baits sooner than older foxes. Two other factors may have contributed to the discrepancy between baiting transects and radio-collared cat deaths in 2003. First, some of the deaths may not have been attributable to Eradicat baits. Only one of the four stomachs sent to Western Australia was found to contain the marker Rhodamine B and an insufficient number of control animals were used for death rate comparisons. The high natural mortality of both control and baited cats in 2006 indicates that high mortality is a common occurrence in the Australian arid zone (Moseby *et al*. 2009*a*). Similarly, the efficacy of Eradicat baiting in 2002 cannot be differentiated from the buried fox baits laid two weeks before, as seven of the nine radio-collared cats died before Eradicat baiting. Second, our transects measure cat activity rather than cat abundance *per se*, a reduction in cat abundance could have led to an increase in the activity of remaining cats (see Christensen and Burrows 1994) or rapid reinvasion into the baited area (see Moseby *et al*. 2009*a*).

Fox activity was successfully reduced using both Eradicat poison baits and dried meat baits but quarterly baiting was required to prevent rapid reinvasion of baited areas. Foxes have been successfully controlled in many areas using 1080 poisoning (Kinnear *et al*. 2002; Algar and Burrows 2004) but reinvasion is common and varies according to season and the size of the baited area. Algar and Burrows (2004) found aerial baiting for foxes in a 160 000 ha area reduced activity for more than twelve months but other studies have found rapid reinvasion when areas of less than 10 000 ha are baited (Saunders *et al*. 1995). Kinnear *et al*. (1988) found monthly baiting was needed in areas less than 300 ha in size and Thomson *et al*. (2000) found higher reinvasion rates six months after baiting, particularly during autumn dispersal. Our reinvasion occurred regardless of season and faster than might have been expected from the size of the baited area. Both arid zone foxes and cats are capable of long range movements of up to 45 km in two days and have larger home ranges than their mesic counterparts (Moseby *et al*. 2009*a*). Arid conditions may trigger higher levels of population transience, severely hampering efforts to reduce their abundance over long time periods without regular baiting. The highest fox response was recorded in 2002 when cats also responded to baiting but there was no relationship in subsequent years between the magnitude of response and bait density or type. Fox baiting at a density of 10 baits per square km was just as effective with dried meat baits as Eradicat baits and much more cost-effective.

Conclusion

Despite aerial baiting trials spanning five years, eight aerial baiting events and four different baiting regimes, cat detection in the baited areas was only significantly lower relative to control areas for a three-month period after one baiting event. Cat activity was positively related to rabbit activity and we concur with other researchers that poison baiting using Eradicat or dried meat baits is unlikely to be effective in areas with high rabbit abundance or when alternative prey is reliably available. While successful baiting events with Eradicat have been documented at 50 and 100 baits per square kilometre (Burrows *et al*. 2003), results are still variable and it is unlikely that this intensity of baiting is cost-effective or sustainable over large areas or long time periods. Fox activity could be sustainably lowered through quarterly baiting at 10 baits per square km but even when baiting a large area of 180 000 ha and reducing fox detection by up to 92%, fox detection rates often reached 10–20% in baited areas within just a few months of baiting. Although some threatened mammal species have responded positively to fox control (Kinnear *et al*. 2002), the presence of even low numbers of foxes can prevent the successful re-establishment of threatened species and we concur with Priddel and Wheeler (1997) that fox baiting may need to be more frequent and widespread to reduce fox populations to a level where threatened species can recover. Rabbit activity increased in the baited area relative to control areas as has been found in other cat and fox control programs (Newsome *et al*. 1989), suggesting that ongoing baiting may increase prey availability and lead to even lower bait uptake by cats. This vicious cycle may be the nemesis of successful cat control as long as we rely on voluntary bait ingestion. The generally poor response of cats to baiting, high reinvasion rates and high densities of baits required to ensure bait uptake suggests that current baiting methods may be more suited to short-term control of cats or eradication from islands or fenced reserves. We feel that long-term, broadscale cat control in areas where rabbits and other prey are present is still an aspirational target rather than an imminent outcome in the Australian arid zone.

Acknowledgements

This study was conducted by Arid Recovery, a conservation partnership between BHP Billiton, The University of Adelaide, the local community and the SA Department for Environment and Natural Resources. We would like to thank John Read for assistance with project design and for providing useful comments on the manuscript. Ross Cunningham provided patient and expert assistance with statistical analysis. Thanks must also go to David Paton and Peter Copley for their support for the project and their involvement on the Arid Recovery Steering Committee. We are indebted to the many volunteers and staff who assisted on this project including John Read, Nicki Munro, Jenny Stott, Jeff Turpin, Jason Briffa, Bree Galbraith, Michelle Thums and Adam Bester. Peter Bird provided invaluable assistance with 1080 injection and obtaining permits and Helen Crisp kindly supplied one figure. This study could not have been conducted without the dedication of the WMC Land Management section including considerable assistance from Pete Paisley, Leo and Marie McCormack and Bobby Hunter. BHP Billiton Environmental Department staff kindly assisted with data collection and provided long-term rabbit datasets and comments from five referees considerably improved the manuscript. Ethics approval for this study was granted by the South Australian Wildlife Ethics Committee (permits 14/2002 and 9/2006).

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Manuscript received 20 December 2010, accepted 1 July 2011