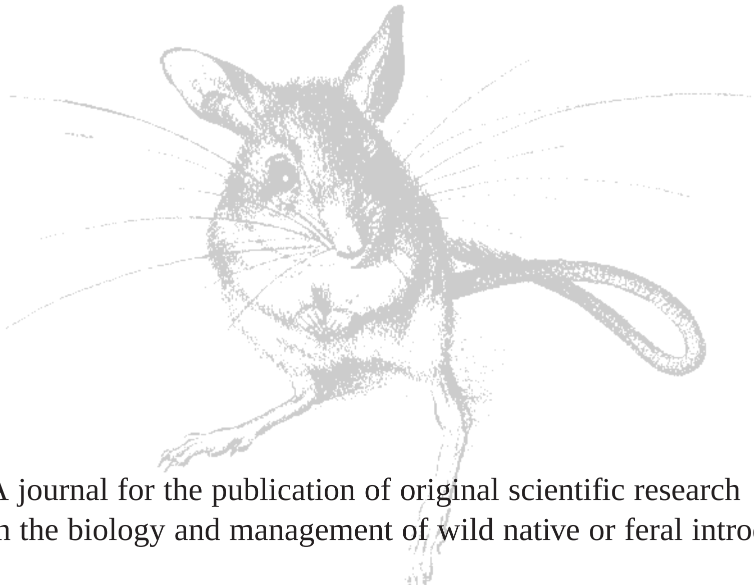
CSIRO PUBLISHING

Wildlife Research

Volume 24, 1997



A journal for the publication of original scientific research
in the biology and management of wild native or feral introduced vertebrates

www.publish.csiro.au/journals/wr

All enquiries and manuscripts should be directed to
Wildlife Research
CSIRO PUBLISHING
PO Box 1139 (150 Oxford St)
Collingwood
Vic. 3066
Australia

Telephone: 61 3 9662 7622
Facsimile: 61 3 9662 7611
Email: david.morton@publish.csiro.au

Published by **CSIRO** PUBLISHING
for CSIRO Australia and
the Australian Academy of Science

 Wildlife Research, 1997, **24**, 703–714

Control of Feral Cats for Nature Conservation. II. Population Reduction by Poisoning

Jeff Short[A], *Bruce Turner*[A], *Danielle A. Risbey*[B] *and Reg Carnamah*[A]

[A]CSIRO Division of Wildlife and Ecology, LMB 4, PO Midland, WA 6056, Australia.
[B]School of Biological and Environmental Sciences, Murdoch University, Murdoch, WA 6150, Australia.

Abstract

A feral cat population was substantially reduced by poisoning at a semi-arid site in Western Australia. The control programme was designed to protect two species of endangered native mammals that had recently been reintroduced to the site. Feral cats were poisoned with carcasses of laboratory mice, each impregnated with 4.5 mg of sodium monofluoroacetate (1080). Baits were placed at 100-m intervals along the track system each night for four consecutive nights. Kill rates were assessed by monitoring survival of radio-collared cats and by spotlight counts of cats before and after baiting. All radio-collared cats were killed and there was a 74% reduction in spotlight counts of cats after baiting. Bait removal varied with the abundance of rabbits, the primary prey item for cats in this area. Effectiveness of control operations against feral cats is maximised by baiting at times of low prey abundance. Monitoring the changing abundance of the primary prey species provides important information for timing control operations against feral cats.

Introduction

Feral cats, *Felis catus*, are believed to be responsible for the extinction of some island populations of mammals (Wood Jones 1923–25, p. 214; Burbidge 1971; Burbidge and George 1978) and birds (Oliver 1955; p. 457; Merton 1977; Taylor 1979), the substantial reduction in population density and threatened extinction of other species (van Rensburg and Bester 1988*a*), and the failure or limited success of programmes to reintroduce endangered mammals to arid Australia (Christensen and Burrows 1994; Gibson *et al*. 1994*a*, 1994*b*).

Control techniques have largely been developed on islands. They include a mix of disease, spotlight shooting, trapping with cage or leg-hold traps, hunting with dogs, and poisoning (Veitch 1985; van Rensburg *et al*. 1987; van Rensburg and Bester 1988*b*; Seabrook 1990; Bloomer and Bester 1992). Attempts to control feral cats at Australian mainland sites have been ineffective (Christensen and Burrows 1994).

Feral cats are being controlled in an area of *c*. 100 km^2 on Heirisson Prong at Shark Bay, Western Australia, as part of a programme to reconstruct a mammal community of species extinct on mainland Australia but surviving on offshore islands (Short 1994; Short *et al*. 1994). Reintroduced species are the burrowing bettong, *Bettongia lesueur*, and the western barred bandicoot, *Perameles bougainville*. Cats are known to be a significant predator of burrowing bettongs, apparently killing all or most of the 40 bettongs reintroduced to the Gibson Desert in 1992 (Christensen and Burrows 1994). Similarly, cats have been implicated in the decline of the only population of the eastern barred bandicoot, *Perameles gunnii*, known to have survived on mainland Australia (Seebeck 1979).

Trapping was the most successful of three methods (spotlight shooting, poisoning and trapping) used on Heirisson Prong to control cats, accounting for 78% of 210 known captures or deaths prior to June 1995 (Short and Turner, unpublished data). However, it is comparatively labour intensive and hence has limited application to control in larger areas. A successful technique for poisoning feral cats offers the advantage of cost-effective broad-area control. However, attempts to poison cats on Heirisson Prong, prior to the work detailed in this study, had had limited success (Short *et al*. 1994; Risbey *et al*. 1997).

10.1071/WR96071 1035-3712/97/060703$05.00

In this study, feral cats were poisoned in two adjacent sites of *c*. 47 and 25 km^2, respectively, on Heirisson Prong. We assessed the kill rate of feral cats by two methods: the kill rate of radio-collared cats, and comparison of spotlight indices along standard routes before and after baiting. We used carcasses of laboratory mice, *Mus musculus*, as the bait medium and sodium monofluoroacetate (1080) as the poison. Mice were chosen because they were a significant item in the diet of feral cats in the area (being found in 31% of 68 stomachs: Risbey 1996*a*), were of a size suitable for use as a bait medium, and were readily available from a commercial supplier.

Following this trial, mouse baits were used in subsequent baitings to maintain and extend control of cats on Heirisson Prong to an area of *c*. 100 km^2. These baitings were conducted at different times of the year and at times of differing prey availability to the initial trial, so providing a comparison of the relative effectiveness of baiting under a range of conditions.

Materials and Methods

Study Area

Heirisson Prong is a peninsula that juts into Shark Bay and forms part of the 805-km^2 Carrarang Pastoral Station. It is a 1200-ha area at the tip of the peninsula that is managed for conservation of endangered mammals by the mining community of Useless Loop and CSIRO Division of Wildlife and Ecology. Details of climate and vegetation are given by Short *et al*. (1994) and Risbey *et al*. (1997).

The poisoning trial was conducted in two areas south-west of Useless Loop and beyond the conservation reserve (Fig. 1). The southern area was grazed by sheep, and dense populations of both rabbits and cats were concentrated around a sheep watering point. The northern site was not grazed by sheep and had no available fresh water. All areas were serviced by sandy station tracks, which are ideal for recognition of animal tracks.

Foxes, *Vulpes vulpes*, were rare in the study area because of the biannual fox baiting carried out since March 1991. Rabbits, *Oryctolagus cuniculus*, were abundant throughout the area, but fluctuated substantially in numbers over time. They were the primary food for feral cats at the site, being found in 68% of 68 stomachs examined (Risbey 1996*a*).

Method of Baiting

The major baiting trial was conducted in June 1995. Frozen mice were obtained from a commercial breeder who supplied the laboratory and zoo trade (Animal Resources Centre, Murdoch, Western Australia). Most mice were white. A single poisoned oat (coated with 4.5 mg 1080) was embedded in the throat of each mouse carcass with a pair of tweezers. Poisoned oats were obtained from the Western Australian Agriculture Protection Board. Their use was favoured over the use of liquid 1080 because of the lower risk to the operator and the ease of transport and storage.

Baits were placed at numbered sites at 100-m intervals along two circular track systems (22 and 16.5 km long). The sand within a 1-m radius of each bait was swept at the time each bait was laid. Three treatments alternated along the bait line: (i) mouse only; (ii) mouse plus visual lure (a stake with *c*. 30 cm of pink flagging tape); and (iii) mouse plus social scent [a commercial lure, Canine Call (Rocky Mountain Wildlife Products, La Porte, CO, USA), that had showed promise as an attractant during previous trapping of cats at the site].

Baits were checked early each morning for four consecutive days. On the first three days, baits were collected in the morning, frozen, and then put out again late that afternoon. Baits were not retrieved at the end of the trial. Data recorded at each bait site included the following: presence or absence of the bait; whether the bait had been moved by an animal but not eaten; presence of tracks (identified to species); and whether an animal had approached to within 1 m of the bait or passed by without deviating towards the bait site. Cat tracks on the sandy track adjacent to the bait were deemed fresh if they overlaid the tyre marks of the previous evening.

The significance of decline in track counts over the four days of baiting was assessed for both cats and birds by linear regression of percentage of bait sites showing tracks of the particular species against day of trial. A chi-square test was used to test whether there was a significant association between bait uptake of cats or crows and the use of visual (flagging tape) or olfactory cues (commercial lure).

Spotlight Surveys

Spotlight surveys were conducted in each area for four nights before and four nights after the baiting. Surveys were carried out immediately prior to baiting and within 10 days of final baiting. Two observers using 100-W spotlights scanned from the tray of a four-wheel-drive vehicle driven at 15 km h^{-1}. Surveys commenced shortly after dark. Sightings of predators were positively identified with 7 × 56 binoculars. Spotlight counts before and after baiting in the two areas were compared by means of two-factor ANOVA.

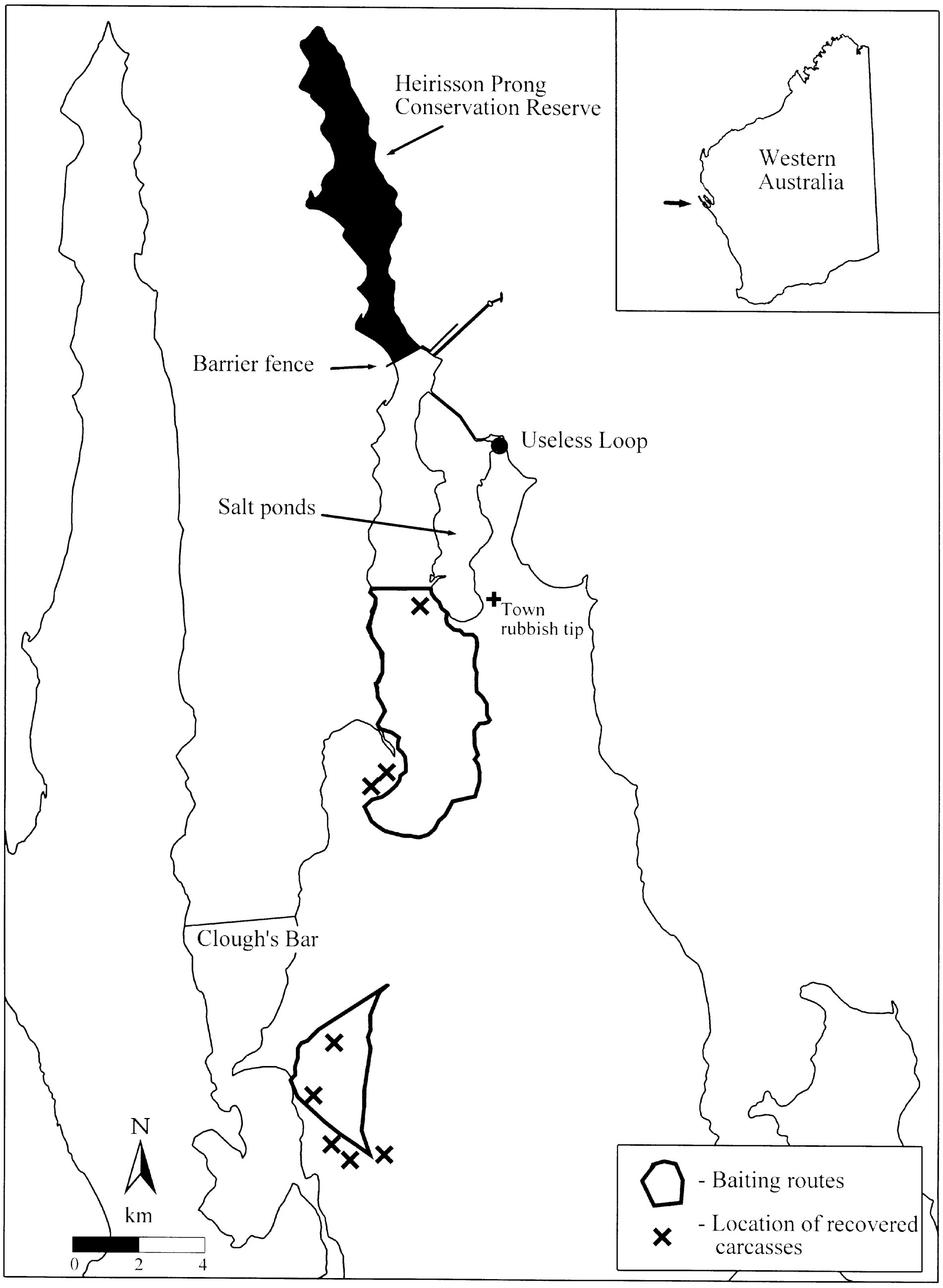


Fig. 1. Heirisson Prong, showing the baiting routes and locations of carcasses of cats recovered after the June 1995 trial.

Radio-telemetry

Details of capture and collaring of cats are described by Risbey *et al*. (1997). Five radio-collared cats were available for the trial (i.e. the animals had functioning collars, could be located before and after the trial, and were in the area of baiting). Cats had been collared 7–13 months prior to the baiting trial.

Radio-collared cats were tracked with a Biotel RX3 radio receiver (Bio Telemetry Tracking, Norwood, South Australia) and a three-element Yagi antenna mounted either on top of a 4-m pole that was used from the roof of a four-wheel-drive station wagon or hand-held and used by walking to high points in the landscape. Cats that had the same location on two successive days after baiting were investigated by approaching until either the animal or carcass was observed.

Post Mortems of Carcasses

Cat carcasses were labelled, weighed and frozen for transport. At the laboratory, the carcasses were thawed and the contents of the stomach and intestines were removed and weighed. The contents were washed over a fine, metal sieve and examined for the presence of mice. Hair was identified to species with the cross-section technique, descriptive key and photographic references of Brunner and Coman (1974). Kidney fat indices (Riney 1955) were calculated for poisoned cats and compared with those from cats heavier than 2.4 kg caught from March to June of previous years at the same location. This allowed a comparison of nutritional status to determine whether cats were in similar or worse condition to that in previous years.

Refinement of the Baiting Technique

Additional baitings were conducted following the June 1995 baiting trial, using the same procedures. The primary purpose of these baitings was to reduce the abundance of feral cats and to limit the possibility of cats reinvading the cat-free area north of the barrier fence. They were conducted in the 100-km^2 area south of the fence (Fig. 1).

These trials were used to assess the impact of rabbit densities on uptake of baits by cats, the range of non-target species taking baits, and the impact of season on desiccation and level of ant attack on mouse baits. Baiting followed the same method as described earlier (mouse baits laid at 100-m intervals along a track system, put out in the late afternoon and collected in the early morning). The number of successive days on which baits were laid was increased from four to six.

Activity at the bait was assessed from tracks in the sand around the bait and bait site. Baits were scored for level of desiccation and ant attack and uptake by non-target species. Desiccation was scored on a 1–5 scale, 1 being a fresh carcass and 5 being a mummified skin. The degree of ant attack was scored as low, medium or heavy for each day.

The willingness of cats to take baits was assessed by comparing the number of mouse carcasses removed by cats compared with the number of approaches to baits by cats. The latter included cats walking down the track past the bait and not deviating toward the bait, cats approaching the bait to within 1 m, and cats picking up the bait but dropping it again nearby. The level of acceptance of mouse baits by feral cats was regressed against density of rabbits. Rabbits were the primary food item in the diet of feral cats at this site (Risbey 1996*a*). Their changing abundance was assessed by spotlighting along a 20-km route from the barrier fence to Clough's Bar (Fig. 1) at *c*. three-monthly intervals for six years. Data were expressed in rabbits per kilometre. The methodology is described by Short *et al*. (1994).

Results

Baiting Trial

Bait loss

A total of 384 baits was laid on the first night of the trial. This was reduced to 269 after four nights (a 30% loss). In all, 58% of baits removed were taken by cats; the remainder were taken primarily by little crows, *Corvus bennetti*. Some 67 baits were taken by cats along 38.5 km of track. Baits were still being taken by both cats and crows on the fourth night of the trial (14 by cats; four by crows).

The visual and olfactory cues did not significantly alter the rate of bait uptake by either cats or crows (Table 1: χ^2 = 3.3, d.f. = 6; P = 0.77). However, the clumped pattern of removal of

Table 1. Effect of visual and scent lures on uptake of baits by cats and birds

Fate of bait	No lure	Visual lure	Scent lure
Untouched	89	88	92
Taken by cat	22	20	25
Taken by bird	17	20	11
Total	128	128	128

baits by birds (87% of baits removed were along six sections of track) suggests that birds may have learnt to follow the road to locate further baits. This may have overridden the influence of the treatments. Cats showed a less extreme clumping of activity (84% of baits were removed along 14 sections of track), but still sufficient to indicate that cats moved down the road to take successive baits. The mean number of consecutive baits approached per day along the bait route was 1.25 for birds (range 1–5) and 1.55 for cats (range 1–6).

Spotlight surveys

In the four nights prior to baiting, 23 sightings of cats were made on the spotlight routes (0.15 cats km^{-1}); five cats were sighted on the four nights following baiting (0.03 cats km^{-1}). Spotlight counts of cats declined by 74% between pre- and post-baiting surveys for the two sites. The result varied from 100% at the northern site to 64% at the southern site (Table 2). The decline between pre- and post-baiting times was significant (F = 19.5, d.f. = 1 and 12, P < 0.001). The analysis of variance indicated also that the densities of cats, as assessed by spotlight counts, were significantly different between the two areas (F = 6.01, d.f. = 1 and 12, P < 0.05). There was no significant interaction between the two factors. The largest reduction in cat numbers was at the site of lowest cat density.

No foxes were seen during either pre- or post-baiting surveys.

Table 2. Spotlight sightings of cats before and after baiting

Lengths of spotlight routes were 22 km for the northern route and 16.5 km for the southern route
Surveys were conducted over four nights before, and four nights after, poisoning

Area	Parameter	Before	After	Reduction
North	Total No. of cats sighted	9	0	100%
	Mean ± s.e. (cats $night^{-1}$)	2.25 ± 0.48	0.00 ± 0.00	
	Density index (cats km^{-1})	0.10	0.00	
South	Total No. of cats sighted	14	5	64%
	Mean ± s.e. (cats $night^{-1}$)	3.50 ± 0.87	1.25 ± 0.25	
	Density index (cats km^{-1})	0.21	0.08	

Radio-telemetry

All five radio-collared cats died either during or shortly after the baiting. Most appeared to have died on the first night of poisoning. One cat died 10 days after the last day of baiting. The fresh carcasses of three uncollared cats and a fox were located by chance when walking to find radio-collared cats.

Activity at bait sites

An uncollared subadult cat was observed running away from a bait site with a mouse carcass in its mouth early in the morning of the third day of the trial, providing additional confirmation that cats were taking baits.

The abundance of tracks of cats and crows along the bait route was highly variable over the four days of survey, perhaps because of variable overnight wind on the four nights of baiting, or the greater exploratory behaviour by cats after the poisoning of other cats from the local area. Track counts declined over the four days of survey (cats from 10 to 6% of bait sites; birds from 9 to 3% of bait sites), but the decline was not significant (cats, $F = 1.43$, d.f. = 1 and 6, $P = 0.28$; birds: $F = 0.81$, d.f. = 1 and 6, $P = 0.40$).

Post mortems of carcasses

Seven of the eight cats whose carcasses were located during the baiting trial were male. These included four radio-collared male cats. Weights varied from 2.8 to 5.4 kg. The stomachs of six of the eight cats (two were too decomposed to be collected) were examined. All but one were empty or nearly so, containing small amounts of hair or wool. The stomach with food items in it contained a brown *Mus musculus*.

Kidney fat indices of poisoned cats were not significantly different from those of cats caught in previous years from March to June (poisoned cats, mean 26.6 ($n = 6$); cats trapped or shot in previous years, mean 39.5 ($n = 15$); $F = 1.37$, d.f. = 1 and 19, not significant), suggesting that the baited population was not significantly food-stressed relative to cats caught or shot in previous years.

Refinement of Baiting Technique

The dates of the baiting trials are shown in Table 3, as are details of the number of approaches by cats to baits, their behaviour at the bait, and the number of baits taken. Uptake of mouse baits was highly variable, ranging from 23 to 74% of baits approached.

Acceptance of mouse baits by feral cats showed a strong negative relationship with increasing abundance of rabbits (Fig. 2). Feral cats took more than 60% of baits approached when the rabbit index was less than 1.0 km^{-1}; this declined to 34% at 3.0 km^{-1}. This relationship is derived from data collected in late summer, autumn and early winter, when rabbits were unlikely to have been breeding successfully. The presence of rabbit kittens and subadults in the population in late winter and spring is likely to considerably reduce acceptance of baits by cats at these times.

The trend of rabbit numbers on Heirisson Prong to the south of Useless Loop is shown in Fig. 3. Spotlight indices vary between 0.49 and 7.2 km^{-1}. Rabbit numbers may have been influenced by the ongoing control of foxes, but fall well within the range of variation at a similar site where no predator control was undertaken (King *et al*. 1983). The horizontal lines at 2.6 and 1.2 km^{-1} indicate the rabbit densities at which there is a predicted bait acceptance of 40 and 60%, respectively.

Table 3. Baits taken by cats during poisoning trials

Date	No. of baits approached	No. of baits passed by at > 1 m	No. of baits approached to < 1 m, then not touched, or taken and dropped	No. of baits taken
June 1995	35	4 (11%)	5 (14%)	26 (74%)
June 1995	67	12 (18%)	14 (21%)	41 (61%)
February 1996	55	6 (11%)	25 (46%)	24 (44%)
May 1996	35	16 (46%)	11 (31%)	8 (23%)

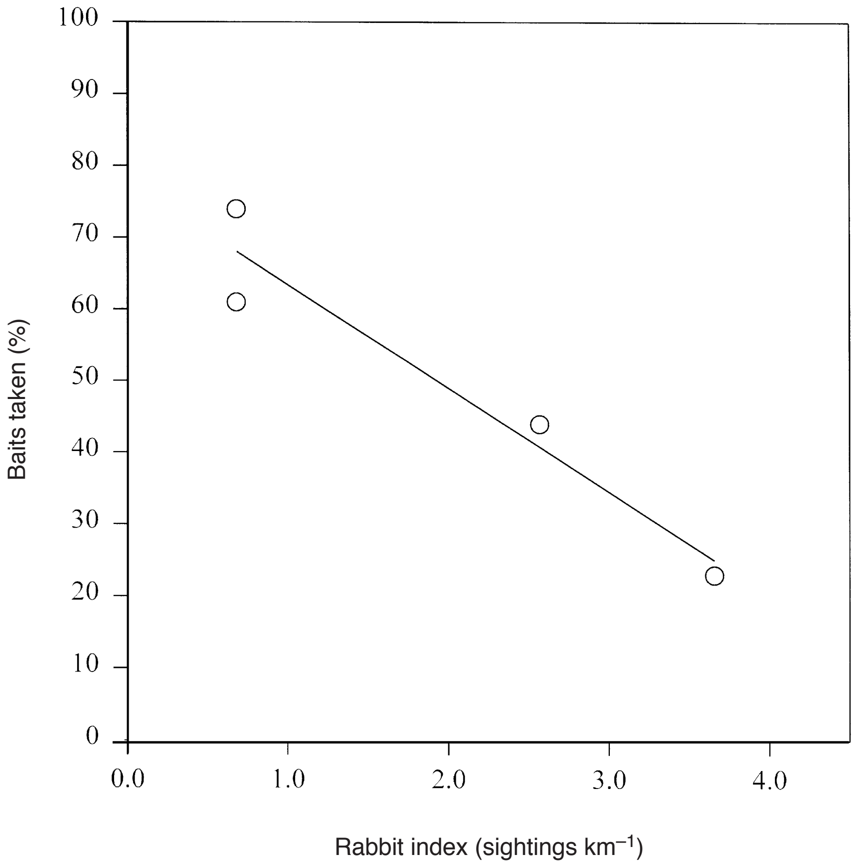


Fig. 2. Baits taken by feral cats (baits removed as a percentage of baits encountered) as a function of rabbit density as indexed by spotlighting. The regression line is $y = 77.91–14.45x$; $r^2 = 0.93$, $F_{1,2} = 27.3$, $P < 0.05$.

If a 40% acceptance is sufficient for cat control, then the data suggest that cats could have been controlled in four years of seven on Heirisson Prong. The exceptions are 1993, 1994 and 1996, when high rabbit numbers would have precluded effective control.

Desiccation of mouse carcasses was far higher in summer (Table 4). In summer, 28% of carcasses suffered substantial desiccation within the first two days, whereas none were affected in late autumn. Ant attack of mouse carcasses was scored as medium to high for 23% of carcasses over the first two days of baiting in summer (Table 4). This compares with less than 5% in late autumn.

Upake of baits by non-target species was substantially reduced in operational cat baiting (Table 4). Non-target uptake was less than 2% in February and May 1996 compared with 3.1% in the June 1995 trial. Birds (principally little crows) were the main non-target species taking baits, although monitors (*Varanus gouldii*) and snakes took some baits in summer.

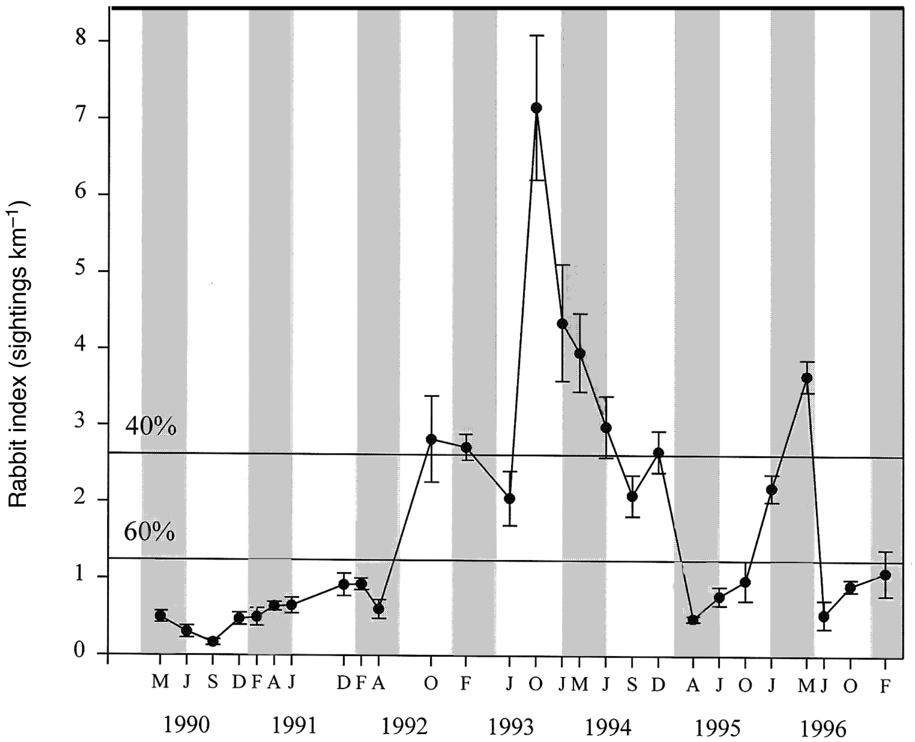


Fig. 3. The changing abundance of rabbits on Heirisson Prong south of the predator-proof fence. Data are spotlight counts (± s.e.) made at *c.* three-month intervals, as detailed by Short *et al.* (1994). The horizontal lines mark rabbit indices of 2.6 and 1.2 km^{-1}, the points at which we predict a 40% and 60% acceptance of mouse baits by feral cats, respectively. The area has been subject to biannual baiting for foxes since March 1991. Stippled bars indicate the January–June periods, which we consider the most effective time for cat control.

Table 4. The percentage of baits affected by desiccation, ant attack, and non-target uptake at different times of the year

Desiccation is the percentage of baits with desiccation scores of 3–5 on the first two mornings of the trial. Ant attack is the percentage of baits scored as having medium or heavy ant attack on the first two mornings of the trial. Non-target bait uptake was scored over the full time of baiting (either four or six days) as the percentage uptake per day

Date of trial	Average No. of baits available per day	Desiccation (%)	Ant attack (%)	Non-target uptake (%)
February 1996	224	28.4	23.2	1.8
May 1996	88	0.0	3.1	0.6

Discussion

Predation by feral cats on native fauna in Australia is well established (Spencer 1991; Paton 1991; Horsup and Evans 1993). In addition, predation by feral cats has been directly implicated in the failure or limited success of attempts to re-establish native mammals in parts of their former range (Christensen and Burrows 1994; Gibson *et al.* 1994*a*, 1994*b*). The latter studies have highlighted our inability to control cats in arid and semi-arid ecosystems.

The current study describes a control operation against feral cats that was successful in substantially reducing numbers. A high proportion of cats within the immediate area of baiting was killed after eating baits. Evidence comes from tracks of cats at sites where baits were removed, the substantial reduction in spotlight counts in both areas that were baited, a cat observed with bait in its mouth, the death of all five radio-collared cats, and fresh carcasses of cats found in the baited areas. No evidence of cats ingesting poisoned mice came from examination of the stomach contents of cat carcasses collected during the trial. However, this was not surprising, as most stomachs were empty of food. This may have been due to the following: (i) vomiting soon after ingesting 1080 poison (McIlroy 1981); (ii) the short passage time of digesta in the gut of cats relative to time till death [cats took 20 h to die in McIlroy's (1981) study, yet the average rate of passage of food particles in the digestive system of cats is 13 h (Warner 1981)]; and (iii) cats are unlikely to feed during the period from first onset of symptoms (1–6 h in cats) until death.

We attribute the success of the baiting programme largely to the choice of bait and to the strategic timing of the baiting during a period of food shortage. Mice are a familiar food item for cats in the local area (Risbey 1996*a*), the mouse carcasses we used were an ideal size for cats (*c*. 15 g compared with 40-g meat baits used for foxes), and they were fresh (stored frozen) rather than dried, so they were likely to be more palatable to cats.

The main baiting trial was scheduled to coincide with a time of food shortage, both within the annual cycle and within the range of year-to-year variation. We chose to bait in late autumn and early winter. Kitten and subadult rabbits were absent and there were fewer reptiles available, because of the cooler conditions. In addition, desiccation of baits, ant attack, and uptake by varanids were lesser problems (Table 4).

These data demonstrate that acceptance of baits by cats is linked to the availability of prey items. The number of baits taken as a percentage of baits approached drops sharply as the principal prey, in this case rabbits, become more abundant.

Clearly, the timing of control is important for feral cats. If effective reduction of feral cat numbers requires a reasonable acceptance of baits by cats (say > 40% of baits approached), then control operations must be timed to occur when rabbits are at low density. In some years, sustained high rabbit numbers restricted the window of opportunity for baiting. Effective baiting could have occurred in four years out of the seven. Poor results were likely in 1993, 1994 and 1996 because of high rabbit densities.

The most effective time within a year to bait at a site dominated by winter rainfall is likely to be in the month after the first significant rain of the year, before the emergence of rabbit kittens. Rabbits are pregnant within 1–2 weeks of rain (Poole 1960), they have a gestation period of 30 days, and kittens take 21 days from birth to grow to the point of emergence from burrows (Williams *et al*. 1995). This lag time of 8–10 weeks between the first significant monthly rainfall and the emergence of rabbit kittens provides the opportunity for managers to target their baiting to the most effective time in the feral cats' annual cycle. At our site this month will vary between years. The probability for the period January–June being preceded by an extended period without rain (months receiving less than 21 mm of rain) is shown in Fig. 4. A manager might choose to bait early in the year, in mid-year or both, depending on rainfall. February has a greater probability of being preceded by 3–4 dry months (and so the presence of young rabbits is less likely), but has greater problems of bait desiccation and ant attack. A baiting in May–June does not have these problems but has a much higher probability of receiving significant prior rain that is likely to initiate rabbit breeding.

The use of condition of cats does not appear to be an effective method for judging the timing of control operations. The body condition of cats killed during the June 1995 trial were not significantly different from those cats caught at about the same time in previous years.

A problem that emerged in our first baiting trial was the high uptake by birds (principally little crows). Many mouse carcasses were highly visible in this trial, especially because of their white colour, the presence of flagging tape marking the location of carcasses, and their location in cleared areas at regular intervals along the road network. Mouse carcasses were also of a size

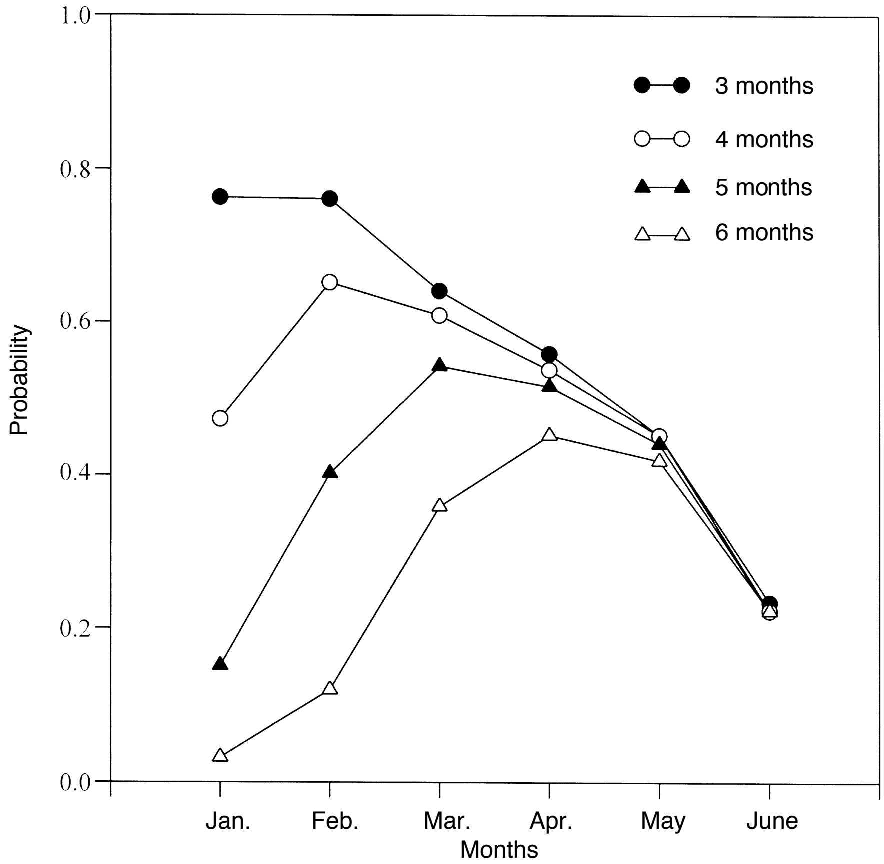


Fig. 4. The probability of any month between January and June being preceded by 3–6 months without significant rain (> 20 mm in a month). Data are from Denham rainfall records (1895–1996). On average, February will be preceded by four months without significant rain in 65% of years, and June in 22% of years.

well suited to corvids. However, because of their flocking behaviour, it is uncertain whether individual crows would consume an entire carcass. Little crows have an LD_{50} (lethal dose for 50% of the population) of 13.4 mg kg^{-1} and an average body weight of 0.39 kg (McIlroy 1984). This suggests that they would survive eating a single poisoned mouse containing 4.5 mg of 1080. We modified procedures in subsequent trials and this resulted in a decline of non-target bait uptake to less than 2% (Table 4).

A possible problem with the general application of mouse baits (or other baits) for cat control will be non-target kill. Baits for cats are typically much smaller than those for foxes, yet they contain the same amount of 1080. In addition, most baits developed for cats are softer and more moist than dried meat baits for foxes. Both factors potentially increase the vulnerability of a wide range of native species. In our study area, two threatened mammal species (the burrowing bettong and the western barred bandicoot) are potentially vulnerable to such baiting, although studies on dunnarts and quolls have indicated that potentially vulnerable species may detect 1080 at sublethal levels (Sinclair and Bird 1984; King 1989). We have avoided this potential problem by partitioning our study area into a core area for endangered mammals (where predators have been eliminated) and a peripheral buffer area of ongoing predator control (Short *et al.* 1994). Clearly, a range of creative solutions to this problem may be needed for other sites.

We suspect that a baiting programme using mouse carcasses would give a high kill of resident foxes. However, it would give less control of invading foxes in the month after baiting than would meat baits or buried eggs because of the limited field life of a mouse carcass (due to desiccation and uptake by non-target species). Our study area was almost entirely free of foxes because of an aerial baiting of 200 km^2 of the surrounding area two months earlier with meat baits, and hence our study provided no measure of the effectiveness of the technique against foxes.

The material cost of mouse baits (mouse plus poisoned oat) was about A$0.15 per unit. This compares with the current retail price of meat baits of A$0.65 each.

The utility of our baiting method could be extended by not collecting baits each day. This would result in a greater loss to non-target species and deterioration of mouse carcasses over several days. Hence, rebaiting would probably be required. Such a change in methodology would be a matter of balancing practicality against risk to non-target species and the cost and availability of baits.

We have achieved effective reduction of a cat population over an area of *c*. 100 km^2 by an integrated strategy of poisoning, trapping at the local rubbish tip with cage traps, and regular trapping with leg-hold traps in areas close to town where poisoning cannot be used. The key to this success was the baiting technique described in this paper: placing mouse carcasses poisoned with 1080 at 100-m intervals along the road system during a time of food shortage. Attempts to reduce cat densities significantly over the previous three years in a smaller area (*c*. 60 km^2) by trapping only (and ineffective attempts at poisoning) had failed, despite the removal of more than 200 cats. Cat densities in the 18 months after baiting have been maintained at about one-third of that prior to baiting.

Acknowledgments

We gratefully acknowledge Shark Bay Salt Joint Venture for funding and logistical support, the Useless Loop Community for support and encouragement (particularly Bryan Cane, Henry Bielawski and Ron O'Keefe), the Agriculture Protection Board and its officers for aerial fox baitings, and Mike Calver and Dennis King for critically reviewing an earlier draft of the manuscript. This work was carried out with Animal Ethics Committee approval (CSIRO WAAP37). Approval for use of unregistered bait for experimental purposes was given by the National Registration Authority for Agricultural and Veterinary Chemicals and the Western Australian Department of Health.

References

Bloomer, J. P., and Bester, M. N. (1992). Control of feral cats on sub-Antarctic Marion Island, Indian Ocean. *Biological Conservation* **60**, 211–219.

Brunner, H., and Coman, B. J. (1974). 'The Identification of Mammalian Hair.' (Inkata Press: Melbourne.)

Burbidge, A. A. (1971). The fauna and flora of the Monte Bello Islands. Report to the Department of Fisheries and Fauna, Western Australia.

Burbidge, A. A., and George, A. S. (1978). The flora and fauna of Dirk Hartog Island, Western Australia. *Journal of the Royal Society of Western Australia* **60**, 71–90.

Christensen, P., and Burrows, N. (1994). Project Desert Dreaming: the reintroduction of mammals to the Gibson Desert, Western Australia. In 'Reintroduction Biology of Australian and New Zealand Fauna'. (Ed. M. Serena.) pp. 199–207. (Surrey Beatty & Sons: Sydney.)

Gibson, D. F., Lundie-Jenkins, G., Langford, D. G., Cole, J. R., Clarke, J. E., and Johnson, K. A. (1994*a*). Predation by feral cats, *Felis catus*, on the rufous hare-wallaby, *Lagorchestes hirsutus*, in the Tanami Desert. *Australian Mammalogy* **17**, 103–107.

Gibson, D. F., Johnson, K. A., Langford, D. G., Cole, J. R., Clarke, D. E., and Willowra Community (1994*b*). The rufous hare wallaby (*Lagorchestes hirsutus*): a history of experimental reintroduction in the Tanami Desert, Northern Territory. In 'Reintroduction Biology of Australian and New Zealand Fauna.' (Ed. M. Serena.). pp. 171–176. (Surrey Beatty & Sons: Sydney.)

Horsup, A., and Evans, M. (1993). Predation by feral cats, *Felis catus*, on an endangered marsupial, the bridled nailtail wallaby, *Onychogalea fraenata*. *Australian Mammalogy* **16**, 85–86.

King, D. R. (1989). An assessment of the hazard posed to northern quolls (*Dasyurus hallucatus*) by aerial baiting with 1080 to control dingoes. *Australian Wildlife Research* **16**, 569–574.

King, D. R., Wheeler, S. H., and Schmidt, G. L. (1983). Population fluctuations and reproduction of rabbits in a pastoral area on the coast north of Carnarvon, W.A. *Australian Wildlife Research* **10**, 97–104.

McIlroy, J. C. (1981). The sensitivity of Australian animals to 1080 poison II. Marsupial and eutherian carnivores. *Australian Wildlife Research* **8**, 385–399.

McIlroy, J. C. (1984). The sensitivity of Australian animals to 1080 poison VII. Native and introduced birds. *Australian Wildlife Research* **11**, 373–385.

Merton, D. (1977). Controlling introduced predators and competitors on islands. In 'Endangered Birds'. (Ed. S. A. Temple.) pp. 121–128. (University of Wisconsin Press: Madison.)

Oliver, W. R. B. (1955). 'New Zealand Birds.' (Reed: Wellington.)

Paton, D. (1991). Loss of wildlife to domestic cats. In 'The Impact of Cats on Native Wildlife'. (Ed. C. Potter.) (Australian National Parks and Wildlife Service: Canberra.)

Poole, W. E. (1960). Breeding of the wild rabbit, *Oryctolagus cuniculus* (L.), in relation to the environment. *CSIRO Wildlife Research* **5**, 21–43.

Riney, T. (1955). Evaluating condition of free-ranging red deer (*Cervus elaphus*), with special reference to New Zealand. *New Zealand Journal of Science and Technology B* **36**, 429–463.

Risbey, D. A. (1996*a*). The impact of feral cats. Final report (Part 1) to Shark Bay Salt Joint Venture, Perth, WA. 66 pp.

Risbey, D. A. (1996*b*). The control of feral cats. Final report (Part 2) to Shark Bay Salt Joint Venture, Perth, WA. 122 pp.

Risbey, D. A., Calver, M., and Short, J. (1997). Control of feral cats for nature conservation. I. Field tests of four baiting methods. *Wildlife Research* **24**, 319–326.

Seabrook, W. (1990). The impact of the feral cat (*Felis catus*) on the native fauna of Aldabra Atoll, Seychelles. *Revue d' Ecologie la Terre et la Vie* **45**, 135–145.

Seebeck, J. H. (1979). Status of the barred bandicoot, *Perameles gunnii,* in Victoria: with a note on husbandry of a captive colony. *Australian Wildlife Research* **6**, 255–264.

Short, J. (1994). Reconstructing arid zone mammal faunas—beating the odds. In 'Proceedings of the 19th Annual Environmental Workshop'. pp. 280–299. (Australian Mining Industry Council: Canberra.)

Short, J., Turner, B., Parker, S., and Twiss, J. (1994). Reintroduction of endangered mammals to mainland Shark Bay: a progress report. In 'Reintroduction Biology of Australian and New Zealand Fauna'. (Ed. M. Serena.). pp. 183–188. (Surrey Beatty & Sons: Sydney.)

Sinclair, R. G., and Bird, P. L. (1984). The reaction of *Sminthopsis crassicaudata* to meat baits containing 1080: implications for assessing risk to non-target species. *Australian Wildlife Research* **11**, 501–507.

Spencer, P. B. S. (1991). Evidence of predation by a feral cat, *Felis catus* (Carnivora: Felidae), on an isolated rock-wallaby colony in tropical Queensland. *Australian Mammalogy* **14**, 143–144.

Taylor, R. H. (1979). How the Macquarie Island parakeet became extinct. *New Zealand Journal of Ecology* **2**, 42–45.

van Rensburg, P. J. J., and Bester, M. N. (1988*a*). The effect of cat *Felis catus* predation on three breeding Procellariidae species on Marion Island. *South African Journal of Zoology* **23**, 301–305.

van Rensburg, P. J. J., and Bester, M. N. (1988*b*). Experiments in feral cat population reduction by hunting on Marion Island. *South African Journal of Wildlife Research* **18**, 47–50.

van Rensburg, P. J. J., Skinner, J. D., and van Aarde, R. J. (1987). Effects of feline panleucopaenia on the population characteristics of feral cats on Marion Island. *Journal of Applied Ecology* **24**, 63–73.

Veitch, C. R. (1985). Methods of eradicating feral cats from offshore islands in New Zealand. In 'Conservation of Island Birds. Case Studies for the Management of Threatened Island Species'. (Ed. P. J. Moors.) pp. 125–141. International Council for Bird Preservation, Technical Publication No. 3.

Warner, A. C. I. (1981). Rate of passage of digesta through the gut of mammals and birds. *Nutrition Abstracts and Reviews Series B* **51**, 789–820.

Williams, K., Parer, I., Coman, B. J., Burley, J., and Braysher, M. (1995). 'Managing Vertebrate Pests: Rabbits.' (Australian Government Publishing Service: Canberra.)

Wood Jones, F. (1923–25). 'The Mammals of South Australia.' (A. B. James: Adelaide.)

Manuscript received 26 June 1996; revised and accepted 22 April 1997