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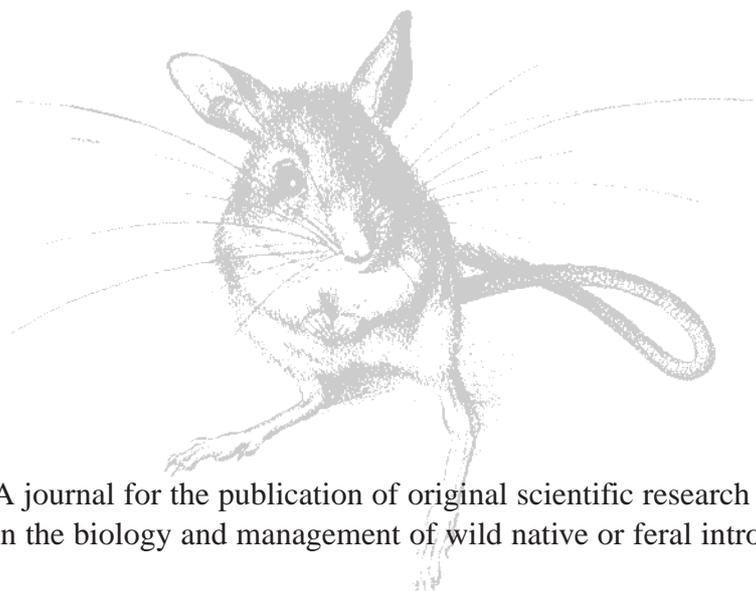
Wildlife Research

A journal for the publication of original scientific research
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Academy of Science

The impact of cats and foxes on the small vertebrate fauna of Heirisson Prong, Western Australia. II. A field experiment

Danielle A. Risbey[A], *Michael C. Calver*[A], *Jeff Short*[B], *J. Stuart Bradley*[A] *and Ian W.Wright*[C]

[A]School of Biological Sciences and Biotechnology, Murdoch University, Murdoch, WA 6150, Australia.
[B]CSIRO Wildlife and Ecology, Private Bag, PO Wembley, WA 6014, Australia.
[C]School of Mathematics and Statistics, Curtin University, Bentley, WA 6102, Australia.

Abstract. The hypothesis that predation by feral cats and introduced foxes reduces population sizes of small, native vertebrates was supported by results of a predator-removal experiment at Heirisson Prong, a semi-arid site in Western Australia. The methods of control used against cats and foxes to protect native mammals reintroduced to Heirisson Prong produced three broad 'predator zones': a low-cat and low-fox zone, where foxes were eradicated and spotlight counts of cats declined after intensive cat control; a high-cat and low-fox zone where spotlight counts of cats increased three-fold after foxes were controlled; and a zone where numbers of cats and foxes were not manipulated. Small mammals and reptiles were monitored for one year before and three years after predator control began. Captures of small mammals increased in the low-cat and low-fox zone, but where only foxes were controlled captures of small mammals declined by 80%. In the absence of cat and fox control, captures of small mammals were variable over the sampling period, lower than where both cats and foxes were controlled, yet higher than where only foxes were controlled. The capture success of reptiles did not appear to be related to changes in predator counts. This study presents the first experimental evidence from mainland Australia that feral cats can have a negative impact on populations of small mammals.

Introduction

Predation by foxes (*Vulpes vulpes*) is regarded as a contributing factor in the decline of a range of mammals (Finlayson 1961; Lee 1995; May and Norton 1996; Smith and Quin 1996; Short 1998) and birds (Priddell and Wheeler 1994) in mainland Australia. Regular fox control is considered a vital part of several management plans for endangered fauna, especially in Western Australia (e.g. Start *et al.* 1992; Maxwell *et al.* 1996), following the outcome of fox-removal experiments (Kinnear *et al.* 1988, 1998; Friend 1990). With no similar evidence for cats (*Felis catus*), the case against cats is more contentious. Claims regarding the impact of feral cats have been based on anecdotal (Finlayson 1961; Spencer 1990; Horsup and Evans 1993; Smith *et al.* 1994) and historical evidence (Dickman *et al.* 1993; Smith and Quin 1996; Calver and Dell 1998; Short 1999). As a consequence, experimental studies have been recommended to determine the response of prey species to the removal of cats (Dickman 1996*a*, 1996*b*). The effect of fox removal on cat populations also requires investigation following speculation that the removal of foxes allows cat numbers to increase (Christensen and Burrows 1994; Dickman 1996*b*; Martin *et al.* 1996). If this is true, then the overall effect of unilateral fox control may be questionable in some environments.

The opportunity to conduct a field experiment to examine the impact of feral cats and the effect of fox control arose when cats and foxes were controlled at Heirisson Prong in a semi-arid region of Western Australia to protect threatened fauna reintroduced to the mainland from nearby islands (Short *et al.* 1994; Short 1999). A related study that examined the diet of both feral cats and foxes at Heirisson Prong (Risbey *et al.* 1999) discovered that, while rabbits were the major prey species for cats and foxes, small mammals were more important to feral cats than to foxes, and reptiles were less important to both predators. We predicted that the control of cats at Heirisson Prong would benefit small mammals, but not necessarily reptiles, and that any increase in the density of feral cats following fox control may have the opposite effect. This paper presents the response of small, native mammals and reptiles and two species of introduced mammals to different levels of cat and fox activity: low cat and low fox; high cat and low fox; and moderate densities of cats and foxes. The following hypotheses were tested: (1) that the unilateral control of foxes leads to an increase in spotlight counts of cats; (2) that the control of cats increases the trap success of small mammals but not reptiles; (3) that small mammal prey in sparsely vegetated habitat are more susceptible to predation from cats and foxes than those living in dense heath; and

(4) that rainfall influences rabbit abundance more strongly than predation by cats and foxes.

Methods

Background to study

The predator-removal experiment described here was an opportunistic study, taking advantage of the reintroduction project described by Short *et al.* (1994) and an unrelated sampling program for small mammals and reptiles conducted at Heirisson Prong in 1990 (C. Majors, unpublished). The latter study provided pre-manipulation data. The methodology described in this study was constrained by the requirements of the reintroduction project and the limitations of the pre-manipulation data.

Study area

This study was conducted on Heirisson Prong (26°10′S, 113°23′E) in Shark Bay, Western Australia. Details of climate are given in Risbey *et al.* (1999), rainfall data for Denham (*c.* 70 km north-east of Heirisson Prong) are given in Fig. 9, and vegetation and topography are described in Risbey *et al.* (1997). Cats and foxes were controlled at this site to protect threatened fauna reintroduced from nearby islands. Control operations began in 1991 and three broad areas of cat and fox activity

Fig. 1. Heirisson Prong showing three zones resulting from different levels of predator control: Zone 1 (cats and foxes controlled) – low densities of cats and foxes; Zone 2 (foxes only controlled) – high cat densities, low fox densities; Zone 3 (no predator control) – moderate densities of cats and foxes.

resulted (Fig. 1) (Short *et al.* 1994). Cats and foxes on the northern tip of Heirisson Prong isolated by an electrified barrier fence (Predator Zone 1, *c.* 12 km²), were poisoned, trapped or shot. Poison baiting involved broadcasting dried meat baits containing 4.5 mg of 1080 toxin along the track system and baiting sea caves with small tins of domestic cat food containing an oat coated with 4.5 mg of 1080. Rabbits were also poisoned with 1080 'one shot' oats (Robertson and Wheeler 1983) in late summer to early autumn in 1992–94 to kill cats and foxes by secondary poisoning. Trapping methods for cats and foxes are given in Risbey *et al.* (1997). To reduce the risk of transient, sub-adult foxes moving into the fenced area (Predator Zone 1), dried 1080 meat baits were broadcast aerially over 120 km² immediately south of the barrier fence. This area was baited annually in February and September since 1991 to create a buffer zone (Predator Zone 2). After two years, the size of this area was increased to 200 km² (Short *et al.* 1994). No cat or fox control occurred in the area extending south of Zone 2 (which formed Predator Zone 3).

Habitat assessment of trapping grids

Site selection for pitfall trapping grids used to monitor capture success of small mammals and reptiles was constrained by the three broad predator zones. Thus, it was not possible to randomly allocate predator-treatment grids along Heirisson Prong. To determine whether there were differences in floristics or vegetation structure associated with the placement of grids in zones that might compound results, we recorded the number of individual plants, height of the tallest plant and estimated cover for each plant species occurring in alternate 1-m² quadrats along a randomly placed 30-m transect line in each grid in October 1992. These data were used to calculate relative density, relative frequency and relative dominance, which were used to calculate an importance value index (Krebs 1985).

Multi-dimensional scaling was then used to determine whether the different grids formed into distinct vegetation groups for each zone, or whether the grids from each zone were intermingled. If the latter was the case, it would be unlikely that systematic vegetation changes along the Prong would bias the results of the animal trapping.

Estimated density of cats, foxes and rabbits

The effectiveness of predator control conducted at Heirisson Prong was monitored using spotlight surveys in each predator zone at approximate three-monthly intervals. Rabbits were counted as well during these surveys to fully explore predator–prey relationships between feral cats, foxes, and prey species identified in Risbey *et al.* (1999). Spotlight surveys were conducted along fixed routes of *c.* 20 km in a straight line in Zones 2 and 3 and along a straight line (*c.* 11.5 km) and a loop (*c.* 7.5 km) in Zone 1. Surveys were conducted over 3–4 nights using a 4WD utility vehicle. Both sides of the track were scanned using a 100-W handheld spotlight and sightings were confirmed using binoculars.

Prey-capture success

Changes in the relative capture success of small mammals and reptiles in response to manipulation of predators were monitored by sampling with pitfall traps in the three predator zones. Eighteen pitfall trapping grids were used in this study, six grids in each predator zone. Each sampling grid had eight pitfall traps spaced *c.* 30–50 m apart, with six pitfall traps in two slightly offset, parallel lines (*c.* 30–50 m apart) and a trap 30–50 m from either side of the centre of these lines. Pitfall traps comprised an aluminium flywire drift fence (10 m long and 25 cm high) with two 20-L plastic buckets (diameter 290 mm) buried *c.* 2.5 m in from each end with the lid of the bucket flush with the ground. Grids in Zones 1 and 2 were set up in 1990 (before predator control) (C. Majors, unpublished). Grids in Zone 3 were set up in May 1992 prior to the sampling session in winter 1992 to monitor capture success in an area where predator numbers were not manipulated. However, since Majors had not trapped in this zone, we lacked pre-manipulation data for this zone.
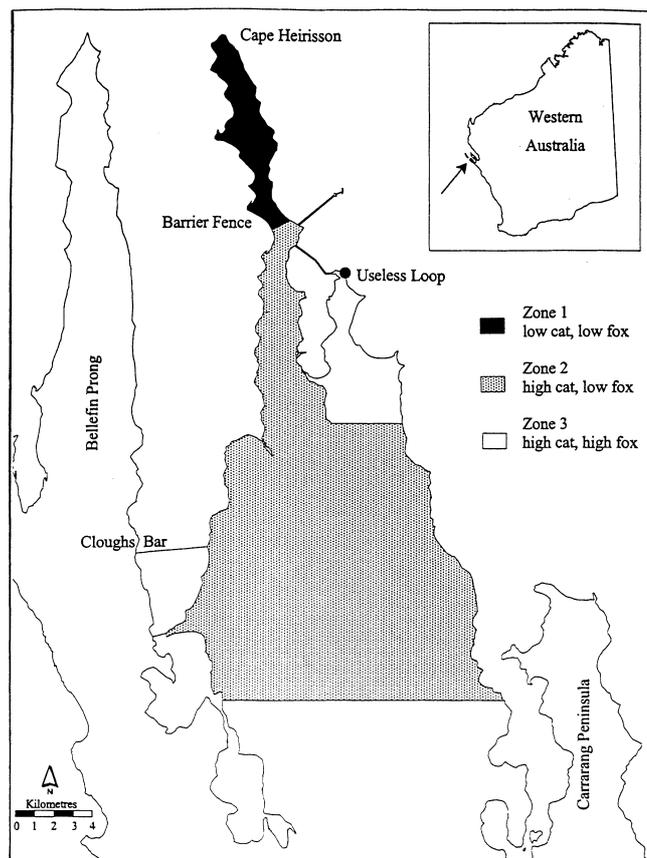
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Two habitat types were sampled in each predator zone. Half of the grids were set up in densely vegetated heath habitat and half were set in sparsely vegetated dune habitat. This was to test the hypothesis that small mammals and reptiles living in open dune habitat would be more susceptible to predation from cats and foxes than those living in dense heath habitat, as cats and foxes are known to forage in open habitat (Dickman 1992). Sampling was conducted over three consecutive days in March–April and June–July for four years in Zones 1 and 2 and 2.5 years in Zone 3.

Six grids were sampled on each day. To avoid bias from variable weather conditions during sampling on each day, traps from one 'heath' grid and one 'dune' grid were opened in each zone. Cardboard shelters and a 2–3-cm layer of sand were used in the buckets to protect captured animals from exposure. Mammals and reptiles caught in the pitfall traps were identified to species level, numbered (mammals were ear-clipped (Ashton 1978) and reptiles were toe-clipped (Swingland 1978)), measured and released. Lids were replaced on buckets once cleared after the third night of sampling.

Data analyses

Trends in spotlight counts of predators in all three zones throughout the study were assessed using Spearman's rank correlation coefficients as described by Thompson *et al.* (1998, Chapter 5). This approach tests the null hypothesis of no significant trend in spotlight counts against the alternative of a significant upward or downward trend. This was appropriate for the spotlight data for predators, which could not be transformed successfully to linear relationships for parametric regression. We applied the analysis to counts taken in spring and summer because of marked seasonal fluctuations in spotlight counts. It was apparent from preliminary examination of spotlight counts of cats that, until February 1992, spotlight counts of cats did not decline as spotlight counts of foxes did. This sparked an intensive cat-control campaign using trapping, shooting and a range of experimental, hand-placed, poison baits. To test the impact of these methods of control on spotlight counts of cats, a further Rs coefficient was calculated for cats for the period of February 1992 to July 1994.

The impact of predator manipulations on small mammal and reptile captures was assessed using repeated-measures analysis of variance. Analyses using reptile data were grouped by family as captures were low for some species. Only capture data for reptile species that could be toe-clipped (i.e. skinks, geckos and dragons) were analysed. Factors included: mammal species (or reptile family), predator zone and vegetation cover, with sampling occasion as the repeated-measures factor and total captures per grid (excluding recaptures within a trapping session of three days) as the dependent variable. All capture data were $\log_e$-transformed to correct for a non-normal distribution. Greenhouse–Geisser epsilons (ϵ) were used to modify the degrees of freedom in all main effects and interactions involving the repeated-measures factor to protect against possible violation of the sphericity assumption. The overall design was incomplete as no data were collected for the first three sampling occasions in Zone 3 (summer and winter 1990, summer 1992), so two separate analyses were performed. The first analysis considered Zones 1 and 2 for the entire period of the study and the second considered all three zones over the last five sampling occasions (winter 1992, summer and winter 1993, summer and winter 1994).

Mammal and reptile captures across the zones were not standardised at the start of the experiment, so the critical terms in the analyses were any interactions involving the factor ZONE. The analysis involving zones 1 and 2 included data both before and after predator control commenced. Thus, three orthogonal contrasts were run for each mammal species (or reptile family) within the ZONE × TIME interaction to compare: (i) number of captures on the first two sampling occasions (pre-manipulation) against the last six (post-manipulation); (ii) the third and fourth sampling occasions against the last four; and (iii) the fifth and

sixth sampling occasion against the last two. The hypothesis that predator manipulation influenced capture success predicts that at least the first contrast should be significant.

Spotlight counts of rabbits were $\log_e$-transformed and analysed using a parametric regression approach. Regressions of log(spotlight counts) against time were determined for each zone and the slopes compared using a regression involving dummy variables (Bowerman *et al.* 1986).

Results

Vegetation assessment

A two-dimensional plot resulting from the multi-dimensional scaling of the plant data is shown in Fig. 2. Grids from high-cover vegetation zones grouped to the left of the figure, and grids from low-cover zones are grouped to the right, with the exceptions of Low-cover Grid 2 from Zone 3 and High-cover Grid 3 from Zone 3. Grids from different zones were interspersed within the basic dense heath grids and open dune grids. Overall, this indicates that the distinction between the two habitat types is real, and that there is no strong evidence for different vegetation structure between the trapping grids in each zone. However, it does not imply that the relative proportions of high and low vegetation types were the same in each zone.

Spotlight counts of cats and foxes

The number of cats and foxes sighted per kilometre was averaged over four nights to give an index of density for each species. These values were plotted against month and year for each zone (Fig. 3). The density of foxes in Zone 1 was initially higher than that of cats in 1990, but dropped considerably once poison baiting began to take effect ($Rs_{(12)} = -0.67$, $P = 0.016$). The density of foxes was kept below 0.01 foxes km^{-1} from December 1991. Following the drop in spotlight counts of foxes, spotlight counts of cats increased and peaked in February 1992 (0.131 cats km^{-1}), and then declined annually. Over the entire period of spotlight surveys, there was no significant trend for increasing or decreasing spotlight counts of cats ($Rs_{(12)} = -0.26$, $P = 0.42$). However, following intensive control targeting cats from 1992 onwards, the declining trend in spotlight counts of cats was significant ($Rs_{(7)} = -0.86$, $P = 0.014$). The density of foxes in Zone 2 was low at the initiation of baiting and remained so throughout the study ($Rs_{(11)} = -0.32$, $P = 0.33$). However, spotlight counts of cats showed a three-fold increase, rising from 0.06 km^{-1} in March 1991 to 0.18 km^{-1} in May 1994 ($Rs_{(11)} = 0.84$, $P = 0.001$). By comparison, spotlight counts of cats and foxes in Zone 3 did not show changes as observed in the other zones (for foxes, $Rs_{(5)} = -0.7$, $P = 0.19$; for cats, $Rs_{(5)} = -0.5$, $P = 0.39$). In summary, the predator manipulation in Zone 1 lowered fox density, and from 1992 onwards lowered cat density, and kept foxes at low density but allowed cats to reach a much higher density in Zone 2. No trends in spotlight counts were observed in the unmanipulated control zone (Zone 3).
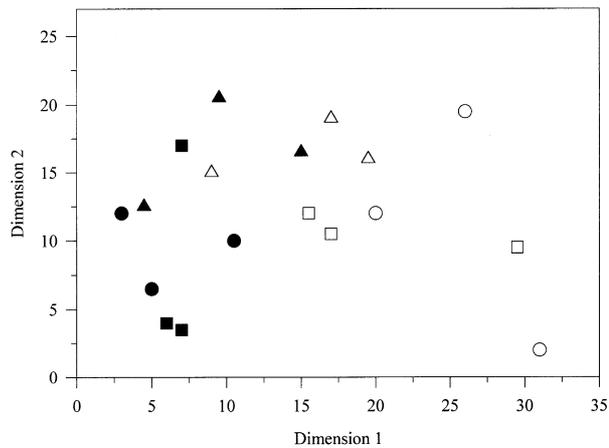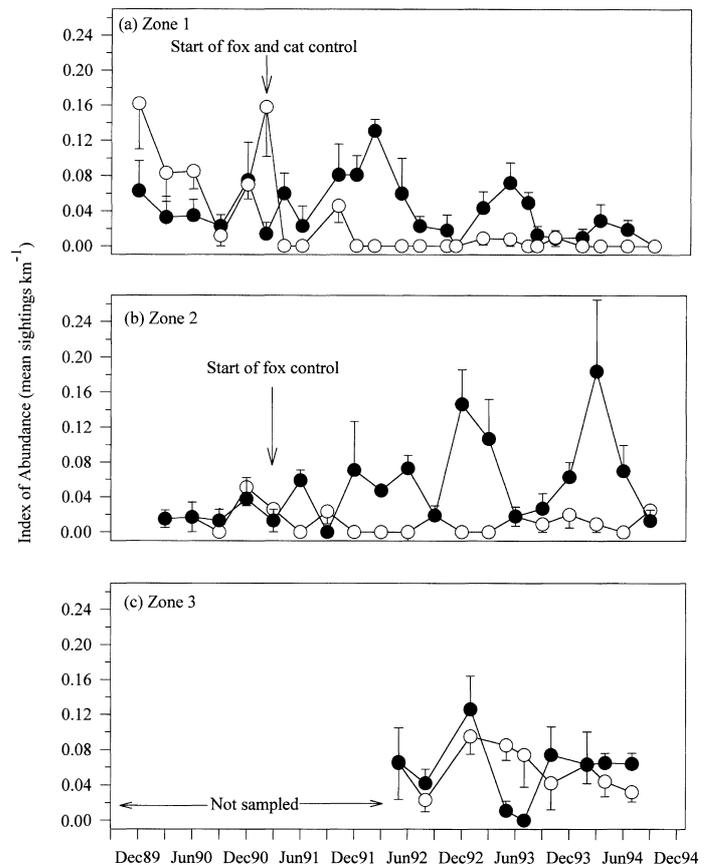
Fig. 2. Multi-dimensional scaling of importance value indices from vegetation surveys of dense heath habitat (solid symbols) and open dune habitat (open symbols) in zones 1 (circles), 2 (triangles) and 3 (squares).

Fig. 3. Esimated density of cats (solid symbols) (+s.e.) and foxes (open symbols) (–s.e.) using spotlight counts recorded from Zones 1, 2, and 3.

Response of small mammals and reptiles to manipulation of predators

A species list of the mammals and reptiles captured in the pitfall traps is given in an Appendix. Most of the capture data came from captures of mammals, dragons, skinks and geckos. The capture success of mammals differed between the three predator zones. Results of the initial repeated-measures ANOVA comparing capture successes of the four mammal species listed in Appendix 1 in Zone 1 (low cat and low fox) to Zone 2 (high cat, low fox) over all eight sampling occasions are shown in Table 1. The hypothesis of a response in small mammal capture success to predator manipulation predicts that there should be significant interactions involving the factor ZONE, and the ZONE × SPECIES × TIME interaction was significant, as well as the subsidiary interactions, ZONE × TIME and ZONE × SPECIES. The interaction plot of the three-way interaction (Fig. 4) shows that the capture successes for three of the mammal species appear to have declined in Zone 2, whereas in Zone 1 the capture success for the ash-grey mouse (*Pseudomys albocinereus*) and sandy inland mouse (*Pseudomys hermannsburgensis*) appear to have increased after predator control. The capture success of the little long-tailed dunnart (*Sminthopsis*

dolichura) and house mouse (*Mus musculus*) appeared to have remained steady. The significance of these trends was tested using three orthogonal contrasts for each species separately within the ZONE × TIME interaction. The first of these tested the 1990 (pre-manipulation) capture success against all subsequent samples, the second tested the 1992 data against all subsequent samples and the third tested the 1993 data against the 1994 data. Results (Table 2) showed significant overall contrasts for the ash-grey mouse and the sandy inland mouse, with the important contrast of pre-manipulation data to post-manipulation data also being significant. We found no evidence that differences in the amount of vegetative cover in the two habitats sampled influenced mammal captures, as none of the interactions involving VEG and ZONE were significant.

The second repeated-measures ANOVA compared trapping success of all mammal species across Zones 1–3 following predator control from winter 1992 to winter 1994 (Table 3). The ZONE × SPECIES and ZONE × TIME interactions were significant; the respective interaction plots are shown in Figs 5 and 6. The capture success of the house mouse and the little long-tailed dunnart appeared similar across the three zones. In contrast, the ash-grey mouse and the sandy inland

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Table 1. Results of repeated-measures ANOVA comparing capture successes of the four species of mammals listed in Appendix 1 in Zone 1 to Zone 2 over all eight sampling times

The degrees of freedom of the main effect TIME and all interactions associated with it were corrected with the appropriate Greenhouse–Geiser ϵ to correct for possible violation of the sphericity assumption. Corrected P values are presented in all these cases where the initial P was less than 0.05

Effect	F	d.f.	P	ϵ	Corrected P	Power
ZONE	39.11	1,32	<0.001	–	–	1.000
VEG	8.02	1,32	0.008	–	–	0.826
SPECIES	65.51	3,32	<0.001	–	–	1.000
TIME	3.21	7,224	0.002	0.667	0.009	0.236
ZONE × VEG	0.07	1,32	0.781	–	–	0.060
ZONE × SPECIES	15.41	3,32	<0.001	–	–	0.915
VEG × SPECIES	5.90	3,32	0.003	–	–	0.514
ZONE × TIME	10.73	7,224	<0.001	0.667	<0.001	0.708
VEG × TIME	1.12	7,224	0.352	–	–	0.204
SPECIES × TIME	4.93	21,224	<0.001	0.667	<0.001	0.210
ZONE × VEG × SPECIES	1.54	3,32	0.222	–	–	0.164
ZONE × VEG × TIME	1.06	7,224	0.391	–	–	0.102
ZONE × SPECIES × TIME	1.93	21,224	0.011	0.667	0.023	0.101
VEG × SPECIES × TIME	1.57	21,224	0.059	–	–	0.090
ZONE × VEG × SPECIES × TIME	1.58	21,224	0.055	–	–	0.090

mouse had highest trap success where cat and fox numbers had been reduced. Zone 1 maintained higher levels of trap success overall across time compared with the other zones,
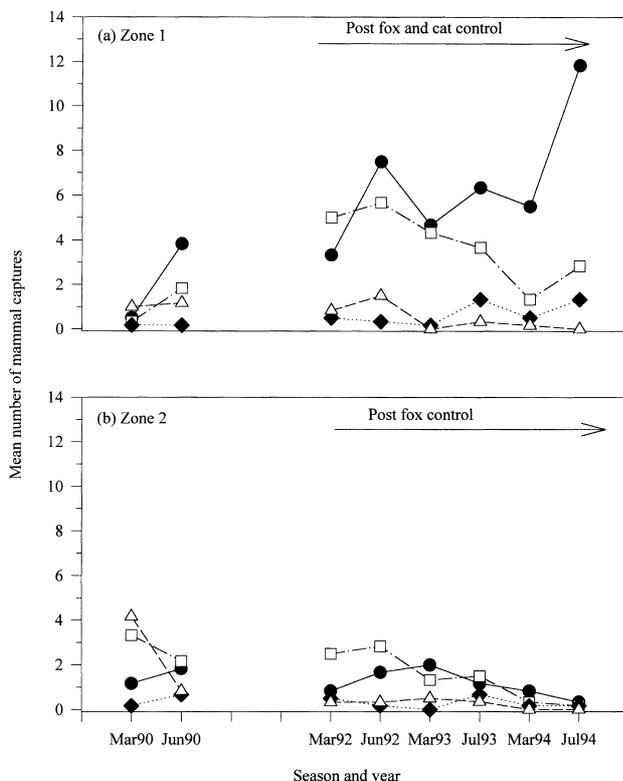

Fig. 4. Captures of four species of mammals before (1990) and after (1992–94) predator control in Zones 1 and 2. Mammals included: ash-grey mouse (●), sandy inland mouse (□), little long-tailed dunnart (◆) and introduced house mouse (△).

Zone 2 showed a steady decline in capture success over time, while capture success in Zone 3, while oscillating, did not decline over the study period although it remained lower than in Zone 1.

The initial repeated-measures ANOVA comparing trapping success of three reptile families in Zone 1 with Zone 2 over all eight sampling occasions showed a significant 3-way interaction between ZONE, reptile FAMILY and TIME (Table 4). However, the interaction plot (Fig. 7) suggests no obvious reason for this other than the slightly higher levels of taxa in Zone 2 throughout the study. Following the same procedure as used for the mammals, contrast analysis within the ZONE × TIME interaction for each family revealed no significant overall contrast for any family (dragons: Rao's $R_{(3,22)} = 2.34$, $P = 0.101$; skinks: Rao's $R_{(3,22)} = 0.87$, $P = 0.472$; geckos: Rao's $R_{(3,22)} = 0.94$, $P = 0.438$). Thus, there was no evidence for an impact from predator manipulation on reptile numbers.

A second repeated-measures ANOVA compared the capture success for three reptile families across Zones 1–3 after predator control from winter 1992 to winter 1994 (Table 5). ZONE × FAMILY was the only significant interaction involving the factor ZONE, and the interaction plot (Fig. 8) suggests little variation in trapping success of skinks and geckos across zones, while dragon numbers rose from Zone 1 to Zone 2 and from Zone 2 to Zone 3. This gives no evidence of a direct negative impact of predator manipulation on capture success of lizards.

Influence of predators and rainfall on rabbits

The indices of abundance of rabbits estimated from spotlight counts in Zones 1–3 between December 1989 and December

Table 2. Results of three orthogonal contrasts for each mammal species within the ZONE × TIME interaction

Mammal species	Test of overall significance	Contrasts	Tests of independent contrasts
Pseudomys albocinereus	Rao's $R_{(3, 300)} = 9.32, P = 0.0002$	1990 *v.* 1992, 1993, 1994	$F_{(1, 32)} = 20.33, P < 0.001$
		1992 *v.* 1993, 1994	$F_{(1, 32)} = 0.39, P = 0.537$
		1993 *v.* 1994	$F_{(1, 32)} = 8.35, P = 0.007$
Pseudomys hermannsburgensis	Rao's $R_{(3, 30)} = 5.59, P = 0.004$	1990 *v.* 1992, 1993, 1994	$F_{(1, 32)} = 17.64, P < 0.001$
		1992 *v.* 1993, 1994	$F_{(1, 32)} = 0.92, P = 0.344$
		1993 *v.* 1994	$F_{(1, 32)} = 0.12, P = 0.734$
Sminthopsis dolichura	Rao's $R_{(3, 30)} = 1.037, P = 0.390$	1990 *v.* 1992, 1993, 1994	$F_{(1, 32)} = 0.92, P = 0.345$
		1992 *v.* 1993, 1994	$F_{(1, 32)} = 1.13, P = 0.294$
		1993 *v.* 1994	$F_{(1, 32)} = 0.93, P = 0.343$
Mus musculus	Rao's $R_{(3, 30)} = 1.013, P = 0.400$	1990 *v.* 1992, 1993, 1994	$F_{(1, 32)} = 1.33, P = 0.257$
		1992 *v.* 1993, 1994	$F_{(1, 32)} = 0.76, P = 0.390$
		1993 *v.* 1994	$F_{(1, 32)} = 0.96, P = 0.335$

Table 3. Repeated-measures ANOVA comparing trapping success of the four mammal species listed in Appendix 1 across Zones 1–3 from winter 1992 to winter 1994

The degrees of freedom of the main effect TIME and all interactions associated with it were corrected with the appropriate Greenhouse–Geiser ϵ to correct for possible violation of the sphericity assumption. Corrected P values are presented in all these cases where the initial P was less than 0.05

Effect	F	d.f.	P	ϵ	Corrected P	Power
ZONE	48.08	2,48	<0.001	–	–	1.000
VEG	3.01	1,48	0.089	–	–	0.415
SPECIES	110.26	3,48	<0.001	–	–	1.000
TIME	3.11	4,192	0.016	0.871	0.028	0.261
ZONE × VEG	0.48	2,48	0.620	–	–	0.088
ZONE × SPECIES	18.37	6,48	<0.001	–	–	0.886
VEG × SPECIES	1.08	3,48	0.368	–	–	0.121
ZONE × TIME	4.70	8,192	<0.001	0.871	<0.001	0.284
VEG × TIME	0.67	4,48	0.616	–	–	0.085
SPECIES × TIME	4.01	12,192	<0.001	0.871	<0.001	0.200
ZONE × VEG × SPECIES	2.17	6,48	0.062	–	–	0.148
ZONE × VEG × TIME	0.88	8,192	0.534	–	–	0.083
ZONE × SPECIES × TIME	1.60	24,192	0.043	0.871	0.053	0.081
VEG × SPECIES × TIME	0.77	12,192	0.684	–	–	0.072
ZONE × VEG × SPECIES × TIME	1.10	24,192	0.342	–	–	0.071

1994 are given in Fig. 9. Regression analysis showed that slopes for the regression of log(spotlight counts) against time did not differ significantly between Zone 1 and Zone 2 ($t_{49} = 1.70, P = 0.095$), but did differ significantly between Zone 1 and Zone 3 ($t_{49} = 3.03, P = 0.004$) and between Zone 2 and Zone 3 ($t_{49} = 2.07, P = 0.043$). The density of rabbits in Zones 1 and 2 was low (<1 rabbit km^{-1}) until an increase was observed in September 1992. A seasonal pattern followed, with rabbit counts tending to increase from winter to spring, and decline from summer to autumn. Rabbit counts in Zone 3 were the same as those recorded prior to predator control in Zones 1 and 2 (i.e. <1 rabbit km^{-1}). The most marked increase observed was in October 1993 when rabbit counts trebled in Zone 2. Rabbit abundance appeared to gradually rise in Zones 1 and 2 during the second half of 1992 when the control of foxes began to take effect. Rabbit baiting in the northern half of Zone 1 (Short *et al.* 1994) may have contributed to rabbit counts being lower during autumn 1992 and winter–spring 1993 than those observed at the same time in Zone 2. However, the effect of rabbit baiting in this zone did not
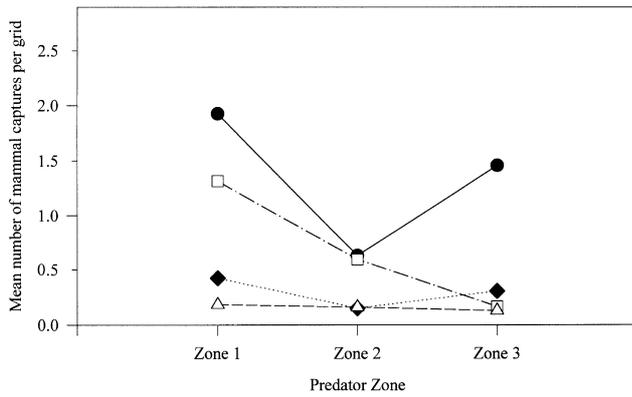
Fig. 5. Interaction plot of ZONE × SPECIES for mammal captures after predator control in Zone 1 (cats and foxes controlled), Zone 2 (foxes only controlled) and Zone 3 (no predator control). See Fig. 4 for explanation of symbols.
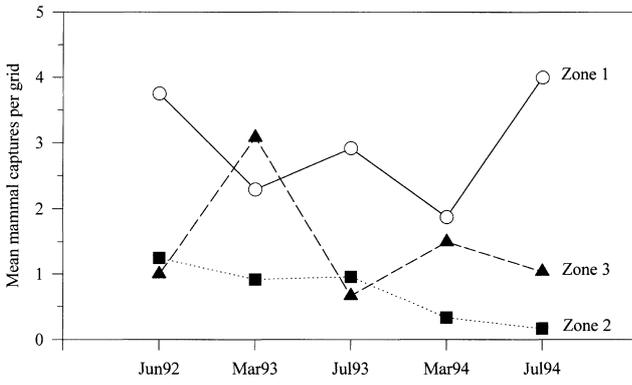

Fig. 6. Interaction plot of ZONE × TIME for mammal captures after predator control was introduced in Zones 1 and 2 in 1991.

appear to be long-term, with counts increasing again in autumn 1994 and no significant shift in regression slope compared with Zone 2. Rainfall data recorded in Denham are presented in Fig. 9 to aid interpretation of changes in abundance. With the average annual rainfall for Denham being 225 mm,
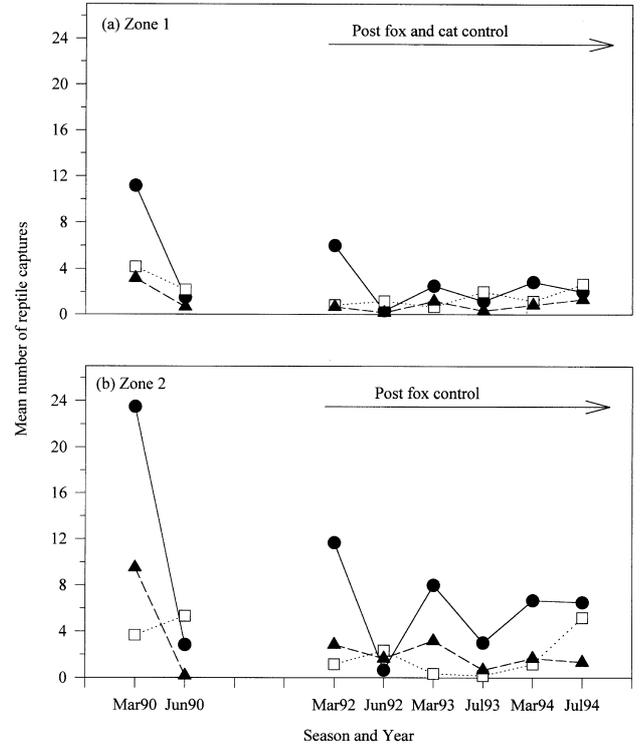

Fig. 7. Captures of dragons (●), skinks (□) and geckos (▲) using pitfall traps in Zone 1 and Zone 2 before (1990) and after (1992–94) predator control.

Table 4. Results of repeated-measures ANOVA comparing trapping success of three families of reptiles in Zones 1 and 2 over all sampling occasions

The degrees of freedom of the main effect TIME and all interactions associated with it were corrected with the appropriate Greenhouse–Geiser ϵ to correct for possible violation of the sphericity assumption. Corrected P values are presented in all these cases where the initial P was less than 0.05

Effect	F	df	P	ϵ	Corrected P	Power
ZONE	35.88	1,24	<0.001	–	–	1.000
VEG	2.20	1,24	0.151	–	–	0.331
FAMILY	36.64	2,24	<0.001	–	–	1.000
TIME	22.53	7,168	<0.001	0.71	<0.001	0.966
ZONE × VEG	9.14	1,24	0.006	–	–	0.856
ZONE × FAMILY	5.07	2,24	0.015	–	–	0.502
VEG × FAMILY	0.81	2,24	0.457	–	–	0.119
ZONE × TIME	0.60	7,168	0.758	–	–	0.077
VEG × TIME	1.01	7,168	0.424	–	–	0.097
FAMILY × TIME	7.93	14,168	<0.001	0.71	<0.001	0.400
ZONE × VEG × FAMILY	2.18	2,24	0.135	–	–	0.245
ZONE × VEG × TIME	1.03	7,168	0.411	–	–	0.098
ZONE × FAMILY × TIME	2.05	14,168	0.017	0.71	0.034	0.117
VEG × FAMILY × TIME	0.50	14,168	0.930	–	–	0.064
ZONE × VEG × FAMILY × TIME	0.82	14,168	0.645	–	–	0.074

Table 5. **Repeated-measures ANOVA comparing the capture success for three reptile families across Zones 1–3 for sampling from winter 1992 to winter 1994**

The degrees of freedom of the main effect TIME and all interactions associated with it were corrected with the appropriate Greenhouse–Geiser ϵ to correct for possible violation of the sphericity assumption. Corrected P values are presented in all these cases where the initial P was less than 0.05

Effect	F	d.f.	P	ϵ	Corrected P	Power
ZONE	9.58	2,36	<0.001	–	–	0.782
VEG	1.90	1,36	0.177	–	–	0.286
FAMILY	21.46	2,36	<0.001	–	–	0.987
TIME	14.67	4,144	<0.001	0.84	<0.001	0.889
ZONE × VEG	3.22	2,36	0.052	–	–	0.338
ZONE × FAMILY	3.64	4,36	0.014	–	–	0.276
VEG × FAMILY	0.27	2,36	0.763	–	–	0.071
ZONE × TIME	0.45	8,144	0.890	–	–	0.066
VEG × TIME	0.13	4,144	0.973	–	–	0.057
FAMILY × TIME	8.91	8,144	<0.001	0.84	<0.001	0.535
ZONE × VEG × FAMILY	1.09	4,36	0.377	–	–	0.108
ZONE × VEG × TIME	1.42	8,144	0.194	–	–	0.107
ZONE × FAMILY × TIME	0.86	16,144	0.613	–	–	0.070
VEG × FAMILY × TIME	0.45	8,144	0.892	–	–	0.066
ZONE × VEG × FAMILY × TIME	0.84	16,144	0.637	–	–	0.070

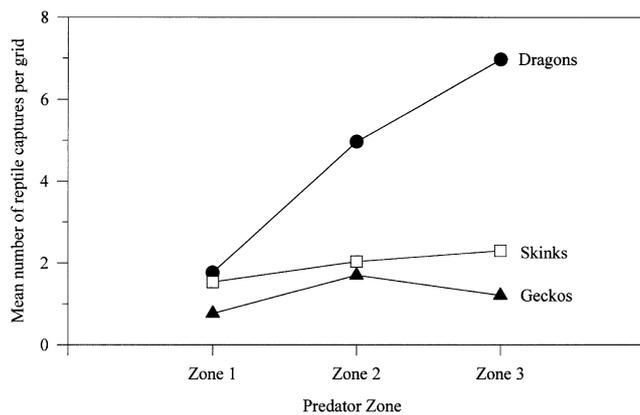**Fig. 8.** Interaction plot of ZONE × FAMILY for reptile captures after predator control in Zone 1 (cats and foxes controlled), Zone 2 (foxes only controlled), and Zone 3 (no predator control).

above-average rainfall fell in 1991 (302 mm) and 1992 (245 mm), and rainfall was below average in 1990 (199 mm), 1993 (177 mm) and 1994 (211 mm).

Discussion

Impact of predation

We believe this study provides the first evidence from a manipulation experiment, as distinct from dietary studies or other circumstantial evidence, that predation by feral cats can cause a decline in small mammal abundance in mainland Australia. It also indicates that cat predation is especially severe when fox numbers have been reduced. Cats and foxes appear to be interactive in their impact on small mammal numbers, but there was no evidence of similar impacts on reptiles. Rabbit populations appear to be regulated by the onset of seasonal rainfall and predation from cats and foxes, and, being an important prey species, rabbits are likely to enhance increases in cat populations following fox control. The strongest responses to predator control were shown by the ash-grey mouse and the sandy inland mouse. Murray and Dickman (1994) used fluorescent markers to trace the movements of sandy inland mice in semi-arid habitat, and found that they spent approximately 40% of their time in open habitat compared with sheltering in spinifex, other shrubs or dense litter. In another study, it was found that the ash-grey mouse spent approximately 61% of its time in the open, whereas in the same semi-arid site, the little long-tailed dunnart spent only *c.* 20% of its time in the open and house mice *c.* 11% (C. R. Dickman, unpublished). These data strongly suggest that ash-grey and sandy inland mice would be at greater risk of predation than the other species of small mammals and our results clearly show that they respond rapidly and markedly to predator control. The stronger response of the ash-grey mouse may reflect a competitive advantage following predator release. However, both *Pseudomys* species appear to suffer declines in the face of increasing cat activity.

Intensive control of cats and foxes in Zone 1 led to a decline in the density of foxes and a more gradual decline in cat numbers. Fox control in Zone 2 led to a decline in spotlight counts of foxes and a three-fold rise in the spotlight counts of cats over three years (March 1991 to May 1994). Where cats and foxes were not controlled in Zone 3, their densities were moderate relative to those in Zones 1 and 2 and no trend of increase or decrease was apparent throughout the study. The seasonal peaks and declines in spotlight counts of cats were similar to those recorded in north-western Victoria (Jones and Coman 1982) and reflect shifts in reproductive season and food
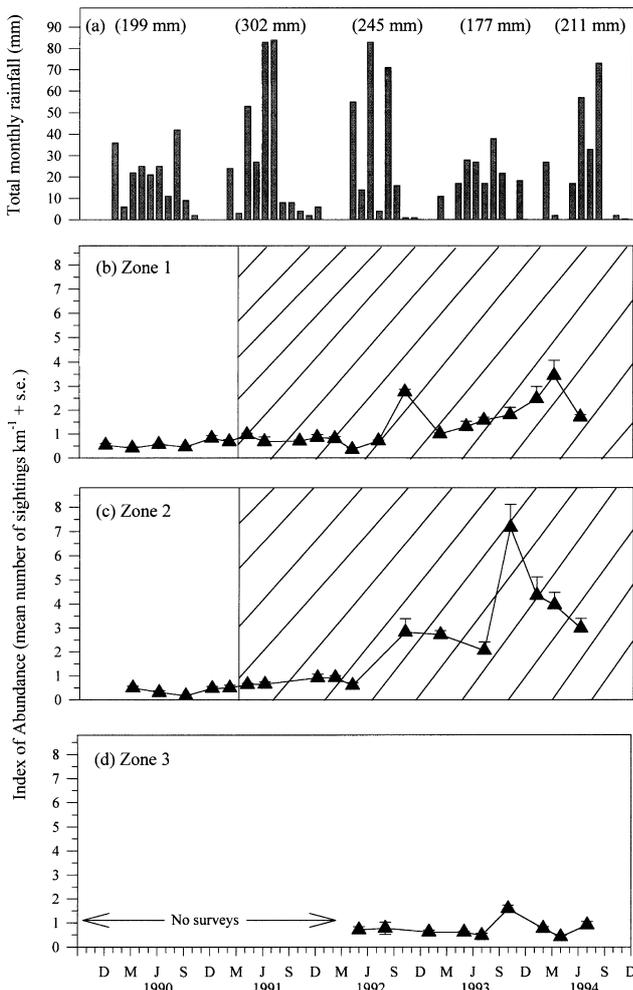
Fig. 9. Rainfall data recorded at Denham (*a*) and estimated densities of rabbits from spotlight surveys of Zones 1 (*b*), 2 (*c*) and 3 (*d*). Stippling indicates post–fox and cat control in (*b*) and post–fox control in (*c*).

availability. Kittens are born in spring and summer (Jones 1989), which explains the peaks occurring in summer to late autumn, and the decline during winter could be due to the emigration of sub-adults or their mortality due to nutritional stress (Jones and Coman 1982; D. Risbey, unpublished).

The impact of different densities of cats and foxes was indicated by changes in the capture success of small mammals before (1990) and during (1992–94) predator manipulation. In Zone 1, where both predators were controlled, the capture success of mammals doubled from 42 captures in June 1990 to 93 captures in July 1994. In contrast, the capture success of mammals did not show a progressive rise or decline over three years of sampling in Zone 3 in the absence of predator manipulation. Where only foxes were controlled (Zone 2), mammal captures declined by 80% over five years from 55 captures in March 1990 to 7 in March 1994. Dense vegetative cover did not appear to benefit small mammals in Zones 2 or 3, which were subject to high preda-

tion by cats and foxes. We can only speculate on whether the difference in the amount of cover in the two habitat types sampled at Heirisson Prong was sufficient to detect a response, or perhaps vegetative cover does not deter cats and foxes when hunting rodent-size prey. Data suggesting that *Pseudomys* spp. prefer to forage in open habitat (Murray and Dickman 1994; C.R. Dickman, personal communication) suggest that they are especially vulnerable.

The capture success of three reptile families (dragons, skinks, and geckos) did not appear to increase following the control of cats and foxes in Zone 1 or following fox control in Zone 2. This may be because reptiles were not as important as mammals in the diet of cats or foxes at Heirisson Prong (Risbey *et al.* 1999). Alternatively, the design of this experiment may not have been sensitive enough to detect the impact from predators because of the specific micro-habitat preferences of reptiles.

Two major factors appear to be important in the regulation of the abundance of rabbits at Heirisson Prong: predation by cats and foxes; and the onset of seasonal rainfall. Spotlight counts of rabbits in Zones 1 and 2 were low until mid–late 1992, when spotlight counts of foxes declined during 1991 as a result of the introduction of fox baiting in March 1991. In contrast, with no fox or cat control in Zone 3, rabbit counts remained low. The removal of foxes may have allowed rabbits to escape predator-regulation even though cats were still present in both areas. During a predator-removal experiment conducted in Yathong Nature Reserve, a semi-arid site in New South Wales, predator–prey interactions between cats, foxes and rabbits were studied for three years during periods of both drought and above-average rainfall. It was found that predation by cats and foxes could regulate rabbit populations only when rabbits were at low densities as a result of drought or disease (Newsome *et al.* 1989; Pech *et al.* 1992). Heirisson Prong experienced below-average rainfall for three years prior to 1991. Low rainfall together with the presence of cats and foxes appears to have held the population of rabbits at a low level. Above-average rainfall in 1991 (302 mm) together with the control of foxes (March 1991) may have enabled rabbits to escape predator-regulation. The abundance of rabbits began to change seasonally in the next year. In Zones 1 and 2, spotlight counts of rabbits increased during winter–spring and declined in summer–autumn. This trend was also observed in the coastal area north of Carnarvon, Western Australia (King *et al.* 1983) and in the area west of the Darling River in New South Wales (Wood 1980). The germination of annuals and new growth of perennials after rainfall stimulates breeding in rabbits (Poole 1960; Wheeler and King 1985), which explains this fluctuation in rabbit abundance with the onset of rainfall.

Fox and cat interactions

Rises in the abundance of cats following the control of foxes or dingoes have been reported in other parts of Australia. Cats

increased in abundance when dingoes were removed in Queensland (Pettigrew 1993) and when dingoes and foxes were controlled in the Gibson Desert (Christensen and Burrows 1994). Exceptional rainfall triggered an eruption of rabbits that enhanced the rise in cat numbers in the latter example. The rise in rabbits in Zone 2 at Heirisson Prong during 1992 and 1993 may have aided the rise in cats in this area along with relief from competitive and predatory forces exerted by foxes. Risbey *et al.* (1999) provided evidence of fox predation on cats at Heirisson Prong. Whether a meso-predator release (Palomares *et al.* 1995) of cats was observed following the decline of foxes, or whether the increase in spot-light counts of cats was caused by an increase in activity by feral cats is not known. What is important is that when only foxes were controlled, captures of small mammals declined. Dickman (1996*b*) and Martin *et al.* (1996) expressed concern that unilateral fox control may lead to exacerbated predation by cats; this concern is supported by this study. However, before the above conclusions can be accepted, the shortcomings in the design must be acknowledged and defended.

Validity of the experiment

It is important to support the conclusions by reference to basic principles of predator-impact experiments, especially given that this study operated within the logistic constraints of the reintroduction work at Heirisson Prong. Dickman (1996*b*) outlined principles for experimental studies of the impact of feral cats on native fauna, grouping them under the broad categories of *a priori* prediction, study design and timing. This study met Dickman's first condition of having *a priori* reasons for suspecting that cats were impacting on native fauna, since Risbey *et al.* (1999) showed that small native mammals were important in the diet of cats and predicted that removal of cats would lead to a recovery in small mammal numbers. Spotlight surveys of cats and foxes also confirmed that significant changes in predator numbers or activity did occur as a result of manipulation.

With regard to study design, Dickman (1996*b*) emphasised the advisability of replicating both experimental and control sites and sampling before and after the experimental manipulation, or alternatively the use of one experimental site and multiple controls, with sampling both before and after manipulation (the 'beyond BACI' designs of Underwood 1994). We could not meet these requirements since the reintroduction study did not replicate impact sites and the pre-manipulation data available to us had not been collected in all three predator zones. Obvious logistical constraints prevented replicating the total design at a second site. Thus, our results cannot be extrapolated beyond the experimental 'universe' of Heirisson Prong (Krebs 1989). However, they do represent a specific case which, in combination with independent studies, may contribute to a valuable generalisation.

A further important design issue is that the use of rabbit poisoning in Zone 1 to remove predators by secondary poi-

soning introduced a manipulation of rabbit numbers not replicated in other zones. However, rabbit poisoning was not extensive (Short *et al.* 1994) and spotlight counts of rabbits still increased in Zone 1 after fox control as they did in Zone 2 where no rabbit baiting occurred. It is possible that over a longer period increased rabbit numbers following predator control might impact small mammals by causing structural change to the vegetation, but we do not believe it was an issue within the time-frame of our study.

The size of the study zones (Zone 1: *c.* 12 km^2; Zone 2: *c.* 200 km^2; Zone 3: extends southwards from Zone 2) met Dickman's recommendation of large study areas, but they were neither separated by distances of >20 km nor interspersed. The distance between zones was most unlikely to be a problem given that (i) the barrier fence between Zones 1 and 2 was largely successful in preventing incursions of cats and foxes, and (ii) large salt ponds divided Zones 2 and 3.

We found no evidence of changes in vegetation structure along the Prong that could have been a confounding factor in the experiment. However, it is possible that reptiles could have responded to very small changes in vegetation cover or topography that we could not detect, perhaps contributing to our failure to demonstrate a response by reptiles to predator manipulation. Finally, sampling spanned five years in Zones 1 and 2 and 2.5 years in Zone 3 so Dickman's recommendation that an experiment should span at least two breeding seasons of the prey was met.

On balance, we believe that after allowance for the limitations of the design, our main conclusions of increases in spotlight counts of cats following fox control, increases in small mammal abundance following control of both cats and foxes, and decline in small mammal numbers where cats were the major predator are robust for Heirisson Prong, but should not be extrapolated elsewhere.

Implications

Early declines of mammals on the Swan coastal plain and the adjoining jarrah forest of Western Australia were attributed to predation by feral cats by Kitchener *et al.* (1978) and Christensen *et al.* (1985) respectively. However, Kitchener *et al.* (1980) argued that environmental patchiness resulting from changes in the pattern of fires following European occupation was the cause of mammal declines in the wheat-belt of Western Australia. Dickman *et al.* (1993) and Dickman (1996*b*) presented strong circumstantial evidence implicating feral cats in mammal decline in New South Wales and arid inland areas. Similarly, Short (1999) provides evidence for the early loss of small mammals (<350 g) in the Western Australian wheat-belt immediately following European settlement, coinciding with the time when cats were most likely to have become established in this area. The findings of our study are consistent with the interpretation that feral cats can suppress small mammal populations. The impact of cats at our site was interactive with the presence of foxes, and

similar interactions have been postulated elsewhere in Australia (Dickman 1996*b*).

Widespread fox-control programs have been implemented in the south-west of Western Australia and appear to be promoting the recovery of a range of threatened, medium-sized mammals (Morris *et al.* 1995; Maxwell *et al.* 1996). Whether these programs influence feral cat numbers and exacerbate predatory impacts on smaller mammals that are not monitored is possible but unclear. We endorse Dickman (1996*b*) in making this area of research a priority for further studies on potential cat impacts. Baiting strategies to target feral cats over large geographical areas are still in the developmental stage (e.g. Risbey *et al.* 1997; Short *et al.* 1997), thus managers of endangered species need to persist with more labour-intensive methods such as trapping and shooting if feral cats are to be controlled.

Acknowledgments

References

Ashton, D. G. (1978). Marking zoo animals for identification. In 'Animal Marking – Recognition Marking of Animals in Research'. (Ed. B. S. Stonehouse.) pp. 24–34. (The MacMillan Press: London.)

Bowerman, B. L., O'Connell, R. T., and Dickey, D. A. (1986). 'Linear Statistical Models: An Applied Approach.' (Duxbury Press: Boston.)

Calver, M. C., and Dell, J. (1998). Conservation status of mammals and birds in south-western Australian forests. I. Is there evidence of direct links between forestry practices and species decline and extinction? *Pacific Conservation Biology* **4**, 296–314.

Christensen, P., and Burrows, N. (1994). Project Desert Dreaming: experimental 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.)

Christensen, P., Annels, A., Liddlelow, G., and Skinner, P. (1985). Vertebrate fauna in the Southern forests of Western Australia. Forest Department of Western Australia, Bulletin No. 94. 109 pp.

Cogger, H. G. (1992). 'Reptiles and Amphibians of Australia.' (Reed Books: Sydney.)

Dickman, C. R. (1992). Predation and habitat shift in the house mouse, *Mus domesticus*. *Ecology* **73**, 313–322.

Dickman, C. R. (1996*a*). Impact of exotic generalist predators on the native fauna of Australia. *Wildlife Biology* **2**, 185–95.

Dickman, C. R. (1996*b*). 'Overview of the Impacts of Feral Cats on Australian Native Fauna.' (Australian Nature Conservation Agency: Canberra.)

Dickman, C. R., Pressey, R. L., Lim, L., and Parnaby, H. E. (1993). Mammals of particular conservation concern in the western division of New South Wales. *Biological Conservation* **65**, 219–248.

Finlayson, H. H. (1961). On central Australian mammals. Part IV. The distribution and status of central Australian species. *Records of the South Australian Museum* **41**, 141–191.

Friend, J. A. (1990). The numbat *Myrmecobius fasciatus* (Myrmecobiidae): history of decline and potential for recovery. *Proceedings of the Ecological Society of Australia* **16**, 369–377.

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.

Jones, E. (1989). Felidae. In 'Fauna of Australia. 1B. Mammalia'. (Eds D. W. Walton and B. J. Richardson.) pp. 1006–1011. (Australian Government Publishing Service: Canberra.)

Jones, E., and Coman, B. J. (1982). Ecology of the feral cat, *Felis catus* (L.), in south-eastern Australia. III. Home ranges and population ecology in semi-arid north-west Victoria. *Australian Wildlife Research* **9**, 409–420.

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.

Kinnear, J. E., Onus, M. L., and Bromilow, R. N. (1988). Fox control and rock wallaby population dynamics. *Australian Wildlife Research* **15**, 435–450.

Kinnear, J. E., Onus, M. L., and Sumner, N. R. (1998). Fox control and rock-wallaby population dynamics. II. An update. *Wildlife Research* **25**, 81–88.

Kitchener, D. J., Chapman, A., and Barron, G. (1978). Mammals of the Northern Swan Coastal Plain. In 'Faunal Studies of the Northern Swan Coastal Plain, a consideration of past and future changes'. pp. 54–93. (Western Australian Museum: Perth.)

Kitchener, D. J., Chapman, A., and Muir, B. G. (1980). The conservation value for mammals of reserves in the Western Australian wheatbelt. *Biological Conservation* **18**, 179–207.

Krebs, C. J. (1985). 'Ecology: the Experimental Analysis of Distribution and Abundance.' 3rd Edn. (Harper and Row: New York.)

Krebs, C. J. (1989). 'Ecological Methodology.' (HarperCollins: New York.)

Lee, A. K. (1995). 'The Action Plan for Australian Rodents.' (Australian Nature Conservation Agency: Canberra.)

Martin, G. R., Twigg, L. E., and Robinson, D. J. (1996). Comparison of the diet of feral cats from rural and pastoral Western Australia. *Wildlife Research* **23**, 475–484.

Maxwell, S., Burbidge, A. A., and Morris, K. (1996). 'Action Plan for Marsupials and Monotremes.' (Wildlife Australia: Canberra.)

May, S. A., and Norton, T. W. (1996). Influence of fragmentation and disturbance on the potential impact of feral predators on native fauna in Australian forest ecosystems. *Wildlife Research* **23**, 387–400.

Morris, K., Orell, P., and Brazell, R. (1995). The effect of fox control on native mammals in the Jarrah Forest, Western Australia. In 'Proceedings of the 10th Vertebrate Pest Control Conference, Hobart'. (Ed. M. Statham.) pp. 177–181. (Tasmanian Department of Primary Industry and Fisheries: Hobart.)

Murray, B. R., and Dickman, C. R. (1994). Granivory and microhabitat use in Australia desert rodents: are seeds important? *Oecologia* **99**, 216–225.

Newsome, A. E., Parer, I., and Catling, P. C. (1989). Prolonged prey suppression by carnivores – predator-removal experiments. *Oecologia* **78**, 458–467.

Palomares, F., Gaona, P., Ferreras, P., and Delibes, M. (1995). Positive effects on game species of top predators by controlling smaller predator populations: an example with lynx, mongooses, and rabbits. *Conservation Biology* **9**, 295–305.

Pech, R. P., Sinclair, A. R. E., Newsome, A. E., and Catling, P. C. (1992). Limits to predator regulation of rabbits in Australia: evidence from predator-removal experiments. *Oecologia* **89**, 102–112.

Pettigrew, J. D. (1993). A burst of feral cats in the Diamantina – a lesson for the management of pest species? In 'Cat Management Workshop Proceedings'. (Eds G. Siepen and C. Owens.) pp. 25–32. (Queensland Department of Environment and Heritage: Brisbane.)

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

Priddell, D., and Wheeler, R. (1994). Mortality of captive-raised malleefowl, *Leipoa ocellata*, released into a mallee remnant within the wheat-belt of New South Wales. *Wildlife Research* **21**, 543–552.

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

Risbey, D. A., Calver, M. C., and Short, J. (1999). The impact of cats and foxes on the small vertebrate fauna of Heirisson Prong, Western Australia. I. Exploring potential impact using diet analysis. *Wildlife Research* **26**, 621–630.

Robertson, M. H., and Wheeler, S. H. (1983). A radio-tracking study of four poisoning techniques for control of European rabbit, *Oryctolagus cuniculus* (L.). *Australian Wildlife Research* **10**, 513–520.

Short, J. (1998). The extinction of rat-kangaroos (Marsupialia : Potoroidae) in New South Wales, Australia. *Biological Conservation* **86**, 365–377.

Short, J. (1999). Decline and recovery of Australian mammals with particular emphasis on the burrowing bettong *Bettongia lesueur*. Ph.D. Thesis, Murdoch University, Perth.

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.)

Short, J., Turner, B., Risbey, D. A., and Carnamah, R. (1997). Control of feral cats for nature conservation. II. Population reduction by poisoning. *Wildlife Research* **24**, 703–714.

Smith, A. P., and Quin, D. G. (1996). Patterns and causes of extinction and decline in Australian conilurine rodents. *Biological Conservation* **77**, 243–267.

Smith, P. J., Pressey, R. L., and Smith, J. E. (1994). Birds of particular conservation concern in the Western Division of New South Wales. *Biological Conservation* **69**, 315–338.

Spencer, P. (1990). Evidence of predation by a feral cat, *Felis catus* (Carvivora : Felidae) on an isolated rock-wallaby colony in tropical Queensland. *Australian Mammalogy* **14**, 143–144.

Start, T., Burbidge, A., and Armstrong, D. (1992). 'Woylie Recovery Plan.' (Department of Conservation and Land Management: Perth.)

Strahan, R. (1995). 'The Mammals of Australia.' (Reed New Holland: Sydney.)

Swingland, I. R. (1978). Marking reptiles. In 'Animal Marking – Recognition Marking of Animals in Research'. (Ed. B. S. Stonehouse.) pp. 119–132. (The MacMillan Press: London.)

Thompson, W. L., White, G. C., and Gowen, C. (1998). 'Monitoring Vertebrate Populations.' (Academic Press: New York.)

Underwood, A. J. (1994). On beyond BACI: sampling designs that might reliably detect environmental disturbances. *Ecological Applications* **4**, 3–15.

Wheeler, S. H., and King, D. R. (1985). The European rabbit in south-western Australia. II. Reproduction. *Australian Wildlife Research* **12**, 197–212.

Wood, D. H. (1980). The demography of a rabbit population in an arid region of New South Wales, Australia. *Journal of Animal Ecology* **49**, 55–79.

Appendix.   Species of mammals (as per Strahan 1992) and reptiles (as per Cogger 1992) captured at Heirisson Prong

Class and Family	Species name	Common name
Mammalia		
Muridae	*Pseudomys albocinereus*	Ash-grey mouse
	Pseudomys hermannsburgensis	Sandy inland mouse
	Mus musculus	House mouse
Dasyuridae	*Sminthopsis dolichura*	Little long-tailed dunnart
Reptilia		
Agamidae	*Ctenophorus maculatus*	Spotted dragon
	Pogona minor	Bearded dragon
	Tympanocryptis butleri	–
Scincidae	*Ctenotus fallens*	–
	Ctenotus australis	–
	Ctenotus schomburgkii	–
	Lerista elegans	–
	Lerista lineopunctulata	–
	Lerista muelleri	Mueller's skink
	Lerista planiventralis	–
	Lerista praepedita	–
	Lerista varia	–
	Menetia greyii	–
	Morethia lineocellata	–
Gekkonidae	*Diplodactylus alboguttatus*	–
	Diplodactylus michaelseni	–
	Diplodactylus ornatus	–
	Diplodactylus spinigerus	Western spiny-tailed gecko
	Gehyra variegata	Tree dtella
	Heteronotia binoei	Binoe's gecko
	Nephurus levis	Smooth knob-tailed gecko
Pygopodidae	*Lialis burtonis*	Burton's legless lizard
	Pletholax gracilus	–
	Pygopus lepidopidus	Common scaleyfoot
Elapidae	*Demansia psammophis*	Yellow-faced whip snake
	Pseudonaja modesta	Common brown snake
	Pseudonaja nuchalis	Gwardar
	Simoselaps littoralis	Banded snake
Typhlopidae	*Ramphotyphlops australis*	Blind snake
Varanidae	*Varanus gouldii*	Bungarra
Amphibia		
Myobatrachidae	*Arenophryne rotunda*	Sandhill frog