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## SPACE USE AND DENNING BEHAVIOUR OF WILD FERRETS (*MUSTELA FURO*) AND CATS (*FELIS CATUS*)

**Summary:** We monitored the behaviour of 62 radio-collared ferrets and 25 radio-collared cats in dry, tussock grassland habitat in New Zealand's South Island. The total home range of adult male ferrets ( $102 \pm 58$  ha, mean  $\pm 1$  s.d.) was marginally greater than that of females ( $76 \pm 48$  ha), and averaged  $90 \pm 55$  ha. Male ferret core ranges ( $27 \pm 15$  ha) were larger than those of females ( $16 \pm 8$  ha). Adult cat home ranges were similar between sexes, and were larger and more variable than those of ferrets ( $225 \pm 209$  ha). Core range size of cats was similar between sexes and averaged  $54 \pm 24$  ha. The upper 95% confidence limits of the mean home range lengths of adult ferrets and cats were 2.7 km and 5.1 km, respectively, indicating the width of buffer zones where predator control should be extended to protect the boundaries of areas targeted for predator control in dry, tussock grasslands.

Although core areas were mostly discrete, home ranges were distributed randomly, and animals that shared space neither avoided nor attracted each other. Little evidence of territoriality may be related to high densities of primary prey. Too few cats were monitored to determine territoriality.

Ferrets used at least  $9.4 \pm 3.2$  dens, and cats used  $11.5 \pm 3.0$  dens during the study. Although 71% of dens were used only once, some were used up to nine times. Day time resting by ferrets was mostly solitary. If transmission of bovine Tb occurs between adult ferrets, simultaneous sharing of dens during the day is unlikely to be a significant mode of transmission in this habitat. We were unable to determine the extent of den sharing by cats. Cats occupied den sites with more shrubs and rocks compared with ferrets. Predator control stations in dry tussock grassland habitat may therefore be more effective at killing cats than ferrets if placed in shrubby, rocky areas.

**Keywords:** ferret; *Mustela furo*; cat; *Felis catus*; home range; range length; core range; range overlap; territoriality; denning behaviour; radio tracking; tussock grasslands.

## Introduction

New Zealand's wild ferrets (*Mustela furo* L.) and cats (*Felis catus* L.) are widely regarded as pests because they prey on native fauna (Lavers and Clapperton, 1990; Fitzgerald, 1990), and carry the disease bovine tuberculosis (Tb) (Ragg, Moller and Waldrup, 1995). Therefore, ferret and cat populations are often artificially controlled. Information on their use of space is useful for determining the optimum distribution of trap or poison stations aimed at controlling ferret and cat populations, and for understanding the epidemiology of bovine Tb. However, the behavioural ecology of ferrets, in particular, is not well understood. The objective of this study was to address some of the knowledge gaps in the ecology of wild ferrets and cats by describing home range size, home range use, the degree of territoriality among animals, and denning behaviour.

As part of a larger study on the effects of rabbit (*Oryctolagus cuniculus*) control on predator

behaviour (Norbury, Norbury and Heyward, 1998), we monitored the behaviour of 62 radio-collared ferrets and 25 radio-collared cats in dry, tussock grassland in the South Island of New Zealand. The results reported here are from data either gathered in the absence of rabbit control, or from areas in which partial rabbit control had no discernible effect on predator space use.

## Methods

### Study sites

The study was conducted between March 1994 and March 1996 in modified short-tussock grassland habitat (Wardle 1991) in New Zealand's South Island. We chose three study sites with similar climate and vegetation; Earnsclough (1,000 ha) and Bendigo (2,500 ha) in the Central Otago district, and Grays Hills (6,000 ha) in the Mackenzie Basin district. Each site was on a pastoral property

extensively grazed by merino sheep. At the beginning of the study, rabbit densities on all study sites were 83–155 per km of spotlight transect; Kerr *et al.* (1987) defined rabbit densities > 40 per spotlight km as “extreme” infestation. Rabbits on the Bendigo and Grays Hills sites were poisoned 6 months into the study, but the effects of reduced rabbit numbers on predator movements were statistically significant only on Grays Hills where the most dramatic declines in rabbit abundance occurred (Norbury *et al.*, 1998). Therefore, the post-poisoning data from the Grays Hills site were excluded from this analysis.

Each site consists of hilly terrain (200–1060 m above sea level) and deep gullies. Mean annual rainfall ranges from 385–456 mm, and mean monthly temperatures range from 3°C in July to 18°C in January. Unusually heavy snowfalls occurred in late June 1995 and snow persisted for 2–3 months, but this did not appear to affect the behaviour of predators. The vegetation consisted of native tussock grasses (e.g., fescue tussock, *Festuca novae-zealandiae* Hark, and silver tussock, *Poa cita* L.), swards of exotic grasses (e.g., browntop, *Agrostis capillaris* L., and sweet vernal, *Anthoxanthum odoratum* L.), herbaceous weeds (e.g., viper’s bugloss, *Echium vulgare* L., woolly mullein, *Verbascum thapsus* L., and hawkweeds, *Hieracium pilosella* L. and *H. lepidulum* Stenstroem), and scattered shrubs of sweet briar (*Rosa rubiginosa* L.) and matagouri (*Discaria toumatou* Raoul).

### Radio-collaring

On each site, we baited 60 cage traps (360 mm high, 330 mm wide, 630 mm long) with skinned rabbit meat and placed them along farm roads at 300–400 m intervals. Because of the steep terrain, it was not feasible to distribute traps evenly across the sites. Every 4–6 weeks, we set traps for four consecutive nights and predators were captured, ear tagged, fitted with a radio-collar, and released. Before handling, most cats and a few ferrets were sedated with an intramuscular injection of 0.5–1.0 ml of 1 part ketamine hydrochloride: 2 parts xylazine. A subcutaneous injection of 1 ml of yohimbine hydrochloride (a xylazine antagonist) reversed the effects of the sedative within about 30 minutes.

We fitted 62 ferrets (20 on Earnsclough, 23 on Bendigo, and 19 on Grays Hills) with radio transmitters (160–161 MHz frequency) and mortality sensors, attached to rubber-coated brass collars (Sirtrack Ltd, Havelock North, New Zealand) that also acted as the antennae. Each radio-collar weighed 27 g and represented 4.1% of the average body mass for ferrets. Low flying aircraft could receive the

signal emitted by these radio-collars from up to 3 km away. Battery life was about 10 months.

It was normal for the body mass and coat density of male ferrets, in particular, to change throughout the year. This caused considerable difficulty in retaining collars on ferrets. Fortunately, ferrets were easily recaptured so we could adjust collars where necessary. Sexual maturity was determined by the external condition of the genitalia, and by measuring body mass (Moors and Lavers 1981). We only radio-collared ferrets at or near adult body mass (minimum mass of collared females = 630 g; males = 930 g).

We fitted 25 cats (eight on Earnsclough, six on Bendigo, and 11 on Grays Hills) with radio transmitters (160–161 MHz) and whip antennae attached to nylon webbed collars (Sirtrack Ltd). Aircraft could receive the signal emitted by these radio-collars from up to 20 km away. Battery life was 14 months. Each radio-collar weighed 48 g and represented 2.5% of the average body mass for cats. Obvious differences in age-related body mass enabled us to differentiate between juveniles, sub-adults, and adults. We radio-collared only sub-adult (four females, minimum mass = 1390 g; and three males, minimum mass = 1830 g) and adult cats.

### Radio tracking

We tracked predators during the day (mostly between 1000 and 1600 h) from a Robinson R22 helicopter equipped with an omni-directional antenna and a directional YAGI antenna. An ATS R2100 scanning receiver (Advanced Telemetry Systems, Isanti, Minnesota, USA) was used to detect transmitter frequencies during extensive searches for animals, and a TR-4 receiver (Telonics, Mesa, Arizona, USA) was used to pin-point locations. We recorded predator locations using a Global Positioning System (GPS) receiver and by marking animal positions on topographic maps. The marked maps were used for the denning behaviour work described later. Latitude and longitude data were transferred from the GPS to a computer database and converted to metric map grid coordinates for input into a home-range analysis programme (RANGESV, Kenward and Hodder 1996). The accuracy of the GPS data was checked on six occasions by taking readings from survey markers at known locations on each study site. GPS points were on average  $83 \pm 34$  m ( $\pm 1$  s.d.) from known locations and in random directions.

One location was obtained during the day every 7–34 days (mean interval = 19 days) per animal from 34 male and 28 female ferrets, and from 11 male and 14 female cats. Because ferrets were short-lived, and

often did not retain their radio-collars, few ferrets provided continuous data for the whole study. We monitored ferrets for an average of 310 days (range = 94-605 days). A similar problem was encountered for cats because several were shot by farmers and a few were killed on roads. We monitored cats for an average of 287 days (range = 153-374 days).

An average of 17 locations was recorded for both ferrets and cats, and the maximum number was 30 and 25, respectively. The minimum number of locations required to adequately describe home range size was determined by plotting the mean cumulative home range size (expressed as a percentage of the total home range area) against the number of locations for both ferrets and cats (Fig. 1). The mean percentage home range size began to stabilize after about 10 fixes, therefore animals with fewer than 10 fixes were omitted from the analysis.

### Space use estimators

#### Home range

Many techniques have been used to analyse home range size (see Harris *et al.*, 1990). We chose the range length (e.g., Murphy and Dowding, 1995) and 100% minimum convex polygon (MCP) (Southwood, 1966) methods. Range length, or the maximum linear distance between any two animal locations, is a simple index of space-use which makes

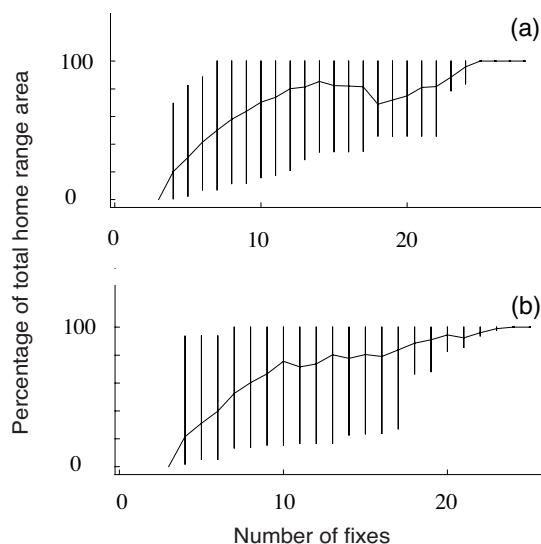


Figure 1: The mean cumulative home range size (expressed as a percentage of the total home range area) of 62 radio-collared ferrets (a) and 25 cats (b) versus the number of radio locations (minimum of 10 fixes per individual). Vertical bars indicate the range of data.

no attempt to measure home range area, and is therefore appropriate for few locations (Harris *et al.*, 1990), as in this study. Range length is also useful for defining the width of buffer zones where predator control should be extended in order to protect an area from predator effects. Because the MCP method has been most commonly used for determining home ranges of ferrets and cats, the results can be compared with those from most other studies, including those based on grid trapping (Jones, 1983). Despite the tendency of MCPs to overestimate home range size when the home range shape is not convex (Harris *et al.*, 1990), they are relatively robust with low sample sizes compared with other analytical techniques (Harris *et al.*, 1990). Also, because MCPs define the total area an animal may visit, and thus the neighbours it may encounter, this information can help us to understand the potential of bovine Tb to spread within and between animal species.

#### Core range

We estimated core range areas using cluster analysis (Anderberg, 1973; Everitt, 1980). This method uses a hierarchical incremental approach which is particularly good for distinguishing range cores from excursive areas (Kenward, 1992). Range cores were subjectively identified for each animal by plotting the percentage of the total home range area against the proportion of locations included in the home range estimation, and then inspecting for a discontinuity in the slope which occurs if the area decreases sharply as a result of excluding outlying fixes (Harris *et al.*, 1990). If no obvious slope discontinuity occurred and the total home range area (i.e., 100% of fixes) was similar to other core areas, the entire home range was considered to be a core.

Total home range and core range estimators were tested for differences between sites and sexes by 2-way analysis of variance.

#### Home range overlap

The proportion of ferret home ranges that overlapped, and the extent to which they overlapped (expressed as a percentage of each animal's range), were calculated within and between sexes by overlapping the polygon of each ferret with the polygon of every other ferret using the RANGESV software (Kenward and Hodder, 1996). Range overlap is reported only for ferrets whose home ranges overlapped by more than 1%, and that co-occurred on the study sites. The same procedure was repeated for core areas of ferrets. Because not all ferrets were radio-collared on each study site, we acknowledge that the degree of overlap is likely to be higher than that reported. No overlap analysis was attempted for cats because only a small number of cats were monitored.

To test for territoriality on each site, two interaction analyses were carried out using RANGESV. Firstly, spacings between home range-centres (harmonic mean centre (Spencer and Barrett, 1984)) were analysed using nearest-neighbour analysis (Clark and Evans, 1954). These were compared with those based on 1,000 computer generated random locations within the study sites using Student's *t*-test. Secondly, "dynamic interaction" analysis (Kenward, Marcstrom and Karlbom, 1993) was carried out to test if animals that overlapped spatially, avoided or attracted each other in time. For example, animals may seldom encounter each other if they rarely visit the same place at the same time. The observed and possible distances between animals whose core ranges overlapped were compared using Jacobs' Index (Jacobs, 1974). Values for the Jacobs' Index fall within a range of +1 to -1, with negative values indicating that animals tend to avoid each other, and positive values indicating that animals tend to attract each other. Although day time locations give some indication of avoidance or attractance between ferrets, this analysis should ideally be repeated on night time fixes when ferrets are active (Lavers and Clapperton, 1990) and interactions between them are more likely.

### Denning behaviour

We determined the number and frequency of use of day time resting areas ("dens") for each animal by inspecting the sequential location of day time locations marked on topographic maps by the helicopter pilot. Because animals were located on average once in 19 days, the mean number of dens and their frequency of use are likely to be minimum estimates because other dens may have been used between tracking sessions. Because cats are sometimes active during the day (Fitzgerald and Karl, 1986), day time locations may not always represent their denning sites. The number of dens used and the distances between consecutively visited dens were tested for differences between sites and sexes by 2-way analysis of variance.

Three broad features of the den site were recorded by the pilot: topography (i.e., located on a ridge, slope, flat, or gully); vegetation (i.e., located in shrubs, tussock, or low herbaceous vegetation); and presence or absence of surface rock. We compared frequency data for den site characteristics between predator species, and between sexes, using 3-way contingency tables using loglinear modelling. Analysis of model deviances were used to select the most appropriate models. Terms which significantly reduced the deviance were added to the model until

no significant improvement could be made and there was no evidence of lack of fit. The data do not describe den site preferences *per se* because they do not include information on the relative availability of den site features in the field.

On 41 occasions radio-collared ferrets were excavated from their dens during the day to correct problems with their collars. Incidences of co-habitation were noted. Self-preservation precluded excavating cats from their dens.

### General data analysis

Given that large management units were required for the larger study on the effects of rabbit control on predator behaviour, it was beyond the resources of this study to monitor more than three sites. The error terms ( $\pm$  *s.d.*) in this paper relate to the subsamples within each experimental site, not to the variation between sites. Dependent variables were tested for normality and equality of variances and, where necessary, data were log-transformed for parametric testing or a non-parametric equivalent used.

## Results

### Space use

#### *Ferrets*

The mean home range size for ferrets was  $90 \pm 55$  ha (Table 1). Home ranges were similar between sexes ( $102 \pm 58$  ha for males,  $76 \pm 48$  ha for females;  $F_{1,56} = 3.36$ ,  $P = 0.072$ ) and sites ( $F_{2,56} = 1.11$ ,  $P = 0.336$ ), and there was no sex x site interactive effect ( $F_{2,56} = 0.06$ ,  $P = 0.938$ ). Because the interaction was not significant we dropped the interaction term and re-tested the effect of sex using an unpaired *t*-test. This showed that sex was only weakly significant ( $t = 2.00$ ,  $n = 62$ ,  $P = 0.0496$ ). The average core range comprised 26% of the total home range of males, and 21% of the total home range of females, accounting for 89% of observations. Male core ranges were larger than those of females ( $27 \pm 15$  ha for males,  $16 \pm 8$  ha for females;  $F_{1,56} = 15.36$ ,  $P < 0.001$ ) (Table 2). Core ranges were similar between sites ( $F_{2,56} = 2.22$ ,  $P = 0.119$ ) and there was no interactive effect ( $F_{2,56} = 1.24$ ,  $P = 0.298$ ). The mean home range length of ferrets was  $1.7 \pm 0.5$  km (Table 3). There were no differences in home range length between sites ( $F_{2,56} = 0.72$ ,  $P = 0.492$ ) or sexes ( $F_{1,56} = 1.95$ ,  $P = 0.168$ ), nor was there any interactive effect ( $F_{2,56} = 0.90$ ,  $P = 0.411$ ).

Table 1: Mean area of the 100% minimum convex polygon of ferrets and cats.

Species, sex	MCP (ha)	s.d. (ha)	Range (ha)	n
<b>Ferrets</b>				
Male	102	58	19-316	34
Female	76	48	16-240	28
Total	90	55	16-316	62
<b>Cats</b>				
Male	189	218	42-742	9
Female	249	208	79-840	13
Total	225	209	42-840	22

Table 2: Mean area of the core range of ferrets and cats.

Species, sex	Core (ha)	s.d. (ha)	Range (ha)	n
<b>Ferrets</b>				
Male	27	15	10-73	34
Female	16	8	5-44	28
Total	22	14	5-73	62
<b>Cats</b>				
Male	52	30	13-102	11
Female	55	19	17-81	14
Total	54	24	13-102	25

Table 3: Mean home range length of ferrets and cats.

Species, sex	Range length (km)	s.d. (km)	Range (km)	n
<b>Ferrets</b>				
Male	1.7	0.5	0.6-2.8	34
Female	1.5	0.6	0.7-3.2	28
Total	1.7	0.5	0.6-3.2	62
<b>Cats</b>				
Male	2.4	1.3	1.2-5.1	9
Female	2.8	1.2	1.3-6.1	13
Total	2.6	1.2	1.2-6.1	22

The percentage of male home ranges that overlapped with other males ranged from 13-34% across sites (Table 4). Female-female overlap was 11-23%, and overlap between sexes was 12-31%. The area shared by overlapping ferrets, expressed as a percentage of each ferret's total home range size, was 22-29% between males, 17-29% between females, and 26-34% between sexes. Core areas were mostly discrete. The percentage of male core ranges that overlapped with other males was 7-14%. Female-female overlap was 3-14%, and overlap between sexes was 3-17%. The percentage of core area that overlapped ranged from only 3-10% between females, 10-31% between males, and 16-34% between sexes. The percentage of overlappers was lowest on Grays Hills, but so was the proportion of resident ferrets that was radio-collared on this site.

Table 4: Home range overlap between ferrets. Percentage of ranges that overlapped is based on the total number of overlap possibilities (e.g., 7 males have  $7^2 - 7$  (self overlap) = 42 possibilities). The percentage overlap of home ranges is calculated from only those animals whose home ranges overlapped. The number of animals studied differs from that presented in other tables because not all ferrets were on the study area at the same time. % collared = the mean number of radio-collared ferrets during each tracking session expressed as a percentage of estimated numbers of ferrets derived from capture probability and survival data from marked and unmarked ferrets gathered during this study (see Norbury and Heyward, 1997).

	Earnsclough	Bendigo	Grays Hills
No. males	7	13	10
No. females	7	10	9
% collared	64	52	26
% of MCPs that overlapped			
male-male	26	34	13
female-female	19	23	11
male-female	29	31	12
% overlap of MCPs			
male-male	23	22	29
female-female	29	17	23
male-female	32	26	34
% of core areas that overlapped			
male-male	10	14	7
female-female	14	4	3
male-female	10	17	3
% overlap of core areas			
male-male	31	10	13
female-female	10	3	5
male-female	33	16	34

On each site, spacings between home range centres of females, and between those of males, did not differ from those based on random location of range centres (Earnsclough: females,  $t = -0.06$ ,  $n = 9$ ,  $P > 0.05$ ; males,  $t = 1.00$ ,  $n = 11$ ,  $P > 0.05$ ; Bendigo: females,  $t = 1.33$ ,  $n = 10$ ,  $P > 0.05$ ; males,  $t = 0.37$ ,  $n = 13$ ,  $P > 0.05$ ; Grays Hills: females,  $t = 0.39$ ,  $n = 9$ ,  $P > 0.05$ ; males,  $t = -0.02$ ,  $n = 10$ ,  $P > 0.05$ ).

Dynamic interaction analyses showed the mean female-female interaction was -0.03 (Jacobs' index), which was similar to the male-male interaction of -0.01, and to the male-female interaction of +0.03 (Kruskal-Wallis test:  $H = 5.22$ ,  $P = 0.074$ ). All indices were close to zero, indicating neither avoidance or attractance within and between sexes.

**Cats**

Three of seven adolescent cats (two on Earnsclough, and one on Bendigo) dispersed up to 15 km from their natal areas soon after capture.

Data from these three cats have been excluded from Tables 1, 3, 4 and 5. These cats were included in the core range data (Table 2) because the size of their core ranges were similar to those of other cats since the method for calculating core range size effectively excludes excursive areas. Cats occupied average home ranges of  $225 \pm 209$  ha (Table 1). There were no differences between sexes ( $189 \pm 218$  ha for males,  $249 \pm 208$  for females;  $F_{1,18} = 0.30$ ,  $P = 0.593$ ) or sites ( $F_{2,18} = 1.04$ ,  $P = 0.373$ ). It was not possible to test for interactive effects because there were no data for male cats on one site. Core areas on average comprised 24% of total home range size, accounting for 91% of observations. The mean core area was  $54 \pm 24$  ha (Table 2). There were no differences in core areas between sexes ( $52 \pm 30$  ha for males,  $55 \pm 19$  for females;  $F_{1,21} = 0.38$ ,  $P = 0.543$ ) or sites ( $F_{2,21} = 0.13$ ,  $P = 0.877$ ). The mean home range length of cats was  $2.6 \pm 1.2$  km (range 1.2-6.1 km; Table 3). There were no differences in home range length between sexes ( $2.4 \pm 1.3$  km for males,  $2.8 \pm 1.2$  km for females;  $F_{1,18} = 0.96$ ,  $P = 0.341$ ) or sites ( $F_{2,18} = 0.64$ ,  $P = 0.539$ ).

### Denning behaviour

#### Den use

Ferrets were located 14 times on average over 310 days in at least  $9.4 \pm 3.2$  different dens (range 4-18,  $n = 55$ ). Seventy-one percent of these dens were used only once during the study, but one ferret used a den nine times (Fig. 2). There were differences in the number of dens used between sites ( $F_{2,49} = 11.17$ ,  $P < 0.001$ ), but there were no sex ( $F_{1,49} = 0.85$ ,  $P = 0.361$ ) or interactive effects ( $F_{2,49} = 2.68$ ,  $P = 0.078$ ).

Cats were located 17 times on average over 287 days in  $11.5 \pm 3.0$  different dens (range 6-17,  $n = 19$ ). Cats used more dens than ferrets (Mann Whitney test:  $T = 933.5$ ,  $P = 0.006$ ). The frequency of den use by cats was very similar to that of ferrets (Fig. 2). One cat used a den eight times during the study. There were no differences in the number of dens used between sexes ( $F_{1,13} = 1.64$ ,  $P = 0.223$ ) or sites ( $F_{2,13} = 0.91$ ,  $P = 0.428$ ), and there was no interactive effect ( $F_{2,13} = 0.62$ ,  $P = 0.551$ ).

#### Inter-den distances

The distances moved by male ferrets between consecutively visited dens were greater than those of females ( $0.6 \pm 0.2$  km for males,  $0.5 \pm 0.1$  km for females;  $F_{1,56} = 5.50$ ,  $P = 0.023$ ) (Table 5). No sex differences were apparent for cats ( $F_{1,18} = 0.17$ ,  $P = 0.688$ ). There were no obvious seasonal trends in inter-den distances for either species.

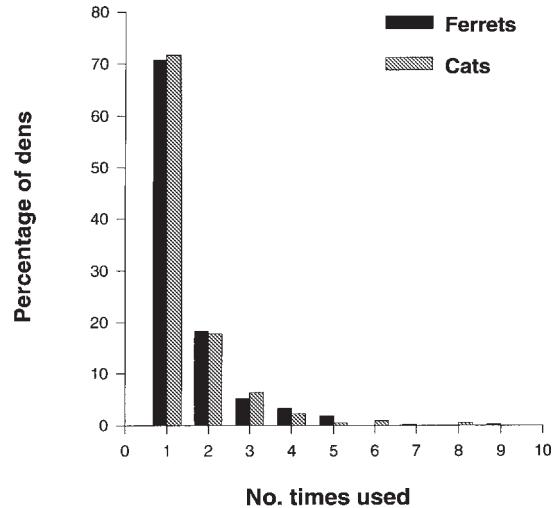


Figure 2: Frequency of den use by ferrets (closed bars) and cats (shaded bars).

#### Den sharing by ferrets

Two of 41 excavated dens (rabbit burrows in nearly all cases) that were known to contain radio-collared ferrets were occupied by another ferret. The shared dens were excavated in May and August, and both were occupied by adult males. One den contained a fresh rabbit carcass. Also, one of these males was relocated by radio telemetry three months later in November, and was occupying the same den as another radio-collared male. Sequential use of dens (i.e., the same den occupied by different animals, but at different times) was occasionally observed for ferrets (unpubl. data). Because cat dens were not excavated, we were unable to determine the extent of den sharing by cats, although we never observed by telemetry a radio-collared cat occupying the same den as another radio-collared cat.

Table 5: Mean distance between consecutively visited den sites of individual ferrets and cats.

Species, sex	Inter-den distance (km)	s.d. (km)	Range (km)	n
Ferrets				
Male	0.6	0.2	0.3-1.1	34
Female	0.5	0.1	0.3-0.9	28
Total	0.6	0.2	0.3-1.1	62
Cats				
Male	0.7	0.2	0.5-1.2	9
Female	0.8	0.4	0.5-1.8	13
Total	0.8	0.3	0.5-1.8	22

### Den site characteristics

There were no differences in den site topography between predator species ( $\chi^2_3 = 3.8$ ,  $P > 0.05$ ) or between sexes ( $\chi^2_3 = 6.5$ ,  $P > 0.05$ ) (Table 6). In regard to den site vegetation, there were differences between predator species ( $\chi^2_2 = 92.8$ ,  $P < 0.01$ ), but these differences also varied according to the sex of the animal ( $\chi^2_2 = 6.9$ ,  $0.01 < P < 0.05$ ). Cats, especially male cats, occupied sites with more shrubs and less tussock and herbs compared with ferrets. Males of both species occupied sites with more shrubs and less herbaceous vegetation than females, although the sex differences were marginal for ferrets. Cats preferred more rocky terrain than ferrets ( $\chi^2_1 = 26.7$ ,  $P < 0.01$ ). No sex differences in den site rockiness were apparent for either species.

## Discussion

### Space use

There have been four studies of ferret home ranges in New Zealand. Moors and Lavers' (1981) and Pierce's (1987) estimates of home range size were derived from locations of trapped animals. Baker's (1989) and Alterio's (1994) estimates were derived from day and night locations of three and seven radio collared animals, respectively. Estimates of home range size range from 12 ha for females and 31 ha for males in mixed dune/pasture/swamp habitat (Moors and Lavers, 1981), to 111 ha for females and 288 ha for males in dry, tussock grassland habitat (Pierce, 1987). Moors and Lavers' (1981) estimates probably underestimated the true home range size because the authors found tagged ferrets beyond their trapping grid. Although ferrets are mostly nocturnal, we were confident our day time telemetry data encompassed the majority of movements because night time captures in cage traps set throughout our study sites were generally

contained within the perimeter of a ferret's day time home range (unpubl. data). Blandford (1987) also found that European polecats (*M. putorius* L.) (from which ferrets are probably domesticated) foraged mostly in the vicinity of their day time resting locations. In five published studies of home range size of European polecats determined by radio telemetry (see reviews in Blandford (1987) and Brzezinski, Jedrzejewski and Jedrzejewska (1992)), home range size ranged from 9-1100 ha. However, this reduces to 20-200 ha if one study with very large home ranges (Weber 1989b in Brzezinski *et al.* 1992) is excluded. Our home range estimates for ferrets are thus within the range encompassed by ferrets and European polecats found in other studies.

There are two published home range studies of cats in New Zealand. The home ranges of cats in a steep-sided valley were mostly long and narrow, and averaged 80 ha for females and 140 ha for males (Fitzgerald and Karl, 1986). Cats in farmland habitat have similar home range sizes (91 ha for females, 134 ha for males) (Langham and Porter, 1991). The mean home range size of resident male and female cats in our study (189 ha and 249 ha, respectively) is within the range of diurnal home ranges of cats (80-615 ha) collectively drawn from Australian (Jones and Coman 1982), Swedish (Liberg 1984), and New Zealand studies (Fitzgerald and Karl 1986, Langham and Porter 1991). Given that nocturnal home ranges of cats appear to be larger than their diurnal ranges (Langham and Porter 1991), our diurnal ranges of cats therefore probably underestimated their true home range size. We were unable to verify this using capture locations because cats were difficult to recapture.

Some adolescent cats dispersed from our study sites. Innate dispersal is characteristic of many sub-adult mammals, particularly of sub-adult males (Dobson 1982). Two of three radio-collared adolescent males dispersed compared with one out of four female adolescents. Although our sample

Table 6: Den site characteristics of ferrets and cats. Values are percentages of dens in each category.  $n$  = no. of animal locations.

Species	Sex	$n$	Topography				Vegetation			Rock	
			Ridge	Slope	Flat	Gully	Shrubs	Tussock	Herbs	Yes	No
Ferret	Male	865	0.2	85.1	9.4	5.3	39.1	33.0	27.9	59.2	40.8
	Female	731	0.4	86.7	9.4	3.4	33.5	32.1	34.3	62.1	37.9
	Total	1596	0.3	85.8	9.4	4.5	36.6	32.6	30.8	60.5	39.5
Cat	Male	330	0.3	88.2	7.0	4.5	66.4	17.0	16.7	72.4	27.6
	Female	356	0.3	89.3	8.1	2.2	48.6	19.9	31.5	71.1	28.9
	Total	686	0.3	88.8	7.6	3.4	57.1	18.5	24.3	71.7	28.3

size is very low, male-biased adolescent dispersal has been reported for rural cats elsewhere in New Zealand (Langham and Porter 1991).

Ferrets and cats concentrated their activities in core areas that represented 24% of their total home range. Blandford (1987) found a similar result for European polecats in Wales. While the larger core areas of male ferrets may allow greater access to females and greater chance of successful breeding, the sex difference in the mean core area was no greater than that predicted by differences in body mass and energetic requirements (Harestad and Bunnell, 1979). The longer inter-den distances of males compared with females, suggest that male ferrets may have been more active than females. Greater mobility of males, and presumably greater interception with traps, may partly explain the male-biased sex ratio (1.3 males to 1 female) of trapped ferrets in this study (unpubl. data). Conversely, there were no apparent sex differences in cat mobility, and the sex ratio of trapped cats was exactly 1:1 (unpubl. data).

In order to mitigate the effects of predators in an area, predator control should be extended in a buffer zone around the area to remove predators which live on the boundary. We recommend that the buffer zone be sufficiently wide to include the upper 95% confidence limits for the mean home range lengths in Table 3 (2.7 km for ferrets, and 5.1 km for cats). Based on the home range sizes of ferrets in this study and that of Pierce's (1987), Moller, Norbury and King (1996) modelled the most cost-effective spacing between trap or poison stations used to control ferret populations. They assumed four different probabilities of killing ferrets with varying numbers of control stations, and found the optimum spacing to be about 500 m.

### Territoriality

Territoriality within sexes appears to occur in many mustelids (Powell, 1979), including mink (*M. vison* Schreber) (Linscombe, Kinler and Aulerich, 1982), weasels (*Mustela* spp.) (Lockie, 1966; King, 1975; Svendsen, 1982), stoats (*M. erminea* L.) (Lockie, 1966), fisher (*Martes pennanti* Erxleben) (Arthur, Krohn and Gilbert, 1989), and marten (*Martes americana* Turton) (Katnik *et al.*, 1994). Powell (1979) found that mustelids with most territoriality within sexes are those that are "most carnivorous, most elongate and most sexually dimorphic". Ferrets have all these features and so would be expected to be intrasexually territorial. Indeed Moors and Lavers (1981) found that overlap within sexes of ferrets was restricted to areas bordering their home range, whereas there was considerable overlap between

sexes. However, Blandford (1987) reported that territoriality in European polecats "appeared to be only weakly developed compared with that of other solitary, dimorphic and highly carnivorous mustelids". Our study concurs with Blandford's in that ferrets appeared to be mostly non-territorial. We found that core range overlap was similar within and between sexes (up to 14% and 17% overlap, respectively). Although core range overlap was quite low, we radio-collared only about half of the ferret populations on average, and so overlap may actually be higher than indicated. We also found random distributions of home range centres and found no evidence of animals avoiding each other in time within shared space during the day. However, we acknowledge that this apparent lack of temporal avoidance may not be the case using night time locations when ferrets are active and more likely to interact.

Powell (1994) hypothesised that mustelids are non-territorial when prey abundance is unusually high or low. Indeed Moors and Lavers (1981) found home ranges of females overlapped considerably at one site when the abundance of prey (mice, *Mus musculus* L.) was unusually high. They considered this departure from the normal spacing pattern to be related to especially favourable food supply. Similarly, primary prey abundance was high on all of our study sites, which may explain why intrasexual territoriality was not obvious in our study.

### Denning behaviour

Ferrets used at least 9.4 dens on average, most of which were used only once during the sampling. We may have found that ferrets occupied more dens if we had located them more often. Nonetheless, Weber (1989) found similar denning behaviour of European polecats in Switzerland, which used an average of 9.7 dens (range 2-30,  $n = 6$  polecats located 10 or more times), many only once. Polecats in the United Kingdom used an average of five dens (maximum 11,  $n = 20$ ) but animals were monitored for only 43 days on average (Blandford, 1987). Feral mink in the U.K. used an average of six dens (range 2-10,  $n = 11$ ) (Birks and Linn, 1982). Stoats in Fiordland, New Zealand, used many dens but only one to three were used regularly (Murphy and Dowding, 1995). All these studies, including those that observed the denning behaviour of only one polecat (Herrenschmidt, 1982; Brzezinski *et al.*, 1992), describe temporary, short-term use of most dens. Most den visits lasted for only 1-2 days (Birks and Linn, 1982; Blandford, 1987; Weber, 1989). The polecat observed by Herrenschmidt (1982) exploited

small areas then abandoned them for several weeks or months before returning. This epitomises what appears to be the general denning behaviour of ferrets in our study. Curiously, ferrets on our Bendigo site occupied significantly more dens than those on the other sites, and so took longer to re-occupy them. The topography on the Bendigo site was dissected by more gullies than on other sites, which may have provided more den sites.

Only 4.9% of ferret dens were used by more than one animal at the same time (in both cases by two adult males), indicating that most day time resting by ferrets is solitary. Den sharing is a possible means of spreading bovine Tb within ferret populations if adult-adult transmission occurs. The low rate of den sharing between ferrets suggests that it is unlikely to be a significant mode of transmission in this habitat.

There did not appear to be any relationship between the location of ferret and cat dens and broad physical features like talus slopes, creek banks, or improved pastures. Similarly, stoat dens in New Zealand beech forest appeared to be randomly located (Murphy and Dowding, 1995). Although cats occupied significantly more dens than ferrets, the larger home ranges of cats, and the greater distances between their dens, indicated the density of cat dens within a given home range was lower than that of ferrets. Cats' apparent preference for den sites with more shrubs and rocks, compared with those chosen by ferrets, may simply be a function of differences in body shape and size. Ferrets are long and slender and adults weighed only 1022 g on average during this study. They are therefore well suited to investigating and occupying rabbit burrows. Cats on the other hand are more bulky and adults weighed 2940 g on average. Most rabbit burrows were therefore probably too small for cats to occupy. In fact two out of 14 radio-collared cats that died of natural causes were found stuck in the entrance of rabbit burrows. Shrubs and rocks provide larger spaces for cats to manoeuvre. Poison or trap stations used for controlling predator populations in dry tussock grassland habitat may therefore be more effective at killing cats than ferrets if strategically placed near shrubby, rocky areas where predators will emerge from den sites.

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