

## Selection of alpine grasslands over beech forest by stoats (*Mustela erminea*) in montane southern New Zealand

Des H.V. Smith<sup>1</sup>, Deborah J. Wilson<sup>2\*</sup>, Henrik Moller<sup>3</sup>, Elaine C. Murphy<sup>1</sup>, Yolanda van Heezik<sup>3</sup>

<sup>1</sup>Department of Conservation, Research, Development and Improvement Division, PO Box 13 049, Christchurch, New Zealand

<sup>2</sup>Landcare Research, Private Bag 1930, Dunedin, New Zealand

<sup>3</sup>Zoology Department, University of Otago, PO Box 56, Dunedin, New Zealand

\*Author for correspondence (E-mail: [wilsond@landcareresearch.co.nz](mailto:wilsond@landcareresearch.co.nz))

Published on-line: 11 May 2007

**Abstract:** Predation by introduced stoats is now considered a major threat to the population viability of several New Zealand endemic bird species. Historically stoat research and management has focused on beech forests and little is known about the ecology of stoats in the alpine grasslands occurring above the natural altitudinal limit of beech forest. Several stoat control operations in beech forest valley floors in southern New Zealand assume that adjacent montane areas act as a barrier to stoat immigration. Stoats were live-trapped and radio-tracked in alpine grasslands above the Borland Burn, Fiordland National Park, during the summer and autumn of 2003 and 2004. Seventeen stoats were radio-collared and home ranges were estimated for 11 of them. These home ranges were used in a compositional analysis which showed that these stoats spent significantly more time in alpine grassland than in adjacent beech forest. Range cores calculated for six of these stoats were located high up in alpine grassland and contained very little beech forest. This means that montane areas that contain alpine grasslands are unlikely to be barriers to stoat immigration; rather they may be a source of dispersing stoats that reinvade control areas. Also, endemic animal species that inhabit alpine grasslands could be at risk from stoat predation.

**Keywords:** home range; *Chionochloa*; habitat use

## Introduction

Stoats (*Mustela erminea*) are introduced mammalian carnivores (King & Murphy 2005) heavily implicated in the decline of New Zealand's native fauna (Elliott 1996; Elliott et al. 1996; McLennan et al. 1996; Wilson et al. 1998). Other introduced carnivores such as feral cats (*Felis catus*), ferrets (*M. furo*) weasels (*M. nivalis vulgaris*), hedgehogs (*Erinaceus europaeus*) and rats (*Rattus* spp.) also prey on New Zealand's native birds, reptiles and insects, but the stoat is the most widespread species of introduced predator in New Zealand's beech forests (*Nothofagus* spp.) (King & McMillan 1982; Murphy & Dowding 1995; Alterio & Moller 1997; Miller et al. 2001).

Most of the national parks in New Zealand's South Island are montane. In these protected areas alpine grasslands dominated by snow tussock (*Chionochloa* spp.) occur above the altitudinal limits of the southern beeches. Fiordland National Park, New Zealand's

largest (1 272 311 ha), has 17% (221 186 ha) of its area above treeline, and much of this is alpine grassland.

Stoats have been shown to inhabit alpine areas in the Northern Hemisphere (Fitzgerald 1977; Martinoli et al. 2001), but New Zealand's alpine grasslands differ in that they do not support the diverse small mammal communities that stoats are known to prey upon in their native range.

Little is known about the ecology of stoats in New Zealand's alpine grasslands. Some studies have assumed that the rugged nature of such areas will prohibit stoat dispersal between adjacent beech forest valleys (Lavers & Mills 1978; Dilks et al. 2003). A previous and more limited radio-tracking study in the Borland and Grebe valleys consistently located stoat activity near valley floors (Purdey et al. 2004). Cuthbert and Sommer (2002) radio-tagged stoats in alpine grasslands in the Kowhai Valley, Seaward Kaikoura Mountains, New Zealand. Their research was specifically related to the management of Hutton's shearwaters (*Puffinus huttoni*),

which were the main prey of stoats there, identified in 99.6% ( $n = 788$ ) of scats examined (Cuthbert et al. 2000). Because Hutton's shearwaters do not live anywhere else, this situation may not be typical of stoat ecology in alpine grasslands generally.

Research in the Murchison Mountains (Fiordland National Park) investigated whether stoats moved between alpine grasslands and beech forest valley floors, but no such movements were observed between the two habitats (Smith 2002; Smith & Jamieson 2005). However, the study ran for only 3 months, and was able to collect home range data for only two stoats in alpine grassland. With the exception of the Murchison Mountains, location of the Takahē Programme (Lee & Jamieson 2001; Smith et al. 2005), stoat control at five mainland sites in Fiordland does not reach altitudes higher than 760 m a.s.l., relying on the assumption that immigration across high-altitude areas is minimal.

The results reported in Cuthbert & Sommer (2002) and Smith & Jamieson (2005) suggest that some stoats may be resident at high altitudes (at least during the summer and autumn), and may incorporate alpine grasslands within their home range. The use and selection of alpine grassland by stoats could mean that endemic animals that inhabit alpine grassland might be at risk from predation, and that alpine grasslands could be an important habitat that is typically outside the focus of management. Further, this behaviour would presumably mean that alpine areas would not act as a barrier to stoat dispersal. This research therefore aimed to answer the following questions: do stoats inhabiting high altitudes incorporate alpine grasslands within their home range and, if so, do these stoats select alpine grasslands over beech forest?

## Methods

### Study site

The Borland Burn (45°40'S, 167°20'E) is 63 km south of Te Anau, New Zealand, in the south-eastern part of Fiordland National Park. The area consists of rugged mountains rising from sea level to >1600 m separated by U-shaped (glacially formed) valleys. The most distinctive ecotone is the beech forest timberline at between 900 and 1000 m a.s.l., above which alpine grasslands dominate. In some places the ecotonal boundary between alpine grasslands and beech forest consists of a narrow band of subalpine scrub. Subalpine scrub is made up of woody shrubs and in the Borland Burn these are typically *Dracophyllum longifolium*, *D. uniflorum*, *Hebe odora*, *Halocarpus bidwillii* and *Olearia colensoi* var. *argentea*. A shingle road built for power line maintenance crosses the Borland Saddle at 990 m a.s.l., providing the easiest access to alpine

grasslands in the national park. During this study there was no heavy beech seedfall in Fiordland.

### Live trapping

Live trapping and radio tracking were undertaken over two 3-month field seasons: the first between 6 January and 23 March 2003, the second between 6 January and 19 April 2004. Because the first field season served partly as a pilot study, some modifications to methods were made in the second field season.

Two lines of live traps were set up in alpine grasslands along ridges on either side of the Borland Saddle. The first, Study Site 1 (S1), headed away from the saddle in a south-easterly direction, while the second, Study Site 2 (S2), headed away to the north-west. The nearest points on the two lines were 2 km apart and traps within lines were 200 m apart. In 2003, S1 was 4 km long and contained 20 traps and S2 was 2 km long and contained nine traps. In 2004 S2 was extended to 4 km in length (20 traps). Two types of traps were used on both lines: aluminum Elliott B traps (Elliott Scientific Equipment™) with an adapted wooden nest box, and wooden Edgar traps (King & Edgar 1977). Each line contained 15 Elliott B traps and five Edgar traps (trap numbers 1, 5, 10, 15 and 20).

Traps were baited with a hen egg and a chunk of rabbit meat. In 2003 sampling commenced when the traps were laid out (6 January). However, prior to the 2004 field season traps were laid out and pre-baited in November 2003, almost 2 months before sampling commenced. The purpose of the pre-baiting was to accustom stoats to having traps within their home ranges, in order to increase their probability of capture and hence the sample size of radio-tracked stoats.

Trap lines were run for 5 nights at the start of each field season and for 5 nights at the end of each field season, but the final 2004 trapping session was disrupted by snowstorms. Between these 5-night sessions, trap lines were run for two nights in each fortnight in order to capture any new animals that might have moved into the area, while still allowing time for radio tracking.

All captured stoats were aged, sexed and weighed, ear-tagged in both ears, and fitted with a radio-collar. Age class was assessed by the presence of enlarged testes on adult males and the presence of visible nipples on adult females (Grue & King 1984).

### Radio tracking

Three types of radio-collars were used. In 2003 they were all two-stage transmitters weighing approximately 10 g, with a 3-mm-wide brass collar that formed the aerial (Sirtrack, Havelock North, New Zealand). In 2004, Sirtrack transmitters with a 6-mm-wide brass collar, modified to weigh 12 g, as well as two-stage cable-tie collars with an external whip aerial, weighing 5 g (Biotrack, Dorset, UK), were used.

The principal radio-tracking technique was triangulation, undertaken using hand-held (TR4) receivers with Yagi aerials and mirror sighting compasses with the declination already adjusted to grid north. Several permanent triangulation stations were identified, including all trap sites and several other stations that provided right angles to the trap lines or coverage of new areas. The establishment of triangulation stations was hence an iterative process developed throughout the season, dependent on the movement of stoats.

Stoat locations were estimated from two or three bearings taken from an individual. To minimise the impact of animal movement on location error, all bearings for a given estimate were taken within 20 minutes of each other. Field workers would delay collecting bearings for a particular stoat until they had determined a cluster of triangulation stations with the strongest signals for that animal. Median error from triangulation was estimated to be 157 m by triangulating transmitters randomly placed in the field (Smith, 2006). Estimates fell in the correct habitat 77% of the time, with risk of an estimate falling in the wrong habitat being highest when transmitters were close to the alpine grassland – beech forest ecotonal boundary (Smith 2006). Sequential locations of the same individuals were obtained at least 2 hours apart in order to reduce any effects of serial autocorrelation (Rooney et al. 1998).

## Analysis of data

### *Triangulations*

Triangulations were calculated with a program developed in Microsoft Access by the Department of Conservation's National Kakapo team. This program had a graphical interface that allowed the removal of bearings. Bearings were removed if (1) they failed to intercept with another bearing or (2) three bearings were intercepted but they did not form a triangle. In this situation the two bearings with an angle of intersect closest to 90° were chosen (White & Garrott 1990).

### *Home range*

In this study, Minimum Convex Polygons (MCPs) (Mohr 1947; White & Garrott 1990) were estimated from 100% of the locations of a stoat. These were used to describe the extent of movements for each stoat, and to assess each stoat's available habitat. Incremental analysis (Kenward et al. 2003) was undertaken for each MCP to determine whether an adequate sample of locations had been achieved. Incremental analysis involves plotting estimates of home-range area against the number of locations used to obtain the estimates, in the order in which they were obtained in the field. In theory, home range area should approach an asymptote

when an adequate sample size is reached (White & Garrott 1990).

Kernel analysis (Worton 1989; Seaman & Powell 1996) was used to estimate utilisation distributions for stoats with more than 40 radio locations. Utilisation distributions plot the area in hectares within contours against the number of locations used to estimate each contour. Contour areas were plotted from 20% to 100% of the actual number of locations, at 5% intervals. For each utilisation distribution the point of inflexion where the slope of the distribution steepened was determined by eye. The area below this inflexion has a higher density of contours than the area above, and indicates a core area of use (Kenward et al. 2003). Range cores were then estimated for each stoat by plotting the contour identified by the inflexion. Adaptive kernels were used instead of fixed kernels because they attach more uncertainty to outer locations (Kernohan et al. 2001), which is desirable because of the error produced from triangulation. Least-squares cross validation was used as the smoothing multiplier and a 'global minimum' band width was selected to prevent the analysis from failing if a minimum band width could not be estimated from the data (Kernohan et al. 2001).

All analyses were undertaken using Ranges 6 software (Anatrack). Two-dimensional home ranges and range cores estimated in Ranges 6 were imported into Arcmap™ and clipped against background contours from the study area so that three-dimensional surface area could be calculated for each home range using the '3D analyst' tool in Arcscene™. These were used to provide an indication of home range size in three dimensions.

### *Habitat use*

The proportion of beech forest, subalpine scrub and alpine grasslands in each two dimensional MCP was assessed in Arcmap using data from the New Zealand 1:50 000 Topomap series. Although use of subalpine scrub is not central to the hypotheses being tested, this habitat was included in the analysis because some radio-location estimates fell within it. These habitat proportions were then used as estimates of 'available habitat' for each stoat, while the proportion of radio locations falling in each habitat provided estimates of 'used habitat' for each stoat (Erickson et al. 2001). 'Available habitat' was compared with 'used habitat' with compositional analysis, a MANOVA technique (Aebischer et al. 1993) that treats the animal as the experimental unit and available habitat as a categorical covariate (Erickson et al. 2001). Compositional analysis constructs a matrix of log-ratios of 'used habitat' versus 'available habitat' from which Wilk's lambda is calculated. A randomisation test (1000 iterations) is undertaken on Wilk's lambda, and if the observed value corresponds with one of the 50 values that falls

within the tail of the distribution (i.e. 0.05), this shows non-random use of this habitat. T-tests are then used in a post hoc manner to find where the actual difference in use occurs between habitats (Aebischer et al. 1993). Compositional analysis makes the assumptions that (1) radio-marked animals are spatially independent of each other, i.e. they do not affect each others movements, and (2) compositions (i.e. estimates of available and used habitat) are equally accurate for different animals. Compositional analysis was undertaken using 'Compositional Analysis Excel tool – Version 3.2' (Smith 2001).

## Results

### Live trapping

In 2003, nine stoats were caught in 492.5 corrected trap-nights (Nelson & Clark 1973), consisting of three adult males, three juvenile males, two adult females and one juvenile female. Six of these stoats were radio-collared. In 2004, 19 stoats were caught in 564.5 corrected trap-nights; 17 of these stoats were radio-collared. The sex and age of all stoats trapped in 2004 are presented in Table 1.

### Radio tracking

In 2003, because of a problem with the design of the 3-mm brass collars, five of these transmitters failed. Thirty-three radio locations were collected for one juvenile male (JM1) over the 3-month period. This stoat had to be radio-collared three consecutive times in order to collect these data. In 2004, 440 radio locations were collected on the 17 radio-collared stoats. Only two of these radio locations fell below 800 m a.s.l., and none fell below 760 m a.s.l.

### Home range

Incremental analysis produced mixed results (Fig. 1). The incremental analysis plots showed strong asymptotes early in their tracking period of some stoats. However, there was no consistent asymptote for some of the stoats with the largest sample sizes of radio locations and tracked over the longest periods (i.e. AM1, AM4). Eleven stoats were judged to have enough radio-location data over a sufficient period to provide reliable home range information (these stoats are denoted by an asterisk in Table 1).

The home range of the stoat radio-tracked in 2003 (JM1) was 84 ha with a range width of 1.4 km. The composition of his home range was 46% alpine grassland

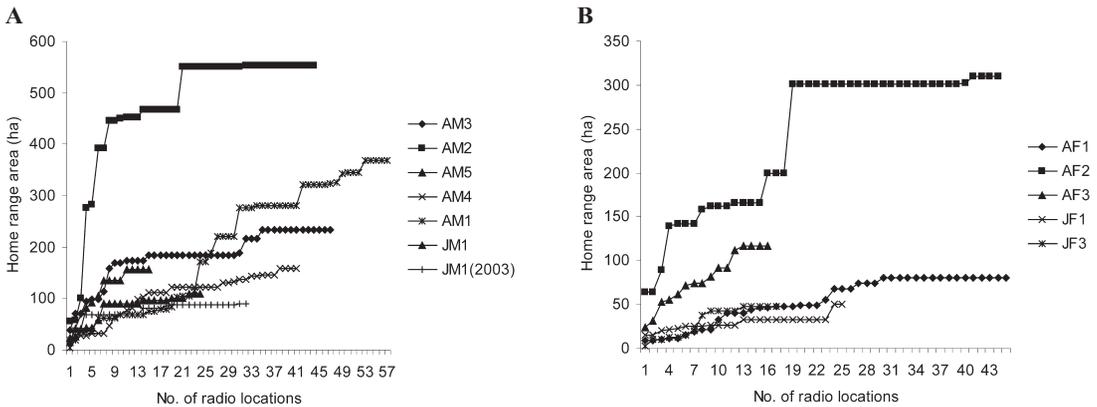
**Table 1.** Home-range and habitat-use parameters for stoats radio-tracked at the Borland Burn study sites between 6 January and 19 April 2004. Home ranges = 100% MCPs. % diff = how much larger, proportionately, a 3D home range is compared with a 2D home range. Under the column 'Stoat' A = adult, J = juvenile, F = female, M = male, e.g. AF1 = adult female 1. Range width is the distance across the home range at its widest point.

Stoat	No of locations	Tracking period (days) <sup>1</sup>	Home range (2D) (ha)	Home range (3D) (ha)	% diff	Core range (ha)	Range width (km)	% MCP in beech forest	% MCP in alpine grassland	% MCP in scrub	No. locations in beech forest	No. locations in alpine grassland	No. locations in scrub
1 (AF1)*	47	84	81.0	103	27	18	1.2	35.8	64.0	0.2	8	38	1
2 (AM1)*	57	82	351.0	418	19	100	2.8	57.5	39.3	3.3	27	27	3
3 (AM2)*	46	81	553.0	626	13	62	4.8	51.7	38.0	10.3	14	32	0
5 (AF2)*	46	81	310.0	350	13	64	2.6	9.0	88.1	2.9	1	45	0
6 (AM3)*	49	81	233.0	281	21	74	2.2	0.0	100.0	0.0	0	49	0
7 (JF1)*	27	80	50.0	55	10		1.2	0.0	100.0	0.0	0	27	0
8 (JF2)	9	29	151.0 <sup>+</sup>	176 <sup>+</sup>	16		2.0 <sup>+</sup>	0.0	100.0	0.0	0	9	0
9 (AF3)*	18	77	87.0	106	22		1.8	76.7	23.3	0.0	15	3	0
10 (JF3)	11	31	52.0 <sup>+</sup>	62 <sup>+</sup>	19		1.6 <sup>+</sup>	23.9	51.9	0.0	8	3	0
11 (AF4)	5	5	66.0 <sup>+</sup>	-			1.7 <sup>+</sup>	0.0	100.0	0.0	0	5	0
12 (AM4)*	43	48	159.0	176	11	110	1.8	8.8	86.2	5.0	3	35	5
13 (JF4)*	18	64	48.0	58	21		1.0	16.7	54.2	29.2	3	10	5
14 (AM5)*	26	47	109.0	127	17		1.8	23.9	61.5	14.7	4	20	2
15 (AF5)*	17	33	153.0	178	16		2.0	32.7	58.3	9.0	4	11	2
16 (JF5)	2	3	-	-			-	-	-	0.0	1	1	0
17 (JM2)	9	15	6.4 <sup>+</sup>	7 <sup>+</sup>	17		0.9 <sup>+</sup>	0.0	100.0	0.0	0	9	0
18 (JF6)	8	4	18.0 <sup>+</sup>	-			0.7 <sup>+</sup>	62.5	37.5	0.0	5	3	0
					Mean% diff	17				Total	93	327	18

\*Stoats used in the compositional analysis

<sup>+</sup>Estimates based off low radio-location sample sizes (estimates should be viewed as minimum observed movements)

<sup>1</sup>Tracking period is the time between first capture and the last radio location for a given animal



**Figure 1.** Incremental analyses of all stoats radio-tracked in the Borland Burn during summer 2003 and summer 2004. A = males, B = females.

and 54% beech forest. Despite this composition, 79% (26 out of 33) of JM1's radio locations were in alpine grasslands while 21% (7 out of 33) were in beech forest. The average home-range size for the 11 stoats radio-tracked in 2004, the home ranges of which could be estimated, was  $194 \pm 47.19$  ha (mean  $\pm$  SE) in two dimensions and  $225 \pm 53.67$  ha in three dimensions. The average values for each sex were  $121.5 \pm 37.23$  ha in two dimensions for females and  $141.67 \pm 45.46$  ha in three dimensions ( $n = 6$ ), and  $281 \pm 79.26$  ha in two dimensions for males and  $325.6 \pm 90.16$  ha in three dimensions ( $n = 5$ ) (error estimates and 95% confidence intervals are provided in Table 2). The 100% MCPs for these stoats are presented in Figure 2.

There were six stoats (AF1, AF2, AM1, AM2, AM3 and AM4) with large enough sample sizes to estimate range cores using kernel analysis. Their utilisation distributions are plotted in Figure 3, along with the points of inflexion used to identify the range cores. Range cores varied in size from 18 to 110 ha (Table 2). The range cores of most stoats exclude much of the

beech forest in their MCPs and any beech forest that is in their range cores is ecotonal (Fig. 4). In general, the range cores are centred in the high-altitude, alpine grassland parts of each stoat's MCP (Fig. 4).

#### Habitat use

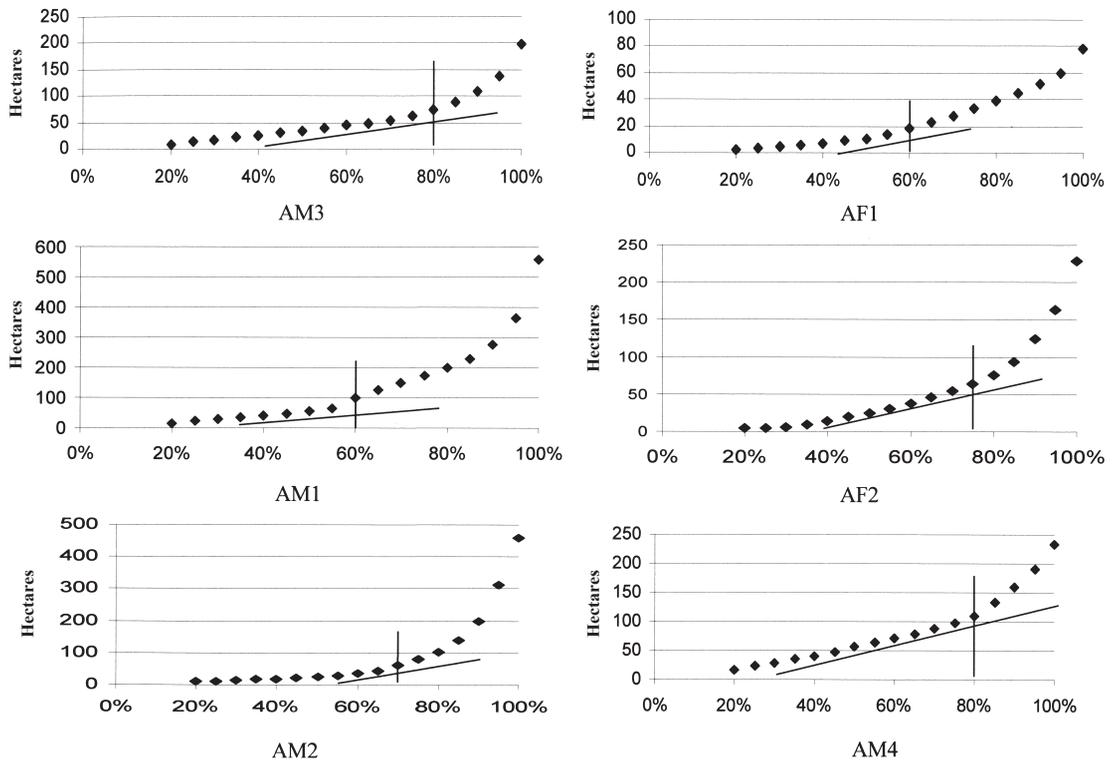
Data from the 11 stoats denoted with an asterisk in Table 1 were used in the compositional analysis. The composition ('available habitat') of their home ranges and the number of locations in each habitat ('used habitat') within their home ranges are shown in Table 1. Because compositional analysis does not work if the use of any habitat is 0% for a given animal, 0% was replaced with 0.1% in seven such situations, as recommended by Aebischer et al. (1993). Overall habitat use by stoats was non-random (Rand  $P = 0.043$ ). Alpine grasslands were ranked significantly over beech forest ( $t_8 = 2.72$ ,  $P = 0.026$ ), but there was no detectable difference between alpine grasslands and subalpine scrub ( $t_7 = 1.07$ ,  $P = 0.43$ ) or between subalpine scrub and beech forest ( $t_7 = -0.58$ ,  $P = 0.63$ ).

**Table 2.** Error and confidence interval estimates for the 11 stoats considered to have sufficient home-range information (denoted with an asterisk in Table 1). HR (home ranges; ha) = 100% MCPs; RW = range width (km); 2D = two dimensional; 3D = three dimensional.

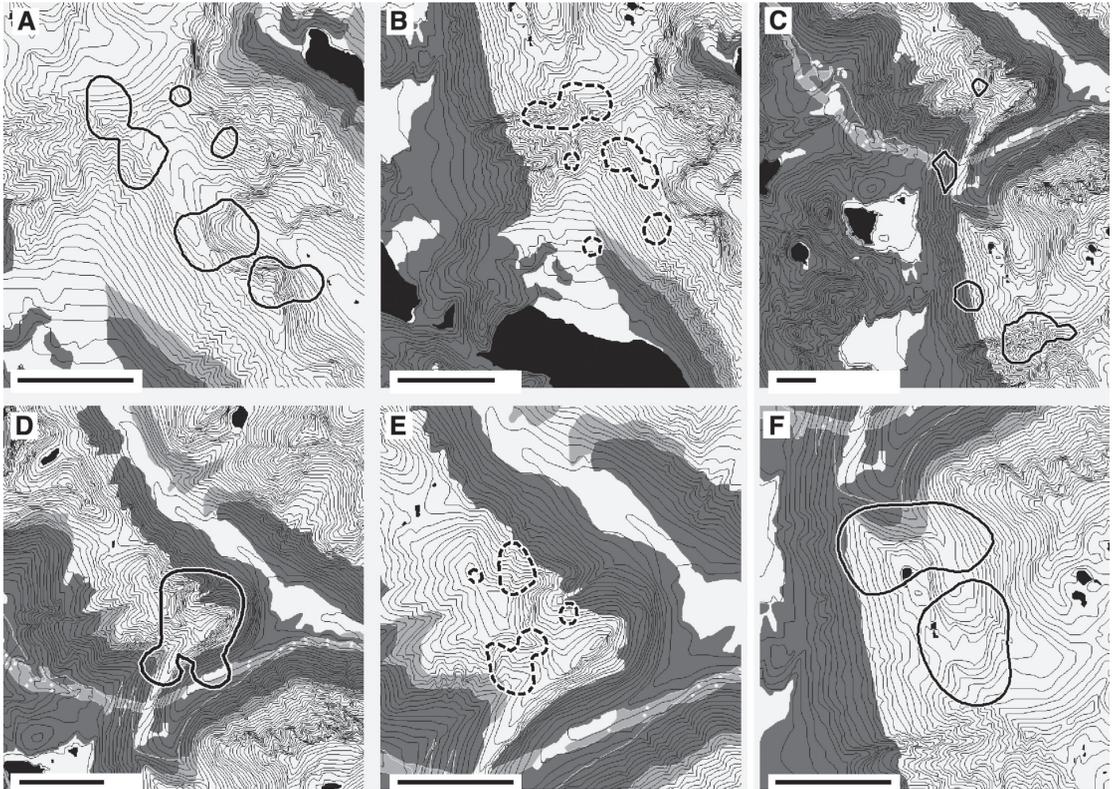
	Females ( $n = 6$ )			Males ( $n = 5$ )			Sexes combined ( $n = 11$ )		
	HR (2D)	HR (3D)	RW (2D)	HR (2D)	HR (3D)	RW (2D)	HR (2D)	HR (3D)	RW (2D)
Mean	121.50	141.67	1.63	281.00	325.60	2.68	194.00	225.27	2.12
SD	91.17	111.36	0.56	177.24	201.61	1.25	156.50	178.00	1.06
SE	37.22	45.46	0.23	79.26	90.16	0.56	47.19	53.67	0.32
95% C.I.	79.91	89.1	0.49	141.82	176.71	1.00	92.48	105.19	0.62



**Figure 2.** 100% Minimum Convex Polygons for the 11 stoats in the Borland Burn used in the compositional analysis (dots = females, solid lines = males). White heavily contoured areas are alpine grassland while dark grey areas are beech forest. Scale bar = 1 km.



**Figure 3.** Utilisation distributions of six stoats in the Borland Burn that had range cores estimated using kernel analysis. For each distribution the proportion of locations falling below the first point of inflexion (indicated with a vertical line) was used to estimate the range core. AF1 = 60%, AF2 = 75%, AM3 = 80%, AM2 = 70%, AM4 = 80%, AM1 = 60%.



**Figure 4.** Range cores of stoats inhabiting alpine grasslands in the Borland Burn, estimated using kernel analysis. (A) = AM3, (B) = AF2, (C) = AM2, (D) = AM1, (E) = AF1 and (F) = AM4. White heavily contoured areas = alpine grassland, dark grey areas = beech forest, light grey areas = subalpine scrub, black uncountoured areas are lakes. Scale bars = 1 km

## Discussion

These results provide evidence that stoats inhabiting high altitudes in south-eastern Fiordland National Park included alpine grassland within their home range during the summer and autumn of 2003 and 2004. The stoats observed in this research used alpine grassland significantly more often than adjacent beech forest. Their range cores were high up in alpine grassland and contained little beech forest (Fig. 4). Range cores are likely to represent den sites, or favoured foraging areas. These results show that these stoats lived in alpine grasslands and spent most of their time there, but that some of them made occasional forays into beech forest areas.

Four stoats that were present in both 2003 and 2004 were originally captured (during 2003) at trap sites within their 2004 home ranges. Nine of the stoats reported in these results were re-trapped at sites within their 2004 home ranges during a cull out of the

population in 2005 (Smith 2006). These observations indicate that this residency in alpine grasslands was maintained between years. It is not known whether these spatial patterns were maintained in winter, but it should not be assumed that stoats move down into the forest during the winter months.

Due to difficult field conditions, the sample sizes of radio locations on individual stoats are variable, with asymptotic approaches that were sometimes vague. However, when the period over which the 11 stoats (selected for compositional analysis) were radio-tracked is considered (Table 1), and given they can move up to 3 km in 3 hours (pers. obs.), there is little doubt these stoats were resident in the areas described by their home range estimates during the summer of 2004. However, given the ambiguity of incremental analysis and the effects of triangulation error, the MCPs should not be seen as precise. Instead, they indicate the scale of movement and home range of the stoats observed, and provide a useful framework

for developing hypotheses about the amounts of each habitat type available to each stoat.

The MCP estimates that took into account relief of the mountains (i.e. three dimensions) were on average 17% larger than those calculated in two dimensions (Table 1). These MCPs should be used by researchers who want to compare results from this study to MCPs calculated for stoats radio-tracked on flat terrain.

The power-line maintenance road did not fall within the home ranges of most stoats (Figs 2 & 4) and did not appear to influence their movements. It is also unlikely that the road permitted invasion of these sites by stoats, which occur at all altitudes throughout New Zealand (King & Murphy 2005), including alpine grasslands far from any road (Smith & Jamieson 2005).

The spatial and temporal replication of this research, when combined with Smith & Jamieson (2005), represents two sites and three summers. This suggests that stoats are likely to be present in alpine grasslands in other areas, which therefore are not acting as barriers to stoat dispersal. The research of Cuthbert et al. (2000) represents a third observation of stoats being present and active in the alpine environments of New Zealand.

Ground weta (*Hemiandrus* spp.) were the most common prey for stoats inhabiting alpine grasslands in the Borland Burn (Smith 2006) and the Murchison Mountains (Smith et al. 2005). Brown hare (*Lepus europaeus occidentalis*) were also common prey for stoats in the Borland Burn (Smith 2006), but hares are absent from the Murchison Mountains. In adjacent low-altitude beech forest in the Borland Burn, birds and mice were the most common prey of stoats (Smith 2006) and this is consistent with stoat diet studies in other beech forest sites in years where there is no heavy beech seedfall (Murphy & Dowding 1995). Ground weta and hares may in part be playing a role in the selection of alpine grasslands by stoats in the Borland Burn, but other ecological phenomena may also be important.

The presence of stoats in alpine grasslands has important implications for protected species management in national parks in New Zealand. The fact that out of 440 radio locations, collected on 17 stoats over a three and a half month period, none fell below 760 m a.s.l. indicates that potentially many stoats live well above the reach of valley-based control operations. While most control focuses on protecting forest species such as mōhua (*Mohoua ochrocephala*) and kākā (*Nestor meridionalis*) (Dilks et al. 2003), all mainland control areas in New Zealand are likely to be subject to reinvasion. The results of this research suggest that nearby high-altitude areas with significant areas of alpine grasslands may be potential sources of reinvasion. Trapping stoats in alpine grasslands will be logistically difficult and therefore expensive. However,

managers aiming to control stoats in different parts of Fiordland or in other national parks should assess whether stoats are present in alpine grasslands. Such assessment could be made using tracking tunnels (King & Edgar 1977).

The selection of alpine grasslands by stoats has the potential to be a complicating factor for conceptual models of stoat population biology developed for New Zealand's national parks, such as the beech mast model (King 1983). For example, what role do alpine grasslands play in the survival and recruitment of stoats in national parks such as Fiordland? Is it possible that stoats in alpine grasslands are important drivers of landscape-level population dynamics in national parks such as Fiordland? This research formed part of a more intensive investigation into stoat ecology in alpine grasslands in the Borland Burn, which concluded that during these years alpine grasslands were not a sink habitat for beech forest populations (Smith 2006). Therefore young stoats dispersing from alpine grasslands may influence landscape-level population dynamics in national parks such as Fiordland. Further, are indigenous species that inhabit alpine grasslands at risk from stoat predation? Such questions can only be answered with continued research.

## Acknowledgements

We thank G. Pickerell and P. Lei for assistance with fieldwork, and D. Shanahan for assistance with the use of GIS. This research was funded by the Department of Conservation's Stoat Technical Advisory Group (Research Contract: 3652) and the Zoology Department, University of Otago. We also thank C. King and an anonymous referee for many useful comments.

## References

- Aebischer NJ, Robertson PA, Kenward RE 1993. Compositional analysis of habitat use from animal radio-tracking data. *Ecology* 74: 1313–1325.
- Alterio N, Moller H 1997. Diet of feral house cats *Felis catus*, ferrets *Mustela furo* and stoats *M. erminea* in grassland surrounding yellow-eyed penguin *Megadyptes antipodes* breeding areas, South Island, New Zealand. *Journal of Zoology* 243: 869–877.
- Cuthbert R, Sommer E 2002. Home range, territorial behaviour and habitat use of stoats (*Mustela erminea*) in a colony of Hutton's shearwater (*Puffinus huttoni*), New Zealand. *New Zealand Journal of Zoology* 29: 149–160.
- Cuthbert R, Sommer E, Davis LS 2000. Seasonal variation in the diet of stoats in a breeding colony

- of Hutton's shearwaters. *New Zealand Journal of Zoology* 27: 367–373.
- Dilks P, Willans M, Pryde M, Fraser I 2003. Large scale stoat control to protect mohua (*Mohoua ochrocephala*) and kaka (*Nestor meridionalis*) in the Eglinton Valley, Fiordland, New Zealand. *New Zealand Journal of Ecology* 27: 1–9.
- Elliott GP 1996. Productivity and mortality of mohua (*Mohoua ochrocephala*). *New Zealand Journal of Zoology* 23: 229–237.
- Elliott GP, Dilks PJ, O'Donnell CFJ 1996. The ecology of yellow-crowned parakeets *Cyanoramphus auriceps* in *Nothofagus* forest in Fiordland, New Zealand. *New Zealand Journal of Zoology* 23: 249–265.
- Erickson PW, McDonald TL, Gerow KG, Howlin S, Kern JW 2001. Statistical issues in resource selection studies with radio-marked animals. In: Millsbaugh JJ, Marzluff JM eds *Radio tracking and animal populations*. San Diego, CA, USA, Academic Press. Pp. 209–242.
- Fitzgerald BM 1977. Weasel predation on a cyclic population of the montane vole (*Microtus montanus*) in California. *Journal of Animal Ecology* 46: 367–397.
- Grue HE, King CM 1984. Evaluation of age criteria in New Zealand stoats (*Mustela erminea*) of known age. *New Zealand Journal of Zoology* 11: 437–443.
- Kenward RE, South AB, Walls SS 2003. *Ranges 6 v1.2: For the analysis of tracking and location data*. Online manual. Wareham, UK, Anatrack.
- Kernohan BJ, Gitzen RA, Millspaugh JJ 2001. Analysis of animal space use and movements. In: Millspaugh JJ, Marzluff JM eds *Radio tracking and animal populations*. San Diego, CA, USA, Academic Press. Pp. 125–166.
- King CM 1983. The relationships between beech (*Nothofagus* sp.) seedfall and populations of mice (*Mus musculus*), and the demographic and dietary responses of stoats (*Mustela erminea*), in three New Zealand forests. *Journal of Animal Ecology* 52: 141–166.
- King CM, Edgar RL 1977. Techniques for trapping and tracking stoats (*Mustela erminea*); a review, and a new system. *New Zealand Journal of Zoology* 4: 193–212.
- King CM, McMillan CD 1982. Population-structure and dispersal of peak-year cohorts of stoats (*Mustela erminea*) in 2 New Zealand forests, with especial reference to control. *New Zealand Journal of Ecology* 5: 59–66.
- King CM, Murphy EC 2005. Stoat. In: King CM ed. *New Zealand handbook of mammals*. 2nd edn. Melbourne, Oxford University Press. Pp. 261–287.
- Lavers RB, Mills JA 1978. Stoat studies in the Murchison Mountains, Fiordland. In: *Seminar on the takahe and its habitat*. Invercargill, Wildlife Service, NZ Department of Internal Affairs.
- Lee WG, Jamieson IG 2001. *The takahe: fifty years of conservation management and research*. Dunedin, University of Otago Press. 132 p.
- Martinoli A, Preatoni DG, Chiarenzi B, Wauters LA, Tosi G 2001. Diet of stoats (*Mustela erminea*) in an Alpine habitat: the importance of fruit consumption in summer. *Acta Oecologica* 22: 45–53.
- McLennan JA, Potter MA, Robertson HA, Wake GC, Colbourne R, Dew L, Joyce L, McCann AJ, Miles J, Miller PJ, Reid J 1996. Role of predation in the decline of kiwi, *Apteryx* spp., in New Zealand. *New Zealand Journal of Ecology* 20: 27–35.
- Miller C, Elliott M, Alterio N 2001. Home range of stoats (*Mustela erminea*) in podocarp forest, South Westland, New Zealand: implications for a control strategy. *Wildlife Research* 28: 165–172.
- Mohr CO 1947. Table of equivalent populations of North American small mammals. *American Midland Naturalist* 37: 223–249.
- Murphy EC, Dowding JE 1995. Ecology of the stoat in *Nothofagus* forest: home range, habitat use and diet at different stages of the beech mast cycle. *New Zealand Journal of Ecology* 19: 97–109.
- Nelson L, Clark FW 1973. Correction for sprung traps in catch/effort calculations of trapping results. *Journal of Mammalogy* 54: 295–298.
- Purdey DC, King CM, Lawrence B 2004. Age structure, dispersion and diet of a population of stoats (*Mustela erminea*) in southern Fiordland during the decline phase of the beechmast cycle. *New Zealand Journal of Zoology* 31: 205–225.
- Rooney SM, Wolfe A, Hayden TJ 1998. Autocorrelated data in telemetry studies: time to independence and the problem of behavioural effects. *Mammal Review* 28: 89–98.
- Seaman DE, Powell RA 1996. An evaluation of the accuracy of kernel density estimators for home range analysis. *Ecology* 77: 2075–2085.
- Smith DHV 2002. *The movement, diet and relative abundance of stoats (Mustela erminea) in the Special Takahe Area, Fiordland National Park*. Unpublished MSc thesis, University of Otago, Dunedin, New Zealand.
- Smith DHV 2006. *Movements, population dynamics and predatory behaviour of stoats inhabiting alpine grasslands in Fiordland*. Unpublished PhD thesis, University of Otago, Dunedin, New Zealand.
- Smith DHV, Jamieson IG 2005. Lack of movement of stoats (*Mustela erminea*) between *Nothofagus* valley floors and alpine grasslands, with implications for the conservation of New Zealand's

- endangered fauna. *New Zealand Journal of Ecology* 29: 45–52.
- Smith DHV, Jamieson IG, Peach RME 2005. Importance of ground weta (*Hemiandrus* spp.) in stoat (*Mustela erminea*) diet in small montane valleys and alpine grasslands. *New Zealand Journal of Ecology* 29: 207–214.
- Smith PG 2001. Compositional Analysis Excel tool user's guide. Version 3.2. Unpublished: 1, Bettws Cottage, Bettws, Abergavenny, NP7 7LG, UK.
- White GC, Garrott RA 1990. Analysis of wildlife radio-tracking data. San Diego, CA, USA, Academic Press. 383 p.
- Wilson PR, Karl BJ, Toft RJ, Beggs JR, Taylor RH 1998. The role of introduced predators and competitors in the decline of Kaka (*Nestor meridionalis*) populations in New Zealand. *Biological Conservation* 83: 175–185.
- Worton BJ 1989. Kernel methods for estimating the utilization distribution in home-range studies. *Ecology* 70: 164–168.

Editorial Board member: Catriona MacLeod