Measuring stoat (*Mustela erminea*) and ship rat (*Rattus rattus*) capture success against micro-habitat factors

J.E. Christie[1,*], J. Kemp[1], C. Rickard[2] and E.C. Murphy[1]

[1]Research, Development & Improvement, Department of Conservation, P.O. Box 13 049, Christchurch, New Zealand

[2]Department of Conservation, P.O. Box 14, Franz Josef, New Zealand

[*]Author for correspondence (E-mail: jchristie@doc.govt.nz)

Abstract: The influence of micro-habitat on stoat (*Mustela erminea*) and rat (*Rattus rattus*) capture success was explored using trapping data collected from large scale predator control operations at the Okarito and Moehau Kiwi (*Apteryx* spp.) sanctuaries. Generalised linear models were used to explore the relationship between micro-habitat predictors and predator kill trapping records from individual trap sites. Our results suggest that micro-habitat information can provide useful predictors of rat and stoat capture success. Evidence from other studies and the current trapping regime provided a reasonable explanation for why some micro-habitat variables were or were not significantly associated with capture success. However, model complexity and the subjective trapping layout made interpretation of some variables challenging. Model results varied considerably between sanctuaries for the same species. We recommend reducing the number of micro-habitat variables to better reflect biological mechanisms; where possible recording variables continuously; nesting small-scale spatial variables within large-scale spatial variables; and standardising micro-habitat variables to allow model comparisons between trapping areas. Future research also needs to disentangle the effects of trapping edge and biased topographical layout from trap capture success. Good study design would resolve many of these problems. Results should help generate new and/or prioritise existing hypotheses for more focused research in the future.

Keywords: *Mustela erminea*; stoats; *Rattus rattus*; ship rats; predator control; micro-habitat; mustelid; kill traps.

Introduction

Introduced stoats (*Mustela erminea*) are a major threat to New Zealand's native fauna. Studies have shown that by reducing stoats to low population levels, survival and productivity of native species can be increased (Elliott, 1996; Basse *et al*., 1999; Gillies *et al*., 2003; Moorhouse *et al*., 2003). Trapping is one of the main tools used to control stoat populations. In recent years both the number and size of trapping operations have increased. Some populations of protected species have increased after stoat control, but predation continues to cause population declines for some native species in all or parts of their range (e.g. McLennan *et al*., 1996; O'Donnell, 1996). Therefore, there is a need to understand the factors that determine stoat distribution across the landscape.

Associated with these stoat trapping operations is a large rat (*Rattus* spp.) by-catch. Introduced rats are a major problem both directly and indirectly. Rats, predominantly ship rats (*Rattus rattus*), live successfully in indigenous New Zealand forests, where they exist on a variety of native fruit, invertebrates and birds (Innes, 2005), while also being an important food source for stoats (King and Murphy, 2005). Although not a major problem when at low densities, periodic surges in rat numbers can result in large reductions in populations of small forest birds and drive stoat populations up to much higher densities (Studholme, 2000; Dilks *et al*., 2003).

To date there has been limited analysis of trap catch data and the conditions that maximise stoat or rat capture rates. Knowledge of the habitat factors that may influence stoat and rat capture success is essential information for improved control strategies and thus improved conservation of endangered native species. Previous studies have investigated the influence of micro-site characteristics at trap sets (B. Lawrence and B. McKinley, Department of Conservation, Dunedin, unpubl. data), trapping grid design (Lawrence and O'Donnell, 1999), bait efficiency and tunnel design (Dilks *et al*., 1996) on stoat capture. By comparison, a number of studies in New Zealand and overseas have looked at patterns of ship rat habitat use (e.g. Dowding and Murphy, 1994; King *et al*., 1996; Blackwell *et al*., 1998; Cox *et al*., 2000; Studholme, 2000), and very

few have investigated trapability and trap success.

We were interested to see if exploratory analysis of trapping records, which are collected on a large scale and at relatively low cost, could be used to identify significant predictors and develop hypotheses as to which habitat factors are driving trap capture success. In this study, we used micro-habitat predictors to attempt to define the factors that maximise stoat and rat capture rates. Although it is possible some findings may result in immediate changes to trapping procedures, it is more likely this research will generate new, or help prioritise existing, hypotheses for focused research in the future. This information may assist in conservation interventions targeting stoats and rats.

Methods

Study areas

Micro-habitat and trapping data were collected from large-scale stoat trapping areas set up to protect kiwi (*Apteryx* spp.). Known as "kiwi sanctuaries", these trapping areas were located at Okarito (43° 15'S, 170°11'E), South Westland, and Moehau, at the tip of the Coromandel Peninsula (36° 43'S, 175° 31'E) (Fig. 1). Both study areas are indigenous forest ecosystems dominated by hardwood species. The underlying

Figure 1. Location of study areas.

landscape and climatic features vary considerably between the two areas. Okarito is a cold temperate lowland (0–520 m a.s.l.) coastal wetland podocarp-dominated forest ecosystem, whereas Moehau is a temperate coastal/alpine (20–860 m a.s.l.) forest ecosystem.

Wooden tunnels containing Mark IV Fenn kill traps were laid out on a semi-permanent basis at approximately 200-m intervals along linear landscape features such as streams and ridge lines. A total of 2200 wooden tunnels were laid out at the Moehau Kiwi Sanctuary covering about 16 500 ha. At Okarito 1500 tunnels covered an area of about 10 000 ha. At Moehau tunnels had one entrance and contained one trap, whereas at Okarito tunnels had two entrances and contained two traps. At both sanctuaries traps were set continuously, baited with one unbroken hen's egg, and checked every 2 weeks from summer to autumn, and once monthly over the winter and spring months.

A suite of micro-habitat predictor variables were recorded for most trap sites at Okarito (n = 1250 tunnels) and a subset of traps at Moehau (n = 360 tunnels). (Table 1). Direct comparison of same-species models between the two areas was not possible because different micro-habitat variables were recorded at each site.

Data analysis

A binary generalised linear model (Logistic regression: Hosmer and Lemeshow, 2000) was used to determine which variables (predictors) best explained the presence of trap capture success (response) for each trapping area. Two separate global models were constructed for each kiwi sanctuary, one for stoat captures and one for rat captures. Logistic regression is used for modelling binary response data by the method of maximum likelihood (SPSS 12.0 Software Products, Chicago, U.S.A. 2004). Where β_0 is the intercept parameter and β_{1-p} are the parameter intercepts:

$$\log\left(\frac{p}{1-p}\right) \rightarrow \beta_0 + \beta_1 X_1 + \ldots + \beta_p X_p$$

Trapping data sets contained information for each time a trap was checked on whether a stoat or rat was caught. Data were pooled within seasonal years for each sanctuary. A seasonal year follows the stoat breeding cycle and is more biologically plausible than a calendar year. This runs from the start of spring through to the end of winter in the following year (i.e. one "years" data). We had two "years" data from Okarito and one "years" data from Moehau. Therefore, our sample unit for the response variable was each trap each seasonal year, with each sample unit assigned either "1" for capture or "0" for no capture.
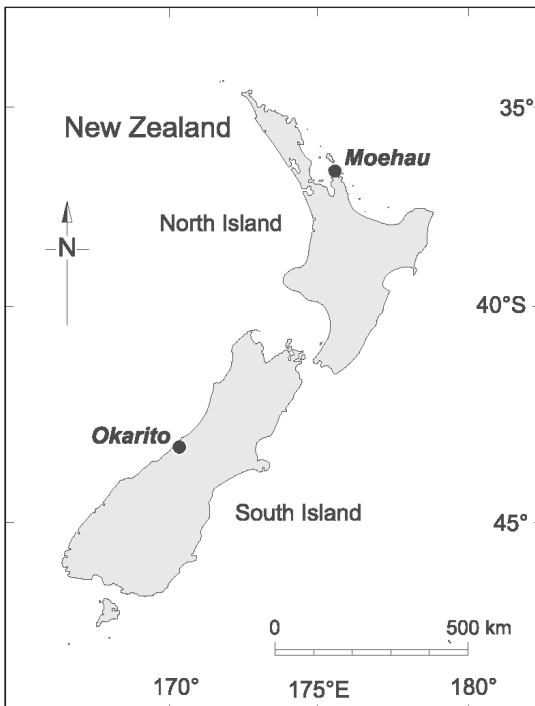
Table 1. Micro-habitat predictor variables used in the analysis.

Name of variable	Description	Type of variable	Unit
Okarito			
Watercourse	Distance to nearest permanent watercourse	Continuous	Scale
Sealed road edge	Presence of sealed road edge	Binary	0/1
Formed track edge	Presence of formed track edge	Binary	0/1
Lake edge	Presence of lake edge	Binary	0/1
Farm edge	Presence of farm edge	Binary	0/1
Stream edge	Presence of stream edge	Binary	0/1
Nearest edge	Distance to nearest edge	Continuous	Scale
Ridge	Presence of a ridge within a 50-m radius	Binary	0/1
Side slope	Presence of a side slope within a 50-m radius	Binary	0/1
Flat ground	Presence of flat ground within a 50-m radius	Binary	0/1
Undulating ground	Presence of undulating ground within a 50-m radius	Binary	0/1
Tall podocarp forest	Presence of tall podocarp dominated forest within a 100-m radius	Binary	0/1
Short sub-canopy forest	Presence of short sub-canopy forest within a 100-m radius	Binary	0/1
Supplejack	Presence of abundant supplejack (*Ripogonum scandens*) dominated forest within a 100-m radius	Binary	0/1
Gahnia	Presence of thick and abundant gahnia (*Gahnia setifolia*) dominated forest within a 100-m radius	Binary	0/1
Kiekie	Presence of thick and abundant kiekie (*Freycinetia baueriana*) dominated forest within a 100-m radius	Binary	0/1
Pakahi swamp	Presence of pakahi swamp within a 100-m radius	Binary	0/1
Drainage	Soil drainage class	Continuous	Scale
Understorey density 15 m	Understorey density (< 1 m height) within a 15-m radius	Continuous	Scale
Altitude	Elevation above sea level	Continuous	Metres
Trapping edge	Location of trap in the inner core trapping zone or trapping edge buffer zone	Binary	Buffer/core
Rat "plague" year	Rat "plague" year	Binary	0/1
Moehau			
Altitude	Elevation above sea level	Continuous	Metres
Ridge	Size class of ridge	Continuous	Scale
Stream	Size class of stream	Continuous	Scale
Hardwood/broadleaf forest	Presence of mature hardwood/broadleaf forest	Binary	0/1
Scrub mosaic	Presence of scrub, including subalpine scrub, grassland/manuka (*Leptospermum scoparium*) and kanuka (*L. ericoides*) scrub mosaics	Binary	0/1
Vehicle access	Class of vehicle road based on usage level and road surface grade	Continuous	Scale
Foot access	Class of track based on usage and track quality	Continuous	Scale
Slope	Estimated slope class	Continuous	Scale

Prior to model fitting, correlations between predictor variables were checked using the non-parametric Spearman's rank correlation statistic (Fowler *et al.*, 1998). Predictor variables with correlations of greater than 0.7 were fitted as single-parameter logistic regression models and compared. The variable with the biggest effect size was selected for inclusion in the global model.

Backward stepwise selection (i.e. the least significant predictor variables are sequentially removed from the global model) was then used to select the best model. The log-likelihood ratio test (Harraway, 1995) was used as the step function. The log-likelihood ratio test tests the significance (χ^2) of all predictor variables by removing one variable at a time from the model whilst leaving all others in place. Models were compared using the Akaike Information Criterion (AIC). AIC is a penalised version of the likelihood function in which the best model is given by the lowest value (Burnham and Anderson, 2000). To determine how good the final models were in an absolute sense, we used Receiver Operating Characteristic (ROC) plots (Fielding and Bell, 1997) and calculated the Area Under the ROC Curve (AUC) and its standard error,

using a non-parametric approach, as a measure of overall model fit. The AUC varies from 0.5 for a chance performance to 1.0 for a perfect fit.

Results

A total of four models (two rat, two stoat) were constructed for Moehau and Okarito. The ROC plots for all the models had AUC values of greater than 0.66 and were highly significant (Table 2). Therefore our model results were significantly better than a chance performance. The ROC plots (Fig. 2) and AUC values were better for the rat models than the stoat models. This is not surprising given that rat capture success was two-to-three times higher than stoat capture success within each sanctuary (Table 2).
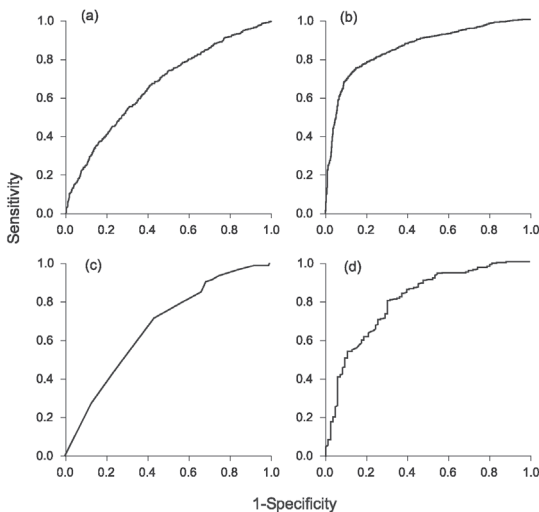

Figure 2. ROC plots for logistic regression models for (a) stoats at Okarito; (b) rats at Okarito; (c) stoats at Moehau; (d) rats at Moehau.

Stoat models

Nine micro-habitat variables were associated with captures of stoats at Okarito. Capture probabilities were highest with the presence of a track, road or farm edge, a ridge or flat topography and pakahi swamp habitat; whereas increasing altitude, drainage and understorey density within a 15-m radius had a negative association with stoat capture probabilities. At Moehau four micro-habitat variables were associated with stoat capture. Capture probabilities were highest with presence of mature hardwood/broadleaf forest and scrub habitats. Stoats were more likely to be caught as ridges became bigger and streams became smaller in size or were absent. Altitude, slope, vehicle and foot access had no effect on stoat capture probability (Table 3).

Rat models

Eleven micro-habitat variables were associated with rat capture at Okarito. Rat capture probability was highest in a rat plague year, in tall podocarp forest, shorter sub-canopy forest, forest with abundant kiekie (*Freycinetia banksii*), and in the core trapping area and near a road or farm edge, and when the dominant topography was not flat or undulating. At Moehau, six variables were associated with rat capture. Capture probability was highest with the presence of mature hardwood/broadleaf forest and scrub. Size of foot access track was positively associated with rat capture. In contrast increasing altitude, ridge size and road grade/usage was negatively associated with rat capture. Slope and stream size had no effect on rat capture probability (Table 3).

Discussion

Micro-habitat requirements of stoats

Evidence from our models suggested linear features such as forest margins and waterways increased the probability of stoat capture success. The probability of stoat capture success increased at Okarito when a road,

Table 2. Model summary statistics for rat and stoat micro-habitat models at Moehau and Okarito (AUC = Area Under the ROC Curve).

Location	Species model	No. of capture successes	Deviance of final model	ROC plot statistics		
				AUC	SE	*P*
Okarito (*n* = 2500)	Stoat	673	2729.9	0.668	0.012	<0.001
	Rat	1413	2315.7	0.855	0.008	<0.001
Moehau (*n* = 360)	Stoat	95	390.2	0.671	0.031	<0.001
	Rat	274	309.3	0.805	0.028	<0.001

Table 3. The best-fit multiple logistic regression models of the probability of stoat or rat capture at Okarito and Moehau as predicted by micro-habitat features (* = significant at the 5% level; ** = significant at the 1% level; *** = significant at the 0.1% level).

Location	Predictor variable	Stoat model			Rat model		
		Parameter estimate ± 1SE		Odds ratio	Parameter estimate ± 1SE		Odds ratio
Okarito	Constant	-0.871 ± 0.259	***	0.419	-1.416 ± 0.254	***	0.243
	Rat 'plague' year	-		-	2.971 ± 0.117	***	19.314
	Trapping edge (buffer/core)	-		-	-1.149 ± 0.202	***	0.318
	Altitude	-0.001 ± 0.001		0.999	-0.002 ± 0.001	***	0.998
	Road edge	1.139 ± 0.169	***	3.122	1.351 ± 0.266	***	3.861
	Track edge	1.562 ± 0.212	***	4.768	-		-
	Farm edge	0.631 ± 0.206	**	1.879	0.660 ± 0.301	*	1.935
	Undulate	-		-	-0.451 ± 0.141	***	0.637
	Flat	1.157 ± 0.200	***	3.181	-1.031 ± 0.296	***	0.357
	Ridge	0.786 ± 0.132	***	2.194	-		-
	Tall podocarp forest	-		-	1.705 ± 0.213	***	5.503
	Short sub-canopy forest	-		-	0.504 ± 0.284		1.656
	Abundant kiekie	-		-	1.069 ± 0.240	***	2.913
	Pakihi	1.350 ± 0.594	*	3.859	-		-
	Drainage	-0.183 ± 0.067	**	0.833	-0.253 ± 0.072	***	0.777
	Understorey 15 m	-0.131 ± 0.085		0.877	-		-
Moehau	Constant	-3.045 ± 0.680	***	0.048	2.170 ± 0.632	***	8.762
	Altitude	-		-	-0.004 ± 0.001	***	0.996
	Stream	-0.475 ± 0.304		0.622	-		-
	Ridge	0.404 ± 0.190	*	1.498	-0.559 ± 0.216	**	0.572
	Hardwood/broadleaf forest	1.890 ± 0.629	**	6.620	1.044 ± 0.523	*	2.840
	Scrub	1.570 ± 0.642	*	4.808	1.174 ± 0.508	*	3.234
	Slope	-		-	-		-
	Vehicle access	-		-	-0.994 ± 0.376	**	0.370
	Foot access	-		-	0.752 ± 0.430		2.121

track or farm margin was present. However, not all linear features increased the probability of stoat capture success. Some were not included in the final models and others such as increasing stream size at Moehau significantly decreased the probability of stoat capture success. Use of edges has been observed in a number of mammalian predator species, including other species of mustelids, and is generally linked to the perceived higher abundance of prey species and relative ease of travel through more open edge-habitat (e.g. Oehler and Litvaitis, 1996; Alterio *et al.*, 1998; Ragg and Moller, 2000) — although the validity of this link has been debated (Lariviere, 2003). Radio-tagging studies, both in New Zealand and overseas, suggest stoats travel along features that provide cover, such as edges, to avoid neighbouring open spaces (Erlinge, 1977; Murphy and Dowding, 1994, 1995; Alterio *et al.*, 1998). However, the amount of open habitat in ungrazed and heavily forested native ecosystems such as Moehau and Okarito will be minimal, suggesting stoats are unlikely to use edges in forested ecosystems for cover. Indeed, Murphy and Dowding (1994) found that stoats

in beech (*Nothofagus* spp.) forest in the South Island showed no preference for use of forest margins. This differential usage of forest margins suggests more research is needed to tease out the effects of forest margins on stoat capture success.

Variables such as a ridge as dominant topography, improving drainage and reducing understorey density at Okarito and presence of scrub or hardwood/broadleaf forest at Moehau also increased the probability of stoat capture success. However, interpretation of these variables was challenging. Variables were surrogates for the factors most likely to drive small mammal distribution — food availability and the presence of suitable shelter — which we were unable to directly measure. Stoats might be expected to avoid wet, poorly drained sites, where they are less likely to find the warm dry den sites they require (King, 1989) and are at higher risk of dying of exposure (Brown and Lasiewski, 1972). They may also seek out habitats where food such as rats and invertebrates are plentiful. However, the mechanisms driving these relationships with topography and habitat type are unclear. In a

related study at the same sites (J. Christie, unpubl. data), stoats were more likely to be caught at traps were a rat had already been caught. Categorical measurement is relatively coarse and may obscure subtle effects and clear interpretation of model results. Measurement of continuous vegetation factors such as species richness, composition and density would allow much better interpretation of model results.

The effects of forest margins and topography on stoat capture success are likely to be confounded by trap location. At both sites road and farm edges represented the sanctuaries trapping boundary. At Okarito traps along road margins were checked more frequently, and therefore would have been able to catch stoats more frequently. At Moehau, roads and farm edges were not included in the final stoat model, probably because the peninsula is also bounded by coast, restricting stoat access. However, at both sites traps on trapping boundaries would catch more stoats precisely because it is the trapping boundary, not because of any particular habitat features. Trapping boundaries are frequently placed along forest margins in both operational pest control operations and for scientific research (e.g. Dilks *et al.*, 1996). The subsequent elevated capture success on these trapping boundaries may have led to the perception that more stoats are caught on forest margins. Traps and tracks also tend to be placed along ridgelines (which tend to have good drainage) to ensure ease of access, thus biasing the dataset towards good drainage trap sites. Many of these factors are confounded by habitat features making them difficult to account for in a model. Future research needs to disentangle the effects of trapping edge and biased topographical layout from trap capture success. Good study design would resolve many of these problems.

Micro-habitat requirements of rats

Evidence from our models suggests that vegetation type has a significant influence on the probability of rat capture success. Rat capture success increased in mature hardwood/podocarp forest types at both sanctuaries and in habitats with scrub at Moehau. The relationship between ship rats and mature podocarp forest and scrub has been previously documented both in New Zealand (King *et al.*, 1996; Harper, 2002) and overseas (White *et al.*, 1997; Cox *et al.*, 2000). In accordance with other studies (Dowding and Murphy, 1994; King *et al.*, 1996; White *et al.*, 1997; Blackwell *et al.*, 1998), habitat margins, such as road and lake margins, either had no effect or decreased the probability of rat capture success. Apparently contradictory results at Okarito may reflect the increased frequency of trap checking around the road and farm edges which bound the trapping area. Vegetation type is also the likely driver behind decreasing rat capture success with increasing altitude, increasingly poor soil drainage, and various types of topography. The low soil fertility associated with poor drainage and high altitude means these sites are likely only to support specially adapted plant species (Leathwick *et al.*, 2003) and may not provide good food sources for rats.

It is likely that forest provides ship rats with a number of benefits. Firstly, ship rats often nest in trees and therefore forest should provide most nest sites (Dowding and Murphy, 1994; Innes, 2005). Secondly, forest may provide more reliable food sources. Ship rats are largely herbivorous, feeding mainly on seeds and flower material (Innes, 2005). Although ship rats in the New Zealand environment have been found to survive on arthropods, this likely reflects annual and seasonal paucity in fruit and seed resources (Innes, 2005). Heavy seeding events have resulted in large increases in rat abundance (Dilks *et al.*, 2003; Ruscoe *et al.*, 2004) and mature forest is likely to contain a greater volume of seed and flower material.

The spatial scale of the micro-habitat variables included in the models might also be important. In this study micro-habitat variables were either assessed over varying scales of 2–100 m or the scale was unspecified. A habitat assessment over a 50-m radius circle will be by necessity broad and lacking in detail, and is more suggestive of macro-scale measurement. Therefore, we were unable to ascertain whether smaller-scale habitat features, such as vegetation structure and habitat complexity, were driving rat capture success. By nesting micro- and macro-scale variables Cox *et al.* (2000) documented preferential use by ship rats of micro-habitats providing a dense understorey, numerous vertical stems and dense leaf litter cover over a 1-m radius within mature forest habitat. Measurement of both large- and small- scale spatial factors is essential to interpret patterns of habitat use and distribution of rats (Morris, 1987; Cox *et al.*, 2000).

How do the rat and stoat models compare?

Many of the micro-habitat variables were shared by the stoat and rat models within each sanctuary. This is not surprising given the majority of studies in podocarp forests indicate that ship rats are a principal food source for stoats (King, 1982; Murphy and Bradfield, 1992; Murphy *et al.*, 2004).

The probability of rat capture success was associated with a higher number of micro-habitat variables than that of stoat capture success. This may reflect differences in each species position in the food web, home range size, and capture rates. Stoats are first-order carnivores with large home ranges (King and Murphy, 2005) and in this study stoat capture rates were 2–3 times lower than for rats. Rats by comparison are further down the food chain, are omnivorous

generalists, and have much smaller home ranges (mean length < 200 m: Innes, 2005). Micro-habitat variables are by their nature small scale (i.e. 2–50 m radius) and reflect vegetation type either directly or indirectly through soil and landform descriptions. It is likely that rats have a closer biological link to these variables, via their position on the food chain and through their spatially restricted, smaller home range sizes. Moreover, distribution of stoat captures may not reflect stoat distribution *per se*. Stoat capture rates have been found to reduce when prey such as rodents are superabundant even though stoat density is high (King and White, 2004). This is likely to be the result of reduced interest in bait and smaller home range sizes (Murphy and Dowding, 1995; Cuthbert and Sommer, 2002; King and White, 2004). This may have affected model results at Okarito where rats reached high densities in the second year of data used in this study. This, along with the overall low number of stoat capture successes, may affect the predictive power of the models of stoat capture success. For these reasons rats may be more suited to distributional analysis of micro-habitat requirements than stoats.

Implications for future research

In future studies investigating the effects of micro-habitat on species occurrence patterns we recommend: reducing the number of micro-habitat variables to better reflect biological mechanisms; where possible recording variables continuously; nesting small-scale spatial variables within large-scale spatial variables; and standardising micro-habitat variables to allow model comparisons between trapping areas. Future research needs to disentangle the effects of trapping edge and biased topographical layout from trap capture success and should focus on habitat factors for which specific predictions can be made about the mechanisms that may be driving patterns of habitat use. This would allow clearer interpretation of models and allow analysis on any interacting factors. Good study design would resolve many of these problems.

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