Short-term influence of snow cover on movements and habitat use by brushtail possums (*Trichosurus vulpecula*)

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Abstract: Climatic events affect the behaviour and ecology of many mammal species (e.g. activity, body condition, home range sizes or predation risk). We investigated short-term changes in movements, activity and habitat use of brushtail possums (*Trichosurus vulpecula*) in response to two major snowfall events in a grassland ecosystem in the southern South Island of New Zealand during winter of 2011. Global positioning system collars were deployed on 21 possums. Generalised linear mixed models showed that, on average, possums reduced their movements and activity (measured by distances between consecutive fixes) during periods of snow cover. One hundred percent minimum convex polygon areas decreased by 37% on average, and 95% and 50% kernel density contour ranges decreased by 34% and 36%, respectively. Two to three possums (depending on the snowfall event) actually increased their movements during snow cover. No dramatic changes in habitat use were observed during the study but rock habitats were used slightly more often during snow periods, probably because rocks provide warmer and drier shelters during harsh weather conditions. Our study illustrates the behaviour of possums in seasonally harsh conditions outside their native range.

Keywords: activity; behavioural plasticity; invasive species; logistic regression

Introduction

The brushtail possum (*Trichosurus vulpecula* Kerr) has the widest native distribution of any Australian marsupial. It is naturally distributed along the eastern seaboard, far south-west, and north of Australia (Kerle 1984), but they are currently in decline throughout much of this range (Kerle et al. 1992; How & Hillcox 2000). In New Zealand, however, where possums were introduced in the 1830s to establish a fur industry (Pracy & Kean 1969), possums are now a major pest. They over-browse indigenous forest, and are vectors and reservoirs of bovine tuberculosis (*Mycobacterium tuberculosis* var. *bovis*) (Coleman & Caley 2000). Possums are successful in New Zealand presumably because of their broad environmental tolerance, their generalist feeding habits, and lack of competitors and predators (Clout & Ericksen 2000).

The biology of possums has been studied extensively in Australia and New Zealand over the past 50 years, but mostly in forest ecosystems. Recent studies in New Zealand's dry grassland/shrubland habitats, where winter snow is common, have revealed some different behaviour patterns to those in forest (Glen et al. 2012; Rouco et al. 2013). These dry ecosystems are located in the rain-shadow east of the main axial mountain ranges. In the South Island, dry ecosystems consist of indigenous and exotic grassland and shrubland species (Rogers et al. 2005), and are characterised by low rainfall and extreme variation in seasonal temperatures.

Snow cover is known to affect the behaviour and ecology of mammals (e.g. Trent & Rongstad 1974; Mysterud et al. 1997; Stenseth et al. 2004), such as reducing home range sizes (Parker et al. 1984; Sanecki et al. 2006a; Matthews & Green 2012) or reducing predation risk (Lindström & Hörnfeldt 1994). There have been several studies of the effects of snow cover on movement and foraging patterns on mammals in Australasia's alpine and subalpine environments. For example in Australia, snow cover affects the digging behaviour of bandicoots (e.g. *Chaeropus ecaudatus*, *Perameles eremiana*), and potoroos (*Potorous platyops*) when foraging for food (Claridge & Barry 2000; Claridge et al. 2008), and it affects the behaviour of other small mammals like bush-rat (*Rattus fuscipes*) and dusky antechinus (*Antechinus swainsonii*) (Sanecki et al. 2006a,b). Snow also affects the movement and foraging patterns of common wombats (*Vombatus ursinus*) (Mathews 2010; Mathews et al. 2010; Mathews & Green 2012) as well as macropods, such as swamp wallabies (*Wallabia bicolor*) and red-necked wallabies (*Macropus rufogriseus*) (Green et al. 2014). In New Zealand, there have been several studies of invasive mammal species in alpine environments (Forsyth & Hickling 1998; Smith et al. 2008; Wilson & Lee 2010), including possums (Parkes & Forsyth 2008), but none have examined the effects of snow cover on their behaviour. We had the opportunity during a research project on habitat selection by brushtail possums in New Zealand to investigate their response to widespread snow cover. We compared their movements, activity, and habitat use during periods with and without snow. We predicted that possums would reduce their movements and alter their use of habitat during periods of snow cover.

Material and methods

Study site

The study was undertaken at the Aldinga Conservation Area, a 400-ha area located in Central Otago in the southern South Island (45º17' S, 169º17' E). The area is at a mean elevation of 370 m above sea level. The climate is continental with extreme temperature fluctuations between summer, when temperatures can exceed 30°C, and winter, when snow is not uncommon and temperatures often drop below 0°C. Average annual rainfall (in the town of Alexandra, 7 km away) is 363 mm (New Zealand National Climate Database of the National Institute of Water and Atmospheric Research; see http://cliflo.niwa.co.nz). The site consists of highly modified semi-arid grassland/shrubland habitat, and contains three major habitat types (rock outcrops, open grass, and dense shrub), which are representative of typical dry grassland/shrubland ecosystems across the southern South Island. Shrub vegetation varies from scattered clumps to dense thickets of exotic sweet briar (*Rosa rubiginosa*) and indigenous matagouri (*Discaria toumatou*) and mingimingi (*Coprosma propinqua*). Pasture species included exotic sweet vernal (*Anthoxanthum odoratum*), brown top (*Agrostis capillaris*), and haresfoot trefoil (*Trifolium arvense*). The possum population we studied has never been subjected to control, and possums occur at densities of 0.4–0.7 per hectare (Rouco et al. 2013).

Monitoring periods and possum movements

Twenty-one possums (10 males, 11 females) were live-trapped in small cages, anaesthetised by intramuscular injection of Zoletil 100® (Virbac New Zealand, Auckland, NZ; Morgan et al. 2012), and fitted with GPS collars (Sirtrack, Havelock North, NZ). Collars had combined GPS and VHF components, and weighed approximately 140 g. To ensure collars were less than 5% of body mass (Animal Care and Use Committee 1998), only adult possums (3351.2 ± 118 g; mean ± 95% CI) (defined by the development of the pouch or testes; Ramsey et al. 2006) were collared. At the end of the study, possums were re-located using a Telonics TR-4 VHF (Phoenix, USA) tracking receiver and a collapsible three-element Yagi antenna (Sirtrack) to recover collars and download the GPS data. The GPS collars were configured to collect up to eight locations at hourly intervals during the night. Locations recorded within approximately 6 h after capture were deleted to avoid potential artefacts of capture. Locations with satellite-derived 'horizontal dilution of precision' (HDOP) greater than 10 were removed due to their inaccuracy (Recio et al. 2011). Because this method of screening inaccurate fixes is prone to discarding accurate data (D'Eon & Delparte 2005; Lewis et al. 2007), we visually assessed fixes with high HDOP values and compared them with the previous and subsequent 10 locations for that animal. If the fix with high HDOP was located inside the boundary of the other locations, it was considered to be biologically reasonable and retained for analysis; otherwise it was discarded. This resulted in 9% of the data being discarded.

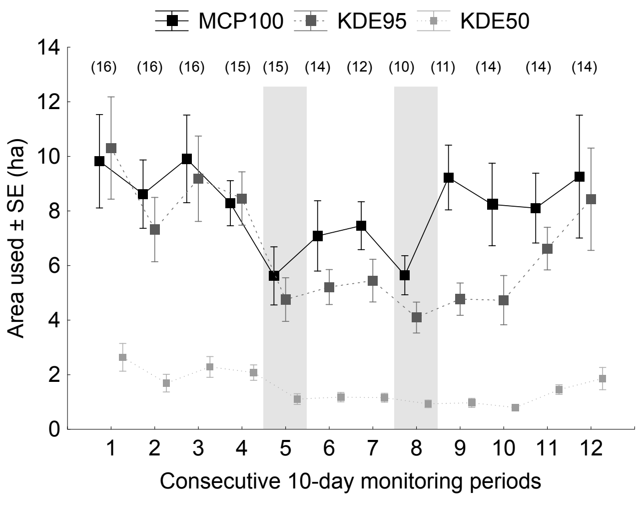

Figure 1. Mean area (± standard error, SE) used by possums during the study period, calculated as 100% minimum convex polygons (MCP100) and 95% kernel density estimates (KDE95) for each 10-day period. Core areas are represented by 50% kernels (KDE50). Shaded areas indicate periods with snow cover. Data points for each period are offset for clarity. Bracketed numerals indicate number of GPS-collared possums per period.

Possum monitoring was not performed exclusively for this study but for a larger research project, therefore we selected the GPS possum data before, during, and after the snowfall events (i.e. from 1 June to 30 September 2011). Between 12 July and 22 August, two major snowfall events occurred. In both cases, 30–50 cm of snow covered the ground for approximately 10 days. Therefore, we divided the study into 12 periods of 10 days each. The first four 10-day periods (P1–P4) were before the first snowfall occurred. The two periods with snow cover (P5 and P8) were each followed by snow-free periods, two between snowfall events (P6, P7) and four after the last snowfall event (P9–P12). Not all the collared possums were collecting fixes during all the periods (see Fig. 1). On average (± 95% CI), 55.9 ± 3.9 fixes were obtained per animal for each 10-day period. Three days separated each period to ensure snow was either fully present or fully absent on the ground. The timing and duration of snow cover was obtained from daily satellite imagery from Near Real-Time Data obtained by Moderate Resolution Imaging Spectroradiometer (NRT-MODIS subset, 500-m resolution, available in http://lance-modis.eosdis.nasa.gov) in Google Earth.

Habitat use

The percentage of the three habitat types at the study site was determined by digitising habitat types from ortho-restricted aerial photographs and converting them to a rasterised habitat map (5-m resolution) using ArcGIS 10 software (ESRI, Redlands, California, USA). The study site consisted of 70% grass (open unimproved pasture with sparse shrub species), 20% shrub (areas with 50–100% shrub cover) and 10% rock (rock outcrops with occasional shrubs). We determined the relative use of each habitat type by possums during the periods with and without snow cover. We used ArcGIS software to overlay all possum fixes on the habitat map, and quantified the relative use of habitats by each possum as the proportion of fixes in each habitat type.

Data analysis

Area used

Areas used by possums were calculated using two estimators: 100% minimum convex polygons (MCP100), and the 95% and 50% kernel density contour range estimates (KDE95 and KDE50, respectively). We used the 'adehabitatHR' package (Calenge 2006) in the R statistical computing environment (version 3.0.2, R Core Team 2013). The KDE95 estimate corresponds to the smallest area over which the probability of locating an animal is 0.95 (Calenge 2006). This estimator generally provides more accurate estimates of range use than the MCP100 (Seaman et al. 1999; Börger et al. 2006) as the MCP100 includes longer-distance forays away from the core home range (Laver & Kelly 2008). Similarly for the KDE50 estimate, the probability of locating an animal is 0.5. This generally represents the core area of the home range (Matthews & Green 2012). The KDE estimates were calculated using the least-squares cross-validation smoothing parameter (Seaman et al. 1999), and the MCP estimates were calculated using the harmonic mean peel centre (Blackie et al. 2011). Areas were log-transformed to satisfy assumptions of normality and homogeneity of variances.

Incremental area analyses were undertaken to confirm that the areas used by possums were fully revealed within the time frame of each 10-day monitoring period and, therefore, comparisons were not biased between periods (Laver & Kelly 2008). Home ranges were considered to be fully revealed if there was an asymptotic relationship between the number of locations collected within the monitoring time frame, and the area used. Incremental area analysis for MCP100s was carried out in Ranges6 (Kenward et al. 2003; Laver & Kelly 2008) and visually establishing if an asymptote was reached (Laver & Kelly 2008; Recio et al. 2010). Asymptotes were reached with an average of 30–40 randomly selected locations collected at one-hourly intervals. Therefore, locations over 10 days fully revealed the area used by possums.

To test our prediction that areas used by possums would decrease during periods of snow cover, we undertook a model selection approach using generalised linear mixed models (GLMMs) (package 'lme4' procedure in program R version 3.0.2) with a normal error structure and an identity link function. We ran separate models for each estimator (i.e. MCP100, KDE95 and KDE50). To test the effect of snow cover on areas used by possums, we ran a model for each estimator using the presence or absence of snow as the explanatory variable. Possum identification was included as a random factor in the models.

Activity

We calculated the straight-line distance between consecutive fixes (inter-fix distance) as a measure of activity (Ungar et al. 2005) using the Geospatial Modelling Environment 0.7.2.0 (Beyer 2012). To test whether possum activity decreased during periods of snow cover, we ran a GLMM (same procedure as above) with inter-fix distance as the response variable. Inter-fix distances were log-transformed to satisfy assumptions of normality and homogeneity of variances. The same explanatory variable and random factor were used as outlined above.

Habitat used

To test whether there was a change in use of habitat type between periods with and without snow cover, we ran a mixed logistic regression with a binomial error structure and a logit link function. We used snow cover as a binomial response factor (1 = present, 0 = absent) and possum ID as a random factor. We ran separate models for each habitat type (i.e. grass, shrub, and rock), which were used as our explanatory variables.

Results

All three estimators of areas used by possums decreased significantly on average during periods of snow cover (Table 1, Fig. 1). However, not every possum responded in the same way. During the first snow period, the MCP100 estimates of 10 possums declined by 56.4% (± 7.9 SE) on average, but two increased by 19% (±3.4), and three did not change (i.e. less than ± 0.5 ha variation in area used). For the KDE95 estimates, the areas used by 13 possums decreased by 55.6% (±6), but three increased by 40.4% (±8.4). For the KDE50 estimates, the areas used by 13 possums decreased by 57.5% (±6.5), and two did not change. During the second snow period, the MCP100 estimates of nine possums declined by 43% (±9.4) on average, except for one possum whose area did not change. Similarly for the KDE95 estimates, declines of 37% (±8.2) on average were recorded, except for two possum whose areas increased by 27% (±10). And finally, the KDE50 estimates declined by 53% (±11.8) on average, except for two possums whose areas did not change.

Possum activity declined overall during the snow cover periods (ß = −0.318, SE = 0.032, 95% CI = −0.38, −0.25, t = −9.91). Mean inter-fix distances nearly halved during the first snow period, then steadily increased thereafter (Fig. 2). During the second snow period, mean inter-fix distances levelled off and then continued to rise as the snow melted. Inter-fix distances during the last monitoring period were back to levels similar to those before the snow events (Fig. 2).

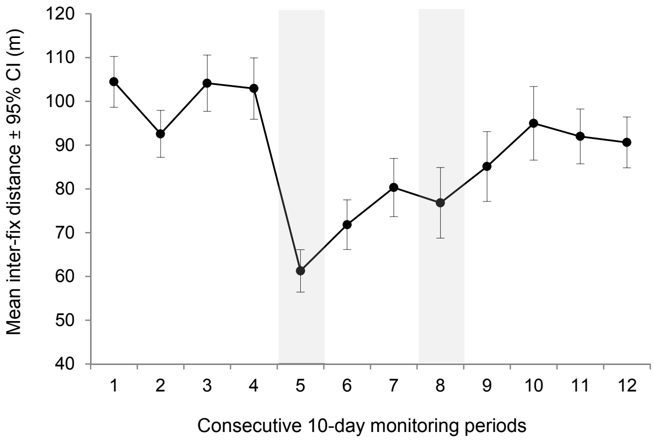

Figure 2. Mean (± 95% confidence intervals) straight-line distances (m) between consecutive GPS fixes during each 10-day period. Shaded areas indicate periods with snow cover.

Table 1. Results of generalised linear mixed model (GLMM) for areas (ha) used by possums between 10-day periods with and without snow cover. Models were run for each estimator – 100% minimum convex polygons (MCP100), 95% kernel density estimates (KDE95) and 50% kernel density estimates (KDE50) – of area used by possums. All t-values were statistically significant.

Model	Fixed effect	β	SE	−95%CI	+95%CI	t-value
MCP100	Intercept	2.379	0.239	1.911	2.847	9.96
	Snow	−0.486	0.104	−0.689	−0.283	−4.69
KDE95	Intercept	2.246	0.219	1.817	2.675	10.26
	Snow	−0.420	0.112	−0.639	−0.202	−3.77
KDE50	Intercept	0.869	0.200	0.477	1.261	4.330
	Snow	−0.332	0.107	−0.542	−0.123	−3.108

Grass habitats were the most frequently used habitat by possums, followed by shrub (Fig. 3). No difference in use of grass and shrub habitats was found between periods with and without snow cover (Table 2, Fig. 3a,b). However, possums significantly increased their use of rock habitats during periods of snow cover (Table 2, Fig. 3c).

Discussion

Most possums reduced their areas of use, and activity (defined by inter-fix distances), during periods of snow cover. Reduced movements during periods of snow cover have been observed for marsupial species in Australia (Matthews & Green 2012), as well as for rodents (Sanecki et al. 2006a), and is consistent with other species such as wombat (Matthews & Green 2012), hare (*Lepus timidus*) (Kauhala et al. 2005), and elk (*Cervus elaphus*) (Anderson et al. 2005), but it is the first time, to our knowledge, that it has been described for brushtail possums. Reduced movements and activity were not unexpected as severe winter conditions are known to often have direct negative effects on animals, for example by increasing the energetic costs of thermoregulation and locomotion (Mysterud et al. 2001). Also, snow cover reduces access to high quality forage for herbivores (Van Vuren & Armitage 1990; Nordengren et al. 2003). Conservation of energy during snow periods appears to be the case for some mammals in seasonally snow-covered environments (Parker et al. 1984; Benson et al. 2006; Sanecki et al. 2006a). On the other hand, some small mammals (e.g. mice, voles, lemmings) move beneath the snow in the subnivean layers because it is easier, safer, and warmer than moving across it (Lindström & Hörnfeldt 1994; Heisler et al. 2014). Some medium-sized mammals, like martens (*Martes americana*), use the subnivean layers for resting (Buskirk et al. 1989). Brushtail possums are probably too big to use the subnivean layer in New Zealand. Apart from conserving energy, the reduction in inter-fix distances suggests they may find it difficult to move about in snow, as shown for some larger herbivores (Mysterud et al. 1997; Luccarini et al. 2006).

There was marked variation in the response of individual possums to snow cover, with some possums actually increasing the areas they used. The possums that increased their mobility were of no particular sex or body size, but they all resided in open grass habitats in between major gullies. Open grass habitats support fewer sweet briar shrubs compared with gullies. Possums feed intensively on the fruits of these shrubs, especially during winter (Glen et al. 2012; Rouco & Norbury 2013). Therefore, the grass-dwelling possums in the open grass habitats may have had to search over a wider area to meet their nutritional requirements during the snow events (Anderson et al. 2005; Kauhala et al. 2005).

No dramatic changes in habitat use were observed during the study, but use of rock habitats increased slightly during snow periods. A study of possum denning behaviour at our study site in the autumn and winter of 2010 showed most dens (~60%) were in rock outcrops, followed by shrubs (~35%). Rock shelters tend to be drier and warmer than dens in shrubs or open grassland (C. Rouco unpubl. data).

Our study illustrates the behaviour of possums in seasonally harsh conditions outside their native range. The findings have implications for improving the cost-effectiveness of controlling possum populations. Control operations in New Zealand (using traps or poison baits) usually occur in winter. Because most possums reduced their movements during periods of snow cover, the effectiveness of control at these times will sometimes be reduced because possums will be less likely to encounter control devices when snow covers the ground. Control operations using ground-based control techniques in dry grassland ecosystems should therefore endeavour to avoid periods of snow cover.

Table 2. Results of mixed logistic regression for changes in habitat type used by possums between periods with and without snow cover. Models were run for each habitat type (* $P < 0.05$). 'n.s.' indicates no significant difference.

Model	β	SE	*z*-value	*P*-value
Grass	−0.016	0.16	−0.1	n.s
Shrub	−0.26	0.18	−1.45	n.s
Rock	0.5	0.24	2.1	*

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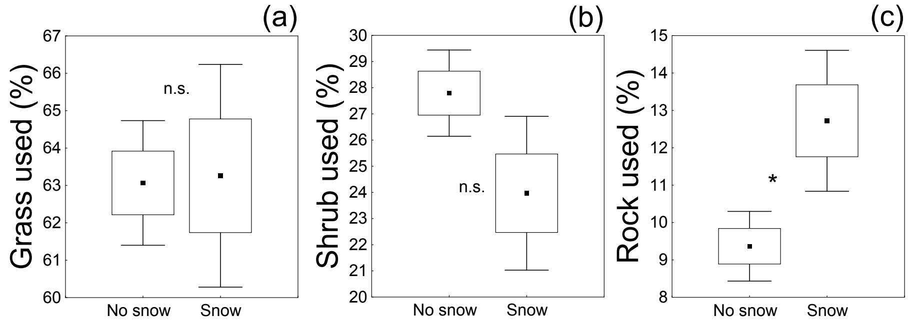

Figure 3. Box plots showing proportion of fixes of possums in (a) grass, (b) shrub, and (c) rock habitats during periods with snow and without snow cover. The dark square inside each box indicates the mean, the bottom and top of each box indicate the standard error, and the whiskers below and above each box indicate the 95% confidence intervals. Asterisk between boxes indicates significant difference (*$P < 0.05$) between periods with snow and without snow cover. 'n.s.' indicates no significant difference.

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References

Anderson DP, Forester JD, Turner MG, Frair JL, Merrill EH, Fortin D, Mao JS, Boyce MS 2005. Factors influencing female home range sizes in elk (*Cervus elaphus*) in North American landscapes. Landscape Ecology 20: 257–271.

Animal Care and Use Committee 1998. Guidelines for the capture, handling, and care of mammals as approved by the American Society of Mammalogists. Journal of Mammalogy 74: 1416–1431.

Benson JF, Chamberlain MJ, Leopold BD 2006. Regulation of space use in a solitary felid: population density or prey availability? Animal Behaviour 71: 685–693.

Beyer HL 2012. Geospatial modelling environment (version 0.7.2.0). [software] URL: http://www.spatialecology.com/gme.

Blackie HM, Russell JC, Clout MN 2011. Maternal influence on philopatry and space use by juvenile brushtail possums (*Trichosurus vulpecula*). Journal of Animal Ecology 80: 477–483.

Börger L, Franconi N, Ferretti F, Meschi F, De Michele G, Gantz A, Coulson T 2006. An integrated approach to identify spatiotemporal and individual-level determinants of animal home range size. American Naturalist 168: 471–485.

Buskirk SW, Forrest SC, Raphael MG, Harlow HJ 1989. Winter resting site ecology of marten in the central Rocky Mountains. Journal of Wildlife Management 53: 191–196.

Calenge C 2006. The package "adehabitat" for the R software: A tool for the analysis of space and habitat use by animals. Ecological Modelling 197: 516–519.

Claridge AW, Barry SC 2000. Factors influencing the distribution of medium-sized ground-dwelling mammals in southeastern mainland Australia. Austral Ecology 25: 676–688.

Claridge AW, Tennant P, Chick R, Barry SC 2008. Factors influencing the occurrence of small ground-dwelling mammals in southeastern mainland Australia. Journal of Mammalogy 89: 916–923.

Clout MN, Ericksen K 2000. Anatomy of a disastrous success: the brushtail possum as an invasive species. In: Montague TL ed. The brushtail possum: biology, impact and management of an introduced marsupial. Lincoln, Manaaki Whenua Press. Pp. 1–9.

Coleman J, Caley P 2000. Possums as a reservoir of bovine Tb. In: Montague TL ed. The brushtail possum: biology, impact and management of an introduced marsupial. Lincoln, Manaaki Whenua Press. Pp. 92–104.

D'Eon RG, Delparte D 2005. Effects of radio-collar position and orientation on GPS radio-collar performance, and the implications of PDOP in data screening. Journal of Applied Ecology 42: 383–388.

Forsyth DM, Hickling GJ 1998. Increasing Himalayan tahr and decreasing chamois densities in the eastern Southern Alps, New Zealand: evidence for interspecific competition. Oecologia 113: 377–382.

Glen AS, Byrom AE, Pech RP, Cruz J, Schwab A, Sweetapple PJ, Yockney I, Nugent G, Coleman M, Whitford J 2012. Ecology of brushtail possums in a New Zealand dryland ecosystem. New Zealand Journal of Ecology 36: 29–37.

Green K, Davis NE, Robinson WA 2014. Does diet constrain the occupation of high elevations by macropods? A comparison between *Macropus rufogriseus* and *Wallabia bicolor*. Australian Mammalogy 36: 219–228.

Heisler LM, Somers CM, Poulin RG 2014. Rodent populations on the northern Great Plains respond to weather variation at a landscape scale. Journal of Mammalogy 95: 82–90.

How RA, Hillcox SJ 2000. Brushtail possum, *Trichosurus vulpecula*, populations in south-western Australia: demography, diet and conservation status. Wildlife Research 27: 81–89.

Kauhala K, Hiltunen M, Salonen T 2005. Home ranges of mountain hares *Lepus timidus* in boreal forests of Finland. Wildlife Biology 11: 193–200.

Kenward RE, South AB, Walls SS 2003. Ranges 6 v1.2: For the analysis of tracking and location data. Online manual. Wareham, UK, Anatrack. http://www.anatrack.com/

Kerle JA 1984. Variation in the ecology of *Trichosurus*: its adaptive significance. In: Smith AP, Hume ID eds Possums and gliders. Sydney, Surrey Beatty. Pp. 115–128.

Kerle JA, Foulkes JN, Kimber RG, Papenfus D 1992. The decline of the Brushtail Possum, *Trichosurus vulpecula (*Kerr 1798), in arid Australia. Rangeland Journal 14: 107–127.

Laver PN, Kelly MJ 2008. A critical review of home range studies. Journal of Wildlife Management 72: 290–298.

Lewis JS, Rachlow JL, Garton EO, Vierling LA 2007. Effects of habitat on GPS collar performance: using data screening to reduce location error. Journal Applied Ecology 44: 663–671.

Lindström ER, Hörnfeldt B 1994. Vole cycles, snow depth and fox predation. Oikos 70: 156–160.

Luccarini S, Mauri L, Ciuti S, Lamberti P, Apollonio M 2006. Red deer (*Cervus elaphus*) spatial use in the Italian Alps: home range patterns, seasonal migrations, and effects of snow and winter feeding. Ethology, Ecology and Evolution 18: 127–145.

Matthews A 2010. Changes in fine-scale movement and foraging patterns of common wombats along a snow-depth gradient. Wildlife Research 37: 175–182.

Matthews A, Green K 2012. Seasonal and altitudinal influences on the home range and movements of common wombats in the Australian Snowy Mountains. Journal of Zoology 287: 24–33.

Matthews A, Spooner PG, Lunney D, Green K, Klomp NI 2010. The influences of snow cover, vegetation and topography on the upper range limit of common wombats *Vombatus ursinus* in the subalpine zone, Australia. Diversity and Distributions 16: 277–287.

Morgan DR, Scobie S, Arthur DG 2012. Evaluation of Zoletil and other injectable anaesthetics for field sedation of brushtail possums (Trichosurus vulpecula). Animal Welfare 21: 457–462.

Mysterud A, Bjørnsen BH, Østbye E 1997. Effects of snow depth on food and habitat selection by roe deer *Capreolus capreolus* along an altitudinal gradient in south-central Norway. Wildlife Biology 3: 27–33.

Mysterud A, Stenseth NChr, Yoccoz NG, Langvatn R, Steinheim G 2001. Nonlinear effects of large-scale climatic variability on wild and domestic herbivores. Nature 410: 1096–1099.

Nordengren C, Hofgaard C, Ball JP 2003. Availability and

quality of herbivore winter browse in relation to tree height and snow depth. Annales Zoologici Fennici 40: 305–314.
Parker KL, Robbins CT, Hanley TA 1984. Energy expenditure for locomotion by mule deer and elk. Journal of Wildlife Management 48: 474–488.
Parkes J, Forsyth DM 2008. Interspecific and seasonal dietary differences of Himalayan thar, chamois and brushtail possums in the central Southern Alps, New Zealand. New Zealand Journal of Ecology 32: 46–56.
Pracy LT, Kean RI 1969. The opossum in New Zealand; habits and trapping. Publicity Item No. 40. Wellington, New Zealand Forest Service. 51 p.
R Core Team 2013. R: A language and environment for statistical computing. Version 3.0.2. Vienna, Austria, R Foundation for Statistical Computing. ISBN 3-900051-07-0. http://www.R-project.org/.
Ramsey DSL, Coleman JD, Coleman MC, Horton P 2006. The effect of fertility control on the transmission of bovine tuberculosis in wild brushtail possums. New Zealand Veterinary Journal 54: 218–223.
Recio MR, Mathieu R, Maloney R, Seddon PJ 2010. First results of feral cats (*Felis catus*) monitored with GPS collars in New Zealand. New Zealand Journal of Ecology 34: 288–296.
Recio MR, Mathieu R, Denys P, Sirguey P, Seddon PJ 2011. Lightweight GPS-tags, one giant leap for wildlife tracking? An assessment approach. PLoS ONE 6: e28225. doi:10.1371/journal.pone.0028225.
Rogers G, Walker S, Lee B 2005. The role of disturbance in dryland New Zealand: past and present. Science for Conservation 258. Wellington, Department of Conservation. 122 p.
Rouco C, Norbury GL 2013. An introduced species helping another: dispersal of a rose seed infesting wasp by a marsupial in New Zealand. Biological Invasions 15: 1649–1652.

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Rouco C, Norbury GL, Smith J, Byrom AE, Pech RP 2013. Population density estimates of brushtail possums (*Trichosurus vulpecula*) in dry grassland in New Zealand. New Zealand Journal of Ecology 37: 12–17.
Sanecki GM, Green K, Wood H, Lindenmayer D, Sanecki KL 2006a. The influence of snow cover on home range and activity of the bush-rat (*Rattus fuscipes*) and the dusky antechinus (*Antechinus swainsonii*). Wildlife Research 33: 489–496.
Sanecki G, Cowling A, Green K, Wood H, Lindenmayer DB 2006b. Winter distribution of small mammals in relation to snow cover in the subalpine zone, Australia. Journal of Zoology 269: 99–110.
Seaman DE, Millspaugh JJ, Kernohan BJ, Brundige GC, Raedeke KJ, Gitzen RA 1999. Effects of sample size on kernel home range estimates. Journal of Wildlife Management 63: 739–747.
Smith DHV, Wilson DJ, Moller H, Murphy EC 2008. Using artificial nests to explore predation by introduced predators inhabiting alpine areas in New Zealand. New Zealand Journal of Zoology 35: 119–128.
Stenseth NChr, Shabarr A, Chan K-S, Boutin S, Knispel Rueness E, Ehrich D, Hurrell JW, Lindjaerde OChr, Jakobsen KS 2004. Snow conditions may create an invisible barrier for lynx. Proceedings of the National Academy of Sciences (USA) 101: 10632–10634.
Trent TT, Rongstad OJ 1974. Home range and survival of cottontail rabbits in southwestern Wisconsin. Journal of Wildlife Management 38: 459–472.
Ungar ED, Henkin Z, Gutman M, Dolev A, Genizi A, Ganskopp D 2005. Inference of animal activity from GPS collar data on free-ranging cattle. Rangeland Ecology & Management 58: 256–266.
Van Vuren D, Armitage KB 1990. Duration of snow cover and its influence on life-history variation in yellow-bellied marmots. Canadian Journal of Zoology 69: 1755–1758.
Wilson DJ, Lee WG 2010. Primary and secondary resource pulses in an alpine ecosystem: snow tussock grass (*Chionochloa* spp.) flowering and house mouse (*Mus musculus*) populations in New Zealand. Wildlife Research 37: 89–103.