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The implications of snow-based recreation for small mammals in the subnivean space in south-east Australia

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ABSTRACT

The increasing popularity of snow-based recreation activities and the development of ski resorts and associated infrastructure have the potential to affect adversely small mammal fauna that over-winter in the subnivean space. We investigated the effects of human activities on the maintenance of the subnivean space, which is critical to the over-winter survival of small terrestrial mammals in Kosciuszko National Park, south-eastern Australia.

The creation of ski pistes, surface ski lifts and over-snow routes involves compression of the snowpack and resulted in small or absent subnivean spaces (average 1.2 cm) and high snow cover densities (generally over 0.5 g cm^{-3} and 0.35 g cm^{-3} respectively). By contrast, the subnivean spaces associated with unmodified snow cover averaged 8–20 cm depending on vegetation type. The density of unmodified snowpack was less than 0.35 g cm^{-3} in June but increased throughout the season to levels comparable to those of compressed snow. When the snowpack was experimentally compressed at 22 sites, destroying the subnivean space, detections of two small mammal species (*Rattus fuscipes* and *Antechinus swainsonii*) significantly ($p < 0.0001$) declined by 75–80%. These species remain active below the snow throughout the winter and depend on the presence of an adequate subnivean space.

The removal of vegetation by fire significantly ($p < 0.0001$) reduced the size of the subnivean space regardless of habitat type. Vegetation clearing occurs as part of ground preparation prior to establishing ski runs. Supergrooming, in which surface soil is also disturbed, is likely to have similar (if not more extreme) effects.

Nival areas used for snow-based recreation should be managed to minimise negative effects on subnivean fauna, by maintaining natural features associated with subnivean space formation (dense shrubs, boulders and/or microtopography) and confining developments to areas where these features are not present.

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1. Introduction

Demand for snow-based recreation continues to increase globally, fuelling the development of new ski resorts and the expansion of existing resorts (Young and Boyce, 1971; Tsuyuzaki, 1994; Pickering and Hill, 2003). In Australia, however, the limited extent of alpine and subalpine areas, comprising only 0.02% of the continental land mass (Green, 1998), means that scope for expansion of snow-based recreation is limited (National Parks and Wildlife Service, 1988; Konig, 1998). Most of the areas subject to the accumulation of suitable snow occur in national parks with high conservation values, placing additional constraints on development. Added to this is the prospect of global warming which may reduce the areas of snow cover in Australia (Whetton et al., 1996) and elsewhere (Houghton et al., 2001). It seems probable that these increased recreation demands will need to be met by an ever decreasing snow resource, and consequently there is an imperative to understand the potential impacts on a range of biota that may result from human activities in snow-covered environments.

For small terrestrial mammals, the subnivean space between the base of the snowpack and the ground surface is essential for survival under snow (Formozov, 1946; Pruitt, 1984; Green and Osborne, 1994; Green, 1998; Sanecki et al., 2006). In Australian snow conditions, the formation and maintenance of the subnivean space (and hence the movement of small mammals) depends almost exclusively on the presence of structures (shrubs, boulders and microtopographic features) able to support the weight of the snowpack above the ground (Sanecki et al., 2006). Human activities that affect the development and persistence of the subnivean space may have impacts upon the winter survival of small mammals (Schmid, 1971; Halfpenny and Ozanne, 1989; Green, 1998; Sanecki, 1999), but there has been little empirical work undertaken to investigate the extent and severity of these impacts.

Australian small mammals known to remain active beneath the snow through winter include the murid rodents, bush rat (*Rattus fuscipes*), and broad-toothed rat (*Mastacomys fuscus*), and the dasyurid marsupials, dusky antechinus (*Antechinus swainsonii*), and agile antechinus (*A. agilis*). Of these the most commonly observed in winter surveys are *R. fuscipes* and *A. swainsonii* (Sanecki et al., 2006). The endangered mountain pygmy-possum (*Burramys parvus*) also occurs in the Australian alpine area, but spends much of the winter in a torpid state (Walter and Broome, 1998).

The compression of the snowpack associated with the movement of over-snow vehicles (Schmid, 1971; Maysk, 1973; Foreman et al., 1976; Keddy et al., 1979) results in impacts on wildlife that have been of concern for some time (Young and Boyce, 1971). Similar impacts would be expected as a result of snow grooming for the creation of ski pistes (downhill ski slopes and cross-country trails) and surface ski lifts (Rixen et al., 2003). Snow compression can cause the subnivean space to collapse, preventing movement of subnivean fauna (Schmid, 1971).

The establishment of ski pistes is frequently preceded by the clearing of vegetation prior to the first snowfall. Supergrooming combines vegetation clearing with levelling of the ground surface to enable skiing on shallower snow, and both activities are likely to reduce the extent of the subnivean space by removing structures vital to its formation and maintenance (Sanecki et al., 2006). In some cases, vegetation clearing has resulted in the cutting of swathes hundreds of metres in length (Sanecki, G., personal observation).

Activities such as the grooming of ski slopes and trails and the preparation of ski lift lines are generally not undertaken by resort operators until a minimum depth of snow cover is obtained (Perisher Blue Pty Ltd, 2000). Often, however, this depth is determined by safety considerations for the operation of machinery rather than on ecological grounds. If suitable depths of snow are achieved in one or two early season snow falls which have low initial physical strength (Seligman, 1962; Mckay and Gray, 1981), the snowpack is easily compacted to ground level.

In this paper, we consider the potential effects of snow cover modification associated with ski resort operation in Kosciuszko National Park, south-eastern Australia. In particular, we examine: (1) how snow cover is affected by recreational use and associated activities; (2) how the distribution of small terrestrial mammals in the subnivean space is affected by the compression associated with these activities; and (3) how the extent of the subnivean space is modified by removal of surface vegetation by opportunistically using the landscape denuded of vegetation by a fire.

2. Methods

2.1. Study area

The Australian Alps are located in south-eastern Australia. They comprise a disjunct series of peaks and plateaux extending for about 350 km in a generally north-easterly direction from their southern extent at about 37°S 146°E to 35°S 149°E. The Alps contain 13 ski resorts with a total downhill skiable area of 2734.5 ha and 379 km of cross-country ski trails (Australian Snow Ski Resorts, 2004). A number of small resorts are also located on the island of Tasmania but ski slope and trail development is not extensive there.

The study area for this investigation was located in the Snowy Mountains (36°S, 148°E) (Fig. 1). The Snowy Mountains contain the largest contiguous alpine and subalpine areas in Australia lying above 1500 m and subject to the accumulation of snow cover during winter (Costin, 1989). The Snowy Mountains are, for the most part, contained within the Kosciuszko National Park. Four ski resorts are located within the boundaries of the park including Australia's largest ski resort at Perisher Valley (36.42°S 148.41°E) with a downhill skiable area of 1245 ha and about 104 km of cross-country ski trails. In total, the four ski resorts in the Snowy Mountains contain 1820 ha or about 67% of Australia's downhill skiable areas and 155 km (41%) of cross-country ski trails.

2.2. Characteristics of modified snow

The characteristics of four types of modified snow were investigated: groomed downhill ski slopes, groomed cross-country ski trails, surface ski lift tracks and over-snow routes. Groomed downhill ski slopes and groomed cross-country ski

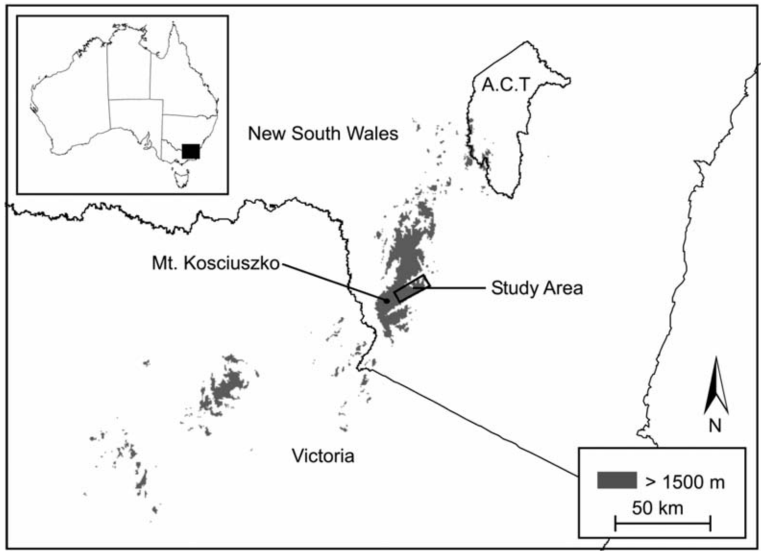

Fig. 1 – Map of the study area.

trails may occur across a range of habitat types. Surface ski lift tracks generally require relatively smooth ground surfaces and thus are located in grasslands or where woody vegetation has been cleared. Over-snow routes which are used by snowmobiles and larger tracked vehicles usually occur on formed roads, but they also may be developed across other ground surfaces.

During July 2003 we measured snowpack density for 15 replicates of each of the four modified snow types at sites within and adjacent to the ski resorts at Charlotte Pass and Perisher Valley in Kosciuszko National Park. Cores were drilled using a PICO hand auger (ESRSF, University of Nebraska – Lincoln) and weighed in the field using a spring balance. Subnivean space size was measured after removal of the core, although this was not practicable in some cases due to snow depth.

Analysis of variance was used to determine differences in snowpack density and subnivean space size between the various types of modified snow. For comparison, density data were obtained from Snowy Hydro Limited for the Spencers Creek snow course (36.43°S, 148.35°E, 1830 m a.s.l), located about 5 km from the Perisher Valley ski resort and, therefore, unlikely to be affected by human activities. Data were recorded (using the same technique as described above) at weekly intervals throughout the winter and thus allowed changes in density to be monitored. Post-hoc comparisons were made using Fisher LSD.

2.3. *Snow compression experiment*

Twenty-two sites were established at locations on snow accumulating aspects between approximately 1550 m and 1700 m a.s.l. Sites were established where there was sufficient habitat structure to permit the development of the subnivean space during the nival period (Sanecki et al., 2006), and where we detected the presence of small mammals during a hair tube survey prior to the onset of snow (see Sanecki and Green, 2005 for hairtubing methods). Each site consisted of two vertical snow-tubes (1 m long and 90 mm diameter) attached to timber stakes located approximately 5 m apart with sufficient habitat structure to permit small mammal movement between them during all seasons. Small hair sampling tubes containing adhesive tape and baited with a mixture of rolled oats, peanut butter and honey could be introduced into the subnivean space through the snow-tubes.

A hair tube survey was conducted once adequate snow cover was established. Snow cover was considered adequate if it was at least 50 cm deep and there was no exposed ground and no visible connectivity between the subnivean space and the snow surface within at least a 5 m radius of each snow-tube.

After the initial survey, we randomly selected one snow-tube at each of the 22 sites and compressed a 1 m wide strip of snow in a circle around each of the selected snow-tubes. Snow was compressed by trampling (and excavation where necessary) to destroy layers in the snowpack that might prevent complete compression. The effectiveness of the compression was determined using a Federal Snow sampler (Carpenter Machine Works, Seattle) to check the size of the subnivean space. At each site, six holes were drilled randomly into the compressed strip. The sampler was drilled until it came to rest on the ground surface, at which point the snow depth was measured. The difference between snow depth and the length of the snow core removed by the sampler was taken to be the size of the subnivean space. Snow compression was considered complete when the subnivean space was less than 2.5 cm. Both snow-tubes at each site were then surveyed using hair tubes. Hair tubes were left in place for seven days after which the adhesive tapes were removed and hair samples were inspected under a compound microscope and identified using the methods outlined by Brunner and Coman (1974) and Brunner and Triggs (2002).

To determine whether snow compression around snow-tubes affected the likelihood of detecting small mammals, we used a binomial generalised linear model with detections of small mammals as the response variable and snow condition (uncompressed, compressed) as fixed effects. Due to the small number of *R. fuscipes* detected we combined both species for analysis.

2.4. Fire effects on habitat structure

During January and February 2003, a wildfire burnt 69% of the area above 1500 m in the Snowy Mountains (Green and Sanecki, 2006). This provided an opportunity to investigate the effect of the removal of vegetation and consequent loss of habitat structure, as occurs on new ski slopes, on the development of the subnivean space.

We used sampling sites at elevations between 1600 m and 1800 m a.s.l. that had been established for previous studies (Sanecki et al., 2006) and randomly selected five burnt and five unburnt replicates of each of the four major habitat types present in the subalpine zone of the Snowy Mountains (wet heath, dry heath, seral woodland, grassland). At each replicate site, the size of the subnivean space was measured twice at each of three sampling plots as described above using a Federal Snow sampler.

The effects of burning and habitat type on subnivean space size were investigated using Analysis of Variance; the unburnt modified snow types were included in the analyses for comparison. Data were log-transformed where necessary to satisfy assumptions of normality. Post-hoc comparisons were made using Fisher LSD.

3. Results

3.1. Characteristics of modified snow

Neither subnivean space size nor snow density was significantly different among all modified snow types. Consequently, data for all modified snow types were combined for further analyses. In many cases, there was no measurable subnivean space under modified snow, rather the snowpack sat directly on the ground. Modified snow was significantly denser than natural snow cover during all months ($F_{5,122}$ 62.75, $p < 0.001$) except October when there was no significant difference between modified and natural snow cover (Fig. 2).

3.2. Snow compression experiment

Two small mammal species were detected in the hair tube surveys: *R. fuscipes* and *A. swainsonii* (Table 1). There was no significant difference in the likelihood of detection between treatment (compressed) and control (uncompressed) plots during the first survey (before snow was modified by compression). During the post-compression survey, both species of small mammals were significantly more likely to be detected at uncompressed plots ($\chi^2 = 19.52$, $p < 0.0001$).

3.3. Fire effects on the subnivean space

The subnivean space was significantly smaller at all of the burnt habitats in comparison to the unburnt habitats ($F_{4,238}$ 331.5, $p < 0.0001$). The unburnt habitats showed a gradational decline in subnivean space size with wet heath and dry heath having significantly larger subnivean spaces than other habitats (Fig. 3). Some structural components of wet heath survived burning and enabled a small subnivean space to form (Fig. 4). Modified snow had significantly smaller subnivean spaces than all burnt habitats ($p < 0.0139$).

Table 1 – Number of small mammal detections in response to the experimental modification of the snowpack by compression and consequent destruction of the subnivean space

	R. fuscipes		*A. swainsonii*	
	Control	Compressed	Control	Compressed
Pre-compression	3	5	16	15
Post-compression	5	1	16	4

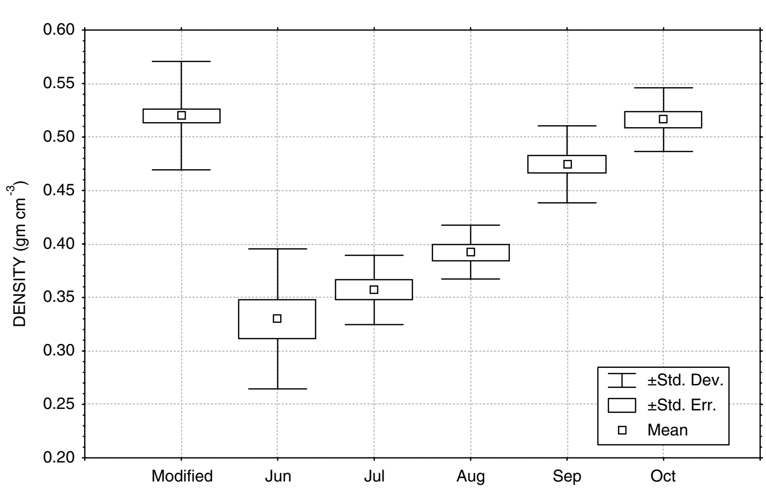

Fig. 2 – Snow density of modified snow in July, including groomed ski trails, over-snow routes, and surface lift tracks in comparison to naturally occurring snow density recorded monthly by Snowy Hydro at Spencers Creek snow course.

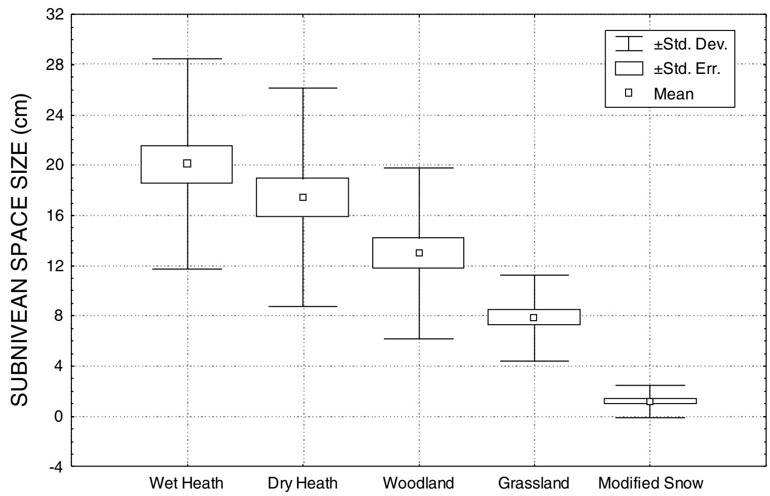

Fig. 3 – Subnivean space size at unburnt habitats. All pairwise comparisons are significant at $p < 0.0246$ except wet heath/dry heath. Modified snow sites were not burnt.

4. Discussion

The bush rat (*R. fuscipes*) is perhaps the most common small mammal in nival areas of the Snowy Mountains, favouring structurally complex habitats including heathlands, woodlands and boulderfields (Hall and Lee, 1982; Carron, 1985; Green and Osborne, 1994). Its diet is quite diverse, and includes fungi and invertebrates as well as a range of plant material, with monocotyledons predominant during the winter (Carron et al., 1990). The dusky antechinus (*A. swainsonii*) is relatively widespread in south-eastern Australia; habitat preference is similar to that of *R. fuscipes* in that, it is generally associated with complex understorey vegetation and litter in which it forages for food, predominantly invertebrates but also small vertebrates such as lizards (Green, 1989). Both species nest in burrows and actively forage throughout the winter (Green and Crowley, 1989; Green and Osborne, 1994).

These winter-active small mammals are dependent on the formation of a subnivean space, which occurs under Australian snow conditions only if structural features such as vegetation, boulders and microtopography are present (Sanecki et al., 2006). Therefore, it was not surprising that the destruction of the subnivean space in otherwise suitable habitat significantly reduced the detection rate of *A. swainsonii* and *R. fuscipes* in our study area at Kosciuszko National Park. Both species experience reductions in home range size during winter where snow is not modified (Sanecki et al., unpublished data), so further reductions of available habitat by snow compression could jeopardise their ability to survive over-winter. Since most recreational use and over-snow activities occur at higher elevations, the impact of subnivean space loss due to compression may be even more detrimental than at lower elevations, where there is more extensive subnivean space development and patchy snow permits small mammals to use both the supranivean and subnivean environments (Sanecki et al., 2006).

The snow cover occurring in Australia is characterised by snow density values (and thus physical strength of snow) that increase progressively following deposition (Fig. 2, Ruddell, 1998). The ability of the snowpack to resist compressive forces is, therefore, lower during the early part of the winter. If early snow falls are accompanied by strong winds, snow will fill between shrubs from the ground level and thus initially inhibit the formation of the subnivean space. If this snow cover is then compacted, a high-density snow layer is formed in contact with the ground. This inhibits subsequent formation of a subnivean space. By contrast, under still conditions, snow may be more readily intercepted by vegetation enabling a subnivean space to form almost immediately; if the snow binds with the vegetation before compaction, the subnivean space may not be as readily destroyed (Sanecki, G., personal observation).

The capacity of snow modification activities to destroy the subnivean space once it is formed is affected not only by the compressive force that is applied to the snow and the snow's ability to resist this force, but also by the strength and complexity of the underlying habitat that supports the snowpack (Sanecki et al., 2006). The removal of vegetation structure in the 2003 fires had a significant effect on the development of the subnivean space (Figs. 3 and 4). This effect could be considered at least partly analogous to the impact caused by the clearing of woody vegetation prior to the establishment of ski pistes. Supergrooming is likely to have even more extreme impacts than fire on habitat integrity since it involves the removal of all woody vegetation as well as other features such as microtopography and boulders, all of which are important structural components of small mammal habitats (Sanecki et al., 2006). This is suggested by the fact that wet heaths, which are often associated with higher microtopographic relief because they tend to occur in drainage lines, had significantly larger subnivean spaces than the other habitats, even after burning had removed the vegetation. The combination of vegetation removal with snow modification results in the virtual destruction of the subnivean space (Fig. 4).

Snow modification has effects on the integrity of vegetation that may compromise its long-term ability to sustain a

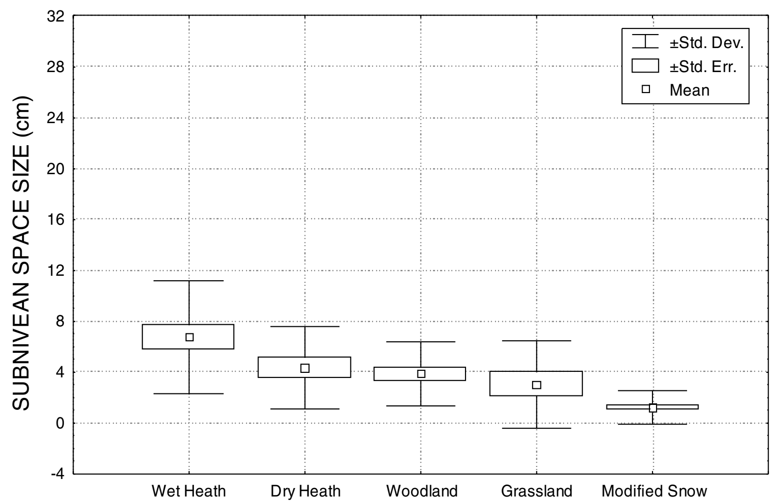

Fig. 4 – Subnivean space size at burnt habitats. Dry heath, woodland and grassland are not significantly different; all other pairwise comparisons are significant at *p* < 0.0271. Modified snow sites were not burnt.

subnivean space. In areas of shallow snow, vegetation protruding through the snowpack may be broken by the movement of vehicles, machinery or skiers (Forbes, 1992; Emers et al., 1995), while vegetation under deeper snow cover may be crushed as the snowpack above it is compacted (Mosimann, 1985). Erect woody plants are the most vulnerable to damage by over-snow vehicles (Neumann and Merriam, 1972; Emers et al., 1995), but other plant communities also suffer adverse effects (Greller et al., 1974; Foreman et al., 1976; Keddy et al., 1979).

The thermal conductivity of snow is directly related to its density (Halfpenny and Ozanne, 1989), consequently a snowpack that has been compacted has less thermal buffering capacity than unmodified snow (Singh, 1999). Under Australian snow conditions, winter-active small mammals appear to favour areas of thermal instability where winter temperatures can fall well below freezing (Sanecki et al., unpublished data). Therefore, changes in the subnivean environment during winter as a result of increased thermal conductivity of snow are likely to have little direct impact on these species. However, this may not be the case for the endangered mountain pygmy-possum (*Burramys parvus*) which experiences periods of torpor throughout the winter months; any changes to thermal regimes may be detrimental to its survival (Walter and Broome, 1998). On a global basis, thermal effects of snow modification on small mammals need to be considered in the context of the ecology of each species and the prevailing climatic and snow cover conditions.

4.1. *Management implications*

The activities associated with ski resort development and snow-based recreation often represent the most intensive examples of human-induced changes to snow-covered ecosystems. Our findings suggest that there need not be a conflict between winter recreation and the over-winter survival of small mammals, provided appropriate consideration is given to ski slope development. For the most part, slopes consisting of grassland or herbfield habitats with little microtopography have limited habitat value for small mammals throughout the year (Sanecki et al., 2006), and if snow modification is focused on these slopes, the negative effects on small mammals will be minimised. In particular, supergrooming should be limited to sites of low habitat value for small mammals.

Shrubby habitats on mid to upper slopes, such as dry heaths and woodlands, are heavily utilised by small mammals during the non-nival period and are probably important in providing sufficient foraging areas to facilitate breeding and dispersal activities (Carron, 1985). Managers should be aware that any deliberate or incidental damage to these habitats as a result of snow modification may reduce the capacity for these habitats to support small mammals during the non-nival period. Grooming and movement of oversnow vehicles may be acceptable over shrubby habitats, but should only occur once snow cover has attained sufficient strength to resist compression of the subnivean space.

The highest quality nival habitats for small mammals include boulderfields, wet heaths and areas of high microtopography such as drainage lines (Sanecki et al., 2006) and it seems probable that these areas act as winter refugia and as population sources for recolonisation of other habitats after snow melt. From a management perspective, the identification and protection of these habitats should receive the highest priority. We recommend that no snow modification be permitted in high quality small mammal habitats and where necessary fencing be used to deter anthropogenic disturbances of all kinds while allowing access by small mammals. The connectivity of high quality habitats should also be maintained.

Subsequent to the 2003 fires, many unburnt small mammal habitats now occur within, or in the vicinity of, ski resorts due to the concentration of firefighting activities on the protection of ski lodges in Kosciuszko National Park. These remnant habitats are vulnerable to disturbance due to heavy usage of snow near resorts and require active measures to ensure their protection. Their management presents particular challenges, since impacts may not only be the result of management decisions by resort operators, but also of unstructured activities (snow play) which are difficult for managers to monitor or control.

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