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Mountain Biodiversity

A Global Assessment

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Ken Green and Catherine M. Pickering

INTRODUCTION

The Snowy Mountains (Figure 19.1) contain the largest contiguous area of subalpine and alpine habitat in Australia. Other subalpine and alpine habitats occur as relatively isolated areas in the mainland Victorian Alps and in the Central Highlands and higher peaks of the island of Tasmania (Costin, 1989). Altogether 11 500 km^2, or 0.15% of the continent is subject to winter snow cover (Green and Osborne, 1994). Predicted changes to the climate are likely to result in a dramatic decline in the total area receiving snow. The Intergovernmental Panel on Climate Change assessment (IPCC, 1996) presented scenarios for global warming for 1990–2100 with predicted warming of 0.7–2.1 °C by 2070. From these, the Australian CSIRO Climate Impact Group estimated regional warming and precipitation values for Australia (CIG, 1996). Under these scenarios the 'best case' scenario for snow is the least increase in temperature and the greatest increase in winter precipitation (see Whetton *et al.*, 1996 for a full discussion). For example, even a modest warming ('best case scenario' of only +0.6 °C by 2070; Table 19.1) will result in a 39% reduction in the area that receives 30 days of snow per year in the Snowy Mountains and Victorian Alps (Figure 19.2; Whetton, 1998). Under the 'worst case scenario' (Table 19.1) a reduction of 96% is forecast by 2070 (Figure 19.2). A reduction of this scale in snow cover will affect the unique and biologically important flora and fauna of the region (Green, 1998). Changes in the diversity and abundance of plants and animals may be particularly severe in Australia because the extent of the true alpine habitat is minimal, with limited high altitude refuges. For example, the highest mountain in Australia, Mt Kosciuszko (2228 m), is 500–600 m lower than the theoretical nival zone (Slatyer *et al.*, 1984), so that there is no opportunity for an altitudinal shift in the alpine zone.

Seasonal cover of snow is regarded as a major determinant of the faunal composition of the subalpine and alpine areas of the Snowy Mountains above 1500 m (Green and Osborne, 1994, 1998). Within the latitudinal band of southeastern mainland Australia which encompasses the Snowy Mountains, 25 species of mammals found between the coast and the western slopes occur in areas of winter snow cover (Green and Osborne, 1998). Most of these are also common at low altitudes with two exceptions, the mountain pygmy-possum (*Burramys parvus*) and the broad-toothed rat (*Mastacomys fuscus*). In the Snowy Mountains, the mountain pygmy-possum is found only above the level of the winter snowline and the broad-toothed rat only above 1000 m (Green and Osborne, 1994). In addition to native species, feral mammals including foxes, hares and horses are found in the mountains (Green and Osborne, 1994). Among the birds there are no species confined to the mountains, however, it is the composition of the avifauna and particularly the absence of some species, which are found nearby at lower

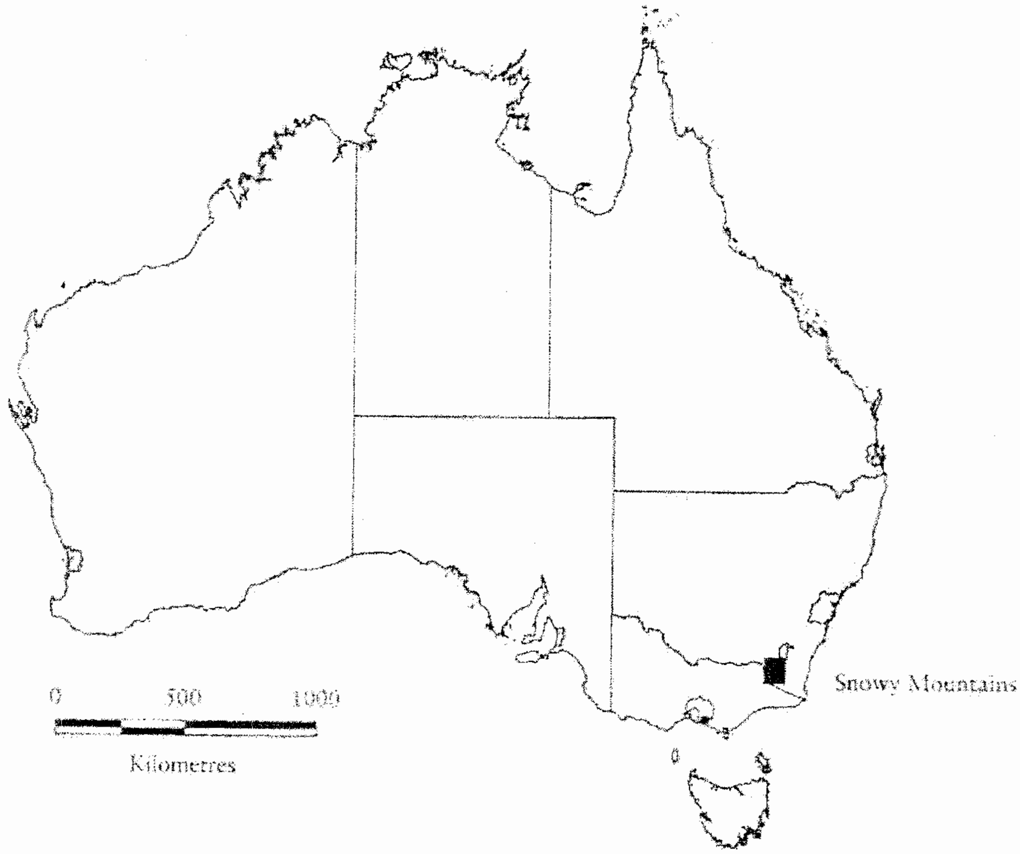

Figure 19.1 Map of Australia showing the location of the study area

Table 19.1 Climate change scenarios for the Snowy Mountains and Victorian Alps from Whetton (1998)

Changes in	*Best case 2030*	*Best case 2070*	*Worst case 2030*	*Worst case 2070*
Temperature	+0.3 °C	+0.6 °C	+1.3 °C	+3.4 °C
Precipitation	0%	0%	−8%	−20%

altitudes which is a characteristic of the snow-country avifauna (Osborne and Green, 1992). Of 271 native species of birds occurring at sea level, only 66 species are found above 1500 m, with only 13 of these being winter residents (Green and Osborne, 1994). In the present paper only the two faunal groups with the best data (mammals and birds) are examined, although there is greater alpine endemism among other groups such as the reptiles and the invertebrates (in which the majority of the endemic species and the alpine adapted forms are to be found) (Green and Osborne, 1994).

To determine whether there is any evidence for existing changes in animal distribution with climate, data on snow cover and animal distribution for the last 45 years are examined. This provides information on the potential impact of the dramatic climatic change predicted for the next 70 years for the Australian snow country.

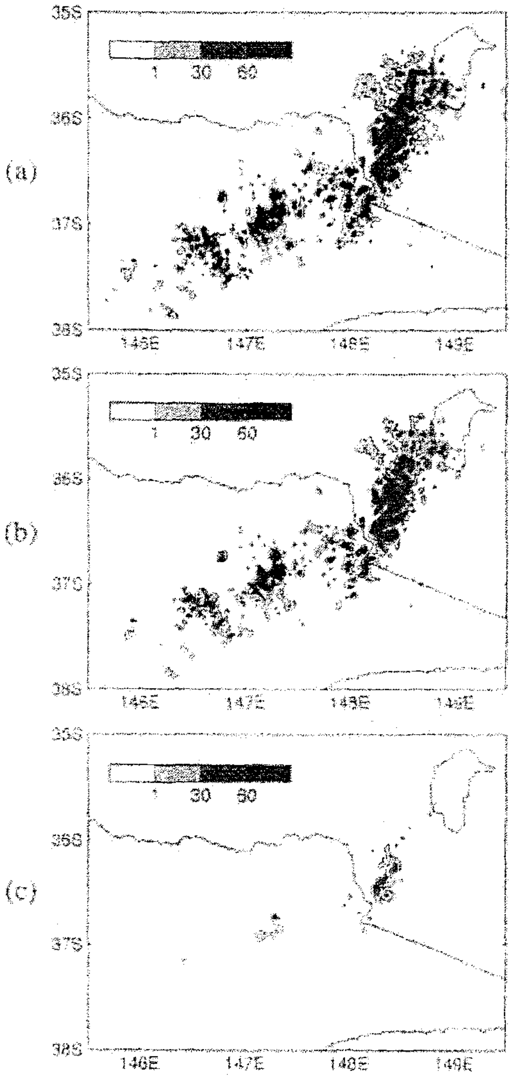

Figure 19.2 Simulated average duration of snow cover in days: a) in the current climate, b) the best case scenario for 2070, and c) for the worst case scenario in 2070 (figures from Whetton, 1998, based on Intergovernmental Panel on Climate Change scenarios for global warming)

METHODS

Site description

Areas of the Australian mainland subject to persistent winter snow are restricted to the southeast of the continent where the Snowy Mountains and the Victorian Alps contain about 2350 km^2 of land subject to a minimum of 60 days of snow cover in winter (Green and Osborne, 1994). The Snowy Mountains (Figure 19.1) lie on a north–south orientation centred on Mt Kosciuszko (36° 27′ S, 148° 16′ E). The alpine zone, extending from around 1830 m at the treeline to the top of Mt Kosciuszko, is characterised by continuous snow cover for at least four months per year and six to eight months with minimum temperatures below freezing. Precipitation is in the range 1800–3100 mm per year with about 60% of this falling as snow (Costin, 1957). The subalpine zone, extending from the winter snowline (around 1500 m) to the treeline is characterised by continuous snow cover for one to four months per year and minimum temperatures below freezing for about six months per year. Precipitation is in the range 770–2000 mm per year (Costin, 1975).

Trends in snow cover for the last 45 years

Snow data were obtained from a Snowy Mountains Hydro-electric Authority snow course at Spencers Creek in the Snowy Mountains that has been visited weekly through the snow season since 1954. To reflect depth and duration of snow cover, these data were transformed into metre-days of snow per year. This was done by multiplying the depth of snow by the numbers of days at that depth and summing the figures for each year. The data are presented by year with the running 5-year mean (Figure 19.3).

Impact of snow cover on animal distribution

The *Atlas of New South Wales Wildlife* which contains wildlife records for the past 30 years was examined to determine how many mammal species occurred in the southeastern corner of New South Wales, between 35° S and the Victorian State border and 147° E and the eastern seaboard. A Geographic Information System was used to allocate altitude to the nearest 100 m for each record. For the species

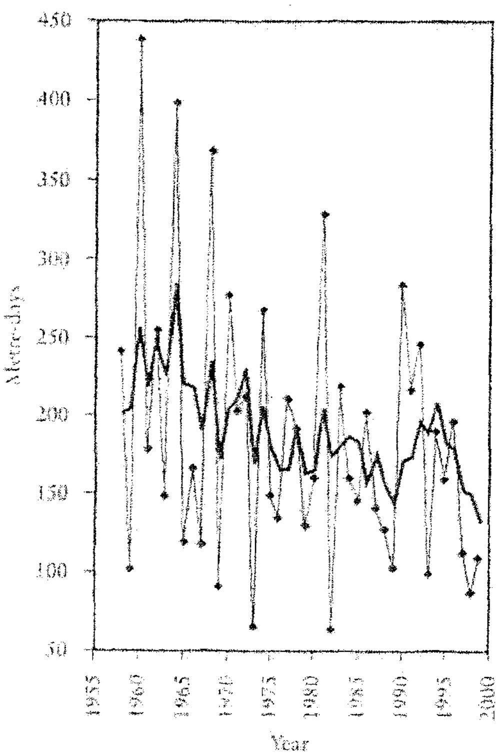

Figure 19.3 Annual snow cover in metre-days at Spencers Creek in the Snowy Mountains, with running five-year mean. Data courtesy of Snowy Mountains Hydro-electric Authority

of terrestrial mammals that declined in number of records with increasing altitude, the effect that snow cover had on their distribution was rated as: no observed effect (group 1), effect through competition (group 2) or direct effect (group 3) (see Green and Osborne, 1998).

To determine the possible impact of a reduction in snow cover on these species, the mean of the three highest records for each species was calculated from the same data set for the three decades 1970–1979, 1980–1989 and 1990–1999. This was only done for those animals found at or about the winter snowline and which did not inhabit the full altitudinal range, in order to determine whether and in what direction there was a shift in the highest altitudinal distribution of species. The search effort over this time is difficult to quantify, but if the number of records placed on the data base per decade is taken as an index of effort, then this appears not to have changed greatly; with the number of records ≥ 1500 m altitude in the three decades being 586, 470 and 597. Sources of information independent of this data set were also recorded, such as observations by long-term residents at higher altitudes where a species had not previously been seen, indirect evidence and data from pest animal control studies.

For all bird species occurring seasonally above 1500 m, the earliest records above that altitude for the three decades were obtained from the *Atlas of New South Wales Wildlife*.

RESULTS AND DISCUSSION

Osborne *et al.* (1998) recorded a significant decline in mean snow cover at Spencers Creek snow course in the two 15-year periods 1960–74 and 1975–89, corresponding to a 27% reduction. Examination of the data from the snow course record show a total of 2283 metre-days of snow in the 1960s, with a 20% reduction to the 1970s (1843 metre-days) and a further 10% reduction in the 1980s and 1990s (1655 and 1706 metre-days, respectively). The last five years, occurring in the warmest decade of the century (Australian Bureau of Meteorology), had the lowest five-year average of the series; 7.5% less than the previous lowest 5 years and 53% less than the highest 5 years (Figure 19.3). If the fauna were sensitive to depth and extent of snow cover, this decline might be expected to be reflected in changes in their distribution.

Based on the pooled data from the *Wildlife Atlas*, 35 species of mammals, six of which are feral, generally decline in number of records with increasing altitude (Table 19.2). For 20 of the species, including all the bats, the decline in number of records with altitude is likely to be unrelated to snow (Green and Osborne, 1998; Group 1 in Table 19.2). For example, the seven possum species are dependent upon trees, and the house mouse *Mus musculus* might be excluded above the winter snowline by lack of suitable food (Green and Osborne, 1998).

Table 19.2 Species of mammal that decline in numbers of records in the *New South Wales Wildlife Atlas* with increasing elevation, together with probable reasons for decline and relatedness to presence of snow

Declining species	*Reason*
Group 1: Decline not snow-related in the short term	
Bats (11 species)	Reduction in flying insects
Possums (7 species)	Require trees
Koala	Absence of food tree species
House Mouse[a]	Lack of food for a specialist granivore
Group 2: Possible changes in the longer term	
Dog[a]	Absence of large prey/competition with fox[a]
Agile antechinus	Competition with dusky antechinus[c]
Swamp rat	Competition with broad-toothed rat[c]
Eastern pygmy-possum	Competition with mountain pygmy-possum[c]
Spotted-tailed quoll	Competition with fox[a]
Group 3: Decline likely to be snow-related	
Kangaroos and wallabies (3 species)	Mobility in snow/access to food
Wombat	Access to ground-based food
Echidna	Access to ground-based food
Bandicoot	Access to ground-based food
Cat[a]	Hunting method
Rabbit[a] Pig[a] Horse[ab]	Access to ground-based food

[a]Feral animals. [b]Within the study area, feral horses are not common below 1000 m. [c]These species increase in numbers with increased altitude

Table 19.3 Mean of three highest records (metres) for mammals in the *New South Wales Wildlife Atlas* (sample size in parenthesis), together with other sources of evidence for an altitudinal shift

Decade	*1970–1979*	*1980–1989*	*1990–1999*	*Other evidence*
Number of records ≥ 1500 m	586	470	597	
Grey kangaroo	1500(10)	1400(39)	1700(28)	
Swamp wallaby	1233(3)	1267(16)	1700(32)	1, 2, 4
Red-necked wallaby	1533(17)	1333(41)	1567(17)	
Cat[a]	1267(3)		1600(3)	1, 3
Horse[a]	1233(3)	1000(2)	1900(17)	1, 2
Pig[a]	1400(22)		1533(12)	1, 2
Rabbit[a]	1670(17)	1300(7)	1800(26)	1, 3, 5

[a]Feral animals. 1. Anecdotal records by long-term residents, 2. indirect evidence (dung or rooting), 3. increased presence in predator scats, 4. occurrence of tracks on regular snow transects, 5. rabbit control required for first time at ski resort at 1800 m

For a second group of species, the excluded or numerically reduced species may be outcompeted by the more common higher altitude species which may derive a competitive advantage from the presence of snow (Dickman *et al.*, 1983). The three successfully competing native species, dusky antechinus *Antechinus swainsonii*, broad-toothed rat and mountain pygmy-possum, are the only ones that increased in numbers of records with altitude. Finally, there is a third group of mammals, six native and four feral species, where snow appears to be the major factor in the reduced numbers of records at higher altitude (Green and Osborne, 1998; Table 19.2).

There is some evidence that there is an increasing altitudinal distribution of animals over the 30-year period to 1999. *Wildlife Atlas* records indicate a higher maximum altitudinal distribution for all macropod species and for the four species of feral mammals (Table 19.3). Other evidence for increasing activity by feral mammals at higher altitudes supports this trend (Table 19.3). In the 1970s, Snowy Plains (1370 m) was regarded as climatically marginal for rabbits (Dunsmore, 1974), yet during the summer of 1998/99 the National Parks and Wildlife Service was forced to institute a rabbit control programme at Perisher Valley (1800 m) (Sanecki and Knutson, 1998). During the period 1980–1988, Green (1988) conducted regular small mammal trapping near the tree-line on the South Ramshead with access up a spur from Dead Horse Gap (1580 m) without once recording evidence of horses above the gap. Currently, this route is heavily used by horses for access to the alpine zone where sightings are now common (Green, pers obs.).

Among the macropods there is little evidence of altitudinal movements of red-necked wallabies *Macropus rufogriseus* and grey kangaroos *M. giganteus* outside of the data set, and these records may be of aberrant individuals. For example, the grey kangaroo is a social species (Bennett, 1995) yet the high altitude records were all of individuals. The situation with the swamp wallaby *Wallabia bicolor* is, however, different. While the other two species of macropods are predominantly grazers, the swamp wallaby is a browser and therefore seasonal snow cover will not severely reduce its access to food. Despite an extensive winter fauna survey (Osborne *et al.*, 1978) and further winter work through 1979 (Green and Osborne, 1981), no tracks of swamp wallabies were observed in winter along the main access trail for these studies, whereas in recent winters (Green, unpublished) swamp wallaby tracks have been observed on this trail on virtually all weekly winter visits.

Additional support for the impact of snow cover on animal numbers comes from the response of species to years of shallow snow cover. In these years there is evidence for a reduction in populations of the three species of native mammal in the second group that increased in number of records with altitude (Table 19.2). Populations of dusky antechinus (Green, 1988) and broad-toothed rats (Green, unpublished) declined in poor snow years, while in the mountain pygmy-possum there was also lowered recruitment (L. Broome, pers. comm. 2000). The latter species depends upon snow cover for stable, low temperatures for hibernation (Walter and Broome, 1998), whereas the two former species are active under the snow throughout winter (Green, 1998) and are therefore subject to predation by foxes (Green and Osborne, 1981). Using a bio-climatic analysis and prediction system to examine present and predicted future animal distribution, Brereton *et al.* (1995) suggested a potential decrease in areas of suitable habitat for broad-toothed rats with global warming. Already the broad-toothed rat is under pressure at Barrington Tops, 600 km north of the Snowy Mountains. The population studied there in the 1980s (Dickman and McKechnie, 1985) was in serious decline by 1999 in the face of invasion by swamp rats *Rattus lutreolus* (Green, 2000). A similar process may occur in the Snowy Mountains with a reduction in snow cover. This is likely to reduce the competitive advantage of broad-toothed rats and may act synergistically with increased incursions of feral animals, particularly foxes, whose hunting is made easier by shallow snow (Halpin and Bissonette, 1988).

In addition to the apparent changes in the distribution of some mammal species associated with changes in snow cover, migratory birds may also be affected. Among the migratory birds, the only observable change in timing of arrival, for those species for which there was a sufficient sample size, was one of earlier arrival in the 1980s and/or 1990s compared to the 1970s. For the 11 bird species for which there were sufficient data (Table 19.4), the earliest record was in the 1990s in five species (four of these occurring in an earlier month) and the 1980s (generally differing by only a few days from the earliest date for the 1990s) in four. For two species (grey fantail *Rhipidura fuliginosa* and silvereye *Zosterops lateralis*) there was virtually no difference across the three decades. Whilst there has been a greater search effort in the 1990s by one of us (KG), the search effort in the period 1971–1980 was boosted by a large fauna survey (CSIRO, unpublished) and two studies of the avifauna

Table 19.4 Time of first records of migratory birds at or above 1500 m after winter, from the *New South Wales Wildlife Atlas* to the end of 1997. The earliest record is given in each decade and all other dates (maximum one per year) earlier than the first record in 1970–1979

Species	*1970–1979*	*1980–1989*	*1990–1999*
Number of records from August to October	124	65	152
Crescent honeyeater	19 Oct	26 Oct	12 Sep, 17 Sep, 30 Sep
Olive whistler	15 Sep	22 Sep	21 Aug
Flame robin	2 Sep	17 Aug	21 Aug
Grey fantail	19 Oct	26 Oct	23 Oct
Striated pardalote	16 Sep	24 Aug, 15 Sep	30 Aug
Yellow-faced honeyeater	18 Sep	26 Oct	12 Sep
Australian kestrel	5 Nov	20 Sep, 26 Oct	30 Aug, 8 Sep, 23 Sep, 28 Sep
Fantail cuckoo	25 Nov	21 Sep, 20 Oct	23 Oct
Red wattlebird	14 Oct	13 Sep, 20 Sep	20 Sep
Richards pipit	16 Sep	5 Sep	28 Aug
Silvereye	19 Oct	18 Oct, 20 Oct	22 Oct, 23 Oct

(Longmore, 1973; Gall and Longmore, 1978). While the earlier records in the 1990s might be ascribed to a greater search effort (152 records entered compared to 124 from August to October in the 1970s), the same explanation cannot be used for the 1980s. There were only half the number of records in the same period in the 1980s and yet six of the nine species that varied in time of immigration were recorded earlier in the 1980s than the 1970s.

The response of the birds is variable depending upon their foraging techniques. The birds that are recorded as arriving earlier include three species of honeyeaters that depend on the flowering of shrubs (see also Osborne and Green, 1992). The Australian kestrel *Falco cenchroides* is largely dependent upon snow-free ground for foraging. The ground-feeding flame robins *Petroica phoenicea* and Richards pipit *Anthus novaeseelandiae* arrive early in spring and feed on insects immobilised on snow, but the very fact of the earlier presence of these insects is associated with sufficient warmth in their point of origin for metamorphosis and flight. Olive whistlers *Pachycephala olivacea* and striated pardalotes *Pardalotus striatus* glean active insects off shrubs and trees and movements of fan-tailed cuckoos *Cuculus flabelliformis* must be attuned to the breeding timetable of their hosts. The two species that appear not to arrive earlier, despite changes in snow cover over the three decades, are the grey fantail which catches insects in flight and the silvereye which is involved in long migratory flights, the timing of which may be independent of local events.

There are obvious problems with the data sets examining altitudinal distribution of mammals and time of first arrival of migratory bird species, such as sample size, sampling effort, sampling timing, and other provisos. The use of the numbers of records ≥ 1500 m entered per decade and the number of records in the three-month period of influx of migratory birds as indices, while not perfect, does suggest that there is no great bias in search effort. This paper does not state unequivocally that all of the changes in animal distribution (both spatially and temporally) are a direct result of observed changes in snow cover. For many of the changes there are plausible alternative explanations. Changing land use, however, is not one of those. During the course of this study period there have been no major changes in land-use patterns at the higher altitudes to explain differences in animal distribution. The study area was declared a State Park in 1944 and summer grazing was withdrawn from the alpine area of the Main Range in 1946 and banned above 1360 m in 1958 (Good, 1992). Any increased use by humans has largely been confined to the few ski resorts and access routes. However, the changes are those that might reasonably be hypothesised to result from reduced snow cover and the observed change in snow cover is the only explanation that can account for all data. Therefore, the patterns documented here could be a model for likely changes to animal distribution, and hence biodiversity, with predicted changes in snow cover. Further global warming resulting in declining snow cover might, therefore, have a major impact upon the faunal composition of the alpine/subalpine areas of the Snowy Mountains, allowing greater access by feral animals and reducing the competitive advantage of the higher altitude species. As such, while possibly increasing the numbers of species in the Snowy Mountains, this process might reduce the regional biodiversity by the loss or serious reduction of populations of endemic species.

CONCLUSION

The only observed impacts of a loss of snow cover on biodiversity in the Snowy Mountains has been on mammals. Of the three classifications used here, there has been no observed altitudinal shift in the group of species whose distribution is unrelated to snow. For other species that increase in numbers of records with increased altitudes, there have been documented impacts of shallow snow in some years, but because of the high fecundity of these species, populations have recovered in subsequent good years and no trend is apparent. It may take a greater loss of snow cover to reduce the competitive advantage of these species more than has so far occurred. In a third group, animals that are constrained by the presence of snow, there is a trend towards higher altitude and/or winter occupancy by species normally excluded by snow cover. Further loss of snow cover may see a greater upward movement of these species. If sufficient snow is lost, an altitudinal increase by the grazing macropods may follow the upward move by the browsing swamp wallaby.

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