Running title: **Plant diversity in Snowy Mountains**

Title: **Vascular plant diversity and climate change in the alpine zone of the Snowy Mountains, Australia**

Biodiversity and Conservation.

Catherine Pickering^a, Wendy Hill^a and Ken Green^b.

^a School of Environment, Griffith University, PMB 50, Gold Coast Mail Centre, Queensland, 9726, AUSTRALIA. E-mail: c.pickering@griffith.edu.au

Ph: + 61 (0) 7 5552 8059, Fax: + 61 (0) 7 5552 8067

^b Ken Green, Snowy Mountains Region, National Parks and Wildlife Service, PO Box 2228, Jindabyne NSW 2627. AUSTRALIA. E-mail.

kenneth.green@environment.nsw.gov.au

Ph: + 61 (0) 2 6450 5538, Fax: + 61 (0) 2 6450 5630

Abstract

This study examines vascular plant species richness along an altitudinal gradient in alpine Australia. Vascular plant composition and soil temperature records were obtained for five summits (from 1729 m to 2114 m a.s.l.) using sampling protocols from the Global Observation Research Initiative in Alpine Environments program. Species richness was examined against altitude, aspect and climatic variables at different spatial scales (10 x 10 cm quadrats, 1 m² quadrats, clusters of 4 * 1 m² quadrats, for the summit area above a line 5 m altitudinally below the summit (the -5 m isoline), for the extended summit down to the -10 m isoline).

75 taxa (70 species, 5 graminoid genera) were recorded, 9 of which are endemic to the small alpine area of ~100 km². There were significant linear relationships between species richness and altitude and climatic variables for the top to -5 isolines on the summits. However, there was no consistent pattern for species richness at other spatial scales, altitude, aspect or climatic variables. The proportion of species for the whole summits with localised distributions (local endemics) increased with altitude. Predicted increasing temperatures and reduced snowcover is likely to result in an increase in species richness as shrubs, herbs and introduced weeds become more common at higher altitude. Because Australian alpine areas occur in narrow altitudinal bands with no nival zone, there are no higher altitudinal refuges available for alpine species. Therefore many of these species are likely to be at risk of extinction from climate change.

Keywords: Alpine zone, altitude gradient, climate change, endemics, weeds, exotics.

Introduction

Mountain regions are important areas of biodiversity, containing many endemic vascular plant species (Körner 2002; 2003). It is estimated that the total alpine flora of the world is 8,000-10,000 species, around 4% of all vascular plant species (Körner 2003). This high diversity is in part due to steep ecological gradients, including in climatic conditions, sharply defined ecotones, and relatively less anthropogenic disturbance compared to lower lands (Körner 2002; Pauli et al. 2007)

The distribution of plant species within alpine areas is often related directly to climate or climate-influenced ecological factors (Körner 2002; 2003; Grabherr et al. 2000; Pauli et al. 2007). Therefore they are considered particularly sensitive to the influence of predicted climatic change (Grabherr et al. 2000; Körner 2002; Pittock 2003; Pauli et al. 2007). As a result, alpine ecosystems are likely to show the effects of climate change earlier and more clearly than some other ecosystems (Grabherr et al. 2000; Pauli et al. 2004). Therefore, long term monitoring programs such as of the Global Observation Research Initiative in Alpine Environments (GLORIA) have been established worldwide on five continents (see www.gloria.ac.at). This program involves recording information about composition of vascular species and soil temperatures according to a common protocol.

Using this protocol it is possible to examine patterns in species richness on the summits of mountains along altitudinal gradients and for different aspects on each summit (Pauli et al. 2004). An important theoretical basis of such monitoring is the assumption that patterns in species richness are related to climate. Many studies in mountain systems have found a pattern of decreasing species richness with increasing altitude at the scale of whole floras, and also at smaller spatial scales (Körner 2002).

Currently 178 summits in 54 target regions have been established world wide (www.gloria.ac.at). Most regions where species richness has been monitored are in the Northern Hemisphere. Currently, in the Southern Hemisphere sites have been set up in Chile, Argentina, Bolivia, Peru, New Zealand and Australia (www.gloria.ac.at, Harald Pauli pers. comm.).

Winter snow-covered landscapes in mainland Australia occurs in the southern section of the Great Dividing Range in the southeast of the continent. Known as the Australian Alps, this area is almost entirely conserved in a series of linked national parks and nature reserves. The alpine zone occurs above the climatic treeline at approximately 1850 m to the top of Australia's highest mountain, Mt Kosciuszko, at 2228 m and covers an area of approximately 135 km² (Costin et al. 2000, Green unpublished data). The largest contiguous alpine area in the Snowy Mountains, and indeed in Australia around Mt Kosciuszko is around 100 km² (Costin et al. 2000). There are other smaller more isolated alpine areas in Victoria, and also in the Central Highlands and higher peaks of the island of Tasmania (Costin 1989).

Annual precipitation ranges from 1800 mm to 3100 mm in the alpine zone, about 60% of which falls as snow in winter, generally persisting for more than four months (Costin et al. 2000). Semi-permanent snow patches on the leeward side of ridges can persist well into summer and autumn and in some years, may still be present the next winter (Green and Osborne 1994; Costin et al. 2000). Frosts are common, with sub-zero temperatures experienced throughout the year.

There is an almost complete layer of alpine humus and associated organic soils in the alpine zone, apart from the rocky areas and scree slopes, or areas still affected by past grazing (Costin et al. 2000). The soil is low in available nutrients, acidic (pH 4-6) and rich in organic matter (Costin et al. 2000).

It has high biodiversity with 212 species of vascular plants, of which around 30 are exclusively alpine and 21 endemic to just this limited (~100 km²) alpine area (Costin et al. 2000). The region was used for cattle and sheep grazing from the 1850's until 1944, with occasional subsequent use in the 1950's. Because the alpine flora of Australia, like the rest of the continent's flora, evolved in the absence of hard-hoofed grazing animals, this summer grazing resulted in massive soil erosion (Costin et al. 2000). As a result, some areas were actively rehabilitated including the use of some exotic species to re-established vegetation cover. Currently there are few grazing mammals in the alpine area, principally introduced hares and the native broad toothed rat (Green and Osborne 1994).

The climate of the Australian Alps is predicted to warm with a temperature rise of + 0.3 to +1.3°C by 2030 (best and worst case scenarios, Whetton 1998). This is predicted to result in changes in snow cover, with the area having a snow cover for more than 30 days a year predicted to decrease by 18% to 66%. Under the worst case scenario, the area of snow cover lasting more than 60 days is predicted to be only 4% of the current area (Whetton 1998). For the summit of Mt Kosciuszko the duration of snow cover is predicted to change from around 187 days to between 152 and 177 days by 2030 (Whetton 1998).

The aim of this paper is to determine how species richness at different spatial scales changed along an altitudinal gradient and horizontal gradient (aspects on each summit). Therefore patterns of richness were examined, to see if the effect of altitude and aspect depended on the spatial scale at which species richness was measured. We also examined if there were correlations in species richness at the different spatial scales with climate variables. Patterns in richness of different groups of species for whole summits including endemics, generalists and weed species richness were examined.

Methods

Study area

Five summits in the alpine zone of the Snowy Mountains were selected and permanently marked (Figure 1). The five summits (CL1 2114 m, CL2, 2079 m, CL3, 1992 m, CL4, 1948 m, and CL5, 1729 m) that were selected for long term monitoring occur on a spur of Mt. Clarke covering a horizontal distance of 1600 m and an altitudinal range of 385 m extending from the lower alpine zone where shrubs are dominant to the upper alpine zone where grassland and herbfields are dominant. In the Snowy Mountains there is no nival zone. However, the highest summit sampled is only 114 m in altitude lower than Mt Kosciuszko, the highest mountain in continental Australia, which is located 3.5 km away.

Each summit was selected using criteria specified by the GLORIA procedure (Pauli et al. 2004). Specifically, summits were not volcanically active, they are exposed to the same local climate, and therefore differences in climate are likely to be due to the altitudinal gradient. They were all flattened summits (rather than cone-shaped), and the vegetation within the summit area was characteristic of other alpine areas at a similar altitude. They all had a similar disturbance history of grazing in the past (>50 years ago by cattle) although, because the spur was not on a major travelling route for transhumance grazing, damage was minimal and did not require rehabilitation works (Green et al. 2005). The summits are not along regular walking tracks and hence have low visitation rates.

The top section of each summit was divided into eight summit area sections – four covering the area above a line 5 m altitudinally below the summit (the -5 m isoline) for each of the four principal compass bearings, and another four covering the four compass bearings for the -10 m to -5 m isolines (Pauli et al. 2004). Where the summit was too flattened the upper area extended 50 m from the summit and the lower extended 100 m. At each of the four compass bearings at the -5 m isoline a cluster of nine 1 m² quadrats was established (3 m by 3 m). Due to the density of shrubs on the lowest summit, permanent clusters of quadrats could not be established.

Vegetation sampling

Species composition was recorded in the four corner 1 m² quadrat in the 3 m by 3 m grid in January 2004. In addition, each 1 m² quadrat was divided into 100 cells (10 x 10 cm) and all species present in each cell were recorded. In each of the eight summit area sections (summit to -5 m isoline, and -5 to -10 m isoline for North, South, East, and West) a complete species list of all vascular plant species was recorded (Pauli et al. 2004). As part of the GLORIA monitoring, species richness data were obtained at six spatial scales: 10 cm² quadrats, 1 m² quadrats, clusters of 4 * 1 m² quadrats, for summit area section for the top 5 m isoline, and for the whole summit area sections (top of peak to -10 m isoline to), and for whole summits. Data on species composition has been submitted for archiving to the GLORIA centre in Vienna (www.gloria.ac.at).

Soil temperature derived variables

Temperature loggers (Tinytag plus -Gemini Data Loggers, Chichester England) were buried 10 cm below the surface on each summit from January 2002 to January 2007 and in the centre square of each of the 3m x 3m quadrat clusters from late January 2004 to early January 2007. Temperatures were recorded every 2 hours. Temperature data from 2005 was used in this analysis as it was the first year after vegetation sampling (conducted in 2004) for which there was a complete annual data set. From this data six soil temperature derived variables were calculated: (1) Absolute minimum soil temperature, (2) annual daily average soil temperature, (3) absolute maximum soil temperature, (4) temperature sums (>5 °C), (5) growing days, and (6) length of the growing season (2004-2005).

Temperature sums were calculated by adding all values above 5 °C for each hour in 2005. Times with temperature above 5 °C was also considered to be considered suitable for plant growth, and hence the number of days available for plant growing in 2005 was calculated as the sum of all times measured that was >5 °C, divided by 12 to convert the 2 hourly values to 'growing days'.

The commencement of the snow free period after winter snow cover in 2004 was the day on which the noon temperature $\pm$ 2 hours went above 3.2 °C while the end of the snow free period was calculated as the day on which the noon temperature $\pm$ 2 hours fell below 3.2 °C and remained below that level. The length of the growing season for (2004-2005) was defined as the difference between these two dates minus days when soil temperature was < 3.2 °C at noon $\pm$ 2 hours.

Absolute minimum soil temperature, annual daily average soil temperature, absolute maximum soil temperatures, length of the growing season and temperature sums have been used to characterise the thermal regimes of alpine areas in Europe (Körner et al. 2003). Also, annual daily average soil temperatures have been used in

analysis of patterns of species richness in other GLORIA sites (Kazakis et al. 2006, Staniski et al. 2005).

Data analysis

To test the effect of aspect and altitude One-Way ANCOVA were performed on species richness values at each of the different spatial scales with altitude as the covariate. Linear regression on the different measures of species richness with altitude and the different soil temperature derived variables were also performed in the statistical package SPSS. Data on the distribution of species was obtained from Costin et al. (2000). Correlations between altitude and the soil temperature derived variables were tested using Pearson's one tailed correlation coefficients.

Results

The five GLORIA summits were relatively rich in vascular plant species with 70 vascular plant species identified in the 58514 m² area sampled for the five summits combined, 35% of the total alpine flora for this region (~100 km²). It was not possible to distinguish between species in the genera *Poa*, *Rytidosperma*, *Agrostis*, *Uncinia* and *Prasophyllum* consistently across different summits and spatial scales unless flowering. As a result data are only presented here at the level of genera for these taxa. In contrast, for the herb *Euphrasia collina* two subspecies can be easily and reliably identified in the field (subsp. *diversicolor* and subsp. *lapidosa*) while for the shrub *Olearia phlogopappa* two varieties are also recognisable in the field (var. *flavescens* and var. *subrepandra*). Therefore a total of 78 taxa were identified across the five summits. Sixteen percent of these were common to all five summits, 9.6% only occurred at the lowest site and 6.8% only occurred on the highest summit.

Biogeographic elements

Of the 70 vascular plant species, 12% were endemic to the alpine area around Mt Kosciuszko (~100 km²), 50% also occur in the alpine and subalpine zone of the Brindabella Ranges in the Australian Capital Territory, 76% could be found in the Victorian Alps, and 38% also occur in the high country of Tasmania which is separated from mainland Australia by Bass Strait. Six species (8%), two of which were recorded on CL5, the highest GLORIA summit sampled, are also found in New Zealand. Only two species of introduced weeds were recorded on any summit, the naturalised (able to grow and spread without human assistance) herbs *Rumex acetosella* (synonymous with *Acetosella vulgaris*, all summits) and *Hypochoeris radicata* (2 summits), but they had low cover values. Nine species endemic to the alpine area around Mt Kosciuszko were recorded. They all had low cover, with the endemic herb *Craspedia costiniana* characteristic of higher altitude summits, while the endemic shrub *Phebalium ovatifolium* (synonymous with *Nematolepis ovatifolia*) was characteristic of the lower altitude summits (Table 1).

The proportion of species at a summit from each of six biogeographic elements varied with altitude (Figure 2). A greater proportion of species at the lower altitude summits can also be found in the Victorian Alps, the Brindabella Range in the ACT, and also in the high country of Tasmania. In contrast, at the highest summit (CL1), the proportion of species that are endemic to the alpine area around Mt Kosciuszko had increased from 7% to 17% (compared to the lowest summit), and there was a

concomitant decrease in species that also occur in other alpine and subalpine areas in Australia.

Altitude, aspect and climatic variables

Species richness per summit varied from 53 for the lowest summit (CL5 1729 m) to 36 for the highest summit (CL1 2114 m Table 2). The high diversity on the lowest altitude summit was due to a high number of herb species (31), many of which were only recorded on this summit. Shrub diversity peaked on the mid summit (CL3, 1992 m) with 29 species, over half of all the species recorded on this summit.

There was a significant linear relationship between species richness and altitude, for -5 m and Top to -10 m summit area sections (Table 3, Figure 3). With each 100m increase in altitude species richness declined by 2.4 in the top -5m summit area sections ($R^2 = 0.345$, Figure 3d) and by 2.7 in the top to -10 m summit area ($R^2 = 0.357$ Figure 3e). There was no clear relationship between species richness at the smaller spatial scales and aspect, with the aspect that had the highest species richness varying among summits (Table 3, Figure 3).

When species richness was tested against different soil temperature derived variables, the only significant linear relationship was for species richness for the -5 m summit area sections with average soil temperatures in 2005, cumulative temperature sum above 5°C and growing season days in 2005, and for the top to -10 m summit area and average soil temperatures in 2005 (Table 3). There was an increase of 7.3 species with a degree rise in annual average temperature at the -5 m summit area sections (Figure 4a, $R^2 = 0.372$), and 6.3 species per degree for the top to -10 m summit area sections ($R^2 = 0.29$). There was no significant relationship between species richness at smaller spatial scales and the climatic variables.

Some of the soil temperature derived variables were correlated with altitude (Table 4), but not temperature sum. There was a decrease in average daily temperature, and growing season days with increasing altitude as would be expected.

Species richness at different spatial scales

Species richness varied with the area sampled as would be expected (Table 2). There was a strong power relationship ($F = 549$, $P < 0.001$, $R^2 = 0.863$), with no consistent increase in richness with area for summit area sections (Figure 5). The -5m summit area sections (average area 830 m²) averaged 27.3 species, while the much larger (2926 m²) top to -10m summit area sections averaged 32.5 species. The 1 m quadrats on average contained 12.7 species, while the 10 cm quadrats averaged only 2.4 species. Species richness at the different spatial scales was correlated as would be expected (Table 5). The only exception to this was between species richness at the largest two spatial scale (summit area sections) and the smallest spatial scale (10 cm quadrats) which were not correlated.

Discussion

In the Snowy Mountains, species richness was related to altitude with a trend of decreasing richness with increasing altitude at the spatial scale of summit area sections and for the whole summits. Decreasing species richness with increasing altitude is a common pattern in mountain regions (Körner 2002). In other GLORIA sites, species richness declines with altitude among summits in the Lefka Ori, Crete

(Kazakis et al. 2006), the central Apennines in Italy (Stanisci et al. 2005) the Rodna mountains in the Romanian Carpathians (Coldea and Pop 2004) the Sierra Nevada in Spain and the North East Alps in Austria (Pauli et al. 2003). However, in the Northern Apennines in Italy, species richness actually increased with altitude (Bertin et al. 2001).

It is particularly interesting that there was an effect of altitude on species richness in the Snowy Mountain. In some other GLORIA target regions, the highest summits sampled were selected to include the transition from the upper alpine to the nival zone, or even to be close to the limits of vascular plant life (Pauli et al. 2007; Erschbamer et al. 2006), and hence were highly likely to contain fewer species than lower altitude alpine summits with greater vegetation cover. In Australia there is no nival zone and all the summits sampled had nearly complete cover of vegetation (Pickering and Green unpublished data).

The 70 vascular plant species (and 5 graminoid genera) recorded for the five summits in the Snowy Mountains, is similar to the number recorded in several other target regions in Europe, but lower than the highly species-rich summits in the North Eastern European Alps, Dolomites, Central European Alps and northern Apennines with values ranging from 137 to 206 (Table 6). The richness per summit also varied within and among target regions with some single summits having over 100 species of vascular plants (Table 6). Few published studies of GLORIA summits examine patterns in species richness at scales smaller than the whole summit areas making it difficult to allow comparison with the results from the Snowy Mountains. Data for three other target regions are available for species richness for the 4 * 1 m quadrats. In the Snowy Mountains, species richness per quadrat cluster ranged from 9.5 to 14.5, which is similar to the richness in the Romanian Carpathians in Europe that ranged from 11-20 (Coldea and Pop 2004), and in New Zealand where it was 15, for the Nfiord Ecological region, and ranged from 12.5-19.3 in the Pisa Range (Mark et al. 2006).

For the -5 m summit areas, in the Snowy Mountains, richness ranged from 22-31.5 which is very similar to values from New Zealand (27.6 for the Fiord Ecological region, and 23.8-28 in the Pisa Range, Mark et al. 2006) and the Sierra Nevada (11-40, Pauli et al. 2003). In contrast, the North East Alps in Europe had much higher values for several of its summits with species richness ranging from 58 to 142 (Pauli et al. 2003). There are published data on only two other GLORIA regions that examined species richness for the -5 to -10 summit area sections. In New Zealand the values were 35.3 for the Fiord Ecological region, and 28-36 in the Pisa Range (Mark et al. 2006) which were slightly higher than the values for the -5m summit areas on those summits.

Endemic species

The greatest risk in alpine areas with climate warming is that there will be the loss of specialised alpine species, particularly those endemic to specific alpine regions. In the Snowy Mountains, there are 21 species endemic to the ~ 100 m² alpine area around Mt Kosciuszko (Costin et al. 2000), six of which were recorded on the highest summit studied here. Species endemic to localised alpine regions in Australia are likely to be particularly at risk, because, unlike many other alpine areas including other GLORIA target regions, there is a limited altitude range, and no nival zone available for potential upward migration. For those species recorded on the highest summit sampled in the Snowy Mountains, there is only another 114 m of mountain area above

them. For this mountain system, that equates into a change of 0.9 °C in air temperature (0.77 °C lapse rate per 100m from Brown and Millner 1989). The number of species endemic to Australia on the GLORIA summits was very high reflecting the high level endemism in the overall Australian flora.

The proportion of endemic species in floras was highly variable among summits within one target region and among GLORIA target regions. For the NE-Alps and Romanian Carpathians the proportion of endemics was very low (2-7%, Pauli et al. 2003, Coldea and Pop 2004). In the Snowy Mountains the proportion endemic to the local alpine region was a little higher, ranging from 7-17%, while the proportion endemic to Australia ranged from 90-94%. In the Central Apennines alpine endemics ranged from 18-45% (Stanisci et al. 2005), while it was much higher in Crete (33-36% Kazakis et al. 2006) and in the Sierra Nevada (28-91% Pauli et al. 2003).

Exotic species

The diversity of exotic plants in the Australian Alps decreases with increasing altitude due in part to the increasing severity of conditions at higher altitude (Mallen-Cooper 1990; Costin et al. 2000; Johnston and Pickering 2001; McDougal and Walsh 2007; Mallen-Cooper and Pickering In press). For example, the shorter growing season in alpine areas may prevent exotic seedlings from establishing, growing and reaching reproductive maturity, with many exotics unable to survive the effects of frost and snow (Mallen-Cooper 1990). Although only two weed species were recorded on the GLORIA summits in the Snowy Mountains, there are at least 14 species of weeds that are considered well established in the alpine area (Costin et al. 2000). Exotics in the alpine are generally restricted to roads and tracks with few, as found here, recorded in sites that have experienced relatively little anthropogenic disturbance (Johnston and Pickering 2001; Bear et al. 2006; McDougal and Walsh 2007). *Rumex acetosella* is the most common exotic in the alpine region of the Snowy Mountains, is considered to be naturalised (Johnston and Pickering 2001, Bear et al. 2006). However it does not appear to be a major problem because it tends to colonise area of bare soil after natural and human disturbance, and appears to be often out-competed by native species as they recover (Pickering and Hill 2007). *Hypochaeris radicata* is a common weed of mountain regions, again benefiting from disturbance. Although not as common as *Rumex acetosella*, it is found along road verges and in natural vegetation in the alpine area, where it can colonise bare ground, but is often difficult to remove once established (Bear et al. 2006, Pickering and Hill 2007).

It is highly likely that increasing temperatures and decreasing snow cover will result in an increase in the range of weed species able to grow in the Snowy Mountains including in the alpine zone (Pickering and Armstrong 2003; Pickering et al. 2004, Bear et al. 2006). Although the decrease of exotic species with altitude is likely to be influenced by differences in the extent of anthropogenic disturbance at different altitudes in the Snowy Mountains in the past, some is also likely to be due to the direct and indirect effects of climate on the distribution of exotics (Mallen-Cooper and Pickering In Press).

Climate change and species richness

Changes in species richness and composition with altitude are a common pattern in mountain regions with an average loss of ~40 species per 100 m increase in altitude for regional floras (Körner 2002). Here, the change on a local level was a decrease of

2.4-2.7 species per 100 m increase in altitude for the GLORIA summit area sections and ~ 4 species per 100 m for the whole summits (17 species/385 m between highest and lowest summit). Among the factors that might contribute to a decline in species richness with altitude in alpine regions is the effect of climate, with shorter growing seasons and lower temperature during the growing season at higher altitudes. In the Snowy Mountains, species richness on summits was not only correlated with altitude, it was also correlated with climatic variables such as annual average daily soil temperatures, cumulative temperature sum above 5 °C and growing season days in 2005, with fewer species as the growing season became shorter and temperatures declined. This result supports the basis of the GLORIA protocol where climate is considered an important factor affecting the composition and species richness of plants on summits (Pauli et al. 2004). It also supports the general prediction that increasing temperatures in alpine areas are likely to, and in some cases, have resulted in changes in increased species richness at a given altitude (Grabherr et al. 1994; Pauli et al. 2004, Pauli et al. 2007).

The alpine region of Australia is considered to be particularly vulnerable to impacts of climate change (Pittock 2003; Pickering et al. 2004). The alpine region where the GLORIA sites were located is particularly vulnerable as it is small in area, (100 km²) with a limited altitudinal range (400 m from the treeline to the summit of Mount Kosciuszko at 2228 m) (Pickering et al. 2004) and lacks a nival zone to act as a refuge for altitudinal succession (Pickering and Armstrong 2003; Pickering et al. 2004).

It has been predicted that a temperature increase of just 3 °C could alter the climate of the area that is currently alpine, to that of the subalpine (Green et al. 1992) with the resulting loss of the rare endemic communities such as the groundwater communities (fens, bogs and peatlands) and the endemic snowbank communities snowbank feldmark and short alpine herbfield communities (Pickering et al. 2004). These latter two communities are the only known locations for four plant species endemic to the Kosciuszko alpine area (Costin et al. 2000). Conversely, higher temperatures are expected to increase the distribution of the dominant alpine and subalpine plant communities (tall alpine herbfield, heath, and sod-tussock grassland) (Pickering and Armstrong 2003; Pickering et al. 2004).

Climate change in the subalpine or montane areas of the Snowy Mountains is expected to benefit exotic species which may be currently excluded from the alpine due to the severe environmental conditions at higher altitudes (Johnston and Pickering 2001; Pickering et al. 2004; Pickering and Hill 2007; Mallen-Cooper and Pickering In Press). With warmer and drier conditions associated with climate change, the altitudinal ranges of some weed species are likely to increase. This invasion process may be facilitated by the predicted increase in frequency of natural disturbances (bushfire and drought) which reduce the cover of native vegetation.

The latest climate change scenarios for the Australian Alps predict a change in temperature of +0.6 °C under a low impact scenario and +2.6 °C under a high impact scenario by 2050 (Hennessey et al. 2003). One method for estimating how this could affect species richness on the GLORIA summits, if temperatures were to change as predicted, is to convert the predicted temperature change using a temperature lapse rate into an equivalent change in altitude. For the Snowy Mountains, the lapse rate is approximately 0.77 °C per 100 m (Brown and Millner 1989). As a result sites that may be currently experiencing equivalent temperatures would be 78 m higher under the best case scenario and 338 m higher for the worst case scenario. Therefore, alpine

climatic conditions potentially could disappear in large parts of the region and locally restricted endemic species could be threatened by a moderate warming.

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