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Increasing the resilience of the Australian alpine flora to climate change and associated threats: A plant functional traits approach

Final Report

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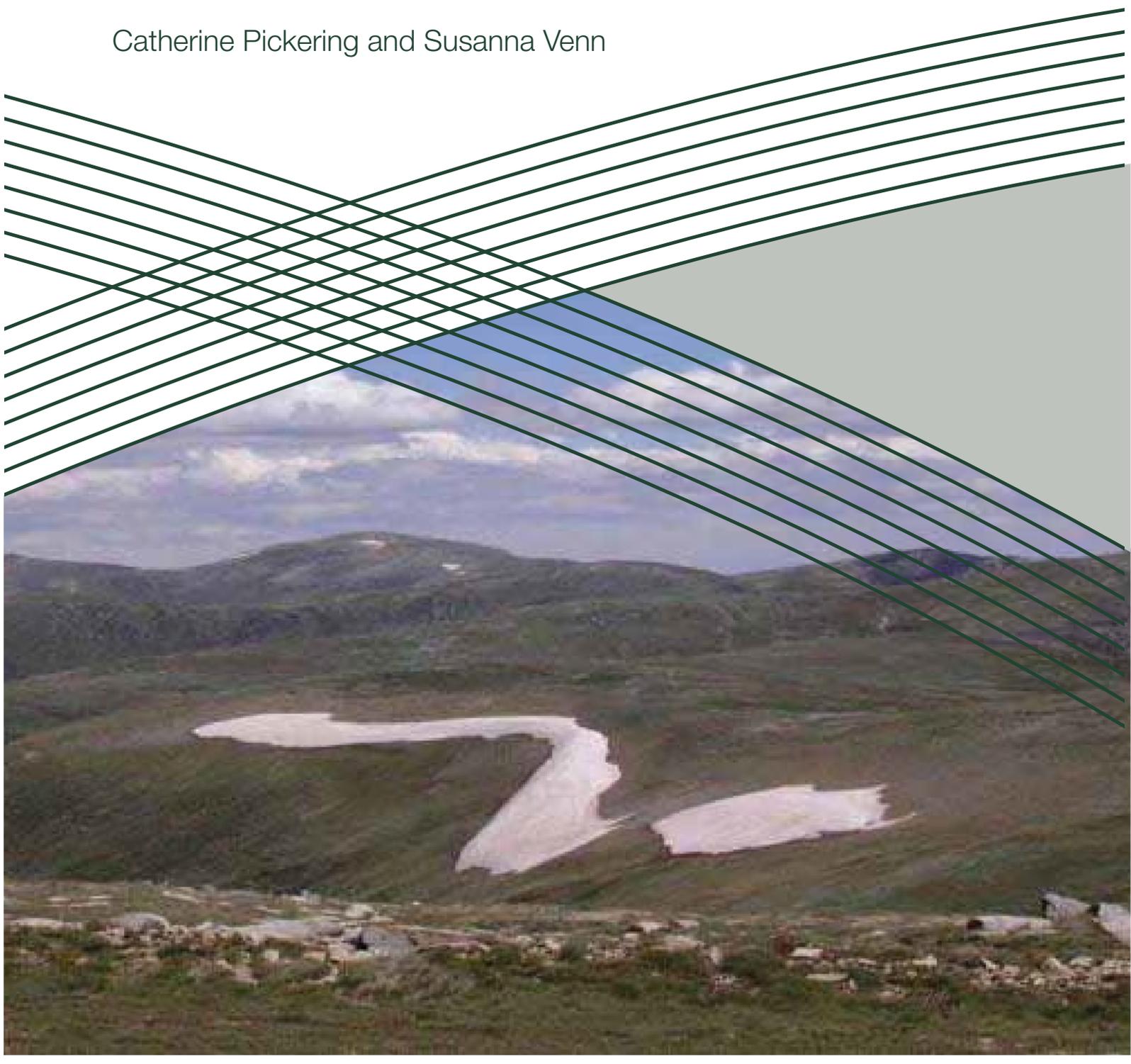
Increasing the resilience of the Australian alpine flora to climate change and associated threats: A plant functional traits approach

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ABSTRACT

The alpine region around Australia's highest mountain, Mt Kosciuszko, is part of one of the three most at risk ecosystems in Australia from climate change. With higher temperatures and decreased precipitation, snow cover is already declining with even greater reductions predicted in the short to medium term (2020 to 2050). Consequently the distribution of many native plants and animals may contract, while the distribution of weeds and feral animals may expand. Wildfires in the region are also likely to be more frequent and intense.

To contribute to our understanding of how changes in the environment alter plant composition and ecological process, we conducted a series of functional trait analyses of existing composition datasets. We collected trait data in the field for 220 species including canopy height, leaf area, leaf dry matter content and specific leaf area (SLA). Variation in traits among the alpine flora was not related to species distributional ranges. Traits were strongly associated with growth forms, with shrubs often taller than herbs and graminoids, but often had small, tough, long-lasting leaves.

Species traits were combined with relative cover values to calculate community trait weighted means, a commonly used measure of functional diversity. Functional diversity varied with altitude/duration of snow cover. For example, shrubs which are taller with small tough leaves dominated lower altitude summits, while at higher altitude summits, large, soft leaved herbs and graminoids dominated. Late lying snowpatches areas with short growing seasons were dominated by low growing herbs and graminoids with small leaves while areas with longer growing seasons were dominated by herbs and graminoids that were taller and had larger leaves.

Recovery from fire differed among plant communities. The composition and functional diversity of recovering tall alpine herbfield is trending towards that of equivalent unburnt sites, while burnt windswept feldmark was colonised by graminoids and herbs that are often found in tall alpine herbfield species, with limited shrub recovery in the first nine years post fire.

Grazing by feral hares had no effect on composition or functional diversity, while vegetation recovering from cattle grazing showed clear changes in composition and functional diversity even 43 years later. Prioritising management for this high value conservation region, therefore, involves enhancing resilience by minimising existing threats, particularly those from fire, weeds and hard-hooved grazing animals which will be exacerbate by climate change.

EXECUTIVE SUMMARY

Context: The snow covered mountains of the Australian Alps are internationally important due to their conservation values and ecosystem services, with economic returns estimated at $5 billion per year. The region is an important biodiversity ark conserving >400 species of plants >25 of which occur nowhere else in the world. Unfortunately, the flora and fauna are threatened by climate change with this alpine region amongst the most vulnerable ecosystems in Australia.

Climate change predictions include higher temperatures and decreased precipitation resulting in reduced snow cover and warmer, drier summers. By 2020 snow cover is predicted to decline by 60% compared to 1990 values. Changes are already occurring with 30% less snow cover overall and 40% less in spring and earlier spring thaws compared to the 1950s. As a result plants are flowering earlier and some mammals, insects and birds are arriving earlier in spring. The distributions of some of the rarest species of native plants, animals and plant communities have contracted including those most dependent on snow. The number and type of weeds and feral animals is also increasing in the region. For Australia's alpine plants and animals there is nowhere higher to retreat as conditions warm. Longer, warmer, and often drier summers are also amplifying existing threats to the region including those from bushfires, weeds and feral animals.

Objectives of the research: This research used functional trait analysis to assess how best to increase the resilience of the Australian alpine flora to climate change and associated threats. Data on the composition of the vegetation was used to demonstrate how plants respond to changes in climate and disturbance, and functional trait data was used to understand why changes occurred. This report summaries these results, with greater detail about the methods and results for individual studies provided in a series of papers produced based on this work, some of which are already published.

Methods: We accessed ~30,000 existing records of the cover of individual species from ~2,500 samples of vegetation plots subject to different natural and experimental treatments. This data was analysed to assess how alpine vegetation responds to different climatic conditions including reduced snow cover, and different types of disturbance such as fire and grazing.

To understand ecological process underlying the changes in composition, we collected data on plant functional traits including 11,800 measurements of vegetative traits such as plant height and the size and shape of leaves for 220 species in the Australian Alps. These traits are related to important ecological process such as succession, competition, stress tolerance and disturbance.

Results: We examined the range of functional traits present across the native and weed flora to see if there were discrete functional groups; that is, groups of species that have similar traits and hence may show similar responses to environmental changes. When we assessed species with similar distributions, we found that there was equivalent variation in traits among weeds as natives, and among plants endemic to just the Kosciuszko alpine area as those with broader distributions.

We did find, as expected, that shrubs, graminoids and herbs represent different functional groups. Alpine shrubs were generally taller than most alpine herbs and graminoids species, but had small, tough long-lasting leaves (scleromorphy). These differences reflect in part, Australia's unique evolutionary history and how it has shaped the leaf morphology. As a result, the functional diversity responses of the alpine vegetation to different types of disturbance such as grazing and trampling differed to those described in recent reviews, particularly involving changes in the shrub cover.

We found that functional diversity, based on species traits, varied with climatic conditions. Potentially more competitive species were growing where conditions are relatively warmer

(lower altitudes) and where the growing seasons are longer. Notably, shrubs are increasingly dominant where conditions are comparatively warmer on lower altitude/warmer summits. Tall alpine herbfield species are increasingly dominating areas on the edge of snowpatches where they are replacing the rare short alpine herbfield community as growing seasons lengthen with reduced snow cover. However, as shrubs are relatively tall and have relatively small leaves compared to herbs and graminoids, this leads to unusual patterns in the functional trait analyses.

We found that tall alpine herbfield is recovering well from the 2003 fire, with composition in burnt sites increasingly resembling that in unburnt sites. In contrast, areas of the very rare windswept feldmark that burnt in 2003 are increasingly dominated by taller grasses and herbs, with limited recovery of key shrub species nine years post fire.

We found that changes in composition after cattle grazing and drought were matched by changes in functional diversity. However, we found that neither species composition, nor species functional traits, appear to be changing with hare grazing, at least at current hare densities.

Main conclusions: The results of the composition and functional trait analyses highlight that climate change, including through the effects of more frequent fire, threatens rare and specialised plant communities such as short alpine herbfield and windswept feldmark. Also, tall alpine herbfield is relatively resilient to threats such as fire and hare grazing, but not to grazing by hard hooved animals such as cattle. Finally, where conditions are warmer, herbs and graminoids are being replaced by more competitive shrubs.

Management Implications: These results reinforce the importance of existing management recommendations that are likely to increase the resilience of the alpine flora to climate change.

We therefore reiterate the importance of park agencies:

1. Managing and minimising the spread of fires into the alpine areas, although this will become even harder on extreme fire days such as those in 2003, when it is virtually impossible to control fires.
2. Limit the spread of feral animals, particularly large introduced mammals such as deer, horses and pigs. In contrast, hares do not appear to be an important threat to the flora at current densities.
3. Limit the spread of weeds in the alpine and subalpine region of the Australian Alps.

Other threats not directly assessed in this report due to time limits are also important and need to be managed, including minimising other types of disturbance such as trampling from increased tourism use of the region.

1. OBJECTIVES OF THE RESEARCH

The snow-covered mountains of the Australian Alps are nationally and internationally important due to their conservation significance, ecosystem services and economic values. Predicted increases in temperature and decreasing precipitation due to climate change will result in dramatic changes in the region with snow cover already declining. In the alpine area, climate changes will adversely affect native plant species and communities through the amelioration of current environmental filters and changes in disturbance regimes. Increased disturbance and competition may result in dramatic changes in community composition and the loss of endemic species.

The challenge for developing an adaptation strategy plan for alpine biodiversity lies in the limited range of options available to managers. First, there are limited refugia options for alpine species to colonise as Australia is without a nival zone (Costin et al. 2000; Green & Osborne 2012). The second challenge lies in the link between the predicted climate change effects (increase in temperatures and decreased overall precipitation including reductions in snow cover duration and extent), with the importance of snow cover for many alpine species, particularly endemics (Costin et al. 2000; Green & Osborne 2012). Unfortunately, adaptation strategies to minimise extinctions such as assisted migration of species, or deliberate alteration of the current habitat to maintain snow cover (shading, snow fences, snow making) are unfeasible due to biophysical, ecological and economic limitations (Morrison & Pickering 2011).

A previous report for NCCARF assessing limits to adaptation strategies to climate change in the Australian Alps (Morrison & Pickering 2011) found that conservation managers in the Australian Alps favour strategies that promote ecosystem resilience and connectivity. Increasing connectivity is increasingly promoted as an adaption strategy for climate change (Worboys et al. 2010) and proposals to increase connectivity at a larger scale including between the Australian Alps and other bioregions (Alps to Atherton, Mackey et al. 2010). This approach, however, has less direct relevance for the Kosciuszko alpine areas as fragmentation is currently not a major threat, but rather reduction in total area due to reduced snow cover.

Resilience refers to the capacity of an ecosystem to resist and recover from different types of natural and human impacts. These include stochastic disturbance events such as fire or more continuous disturbances such as those from grazing by feral animals. It can also include the impact of increased competition for resources due to the establishment and spread of new species such as weeds. In some cases, the severity of the impacts may exceed the capacity of the ecosystem to recover if impacts exceed some threshold level. For the alpine flora the resilience of the ecosystem is threated by reduced snow cover and other direct biophysical impacts of climate change, fire, grazing, weeds and tourism (Morrison & Pickering 2011). Dealing with these threats is expensive and difficult and requires carefully focused management responses (Morrison & Pickering 2011). Research assessing how (composition) and why (ecological process) the alpine flora responds to these types of disturbance will help determine how management responses should be prioritized.

Using this type of approach to better understand how, and why, the alpine flora responds to climate and disturbance directly addresses key research gaps identified by end-users as specified in recent policy and review documents including:

1. Pickering, C.M., Good, R.B. & Green, K. 2004. *Potential Effects of Global Warming on the Biota of the Australian Alps.* Australian Greenhouse Office, Canberra.
2. Worboys, G.L., Good, R.B. & Spate, A. 2010. *Caring for Our Australian Alps Catchments: A Climate Change Action Strategy for the Australian Alps to Conserve the Natural Condition of the Catchments and to Help Minimise Threats to High Quality Water Yields.* Australian Alps Liaison Committee and Australian Department of Climate Change, Canberra.

3. Morrison, C. & Pickering, C.M. 2011. *Climate Change Adaptation in the Australian Alps: Impacts, Strategies, Limits and Management*. National Climate Change Adaptation Research Facility, Griffith University, Gold Coast.
4. Pickering, C.M., Guitart, D., Ballantyne, M. & Morrison, C. 2012. *Climate Change Research and Monitoring Needs for the Australian Alps National Parks: Survey of Parks Staff and Researchers*. Report for the Australian Alps Liaison Committee, Canberra.

For example, a lack of knowledge regarding impacts, insurance populations, invasive species and the complexity of impacts were all identified as limits to adaptation by stakeholders in the Australian Alps in a previous NCCARF funded project (Morrison & Pickering 2011). Following on from that report and running in tandem with the functional trait analysis, a more extensive survey of Parks agency staff was produced for the Australian Alps Liaison Committee (Pickering et al. 2012). It provided more details regarding exactly what climate change related research Park staff require to help manage climate change and associated threats in the Australian Alps. Parks staff stated that they need more information about threats to endemic species and plant communities, invasive species, and the increased risk of fires. Specifically, they wanted more information about the threatening processes for particular alpine plant communities including;

 "The high alpine and bog and fen ecosystems to ensure they are resilient to withstand changes brought about by climate change, particularly to be resilient to movement upwards of invasive species, both plant and animal, increased fire and deceased soil moisture."

"As a priority all obligate alpine and endemics but all communities and species need some attention to ensure maintenance and survival."

They also need more information about weeds and feral animals including:

"Horses, pigs, deer, cats, foxes, rabbits and hares all require control programs and co-ordinated research."

"Feral horses, feral pigs, rabbits and hares, exotic daisies, brooms, seeding willows, weeds of alpine bogs and streams."

"…increased pressure will come from the upwards movement of Broom, Blackberry, Willow, Feral Horses, Deer et al."

Parks agency staff also indicated that they require long-term monitoring projects to be established and/or supported. Examples need include:

"Vegetation change data-sets in alpine/sub-alpine areas too -specifically changes to woody vegetation (trees/shrubs)."

"Vegetation changes including both native and non-native plant species transition into higher altitudes and habitats not previously seen."

"Using historical data (plots, photos) gives us the best data to assess how climate change is already affecting the Alps."

This current NCCARF funded research project directly addresses these issues by using existing short and long term datasets to analyse how alpine vegetation responds to climate change and associated threats. It combines traditional analysis of changes in the distribution and composition of plant communities with a functional trait analysis that more directly assesses ecological process.

Functional trait analysis can not only explain what happens in response to environmental change, but why species and plant communities respond (Grime 2001; Cornelissen et al. 2003; Westoby et al. 2002; Diaz et al. 2007; Tecco et al. 2010; Bernhardt-Romermann et al. 2011). For example, changes in the relative dominance of species with particular traits such as specific leaf area, the % dry matter content in leaves, leaf area, timing and duration of

flowering, canopy height and lateral spread indicate how species compete and respond to stress (Grime 2001; Cornelissen et al. 2003; Westoby et al. 2002). By characterising the functional traits of alpine, subalpine and weed species, it will be possible to identify functional groups: that is groups of species with similar traits that are likely to respond in similar ways to changes in climate and disturbance regimes. By assessing changes in the relative dominance of species with different traits within a plant community it is also possible to assess how plant communities are likely to respond including which communities distributions may expand and which may contract.

The specific research objectives were to:

1. Evaluate the latest climate change research for the Kosciusko alpine area including documented and predicted changes in the region (Section 3).
2. Summarise the theory behind the use of functional trait analysis in ecological research. This included using the results of recent reviews of functional traits to make predictions about the potential response of Australian alpine plants to climate change and related threats (Section 4).
3. Identify the functional traits of a large number of alpine species including identifying functional groups (Section 5)
4. Assessing how plant communities respond to changes in climatic gradients (Section 6) and disturbance regimes (fire – Section 7 and grazing – Section 8) using changes in composition to assess how they respond and functional diversity to assess the underlying ecological process driving changes in composition.
5. Make recommendations regarding prioritizing resilience adaptations strategies based on the results from the composition and trait analyses (Sections 9 and 10).

2. THE SOCIAL AND ENVIRONMENTAL CONTEXT

2.1 The Australian Alps

Snow cover is spatially and temporally limited in Australia (Costin et al. 2000). Approximately 0.15% of the continent receives regular winter snow falls (Costin et al. 2000). Outside of Tasmania, regular snow is limited to the highest ridges of the Great Dividing Range that extends over 500 km including parts of NSW, ACT and Victoria (Green & Osborne 2012). Nearly all this snow country is conserved in the Australian Alps National Parks (Figure 1). These eleven national parks and reserves occupy 1.644 million hectares and extend across the majority of the Alps Bioregion (Crabb 2003). Although responsibility for each individual park resides with the state/territory parks agencies, there is collaboration in the management of the parks through the Australian Alps Liaison Committee, one of the first transboundary collaborative park agencies in the world (Crabb 2003). The Australian Alps Cooperative Management Program operates under a memorandum of understanding between the ACT, Victorian, NSW and Commonwealth park management agencies to foster cooperative management. The Alps program supports scientific research and places a strong emphasis on linking science and management.

Figure 1: Location of the Australian Alps National Parks and the Australian Alps walking track which traverse the Parks. Reproduced with permission from Australian Alps National Parks.

The importance of the Alps bioregion is recognised nationally and internationally. It is a National Landscape and considered to be of world heritage quality (Kirkpatrick 1994; DEWHA 2010). The Australian Alps provide a range of economic benefits through tourism and through ecosystem services such as clean water, soil conservation and biodiversity (ISC 2004; Worboys et al. 2010). The Alps is a major tourism destination including the ski tourism resorts in, and adjacent to, the Parks, with winter visitation to the region worth AU$906 million in 2005 (0.1% of GDP in 2005, NIEIR 2006; Pickering & Buckley 2010). At lower altitude, many towns depend to a large extent on jobs and incomes generated from the Alps including in tourism (NIEIR 2006). Agricultural and other productive industries in areas around the Australian Alps depend on water from the mountains, while much of south-eastern Australia utilises hydroelectric power generated within the Australian Alps (Worboys et al. 2010). As a result the value of the Australian Alps is estimated at $5 billion per year to the nation in terms of water resources, hydroelectric power and tourism (Worboys et al. 2010).

2.2   Kosciuszko National Park

This report summaries research conducted in the alpine area of Kosciusko National Park. It is the largest and highest of the Australian Alps National Parks with a total area of (6,900 km^2) (Good 1992a; ISC 2004). The Park is an UNESCO Biosphere Reserve that contains examples of glacial and periglacial features including block streams and erratics, while the largest of the four glacial lakes in the alpine zone, Blue Lake, is a RAMSAR wetland (Good 1992a; ISC 2004). It is also one of the World Conservation Union 167 world centres of biodiversity (DEC NSW 2006).

The Park was used by Aboriginal people of millennium, particularly in the summer for ceremonial practices and gathering food (ISC 2004). From around the 1820s pastoralists started using the area for grazing cattle and sheep particularly in summer (ISC 2004). This transhuman grazing lasted around 135 years, with cattle and sheep grazing removed from the Park starting in the most sensitive alpine regions.

The Park has become a popular tourism destination with an estimated 1 to 3 million visitors per year, making it the most popular Park in NSW (DEC NSW 2006). Winter tourism is concentrated in, and around, four ski resorts, which are run by for profit by private organisations that lease land from the Park (Table 1). The Park is also a popular tourism destination during the snow free period, providing a range of nature-based tourism activities. The most popular activities in summer are bushwalking/hiking, including summiting the highest mountain in continental Australia: Mt Kosciuszko (2,228 m). Other popular activities include camping, fishing, rafting, canoeing, kayaking, rock climbing, mountain biking, orientation and horseback riding (Mules et al. 2005). Historical tourism along with music, food and art festivals are increasingly promoted by ski resorts and local towns.

Table 1: Characteristics of four ski resorts within Kosciuszko National Park.

Resort	Altitude (max. in m)	Skiable area (ha)*	Resort management
Perisher Blue	2034	1245	Perisher Blue Pty Ltd
Thredbo	2037	480	Kosciuszko Thredbo Pty Ltd
Charlotte Pass	1954	50	Charlotte Pass Village Pty Ltd
Selwyn Snowfields	1614	45	Mount Selwyn Snowfields Pty Ltd

Data from the Australian Resort Statistics for the Australia Ski Areas Association website accessed February 2011.

There are 852 vascular plants, and 221 non vascular plants in the Park, with around 380 species of vascular plants found in the alpine and subalpine areas (DEC NSW 2006). Over 330 weed species have been recorded in the Park, with two thirds found in the alpine and subalpine areas (DEC NSW 2006). There are around 300 native terrestrial vertebrate species including 31 species of mammal and 202 species of birds (DEC NSW 2006). A total of 61 of these species (~21%) are considered rare, vulnerable or threatened (ISC 2004). The number of invertebrates species is unknown, but the Park is host to a great diversity of invertebrates, some of which are resident year round, while others such as the Bogong moths (*Agrotis infusa*) are summer migrants (DEC NSW 2006; Green & Osborne 2012).

The problematic feral animals in the Park consist of dogs, horses, pigs, foxes, cats, goats, rabbits, hares, deer, starlings, black rats, house mice, several fish species and European bees (DEC NSW 2006; Green & Osborne 2012). Some feral animals such as black rats, mice, starlings, cats and to some extent foxes, are mainly found in, and around, resorts where they benefit from food and shelter particularly during winter. Other feral animals such as deer, pigs, dogs and horses are more widespread in the Park often avoiding areas of concentrated human use such as ski resorts (DEC NSW 2006; Green & Osborne 2012).

2.3   The Kosciuszko alpine zone

This research assessed climate change threats and other threats to plants in the alpine area around Mt Kosciuszko. This is the largest and highest contiguous alpine area in the Australian Alps and extends from South Ramshead near Mt Kosciuszko to Dicky Cooper Bogong 28 km to the north (135 km^2) (Green 2009a) (Figure 2). The alpine zone extends from the treeline at approximately 1,850 m to the highest peak in continental Australia, Mt Kosciuszko (2,228 m). It is characterised by continuous snow cover for at least four months per year, with minimum temperatures below freezing for 6 to 8 months per year. Precipitation is in the range of 1,800 to 3,100 mm per year, with ~60% of this falling as snow as a result of predominantly westerly winds and associated low pressure systems (Costin et al. 2000).

The soils and topography of the Kosciuszko alpine area contrast with the steeper and rockier mountains of New Zealand, the Andes, Europe and Asia (Good 1992a; Costin et al. 2000). There has been limited tectonic uplift in the Australian Alps compared to the more active mountain ranges on the edges of continental plates in Asia, North and South America (Good 1992a; Costin et al. 2000). The Australian Alps have also experienced limited glaciation resulting in more rounded mountains with deep soils of aeolian (windblown) origin (Costin et al. 2000). As a result there is near complete (99%) vegetation cover in Kosciuszko alpine area on deep, well developed alpine humus soils (Costin et al. 1979) (Table 2).
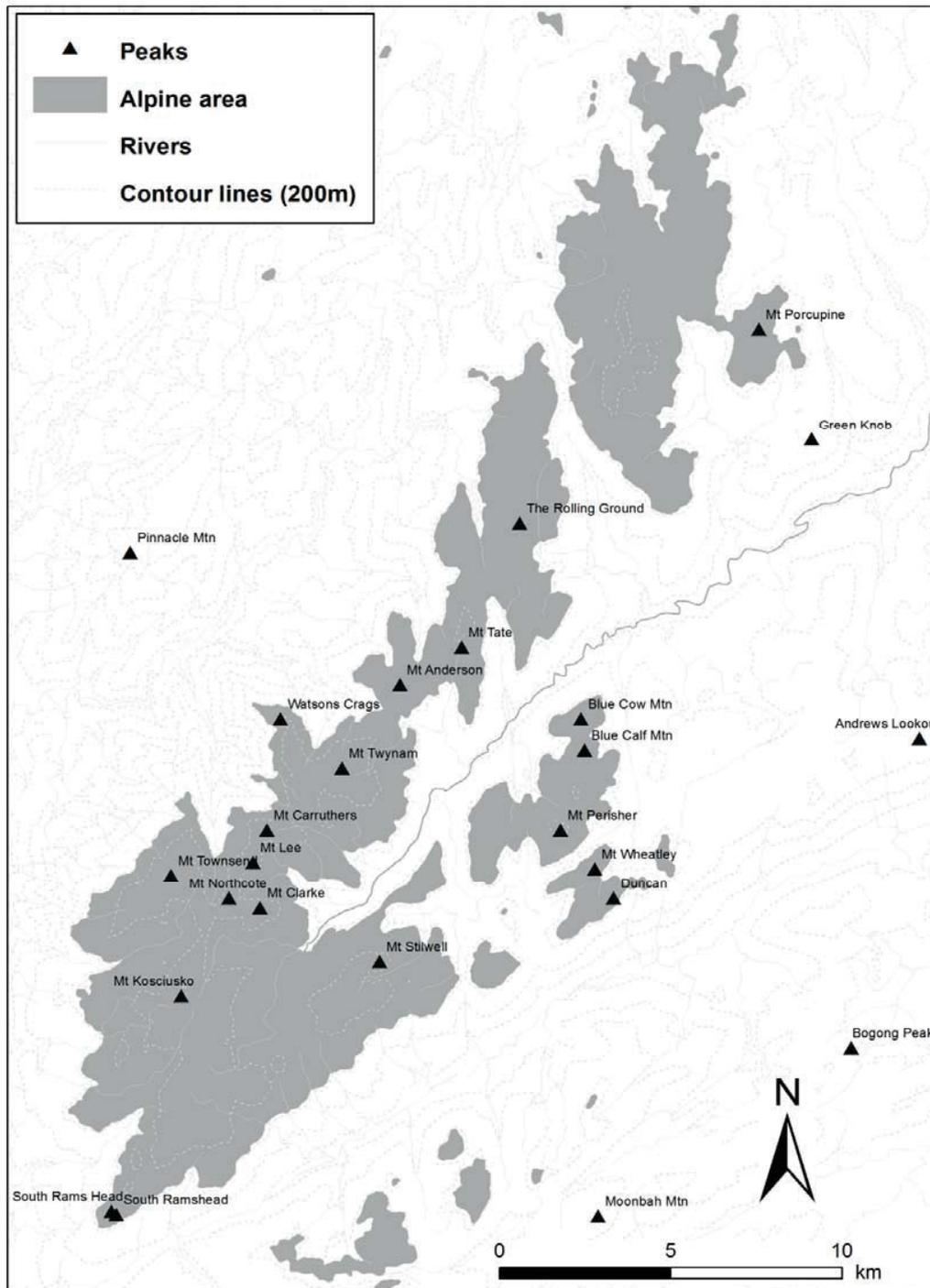
Figure 2: Location of the Kosciuszko alpine area.

The alpine zone has high plant biodiversity with 212 species of vascular plants, of which 21 are endemic to just this alpine area and 33 are rare (Costin et al. 2000). Eleven plant communities are recognised from the alpine zone, with tall alpine herbfield the most

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common, covering approximately 55% of the area (Costin et al. 1979) (Table 2, Figures 3 & 4). The plant communities with the most restricted distribution are windswept feldmark which is limited to the ridgeline of the highest ridges and peaks in the Park (Figures 3 & 4) and two communities restricted to the small areas of very late lying snow: snowbank feldmark and short alpine herbfield (Table 2, Figures 3 & 4) (Costin et al. 1979). These communities are among the most threatened in Australia due to their limited distribution and association with particular snow cover conditions.

Table 2: Area and % cover of the main plant communities in the Kosciuszko alpine area. Modified from Costin et al. 1979.

Mapping unit	Area (ha)	% area	mapped
Windswept feldmark	28.5	0.30	
Snowbank feldmark	156	1.62	
Short alpine herbfield	82.2	0.85	
Tall alpine herbfield (a)*	5340.6	55.34	
Tall alpine herbfield (b) – rocky sites	606.7	6.29	
Oxylobium-Podocarpus heath	2182.1	22.61	
Kunzea heath	266.8	2.76	
Fen and bogs*	559.4	5.80	
Subalpine woodland islands	292	3.03	
Lakes	27.8	0.29	
Rock screes	41.4	0.43	
Rock outcrops	53.1	0.55	
Eroded areas	13.6	0.14	
Total area	9650.2		
Total area of vegetation	9514.3	98.59	

* The mapped area for fens and bogs include the three plant communities that could not be separated out from aerial mapping: Fen, Valley bog and Raised bogs, while the Tall alpine herbfield (a) includes Sod tussock grasslands.
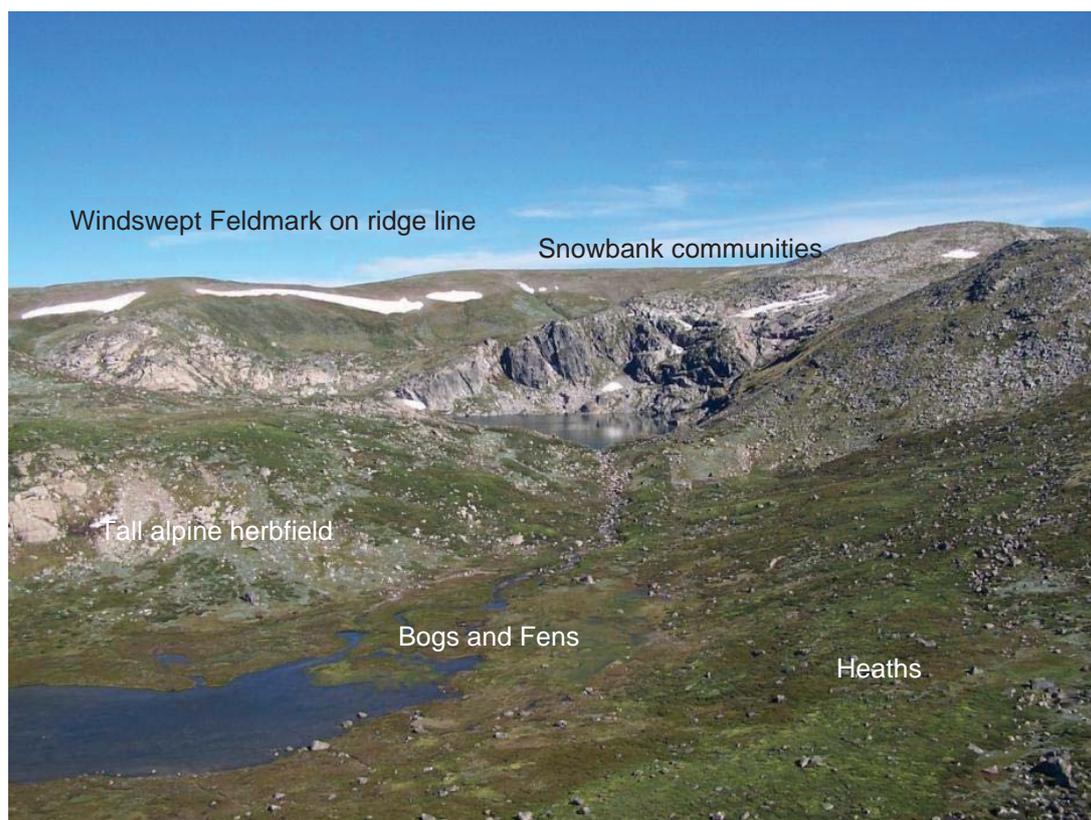
Figure 3: Blue Lake and Headly Tarn showing some of the different plant communities found in the Kosciuszko alpine area. Photo: Catherine Pickering

In contrast to the high plant biodiversity in the alpine zone, vertebrate diversity is low with few resident vertebrate species. There are just five species of mammals resident in the alpine area: the relatively common bush rat (*Rattus fuscipes*), dusky antechinus (*Antechinus swainsonii*) and agile antechinus (*Antechinus agilis*), the rare and threatened broad toothed rat (*Mastacomys fuscus)* and the endangered mountain pygmy-possum (*Burramys parvus*) (Green & Osborne 2012). The dusky and agile antechinus eat a range of invertebrates, mostly insects and some lizards (Green & Osborne 2012). The broad toothed rat is the largest native grazing mammal in the Kosciuszko alpine zone at around 150 gm. It mainly feeds on grass but also eats leaves and seeds of other plants. Mountain pygmy-possums have a more diverse diet including invertebrates such as the Bogong moths along with some plant material, mostly the 'fruit' of the Plum pine (Green & Osborne 2012).

There are nine species of lizards in the alpine area, some of which are endemic to the Park. This diversity is high compared to alpine areas in many other countries, where often there is only a single species of alpine lizard (Ken Green, pers. comm.). There were three species of frogs resident in the Kosciuszko alpine area, but two are now locally extinct due to infection by the chytrid fungus (Green & Osborne 2012).

The Kosciuszko alpine area was used for cattle and sheep grazing from the 1850s until 1944, with some use in the 1950s (Costin 1954; 1958; Costin et al. 2000). Because the alpine flora of Australia evolved in the absence of hard-hoofed grazing mammals, this summer grazing resulted in massive soil erosion among other impacts (Costin 1954; 1958; Costin et al. 2000). Damage from cattle grazing included the loss of vegetation cover, declines in many plant communities including bogs and fens due to incision and drainage, and the near extinction of several endemic palatable plant species (Costin 1954; 1958;

Costin et al. 2000). Active rehabilitation of much of the alpine area post grazing was expensive, and had its own impacts (Good 1992a).

Figure 4: Four of the plant communities affected by climate change, fire and grazing in the Kosciuszko alpine area. Top to bottom: Windswept feldmark, tall alpine herbfield, heath and short alpine herbfield. All images by Catherine Pickering, except general snowbank (Michael Campbell) and close up of short alpine herbfield species (Mark Ballantyne).

Fire in the alpine area was uncommon before the arrival of pastoralists. Fires in the snow country of the Australian Alps are infrequent with decades or even centuries between fires in some areas prior to the arrival of Europeans with about one major fire event per century (Wimbush & Forrester 1988; Williams & Costin 1994; Williams et al. 2006; Williams et al. 2008). The alpine zone often acts as a large fire break, restricting the spread of large scale fires (ISC 2004). During 2003, however, 70% of the alpine and subalpine area of the Australian Alps burnt (Green & Sanecki 2006; Williams et al. 2008). Recovery of the alpine and subalpine vegetation from fires varies depending on climatic conditions, vegetation characteristics, time between fire events and impacts of other types of disturbance (Wimbush & Forrester 1988; Williams & Costin 1994; Pickering & Barry 2005; Bear & Pickering, 2006; Williams et al. 2006, 2008).

Around 50 species of weeds have been recorded in the Kosciuszko alpine area, although only 14 species are common (Costin et al. 2000; Johnston & Pickering 2001; McDougall et al. 2005; Bear et al. 2006; Pickering & Hill 2007). Many species were deliberately introduced into the region to assist with revegetation after grazing, stabilisation of ski slopes or as resort garden plants (Johnston & Pickering 2001; McDougall et al. 2005; Bear et al. 2007; Mallan-Cooper & Pickering 2008; McDougall et al. 2010).

The main feral animals in the Kosciuszko alpine area are hares and foxes, with cats, deer and horses sometimes moving into the alpine area temporarily during summer. Honeybees are occasional found, but may have been blown up from lower altitudes (Pickering, author obs.).

3.   CLIMATE CHANGE IN THE AUSTRALIAN ALPS

Mountains are among the most globally vulnerable ecosystems to climate change (Grabherr et al. 1994; Pauli et al. 2004). This is in part due to their limited area, narrow ecotones, with the distribution and diversity of flora and fauna strongly related to climatic conditions (Körner 2003; Green & Osborne 2012). Changes in climatic conditions due to human causes have already been documented in many mountain regions globally (IPCC 2007). This includes changes in snow cover, increasing temperatures, melting glaciers and glacial flood outbursts (Beniston 2003; Casty et al. 2005; IPCC 2007).

3.1   Biophysical impacts

The alpine zone of the Australian Alps is one of the three most at risk ecosystems in Australia from climate change, along with Kakadu National Park and the Great Barrier Reef (Green 2009b; Steffen et al. 2009; Lindenmayer et al. 2010). Predicted climatic changes in the Australian Alps involve increasing temperatures and changes in precipitation which then result in reduced snow cover (Whetton 1998; Hennessy et al. 2008) (Table 3). Climate change predictions have been made by using 1990 data as a base line and then incorporating the impact of predicted temperatures and precipitation changes based on best and worst case scenarios to determine future patterns in snow cover for the region (Whetton 1998; Hennessy et al. 2008) (Table 3). Under a worst-case scenario, snow cover is predicted to reduce by 60% by 2020, and by 96% by 2050 in the alpine areas.

Table 3: Summary of climate change predictions for the Australian Alps under different climate change scenarios. Modified from Hennessy et al. 2008. Predicted values relate to changes compared to 1990 values for snow cover and season length.

Changes in:	Best case 2020	Worst case 2020	Best case 2050	Worst case 2050
Temperature	+0.2^{o}C	+1.0^{o}C	+0.6^{o}C	+2.9^{o}C
Rainfall	+0.9%	-8.3%	+2.3%	-24.0%
Reduction in area with snow cover				
At least 1 day	9.9%	39.3%	22.0%	84.7%
At least 30	14.4%	54.4%	29.6%	93.2%
At least 60	17.5%	60.3%	38.1%	96.3%
Average length of the snow season	- 5 days	- 30-40 days	- 15-20 days	- 100 days

A range of secondary biophysical effects are predicted to occur as a result of changes in temperature, precipitation and snow cover (Table 4). These include more cloud-free days, lower humidity and increased total solar radiation (Howden et al. 2003). More variable and extreme climatic regimes and erratic weather events, such as high-intensity rainfall and storms, are also predicted (Garnaut 2008; Hennessy et al. 2008). Other biophysical impacts of climate change in the region include decreased soil moisture, increased soil erosion, increased risk of landslides, intensive storms, drier summers and decreased water availability (Hennessy et al. 2008; Worboys et al. 2010; Morrison & Pickering 2012b) (Table 4).

Table 4: Predicted and observed environmental impacts of climate change in subalpine and alpine areas of the Australian Alps. Updated and expanded from Morrison & Pickering 2012a.

Impact	Predicted	Observed
Biophysical impacts		
Higher temperatures	Whetton 1998; Hennessy et al. 2008	Nicholls 2005; Hennessy et al. 2008; Davies In press; Wahren et al. In press
Decreased precipitation	Whetton 1998; Hennessy et al. 2008	Wahren et al. In press
Loss of snow cover	Whetton 1998; Hennessy et al. 2008; Pickering & Buckley 2010	Davies 1998; Green & Pickering 2002; Nicholls 2005; Edmonds et al. 2006; Hennessy et al. 2008; Green & Pickering 2009a; Green 2010; 2011; Davies In press
Loss of ice cover	Green 2011a, 2012	Green 2011a
Decreased soil moisture	Garnaut 2008; Worboys et al. 2010	
Increased soil erosion	Garnaut 2008; Worboys et al. 2010	
Increase intensive storms	Garnaut 2008; Morrison & Pickering 2012b	
Drier summers	Hennessy et al. 2008; Worboys et al. 2010; Morrison & Pickering 2012b	Wahren et al. In press
Decreased water availability	Hennessy et al. 2008; Pickering & Buckley 2010; Morrison & Pickering 2012b	
Increase in threats to native biota due to		
Increased diversity of weeds	Pickering et al. 2004; Pickering 2007; Mallen-Cooper & Pickering 2008; Pickering et al. 2008; Worboys et al. 2010	Venn et al. 2012
Increased diversity of feral animals	Pickering et al. 2004	Green & Pickering In press
Increased extreme fires	Williams et al. 2001; Cary 2002; Worboys 2003; Walsh & McDougall 2005; Williams et al. 2006; Lucas et al. 2007; Pitman et al. 2007; Garnaut 2008; Sanders et al. 2008; Jarrad et al. 2009; Morrison & Pickering 2012b	
Decreased connectivity	Pickering et al. 2004; Anderson & Atkins 2010; Worboys et al. 2010	

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Decreased resilience	Pickering et al. 2004; Anderson & Atkins 2010; Worboys et al. 2010	
Impacts on native flora and fauna		
Changes to plant phenology	Pickering et al. 2004; Pickering 2007; Jarrad et al. 2008; 2009; Hoffman et al. 2010	Gallagher et al. 2009; Green 2010
Changes to animal phenology	Pickering et al. 2004; Pickering 2007	Green 2002; Green & Pickering 2002; Norment & Green 2004; Green 2010
Temperature damage to plants	Venn et al. In press	
Upward migration of native plants	Pickering et al. 2004; Pickering 2007; Pickering et al. 2008	Venn et al. 2011; Venn et al. 2012
Upward migration of native animals	Pickering et al. 2004; Pickering 2007; Green et al. 2008	Green 2002; Green & Pickering 2002; Green 2010; Green & Osborne 2012
Increase in feral animals	Pickering et al. 2004; Green & Osborne 2012	Green & Pickering In press
Increase in weeds	Johnston & Pickering 2001; McDougall et al. 2005; Bear et al. 2006; Pickering & Hill 2007; Pickering et al. 2007	Johnston & Pickering 2001; Pickering et al. 2007
Increase in shrubs	Pickering et al. 2004	Venn et al. 2012; Wahren et al. In press
Loss of endemic plants	Pickering et al. 2004; Williams et al. 2006; Pickering 2007; Pickering et al. 2008; Green & Pickering 2009a	Green & Pickering 2009a,b; Venn et al. 2011, 2012
Loss of endemic animals	Pickering et al. 2004; Pickering 2007; Green et al. 2008	Green & Osborne 2012
Loss of endemic plant communities	Pickering 2007; Garnaut 2008; Williams et al. 2006; Pickering et al. 2006; Pickering et al. 2008; Green & Pickering 2009a	Edmonds et al. 2006; Green & Pickering 2009a,b; Venn et al. 2011, 2012

3.2 Direct biological effects of climate change

Changes in climate including reduced snow cover and increasing temperatures will directly affect growing conditions for alpine plants and plant communities. These changes in climate are likely to directly affect endemic plants adapted to the higher stress conditions associated with short growing season and low temperatures while benefiting other more competitive species with distributions currently restricted by shorter growing seasons in the alpine areas of the Park. Changes in the dominance of shrubs, herbs and graminoids are also likely with warmer and dryer conditions (Wahren et al. In press). There may be reductions in the populations of some specialised snow dependent species. However, even if there is now more recruitment into the population, a few long-lived individuals of the species may survive for longer, masking the functional loss of the species.

There are also predicted changes in many phenological events for the alpine area (Pickering et al. 2004; Hoffman et al. 2010). This includes the summer migration of birds, insects and mammals (Green & Pickering 2002; Norment & Green 2004; Pickering et al. 2004; Green & Osborne 2012) along with the earlier flowering and seeding of many species of plants (Pickering et al. 2004; Pickering 2007; Jarrad et al. 2008; Gallagher et al. 2009; Green 2010; Hoffman et al. 2010). Experiments in the field involving artificially warming have already demonstrated how a rise of >2 degrees in temperature can result in a range of changes in flowering and seeding including earlier flowering for some subalpine plants (Jarrad et al. 2008; Hoffman et al. 2010). It has also been found that the growth rates of some alpine species increase with warming, at least in the short term (Jarrad et al. 2009).

Climate change is also likely to reduce the distribution of rare endemic communities such as the snowbank feldmark and short alpine herbfield communities, possible resulting in their extinction (Pickering et al. 2004; Venn & Morgan 2007; Green & Pickering 2009a,b; Venn et al. 2011). Conversely, higher temperatures, less snow and longer growing seasons are expected to expand the distribution of some of the more common alpine and subalpine plant communities such as tall alpine herbfields, heaths, sod-tussock grasslands and heaths (Pickering & Armstrong 2003; Pickering et al. 2004; Wahren et al. In press).

3.3 Climate change is already occurring

The climate is already changing in the Australian Alps and a wide range of climate change impacts have already been documented (Green & Pickering 2002; Nicholls 2005; Hennessy et al. 2008; Green & Pickering 2009a; Green 2010; Davies In press; Wahren et al. In press) (Table 4). Recent modelling of the longest term temperature datatsets available for the region indicates that winter maximum temperatures have been increasing since 1881, while maximum snow depth has declined, particularly between 1981 and 2010 (Davies In press). Direct measures of temperature from weather stations in the Australian Alps have found a 0.2°C increase in temperature per decade over the past 35 years (Hennessy et al. 2008), along with warmer temperatures in spring and declines in precipitation (Wahren et al. In press). This included the most severe drought on record in south-eastern Australian with the 1996-2009 period the driest on record (Wahren et al. In press). Overall snow cover has declined by 30% since the 1950s based on snow course data (Green & Pickering 2009a,b; Green 2010, 2011), with a 40% reduction in snow cover in spring (Nicholls 2005). The date when ice melts on glacial lakes and the date of the general thaw in spring are also earlier than in the past (Green 2011a; Green & Osborne 2012). The extent and duration of areas with late lying snow also appear to have reduced over the last fifty years (Edmonds et al. 2006; Green & Pickering 2009b; Green & Osborne 2012).

Parallel to these changes in climate and other biophysical factors, are already changes in the biota. This include changes in the migration patterns of animals including the earlier arrival of some migratory birds, mammals and insects (Green 2002; Green & Pickering 2002; Norment & Green 2004; Green 2010; Green and Obsborne 2012), earlier flowering of many alpine plants (Green 2010; Ken Green 2012 unpublished data), contractions in the distribution of

some rare plant communities associated with late lying snow (Edmonds et al. 2006; Green & Pickering 2009a; Pickering & Green 2009; Venn et al. 2012), increased diversity of weeds (Johnston and Pickering 2001), changes in the dominance of graminoids, herbs and shrubs (Wahren et al. In press) and increases in feral animals such as hares (Green & Osborne 2012; Green & Pickering In press).

3.4 Climate change exacerbates existing threats

Climate change in the Australian Alps does not occur in isolation: it often amplifies existing threatening process such as fire, weeds, feral animals and summer tourism further eroding the resilience of the biota and decreasing connectivity (Pickering et al. 2004; Pickering 2007; Anderson & Atkins 2010; Worboys et al. 2010; Green & Osborne 2012; Morrison & Pickering 2012a,b) (Table 4). Although fires are a natural process for much of south-eastern Australia, the severity and frequency of the fires will be increase dramatically, resulting in major changes in the flora and fauna (Hughes 2003; ISC 2004; Pickering et al. 2004; Williams et al. 2006; Williams et al. 2008). By 2020, the number of extreme fire danger days, where fire suppression is virtually impossible, is predicted to increase by 15-65% and 100-300% by 2050 for south-eastern Australia (Lucas et al. 2007). Although some alpine vegetation recovers from infrequent fires (Williams et al. 2008), and shows many of the adaptations seen in lower altitude flora for surviving fire (Williams et al. 2008), the capacity to survive more frequent and intense fires is low (Wahren et al. 2001; ISC 2004; Williams et al. 2006; Bear & Pickering 2006; Williams et al. 2008). Traddtionally fires are rare in the alpine, around every 60 years. However, recently some areas have experienced repeated burning of alpine areas with a few years (Williams et al. 2008). For example, some areas burnt in the large landscape level fires of 2003 burnt again in 2006 (Snowy Mountains) or 2007 (Victoria high country) (Williams et al. 2008) and some again in 2013.

The diversity, density and distribution of weeds are all likely to increase due to climate change in the Australian Alps, including the Kosciuszko alpine area. Weed distribution in the region may in part to be partly limited by climatic factors, in particularly the duration of snow cover (Pickering et al. 2004; McDougall et al. 2005; Bear et al. 2006). Predicted reductions in snow cover may result in an increase in the diversity and abundance of weeds at any given altitude (Pickering et al. 2004; McDougall et al. 2005; Bear et al. 2006; Pauchard et al. 2009; McDougall et al. 2010). Weeds may also benefit from disturbances associated with climate change which include changes in the patterns of human use, especially as a summer tourism destination. Increased use of the area for hiking, camping and bike riding often favours weeds over natives, with the verges of tracks and ski resort gardens colonised by exotic plants, some of which then spread further in the Park (McDougall et al. 2005; Bear et al. 2006; Pickering & Hill 2007; Mallan-Cooper & Pickering 2008; Pauchard et al. 2009; McDougall et al. 2010). Tourists can also spread weed seed in the alpine area on their clothing and footwear (Mount & Pickering 2009; Pickering & Mount 2010; Pickering et al. 2011a).

Range expansion is predicted for some native animals previously restricted to lower altitude subalpine or montane areas such as wallabies, while range restrictions are predicted other more snow dependent species such as the Broad-toothed Rat and Mountain Pygmy Possum (Pickering et al. 2004; Green et al. 2008; Green & Pickering 2009a; Green & Osborne 2012). Correspondingly there is likely to be range expansion of some feral animals including rabbits and hares (Green & Osborne 2012), and possible increases in the abundance and distribution of feral animals that already utilise the alpine area in the summer including horses and deer.

The timing, location and types of tourism in the alpine area will also be affected by climate change. Resort operators and others in the local tourism industry are increasingly promoting the region as a summer destination, at least in part, to offset declines in winter use (Pickering & Buckley 2010; Morrison & Pickering 2011; 2012a,b). Tourism use of the region has a range of environmental impacts including on the flora, fauna, soils and aquatic systems (Scherrer 2003; Johnston & Johnston, 2004; Growcock 2005; Johnston 2005; Scherrer & Pickering 2005; Pickering & Growcock 2009; Pickering et al. 2007; Pickering & Hill 2007; Mount &

Pickering 2009; Growcock & Pickering 2011; Green & Osborne 2012). Without adequate research and management increased tourism use will further damage the environment (Pickering et al. 2004; Pickering 2007; Morrison & Pickering 2011, 2012a,b; Green & Osborne 2012).

3.5   *Monitoring climate change and impacts*

Long-term physical and biological datasets are limited in the Australian Alps, compared to European and North American mountains but are an important resource within the Australian context (Hennessy et al. 2008; Green 2010; Pickering 2011; Green & Osborne 2012; Davis In press; Wahren et al. In press). Only a few climate stations have been continuously monitoring temperatures for 50+ years in the Australian Alps (Hennessy et al., 2008; Davis In press). Additional automated weather stations have been established with the highest currently at the Thredbo Top Station at 1957 m on the edge of the Kosciuszko alpine area. In addition, regular snow depth monitoring is limited to four snow courses with only three monitored continuously since the 1950s (Hennessy et al. 2008; Green 2010; Pickering 2011; Green & Osborne 2012).

More detailed monitoring of localised climatic conditions have been established in many sites including using soil temperatures loggers to provide a range of climate measures including duration of the snow season, date of thaw, duration of the growing season and average temperature which can be related spatial and temporal variation in flora and fauna (Green & Pickering 2008a,b; Venn et al. 2011; Green & Pickering In press; Wahren et al. In press). Mapping of snow cover on ground and using aerial photographs are also being used to assess declining snow cover particularly for late lying snow banks (Edmonds et al. 2006; Green & Pickering 2008a,b). Temperature loggers have also been used along with direct observations to assess duration of ice coverage and melt date for alpine lakes (Green 2011a, 2012).

Some long term monitoring of the composition of vegetation in alpine and subalpine regions including plots in Victoria (Carr & Turner 1959a,b; Wahren et al. 1994; Wahren et al. In press) and NSW (Wimbush & Costin 1979a,b; 1983) originally established to assess the impacts of grazing, are now utilised to assess climate impacts (Scherrer 2003; Scherrer & Pickering, 2005; Wahren et al. In press). There is also long term monitoring of animal populations including the Broad-toothed Rat (*Mastacomys fuscus*), Mountain Pygmy Possum (*Burramys parvus*) and Corroboree Frogs (*Pseudophryne corroboree* and *P. pengilleyi*) that is being utilised to assess climate change (Green & Osborne 2012). Incidental monitoring by long term researchers in the region is also being utilised to assess climate change on alpine plants, insects and birds (Green 2010).

Monitoring programs specifically assessing changes in vegetation from climate change have been established including the Global Observation Research in Alpine Environments (GLORIA) (Pickering et al. 2008; Venn et al. 2012) and the International Tundra Experiment (ITEX) (Jarrad et al. 2008; 2009; Williams et al. 2008; Hoffman et al. 2010; Wahren et al. In press) and the Mountain Invasion Research Network (MIREN) (Pauchard et al. 2009; McDougall et al. 2010). Monitoring programs quantifying changes in flowering have been established under natural conditions (Ken Green 2012 unpublished data; Catherine Pickering 2012 unpublished data) and under artificial warming (Jarrad et al. 2008; Hoffmann et al. 2010) including after fire (Jarrad et al. 2009). Herbarium records have been used to assess changes in the timing of flowering for selected species (Gallagher et al. 2009). Reciprocal transplant and common garden experiments have also been used to assess local adaptation for alpine plants as part of assessing their risk from climate change (Byars et al. 2009; Byars & Hoffmann   2009).

4. FUNCTIONAL TRAITS AND FUNCTIONAL DIVERSITY

The rest of this report present the results of research combining more classical ecological analysis assessing changes in species richness and composition with a new functional trait approach to help determine the underlying mechanisms that drive species distribution, community composition and ecosystem functioning in the face of a changing climate. In this Section, we provide a general overview of functional traits, what they are, why they are increasingly utilized in ecological research, and how they are predicted to respond to climate and different types of disturbance based on recent reviews of the functional trait research literature.

4.1 Theory

Increasingly ecological research is utilizing functional traits to better understand the ecological process that drive changes in species richness and composition (Grime 2001; Cornelissen et al. 2003; de Bello et al. 2010). A **functional trait** is any trait that **directly influences performance** (Table 5). Importantly, functional traits provide information about how plants capture and conserve resources, how well a species can withstand the pressure of competitors; and how it copes with environmental stress. As a result they provide information about why changes in composition occur. They also allow us to test how the flora is responding to different stressors, and hence make predictions about how it is likely to respond in the future. Basically how individuals respond to climate change and disturbance ultimately depends on how they **function** within their community and **interact** with other species, which can be determined from the functional traits they exhibit. **Functional groups** are groups of plants with similar sets of traits (Table 5). For example groups of plants that all have similar 'acquisitive' traits such as large soft leaves with high specific leaf areas are likely to respond differently to disturbance than groups of plants that all have 'conservative' traits such as tough, small leaves with low specific leaf area and % dry matter content (Tecco et al. 2010). Similarly we can assess how plant communities respond to changes in climate and disturbance by assessing changes in **functional diversity**: that is the average traits within vegetation (Table 5). Functional divergence will vary as a result of changes in dominance of certain species depending on their traits.

Table 5 Definition of common terms used in functional trait research. Information from Cornelissen et al. 2003, de Bello et al. 2010 and Mouillot et al. In press.

Functional trait: a characteristic of a plant that has a direct link to its function. They reflect adaptations to particularly physical and abiotic conditions and trade-offs among different functions within a plant. Important traits commonly used in research include plant height, leaf area, specific leaf area, % leaf dry matter content, dispersal mode, seed mass, re-sprouting capacity, life-form, clonality, etc.

Functional group: a collection of plants with similar sets of traits. As a result they may have similar responses to environmental factors and effects on ecosystem process. The same or similar to functional types or functional syndromes.

Functional diversity: the dominant or average traits in a community as measured by community trait weighted means (the average trait value in a community weighted by the relative abundance of that species).

4.2 Selection of functional traits for this analysis

This research investigates plant community responses to changes in climate and disturbance regimes (fire and grazing). To do this, we selected plant functional traits that directly relate to important ecosystem functions and processes (Tables 6 & 7). We used easy to measure 'soft' traits, such as plant height, leaf area, leaf dry matter content and phenology to infer 'hard'

functional traits, which are then used to discern competitiveness, stress tolerance, or productivity of species, for example (Westoby et al. 2002).

Table 6: Specific details of the functional traits utilised in this research, how they are measured and what they indicate (Grime 2001; Cornelissen et al. 2003).

Trait (unit)	Description	Functional indicator
Continuous vegetative traits		
Plant height (mm)	Shortest distance between the upper boundary of the main photosynthetic material (usually the canopy) and ground level.	A measure of species overall competitive ability at plant maturity. Species that are relatively taller will be more competitive, usually for light. Indirect measurement for biomass, lateral spread, rooting depth and leaf size.
Leaf area (mm^2)	One-sided projected surface area of an average leaf.	A measure of stress tolerance. Small leaves tend to be favoured under heat stress, cold stress, drought stress, and high-radiation stress. Within a climate zone, leaf size tends to increase with plant height and soil nutrients, but decreases with disturbance. Larger leaves are expected in more productive landscapes.
Leaf dry matter content (LDMC)(mg g^{-1}) or %	The ratio of the oven-dry mass of a leaf to the fresh weight of the leaf. The % of the oven-dry mass of a leaf to the fresh weight of the leaf.	Indirectly represents the mean density of leaf tissue, relates to the inverse of SLA. Low LDMC can indicate fast resource acquisition. Leaves tend to be more resistant to physical stress such as wind and hail. Species with low LDMC tend to be associated with highly disturbed environments and high productivity.
Specific leaf area (SLA) (mm^2 mg^{-1})	Ratio of one sided area of a fresh leaf to its oven dry mass.	Low values correspond to relatively high investments in defences to harsh conditions including long life spans and structural adaptations. Reflects the expected return on previously captured resources such as light and nutrients. A good positive correlate of potential growth rate.
Categorical traits		
Start of flowering	The month in which the species is first recorded flowering.	Species in more favourable conditions may flower earlier.
Duration of flowering	The number of months in which the species is recorded flowering.	Species in more productive sites, or more disturbed sites are likely to flower for longer.
Lateral spread	Classification of potential lateral spread of plants using a 6-point classification system.	Greater lateral spread often associated with highly competitive plants, with those adapted to high disturbance conditions having limited lateral spread.

Canopy height provides a useful measure of species overall competitive ability at plant maturity (Westoby et al. 2002; Cornelissen et al. 2003). The relationship between canopy height and competitive ability, mostly for light, is true for any stage in the successional process

(Westoby et al. 2002). However, achieving greater height than neighbours incurs costs for growth, maintenance of stems and support structures, and the costs associated with transporting water greater distances (Westoby et al. 2002). Therefore, in the absence of competition, growing close to the ground maximises productivity per leaf area by minimising costs associated with height (Westoby et al. 2002). Species that do not use height as a strategy are open to colonisation by species that have diverted resources to growing taller (Westoby et al. 2002). Height is also negatively associated with grazing, with grazing by ungulates favouring shorter plants, but mainly in ecosystems that long history of grazing by these animals (Diaz et al. 2007). Similar habitats with longer periods between fires often favour taller species (Cornelissen et al. 2003). Where disturbance removes competition, functional turnover may result where early colonisation is by low growing species which are gradually replaced by species with higher species canopy height. However, there is some trade-off between height and tolerance or avoidance of environmental stress (Cornelissen et al. 2003).

Table 7: Relationship between vegetative functional traits and responses to environmental filters (climate, CO_2, soil resources and disturbance), plant competition and plant defence against herbivores and pathogens (biological filters). Modified from Cornelissen et al. 2003.

	Response to				Competitive strength	Plant defence/ protection
	Climate	CO_2	Soil resources	Disturbance		
Plant height	Yes	Yes	Yes	Yes	Yes	Yes
Leaf size	Yes	?	Yes		Yes	Yes
Leaf dry mater content	Yes	?	Yes			Yes
Specific leaf area	Yes	Yes	Yes		Yes	Yes

Leaf area provides a useful measure of stress tolerance, as it has important consequences for leaf energy and water balance (Cornelissen et al. 2003). Variation in leaf size has been found to be related to stress factors including climate variation, geology, latitude and altitude, where small leaves tend to be favoured under high heat, cold, drought and high-radiation (Cornelissen et al. 2003). Leaf area has been found to be negatively correlated with resistance, so that plants with small leaves are more resistant (less initial damage) to trampling by hikers (Bernhardt-Romermann et al. 2011). Within a climate zone, leaf size is related to other vegetative factors such as plant height (Westoby et al. 2002; Cornelissen et al. 2003).

Leaf dry matter content (LDMC) is related to the average density of tissue and leaf 'toughness', and so often scales with 1/SLA (Cornelissen et al. 2003). Leaf dry matter content is also tightly correlated with the stress factors (Westoby et al. 2002). Species with high LDMC tend to be more resistant to stress such as grazing, wind and hail (Cornelissen et al. 2003). Species with low LDMC tend to be associated with highly disturbed environments and high productivity (Cornelissen et al. 2003). Species with low LDMC tend to be less resilient (e.g. rate at which they recover from damage) to trampling by hikers (Bernhardt-Romermann et al. 2011). The relationship between LDMC and stress has also been found to be stronger than SLA, although both should be measured where possible as they may not capture exactly the same functions (Westoby et al. 2002; Cornelissen et al. 2003).

Specific leaf area (SLA) is often positively correlated with a species potential relative growth rate or mass-based maximum photosynthetic rate (Cornelissen et al. 2003), that is species with larger SLA values often grow faster than others. Specific leaf area corresponds to

relatively high investments in defences to harsh conditions including long leaf lifespans and structural adaptations (Cornelissen et al. 2003). Specific leaf area tends to be relatively lower in stressful environments such as those with low rainfall and soil nutrients (Westoby et al. 2002). It also contributes to resilience, potentially due to its association with higher growth rates (Bernhardt-Romermann et al. 2011).

Originally we proposed to use a functional trait analysis whereby the measured soft traits become useful in determining the competitiveness, stress-tolerating ability and ruderality (CSR) of species, using a system originally developed by Grime and colleagues (Hodgson et al. 1999; Grime 2001; Diaz et al. 2004; Hunt et al. 2004). In this approach, data for seven traits (canopy height, dry matter content, leaf dry weight, specific leaf area, flowering start, flowering period and lateral spread) are used to calculate where each species sits within the CSR triangular space (Hodgson et al. 1999). We have not included this analysis in this report because (1) it currently only applies to graminoids and herbs, not shrubs and trees, (2) it is difficult to obtain accurate flowering data for species in Australia compared to places with longer natural history records and herbarium samples, and hence it is difficult to obtain all seven traits for many of the alpine species, and (3) currently the CSR strategy system is not a widely accepted a method for analysis of individual functional traits and functional diversity. Instead, we concentrated on vegetative traits that were easy to collect and provide the most meaningful ecological relationships within alpine environments. The flowering and lateral spread traits relate specifically to regeneration and recruitment pathways; important in areas with a rapidly changing climate. Also, seed mass, another useful indicator of regeneration success and dispersal (Cornelissen et al. 2003), was not used in these analyses due to difficulties in obtaining values for every species during the project timeframe.

4.3   Functional diversity

To relate the continuous functional traits of species with how ecological processes affect vegetation, we calculated **functional diversity** using community trait-weighted means (Lepš et al. 2006). It is calculated by taking the value for a given trait for each species recorded in a plot adjusted by the species relative cover. For example if a plot contained two species where the taller species was 1 m in height and covered 50% of the plot, while the other shorter species was 0.5 m tall, and covered the other 50% of the plot, then the community trait-weighted mean height for the plot would be 0.75 m. In this study we did not measure each trait in each plot but used the average value for a species obtained from plants in the alpine area (See section 5 for details of how these values were obtained).

The community trait-weighted mean can then be used as an estimate of functional diversity and used to compare plots to determine how functional diversity can change in response to different climatic conditions or different types of disturbance such as fire and grazing. For example, vegetation growing where snow lasts the longest in summer under snowbanks might be dominated by species that are shorter and have smaller leaves (snowbank feldmark and short alpine herbfield). Areas surrounding the snowbanks where the growing season is much longer as the snow melts earlier in spring (tall alpine herbfield) are likely to be dominated by taller species with bigger leaves (Venn et al. 2011). The areas with a greater cover of species that are taller and have larger leaves are likely to be more competitive and have higher levels of productivity than areas dominated by shorter plants with small leaves.

By utilizing existing data sets of species cover from plots sampled across environmental/climatic gradients and disturbance regimes, combined with a new database of plant functional traits we can calculate how functional diversity changes, and hence how resilient is the ecosystem to perturbations such as fire and grazing. It helps demonstrate how the ecosystems respond, but also why changes occur.

Changes in functional diversity are also important because functional diversity is associated strongly with the ecosystem services. For example, changes in the community trait-weighted means for plant height have been associated with changes in the ecosystem services

provided by plant communities including climate regulation, water regulation, soil stability, and to a lesser extent, natural hazard prevention and soil fertility (de Bello et al. 2010). Similar changes in the community trait weighted means for leaf dry matter content and SLA have been as associated with changes in ecosystem services such as soil fertility, bio-control and natural hazard prevention (de Bello et al. 2010).

4.4 Overview to the research activities and methods

Research including some conducted for this project has assessed how species composition in the Kosciuszko alpine area changes in relation to climatic gradients (Pickering et al. 2008; Green & Pickering 2009a,b; Pickering & Green 2009; Venn et al. 2011, 2012), fire (Bear & Pickering 2006; Williams et al. 2008; Butler & Pickering in review), various types of introduced grazing (Costin 1954; 1958; Wimbush & Costin 1979a,b; Scherrer 2003; Scherrer & Pickering 2005), and tourism (McDougall & Wright 2004; Growcock 2005; Pickering & Growcock 2009; Pickering et al. 2011b).

Here our understanding of ecological process in the alpine region increases through using existing data to assess how various stressors may affect ecosystem process. The research consisted of collecting functional trait data for as many alpine species as possible along with specific subalpine species. This involved collecting 11,800 new records of individual trait measures across approximately 220 species. In addition, new analyses of existing datasets consisting of approximately 35,000 records of individual species were compared with 2,200 measures of functional traits for individual species and over 2,600 estimates of functional diversity for individual quadrats/plots.

The results of some of the current functional traits analyses are already published as Venn et al. (2012), are In press (Green & Pickering In press), while others are under review (Venn et al. in review; Butler & Pickering in review), some will be incorporated into future papers (Sections 5, and 8.1) and some are only presented in this report (Sections 6.1, 8.2).

The initial analyses involved assessing the range of traits present among the alpine flora, and determining if there were any groups of species with similar traits e.g. functional groups or functional types. In particular we wanted to compare traits among species with different distributions (species endemic to just this alpine area, native species that occur in this and other alpine areas, alpine weeds, subalpine natives and subalpine weeds) and among growth forms (herbs, shrubs and graminoids) (Table 8, Section 5).

Trait data for individual species was then converted into functional diversity as measured by the community trait-weighted means so the effect of climatic gradients and disturbance regimes could be assessed (Table 8). The effect of climate on functional diversity was assessed using three datasets. The effect of short-term variation in climate conditions on functional diversity of tall alpine herbfield dominated by graminoids was assessed over 6 years (Section 6.1). The second dataset compared changes in functional diversity at different spatial scales sampled across five summits that represent an altitudinal gradient, using space as a surrogate for time (Section 6.2). The third analysis was on a smaller scale but used the same approach of using space as a surrogate for longer term climatic change by comparing traits across a strong gradient in climatic conditions across areas of late lying snow (Section 6.3).

To assess the effect of fires on functional traits data on changes in composition and traits for two plant communities (windswept feldmark and tall alpine herbfield) were compared in burnt and unburnt sites over ten years (Section 7).

The effect of grazing by non-native mammals was assessed using two datasets: the first examined long-term changes (43 years) in composition and traits for tall alpine herbfield on a transect after grazing by cattle and sheep was banned (Section 8.1). The second compared the effect of hare grazing using exclosures and controls in tall alpine herbfield over six years (Section 8.2).

Table 8 Details of the datasets used in the analysis of functional traits for individual plants and functional diversity for quadrats/plots for Kosciusko alpine plants and communities. # species records is the number of quadrats sampled times the number of sampling periods times the number of species. # trait records is the number of quadrats sampled times the number of sampling periods times the traits analysed (either raw traits for species or functional diversity for quadrats).

	Comparison of variation in	#species records	# trait records	Data from	Source
Functional traits among species…					
Section 5.4	..depending on species distributions	220	1346	2010-02-03	This study
Section 5.4	..depending on species **growth form**	220	~880	2010-02-03	This study
Functional diversity with climate					
Section 6.1	… in relation to **short term** (winter and spring) **climatic conditions** using control data from experiment to assess impact of hare grazing on tall alpine herbfield	3,420	360	Six years	Green & Pickering In press
Section 6.2	….in functional diversity **across an altitudinal/climatic gradient** for five summits used for long term monitoring of climate as part of the GLORIA program.	12,800	640	2004 & 2011	Pickering et al. 2008; Pickering & Green 2009; Venn et al. 2012; Venn et al. in review
Section 6.3	..in functional diversity across a **short but steep environmental/climatic gradient** across seven late lying snowpatches from tall alpine herbfield through short alpine herbfield to snowbank feldmark	3,320	498	2007	Green & Pickering 2009a, b; Venn et al. 2011
Functional diversity with disturbance regimes					
Section 7	in functional diversity with **initial impact** of fire, and **recovery from fire** for windswept feldmark and tall alpine herbfield across seven late lying snowpatches	5,832	288	2004-05-06-07-08 & 2012	Butler & Pickering in review
Section 8.1	functional diversity for a transect sampled 9 times from 1959 till 2002 to assess impact of **recovery from cattle grazing** in tall alpine herbfield	208	46	1959, 61, 64, 68, 71, 78, 99, 2002	Scherrer 2003
Section 8.2	functional diversity between exclosures and controls in experiment to assess impact of **hare grazing** on tall alpine herbfield.	6,840	720	2005-06-07-08-09-2010	Green & Pickering In press

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4.5   Predicting changes in functional diversity

Based on the increasing body of published studies assessing functional traits and our own and others research on the ecology of this alpine region, it was possible to make some general predictions about how alpine species with particular traits may respond to climate and disturbance regimes (Table 9). For example, in a warmer climate, it is more likely that competitive and vigorous plant species with acquisitive traits (e.g. those that are taller, with larger leaves, and higher specific leaf areas, but lower leaf dry matter content) might become more common. Conversely, those species with more conservative traits may start to decline in abundance.

Table 9: Common responses of vegetative functional traits to warming climate and changes in disturbance regimes based on research from other ecosystems (Westoby et al. 2002; Cornelissen et al. 2003; Diaz et al. 2007; Bernhardt-Romermann et al. 2011).

	Warmer climate	Initial impact fire	Fire recovery	Recovery from cattle grazing	Recovery from hare grazing
Plant height	↕	↓	↑	↕	↑
Leaf size	↕	↓	↑	↕	↑
Leaf dry mater content	↕	↑	↓	↕	↓
Specific leaf area	↑	↑	↑	↑	↑

The Australian alpine flora may respond differently to the ways predicted based on recent reviews (Table 8), as there are few annual species among the Australian alpine flora. Unlike many lowland floras, alpine floras are characterised by perennial long-lived species (Körner 2003), and this is true for the Kosciuszko alpine flora with only seven species of native annual flowering plants (Pickering 1997; Costin et al. 2000). Therefore, most Australian alpine species are likely to be at the more 'conservative' rather than 'acquisitive' end of the trait distribution spectrum, and especially so when compared to the composition of floras that include more short-lived species including annuals.

Trees and shrubs may respond differently than herbaceous species, due in part to the effect of resource investment in wood (Grime 2001; Cornelissen et al. 2003; Diaz et al. 2007). By definition, there are no 'trees' in alpine areas, although shrubs are common in many alpine floras and can dominate some plant communities (Körner 2003). In the Kosciuszko alpine area, there are 36 species of shrubs, and they comprise an important component of several plant communities including heaths, raised bogs and windswept feldmark with some species, such as *Epacris* in windswept feldmark, known to be long lived and very slow growing (Costin et al. 2000; McDougall & Wright 2004).

The functional traits of Australian alpine vegetation may differ from other alpine floras that have had a long history of trampling by hard hooved large grazing mammals. In addition, many Australian shrubs exhibit sclerophyllous traits such as short internodes, small hardy long-lived leaves with low SLA and high dry matter content. Such traits are thought to be an adaptation to the low levels of soil nutrients, particularly phosphorous (Barlow 1994). As such, many alpine species are well adapted to low soil nutrients and drought conditions found in much of Australia. Sclerophyllous traits are also thought to contribute to the negative impacts of some types of trampling, grazing and possibly snow-shear, as they have brittle

stems and branches and are slow to recover from damage (Newsome et al. 2002; McDougall & Wright 2004).

As a result of these factors, it is important to determine which functional traits Australian alpine species exhibit, and how they may respond to climate change when compared to alpine floras worldwide.

5. FUNCTIONAL TRAITS OF AUSTRALIAN ALPINE PLANTS

5.1 Context

This section summarises the functional traits data for alpine natives and weeds and some subalpine species collected as part of this NCCARF funded project. It assesses how traits differ depending on the distribution, and growth form of the species. A more detailed analysis specifically focusing on the alpine species will be included in a paper to be submitted after the completion of this project.

5.2 Background

It is assumed that groups of plants with similar traits will have similar responses to the environment (Cornelissen et al. 2003; de Bello et al. 2010), and that plants growing in particular locations are a subset of the species in the region that have traits particularly advantageous for the local environment (Tecco et al. 2010). Where groups of plants share many functional traits attributes, they are called **functional groups** (de Bello et al. 2010). Identifying functional groups provide useful information regarding how groups of plants are likely to respond to different types of environmental change including changing climate and disturbance regimes. Therefore, they have important predictive power when making and testing generalisations about the management of ecosystems (Keith et al. 2007).

We could expect to find functional groups among the Australian alpine plants depending on their distribution and growth form. It is possible that alpine plants with narrow distributions, such as those endemic to just the Kosciuszko alpine area, will have different combinations of traits to those species with more broad distributions. For example, there may be more species with conservative traits (tough, small leaves with low specific leaf area and high % dry matter content) among the Kosciuszko alpine endemics than the more broadly disturbed weeds and natives which may have more acquisitive traits.

Similarly we could expect that the three main growth forms: shrubs, graminoids and herbs will differ in height, leaf area, specific leaf area and % dry matter content. Differences in strategies between woody and herbaceous species have been found in a range of ecosystems (Tecco et al. 2010) and affect how species respond to disturbances such as grazing (Diaz et al. 2007). Here we might expect shrubs to be taller, but have smaller tough leaves (e.g. low SLA but high % leaf dry matter content) as they keep their leaves from year to year and have more scleromorphic traits than the alpine herbs and graminoids that often produce new larger leaves with high SLA and lower % dry matter content each year during the thaw.

The aim of this section was to: (1) document the range of functional traits present across alpine and subalpine species, (2) determine if functional traits of species vary depending on their distributional range and if variation is consistent with theories regarding traits favourable in higher 'stress' environments such as the Kosciuszko alpine area, and (3) determine if functional traits vary among growth forms.

5.3 Methods

During peak growing seasons of 2010, 2011 and 2012 functional trait data were collected for as many plant species as possible within the Kosciuszko alpine area, along with selected native and weed species from the subalpine zone. Data on vegetative traits were obtained from approximately ten full grown plants of each species in the field following the protocols outlined in Cornelissen et al. (2003). Maximum height (mm) of each plant was measured as the shortest distances between the top of the tallest photosynthetic tissue (leaf) and the ground, and then averaged to obtain a single value for each species. To obtain measures of leaf characters, one fully expanded leaf per plant was selected from each of ten plants in the field. The leaf (including petiole) was harvested, kept cool and moist in a sealed bag and

transported to a laboratory where it was kept in cold storage prior to processing. For plants with very small leaves a short section of stem was collected in the field and then leaves removed from stems prior to processing in the laboratory. The fresh weight (mg) of leaves was obtained in the laboratory for each species, either for individual leaves and averaged, or where leaves were very small all ten leaves were measured at once. Leaf area as measured by the surface area of a leaf (mm^2) was obtained either using the Leaf Area Measurement program (available from the University of Sheffield), or for leaves that could not be laid flat on a scanner, the leaves were pressed down on graph paper with 1 mm^2 grids and the number of squares counted. Leaves were then oven dried at around 70°C for ~2 days, re-weighed to obtain dry leaf weights. From these data % leaf dry matter content and SLA were calculated.

We also collected additional data on traits for use in a CSR analysis. This included data on flowering and vegetative spread. Two flowering measures were also obtained for as many of the species with vegetative traits as possible: (1) the month in which the species began flowering and (2) the number of months the species flowers. As flowering phenology patterns vary with altitude, we recorded phenological events in the alpine zone whenever possible. Where available, we used previously collected data for the Kosciuszko alpine area (106 species) where flowering was observed every five days during the snow free period for four years (Ken Green 2012 unpublished data). Where direct data from the plants in the field was not available, herbarium specimens were used, but only if there were at least 5 herbarium records for a species that were marked as flowering (or flowering/seeding for graminoids). For 38 species it was possible to use data just from specimens in the Kosciuszko Herbarium maintained by the New South Wales National Parks and Wildlife Service of species collected within the alpine and subalpine areas of the Park. For those species where this data was incomplete, data from the Australian National Herbarium database online was used. Again we ensured that flowering data was as relevant as possible to the alpine/subalpine area of Kosciuszko National Park; data was only used for species collected above 1,500 m altitude (10 species) or, if where there were still too few records, for the 'NST' region of New South Wales (8 species). For a final two species, all herbarium records had to be used.

The first record flowering (flowering start) was converted to a six point classification where 1 = first flowering in September or earlier, 2 = in October, 3 = in November, 4 = in December, 5 = in January, and 6 = in February or later. As data from different years was included, the start of flowering is the earliest month the species was recorded flowering, while for flowering period, we recorded the earliest and latest values. Therefore, the flowering period is likely to be an overestimate of the actual duration of flowering in any given year, and the flowering start will be earlier than it is in most years. For graminoids (sedges, rushes and grasses) herbarium and field records are for the presence of heads, and so are likely to also include when seed are produced as well as flowering.

There are a range of measures of vegetative spread/longevity and growth form used in functional trait analysis (Cornelissen et al. 2003). Here we used the six-step categorical system developed for the lateral spread of herbs and graminoids as in the CSR system (Hodgson et al. 1999). The categories were: 1 = short lived plant, 2 = loosely tufted ramets radiating around a single axis, no thickened rootstock (graminoids) or compactly tufted about a single axis, no thickened rootstock (herbs), 3 = compactly tufted ramets apprised to each other at base (graminoids) or compactly tufted about a single axis, thickened rootstock present (herbs), 4 = shortly creeping, < 40 mm between ramets, 5 = creeping, 40-79 mm between ramets and 6 = widely creeping > 79 mm between ramets.

Statistical Analysis

To assess variation in vegetative traits among the 220 plants, and if there were any correlations between vegetative functional traits each pair of traits were graphed against each other and compared using Spearman's correlation co-efficients.

Mean and range values for individual traits were calculated for plants in five distribution categories: species that are restricted to just this alpine area (endemics), species that occur

in this and other alpine areas of Australian, alpine weeds, subalpine natives and subalpine weeds and for three growth form categories: herbs, graminoids and shrubs. To determine if there were any differences in the vegetative functional traits with distribution or growth form separate One-Way ANOVA were performed on transformed data. Where transformed data could not satisfy the assumptions of normality, non-parametric statistics were used.

To assess variation in all four traits in combination, the trait data was analysed using ordinations in the multivariate statistical package PRIMER (Version 6). Dissimilarity matrices were calculated using Euclidian dissimilarity measures for individual species trait data (normalised). Then non-metric multidimensional scaling (n-MDS) was used graphically to describe the maximum variation among species in two dimensions (n-MDS axis 1 and 2) with the closeness of fit of the MDS axes to the dissimilarity matrix expressed in terms of stress. This type of ordination has produced reliable, simple and statistically significant analyses of a wide range of ecological community data and is commonly used to analyse composition data (Clarke 1993; Clarke et al. 2006). To determine whether there were significant differences among species with different distributions, Analysis of Similarity (ANOSIM) was performed. The ANOSIM is a non-parametric permutation procedure applied to the rank dissimilarity matrix that is analogous to Analysis of Variance (Clark 1993). The contribution of important traits in explaining significant variation (r^2) in the ordinations was calculated using Pearson's correlation co-efficients with vectors of significant traits displayed on the ordinations.

5.4   Results

5.4.1   Variation in functional traits among species

Vegetative functional trait data was obtained for a total of 220 species. This represents 76% of all the native alpine flowering plants, 81% of all the alpine endemics, and 93% of the alpine weeds. Trait data was also collected for a further 36 subalpine weeds and 15 native subalpine species, for the analysis of some datasets collected in the subalpine including assessing disturbance due to hiking and mountain biking. Data on flowering period, start of flowering and lateral spread that were originally collected to calculate CSR values but the required flowering trait data could only be obtained for around 160 species (Table 10) reflecting the limited flowering data currently available either from field observations or herbarium specimens for Australian alpine plants. All though this categorical data is available from the authors, it has not been included in the rest of the analyses in this report.

Table 10: The number of species for which functional trait data was collected during this project based on their distribution.

Distribution	Canopy height	Leaf area	% dry matter content	SLA	Flowering period	Start of flowering	Lateral spread
Endemic alpine	16	16	16	16	15	15	15
Alpine native	140	140	135	135	120	120	103
Alpine weed	13	13	13	13	9	9	13
Subalpine	15	15	15	15	10	10	11
Weeds	36	36	35	36	8	8	11
Total	220	220	214	215	162	162	153

Vegetative traits varied among species with canopy height varying from 1.9 mm for the small native alpine herb *Gonocarpus micranthus* subsp. *micranthus* to 1,052 mm for the large subalpine weed Spear thistle (*Cirsium vulgare*). The plant with the smallest leaf area was the native alpine endemic cushion plant *Colobanthus pulvinatus* (1.66 mm^2), while the largest

leaf was the native alpine Flax lily, *Dianella tasmanica* (14,363 mm^2). The % dry mater content of leaves varied from a low of 3.1% for native alpine herb *Erigeron bellidioides* to 97.5% for the native alpine grass *Agrostis meionectes*. Specific leaf area varied from a low of 0.46 for *Colobanthus pulvinatus* to a high of 84.4 for *Erigeron bellidioides.* Generally, there were many species with low/small trait data, and a few species with very high/large values (Figure 5) resulting in non-normal distribution for the traits canopy height and leaf area in particularly.

The four vegetative traits were correlated with each other as would be expected (Table 11), although the relationships were not very strong with considerable variation between pairs of traits (Figure 5). Taller plants tend to have larger leaves, higher dry matter content, but smaller SLA. As leaf area increased, the % dry matter content of the leaves decreased, but SLA increased. Correspondingly as % dry matter content increased, SLA decreased.

Table 11: Results of Spearman's correlation co-efficients comparing the four vegetative functional traits. P values in bold are significant.

		Canopy height	Leaf area	% dry matter content
Leaf area	Test	0.356		
	P	<0.001		
% dry matter content	Test	0.163	-0.365	
	P	0.017	<0.001	
Specific leaf area	Test	-0.184	0.173	-0.554
	P	0.007	0.011	<0.001

Figure 5: Correlations between pairs of vegetative functional traits per species from 220 species of alpine, subalpine and weeds sampled in Kosciuszko National Park.
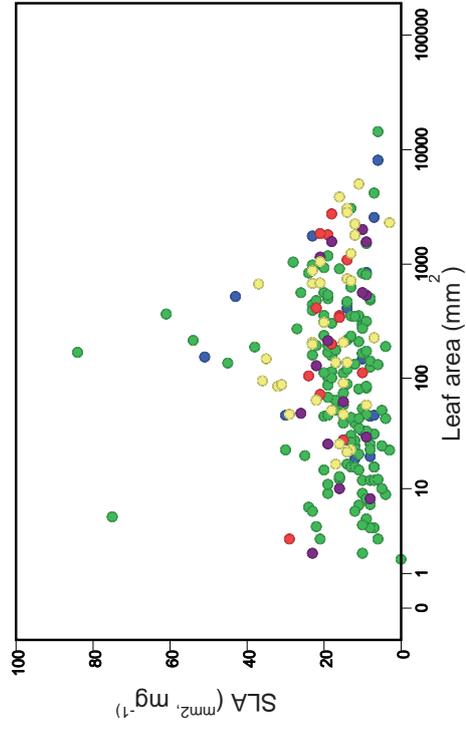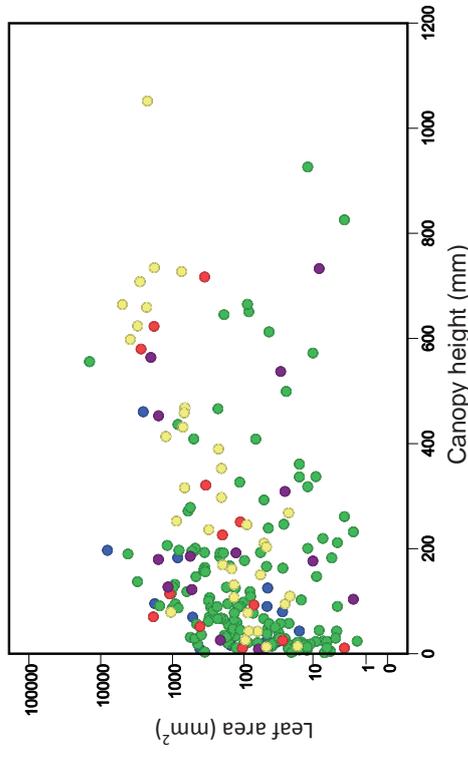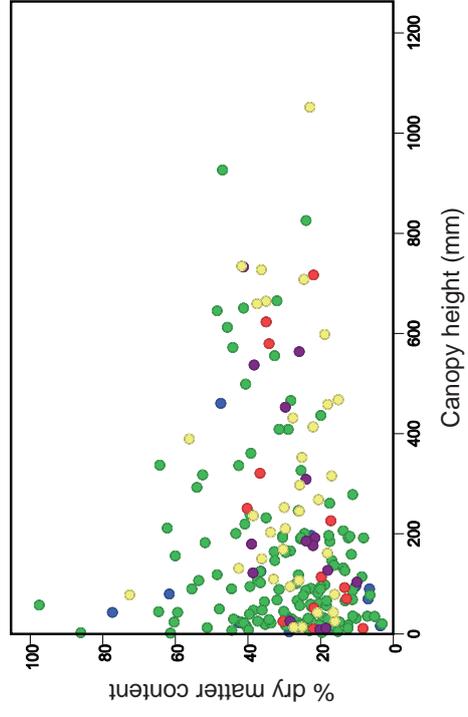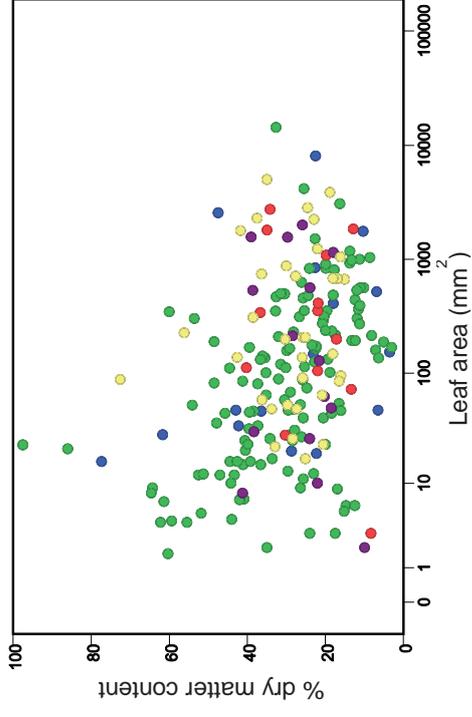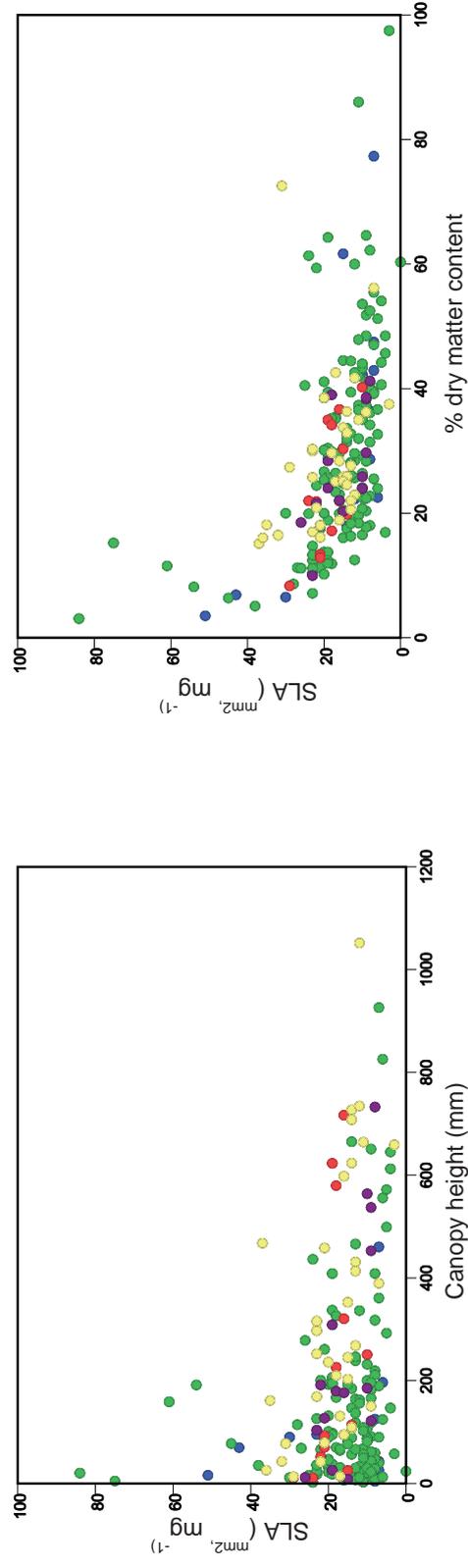
Blue = endemics, Green = other alpine natives, Red = alpine weed, Purple = subalpine natives, Yellow = subalpine weeds

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5.4.2 Variation in functional traits depending on distribution

There were some significant differences in vegetative functional traits depending on species distribution (Figure 6). This included canopy height where subalpine weeds tended to be taller than Kosciuszko endemic species and the more broadly distributed alpine species (One-Way ANOVA on natural log transformed canopy height, F = 6.247, P < 0.001, Tukey post hoc tests, P < 0.05). For leaf area, subalpine weeds tended to have larger leaves than broadly distributed alpine species (One-Way ANOVA on natural log transformed canopy height, F = 4.601, P = 0.001, Tukey post hoc tests, P < 0.05). One species, the native Flax lily was excluded from the analysis as it has a dramatically larger leaf area than any other non-endemic alpine species. For specific leaf area, there was a significant difference among species (Kruskal-Wallis test, P = 0.009) with alpine weeds having larger SLA than some other such as alpine endemics. For % dry matter content, there was no significant difference depending on the distribution of the plants (One-Way ANOVA on arcsine square root transformed data, F = 0.583, P = 0.675). When ordinations were used to compare all the vegetative traits simultaneously, variation in traits was unrelated to the distribution of species (One-Way ANOSIM, Rho = 0.017, P = 0.309) (Figure 7).
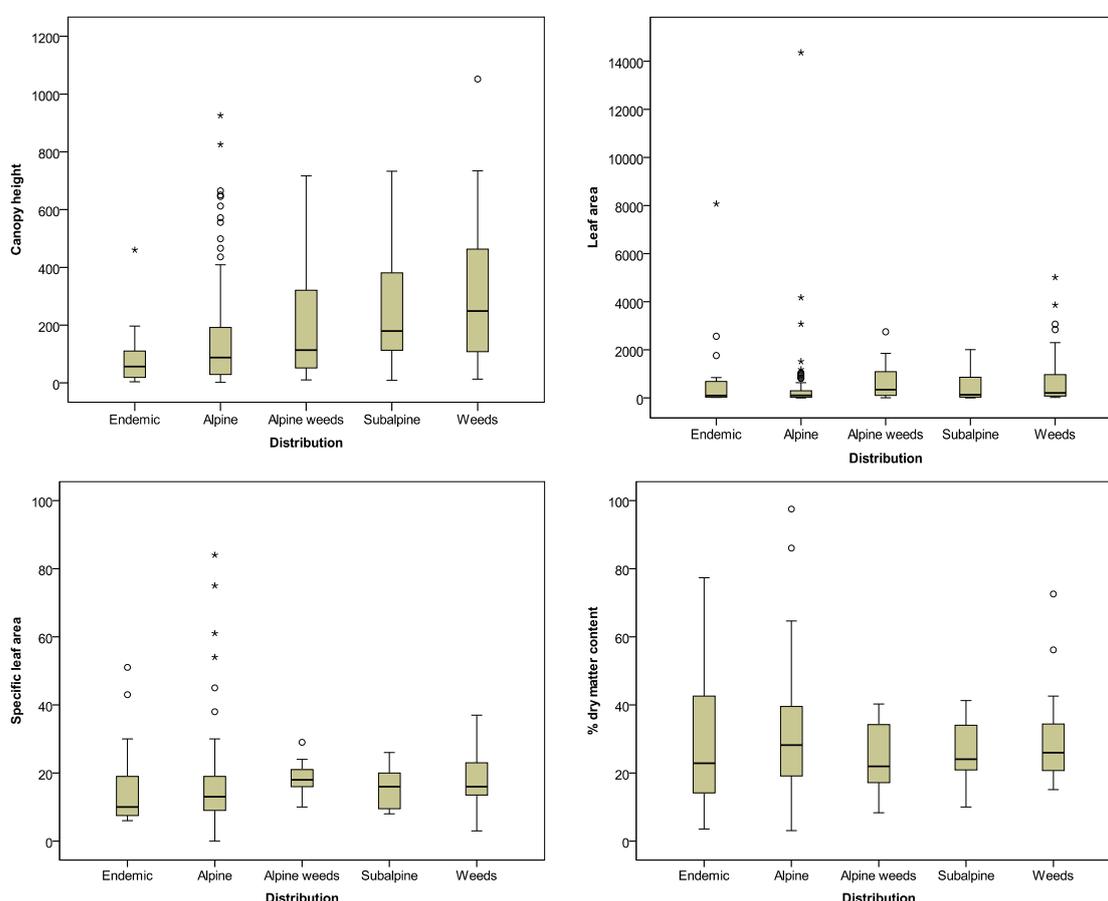
Figure 6: Mean and variation (box plots) in vegetative functional traits for 220 plant species depending on the species distribution. Endemics = species endemic to just this alpine area. Alpine = species that also occur in other alpine areas in Australia. Canopy height is in mm, leaf area in mm2 and specific leaf area in mm2 mg-1.
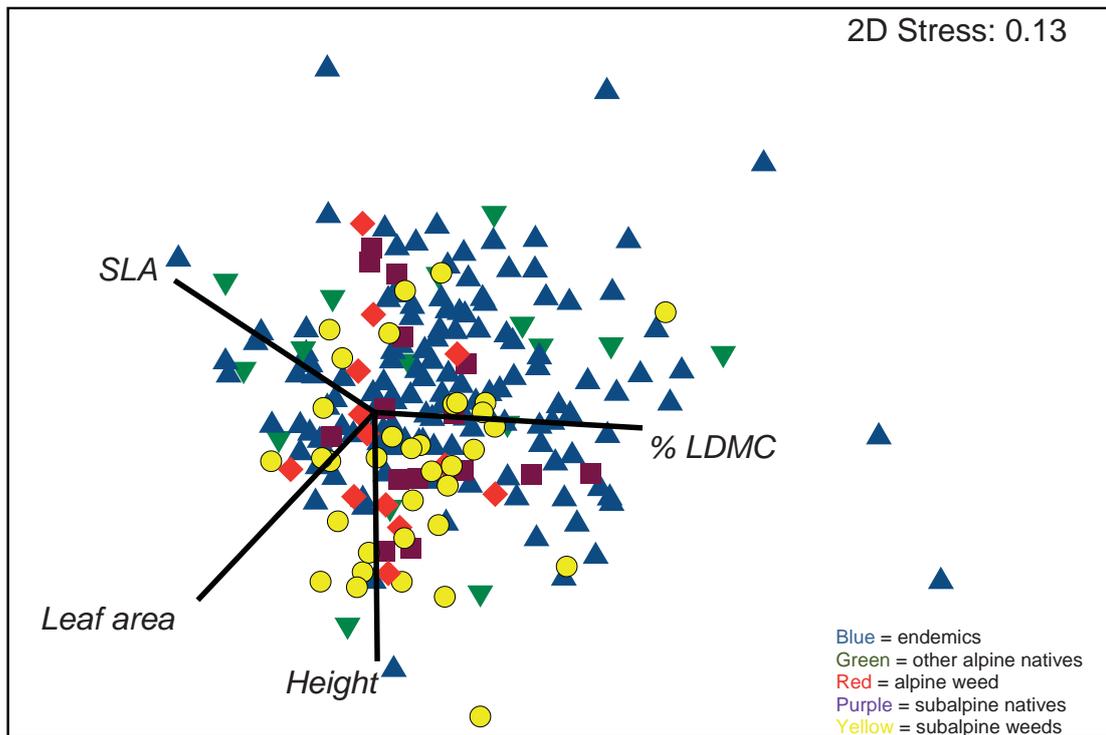
Figure 7: Two-dimensional n-MDS ordinations of vegetative functional traits (normalised, Euclidian distances) depending on species distributions. The functional traits were canopy height (logged), leaf area (logged), % leaf dry matter content and specific leaf area (SLA logged). Vectors are based on Pearson correlation coefficients and indicate the direction in which the values for a trait increase.

To assess species position in functional space and hence how they may respond to changes in environmental conditions that benefit species with specific traits (Mouillot et al. In press), we compared the location in trait space of the Kosciusko alpine endemics with that of alpine weeds (Figure 8). Using this data it was possible to identify species with combinations of vegetative traits that are more conservative and hence may benefit from a warmer climate such as those with larger leaf areas, greater lateral spread and taller canopies, compared with species that have more conservative traits and hence are less competitive (Figure 8).
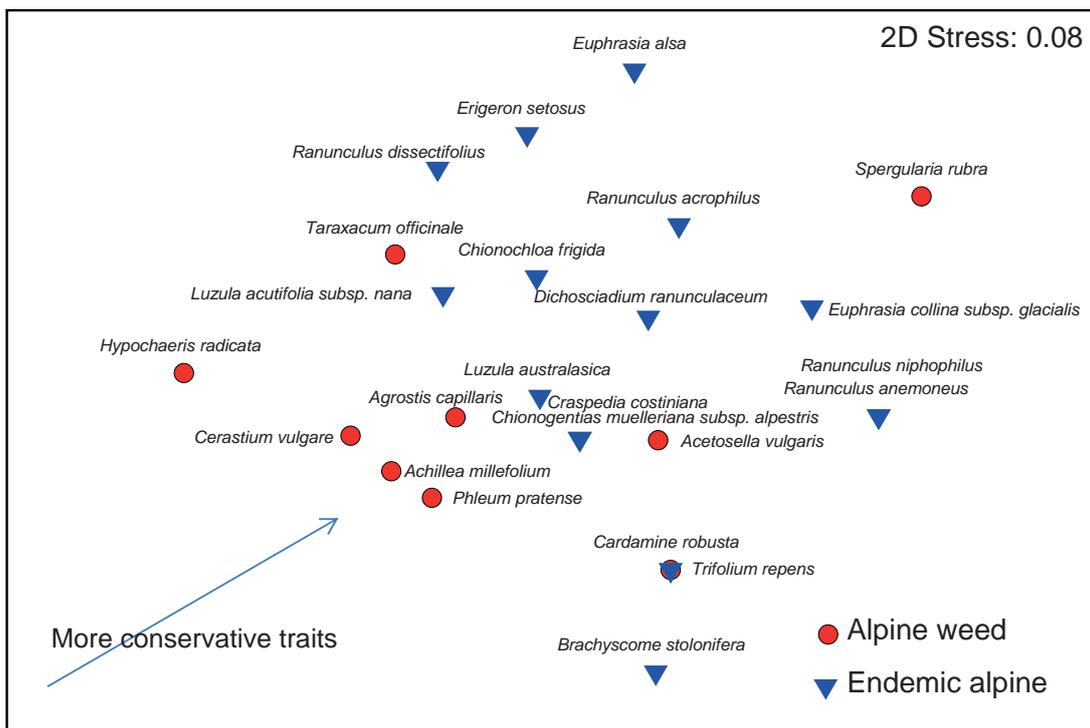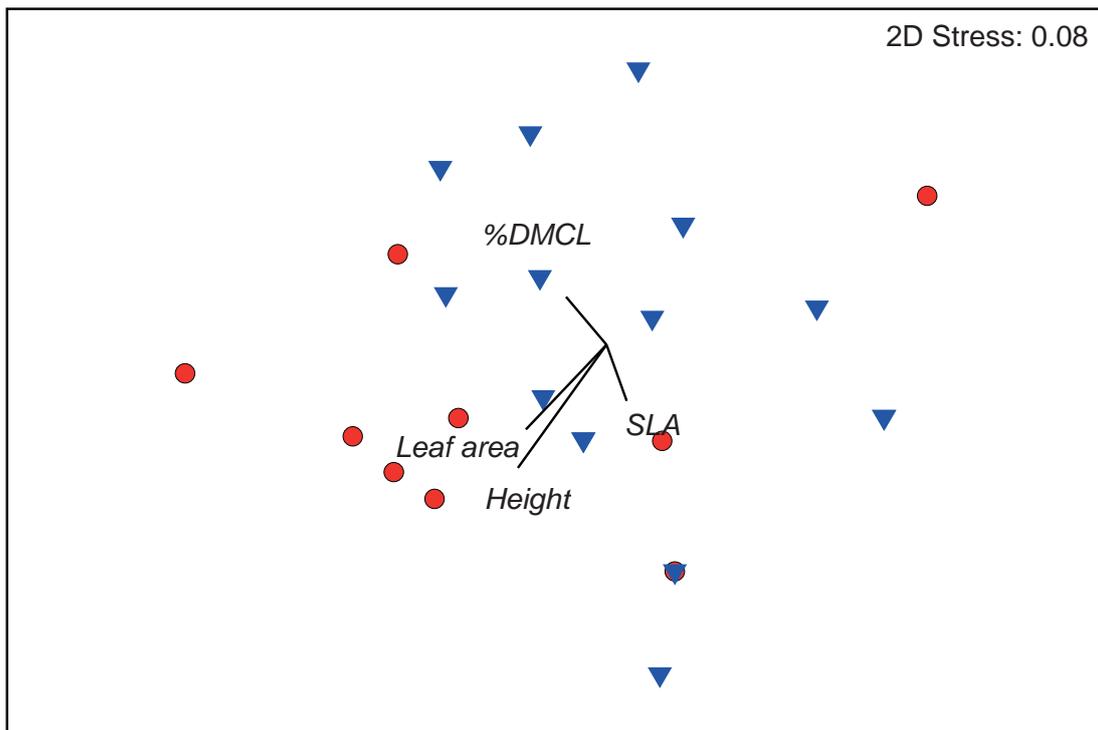
Figure 8: Two-dimensional n-MDS ordinations of vegetative traits (normalised, Euclidian distances) for Kosciuszko alpine endemics and alpine weeds. The arrow indicates the direction of traits that are more conservative and so may be less beneficial for species in warmer climates. The specific traits were canopy height (logged), leaf area (logged), % leaf dry matter content and specific leaf area (logged).

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Based on their location in functional trait space, endemic alpine species that have traits that are more conservative and hence might decline with a longer growing season and warmer temperatures include the small annual herb *Euphrasia alsa,* the perennial small herbs *Erigeron setosus, Ranunculus dissectifolius, Euphrasia collina* subsp. *glacialis* and the small annual weed *Spergularia rubra.* Endemics that have more acquisitive traits and are located in trait space close to many weeds are the endemic herbs *Ranunculus anemoneus Brachyscome stolonifera, Cardamine robusta* and *Craspedia costiniana* which are close to all the other alpine weeds. These species tend to be taller and have larger leaves, traits that are thought to be more acquisitive and hence may be more competitive in a warmer climate.

5.4.3 Variation in functional traits amongst growth forms

As would be expected growth forms relate to functional groups. There were clear differences in vegetative functional trait data between the 131 herbs, 53 graminoids and 36 species of shrubs where data was available (Figure 9). However, it should also be noted that there was still considerable variation in the traits within growth forms.
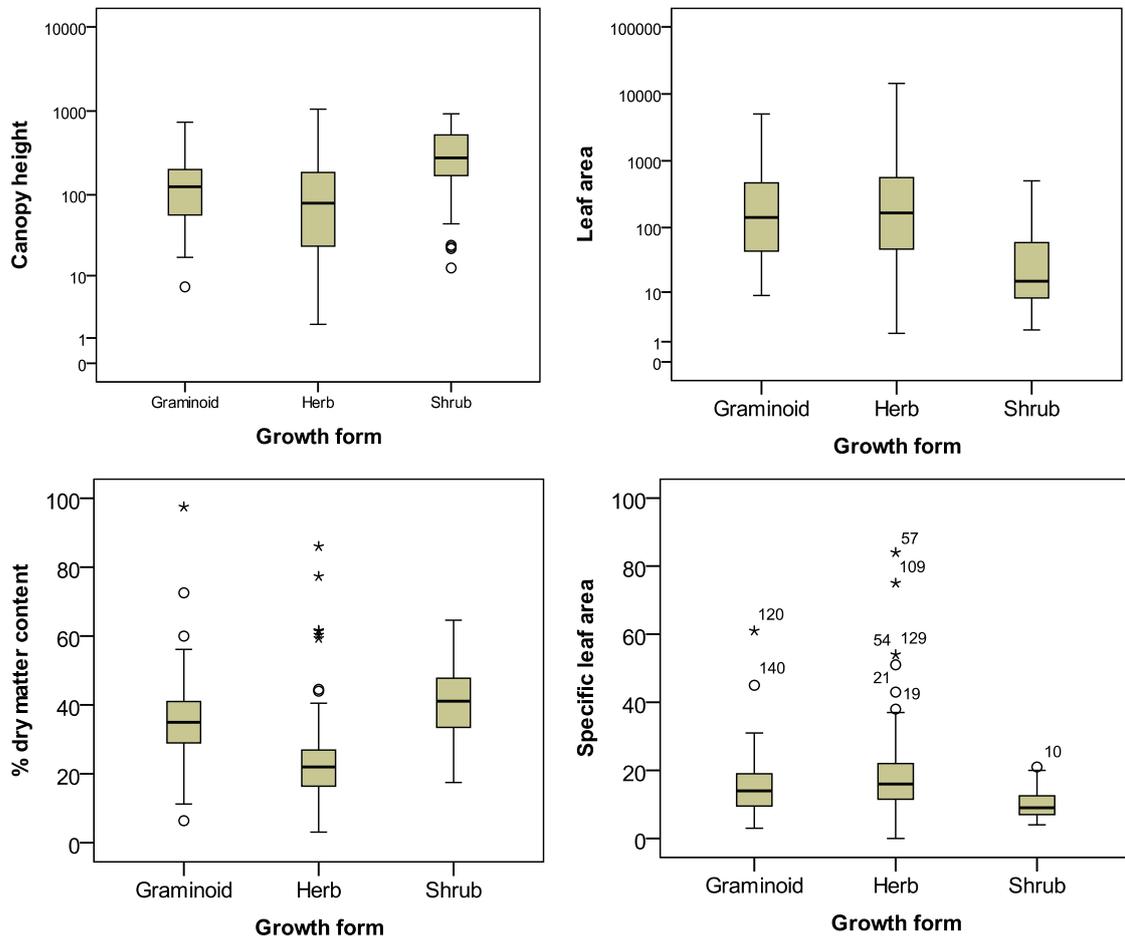
Figure 9: Boxplots showing variation in vegetative traits depending on the species growth form. NB Canopy height and leaf area are displayed on a log scale. Canopy height in mm, leaf area in mm2 and specific leaf area in mm2 mg-1.

Shrubs tended to be tallest, then graminoids with herbs tending to be smaller (One-Way ANOVA on log transformed data, F = 14.956, P < 0.001, Tukey post hoc tests, P < 0.05). Herbs and graminoids tended to have leaves of similar size, but both tended to have larger

leaves than shrubs (One-Way ANOVA on log transformed data, F = 12.128, P < 0.001, Tukey post hoc tests, P < 0.05). Herbs had leaves with lower % dry matter content than shrubs and graminoids which had leaves similar to each other (One-Way ANOVA on arcsine square root transformed data, F = 30.730, P < 0.001, Tukey post hoc tests, P < 0.05). Herbs had higher SLA values than graminoids which were larger than shrubs (One-Way ANOVA on log transformed data, F = 18.359, P < 0.001, Tukey post hoc tests, P < 0.05).

When differences in the vegetative traits are combined using ordination, the effect of growth forms is even clearer (ANOSIM, Rho = 0.188, P = 0.001) (P < 0.05) (Figure 10). Shrubs had smaller tough leaves with higher % dry matter content and lower SLA than graminoids, while herbs had leaves with the lowest % dry matter content and highest SLA (n = 212).
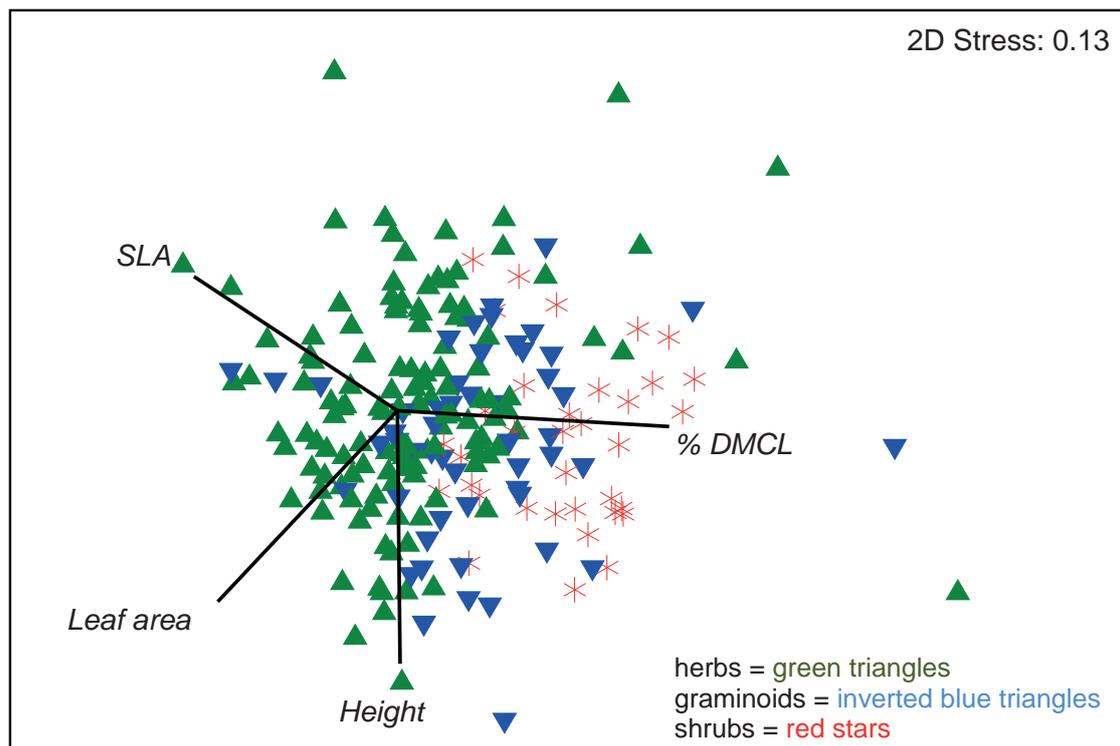
Figure 10: Two-dimensional n-MDS ordinations (normalised, Euclidian distances) of vegetative functional traits depending on species growth form. The vegetative functional traits were canopy height (logged), leaf area (logged), % leaf dry matter content and specific leaf area (logged). Vectors are based on Pearson correlation coefficients and indicate the direction in which the values for a trait increase.

When the analysis was repeated for just native alpine species, the effects of growth form were still evident, with shrubs significantly taller, with smaller leaves, lower SLA but higher leaf dry matter content than herbs and graminoids. The only differences between the native alpine herbs and graminoids were in leaf dry matter content, where graminoid leaves had higher values than herbs.

5.5 Implications

The alpine herbs, graminoids and shrubs differ in functional traits and hence can be treated as functional groups when making and testing predictions about how alpine plants may respond to climate change and disturbance. Shrubs tend to have leaves with higher % dry matter content, adaptations consistent with slow resource acquisition as they are conservative/stress tolerant traits. In contrast herbs tended to have traits characteristics of fast resource acquisition including low % dry matter content and high specific leaf areas.

Within growth forms there was variation in other traits including in height, and to some extent leaf area, i.e. there were some small shrubs and some tall graminoids and herbs. Reflecting the importance of the effect of growth forms in some of the following analyses where there was high shrub cover an additional functional trait, woodiness (e.g. the proportion of woody vegetation) was included as a 'trait'.

Distribution had less effect on vegetative traits than originally anticipated. This was particularly apparent when alpine endemics were compared to alpine weeds, with no clear separation in traits despite very different distributions and evolutionary histories. Additional analysis of the trait data including more systematic sampling of subalpine species and the inclusion of additional traits may identify patterns that may explain why some species are broadly distributed (those found in the alpine and subalpine), while others are either excluded from the alpine (subalpine natives and weeds), or limited to the alpine (alpine endemics).

One benefit of the current data is that it was collected from plants growing in this alpine/subalpine region. When analyses are conducted using trait data from large on-line datasets it is possible that specific values are not relevant to that location. This is particularly important for broadly distributed species that may show clinal variation in traits. Preliminary analysis undertaken for the current project indicated that CSR trait values for weeds differed among existing online datasets depending on where the samples were obtained.

In the next section we will assess if functional diversity varies with climate in the alpine area, and if changes in climate either across climatic gradients or over time, result in the predicated changes in the dominance of species with specific functional traits. The third results section assesses how species with different traits respond to different types of disturbance regimes that are likely to alter with climate change (fire and grazing).

6. FUNCTIONAL DIVERSITY VARIES WITH CLIMATIC CONDITIONS

Having established that there is considerable variation in traits among the species, including among growth forms, the next stage of the research involved determine if there were changes in functional diversity depending on climatic conditions and to see how any patterns found relate to predictions. This involved analysing three datasets. The first assessed the effect of short-term changes in climate on tall alpine herbfield where climatic variables in winter and spring were related to the functional diversity the following summer. The second and third compositional datasets used environmental gradients to assess the effects of longer-term differences in climate on functional diversity. This included assessing differences in functional diversity over five summits over an 300 m altitudinal range and 1,600 m distance (Venn et al. 2012), and a much shorter but potentially even steeper climatic gradient across late lying snowbanks, where growing season varied from 152 days down slope from the snowbank to 62 days in the area where snow was deepest (Green & Pickering 2009b).

6.1 Short term climate variation and functional diversity

6.1.1 Context

We compared functional diversity with climatic conditions in spring for the same set of plots each year over six years, to see if it was possible to identify short term (within a year) responses to climate, as well as longer term trends. This section presents the results of a functional trait analysis undertaken as part of this NCCARF funded project using existing data assessing changes in the composition of tall alpine herbfield over 6 years (Green & Pickering In press). That analysis had already identified that although there was variation in climate among years, but no consistent trend over the 6 years.

6.1.2 Background

In addition to long term trends in climate that are likely to affect the composition and functional diversity of alpine vegetation, it is possible that short term variation may also have an effect. Here we wanted to test if there was any relationship between the growing conditions experienced by plants in spring and the functional diversity of plots sampled in the following summer. For example, if there was an early thaw and warm spring would species with acquisitive traits increase in cover compared to those with more conservative traits? If so, functional diversity in the summer would show a relative increase in the cover of taller, larger leaved species with higher SLA compared to shorter species with smaller leaves.

The aim of the study was to identify if any relationships existed between climatic conditions in winter and spring and functional diversity measured in summer for tall alpine herbfield, the most common plant community in alpine area. The predictions would be that shorter winters and warmer, earlier springs would favour species with acquisitive traits (larger leaves with higher specific leaf areas) over those with conservative traits (smaller, tougher leaves with lower specific leaf areas).

6.1.3 Methods

In the middle of the growing season in January each year from 2005 to 2010, the plant species composition of tall alpine herbfield was recorded in fifteen 1 m^2 quadrats across Kangaroo Ridge (2,040-2,050 m altitude) in the Kosciusko alpine area. In 2007 one quadrat could not be relocated resulting in 179 estimates of cover covering 6 years for 15 quadrats. Overlapping cover of all species of vascular plants present in a quadrat was estimated visually to 1% accuracy. This data was adjusted by total vegetation cover to obtain proportional cover values for each species. There was nearly complete vegetation cover in the quadrats averaging 97% which was predominantly graminoids (85.6% of vegetation cover), with only 8.2% herbs and 6.2% shrubs.

Data for four traits (canopy height, leaf area, % leaf dry matter content and specific leaf area) for the 37 plant species recorded was obtained from the functional trait database. The functional traits data for each species was combined with their cover values to calculate community trait-weighted means for each quadrat. Calculations were based on the functional diversity index proposed by Mason et al. (2003, 2005) and refined by Lepš et al. (2006). The mean trait value is calculated based on the average trait value of each species present weighted by their relative cover.

In addition, climatic conditions for the winter and spring preceding each year's sampling were obtained from soil temperature loggers at a similar altitude to the quadrats located on an adjacent mountain range (Mt Clarke). The three climatic variables assessed were (1) snow cover the previous winter (metre days of snow cover for the whole period with snow), (2) number of season days for the current growing season (from thaw date in spring to 20th January) and (3) Julian thaw date in spring. The average temperatures from melt date to 20th January were not used in this analysis as it showed little variation among years. Additional details of the sampling protocol and climatic data are available in Green & Pickering (In press).

The relationship between year, climatic variables and the community trait-weighted means (average of 15 plots) were assessed using graphs and Spearman's correlation co-efficients. To see if there was any consistent difference in climate variables among plots between years, and between functional diversity among years, non-dimensional scaling (n-MDS) ordinations were performed on Euclidian dissimilarity matrices of normalised values in the multivariate statistical package PRIMER (version 6). This included analysis of community trait-weighted means per quadrat, and per year averaged over quadrats (giving a single value per year). Significant differences among years were tested using ANOSIM for the community trait-weighted means per quadrat data.

6.1.4 Results

Despite considerable variation among years in climatic variables, there were no consistent climatic trends over the 6 years (Figure 11a). Snow cover varied from 68 to 197 metre days, the duration of the growing season prior to sampling varied from 82 to 105 days, the thaw date varied from 279 Julian days to 303 days while average temperatures prior to sampling varied from 6.2 to 8.9^{o}C (Figure 12). There were also no significant correlations among the climatic variables (Table 12), indicating that an earlier thaw or deeper snow cover did not necessarily result in a longer growing season, although this may be due to the small sample size (6 years), with the correlation between snow cover and season days close to significant (P = 0.072). When all the climatic variables are combined, each year had a different combination of climatic variables (Figure 11a).
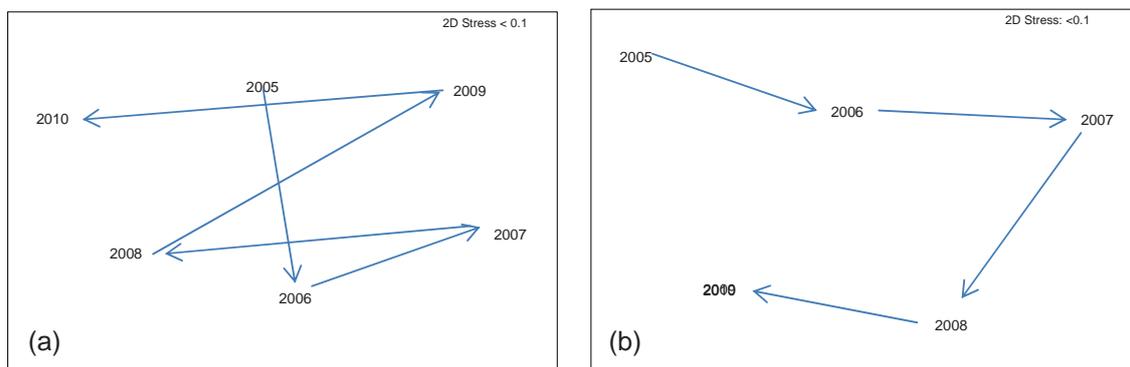
Figure 11: Two-dimensional n-MDS ordinations of (a) climatic variables for the preceding winter and spring prior to sampling in six years and (b) functional diversity as measured by community trait-weighted means (normalised and Euclidian distances) averaged over 15 quadrats sampled each year. Functional diversity were average canopy

height, leaf area, % leaf dry matter content and specific leaf area within each quadrat weighted by the relative cover of the species. Arrows show the order of years.

Both composition and functional diversity varied within and among years (Figures 11, 12 & 13). There were no correlations, however, between functional diversity for each trait and any of the climatic variables (Table 12, Figure 13), and no consistent patterns among quadrats in their response to climatic conditions in the ordinations (ANOSIM, Rho = 0.007, P = 0.284) (Figure 11).
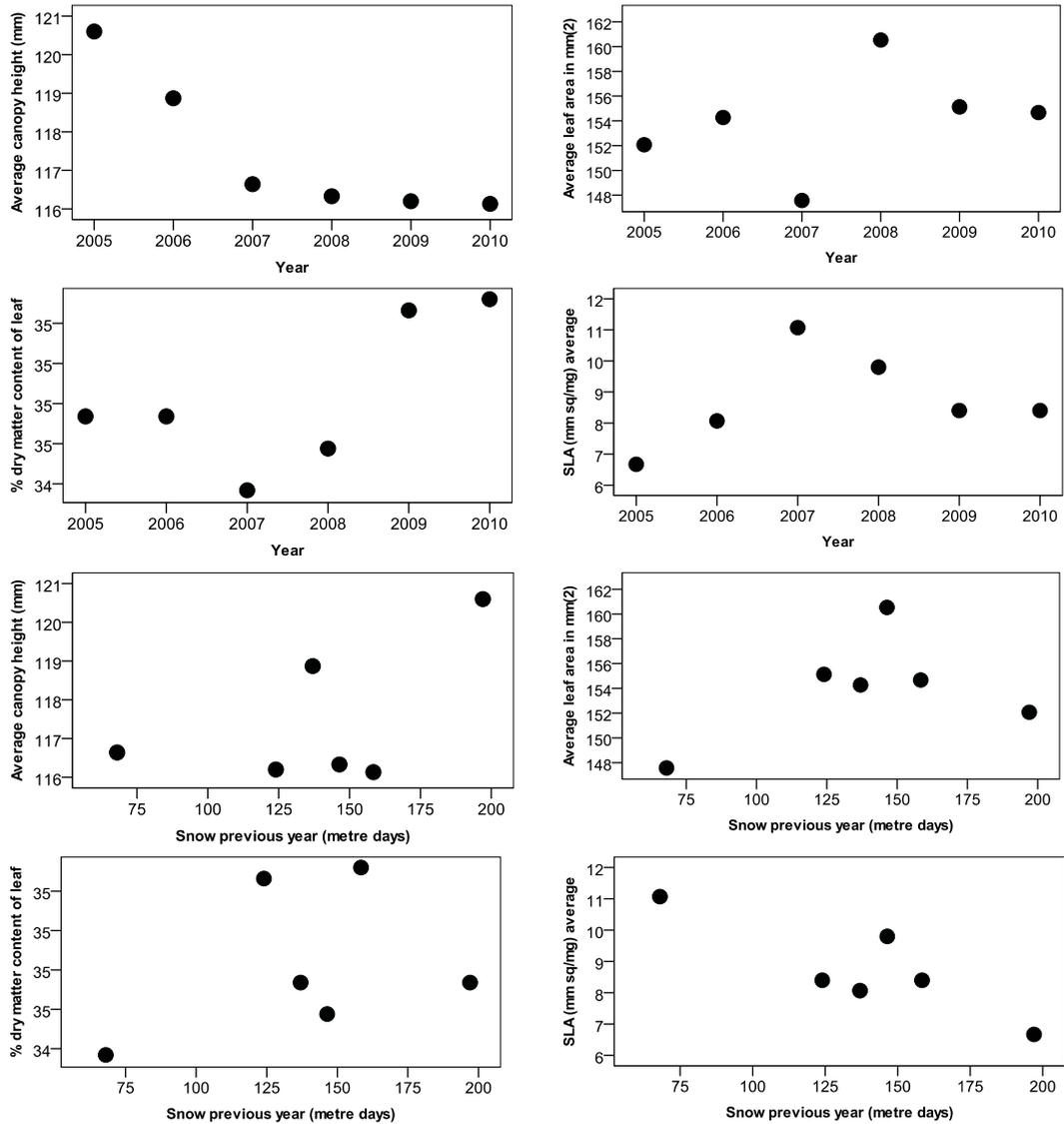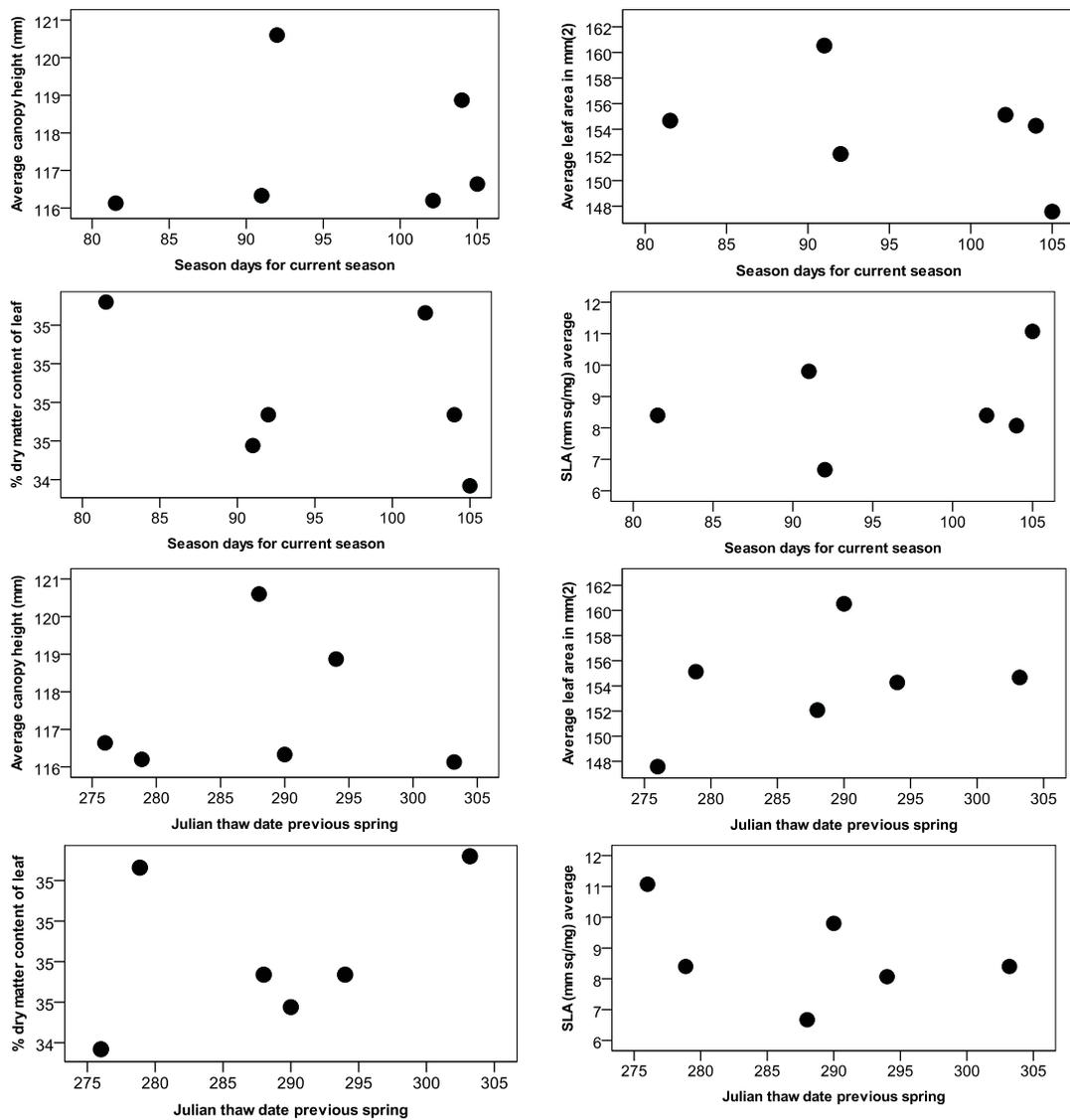
Figure 12: Functional diversity measured by community trait-weighted means averaged over 15 quadrats for the four vegetative functional traits; plant height, leaf area, % leaf dry matter and specific leaf area (SLA) compared to the climatic variables: snow cover in the preceding winter, season days prior to sampling, Julian thaw date and average temperatures from snow melt to vegetation sampling.
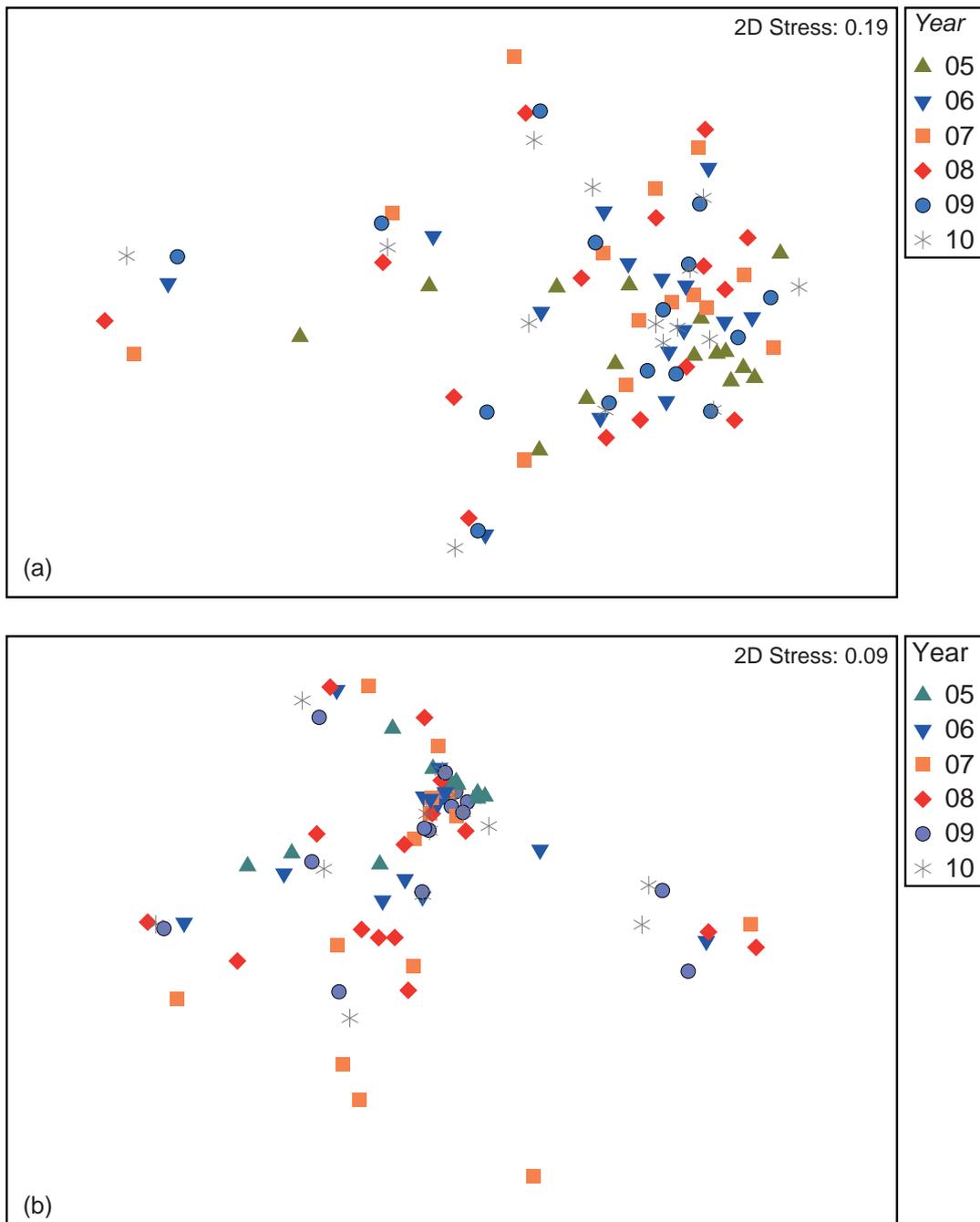
Figure 13: Two-dimensional n-MDS ordinations of (a) cover of compositional data species (square root transformation, Bray Curtis distances) and (b) functional diversity as measured by community trait-weighted means (normalised, Euclidian distances) for 15 quadrats sampled each year for six years. Functional traits were average canopy height, leaf area, % leaf dry matter content and specific leaf area within each quadrat weighted by the relative cover of the species.

Table 12: Results of Spearman's correlation analyses comparing climatic and community weighted functional traits (averaged over 15 quadrats) data among years. N = 6. Functional traits were average canopy height, leaf area, % leaf dry matter content and specific leaf area (SLA) within each quadrat weighted by the relative cover of the species. Climatic variables were snow cover, season days, Julian thaw date and average temperatures from snow melt to vegetation sampling.

		Av. canopy height	Av. leaf area	% dry mat. of leaf	SLA	Snow cover	Season days	Julian thaw date
Leaf area	Test	-0.600						
	P	0.208						
% dry mat. of leaf	Test	-0.522	0.348					
	P	0.288	0.499					
SLA	Test	-0.464	0.116	-0.500				
	P	0.354	0.827	0.312				
Snow cover	Test	0.143	0.143	0.406	-0.638			
	P	0.787	0.787	0.425	0.173			
Season days	Test	0.486	-0.600	-0.551	0.174	-0.771		
	P	0.329	0.208	0.257	0.742	0.072		
Julian thaw date	Test	-0.257	0.371	0.551	-0.377	0.600	-0.657	
	P	0.623	0.468	0.257	0.461	0.208	0.156	
Average temp.	Test	-0.213	0.334	-0.154	0.277	0.455	-0.638	0.577
	P	0.686	0.518	0.771	0.595	0.364	0.173	0.231

6.1.5 *Implications*

Although there was variation in composition and functional traits among years, there were no obvious effects of the preceding winter and spring climate on the composition or functional diversity of a plot. It may be that the vegetation does not respond to short term variation in climate although it does appear to respond to long term differences seen over altitudinal gradients (See section 6.2 and 6.3). It is also possible that there are short term effects but they are weak and therefore not apparent from just 6 years of data. It also possible that the lack of correlation among climatic traits means that no given season was any 'better' in terms of plant growth than any other. As the vegetation in the quadrats consisted nearly entirely of graminoids, the results also do not indicate how shrubs and herbs may respond to short term climatic variation.

The following two datasets test if longer term differences in climate affect functional traits by using space as a surrogate for time, where traits are sampled across climatic gradients and where quadrats had higher cover of herbs and shrubs.

6.2 Climate and functional diversity: GLORIA

6.2.1 Context

This section summarises the latest results from the Global Observation Research Initiative in Alpine Environments (GLORIA) sites in Australia and includes the results of a new analyses of species richness, species composition and functional traits produced as part of this NCCARF funded project. It complements the research findings in Venn et al. (2012) and Venn et al. (in review) produced as part of this project.

6.2.2 Background

The GLORIA network operates at a global scale. It is a standardised long-term observation network of alpine summits, devised to detect changes in vegetation patterns with rising global temperatures. Sites are directly comparable worldwide, given the standard methodology, and are re-surveyed every 5-7 years to detect trends and changes in floristic composition in relation to temperature changes. Here, we present the recent results from the five Australian GLORIA summits; a series of summits on a ridge leading up to the top of Mt Clarke, in the Kosciuszko alpine area. An important theoretical basis of this study is the assumption that patterns in species richness are related to climate. Evidence for this includes patterns of decreasing species richness with increasing altitude at the scale of whole floras and at smaller spatial scales (Körner 1992), as well as the association between vegetation composition and climatic variables already demonstrated for these GLORIA summits using the initial sampling (Pickering & Green 2009). In the European Alps, 867 vegetation samples above the treeline from 60 GLORIA summit sites show that ongoing climate change is gradually transforming mountain plant communities (Gottfried et al. 2012). This has been described as thermophilization; the more cold-adapted species decline and the more warm-adapted species increase. At the scale of individual mountains this general trend may not be apparent, but at the larger, continental scale, there was a significantly higher abundance of thermophilic (heat loving) species in 2008, compared with 2001. This thermophilization of mountain plant communities mirrors the degree of recent warming in Europe and is more pronounced in areas where the temperature increase has been higher. With respect to projected climate changes, the observed transformation suggests a progressive decline of cold mountain habitats and their biota (Gottfried et al. 2012).

As minimum and maximum temperatures in high mountain areas in Australia have risen over the past 50 years (Nicholls 2005) and snow cover has declined (Green & Pickering 2009), long term monitoring using the GLORIA protocol is therefore timely and essential for detecting and predicting Australian alpine species' responses to local climate change.

6.2.3 Methods

Five summits were chosen in 2003 to represent the Australian GLORIA sites according to the strict GLORIA protocol (Pauli et al. 2004). Specifically, the summits are 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 are all flattened summits (rather than cone-shaped), and the vegetation within the summit area is characteristic of other alpine areas at a similar altitude. They all have a similar disturbance history of grazing in the past (> 50 years ago by cattle). The summits are not along regular walking tracks and hence have low visitation rates.

The sampling regime began in January 2004. The top section of each summit was divided into eight summit area sections – four covering the area above a line 5 m attitudinally 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) (Figure 14). 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 m^2 quadrats was established (3 m by 3 m) (Figure 14). Due to the density of shrubs on

the lowest summit, permanent clusters of quadrats were not established there. Species composition was recorded in the four corner 1 m^2 quadrats, in the 3 m by 3 m grid. 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).
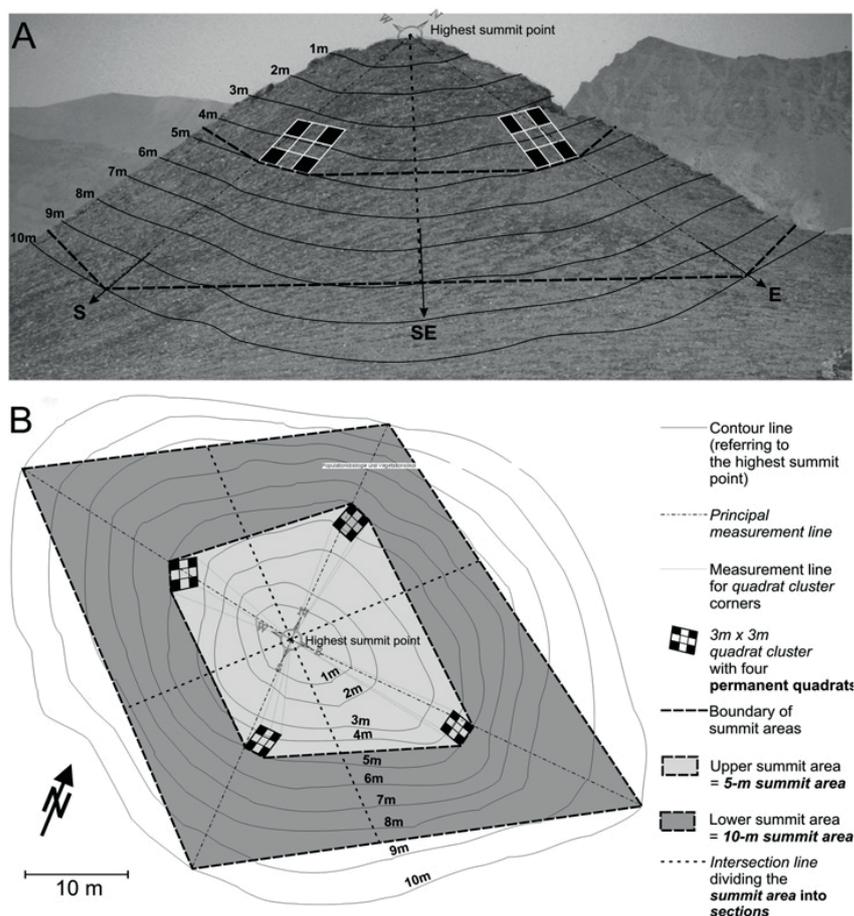
Figure 14: The layout of sampling methodology of the GLORIA summits showing (A) the positioning of the upper and lower summit area sections (SASs) and clusters of 1 m2 quadrats, and (B) as viewed from above on a hypothetical summit (modified with permission from Pauli et al. 2004).

In addition to the vegetation data, temperature loggers were buried 10 cm below the surface on each summit in the centre square of each of the 3 m x 3 m quadrat clusters, recording soil temperatures every two 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). Annual daily average soil temperatures have been used in analysis of patterns of species richness in this (Green & Pickering 2009) and other GLORIA sites.

In addition to using various species richness metrics to discern temporal and altitudinal differences, we undertook a functional approach in order to investigate the ecological processes that drive community assembly patterns across the gradient of sites and identify the underlying mechanisms that determine species distribution, community composition and ecosystem functioning. For every species recorded we measured four morphological traits; plant height, leaf area, leaf dry matter content and specific leaf area. We combined the

species abundances with the trait values in an index of functional diversity in order to produce a community trait-weighted mean for each trait. We then combined the results from the species surveys with the functional diversity data in order to determine how the alpine vegetation varies along an altitudinal/environmental gradient.

The initial sampling of the Australian GLORIA summits (2004) resulted in publications detailing the vascular plant diversity and relationships with climate change in the region (Pickering et al. 2008) and the relationships between vascular plant distribution with topography, soils and micro-climate at five GLORIA sites (Pickering & Green 2009). The first re-survey of the GLORIA sites occurred in January 2011 has since resulted in one published article (Venn et al. 2012), with another currently in review (Venn et al. In review).

6.2.4 Results

The initial 2004 survey identified 75 vascular plant species, 9 of which are endemic to just this alpine area. There were significant linear relationships between species richness and altitude and climatic variables for the upper summit area sections. The proportion of species for the whole summits with localised distributions (Kosciuszko alpine endemics) increased with altitude. The summits differed in plant composition, with a decrease in the cover of shrubs, and an increase in herbs and graminoids with increasing altitude. Altitude was the main determinant of species composition, accounting for more than 80% of the variation among summits. Soil temperature variables accounted for more than 40% of the variation in composition among summits.

In the first re-survey, conducted in January 2011, 80 species were recorded across all summits. Mean species richness increased at the whole-of-summit scale from 45 to 50 species (about 12%). At this scale, the rate of species richness increase was almost one new species per year, with 15 new species recorded at one summit. Turnover at the species and community level was typically moderate at all spatial scales and on all summits. The strength and direction of species richness change (the difference in species richness between the two sample periods, was not related to altitude nor to recent or longer-term variation in climate (Venn et al. 2012). There were clear differences in composition among summits but not among years for the top 5 m area of the summits (ANOSIM, Year Rho = 0.023, P = 0.562, Summits, Rho = 0.525, P = 0.001, Figure 15). There were however, clear differences in functional traits among summits (ANOSIM, Rho = 0.887, P = 0.001) but also between years (Rho = 0.329, P = 0.002). Growth form strongly affected compositional changes and functional diversity among summits. Changes in shrub cover, although not enough to result in significant differences in composition, is likely to have contributed to changes in traits between the two years, with shrubs increasingly dominant at lower altitude summits. As a result, functional diversity for plant height and leaf dry matter content significantly decreased with altitude, whereas for leaf area and specific leaf area it significantly increased reflecting the increased dominance of herbs and graminoids at higher altitude summits.

6.2.5 Implications

The GLORIA data are an important example of long-term vegetation monitoring in Australia's alpine region, given empirical evidence of vegetation shifts in response to recent climate change is largely unavailable and also provides an important baseline for future researchers. Over the short-term, increases in shrub and graminoid species were more pronounced at the lower altitudes. Additionally, the changes in overall vegetation composition between the two survey periods and the abundance of competitive (taller) species at lower elevations, reflects the increasing dominance of shrubs. The results from the 2011 re-survey do not suggest that Kosciuszko endemic species at these sites are any more or less threatened by variation in climate than widespread species, however, future surveys will reveal whether these species become more marginalised.
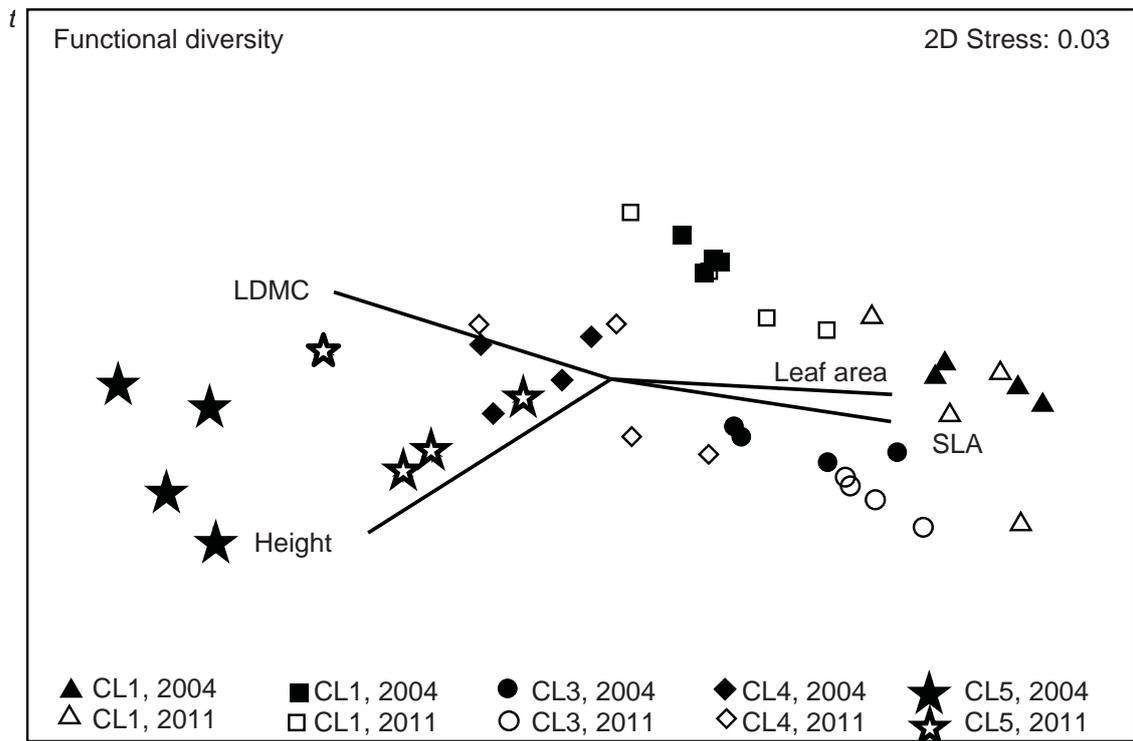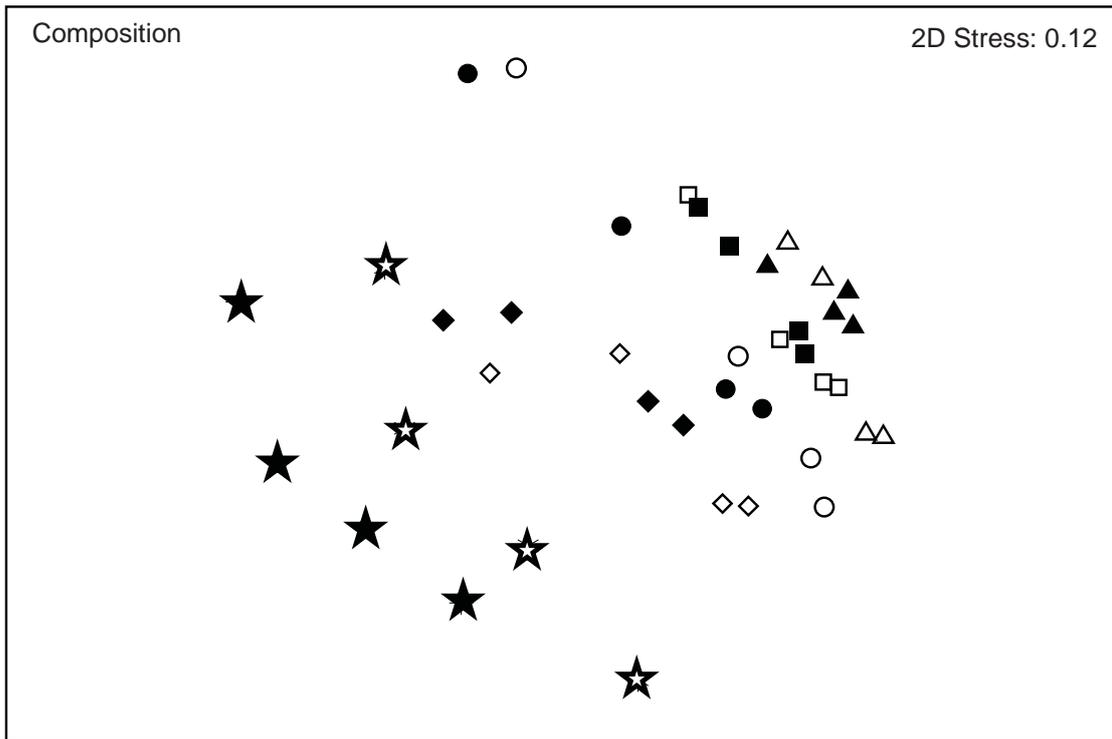
Figure 15: Two-dimensional n-MDS ordinations (Bray Curtis distances) of the upper summit area sections (using aspects, north, east, south, west) to illustrate differences in vegetation composition and traits (abundance) between 2004 (closed shapes) and 2011 (open shapes). Data from Clarke 1 = triangles, Clarke 2 = squares, Clarke 3 = circles,

Clarke 4 = diamonds Clarke 5 = stars. Vectors are based on Pearson correlation coefficients and indicate the direction in which the values for a trait increase.

6.3   Climate and functional diversity: snowpatches

6.3.1 Context

This section summarises the results from the first published functional traits analysis of Australian alpine plants (Venn et al. 2011) which was conducted prior to this NCCARF project. This research provided the basis for our understanding of the relationship between climate and changes in functional traits. Here we summarise this work (Venn et al. 2011) including describing the relationship between snowmelt date and functional traits, and how the functional diversity of each trait can then be used to examine ecological processes operating across a gradient of snowmelt.

6.3.2 Background

Snowpatch plant communities in Australia are highly specialised and restricted, occurring only in alpine areas where snow accumulates and persists on lee slopes for several months after adjacent areas have thawed. Snow can last well into summer or autumn (Costin et al. 2000; Wahren et al. 2001; Venn & Morgan 2007; Green & Pickering 2009a,b) substantially reducing the length of the growing season. The occurrence of late-lying snow is sufficient to inhibit the growth of non-specialised species even if they occur in close spatial proximity (Edmonds et al. 2006; Green & Pickering 2009b). Future reductions in snowpack depth and earlier thaw dates could potentially lead to reductions and the loss of rare snowpatch plant communities including short alpine herbfield (Green & Pickering 2009b). We used a functional traits approach to understand and predict community responses to reduced snowmelt. From this, we made predictions about the likely trait changes that may occur with global warming in alpine snowpatch communities.

6.3.3 Methods

Within seven snowpatches across the Main Range, in the Kosciuszko alpine area, we assigned various sub-communities to one of three snowmelt zones, early, mid and late melt. For every vascular plant species sampled within these zones, we measured three functional traits; plant height, seed mass and leaf area, based on at least 10 adult individuals local to the study area. We then related the abundance of all plant species to the functional traits, using functional diversity (Mason et al. 2005; Lepš et al. 2006) measured using community trait-weighted means. We could then assess how plant functional diversity varies with the timing of snowmelt.

6.3.4 Results

The inter-annual variability in the timing of snowmelt between the three zones was high, however, the order of snowmelt remained consistent through the years. The strong relationship between the composition of the vegetation and snowmelt zones across all seven snowpatches were reflected in functional diversity. For two of the three plant traits measured, functional diversity was sensitive to the timing of snowmelt and hence, growing season length (Figure 16). We observed that functional diversity for leaf area and plant height were significantly higher (245 and 212%, respectively) in the areas were snow melted earlier than areas where it melted later. Functional diversity in mid snowmelt zones were more similar (not significantly different) to late snowmelt zones for both leaf area and plant height. The functional diversity for seed mass, however, was not significantly different across the three snowmelt zones (Figure 16).
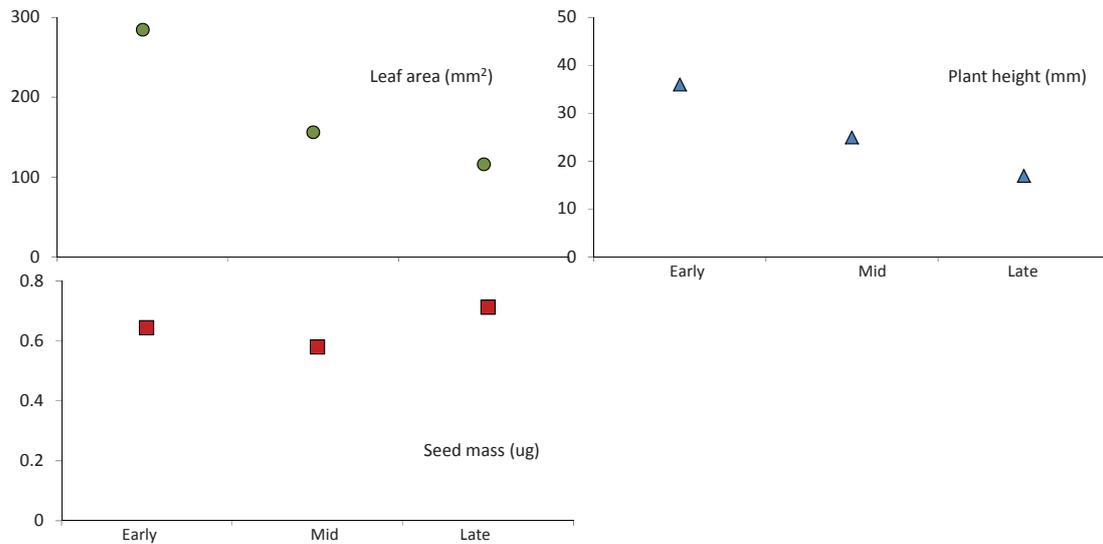
Figure 16: Mean functional diversity as measured by community trait- weighted means for: (a) leaf area, (b) plant height, and (c) seed mass respectively, for the three snowmelt zones across the seven snowpatches. Symbols represent the mean in functional diversity for each trait across quadrats in each zone.

6.3.5 Implications

We saw substantial differences in functional diversity in early and late snowmelt zones within snowpatches. Early melting zones tended to have a higher cover of species with larger leaves that are taller than areas where the snowpatch melted later. Total vegetation cover was also substantially higher in early snowmelt zones (Green & Pickering 2009b), which is likely to translate to higher annual primary productivity (Baptist & Choler 2008). Hence, even over very small spatial scales, the composition of vegetation is strongly associated with the duration of snow cover, and is related to traits that benefit plants in each zone. With reductions in snow cover, the rare short alpine herbfield plant community is likely to be further colonized by the more competitive alpine herbfield plants that are taller and have larger leaves.

7. FUNCTIONAL DIVERSITY AND FIRE

7.1 Context

Here we present the results of new analyses undertaken as part of this NCCARF project to better understand the impacts and recovery of plant communities affected fire in the alpine zone. The initial analysis of the vegetation data including composition has already been submitted as a paper (Butler & Pickering In review), with a second paper based on the functional traits analysis to be submitted soon (Butler et al. in prep).

As discussed in Section 2, large scale wildfires are relatively rare in the alpine area around Mt Kosciuszko. In 2003, large-scale wildlife swept across the Australian Alps, affecting several areas above the treeline within Kosciuszko National Park. The fires also burnt into some highly specialised habitats, including the windswept feldmark (Figure 17). This plant community is therefore experiencing the compounded influences of fire and climatic changes. As a result, the recovery trajectory could potentially lead to altered states and/or vegetation structures. Additionally, the timing of recovery can differ drastically from one community to the next. Here we present the results from repeated surveys in fire-affected areas in the proximity of the Main Range in the Kosciuszko alpine area and suggest possible post-fire recovery paths for the windswept feldmark and the tall alpine herbfield using various analyses of species richness, vegetation composition and plant functional traits.

Figure 17: Areas of burnt feldmark and tall alpine herbfield along the main range between Mt Caruthers and Mt Twynam in the Kosciusko alpine area 5 weeks after the 2003 wildfires. Photo by Griffith University staff.

7.2 Background

Although fire and drought are regular events in Australia, the effect of these major types of natural disturbance on Australia's alpine ecosystems is not as well understood as for some other vegetation communities (McDougall 1982; Good 1992a,b; Wahren et al. 2001; Williams et al. 2006, 2008). This is because large-scale fire and drought are reasonably rare historical events in the Australian Alps. In the last 100 years there have been few landscape level fires that have reached the Kosciuszko alpine areas and none that have burnt through these areas (Leaver 2004; Williams et al. 2008). Deliberate burning of large areas of the alpine occurred

each autumn during the 100 years of grazing, which ceased with the removal of cattle grazing in the 1950's (Costin 1954; McDougall 1982; Good 1992a,b; Costin et al. 2000; Wahren et al. 2001). In the summer of 2003 landscape level fires burnt an estimated 1.73 million ha of the Australian Alps: the largest fires in 60 years (Worboys 2003).

The fires, which burnt for almost two months, were started by electrical storms. At its peak, the fire front was a continuous line from the north of Canberra to central Victoria (Worboys 2003). Fire from the steep western escarpments of the Main Range reached the alpine area around Mt Caruthers/Mt Twynam during the extreme weather conditions on January 24-25th. The 2003 bushfires had a substantial impact on the flora, fauna and soils of the Australian Alps National Parks. Around 612,000 ha of Victorian high country burnt, chiefly in Alpine National Park, around 337,000 ha of Kosciuszko National Park was affected, and almost all of the 11,500 ha Namadgi National Park in the ACT (Worboys 2003a). As predicted, the alpine area of the Main Range acted as a natural fire break (Costin et al. 2000; Leaver 2004), with most of the western faces burnt, but fire coming over the ridgeline petering out as it reached tall alpine herbfield communities (Green 2003). Consequently, only small sections of alpine vegetation burnt, as the fire extended first into windswept feldmark communities on the exposed ridges of Mt Caruthers/Mt Twynam and then 30-50 m into the tall alpine herbfield (Worboys 2003; Green 2003, Figure 17). Spot over burns occurred in nearby heath communities on the south of Blue Lake. In particular, it seems that snowgrass (*Poa* spp) was only able to sustain fire during conditions of high heat and wind and that Pineapple Grass (*Astelia* spp) and Snow Daisies (*Craspedia* spp) may be fire retardant (Green 2003). Visual estimates put the burnt alpine area at around 10-15 ha (Worboys 2003; Green, K. NPWS 2003 pers comm).

In this study we assessed the impact and initial recovery from the fire of the very rare windswept feldmark and the more common tall alpine herbfield. The fire in January 2003 during the peak of the growing season resulted in the loss of more than 97% of vegetation cover in burnt areas with only two species found a few weeks after the fire in each community.

7.3   Methods

The vegetation was initially surveyed in both burnt and unburnt feldmark and tall alpine herbfield, five weeks after the fires had burned through the region. Subsequently, the vegetation was resurveyed each year in January/February from 2004 till 2008 and then again in 2012 using three 600 m^2 quadrats in each community type (12 in total) in the area between Mt Lee and Mt Twynam, within an area of approximately 1 km^2. The low replication of sites reflects the restricted nature of feldmark in the landscape, and the low proportion of feldmark that remained unburnt.

Within each of the 12 quadrats, the cover of each species, bare rock, bare soil, bare soil with roots exposed, litter, burnt litter, burnt shrub, burnt herb or burnt graminoid was assessed using 200 randomly located points, with the number of points touched recorded. If a species was found in a quadrat, but not touched by one of the 200 points it was assigned a low cover value of 0.01%. The relative cover of growth forms (herbs, shrubs and graminoids) and species was calculated by dividing its cover by the cover of vegetation in that quadrat.

Differences in vegetation parameters among the four combinations of 'treatments' e.g. burnt feldmark, unburnt feldmark, burnt tall alpine herbfield and unburnt tall alpine herbfield were initially tested using One-way Repeated Measures ANOVA. In cases where the interaction between 'time' and 'treatment' were significant, individual One-way ANOVAs were performed for vegetation cover and species richness in each year. Functional diversity was calculated using community trait weighted means the four vegetative traits; canopy height, leaf area, leaf dry matter content and specific leaf area.

To describe the major gradients in species composition and functional traits, non-metric multidimensional scaling (NMDS) was performed. In addition, One-way Analysis of Similarities (ANOSIM) was performed to determine whether there were significant differences in species composition and traits between burnt and unburnt quadrats.

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7.4 Results

The initial impact of the fire was to dramatically change species composition and relative cover in both communities with few species limited vegetation cover 5 weeks post fire (Figures 18 & 19). Species richness recovered relatively rapidly in both communities (Figure 19). In tall alpine herbfield vegetation cover was still recovering 9 years post fire, while in feldmark it was similar by 2012. As burnt tall alpine herbfield recovered, its composition became more and more like that of unburnt tall alpine herbfield (Figure 20) with no significant difference in their composition in 2012 (Rho = 0.037, P = 0.30). In contrast, as burnt feldmark recovered, it did not converge towards unburnt feldmark, but towards unburnt tall alpine herbfield with tall alpine herbfield species increasingly dominating all burnt quadrats while species characteristic of unburnt feldmark including shrubs showed limited recovery.
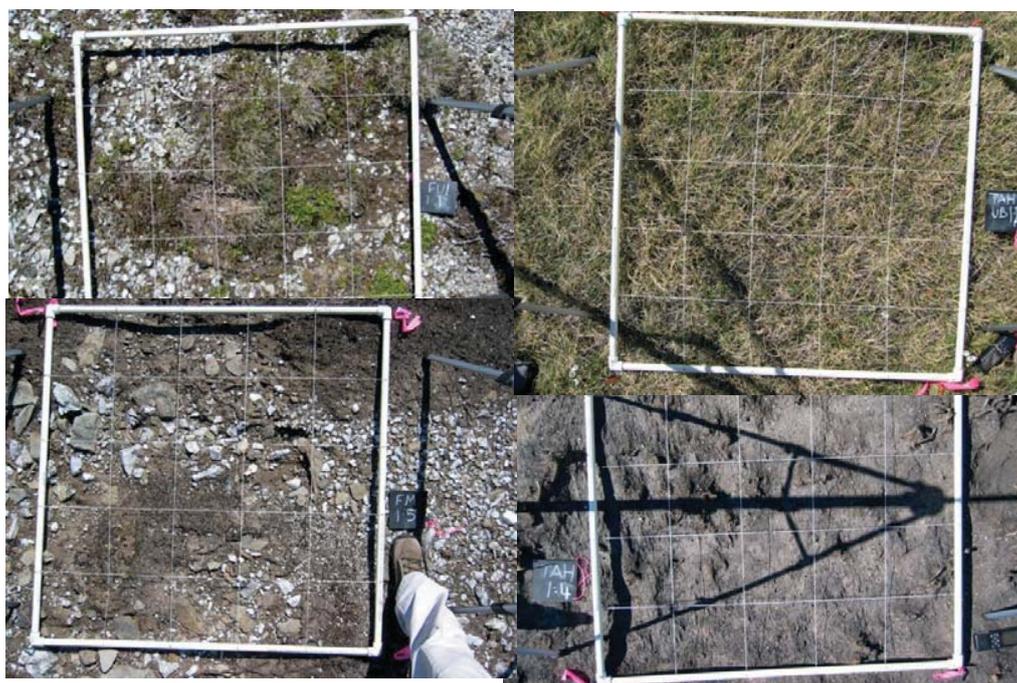
Figure 18: Unburnt (top row) and burnt (bottom row) windswept feldmark (left) and tall alpine herbfield (right), photographed 5 weeks after the 2003 bushfires. Photos Griffith University staff.
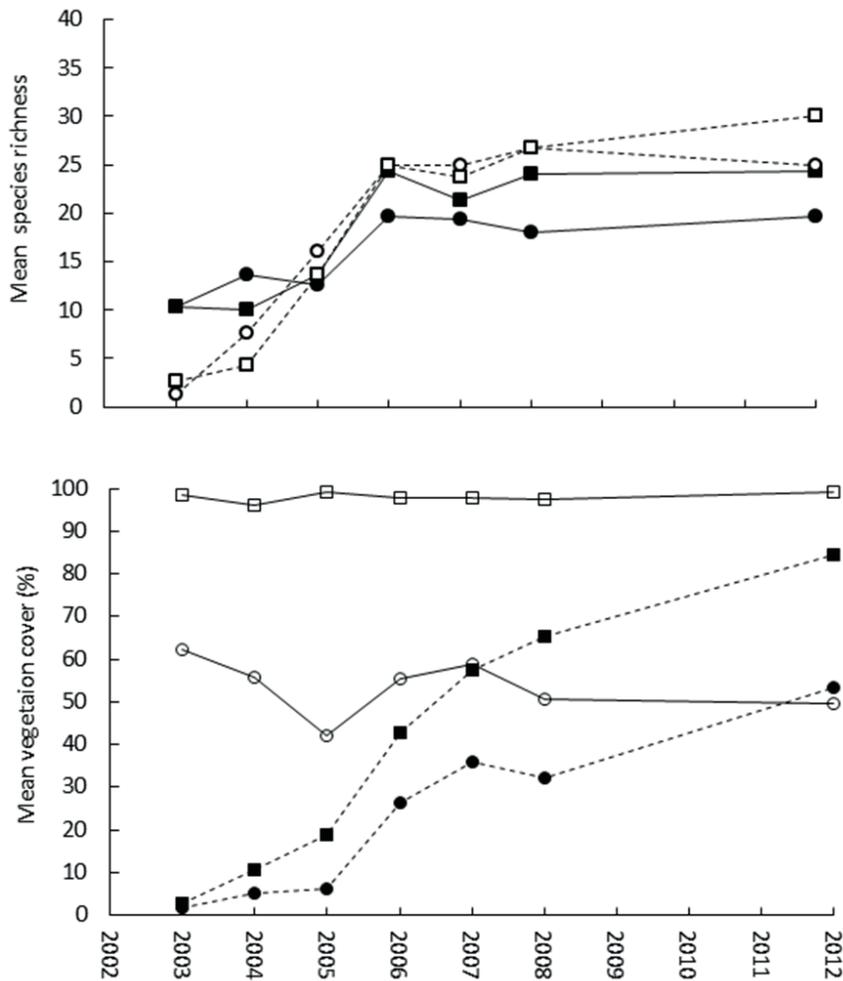
Figure 19. Mean of (a) species richness and (b) vegetation cover within burnt (black) and unburnt (white) quadrats of feldmark (circles) and tall alpine herbfield (squares) from 2003 to 2012.

Unburnt tall alpine herbfield was dominated by taller species than unburnt feldmark. Immediately post fire there was considered variation in functional diversity in the burnt plots due with the traits of the one or two plants that survived the fire determining the overall measure. Over time, as species recovered, so did functional diversity which became more and more similar to that in the unburnt plots. Species with high specific leaf area and low leaf dry matter content quickly recolonised all the burnt quadrats. In the feldmark, early colonisation was dominated by short species and those with low leaf dry matter content and high specific leaf area. In contrast, initial colonisation after fire in the tall alpine herbfield was by taller species, although through time the high proportion of taller species diminished. Ordinations of functional diversity within unburnt and burnt quadrats of both communities across years showed a clear trend of burnt tall alpine herbfield and feldmark recovering through time, although there was still significant differences between the four types of plots in 2012 (P = 0.01, Figure 20).
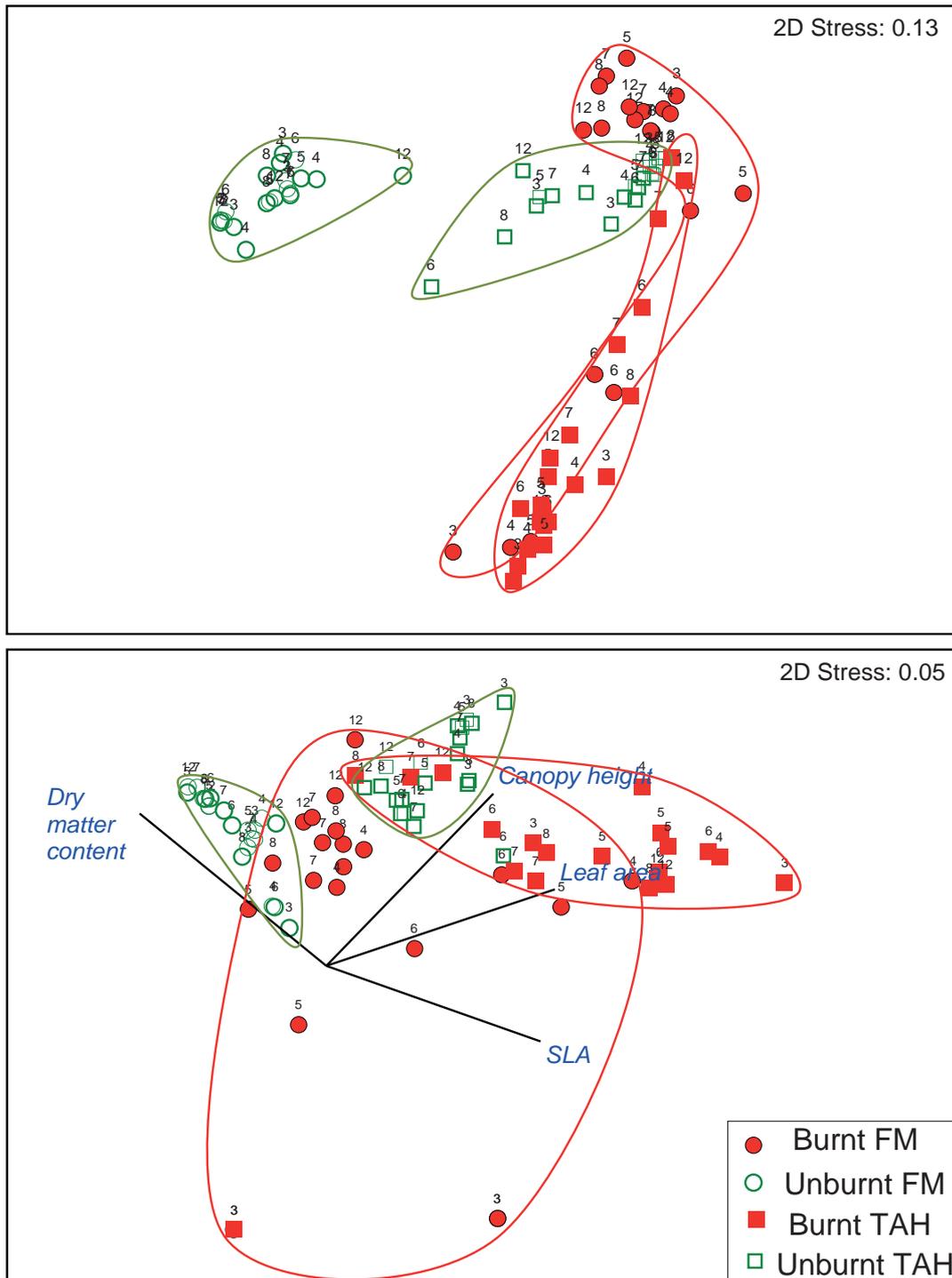
Figure 20. Two-dimensional n-MDS ordinations of (a) species composition based on relative cover of species (Bray Curtis) and (b) functional traits (normalised, Euclidean distances) between windswept feldmark (circles) and tall alpine herb field (squares) burnt (black) and unburnt (white) quadrats over time (2003-2012). Vegetative functional traits were average species canopy height, leaf area, leaf dry matter content and specific leaf area within each quadrat weighted by the relative cover of the species. Vectors are based on

Pearson correlation coefficients and indicate the direction in which the values for a trait increase.

7.5 Implications

The typical 'live fast, die young' strategy of initial colonisers was evident in the burnt quadrats of both communities, as determined by their functional traits. However, nine years post fire, the composition of the burnt feldmark has converged with tall alpine herbfield, with sites not significantly different from the unburnt tall alpine herbfield. The recovery of burnt feldmark to represent that of the unburnt feldmark appears unlikely in the short term. The compounding effects of the fire with warmer temperatures and reduced snow cover may mean that the existing unburnt feldmark in the region will be remain the only representative of this community type, maintaining its existence through sheer tenacity (holding their ground) and competitive exclusion of potentially more competitive species. However, given the harsh nature of the windswept feldmark environment, short-statured, compact herbs and shrubs may again dominate regardless of climate warming, should the initial colonising species fail to maintain current populations and shrubs recolonize these sites.

8. FUNCTIONAL DIVERSITY AND GRAZING

As discussed above, the Australian Alps are unusual when compared with many northern Hemisphere mountainous regions, as there are no common medium or large sized native grazing mammals in the Australia alpine region. In the Kosciuszko alpine area the only native grazing mammal is the small, and increasingly rare, Broad-toothed Rat (Costin et al. 2000; Scherrer 2003; Green & Osborne 2012). As a result, the alpine plants are less likely to possess the suites of traits seen in floras that evolved with large hard hooved grazing mammals. Traits commonly associated with grazing by these animals include an annual life history, short stature, prostrate, and stoloniferous or rosette architecture as grazing does not favour perennial plants or those which are tall, erect and/or with tussock forms (Diaz et al. 2007).

Here the effects of grazing by two different types of introduced mammals are assessed. The first is recovery of vegetation from grazing by hard hooved animals (cattle) and the second is an assessment of the impact of hares, which have increased in density in the alpine area over the past decades.

8.1 Recovery from cattle grazing and functional diversity

8.1.1 Context

Vegetation change in Kosciuszko National Park was assessed over a 43 year period using six long term monitoring transects that were originally established to assess recovery from cattle grazing (Wimbush & Costin 1979a,b; Scherrer 2003). Changes in composition data and other variables including cover has previously been analysed (Wimbush & Costin 1979a,b; Scherrer 2003; Scherrer & Pickering 2005). Here the composition data for one of the six transects was combined with functional trait information to calculate functional diversity values in order to assess recovery from cattle grazing. A more extensive trait analysis of this data will be undertaken in the future. Additional details regarding the sampling protocols and changes in composition can be found the above references.

8.1.2 Background

Cattle grazing in the Kosciuszko alpine area resulted in extensive damage to vegetation, soils and aquatic systems, requiring extensive and expensive rehabilitation, with damage to the region taking decades to recover (Costin 1954; Costin et al. 2000; Scherrer 2003; Scherrer & Pickering 2005). Impacts of cattle grazing in the past include changes in plant composition with the loss of palatable species, reduced biomass, overall reductions in vegetation height and declines in species richness (Costin 1954; Costin et al. 2000; Scherrer 2003; Scherrer & Pickering 2005). Reflecting these changes in composition, it is likely that the functional diversity of the alpine flora will also change as the vegetation recovers from cattle grazing. It is likely that many larger-leaved more palatable herb species and shrubs may increase after the effects of trampling and grazing are removed. Therefore, patterns in the functional traits may be a mixture of increases in the overall abundance of species with larger leaves, such as herbs, but this may be countered by the recovery shrub species which generally have smaller leaves. An increase in shrubs may also lead to an overall increase in plant height of the communities.

8.1.3 Methods

Compositional data from a transect on the eastern side of Mt Gungartan was recorded in late January and early March in 1959, 1961, 1964, 1968, 1971, 1978, 1990, 1999, and 2002. This transect (Gungartan North), extend up the wind exposed west facing slope of Mt Gungartan at around 2100 m altitude. It traversed degraded tall alpine herbfield with areas of bare ground and exposed rocks. Soil erosion was obvious at the start of monitoring in 1953, one year after grazing was banned at the site (Wimbush & Costin 1979a,b). Changes in composition over the first 19 years of sampling covering 1951-1978 were published in 1979 where they found that

the recovery of vegetation was interrupted by a severe drought from 1961 to 1967 (Wimbush & Costin 1979a,b). Additional monitoring was undertaken in 1999 and 2002, which makes it one of the longest studies of vegetation dynamics in Australian, spanning 43 years (Scherrer 2003).

The composition data for all flowering plants were converted into relative cover prior to calculating functional diversity. Although 41 taxa were recorded over the 43 year sampling period, only 23 were identified to the level of species (Table 13). For those identified as genera, we used functional traits for the most common/likely species from that the genera in the tall alpine herbfield (Table 13). For the uncommon *Cassinia aculeate,* we did not have functional trait data so it was removed from the analysis.

Table 13. Taxa recorded in repeated sampling of the Gungartan North transect over 43 years. Data from Scherrer 2003. * = weed.

Taxa as recorded	Form	Species used for functional traits	Total hits
Acaena spp.	Herb	Acaena sp.	11
Acetosella vulgaris*	Herb	Acetosella vulgaris*	65
Aciphylla spp.	Herb	Aciphylla glacialis	24
Agrostis spp.	Grass	Agrostis muelleriana	80
Asperula spp.	Herb	Asperula gunnii	348
Australopyrum velutinum	Grass	Australopyrum velutinum	61
Brachyscome spp.	Herb	Brachyscome scapigera	8
Cardamine spp.	Herb	Cardamine lilacina	7
Carex spp.	Sedge	Carex breviculmis	281
Celmisia sp.	Herb	Celmisia costiniana	1,025
Chionogentias muelleriana	Herb	Chionogentias muelleriana	15
Colobanthus spp.	Herb	Colobanthus pulvinatus	2
Cotula alpina	Herb	Cotula alpina	18
Craspedia spp.	Herb	Craspedia costiniana	292
Deyeuxia spp.	Grass	Deyeuxia crassiuscula	160
Empodisma minus	Rush	Empodisma minus	768
Epacris spp.	Shrub	Epacris glacialis	1,948
Erigeron spp.	Herb	Erigeron bellidioides	13
Euchiton spp.	Herb	Euchiton argentifolius	11
Euphrasia spp.	Herb	Euphrasia collina subsp. diversicolor	32
Ewartia nubigena	Shrub	Ewartia nubigena	151
Gonocarpus micranthus	Herb	Gonocarpus micranthus	1
Grevillea australis	Shrub	Grevillea australis	182
Hypochaeris radicata*	Herb	Hypochaeris radicata*	1
Leptorhynchos squamatus	Herb	Leptorhynchos squamatus	68
Leucopogon montanus	Shrub	Leucopogon montanus	31

Luzula spp.	Rush	Luzula alpestris	158
Melicytus sp.	Shrub	Melicytus sp.	13
Microseris lanceolata	Herb	Microseris lanceolata	25
Oreomyrrhis spp.	Herb	Oreomyrrhis eriopoda	5
Pentachondra pumila	Shrub	Pentachondra pumila	3
Pimelia spp.	Shrub	Pimelea alpina	195
Plantago spp.	Herb	Plantago euryphylla	2
Poa spp.	Grass	Poa costiniana	3,540
Pratia surrepens	Herb	Pratia surrepens	1
Ranunculus spp.	Herb	Ranunculus gunnianus	12
Rytidosperma spp.	Grass	Rytidosperma nudiflorum	35
Scleranthus spp.	Herb	Scleranthus biflorus	120
Senecio spp.	Herb	Senecio pinnatifolius	103
Trisetum spicatum	Grass	Trisetum spicatum	30
Viola betonicifolia	Herb	Viola betonicifolia	3

Vegetation cover, number of genera and functional diversity as measured by community trait-weighted means were plotted against year. Cover data per taxa and functional diversity were then analysed using ordinations. To determine if there were patterns in the composition and functional diversity of the transect over time, non-dimensional scaling (n-MDS) ordinations were performed using Bray-Curtis dissimilarity matrixes of square-root transformed data for cover data and Euclidian dissimilarity matrices of functional diversity data in the multivariate statistical package PRIMER (version 6).

Results

As vegetation recovered from grazing there was a general increase in diversity at the level of genera with a decline in 1968 during the drought (Figure 21). Vegetation cover was relatively high initially, dropped between 1968 and 1971 during the drought, before recovering. There was directional change in flowering plant composition over time, with a clear sequence in composition from 1959 till 2002 (Figure 21).
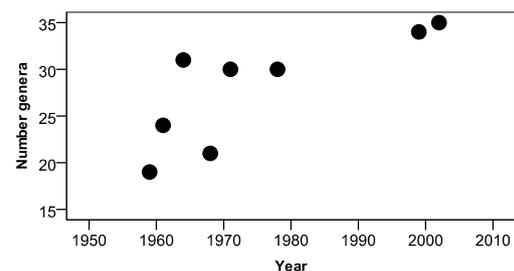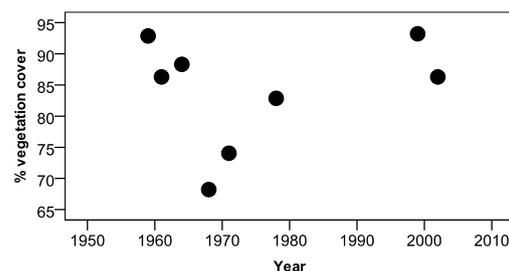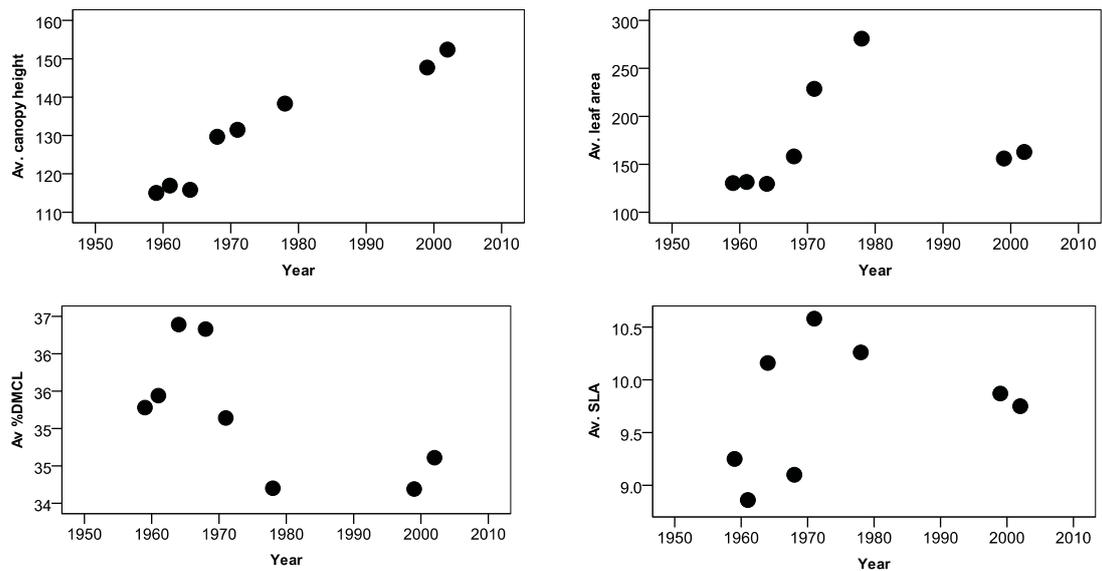
Figure 21. Variation in % vegetation cover, number of genera and functional diversity measured as community trait-weighted means for canopy height (mm), leave area (mm²), % dry matter content of leaves (DMCL) and specific leaf area (SLA) for Gungartan North Transect.

The % cover of growth forms showed three different patterns. For shrubs there was initial increase from 1959 till 1971, after which values remaining relative stable (Figure 22). Graminoids and herbs showed the opposite pattern to each other with graminoids decreasing while herbs increased until 1971, when graminoids recovered and herbs declined.
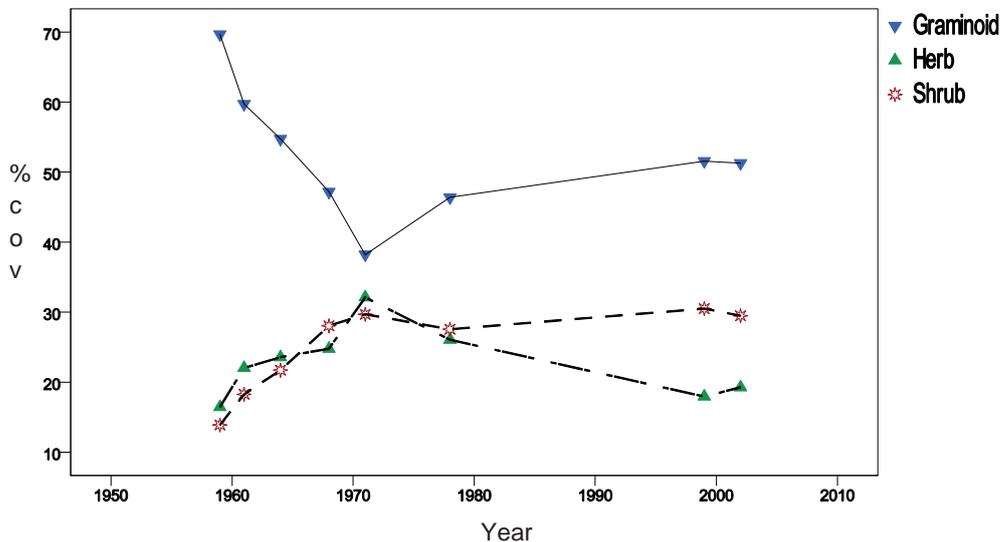
Figure 22. Changes in % cover of vegetation consisting of graminoids, herbs and shrubs over time for the Gungartan North Transect.

Each of the four functional traits showed a different trend over time. For canopy height there was a relatively consistent increase over the 43 years (Figure 21). Leaf area and specific leaf area initially increased before declining around or post 1980. The % dry matter content of leaves increased between 1959 and 1968, then declined in the 1970s with values remaining relatively low after that (Figure 21).

Three distinct groupings are apparent from the ordinations of composition data, values from 1959 to 1964, from 1968 to 1978 and the last two measurements in 1999 and 2002 identical (Figure 23a). For functional traits a different pattern was apparent, with an overall trend for plants with larger leaves and SLA and shrub cover from 1959 till 1978, and then a decline in shrub cover, leaf area and SLA (Figure 23a).
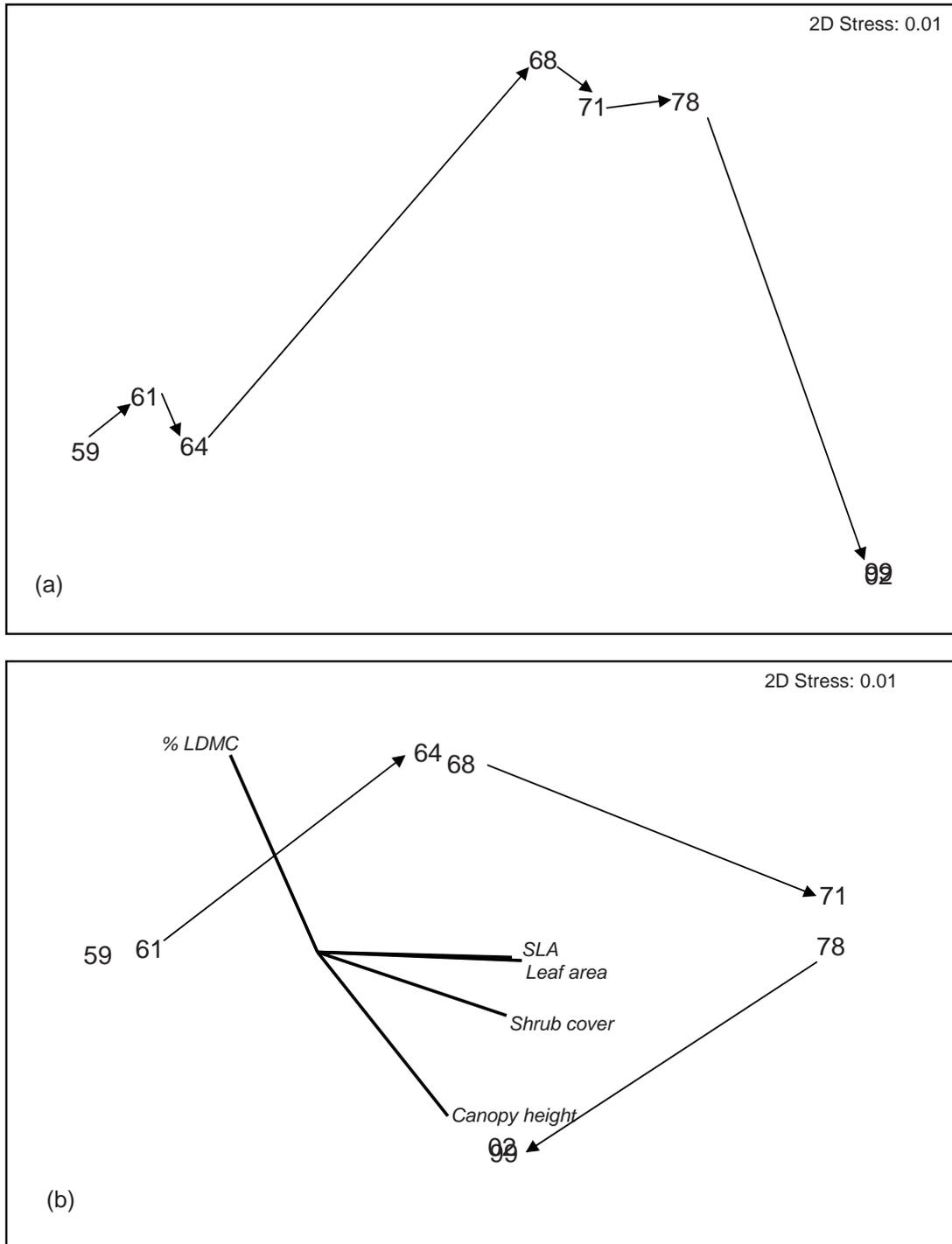
Figure 23. Two-dimensional n-MDS ordinations of (a) cover of individual species (square root transformation, Bray Curtis dissimilarity) and (b) functional diversity as

measured by community trait-weighted means (normalised, Euclidian distances) including % cover of shrubs as an estimate of woodiness, for the Gungartan North transect sampled over 43 years. Functional traits were canopy height, leaf area, % leaf dry matter content and specific leaf area within each quadrat weighted by the relative cover of the species. Vectors area based on Pearson correlation coefficients and indicates the direction in which the values for a trait increase.

8.1.4 Implications

With the removal of grazing there were clear changes in the composition and functional traits of the tall alpine herbfield with taller species, including shrubs, more dominant and graminoids declining. The pattern over the 43 year period is likely to also reflect other factors, such as droughts and the general trend of declining and variable, snow cover. Therefore, we assume that the initial pattern from 1959 to 1978, indicated recovery from grazing impacts, with an increase in leaf area, SLA and canopy height as vegetation recovered. A more detailed analysis of all the transects and from photoquadrats taken during the same period will no doubt provide a clearer understanding of how functional diversity has changed over time at these sites.

8.2 Hare grazing and functional diversity

8.2.1 Context

This section follows on from the results of a study assessing the impact of hare grazing analysed during the current project (Green & Pickering In press). The functional trait analysis presented here was not included in the paper, although additional details on how the experiment and how the composition data was collected are available in the paper.

8.2.2 Background

The altitudinal distribution and density of some feral mammals is increasing in the subalpine and alpine areas of the Australian Alps including horses, deer, pigs and rabbits in subalpine areas (ISC 2004; Green & Pickering In press). Hare numbers appear to have increased in the Kosciuszko alpine area, possible due to reduced snow cover (Green & Pickering In press). Hares cause considerable to damage alpine vegetation in regions where they are not native including New Zealand (Flux 1967).

To assess impacts of grazing by hares in the Kosciuszko alpine area, a manipulative field experiment was conducted where the composition of tall alpine herbfield in exclosures was compared to control quadrats over six years (Green & Pickering In press). In the original analysis, hare grazing appeared to have no effect, with plant height, biomass, species richness and composition similar between control and exclosure quadrats (Green & Pickering In press). Here we assessed if there were any differences in functional diversity between the exclosures and controls.

Figure 24. One of the fifteen hare grazing exclosure plots on Kangaroo Ridge in the Kosciuszko alpine area monitored for 6 years.

8.2.3 Methods

Plant composition was visually assessed in 1 m^2 quadrats within 15 exclosures (Figure 24) and paired control quadrats at the peak of the growing season in January each year from 2004 to 2010. Functional trait data was available for all 38 vascular plant species recorded. Functional diversity was calculated using community trait-weighted means per quadrat. This data was analysed using ordinations to assess variation in functional diversity as measured by community trait weighted means between exclosures after six years of excluding grazing and in the controls.

8.2.4 Results

There were no significant difference in functional traits between exclosures and controls either overall, or for values from just 2010 after six years of excluding hares (Figure 25). This was true for all years (Treatment nested within year ANOSIM, Rho = 0.035, P = 1.00) and for just 2010 after 6 years of excluding hares (One-Way ANOSIM, Rho = 0.03, P = 0.828).

8.2.5 Implications

Hare grazing over the duration of this experiment did not appear to affect the composition or functional diversity of the tall alpine herbfield. However, other data indicates that hares are selectively grazing some species, and so may be having specific impacts not obvious at the scale of sampling used here (Green & Pickering In press).
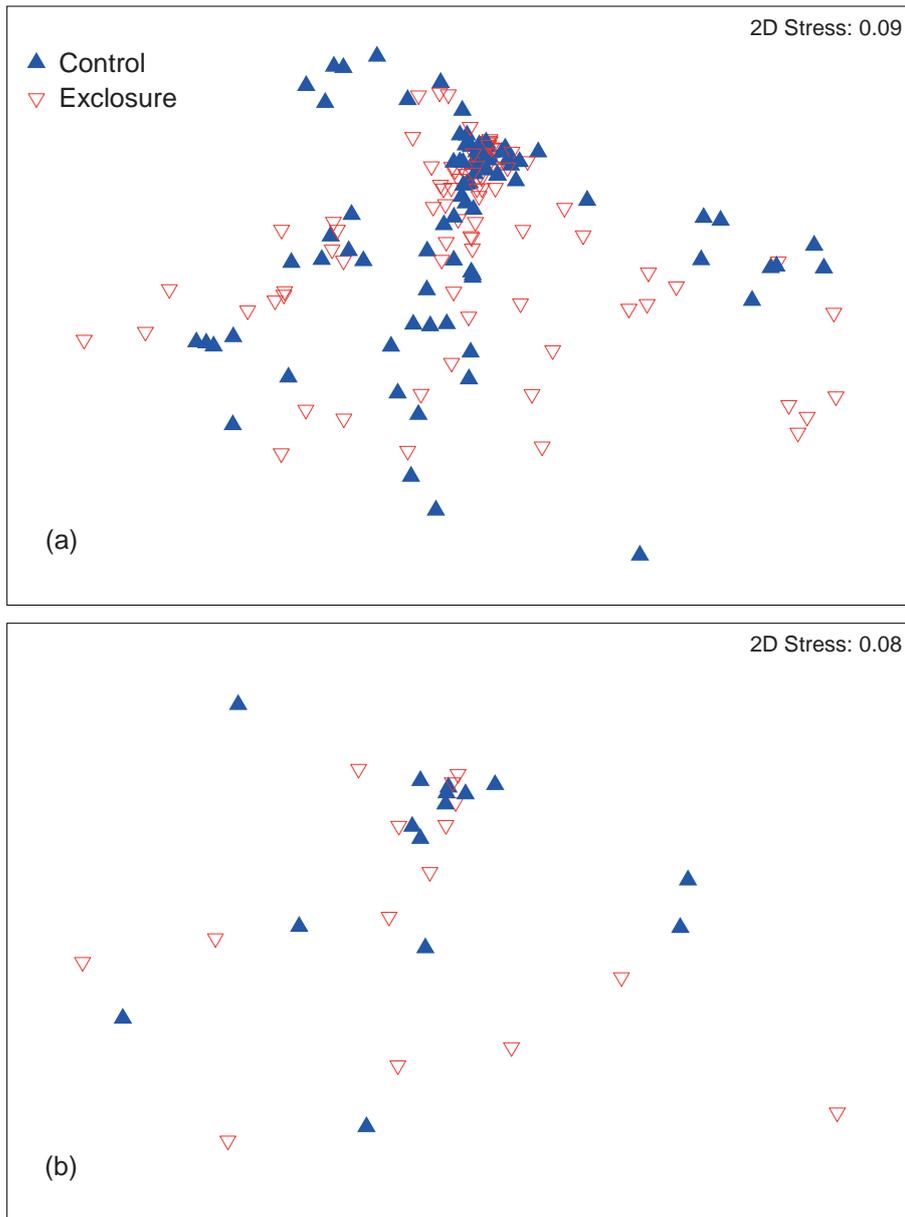
**Figure 25. Two-dimensional n-MDS comparing functional traits as measured by community trait-weighted means** (normalised, Euclidian distances) for Exclosures and Control quadrats sampled over (a) 6 years and (b) just in 2010 after 6 years of excluding hares. Functional traits were average canopy height, leaf area, % leaf dry matter content and specific leaf area within each quadrat weighted by the relative cover of the species.

9. DISCUSSION

9.1 Importance of functional traits and functional diversity

The results presented in this report provided important insights into the response of the alpine flora to climate change and related threats. We collected 11,800 new records of individual traits for 220 species, conducted analyses of existing datasets consisting of ~35,000 records of individual species presence/absence and % cover, and then compared 2,200 measures of functional traits per species with over 2,600 estimates of functional diversity for individual quadrats/plots. The analysis of composition data provide information about how this flora respond to changes in abiotic and biotic conditions. This includes changes in species, growth forms and communities in response climatic gradients (Section 6, Venn et al. 2001; Venn et al. 2012; Venn et al. In review), fire (Section 7, Butler & Pickering In review, Butler et al. In prep) and grazing by introduced animals (Section 8, Green & Pickering In press).

Functional trait analysis complemented and expanded on the analyses of changes in the distribution of species and growth forms and changes in composition by explaining why changes occurred. As discussed in Section 4, plants response to climate change and disturbance depends on how they function within their communities and interact with other species. Functional traits are characteristics of plants that reflect adaptations to specific environmental and biotic conditions and trade-offs in these functions. They can reflect trade-offs between adaptions to stress, disturbance and competition. Therefore they increase our understanding of how best to increase the resilience of the alpine flora to changes in climate (reduced environmental stress and potentially increased competition), increased fires (increased disturbance and reduced competition at least in the short term) and grazing (increased disturbance and reduced competition). In this report we have summarized patterns and directional changes in functional traits and functional diversity for the Kosciuszko alpine area in response to these threats.

A functional trait analysis of the Kosciuszko alpine flora was only possible because:

1. there are relatively detailed climate change predictions for the region,
2. the flora is well described,
3. there are clear links between climate and plant species distributions and abundance,
4. a range of secondary effects of climate change involving the amplifying existing threats have been identified,
5. large vegetation composition datasets were available to the authors that could be used to actually test the responses of species and communities to changes in climate and disturbance regimes.

Therefore, the functional trait analysis summarised in this report provides an important opportunity to test the benefits of using this approach to assess climate change risk and impacts for a specific region. It helps determine if functional trait analysis should be applied more broadly to assess climate change threats in other regions of Australia. The results obtained for the Kosciuszko alpine area demonstrated that trait analysis not only provided new insights into the ecology of the region, but also have important practical benefits in refining adaptation strategies.

Within increasing use of functional traits globally, we were able to may predictions at the outset (Section 4) about the response of the Kosciuszko alpine flora based on recent reviews of the association between particularly plant traits and different types of disturbance such as grazing, fire and trampling (Diaz et al. 2007; Cornelissen et al. 2003; Bernhardt-Romermann et al. 2011), climatic stress (Westoby et al. 2002; Cornelissen et al. 2003) and competition (Westoby et al. 2002; Cornelissen et al. 2003). Some of these predictions were born out by the analysis for the functional trait data for the Kosciuszko alpine flora. In other cases, however, the predictions did not match what was found in recent reviews due to distinctive features of the Australian flora.

9.2 Some results matched predictions

We found that there are functional groups among the alpine flora: that is groups of plants that differ in traits in such a way that predictions can be made about how they are likely to respond to climate change. The key functional groups for the alpine flora appear to be growth forms (Table 14). The alpine shrubs, herbs and graminoids, have different combinations of functional traits, which affect how they respond to changes in climate, fire and grazing.

We found we could make accurate predict changes for one of the four functional traits from the outset. We found that plant height, which is seen as a measure of species overall completive ability increased in situations where there was likely to be increased competition among plants. We found that, as predicted, warmer conditions (lower altitudes/longer growing season) results in increased dominance of taller species, including shrubs that are likely to be at a competitive advantage. The recovery of vegetation after fire, also involved an increasing dominance of taller species in the windswept feldmark as the vegetation recovers and hence competition increases (Table 16, Section 7). Similarly, as the vegetation recovered from cattle grazing, there was an increasing dominance of tall vegetation, as predicted (Table 16).

Table 14. General differences found in plant functional traits among the three main growth forms indicating that they respond as functional types (Section 5).

	Herbs	Graminoids	Shrubs
Plant height	smaller	smaller	taller
Leaf area	larger	larger	smaller
Leaf dry matter content	low	moderate	higher
Specific leaf area	larger	larger	smaller

As predicted, we found that shrubs appear to benefit from warmer, more favourable conditions, providing additional evidence to support previous predictions that heaths are likely to expand into areas of tall alpine herbfield with climate warming. We also found as predicted in the past, that shrubs are slow to recover from fire, and so fire favours herbs and graminoids at least in the short term.

The results also demonstrate how, and why, two of the rarest plant communities in Australia are threatened by climate change. For short alpine herbfield the threat is declining snow cover resulting in the colonization of snowpatches by more competitive, taller alpine herbfield species. In the snowpatches, which contain only a few shrub species, our predictions matched results, with plants with bigger leaves and hence capable of acquiring resources faster, increasing with longer growing seasons (Section 6.3, Venn et al. 2011). For windswept feldmark, it is the impact of fire which causes dramatic changes in composition at least in the short (<10 years) term.

9.3 Some results were different to those predicted

We found that the patterns for leave size, leaf dry matter content and SLA patterns often did not match predictions, partly due to shrubs having small tough leaves than herbs and graminoids (Table14) the reverse of the pattern found in many other ecosystems (Table 15). Small tough leaves are considered to be an adaptation to high stress environments, with these types of leaves tending to be more resistant to physical stress including grazing and trampling, but are also negatively correlated with growth rates, and so less competitive. Therefore, we predicted that in conditions where competitive species would have the advantage, there would be an increase in the dominance of species with large, soft leaves. Instead we found that the functional diversity for leaf size sometimes declined with warmer conditions (lower altitude

sites) due to the increased dominance of shrubs over herbs and graminoids (Section 6.2, Table 15).

Results for recovery from fire were mixed, with either recovering vegetation having larger leaves than unburnt vegetation (windswept feldmark), or leaf size declining, which contradicted predictions (Section 7). However, this was not due to an increasing dominance of shrubs; with shrub cover still very low nine years post fire (Butler & Pickering In review). The dominance of species with larger leaves increased as vegetation recovered from grazing, which was as predicted.

The 21 species of herbs and graminoids that are endemic to just the Kosciusko alpine area are a particular focus for conservation with regard to climate change (Pickering et al. 2004; Pickering et al. 2012). We predicted that they may form a discrete functional group characterise by shorter species with small tough leaves reflecting adaptations to low temperatures and the short growing seasons of the alpine area. Instead we found that there were considerable variations in traits within this group, indicating that these species are unlikely to all respond in similar way to changes in climate, and disturbance: that is they are not a single functional group. It may be that some of the taller, large leaved Kosciuszko endemics such as *Ranunculus anemoneus* (Anemone Buttercup) and *Chionochloa frigida* (Ribbony Grass) will actually increase in abundance and expand their distribution, or at least their distributions many not contract, with climate warming. The distribution of both species has expanded since cattle grazing ceased. In contrast some endemics such as the small herbs *Euphrasia alsa, Erigeron setosus, Ranunculus dissectifolius* and *Euphrasia collina* subsp. *glacialis* may be over grown by taller competitive species that can acquire resources faster as climatic conditions warm.

We had also expected that the alpine weeds would form a discrete functional group characterised by species with highly competitive traits including large soft leaves. Instead we found that the alpine also varied in functional traits, with some having more conservative traits (small tough leaves) and others more acquisitive traits (large soft leaves). In contrast it does appears that there are important trait differences between the weeds common in the alpine areas and the weeds that are rare in the alpine but dominate disturbed subalpine areas (Section 4). For example, all but one of the alpine weeds are perennial while many of the subalpine weeds are annual. It may be that the alpine weeds currently found in the alpine area are a different functional group to the subalpine weeds that with warmer climatic conditions and increases in other types of disturbances, subalpine weeds that have acquisitive traits might expand their distribution into the alpine zone. Increased disturbance will tend to favour many weed species including those associated with tourism use of the region (Johnston & Pickering 2001; McDougall et al. 2005; Bear et al. 2006; Pickering & Hill 2007; Mallan-Cooper & Pickering 2008).

Table 15. Predicted and actual patterns of functional diversity in relation to warmer growing conditions (Section 6, Venn et al. 2011, Venn et al. in review), recovery from fire (Section 6, Butler et al. in prep), and grazing (Section 8). TAH = Tall alpine herbfield. High flat arrows represent no change over time, but higher values than in the unburnt control plots. Predicted patterns are based on the results of recent reviews of functional trait responses from other ecosystems (Westoby et al. 2002; Cornelissen et al. 2003; Diaz et al. 2007; Bernhardt-Romermann et al. 2011).

	Warming climate				Recovery from fire			Grazing		
	Predicted	Short term	GLORIA	Snowbank	Predicted	Actual in Feldmark	Actual in TAH	Predicted	Actual cattle	Actual hare
Plant height	←	no effect	↔	←	↔	←	↑	←	←	no effect
Leaf area	←	no effect	→	←	↔	↑	⊢⊣	←	←	no effect
Leaf dry matter content	→	no effect	←	NA	→	←		→	→	no effect
Specific leaf area	←	no effect	→	NA	←	←	↑	←	←	no effect

9.4   *Management implications from functional diversity analyses*

The results obtained in this study help to explain what changes are occurring and why in the alpine flora in response to changing climatic conditions and disturbance. They have provided new insights into management of the region in the face of multiple threats. Mainly they have highlight that many current management actions already being discussed and implemented for this region are important, but even more so than we realised before. This includes the importance of managing fire, weeds, grazing by feral animals and other threats.

Fire: The results provide even more support for the importance of managing frequent intensive fires in alpine and sub-alpine areas. This includes managing wildfires, but also ensuring that controlled fires do not extend into the alpine (Williams et al. 2006, 2008; Section 7). Fire in the Kosciuszko alpine area has dramatic impacts in terms of vegetation cover, biomass and the composition of plant communities, as the recovery after fire of some alpine plant communities is likely to take many decades (Williams et al. 2008; Section 7). This is particularly the case for communities dominated by shrub species that do not appear to survive fire, and hence regenerate slowly from seed post fire. Therefore, in sites with slow-growing species and where shrubs appear to facilitate other species such as the windswept feldmark, it is possible that at least in the shorter term, burnt feldmark will be colonised by tall alpine species with functional traits similar to unburnt feldmark, and not feldmark species (Section 7). Therefore repeat fires may even permanently change the composition and reduce the distribution of one of the highest (in altitude) and rarest plant communities in Australia.

Weeds: The control of weeds is important, with the potential that weeds will increase in diversity, distribution and abundance with climate change and related threats. We have found that alpine and subalpine weeds differ in some traits, but that alpine weeds have traits similar to many native alpine species. As climatic and disturbance regimes change, the alpine zone might be colonised by more resource acquisitive weed species currently more common in the subalpine. Managing weeds involves minimising propagule pressure, minimising disturbances that favour weeds and controlling weeds that have become established. This remains challenging and costly for the Kosciuszko alpine area and other high altitude parks (McDougall et al. 2005; McDougall et al. 2010).

Feral Animals: We documented that some types of disturbance are not as important currently as others. For example, grazing by hares does not appear to affect the composition of tall alpine herbfields even if they may be affecting individual species (Green & Pickering In press, Section 8.2). Therefore they are not as great a management priority as the control of other feral animals. In contrast, the impacts of larger hard hooved introduced mammals on vegetation are severe, as has repeatedly been demonstrated including in this project. Australian alpine areas have low tolerance to trampling and grazing by these types of animals, and recovery takes decades (Section 8; Costin 1954; 1958; Costin et al. 2000, Scherrer 2003).

Other challenges: It is possible that grazing by larger native mammals in the alpine area, such as wallabies, may occur in the future where they expand their range into higher areas as conditions become more tolerable. Management of the impacts of grazing by these species is a challenge, especially if they selectively browse on the most palatable alpine species such as the endemics Anemone Buttercup *Ranunculus anemoneus* and Ribbony Grass, *Chionochloa frigida* that were selectively grazed by cattle in the past. Management options for these and other examples of range of expansion of native species with climate will often be difficult.

Tourism has a range of impacts on the alpine flora including contributing to the spread of weeds, damage vegetation and other impacts (Section 2 and 3). Although a functional analysis of the impacts of different recreational activities was undertaken as part of this study, it had to be removed from this report due to space and time limitations. The trait analysis highlighted, that trampling by hikers and other recreational activities changes the dominance of different species, depending on their traits. Managing increased tourism use of the region

remains an important challenge for park agencies, particularly if summer tourism is promoted as an adaption strategy to the local tourism industry to deal with climate change.

10 KNOWLEDGE GAPS AND FUTURE RESEARCH DIRECTIONS

The use of plant functional trait analyses is still comparatively rare in Australia, in part due to the absence of large publically available databases of plant traits like those available online for Europe such as the BiolFlor, CLOPA and LEDA databases. As a result, those undertaking functional trait analyses in Australia have often collected data for as many species as possible within a region. This is expensive in terms of time and resources, particularly for highly diverse ecosystems. As mentioned earlier, data for traits such as flowering start and flowering period are not readily available from herbaria and other long term natural history sources in Australia, unlike in some other parts of the world. Therefore, establishing trait datasets for regional floras should be a priority for ecosystems in Australia. Here, we have contributed to this process by obtaining functional trait data for 220 species, including more than 75% of the Kosciuszko alpine flora.

Using functional traits for the alpine flora provides important information for understanding how this important ecosystem functions, including responses to climate change and other related threats. Although having contributed to our understanding of key ecological process, there remain important knowledge gaps that should be addressed by future research including:

1. The specific role of shrubs in driving vegetation changes in relation to climate change.
2. More research on the impacts of fire and recovery from fire, including longer term studies to assess if shrubs do recover and how their recovery affects functional diversity. In particular longer term monitoring of the windswept feldmark should be undertaken to see if they continue to homogenise in composition with tall alpine herbfield, or if, over time the dominant shrubs (*Epacris* species) return.
3. Collecting data on other traits including traits related to reproductive success, such as seed size and seed mass which will provide additional insights into this ecosystem.
4. Further research assessing and comparing traits of weed species to better understand current limits on their distribution including if climate and/or other factors are important.
5. Longer term monitoring of changes in composition and traits of snowpatch communities, as they appear to be particularly vulnerable to climate change and are already in decline.
6. More detailed analysis of the traits of endemic plants to better understand why their distributions is currently limited to this alpine area and how they may respond to climate change.

11 CONCLUSIONS

This study has provided new insights into ecological processes in this high conservation region including how the flora responds to environmental/climate gradients and different types of disturbance. It allows us to refine management priorities based on an increased understanding of how and why the flora responds to climate and disturbance. It also highlights the complexity and limits of our knowledge about even this comparatively well researched high conservation region, including how it is already responding to climate change and associated impacts and how climate change will fundamentally alter it within a few decades.

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