Australian alpine plant research, conservation and management

Report of a symposium on Australian alpine plant research, conservation and management
Australian National Botanic Gardens 12 June 2014

Including findings of an Australian Research Council Linkage Project
Australian alpine seed ecology: plant conservation and adaptation to climate change

AUSTRALIAN NATIONAL BOTANIC GARDENS

Australian National University

Friends of the Australian National Botanic Gardens

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Her Excellency Lady Cosgrove
Patron, Friends of the ANBG

It is my pleasure to introduce this special report, which brings together a summary of the findings of the *Alpine Project*. This project involved a major contribution from the Friends, who provided significant funding and in-kind support along with the ANU, the ANBG and the University of Queensland. Five years of work culminated with the 12 June symposium held at the ANBG. The discussions highlighted the benefits gained from the engagement of community organisations such as the Friends in this vital research. I am confident that the report of the symposium will be a useful reference point for future assessment and research on Australia's unique alpine flora.

Contents

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A copy of this report can be downloaded at http:friendsanbg.org.au/newsletter

Front cover: Kosciuszko National Park. Photo Roger Good collection

The Friends of the Australian National Botanic Gardens (ANBG) are making available this report, of a symposium held at the ANBG in June 2014, on *Australian alpine plant research, conservation and management* for all with an interest in Australian alpine regions. The report includes findings of the Australian Research Council (ARC) Linkage Project *Australian alpine seed ecology: plant conservation and adaptation to climate change*, in which the Friends partnered with the ANBG, the Australian National University (ANU) and the University of Queensland to secure the ARC grant. The report has been compiled and edited by Roger Good, Lydia Guja, Kristiane Herrmann and Adrienne Nicotra.

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Summary

Alpine areas occur in the Australian Capital Territory (ACT), New South Wales (NSW), Victoria and Tasmania (including sub-Antarctic Islands). They have diverse biota and landscapes and major catchments from which the Australian economy, communities and the environment derive significant benefits. In recognition of their national importance mainland alpine regions have been heritage listed. Inter-state collaborative management was established in 1986 for Australian Alps national parks.

This summary and the papers in this report describe Australian alpine research activities covered through a symposium on Australian alpine plant research, conservation and management held at the Australian National Botanic Gardens (ANBG) on 12 June 2014, attended by personnel from Government agencies, research institutions and community groups.

The importance of alpine plants and vegetation cover

Plants are a critical component of the natural values of Australian alpine areas and ecosystems. Changes in vegetation cover have implications for ecological communities and activities dependent on healthy and functioning alpine ecosystems especially through effects on soils, water quality and yield. Alpine sphagnum bogs and associated fens, for example, are a vital alpine ecosystem, already endangered and the focus of special research and ecological restoration efforts.

Alpine plants and ecosystems can be adversely affected by periodic events such as drought, bushfire and changes in snow regime and are threatened by forecast long-term increases in ambient temperatures. Knowledge about how plants recover in their natural environment after periodic events and their adaptive capacity to tolerate or respond to predicted long-term temperature increases is integral to effective conservation and management of alpine areas, including ecological restoration.

Alpine plant research and findings

Ecological research in Australian alpine areas has a long history, dating back to the late 1800s. The first long-term ecological monitoring plots were established in the 1950s. These together with new plots provide empirical evidence of vegetation cover changes already occurring in Australian alpine regions as a response to climate change and seasonal drift.

The research reported here covers factors affecting Australian alpine plants, alpine ecosystems and their components. Weather, soils, animals and insects, as well as threats to and impacts on alpine ecosystems from fire, feral animals, weeds and pathogens are addressed. Future collaborative directions are outlined. Future planned research includes an increasing focus on threatened ecosystems, species' seed traits, phenology, the distribution of genetic variation within species, species resistance to increases in ultraviolet radiation and effects of changing snow depth and distribution.

To examine vegetation changes in the context of predicted increases in temperature from a changing climate, a major Australian National University (ANU), ANBG and University of Queensland (UQ) collaborative research project on alpine seed and seedling ecology commenced in 2009 through a research grant from the Australian Research Council (ARC) and with support from the Friends of the ANBG. Also described as the *Alpine Project* in this report, this alpine seed ecology research program has examined many species of alpine plants and, using both controlled laboratory and field experiments, has assessed how conditions such as temperature, soil, elevation and snow cover affect seed germination and seedling survival. The findings indicate significant differences in responses to temperature both between species and among populations within species and suggest that with increases in temperature there will be changes in the composition of alpine plant species and cover. These changes are, in part due to differences in how seeds germinate from the soil seed bank and the different adaptive capacities of key plants to increased temperatures. Researchers suggest and outline features for development of a scientific risk assessment framework based on plant resilience and adaptive capacity considerations such as those examined in the *Alpine Project*. The objective of this framework is to help inform future alpine plant management, conservation and ecological restoration work through practical and cost effective measures.

Other current research has found the long-term survival of plants with limited distribution and high conservation value in snowpatch and sphagnum mire areas is threatened by competition from, and colonisation by, other alpine species that have a competitive advantage in the changed environmental conditions. Pressure also exists on endemic alpine plant species from grazing and associated soil disturbance by domestic and feral animals. More intense and frequent climate change induced fire events change regrowth patterns, vegetation cover and composition and adversely impact catchment hydrology and unique systems such as alpine sphagnum bogs and associated fens. There is increasing intrusion of weeds along roads and walking tracks and in other disturbed sites and the introduction and spread of pathogens are threatening the long-term survival of alpine species and resulting in vegetation changes.

Plant conservation, collaboration and future directions

Botanic gardens and associated seed banks and herbaria play an essential role in the conservation of and ecological research into alpine plants and in developing resilient alpine plant communities. Seed collection for long-term *ex situ* conservation and for research into seed and seedling viability, seed and seedling characteristics and genetic structure plays a vital 'insurance' role for alpine plants, and potentially for future ecological restoration work. Collaborations such as those established under the Australian Seed Bank Partnership, through the *Alpine Projec*t, current work on sphagnum bogs and associated fens and innovative initiatives such as *Bush Blitz,* are enabling Australian researchers, conservation and land management agencies to significantly increase Australian alpine seed conservation collections in seed banks. However further targetted work and collections are required to represent more adequately species and species level genetic variation in collections, especially of foundation species likely to be threatened by rising temperatures.

The importance of strong and effective partnerships in achieving scientific, conservation, industry and community engagement is being demonstrated through research activities at many levels, including through funding and volunteer participation such as under the *Alpine Project* and *Bush Blitz*. Although there is already good communication and collaboration among various groups of stakeholders, there is an identified need to strengthen links and communication between different interest groups, even at a local level. Land managers and other decision makers have to balance competing demands and priorities in alpine areas. Science has an important role in informing decisions but needs to be communicated effectively if it is to influence practical policy decisions and management actions and to build trust for decision making within regulatory frameworks.

At the local level, opening up new lines of communication among different alpine stakeholder groups will facilitate broader application of conservation objectives and innovative ecological restoration techniques in alpine areas.

Every opportunity needs to be taken for seed collection to help maintain the genetic diversity of plants and provide seed stock for ecological restoration work. For example, by working together conservation, development, resort and utility interests can take advantage of opportunities for larger scale local seed collection and innovative restoration work when regulatory land development is undertaken.

Researchers have emphasized the importance of maintaining and expanding the network of alpine monitoring plots as part of ongoing Australian ecological research on alpine plants to further understand and contribute to ecological restoration activities. Researchers in Tasmania and the mainland alps are participating in international studies, such as the International Tundra Experiment and the Global Observation Research Initiative in Alpine Environments, which are examining plant responses to increases in temperature through internationally established and standardised monitoring field work.

Symposium presenters and panellists (left to right). Back row: Adam Millar, Dick Williams, Roger Good, Susanna Venn, Bindi Vanzella, Deborah Segal, Veronica Briceño, Lydia Guja, Annisa Satyanti, Catherine Pickering, Ary Hoffmann, Anthony Evans.
Front row: John Morgan, Jennie Whinam, Judy West, Adrienne Nicotra, David Coutts, Stuart Johnston. Photo Tobias Hayashi

Alpine seed and plant ecology in Australian alps

Judy West

It was timely in June 2014 to consider activities relating to research of Australia's alpine flora and vegetation communities. I had the privilege to welcome a range of participants with diverse interests to a symposium covering alpine research, conservation and management. Adrienne Nicotra of the ANU had the vision to bring together researchers, industry representatives and conservation, restoration and management practitioners to consider ecological research activities of the past, current approaches to understanding the complexities of our alpine ecosystems, and to look to the future and scan the research and land management horizons, particularly given changing environmental conditions.

It was particularly useful for the ANBG to consider, in the broader context of alpine research in Australia, the outcomes of recent participation in the alpine seed and seedling ecology research project. For the ANBG, the *Alpine Project* provided a welcome stimulus to our alpine seed collecting, and the seed biology research conducted in the Gardens. The collaboration of the ANU, UQ, ANBG and Friends of the ANBG over the past five years has involved ANU researchers and students, and Gardens staff and Friends working together in the field, in the laboratories and in the National Seed Bank.

Such collaborative efforts often enhance capability while also resulting in other benefits, particularly of a social nature. The interactions developed during the *Alpine Project* built productive working relationships, with sharing and exchange of experience and skills providing long-term benefits for each of the partner organisations. Students and volunteers gained skills in seed collecting, processing of collections, development of laboratory experiments and an understanding of the importance of accurate data recording. ANBG staff with expertise in the alpine flora were able to familiarise others with species identification, and horticultural staff were exposed to more ecologically oriented field studies.

Further, the project indirectly contributed significantly to the diversity and quantity of seed of alpine species incorporated into the National Seed Bank collection. These recent, well-documented alpine seed collections will form the basis of ongoing collaborative research into seed biology and functional ecology of key species of our alpine and subalpine vegetation communities.

The symposium sought to steer the future direction of alpine plant research in Australia by drawing on the expertise of a diverse group. This special report is a fitting way to capture the significant outcomes of what was a productive and stimulating day.

Dr Judy West is the Executive Director of the ANBG and Assistant Secretary, Parks Island and Biodiversity Science in Parks Australia, which entails oversight of the science and natural resource management activities undertaken in the Commonwealth National Parks. Her scientific expertise is in plant systematics and phylogenetics, biodiversity informatics and conservation biology.

Engagement of the ANBG Friends with alpine seed ecology

David Coutts

The Friends of the ANBG are a volunteer group of over 1,800 members dedicated to supporting the ANBG. The Friends make contributions toward conservation and display of the living collection, research on native plants, education of the community, promotion of continuing development of the ANBG and raising funds for ANBG projects. The Friends also provide volunteers for a range of projects and activities, funding for projects and help leverage other resources for such projects.

In recent years the Friends have given priority to supporting research projects in and involving the Gardens. When the chance arose to support the ANBG and the ANU work on alpine seed and seedling ecology through an ARC grant, we immediately saw it as an exciting opportunity and understood our involvement was crucial in securing ARC funding. This project harmonised with our long-term priorities, including establishing ANBG as a major centre for alpine plant research, an enhanced role for the ANBG seed bank and a focus on educating the community about the importance of Australian alpine flora, especially in the context of climate change.

The Friends contributed $66,000 over three years to this cause which was, by far, the largest financial commitment made by the Friends to a single project. Some of this funding was used to upgrade the facilities of the ANBG seed bank and thus have a wider and ongoing application. In addition, a number of Friends have contributed their time and expertise to the project, through assisting with seed collecting in the Alps, working in the seed bank and liaising with researchers on the overall objectives and progress of the project.

We have been pleased to see the wide range of research papers that have been published to date as a result of this project. We remain committed to the establishment of a permanent display and information centre for alpine flora at the ANBG and the wider use of information gleaned from this work to raising awareness of the threats to Australian alpine flora. We will also look closely at participating in any continuing alpine research that is proposed, particularly that which directly supports the ANBG.

David Coutts has been on the Friends Council since 2007 and President since 2011. He trained as an agricultural scientist and worked for the Commonwealth on agricultural policy and trade, for the OECD Directorate of Agriculture in Paris, and as Australia's representative to the UN FAO Council in Rome. He has a particular interest in furthering research programs at the ANBG.

History of Australian alpine ecology research

Roger Good

Ecological research in the mainland alps could be considered to have commenced in the late 1800s with people such as the botanists Baron Ferdinand von Mueller, John Maiden and Richard Helms. These researchers recorded very graphically their concerns for the degradation of the vegetation and soils of the subalpine and alpine zones of the Snowy Mountains as a result of the many years of domestic stock grazing. Unfortunately this early observation and their concerns for the degradation of high mountain catchments were not heeded by the Government or any land management agency until some 40 years later when Baldur Byles and Dr Lane Poole carried out a survey of the forest resources of the mountains. The Byles report on this survey noted the extreme and continuing decline of the alpine vegetation and the massive loss of organic soils from the alpine catchments. The Byles report can arguably be considered to have initiated alpine ecological research in the Snowy Mountains and this research was given support by the Snowy Mountains Hydroelectric Authority (SMHA) that viewed the impacts of snow lease grazing as detrimental to the efficient functioning of the hydroelectric scheme. The SMHA established its own research and soil conservation sections with notable research personnel such Marie (Betty) Phillips and Raeder-Roitzsch. They undertook many vegetation surveys and research projects and worked with Alec Costin and Dane Wimbush of the then Commonwealth Scientific and Industrial Research Organisation (CSIRO) Alpine Ecology Unit.

It was the latter two CSIRO researchers that established the many vegetation, soils and catchment study sites in the mountains and are recognised as being the founders of alpine research in the Snowy Mountains in NSW. Alec Costin's book *Ecosystems of the Monaro* (first published in 1954) remains as the classic ecological resource text while the many Costin and Wimbush published scientific and technical papers have been the baseline data for mountain research, conservation management, ecosystem restoration and flora studies over the past 50 to 60 years.

Costin and Wimbush studies

Costin and Wimbush also established a number of research sites to study the impacts of tree loss on catchment water yields and the benefits of replanting subalpine woodlands where they had been destroyed by high frequency bushfires and grazing. Their work led to a number of ecological research projects focused on catchment restoration and restoration techniques, particularly for the extensive alpine herbfields and mires (peat bogs and fens). These studies contributed to the decision by the NSW State Government in the late 1950s, to remove grazing from the Kosciuszko high country and the commencement of the widely acknowledged Summit Area Works Program by the NSW Soil Conservation Service (SCS). This program of alpine ecosystem restoration involved an expenditure in the order of \$10-\$12m (in today's terms) and was supported by specific soil and vegetation research that was directly applied during the course of the restoration works. While acknowledged as a great success story, the restoration program raised many questions regarding the improvement of restoration of alpine ecosystems in the future. A number of these have been addressed over the past 40 years, including native species suitability for use in restoration works; organic soils (alpine humus soils) and plant nutrition; the use of mulches and mulching rates, and the impacts of zinc toxicity from galvanised wire used in restoration.

Alpine plant studies

Early plant species studies were a collaboration between the ANBG, CSIRO and the NSW SCS. However, at the conclusion of the collaborative program in the mid-1970s much of the planned research program still remained to be addressed. In the early 2000s the research on aspects of plant ecology, restoration and predicted climate change impacts was once again initiated. The widespread 2003 wildfires across the mainland alps also provided an impetus to, and initiated, a number of research projects related to native plant ecology, including seed germination, and post-fire restoration, particularly that of bogs and fens.

Severely eroded subalpine woodland after fire and grazing in the 1960s.

The same subalpine woodland site as in the photo above, demonstrating vegetation recovery in 1972 following long-term restoration work.

Kosciuszko Summit area soil and vegetation restoration works. Left, site at commencement of works in the 1960s, right the same site in 1972.
All photos in this paper Roger Good collection

The *Alpine Project* on seed and seedling ecology collaborative research (established in 2009) is investigating herbfield plant phenology, seed germination and seedling growth traits to support more effective use of native species in *in situ* restoration and *ex situ* conservation programs. The program is being led and coordinated by Adrienne Nicotra (ANU), with the seed collecting undertaken by ANBG staff and ANU researchers, with field assistance from the Friends of ANBG. The seed collecting and horticultural aspects of the project are being led by Joe McAuliffe of the ANBG. Plants grown as part of the seed ecology research program are being planted in an alpine plant display in the ANBG.

Over the years alpine research in NSW has been very much paralleled in the Victorian high country, initially by Maisie Fawcett Carr and her research associates and students, while in Tasmania alpine ecological research has been undertaken by Bill Jackson, Jamie Kirkpatrick and, fellow research associates. Maisie Carr's work in particular has contributed to our understanding of alpine ecosystems, with the alpine vegetation exclusion sites established in the 1940s, being a significant legacy for current and future research staff. The 'Maisie Carr' exclusion plots remain to this day and are the longest continuously monitored vegetation plots in the mountains.

Severely eroded and dry sphagnum bog during the 1960s.

The same sphagnum bog as in the photo above, demonstrating recovery in 1972 following long-term restoration work.

The early alpine research of Costin, Wimbush, Carr, Jackson and their fellow research associates has been a motivation for many notable alpine scientists over the past 60 years and underpins much of the current research.

Roger Good is currently a visiting fellow, Fenner School of Environment ANU and research associate ANBG. His career has spanned more than 40 years in NSW Government in the NSW SCS and National Parks and Wildlife Service including research, management and ecological restoration programs in Kosciuszko National Park. He has special research interests in alpine vegetation ecology, soils, and climate change impacts, particularly that of ultra-violet light on plant adaptation and resilience.

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The role of botanic gardens in Australian alpine plant *ex situ* conservation, research and restoration

Lydia Guja, Cathy Offord, Neville Walsh

Role of botanic gardens

Botanic gardens are extremely diverse institutions involved in horticulture, education and community engagement. Many botanic gardens today focus on conservation of rare plants, plant biology research and the application of this research in the field. Conservation of rare species often involves storage of seed collections outside a threatened plant's natural habitat (that is *ex situ*) under specialised conditions to maintain long-term seed viability. *Ex situ* seed banks provide 'insurance' against extinction, and their conservation collections are used for plant research, restoration and translocation activities. Australian botanic gardens collaborate on many activities.

Ex situ seed banking

In the past decade seed banking for conservation has grown into an international endeavour. Australian institutions, including the National Seed Bank (NSB) at the ANBG, the Australian Plantbank (PlantBank) at The Australian Botanic Garden Mount Annan and the Victorian Conservation Seedbank have contributed many collections to initiatives such as the Millennium Seed Bank Partnership (http://www.kew.org/science-conservation/millennium-seed-bank).

The new Australian PlantBank facility at Mount Annan, NSW.
Photo Simone Cottrell © RBG Sydney

Seed banks build knowledge and expertise in a number of areas and their scientists undertake biological research on collections. Associated herbaria offer reciprocal benefits such as voucher specimen documentation, verification of species' identity and accumulation of plant distribution and ecology data that are made available via tools such as Australia's Virtual Herbarium. Seed banks also collect a variety of seed-related data including seed functional traits and seed germination requirements. There have been recent advances in database capability and accessibility through 'Australian Seed Bank Online' (http://asbp.ala.org.au/), an initiative of the Australian Seed Bank Partnership. This combines partners' data on seed collections. Capability is being developed to report results of germination tests.

Australian alpine seed conservation

Over the past 40 years several Australian seed banks have focused on collecting the unique flora of Australian alpine regions with the aim of protecting and better understanding the biology of Australian alpine seeds. Indeed, alpine seed collections and seed research are national priorities for the Australian Seed Bank Partnership.

Collectively the NSB, PlantBank, the Victorian Conservation Seedbank, and the Tasmanian Seed Conservation Centre hold 2218 collections of 618 alpine taxa under long term conservation conditions, sourced from wild alpine plant populations in NSW, the ACT, Victoria and Tasmania as shown on the map below.

The red dots on the map show the locations where seed has been collected from populations of wild alpine plants in Tasmanian and mainland alpine areas.

Well supported, targetted research and collaborative seed collection programs can significantly increase collections in *ex situ* storage in a relatively short period of time as demonstrated at the NSB. Alpine seed collections at the NSB have increased significantly since 2007 under collaborative arrangements involving ANBG staff, ANU staff and students, and volunteer seed collectors and seed cleaners from the Friends of ANBG. Of the 1409 seed collections made between 1973 and 2013 and held at the ANBG, 56% have been collected since 2007.

Extraordinary collecting opportunities

Seed collecting and conservation programs targeted at particular areas or plant communities generally support the conservation of many taxa, but may overlook ephemeral species which are often rare in time and space. To collect such species requires flexibility so that resources can be directed towards them if, and when, those species appear in the landscape. Having ongoing collection programs allows collectors to take advantage of rare germination-promoting events in the environment. For example, the Victorian Conservation Seedbank made opportunistic collections in the Victorian Alps after strong regeneration following alpine fires in 2003 and 2006. From this work they obtained seed of a range of rare fire-promoted species. These included species not previously recorded in the Victorian Alps, *Chenopodium erosum* (Papery Goosefoot), and previously uncommon *Drabastrum alpestre* (Mountain Cress) and *Pelargonium helmsii* (Alpine Stork's-bill). The seed collections from these species are valuable for both conservation and research.

Before fires in 2003 and 2006 no chenopods were known to occur in the Victorian Alps. Post-fire species such as *Chenopodium erosum* (pictured above) appeared in some areas and were locally common. This unusual occurrence allowed collection of seed for long-term *ex situ* conservation of a species rare in space and time. Photo © RBG Melbourne

Collecting approaches (which target communities and species), together with critical analysis of data (to identify gaps in collections) enable the building of collections that are representative of the alpine flora. On the mainland from among 1880 collections of 438 taxa, the most collected families are *Asteraceae* (daisies), *Ranunculaceae* (buttercups), *Cyperaceae* (sedges), *Apiaceae* (carrot family) and *Poaceae* (grasses). Further work should assess whether these collections are adequate (in size and quality) for long-term conservation, and representative (genetically, spatially and in species composition) of wild communities and populations.

Use of collections in research and for ecological restoration

Current seed biology research by botanic gardens includes understanding germination requirements of Australian alpine species to try to predict germination responses of alpine species generally and investigations of seed persistence and germination patterns in endangered alpine communities. Such considerations are important in determining the vulnerability of species, determining long term *ex situ* conservation and collection priorities and restoration and translocation activities.

Many Australian native seeds are difficult to germinate in the laboratory or nursery due to seed dormancy. Some seeds require cold stratification (chilling) before germination will occur. Scientists at PlantBank investigated 19 Australian high altitude species and found the seeds of each tested species had different responses to cold stratification (Sommerville et al. 2013). The biological structure of the seeds, species elevation, position and distribution are key factors in how plants fare with temperature changes.

A current ANBG research project involves understanding the germination ecology of species that occur in endangered '*Alpine Sphagnum Bogs and Associated Fens*' (Guja and Huttner-Koros 2013). These communities occupy only very small areas (average 0.5 ha each) of the Australian Alps, but are significant because they provide ecosystem services such as filtration of drinking water at catchment sources, and breeding habitat for critically endangered frogs.

These communities have experienced significant disturbance regimes through fires in 2003 and 2006. Research into effective restoration techniques has ensured their regeneration after fire (Hope et al. 2005). However, the current restoration practices rely on existing soil seed banks, and the persistence and dynamics of these soil seed banks remain unknown. As part of this research, ANBG scientists are testing whether seed persistence in the field is affected by substrate or seed characteristics such as size, shape, and dormancy or germination syndromes. Over time we will learn more about the germination strategies of alpine-peatland seeds, their persistence in the soil, and the environmental factors that drive germination. Ultimately, this knowledge can be applied to restoration and land management.

Understanding seed ecology and biology of wetland species also helps in restoration projects. This has been demonstrated successfully in Italy where effluent from an alpine 'rifugio' is being treated using indigenous wetland species, including familiar genera that occur in Australia such as *Rumex*, *Carex*, *Epilobium*, *Senecio*, and *Caltha*. Before growing plants for use in the ecological restoration germination optimisation was required for all species. Such approaches and knowledge can be applied in Australian alpine regions.

Dr Lydia Guja is Seed Conservation Biologist at the ANBG and the Centre for Australian National Biodiversity Research. She is interested in conservation biology, germination ecology and stress physiology of Australian native seeds, including Australian alpine flora.

Neville Walsh, Senior Conservation Botanist, Royal Botanic Gardens (RBG) Melbourne focuses on taxonomic research, botanical survey (particularly alpine/subalpine vegetation) and development of recovery strategies for threatened Victorian plants.

Dr Cathy Offord, is the Manager Horticultural Research, Royal Botanic Gardens and Domain Trust, NSW. Her research interests are germplasm, rare and threatened plants and communities conservation, seed biology, effects of climate change and other threats on NSW species, development of Australian plants for horticulture, and horticultural research.

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Australian alpine seed ecology: plant conservation and adaptation to climate change – ARC Linkage Project

Adrienne Nicotra, Gemma Hoyle, Kathryn Steadman, Roger Good

Since October 2009, the authors have had the pleasure of working together on this highly rewarding alpine seed and seedling project thanks to funding from the ARC and the Friends of the ANBG. The *Alpine Project* has involved a large and collaborative group of researchers, staff and volunteers from the ANU, UQ, ANBG and Friends of the ANBG and has received valuable assistance in the Alps by staff from the NSW Parks and Wildlife Service.

The project focused on alpine seeds and seedlings because seeds play a crucial role in alpine plant migration and response to disturbance and because most alpine species rely on seeds for dispersal and recruitment. There is little research on the ecology of alpine seeds and seedlings.

According to climate scientists, warming is occurring more rapidly in high, alpine areas than at lower elevations, putting pressure on alpine plants to shift distributions to cooler, wetter, often higher niches. Alpine plants have little opportunity to move to higher elevations, however, the alpine environment presents a mosaic of microclimates, leading to opportunities for differentiation in space and among populations of a given species.

The project has assessed germination strategies that exist among alpine seeds, variation in seed and seedling traits within species and along elevational gradients and the role of maternal environments in seed traits. In addition, the project examined the potential impacts of climate change on the ability of alpine plants to reproduce via seed. There also was a recognition of the need to widely communicate the results of this work to ANBG visitors, the broader community and to fellow researchers in Australia and overseas.

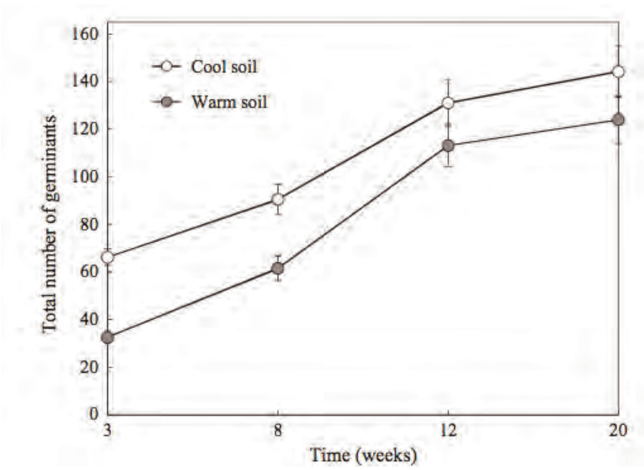

Figure 1 Total number of germinants from the alpine soil seed is depressed when soil is warmed to projected future conditions as compared to current, cooler conditions. Modified from Hoyle et al (2013) *Global Change Biology* with permission.

Alpine seed germination strategies

The investigations into the phenology of alpine seeds' germination revealed that roughly half of the 54 species studied dispersed dormant seeds, while seeds of the other half appeared ready to germinate immediately after dispersal. Interestingly, there were a range of 'staggered' germination strategies, namely seedlots in which some seeds germinated immediately while others postponed germination until the following growing season. Further research is needed to evaluate the advantages that different strategies bestow upon seedlings and to determine whether 'staggered' strategies reflect differences between seeds produced by different individual plants, or whether single plants produce seeds of multiple strategies.

The research also demonstrated that populations of a single species can vary markedly in germination characteristics, and that these differences seem to reflect both microsite differentiation and elevation.

Potential effects of climate change

Warming climates will be associated with earlier/longer growing seasons. Therefore the project examined how reduced duration of cold conditions will affect germination of a species that relies on winter temperatures for dormancy alleviation. Results to date suggest that, provided winter conditions continue to persist for five weeks or longer, germination of *Aciphylla glacialis* (Mountain Celery) will not be compromised. Whether or not this is true for other alpine species with physiological dormancy, is yet to be determined.

Shorter duration and depth of snow cover during winter mean that vegetation is exposed to freezing conditions where once they were insulated by the snow. *Aciphylla glacialis* seeds from populations that were exposed to early snow melt, and therefore severe early spring frosts, showed greater seedling resistance to freezing than those from populations where snow insulated the plants for longer. The early snow melt seedlings also demonstrated a greater ability to acclimate to cold.

The research also examined responses to warming, as predicted by climate models. Soil warming reduced germination from the alpine soil seed bank, but increased the diversity of species that did germinate (Figure 1). Warming may therefore have significant impacts on community composition as mediated by direct effects on germination from the soil seed bank. Finally, the research assessed whether there was any variation within species in response to a warming climate. *Wahlenbergia ceracea* (Waxy Bluebell) plants were grown from seed collected at low, mid, and

ANBG and ANU staff and researchers, students and volunteers at Kosciuszko National Park. Left and centre, alpine seed collecting in tall alpine herbfields; right, surveying their experiment sites on alpine plant response to warming. Left to right: Craig Cosgrove, Annette Harry, Mary Lovett, Joe McAuliffe, Roger Good, Nick Wilson, Tobias Hayashi, Sonya Geange, Adrienne Nicotra, Annisa Satyanti. Photos (left to right) Lydia Guja, Kristiane Herrmann, Tobias Hayashi

high elevation locations under cool and warm glasshouse conditions. The results indicate that low elevation plants had the greatest ability to increase growth when warmed. Among these low elevation plants, those that demonstrated the greatest plasticity (that is, ability to respond to warming), performed the best. In contrast, among the high elevation plants, those plants with the most plasticity performed worst. This indicates differentiation in evolutionary trajectories over very small geographical scales, meaning that efforts to use some of these species in conservation and restoration should take into account diversity of response within the species.

Further information on the *Alpine Project* and related seed and seedling ecology work is on the following two pages.

Summary

This brief overview of the approach and research findings for the *Alpine Project* demonstrates that a focus on seeds and seedlings yields much needed basic biological information that reveals not only species differences, but significant variation between populations from differing microclimates and among individuals within populations.

The approach taken benefitted from combining field, laboratory and glasshouse techniques to examine seeds and seedlings from ecological and physiological perspectives. Future work aims to extend research to better understanding mechanisms underlying variation within species to improve predictions about plant responses to climatic change. Doing so would provide important resources for conservation, ecological restoration and management.

It has not been difficult to find audiences for such interesting and timely scientific research on Australian alpine seed and seedlings. The *Alpine Project* findings have already been presented at national and international conferences and published in peer-reviewed scientific journal publications. Wider communication includes interviews on ABC radio, and updates through the ANBG Friends newsletters and the Australasian Network for Plant Conservation. The project team will continue to broaden communication of findings through further publications and through interpretive resources at ANBG.

Future directions

During the planning and implementation of the Alpine Project, it was recognised that the overall program should not only address the seed germination traits of the common alpine plant species but should address the ecology (including seed germination traits) of all alpine threatened species. This was recognised as necessary as predicted climate and weather changes were likely to increase the threat to their survival. The conservation of these species through *in situ* and *ex situ* research and management programs has been a priority for biodiversity conservation by the Inter-state Alps Cooperative Management Program for many years.

As part of the above program, our future ecological research on alpine plant species will be focused on plant response to climate change impacts (for example, rising temperature, climate variability and ultra-violet light levels). In particular we will seek correlates between plant traits and plasticity therein and vulnerability to climate change. We are establishing collaborative investigations of plant ecology under climate change at local and international levels but these will need to be supported financially and promoted to ensure that long-term studies are maintained for the benefit of our very small but internationally recognised alpine flora.

Adrienne Nicotra is Associate Professor and Future Fellow in the Research School of Biology at the ANU, researching responses of native plants to their environments.

Gemma Hoyle, an ARC & ANU Postdoctoral Fellow on the *Alpine Project,* is interested in the ecology and evolution of seed germination and dormancy strategies.

Associate Professor Kathryn Steadman from the UQ researches the biology and chemistry of plants, particularly seeds.

Roger Good is currently a visiting fellow, Fenner School of Environment ANU and research associate ANBG. Further details are in the earlier paper 'History of Australian alpine ecology research'.

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Winter is coming, and *Aciphylla glacialis* remembers

Verónica Briceño, Adrienne Nicotra

Snow has a very low thermal conductivity and protects alpine plants from winter frost damage, keeping them at warmer, more stable temperatures than if there were no snow. Future climate scenarios for alpine areas predict less snow cover and earlier snow melt; these changes will paradoxically expose plants to freezing damage.

It has been demonstrated that seedlings of the alpine herb *Aciphylla glacialis* originating from locations with early snowmelt have higher freezing resistance. Intracellular ice formation, which is lethal for plants, forms at much lower temperatures in early snowmelt plants compared to late. In addition, seedlings from early snowmelt origins have greater capacity to increase freezing resistance in response to low temperatures than seedlings from late snowmelt origins, when grown in common garden conditions. We assessed whether the same pattern occurs in adult plants living in early and late snowmelt sites. In addition, we examined whether differences in cold tolerance are related to specific microenvironment conditions (daily mean, maximum and minimum temperatures, freezing events and snow duration).

We found that adult plants from early snowmelt sites are exposed to more frequent and severe freezing events and are also more resistant to freezing. In addition, adult plants from early snowmelt sites have higher tolerance to dehydration induced by extracellular ice formation. Surprisingly, regression analysis showed that changes in freezing resistance are related to snow duration the previous winter. What causes this 'snow memory' needs further research. Early snowmelt and reduction of snow the previous winter might 'prepare' plants to cope with frequent and severe freezing events the subsequent winter.

Verónica F. Briceño in the field in the Snowy mountains. Veronica has recently completed her PhD in the ecology of the alpine plant *Aciphylla glacialis* as a member of the ANU Nicotra laboratory. She enjoyed 4 years of working in the Australian Alps and on her return to Chile will apply her Australian alpine study experiences to the Chilean Andes. Photo Verónica Briceño collection

Additional information

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Snow, shrub and climate feedbacks: impacts of shrub expansion in the Australian alpine zone

Susanna Venn

This project aims to understand the mechanisms promoting shrub expansion in alpine areas and the consequences of a shrub-dominated landscape; in terms of shrubs as hydrological mediators and as biodiversity and ecosystem modifiers. Some shrub species trap wind-blown snow, thereby facilitating seedling survival through soil insulation and increases to meltwater. However, if adaptive and plasticity responses to climate change allow, shrub expansion will have significant negative impacts on alpine biodiversity and ecosystem function, via several positive feedback loops. This project teases apart the interacting effects of snow, recruitment and adaptation to provide models of shrub increase and determine how shrubs modify alpine ecosystem processes and upper catchment hydrology. Field and laboratory techniques are used to test ecological theory and innovative tools, such as chlorophyll fluorometry, help to understand freezing resistance of species in relation to their current and potential landscape distributions. Identification of plant functional traits will help understand local ecosystem processes and determine species' roles (such as competitor) in future community assemblages.

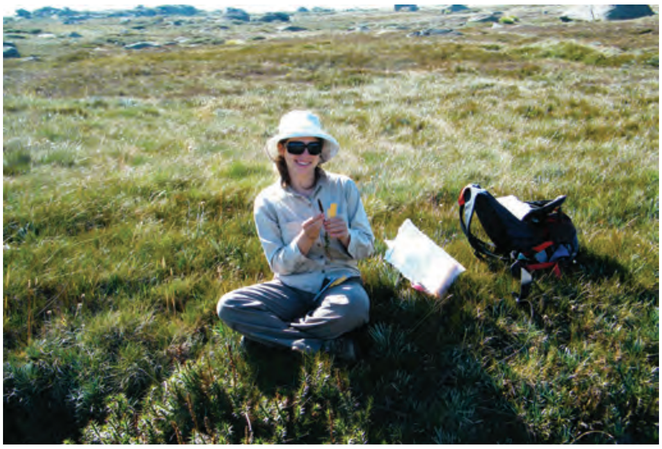
Dr Susanna Venn is a newly appointed ARC DECRA Fellow at ANU. Current research is focused on shrub propagation, regeneration and encroachment in alpine areas. Susanna has wide research interests from plant regeneration to ecosystem ecology; how environment influences plant community patterns, processes and community (re)assembly through species life-history and recruitment traits. Photo Susanna Venn collection

Elevation gradients in seed and vegetative traits in alpine plant species

Deborah Segal, Amy Davidson, Gemma Hoyle, Roger Good, Adrienne Nicotra

A changing climate requires an understanding of mechanisms that account for variation in plant traits. Demonstration of altitudinal gradients and commonalities across regional biomes will help to better understand species' range shifts in a future climate scenario.

Two distinct approaches were used to assess elevation variation in vegetative and reproductive traits in alpine species. The first focused on assessing changes in a broad range of traits of eight Australian alpine species that naturally occur along an elevation gradient. This found plant height to decrease and reproductive allocation patterns to change as elevation increased; plants generally produced fewer, heavier seeds at higher altitude. The second approach was a meta-analytical one, to assess global trends in a smaller set of vegetative and reproductive traits among plants along altitudinal gradients and to determine whether such relationships depended on select geographic factors. This analysis confirmed findings from the field study of decreasing plant height with altitude, however seed number was found to change significantly across gradients, whereas seed mass did not. Identifying and analysing the relationship between low and high altitude plants across a variety of scales will better direct conservation and management of sensitive alpine areas.



Deb Segal investigating trends in plant traits along an elevational gradient in the Australian Alps. Deb completed her Honours degree in alpine ecology at ANU, conducted research at CSIRO and is currently teaching secondary science (Sydney). Photo Deb Segal collection

Are Australian alpine seeds short-lived?

Annisa Satyanti, Lydia Guja, Adrienne Nicotra

Alpine plants are highly vulnerable to climate change and, within the Australian Alps, endangered communities such as alpine bogs and fens are particularly at risk. It is likely that not all species will have the same response to climate change because alpine plants occur in a variety of habitats and exhibit different germination strategies. Some alpine plant species are generalists and occur across many different habitats and others are specialists and only occur in either wet or dry habitats. Some Australian alpine seeds have been found to germinate immediately following dispersal, while others postpone germination via dormancy. Seed is important because it is the primary way plants can move and respond to disturbance, such as climate change. *Ex situ* conservation through seed banks is one method used to safeguard alpine plants and can provide propagation material for restoration. Direct measurement of seed longevity *in situ* and under *ex situ* banking conditions is difficult to obtain, thus artificial controlled ageing protocols are used to provide a proxy for longevity in *ex situ* seed banking and this may also be correlated with seed persistence *in situ*. This study aims to determine the longevity of Australian alpine species stored at the National Seed Bank, Canberra, using a standard rapid ageing protocol developed by the Royal Botanic Gardens Kew's Millennium Seed Bank. Over 100 accessions of 89 species from 23 families from a range of alpine vegetation types, exhibiting immediate and postponed germination strategies, are being screened for initial viability. Through controlled ageing experiments we address the following hypotheses: (i) Species with immediate germination will have shorter seed longevity compared to those with a postponed germination strategy, and (ii) Specialist species will have shorter seed longevity compared to generalists. The results will be crucial for effective *ex situ* seed bank management and restoration to support *in situ* conservation.

Annisa Satyanti checking alpine seed germination in an incubator as part of her PhD studies at ANU (with Nicotra) on Australian alpine seed germination ecology. Annisa is on study leave from Bogor Botanic Garden. She has extensive research experience on oil seed germination and seedling drought tolerance and is a former Humboldt International Climate Protection Fellow. Photo Annisa Satyanti collection

Alpine evolutionary diversity and adaptive potential

Ary Hoffmann, Adam Miller, Rachel Slatyer, Nick Bell, Meg Hirst

Our current research is concerned with assessing the adaptability of alpine animals and plants to climate change and other related stressors, working mainly in the Bogong High Plains, Victoria. This work is summarised below.

Uniqueness of plants and animals from different mountains

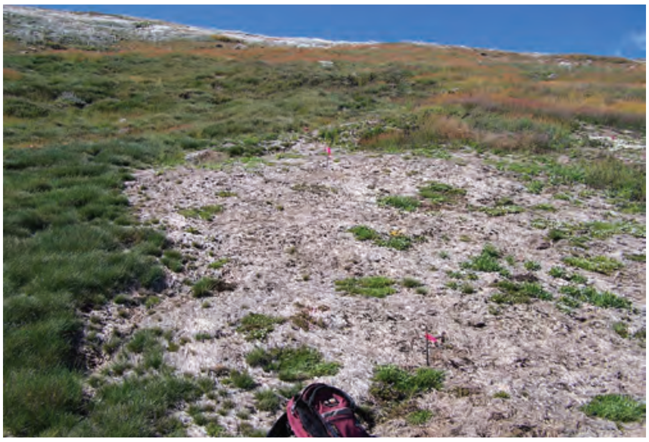
Mountain level patterns in uniqueness are being assessed using the latest DNA technologies to determine the genetic structure of multiple plant and invertebrate species, identifying patterns of endemism (that is, whether a species is unique to the Australian Alps), and linking this information to species traits. This work will help inform management around conservation priorities through the identification of genetically unique and genetically diverse alpine communities, reflecting evolutionary bioregions and refugia, respectively.

Physiological limits in alpine plants and animals

We are examining at what limits species are likely to 'fall over' or whether they have large safety margins. To do this we are accumulating information on heat and cold tolerance limits in invertebrates (mostly grasshoppers so far), and on drought tolerance limits in plants. This information will be used to predict how much stress the biota can deal with into the future.

The extent to which plants locally adapt along elevation gradients

To assess whether adaptation is based on genetics or on plasticity (that is, the ability of an organism to adapt to changes in its environment), or a combination thereof, a series of transplants is being conducted in grasses, sedges and, more recently, *Brachyscome* daisies. The issue is also being explored by establishing patterns of relatedness across taxa and by looking for lineages that lack adaptive potential. This information indicates which plants are resilient and which are fragile. It can help to inform revegetation strategies and inform recovery plans for threatened species.



One of the transplant sites where we are looking for local adaptation in *Brachyscome* species. Photo supplied by Ary Hoffmann.

Entry of invasive invertebrates into alpine environments

Collection of baseline information on invertebrate distributions in the Bogong High Plains and long-term monitoring will indicate whether there are changes to the composition of invertebrates. This is currently funded by the Long-term Ecological Research Network (LTERN).

Moth damage to alpine grassland in Bogong High Plains and invasion of vacant area by sorrel. Photo supplied by Ary Hoffmann

How flowering time and seed set is changing in alpine environments

A phenology gradient has been established to allow us to monitor flowering time and seed set regularly during the growing season across multiple species. The gradient encompasses a range of elevations. Because plasticity in flowering time is a sensitive indicator of plant vulnerability to climate change, it is important to monitor changes in flowering time across different conditions. This gradient is also funded through LTERN.

Scope for rescuing threatened species by combining populations from different areas

Finally we are undertaking crosses among populations of trigger plants and sedges from different areas to assess long distance incompatibility. This provides information on the potential benefits and dangers of inter-population crosses which have been proposed as a way of building species resilience under climate change.

Professor Ary Hoffmann is an ARC Laureate Fellow at the University of Melbourne working on environmental stress adaptation. Adam Miller is a postdoc in his group. Rachel Slatyer, Nick Bell and Meg Hirst are student researchers in the group. The Hoffmann laboratory is involved in ongoing research in the Victorian Alps and uses genetic markers, transplants, and monitoring to identify species vulnerability, evolutionary processes, and community resilience.

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Alpine plant distributions and abundance

John Morgan, Keith McDougall, Susanna Venn

The distribution of plants is not random in nature. Species sort themselves into preferred habitats where their requirements for water, light and temperature are met. So, across a mountain side, it is easy to see those species that do not like the highest elevations where it is coldest (such as Snow Gums, which tend to be found on the lower slopes), while other species are restricted to areas where the snow melts late in the season, preferring areas where it is moist all year-round and snow cover insulates against frost. 'Abiotic' factors are the aspects of the environment that govern the fundamental distribution of a species (that is, its climate and soil envelope).

Plant dynamics and adaptation

Plants in alpine regions, regardless of elevation, have to deal with an ever changing environment. Disturbance, such as fire, help to shape the structure and composition of plant communities. Exotic species invade and compete with the native species. Pathogens can arrive and negatively impact species. And, increasingly, extreme events (such as intense drought) affect the dynamics of ecosystems. Our research, alongside students and many collaborators, aims to understand how these dynamic aspects of the alpine environment shape plant communities.

Recording plant species occurrence at study sites Mt Howitt, Victoria. Photo John Morgan

Vegetation dynamics studies

Vegetation dynamics are studied over long periods, a pre-requisite for understanding cyclic versus directional change. One area of special interest is the effect that fire plays in high mountains and, in particular, how long it takes for plant communities to recover. Some communities, such as grasslands, recover rapidly after fire while others respond much more slowly. Another different kind of change being examined is the movement of both native and exotic plants, from the lowlands to the Alps, along roadsides. Many species are using roads to gain a foothold in the Alps. Indeed, weed

Mt Bogong-Hotham tall alpine herbfield study site. Photo John Morgan

invasion is not something that will happen in the future; it is already happening. Thirdly, we're conducting research on the dynamics of mountain summits or, as some call them, 'sky islands'. Here, many species are growing at their altitudinal limits and have nowhere else to go in a warming world. Our work aims to identify how species might respond to climate warming, and to see if there is evidence for these changes. This work is part of a global initiative to document the vulnerability of alpine systems to climate warming.

Future research directions

The research team recognises that alpine systems are dynamic, but to respond to change, plant species need to be able to persist *in situ* (perhaps clonally), or disperse to new areas. Little is currently known about how far alpine plants disperse and under what conditions seedlings then successfully establish. This will be the focus of future work.

Dr John Morgan is a plant ecologist at La Trobe University interested in how the world changes. In natural ecosystems, including alpine areas and threatened native grasslands, he tries to understand how factors such as fire interact with seeds to allow species to persist. This involves lots of careful measurements made over long periods of time.

Dr Keith McDougall is a botanist with the Office of Environment and Heritage in NSW.

Dr Susanna Venn is a newly appointed ARC DECRA Fellow at ANU. Further details are in an earlier paper in this report.

Additional information

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Long-term ecological monitoring and observed vegetation changes in the Victorian Alps

R.J. (Dick) Williams

Long-term ecological research has been a feature of the scientific effort in Australian alpine regions for many decades. Plots established by various researchers in alpine and high sub-alpine sites in Victoria, NSW and Tasmania are some of the oldest plots of their type in Australia. Long-term research at these sites, in conjunction with manipulative experiments, have investigated vegetation dynamics, diet and behaviour of domestic livestock, fire regimes and post-fire recovery, rare fauna, population genetics, and the effects of climate change on ecosystems. Here, I summarise some of the major discoveries resulting from long-term ecological research in the Victorian Alps. More detail can be found in Williams et al. (2014).

Mrs Maisie Carr (nee Fawcett) and Prof. John Turner, from the University of Melbourne School of Botany, established a series of plots at Rocky Valley and Pretty Valley on the Bogong High Plains in the 1940s. These plots have been maintained through the past seven decades, and have been augmented by dozens of additional long-term monitoring plots established since the 1970s.

Rocky Valley & Pretty Valley plots. Photo Dick Williams collection

These plots have yielded valuable insights into the dynamics of the vegetation of the Bogong High Plains in relation to livestock grazing. Major findings include how changes in the relative abundance of shrubs, grasses and forbs vary at decadal timescales, how these changes are driven by life-history characteristics and differential sensitivity to livestock grazing, and how livestock grazing increases the abundance of bare ground (with consequent effects on shrub dynamics and catchment condition). Monitoring has also shown how alpine vegetation can recover following the cessation of grazing. These major findings have been corroborated by the results of various other long-term experimental and monitoring studies in comparable vegetation across alpine Victoria, NSW and Tasmania.

Australian alpine vegetation is subject to recurrent fire, at intervals of decades to centuries. The network of long-term monitoring plots has been invaluable in interpreting alpine fire regimes and the patterns of post-fire recovery in the vegetation. In the extensive fires of 2003, about half of the vegetation of the Bogong High Plains burnt. The patterns of burning were highly dependent on vegetation type, with heathlands far more flammable than grasslands. Post-fire monitoring showed that alpine grasslands and heathlands of mainland Australia are resilient to large fires. Importantly, there was no effect of cattle grazing on patterns of fire extent or severity, and grazing has had little or no effect on the abundance of the major propagating fuels in alpine environments, the tall shrubs. The conclusion from these long-term studies is very clear: alpine grazing does not reduce blazing at landscape scales. Claims to the contrary are devoid of supporting quantitative evidence. Indeed, the long-term studies have shown clearly that both domestic and feral stock have no place in Australian alpine ecosystems, and should be removed.

International climate study - Bogong High Plains

Alpine vegetation globally is vulnerable to the effects of climate change, particularly rising temperatures. As part of the International Tundra Experiment, a long-term climate change experiment was established on the Bogong High Plains in 2003. Alpine grasslands and open heathlands show a range of responses to experimental warming of 1-2° C. These include earlier flowering, delayed seed set and enhanced growth. Of particular note is the effect of experimental warming on shrubs; a 1-1.5° C increase in mean growing season temperatures can double shrub growth rate.

Future Directions

Interpreting past vegetation changes in response to variation in disturbance regimes in the Victorian Alps would not have been possible without the extensive network of long-term monitoring plots. In the coming century, the vegetation of Australian alps will continue to change as a result of climate change, changing fire regimes, expansion of exotic plants and animals and changing patterns of land use. The network of plots will need to be expanded so that vegetation changes can be detected, thresholds of concern articulated and appropriate mitigation strategies designed and implemented.

Dr Richard J. (Dick) Williams is a plant ecologist with 35 years alpine research experience. He examines long-term vegetation change, fire ecology, climate change, carbon dynamics, and management of natural ecosystems, especially in alpine regions and savannas of northern Australia.

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Plant conservation in the Snowy Mountains in a changing climate

Catherine Pickering

Climate change has already arrived in the Snowy Mountains in NSW. Snow cover is declining, with a 30% decline overall and a 40% decline in snow in spring over the last 60 years. This reduction in the depth and duration of snow is associated with higher temperatures and reduced precipitation. In addition, summers appear to be getting hotter and drier, resulting in increased risk of fires in the lower areas of the Snowy Mountains. These changes are affecting the plants growing in this, the highest alpine region in Australia.

There are over 212 species of vascular plants in the alpine area around Australia's highest mountain, Mt Kosciuszko (2228 m), of which 30 are restricted to alpine regions and 21 to just this one alpine region. There are 11 distinct alpine plant communities. Those associated with the latest lying snow banks (Short Alpine Herbfields and Snowbank Feldmark), and the highest ridges (Windswept Feldmark), have very limited distributions and high conservation value.

Observed changes

Changes in the alpine flora as a result of reduced snow cover and warmer summers are already occurring. This includes earlier flowering of many attractive and distinctive alpine plants, with the peak of flowering moving from late January to early January, and in some years, early December. More animals, native and feral, including wallabies, hares, horses and deer, are migrating higher into the Snowy Mountains, arriving earlier and staying longer at higher altitude sites in summer. There has also been increased diversity and abundance of weeds in the alpine area, particularly along walking tracks and other disturbed sites.

As a result of the direct effects of climate change, and these associated changes in other biota, there have been changes in the distribution of important plants and plant communities in the Kosciuszko alpine area. This includes a decrease in the area and distinct composition of some of the rarest plant communities associated with snowbanks, as they are increasingly colonized by Tall Alpine Herbfield species.

The 2003 fires impacted on some areas of rare Windswept Feldmark along the highest ridgelines, with limited regrowth of the dominant Epacris shrubs after the fire. These changes have often involved species with more competitive traits such as taller canopies and larger leaves, overtaking areas previously dominated by species with shorter canopies and small, tough leaves that were better adapted to more stressful environments.

In some areas, shrubs have increased in diversity and cover, potentially overtaking areas previously dominated by grasses and herbs. However, a recent addition to this mix of impacts is the spread of the pathogen *Phytopthera cambivora* (causing root rot), which appears to have killed hundreds of the shrub *Nematolepis ovatifolia* (formally *Phebalium ovatifolium, Rutaceae*) in the last few warmer but wetter years. How other species respond to the dieback of this shrub, which is endemic to the alpine and subalpine regions of the Snowy Mountains, is not clear.

Field team surveying changes in species composition on five summits in the Snowy Mountains as part of an international monitoring program, Global Observation Research Initiative in Alpine Environments (GLORIA). Photo Catherine Pickering

Summary and future directions

What is increasingly apparent is that this alpine area is changing, and often at the expense of the rarer endemic plants. Reducing the impacts of climate change on the ground in the Snowy Mountains involves increasing the resilience of the environment to these changes, with priority actions involving reducing the impacts of feral animals, weeds, tourism and pathogens. *Ex situ* conservation of alpine species, including storing their seeds in seed banks, adds to our capacity to offset these threats and will ensure the long-term survival of this alpine flora.

Professor Catherine Pickering is based at Griffith University and has researched alpine plants in the Snowy Mountains for over 25 years. Studies include plant reproductive ecology, plant-animal interactions and assessing the impacts of tourism, fires, weeds, feral animals and climate change on the flora. Research collaborators include Dr Ken Green & Dr Susanna Venn.

Additional information

A summary of recent research on climate change for the region, is available online at http://apo.org.au/old-site/files/docs/Pickering-Venn-2013-Alpine-flora-climate-adapt-WEB.pdf

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Research for conservation in Tasmanian alpine environments

Jennie Whinam

Much of the Tasmanian alpine country is located in the Tasmanian Wilderness World Heritage Area (TWWHA). Research and monitoring priorities for the TWWHA for 2013-2018 have been identified through a series of stakeholder workshops that reviewed previous research and monitoring and identified knowledge gaps. These priorities have been guided by the outstanding universal natural values (as defined by UNESCO) that have been identified for the property along with key threats and conservation requirements.

Two management issues identified of primary importance for maintaining natural values of alpine ecosystems are fire and climate change. These two issues are intrinsically linked.

Data collection and monitoring

One of the knowledge gaps identified in regards to impacts of climate change is the lack of quantifiable weather data collected from alpine areas. This has led to the placement of weather stations either side of the alpine ecotone at Mt Sprent and a weather station on Cradle Plateau. This is in conjunction with a program to monitor changes at the subalpine/alpine ecotone.

Jennie Whinam, Kerry Bridle, Jayne Balmer and Jamie Kirkpatrick, at the subalpine/alpine ecotone monitoring site Mt Sprent. Photo Jenny Styger

Tasmanian researchers are engaged in the International Warming Experiment Network, installing two monitoring sites as part of a global network examining the combined and relative influence of interactions among species and temperature change on community structure and ecosystem function in montane systems. Each study area in the global experiment contains a pair of sites separated by >500 m in elevation. At the Tasmanian montane grassland sites (one ~1000 m above sea level (a.s.l.) and one ~ 500 m a.s.l.), temperature will be increased by 2°C on average using ITEX-style open top clear plastic chambers. This will indicate whether the dominance of individual species influences the way that ecosystems respond to global warming. Both ecosystem and community level responses will be measured.

A weather site installed on Cradle Plateau (Barn Bluff behind) to monitor soil and air temperature and moisture parameters to address climate change research gaps in Tasmania. Photo Micah Visoiu

Seed Collection

The Royal Tasmanian Botanic Gardens (RTBG) undertook targetted seed collections in alpine areas in 2013 as part of a Caring for Our Country program, resulting in 50 collections of 43 species and >696,000 viable seeds from 29 locations. As part of the Central Highlands 'Bush Blitz' 2014, the RTBG took part in a joint collecting program which resulted in 17 collections, with 8 from nationally endangered listed *Sphagnum* bog communities.

Macquarie Island

Long-term botanical research on Macquarie Island covers the impacts of rabbit grazing and disturbance on species and communities and documenting vegetation recovery following successful pest eradication. It is likely to be many years before the ecosystem reaches a new equilibrium.

The decline of the Macquarie Island endemic cushion plant, *Azorella macquariensis,* resulted in it being listed as Critically Endangered in 2010. Measurements from photographs over the period 2009-2013 suggest three distinct types of dieback were independently consistent with wind, rabbit-grazing and pathogen damage. A research is proposal has been submitted to examine whether identified pathogens are causing primary or secondary dieback and whether changing climate is implicated in the initiation and spread of the dieback.

Dr Jennie Whinam is Senior Ecologist (TWWHA) Tas. Dept. Primary Industries Parks, Water & Environment. She has spent over 25 years working on Tasmania's WH (including sub-Antarctic) areas. Her interests include peatland ecology, restoration and impacts of climate change in alpine areas.

Additional information

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Towards a collaborative approach to adaptive ecological restoration and management in the Australian Alps

Adrienne Nicotra, Ary Hoffmann, John Morgan, Adam Miller

Introduction

The Australian Alps are a multi-use landscape of cultural, biological, hydrological and economic significance. The region is heritage listed, is one of 11 Australian centres of plant diversity and one of the world's 187 biodiversity hotspots. The Australian Alps have been identified by the International Panel on Climate Change (IPCC), CSIRO, researchers and the Australian Alps Liaison Committee as critically vulnerable to climate change.

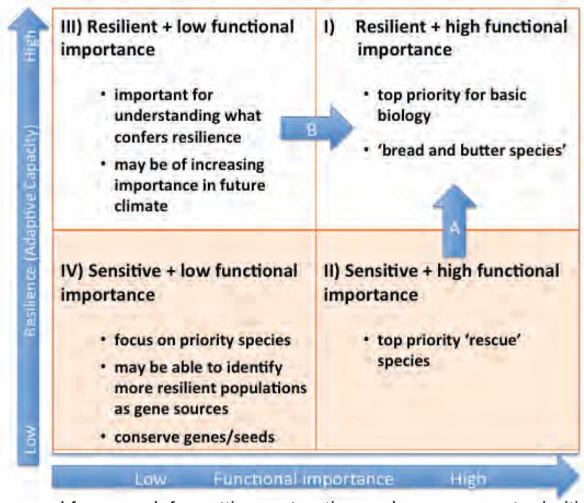
Science-based ecological restoration

Here we propose a research-based scientific assessment framework to assist in making decisions about management actions necessary to address ongoing challenges of alpine conservation. This proposed framework departs from managing the rarest species first, because we recognize that the scale of change in the Alps is likely to be huge. Climate models project that the Alps will warm dramatically and snow will largely disappear. Management approaches will need to adapt to consider how species, particularly plant species, that have evolved under cool, wet conditions will fare in warmer and drier environments. We provide a starting point for setting priorities for ecological restoration and management based around abundance and functional significance of plant species. Our aim is to contribute to practical management strategies that maximise the adaptive capacity of alpine biodiversity, the success of future ecological restoration projects and the maintenance of ecosystem processes.

Such a framework will enable researchers, regulators, industry partners and community groups to devise guidelines for alpine restoration and land-use management that minimise maintenance costs, reduce risks to restoration projects and promote species and ecosystem resilience. It will provide regulators and industry with tools for cost-effective and long-lasting restoration informed by cutting edge technologies. We envision that it will also lead to development of guidelines for plant and seed sourcing and propagation. Research outputs based around the framework would provide a resource for future monitoring and provide insight into causes of species and ecosystem decline.

The framework proposed revolves around a scientifically based system of ranking species based on their functional importance and environmental significance. The information for ranking species is derived from observed (historical and current data), expert scientific opinion along with research on ecological characteristics and adaptive capacity.

The model for rankings is described schematically in the following diagram. The four quadrats define the relative importance of functional importance and adaptive capacity and provide information to inform priorities for action.



Proposed framework for setting restoration and management priorities.

In this Framework diagram, the x-axis represents the functional contribution of the species to the ecosystem. High scoring species would include those having high functional importance, including keystone species, highly abundant species, or species making significant contributions to ecosystem function. The y-axis represents the resilience (or adaptive capacity) of a species. Low scoring species include those already showing signs of decline in abundance, slowed growth or reproduction, or increased sensitivity to pests and diseases. These would also include species with narrow environmental limits or limited genetic variation. Identification of these categories based on historical data and expert knowledge provides a starting point for prioritising management efforts. Further refinement of the scheme would be based on directed ecological and genetic research on select species.

Management considerations

Species falling in Quadrat I are both functionally important and resilient. These should be our 'bread and butter' species for restoration efforts and thus are also important species to maintain *ex situ*. Obtaining basic biological information on these species, including information about environmental tolerances and patterns of genetic variation across species distributions, will provide much-needed spatial context for identifying and protecting alpine refugia, and guiding seed/plant collections for restoration projects.

Species in Quadrat II are of high functional importance but likely to be sensitive to climate change. Conservation efforts should strive to maximise adaptive capacity where possible, including 'genetic rescue' activities. Alternatively, these are species that are likely to be replaced in the community and preparation for that change should be considered. For some species, genetic variation may exist within the species that could provide more resilience. Where possible such variants should be favoured for conservation and restoration (Arrow A in Quadrats I and II).

Species in Quadrat III are highly resilient, but currently play a small functional role in the ecosystem. It is possible that direct or indirect effects of climate change may increase the role that these species play in the community (Arrow B in Quadrats I and III). Species in Quadrat III are also of interest as they can contribute to our understanding of what traits define a resilient species.

Finally, species falling in Quadrat IV show signs of low resilience and currently play a low functional role in the community. These may include species that are rare or at the current edge of their distribution. Quadrat IV species are those least likely to persist in future alpine communities. These species should be considered low priority for management or restoration, but should be conserved *ex situ*.

This framework provides a useful starting point for prioritising action. The categorisation of species would be an iterative and interactive process. Species' assignments would initially be made based on expert opinion and available historical data. These assignments would subsequently be validated by research that examines factors determining species resilience: (i) innate ecological characteristics (such as life history traits), (ii) genetic variation which confers the potential for an adaptive evolutionary response, and (iii) plasticity that buffers climate change, broadens environmental tolerance, and/or provides time for adaptive evolution and range shifts to occur.

If developed collaboratively, and with a focus on an ecosystem resilient to projected climate change, this framework will lead to practical guidelines for collection, storage, germination and propagation of target species, as well as ecological restoration, management and conservation plans that reduce long-term maintenance costs in the Australian Alps.

Information for alpine management and ecological restoration from long-term monitoring plots – examples

Professor Geoff Hope taking peat sample from bog survey plot at Kosciuszko National Park (KNP) to record peat depth and composition.

Recording plant growth and diversity in KNP monitoring plot, part of the Global Observation Research Initiative in Alpine Environments (GLORIA) network examining impacts on alpine environments from climate change.

Plains of Heaven (KNP) long-term vegetation monitoring plot examining effects of grazing (right) and exclusion of grazing (left).

A Victorian International Tundra Experiment (ITEX) vegetation plot that is assessing climate change impacts on alpine communities in a growth chamber which controls temperature conditions for plant growth.
All photos Roger Good collection

Panel discussion and concluding comments

Dr Rosemary Purdie moderated a concluding symposium panel and general discussion. This covered issues and key themes raised during the symposium and challenges and opportunities to help in ongoing government, research and community efforts towards alpine research, conservation and management in Australian alps. Key themes and practical measures are summarised below.

The panellists (pictured above from left to right) were Dr Jennie Whinam, Dr Dick Williams, Professor Ary Hoffmann, Mr Anthony Evans, Dr Stuart Johnston, Ms Bindi Vanzella and Dr Judy West.

Key themes

The need to involve all the stakeholders in any discussion about priorities for ecological restoration and management in Australian alps

Alpine stakeholders include industry (primarily power and tourism), regulators, managers, researchers and community groups, from states and the ACT with alpine areas. Managers get very different sets of demands and priorities from different stakeholders: tourism, researchers, conservation bodies and policy makers. Given that individual groups seldom hear the demands of others, it is difficult to prioritise broadly.

Traditional modes of science communication are not an effective means of translating science to practice and policy. Those with responsibility for on-ground management, as well as those responsible for directing policy, do not always have access to a good overview of research developments. Face to face discussions and targetted presentations can aid that transfer of information.

In many cases the social challenges are greater than the scientific, and there may be direct trade-offs between the two. For industry to get involved, the importance needs to be translated to what matters to the business, or what the business is required to do by regulation. This requires regulatory drive, leadership and incentives.

Management is focused on response to immediate concerns. Restoration is driven by regulatory requirements

For the most part, restoration and management decisions are made in response to immediate requirements and regulations. Seldom are there additional resources to be spent on longer-term planning or preparation for climatic changes. Getting ahead of these immediate demands will take leadership and support at regulatory levels.

Following on from the symposium, it would be beneficial to see how research could be applied in the field to assist in the ongoing management or ecologically sound restoration works on, for example, utility assets (namely easements) that traverse the Australian Alps. Research may be able to play a key role in assisting in the ongoing dialogue between utilities and environmental regulators in managing assets in these environmentally sensitive areas. Using science may assist in managing these areas through collaborative engagement to achieve the best outcomes for all.

Diversity in collection – when local is not best

When collecting seed for conservation and restoration the source, or provenance, of the seed matters. For many years restoration and revegetation projects have been conducted under the mantra of 'local is best'. But with climatic conditions changing and restoration being conducted in a complex matrix of land uses, it is rapidly becoming clear this simple maxim is not foolproof. Rather, now we want people to think about what 'local' will be in the future. Broadly collected provenances and conservation seed banks can make an important contribution to this change in approach.

We don't need to throw out the many years of experience in alpine area restoration, but we can take advantage of what we know about species when making decisions about what to use for restoration purposes. Restoration materials should reflect local types, should encompass genetic variation, and should confer some resilience by virtue of that diversity. Newly emerging technologies, combined with a solid understanding of basic biology and natural history will provide a sound basis for making such decisions.

Indeed, new technological developments mean that genetic tests, once restricted to well-funded research laboratories, can now be used much more broadly to describe the history and makeup of plants and animals. However, the excitement around the potential of modern genetics is not something that has yet permeated the day-to-day lives and thinking of alpine land managers. It is important that we build a broader understanding of the potential, and limitations, of genetic techniques to contribute to cost effective and efficient decision making about restoration and management.

Restoration and management should be to future, not previous, conditions

If we want to manage for alpine ecosystems that continue to deliver the services that both industry and the environment require, we will have to be ready for change. In many cases to understand resilience there is a need to understand processes, via experiments and models. Even now we are often working with highly altered and managed systems that have been responding to a broad range of perturbations for a very long time. In a sense there is no original, natural or pristine state remaining in the alpine ecosystems. Rather than focus on individual species, a broader perspective encompassing longer term goals and emergent properties of the system is needed. In addition, care must be taken not to exacerbate problems associated with invasive pests and pathogens.

Practical actions to help advance alpine research, conservation, restoration and management

Maintaining and developing communication lines

Conversations and symposia such as this one are a valuable opportunity to communicate science and discuss priorities for conservation, restoration and management. Making this into a more regular event and expanding the participants to include more stakeholders from regulatory, industry, management and community groups would be very useful.

Marketing the research into stories

Researchers, members of community groups and institutions such as botanic gardens can be instrumental in getting the message out about what is happening, and what is likely to happen, in alpine areas. Social media also has great potential to assist.

Synthesizing historical data

There are a lot of historical data about alpine community composition (especially for plants) across states and the ACT spanning several decades. These data need coordinated synthesis, as through syntheses of historical patterns we may be able to determine which species are already responding to environmental changes, including warming, fire, grazing and other disturbances.

Improving understanding of the population structure and characteristics of key species

By drawing on seed collections combined with expert opinion, we could identify and start exploring the population structure of those species most likely to be needed for restoration and management in the future.

Building dedicated alpine seed collections for restoration

Dedicated alpine seed collections and seed production areas should be established now, running parallel to ongoing seed research. What species to collect, where from and for what purpose, such as type of current and predicted disturbance (for example fire, pest animals, weeds, temperature changes, dieback etc) needs articulating. Further, we need to determine which species need to be re-established/restored from seed, versus re-establishment from propagated cuttings or clones.

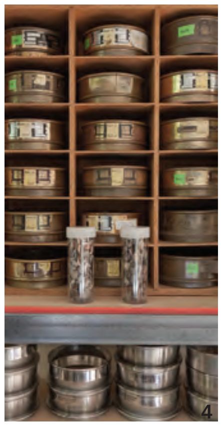
Anthony Evans, is NSW Parks Area Manager, Alpine Queanbeyan Area. Responsibilities involve operational management of the reserves, including biodiversity, weeds and pests, visitors, natural and cultural heritage, and fire management. He was previously the Australian Alps Program Manager under the interstate cooperative program.

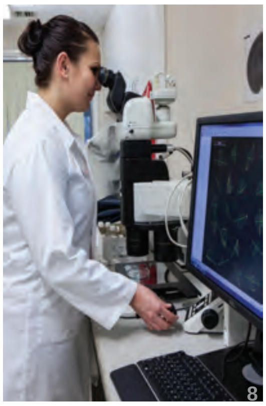
Dr Stuart Johnston is Program Manager, Energy & Gas Infrastructure, Energy Network Association the peak industry body. During his career he has had extensive experience in the Snowy Mountains with Transgrid and NSW NPWS in environmental management and research.

Dr Rosemary Purdie is a plant ecologist, currently Hon. Associate, Centre for Australian National Biodiversity Research. Her work for Queensland, ACT and Commonwealth government agencies since 1976 includes vegetation description and mapping, assessment of threatened species and ecological communities, developing and implementing natural heritage and nature conservation policies.

Ms Bindi Vanzella is currently Business Development Coordinator, Greening Australia. She has an extensive background in ecological restoration activities with native vegetation and collaborative work with government and community groups in NSW and the ACT.

Other panellists were presenters and their biographies are in earlier papers. Panellist photos Tobias Hayashi





Collecting, conserving and using alpine seeds – key steps and considerations

Seed collection for science

Availability of seed for collection is dependent on having the right conditions for alpine plants to flower and set mature seed, including in many cases for plants to grow from existing seeds in the soil (namely the soil seed bank).

Approvals, such as permits, are required to collect seeds.

The quantity collected from each plant and group of plants (population) growing in an area is determined according to scientific criteria and permit conditions.

Seed is collected sustainably from as many individuals and populations as possible to increase the genetic diversity of the collection and to facilitate future research to determine how plants differ from one another.

To ensure accurate identification of the species from which seed has been collected a herbarium specimen is collected in the field along with data about the plant location and environment.

Preparing seeds for *ex situ* conservation in a seed bank

Collected seed has to be 'cleaned' by sorting and separating it from chaff and other material. This is often achieved manually using different size sieves and microscopes. Seeds are often very small. Photos 1-4

Seed viability is assessed by germination tests of seed samples under controlled and sterile conditions in Petri dishes in incubators. The proportion of seeds which germinate is used to monitor any viability loss over time. Photos 5,6

Preparation of seed for long-term (that is, up to hundreds of years) conservation involves measuring, weighing, drying to the right moisture content, vacuum packaging and recording data. Photos 7,8

For long-term conservation seed is kept dry and under controlled conditions at very low temperatures (generally -20 ° C) to extend seed longevity. Photo 9

Using seeds

Having access to seeds is vital for much research such as that covered in this report. For example, seed can be used to investigate alpine plant vulnerability, adaptation potential to increasing temperatures, the functioning of ecosystems and ecological restoration.

Seeds are important for ecological restoration work and for field experiments. Photo 12

Botanic gardens, through their work involving conservation of living plants, improve horticultural understanding of how plants (such as alpine plants) grow under new conditions outside their natural environment. Photos 10-11

The ANBG has grown some alpine plants for display from alpine seeds germinated from viability testing during the *Alpine Project*.

Photos above 1-8,10,11 Andrew Tatnell © ANBG, 9 Roger Good collection, 12 Ary Hoffmann

Alpine vegetation communities and environment

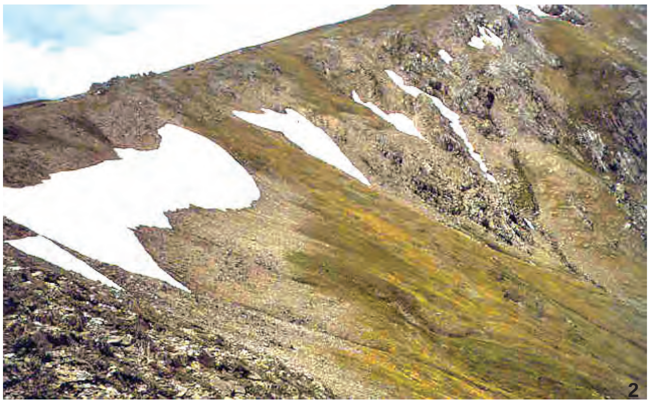
The Australian mainland alpine zone occurs above the treeline at around 1850 metres altitude and is dominated by tall alpine herbaceous species and woody heath communities. Other small communities (short alpine herbfield, sphagnum bogs, fens, sod tussock grassland, feldmark), occur where soil moisture, aspect, slope, drainage, exposure levels (ultraviolet light), temperature, and / or snow cover limit the growth of the dominant communities.

The subalpine zone occurs between approximately 1400 and 1850 metres elevation and is the most extensive zone in the Alps. The zone is dominated by Snow gums *Eucalyptus niphophila/pauciflora* generally with a well developed shrub understorey. *E.niphophila* occurs at the highest altitudes but grades into *E.pauciflora* in the lower subalpine zones. The altitudinal limit of tree growth is controlled by the mean summer temperature of about 10° C but this is also influenced by other physical features and hence the treeline elevation varies as a response to these features and to micro-environmental conditions.

The pictures opposite in Kosciuszko National Park depict some alpine vegetation communities and the type of environment in which they occur.

1. Tall alpine herbfield with grasses, herbs (such as *Celmisia sp*)
2. Short alpine herbfield below snowpatch
3. Windswept feldmark in areas with little soil
4. Snowgums and shrubland at tree line, subalpine.

Photos Roger Good collection



Additional information

In addition to that in various research papers in this report, more information about alpine areas (including vegetation, soils and geology) and alpine research, conservation and management is available on the web (references below correct at October 2014) and in recent publications.

The Australian Seed Bank Partnership (http://seedpartnership.org.au/), provides links to government and other agencies' websites and activities relating to seed (including alpine) conservation, collection and research.

The Council of Heads of Australian Botanic Gardens (http://www.anbg.gov.au/chabg/), is a not for profit association supporting Australian plants and their ecosystems through research, conservation, management and information dissemination. The website has information on activities being undertaken through the forum and links to Australian botanic gardens.

The website on interstate cooperative management arrangements for the Australian Alps (http://www.environment.gov.au/heritage/places/national/australia-alps) has details about Alps vegetation, soils and geology (including education resources, http://theaustralianalps.wordpress.com/the-alps-partnership/education/).

The Australian Institute of Alpine Studies (http://aias.org.au/), is an umbrella organisation for alpine researchers of all disciplines, including those represented in this report.

Worboys, G.L. and Good, R.B. (2011) *Caring for our Australian Alps Catchments: Summary Report for Policy Makers (*2011) Department of Climate Change and Energy Efficiency, Canberra. This report contains information about the natural values of the Alps. A PDF version is available at http://apo.org.au/research/caring-our-australian-alps-catchments.

Cris, R. Buckmaster, S. Bain, C Reed, M. (EDs) (2014) Global Peatland Restoration demonstrating SUCCESS. IUCN UK National Committee Peatland Programme, Edinburgh. This contains information on global efforts to restore peatlands. Details on restoration of mires in the Australian Alps following the 2003 fires are described.