Prospects for research in Australia's High Country

Image by Sarah Clement

Image AMRF

Image by Phil Gibbons

Australian National University | ANU College of Science

Science for Australia's high country

Rapid change with major consequences

The world's high mountains define the water catchments that drive our societies, capture massive amounts of carbon (in tall wet forests, peat swamps and organic soils), are biodiversity hotspots and hold tremendous cultural significance. Mountains support irrigated agriculture to provide food for more than half of the world's population. The future of our high country therefore has pervasive implications for society and the natural world. And these regions are under growing pressure.

Around the world, alpine, sub-alpine and montane ecosystems (hereafter referred to as the high country) are showing the impacts of global change more clearly and rapidly than most other systems. These changes are being driven by how humans manage our land and water resources, invasive animals and plants, and climate change.

Temperatures are rising, snow levels are in decline, ecosystems are under stress, biodiversity is being threatened. These trends are being seen in the high country all around the world including the Himalaya and the Rockies. In Australia, the impacts on our high country are increasingly visible and growing. However, as is often the case, Australia's situation presents its own unique set of circumstances.

Australian mountain regions are smaller, flatter and lower, and already show greater impact from climate change than many other alpine regions. Our high mountains are globally unique in that they are old and have well-developed, deep organic soils in the alpine zones. They are also dominated by eucalypts rather than conifers in the sub-alpine and montane zones. Already warming effects are well documented. Whereas mountain systems elsewhere in the world have potential to harbour refugia upslope for migrating species, options for Australian species are more limited.

"Latest models predict warming in the alpine region will exceed former projections and reach increases of 3.5 – 6°C by 2100. Snow depth and duration are predicted to decrease by more than 90%. Australia's high mountain geography makes it a 'canary in the coalmine', and its high values – biological, social and economic – make it a critical focus for research and pro-active management."

Transformational change in Australia's high country is almost certain. But while change is inevitable, integrated, interdisciplinary and socially responsive science can provide the tools we need to identify possible future scenarios, influence the direction of change, improve adaptive capacity, and maximize our potential to sustain multiple values.

The Australian National University has a rich history of research in the high country. It possesses some of our countries most experienced and highly regarded scientists working across a broad spectrum of high country themes. This document* presents a cross section of some of these people from the Research School of Biology (RSB) and the Fenner School of Environment and Society (FSES) with summaries on some of the projects they are involved in.

It is our hope that given this level of expertise, and the growing investment in high country research infrastructure (such as the newly founded Australian Mountain Research Facility), that we might build a critical mass to meaningfully confront the growing challenges facing our precious and vulnerable high country.

The truth is we need to act now. We must accelerate research to meet the challenges our high country systems face. Delay and we increase the risk of catastrophic fire, species loss, potentially irreversible vegetation change, and failing societies and regional economies.

Professor Adrienne Nicotra

High Country Research Initiative
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Photo courtesy Beth Slatyer

ANU mountain research stretches back more than 50 years as shown by this picture of Prof Ralph Slatyer and family on a field trip with the 'portable' photosynthesis system in the 1970s. (The modern equivalent photosynthesis system is the size of a shoebox, rather than a trailer).

Contents

Image AMRF

Prospects for research in Australia's High Country

4 **Dealing with snow gum dieback**

7 **Plants adapting to climate change**

11 **Recovery from fire**

14 **Water and the high country**

17 **Saving threatened species in a changing landscape**

20 **Capturing the many values of the high country**

23 **The Australian Mountain Research Facility**

The highest snow gum in the world

One of the key questions that has attracted biologists for decades is 'what controls the elevation at which trees grow in mountain regions?' This question is even more relevant now that global warming is increasing temperatures through the sub-alpine and alpine regions of Australia. Will rising temperatures enable woody plants such as snow gums to establish at higher elevations – with consequences for the elevation of the tree line?

It was with these issues in mind that back in 1972, Professor Ralph Slatyer from the ANU explored the ability of snow gum to grow at elevations above the natural tree line (currently 1900 m above sea level). Ralph and his team planted seeds, seedlings and 5-year old saplings of snow gums at several sites below and above the tree line. While trees failed to establish from seeds and seedlings, Ralph had success with 5-year old saplings at two sites near Thredbo, both above the current tree line.

The phote here shows a 50-year-old snow gum growing at the highest elevation (2112 m above sea level) of this particular experiment. The trees are doing quite well, albeit with their foliage being stripped back each year whenever blizzard conditions occur in the absence of the protection of deep snow cover.

The experiment provides important insights into the ability of snow gum to survive at higher elevations. It suggests that warming could instigate the migration of snow gum to higher elevations in line with treeline elevation shifts elsewhere in the world. But, as discussed later in this volume, several other variables (drought, fire and dieback to name three) will also influence where snow gums are able to grow.

Image AMRF

A snow gum planted over 200 m higher than the tree line. It was planted here by ANU researchers around 50 years ago.

The experiment (and this image) also symbolise the rich and enduring connection between ANU scientists and research in the high country. It's a tradition that the university hopes to build upon in the decades in front of us, decades that promise to see profound change through Australia's high country.

Death of an icon

Image by Jozef Meyer

If the snow gum disappears from an area, the landscape alters in form and function, and vital animal habitats are lost.

Dealing with snow gum dieback

Regarded by many as one of the most beautiful eucalypts in Australia, the snow gum is amongst the hardiest of all eucalypt species, being capable of surviving the severe winter temperatures of the Australian Alps. However, as temperatures warm, these iconic trees are being threatened on multiple fronts. First it was drought and fire, now dieback is spreading across the gum tree's distribution.

The snow gum is home to an astonishing array of flora and fauna, and they provide a range of vital ecosystem services. The trees, for example, have been shown to increase snowpack accumulation and moderate melt, making snow gum critically important to the hydrology and water resources of southeast Australia.

Image by Matt Brookhouse

"My experiences out in the field combined with what we are learning from the microscopic attributes of tree rings is revealing that climate change & human modification of the high country is posing serious challenges to this region."

Matthew Brookhouse

"We are at a point in time where we need to not only identify the drivers of this dieback event, but frame the landscape of potential responses to it."

Adrienne Nicotra

Dr Matthew Brookhouse
Dendrochronologist, FSES

Matt is dendrochronological and wood anatomical researcher; he studies the structure of wood to understand the connection between trees, forests and their environments. Matthew has also completed post-doctoral studies focussed on forest structural complexity at the landscape scale, dendrohydrological reconstruction in forested catchments, water use and hydraulic properties of in mountain-ash forests and [CO_2] responsiveness in controlled experiments of commercial forest species. Matthew's background means that he brings a broad suite of research skills and forest-ecological knowledge to high-country research.

A connection with the high country

"My interest in the high country was piqued through exposure to sub-alpine woodlands and the potential of tree rings for understanding forests. Dual interests in sub-alpine ecology and wood anatomy now drive my research in the high country—a region in which wood anatomy is highly responsive to climate variability and change."

Snow gum dieback

Continued from page 4

Snow gums have some capacity to endure individual fire events; established trees can resprout from an underground lignotuber that stores carbohydrates. However, we are seeing a general trend of increasing frequency and intensity of fire in the high country, and the snow gum's ability to cope with this is limited.

Some areas in the Victorian Alps have had two to three fires in quick succession with some sites seeing no regeneration and being left barren with erosion.

Now, on top of drought and fire, the iconic tree is battling dieback caused by a small, native wood-boring beetle nicknamed the ring-barker borer (*Phoracantha mastersi*). The beetle has infested snow gums living above 1,600 metres, right across the Alps from Victoria to the ACT. The insect ring-barks its victims causing their slow death. And no tree, no matter what age, is safe.

As with all ecosystems, cause and effect are complex with drought, fire and dieback interacting through multiple feedbacks. Drought appears to make the snow gums more susceptible to infestation by wood borers, the dieback caused by the beetle weaken the trees making it harder for

Image by Matt Brookhouse

*Larval ring-barker borer (*Phoracantha mastersi*) in the palm of a hand. This specimen was extracted from an infested snow gum near the alpine treeline in Kosciuszko National Park.*

An iconic Australian tree

Snow gums thrive in cooler, wetter conditions. Australia's six sub-species of snow gums grow in isolated pockets of mountains from Victoria, to southern Queensland, as well as Tasmania. While they can grow above the snowline, they can also be found as low as Bega on the south coast of New South Wales. But as temperatures warm, these iconic trees are being threatened by drought, fire and disease. Snow gums are better adapted to fire than some other mountain species like alpine ash (which only recovers from seed). Even though fire takes out the crowns of snow gums, established trees can resprout from an underground lignotuber that stores carbohydrates.

Image by Rob Gibbs(NSW NPWS)

Snow gums symbolise our mountain landscapes. When you see a snow gum in the snow, you know you are in Australia.

Snow gum dieback

Continued from page 5

them to regenerate after fire. If they regenerate, they are more susceptible to further reinfestation, and if whole stands die they make the landscape more flammable.

Droughts, fires and native wood borers have all been witnessed in Australia's high country in the past, but never at the frequency, intensity and scale that is currently being observed. Researchers at ANU are attempting to unpick the complex web of interactions surrounding snow gum dieback to better understand why some trees show limited resistance to the process where others succumb; map the distribution of the process; and develop options for managers to arrest the dieback in places where this is possible.

One of these options could be to plant lower elevation sub-species of snow gums that are not currently affected by the insect into the ranges of the higher elevation sub-species that are more susceptible. Unfortunately, such trials take time and would be undertaken as the high country is experiencing a range of climate related changes. Time is not on our side.

Celeste Linde
Evolutionary Ecologist, RSB

Celeste's research focusses on the microbial interactions with plants and their environment. Of all the microbes, she is particularly passionate about the interactions with fungi. Fungi can be grouped into a number of guilds such as pathogens, symbionts (eg, mycorrhizal fungi), or simply as saprotrophs. In all forms, fungi play an important role in how plants perform. Celeste's work aims to understand how these microbes shape ecosystems, how they are affected by climate change, and whether we can use beneficial microbes to assist in plant performance and disease tolerance.

A connection with the high country

"The first time I visited the high country of Kosciuszko National Park is deeply etched in my memory. It's so different to what I had experienced in Europe. To see eucalypts among snow was absolutely mind blowing. It still is. Most people do not realise just how unique Australia's high country is."

"Microbial processes are critical to plant growth in the high country. Mycorrhizal fungi on plant roots, for instance, can alleviate drought stress, increase disease resistance, and help plants acquire nutrients. Yet, we know very little how these fungi perform under extreme conditions such as we are likely to face under future climate change."

Celeste Linde

Dr Megan Head
Insect Ecologist, RSB

Megan's research focuses on how insects interact with their environment. She has particular interest in understanding the impacts of climate change on insect behavior and physiology, and how this is likely to affect their geographical distribution as well as how they interact with each other and their host plants.

A connection with the high country

"Having grown up in Canberra, the high country has always been dear to my heart. Thinking back to childhood summer road trips brings back memories of the sweeping plains of the Monaro, quiet country towns, and pristine swimming holes – along with peacefulness that grounds the soul."

"Understanding how insects respond to climate change is integral to maintaining a well-functioning alpine ecosystem. The challenges lie in how to get people to care about these often overlooked critters, and how to advance our understanding of their ecology when we often don't even know what species are present."

Megan Head

The heat is on

Image by Tobias Hayashi

Life in the high country is tough and plants deploy an extraordinary array of strategies to survive and prosper in this extreme environment. Whether these strategies will still prove as effective in a warming environment is largely unknown.

Plants adapting to climate change in the high country

Climate change is transforming Australia's high country. How will the region's flora adapt to these changes? At this point, we really don't know. We're only now uncovering some of the remarkable range of life strategies being used by plant communities and species in the high country, strategies that enable them to live in this harsh environment. How these strategies will assist or hinder them in a warming climate is difficult to predict.

Too often our knowledge on how plants live at upper elevations is incomplete and superficial. We base our models and assumptions on part of the plant's form or lifecycle without realising we need to assess the whole plant life cycle to fully appreciate the species' strengths and vulnerabilities – as seeds, seedlings, juveniles and adults.

"In the face of rapid climate change and biodiversity loss we need to understand how the component plants and animals of these ecosystems will respond and how their interactions will change if we are going to be able to effectively manage these systems and maintain their amazing values."

Adrienne Nicotra

Prof Owen Atkin
Plant Physiologist, RSB

Owen's research focuses on assessing the impact of environmental gradients on plant physiological processes, particularly photosynthesis and respiration. The high country allowed him, during his undergraduate degree, to study what controls distribution of plant communities in the physically challenging environmental gradients of the alpine zone of the Snowy Mountains. More recently, he has studied temperature responses of leaf metabolism in snow gums in the Thredbo Valley.

A connection with the high country

"My interest in this area began way back when I was a Melbourne-based high school student when I was introduced to the delights of cross-country skiing among snowgums. For me, the high country of Kosciuszko National Park is a special place – unique in all its qualities and a wonderful place to recharge and reflect."

Plants adapting to climate change

Continued from page 7

Adrienne Nicotra and colleagues have been researching the ecology of alpine plants for many years to better understand how our alpine flora has evolved in this extreme environment. They are hoping that this knowledge will help them predict how climate change will impact on plants in the high country, and that this understanding will ultimately inform conservation and management of this vulnerable region.

Our understanding of plant reproduction of alpine species has improved substantially in recent years. Once upon a time conventional wisdom held that in response to the short growing season and poor conditions for germination that alpine plants reproduce primarily via vegetative strategies. Adrienne's research, along with collaborations with seed biologists around the world, has shown that recruitment from seed is an important factor. Indeed, they have shown that alpine plant species display a remarkable array of different germination strategies: some with dormant seed, others without, and yet others with the capacity to alter germination traits in response to conditions. In some species they revealed there was even variation in these traits among populations. That such a fundamental aspect of reproductive biology should be so sensitive and responsive is quite remarkable. However, such variety makes the task of understanding the impacts of climate change even more challenging.

Prof Adrienne Nicotra
Evolutionary Ecologist, RSB
Director, AMRF

Adrienne is a plant evolutionary ecologist whose research focusses on the capacity of plants to respond to environment and environmental change. She has passion for how mountain flora in particular deal with a shifting environment and what this means for alpine ecosystems. Adrienne's work considers all stages of the plant lifecycle: understanding how seeds germinate and establish, how young plants transition to adulthood, and how plants provision their offspring to persist and succeed in future generations. Adrienne's work scales across the system from understanding physiology of individual organs on a given plant to understanding how the plants and animals interact across the community.

A connection with the high country

"Since coming to Australia from the US in the late 90's, I've been drawn to the mountains. I grew up in the mountains of New York State and I just feel at home in the hills. But what drew me to and kept me working here is the community of people who work in and are so committed to the high country: researchers and managers and the community more broadly."

"With climates changing, how can we help develop the biological and ecological knowledge needed to improve management of the high country?"

Owen Atkin

Much of the current research in this area has focussed on impacts of climate change on adult plants. This ignores critical bottleneck phases in the plant population demography. In the face of disturbance (eg, more frequent extreme events, bushfires, not to mention land use, development, ski resorts, hydro power and electric lines), understanding plant recruitment becomes key. And, indeed, one can't really reach useful conclusion without taking a whole-of-life approach.

Global warming is affecting plant phenology, growth and reproduction in complex ways and is particularly apparent in vulnerable alpine environments. Warming effects reproductive and vegetative traits, as well as the timing of flowering itself, as keen bushwalkers have been noting. Thus, to make predictions about the persistence of species or their conservation and management we must look at broad comparative patterns across the flora at all life stages – assessing what the drivers of seed and vegetative traits are and seeking general patterns within Australia as well as globally – with detailed case studies of a few model species systems.

For example, work by Nicotra, Annissa Satyanti and Lydia assessed trait variation in response to warming in the alpine caraway (*Oreomyrrhis eriopoda*), an Australian native montane herb. Populations of the caraway vary in germination strategy. Some produce seeds that are dormant and require winter cold to alleviate dormancy and enable subsequent germination; other populations have no dormancy, and yet others produce a mix of dormant

"Climate change is a huge challenge for plants in the high country. High altitude species have nowhere to migrate up to. This makes them especially vulnerable to the warming predicted for the coming decades."

Danielle Way

Plants adapt to climate change

Continued from page 8

and non-dormant seeds on the one individual plant. These populations also show differences in tolerance of and response to warming in ways that will affect their relative chances for long term persistence under climate change. Warming experiments show that increased temperatures accelerate growth in the early stages of development, reduce flower and seed production and increase mortality. Following the entire life cycle reveals that warming will have some potentially positive effects (on early growth rates), and some negative effects (on reduced reproductive output) for the alpine caraway.

In another system (the waxy bluebell, *Wahlenbergia ceracea*), Pieter Arnold, Rocco Notarnicola, Loeske Kruuk, Nicotra and others showed that warming also leads to changes in physiological thermal tolerance of the leaves, as well as elements of reproduction. The group has shown that leaves of adult plants have remarkable physiological tolerance of both heat and cold extremes, which bodes well for surviving warmer summers. They've also shown that this thermal tolerance of photosynthesis varies among individuals in ways that could influence success under future climates. Though there is higher seed germination in warmer conditions, this increase falls far short of offsetting the more than fourfold reduction in parental fitness arising from the reduction in seed production.

Work over the years in the high country by several groups, including Marilyn Ball, Owen Atkin and Nicotra's has shown that establishment and success of alpine plants is strongly affected by frost exposure and snow cover. Though highly frost tolerant, young plants can accumulate leaf damage that slows growth and can lead to mortality if frosts come when the plants are not acclimated to the cold. Snow provides a perhaps counter-intuitive insulating effect protecting plants from freezing by keeping them at a comfortable temperature (around1oC) for most of winter. Changes in snow depth and duration will therefore increase the likelihood of cold-driven mortality in a warming climate.

Dr Danielle Way
Plant Ecophysiologist, RSB

Danielle has extensive experience in evaluating how cold-adapted tree species cope with climate change (elevated CO_2, warming, high VPD). Her focus on physiological responses at the whole plant and leaf levels (photosynthesis, respiration, water fluxes, growth and mortality) with some experience in measuring Eucalypts. Having just moved to Australia, Danielle wants to use her experience from high latitude species to study how high elevation species here are responding to those same global change drivers.

Dr Pieter Arnold
Ecophysiologist, RSB

Pieter's research investigates how plants tolerate and respond to heat stress and water limitation. He has a strong interest in the capacity of alpine plants and communities to respond to short-term extreme events and long-term environmental changes. Pieter explores aspects of plant responses, including seed germination, growth, photosynthetic function, thermal tolerance, flowering, and seed production. His research ultimately aims to determine whether plants have flexibility to function under environmental conditions that are expected in future, and the capacity to keep up with these changes through physiological adjustment and evolution.

A connection with the high country

"The alpine ecosystems in the high country are simply incredible places to be. They are filled with organisms with fantastic adaptations to cope with challenging conditions that we can learn from. I love that they offer such a powerful place for people of all walks to life to really reconnect with nature."

Plants adapt to climate change

Continued from page 9

Together these studies show that, ultimately, impacts of climate change will depend on how these effects play out in the field. While warming may lead to early establishment and an accelerated trajectory to seed maturity, it's not clear whether this offsets the trade-off with overall seed production or what the net effect on growth, carbon gain and lifespan will be. It's also clear that warming effects cannot be considered in isolation: concurrent drought or changed competitive landscapes are likely to alter ultimate outcomes at the community and landscape scale.

Small differences among growth rates, physiological tolerance of warming (and drying) and germination strategies may cascade to larger effects, with important implications for persistence of species in the alpine landscape. The tolerances of seeds, seedlings, young and mature plants are likely to differ and need be considered if we are going to assess the longer term persistence of species in our alpine landscapes.

Prof Justin Borevitz
Evolutionary Ecologist, RSB

Justin's focus is on landscape regeneration for climate change resilience. His research advances next generation sequencing and remote sensing in foundation species of agriculture and ecosystems to predict and manage for adaptability. His work aims to determine the genetic basis of climate adaptation in plants and microbes to augment restoration programs with precision treatments to limit the effects of drought, fire and flood.

A connection with the high country

"I love the mountains to get away and feel small in the rugged wilderness: skiing, hiking, and enjoying the diversity and development of the high forests that clean the air and water which sustain a large part of Australian life."

Simulating climate change in situ – the FutureClim snow-house

How do you simulate climate change for an alpine plant? Most experiments involve growing the plant in isolation in a greenhouse geographically remote from where it naturally occurs and manipulating its environment to simulate a climate-changed future (ie, raised temperatures and modified precipitation). Such experimental manipulations yield valuable insights but often fail to replicate how the species actually performs when growing as part of its plant community in its natural habitat.

To realistically explore how plants and plant communities perform in situ, researchers have developed the FutureClim experiment as part of the new Australian Mountain Research Facility (AMRF). The FutureClim infrastructure is installed over intact alpine grassy herbfields and uses solar-powered, in-ground heating to simulate the 4°C temperature rise and 20% precipitation reduction that alpine communities will face with climate change.

The FutureClim experiment will enable researchers to measure species and community-level responses to climate change in the vulnerable alpine region. The potential for plant, animal and microbial species to tolerate or respond to climate change will reflect community context, short-term plasticity in form and function and longer-term changes in gene frequencies. The facilities will enable researchers to answer the fundamental questions: What is the relative importance of fundamental physiology, phenotypic plasticity and interspecies feedbacks in determining climate change response at the community level? And thus, what is the potential for contemporary evolutionary response of the component species?

FutureClim: Climate control chambers for realistic, replicated, factorial field simulation of future warming & precipitation regimes.

After the flames

Image by Phil Gibbons

On 27 January 2020, the Orroral Valley fire swept through Namadgi eventually burning about 80% of Namadgi National Park (82,700 ha).

Recovery from fire

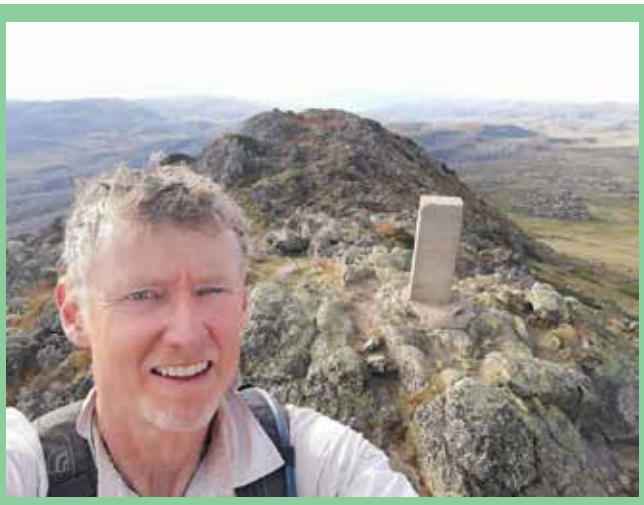
Fires are not unknown in Australia's high country. However, it appears that climate change combined with European land management are changing the fire regime across the high country causing wildfires to increase in frequency, severity and magnitude. What's more, in some areas it's believed intensifying wildfire regimes are driving the proliferation of woody shrubs. In other words, a potential feedback loop may be forming between increasing fire, the proliferation of woody biomass and landscape flammability.

The consequences of this are enormous for the environment, the economy and society but at the moment the dimensions of this challenge are largely unknown.

Most Australian animals and plants have some capacity to deal with fire, but are vulnerable to changes in fire regime, especially when that change occurs rapidly. Most vegetation

"Fire regimes are changing, with more frequent high-severity fire affecting high country landscapes. This shift toward more frequent fire is threatening the existence of long-unburned areas in these landscapes and compromising biodiversity conservation objectives more generally."

Geoff Cary



Prof Philip Gibbons
Landscape Ecologist, FSES

Phil's research focus is on the management of native vegetation for conservation outcomes. He has a particular interest in fire and he is involved in several projects that seek to inform how we manage fire and native fauna in the high country. To this end, Phil and his team in collaboration with the ACT Government have been researching relationships between fire frequency and the persistence of fauna; using artificial structures to help recover fauna after fire; and how to best manage landscapes to reduce the loss of property.

A connection with the high country

"My connection with the high country began in primary school when I read every novel in the Silver Brumby series by Elyne Mitchell. It's funny to think how brumbies have moved from being romantic icons to become a major threat to the high country."

Fire and refuge

Not only are Australian plants and animals adapted to some degree to fire, many species depend upon it. Take tree hollows as an example. More than 300 species of Australian vertebrates rely on tree hollows in some manner during their life cycle. Fires help create tree hollows in young and healthy trees because it exposes heartwood to fungal and insect attacks (which go on to produce tree hollows). Yet, repeated fires can kill the trees before they are old enough to develop hollows. Diego Avi, working with Phil Gibbons, is seeking to clarify the relationship between fire regimes and the current and future availability of tree hollows in the montane forests in Namadgi National Park south of Canberra.

When tree hollows are in short supply you often hear people advocating nest boxes as a solution. But the value of these artificial structures placed up trees is quite contested given that they may show low occupancy rates, are often taken over by unwanted, non-target species (eg, honeybees) and they usually degrade in under a decade. Nicole Damaggio, also working with Phil Gibbons in the Namadgi National Park, will be the first to empirically test the effectiveness of nest boxes in recovering hollow-dependent fauna populations in bushfire-affected areas after the 2020 Orroral Valley Fire.

Another major challenge for native animals following fire is the loss of protective ground cover, leaving them vulnerable and exposed to feral predators (cats, foxes and dogs). Heather Burns is testing the value of creating artificial refuges on the ground as added protection from introduced predators for reptiles and small mammals.

Image by Phil Gibbons

Can artificial refuges like this protect native fauna from introduced predators?

"How can we manage the high country's native fauna so they are more resilient to larger and more frequent fires that are predicted to impact Australia's high country with climate change?"

Phil Gibbons

Recovery from fire

Continued from page 11

communities and species in the high country, for example, have recovered following a single wildfire, regardless of the severity.

However, the impacts of increasing wildfire frequency are unclear for many vegetation communities and species. Obligate seeders (plants that regenerate via seed) are among those at risk from more frequent fires.

Less is known about the impact of intensifying wildfire regimes on the fauna of the Australian Alps, but impacts are likely to be most severe for those species inhabiting highly flammable shrublands, woodlands and forests. Research undertaken by Kelly Dixon, Geoff Cary and Phil Gibbons has demonstrated that animals are sensitive to time since fire with mammals and reptiles in montane forests becoming less common as fire frequency increases, a trend that is expected to worsen with global warming. Indeed, landscape-scale simulation modelling undertaken by Geoff Cary suggest that montane fire regime intervals in the ACT may approximately half with 2°C of global warming or by 2070.

Furthermore, the loss of vegetation in a post-wildfire landscape can lead to severe erosion of soils and the silting of streams. Thus, intensifying wildfire regimes also threaten a range of ecosystem services being provided by high country landscapes such as carbon sequestration and the regulation and provision of water.

The Australian Alps also provides billions of dollars of tourism revenue each year which is also threatened by lengthening wildfire seasons and increasing frequency. As one example, the Selwyn Snow Resort was incinerated in the massive Black Summer wildfires (2019/20) and is yet to reopen.

Image by Phil Gibbons

Blackened stumps following the wildfires that swept through the NSW high country during the Black Summer (2019/20).

Image by Marta Yebra

A sphagnum bog incinerated by the Orroral Valley fire of 2020. Bogs such as these provide critical habitat for threatened species as well as ecosystem services of water purification.

Assoc Prof Marta Yebra
Environmental Engineer, FSES

Marta's research focuses on using remote sensing data to monitor, quantify and forecast natural resources, natural hazards, and landscape function and health at local, regional and global scales. She is the Director of the ANU/Optus Bushfire Research Centre of Excellence which aims to protect Australia from catastrophic bushfires.

A connection with the high country

"Nature recharges me, and this applies especially to the high country which I experience through hiking, skiing, kayaking and all sorts of outdoor activities with family and friends. I am also passionate about photography and I find the high country landscapes to be some of the most inspiring a photographer could hope for."

Prof Geoff Cary
Bushfire Scientist, FSES

Geoff studies bushfires from multiple perspectives involving different scales (of time and space), regions and ecosystems. His research foci include landscape-scale simulation of fire management & climate change effects on fire regimes; fire ecology from genes to communities; house loss in wildland fire; and laboratory experimentation of fire behaviour.

A connection with the high country

"The high country is where I work and play. For two decades I have run university field trips to the montane landscapes of the ACT, teaching and learning about bushfire occurrence and dynamics. I've also been associated with numerous fire ecology studies in these landscapes. I also enjoy spending time hiking in montane and alpine landscapes across south-eastern Australia (as well as the high country landscapes in Canada, USA and Europe)."

"Areas such the high country that would not typically burn are now burning all the time, compromising the integrity of its diverse ecosystems"

Marta Yebra

Filling the gaps

Intensifying wildfire regimes present a multifaceted and novel threat to the Australian Alps and high country. To date, there are only a handful of published studies on the impacts of wildfires in the high country with many stemming from single, widespread wildfire events such as the 2002/03 and the 2019/20 (Black Summer) megafires. Researchers are now working to review and quantify the current state of knowledge (and knowledge gaps) concerning wildfires in the Australian Alps. Part of this involves mapping the history, geography, severity and trajectory of the wildfires across the Australian Alps since 1990; and modelling the potential feedbacks between climate, hydrology, vegetation and land management. With this information they hope to contribute to management action plans that will enable cost-effective solutions to maintain the biodiversity and ecosystem services of the Australian high country.

Landscape & flow

Image by Sarah Clement

Our mountains are Australia's water towers. Our nation's sustainable future depends on our capacity to protect and steward this critically important region.

Water & the high country

Water is central to our engagement with the high country. The way we have managed it in the past leaves a lot to be desired; and the way we need to manage it into the future will require enormous change and the filling of many knowledge gaps.

Our mountains are Australia's water towers. They are critically important for both irrigation downstream and the country's largest store of renewable energy, hydro-electricity. While covering less than 0.5% of Australia's land area, the Australian Alps are the source of over half of river flows in the Murray-Darling Basin which contains over 45% of Australia's irrigated production valued at over $10 billion.

The importance of that freshwater for a warming and increasingly drought-prone continent cannot be underestimated, yet this resource is under a real and growing threat. Warming effects are already well documented and the latest models predict that temperatures in the alpine region will increase by 3.5 – 6°C by 2100. Snow depth and duration are predicted to decrease by more than 90%.

Researchers at ANU are involved in multiple investigations on water in the high country. One of these involves the establishment of MountainFlows, a component of the AMRF. MountainFlows will monitor stream health and processes and assess the effect of experimental warming under different flow regimes on benthic organisms in small mountain streams.

A major concern is the dieback of the iconic snowgum eucalypts. The current hypothesis is that a warmer climate is enabling greater populations of a beetle to survive winters in the mountains. These beetles are ring barking the snowgums. The trees increase snowpack and water yields by 15%, so loss of the snowgums jeopardizes our rivers. The ANU research is assessing management options to address the tree dieback.

Further, the spongy peat bogs formed from mosses on the mountain tops play key roles in holding and cleaning water, and slowly releasing it into streams. These bogs are also habitat for threatened species, such as the corroboree frogs. Unfortunately, extensive areas of these bogs were destroyed

"How can we do a better job of monitoring water, fresh water biodiversity, the health of the wetlands, and the socio-economic benefits of using water? How can we do a better job of monitoring so that we make better decisions every week, every month, every year?"

Jamie Pittock

MountainFlows

Part of the infrastructure being developed within the Australian Mountain Research Facility (AMRF) is the project called MountainFlows. It will enable real-time measures of physiochemical water parameters and biotic sampling from high country streams paired with mesocosm manipulations of flow and temperature to assess impacts on stream organisms. This will yield critical data to quantify the effects of altered precipitation and warming on freshwater community dynamics, water quality and catchment health.

Dr Zach Brown
Biogeochemist, RSB

Zach's studies terrestrial biogeochemistry with a focus on dynamics of carbon, nitrogen, and water. These dynamics are influenced by (and influence) the biotic and abiotic processes of mountain ecosystems. These processes result in complex mountain ecosystems in which cool, moist conditions lead to carbon-rich soils and a diverse patchwork of species across the landscape. Consequently, shifts in these processes due to rising temperatures or shifting water availability can have cascading impacts on biodiversity, carbon pools, and water yield.

A connection with the high country

"I've been drawn to the mountains since my parents first took me skiing near my childhood home in the USA. I love the dramatic topography, harsh conditions, and adventure opportunities of the high country. The establishment of AMRF has been a phenomenal opportunity for me to work and play in the Australian Alps."

Professor Jamie Pittock
Environmental Policy Scientist, FSES

Jamie's research focuses on environmental policy, and specifically on how governments and societies can make better decisions on sustainable water management while conserving biodiversity, generating energy, growing food and responding to climate change. He has a particular interest in the energy/water nexus and has been involved in many investigations on river ecosystems in the high country including studies on returning environmental flows to rivers, and reducing the environmental impacts of the Snowy Hydro Schemes.

A connection with the high country

"I remember the excitement of childhood trips to the mountains. I have subsequently explored much of the high country from the northern tip right down through Victoria, including on a 21 day hike, as well as trips on the Snowy River. I feel privileged to be able to live on the doorstep of the mountains and it is a real pleasure to be able to do conservation science in the high country."

Water & the high country

Continued from page 14

by overgrazing by colonial pastoralists. Now, they are threatened by growing populations of introduced herbivores (horses) cutting tracks through the bogs, trampling and draining them. These wetlands are then at risk of drying out and burning, threats exacerbated in the warming climate. Restoration of these bogs can help them become more resilient, recover populations of threatened species and sustain water resources.

Also being studied from multiple perspectives are what's happening to our high country rivers. Many species and ecosystems, some critically endangered, are dependent on the maintenance of natural water flows; flows that have been considerably modified in the past by our regulation of rivers running through the high country.

For example, in 1972, 99% of the headwaters of the Snowy River were diverted into the Snowy Hydro-Electric Scheme (adjusted from 2002 to over 79%). Riverine ecosystems are adapted to a natural flow regime – volume of water, timing, frequency and duration. Following its damming, the Snowy River went into severe decline being overrun by weeds, clogged by sediment, and experiencing massive losses of

"The mountains are a major water catchment, carbon sink, and cultural site vital to the Australian people. Effective understanding and management of this system is essential to ensure these resources are available for years to come."

Zach Brown

Water & the high country

Continued from page 15

native fish and fauna. Following three decades of political action by grass-root community groups, attempts have been made to restore environmental flows to the Snowy and other mountain rivers. A lack of water due to drought and a lack of environmental monitoring has made it difficult to ascertain the success of these efforts. ANU researchers led by Jamie Pittock have been working on policy and management surrounding to enhance this river restoration.

While the Snowy Hydro-Electric Scheme unlocked considerable economic development by harnessing water for power and irrigation, the environmental costs of the venture were never fully addressed. In an effort to prevent repeating some of these mistakes, ANU researchers, again led by Professor Pittock, are working on ensuring the potential environmental impact of the new Snowy 2.0 pumped hydro project and additional development proposals are acknowledged up front and managed effectively.

The Snowy pumped hydro scheme involves linking two existing dams, Tantangara and Talbingo, through 27 km of tunnels and building a new underground power station. This will create a vast store of potential hydroelectricity to back up the nation's transition to renewable energy. Besides the disruption from construction of the generating infrastructure, transmission lines for the energy produced are set to run through Kosciuszko National Park (a move that has been described as 'like putting in a transmission line over the Opera House' by the National Parks Association of NSW).

Australia's high country holds so many cultural, economic and environmental values, and water flows through all of them. It's high time we began giving water the priority it deserves.

"Understanding hydrogeological context allows consideration of scenario-based change, including climate change, change associated with major landscape impacts (eg, bushfire, dieback) and change associated with land use or land management actions."

Leah Moore

Dr Leah Moore
Hydrogeologist, FSES

Leah is regolith geologist, soil scientist and hydrogeologist who has spent more than three decades evaluating how weathered rock and soil (regolith) are configured in the landscape, how water moves through the landscape and how surface water and groundwater interacts with regolith. She has worked to establish an array of rainwater, surface water, snow, soil moisture and groundwater sensors at Australian Mountain Research Facility sites in the ACT, NSW and Tasmanian high country. Leah has recently established the Applied Water and Soils Hub at FSES and this group will continue to work with colleagues from across the AMRF network to better understand hydrological and hydrogeological function in Australian alpine landscapes.

A connection with the high country

"The High Country is an important source of water to Australia's economy, environment and society, and the quality of this water is under assault on many fronts."

Image by Jamie Pittock

Environmental flows have been partially restored to the Snowy River. As yet it is still uncertain as to whether this has improved ecosystem health.

Biodiversity in the high country

Image AMRF

Traditionally, conservation management has focused on maintaining existing suites of species where they were originally found. Climate change and ecological transformation mean that this approach may no longer be viable into the future.

Saving threatened species in a changing landscape

Australia's high country is home to plants and animals that are found nowhere else in the world. Many of these species are threatened, and their survival depends on protecting their remaining habitat as best we can while also understanding the nature of the threats that have led to their decline. On top of this, we need a framework of adaptive management in order to learn 'how to manage' as the whole region shifts under climate change.

Kosciuszko National Park is one of our countries most significant protected areas. It provides habitat for multitude of endangered species including two species of corroboree frog (both critically endangered), the alpine she-oak skink (endangered), the broad-toothed rat (vulnerable), the smoky mouse and the stocky galaxias (a critically endangered native fish).

But just being inside a protected area is not enough to ensure the continued existence of these threatened animals. As the climate has warmed, the cool mountain habitat of these species is shrinking and massive bushfires have ripped into what's left. Australian ecosystems can recover from fire if given time but some believe it might take centuries to recover from the massive Black Summer fires of 2019/20; and the frequency of wildfires in the high country is increasing.

Wild horses are also now a growing threat to the ecological integrity of Kosciuszko National Park, doing irreparable damage to the fire-damaged bogs and water courses. Not only is this having a marked impact on water quality, it's

Frogs on the edge

The northern corroboree frog is a small, vividly-coloured species restricted to Namadgi National Park, in southern ACT, and adjacent areas of Kosciuszko National Park. Males call from moist edges of pools in sphagnum bogs. The eggs wait for autumn rains or snow melt before the tadpoles hatch. Its striking yellow and black longitudinal markings make it one of Australia's most easily recognised frogs. But even with no known predators and a distribution almost entirely within a pristine wilderness area, thanks to chytrid the northern corroboree frog is one of Australia's most threatened vertebrates. Pictured here is a frog in a sphagnum bog shortly after the Black Summer fires.

Image by Ben Scheele

Saving threatened species

Continued from page 17

also destroying critical habitat for threatened species such as the corroboree frogs. Ecologists have been calling for an urgent culling program but the whole issue is caught in a political battle over the right of the horses to be present in this region.

As wild horse populations have boomed – in part due to warmer temperatures – the issues associated with their management highlight just how politically sensitive land management decision-making can be. That's why social scientists such as Associate Professor Carina Wyborn are involved in attempting to understand the the social, cultural, and political dynamics that underpin what we value, and what trade-offs we are prepared to accept. Her research has revealed that a great diversity of people love the high country landscape, and while they all enjoy it in different ways, they feel that they have a right to enjoy the place as they always have. The challenge is that these conflicting values (eg, wild horses being allowed in national parks vs management removing the population) sometimes aren't aways compatible with each other, or with the nature conservation objectives of park management.

And if climate change, wildfires and hard hoofed ferals weren't enough of a threat to the tiny iconic corroboree frogs, disease in the form of the chytrid fungus might just be the breaking straw that pushes them over the edge. Captive breeding programs at zoos have enabled numbers of corroboree frogs to be built up but to what end if they simply die of chytrid disease when released into the wild. Dr Ben Scheele has been studying how best to reintroduce and manage threatened species in general, but with a specific focus on frog species and the corrobboree frogs. He has shown that a detailed understanding of a species behaviour and demographics might hold the key to helping frogs cope with chytrid, and points to the situation of the alpine tree frog as an example.

Dr Ben Scheele
Conservation Scientist, FSES

Ben's focus has been on examining threats to the iconic and critically endangered corroboree frogs; specifically, the impacts of climate change and the invasive chytrid fungus. This work has focused on identifying conditions that are conducive to the coexistence of corroboree frogs with chytrid fungus, and then using this information to guide the development of an innovative translocation program for the species. This project is a close collaboration between the captive breeding program at Tidbinbilla Nature Reserve, ecologists from the ACT Government and ANU.

A connection with the high country

"I remember the excitement of childhood trips to Tidbinbilla at the foot of the mountains. I have subsequently explored much of the high country from the northern tip right down through Victoria. I feel privileged to be able to live on the doorstep of the mountains and it is a real pleasure to be able to do conservation science in the high country."

Professor Scott Keogh
Evolutionary Biologist, RSB

Scott's research focuses on the evolutionary relationships of Australian animals. His research group builds phylogenetic (evolutionary) trees for species and populations and then uses them to address problems in conservation and to study the evolution of traits. He has worked on the population genetics and evolution of high-country reptiles and frogs with a particular eye toward understanding how mountains have shaped the genetic patterns we see today.

A connection with the high country

"I have a personal connection to the high country through our work on the conservation genetics of the most iconic frogs of the high country - the corroboree frogs. We are studying both historical wild diversity and we are helping guide the captive breeding programs for these critically endangered frogs."

Saving threatened species

Continued from page 18

The alpine tree frog experienced a similar pattern of decline to the corroboree frogs. Remnant populations of alpine tree frogs, however, now appear relatively stable despite the continued presence of chytrid. Studying these populations, they found that their persistence is facilitated by high juvenile frog recruitment. Chytrid is rare in tadpoles and juvenile frogs. This allows the next generation to disperse into woodland habitat free of the disease. Because chytrid is an aquatic pathogen, individuals have low risk of becoming infected in terrestrial environments. However, when individuals reach sexual maturity they re-turn to wetlands to breed and subsequently become infected. Luckily, adults are able to breed prior to succumbing to the disease.

Assessing which management strategies are most suitable for a given frog species depends on a detailed understanding of chytrid dynamics and frog species ecology. Ben's research is suggesting that interventions against chytrid should target amphibian life history stages most affected by disease or at high risk of chytrid exposure. For most species, a variety of approaches implemented at different spatial scales will be necessary. The important point here is that given the lack of proven effective strategies, all interventions should be implemented within an experimental framework. To optimize progress, research aimed at understanding the mechanisms underlying interventions should occur concurrently with their application.

This extends beyond frogs to saving threatened species and conserving biodiversity in general across Australia's high country. Because climate change is shifting the baseline of how these landscapes function, all our management needs to be treated as an ongoing experiment in which research informs management and vice a versa in a framework of adaptative management.

We will also need to acknowledge that change is inevitable and that our expectations on which natural values we can expect to keep will need to be revisited. Traditionally, conservation management has focused on maintaining existing suites of species in situ. Climate change and ecological transformation mean that this approach may no longer be viable into the future. This makes decision-making incredibly difficult: when and how do managers decide to shift perspectives to consider managing for the suite of species that will be there in the future? What does this mean for the threatened species that we hold so dear right now? How do we build broad social acceptance for changing the objectives of management to maintain future-use values as opposed to those of the past? And what knowledge might we need to support these decisions?

Dr Mitzy Pepper
Biogeographer, RSB

Mitzy is a lizard biogeographer; she builds genetic trees of different species to investigate evolutionary patterns and processes. She's particularly interested in understanding how geology and past environmental change shapes genetic structures of populations across landscapes. The high country has experienced a tumultuous environmental history unlike any other place in Australia. Mitzy's work is helping to determine how alpine biodiversity evolved, which will help inform priority areas for management in the face of rapid environmental change.

A connection with the high country

"I have been astounded to learn about the dynamic geological and climate history Australia's alpine landscapes have experienced in the recent past. That indigenous Australians witnessed the complete transformation of rainforest and woodlands in the high country to cold, bare open grasslands all the way down to the elevation of Black Mountain in Canberra just 20,000 years ago - the impact of this environmental turnover and the widespread displacement of species that lived there just boggles my mind."

Prof Saul Cunningham
Systems Ecologist, Director, FSES

Saul is interested in plant-insect interactions in the high country, including pollination networks and the relationship between snow gum and the dieback-causing beetle, and how these will respond to global change.

A connection with the high country

"I grew up in Victoria and visited the high country regularly from my teenage years onward. From the outset was captivated by the spectacular landscapes."

Framing values & rules

Image by A Cary

Australia's high country contains many values, some easily measurable, others highly contestable. In a time of ongoing change, how can we frame these values in order to explore how they will interact in an uncertain future?

Capturing the many values of the high country

While Australia's high country is much loved by Australians and provides so many vital functions to society, it is surprisingly 'forgotten' when it comes to setting national priorities. It's rich in environmental, cultural and economic values, all under threat by global and regional change, yet it receives less attention compared to other 'iconic' regions of Australia.

Consider the Great Barrier Reef. Two million people visit the Reef every year; you'll see colourful images of fish, tourists and coral on the Reef in any tourism literature promoting Australia; multiple institutions have been established to manage and carry out research on the Reef; and many studies have been undertaken by multiplie organisations attempting to capture the Reef's many values. One recent high profile study, undertaken by the economic consultant group Deloitte, found that over 60,000 people are employed by tourism businesses on the Reef and that this sector alone generates over $6 billion every year.

"While conservation management has traditionally focused on maintaining existing suites of species in situ, climate change and ecological transformation mean that this approach may no longer be viable into the future. How do we build broad social acceptance for changing management objectives to maintain future use values as opposed to those of the past?"

Carina Wyborn

Assoc Prof Carina Wyborn
Social Scientist, FSES

Carina works at the intersection of science, policy, and practice, where she is interested in understanding how decisions are made in complex and contested environmental management challenges. She is particularly interested in the capacities that enable future-oriented decision making, and the methods and practice that are used to support decision-making in the context of uncertainty. She cut her teeth in this field researching perceptions of climate change among land managers and recreational users of Kosciuszko National Park.

A connection with the high country

"Both of my parents did their PhD research (geology) in the region, and so our family would go there for work field trips, holidays, camping and skiing. Now that I have my own family, I am passing on the family tradition, camping by the same rivers I visited as a kid, and one of my greatest joys is seeing my son adventure in the high country, and get as excited as I am about returning there each year."

Capturing high country values

Continued from page 20

These numbers are comparable to the economic activity generated by tourism in Australia's high country yet no comprehensive up-to-date evaluation bringing this information together is available.

It is estimated that the Alps provide $10 billion in water to the national economy every year but no comprehensive study has been done on how this fits into the national economy or what this means for the wellbeing of society or what would happen under different land-use scenarios in the high country.

The Great Barrier Reef is experiencing multiple events of mass coral bleaching caused by warming waters associated with global warming. This threatens to transform the very identity of the Reef, and every mass bleaching event is associated with extensive media coverage and considerable debate and research on how this challenge might be met.

Australia's high country is grappling with a mass ongoing snow gum dieback event which, like the bleaching of the Reef, threatens the very identity of this region as well. Dieback has been present for decades at low level; its recent emergence at outbreak levels is only now being given serious attention with solutions largely being poorly understood. What would it take for snow gum dieback to be given the same national priority as mass coral bleachings on the Reef?

Then there are the many cultural values of the high country; think of the disappearing bogong moths and their cultural significance to First Nations peoples or the pastoral traditions that gave us the myth of the Man from Snowy River. How are such values incorporated into our value frameworks and how do these things affect decision-making processes? For example, "brumbies" are much revered icons of cultural heritage for those communities who grazed cattle in the high country prior to the creation of the national parks. Yet for others, the populations of "feral horses" have now reached levels that are threatening the natural heritage values of the parks. Different communities will have different perspectives on which of these values should take precedence, placing decisions over the management of these horses at the intersection of strongly opposing views, fierce politics, and historical conflicts over the termination of pastoral leases when the parks were established in the

"If we are to make the tough decisions needed to properly manage these regions, we need integrated environmental and economic information. Environmental accounts provide this and can bring multiple values of the high country into the national decision-making."

Michael Vardon

"To address the environmental challenges facing the high country we need to change how we think about governance: the how, where, and why we intervene."

Sarah Clement

Assoc Professor Michael Vardon
Environmental Accountant, FSES

Michael's initial career focused on animal population dynamics and wildlife management but this shifted to environmental accounting when he saw the urgent need for methods to incorporate a range of natural, economic and social values into our national decision making. Since then he has carved out an international reputation as a champion and developer of the UN backed System of Environmental-Economic Accounting, and has demonstrated its value by applying it to many diverse situations, including the high country. Michael's production of environmental accounts for Victoria's Central Highlands demonstrated for the first time that the traditional forestry industry is worth a tiny fraction of the water and carbon storage value of the region.

A connection with the high country

"I love the high country, but I sometimes wonder how we can compare the values of giant dams and wild horses with all the other things that give value to our alpine landscapes."

"People use the high country in so many different ways and at the same time its capacity to keep providing everything that we want is changing. The big challenge is how to jointly guide decision makers towards the best collective outcome for the future."

Saul Cunningham

Capturing high country values

Continued from page 21

1950s.

Then there is the question of water. The high country is the source of water for a significant portion of Australia's agriculture, but it also holds a range of other values. It is critical to the generation of electricity (hydro and stored hydro power) and important for recreation while also sustaining many riverine ecosystems. How are these different values compared, reconciled and managed together?

There are no neat or comprehensive answers to these challenges but ANU researchers are working on a number of methods that enable us to capture a range of these values from the high country and make them more visible to decision makers and managers. Approaches such as environmental accounts and the three-infrastructures framing for water are methods that seek to reveal the trade-offs between multiple values. Traditionally, decision makers have focused exclusively on economic values and ignored cultural and environmental values because dollars are more easily measured than the love of bogong moths or the loss of a threatened alpine bog. This has meant that these non-economic values are often discounted and forgotten in our decision making, and often lost altogether.

By capturing the multiple values of the high country in frames that bring them together, we have a better base for our management and policy; such a framework enables trade-offs to be assessed. In the process, the significance of Australia's high country is likely to be better appreciated by

Dr Sarah Clement
Policy Scientist, FSES

Sarah's expertise is in environmental governance and policy: how we make decisions, prepare for the future, and design policies to help society effectively confront environmental challenges and their social causes. Her current project focuses on enhancing our capacity to deal with the risks and consequences posed by bushfires. She aims to identify the best ways to address these current and future challenges not only in the Alps, but across Australia. Previously she investigated the governance surrounding biodiversity management in the Australian Alps.

A connection with the high country

"The High Country holds a special place in my heart: I love wombats, and at the time I was living in Western Australia, not exactly a wombat hotspot! The first place I got to see wombats in the wild was after I proclaimed my love for them at a workshop in Jindabyne, and a kind person obligingly took me to see them in Kosciuszko National Park."

Change and reform in the high country

Change is coming to the high country. Everyone appreciates this, but no-one knows exactly what it will look like. Governance is all about the how, the where, and why we intervene in the face of this change. Changes in any area of governance affects outcomes – for better or for worse. Sarah Clement believes the constant cycles of disaster, inquiry and (often partial) reform have made our relationship with 'change' fraught with difficulty. One of our biggest challenges is to abandon the idea that reform means apportioning blame and accountability, and that governance itself is a barrier to change. Sarah says, instead, we need to view reform as a way to effectively address the causes and consequences of environmental impacts. Reforms of governance need to be targeted at the factors which are most likely to influence these outcomes. This is a major challenge in research, but one, if accomplished, would lead to more feasible and focused plans that result in a resilient and sustainable high country.

Take fire for example. Sarah's research is focussed on three main challenges posed by bushfires: protecting life and property, protecting the environment and biodiversity, and adapting to the risks posed by future climate change. She aims to identify the best ways to address these current and future challenges not only in the Alps, but across Australia. Using new and existing data, she aims to identify the most important factors in addressing these challenges and test options to reduce their impacts: including those that threaten the high country with transformative change. Her project also focuses on other key aspects of fire: debates around fuel management; and how knowledge, values, and preferences impact management actions, with the aim of developing strategies to productively manage conflicts on these contentious issues.

The Australian Mountain Research Facility (AMRF) brings together leading institutions and researchers across four states and territories to produce world-leading ecosystem, evolutionary and biophysical science to guide adaptive management of high mountains across Australia.

AMRF supports research to assess the extent and effects of changing climate, water and fire regimes on ecosystem processes and their feedbacks and provide a structure for integrated research, management and governance of Australia's mountains.

AMRF consists of replicated field sites spread across the ACT, NSW, Victoria and Tasmania. Sites are comprised of 1ha monitoring plots (**the AMON** - Australian Mountain Observation Network) whose sensor arrays provide open access, live data-streams for a wide range of microclimatic and hydrological variables. These data-streams are available for anyone who wants to use them. In addition, several pieces of experimental infrastructure provide opportunities to simulate future climate conditions and assess response of alpine organisms. **Mountain Flows** is a fresh water warming and flow regime experiment to monitor abiotic and biotic components of stream health. **DroughtNet** rainout shelters reduce precipitation and feed data into an international network of sites to deliver data on impact of altered precipitation on vegetation growth and community composition. **FutureClim** is an in situ soil warming and drying infrastructure for realistic field simulation of future warming & precipitation regimes.

AMRF seeks to support capacity building and research to assess the extent and effects of changing climate, water and fire regimes on ecosystem processes and their feedbacks and to provide a structure for integrated research, management and governance of Australia's mountains.
This ARC LIEF (Linkage Infrastructure Equipment and Facilities) funded project provides open access data streams and aims to catalyse interdisciplinary research and collaborations with strong links to industry and management stakeholders.

AMRF
AUSTRALIAN MOUNTAIN RESEARCH FACILITY

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University of Tasmania
University of Canberra
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