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traditional knowledge while targeting mountain biodiversity genetic resources research. Geo-coded information is essential in the inventory and assessment of biodiversity through biological and ethnobotanical studies on LSS in the Himalayas, Central Asia, Andes, Alps and other mountain regions.

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Spread of Non-Native Plant Species into Mountains: Now is the Time to Act

Keith McDougall, Sylvia Haider, Tim Seipel, Christoph Kueffer and MIREN Consortium

Mountains are hotspots for biodiversity and of great importance to human societies. The worldwide placement of mountain areas in conservation reserves is recognition of their value. Managers have to remain vigilant to protect mountain ecosystems from future threats. One such threat is invasive, non-native plants. Invasive plants alter plant communities, affect grazing lands and homogenise the world's flora. Mountain areas have not been as intensely affected by plant invasions as low elevations because of harsh climatic conditions, isolation and limited human pressure. The relative resistance of mountain ecosystems to plant invasions may be transient, however, in light of ongoing global change (e.g. climate change, expansion of human pressures). Unique mountain flora, fauna and habitats may become increasingly susceptible to invasions.

Building a knowledge base for managing plant invasions in mountains

In 2005, the Mountain Invasion Research Network *(MIREN, www.miren.ethz.ch)* was launched to investigate the degree of plant invasion in mountain ecosystems, to understand the invasion process using elevational gradients as a model system, and to evaluate and communicate the future threat from plant invasions associated with global warming and changing land use patterns (Dietz et al. 2006). MIREN is associated with the Consortium for Integrated Climate Research in Western Mountains (CIRMOUNT), the Global Mountain Biodiversity Assessment (GMBA) and the Mountain Research Initiative (MRI). The MIREN core program comprises comparative research in six mountain regions (Pacific Northwest USA, Swiss Alps, Chilean Andes, Australian Alps, Hawaii, and the Canary Islands Spain), covering major climatic zones including island and continental systems (Figure 1). Beyond the core program, MIREN networks with researchers and managers in mountain regions worldwide. In an issue of 'Perspectives in Plant Ecology, Evolution and Systematics' on plant invasions into mountains (Vol 7, No 3), MIREN showed that non-native plants are present in mountain ecosystems around the world, but that the distribution patterns and impacts along elevation gradients differ between regions. In an upcoming article of 'Frontiers in Ecology and the Environment' (Pauchard et al. in press), we present a

Figure 1: Lupinus polyphyllus, a native of the Pacific Northwest of North America is a garden escapee a) in the mountains of Switzerland and b) in the abandoned gold mining village of Kiandra in the Australian Alps. Lupinus illustrates the future threat of invasions by amenity species to mountain areas. Photos: T. Seipel, S. Haider.

Figure 2: Unlike most non-native species in the Australian Alps, Hieracium aurantiacum (Orange Hawkweed) does not require disturbance for establishment in natural vegetation. It grows in a large range of habitats and has a reproductive advantage over native species by using vegetative spread, asexual seed production, seedling establishment and flowering over several months, with long distance wind dispersal of seeds. Photo: K. McDougall.

conceptual framework for understanding these differences and, more generally, plant invasion into mountains. Although factors determining plant invasions at high elevations are the same as in other ecosystems, the manner by which they influence the outcome of invasions differs in mountains because of the extreme conditions.

A database of non-native plants in mountains worldwide (McDougall et al., in preparation) contains almost 1,500 naturalised or invasive plant taxa. In a more detailed analysis of 13 mountain regions harbouring c. 1,000 taxa, more than half the taxa were recorded in only one region, suggesting that the total pool of potential invasive species is large. Adjoining lowland areas act as the main source of non-native plants, as indicated by the high degree of similarity between lowland and high elevation non-native floras in particular regions. The most widespread mountain plant invaders are species typical of native European pastures (e.g. *Dactylis glomerata, Rumex acetosella, Trifolium repens)*, which were probably introduced to many regions during the past few hundreds years in association with livestock grazing. Only a few of these (e.g. *Achillea millefolium, Holcus lanatus, Verbascum thapsus)* are regarded as threats to biodiversity where they occur. In contrast, woody species (e.g. *Acacia spp., Cytisus scoparius, Pinus spp., Salix spp., Ulex europaeus)*, which were often introduced for soil improvement or forestry, are widely regarded as problematic because they alter vegetation structure, soil chemistry and fire susceptibility. Further, taxa from the genera *Centaurea, Hieracium* and *Linaria* are of particular management concern in many regions. These species were introduced as amenity plantings in gardens. With the shift in many mountain regions from agriculture to tourism, the threat from ornamental plants such as these species is likely to grow.

A field survey of non-native plants along elevational gradients in the MIREN core areas corroborates these patterns. We found the highest number of non-native plants at the lowest elevations and the decline in the species richness gradient is remarkably consistent between regions. The species found at high elevation are generalist species that occur over large elevational ranges. It seems that most of the current mountain non-native flora was first introduced to lowland areas and later spread to higher elevations. It has been argued that this introduction pathway through lowland climates may act as a "filter" and reduce the risk of mountain invasions (Becker et al. 2005). If, however, mountain specialists are directly introduced from one mountain region to another one through the horticultural trade, the lowland filter will break down.

Towards a global, proactive strategy against the emerging risk of mountain plant invasions

Mountains are one of very few ecosystems not yet severely affected by plant invasions. This gives researchers and managers the unique opportunity to respond in time to this emerging threat. While prevention is the most cost-efficient management strategy, new non-native species are bound to arrive. Managers must therefore employ a range of strategies. Our results indicate that, in many mountain regions, a shift is taking place in land use from pastoral (e.g. range improvement and grazing of native pastures) to tourism activities. With this change, managers can expect a shift in the composition of their non-native plants and, in places, an increase in the threat posed by them. Non-native plants that came with grazing animals were mostly generalists that have relied on disturbance from humans and stock for their persistence and were not specifically adapted

to a mountain climate. Species arriving with tourist infrastructure, in contrast, have often been selected for their cold-hardiness. Many horticultural introductions are relatively recent (e.g. from the very species-rich mountain region of Yunnan in China; Mack and Sun 2002), and their potential to become invasive is not known. The safest approach for mountain managers is therefore to restrict the deliberate introduction of all novel non-native species to mountains.

An inventory of non-native plants is an important resource for managers of any biodiversity reserve and should be a priority for mountain areas, which face a growing threat from invasions. MIREN is developing an online database of mountain invasive plant species that will allow managers to evaluate the threat that such species may pose in their regions. It is also important to monitor populations of non-native plants as some will be benign or transient and some will be deleterious. Such a monitoring programme needs to include contingency plans for the event that a highly invasive non-native species is discovered. Eradication is possible only in a very early phase of an invasion and this is particularly true in the complex topography of mountains. In the Australian Alps, MIREN has worked with local land managers on the eradication of two Hieracium species (*H. aurantiacum and H. praealtum*) (Figure 2). Both species are thought to have been introduced through tourist infrastructure in recent decades (Williams and Holland 2007). They have spread rapidly, aggressively competing with natural vegetation, and, although only discovered in the last decade, are now the most costly non-native species being managed in the Alps and one of the greatest threats to these mountain ecosystems. In Australia, at least, the old notion that mountains are somehow resistant to serious plant invasions has been destroyed.

A comprehensive strategy against plant invasions may include more than prevention of novel introductions, monitoring and eradication. For instance, codes of conduct on cleaning clothes, tools and machines before entering natural areas may reduce the risk of spreading non-native species by visitors and managers of natural areas. More generally, awareness building and networking with stakeholders (e.g. the horticultural and tourism industries and the general public) are vital. In the European Alps, MIREN has begun collaboration with the Alpine Network of Protected Area *(www.alparc.org/)* and with the EU Alpine Space project ECONNECT on developing a comprehensive strategy for dealing with the risk of invasive plants. Experiences from this pilot project will later be tested and adapted in other mountain areas. MIREN welcomes inputs about best-practice approaches from managers who already have experience with managing invasive plants in mountains.

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Changes in Biodiversity Patterns in the High Andes - Understanding the Consequences and Seeking Adaptation to Global Change

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Over the past decade, a multinational group of investigators has been working in concert to observe, understand and develop adaptations to climate change and its impacts on species, habitats and people in the uppermost reaches of the biosphere at high alpine field sites along the central Andes of Peru, Bolivia and Argentina.

Global context

As infrared radiation is captured by greenhouse gases in the higher atmosphere, there is a faster rate of temperature increases at higher altitudes, with consequent destabilisation and changes in other high altitude climate parameters. Whole regions will develop entirely new (no-analog) climate suites, to which only certain more ruderal (opportunistic) species will be able to adapt. With the speed of change, plant and animal species may not be able to migrate fast enough. In addition to invasive exotics, disease advances are already being documented (Seimon et al., 2007; UNFCCC, 2007).

In the high Andes, changes in physical environments impinge on a complex and intricately interrelated mosaic of human land use and biodiversity with different degrees of impacts. The usual temporal variability of climate is superimposed in these landscapes on a fine grain spatial variability; cloud forest can give way to dry shrublands or grasslands within tens of metres.