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The Impacts of Skiing and Related Winter Recreational Activities on Mountain Environments

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FOREWORD

Not only do mountain regions cover a significant proportion of the land area of many countries of the world, they are also home to 10% of the world's population, and furthermore provide half of humanity with essential goods and services. Mountain habitats cover broad altitude ranges and contain large geological, topographical and climatic diversity. External influences such as atmospheric changes and human land use interact with these gradients, which in turn affect biodiversity, ecosystem processes and landscape functions. However, mountain ecosystems recover slowly if disturbed. Hence, they must be classified as particularly sensitive to change. Due to the close interactions between highlands and forelands, the impact of transformations on mountain environments is not restricted to the mountain regions themselves but may have far-reaching downstream effects.

Mountain Agenda estimates that about 15 to 20% of the world's tourist industry is located in mountain areas, which generates about 70 to 90 billion US$ per year. Growth rates in tourism are generally estimated to be at around 5% per year; however, growth in mountain tourism is quite inconsistent. The variable topography and scenic beauty of mountains, the high diversity of natural and near-natural habitats as well as the diversity of cultural landscapes, and the clean and cold air appeal to the "wellness and health" and eco-tourist. Moreover, mountain regions provide various opportunities for sports and leisure activities which attract tourists in summer as well as in winter. However, mountain tourism is increasingly characterised by extensive structural changes. Conventional divisions are starting to disintegrate due to today's value pluralism. For example, the typical (alpine) summer or winter tourist does not exist anymore, and the boundaries to seaside and city tourists are fluid. The trend towards so-called "stand-by-tourists", who are taking their decisions at increasingly shorter notice, is continuing. Although mountain and especially skiing tourism has been increasing in many parts of the world and is perceived as a fast way to boost economy and gain wealth in mountain regions, the influence of demographic change on winter sports in particular has been evident for quite some time in Europe. It became apparent that the older target group is expecting a specific experience, with nature playing quite an important role, but culture and health as well as service are important aspects too. Even today, skiing federations are complaining about a decreasing number of young athletes. One reason for this decrease may be the increasing distances which have to be covered in order to learn and practise winter sports. Tourism is also extensively affected by a change of demands which stresses the diversity of experiences over the duration of the holiday.

Besides these structural changes, the winter tourism industry has to address the challenge of climate change. Mountains are among the regions most sensitive to climate change, and mountain tourism will be greatly affected by it. Today's adaptation strategies are usually technical: enhancing the conditions of artificial snow production, levelling the surface of ski slopes in order to reduce the amount of artificial snow needed, and expanding and developing new skiing areas at higher altitudes and on glaciers. The intrinsic problem of these strategies is the degradation of natural ecosystems, which is increasing with the area affected by ski-lifts and ski-pistes, artificial snow, and ground levelling. It is therefore all the more important to know and understand the impact of ski-tourism on mountain ecosystems.

Even though the first investigations on the ecological effects of ski-pistes were conducted in the 1970s, an extensive work collecting the state-of-the-art knowledge on the topic has thus far been lacking. This eBook is filling that knowledge gap by providing comprehensive information concerning the global impact of ski-tourism on mountain ecosystems, with a special emphasis on vegetation, soils, wildlife and restoration ecology. May it help to raise awareness of the vulnerability of mountain regions and promote the precautionary principle in their management! It is my hope that it will also encourage sustainable strategies of tourism development in mountain areas in our fast changing world.

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PREFACE

At the beginning of 2009, we were considering the possibility of writing an eBook about the impact of skiing on mountain ecosystems. Antonio Rolando had been studying the impacts of ski-pistes on birds and ground-dwelling arthropods since 2003, had experienced the celebration of the XX Olympic Winter Games of Turin in 2006, and had become convinced that the effects of winter sports and tourism on the Alpine environment needed attention. Christian Rixen had been studying the effects of skiing on alpine vegetation since 1999. The option to write an eBook produced by Bentham Publishers provided an ideal opportunity to synthesize the current key research on impacts of skiing on mountain environments. After more than two years of hard work, the eBook is finally realized.

Mountain ecosystems represent one of the last strongholds of natural and semi-natural terrestrial ecosystems. In present-day Europe, in particular, many lowland ecosystems are being transformed at an alarming rate by urbanization or by the intensification of agriculture. Mountain areas are usually less anthropomorphically impacted, but, on the other hand, are also more sensitive to human disturbance, *e.g.* as caused by winter tourism. The European Alps, with relatively high levels of development and high population density, epitomize the difficulties in reconciling tourism and nature conservation. They are one of the most frequently visited mountain regions of the world. International arrivals are estimated to amount to about 30 million people every year, a little less than 4% of the world's total human population and almost 7% of that in Europe (CIPRA 2010). Overall, the Alps rank as the second largest tourist destination in the world after the Mediterranean coast. The great number of tourists brings economic benefits to local communities, but can also impact sensitive ecosystems and species, mainly due to the construction of new buildings, access roads and other human installations. Winter sports in general, and the skiing industry in particular, hold a prominent role as an impacting factor because of the large scale changes they cause at the ecosystem and landscape levels. The establishment of ski-pistes for downhill skiing (also referred to as ski runs) involves significant impacts on ecosystems along a broad altitudinal range that can affect both the montane/subalpine and alpine belts (forest and treeless zones, respectively). During ski-piste construction in particular, pastures or forest tracts are often clear-cut or treated with heavy machinery, resulting in considerable ecosystem damage. The increase in free-riding snow-sports away from the prepared ski pistes, although less directly impacting on habitats, can represent a novel threat for wildlife. Attempts to restore disturbed sites are often made, but are not always successful. One of the most pressing issues with winter tourism today is therefore to define and protect the most sensitive natural areas, but also to restore disturbed sites by the best possible means.

The main aim of our eBook is to provide information concerning the global impact of ski-tourism on the soils, vegetation and wildlife of mountain ecosystems to academics, corporate researchers, graduate and under-graduate students and, obviously, policy-makers. Such knowledge is, in fact, the necessary pre-requisite to formulate policies for sustainable development in mountain areas.

This eBook is a truly international product, with contributing authors from many different countries (Austria, Canada, France, Italy, Switzerland and U.S.A.) even though, admittedly, most of the research described herein has been carried out in the European Alps.

The sequence of ten chapters intends to emphasize the ecological importance of mountain habitats, to describe the impact of skiing on soil, vegetation and fauna and, last but not least, to illustrate the state of the art in restoration ecology. The chapters are written either as review papers or as research papers (presenting new data or illustrating the results of previous research).

Chapter one, by Kathy Martin, deals with the ecological value of the mountain environment. She considers North American mountains and warns that, although most alpine habitats appear to have remained relatively intact, ecological change within and adjacent to mountain habitats is occurring rapidly over extensive areas. Alpine ecosystems in North America have experienced large increases in the amount and diversity of human land use, with some areas showing significant deterioration due to recreational activities (such as skiing), livestock grazing, mining, and airborne contaminants. High elevation habitats are vulnerable to erosion, and vegetation recovers slowly after such disturbances. At a landscape scale, developed valley bottoms constitute dispersal barriers for wildlife species with seasonal vertical movements. Since we lack a comprehensive understanding of what is required to maintain ecological processes in alpine habitats, and have limited experience in restoring these sensitive ecosystems, Martin strongly advises the precautionary principle for managing mountain ecosystems. The remaining nine chapters mostly focus on studies carried out in the European Alps, and research carried out in other European (*e.g.* the Pyrenees) and non-European mountain areas (in North America and Australia) is also described.

Chapter two by Christoph Marty addresses the snow cover and changes in snow reliability in ski areas. A general decrease in snow cover has already been observed in most alpine countries since the 1980's. Warmer winters have caused a reduction in snow cover at low and medium elevations in ski resorts. However, above 2000 m a.s.l. precipitation usually determines the depth of the snow cover. According to climate projections, the snow reliability will probably decrease further, especially at low elevations, in inner-alpine valleys or on southern slopes. The winter tourism industry has responded to the observed changes in snow cover with technological measures such as snow-making, which presents a new form of pressure on mountain ecosystems (see also chapter four).

Chapter three by Michele Freppaz and collaborators reviews one of the most severe impacts of skiing on alpine terrain: the disturbance of the soil due to skiing and the construction of ski-runs. When ski-runs are created, the rough soil surface is usually leveled with heavy machinery, which perturbs the topsoil and often entirely removes weathered soil horizons. Subsequent problems are soil compaction and reduction of water and air permeability. Restoration through the seeding of plant material is difficult because of a depletion of organic matter in the soil, a reduction of soil aggregate stability and nutrient imbalance. Hence, one of the most crucial challenges in restoration of disturbed sites at high altitudes remains the improvement of the soil organic matter and nutrient status (see also chapters nine and ten).

Chapter four by Christian Rixen summarizes the impacts of skiing-related disturbance on alpine and subalpine vegetation. The main types of disturbance on ski pistes are the construction of ski pistes, snow compaction, and the production of artificial snow. The construction of ski pistes represents the most severe disturbance, especially at high elevations above the treeline, because the entire vegetation and topsoil is often removed (see chapter 3). The compaction of the snow by skiers and snow-grooming machines can induce soil freezing and can physically damage plants. Artificial snow production can change the vegetation composition due to an input of water and ions and because snowmelt is delayed by 2-3 weeks. Although restoration measures have improved considerably in the past decades, full recovery of the vegetation is still not achieved. Restoration measures according to the highest standards (*e.g.* using locally adapted plant material) need to become standard (see chapters nine and ten).

Chapters five and six were written by Antonio Rolando and his colleagues and take into account the impact of ski-pistes on invertebrates (ground-dwelling arthropods, in particular) and vertebrates (passerine birds and small mammals). Both chapters present the results of previous research (apart from some data on small mammals, that are presented here for the first time) and, taken together, demonstrate that the effect of ski-pistes depends on the animals and habitats considered. For example, forest ski-pistes represent a severe habitat loss for birds, small mammals and brachypterous (*i.e.* reduced wings or wingless) ground beetles, but, at the same time, they provide a habitat that can be colonized by macropterous ground beetles and spiders. Analogously, forest ski-pistes do not represent an ecological barrier for birds, but they probably are an obstacle to the movements of small mammals. Animal biodiversity of ski-pistes is generally low because of the poor vegetation cover of these anthropogenic linear elements; accordingly, the construction of ski-pistes with less or no vegetation removal would be the simplest way to maintain high levels of animal biodiversity.

Nathalie Buffet and Dumont-Dayot (chapter seven) provide interesting results on the fatal collisions of birds (galliformes) with overhead ski-cables. After having investigated collisions involving six galliform species in the Alps and in the Pyrenees (especially affected are the black grouse *Tetrao tetrix* in the Alps and the capercaillie *Tetrao urogallus* in the Pyrenees), they describe and discuss methods to reduce mortality by placing visual devices on the sections of wires where mortality risk is greatest.

Chapter eight, by Raphael Arlettaz and collaborators, focuses on the effects of winter tourism on the black grouse, which they consider as the most emblematic species of alpine biodiversity. The studies of Arlettaz's team demonstrate that outdoor winter recreation can significantly impact on the physiology, behaviour and demography of wildlife. However, some observations, seem to suggest that the black grouse (and, possibly, wildlife in general) can habituate, if not adapt, to human presence if direct contact with people practicing winter sports is avoided. The recognition of the specific environmental and species-specific preconditions for habituation and adaptation will be a further essential element to increase – *e.g.* by a set of finely adjusted measures - the tolerance of wildlife towards human presence. If such measures could be adopted in the Alps, the future of the black grouse in ski-developed areas could be brighter than it is currently believed: to some extent, successful human-wildlife coexistence may be mostly a question of fine-tuning of spatio-temporal land use by humans and wildlife. Finally, the authors are confident that the creation of winter refuges, once enforced over wide areas, would deliver beneficial outcomes for the preservation not only of black grouse, but also of other related Alpine wildlife threatened by the rapid expansion of outdoor snow sports.

Brigitte Klug, Berhard Krautzer and collaborators address high-altitude restoration in chapters nine and ten. Brigitte Klug *et al.* compared vegetation data from restored ski runs between the 1980's and the 2000's. She found that modern, regional and locally adapted plant mixtures were better suited to form a sustained vegetation cover on ski pistes than former standard plant and seed mixtures. Bernhard Krautzer and colleagues lay out in chapter ten the basic principles for a sustained ecological restoration of ski runs. A successful restoration at high elevation requires the combination of high quality application techniques and site-specific seed or plant material, containing species that are adapted to the given site conditions. On steep slopes with an inclination between 30% and 45%, additional mulching is necessary to reduce surface drainage and surface soil erosion during the first two vegetation periods. In the long term, only ecologically adapted subalpine and alpine plant species are stable and enduring enough to provide sufficient protection against erosion.

Skiing causes ecological disturbance, a very widespread phenomenon in nature, which may be defined as a discrete event in time that modifies landscapes, ecosystems, communities and population structure, changing the physical environment and the availability of resources. It should be stated that every landscape is shaped, maintained and/or changed by disturbance. Certain organisms may be negatively affected by disturbance, others positively. However, disturbance through skiing seems to exert more negative effects on soil, vegetation and animal communities than natural disturbance. The knowledge and awareness of potential threats of skiing represent an important starting point to develop a more sustainable policy of mountain land-use. Winter tourism is an important way to preserve and sustain human mountain communities, bringing revenue and jobs. The future challenge is therefore that of reconciling human requirements and nature conservation. Human activities are not automatically negative for mountain ecosystems, as sustainable grazing with livestock for thousands of years demonstrates. However, the negative impacts of skiing should be reduced through appropriate mitigation and restoration measures both during and after construction of infrastructures.

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CHAPTER 1

The Ecological Values of Mountain Environments and Wildlife

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Abstract: Mountain ecosystems consist of alpine zones characterized by rugged, partially vegetated open terrain with snowfields and rocky ridges above montane forests. These alpine grasslands and shrublands, sub-alpine parkland and montane forest habitats are high energy environments characterized by prolonged snow cover, steep terrain, extremes of heat and cold, and intense ultraviolet radiation. With increasing elevation, time for growth and reproduction decreases, environmental conditions become harsher with increasing stochasticity; at the highest elevations, hypoxic conditions add additional energetic living costs. For plants, dispersal of pollen, seeds or ramets may be limited by topography, weather conditions and patchy habitats where access to nutrients may be limited. These factors result in short, intense growing and breeding seasons.

Only a few plants and animals live exclusively in the alpine, while many mountain species breed in both alpine and lower elevation habitats. To cope with their difficult environmental conditions, plants and wildlife living in mountain habitats have adopted a slower lifestyle where they may produce fewer offspring each year compared to populations at low elevations, but many live longer and thus have more years to breed and replace themselves. The compression of several habitat types and variable environmental conditions within small spatial areas often results in high species endemism and biodiversity in mountain areas. High elevation ecosystems are used by migrating wildlife after breeding, a time when mountain habitats offer rich food resources and when productivity in many low elevation habitats has declined. Thus, we need to include life history periods outside the breeding season to accurately evaluate the biodiversity of mountain habitats. Connectivity is a key ecological process for high elevation wildlife populations. Connectivity needs to be maintained (1) among patchy habitat islands for breeding populations, (2) along mountain corridors for north-south migrants, and also (3) between alpine and adjacent lower elevation habitats and valley bottoms for both breeding populations and migrants.

Many European and Asian mountain ecosystems are heavily altered by agriculture, forestry and intense recreational activities such as skiing developments. Although most alpine habitats in North America appear relatively intact, ecological change is also

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Christian Rixen and Antonio Rolando (Eds)

taking place over extensive areas, with some areas showing deterioration due to recreational activities, livestock grazing, mining, and airborne contaminants. Ski area development has dramatically increased in America and Europe. In addition to habitat loss from resort areas and ski pistes, high elevation habitats impacted by ski developments are vulnerable to erosion, with slow recovery of vegetation after such disturbances. On a landscape scale, developed valley bottoms constitute dispersal barriers for wildlife species with seasonal vertical movements. The cumulative impacts of ski developments and climate change increase the challenge of maintaining the key ecological processes for the persistence of flora and fauna in sensitive mountain ecosystems.

Keywords: Mountain environments, ecological processes, connectivity, endemism, human alterations, life history traits, wildlife adaptations, alpine ecology, elevational gradients and biodiversity, life history variation, alpine plants, mountain breeding vertebrates, impacts of skiing on vertebrate ecology.

THE NATURE, DISTRIBUTION AND BIODIVERSITY OF MOUNTAIN HABITATS

A mountain is a landmass arising above the general landscape that induces a change in climate that affects plant and animal life [1]. Mountain habitats include alpine treeless and partially vegetated areas at the top, the sub-alpine, which is a zone with woody shrubs, the upper limits of small trees, and montane forest comprised of open parklands and closed high elevation forest (Fig. (**1**)). Overall, mountain habitats cover ~ 40 million km^2, about 27% of the global landmass including the Antarctic continent [2]. The global alpine landmass comprises about 4 million km^2, about 30% of which is vegetated [3]. Mt. Everest (8, 848 m) on the Tibet-Nepal border is the highest elevation on earth, and Mt. Blanc (4, 810 m) and Mt. Denali (6, 194 m) are the highest peaks in Europe and North America, respectively. In Eurasia, the highest vascular plants grow at over 6100 m and the *Grandala coelicolor*, an alpine passerine, is the highest breeding bird recorded nesting up to 6, 600 m [4, 5]. Above the vegetated zone (including lichens and mosses) is the Aeolian Zone, composed of wind-blown organic matter (pollen, fungal spores, bacteria, insect bodies) that supports communities of hardy insects and invertebrates.

The word *alpine,* which comes from the Alps, refers to the zone above the natural treeline, with persistent or permanent snowfields, rocky ridges, occasional wind-shaped trees and continuous to scattered tundra vegetation [6]. Several factors define the alpine zone, including elevation, aspect and high relief, but climate is probably the best determinant of where alpine zones begin [1, 3]. Temperate alpine climates are characterized by low effective moisture, prolonged snow cover, and intense ultraviolet radiation [7]. Alpine ecosystems are structurally simple with steep local gradients in snow cover and soil moisture that govern the productivity and distribution of alpine plants. Alpine plants are slow growing in soils that have developed over centuries, and many species have developed a slow life history where they are long-lived and have well-developed systems of vegetative reproduction [2, 4]. Their phenology and distribution may be governed by snow melt patterns [8]. Their recovery from disturbance and re-vegetation is usually slow (see Chapter 4 of this eBook).

Figure 1: Hudson Bay Mountain in British Columbia, showing alpine and sub-alpine habitats above montane forest indicating the diversity of habitats in proximity along elevational gradients in mountain ecosystems (Photo by K. Martin, July, 2002).

About one third of the global mountain landmass is comprised of closed forests covering over 9 million km^2, and these mountain forests represent about 28% of the world's closed forest area [9, 10]. Topography varies from steep to gentle, and winter snow pack can range from 2 to 20 meters in gullies to exposed windswept ridges. Although the vegetation structure is relatively simple, variation in slope and aspect results in rapid changes in habitat types with only modest changes in elevation, thus generating significant structural complexity to mountain forest habitats. Globally, about 4 million km^2 of mountain forests are coniferous forest and the rest are broad leaf forests, of which about 2 million km^2 are moist tropical forests [9]. Mountain forests play vital roles in ensuring the quality and reliable quantities of fresh water flows by capturing and storing rainfall, regulating flows and reducing soil erosion and downstream sedimentation [11]. Mountain forests support exceptional levels of biodiversity and often high endemism, because as different life zones succeed one another with increasing elevation, a wide range of ecosystems are compressed into a relatively short horizontal distance [12]. Mountain forests provide important resources for local and industrial forestry, non-wood products, and hunting and gathering opportunities for mountain people. In addition, they are important sacred places, and sites for tourism and recreation [9]. Overall, mountain forests provide a wide range of benefits to both mountain people and downstream low elevation populations in terms of watershed protection and transportation infrastructure. A significant proportion of ski stations and mountain resort areas occurs in these productive mountain forest ecosystems.

Mountain habitats are essentially vertical islands. Alpine plants are constrained by their substrate and have to depend on wind, or animal dispersal to move between these discrete habitat patches. Alpine specialist animals, such as white-tailed ptarmigan (*Lagopus leucura*), alpine marmots (*Marmota marmota*) and chamoix (*Rupicapra rupicapra*) remain in their high elevation 'islands' year-round and leave only to travel to other alpine patches. However, the majority of species move to lower elevation habitats at some life history stage. A surprising number of species breed across elevation gradients from sea level to over 4000 m, and the high elevation populations for these species show strong ecological and life history variation [13, 14]. Finally a wide range of species breeding at low elevations or in northern latitudes make seasonal movements to higher elevations after the breeding season to capitalize on the late season food resources [15, 16]. In North Western North America, about one third of the ~ 590 species of vertebrate fauna regularly use high elevation sites. Thus, connectivity is a key ecological process to maintain for mountain species.

Mountain plants and animals, are well adapted for extreme environmental conditions, but they are vulnerable to anthropogenically-induced changes such as increased environmental extremes, competition from both invasive species and low elevation generalist species, increased predation pressure or unfamiliar physical barriers ([17, 18], see also Chapter 7). Thus the main ecological values of mountain plants and animals that I will cover in this chapter relate to patterns of life history variation and endemism, seasonal movements of species across elevation gradients, and the critical connectivity processes across time and space needed to maintain these levels of biodiversity. All of these entities are threatened to varying degrees by ski operations. The following chapters in this eBook cover topics related to many of these threats including habitat loss and degradation due to on-site mechanical disturbance of soil and removal or damage of vegetation, and the challenges to achieve vegetative restoration in fragile plant communities. Other chapters examine the influences on animal populations and communities due to habitat loss and degradation, the disruption of animal activities and movements, and the impacts of disturbance by skiers and the placement of physical barriers in mountain habitats. The larger issue of climate change and reliable snow cover in the European Alps, as well as many mountain areas with a significant ski industry, poses additional concerns for the persistence of alpine plant and animal communities.

ENVIRONMENTAL CONDITIONS AND WILDLIFE ADAPTATION FOR HIGH ALTITUDES

Wildlife living at high elevations must be able to cope with high winds, cold temperatures and desiccation, since often little precipitation originates from rainfall and it drains quickly through the shallow soils with limited organic matter (see Chapter 3). Although alpine soils are normally cold, daily summer temperatures near the ground range from a few degrees below freezing to almost 50ºC [19, 20]. Thus, during mid day, dessication and overheating can be a problem for mountain species. On elevational gradients, resources can be patchily distributed in narrow bands of diverse habitat types that vary sharply in time within a season (*e.g.*, plant phenology or insect emergence). Spatial and temporal variation in resources can extend the availability of food and cover for wildlife, but accessing these temporally variable resources requires good mobility and longer movements from patchy breeding habitats to winter areas [21]. Alpine environments also show significant stochasticity in environmental conditions annually with some years of low snow cover leading to an absence of cover for sub-nivean species and, in other years, such as in el nino years in the Pacific Northwest of North America, much alpine breeding habitat can remain snow-covered for the entire season [22, 23]. With increasing elevation, time for breeding decreases and environmental stochasticity increases, and at the highest elevations, hypoxic conditions add additional energetic living costs [13, 15, 24, 25]. These factors result in short, intense breeding seasons for wildlife, and the need for seasonal movements from patchy breeding habitats to winter areas. However, there are a number of advantages species have for living and breeding in alpine environments (Table **1**).

Table 1: Advantages to Living in Alpine Habitats

1.	Extensive snow pack provides reliable sub-nivean habitats and cover for winter dormancy, hibernation and snow roosting.
2.	Windswept ridges and increasing snow level through winter provide new feeding areas temporally.
3.	Progressive snow melt in summer provides a continuing new supply of areas for germination and foraging.
4.	Lower inter- and intra-specific competition for food and growing space compared to low elevations.
5.	Low levels of parasitism and disease.
6.	For migratory animals, low elevation habitats in relatively close proximity to alpine.
7.	Thermal inversions at mid-mountain slopes may provide warmer temperatures in winter than valley bottoms for wildlife.

Mountain animals respond to living in extreme environments in several ways; they can migrate to warmer environments, hibernate or stay active all year. Animals living at high elevations have developed behavioral, morphological, and physiological adaptations to conserve energy and survive in these extreme habitats [15]. The type of adaptation may increase with increased time spent at high elevation. For example, species that use high elevation habitats for short periods may require only behavioral adjustments like moving to more sheltered sites to conserve energy [26-28]. The invertebrates, amphibians, and reptiles living in mountain environments are almost universally dark-colored. Melanism can contribute to heat absorption and help protect them against ultraviolet radiation [1, 29]. Hummingbirds exploiting the rich resources in sub-alpine meadows during migration go into night-time torpor if their energy reserves fall below a critical point [30]. With their small body size, alpine songbirds face special challenges to survive and breed in mountains as they must cope with cold temperatures and high winds as well as incubate small eggs that cool rapidly in near freezing temperatures. Alpine passerines breeding at high elevations survive well despite storms and inclement weather [14]. Nest structures in some high elevation bird populations weighed almost twice as much as those at low elevations and, presumably conferred greater insulative warmth [31, 32]. Mountain songbirds may increase their parental care to warm and feed their nestlings [28, 33].

With less vegetative cover for concealment, many alpine mammals and birds have developed cryptic appearances and behaviours to enhance blending into the landscape. Ptarmigan are renowned for their cryptic plumage, but larger mammals such as bighorn sheep (*Ovis canadensis*) and coyotes (*Canis latrans*) also blend exceptionally well in these open landscapes. Mountain animals such as marmots, pika and ptarmigan have territorial and social contact calls that are difficult to localize, which may reduce the risk of their being detected by predators when calling. Animals living at high elevations increase insulation by developing fat deposits or thicker fur during winter, as well as using snow roosts or burrows during storms or periods of cold weather (Fig. (**2**)). True alpine species may

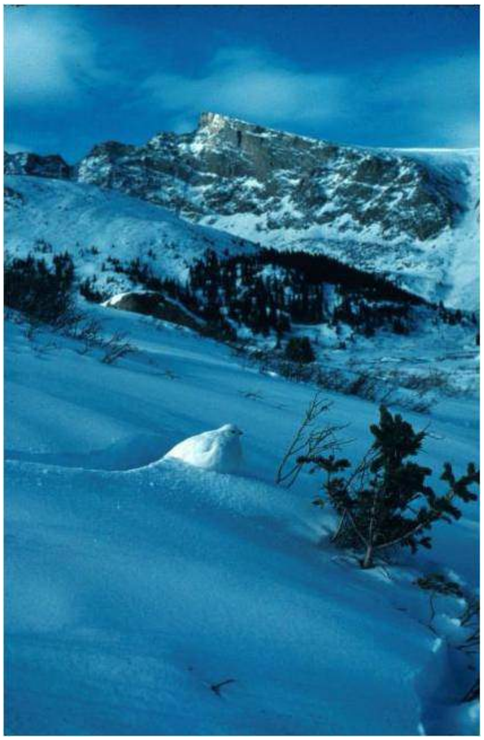

Figure 2: Only a few vertebrates remain in their alpine sky islands year round like this white-tailed ptarmigan in its winter habitat at Guanella Pass, Colorado, USA. Mt. Evans, one of their breeding habitats is shown in the background (Photo by K. Martin, January 1988).

develop structural adaptations. Alpine finches show ecological and morphological differentiation across an elevational gradient in the Himalayas with the heaviest species occupying the highest elevations [27, 34, 35]. These alpine passerines have long pointed wings for efficient flight performance in strong and variable winds [5]. Finches and chats at the highest elevations have square-ended or shallow forked tails for flight stability in wind, and elongated hind toes for grasping during ground foraging. Winds may pose problems for smaller animals, but larger animals such as raptors use wind to remain aloft and glide efficiently. Species living at the highest elevations for extended periods make biochemical adjustments such as increasing their blood hematocrit concentrations, including tropical birds that move to higher elevations in winter [25, 36, 37]. In some small mammals, life at high elevation is facilitated with genetic adaptations [38].

LIFE IS SLOW ON THE MOUNTAIN TOPS

The reduced time for breeding within a season may alter life history traits. Generally, vertebrate species living at high elevations exhibit lifestyles whereby they have slower development and lower annual fecundity (Table **2**). For some species, these traits are accompanied by longer life spans, differences in body size or shape and more developed social behaviours. Food supplies for animals in mountain habitats in summer are plentiful generally, but of short duration in a specific location, but receding snowfields in summer continually provide new foraging areas (Fig. (**3**) [22, 39]). Most alpine animals are both granivorous and insectivorous, and often forage on chilled and dead wind-blown arthropods deposited on snowfields [40, 41].

Poikilothermic (cold-blooded) animals such as frogs, salamanders and snakes have special problems moving and reproducing in cold climates because the low alpine temperatures result in prolonged development times for amphibians and reptiles. In alpine habitats, frogs commonly pass the first winter as tadpoles and require an extra year to achieve full development [29], in contrast to lower elevation individuals that usually achieve full maturity in their first year. In the European Alps, all three reptiles, green lizard (*Lacerta vivipara*), common viper (*Vipera berus*) and blind-worm (*Anguis fragilis*) are viviparous (bear live young). Although reptile eggs normally can not develop and hatch in such cold climates,

Figure 3: Mountain habitats exhibit exceptional seasonality with delayed snow melt in May, standard growing and breeding season conditions in June and a profusion of alpine vegetation in July that attracts vertebrates and hikers to move up to the alpine in late summer. This alpine prairie occurs on the Hudson Bay Mountain ski area, Smithers, British Columbia, Canada (Photos by K. Martin).

when female snakes or lizards at high elevations retain eggs in their body, they can speed embryonic development by basking in the sun during the day, and moving to sheltered locations at night. Snakes in the European Alps show delayed sexual maturity and reproduce every two to four years in the alpine, rather than annually as found in low elevation populations [42, 43].

Only a few North American bird species, white-tailed ptarmigan, American pipit (*Anthus rubescens*), black-crowned rosy finch (*Leucosticte atrata*), gray-crowned rosy finch (*L. tephrocotis*), the alpine sub-species of horned lark (*Eremophila alpestris alpinus*), and golden-crowned sparrow (*Zonotrichia atricapilla*) breed exclusively in alpine and sub-alpine habitats [15]. Of these, only the alpine ptarmigan are year-round residents. Population densities of species that breed across a range of elevations might be expected to decrease with increasing elevation, but this was not found for garden warblers (*Sylvia borin*) [31]. In Europe and Asia, black redstarts (*Phoenicuros ochruros*), European skylarks *Alauda arvensis* and Himalayan chats increased in density with elevation [34, 44, 45].

A number of birds breeding in mountain habitats are able to do so because they shift to a slower life history with increasing elevation [13, 14, 31]. Mountain breeding songbirds have only about 50% as much time to breed as lower elevation populations because onset of breeding is delayed by several weeks at high elevation, and high elevation songbirds in Europe and North America do not extend their egg laying period beyond that of low elevation populations. Most species breeding across elevation gradients produced fewer broods annually at higher elevations, with generally only a single brood at high elevations [28, 46, 47]. At high elevations, White-tailed ptarmigan (*Lagopus leucura*), showed slower laying rates, smaller clutches, longer incubation periods with higher reproductive failure and a larger body size compared to their arctic breeding conspecifics and congenors, willow ptarmigan (*L. lagopus*) [48-51]. Both alpine specialist and generalist breeding birds produced fewer young annually, but their annual survival was 10 to 20% higher (Fig. (**4**)). It has not been established whether the mechanisms underlying this life history variation represent genetic differences or are achieved by phenotypic plasticity.

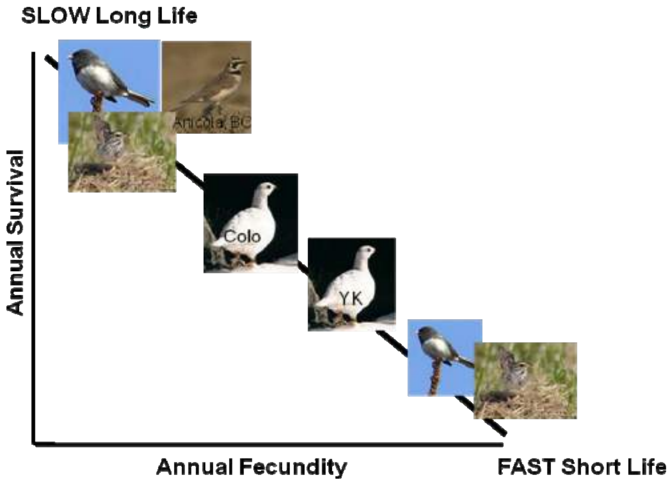

Figure 4: Life history varies within species and is slow on mountain tops. Conspecific populations of birds living at high elevations have lower annual production of offspring, but they live longer and thus have more time to replace themselves. In some cases, these slow lifestyle populations are stable while the low elevation populations are declining such as the horned lark, or have been extirpated as in the case of the black grouse in Central Europe.

A study of golden-mantled ground squirrels (*Spermophilus lateralis*) across five elevations in the Sierra Nevada in California showed delayed age of maturity, lower litter size and greater survivorship of females with increasing elevation [52]. At high elevations, Columbian ground squirrels (*S. columbianus*) have lower litter size, lower female body weight, lower proportion of young females breeding, and higher adult survival relative to low elevation populations. Some of these within-species differences (*e.g.*, litter size and proportion of young females with litters), disappeared when high elevation populations were food-supplemented suggesting that ground squirrel populations showed a phenotypically plastic life history response to variation in food availability with elevation [53, 54]. Alpine marmots (*Marmota marmota)* have prolonged parental care, live and hibernate in larger groups and take longer to reach maturity compared to marmot species living at lower elevations [55-58].

In summary, there may be high ecological costs to living at high elevations as the need to move for food or cover may result in increased risk of detection by predators. However, alpine animals likely experience lower levels of inter-specific competition than wildlife occupying lower elevation habitat types. To cope with difficult environmental conditions at high elevations, some mountain species have adopted a slower lifestyle where they produce fewer offspring annually compared to those at low elevations, but they live longer and thus have more years to breed and replace themselves (Summary given in Table **2**). Other species of birds and mammals may also have differentiated high elevation ecotypes or subspecies yet to be discovered. It is important to know about the nature of wildlife adaptations to living in high elevation environments as the adverse impacts of ski operations on populations such as increased mortality due to ski cables or disruption of their snow burrowing behaviours or foraging activities by skiers will have a greater impact on animal populations with slow lifestyles than those that depend less on longevity to replace themselves. Thus, we cannot assume that studies on animals or plants are directly comparable for low and high elevation populations.

Seasonal migration to mountain habitats: From late summer to fall, alpine areas support a high diversity and abundance of invertebrates, birds, and mammals that move up from lower elevations, or down from higher latitudes. In North America,

Table 2: Ecological Values and Processes Associated with Plants and Animals Living in Mountain Environments

	Plants	**Animals**
Ecological Traits	Cushion plants Vegetative reproduction Limited number of pollinators	Larger body size Good dispersal abilities Flexible breeding schedules
Connectivity	Seed and ramet dispersal	Need to disperse to winter areas to recruit to new breeding sites
Life History Strategy for both specialists and generalist alpine species	Long lived, mostly perennials High reliance on vegetative reproduction	Larger body size Shift to slower lifestyle
Threats due to Skiing	Habitat loss due to ski pistes and structures Sensitive to soil disturbance and compaction Slow to recover from disturbances	Habitat loss Seasonal movements more difficult Disturbance/harassment in winter habitat Mortality due to infrastructures and predation
Threats due to Climate Change	Habitat loss/degradation Less reliable winter conditions; Mortality due to thaw/freeze events	Habitat loss with winter warming Tree and shrub line will rise Ice/storm events increase mortality
Other Threats	Upward range shifts of invasive species and competitors	Upward range shifts of invasive species and competitors

about 240 species of birds, and many mammals and invertebrates make seasonal migrations to use alpine, sub-alpine and montane habitats in late summer as stopovers for replenishing body reserves. [1, 59, 60]. However, the importance of this phenomenon and the key ecological processes has received little study, especially in relation to ski operations. About 80% of the 114 bird species observed from early August to October during a three year field study in British Columbia, Canada did not breed at high elevation [16]. Some species were migrants from higher latitudes using alpine sites as migration corridors including arctic shorebirds like Baird's sandpipers (*Calidris bairdii*) and greater yellowlegs (*Tringa melanoleuca*), and raptors such as sharp-shinned hawks (*Accipiter striatus*) and northern goshawks (*Accipiter gentilis*). A high proportion of birds arriving in the alpine were probably elevational migrants of local origin such as some forest birds, (*e.g.*, nuthatches and siskins), that moved up the mountain to track emerging food resources (insects/ flower/ fruit) from snow melt and green-up in late summer. The proximity of mountain habitats to forest, grasslands, shrub steppe or coastal habitats at lower elevations means that animals can move quickly between these habitats (Fig. (**5**)). Rufous hummingbirds (*Selashorus* *rufus*) are generally the first avian migrants to move up to sub-alpine meadows in late summer and defend territories around flower patches [61, 62]. From mid August to early September, alpine grasslands support large numbers of grasshoppers that are eaten by kestrels (*Falco sparverius*), and songbirds in both Europe and North America [22]. Migrating raptors use the open mountain terrain to hunt for landbirds and small mammals, often using updrafts along cliff faces and ridges. The use of high elevation sites as migration stopover habitats may be increasing in importance especially where late summer fruits in the sub-alpine such as huckleberry (*Vaccinium deliciosum*), crowberry (*Empetrum nigrum*), and bearberry (*Arctostaphylos uva-ursi*) are available. Their availability may offset some of the loss of traditionally used low elevation migration stopover habitats. Ungulates and carnivores also make seasonal movements up to alpine areas in late summer and fall. With the continued expansion of large mountain resort areas, there has been a strong increase in 'shoulder season' recreation activities such as mountain biking on or near ski pistes that can lead to conflicts between recreational activities and fall feeding activities of these migrant wildlife species. At Whistler and Blackcomb ski resort, British Columbia, bears feeding in the late summer vegetation in subalpine meadows have been disturbed and sometimes hit by mountain bikers.

Figure 5: Seasonal connectivity. Many species of vertebrates migrate upslope or from higher latitudes for a period of several months in late summer and autumn to capitalize on the abundant food resources. A few species migrate up to the treeline in winter. Recreational and ski activities can negatively impact these seasonal movements of medium-sized and large vertebrates (Photo by Steve Ogle).

Winter Residents: In North America*,* relatively few wildlife species winter in alpine areas, and fewer still remain active in winter. Some birds, including white-tailed ptarmigan, raven, and rosy finches remain at the highest elevations during winter, and a few arctic or northern species like snowy owls (*Nyctea scandiaca*) and snow buntings (*Plectrophenax nivalis*) migrate south to use alpine areas in the Pacific Northwest. Rosy finches forage for exposed seeds on windswept alpine ridges [63]. Gray jay (*Perisoreus canadensis*), raven, Clark's nutcracker (*Nucifraga columbiana*), and hardy songbirds like golden-crowned kinglets (*Regulus satrapa*) and dark-eyed juncos (*Junco hyemalis*) in North America use tree islands in sub-alpine parklands in winter. Mammals using alpine and sub-alpine habitats in winter include pika, mountain caribou (*Rangifer tarandus*), and mountain goat (*Oreamnos americanus*) and their predators, fox, coyote, pine marten (*Martes americana*), wolverine (*Gulo gulo*), lynx (*Lynx canadensis*), bobcat (*Lynx rufus*), and mountain lion (*Felis concolor*) hunt along or above the treeline. White-tailed jackrabbits (*Lepus townsendii*) winter at the interface of wind swept ridges and the krummholz [64]. For marmots and ground squirrels that hibernate at high elevations, their choice of burrow and amount of snow cover can be crucial to overwinter survival [56-58]. Pika, weasel and vole remain active in the sub-nivean layer where they have temporary reprieve from predators and winter storms.

Winter may be a period of great sensitivity, with human disturbances from both nordic and alpine skiing possibly causing the most adverse impacts on wildlife [65]. In winter, many grouse and ungulates occur in social groups and live at about the same elevational range as alpine and Nordic ski facilities. On Vancouver Island, British Columbia (Canada), for example, white-tailed ptarmigan move from an average summer elevation of 1676 m down to treeline (1372 m) in winter [22], while sooty grouse (*Dendragapus fuliginosus*) move up to the treeline elevation [66]. In Bavaria, black grouse (*Tetrao tetrix*) are largely restricted to using treeline islands in the sub-alpine in winter where they are hindered from feeding during the day by disturbance from skiers [67]. The soft snow used by mammals and grouse for snow burrows to take refuge from winter storms, is also sought by back-country skiers (see Chapter 8). In addition, mortality due to collision with ski cables can result in strong negative impacts on some alpine winter resident birds (see Chapter 7).

Increases in recreational use of high elevation areas can result in increased food availability for generalist predators and also human activities at lower elevations may influence ecological processes in the alpine. High elevation habitats are generally unsuitable for corvids such as crows, jays or choughs, but populations can persist if there are dwellings or dumps nearby [68]. In winter, the alpine chough (*Pyrrhocorax graculus*) roosts in holes in high cliffs, but individuals usually make daily elevational movements of over 10 kilometers to the snow free valleys. However, choughs near ski-resort towns remain at high altitude and feed on tourist scraps (see Chapter 6). Over-winter survival of generalist predators may also be improved by road-kills, dumps in adjacent urban areas, or from feeding from homes in the montane forest. When these anthropogenic food supplies are available, generalist predators are less dependent on traditional prey year-round to survive. Densities of foxes and corvids tend to be higher close to ski resorts, which may thus increase the predation pressure on the birds [69]. If predator densities near ski stations are higher, prey species breeding in the proximity will in some cases be negatively impacted. In the Cairngorm Mountains in Scotland, ptarmigan densities were lower and were associated with an increased predation rates on nests, young or adults near ski resorts compared to areas less frequented by humans [70, 71]. The cumulative impacts from ski facilities and the activities of skiers can have serious adverse impacts on a range of taxa that are observed over considerable distances in all seasons. Generally, this topic is not well studied, but some of the ecological impacts are covered in detail in succeeding chapters in this eBook.

In summary, about one third of the vertebrate fauna in western North America use mountain habitats at some critical period in their life history. It is difficult to generalize about the relative reproductive success and survival for wildlife species living at high and low elevations, because there are so few studies of the ecology, behaviour, and life history of the upper elevational ranges. The few studies done suggest there is greater local adaptation and life history diversity than previously realized. The period of highest biodiversity in mountain habitats is between late July and October. To accurately characterize the biodiversity of mountain ecosystems, we need to consider life history periods outside the breeding season. Ski resorts and their associated activities during winter and fall can adversely impact the foraging activities of winter resident species and fall migrants by restricting the areas or times when wildlife can feed without harassment or stress.

For some species, survival is reduced or population density is also reduced near ski resorts, but for most species, the potential impacts have not been studied.

CONNECTIVITY IN MOUNTAIN HABITATS

Connectivity is a key ecological process for high elevation plant and animal populations across all seasons. Connectivity needs to be maintained (1) among populations breeding in patchy alpine habitats, (2) along mountain corridors for north-south migrants, and also for (3) elevational migration between high elevations and adjacent lower elevation habitats.

Demographic connectivity across patchy habitats. – The ability of pollen, seeds or individuals to achieve dispersal and recruitment are crucial requirements for the persistence of mountain species given the patchy nature of high elevation habitats. Generally, alpine plants are long-lived and rely heavily on clonal growth to maintain populations. Dispersal of pollen and seeds by either wind or animals can be critical to colonize new alpine patches or to restore damaged vegetation. However, colonization can be a slow process as the number of pollinators generally decreases with elevation, given the colder environmental conditions and the glow growth [3]. Restoration and re-vegation using clonal growth can be done, but is also slow and works better for smaller areas of disturbance ([72], see also Chapters 9 and 10).

Despite the tendency for small population sizes, animals adapted to live in naturally fragmented alpine habitats may generally have well developed dispersal abilities. The enabling factors for this extensive external recruitment appear to be low costs to dispersal and low benefits to philopatry. Populations of white-tailed ptarmigan breeding in highly fragmented alpine habitats, with corresponding small populations, in the Rocky Mountains of Colorado, USA showed dramatic variation in offspring production and survival of adults across years and sites, yet breeding populations remained relatively stable [21, 49]. Although population simulation models predicted that all populations should go extinct in 2 to 10 years all have persisted for at least 4 to 5 decades. Local populations were able to avoid extinction due to external recruitment; about 95% of females and 75% of males recruiting to alpine sites did not originate from any of the study populations. On

Vancouver Island, British Columbia, there was little genetic differentiation observed for ptarmigan breeding in highly fragmented and stochastic coastal alpine habitats, indicating there was extensive dispersal of alleles at a landscape scale [73]. For small populations in stochastic environments, maintaining connectivity between populations is crucial and can be achieved as long as there is a balance of populations producing recruits in reasonable proximity to populations requiring rescue [21, 48-50]. However, some mountain vertebrates are not able to disperse readily between unconnected patches. The development of ski-pistes was found to limit movements for small mammals that are reluctant to cross open spaces (Fig. (**6**), [74], see also Chapter 6). When ski activities are combined with other sources of habitat loss and fragmentation at larger spatial scales, population sizes become smaller and genetic diversity is reduced as found for mountain forest grouse in central Europe [75].

Figure 6: Development in narrow valley bottoms associated with skiing, other recreations and transportation activities can impede animal movement, thus fragmenting wildlife populations at the landscape scale (Photo by Amanda Adams, Canmore near Banff National Park, Alberta, Canada. June, 2010).

Latitudinal migration along mountain corridors and elevational migrants - Alpine habitats function as seasonal migration and dispersal corridors for wildlife. High latitude birds use alpine and sub-alpine habitats as migration highways to move from northern breeding territories to southern winter areas [16]. Stopovers in mountain areas in spring occur to a much lesser extent as these areas are generally fully snow-covered during spring migration. The continued loss of low elevation migration habitat such as riparian and coastal areas strengthens the need to understand and manage for such ecological functions as alpine migration corridors.

The issue of connectivity between high and low elevation habitats is an important biological and management question. A high proportion of habitats in parks in the Rocky Mountains of North America are at high elevation, and most parks do not contain year-round habitat requirements for wildlife species such as migratory elk (*Cervus elaphus*) in Banff National Park (Alberta, Canada) [76, 77]. For alpine residents, we need to ensure that connectivity is maintained from alpine habitats to adjacent lower elevation forests and valley bottoms. Since many alpine areas are not continuous, larger area sensitive mammals in North America and Europe often require access to valley bottoms to move between mountain chains. In North America, urban areas and transportation infrastructure in valley bottoms generally interrupt wildlife movements, act as a dispersal barrier, restrict access to seasonally-used habitats and can permanently sub-divide populations of large ungulates and predators (Fig. (**7**), [17]).

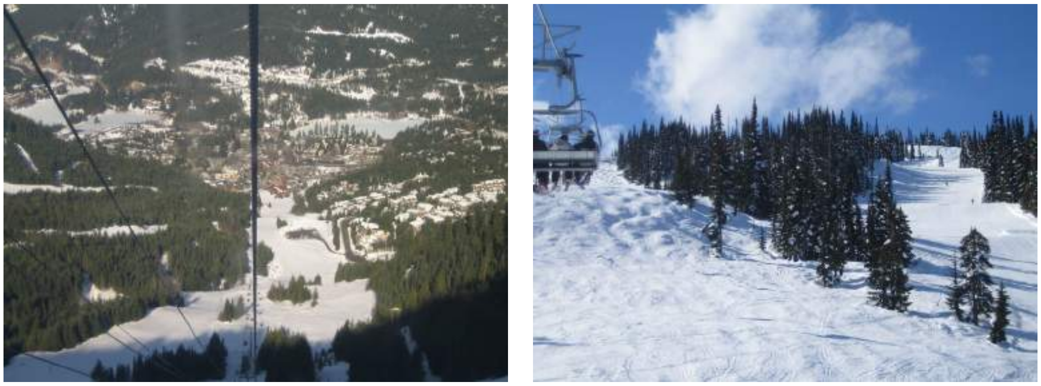

Figure 7: Smaller scale cutting for ski runs can impede wildlife movements and reduce the quality of denning areas for mountain mammals. Whistler, British Columbia, Canada (Photos by Kathy Martin, March 2011).

The most severe wildlife-human conflicts occur in mountain landscapes with narrow valleys that are densely settled or developed. Barriers to seasonal movements or population dispersal pose a serious problem in mountain systems such as Banff

National Park, Canada where urban developments, major highways and railways in the narrow Bow Valley have greatly impeded movements of large mammals and fragmented their populations causing increased mortality due to collisions with motor vehicles or trains [78]. Even if infrastructures are designed to facilitate dispersal movements, species can vary in their willingness to cross such dispersal barriers (Fig. (**8**), [77, 79]). Mountain passes are also important for seasonal access or population connectivity, and these tend to be where roads, trails and recreational huts are situated. Determining the ecological value of the alpine as migration habitat and minimizing interruptions of wildlife movements in mountains are high priorities for additional research on the ecological impacts of ski areas.

Figure 8: The TransCanada Highway, a railway and the town of Banff are all situated in the narrow valley bottom of the Bow Valley in Alberta. These structures have been found to impede the movements of large ungulates and carnivores. The wildlife connectors shown here have been installed over the highway to reduce mortality and facilitate movements of animals across the valley. Banff-Jasper Highway, Alberta, Canada (Photo by Kathy Martin, March 2011).

UPWARD SHIFTING OF SPECIES ELEVATIONAL DISTRIBUTIONS

Some wildlife species that formerly used habitats over a broad range of elevations are becoming restricted to the upper elevations of their historical range. ‘Upward shifting’ is a well advanced phenomenon in central Europe where most forest grouse species that originally occupied a range of habitats from low elevation bogs, heaths, and moorlands up to the sub-alpine treeline have been extirpated from the low elevations in the past century, due to intensive agricultural and forestry activities. Black grouse (*Lyrurus tetrix*) in central Europe are now 'de facto' sub-alpine parkland species due to the current unsuitability of their traditional low elevation habitats [67, 75]. In northern Italy, skylarks and golden eagles (*Aquila chrysaetos*) are largely confined in the Alps [45]. As well, wolves and brown bears (*Ursis arctos*) in Europe are largely restricted to high latitudes and mountain habitats [80]. Many of these 'upshifted' species are now endangered, because they regularly experience total reproductive failure due to reduced cover and the generally high numbers of predators in their high elevation habitats and possibly due to the lack of recruitment of individuals from lower elevation populations [75]. Predation risk might also be increasing at some high elevation locations if generalist predator densities have increased as a result of human presence [69, 70]. The upshifting of species ranges is an ecological process that also has begun in western North America, where many low elevation coniferous forests have been converted to intensive agricultural, industrial or urban areas and, many low elevation wetlands have disappeared [81, 82]. Hence, wildlife species that traditionally occupied a broad elevational range of habitats have also experienced significant range reduction, accompanied with an 'upward shift', including such species as white-tailed jackrabbit, western toad (*Bufo boreas*), other amphibians, sooty grouse, and ruffed grouse (*Bonasa umbellus*). For example, sooty grouse numbers have declined in many low elevation areas of Washington and Oregon, while the high elevation populations remain unchanged [83]. Medium- and large-sized predators such as grizzly, wolf or lynx that do not persist easily near urban areas have also moved higher. For most of the large predators and ungulates, the 'upward shift' in population distribution is facilitated by greater conflicts with humans as well as habitat loss at low elevations.

For those wildlife species living at higher elevations, we need to determine which species have experienced the largest elevational increases and whether their populations appear in difficulty. As discussed earlier, there are potential increased energetic costs of living at higher elevations as well as the impacts on reproductive success and population viability as the frequency and severity of stochastic events increase [13, 21]. For large carnivores in both North America and Europe, the retreat to high elevation habitat patches results in populations being more fragmented than formerly by anthropogenic barriers [17, 84]. After the low elevation population segment is extirpated, the risks to population viability of wildlife species in spatially separated high elevation 'islands' will increase due to habitat fragmentation and reduced effective population size, especially in areas with a high density of large ski resorts. The presence of other winter sport activities such as Nordic skiing, snowmobiling and dog sledding in proximity to intensive alpine ski stations increases the cumulative impacts to mountain species and over a larger spatial scale. Disturbance due to skier activities represents a serious additional threat especially to populations already in trouble from other stressors (see Chapters 2 and 8, [85]).

OTHER CHANGES IN ECOLOGICAL PROCESSES AND RESEARCH NEEDS AT HIGH ELEVATIONS

In the past three decades, there has been a dramatic increase in the number and ecological footprint of alpine and Nordic ski stations, and in the use of helicopters to access remote areas for skiing, fishing, and hiking. Helicopter-supported activities do not result in many visits to each mountain, but they increase dramatically the overall size of area impacted especially for area sensitive species like mountain goats or chamois [85, 86]. The increased use of alpine facilities in fall, particularly with late summer hiking and mountain biking, results in conflicts with the seasonal movements of wildlife. Careful evaluation of habitat use is needed and the seasonal wildlife travel corridors need to be determined in advance of designing and approving new ski developments or expanding existing operations [87]. Reviews of proposed new housing and other amenity developments or expansions of ski resort areas should consider off-site impacts. Potential impacts should be evaluated at a sufficiently large scale to include connectivity issues discussed earlier for maintaining viable populations of mountain flora and fauna [88]. Proposed mountain recreational developments should demonstrate that they have allowed for the maintenance of the usual ecological and connectivity processes.

Alpine and sub-alpine areas have increased in value as wildlife habitat, given habitat loss and changes in ecological processes at low elevations. Research is needed to determine the important ecological processes and habitat functions required by mountain plants and animals. Life history studies are needed for alpine generalist species that are experiencing extensive habitat loss at low elevations. Most research for alpine fauna has been done in summer and, thus our knowledge of their use of mountain areas in other seasons is limited. Better understanding is required about the importance of maintaining connectivity across time and space for species with seasonal altitudinal shifts. For ungulates and large carnivores, we need to ensure that alpine species have access to valley lowlands and other important wintering habitats.

Increases in predator density or the amount of time predators spend in the alpine could significantly increase the risk of predation for alpine and sub-alpine species, as well as for those 'upward shifted' elevational generalist species. Better understanding of the possible factors that increase generalist predator densities in or near high elevation areas, and whether these increases significantly impact alpine wildlife populations. Thus field research is needed on how to maintain the normal balance of predator-prey dynamics in mountain areas in proximity to ski pistes and other structures associated with ski operations to minimize the potential negative impacts on survival for alpine plants and wildlife.

Research is needed on the influence of montane forest cutting on the distribution and abundance of generalist predators, and the consequent impacts on survival and reproduction of plants and wildlife in adjacent sub-alpine and alpine habitats.

Most urgently, research is needed to improve predictions on how wildlife species will cope with changing climatic and environmental conditions ([89], see also Chapter 2). To detect and predict the ecological effects of global climate change, it will be crucial to establish and maintain existing long-term mountain habitat and species monitoring programs similar to programs in the Austrian Alps [90], northern Finland [91], or in the Rocky Mountains [92]. Plants and animals living in alpine patches that are shrinking will have smaller populations and be required to disperse longer distances to other alpine patches, or pay the consequences of not dispersing [21, 93]. Although some subalpine species will experience an increase in habitat, many alpine species will need to cope with a reduction and fragmentation of their habitat supply, while also experiencing increased competition from species invading and upshifting from lower elevations [18].

In sum, alpine and sub-alpine areas have increased in value as wildlife habitat, given habitat loss and changes in ecological processes such as climate change and upshifting of invasive and competitive species from low elevations. With the limited data for baseline conditions, we are poorly positioned to detect changes in ecological processes or population declines at an early stage, especially if processes such as predation are shifting at large cross-habitat scales. Research on most of these issues is limited, especially in North America. The following chapters focus on studies conducted in the European Alps, and are excellent examples of the kinds of research needed for the management and mitigation of impacts from recreational activities in mountain areas. They develop in detail the chronic and acute problems experienced by soils, habitats, plants and animals associated with the direct and indirect impacts from alpine and Nordic ski operations and associated synergistic interactions with climate change processes.

CONFLICT OF INTEREST

The author confirms that this article content has no conflict of interest.

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REFERENCES

[1] Price, L.W. *Mountains and man: a study of process and environment*; University of California Press: Berkeley, USA, **1981**.

[2] UNEP. *World Conservation Monitoring Centre: Mountain Watch*. Cambridge, UK, **2002**.

[3] Körner, C. *Alpine Plant Life: functional plant ecology of high mountain ecosystems*, 2nd ed.; Springer-Verlag: Heidelburg, Germany, **2003**.

[4] Bliss, L.C. Arctic and alpine plant life cycles. *Ann. Rev. Ecol. Syst.,* **1971**, *2*, 405-438

[5] Potapov, R.L. Adaptations of birds to life in high mountains in Eurasia. *Acta Zool. Sin.,* **2004**, *50*, 970-977.

[6] Love, D. Subarctic and subalpine: where and what? *Arct. Alp. Res.*, **1970**, 2, 63-73.

[7] Billings, W. D. Alpine vegetation. In: *Terrestrial vegetation of North America*; Billings, W.D., Peet, R.K., Eds.; Paragon Books, **1989;** pp 392-420.

[8] Kudo, G.; Ito, K. Plant distribution in relation to the length of the growing season in a snow-bed in the Taisetsu Mountains, northern Japan. *Vegetatio*, **1992**, *98*, 165-174.

[9] Price, M. F. Why mountain forests are important. *For. Chron.,* **2003**, *79*, 219-222

[10] Kapos, V.; Rhind, J.; Edwards, M.; Price, M.F. Developing a map of the world's mountain forests. In: *Forests in Sustainable Mountain Development: A State of Knowledge Report for 2000*; Price, M.F., Butt, N., Eds.; CABI International, Wallingford, **2000**; pp. 4-9.

[11] Hamilton, L. S.; Bruijnzeel, L.A. Mountain watersheds – integrating water, soils, gravity, vegetation, and people. In: *Mountains of the world: a global priority*; Messerli, B., Ives, J.D., Eds.; Parthenon Publishing Group: London, UK. **1997**; pp. 337-370.

[12] Grabherr, G. Biodiversity of mountain forests. In: Price, M.F., Butt, N., Eds.; *Forests in Sustainable Mountain Development: A State of Knowledge Report for 2000.* CABI International, Wallingford, **2000**; pp. 28-38.

[13] Bears H.; Martin, K.; White, G.C. Breeding in high-elevation habitat results in shift to slower life-history strategy within a single species *J. Anim. Ecol.,* **2009**, *78*, 365-375.

[14] Martin, M.; Camfield, A.F.; Martin, K. The demography of an alpine population of Savannah Sparrows (*Passerculus sandwichensis*). *J. Field Ornithol.*, **2009**, 80, 253-264.

[15] Martin, K. Wildlife in alpine and sub-alpine habitats. In: *Wildlife-Habitat Relationships in Oregon and Washington*; Johnson, D.H., O'Neil, T.A. (Manag. Dirs.), Oregon State University Press, **2001**.

[16] Wilson, S.; Martin, K**.** High elevation habitat associations of birds during fall migration. *Ecoscience*, **2005**, *12*, 561-568.

[17] Breitenmoser, U. Large predators in the Alps: the fall and rise of man’s competitors. *Biol. Cons.*, **1998**, *83*, 279-289.

[18] Forister, M.L.; McCall, A.C.; Sanders, N.J.; Fordyce, J.A.; Thorne, J.H.; O’Brien, J.; Waetjen, D.P.; Shapiro, A.M. Compounded effects of climate change and habitat alteration shift patterns of butterfly diversity. *Proc. Natl. Acad. Sci.*, **2010**, *107*, 2088-2092.

[19] Wiebe, K.L.; Martin, K. Effects of predation, body condition and temperature on incubation rhythms of ptarmigan. *Wildl. Biol.*, **1997**, *3*, 219-227.

[20] Camfield A.F.; Martin, K**.** The influence of ambient temperature on horned lark incubation behaviour in an alpine environment. *Behaviour*, **2009**, *146*, 1615-1633.

[21] Martin, K.; Stacey, P.B.; Braun, C.E. Recruitment, dispersal and demographic rescue in spatially-structured white-tailed ptarmigan populations. *Condor*, **2000**, *102*, 503-516.

[22] Martin, K. Personal Communication. Department of Forest Sciences, University of British Columbia, Vancouver, Canada, **2011**.

[23] IPCC 2007. Climate change 2007. Synthesis Report. Contribution of the working groups I, II, and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva: IPCC., **2007**.

[24] Bullard, R.W. Vertebrates at altitudes. In: *Physiological adaptations, desert and mountain*; Yousef, M.K., Horvath, S.M., Bullard R.W. Eds; Academic Press: New York, USA. **1972**; pp 209-226.

[25] Carey, C. Adaptation of the avian egg to high altitude. *Am. Zool.,* **1980**, *20*, 449-459.

[26] Cody, M.L. Habitat selection in grassland and open country birds. In: *Habitat selection in birds*; Academic Press: New York, USA, **1985**; pp 191-226.

[27] Landmann, A.; Winding, N. Guild organisation and morphology of high-altitude granivorous and insectivorous birds: convergent evolution in an extreme environment. *Oikos*, **1995**, *73*, 237-250.

[28] Camfield A.F.; Pearson, S.; Martin, K. Life history variation between high and low elevation subspecies of horned larks *Eremophila* spp. *J. Av. Biol.,* **2010,** *41*, 273-281.

[29] Allee, W.C.; Schmidt, K.P. *Ecological Animal Geography*; John Wiley and Sons Inc: New York, **1951**.

[30] Carpenter, F.L.; Hixon, M.A.; A new function for torpor: fat conservation in a wild migrant hummingbird. *Condor*, **1988**, *90*, 373-378.

[31] Widmer, M. Phänologie, Siedlungsdichte und Populationsökologie der Gartengrasmucke *Sylvia borin* in einem subalpinen Habitat der Zentralalpen *J.Ornithol.*, **1996**, *137*, 479-501.

[32] Lu, X. Breeding ecology of an old world high-altitude warbler, *Phylloscopus affinis J.Ornithol.*, **2008**, *149*, 41-47.

[33] Badyaev, A.V.; Ghalambor, C.K. Evolution of life histories along elevational gradients: trade-off between parental care and fecundity. *Ecology*, **2001**, *82*, 2948-2960.

[34] Landmann, A.; Winding, N. Niche segregation in high-altitude Himalayan chats (Aves, Turdidae): does morphology match ecology? *Oecologia*, **1993**, *95*, 506-519.

[35] Landmann, A.; Winding, N. Adaptive radiation and resource partitioning in Himalayan high-altitude finches. *Zoology*, **1995**, *99*, 8-20.

[36] Carey, C.; Martin, K. Physiological ecology of incubation of ptarmigan eggs at high and low altitudes *Wildl. Biol.*, **1997**, *3*, 211-218.

[37] Borras, T.; Senar, J.; Cabrera, J. Hematocrit variation in response to altitude changes in wild birds: a repeated-measures design. *Condor*, **2010**, *112*, 622-626.

[38] Storz, J.F.; Runck, A.M.; Sabatino, S.J.; Kelly, J.K.; Ferrand, N.; Moriyama, H.; Weber, R.E.; Fago, A. Evolutionary and functional insights into the mechanism underlying high-altitude adaptation of deer mouse hemoglobin. *Proc. Natl. Acad. Sci.*, **2009**, *106* (34), 14450-14455.

[39] Johnson, R.E. Reproductive activities of rosy finches, with special reference to Montana *Auk*, **1965**, *82*, 190-205.

[40] Spalding, J.B. The aeolian ecology of White Mountain Peak, California: wind-blown insect fauna *Arct. Alp. Research*, **1979,** *11*, 83-94.

[41] Verbeek, N.A.M. Nesting success and orientation of water pipit *Anthus spinoletta* nests *Orn. Scand.*, **1981**, *12*, 37-39.

[42] Capula, M.; Luiselli, L.; Anibaldi, C. Complementary study on the reproductive biology in female adder, *Vipera berus (L.)* from eastern Italian Alps. *Vie Milieu*, **1992**, *42*, 327-336.

[43] Saint Girons, H. Strategies reproductrices des viperidae dans les zones temperees fraiches et froides *Bull. Soc. Zool. Fr.,* **1992**, *117*, 267-278.

[44] Kollinsky, C.; Landmann, A. Altitudinal distribution of male black redstarts: are there age-dependent patterns? *Bird Study*, **1996**, *43*, 103-107.

[45] Rolando, A. Personal Communication. Department of Life Science and Systems Biology, University of Turin, Italy, **2011**.

[46] Verbeek, N.A.M. Breeding biology and ecology of the horned lark in alpine tundra. *Wilson Bull.*, **1967**, *79*, 208-217.

[47] Kingery, H.E. American Dipper *(Cinclus mexicanus)*. In: *The birds of North America, No. 229*; Poole, A., Gill, F. Eds; The Academy of Natural Sciences: Philadelphia. Washington, D. C., USA, **1996**; pp 1-28.

[48] Sandercock, B.K.; Martin, K.; Hannon, S.J. Life history variation in extreme environments: comparative demography of arctic and alpine ptarmigan. *Ecology*, **2005**, *86*, 2176-2186.

[49] Sandercock, B.K.; Martin, K.; Hannon, S.J. Demographic consequences of age-structure in extreme environments: population models for arctic and alpine ptarmigan. *Oecologia*, **2005**, *146*, 13-24.

[50] Wilson S.; Martin, K. Variable reproductive effort for two ptarmigan species in response to spring weather in a northern alpine ecosystem. *J. Av. Biol.*, **2010**, *41*, 319-326.

[51] Wilson, S.; Martin, K. Life-history and demographic variation in an alpine specialist at the latitudinal extremes of the range. *Popul. Ecol.*, **2011,** *53*, 459-471.

[52] Bronson, M.T. Altitudinal variation in the life history of the golden-mantled ground squirrel *(Spermophilus lateralis). Ecology*, **1979**, *60*, 272-279.

[53] Dobson, F.S.; Zammuto, R.M.; Murie, J.O. A comparison of methods for studying life history in Columbian ground squirrels *J. Mammal.*, **1986**, *667*, 154-158.

[54] Dobson, F.S.; Murie, J.O. Interpretation of intraspecific life history patterns: evidence from Columbian ground squirrels. *Am. Nat.*, **1987**, *129*, 382-397.

[55] Arnold, W. The evolution of marmot sociality: I. Why disperse late? *Behav. Ecol. Sociobiol.*, **1990**, *27*, 229-237.

[56] Arnold, W. The evolution of marmot sociality: II. Costs and benefits of joint hibernation. *Behav. Ecol. Sociobiol.*, **1990**, *27*, 239-246.

[57] Arnold, W. Social evolution in marmots and the adaptive value of joint hibernation *Verh. Deutsch Zool. Ges*., **1993**, *86*, 79-93.

[58] Armitage, K.B. Evolution of sociality in marmots *J. Mammal.*, **1999**, *80*, 1-10.

[59] Pattie, D.L.; Verbeek. N.A.M. Alpine birds of the Beartooth Mountains. *Condor*, **1966**, *68*, 167-176.

[60] K. Martin, Field Surveys, Centre for Alpine Studies (UBC): http://www.forestry.ubc.ca/alpine/

[61] Sutherland, G. D.; Gass, C.L.; Thompson, P.A.; Lertzman, K.P. Feeding territoriality in migrant rufous hummingbirds: defense of yellow-bellied sapsucker *(Sphyrapicus varius)* feeding sites. *Can. J. Zool.*, **1982**, *60*, 2046-2050.

[62] Gass, C.L.; Sutherland, G. Specialization by territorial hummingbirds on experimentally enriched patches of flowers: energetic profitability and learning. *Can. J. Zool.*, **1985**, *63*, 2125-2133.

[63] French, N.R. Life history of the black rosy finch. *Auk*, **1959**, *76*, 158-180.

[64] Braun, C.E.; Streeter, R.G. Observations on the occurrence of white-tailed jackrabbits in the alpine zone *J.Mammal.*, **1968**, *49*, 160-161.

[65] Arlettaz, R.; Patthey, P.; Baltic, M.; Leu, T.; Schaub, M.; Palme, R.; Jenni-Eiermann, S. Spreading free-riding snow sports represent a novel serious threat for wildlife. *Proc. R. Soc. B,* **2007**, *274*, 1219-1224.

[66] Zwickel, F.C.; Bendell, J.F.; Blue Grouse (Dendragapus obscurus), *The Birds of North America Online*; Poole, A. Ed.; Ithaca: Cornell Lab of Ornithology; Retrieved from the Birds of North America Online, **2005**.

[67] Zeitler, A.; Glanzer, U. Skiing and grouse in the Bavarian Alps *Grouse News,* **1998**, *15*, 8-12.

[68] Rolando, A.; Laiolo, P.; Carisio, L. Urbanization and the flexibility of the foraging ecology of the Alpine Chough *Pyrrhocorx graculus* in winter *Rev. Ecol. (Terre Vie)*, **2003,** *58*, 337-352.

[69] Storch, I.; Leidenberger, C. Tourism, mountain huts and distribution of corvids in the Bavarian Alps, Germany. *Wildl. Biol.,* **2003**, *9*, 301-308.

[70] Watson, A.; Moss, R. Impacts of ski-development on ptarmigan (*Lagopus mutus*) at Cairn Gorm, Scotland. *Biol. Cons.,* **2004**, *116*, 267-275.

[71] Watson, A. Bird and mammal numbers in relation to human impact at ski-lifts on Scottish hills. *J. Appl. Ecol.,* **1979**, *16*: 753-764.

[72] Rochefort, R.M.; Gibbons, S.T. Mending the meadow: high altitude meadow restoration in Mount Rainier National Park. *Restor. Manage. Notes*, **1992**, *10*, 120-126.

[73] Fedy, B.C.; Martin, K.; Ritland, C.; Young, J. Genetic and ecological data provide incongruent interpretations of population structure and dispersal in naturally subdivided populations of white-tailed ptarmigan (*Lagopus leucura*). *Mol. Ecol.*, **2008**, *17*, 1905-1917.

[74] Rolando, A.; Caprio, E.; Rinaldi, E.; Ellena, I. The impact of high-altitude ski-runs on alpine bird communities. *J. Appl. Ecol.*, **2007**, *44*, 210-219.

[75] Storch, I.; Segelbacher, G. Genetic correlates of spatial population structure in central European capercaillie *Tetrao urogallus* and black grouse *T. tetrix*: a project in progress *Wildl. Biol.*, **2000**, *6*, 305-310.

[76] Woods, J.G. *Ecology of a partially migratory elk population*. Ph.D. Thesis. University of British Columbia: Vancouver, **1991**.

[77] Weaver, J.L.; Paquet, P.C.; Ruggiero, L.F. Resilience and conservation of large carnivores in the Rocky Mountains *Cons. Biol.*, **1996**, *10*, 964-976.

[78] Noss, R.F.; Quigley, H.B.; Hornocker, M.G.; Merrill, T.; Paquet, P.C. Conservation biology and carnivore conservation in the Rocky Mountains. *Cons. Biol.*, **1996**, *10*, 949-963.

[79] St. Clair, C.C. Comparative permeability of roads, rivers and meadows to forest songbirds in Banff National Park. *Cons. Biol.*, **2003**, *17*, 1-11.

[80] Sutherland, W.J.; Reynolds, J.D. Sustainable and unsustainable exploitation. In: *Conservation science and management;* Sutherland, W.J. Ed.; Blackwell: Oxford, UK. **1998**; pp 90-115.

[81] Edge, W.D. Wildlife communities of agriculture, pastures, and mixed environs. In: *Wildlife-Habitat Relationships in Oregon and Washington*; Johnson, D.H. O'Neil, T.A. (Manag. Dirs.). Oregon State University Press, **2001**.

[82] Ferguson, H.L.; Robinette, K.; Stenberg, K. Wildlife communities of urban habitats. In: *Wildlife-Habitat Relationships in Oregon and Washington*; Johnson, D.H. O'Neil, T.A. (Manag. Dirs.). Oregon State University Press, **2001**.

[83] Schroeder, M.A. Personal Communication. Washington Department of Fish and Wildlife, USA, **2011**.

[84] Wielgus, R.B. Minimum viable population and reserve sizes for naturally regulated grizzly bears in British Columbia. *Biol. Cons.*, **2002**, *106*, 381-388.

[85] Hamr J. Disturbance behavior of chamois in an alpine tourist area of Austria. *Mt. Res. Dev.*, **1988**, *8*, 65–73.

[86] Côté, S. D. Mountain goat responses to helicopter disturbance. *Wildl. Soc. Bull.*, **1996**, *24*, 681-685.

[87] Lindh, H.; Martin, K. Utility of systematic reserve selection approaches for conservation of North American mountain resort communities: a case study in Whistler, Canada. *Mt. Res. Dev.*, **2004**, *24*, 319-326.

[88] Sekercioglu, C.H.; Schneider, S.H.; Fay, J.P.; Loarie, S.R. Climate chance, elevational ranges shifts, and bird extinctions *Cons. Biol.,* **2008**, *22*, 140-150.

[89] Kracik, K. All downhill from here? *Science,* **2004**, *303*, 1600-1602.

[90] Grabherr, G.; Pauli, M.G.H. Climate effects on mountain plants *Nature*, **1994**, *369*, 448.

[91] Järvinen, A. Effects of climate change on mountain bird populations. In: *Potential Ecological impacts of climate change in the Alps and Fennoscandian Mountains.* Guisan, A. *et al.*, Eds.; Conservatoire et Jardin botaniques de la Ville de Genève: Geneva, Switzerlan, **1995**; pp 73-74.

[92] Inouye, D.W.; Barr, B.; Armitage, K.B.; Inouye, B.D. Climate change is affecting altitudinal migrants and hibernating species. *Proc. Natl. Acad. Sci.*, **2000**, *97*, 1630-1633.

[93] Roland, J.; Keyghobadi, N.; Fownes, S. Alpine *Parnassius* butterfly dispersal: effects of landscape and population size. *Ecology*, **2000**, *81*, 1642-1653.

CHAPTER 2

Climate Change and Snow Cover in the European Alps

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Abstract: Climatic changes are already having a significant impact on snow cover in the European Alps. Several studies from Switzerland, France, Austria, Italy and Germany have noted a general decrease in snow depth and snow cover duration since the end of the 1980s throughout the European Alps. Investigations of snow cover and climate change have revealed that the reduction in snow reliability observed in low and medium altitude ski resorts is mainly caused by warmer winter temperatures. Precipitation becomes the determining factor for a snowy winter only above 2000 m asl. Projected changes in temperature and precipitation are expected to cause further significant decline in the snowreliability of Alpine ski areas. The impacts of these changes, however, are not uniform. They depend on altitude, region and local factors. For example, the impact of climate change is stronger at low altitudes, in inner-alpine dry valleys and on southern slopes, which leads to winners and losers among the different ski areas. The winter tourism industry has already begun to respond to the implications of these observed changes. A range of technological and behavioural measures have been put into practice to offset the adverse impacts. However, adaptation measures, such as the widespread use of snow-making, put new pressures on the ecology of the mountain environment.

Keywords: Adaptation measures, precipitation change, snow depth, snow reliability, temperature change, winter tourism.

INTRODUCTION

Snow influences human life and society in many ways. The amount and duration of snow in a ski-resort has high socio-economic significance for tourism. Many mountain towns and villages depend heavily on snow, because their economy is dominated by winter tourism (by up to 90 %) [1]. The vast majority of customers of such ski areas live in the pre-alpine regions of Switzerland, Austria, Germany,

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Italy and France. A longer sequence of almost snowless winters in these heavily populated regions, such as observed between the late 1980s and mid 1990s, caused problems for some ski areas and initiated a discussion about how exceptional were such winters. To test for possible connections with climate change, a number of studies have tried to investigate past variability, and to predict future trends, for Alpine snow cover.

The financial viability of winter tourism depends to a great extent on favourable snow conditions and reliable snow in the ski areas. A certain amount of snow is required to groom the slopes, protect the ground, guarantee safe operation of the slopes, and to provide the skiers with an enjoyable experience. The minimum snow depth from an operational point of view, which may differ from the skiers' perspective, depends on the nature of the slopes. In general, a snow depth of 30 cm is considered sufficient, 50 cm good, and 70 cm excellent [2]. However, rocky slopes at higher elevations may require much greater snow depths to be skiable (up to 1 m).

To investigate the impact of climate change on winter tourism in the Alps, it is therefore important to understand the notion of natural snow reliability. Various criteria have been proposed in the literature to assess the natural snow reliability of ski areas. The so-called 100-day rule, first suggested by Witmer [2] is the most widely accepted definition. According to this rule, there is natural snow reliability if it is possible to successfully operate a ski area with sufficient snow cover for skiing for at least 100 days during 7 out of 10 seasons [3]. However, there is no generally applicable minimum snow depth to operate slopes, as this depends on the characteristics of the resort and slopes, *e.g.,* rockiness or north–south orientation.

In the Swiss Alps, Laternser and Schneebeli [4] found that the criteria for the 100-day rule with a 30 cm threshold for snow depth, are currently fulfilled by areas at altitudes above about 1300 m asl. This suggests that one of the conditions required to run a successful ski business under current climate conditions in Switzerland is a minimum elevation of about 1300 m asl, which is assumed to be the line of natural snow-reliability (Fig. (**1**)). But this line varies across the Alpine is due to the considerable variation in Alpine climate. Colder regions will have natural snow-reliability at lower altitudes than warmer regions. Wielke *et al.* [5]

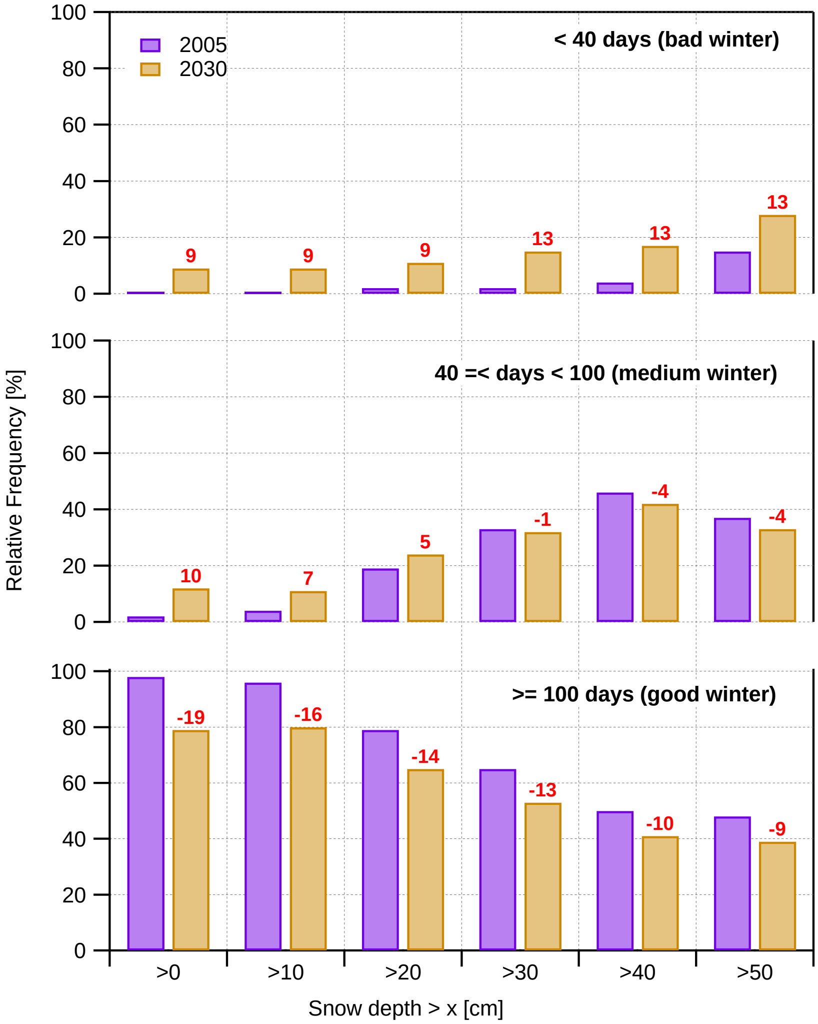

Figure 1: Probability of good, medium and bad winters for a ski area in the eastern Swiss Alps with a mean altitude at 1200 m asl for past (1958-2007) and future (2030) conditions. The 100-day rule can only be fulfilled with the 20 cm threshold for past winters (violet) and 10 cm threshold for future winters (brown). The red numbers show the percentage change between past and future winters (1 December - 15 April).

compared snow cover duration in the Alps and found the patterns in Switzerland and Austria were similar, but comparable features were located about 150 m higher in Switzerland than in eastern Austria. This indicates a transition from an Atlantic-maritime to a more continental climate, with colder winters in the more eastern parts of the Alps. The baseline of natural snow-reliability as established in Switzerland is therefore probably 150 m lower (*i.e.* at 1050 m asl) in eastern

Austria. On the other hand, Marty [6] showed that the ski resorts above 1300 m asl on the southern side of the Swiss Alps experience about 20 % fewer snow days, *i.e.* days with at least 50 cm of snow, than the ski resorts on the northern side of the Alps. This indicates that the line of natural snow-reliability for ski areas influenced by a warmer Mediterranean climate is lower than that for the northern parts of the Alps.

Some Alpine countries have a relatively dense network of measurement stations, where daily snow depth and snowfall have been measured with the help of a permanently mounted snow stake and a new snow board for 50 years or more. The availability of this comprehensive dataset, as well as the socio-economic importance of snow in Alpine countries, make the Alps a preferred region to investigate changes in snow cover. The measurement locations are not always in ski resorts, but are often close by or at similar altitudes and regions. Remote-sensing data for Alpine snow cover have not yet been used for climatological purposes due to the lack of longer time series and the limited data quality arising from the steep topography of the Alps.

This chapter provides an assessment of the impacts of climate change on snow cover (snow reliability) on ski areas in the European Alps. I present: 1) an overview of observed snow cover changes in the different Alpine countries, 2) the results of climate change scenarios for future snow cover, and finally 3) some adaptation strategies adopted by ski area managers. The implications of this assessment, however, extend beyond the European Alps. Insights into adaptation strategies, for example, are also likely to be relevant for other mountain regions facing similar climatic changes, such as North America, Australia and New Zealand.

OBSERVED CHANGES

The seasonal snow cover in the Alps is primarily influenced by high year-to-year variability due to anomalies in large-scale weather patterns [7]. Several studies have nevertheless noted a general decrease in snow depth and snow cover duration since the end of the 1980s at low-lying stations throughout the European Alps.

In the Swiss Alps, a significant decrease in snow depth for elevations below 1300 m asl was observed in the late 20th century with measurements from more than 100 stations [8], whereas no significant differences could be detected for high-altitude stations above 2000 m asl [30]. The long-term snow trends in the Swiss Alps appear to be similar for all three variables: snow depth, the duration of continuous snow cover and the number of snow fall days [4]. Earlier investigations concluded that the length of the snow season and the amount of snow have substantially decreased since the mid 1980s, but during several periods in the records, *e.g.,* in the 1930s, the snow depth was as low as during the late 1980s [9]. However, a newer study using more data from the last 130 years indicated that the series of snow-poor winters over the 20-year period from 1988 to 2007 was unique [6]. In particular, it showed that the decline was caused by an abrupt change, rather than by a continuous decrease (Fig. (**2**)). The number of snow days, *i.e.* days with snow depth of at least 30 cm, at ski resorts between 800 and 1200 m asl, for example, dropped by about 35 % after the end of the 1980s compared to the long-term mean before the change. The determining signal for this change was mainly temperature and not precipitation [6, 8], and this has had considerable impact on the mean evolution of snow cover during the last twenty years (Fig. (**3**)).

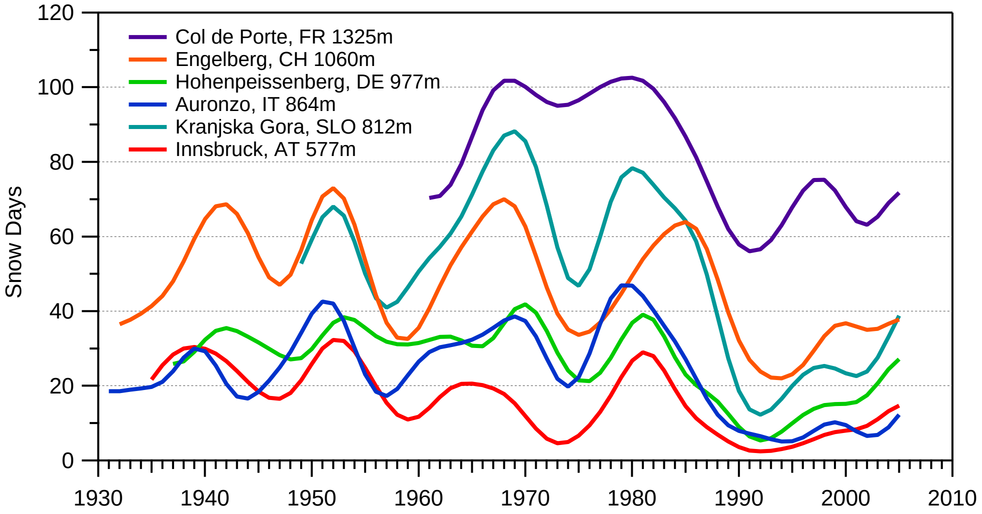

Figure 2: Number of snow days, *i.e.* days with at least 30 cm snow on the ground (with exception of Innsbruck (20 cm) and Col de Porte (50 cm)), at ski resorts in 6 Alpine countries. All stations show a striking shift towards significantly less snow in the last 20 years. The values are based on 10-year low-pass filtered values of annual snow days between December and March.

In the Austrian Alps, various snow parameters at 98 long-term stations were investigated and a more diverse picture was found [10]. The two 20-year periods between 1980 and 2000 and between 1896 and 1916 were compared and tested for changes. Statistical tests detected decreasing trends at the majority of the stations, but the decline was only significant at the southern Austrian stations. There, a clearly decreasing trend was found for the duration of winter snow cover and the days with snow depths of more than 1 cm. A separate analysis of 14 stations with 100 years of data revealed similar results with snow day trends in southern Austria mostly significantly decreasing and no significant trends in the remaining parts of the country.

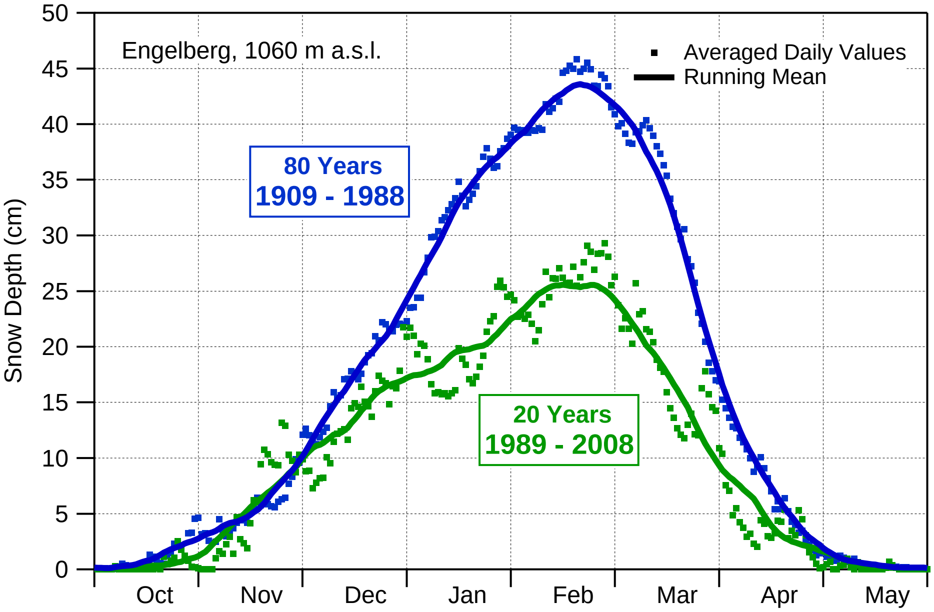

Figure 3: The less snowy winters during the last 20 years result in a clear reduction of the snow depth during the winter season, as shown here for the ski resort of Engelberg in the Swiss Alps. Note that the spring snow cover seems to be more affected than early-winter snow cover.

In the Italian Alps, a general decrease in snow depth and snow duration during the last twenty years was found in the analyzed time series between 1920 and 2009 using data from 30 stations [11]. The authors relate this decrease to reduced snow fall, which in turn may be caused by a higher ratio of liquid precipitation due to warmer winter temperatures as recently demonstrated [31]. The spring reduction in snow depth was not as unique as the reduction over the whole winter. Surprisingly, these results were confirmed by 20 stations situated between 2000 and 3000 m asl in a small area in northern Italy [12]. In the German Alps, a 20-30

% reduction in snow cover duration was found for low-lying areas between 1952 and 1996 [13]. A smaller reduction of about 10 % was observed in higher areas. In the French Alps, snow trends between 1958 and 2005 were investigated with the help of an automatic system that combined three numerical models to simulate meteorological parameters and snow stratigraphy [14]. As input data, the system was fed with meteorological observations and 40 years re-analysis data (ERA-40) from the European Centre for Medium-range Weather Forecasts (ECMWF). The few available long-term snow observations were finally used for verification. The results demonstrate a significant decrease in snow depth at low and mid altitudes, but this signal is weaker in the south than in the north and less visible at high elevations. Concerning snow duration, a shift in the mean values at the end of the 1980s confirmed the finding reported in Marty [6]. The results have also been interpreted in terms their implications for a viable ski industry. French downhill ski resorts are currently economically viable above elevations ranging from about 1200 m asl in the northern foothills to 2000 m in the south.

FUTURE CHANGES

Climate models today can successfully reproduce large-scale parameters such as temperature. However, investigations on the evolution of the future snow pack under changing climate conditions all battle with the fact that the current climate models have difficulties in representing the fine-scaled spatial and temporal variability of snow. Some studies therefore use physical models driven by artificially generated data of future weather conditions to predict the snow depth and duration at local levels. Other studies estimate future snow conditions based on a sensitivity analysis of the current variability.

For example, Hantel and Hirtl-Wielke [15] assessed the snow-temperature sensitivity in the European Alps based on data recorded during the past 40 years at 268 stations and came to the conclusion that the number of snow days (days with snow depths greater than 5cm) will decrease by 33% per 1°C increase in temperature. This corresponds to a reduction of snow cover duration of about 1 month at the altitude of maximum sensitivity (about 700 m asl), but falls rapidly above and below that level. The future snow reliability of 666 Alpine ski resorts in 6 European countries was investigated by Abegg *et al.* [16]. They calculated the impact of temperature increases of 1°C, 2°C and 4°C based on the assumption that the altitudinal limit of natural snow-reliability will rise by 150 m per 1°C warming. They concluded that the number of naturally snow-reliable areas would drop by 25% with a temperature increase of 1°C, by 40% with 2°C, and by 70 % with a 4°C warming (Fig. (**4**)).

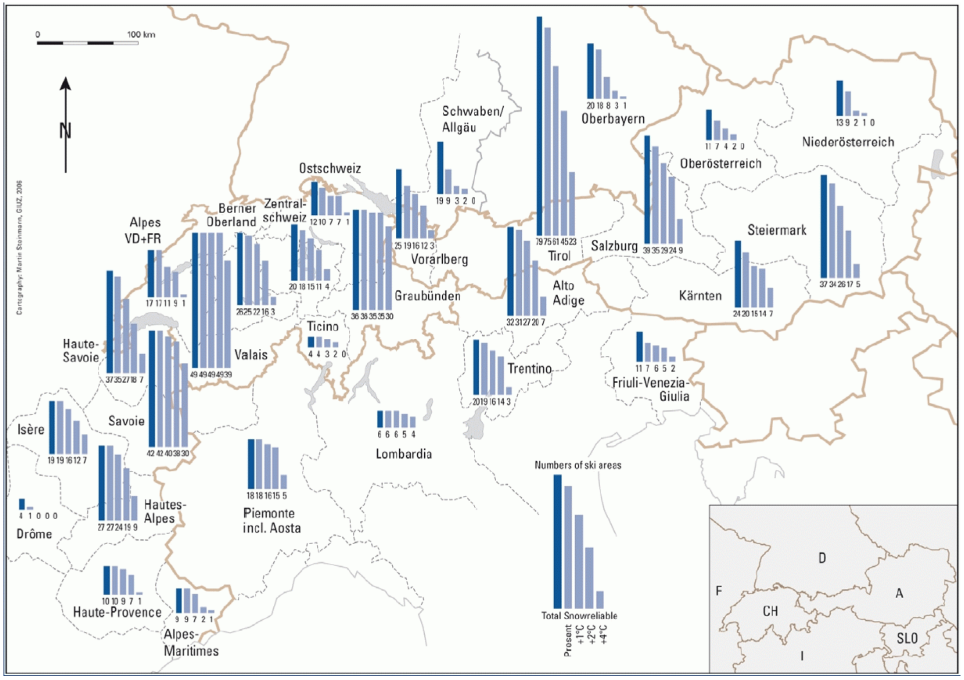

Figure 4: Number of naturally snow-reliable ski areas in the European Alps under present and future climate conditions. Regions with low-altitude ski areas, for example in southern Germany, are most affected by future warming (Adapted from Abegg *et al.* [16]).

Future Austrian snow conditions were analyzed using a simple temperature- and precipitation-dependent snow model by Breiling and Charamza [17]. They concluded that the impact of 2°C warming would mean only a few locations at higher altitudes would be suitable for winter tourism and skiing. None of these studies [15-17] took into account the local influences of topography or orientation at each location, and they assumed that the current sensitivity of the snow cover will not change in the future.

The other approach of coupling existing snow-cover models with meteorological input data from regional climate models (RCMs) for future climate scenarios was first applied by Beniston *et al.* [18] in the Swiss Alps. Using a single-layer snow-cover model and assuming a 4°C temperature increase by the end of this century, they found a 50 % reduction in snow volume with a termination of the season about 50 days earlier at 2000 m asl. For the French Alps, Martin and Etchevers [19] used future temperature fields from a GCM as input for their multi-layer snow-cover model. They found a 50 % reduction in snow depth below 1500 m asl and 30 % smaller snow covered area in mid-winter with a 1.8 °C temperature increase, when precipitation was kept constant. They concluded that changes of this magnitude could have a major impact on the skiing industry in the French Alps, especially at lower elevations. The length of the skiing season could decrease substantially and ski areas may increasingly move into less temperature-sensitive high-elevation areas.

The sensitivity of snow cover to future climate has recently been analyzed at 20 ski resorts in the Swiss Alps using a more sophisticated approach [20]. With a well-elaborated perturbation method and RCM model data as input for their single layer snow cover model, the researchers computed snow reliability at the end of this century with a predicted 4° C increase in temperature. With this scenario, snow will become scarce on the lower ski runs in all resorts and days when the snow depth is more than the critical 30 cm snow depth will drastically decrease at more than half of the stations. In addition, at the critical altitude, *i.e.* the altitude above which snow is required for the ski lifts to run, more than half of the stations, on average, will have snow depths below the critical 30-cm level.

Hydrological studies that investigate the impact of climate change on snow cover as a water resource can often also be used for the analysis of snow reliability of ski resorts, which are situated within water catchments. Potential future changes in two such Alpine river basins (above 800 m asl) in the Swiss Alps have been investigated with the help of the distributed catchment model WaSiM-ETH [21]. According to 23 regional climate models, 2.5°C warming and small changes in precipitation can be expected by the end of the 21st century. The model predicted a decrease of 70 % in the annual mean snow-water equivalent, two months less continuous snow cover and a snowline rise of 450 m. Bavay *et al.* [22] and Magnusson *et al.* [23] focused on three other alpine river basins (above 1600 m asl) using the spatially distributed model system Alpine3D and the IPCC A2 and

B2 scenarios output from 6 RCMs. Their results indicated that the snow volume and the maximum snow water equivalent at the end of the 21st century are likely to be reduced by about 40%. The complete melt of the snow cover will occur about 40 days earlier and the snow line will be shifted by about 900 m, which would mean most of the glaciers in these basins would disappear and limit the natural snow reliability to altitudes above 2000 m asl.

ADAPTATION STRATEGIES

Managers of ski areas and stakeholders in tourism are not just waiting to see what the consequences of climate change are, but have already begun to prepare for less snowy winters [3, 24-26]. They realize that the ski industry is highly dependent on snow conditions and that snow-deficient winters pose a risk. Adaptation practices found among ski area operators can be divided into two main categories: technological and behavioral [16].

Technological adaptations appear so far to be the adaptation strategies most favored by tourism stakeholders in the European Alps. The three main types are listed here in order of priority. Their impacts on the mountain environment are discussed in detail in the other chapters:

- Landscaping: This strategy involves the landscaping of large ski areas (*e.g.*, machine-grading or bulldozing of ski runs, creation of shaded areas) and the contouring or smoothing of smaller areas (*e.g.*, the leveling of rough and bumpy surfaces, and the removal of obstacles such as rocks and shrub vegetation). The aim is to reduce the snow depth required for ski operation, which also means a reduction of the necessary amount of artificial snow.

- Artificial snow-making: Snow-making is used to extend the operating season and to increase the range of climate variability and climate change with which a ski area can cope. While artificial snow-making was initially viewed as a luxury and then a back up strategy, it now appears to be viewed as a necessity. According to Pröbstl [27], the rapid expansion of snow-making in the Alps was triggered by the need to secure and guarantee the revenues of the ski area managers and by the success of the ski resorts that could provide a "snow guarantee".

- Going higher and facing north: The aim of this strategy is to concentrate ski operations in locations with a climatic advantage. The different options for this strategy include: moving operations to the upper part of an existing ski area or building new ski areas on north-facing slopes, at higher elevations and possibly on glaciers.

Behavioral adaptations range from new business models and new financial tools to a change in operational practices and a move towards the diversification of activities:

- Mergers and corporations: A very common form of cooperation is the merger of different companies in one valley or even from neighboring valleys with the aim of reducing marketing and operational costs. Another form of cooperation is the regional association, which offers one ski pass for several ski areas. A less well-known form of cooperation is the collaboration between a small low-altitude, but close-to-the-city, ski area and a large mountain ski area to "nurse" future customers and to have a marketing platform close to heavily populated regions.

- Financial support: A growing number of ski area managers consider snow-making to be a public service and therefore claim that all those who benefit should contribute to the costs. The options go from sharing the cost of snow-making with the accommodation sector to governmental subsidies for the ski area. Local authorities can, for example, make one-off or annual contributions, issue loans or take a share in the business. This is highly beneficial for a ski resort as the local authorities generally receive better financial ratings than ski area managers.

- Diversification: Many resorts have made substantial investments to cater for the growing market of non-skiers. The most popular activities are winter hiking, tobogganing and snowshoeing. The problem, of course, with these non-ski related activities is that they

> also require snow, although less than for downhill skiing. Moreover, these new activities, which often take place in previously undisturbed surroundings, may cause new problems for some animals already struggling to cope with the harsh winter environment.

However, these strategies cannot all be causally linked only to climate change, as trends in tourism, prestige, and competitive advantage are also important factors.

Figure 5: Snow as a resource: Artificial snow from the previous winter is preserved during summer under a thick layer of woodchips at 1600 m asl in Davos, Switzerland. In the early winter of the same year, this pile of snow will help to produce a cross-country ski track. Such management of snow supplies and snow reserves is called snow farming. Snow farming is nowadays practiced by many ski resorts in order to keep the slopes well-stocked with snow to attract visitors (Photo: SLF).

DISCUSSION AND IMPLICATIONS

The seasonal snow cover in the Alps is primarily influenced by a high year-to-year variability due to large-scale weather patterns. Despite this variability, a general decrease in snow depth and snow cover duration has been apparent since the end of the 1980s at low-lying stations throughout the European Alps. The decline could be linked to the anomalously warm winter temperatures during the last twenty years [6, 8], which seem to be unique over at least the last 500 years [28]. During the past 100 years in Switzerland, for example, the observed warming has been roughly twice as high as the global average [29].

The development of winter tourism and skiing infrastructure in the European Alps during the past 30 years has tended to follow the decadal temperature variations. The period 1965-1985, when an expansion of ski areas occurred, was a relatively cold one. The period 1985-1995, was considerably warmer, and most winter resorts had snow problems during this time, many of them serious, and artificial snow making became popular. A rise of just 0.8 °C in temperature necessitated considerable adaptation, which is still required today.

Research on future snow cover has taken two different approaches, one based on physical models and the other based on current snow-temperature sensitivity. Assuming 2°C warming, both came to similar results: Snow depth will drastically decrease by about 40-60% below 1800 m; the snow cover will last 4 to 6 weeks less and the snow line will rise by about 300-500 m. According to the RCM projections, the warming in the Alps will be accompanied by a small increase in winter precipitation. Some authors therefore concluded that, at higher altitudes, where the temperatures are still cold enough for substantial snowfall, the snow depth may even increase with climate warming. However, the outcomes of two recent studies imply that the projected increase in winter precipitation over the Alps will not compensate for the projected increase in temperature even at the higher resorts [20, 22].

These projected changes in temperature and precipitation will most certainly be a challenge for the winter tourism sector. Since the Alpine snow cover is very sensitive to temperature, the depth, length and duration of the snow cover is greatly influenced by climate change. As warming progresses in future, regions where snowfall is the current norm will increasingly experience rain, and the snow on the ground will melt faster. To mitigate the effects of this process, innovative technical solutions and behavioral adaptations are needed to conserve energy and to ensure the mountain environment is harmed as little as possible. Sophisticated storage methods, (see Fig. (**5**)), or improved artificial snow production may help to safeguard winter tourism in regions where few other economic resources are available. Future perspectives leave no doubt, however, that the projected climate changes will have considerable impact on the economic, social, hydrological and biological systems in the Alpine region.

CONFLICT OF INTEREST

The author confirms that this article content has no conflict of interest.

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REFERENCES

[1] Elsasser, H. and P. Messerli, The Vulnerability of the Snow Industry in the Swiss Alps. *Mountain Research and Development*, **2001**. *21*: p. 335-339.

[2] Witmer, U., *Erfassung, Bearbeitung und Kartierung von Schneedaten in der Schweiz*. Geographica Bernesia. Vol. G25. **1986**: Geographisches Institut der Universität Bern.

[3] Bürki, R., *et al.*, Climate change and tourism in the Swiss Alps., in *In Aspects of Tourism. Tourism, recreation and climate change*, C.M. Hall and J. Higham, Editors. **2005**. p. 155-163.

[4] Laternser, M. and M. Schneebeli, Long-term snow climate trends of the Swiss Alps (1931-99). *International Journal of Climatology*, **2003**. *23*(7): p. 733-750.

[5] Wielke, L.-M., L. Haimberger, and M. Hantel, Snow cover duration in Switzerland compared to Austria. *Meteorologische Zeitschrift*, **2004**. *13*: p. 13-17.

[6] Marty, C., Regime shift of snow days in Switzerland. *Geophys. Res. Lett.*, **2008**. *35*.

[7] Scherrer, S.C. and C. Appenzeller, Swiss Alpine snow pack variability: major patterns and links to local climate and large-scale flow. *Climate Research*, **2006**. *32*(3): p. 187-199.

[8] Scherrer, S.C., C. Appenzeller, and M. Laternser, Trends in Swiss Alpine snow days: The role of local- and large-scale climate variability. *Geophys. Res. Lett.*, **2004**. *31*.

[9] Beniston, M., Variatons of snow depth and duration in the Swiss Alps over the last 50 years: Links to changes in large-scale climatic forcings. *Climatic Change*, **1997**. *36*: p. 281-300.

[10] Jurkovic, A., *Gesamtschneehöhe - Vergleichende Zeitreihenanalyse*, in *Meteorology*. **2008**, University of Vienna: Vienna.

[11] Valt, M. and P. Cianfarra, Recent snow cover variation and avalanche activity in the Southern Alps. *Cold Regions Science and Technology*, **2010**. 64(2): 146-157.

[12] Bocchiola, D. and G. Diolaiuti, Evidence of climate change within the Adamello Glacier of Italy. *Theoretical and Applied Climatology*, **2009**.

[13] Günther, T., M. Rachner, and H. Matthäus, *Langzeitverhalten der Schneedecke in Baden-Württemberg und Bayern. KLIWA-Projekt A 1.1.4: "Flächendeckende Analyse des*

Langzeitverhaltens verschiedener Schneedeckenparameter in Baden-Württemberg und Bayern., in *KLIWA Berichte*, A. KLIWA, Editor. **2006**. p. 76.

[14] Durand, Y., *et al.*, Reanalysis of 47 Years of Climate in the French Alps (1958-2005): Climatology and Trends for Snow Cover. *Journal of Applied Meteorology and Climatology*, **2009**. *48*(12): p. 2487-2512.

[15] Hantel, M. and L.-M. Hirtl-Wielke, Sensitivity of Alpine snow cover to European temperature. *International Journal of Climatology*, **2007**. *27*(10): p. 1265-1275.

[16] Abegg, B., *et al.*, Climate change impacts and adaptation in winter tourism, in *Climate Change in the European Alps*, S. Agrawala, Editor. **2007**, OECD: Paris. p. 25-60.

[17] Breiling, M. and P. Charamza, The impact of global warming on winter tourism and skiing: a regionalised model for Austrian snow conditions. *Regional Environmental Change*, **1999**. *1*(1): p. 4-14.

[18] Beniston, M., *et al.*, Estimates of snow accumulation and volume in the Swiss Alps under changing climatic conditions. *Theoretical and Applied Climatology*, **2003**. *76*(3): p. 125-140.

[19] Martin, E. and P. Etchevers, Impact of climatic changes on snow cover and snow hydrology in the French Alps, in *Global Change and Mountain Regions: An Overview of Current Knowledge*, U.M. Huber, H.K.M. Bugmann, and M.A. Reasoner, Editors. **2005**, Springer. p. 235-242.

[20] Uhlmann, B., S. Goyette, and M. Beniston, Sensitivity analysis of snow patterns in Swiss ski resorts to shifts in temperature, precipitation and humidity under conditions of climate change. *International Journal of Climatology*, **2008**.

[21] Jasper, K., *et al.*, Differential impacts of climate change on the hydrology of two alpine river basins. *Climate Research*, **2004**. *26*(2): p. 113-129.

[22] Bavay, M., *et al.*, Simulations of future snow cover and discharge in Alpine headwater catchments. *Hydrological Processes*, **2009**. *23*(1): p. 95-108.

[23] Magnusson, J., *et al.*, Snow cover response to climate change in high alpine and half glaciated basin in Switzerland. *Hydrology Research*, **2010**. 41(3-4): 230-240.

[24] Wolfsegger, C., S. ssling, and D. Scott, Climate Change Risk Appraisal in the Austrian Ski Industry. *Tourism Review International*, **2008**. *12*: p. 13-23.

[25] Steiger, R. and M. Mayer, Snowmaking and climate change. *Mountain Research and Development*, **2008**. *28*(3/4): p. 292-298.

[26] Hoffmann, V.H., *et al.*, Determinants of corporate adaptation to climate change in winter tourism: An econometric analysis. *Global Environmental Change*, **2009**. *19*(2): p. 256-264.

[27] Pröbstl, U., *Kunstschnee und Umwelt - Entwicklung und Auswirkungen der technischen Beschneiung.* **2006**, Bern: Haupt Verlag 232

[28] Luterbacher, J.r., *et al.*, Exceptional European warmth of autumn 2006 and winter 2007: Historical context, the underlying dynamics, and its phenological impacts. *Geophys. Res. Lett.*, **2007**. *34*.

[29] Rebetez, M. and M. Reinhard, Monthly air temperature trends in Switzerland 1901–2000 and 1975–2004. *Theoretical and Applied Climatology*, **2008**. *91*(1): p. 27-34.

[30] Marty, C. and Meister, R., 2012: Long-term snow and weather observations at Weissfluhjoch and its relation to other high-altitude observatories in the Alps. Theoretical and Applied Climatology:1-11. doi:10.1007/s00704-012-0584-3.

[31] Serquet, G., Marty, C., Rebetez, M. and Dulex, J.P., 2011: Seasonal trends and temperature dependence of the snowfall/precipitation day ratio in Switzerland, Geophysical Research Letters, 38, L07703, doi:10.1029/2011GL046976.

CHAPTER 3

Soil Properties on Ski-Runs

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Abstract: Much of the surface area in mountain regions has been converted to recreational activities in recent decades due to the increasing demand of tourists for winter sports. In general, ski-run construction and management have a great influence on the chemical and physical properties of underlying soils. To create ski-runs the natural landform is often changed to level the surface, thus exposing unweathered parent material or deep soil horizons. Thus the original soil thickness can be reduced, often resulting in a "turbated" topsoil. The result is that soils in ski-runs have an almost complete lack of structure, with subsequent problems of soil compaction and reduction of water and air permeability. Erosion on ski-runs is thus enhanced. One control that is often pursued is artificial seeding. However, depletion of soil organic matter, reduction in soil aggregate stability, and nutrient imbalance may affect plant development. In ski-run restoration the improvement of soil organic matter and nutrient status is one of the most crucial tasks. A greater understanding of soil physico-chemical characteristics, plant colonisation and soil microbial activity after ski-run construction is necessary to enhance conservation and restoration of these disturbed pedoenvironments.

Keywords: Soil formation, artificial snow, erosion, soil compaction, soil nutrients, soil structure, pedogenesis, soil classification, winter sports, cold temperature, roots, anthropogenic soils, ski-run construction, ski-run restoration, soil/snow interaction, soil microbial biomass, best practices, land management.

INTRODUCTION

Winter-based ski tourism is a major use of many mountain regions, with large-scale ski resorts located in Europe, Asia, North and South America, New Zealand and Australia [1-3]. In mountain regions the traditional use of land is nowadays

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Christian Rixen and Antonio Rolando (Eds)

combined with surfaces devoted to recreational activities because of the increasing tourist demand for winter sports. As with many human activities, the development of winter sport resorts may impact mountain landscapes and environments. Construction and operation of ski-runs and lifts may have a large impact on soil resilience at high elevation areas as their construction induces many environmental transformations, such as removal of the soil and vegetation cover, road construction and artificial snow.

Further, the evolution of skiing to a mass sport has increased the demand for wide smooth ski-runs because of their large capacity for skiing and easy slope preparation with artificial snow and snow groomers. All these operations may induce geomorphologic hazards such as an increase of flow and sediment loads [4], soil erosion and interferences with flora and fauna that lead to loss, deterioration and fragmentation of ecosystems, and consequent modifications in animal behaviour [5-8]. In spite of these threats ski resorts are widespread all around the world where latitude and/or altitude are suitable. In the past much of the landscape transformations necessary to establish ski resorts were brought about without adequate concern for the potential effects on ecosystems and soils, and after decades, the negative impacts became evident. In this chapter we report the modifications in soil properties that occur in the wake of the construction and management of ski areas.

DEVELOPMENT OF SKI RESORTS

The major winter skiing destinations in Europe are in the countries of France, Switzerland, Austria and Italy. These four countries combined provide over 85% of Europe’s skiing area, with a skiing domain greater than 350.000 hectares [9]. In all four countries, human pressure on mountain ecosystems has increased since the beginning of the 1970s with the development of ski resorts. This brought on frequent manipulations of the alpine environment through the construction of ski-runs and associated infrastructures, resulting in a consequent diffused change in land use [10]. In Northern Finland, many ski resorts embarked on heavy construction projects for ski-runs at the end of the 1980s. Since then, the growth of ski resorts has been extensive while the environmental impact of constructions and management has generally not been evaluated [11, 12].

Since the beginning of the 1950's, Mediterranean mountains have undergone even more development to cater for tourist activities. This was partly because traditional practices such as livestock, agriculture, forestry, were unable to generate enough income to maintain farms and the social structure [13]. The tourism-based development strategy of modifying land management practices to incorporate touristic infrastructures has followed that was observed in the European Alps some decades earlier. In the Spanish Pyrenees, for example, ski resorts were able to generate significant revenues while other approaches substantially failed [13]. Even in the United States of America development of ski resorts was a common strategy that successfully revived the economies of mountain settlements [14]. For example, in the U.S. Rocky Mountains former mining and ranching settlements frequently sought to reinvent themselves as ski resorts to reinvigorate the economies of mountain communities. Following World War II, skiing became an increasingly middle-class recreation, popular for both local and national markets. The world's longest chairlift opened in 1947 in Aspen (Colorado), a mining town that foundered after the silver panic of 1893 and that was restored as a ski center [14].

The construction and management of ski-resorts are also expected to be impacted by global warming. The predicted increase in temperatures and the expected shift of the seasonal snow-line towards higher elevations [15] may push the ski industry to higher altitudes without a decline in demand for skiing/snowboarding activities [2, 16-22], but with a possible further deterioration of montane ecosystems.

EFFECTS OF SKI-RUN CONSTRUCTION ON SOIL CHEMICAL AND PHYSICAL PROPERTIES

The pedosphere provides essential chemical, physical and biological properties that are relevant for other ecological spheres. For instance soil thickness, structure and texture determine hydrologic characteristics that, in turn, affect plant and animal communities. The soil also provides additional resources such as nutrients and oxygen for the development and growth of vegetation, and is a habitat for organisms which are important factors of biodiversity and pedogenesis. Human impact on mountain ecosystems may produce shifts in soil quality, the direction and degree of which depends on climate, soil conditions, and land use. Because of the multi-factorial nature of the ecosystem, human pressure on mountain environments has modified land use towards economic activities that result in unknown ecological effects. Ecological sustainability of land use requires that essential soil functions such as biogeochemical cycling, portioning of water, storage and release of nutrients, buffering of pollutants such as acid rain, and energy partitioning be maintained [23]. These ecosystem services provided by mountain soils can be affected by perturbations resulting from ski-run construction with machine-grading, which is the process of smoothing the slopes by the removal of topsoil, boulders, and vegetation [24], involving the use of heavy earth-moving machinery necessary also to construct drainage and create retaining walls (Table (**1**)).

Table 1: Soil Management Practices in the Construction of Ski-Runs Around the World

Country/Elevation (m a.s.l.)	Ski Pistes Realization (Year)	Soil Management Practices	Author
Scotland/450-1100	1960's	Bulldozing, rocks incorporation in banks of spoil, chemical fertilization.	[25]
Italy/1350-2000	1960-1990	Bulldozing, levelling.	[26]
Spain/2000-3000	Before 1989	Disturbed topsoil through stripping, storage and reinstatement. Addition of crushed dolomite.	[27]
France/2300	1988-2001	Surface soil scraped from the bumps, stones crushed to gravel and material used to fill depressions in the slopes. The surface covered with a top layer of the same material. Bulldozing.	[28]
Italy/1990-2700	1990	Natural vegetation cover and organic topsoil removed, boulders re-arranged to form the ski-run bed, and coarse materials from lower horizons mixed with finer upper soil and replaced to form the top layer.	[29]
France/2200-2350	1974-1979	Initial uppermost soil layer removed during the trail construction. Organic compost and fertilizers spread in some places.	[30]
Finland/330-490	1985-1995	Vegetation and topsoil removed and machine-levelled. Before re-vegetating, crushed rock, sand, sawdust and peat spread on the ski-runs to level the ground surface.	[31]
Germany/980-1210	1970	Soil on the ridge crest bulldozed and dumped. The relief completely remodelled. Nowhere the original topsoil found in depths less than one meter.	[32]

Table 1: cont....

Finland/450-500	1990	Forest clear-cut, and the forest floor vegetation and surface soil removed. Stones machine-graded and topography levelled. Peat spread on the slopes along with seeding with foreign grass species.	[24]
Canada/675-1150	1980	Bulldozers removed stumps and smoothed the slopes. Lime applied at a rate of 225 kg ha^{-1} and worked by a spring-tooth cultivator. A grass-legume seed mixture was sown by machine at a rate of 170 kg ha^{-1}, and a 21% N, 7% P_2O_5, 14% K_2O fertilizer applied at a rate of 170-230 kg ha^{-1}.	[33]
Japan/500-760	1988	Ground surface modified mechanically to remove obstacles including plant underground organs. Not only nutrient rich surface soil but also seed-bank was removed. The depth of soil removal was more than 1 m.	[34]

These operations are carried out mainly during the summer months, sometimes by the same operators who are responsible for operating and maintaining ski-runs during the winter season (*e.g.,* snow grooming). Their aim is to smooth the surface of the ski run to reduce the snow thickness required for safe and pleasurable skiing. Moreover, surface smoothing also reduces artificial snow requirements when employed. Additional snow management measures to support this strategy are snow fences to capture drifting snow, the plantation or maintaining of tree hedges to partially shade the ski-runs, and the drainage of wetland areas in order to avoid delayed snow accumulation and premature snow melt [9]. Snow density changes due to grooming and the use of artificial snow during the ski season may also strongly influence soil characteristics of the ski-slopes. Therefore, at each location prevailing site conditions in terms of geology, geomorphology, climate and vegetation determine the degree and type of soil perturbation induced.

GEOMORPHOLOGY AND HYDROLOGICAL CYCLE

Development of ski resorts generally causes modifications and topographic adjustments that imply degradation of soil and vegetation [35]. The consequent alteration of both ecological and geomorphologic processes caused by heavy machines such as earth moving equipment and snow groomers has an impact on soil properties, biomass production and composition of plant species, thereby increasing the risk of land degradation caused by erosion, landslides and avalanches [36-38]. In turn, hydrologic changes may also occur and, to a large extent, are caused by the removal of soil material that could store water. In fact, more intensive disturbance of slopes generally leads to less water holding capacity, while soils on undisturbed or minimally disturbed pastures may hold much more water. This difference in soil water storage becomes even more important if the greater content of rock fragments (soil particles with a diameter larger than 2 mm) in ski-runs that have been graded by machines is taken into consideration. Machine-grading is carried out to remove obstacles like trees and rocks or to level rough or bumpy soil surfaces (Fig. (**1**)). During machine-grading the upper soil layers and vegetation are removed or heavily damaged [24, 25, 39, 40]. These operations generally tend to reduce infiltration of melting snow and may increase peak stream flow and overall water yield, as well as sediment yield [4]. Obviously, soil hydrological functions on less disturbed ski-runs are more appropriate for plant growth and potential re-vegetation with respect to machine graded slopes [41].

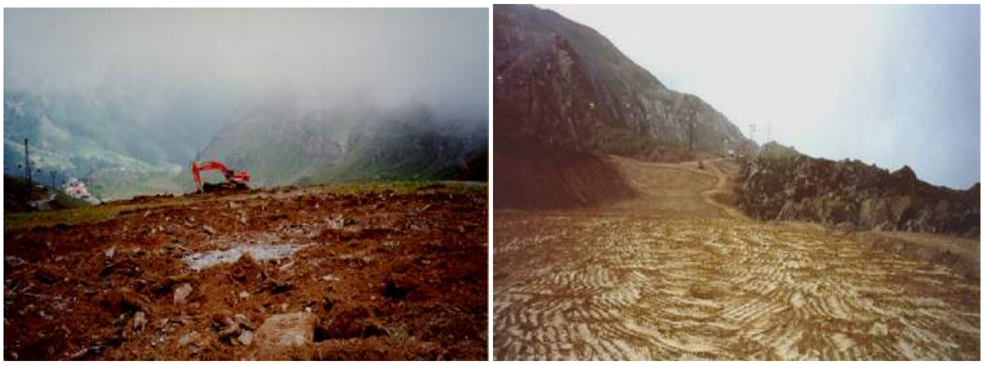

Figure 1: Ski-run construction (Courtesy Monterosa Ski Resort).

Seed mixture is often applied to accelerate re-vegetation, but the success of this operation declines with increasing altitude [42] leading to an increase in potential erosion with elevation. In addition, in areas where the topsoil layer is completely removed there is an increasing difficulty to re-vegetate the slopes. Studies conducted in Europe have indicated that machine-grading significantly impacts vegetation and water infiltration [24, 25, 43]. In the early 1960s in Scotland, during bulldozing to prepare ski-runs, most rocks were incorporated into the banks of spoil and the soil surface of the excavated hollows appeared freely drained and gritty because of the presence of granite gravel [25]. The removal of large rocks may severely disturb the thermal characteristics of the soil especially in high alpine permafrost regions [44]. In Europe, the timberline oscillates around 2,000 m above sea level and surface corrections below that limit mainly concern forest soils, vegetation cover and single obstacles in the landscape such as big boulders or groups of trees. In areas above the timberline, geomorphologic features such as rock glaciers or outcropping bedrock are the main targets that could be destroyed, although the disturbance to soil properties and alpine vegetation have to be considered. For example, rock glaciers are important buffers for the geo-hydrologic cycle because of their water storage capacity and their slow release of water to the surrounding areas during the growing season.

SOIL THERMAL STATUS

The groomed snow on ski-slopes has a large effect on snow properties and hence on underlying soils. Groomed snow increases snow density and reduces snow depth compared to ungroomed areas. In turn, these changes may result in reduced insulation capacity of the snowpack and thus, the underlying ground may become much colder with subsequent effects on soil nutrient dynamics and plant development. On ski-runs, Newesely [45] found indications that the increased thermal conductivity of compacted snow can cause severe frost in the soil. In a snow-density manipulation study Rixen *et al.* [46] found that a denser and thinner snow cover reduced soil insulation and lowered soil temperatures, with a consequent increase in net N mineralization. Furthermore, a denser snow cover resulted in a delay in plant phenology of up to five weeks after melt-out.

On ski-runs with natural snow the thin and compacted snow cover could lead to severe and long lasting seasonal soil frost. Winter soil temperature regime can directly affect soil nutrient status [47-49]. Microbes can be active below 0°C [50] and thus have an impact on N cycling in the soil [51] including N availability for plants even during the winter. Hence, preventing frost in soils that are usually not exposed to temperatures much below freezing point can be considered as beneficial. Nonetheless, ground temperatures on ski-runs with natural snow showed parallel characteristics to those from permafrost sites [39]. The ground cooling in the ski-runs may, in the long run, change ski-runs into slopes of coarse debris [39] because of the considerably greater erosion problems. If permafrost is induced on a ski-run, feedback mechanisms like the increase in lateral runoff can further enhance erosion. However, it is still an open question as whether permafrost can result from activities on ski-runs [44]. On some ski-runs with artificial snow, soil frost occurred less frequently because of higher insulation due to greater snow depths. However, due to the greater snow mass the beginning of the snow-free season was delayed by more than 2 weeks [44, 52] (Fig. (**2**)). The late melting of the artificial snow can additionally increase the risk of erosion during the warm season.

Figure 2: A ski-run during the spring snowmelt.

SOIL THICKNESS AND HORIZONATION

Because of the construction of ski-runs the original soil thickness can be reduced with the loss of previous soil horizonation, generally resulting in altered topsoil. In Spain, Delgado *et al.* [27] recognized soils such as Orthents and Ochrepts [53] or Anthropic Regosols and Humic Regosols [54] in different areas including (1) seeded ski-runs with disturbed topsoil by stripping, storage and reinstatement, (2) seeded ski-runs without topsoil conservation, (3) ski-runs with failed grass seeding, and (4) not seeded soils between ski-runs. Along a ski-slope in north-western Italy seeded in the late 1990's, Filippa *et al.* [55] found Lithic Cryorthents in the upper part of the sequence (above 2,500 m a.s.l.), and Typic Cryorthents between 2,500 and 2,400 m a.s.l., while Inceptisols were predominant between 2,400 and 2,200 m a.s.l. [53].

Descroix and Mathys [56] evaluated the influence of mountain management on alpine erosion and found that gully erosion and solifluctions were sometimes provoked by the development of ski resorts in the Northern Alps (Eglise and Ravoire Torrents downstream of Les Arcs resort, in the upper Isère valley, Savoie), as well as in the Southern Alps (for example in Vars). Slopes that have been disturbed through roadway, ski-runs or other constructions often produce more sediments than less disturbed sites, with the loss of nutrient-containing topsoil essential for plant growth [57]. In the French Alps, the perennial vegetation of native grassland and the soil surface were removed to establish ski-runs, stones were crushed and the topography levelled with spare residual materials from bumps and upland re-shaping. This resulted in severe deterioration of vegetation dynamics and soil physico-chemical properties [28]. As in mountain ecosystems bare soils are susceptible to erosion, re-vegetation with native or foreign grasses and restoration of a favourable soil structure are necessary [58].

Titus and Landau [59] reported that the anthropogenic effects of ski-slope construction involved removal of the A horizon and part of the B horizon to provide comfortable slopes for skiers. The loss of topsoil and fines from the ski-runs had left a gravely surface of dolomitic limestone with consequent reduction in the water holding capacity. Pintar *et al.* [41] found that the presence of Lithic Leptosols was significantly higher in plots where the soils were most disturbed (machine-graded ski-slopes). On the other hand, the same plots contained the greatest share of Haplic Cambisols indicating that the development of soils on the ski resort was mostly influenced by geological substratum, relief and management of the vegetation cover. As a result of the micro-relief, especially in the lower parts of the slopes where steepness and disturbance were less influencial, Haplic Cambisols seemed to be more abundant [41]. Barni *et al.* [29] assessed that none of the physico-chemical soil properties considered in their work (organic carbon, pH, aggregate breakdown) were correlated with ski-run age, showing that pedogenesis in those environments was extremely slow and site specific.

SOIL STRUCTURE AND TEXTURE

The perturbation of ski-run soils results in an almost complete loss of structure with subsequent problems of soil compaction and reduction in water and air permeability [60]. Soil structure is a key indicator of soil ecological function, and is expressed by aggregation of single particles and pore architecture [61]. Soil aggregation is important because it affects infiltration capacity, hydraulic conductivity, water retention capacity, gas exchange, decomposition of organic matter and resistance to erosion [27]. Barni *et al.* [29] found a significant decrease in aggregate stability in ski-runs constructed above timberline and hydro-seeded at different times (4-12 years). In the same work the soil aggregate breakdown was inversely correlated with organic matter content. Soil aggregates in upper horizons contain fine material, organic substances, subterranean organs of some plant species and soil organisms, and they are well known for their high water holding capacity. The destruction of aggregates decreases soil water retention and therefore plant-available water, and encourages rapid drainage. As water availability is one of the most important factors for plant growth, and soil hydrological functions (*e.g.,* soil ability to hold water at a certain depth) are controlled by soil aggregation, this factor needs to be taken into consideration for successful re-vegetation of a levelled ski-slope [41].

Disturbances due to ski-run construction may also result in significant changes in particle-size distribution and content of organic carbon, influencing aggregate stability and porosity. The soils of ski-runs are often characterised by abundant rock fragments, Fig. (**3**) as the presence of clasts and sand particles increases as a result of the mechanical crushing of stones during ski-run establishment [28]. In natural soils of the Sierra Nevada, a significant decrease in clay and organic carbon content was found with increasing altitude. This trend was not observed in ski-run soils where the influence of management seemed more important than environmental factors [27]. However, our knowledge of soil ecology after re-vegetation is still scarce.

Figure 3: Effect of ski-run construction on the abundance of rock fragments in the Italian Western Alps (Monterosa Ski Resort, NW-Italy, 2620 m a.s.l.).

SOIL NUTRIENT CONTENT

The soils of ski-runs are subjected to more intense freezing, higher CO_2 content, and changes in pH and nitrogen fixation. Ruth-Balaganskaya and Myllynen-Malinen [24] found that the soils of ski-runs have a poor nutrient status. Gros *et al.* [28] examined the effect of disturbance on aggregate stability, particle size distribution, C and N content and porosity (Table (**2**)) and found that plants seem to have an important role in the restoration process; also, results of this study demonstrated that re-vegetation with a succession of native and non-native grasses facilitated recovery of some key soil physico-chemical properties, including soil structure, particle size distribution, and total soil carbon.

Kangas *et al.* [31] found that both soil pH and electrical conductivity were significantly higher under ski-runs compared to nearby sites that were undisturbed. Similarly, concentrations of K, Mg, Ca and available P were significantly higher in the ski-run soil than in the nearby forest soil. Delgado *et al.* [27] found an electrical conductivity of 0.65 dS m^{-1} and 8.2% calcium carbonate equivalent in soils of ski-runs. These values are not common for soils on felsic rocks with a mean annual precipitation between 970 and 1270 mm. This apparent discrepancy was attributed to the application of dolomite, additives for artificial snow production, salts to harden the snow in race ski-runs and fertilizers for grass growth. An unexpected finding was the relatively high exchangeable sodium percentage (ESP) measured, although these soils did not display serious sodicity problems. The ESP values ranged between 5.5 and 8.0 even in soils not directly managed, implying a diffuse contamination of Na caused by the treatment of ski-runs with Na-containing products and by salting of roads. The contamination was the result of downhill movement of the soil solution, continuous reworking of the ski-runs, and wind redistribution. The same authors also noted a lack of correlation between organic C content and other properties of the ski-run soils. When the data of the undisturbed sites were excluded, cation exchange capacity, water retention at 33 and 1500 kPa, total N and exchangeable K were positively correlated with the clay content, but not with organic C. Thus, it seemed that the effect of organic material on water retention and ion adsorption had been reduced by ski-run preparation. In this case the soils of the ski-runs showed a low organic matter content although the degree of humification evaluated through the C:N and humic:fulvic ratios, was similar to that of the natural soils as the pedogenic factors were similar in both natural and disturbed soils.

Management practices often involve earth filling with peat and fertilization of ski-runs. Fertilization has an impact on soil nutrient concentrations and vegetal composition [62]. Intensive fertilization of ski-runs may pose a greater risk to the environment than the spread of non-native species used for re-vegetation. In addition, nutrient leaching from ski-runs can affect the quality of water bodies situated close to ski resorts [63]. A recent study conducted at Ruka (Finland) showed that water bodies surrounding a ski resort had higher temporal variability in nutrient concentrations and higher nutrient levels than control lakes nearby [31]. The environmental impacts of fertilization are amplified by artificial snow that increases the total snow mass [44] and, thereby, intensifies the surface runoff due to additional water. Artificial snow also increases the nutrient concentrations and soil pH [43, 64]. The impact of the addition of water, ions, bacteria and salts through artificial snow production on soil is unclear [65]. In soils down to a depth of 15 cm, Kammer and Hegg [66] recorded significantly higher pH-values on snowed ski-runs compared to control plots. They attributed the differences to the high pH of the river water that was used for snow production. Salts are used for ski-run preparation, especially on race ski-runs, to improve the snow quality for skiing purposes if, for example, snow is too cold, too sticky or hard ice [67, 68]. Comparable to salts used on roads, the chemicals used on ski-runs melt the uppermost layer of the snowpack thus changing snow quality [69]. Impacts of ski-runs in general, and of artificial snowing in particular, appear comparatively moderate although not negligible. With the ongoing intensification of ski resorts the use of artificial snow will become more prevalent [70] and the vegetation and soil properties will change over an increasing area. Moreover, the impacts of artificial snow are cumulative and will become even more pronounced in the long term.

Table 2: Soil Characteristics Under Ski-Runs and Undisturbed Areas. In the "Δ Major Changes" Column, the Arrow ↑ Indicates an Increase in the Value of the Selected Soil Property with Respect to the Undisturbed Soil, While the Arrow ↓ Indicates a Decrease in its Value

Country/Elevation (m a.s.l.)	**Undisturbed**	**Ski-Runs**	**Δ major Changes**	**Authors**
Italy/1350-2000	pH, 3.7-4.7 TOC, 31-61 CEC, 12-39	pH, 3.8-5.7 TOC, 18-49 CEC, 7-20	pH↑ TOC↓ CEC↓	[26]
Switzerland/1150-2515	t_u, -0.10	t_{art}, -0.60 t_{nat}, -2.04	t↓	[44]
Italy/1530-2090	pH, 7.05	pH, 7.44	pH↑	[10]
Spain/2000-3000	Crumbly structure BD, 0.82 pH, 5.0-6.0 BS, <55	Weak granular structure BD, 1.41-1.59 pH, 6.9 ±0.1 BS, 68±6	BD↑ pH↑ BS↑	[27]
France/2300	Loam pH, 4.5 TN, 4.7	Sandy loam pH, 5.1-5.7 TN, 1.5-3.0	sand↑ pH↑ TN↓	[28]
Italy/1990-2700	Loamy sand pH, 4.8-5.9 CEC, 14-29 TOC, 17-57	Sandy loam pH, 6.0-7.9 CEC, 6.9-14 TOC, 11-26	Sand↑ pH↑ CEC↓ TOC↓	[29]
Finland/330-490	pH, 4.5 EC, 32.1	pH, 5.1 EC, 26.6	pH↑ EC↓	[31]

Abbreviations: TOC, total organic carbon (g kg^{-1}); CEC, cation exchange capacity (cmol(+) kg^{-1}); t_u, soil temperature under undisturbed snow cover; t_{art}, ski-run soil temperature under artificial snow cover; t_{nat}, ski-run soil temperature under natural snow cover; BD, bulk density (g cm^{-3}); BS, base saturation (%);TN, total nitrogen (g kg^{-1}); EC, electrical conductivity (µS cm^{-1}).

SOIL MICROBIAL ACTIVITY

Gros *et al.* [28] observed that ski-runs are degraded ecosystems that need to restore relationships among soil physico-chemical properties, plant colonization and soil microbial activity. In fact, along a chronosequence of restored alpine grasslands these authors observed that recurrent changes in microbial habitats, such as aggregate-size habitats, rhizosphere soil, and heterogeneous resource input, had initiated shifts in the structure of the microbial community. In this case study, microbial communities became very unstable during the early stage of ski-run operation (<13 years) and construction and rehabilitation processes induced wide and long lasting changes in soil microbial life. As ski-run construction promotes aggregate breakdown it may induce the release and subsequent degradation of previously protected organic matter. Potential N_2 fixation slightly increased during the first year of restoration, and then strongly increased in the successive stages. Soil respiration in these ski-runs was also low indicating that 13–14 years is too short for the stabilization of biological activity in these soils.

BEST PRACTICES TO IMPROVE THE FUNCTIONALITY OF SOILS IN THE SKI-RUNS

The rate of soil formation is influenced mainly by biological activity, which is in turn controlled by interactions among climate, underlying rocks, soil animals, fungi, bacteria and plants [71]. This web of interactions is disturbed during ski-run construction, which induces the loss of soil structure, the depletion of soil organic matter, the decrease in biomass carbon, and nutrient imbalance. The restoration of these disturbed soils is a challenge that should aim at promoting the long-term re-establishment of a functional plant-soil system [72, 73].

In order to reduce sediment loading from ski-runs, a possible goal of restoration efforts should be the re-creation of ‘native’-like soil conditions [57]. Therefore, one of the most crucial tasks during ecosystem restoration work is the improvement of soil organic matter and nutrient status. Long-term stability of restored ecosystems, in fact, depends on the availability of an adequate nutrient pool that can be maintained without repeated application of fertilizers. Delgado *et al.* [27] reported how after 14 years of grass seeding the values of some soil quality indicators were restored. The effect of seeding depended on how it was carried out, with the most favourable quality indicators resulting from grass seeding on reinstated topsoil. However, the microstructure of the seeded soils remained unstable as organic cements and binding by fungal hyphae were not restored to the same level at which they occurred in natural soil.

Barni *et al.* [29] showed how the use of appropriate agronomic techniques, conservation of the topsoil, selection of suitable plant material, and manuring after sowing have led to the establishment of a sufficiently dense plant cover, although it did not reach the cover values of the adjacent natural alpine pasture. These results, together with data collected in other ski resorts in the Italian Alps [74, 75] show that progress in re-vegetation techniques has led to the achievement of satisfactory results in terms of obtaining a protective cover even above timberline. Establishment of native species is limited by their stress tolerant strategies, but also in great measure by the persistence of soil alteration caused by ski-run construction. Substantial alteration of the ski-run soils was evidenced by the rising of pH values, organic matter impoverishment, and loss of both fine particles (clay) and aggregates. In spite of manuring and pasturing, organic carbon was often lower in ski-runs than in the adjacent soils, and this may be the cause of significantly higher soil pH and aggregate breakdown. Shallow incorporation of manure or other amendments during ski-run preparation may effectively improve the soil by helping to restore structure and stabilizing pH. Nevertheless, above tree line the addition of 1 kg of "garden soil" per m^2 had no significant effect on the establishment of transplanted plants on machine-graded ski-runs in the Swiss Alps (Jakobshorn Mountain - Davos); the failure was partly attributed to the steep slope as the garden soil was rapidly washed away because of uncontrolled erosion [76].

Damage due to grazing may be severe in the establishment of transplanted plants on ski-runs above tree line, and thus the presence of herbivores should be prevented in the first years after restoration [76]. Animal activities such as burrowing or trampling also modify soil morphology by creating depressions and mounds. However, contradictory effects have been observed with wild ungulates and cattle as they may either increase soil erosion [35, 77] or improve plant community regeneration [30]. Because disturbances such as herbivores and trampling can jeopardize re-vegetation efforts, the role of grazers in restoration processes is ambivalent.

As a recommendation for re-vegetation of ski-runs, several authors propose incorporation of substrate composed of the upper horizons of the initial soil. Such substrate can be collected during the construction work on ski-runs. These substrates should contain all needed plant nutrients in acceptable forms and proportions as well as soil microbiota, including mycorrhizae, which are essential to re-vegetate specific areas [24].

In summary, mountain regions with a high proportion of areas with extensive outdoor recreation activities, like the European Alps, are facing continuous changes to their traditional unique environment and vegetation. Therefore, we recommend that environmental goals in ski resort management should be established and respected. In particular, it is important to carefully record soil characteristics in a specific area before any intensification in the use of ski-runs. This step is the key to allow the integral conservation of soils with high ecological values (*e.g.,* Histosols).

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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REFERENCES

[1] NIEIR (National Institute of Economic and Industry Research) *The Economic Significance of Australian Alpine Resorts*. National Institute of Economics and Industry, Melbourne, Australia, **2006**.

[2] Agrawala, S. *Climate Change in the European Alps, Adapting Winter Tourism and Natural Hazard Management.* Organization for Economic Cooperation and Development Publications, Paris. **2007**.

[3] Scott, D; McBoyle, G. Climate change adaptation in the ski industry. *Mitigation, Adaptation Strategies to Global Change*, **2007**, 12, 1411–1431.

[4] David, G.C.L.; Bledsoe, B.P.; Merritt, D.M.; Wohl, E. The impacts of ski slope development on stream channel morphology in the White River National Forest, Colorado, USA. *Geomorphol.*, **2009**, 103, 375–388.

[5] Arrowsmith, C; Inbakaran, R. Estimating environmental resiliency for the Grampians National Park, Victoria, Australia, a quantitative approach. *Tourism Manag.*, **2002**, 23, 295–309.

[6] Geneletti, D. Impact assessment of proposed ski areas, A GIS approach integrating biological, physical and landscape indicators. *Environ. Impact. Asses.*, **2008**, 28, 116–130.

[7] Geneletti, D.; Dawa, D. Environmental impact assessment of mountain tourism in developing regions, a study in Ladakh, Indian Himalaya. *Environ. Impact. Asses.*, **2009**, 29, 229-242.

[8] Negro, M.; Isaia, M.; Palestrini, C.; Rolando, A. The impact of forest ski-pistes on diversity of ground-dwelling arthropsods and small mammals in the Alps. *Biodivers. Conserv.*, **2009**, 18, 2799–2821.

[9] OECD (Organization for Economic Co-operation and Development) *Climate change in the European Alps, adapting winter tourism and natural hazards management.* Shardul Agrawala (Ed.), **2007**.

[10] Caravello, G.; Crescini, E.; Tarocco, S.; Palmeri, F. Environmental modifications induced by the practice of “Artificial snow-making” in the Obereggen/Val D’Ega Area (Italy). *Journal of Mediterranean Ecology*, **2006**, 7, 31–39.

[11] Malinen, K. Ympäristön kunnostuksen näkökulma laskettelurinteiden kasvillisuuden palautamiseen pohjois-suomessa. *Acta Universitatis Ouluensis*, **1991**, 97, 305–317.

[12] Malinen, K. *Luonnonkasvein käyttö rakentamisen aiheuttamien maisemavaurioiden korjaamisessa pohjoisilla alueilla*. MSc. thesis. University of Oulu, Finland, **1997**.

[13] Lasanta, T.; Laguna, M.; Vicente-Serrano, S.M. Do tourism-based ski resorts contribute to the homogeneous development of the Mediterranean mountains? A case study in the Central Spanish Pyrenees. *Tourism Manag.*, **2007**, 28, 1326–1339.

[14] Silberman, J.A.; Rees, P.W. Reinventing mountain settlements, A GIS model for identifying possible ski towns in the U.S. Rocky Mountains. *Appl. Geogr.*, **2010**, 30, 36–49.

[15] Beniston, M. Climatic change in mountain regions: a review of possible impacts. *Climatic Change*, **2003**, 59, 5-31.

[16] König, U.; Abegg, B. Impacts of climate change on winter tourism in the Swiss Alps. *J. Sustain. Tour.*, **1997**, 5, 46–58.

[17] Behringer, J.; Buerki, R.; Fuhrer, J. Participatory integrated assessment of adaptation to climate change in alpine tourism and mountain agriculture. *Integrated Assessment*, **2000**, 1, 331–338.

[18] Lazar, B.; Williams, M. W. Climate change in western ski areas: Potential changes in the timing of wet avalanches and snow quality for the Aspen ski area in the years 2030 and 2100. *Cold Reg. Sci. Techn.,* **2008**, 51(2-3), 219–228.

[19] Fukushima, T.; Kureha, M.; Ozaki, N.; Fujimori, Y.; Harasawa, H. *Influences of air temperature change on leisure industries, case study on ski activities.* Mitigation and Adaptation Strategies for Global Change, **2002**, 7, 173–189.

[20] Bicknell, S.; McManus, P. The canary in the coalmine, Australian ski resorts and their responses to climate change. *Geogr. Res.*, **2006**, 44, 386–400.

[21] Hennessy, K.L.; Whetton, P.H.; Walsh, K.; Smith, I.N.; Bathols, J.M.; Hutchinson, M.; Sharples, J. Climate change effects on snow conditions in mainland Australia and adaptation at ski resorts through snow making. *Climate Res.*, **2008**, 35, 255–270.

[22] Scott, D.; Dawson, J.; Jones, B. Climate change vulnerability of the US Northeast winter recreation – tourism sector. *Mitigation, Adaptation Strategies to Global Change*, **2008**, 13, 577–596.

[23] Sanchez-Maranon, M.; Soriano, M.; Delgado, G.; Delgado, R. Soil quality in Mediterranean mountain environments, effects of land use. *Soil Sci. S. Am. J.*, **2002**, 66, 948–958.

[24] Ruth-Balaganskaya, E.; Myllynen-Malinen, K. Soil nutrient status and revegetation practices of downhill skiing areas in Finnish Lapland-a case study of Mt. Ylläs. *Landscape Urb. Plann.*, **2000**, 50, 259–268.

[25] Bayfield, N.G. Long-term changes in colonization of bulldozed ski pistes at Cairn Gorm, Scotland. *J. Appl. Ecol.*, **1996**, 33, 1359–1365.

[26] Freppaz, M.; Lunardi, S.; Bonifacio, E.; Scalenghe, R.; Zanini, E. Ski slopes and stability of soil aggregates. In:, Advances in GeoEcology 35; Pagliai, M., Jones, R., Eds.; Sustainable Land Management-Environmental Protection, Catena Verlag, Reiskirchen, Germany, **2002**; pp.125–132.

[27] Delgado, R.; Sanchez-Maranon, M.; Martin-Garcia, J.M.; Aranda, V.; Serrano-Bernardo, F.; Rosua, J.L. Impact of ski pistes on soil properties, a case study from a mountainous area in the Mediterranean region. *Soil Use Manag.*, **2007**, 23, 269–277.

[28] Gros, R. ; Monrozier, L.J. ; Bartoli, F. ; Chotte, J.L. ; Faivre, P. Relationships between soil physico-chemical properties and microbial activity along a restoration chronosequence of alpine grasslands following ski run construction. *Appl. Soil. Ecol.*, **2004**, 27, 7–22.

[29] Barni, E.; Freppaz, M. Consolata S. Interactions between vegetation, roots and soil stability in restored high altitude ski runs on the Western Alps, Italy. *Arc. Antarct. Alp. Res.*, **2007**, 39, 25-33.

[30] Isselin-Nondedeu, F.; Rey, F. ; Bédécarrats, A. Contributions of vegetation cover and cattle hoof prints towards seed runoff control on ski pistes. *Ecol. Eng.*, **2006**, 27, 193–201.

[31] Kangas, K.; Tolvanen, A.; Kälkäjä, T.; Siikamäki, P. Ecological impacts of revegetation and management of ski slopes in northern Finland. *Environ. Manage.*, **2009**, 44, 408–419.

[32] Ries, J.B. Landscape Damage by Skiing at the Schauinsland in the Black Forest, Germany. *Mt. Res. Dev.*, **1996**, 16, 27–40.

[33] Thompson, J.D.; Hutchinson, I. Cohabitation of species in an artificial grass-legume community on ski-slopes on Whistler Mountain, British Columbia, Canada. *J. Appl. Ecol.*, **1986**, 23, 239–250.

[34] Tsuyuzaki, S. Ski slope vegetation in central Honshu, Japan. *Environ. Manage.,* **1995**, 19,773–777.

[35] Isselin-Nondedeu, F.; Bédécarrats, A. Influence of alpine plants growing on steep slopes on sediments trapping and transport by runoff. *Catena*, **2007**, 71, 330–339.

[36] Cavallin, A.; Marchetti, M.; Panizza, M. Geomorphology and environmental impact assessment, a methodological approach. In:,*Geomorphologic analysis and evaluation in environmental impact assessment*; Panizza, M., Fabbri, A.G., Marchetti, M., Patrono, A. Eds;, vol. 32. Enschede, ITC publication, **1996**; pp. 308–310.

[37] Jamieson, B.; Stethem, C.Snow avalanche hazards and management in Canada, challenges and progress. *Nat. Hazards*, **2002**, 26, 35–53.

[38] Arnaud-Fassetta, G.; Cossart, E.; Fort, M. Hydro-geomorphic hazards and impact of man-made structures during the catastrophic flood of June 2000 in the Upper Guil catchment (Queyras, Southern French Alps). *Geomorphology*, **2005**, 66, 41–67.

[39] Haeberli, W. Construction, environmental problems and natural hazards in periglacial mountain belts. *Permafrost Periglac.*, **1992**, 3, 111–124.

[40] Titus, J.H.; Tsuyuzaki, S. Ski slope vegetation of mount Hood, Oregon, USA. *Arct. Antarct. Alp. Res.*, **1999**, 13, 97–104.

[41] Pintar, M.; Mali, B.; Kraigher, H. The impact of ski slopes management on Krvavec ski resort (Slovenia) on hydrological functions of soils. *Biologia*, **2009**, 64, 639–642.

[42] Urbanska, K.M. Restoration ecology research above the timberline, colonization of safety islands on a machine-graded alpine ski run. *Biodiv. Conserv.*, **1997**, 6, 1655–1670.

[43] Wipf, S.; Rixen, C.; Fischer, M.; Schmid, B.; Stoeckli, V. Effects of ski piste preparation on alpine vegetation. *J. Appl. Ecol.*, **2005**, 42, 306–316.

[44] Rixen, C.; Casteller, A.; Schweingruber, F.H.; Stoeckli, V. Age analysis helps to estimate plant performance on ski pistes. *Botanica Helvetica*, **2004a**, 114, 127–138.

[45] Newesely, C. *Auswirkungen der kiinstlichen Beschneiungv on Schipisten auf Aufbau, Struktur und Gasdurchlassigkeit der Schneedecke, sowie auf den Verlauf der Bodentemperaturun das Auftreten von Bodenfrost*. Dissertation, Naturwissenschaftliche Fakultit, Leopold Franzens Universität, Innsbruck, **1997**.

[46] Rixen, C.; Freppaz, M.; Stoeckli, V.; Huovinen, C.; Huovinen, K.; Wipf, S. Altered snow density and chemistry change soil nitrogen mineralization and plant growth. *Arct. Antarct. Alp. Res.*, **2008**, 40, 568–575.

[47] Freppaz, M.; Williams, B.L.; Edwards, A.C.; Scalenghe, R.; Zanini, E. Labile nitrogen, carbon, and phosphorus pools and nitrogen mineralization and immobilization rates at low temperatures in seasonally snow-covered soils. *Biol. Fert. Soils*, **2007a**, 43, 519–529.

[48] Freppaz, M.; Williams, B.L.; Edwards, A.C.; Scalenghe, R.; Zanini, E. Simulating soil freeze/thaw cycles typical of winter alpine conditions, implications for N and P availability. *Appl. Soil Ecol.*, **2007b**, 35, 247–255.

[49] Freppaz, M.; Icardi, M.; Filippa, G.; Zanini, E. 2009. *Soil nitrogen dynamics in high-altitude ski runs during the winter season (Monterosaski - Vallée d'Aoste – Italy)*. Geophysical Research Abstracts, Vol. 11, EGU 2009-9065, 2009. EGU General Assembly, **2009**.

[50] Brooks, P.D. Williams M.W., Schmidt SK. Microbial activity under alpine snowpacks, Niwot Ridge, Colorado. *Biogeochemistry*, **1996**, 32, 93–113.

[51] Brooks, P.D.; Williams, M.W. Snowpack controls on nitrogen cycling and export in seasonally snow-covered catchments. *Hydrol. Proc.*, **1999**, 13, 2177–2190.

[52] Keller, T.; Pielmeier, C.; Rixen, C.; Gadient, F.; Gustoffson, D.; Stahli, M. Impact of artificial snow and ski-slope grooming on snowpack properties and soil thermal regime in a sub-alpine ski area. *Ann. Glac.*, **2004**, 38, 314-318.

[53] Soil Survey Staff *Soil taxonomy, a basic system of soil classification for making and interpreting soil surveys*. 2nd ed., U.S. Department of Agriculture, Natural Resources Conservation Service, Agriculture Handbook Number 436, **1999**.

[54] FAO/ISRIC/ISSS.*World Reference Base for Soil Resources*. World Soil Resources Report, No 84. FAO, Rome, **1998**.

[55] Filippa, G.; Freppaz, M.; Letey, S.; Corti, G.; Cocco, S.; Zanini, E. *Soil properties in high-elevation ski slopes*. Geophysical Research Abstracts Vol. 12, EGU2010-3638, 2010; EGU General Assembly, **2010**.

[56] Descroix, L.; Mathys, N. Processes, spatio-temporal factors and measurements of current erosion in the French Southern Alps, a review. *Earth Surf. Proc. Land.*, **2003**, 28, 993–1011.

[57] Grismer, M.E.; Hogan, M.P. Simulated rainfall evaluation of revegetation/mulch erosion control in the lake Tahoe basin, 2. bare soil assessment. *Land Degrad. Dev.*, **2005**, 16, 397–404.

[58] Muller, S.; Dutoit, T. ; Alard, D. ; Grevilliot, F. Restoration and rehabilitation of species-rich grassland ecosystems in France, a review. *Rest. Ecol.*, **1998**, 6, 94–101.

[59] Titus, J.H.; Landau, F. Ski slope vegetation of Lee Canyon, Nevada, USA. *The Southwestern Naturalist*, **2003**, 48, 491–504.

[60] Tsuyuzaki, S. Environmental deterioration resulting from skiresort construction in Japan. *Environ. Conserv.*, **1994**, 21, 121–125.

[61] Bronick, C.J.; Lal, R. Soil structure and management, a review. *Geoderma*, **2005**, 124, 3-22.

[62] Densmore, R.V. Succession on an Alaskan tundra disturbance with and without assisted revegetation with grass. *Arct. Alp. Res.*, **1992**, 24, 238–243.

[63] Chambers, J.C.Restoring alpine ecosystems in western United States, environmental constrains, disturbance characteristics, and restoration success. In:, *Restoration ecology and sustainable development*; Urbanska, K.M., Webb, N.R., Edwards, P.J. Eds.; Cambridge University Press, Cambridge, **1997**; pp. 161–187.

[64] Kammer, P.M. Floristic changes in subalpine grasslands after 22 years of artificial snowing. *J. Nat. Conserv.*, **2002**, 10, 109–123.

[65] Rixen, C.; Stoeckli, V.; Ammann, W. Does artificial show production affect soil and vegetation of ski pistes? A review. *Perspect. Plant Ecol.*, **2003**, 5, 219–230.

[66] Kammer, P.; Hegg, O. Auswirkungen von Kunstschnee auf subalpine Rasenvegetation. *Verhandlungen der Gesellschaft für Ökologie*, **1990**, 19, 758–767.

[67] USSA *Alpine Officials Manual, US Skiing, Chapter VII, The Race Course.* US Ski and Snowboard Association (USSA); **1996**.

[68] Raguso, V. *Alpine Education Guidebook*. Alpine ski racing education series, New York State Ski Racing Association (NYSSRA), **2000**.

[69] Kobayashi, T.; Endo, Y.; Nohguchi, Y. Hardening of snow surface – 'natural/artificial'. In, Proceedings of the fourth International Conference on Snow Engineering, Snow Engineering, Recent Advances and Developments; Hjorth-Hansen, E., Holand, I., Löset, S., Norem, H. Eds.; Trondheim, Norway, **2000**; pp. 99–103.

[70] Freppaz, M.; Filippa, G.; Francione, C.; Cucchi, M.; Colla, A.; Maggioni, M.; Zanini, E. *Artificial snow production with respect to the altitude, a case study in the Italian Western Alps*. Geophysical Research Abstracts, Vol. 10, EGU 2008-A-9801, 2008. EGU General Assembly, **2008**.

[71] Liddle, M. *Recreation Ecology, The Ecological Impact of Outdoor Recreation and Ecotourism*. Chapman and Hall, Australia, **1997**.

[72] Lal, R.; Stewart, B.A. Need for land restoration. In: *Advances in Soil Science*; Lal, R., Stewart, B.A. Eds.; Springer, New York, **1992a**; pp. 1–11.

[73] Lal, R.; Stewart, B.A. Research and development priorities for soil restoration. In:, Advances in Soil Science; Lal, R., Stewart, B.A. Eds.; Springer, New York, **1992b**; pp. 433–439.

[74] Argenti, G.; Merati, M.; Staglianò, N.; Talamucci, P. Establishment and evolution of technical ski slope covers in an alpine environment. *Rivista di Agronomia*, **2000**, 34, 186–190.

[75] Bozzo, F.; Magro, F.; Casarotto, A.; Dossi, P. Artificial grass regeneration of ski-runs, evaluation of grass mixtures and novel seeding techniques. *Rivista di Agronomia*, **2000**, 34, 213–219.

[76] Fattorini, M. Establishment of transplants on machine-graded ski runs above timberline in the Swiss Alps. *Rest. Ecol.*, **2001**, 9, 119–126.

[77] Hall, K.; Lamont, N. Zoogeomorphology in the Alpine, some observations on abiotic–biotic interactions. *Geomorphology*, **2003**, 55, 219–234.

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CHAPTER 4

Skiing and Vegetation

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Abstract: Impacts of skiing on alpine and subalpine vegetation are expressed by multiple disturbances: snow is being compacted by skiers and heavy machinery, new ski pistes are constructed by means of machine-grading and, increasingly, artificial snow is being produced by snow-making facilities.

This review compiles studies on ski piste vegetation from more than three centuries and skiing destinations across the world and distinguishes between different types of disturbances and elevations. Skiing in general can exert disturbances in the vegetation because of the changed snow conditions. The compaction of the snow can induce hard soil frost and mechanically damage plants. Machine-grading in summer to create smooth surfaces represents the most drastic disturbance on ski pistes especially at elevations around and above treeline. Artificial snow production has the potential to change vegetation through an input of water and ions and through postponing the time of melt-out.

Restoration measures to re-establish local vegetation after machine-grading have improved considerably in the last decades, however, still the vegetation and soil rarely fully recovers after major disturbance. If constructions are unavoidable, it is vitally important that restoration measures follow restoration guidelines that represent today's state of the art.

Keywords: Alpine vegetation, artificial snow, machine-grading, restoration, ski-piste construction, snow, snow-making.

INTRODUCTION

Winter tourism has become a major economic factor in many mountain regions of the world [1], and especially downhill skiing represents the economically most important activity in resorts for winter sports. However, downhill ski areas can have dramatic effects on vegetation and, as a result, the esthetics of the landscape. Numerous studies have looked intensively into skiing effects on vegetation for

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more than three decades *e.g.,* [2, 3]. A large number of studies originates from the European Alps [3-5] and North America [6-9], but basically studies are available from most regions worldwide with a skiing industry, *e.g.,* from Scotland [10-12] and Scandinavia [13, 14], Japan [15], New Zealand [16] or Argentina [17].

The effects of downhill skiing and construction of ski pistes are probably that dramatic because alpine ecosystems are highly susceptible to damage. Alpine plants are slow-growing, and alpine soils have slowly developed over many decades or centuries due to low temperatures and a short growing season [18]. Any perturbations and disturbances in alpine habitats are likely to cause damages in soil and vegetation that are visible for a long time.

Changing the snow cover by grooming and skiing is another likely reason for changes in vegetation. Snow is the predominating environmental factor in alpine ecosystems, and the vegetation period between snowmelt and fall amounts only a few weeks in some alpine depressions [19]. Most plant species are highly adapted to specific snow conditions: some species grow exclusively on windy ridges with very little snow during the winter but extreme temperature fluctuations, others, the so-called snowbed species, are adapted to deep snow cover and a very late melt-out in spring and summer [18, 20]. Mapping the timing of melt-out and alpine plant communities can therefore show almost identical patterns [21]. Changing snow properties by compacting snow on ski pistes and potentially changing the timing of melt-out is therefore a likely cause for vegetation changes.

Skiing intensity has increased considerably in the last decades. Modern transportation facilities enable a growing number of skiers to visit ski areas. Consequently, snow preparation techniques have to meet the growing demands of skiers. Modern skiing styles like carving require wider ski pistes that result in ever more piste constructions. Less natural snowfall due to warmer temperatures and, in some areas even more importantly, an increasing demand of skiers for perfect growing conditions early in the winter season are met with installations of snow-making facilities [22]. The search for reliable snow conditions results in the construction of new ski pistes at higher elevations than before, in areas that are knowingly highly susceptible to disturbance. Hence, despite decades of research into effects of skiing and piste construction, the need to find solutions to minimize negative impacts of skiing on the environment is more pressing than ever.

In this chapter, I review a plethora of studies to illustrate how downhill skiing, snow preparation and ski piste construction affect vegetation. To better demonstrate mechanisms how plants are affected, I will differentiate different factors, namely the 1) snow compaction and skiing, 2) the construction and machine-grading of pistes and 3) technical snow production. Finally, I will briefly discuss restoration measures and solutions that can help minimizing negative effects of ski management practices in ski areas.

SNOW COMPACTION BY SNOW-GROOMING VEHICLES AND SKIERS

The compaction of snow on ski pistes leads to decreased insulation of the ground below the snow. Usually, in snow-dominated climates a snow cover more approx. 70 cm deep insulates sufficiently to decouple temperature fluctuations above the snow from the ground below the snow [23]. As a result, temperatures at the snow-ground interface (Bottom Temperatures of the Snow cover, BTS) remain constant during the winter at precisely 0°C. In permafrost areas, the ground temperatures go down to approx. -2 to -3°C [23]. The insulation properties of compacted snow on ski pistes however are only about half that of uncompacted snow [24], which can lead to considerable fluctuations of ground temperatures that can drop to -15°C [25].

Freezing of the ground can have profound ecological consequences either directly by affecting plants or indirectly by changing soil processes [26]. The clover *Trifolium repens*, for instance, was found to suffer directly from frost damage on ski pistes [27]. Damage of fine roots can be caused by movement of soil aggregates due to freeze-thaw cycles [28]. Soil freezing also influences the microbial activity, which can alter nutrient dynamics and, subsequently, can also affect plant growth [29]. Compaction of the snow by grooming can also cause ice layers in the snow cover [27]. Such ice layers hinder the gas exchange through the snow cover leading to oxygen depletion below the ice layer due to respiration of microbes. This oxygen depletion could make plants even more susceptible to frost or pathogen damage [30].

The soil freezing leads to a delayed development of plants (phenology) in spring after melt-out even if the actual melt-out is not delayed (Fig. (**1**)). The adverse winter conditions can damage plants to the extent that the delay in development is still visible in summer – several weeks after melt-out [29]. This example illustrates how winter conditions can have long-lasting effects during the growth period, even if summer conditions are actually unchanged.

Figure 1: Cross-country ski track during winter, spring and early summer in Davos. Although the melt-out on the ski track is only marginally postponed, the phenology of flowering and fruit production of the dandelion (*Taraxacum officinale* agg.) is still visibly delayed in June (Photo: Priska Hiller).

The plant phenology responds immediately (*i.e.* the same year) to altered snow conditions. However, also the plant species composition changes a few years after snow pack properties have been changed. In experiments where snow was added to plots, species from higher elevation had increased after five years [31]. On ski pistes, two ecological plant groups can be affected. First, species that are characteristic for windy ridges became more frequent on ski pistes than on ambient plots (*e.g., Elyna myosuroides* and *Loiseleuria procumbens*, [32]). This was probably because the winter conditions with soil freezing on ski pistes resembled those on ridges where the low insulation of the thin snow cover also causes soil freezing. Second, early-flowering species were reduced on ski pistes in comparison to control plots next to pistes [5, 33]. The early-flowering species probably had a disadvantage in development compared to late-flowering species because of the harsh winter and spring conditions. Alpine early-flowering species often start to grow and even flower while they are still covered in snow. Solar radiation can be recognized by the plant's photo-sensitive physiological systems through a snow cover that is still more than 30 cm deep [34], and plant growth can start in anticipation of the soon snow-free conditions. That way, some plant species flower on the day or a day after melt-out (*e.g., Crocus albiflorus*), or their flowers even penetrate the still existing snow cover, *e.g., Soldanella pusilla* (Fig. (**2**)). If, however, this subnivean (under snow) development is hampered by hard frosts and subsequent damage on ski pistes, the temporal niche of the early-flowering species may be reduced in comparison to late-flowering species, which do not experience much change in growing conditions.

Figure 2: The early-flowering snowbed species *Soldanella pusilla* can sense solar radiation penetrating the snow cover and starts growing and even flowering under the snow.

Mechanical damage by skiers and snow-grooming vehicles represents an obvious disturbance to plants on ski pistes. Especially when the protecting snow cover is thin, like early in the winter season, vegetation and soil are threatened by snow-grooming machinery and the sharp metal edges of skis. Most sensitive are woody plant species that have sensitive tissue above ground in winter. Those branches contain flowering and vegetative buds, and breakage of branches is a considerable loss to the plant. Woody species were indeed much less frequent on ski pistes than on ambient plots [5, 35]. Winter buds of other plant species, such as hemicryptophytes, are located directly at the ground surface and are therefore much less in danger of damage.

The sum of impacts on ski pistes often (but not always) resulted in a decrease in above-ground annual productivity, in plant diversity (as expressed in species numbers) and vegetation cover [5, 35]. In some ecosystems, especially productive ones, disturbances can also increase diversity when dominant species are suppressed [36]. However, in alpine habitats, productivity and dominance are already low due to abiotic stress. Hence, additional disturbance on ski pistes in the alpine zone apparently only further decreases plant diversity [37].

MACHINE-GRADING

Machine-grading during summer exerts the most drastic disturbance on ski pistes (Fig. (**3**), [14]). Soil and vegetation are usually removed by heavy machinery to create a smooth ground surface. The smooth ground facilitates snow-grooming early in the winter season when the snow cover is still thin. Restoration measures after machine-grading are not always successful or not applied at all ([7, 11, 38, 39] see also 'High-altitude restoration' below). As a result, plant productivity, diversity and vegetation cover are considerably decreased and the proportion of bare ground increased [5, 9, 40, 41] (see also chapter 3 by Michele Freppaz *et al.*) The proportion of bare ground was five times higher on graded that on ungraded ski pistes [5]. Unvegetated ground makes the soil particularly vulnerable to surface run-off and erosion [3, 42]. Plant species that suffer most the intense disturbance are woody species. Species that profit are those that require high light values and low competition [5].

Figure 3: A machine-graded ski piste is not easily re-colonized by plant species.

ARTIFICAL SNOW

The production of artificial snow represents yet another factor influencing vegetation on ski pistes. While in the 1990s snow production was applied only locally to stabilize the snow cover on very steep sections of ski pistes, nowadays the majority of ski pistes is covered by artificial snow in many countries [43]. The effects of artificial snow are not only negative: the additional amount of snow can actually help to protect vegetation and soil to some extent from mechanical damage from snow-grooming vehicles and skiers [5]. Furthermore, the extreme temperatures that can lead to the freezing of the ground under the compacted snow on ski pistes can be attenuated by the additional artificial snow. Although artificial snow is even denser than compacted natural snow, the deeper snow cover of artificial plus natural snow insulates the ground better than only compacted natural snow [25]. However, the large amounts of snow on pistes with snow production require a much longer time to melt than just the natural snow: the delay in melt-out amounts on average two to three weeks (Fig. (**4**)), but in some cases up to four weeks [25]. The delay in melt-out also causes a delay in plant development that can not always be made up for by the vegetation and results in a change in species composition (*e.g.,* an increase in snowbed species, see (Fig. (**3**) [5]). The application of artificial snow also exerts an additional input of melt-water during spring and summer. Furthermore, the water quality of artificial snow differs from that of natural snow: the input of ions was approximately 8 fold higher on artificially snowed pistes [44]. The input of water and ions has the potential to alter vegetation, which can benefit species that require moist and base-rich conditions but suppress species from dry and acidic and/or nutrient poor habitats [45]. However, the comparison between ski pistes with and without artificial snow shows that despite some differences in vegetation, on both piste types the disturbance is considerable and leads to a reduction in species diversity and productivity [5].

Figure 4: Artificial snow postpones the melt-out in spring and early summer by a mean of two to three weeks.

HIGH-ALTITUDE RESTORATION

Most studies on ski pistes investigated the restoration success on machine-graded pistes (see also chapter 10 by Bernhard Krautzer *et al.*). In the alpine zone, many European studies found extremely slow succession after machine-grading when no additional restoration measures, *e.g.,* by seeding, were taken [3, 5, 12, 39, 41, 46, 47].

But also below treeline, machine-grading changed the soil and vegetation structure to such extent that natural recovery of the systems did not occur without additional restoration measures [13]. On ski pistes below treeline, it makes a considerable difference if they were created by just clearing the forest (cutting and removing tall vegetation) or by clearing and machine-grading [9]: cleared pistes retained many ecological similarities to adjacent undisturbed forest, whereas machine-graded pistes showed considerable damage in multiple vegetation and soil parameters.

Mosimann [3] concluded from the analysis of more than 200 sites the following about restoration success in the Central Alps (treeline at approx. 2000 m asl): 1) Re-establishment hardly ever occurred at elevations above approx. 2200 m asl even when re-seeding was applied. Plants rarely colonized the pistes (see also [48]). 2) Between approx. 1600 and 2200 m asl, the local microclimate largely determined re-vegetation, resulting in large variation in restoration success. 3) Below approx. 1600 m asl, restoration with both natural and seeded plant species was usually rapid and successful apart from areas with poorly drained soils.

Nevertheless, restoration ecology made progress in the years after the study of Mosimann [3], and a few re-vegetation measures were successful even at approx. 2500 m asl in the Central Alps: Urbanska [46] found that safety island could increase the restoration success after machine-grading considerably. Such safely island consisted of turfs of natural local vegetation and provided both seeds that were necessary to re-colonize the graded area and sites where seeds could germinate and establish (see also [8, 49]). Also some sites in Scotland showed success with restoration measures at that time. Machine-graded and re-seeded pistes at approx. 1000 m asl (treeline at approx. 650 m asl) blended well in with the surrounding ground 25 years after construction [12]. Local vascular plant species had gradually increased and exceeded the seeded grass species in cover. However, despite some successful examples, machine-grading at high elevation exerts high risk of erosion and permanent damage to ecosystem functions, and even successful restorations do rarely succeed in re-establishing the natural vegetation, but the vegetation of the ski pistes usually differs from adjacent climax vegetation [12, 50].

Recently, research has focused on the effects of biodiversity on ecosystem functions like soil stability and surface erosion [35, 51, 52]. Investigations of soil aggregate stability on ski pistes showed that the number of plant species was positively correlated with soil aggregate stability, and species number was a better explanatory variable than any other variable related to soil or vegetation [35]. Higher plant diversity was associated with a higher number of different root types. Another study with rainfall simulation experiments showed that surface erosion was strongly driven by the percent of vegetation cover, but at a vegetation cover of approx. 60%, an increase in plant diversity significantly reduced surface erosion [51]. These findings imply that the restoration focus should include the re-establishment of a divers vegetation and not only on creating a high percentage of vegetation cover.

IMPLICATIONS FOR MANAGEMENT

The review of the literature indicates that skiing impacts on vegetation vary greatly between regions, elevations and, especially, the type of impact. Based on the findings of many studies, the following recommendations regarding specific elevations and types of impact can be made.

Machine-grading has the most dramatic and negative effects on vegetation and soil and should therefore be avoided or carried out with greatest care. Even below treeline, machine-grading can damage the soil structure almost irreparably and cause erosion. Only at elevations several hundred meters below treeline (*e.g.,* 1600 m asl in the Central Alps), re-establishment of vegetation occurs rapidly and reliably.

When ski pistes are constructed in the forest zone, clearing of the vegetation (cutting of tall vegetation) is preferable to machine-grading of the ground.

Restoration technology has made considerable progress in recent years, and specific re-vegetation measures are available that make use of local seeds and plants that are adapted to and suited for high elevation. The available practical and detailed guidelines need to be followed in all constructions at high elevation (*e.g.,* installations of snow-making facilities, machine-grading *etc.*) [53].

Regarding the increasing application of artificial snow, it can be concluded that not all impacts are negative because some impacts of skiing in general (*e.g.,* mechanical disturbance by skiers and snow-grooming vehicles) are mitigated. Nevertheless, artificial snow can cause changes in vegetation *e.g.,* through an input of ions and water and altering the timing of melt-out that is postponed by two to three weeks. In sensitive vegetation types such as nutrient-poor as fens and low-nutrient meadows, the input of water and ions may exert the threat that endangered species are suppressed by more competitive species.

In areas with very sensitive vegetation or high erosion risk, ski pistes with or without artificial snow may have negative effects because plant diversity and productivity are often decreased on both piste types. However, large alpine areas can be suitable for skiing, *e.g.,* where land is already utilized by man as fertilized meadow or pasture.

CONFLICT OF INTEREST

The author confirms that this article content has no conflict of interest.

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REFERENCES

[1] a) Abegg, B., Koenig, U., Buerki, R., and Elsasser, H., Climate Impact Assessment im Tourismus. *Die Erde* **1997**, *128*(2), 105; b) Elsasser, H. and Messerli, P., The vulnerability of the snow industry in the Swiss Alps. *Mt. Res. Dev.,* **2001**, *21*(4), 335.

[2] a) Bayfield, N., Burial of vegetation by erosion debris near ski lifts on Cairngorm, Scotland. *Biol. Conserv.* **1974**, *6*(4), 246; b) Cernusca, A., Beurteilung der Skipistenplanierungen in Tirol aus ökologischer Sicht. *Verhandlungen der Gesellschaft für Ökologie* **1977**, *XII*(Bern 1982), 137; c) Bayfield, N. and Barrow, G. C., *The ecological impacts of outdoor recreation on mountain areas in Europe and North America*. (Recreation Ecol. Research Group Report, Wye College, Asford (England), **1985**).

[3] Mosimann, T., Geo-ecological impacts of ski piste construction in the Swiss Alps. *Appl. Geography.,* **1985**, *5*, 29.

[4] a) Urbanska, K. M. and Schütz, M., Reproduction by seed in alpine plants and revegetation research above timberline. *Botanica Helvetica* **1986**, *96*, 43; b) Rixen, C., PhD thesis, University of Zurich, **2002**.

[5] Wipf, S., Rixen, C., Fischer, M., Schmid, B., and Stoeckli, V., Effects of ski piste preparation on alpine vegetation. *J. Appl. Ecol.,* **2005**, *42*(2), 306.

[6] Price, M. F., Impact of recreational activities on alpine vegetation in western North America. *Mountain Research and Development.,* **1985**, *5*, 263.

[7] Titus, J. H. and Tsuyuzaki, S., Ski slope vegetation of Mount Hood, Oregon, USA. *Arct. Antarct. Alp. Res.,* **1999**, *31*(3), 283.

[8] Van Ommeren, R. J., Species composition on reclaimed ski runs compared with unseeded areas. *Journal of Range Management.,* **2001**, *54*(3), 307.

[9] Burt, J. W. and Rice, K. J., Not all ski slopes are created equal: Disturbance intensity affects ecosystem properties. *Ecol. Appl.,* **2009**, *19*(8), 2242.

[10] Bayfield, N. G., Replacement of vegetation on disturbed ground near ski lifts in the Cairngorm Mountains, Scotland. *J. Biogeogr.,* **1980**, *7*, 249.

[11] Bayfield, N. G., Urquart, U. H., and Rothery, P., Colonization of bulldozed track verges in the Cairngorm Mountains, Scotland. *J. Appl. Ecol.,* **1984**, *21*, 343.

[12] Bayfield, N. G., Long-term changes in colonization of bulldozed ski pistes at Cairn Gorm, Scotland. *J. Appl. Ecol.,* **1996**, *33*(6), 1359.

[13] Ruth-Balaganskaya, E. and Myllynen-Malinen, K., Soil nutrient status and revegetation practices of downhill skiing areas in Finnish Lapland - a case study of Mt. Ylläs. *Landscape Urban Plann.,* **2000**, *50*(4), 259.

[14] Kangas, K., Tolvanen, A., Kalkaja, T., and Siikamaki, P., Ecological Impacts of Revegetation and Management Practices of Ski Slopes in Northern Finland. *Environ. Manage.,* **2009**, *44*(3), 408.

[15] a) Tsuyuzaki, S., Species Composition and Soil Erosion on a Ski Area in Hokkaido, Northern Japan. *Environ. Manage.,* **1990**, *14*, 203; b) Tsuyuzaki, S., Miscanthus sinensis grassland is an indicator plant community to predict forest regeneration and development on ski slopes in Japan. *Ecol. Indicators* **2005**, *5*(2), 109.

[16] Wardle, K. and Fahey, B., Environmental effects associated with snow grooming and skiing at Treble Cone Ski Field. Part 1. Vegetation and soil disturbance. *Sci. Conserv.* **1999**, *120A*, 1.

[17] Puntieri, J. G., Vegetation response on a forest slope cleared for a ski-run with special reference to the herb Alstromeria aurea Graham (Alstromeriaceae), Argentina. *Biol. Conserv.* **1991**, *56*, 207.

[18] Körner, C., *Alpine plant life*, 2nd ed. (Springer Verlag, Berlin, **2003**).

[19] Jones, H. G., Pomeroy, J. W., Walker, D. A., and Hoham, R. W., *Snow ecology*, 1st ed. (Press Syndicate of the University of Cambridge, Cambridge University Press, **2001**).

[20] Ellenberg, H., *Vegetation ecology of Central Europe*, 4th ed. (Cambridge University Press, Cambridge, **1988**).

[21] Friedel, H., Schneedeckendauer und Vegetationsverteilungen im Gelände. (Snow cover duration and vegetation patterns in alpine terrain.). *Mitteilungen der Forstlichen Bundesversuchsanstalt Mariabrunn (Wien)* **1961**, *59*, 317.

[22] Mosimann T., Beschneiungsanlagen in der Schweiz. Weitere Entwicklung - Umweltverträglichkeit und Folgerungen für die Prüfung und Bewilligung von Beschneiungsanlagen. Studie im Auftrag des Schweizerischen Verbandes der Seilbahnunternehmungen, Bubendorf und Hannover, **1998**.

[23] Haeberli, W., Die Basistemperatur der winterlichen Schneedecke als möglicher Indikator für die Verbreitung von Permafrost in den Alpen. *Zeitschrift für Gletscherkunde und Glazialgeologie.,* **1973**, *9*(1-2), 221.

[24] Geiger, R., *Das Klima der bodennahen Luftschicht*. (F. Vieweg, Braunschweig, **1961**).

[25] Rixen, C., Haeberli, W., and Stoeckli, V., Ground temperatures under ski pistes with artificial and natural snow. *Arctic Antarctic and Alpine Research.,* **2004**, *36*(4), 419.

[26] a) Monson, R. K., Lipson, D. L., Burns, S. P., Turnipseed, A. A., Delany, A. C., Williams, M. W., and Schmidt, S. K., Winter forest soil respiration controlled by climate and microbial community composition. *Nature.,* **2006**, *439*(7077), 711; b) Groffman, P. M., Driscoll, C. T., Fahey, T. J., Hardy, J. P., Fitzhugh, R. D., and Tierney, G. L., Colder soils in a warmer world: A snow manipulation study in a northern hardwood forest ecosystem. *Biogeochemistry.,* **2001**, *56*(2), 135.

[27] Newesely, C., PhD thesis, Auswirkungen der künstlichen Beschneiung von Schipisten auf Aufbau, Struktur und Gasdurchlässigkeit der Schneedecke, sowie auf den Verlauf der Bodentemperatur und das Auftreten von Bodenfrost Leopold Franzens Universität, **1997**.

[28] Tierney, G. L., Fahey, T. J., Groffman, P. M., Hardy, J. P., Fitzhugh, R. D., and Driscoll, C. T., Soil freezing alters fine root dynamics in a northern hardwood forest. *Biogeochemistry.,* **2001**, *56*(2), 175.

[29] Rixen, C., Freppaz, M., Stoeckli, V., Huovinen, C., Huovinen, K., and Wipf, S., Altered snow density and chemistry change soil nitrogen mineralization and plant growth. *Arctic Antarctic and Alpine Research.,* **2008**, *40*(3), 568.

[30] Newesely, C., Cernusca, A., and Bodner, M., Entstehung und Auswirkung von Sauerstoffmangel im Bereich unterschiedlich präparierter Schipisten. *Verhandlungen der Gesellschaft für Ökologie.,* **1994**, *23*, 277.

[31] a) Knight, D. H., Weaver, S. W., Starr, C. R., and Romme, W. H., Differential response of subalpine meadow vegetation to snow augmentation. *Journal of Range Management.,* **1979**, *32*(5), 356; b) Wipf, S. and Rixen, C., Winter climate change in arctic and alpine ecosystems: a review of snow manipulation experiments. *Polar Res.,* **2010**, *29*, 95.

[32] Wipf S., Rixen C., Freppaz M. & Stoeckli V. (2002). Ski piste vegetation under artificial and natural snow: patterns in multivariate analysis. In: Interdisciplinary Mountain Research (eds. Bottarin R & Tappeiner U). Blackwell Stelvio National Park, Italy, pp. 170-179.

[33] Roux-Fouillet, P., Wipf, S., and Rixen, C., Long-term impacts of ski piste management on alpine vegetation and soils. *Journal of Applied Ecology,* **2011**, 48, 906-915.

[34] Starr, G. and Oberbauer, S. F., Photosynthesis of arctic evergreens under snow: Implications for tundra ecosystem carbon balance. *Ecology.,* **2003**, *84*(6), 1415.

[35] Pohl, M., Alig, D., Körner, C., and Rixen, C., Higher plant diversity enhances soil stability in disturbed alpine ecosystems. *Plant Soil.,* **2009**, *324*, 91.

[36] Connell, J. H., Intermediate-Disturbance Hypothesis. *Science* **1979**, *204*(4399), 1345; Vujnovic, K., Wein, R. W., and Dale, M. R. T., Predicting plant species diversity in response to disturbance magnitude in grassland remnants of central Alberta. *Canadian Journal of Botany-Revue Canadienne De Botanique.,* **2002**, *80*(5), 504.

[37] Kammer, P. M. and Möhl, A., Factors controlling species richness in alpine plant communities: an assessment of the importance of stress and disturbance. *Arct. Antarct. Alp. Res.,* **2002**, *34*(4), 398.

[38] Urbanska, K. M., Biodiversity assessment in ecological restoration above the timberline. *Biodivers. Conserv.,* **1995**, *4*(7), 679.

[39] Fattorini, M., Establishment of transplants on machine-graded ski runs above timberline in the Swiss Alps. *Restor. Ecol.,* **2001**, *9*(2), 119.

[40] Rixen, C., Casteller, A., Schweingruber, F. H., and Stoeckli, V., Age analysis helps to estimate plant performance on ski pistes. *Botanica Helvetica.,* **2004**, *114*(2), 127.

[41] a) Delgado, R., Sanchez-Maranon, M., Martin-Garcia, J. M., Aranda, V., Serrano-Bernardo, F., and Rosua, J. L., Impact of ski pistes on soil properties: a case study from a mountainous area in the Mediterranean region. *Soil Use and Management.,* **2007**, *23*(3), 269; b) Barni, E., Freppaz, M., and Siniscalco, C., Interactions between vegetation, roots, and soil stability in restored high-altitude ski runs in the Alps. *Arctic Antarctic and Alpine Research.,* **2007**, *39*(1), 25.

[42] a) Löhmannsröben, R. and Cernusca, A., Bodenverhältnisse, Oberflächenabfluss und Erosionsgefährdung im Skigebiet im Stubnerkogel. *Verhandlungen der Gesellschaft für Ökologie.,* **1990**; b) Florineth, F., presented at the International Conference on Vegetation and Slopes - Stabilisation, Protection and Ecology, Oxford, England, 1994 (unpublished).

[43] Pröbstl, U., *Kunstschnee und Umwelt - Entwicklung und Auswirkungen der technischen Beschneiung*. (Haupt, Bern, Switzerland, **2006**).

[44] Rixen, C., Stoeckli, V., and Ammann, W., Does artificial snow production affect soil and vegetation of ski pistes? A review. *Perspectives in Plant Ecology Evolution and Systematics.,* **2003**, *5*(4), 219.

[45] a) Kammer, P. and Hegg, O., Auswirkungen von Kunstschnee auf subalpine Rasenvegetation. *Verhandlungen der Gesellschaft für Ökologie.,* **1990**, *19*(2), 758; b) Kammer, P. M., Floristic changes in subalpine grasslands after 22 years of artificial snowing. *J. Nat. Conserv.,* **2002**, *10*, 109.

[46] Urbanska, K. M., Restoration ecology research above the timberline: Colonization of safety islands on a machine-graded alpine ski run. *Biodivers. Conserv.,* **1997**, *6*(12), 1655.

[47] a) Urbanska, K. M. and Fattorini, M. S. O., Seed bank studies in the Swiss Alps. I. Un-restored ski run and the adjacent intact grassland at high elevation. *BOTANICA HELVETICA* **1998**, *108*(1), 93; b) Gros, R., Monrozier, L. J., Bartoli, F., Chotte, J. L., and Faivre, P., Relationships between soil physico-chemical properties and microbial activity along a restoration chronosequence of alpine grasslands following ski run construction. *Applied Soil Ecology* **2004**, *27*(1), 7.

[48] Delarze, R., Vegetation dynamics on the artificially sown ski runs of Crans-Montana (Valais, Switzerland) - Altitude effects. *Botanica Helvetica.,* **1994**, *104*, 3.

[49] Isselin-Nondedeu, F., Rey, F., and Bedecarrats, A., Contributions of vegetation cover and cattle hoof prints towards seed runoff control on ski pistes. *Ecol. Eng.* **2006.**, *27*(3), 193.

[50] Isselin-Nondedeu, F. and Bedecarrats, A., Assessing the dominance of Phleum pratense cv. climax, a species commonly used for ski trail restoration. *Applied Vegetation Science.,* **2009**, *12*(2), 155.

[51] Martin, C., Pohl, M., Alewell, C., Körner, C., and Rixen, C., Interrill erosion at disturbed alpine sites: Effects of plant diversity and vegetation cover. *Basic Appl. Ecol.,* **2010**, *11*, 619.

[52] Rixen, C., Huovinen, C., Huovinen, K., Stockli, V., and Schmid, B., A plant diversity x water chemistry experiment in subalpine grassland. *Perspectives in Plant Ecology Evolution and Systematics.,* **2008**, *10*(1), 51.

[53] a) Krautzer, B., Wittmann, H., Peratoner, G., Graiss, W., Partl, C., Parente, G., Venerus, S., Rixen, C., and Streit, M., *Site-specific high zone restoration in the alpine region - the current technological development*. (Federal Research and Education Centre (HBLFA) Raumberg-Gumpenstein, Irdning, **2006**); b)_Locher Oberholzer, N., Streit, M., Frei, M., Andrey, C., Blaser, R., Meyer, J., Müller, U., Reidy, B., Schutz, M., Schwager, M., Stoll, M., Wyttenbach, M., and Rixen, C., Richtlinien Hochlagenbegrünung. *Ingenierbiologie* **2008**, *2*, 3.

CHAPTER 5

Ground-Dwelling Arthropods and Ski-Pistes

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Abstract: Research on the impact of ski-runs on ground-dwelling arthropods has so far been largely neglected, despite the fact that such invertebrates may provide goods and services that are fundamental for mountain ecosystem functioning, and may be usefully employed as bio-indicators of human-induced environmental disturbance. In this chapter we present the results of previous research carried out in the north-western Italian Alps by pitfall trapping on ski-pistes, in adjacent habitats (*i.e.* forests or alpine prairies) and at the habitat edge. Research focused mainly on ground beetle and spider assemblages, but several results on other groups of arthropods (harvestmen, grasshoppers) were also provided. Below the tree line, all parameters of diversity (*i.e.* mean abundance, species richness and Shannon index) of brachypterous carabids (reduced wings or wingless) significantly decreased from forest interior to open habitats (*i.e.* ski-piste or pasture), whereas those of spiders and macropterous carabids (full-sized wings) increased from forest interior to open habitat. Ski-pistes showed lower values than pastures in all community parameters. Indicator Species Analysis showed that there were fewer species significantly preferring forest ski-pistes compared to those preferring pastures, and that there were very few species which were exclusive to ski-pistes (mainly generalist/eurieciouos species). Above the tree line, mean abundance and species richness of brachypterous carabids, spiders and grasshoppers decreased significantly from natural grasslands to ski-pistes. This was not true for the guild of macropterous beetles, which was composed of species with contrasting ecological requirements. Most of the species (some of them endemic to restricted areas in the western Italian Alps) had clear preferences for natural grassland and only two species of ground beetles (one being a generalist) had preference for ski-pistes. Both below and above the tree line, generalized linear models showed that the poor grass cover of ski-pistes is a serious hindrance to colonization by ground-dwelling arthropods. The potential impact of ski-pistes on the functioning of high altitude ecosystems and on the conservation of endemic species is discussed.

Keywords: Ground beetles, grasshoppers, harvestmen, ecosystem functioning, endemic species, diversity, ground beetles, ski-pistes, spiders, treeline.

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INTRODUCTION

Studies focusing upon the impact of ski-pistes on animal communities have mostly considered birds and, to a lesser extent, mammals (see chapters 6 of this eBook), whereas other animals, especially ground-dwelling arthropods, have so far been largely neglected. This lack of knowledge represents a serious gap because such invertebrates may provide goods and services that are fundamental for mountain ecosystem functioning and may be usefully employed as bio-indicators of human-induced environmental disturbance.

Spiders and most ground beetles are predators that play a key role in regulating populations of soil invertebrates, and they also serve as prey for salamanders, small mammals and birds [1, 2]. Grasshoppers may be abundant during summer when they become an important resource for typical alpine birds [3, 4]. Within the framework of the BEF (Biodiversity and Ecosystem Functioning) approach [5-7], any substantial impact of ski-pistes on diversity of these assemblages may therefore induce a disruption of local ecosystem functionality, which, in turn, may hinder the recovery of original natural habitats.

Ground-dwelling arthropods are small, diverse, and sensitive to environmental variability and may be therefore used as indicators of habitat heterogeneity, ecosystem diversity and environmental stress [8]. Ground beetles (Coleoptera: Carabidae) and spiders (Araneae), in particular, have been widely recommended as bioindicators [9, 10], both groups being negatively affected by anthropogenic activities [11-13]. In the Alps, carabids and spiders have also been used in a global change framework, by assessing the chronosequence of a glacier foreland [14].

The study of ground-dwelling arthropods may also have conservation implications. The Alps, in particular, are a true hot spot of ground-dwelling arthropod diversity. With regards to ground beetles, for example, more than 25% of the total number of species occurring in the southern Italian Alps (some 800 species) are endemic [15, 16]. Some of these species may qualify as endangered because they are found in few sites and/or are characterized by small population size. Recent surveys have shown that large-bodied, specialist, and brachypterous carabids are more subject to decline because of rapid changes in the environmental structure of their habitat [17]. The construction of ski-pistes in diversity hot-spots is obviously of particular conservation concern.

The zone of transition between two different habitat types may be termed as an ecotone and the demarcation between them as a habitat edge [18]. When edges between habitats are sharp and abrupt, and lack the transitional vegetation (*e.g.*, dense bushes and herbaceous vegetation), they are termed “hard edges”. On the contrary “soft edges” are found in ecotones where the transition between habitats has varying degrees of softness [19]. Edges (mostly forest edges) have been a focus of both ecological [20-22] and conservation research [23, 24]. However, despite the great importance of arthropods in community interactions (*e.g.*, as pollinators, parasites, scavengers, prey), few studies have attempted to determine edge effects on arthropods. Monitoring this abrupt change is important for assessing human impacts on biological diversity [25, 26].

An important issue when considering ski-pistes construction is therefore the creation of “hard edges”.

In this chapter, we focus on the impact of ski-pistes on ground-dwelling arthropods of the western Italian Alps by presenting the results of previous research on ground beetles and spiders of coniferous forests [27] and on ground beetles, spiders, grasshoppers and harvestmen of high altitude prairies [28]. Results of research on the effect of human-induced habitat changes on carabids are also reviewed to highlight potential implications for ski-developed resorts. Lastly, outcomes of a new investigation on butterflies (which are not ground-dwelling arthropods) are also briefly discussed in the conclusions.

MATERIAL AND METHODS

To assess the impact of ski-pistes on assemblages of ground-dwelling arthropods of forests and alpine prairies, we examined the structure of assemblages (expressed as abundance, species richness and Shannon diversity index) by sampling (pitfall traps) at the edge and in each of the adjacent habitats (*i.e.* in ski-pistes and forest below the timberline and in ski-pistes and alpine prairies above the timberline).

Pitfall traps were 7.5 cm in diameter at the mouth and 9 cm deep, filled with 150 ml of a standard mixture of wine vinegar and sodium chloride solution to preserve individuals. Trapped ground beetles and spiders were sorted and identified, whenever possible, to the species level using updated standard keys or specialist works. Nomenclature follows Platnick [29] for spiders and Audisio and Vigna Taglianti [30] for ground beetles.

Coniferous Forests

This study was carried out at two ski resort sites, *i.e.* Torgnon and Gressoney St. Jean, located in Valtournenche and the Gressoney Valley, respectively (two parallel valleys located in the north-western Italian Alps, Aosta Valley). In Torgnon, we surveyed ski-pistes (1700-2000 m a.s.l, 30-70 m width) which cut through coniferous forests dominated by larch *Larix decidua* and Norway spruce *Picea abies*. The understorey was sparse, and mainly composed of juniper *Juniperus communis*, alpenrose *Rhododendron ferrugineum*, bilberry *Vaccinium myrtillus* and bearberry *Vaccinium uliginosum*. In Gressoney St. Jean, we surveyed ski-pistes (1500-1900 m a.s.l, 40-70 m width) which cut through coniferous forests dominated by fir *Abies alba*, larch and Norway spruce, with an under-storey mainly composed of bilberry.

In addition to forest/piste ecotones, forest/pasture ecotones were also considered to test whether assemblage diversity parameters were lower on ski-pistes than on pastures. We selected 36 sampling plots at Torgnon (18 in forest/pastures ecotones and 18 in forest/ski-piste ecotones) and 50 at Gressoney St. Jean (25 for each ecotone type). Each plot was located at a minimum distance of 100 m from the next nearest sampling plot. Nine pitfall traps were placed at each sampling plot: three (5 m apart) were placed in the forest, three in the ski-piste (or pasture) and three along the edge between the two habitats. Traps in forest and ski-piste (or pasture) were aligned in parallel with the edge, at 20 m distance. Traps were placed at the beginning of July 2006 and emptied after three weeks. Environmental characteristics of ski-pistes were recorded at each plot.

In circular areas of 20 m radius (centred on the second pitfall trap) we measured percentages of grass, soil and rubble cover (estimated by eye), mean grass height (ten measurements, in centimetres), aspect, altitude and width of the ski-piste (in metres).

Alpine Prairies

This study was conducted on ski-pistes (2500-2900 m asl, 20-50 m width) and in high altitude grasslands located at the top end of the Gressoney Valley, in the north-western Italian Alps (Aosta Valley). The survey area is located within one of the Alps' most important ski districts (Monterosa Ski). Around the timberline, coniferous forests (which are thin and characterized by larch *Larix decidua*) are interspersed with patches of alpine moorland (composed of *Vaccinium uliginosum*, *V. myrtillus*, *Rhododedron ferrugineum* and *Juniperus nana*). Above the timberline, the typical vegetation of pastures on acid or acidified substrates is found, dominated by grasses such as *Carex curvula*, *Nardus stricta* and geophytes such as *Arnica montana*, *Pulsatilla alpina* and *Trifolium alpinum*. On ski-pistes the pre-existent habitat has been completely removed and cover - both artificial and recovering grass - was poor.

We selected 48 sampling plots spread over several ski pistes and set at a minimum of 200 m linear distance from the nearest neighbouring plots. Three pitfall traps (aligned at 20 m intervals) were placed at each sampling plot: one was placed on the pasture adjacent to the ski run, one on the ski piste and one at the edge between the two habitats. A total of 144 samples was potentially obtainable (48 plots x 3 traps) per sampling period and a total of 864 samples was obtainable altogether (144 x 6 sampling periods). However, several traps were damaged by tourists and ibexes *Capra ibex*, or inactivated by heavy rain, and were excluded from statistical analyses. Pitfall traps were placed at the beginning of July 2007 and emptied fortnightly until the end of September (six replicates). Pitfall trapping was originally chosen to catch ground beetles, harvestmen and spiders. However, over the course of the study it became apparent that pitfall traps were also capturing grasshoppers. They were therefore collected, preserved in alcohol and identified *a posteriori*, as per Clayton [31].

Structural characteristics of each habitat type (*i.e.* ski piste, edge and natural grassland) were recorded for each trap: in circular areas of 2 m radius centred on the pitfall trap we measured grass cover, soil-rubble cover, rock cover (estimated by eye) and mean grass height (ten measurements randomly located, in centimetres). Moreover, slope and altitude were also recorded.

RESULTS

Coniferous Forests

A total of 171 ground-dwelling arthropod species (corresponding to a total of 12, 053 individuals) were sampled altogether. Spiders (113 species) were dominated by dispersive species (95.3% of the capture), whereas ground beetles (58 species) were mostly represented by brachypterous (60%) and macropterous species (24%) and, to a lesser extent, by pteridimorphic species (*i.e.* species with both winged and short-winged individuals, which were excluded from subsequent statistical analyses because of inadequate sample size).

Ski pistes at Torgnon had low grass cover: accordingly, mean grass cover was in fact significantly lower at Torgnon than at Gressoney St. Jean (ANOVA).

Mean abundance, species richness and diversity of spiders and macropterous ground beetles were significantly different between the three habitat types, and increased from the forest interior to the open habitats (ski-piste or pasture). A noticeable exception to this pattern was the forest/ski-piste ecotone at Torgnon, where species richness and diversity were significantly lower on ski-pistes than at the edge. In contrast to macropterous carabids and spiders, diversity values of brachypterous carabids significantly decreased from the forest interior to the open habitat (Fig. (**1**)).

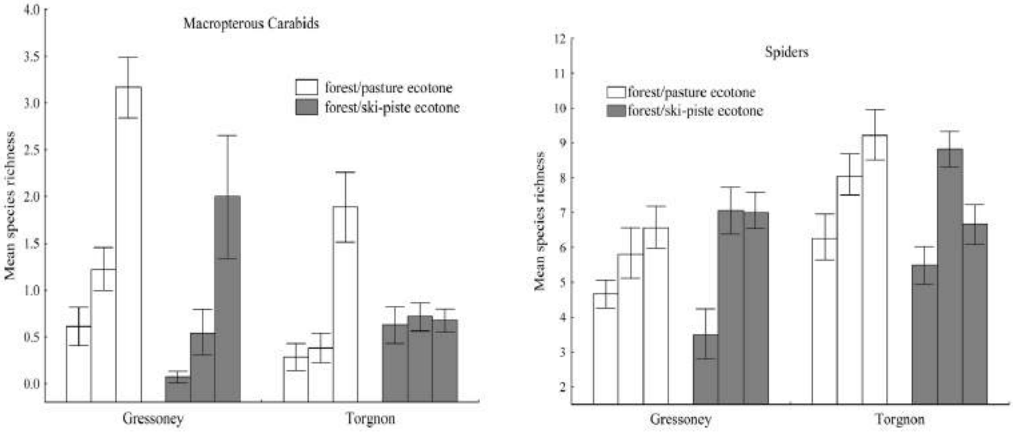

Figure 1: Ski-pistes below the treeline. Differences in mean species richness of spiders and macropterous carabids between habitats. Error bars are ± SE.

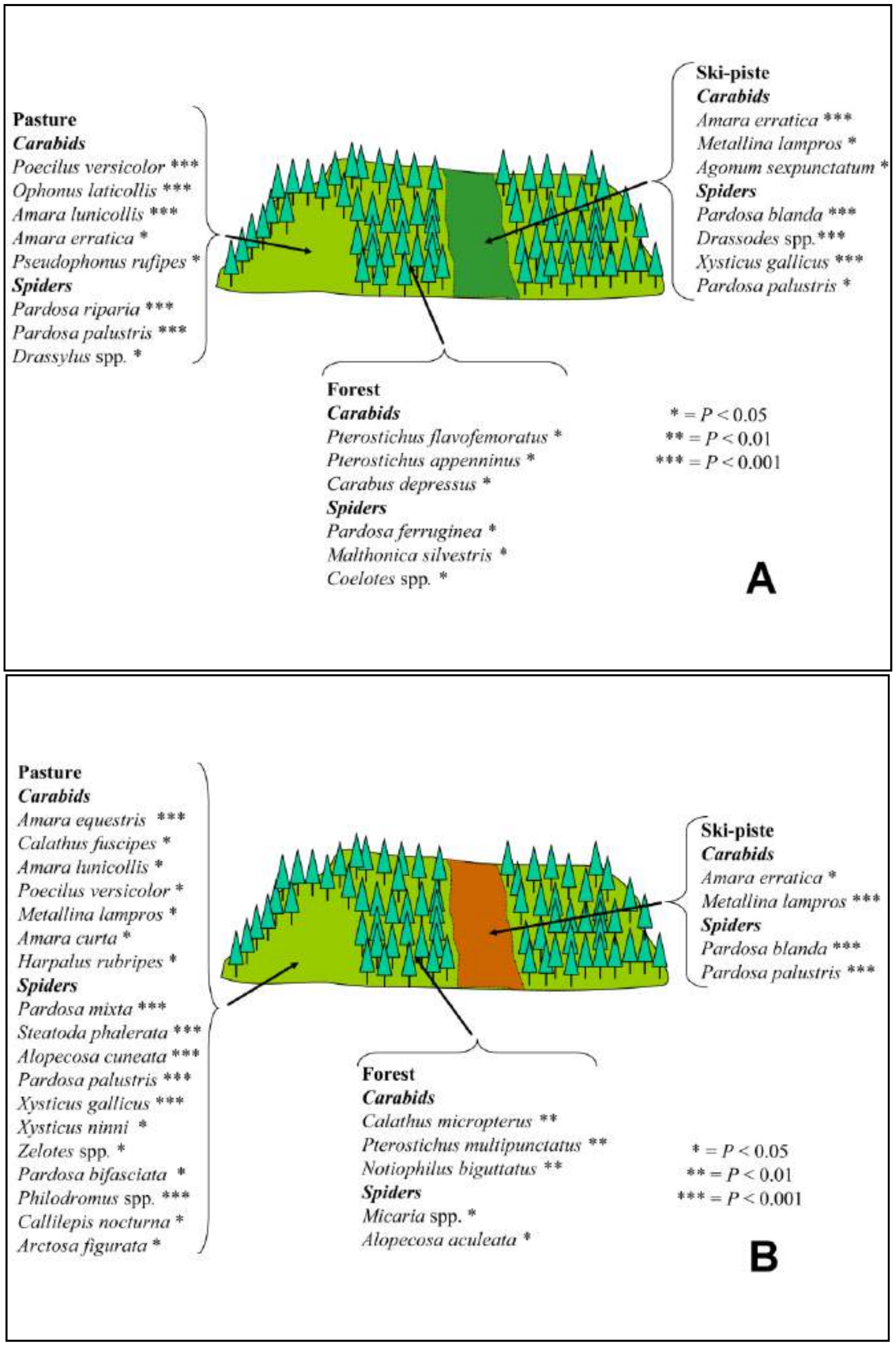

Figure 2: Ski-pistes below the treeline. Species that significantly indicated forest, pasture and ski-piste at Gressoney (A) and Torgnon (B). Statistical significance was obtained by Monte Carlo randomization tests (1, 000 runs).

Differences between ski-pistes and pastures might depend on differences between plots. Hence, data were standardized by calculating the ratio of the value of each diversity parameter (abundance, species richness and diversity) of the open habitat (ski-piste or pasture) to the average value of the same parameter at each plot (the average among the three habitats). This enabled us to measure the relative contribution of the open habitat to the mean diversity of each plot. Mean ratios of abundance, species richness and diversity of macropterous ground beetles were usually higher on pastures than on ski-pistes at both sites, and the same pattern was also observed for spiders at Torgnon. This may indicate that the relative contribution of ski-pistes to the mean diversity of plots was lower than that of pastures.

Generalised linear models (GLM) were used to test for the effects of environmental descriptors on diversity parameters (see chapter 6 for more details). Results showed that ecological parameters were positively associated with grass cover in six selected models out of nine (diversity of spiders at both sites, abundance and species richness of spiders at Torgnon, abundance and species richness of macropterous carabids at Gressoney St. Jean) and with width of ski-pistes in three out of nine (abundance of spiders at Torgnon, abundance and species richness of ground beetles at Gressoney St. Jean).

Specificity and fidelity of each species within habitats was explored by the Ind Val (Indicator value) procedure [32]. In general, species that significantly preferred ski-pistes were less numerous than those preferring pastures, especially at Torgnon (Fig. (**2**)). Only three species were exclusive indicators of ski-pistes (*i.e.* they were never classed as an indicator of any other habitat).

Alpine Prairies

A total of 56 different species (corresponding to a total of 5, 627 individuals) were sampled in total. Carabids (22 species) were dominant because they accounted for 46.9% of the total number of individuals collected, followed by harvestmen (5 species, 23.7%), spiders (25 species, 22.2%) and grasshoppers (4 species, 7.2%).

The sampled arthropod assemblage turned out to be of noteworthy interest from a faunistic and biogeographical point of view: eight species were endemic to the Alps and eight taxa were endemic to the north-western part of the chain.

Total abundance and species richness of spiders and brachypterous carabids varied significantly between habitat types (Fig. (**3**)).

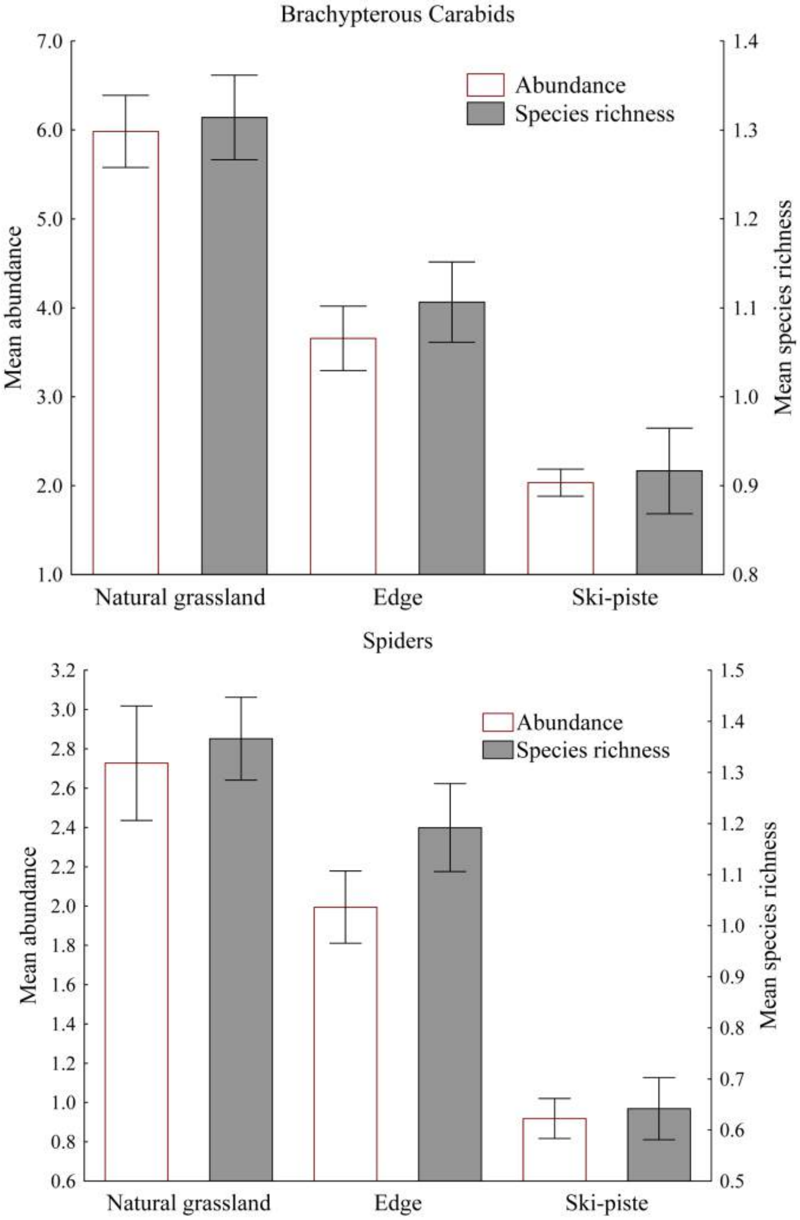

Figure 3: Ski-pistes above the treeline. Mean species richness and abundance of brachypterous carabids and spiders on natural grassland (*i.e.* alpine praire), edge and ski-piste. Bars are ± standard errors

However, abundance and richness of macropterous ground beetles did not vary. Analysis of variance (ANOVA) could not be properly employed to evaluate differences between habitat types because several assumptions were not met. Because of these violations, differences in mean species richness and abundance among the three habitat types and the six sampling periods were tested by means of a generalized linear model (GLM) considering two categorical factors (see original article [28] for more details). Estimates showed that abundance and species richness of spiders on ski-pistes were significantly lower than in both grasslands and edges, whereas abundance and species richness of brachypterous carabids on ski-pistes were significantly lower than in grasslands only.

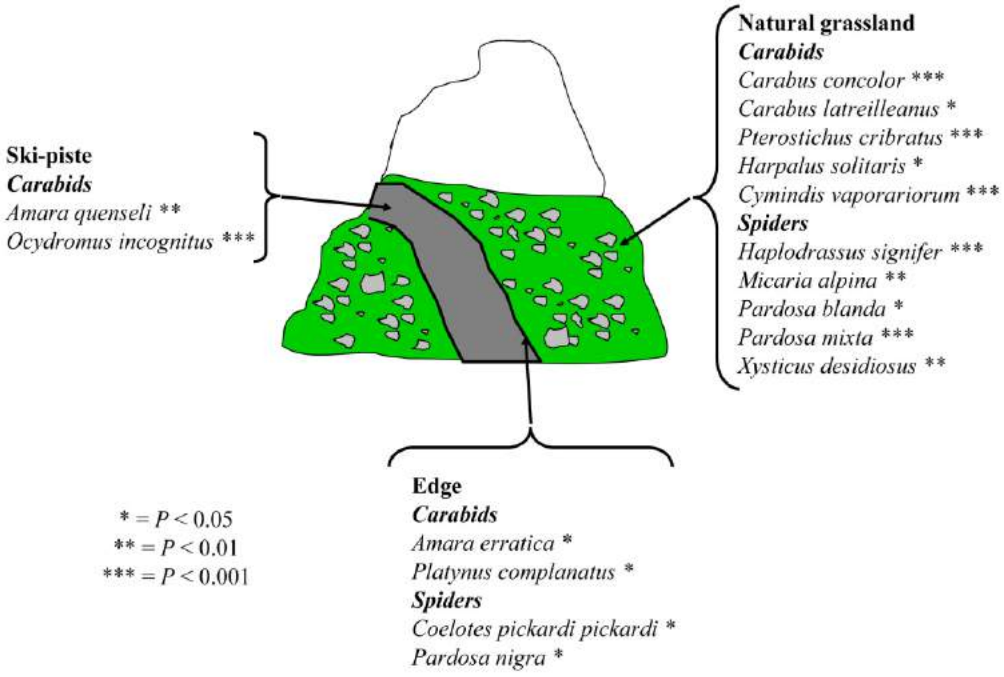

Figure 4: Ski-pistes above the treeline. Species that significantly indicated one of the three habitat types above the treeline are shown. Statistical significance was obtained by Monte Carlo randomization tests (1, 000 runs).

The abundance of all species of grasshoppers progressively and significantly decreased from natural grasslands to ski-pistes ($\chi 2$ test). A reverse trend was observed in harvestmen (disproportionately represented by a single species, *Mitopus morio*), that were more abundant on ski-pistes.

The analysis of indicator species by IndVal showed that all brachypterous carabids and most spiders preferred natural grasslands. Macropterous carabids did not show the same preference pattern because indicator species were evenly distributed among habitat types: two species preferred natural grasslands, two edges and two ski-pistes (Fig. (**4**)).

Results of GLMs showed that richness and abundance of brachypterous carabids and spiders were positively associated with PC1, a principal component describing a grassy gradient from high grass cover of natural grasslands to low grass cover of ski-pistes. This result suggests therefore that diversity increased along with grass cover. Another significant predictor was altitude, which was positively associated with the abundance of both brachypterous carabids and spiders. Macropterous carabids were omitted from these analyses because of the lack of differences between habitat types.

DISCUSSION

Coniferous Forests

Despite their relative proximity, the two areas considered in this study differed greatly in terms of arthropod species composition, due to environmental and historical events [15]. Nevertheless, ecological results were similar at the two sites and showed that mean abundance, species richness and diversity of spiders and macropterous carabids increased from the forest interior to the open habitat (ski-piste or pasture). Both assemblages (at both sites) were characterized by open habitat species capable of colonizing new habitats (dispersive spiders, small winged carabids). Contrary to macropterous beetles and spiders, the diversity of brachypterous carabids significantly decreased from forest interior to open habitat. These ground beetles are medium-large species, wingless or with reduced wings, that are incapable of long distance movements or dispersal by flight [33-35]. Hence, our study emphasized that when/where assemblages are heterogeneous (ground beetles, in this study), distinct ecological guilds should be considered separately.

Although both open habitats (pastures and ski-pistes) were positively selected by spiders and macropterous carabids, comparisons between the two habitats suggested that ski-pistes were less attractive than pastures, in particular for carabids. IndVal analyses strengthened these conclusions because the number of typical pasture species was usually higher than that of ski-piste species. Furthermore, ski-piste assemblages were characterized by highly adaptable generalist species. GLM analyses suggested that the local degree of grass cover of ski-pistes can significantly affect spider and macropterous ground beetle diversity, which increased with increasing grass cover. This explains why at Torgnon, where the impact of ski-pistes on the habitat (in terms of scarce grass cover) was great, species richness and diversity were significantly lower on ski-pistes than on the edge. Ski-piste width was another predictor of ground-dwelling arthropod diversity, showing a positive effect. We believe both predictors concur to explain why ski-pistes are less attractive to macropterous carabids and spiders than pastures. On the one hand, migration to ski-pistes is more difficult because they are perceived as narrow pastures enclosed in the forest matrix; on the other, colonization is more difficult because of the lower grass availability.

Apart from a few endemic spider species (*Coelotes rudolfi*, *Cybaeus intermedius*, *Berlandina nubivaga*, *Metopobactrus schenkeli*), the assemblage was dominated by common species. Nevertheless, our results suggested that the poor grass cover of ski-pistes is a serious hindrance to optimal colonization of macropterous ground beetles and spiders. Our results also indicated that typical brachypterous forest carabids may be heavily affected by ski-piste construction because they are unable to colonize these open habitats. For these species, forest removal along narrow strips can cause habitat loss and habitat fragmentation, both potentially exerting negative effects on their diversity [18, 36].

Alpine Prairies

In our study area, ski-pistes were devastated environments where the original grassy vegetation had been almost completely removed. In such an environmental context, our results showed that the diversity of brachypterous carabids, spiders and grasshoppers decreased progressively from undisturbed natural grasslands to ski-pistes. For these species the construction of ski-pistes, *i.e.* the removal of grass along narrow strips, may be perceived as habitat loss and habitat fragmentation, both of which potentially exert negative effects on arthropod diversity [18, 36]. This pattern of selection was not true for macropterous ground beetles because species of this guild had contrasting ecological requirements (some positively selected natural grasslands, some ski-pistes, according to IndVal). The case of the dominant harvestman *Mitopus morio* (more individuals caught on ski-pistes than in the other two habitats) could be different. Harvestmen are able to walk through dense vegetation by wrapping their bendable tarsi around small twigs and blades of grass. It may be assumed that in natural grasslands, animals were prevented from falling into pitfall traps by the availability of three-dimensional pathways, while on ski-pistes (where plant cover was often missing or highly reduced) they were easily trapped. This might be therefore a good example of the fact that trapping success may significantly depend on differential activity according to habitat type and that pitfall trapping outputs, in certain ecological contexts, may be sampling artifacts.

GLM analyses that considered environmental characteristics as covariates revealed that the local degree of grass cover significantly affected brachypterous carabids and spiders, since diversity parameters increased along with grass cover. Poor grass cover of ski-pistes was therefore a serious hindrance to colonization by ground-dwelling arthropods. In machine-graded ski-pistes, herbaceous cover and specific composition, root density and physico-chemical soil properties change significantly with respect to undisturbed grasslands [37]. Our results indicate that these environments, in addition to soil and vegetation modification, also suffer from heavy arthropod depletion.

The BEF Paradigm

Biological communities are threatened through a variety of activities that increase rates of species invasions and species extinctions, at all scales, from local to global [6]. These changes have a strong potential to alter ecosystem properties and the goods and services they provide to humanity [5, 6]. These issues are at the core of an emerging paradigm in ecology known as the biodiversity ecosystem functioning (BEF) hypothesis. The central tenants of the BEF hypothesis are that an ecosystem with more species will process resources more completely, be more productive, be more stable over time and be less subject to invasions than an ecosystem with fewer species [38]. When alpine grassland is turned to bare ground, it typically does not revegetate for decades [39] (See also chapter 4).

On the grounds of the BEF paradigm and the relevance of arthropods to alpine ecosystem functioning, we hypothesize that the disruption of ski-piste food webs due to the reduction of arthropod diversity above the tree line might be partly responsible for the natural restoration inertia of these altered linear patches. Alpine arthropods (particularly herbivorous taxa) in natural grasslands are known to accelerate ecosystem mineral cycling, because they reduce the high proportion of standing dead material and play a key role in the carbon-nitrogen balance, through concentration of nitrogen in faeces and herbivore biomass [40]. Furthermore, ground-dwelling arthropods may also contribute to the maintenance of plant species richness [40, 41]. In a recent study, Otto *et al.* [42] pointed out that the reduction of arthropod predators increases herbivore biomass and survivoral, and consequently increases the amount of plant biomass consumed *via* a trophic cascade, with a final adverse impact on plant diversity. Eventually, it is likely that a reduction of ground-dwelling arthropods on ski-pistes may be partly responsible for the low attractiveness of these linear patches to alpine birds which prey upon them [43].

In order to fully grasp the potential impact of ski-pistes in the Alps, it should be kept in mind that the total length of pistes might be several thousands of kilometers [43] and that, as a counterbalance to global warming, ski-pistes could be constructed at higher altitudes, just where ecosystems are more fragile and vulnerable.

Conservation Concerns

Despite the fact that ground-dwelling arthropods receive little attention from a conservation standpoint [only one ground beetle species (*Carabus olympiae*) and one spider species (*Macrothele calpeiana*) have international conservation significance], alpine arthropods and, in particular, ground beetles, deserve high conservation priority because, in addition to the relevant ecological roles they play, several species have restricted distributions and are suffering alarming population declines. Recent surveys carried out in several European countries have shown that large-bodied, steno-endemic and brachypterous ground beetles are increasingly prone to extinction risk due to habitat transformation [17].

The high overall arthropod diversity of the study sites reflects the environmental and biogeographical events of the area, known to be an important faunistic glacial refugia [15]. Several endemic species were in fact collected in both studies. Three medium-large ground beetle species typical of forests (*Pterostichus flavofemoratus*, *P. muntipunctatus*, *Carabus depressus*) and three of alpine prairies (*Carabus concolor*, *Carabus latreilleanus* and *Pterostichus cribratus*) were restricted to more or less extended alpine areas [15]. As for spiders, the subspecies *Coelotes pickardi piackardi* was steno-endemic to the north western Alps, whereas the three species *Meioneta alpica*, *Sitticus longipes* and *Zelotes devotus* were endemic to the Alps and only found at the highest altitudes. Also, restricted alpine endemics of high altitudes were the harvestman *Megabunus rhinoceros* (confined to the north western Alps) and the grasshopper *Anonconotus alpinus*, surviving in only a few glacial refugia of the southern slopes of the Alps [44].

Most of the endemic species quoted above may suffer from habitat transformation induced by the construction of ski-pistes. Moreover, ski-pistes, as other man-made linear elements, might potentially act as ecological barriers. It is known that flightless carabids and spiders are unable to cross large roads [45-47], which leads to significant intraspecific genetic differentiation [48]. Ski-pistes might potentially act in the same way, by preventing or reducing movements of flightless individuals between adjacent patches.

Future studies on marked individuals would be useful to confirm whether ski-pistes really do act as true ecological barriers to ground-dwelling arthropods. Radio-tracking might be particularly useful in this context. This technique was successfully tested on the large steno-endemic species *Carabus olympiae* [34, 35], (Figs. (**5**) and (**6**)). This species inhabits beech forests and alpen rose (*Rhododendron ferrugineum*) formations of two sites (a few hectares each) of the western Italian Alps. Occasional observations of radio-tagged individuals from within a shrub, which on reaching the border with the ski-piste (used in summer as pasture for cattle) immediately turned round and went back to the shrubs, seem to suggest ski-pistes may act as barriers.

Figure 5: Two iridescent individuals of the endangered ground beetle species *Carabus olympiae* preying upon snails (Photos by Matteo Negro and Andrea Battisti)

Figure 6: A female of the ground beetle species *Carabus olympiae* radio-tagged and tracked in the field (Photo by Matteo Negro). A few movements of radio-tagged individuals seem to suggest that ski-pistes are deliberately avoided and that they act, therefore, as true barriers.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Our research has demonstrated that ski-pistes exert a negative effect on ground-dwelling arthropods both below and above the tree line.

Forest ski-pistes (below the tree line) negatively impacted brachypterous carabids, in terms of habitat loss. On the other hand, open habitat spiders and macropterous carabids were able to colonize ski pistes with sufficient grass cover.

High altitude ski-pistes (above the tree line) negatively impacted spiders and brachypterous carabids, but they were colonized by few generalist macropterous species.

Both studies demonstrated therefore that a guild-based approach, and a species-identity approach, is indispensable to better understand all the consequences of anthropogenic alterations.

Generally speaking, however, apart from a few peculiar instances (*e.g.,* macropterous ground beetle species *Amara quenseli* and *Ocydromus incognitus*) all species suffer from the poor grass cover and soil removal characteristic of ski-pistes. The decrease of epigean arthropods may cause indirect consequences, such as the slowdown of biogeochemical cycles, an effect on the nitrogen-carbon balance [40] and the abandonment of their natural predators (birds) of ski-pistes and adjacent habitats [43].

Therefore, to retain the arthropod fauna of ski areas, new, environmentally friendly ways of constructing pistes should be developed. Only rocks should be removed and only the roughest (and most dangerous for skiers) ground surfaces should be leveled in order to preserve as much soil and natural vegetation as possible. In all alpine areas ski-pistes should be restored through management to prevent soil erosion and promote the recovery of local vegetation. Transplantation of single plants [49] or turf transplants of wild alpine species to create a wholly autonomous community [50-53] are particularly promising methods. To make movements between forest patches easier, a possible management intervention could be that of restoring the gradual transition from forest to open habitat by enhancing a partial shrub colonization of ski-pistes. It has been demonstrated that the presence of shrubs facilitates the movements of the ground beetle *Carabus olympiae*, which likely uses shrubs as shelter and protection from predators [34, 35]. Moreover, shrub cover may increase the amount of prey available to carabids and may provide a more uniform resource distribution in time [20, 54]. Once revegetation is achieved, vegetation cover should be preserved without compromising the safety of the ski-runs. Grassy and shrubby vegetation, for instance, can be kept low through cattle-grazing and direct pruning without applying ground levelling.

Finally, it is worth mentioning that all the management measures here proposed have a broader ecological significance because they may simultaneously be useful to preserve bird and small mammal diversity (see chapter 6). These measures may also be useful for butterflies (Lepidoptera Rhopalocera). A new investigation suggests forest ski-pistes are probably sub-optimal habitats for butterflies in the Alps. Nevertheless, in a natural reforestation framework, they may be useful to butterfly conservation, on condition that they are completely re-vegetated and that grass (and flower) cover of ski-pistes are favoured and maintained to facilitate their colonization [55].

DISCLOSURE

Part of the information included in this chapter has been previously published in Biodiversity and Conservation (Vol. 19, Number 7, 1853-1870).

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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REFERENCES

[1] Clarke, R.D.; Grant, P.R. An experimental study of the role of spiders as predators in a forest litter community Part 1. *Ecology.*, **1968**, *49*,152–154.

[2] Hance, T. Relationship between crop types, ground beetle phenology and aphid predation in agroecosystems. In: *The role of ground beetles in ecological and environmental studies;* Stork, N.E., Eds.; Intercept, Andover **1990**.

[3] Rolando, A.; Patterson, I.J. Foraging behaviour and diet of the Alpine chough Pyrrhocorax graculus in relation to human developments in the Italian Alps in summer. *J. Ornithol.*, **1993**, *134*,181-187.

[4] Rolando, A.; Laiolo, P. A comparative analysis of the diet of the Chough (*Pyrrhocorax pyrrhocorax*) and the Alpine Chough (*P. graculus*) co-existing in the Alps. *Ibis*, **1997**, *139*,388-395.

[5] Loreau, M.; Naeem, S.; Inchausti, P.; Bengtsson, J.; Grime, J.P.; Hector, A.; Hooper, D.U.; Huston, M.A.; Raffaelli, D.; Schmid, B.; Tilman, D.; Wardle, D.A. Biodiversity and Ecosystem Functioning: Current Knowledge and Future Challenges. *Science.*, **2001**, *294*(5543),804-808.

[6] Hooper, D.U.; Chapin III, F.S.; Ewel, J.J.; Hector, A.; Inchausti, P.; Lavorel, S.; Lawton, J.H.; Lodge, D.M.; Loreau, M.; Naeem, S.; Schmid, B.; Setälä, H.; Symstad, A.J.; Vandermeer, J.; Wardle, D.A. Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. *Ecol. Monogr.*, **2005**, *75*,3-35.

[7] O'Connor, N.E.; Crowe, T.P. Biodiversity loss and ecosystem functioning:distinguishing between number and identity of species. *Ecology*, **2005**, *86*(7),1783-1796.

[8] McGeoch, M.A. The selection, testing and application of terrestrial insects as bioindicators. *Biol. Rev. Camb. Philos. Soc.*, **1998**, *73*,181–201.

[9] Churchill, T.B. Spiders as ecological indicators: an overview for Australia. *Mem. Nat. Mus. Vict.*, **1997**, *56*,331–337.

[10] Rainio, J.; Niemelä, J. Ground beetles (Coleoptera: Carabidae) as bioindicators.*Biodivers. Conserv.*, **2003**, *12*,487–506.

[11] Alaruikka, D.; Kotze, D.J.; Matveinem, K.; Niemelä, J. Carabid beetle and spider assemblages along a forested urban–rural gradient in southern Finland. *J. Insect. Conserv.,* **2002**, *6*,195–206.

[12] Öberg, S.; Ekbom, B. Recolonisation and distribution of spiders and carabids in cereal fields after spring sowing. *Ann. Appl. Biol.*, **2006**, *149*,203–211.

[13] Pearce, J.L.; Venier, L.A.The use of ground beetles (Coleoptera: Carabidae) and spiders (Aranae) as bioindicators of sustainable forest management: a review. *Ecol. Indic.*, **2006**, *6*,780–793.

[14] Gobbi, M.; De Bernardi, F.; Pelfini, M.; Rossaro, B.; Brandmayr, P. Epigean arthropod succession along a 154 year glacier foreland chronosequence in the Forni Valley (Central Italian Alps). *Arct. Antarct. Alp. Res*, **2006**, *38*,357–362.

[15] Casale, A.; Vigna Taglianti, A. I Coleotteri Carabidi delle Alpi occidentali e centro-occidentali (Coleoptera, Carabidae). *Biogeographia.*, **1992**, *16*,331–399.

[16] Casale, A.; Vigna Taglianti, A. Coleotteri Caraboidei delle Alpi e Prealpi centrali e orientali, e loro significato biogeografico (Coleoptera, Caraboidea). *Biogeographia.*, **2005**, *26*,129–201.

[17] Kotze, D.J.; O'Hara, R.B. Species decline—but why? Explanations of carabid beetle (Coleoptera, Carabidae) declines in Europe. *Oecologia*, **2003**, *135*,138-148.

[18] Odum, E.P.; Barrett, G.W. *Fundamentals of ecology*, 5th ed.; Thomson Brooks/Cole, Belmont, **2005**.

[19] Forman, R.T.T. *Land Mosaics: The Ecology of Landscapes and Region*; Cambridge University Press: Cambridge, UK, **1995**.

[20] Magura, T. Carabids and forest edge: spatial pattern and edge effect. *For. Ecol. Manage.*, **2002**, *157*,23–37.

[21] Magura, T.; Tóthmérész, B.; Molnár, T. Forest edge and diversity: carabids along forest-grassland transects. *Biodivers. Conserv.*, **2001**, *10*, 287-300.

[22] Yu, X-D.; Luo, T-H.; Zhou, H-Z. Distribution of ground-dwelling beetles (Coleoptera) across a forest-clearcut ecotone in Wolong Natural Reserve, sourthwestern China. *Insect. Science.*, **2006**, *13*,127-136.

[23] Niemelä, J.; Langor, D.; Spence, J.R. Effects of clearcut harvesting on boreal ground-beetle assemblages (Coleoptera: Carabidae) in western Canada. *Conserv. Biol.*, **1993**, *7*,551-561.

[24] Heliölä, J.; Koivula, M.; Niemelä, J. Distribution of carabid beetles (Coleoptera, Carabidae) across a boreal forestclearcut ecotone. *Conserv. Biol.*, **2001**, *15*,370-377.

[25] Hutcheson, J.; Jones, D. Spatial variability of insect communities in a homogenous system: Measuring biodiversity using Malaise trapped beetles in a Pinus radiata plantation in New Zealand Forest. *Ecol. Manag.*, **1999**, *118*,93-105.

[26] Kotze, D.J.; Samways, M.J. Invertebrate conservation at the interface between the grassland matrix and natural Afromontane forest fragments. *Biodivers.Conserv.*, **1999**, *8*,1339-1363.

[27] Negro, M.; Isaia, M.; Palestrini, C.; Rolando, A. The impact of forest ski-pistes on diversity of ground-dwelling arthropods and small mammals in the Alps. *Biodivers. Conserv.*, **2009**, *18*,2799-2821.

[28] Negro, M.; Isaia, M.; Palestrini, C.; Schoenhofer, A.; Rolando, A. The impact of highaltitude ski pistes on ground-dwelling arthropods in the Alps. *Biodivers.Conserv.*, **2010**, *19*,1853–1870.

[29] Platnick, N.I. The world spider catalog, version 8.5. American Museum of Natural History. [WWW document]. URL http://research.amnh.org/entomology/spiders/catalog/index.html, **2008**.

[30] Audisio, P.; Vigna Taglianti, A. Fauna Europaea: Coleoptera, Carabidae. Fauna Europaea Version 1.1. http://www.faunaeur.org, **2004**.

[31] Clayton, J.C. The effects of clearcutting and wildfire on grasshoppers and crickets (Orthoptera) in an intermountain forest ecosystem. *J. Orthopt. Res*., **2002**, *11*,163–167.

[32] Dufrêne, M.; Legendre, P. Species assemblages and indicator species: the need for a flexible asymmetrical approach. *Ecol. Monogr*., **1997**, *67*,345-366.

[33] Den Boer, P.J. On the significance of dispersal power for populations of carabids beetles (Coleoptera, Carabidae). *Oecologia*, **1970**, *4*,1-28.

[34] Negro, M.; Casale, A.; Migliore, L.; Palestrini, C.; Rolando, A. The effect of small-scale anthropogenic habitat heterogeneity on assemblages of macro-carabids (Coleoptera, Caraboidea) endemic to the Alps. *Biodivers. Conserv*.,**2007**, *16*,3919–3932.

[35] Negro, M.; Casale, A.; Migliore, L.; Palestrini, C.; Rolando, A. Habitat use and movement patterns in the ground beetle endangered species *Carabus olympiae* (Coleoptera, Carabidae). *Eur. J. Entomol*., **2008**, *105*,105-112.

[36] Hanski, I. *Metapopulation Ecology*; Oxford University Press, Oxford, **1999**.

[37] Barni, E.; Freppaz, M.; Siniscalco, C. Interactions between vegetation, roots, and soil stability in restored high-altitude ski runs in the Alps. *Arct. Antarct. Alp.Res.,***2007**, *39*,25–33.

[38] Beisner, B.E.; Romanuk, T.N. Insights from studies of relationships between diversity, productivity and invasibility: assessing community resistance and change.In: *Dynamic Food Webs: Multispecies Assemblages, Ecosystem Development and Environmental Change*; Ruiter, P.C., Wolters, V., Moore, J.C., Eds.; Elsevier Academic Press, **2006**.

[39] Martin, K. Wildlife in alpine and sub-alpine habitats. In: *Wildlife-Habitat Relationships in Oregon and Washingto*n; Johnson, D.H.; O'Neil, T.A., Eds.; Oregon State University Press, Corvallis, OR, **2001**; pp. 285-310.

[40] Blumer, P.; Diemer, M. The Occurrence and Consequences of Grasshopper Herbivory in an Alpine Grassland, Swiss Central Alps. *Arct. Alp. Res*., **1996**, *28*,435-440.

[41] Ritchie, M.E.; Tilman, D. Predictions of species in-teractions from consumer-resource theory: experimental tests with grasshoppers and plants. *Oecologia*, **1993**, *94*,516-527.

[42] Otto, S.B.; Berlow, E.L.; Rank, N.E.; Smiley, J.; Brose, U. Predator diversity and identity drive interaction strength and trophic cascades in a food web. *Ecology*, **2008**, *89*,134-144.

[43] Rolando, A.; Caprio, E.; Rinaldi, E.; Ellena, I. The impact of high-altitude ski-runs on alpine grassland bird communities. *J. Appl. Ecol.*, **2007**, *44*,210-219.

[44] Galvagni, A.; Fontana, P. The species of the genus *Anonconotus* Camerano, 1891, from the Eastern Alps (Insecta Orthoptera Tettigoniidae). *Atti dell'Accademia Roveretana degli Agiati*, **2004**, *8*(*4*),71-96.

[45] Mader, H.J. Animal habitat isolation by roads and agricultural fields. *Biol. Conserv*., **1984**, *29*,81-96.

[46] Mader, H.J. The significance of paved agricultural roads as barriers to ground dwelling arthropods. In: *Connectivity in Landscape Ecology*; Schreiber, K.F., Eds.; Muntersche Geographische Arbeiten 29, Ferdinand Schoningh, Paderborn, Germany, **1988**; pp. 97–100.

[47] Koivula, M.J.; Vermeulen, H.J.W. Highways and forest fragmentation—effects on carabid beetles (Coleoptera, Carabidae). *Landscape. Ecol.*, **2005**, *20*,911– 926.

[48] Keller, I.; Nentwig, W.; Largiadèr, C.R. Recent habitat fragmentation due to roads can lead to significant genetic differentiation in an abundant flightless ground beetle *Mol. Ecol*., **2004**, *13*,2983–2994.

[49] Florineth, F. Pioneers in the height. *Acer*, **2002**, *5*,67-69.

[50] Conlin, D.B.; Ebersole, J.J. Restoration of an alpine disturbance: differential success of species in turf transplants, Colorado, USA. *Arct. Antarct. Alp. Res.*, **2001**, *33*, 340–347.

[51] Ebersole, J.J.; Bay, R.F.; Conlin, D.K. Restoring high-alpine social trails on the Colorado Fourteeners. In: *Handbook of Ecological Restoration*; Perrow, M.R., Davy, A.J., Eds.;. Cambridge University Press, Cambridge, UK, **2002**; pp. 89–391.

[52] Urbanska, K.M. Restoration ecology research above the timberline: colonization of safety islands on a machine-graded alpine ski run. *Biodivers. Conserv.*, **1997a**, *6*,1655-1670.

[53] Urbanska, K.M. Restoration ecology of alpine and arctic areas: are the classical concepts of niche and succession directly applicable? *Opera. Bot.*, **1997b**, *132*,189-200.

[54] Niemelä, J.; Spence, J.R. Distribution of forest dwelling carabids (Coleoptera): spatial scale and the concept of communities. *Ecography*, **1994**, *17*,166–175.

[55] Rolando, A.; Negro, M.; Passerin d'Entrèves, P.; Balletto, E.; Palestrini, C. The effect of forest ski-pistes on butterfly assemblages in the Alps. *Insect Cons. Divers.*, **2012**, in press: DOI 10.1111/j.1752-4598.2012.00204x.

The Impacts of Skiing on Mountain Environments, **2013, 101-122**

CHAPTER 6

The Effect of Ski-Pistes on Birds and Mammals

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Abstract: The focus of this chapter is on the effect of ski-pistes on birds and small mammals. We present the results of previous research carried out in the north-western Italian Alps both below and above the tree line. Data from other mountain areas are also incorporated. Ski-pistes below the tree line produce a *negative edge effect*: forest plots at their edges have lower bird diversity and species richness than those far from edges; conversely, species richness is enhanced when the forest grades into a pasture (positive edge effect). Ski-pistes above the tree line are characterized by low bird species richness and diversity. Moreover, plots adjacent to ski-pistes support a significantly lower bird abundance than plots far from ski-pistes, suggesting these ski-pistes, besides exerting a *direct* negative effect upon their avifauna, may also exert an *indirect*, detrimental effect on the number of individuals utilizing nearby areas. Small forest mammals clearly avoid ski-pistes, but open habitat species are able to colonize them. The effects of other ski-developments (*i.e.* roads, buildings, car parks, lifts *etc.*) on ski-resorts are also discussed by considering research on the alpine chough in Italy, the elk in the USA and the mountain pygmy possum in Australia. As a conclusion, considering both the impact of ski-pistes on vertebrates and invertebrates, we urge a new, environmentally friendly way of constructing ski-pistes, such as only removing rocks and/or levelling the roughest ground surfaces (to preserve as much soil and natural vegetation as possible). The creation of a gradual transition from forest to ski-run, the retention of tree islands, and the incorporation of woody debris may be other useful interventions.

Keywords: Alpine and sub-alpine belts, birds, diversity, Italian Alps, negative edge effect, ski-developments, ski-pistes, small mammals.

INTRODUCTION

As a general rule, alpine and subalpine zones all over the world have increased in relative value as wildlife habitats, given changes in habitats and processes at lower altitudes. Species that formerly used habitats over a broad range of elevations are becoming restricted to the upper elevations of their former range

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[1]. This suggests that mountain environments should be carefully managed in order to preserve viable bird and mammal populations. Among human activities, the ski industry certainly represents the major threat to mountain wildlife, and ski-pistes in particular probably represent the development which has had, and continues to have, a significant effect on wildlife habitat and landscape [2, 3]. During construction, depending upon the habitat involved, forest and/or grassland tracts and soils are usually removed by bulldozers and power shovels. After construction, artificial seeding is usually carried out to control soil erosion. In ski-pistes, soil is severely affected [4, 5] and vegetation, especially at high altitude, is also significantly modified [6, 7]. Moreover, soil and vegetation may be further damaged by artificial snow, skiing and ski-piste preparation by snow-grooming [8-11].

Given the profound modification of soils and vegetation, ski-pistes are expected to negatively affect ground-dwelling animals, like small mammals. Moreover, they may also impact other vertebrate communities through the alteration of wildlife habitats and landscapes and the direct disturbance produced by skiers.

The construction of ski-pistes below the timberline (*i.e.* in the *montane* and the *sub-alpine belts*) may be particularly damaging to wildlife because forest tracts are abruptly clear-cut, thus producing apparent habitat fragmentation and the creation of *edges* (*i.e.* the sharp demarcation between adjacent habitats). In theory, the impact of ski-pistes above the timberline (the *alpine belt*) may be less detrimental to wildlife because their construction does not require the permanent elimination of the habitat itself, as occurs below the timberline, where the forest is totally and permanently removed from the track. This assumption is largely visually-induced, given that the elimination of the arboreal biomass produces evident long breaks through the forested matrix, but it is probably incorrect. Shrubby and rocky habitats (the typical scree slopes) above the timberline are complex habitats as well, and the removal of shrubs and large and medium-sized rocks from the track is a permanent elimination of the habitat, precisely like the elimination of trees. Even in typical alpine prairies, the removal of the original grass cover is equivalent to habitat elimination for alpine grassland vertebrates; moreover, it should be considered that the success of re-colonization by the original grassland vegetation declines with altitude [12], so that ski-pistes above the timberline usually remain grass-free, similar to the tracks below the tree line, which remain un-forested.

In summary therefore, both below and above the timberline wildlife may be severely disturbed because of the habitat loss and fragmentation produced by ski-pistes. Animals may be displaced, or their movements restricted. Winter disturbance by skiers may also stress resident individuals [13], potentially reducing their fitness.

In this chapter, we focus on the impact of ski-pistes on birds and mammals of the western Italian Alps. We present the results of previous research regarding forest [14] and high altitude birds [15], especially passerines. For mammals, we present both the results of previous studies [16] and new data regarding small mammals of coniferous forests. The results of our research are discussed and compared with those obtained in other areas by taking into account, in particular, research on small mammals carried out in forest ski-pistes of Colorado [17, 18].

The effects of ski-developments (*i.e.* those in addition to ski-pistes, *e.g.,* roads, buildings, car parks, lifts *etc.*) in ski resorts are also considered before the final conclusions. In this broader context, interesting research has been carried out on the Alpine chough *Pyrrhocorax graculusin* the Italian Alps [19], the elk (*Cervus canadensis*) in the USA [20] and the mountain pygmy possum (*Burramys parvus*) in Australia [21, 22]. The impacts of ski-developments on black grouse *Tetrao tetrix* and other tetraonids are also rather well known, and they are treated in chapters 7 and 8 of this book.

MATERIAL AND METHODS

Birds of Coniferous Forests

This study was carried out in the coniferous forests of Susa, Chisone and Germanasca valleys (western Italian Alps) in spring 2003. We surveyed 10 ski-localities (where the XX Olympic Winter games took place in 2006) and a Natural Park. Coniferous forests were dominated by the larch *Larix decidua*, but the Arolla pine *Pinus cembra*, Norway spruce *Picea abies*, silver fir *Abies alba* and

Scots pine *Pinus syslvestris* also occurred. Birds were counted using 50-m radius point-counts (7 min duration) in early morning [23]. Three types of plots were defined: forest interior plots (n=112), ski-run edge plots (n=68) and pasture edge plots (n=72). The centre of edge plots was located 50 m from ski-pistes and pastures, so that the external perimeter of the plots embraced forest edge on one side. The centre of forest interior plots was located >200 m from edges. Structural parameters of vegetation (average tree height, arboreal diversity, variability of canopy profile *etc.*) were measured in circular plots of 20m radius centred in each census plot.

Birds of High Altitudes Alpine Prairies

This research was carried out in the grasslands of the western Italian Alps in spring-summer 2004 and 2005. We surveyed 7 ski-localities above the treeline (between 2010m and 2892m a.s.l.) located at the top end of Susa valley (where the XX Olympic Winter games took place in 2006) and around the Monte Bianco and Monte Rosa massifs (Aosta Valley). Prairies and pastures were dominated by grasses (*Festuca* and *Nardus* spp., in particular). Shrubs were predominantly represented by juniper *Juniperus communis* and alpen rose *Rhododendron ferrugineum*. Bird densities at high altitudes are low and landscapes relatively heterogeneous (different topography, rock and grass cover). Hence, birds were counted using a standardized area count method [23]. A count lasted 15 min; during the first 10 minutes the observer stood still and quiet as in standard point counts: for the last 5 min the observer actively searched the plot to flush secretive individuals. Three types of plots were defined: plots centred on the ski-pistes (n=80), grassland habitats adjacent to ski-pistes (n=71) and natural grassland habitats far from the ski-pistes and located in areas with no ski-developments (n=72). As for ski-pistes, we chose plots where the impact of ski-run construction was severe due to the total elimination of the pre-existing habitat and the paucity of grass cover. For each plot, habitat structure variables (percentage of shrub cover, percentage of stone-rock cover, mean height of the vertical component of the habitat *etc.*) were measured. We also carried out rapid assessments of insect and spider availability in the plot by counting all individuals detected in 1 m^2 of vegetation (six replicates per plot).

In both studies, avian communities were described in terms of bird species richness, species diversity (Shannon index $H'=\Sigma(p_i)\ \ln p_i$ where p_i is the relative frequency of species i) and abundance of individuals. Each census plot was visited twice; the total number of species from the two censuses was used as a measure of species richness and the highest number of individuals per visit was used as a measure of species abundance per plot.

Small Mammals of Coniferous Forests

Data on small mammals of coniferous forests were obtained as a by-product of a study originally focused on ground dwelling arthropods carried out in the coniferous forests of Gressoney and Tournanche valleys (Aosta valley, western Italian Alps) in summer 2006. To sample arthropods, we had placed pitfall traps in the ski-piste, at the edge between the piste and the forest and in the forest interior (see chapter 5 for sampling details). Voles and shrews were sometimes found in these traps, in spite of the presence of flat stones covering them; we took advantage of this by extending our study to small mammals (see [16] for sampling details).

Sherman traps (box-style traps designed for the live capture of small mammals) were also used to study habitat use in the ski-pistes of the Ayas valley (between the Gressoney and the Tournanche valleys). Traps were arranged in three rows located in the centre of the pistes, in the forest and at the edge between the former two habitats. Traps were lined with polyester bedding for warmth and baited with hazelnut cream and nuts. About 100 traps were used, from 5 to 15 July 2007. Traps were closed for the day after the morning session and reopened within a few hours of dusk. On first capture, animals were marked by cutting their fur in unique patterns.

In all the three valleys, we surveyed ski-pistes which cut coniferous forests dominated by larch *Larix decidua* and Norway spruce *Picea abies* (silver fir *Abies alba* was only found at Gressoney). The understorey was sparse, mainly composed of juniper *Juniperus communis* and alpenrose *Rhododendron ferrugineum*.

RESULTS

Birds

Coniferous Forests

Differences between forest interior, ski-pistes and pasture-edge plots were tested by means of nested ANOVAs (plots nested within 10 ski-localities) after log-transforming Shannon diversity values and square-root-transforming species richness and abundance. Differences were significant: plots located at the edge of pastures supported the greatest species richness and diversity, whereas those at the edge of ski-pistes had the lowest values. The abundance of woodland species was greatest in forest interior and pasture-edge plots, while that of ecotone-shrub species peaked in the plots at the edge of pastures (Fig. (**1**)). Generalised linear models (GLM) were used to test for the effects of vegetation structure, percent larch cover, elevation, ski-locality and plot type (a categorical variable defining

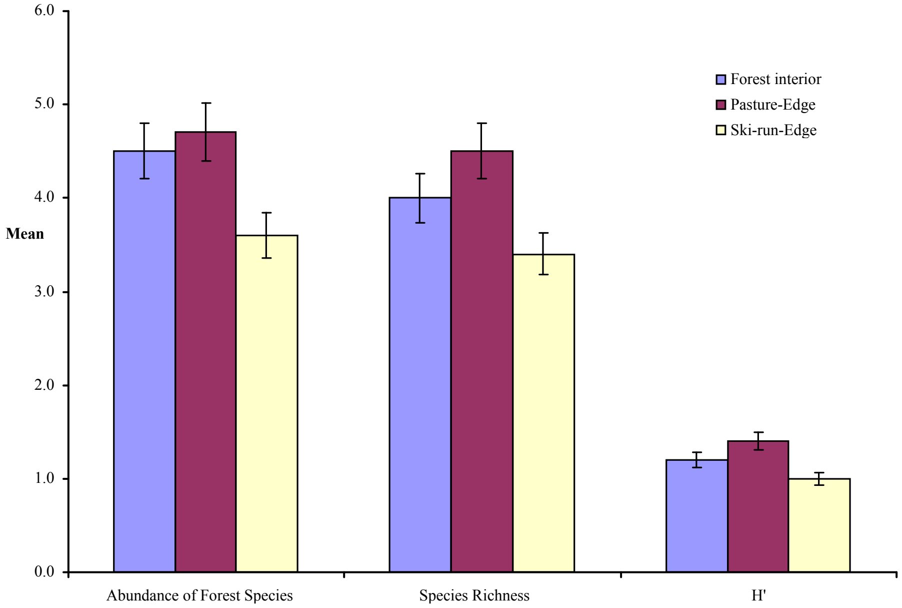

Figure 1: The impact of ski-pistes on bird communities below the tree line. Mean diversity (H’), species richness and abundance of forest bird species are presented for three plot types (forest interior, pasture-edge and ski-run-edge). Error bars are ± standard errors (Modified from [14]).

forest interior, ski-run and pasture-edges). Bird species richness and diversity were best modelled (minimum Akaike Information Criterion) by plot type (forest interior and pasture-edge) alone. The abundance of woodland species was best modelled by plot types, elevation and larch cover, that of ecotone-shrub birds by plot type (pasture edge) and elevation. In all analyses, forest interior and pasture-edge plot types were positively correlated with diversity parameters, whereas elevation and larch cover were negatively correlated.

Results of GLM analyses showed that bird species richness and diversity, and the abundance of woodland birds, were positively correlated with pasture-edge and forest interior plots, whereas the abundance of grassland birds was negatively correlated with forest interior plots. Elevation also significantly and negatively affected the abundance of woodland and ecotone-scrub birds.

Alpine Prairies

Plots located in natural open grassland supported the greatest species richness, diversity and the greatest grassland species abundance, whereas those on the ski-pistes had the lowest values (Fig. (**2**)). Least-squares deviation (LSD) post hoc tests showed that species richness and diversity were not significantly different between plots located in natural habitat and those adjacent to ski-pistes, whereas the abundance of grassland species was significantly greater in natural grassland.

The great scarcity of birds present in ski-run plots was emphasized even more when we consider that in 35% of the ski-run plots not one bird was detected, and that 69.5% of birds recorded on the remaining plots were located outside the actual strip of the ski-run.

The three plot types also showed significant differences in terms of richness, diversity and abundance of arthropods: LSD post hoc tests showed that arthropod richness and abundance were significantly lower in ski-pistes than in the other two plot types, whereas there was no difference between plots located in natural habitat and those adjacent to the ski-pistes.

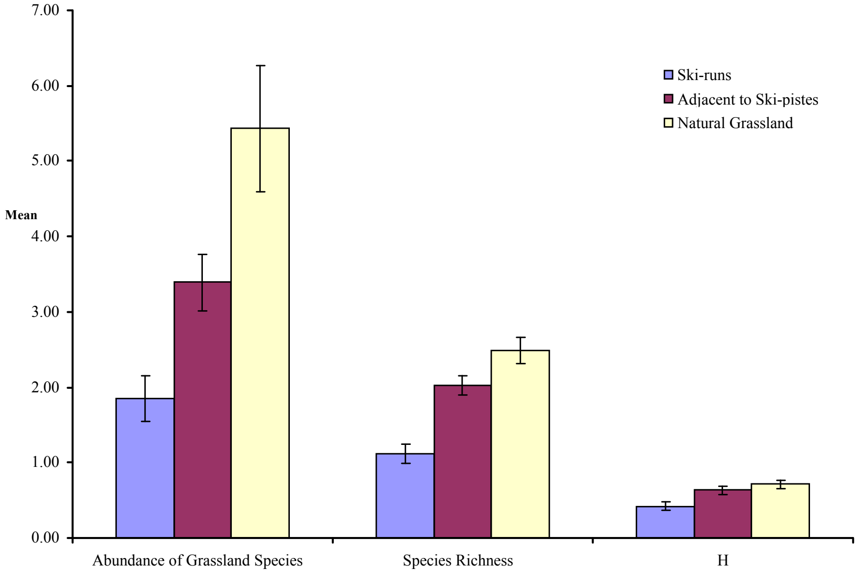

Figure 2: The impact of ski-pistes on bird communities above the tree line. Mean diversity (H'), species richness and abundance of grassland bird species in three different plot types (natural grassland far from the ski-pistes, grassland adjacent to ski-pistes and ski-pistes). Error bars are ± standard errors.

We used GLM to test for the effects of habitat structure, distance from buildings, altitude and plot type (categorical variable defining ski-pistes, plots to the side of the ski-pistes and natural grassland) on bird species richness and diversity and abundance of grassland birds.

Results of GLM analyses without taking into account arthropod abundance showed that species richness, species diversity and abundance of grassland birds were negatively correlated with ski-run plots and altitude (the latter with the exception of abundance of grassland birds). Models obtained after taking into account arthropod abundance included the same significant variables as before; however, arthropod abundance was also included in the models regarding species diversity and the abundance of grassland birds, which slightly but significantly increased when arthropod abundance increased.

Small Mammals of Coniferous Forests

Three small mammal species were sampled in both study areas: the bank vole *Myodes glareolus*, the common shrew *Sorex aranaeus* and the pygmy shrew

Sorex minutus. In this case, given the low number of trapped individuals, data from the two study sites were merged into a single sample for each species. All three species were virtually absent from ski-pistes; for this reason observed frequencies in the three adjacent habitats were significantly different from expected ones (χ^2 test for the goodness of fit; single classification, expected frequencies based on hypothesis extrinsic to the sampled data, *i.e.* under the assumption of an equal use of the three habitats) for the bank vole and the pygmy shrew (Fig. (**3a**)). Similar results were also obtained for the bank voles we captured using Sherman traps (Fig. (**3b**)).

DISCUSSION

The effects of ski-pistes on wildlife in the Alps were until recently poorly known. Our studies focused for the first time on this topic, and demonstrated that ski-pistes exert a negative impact on birds and small mammals of coniferous forests and on birds of high altitude grassland habitats. Our results are discussed below, together with those regarding the effect of ski-pistes on small mammals in the USA [17, 18].

Birds of Coniferous Forests

Our study demonstrated that forest ski-pistes are detrimental to forest birds. Bird species richness and diversity of forests adjacent to ski-pistes are significantly lower than those of undisturbed patches. This could be ascribed to the *negative edge effect* that ski-pistes produce in the forest: plots at their edges have lower bird diversity and species richness than those far from edges; conversely, species richness is enhanced when the forest grades into pasture, producing a *positive edge effect*. The negative edge effect induced by ski-pistes may be ascribed to several factors. First, ski-pistes are linear landscape features that create high-contrast edges and bisect patches: the forest ends abruptly (creating hard edges) and shrub and tree encroachment is prevented by regular pruning and cutting. Several studies in temperate forests have shown that the presence of bushes and grassy headlands in forest margins (soft edges) can increase bird diversity [24-26]. Second, several ski-pistes, especially the steepest ones, have a high proportion of bare ground (due to the removal of grass cover during ski-piste construction and subsequent soil erosion) and this may limit insects and other resources available to birds.

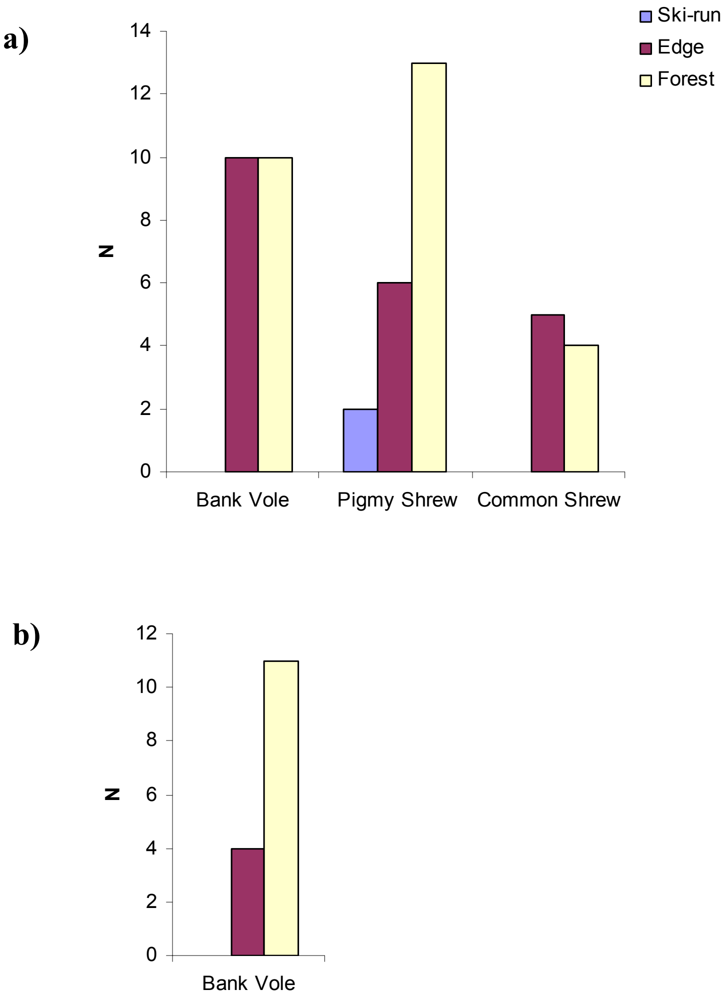

Figure 3: The impact of ski-pistes on small forest mammals. Habitat use (forest interior, edge and ski-piste) of the pygmy shrew *Sorex minutus*, the common shrew *S. araneus* and the bank vole *Myodes glareolus*. Values are numbers of individuals caught in traps. No bank vole and no common shrews were trapped in ski-pistes. a) Pitfall trap captures (modified from [16]); b) Sherman trap captures.

In theory, forest clearing for winter sport activities might be favourable to open-habitat species which are threatened by pastoral abandonment. Depopulation of rural areas and reduction of stocking levels is a long-term trend that is still omnipresent throughout the Alps [27, 28]. The ecological consequences of under-grazing or complete elimination of grazing are evident below the timberline where conditions are suitable for tree and shrub cover: through processes of natural succession, grassland gradually turns into shrubs and, ultimately, to forest. It has been shown that the generalised trend towards pastoral abandonment in the Italian Alps leads to an overall increase in avian diversity, but most bird colonists of abandoned pastures are already common, whereas several grassland bird species that are dependent upon grazed pastures have an unfavourable conservation status. Pastoral abandonment below the timberline, in particular, may be considered as detrimental to a certain number of vulnerable and declining grassland species such as the skylark *Alauda arvensis* (Fig. (**4**)), and the red-backed shrike *Lanius collurio* [29]. From this point of view, the construction of ski-pistes below the timberline, due to the creation of open habitat strips in forests, might be useful in a conservation framework, at least for open-habitat species. However, our observations suggest this is not true because several open-habitat species (rock bunting *Emberiza cia*, yellowhammer *Emberiza citrinella*, red-backed shrike, whinchat *Saxicola rubetra* and rock sparrow *Petronia petronia*) occurred in open pastures but avoided ski-pistes. We believe that ski-pistes are linear elements within forests that are not perceived as open habitats by true grassland species.

Figure 4: European skylark (*Alauda arvensis*) on alpine grassland taking food to the nest (Photo by Giovanni Soldato).

Birds of Alpine Prairies

Grasslands of high altitude represent a semi-natural habitat, where pastoral activities have been practiced for thousands of years [30].

In opposition to what was observed in the montane belt below the timberline, abandonment of grazing has few effects on bird species diversity and abundance at these altitudes in the Alps [29] and therefore the most detrimental present-day anthropogenic threat to bird communities of these habitats is most probably represented by the development of ski-resorts. Our research demonstrated that bird species richness and diversity, and the abundance of grassland species, are significantly lower on ski-pistes than in areas adjacent to ski-pistes and in natural areas without ski-development. GLM modelling confirmed, in particular, that ski-pistes were negatively associated with all three of the community parameters considered (*i.e.* richness, diversity and abundance). In addition, no birds were detected in about one-third of ski-run plots and most birds recorded on these plots were located outside the actual ski-run. Ski-pistes also exert a direct, detrimental effect on local arthropods, whose richness, abundance and diversity were significantly lower than those found in grasslands off-piste and in natural areas. Many insects sampled in the study area (especially grasshoppers and beetles) are known to be part of the diet of several alpine grassland bird species [31]. GLM analyses suggested that arthropod abundance can affect the organization of bird communities. The low food availability of ski-pistes may thus be one factor explaining why few birds occur on these sites, even though the alteration of the original habitat may be the key reason. Our results are in keeping with previous observations on radio-marked alpine choughs which interrupted foraging in certain alpine prairies when these were developed for ski-pistes [32]. It must be underlined that the ski-pistes we sampled were devasted environmental patches, from which shrubby and herbaceous native vegetation had been removed and/or severely damaged and grass cover, if any, was very poor. By selecting such habitats, we could have over-emphasized the negative impact of ski-pistes on bird communities. However, in the Alps, ski-pistes completely re-colonized by original local grassland vegetation are infrequent because restoration is regularly counteracted by management to keep tracks smooth and shrub-free and because re-colonization of indigenous vegetation, at high altitudes, is very slow [6]. Plots adjacent to ski-pistes supported a significantly lower bird abundance. This suggests that pistes at high altitudes, beside exerting a *direct* negative effect upon their avifauna, may also exert an *indirect*, detrimental effect on the number of individuals utilizing nearby areas. Moreover, the results of an analysis at the landscape level suggest ski-pistes are perceived by birds as detrimental features of the alpine landscape. In this analysis, we modeled local probability distributions of bird species according to simulated different scenarios of ski-piste restoration and ski-piste proliferation. Grassland species richness, and the probability of occurrence of water pipit *Anthus spinoletta*, wheatear *Oenanthe oenanthe* and black redstart *Phoenicurus ochruros*, significantly decreased with increasing extent of ski-pistes. The scenario considering perfect grassland restoration provided the highest probabilities of species occurrence [33].

Small Mammals of Coniferous Forests

Small mammals are known to be affected by habitat loss and fragmentation [34, 35]. It might be assumed that for bank voles and pygmy shrews, which are typical forest species [36], the construction of ski-pistes equates to *habitat loss*. Our results are in line with such predictions, given that these species virtually avoided ski-pistes. If we assume avoidance is complete, ski-pistes might also represent a barrier to the movement of these small forest mammals, inducing individuals of different forest patches to remain isolated from each other. Tracking of marked individuals and in particular radio-telemetric studies are therefore necessary to verify whether ski-pistes may be crossed by small forest mammals. Research in this framework is under way in beech forests of the Sessera valley, north-western Italian Alps. Results suggest ski-pistes are ecological semi-permeable ecological barriers to small mammals (Fig. (**5**), [46]).

Patterns of density and survival in small mammals have also been considered through capture-recapture studies in a ski-developed area (Vail) in Colorado, USA, by Hadley & Wilson [17, 18]. Study sites were located in spruce-fir forests of the White River National Forest.

In the first study [17], the authors compared a new ski-run, an experimental ski-run with added woody debris, a forest adjacent to a new ski-run, and a control forest outside the ski development, by estimating density and survival of common small mammals through live-trapping. In four summers (1998-2001) they captured 668 individuals. The red-backed vole (*Clethrionomis gapperi*) was most abundant in forested areas; in particular, density was greatest in the forested site adjacent to the new ski run and next highest in the experimental ski-run. It should be underlined that ski-pistes of the study areas were peculiar because they maintained isolated stands of trees (‘tree islands’) which were encompassed by the authors’ trapping effort. Red-backed voles in particular were only captured in tree islands on new ski-pistes; however, they were captured throughout the experimental run, suggesting that voles not only can persist in, but also can travel across, ski-pistes, when tree islands and woody debris are present. Densities of the deer mouse (*Peromyscus maniculatus*) and the least chipmunk (*Tamias minimus*) were greatest on the new ski run and lowest in the control. These results party reflected habitat preferences of the species: the red-backed vole prefers closed-canopy forests, whereas the deer mouse and the least chipmunk prefer open areas and avoid closed forests.

Figure 5: Dormouse (*Glis glis*) perched on a beech tree (*Fagus sylvatica*) (Photo by Matteo Negro).

In the second study [18], Hadley and Wilson compared small mammal density and survival on two ski-pistes paired with forested sites (771 individuals, captured from 1998 to 2001). Based on abundance estimates from the program CAPTURE, ski-pistes had lower densities of red-backed voles, which were captured only in forest edges of ski-pistes, but higher densities of deer mice and least chipmunks than adjacent forest sites. However, contrary to the authors’ predictions, survival of red-backed voles (based on survival estimates from program MARK) was greater in forested edges than forested sites (survival estimates could not be obtained for the other two species). This may be due to decreased competition for food from other red-backed voles, or proximity to a wider variety of food sources such as bark and fungi from the forested area as well as seeds and herbaceous material from the open ski-pistes. The authors also state the possibility that clearings created by ski-run development may present a formidable obstacle to these voles, at least when wood debris is not retained.

The Effect of Ski-Developments

Several pieces of research have not focussed on ski-pistes *per se*, rather they have also considered other ski-developments which can be found in ski resorts (such as roads, buildings, lifts *etc.*) and direct human disturbance. Several villages and towns in the Alps have either been built or have been enlarged as a consequence of the skiing industry. These ski-resorts may be visited by local wildlife, which reproduce or forage there.

The effects of ski-developments are considered here by taking into account our research on the Alpine chough *Pyrrhocorax graculus* in the Italian Alps [19], studies on the elk in the USA [20] and on the pygmy possum in Australia [21, 22].

We analysed the potential effects of high altitude urbanisation on the foraging ecology of the Alpine chough by studying the autumn and winter ranging behaviour of radio-marked birds in two north-western Italian valleys [19]. Both populations roosted in steep cliffs above 3000 m. However, their foraging ecology during the day differed greatly. We found that the population of the heavily developed site (Cervinia, Valtournanche) spent all day in the town at high altitude (2000 m) making use of the food provided by humans, whereas the population of the less developed/natural site (Cogne, Valle di Cogne) came down every day to the bottom of the valley to forage on snow-free patches and apple orchards. These differences in daily movements likely depended upon differences in food availability and distribution and demonstrated that the foraging ecology of this species was highly flexible. Although the birds' energetic budget was not directly addressed, we assumed birds staying in the town might pay costs due to a poor diet (bread and other scraps), low daily temperature, competition for concentrated food and breakdown of their typical flock cohesion (individuals were dispersed among buildings). However, it is unlikely that urbanized individuals did not gain any advantage; one obvious benefit came from the energy and time saved because they did not fly back and forth every day for many kilometres, and thousands of metres in altitude, as birds of the natural site did.

Morrison *et al.* [20] documented the effect of ski resort expansion on elk in the USA. They considered two sites in the Rocky Mountains (Vail and Beaver Creek, Colorado) and concluded that the greater decrease of elk seen depended mostly on physical disturbances (clear cuts) in one area and on human activities in the other area. Post-development use at both study sites indicated elk partially acclimated behaviourally because the number of individuals seen increased linearly every year after development. The authors only measured the average number of elks seen and were not able, therefore, to know if changes detected were due to a reduced fitness or to a mere redistribution of individuals.

Mansergh and Scotts [21] studied the mountain pygmy-possums *Burramys parvus* at a ski resort (Mount Hotham) in south-eastern Australia. This possum (endemic to alpine and subalpine areas) is able to survive the extended period of winter snow cover by undergoing deep, seasonal hibernation. The authors found that roads and other developments in one area interrupted movements (thereby disrupting social organization and affecting survival rate). They restored habitat continuity by constructing a corridor leading to two tunnels beneath a road that bisected the breeding area, thus allowing males to disperse from the female breeding areas. As a consequence, after construction the population structure and survival rate in the disturbed area changed to those observed in the undisturbed area. However, a multi-year study later carried out by Broome [22] found no evidence that ski resorts showed a declining trend in population size or any changes in demographics which could not be attributed to natural demographic variability. On the contrary, because of the extent and quality of habitat within their boundaries, resort areas supported two of the largest populations found in the study area (the Koskiuszco plateau). However, they recognized that the asynchronous population dynamics, a small amount of migration between habitat patches, differences in site quality and heterogeneity in site structure and aspect, which may contribute to population persistence, required a metapopulation approach [37] and careful monitoring and management to ensure the conservation of this species.

CONCLUSIONS AND MANAGING IMPLICATIONS

Ski-Pistes

Most of the studies carried out so far suggest that the impact of ski-pistes on wildlife of the original habitat is mostly (although not totally) negative, irrespective of altitude and the animals considered. This is of particular concern because the area affected by ski-pistes is large and is still increasing both in Europe [11, 38, 39] and in North America [20]. As for the European Alps, in particular, it should be borne in mind that that in the Alpine chain, the total length of pistes for Alpine skiing exceeds several thousand kilometres. We previously calculated that the total length of pistes at about 4000 km in Italy, 2000 km in Switzerland and 6000 km in Austria [15], but recent re-calculation suggest figures may be higher.

Below the treeline, the negative edge effect induced on forest birds from ski-pistes may be partly ascribed to the presence of hard edges. Therefore, the only way to diminish the negative impact of forest ski-pistes on birds and preserve as much biodiversity as possible, may be the creation of a gradual transition from forest to the open habitat created by ski-pistes. This could be achieved without compromising the safety of the ski-pistes, by managing edge vegetation and encouraging side canopies.

Data on small mammals are more controversial. Research has demonstrated that forest species are severely affected because their habitat is definitely lost and ski-pistes might work as barrier to movements between forest patches. However, survival of forest species seems to be higher in forest edges than in forest interiors and open habitat species are able to use ski-pistes. Additional studies on the impacts of ski-development are therefore needed to understand small mammal responses and to promote effective management strategies for maintaining populations of forest-dwelling animals. Interesting management interventions are already available. The experimental test carried out by Hadley and Wilson [17] for instance, was very successful because it suggested that ground-dwelling small forest mammals (the red-backed vole, in this case) may inhabit ski areas on condition that ski-pistes retain tree islands and incorporate woody debris. Ski-pistes retaining a partial shrub cover may also be beneficial to small mammals which were seen to quickly use shrubs as refuges when released in to the open (Matteo Negro, personal observations). This very same intervention might also be useful to preserve certain bird species.

It should also be considered that the compression of the snowpack associated with ski-piste preparation has the potential to affect adversely small mammal fauna that over-winter in the subnivean space. The experimental compression of the snowpack at 22 sites in south-east Australia induced a decline of two local mammals species (*Rattus fuscipes* and *Anthechinus swainsonii*) by 75-80% [40].

In purely conservationist terms, ski-pistes represent a serious threat when the conservation status of the species involved is poor or they are endemic to the area considered; hence conservation priorities cannot be *a priori* set because they should be locally established on the ground within the range of the species involved.

Conservation of high altitude wildlife threatened by ski-pistes deserves more attention because several high altitude species are rare or declining. More than one-quarter (7/26) of the grassland and shrub species recorded in the study we carried out at high altitudes, for instance, had been classed as species of European conservation concern, *i.e.* SPEC2 and SPEC3 category (*sensu* [41]). In particular, rock partridge *Alectoris graeca*, red-billed Chough *Pyrrhocorax pyrrhocorax* and wheatear *Oenanthe oenanthe* are declining species, whereas black grouse, rock thrush *Monticola saxatilis*, skylark and rock bunting are considered as depleted. Retaining the avifauna of these zones is likely to involve developing new, environmentally friendly ways of constructing pistes, such as only removing rocks and/or levelling the roughest (and most dangerous for skiers) ground surfaces, in order to preserve as much soil and natural vegetation as possible. When necessary, ski-pistes should be restored through management to prevent soil erosion and promote the recovery of local vegetation. Transplantation of single plants [12, 42] or turf transplants of wild alpine species to create a wholly autochthonous community [43, 44] seem to be particularly promising techniques. Once the natural vegetation is achieved, it should be preserved without compromising the safety of the ski-pistes. Shrubby vegetation, for instance, can be kept low through direct pruning and/or cattle-grazing.

Ski-Developments

It may be assumed that any significant enlargement of ski-developments as well as the creation of new ski resorts results in the destruction of natural habitats used by animals. Although this is obviously true in most cases, it should be underlined that wildlife is surprisingly able to acclimate behaviourally, as observed by Morrison *et al.* [20] in the case of elk and by us in the case of the Alpine chough [19]. Moreover, several alpine bird species (*e.g.,* black redstart, northern wheatear, snowfinch *Montifringilla nivalis* and Alpine chough) frequently perch on and/or nest in anthropogenic structures such as buildings, pillars, ropes and electricity cables [15]. One of the major concerns in ski resorts is that of ensuring free movement of local wildlife. Corridors and tunnels beneath barriers are useful tools, as shown for the mountain pygmy possums by Mansergh and Scott [21].

It should be acknowledged that ski developments in mountain areas have usually brought employment and prosperity to local human populations and provide healthy recreation to thousands of tourists from lowland territories. Combining wildlife protection with ski land-management is therefore a central concern for nature conservation, but requires a collaborative, problem-solving approach, by guaranteeing the participation of stakeholders in the decision process. Within this framework, a modelling procedure has recently been proposed for the evaluation of changes in wildlife habitat suitability following ski-development on the occasion of the Turin 2006 Winter Olympic games [45]. A habitat suitability index was calculated for the roe deer *Capreolus capreolus* and was used to compare different hypothetical land-use scenarios and make decisions about the location of ski-developments to minimize habitat loss and to assess the consequences of human activities in relation to an ecological benchmark. This method provides a way to involve local populations and stakeholders in the decision-making process, and thus may be a useful tool for the formulation of land-use policies.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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REFERENCES

[1] Martin, K. Wildlife in alpine and sub-alpine habitats. In: *Wildlife-Habitat Relationships in Oregon and Washington.* Johnson, D.H.; O'Neil T.A., Eds; Oregon State University Press: Corvallis, OR, **2001**; pp. 285-310.

[2] Simons, P. Aprés ski le deluge. *New Scient.*, **1988**, *117* (1595), 49-52.

[3] Mackenzie, D. Alpine countries seek controls on skiers, builder and roads. New Scient., **1989**, *124* (1686), 22.

[4] Freppaz, M.; Lunardi, S.; Bonifacio, E.; Scalenghe, R.; Zanini, E. Ski runs and stability of soil aggregates. *Adv. Geoec*., **2002**, *35*, 125-132.

[5] Delgado, R.; Sánchez-Maranon, M.; Martín-García, J.M.; Aranda, V.; Serrano-Bernardo, F.; Rosúa, J.L. Impact of ski pistes on soil properties: a case study from a mountainous area in the Mediterranean region. *Soil Use Manag*., **2007**; *23*, 269-277.

[6] Barni, E.; Freppaz, M.;, Siniscalco, C. Interactions between Vegetation, Roots, and Soil Stability in Restored High-altitude Ski Runs in the Alps. *Arct. Antarct. Alp. Res.,* **2007**, *39*, 25-33.

[7] Tsuyuzaki, S. Vegetation development patterns on ski-runs in lowland Hokkaido, northern Japan. *Biol. Cons.,* **2002**, *108*, 239-246.

[8] Keller, T.; Pielmeier, C.; Rixen, C.; Gadient, F.; Gustafsson, D.; Stähli, M. Impact of artificial Snow and Ski-slope Grooming on Snowpack Properties and Soil Thermal Regime in a Sub-alpine Ski area. *Ann. Glaciol.*, **2004**, *38*, 314-318.

[9] Rixen, C.; Stoeckli, V.; Ammann, W. Does artificial snow production affect soil and vegetation of ski pistes? A review. *Perspect. Plant Ecol. Evol. Systemat.*, **2003**, *5*, 219-230.

[10] Rixen, C.; Haeberli, W.; Stoeckli, V. Ground temperatures under ski pistes with artificial and natural snow. *Arct. Antarct. Alp. Res*., **2004**, *36*, 403-411.

[11] Wipf, S.; Rixen, C.; Fischer, M.; Schmid, B.; Stoeckli, V. Effects of ski piste preparation on alpine vegetation. *J. Appl. Ecol*., **2005**, *42*, 306-316.

[12] Urbanska, K.M. Restoration ecology research above the timberline: colonization of safety islands on a machine-graded alpine ski run. *Biodivers. Conserv*., **1997**, *6,* 1655-1670.

[13] Arlettaz, R.; Patthey, P.; Baltic, M.; Leu, T.; Schaub, M.; Palme, R.; Jenni-Eiermann, S. Spreading free-riding snow sports represent a novel serious threat for wildlife. *Proc. R. Soc. B*., **2007**, *274*, 1219-1224.

[14] Laiolo, P.; Rolando, A. Forest bird diversity and ski-runs: a case of negative edge effect. *Anim. Cons*., **2005**, *7*, 9-16.

[15] Rolando, A.; Caprio, E.; Rinaldi, E.; Ellena, I. The impact of high-altitude ski-runs on alpine grassland bird communities. *J. Appl. Ecol.* **2007**, *44*, 210-219.

[16] Negro, M.; Isaia, M.; Palestrini, C.; Rolando A. The impact of forest ski-pistes on diversity of ground-dwelling arthropods and small mammals in the Alps. *Biodiv. Conserv.*, **2009**, *18*, 2799-2821.

[17] Hadley, G.L.; Wilson, K.R. Patterns of small mammal density and survival following ski-run development. *J. Mammal.*, **2004**, *85*, 97-104.

[18] Hadley, G.L.; Wilson, K.R. Patterns of density and survival in small mammals in ski runs and adjacent forest patches. *J. Wildl. Manage.* **2004**, *68*, 288-298.

[19] Rolando, A.; Laiolo, P.; Carisio, L. Urbanization and the flexibility of the foraging ecology of the Alpine Chough *Pyrrhocorx graculus* in winter. *Rev. Ecol. (Terre Vie)*, **2003**, *58*, 337-352.

[20] Morrison, J.; de Vergie, W.J.; Alldredge, A.W.; Byrne, A.; Andree, W.W. The effects of ski area expansion on elk. *Wildl. Soc. Bull.* **1995**, *23*, 481-489.

[21] Mansergh, I.M.; Scotts, D.J. Habitat continuity and social organization of the mountain pygmy-possum restored by tunnel. *J. Wild. Manage.*, **1989**, *53*, 701-707.

[22] Broome, L.S. Intersite differences in population demography of mountain pygmy-possums *Burramys parvus* Broom (1986-1998): implications for metapopulation conservation and ski resorts in Koskiuszkio National Park, Australia. *Biol. Cons.*, **2001**, *102*, 309-323.

[23] Bibby, C.J.; Burgess, N.D.; Hill, D.A.; Mustoe, S.H. *Bird census techniques*, 2nd ed. ; Academic Press: London, **2000**.

[24] Kroodsma, R.L. Effect of edge on breeding forest bird species. *Wilson Bull.*, **1984**, *96*, 426-436.

[25] Fuller, R.J.; Warren, M.S. Conservation management in ancient and modern woodlands: responses of fauna to edges and rotations. In: *The scientific management of temperate communities for conservation*: Spellerberg, I.F.; Goldsmith, F.B., Morris, M.G., Eds.; British Ecological Society Symposium No. 31, Blackwell Scientific Publications, Oxford, **1991**; pp. 445-771.

[26] Fautsch, M.; Delvingt, W.; Paquet, J.Y. L'influence de la structure des lisières forestières sur leur capacité d'accueil pour l'avifaune dans l'Ardenne Belge. *Alauda*, **2003**, *71*, 253-260.

[27] Cernusca, A.; Tappeiner, U.; Bayfield, N. Land-use changes in European mountain ecosystems. Blackwell Wissenschaft-Verlag: Berlin, **1999**.

[28] Dirnböck, T.; Dullinger, S.; Grabherr, G. A regional impact assessment of climate and and-use change on alpine vegetation. *J. Biog.*, **2003**, *30*, 401-407.

[29] Laiolo, P.; Dondero, F.; Ciliento, E.; Rolando A. Consequences of pastoral abandonment for the structure and diversity of alpine avifauna. *J. Appl. Ecol.* **2004**, *41*, 294-304.

[30] Lichtenberger, E. Die Alpen in Europa. Österreochiske Academie der Wissenshaften. *Veröffentlichungen der Kommission für Humanökologie*, **1994**, *5*, 53-86.

[31] Rolando, A.; Laiolo, P. A comparative analysis of the diet of the Chough (*Pyrrhocorax pyrrhocorax*) and the Alpine Chough (*P. graculus*) co-existing in the Alps. *Ibis*, **1997**, *139*, 388-395.

[32] Rolando, A.; Patterson, I.J. Foraging behaviour and diet of the Alpine chough *Pyrrhocorax graculus* in relation to human developments in the Italian Alps in summer. *J. Ornithol.*, **1993**, *134*, 181-187.

[33] Caprio, E.; Chamberlain, D.E.; Isaia, M.; Rolando, A. Landscape changes caused by high altitude ski-pistes affect species richness and distribution in the Alps. *Biol. Cons.*, **2011**, *144*, 2958-2967.

[34] Bentley, J.M.; Catterall, C.P.; Smith, G.C. Effects of fragmentation of Araucarian vine forest on small mammal communities. *Conserv. Biol.*, **2000**, *14*, 1075-1087.

[35] Laakkonen, J.; Fisher, R.N.; Case, T.J. Effect of land cover, habitat fragmentation and ant colonies on the distribution and abundance of shrews in southern California. *J. App. Ecol.*, **2001**, *70*, 776-788.

[36] MacDonald, D.W.; Barrett, P. *Mammals of Britain and Europe*. Harper Collins Publishers: London, **1993**.

[37] Hanski, I. *Metapopulation Ecology*. Oxford University Press: Oxford, **1999**.

[38] Abegg, B.; Koenig, U.; Buerki, R.; Elsasser, H. Climate impact assessment im tourismus. *Die Erde*, **1997**, *128*, 105-116.

[39] Elsasser, H.; Messerli, P. The vulnerability of the snow industry in the Swiss Alps. *Mount. Res. Develop.*, **2001**, *21*, 335-339.

[40] Sanecki, G.M.; Green, K.; Wood, H.; Lindenmayer, D. The implications of snow-based recreation for small mammals in the subnivean space in south-east Australia. *Biol. Cons.,* **2006**, *129*, 511-518.

[41] BirdLife International. *Birds in Europe: population estimates, trends and conservation status.* BirdLife Conservation Series No. 12. BirdLife International: Cambridge, **2004**.

[42] Florineth, F. Pioneers in the height. *Acer*, **2002**, *5*, 67-69.

[43] Conlin, D.B.; Ebersole, J.J. Restoration of an alpine disturbance: differential success of species in turf transplants, Colorado, USA. *Arct. Antarct. Alp. Res*., **2001**, *33*, 340–347.

[44] Ebersole, J.J.; Bay, R.F.; Conlin, D.K. Restoring high-alpine social trails on the Colorado Fourteeners. In: *Handbook of Ecological Restoration*; Perrow, M.R.; Davy, A.J., eds.; Cambridge University Press: Cambridge, UK, **2002**; Vol. *2*, pp. 389–391.

[45] La Morgia, V.; Bona, F.; Badino, G. Bayesian modelling procedures for the evaluation of changes in wildlife habitat suitability: a case study of roe deer in the Italian Alps. *J. Appl. Ecol*., **2008**, *45*, 863-872.

[46] Negro, M.; Novara, C.; Bertolino, S.; Rolando, A. Ski-pistes are ecological barriers to forest small mammals. *Eur. J. Wild. Res*., **2012**; DOI 10.1007/s10344-012-0647.

CHAPTER 7

Bird Collisions with Overhead Ski-Cables: A Reducible Source of Mortality

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Abstract: With the expansion of resorts for winter sports, the number of ski lifts has increased dramatically. The overhead cables of these structures are dangerous for birds, particularly for grouse and partridges living in the mountains, and cases of collisions are frequently reported. In 1997, the Mountain Galliformes Observatory (OGM) initiated a survey of sections of cables where dead birds had been discovered in all French ski areas in the Alps and the Pyrenees. The aim was to identify avian collision mortality sites in ski areas and to provide recommendations for reducing cable collisions in respective habitats. During the 1997-2009 period, 835 mortality events were identified on 137 of the 225 ski lifts investigated. The collisions involved six species of Galliformes present in the mountains of France. The species suffering the highest losses were the black grouse (*Tetrao tetrix*) in the Alps and the capercaillie (*Tetrao urogallus*) in the Pyrenees (capercaillie disappeared from the French Alps early in the decade; black grouse is not present in the Pyrenees). The collisions were mostly due to button lifts. It is possible to reduce mortality by installing marking devices on the more dangerous sections of cable. Collection and analysis of the type of data presented here can facilitate the characterisation and visualisation of potentially dangerous sections of existing and future installations.

Keywords: Black grouse, capercaillie, french alps and pyrenees, marking devices, ski-lifts, tetraonids, impact, collision, bird mortality, visualisation, button lifts, overhead cable, grouse, partridges, ski areas, floaters, mountain galliformes observatory.

INTRODUCTION

Since the 1960s, winter sports activities have greatly expanded. The creation and expansion of ski areas have resulted in the appearance of heavy infrastructures (*e.g.,* hotels and mountain lodges, ski runs, ski lifts, parking areas, toboggan runs) that cause many changes to the environment. These changes alter habitats, and

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Christian Rixen and Antonio Rolando (Eds)

detrimental impacts have been demonstrated on many populations of mountain bird species, and particularly on grouse [1-5].

The demography of galliform populations is indirectly affected by factors related to the development of ski resorts, such as the pressure from growing numbers of tourists in certain areas in winter, which can involve a large. number of people present over a short period of time. Human dispersion into the natural environment can cause disturbance to species during a critical period in their annual cycle, when natural mortality may already be high even in the absence of disturbance. Birds are not equipped to meet the extra pressure, and the constant disturbance can lead to the loss of wintering areas. This can produce a drastic fall in numbers, as observed in a population of capercaillie in the Pyrenees [6]. Experiments have been conducted to try to reduce or to channel human activity, but this has been found to be difficult to implement and often requires communication and public awareness-raising measures [7].

Other factors have a direct impact on the demography of birds. Collisions with overhead cables of ski lifts and cables for the transportation of explosives have one of the strongest impacts on bird populations. This is now a well-known factor in bird mortality, in particular among relatively large species with a fast and direct flight such as birds of prey, woodcock, rock partridge and especially grouse [8-10].

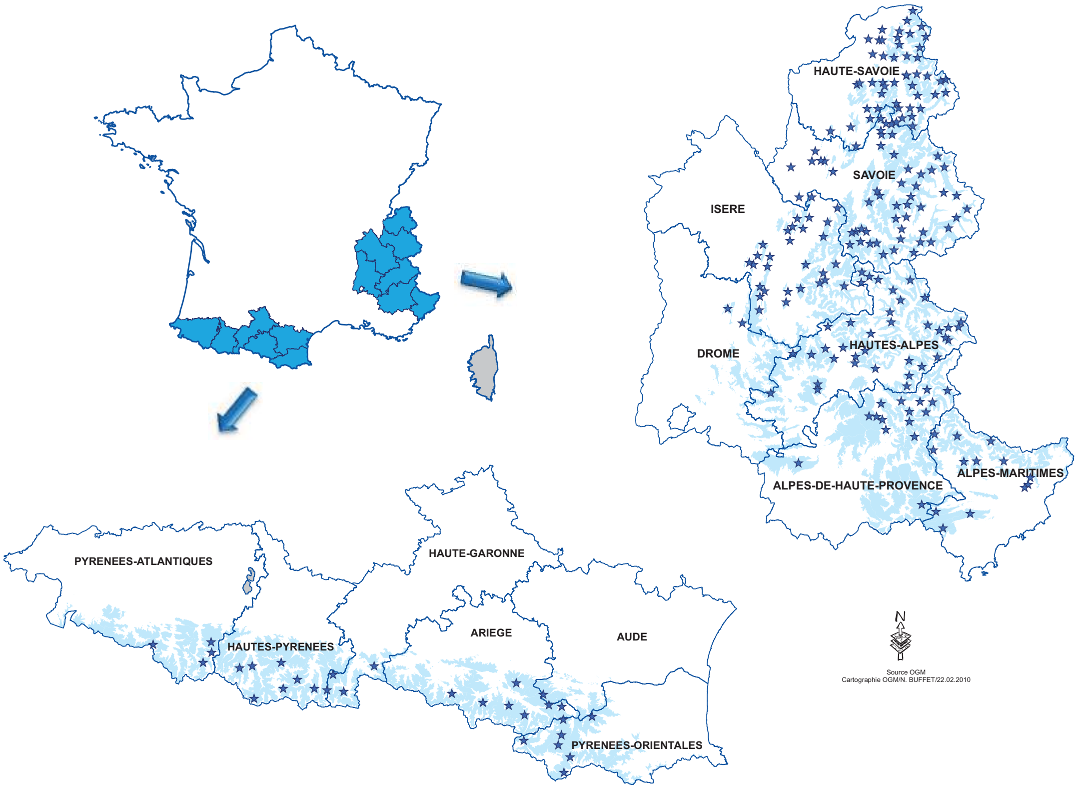
It is possible to considerably reduce the risk of collision by installing marking devices on cables to make them more visible to birds in flight [11, 12]. However, it is not possible or even necessary to mark all the existing cables over their total length in a given ski resort because most mortality events seem to be limited to specific cable sections. Identifying the location of these dangerous sections is therefore a prerequisite if we want to avoid wasting resources and to undertake targeted, more effective, action.

If we wish to maintain viable populations around ski resorts, it is necessary to limit the range of factors that have a detrimental impact on bird populations, and also to evaluate the effectiveness of the implemented actions.

For this reason, the Mountain Galliformes Observatory (OGM) has conducted research with the following aims: 1) to census the mortality events of mountain galliformes due to collision with ski-lifts, and to document the location of the cable sections concerned, 2) to evaluate the influence of the characteristics of the cables responsible for mortality events, 3) to assess the effectiveness of various marking devices for limiting collisions.

METHODS

A large survey was conducted between 2000 and 2004 on the 225 French ski areas in the Alps and the Pyrenees (Fig. (**1**)). OGM partners (foresters, gamekeepers, hunters, agents of protected areas) contacted officials of the ski areas to collect the following information: type and identification of each ski lift, location and characteristics of the cable sections under which dead birds were found (length, amplitude of the ground cable) and the level of mortality (species, number of cases known).



Source OGM
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Figure 1: Ski areas investigated in the French Alps and Pyrenees.

This survey was not based on a scientific method with a rigorous monitoring protocol in the field. It was simply an organized collection (by survey form) of cases of cable-related bird collision mortality that OGM partners or the staff of ski resorts recalled having seen.

An annual update since the completion of the initial survey in 2006 has allowed incorporation of changes brought to the ski lift network, identification of new mortality cases and an assessment of the effectiveness of the mitigation systems set in place.

A data analysis was performed to determine the factors that may favour collisions (number of cables, ground clearance, topographic position, surrounding vegetation *etc.*), and the features that dangerous sections could have in common. For this, groups of data were created according to the types of structure and the species or species group of galliforms affected (Galliformes living in forests: black grouse, capercaillie, hazel grouse; or Galliformes inhabiting open environments: ptarmigan, rock partridge, grey partridge). Such a study is very useful for identifying the sections that can be considered dangerous from the outset.

RESULTS

Cases of bird mortality resulting from cable collision were reported from 137 of the 225 ski resorts investigated (Fig. (**2**)).

On all ski resorts, a total of 835 dead birds were found under 764 portions of cables from 467 ski lifts or cables for the transportation of explosives. These figures are obviously regarded as a minimum given that only a fraction of dead birds are likely to be found: not all dead birds will fall directly below the cables (a rock ptarmigan was discovered more than 600 meters away from a cable – [13]), predators may quickly dispose of the carcasses, and moreover, a smaller proportion of mortality events occurs outside the ski season, when the traffic on the ski lifts is much less regular and the ground vegetation makes the discovery of bird remains more difficult.

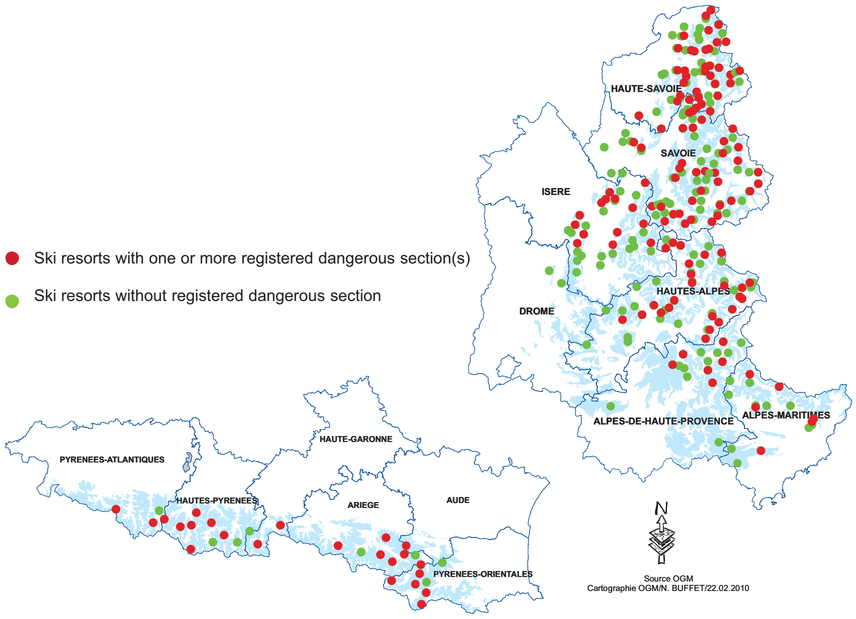

Figure 2: Ski areas with and without dangerous cable sections.

a) Button lifts are Especially Deadly

The button lifts were the infrastructure type that caused the highest proportion of deaths (78%) (Fig. (**3**)). This was not explained by the higher number of button lifts, although they represented 57% of all ski lifts (Fig. (**4**)), but by their features, which made them more dangerous than the other types of structure (X^2=56, p.001).

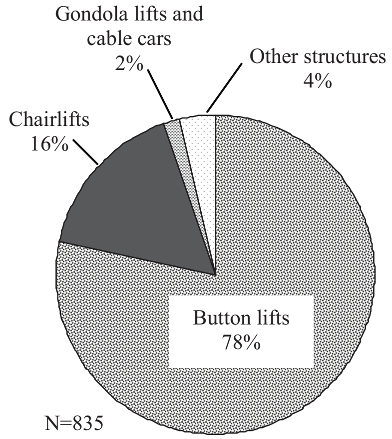

Figure 3: Causes of bird mortality by type of structure.

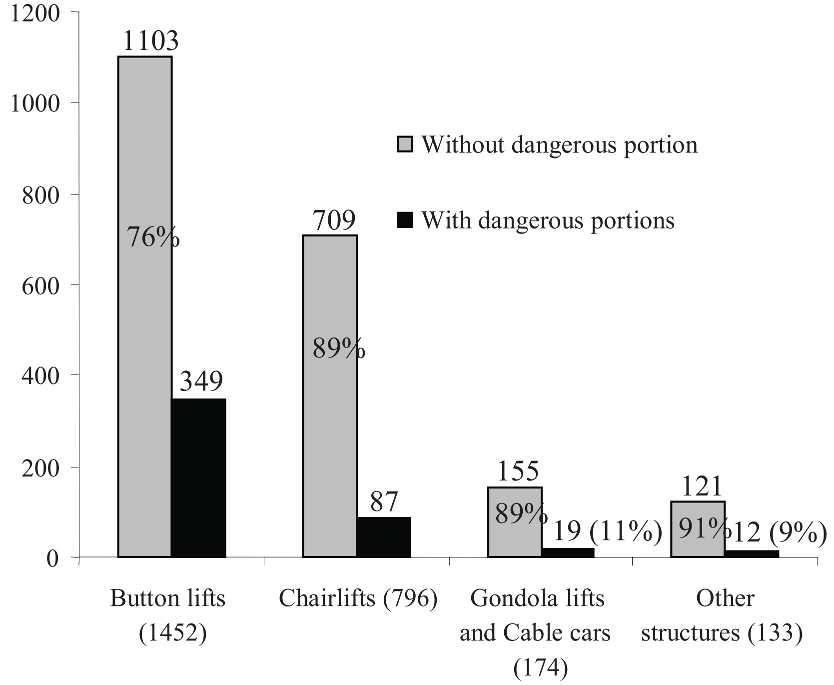

Figure 4: Number of dangerous structures by type of structure.

b) The Black Grouse in the Alps and the Capercaillie in the Pyrenees, are the Species Most Affected

All species of mountain Galliformes suffered losses due to collisions with cables. However the black grouse in the Alps and the capercaillie in the Pyrenees appeared to be the most common victims of collisions with ski lifts (Fig. (**5**)), and, button lifts in particular (Fig. (**3**)). These two species alone accounted for 70% and 45% of deaths, respectively. The predominance of capercaillie in collision cases has already been shown by other studies [14]. For both species, this cannot be explained by the amount of cable in respective habitats. Indeed, if we compare the expected mortality rates linked with cable density in different habitats to the mortality rates observed using a chi² test, they are significantly different ($p=0,0011$ for the Pyrenees and $p<2.2\ e^{-16}$ for the Alps). One possible explanation is that the collision risks are more important for these birds because of their larger size. We can also assume that black grouse and capercaillie deaths are more easily detectable by observers owing to their size and the colour of the males. Other biological factors may also influence collision risk, in particular movement patterns during the winter and activity patterns at dusk. In addition to the possible influence of biological factors, the high level of mortality in black grouse and capercaillie may be due to the fact that most ski resorts are distributed in the typical habitat of these two grouse species. To provide guidelines, we decided to focus our research on the influence of ski lift features on mortality.

French Alps

Species	Number of mortalities
Black grouse	476
Rock ptarmigan	103
Rock partridge	38
Hazel grouse	10
Bird of prey	14
Other	43
TOTAL	684

French Pyrenees

Species	Number of mortalities
Capercaillie	68
Rock ptarmigan	41
Grey partridge	35
Bird of prey	3
Other	4
TOTAL	151

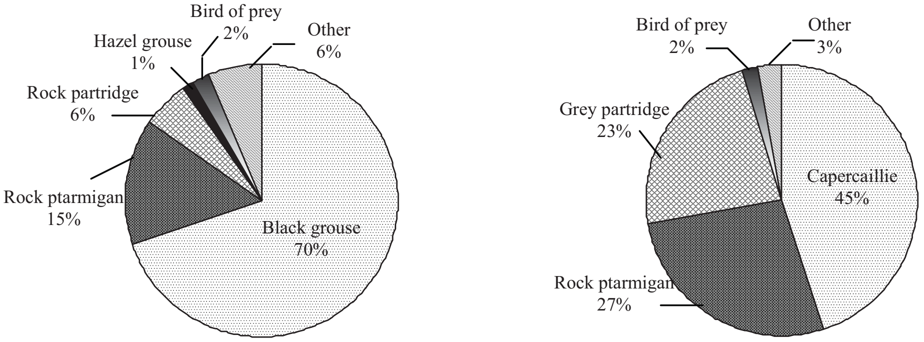

Figure 5: Mortality of bird species.

c) Characteristics of the Sections with the Highest Mortality Rate

In the most common collisions (black grouse /button lift and capercaillie /button lift), preliminary results of this study suggested that the sections concerned were characterized by the highest cable, at 8.5 m above the ground (Fig. (**6**)). This is the case in areas of compression, or slope break, when the return cable does not pass through all the pylons.

For black grouse, the collision risk increased with:

- An altitude between 1600 and 2200 m, which corresponds to the typical altitude of the treeline and is hence the altitude most frequented by the species (Fig. (**7**)),

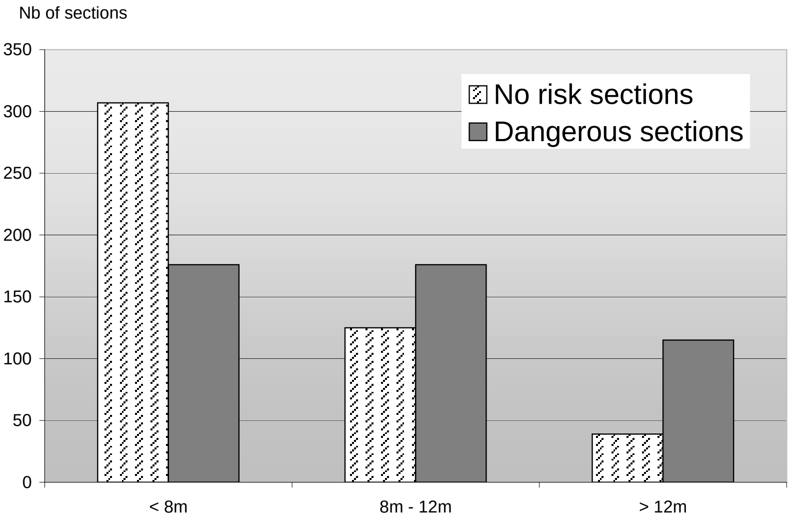

Figure 6: Frequency of dangerous sections and no risk sections according to cable height.

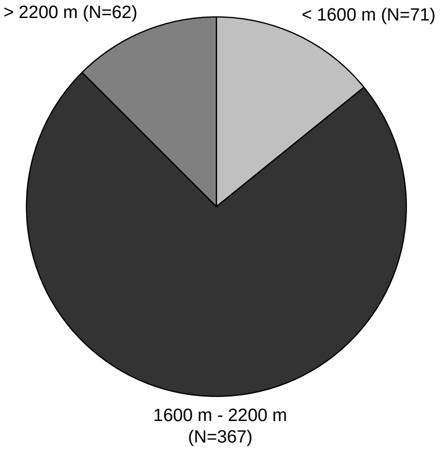

Figure 7: Proportion of dangerous sections for the black grouse according to altitude.

- Closed surrounding vegetation (forest or forest edge). These criteria can help identification of sections with potential risks in addition to those located in the survey (Fig. (**8**)).

d) Installation of Marking Devices on Dangerous Cable Sections and an Assessment of their Effectiveness

The installation of various marking devices on specific portions of the overhead cables to increase their visibility can greatly reduce the risk of collision. The type of visual device depends on the type of structure.

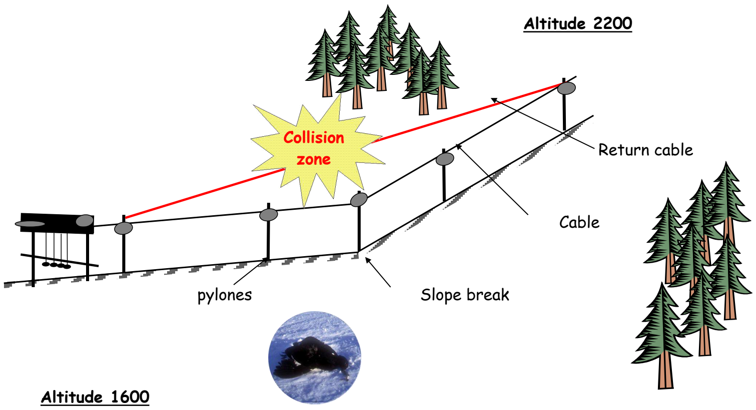

Figure 8: A cable potentially causing mortality risk for black grouse.

Several experiments have shown the colour red to be the most effective [15] for various devices:

- ✓ floaters on the safety cord for button lifts (Fig. (**9**)).
- ✓ PVC coiled tubing on multicore for chairlifts (Fig. (**10**)).
- ✓ checkered flags or red paint lines on cables (Fig. (**11**)) for transport of explosives (catex).

Figure 9: Floaters on the safety cord for button lifts.

Figure 10: Checkered flags or red paint lines on cables for catex.

Figure 11: Coiled tubing for chairlift.

Information and awareness-raising actions have been undertaken with various ski area officials to encourage the addition of visual devices on the sections of cable at risk.

To date, the installation of marking devices has been initiated on 66 ski lifts among the 137 with sections at risk (Fig. (**12**)).

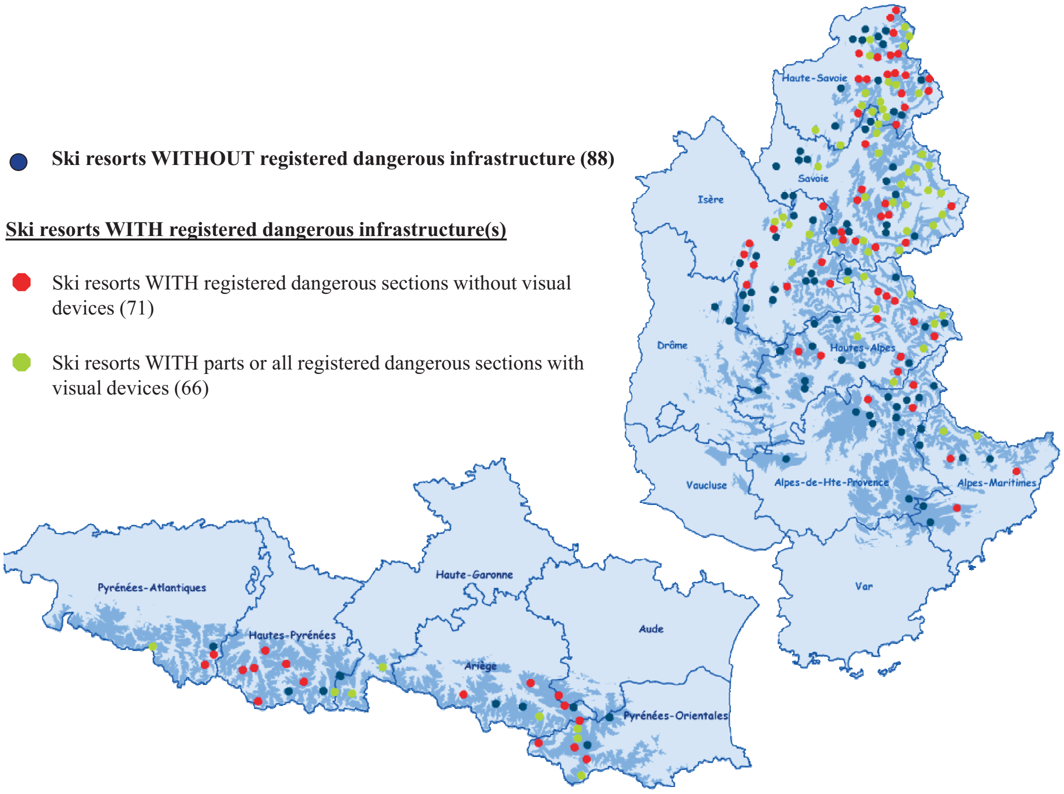

Figure 12: Level of coverage of visual devices.

A total of 87 of the 467 installations identified as hazardous were marked and 86 have been dismantled.

Under the 78 sections of ‘at risk’ button lifts equipped with floaters, 18 mortality cases (12 black grouses, 2 ptarmigans, 1 rock partridge, 3 others) were recorded after the marking of the cables over a period of more than 12 years. The sections at risk were those only partially equipped with floaters or defective floaters (damaged or discolored). No cases of mortality were identified on the sections of ski lifts that were fully equipped with weatherproof and UV resistant floaters.

High quality visual devices applied along the entire length of cable at risk, both UV resistant and weatherproof, are particularly recommended for:

- Their effectiveness in reducing collisions,
- Their safety with respect to the functioning of the structure,
- And their cost effectiveness.

In relation to the infrastructure, the impact on the landscape is insignificant.

DISCUSSION AND CONCLUSIONS

Collision mortality events in mountain Galliformes have been recorded not only with ski lift cables, but also with power lines and fences. Collisions with fences and power lines are a major source of mortality for black grouse, capercaillie and ptarmigan in Norway [16] and for black grouse, capercaillie and red grouse *Lagopus lagopus scoticus* in Scotland [17, 18]. Although no specific survey has been conducted on this subject in France, the victims of such collisions are presumably less numerous than those caused by the ski lift cables, which form a particularly dense network, especially in major ski areas.

Although collisions with cables may contribute less to the population declines of galliformes than habitat changes resulting from the expansion of ski areas, a modelling approach [19] showed that collision mortality may have a negative impact on long-term survival of capercaillie in the Pyrenees. This is presumably also the case for the black grouse, given the high incidence of mortality observed. Further research should estimate the relative contribution of collision mortality to the total mortality of mountain Galliformes in order to assess the impact on the population dynamics of these species.

Preliminary data on bird collisions with overhead ski-cables in France has been previously reported [20, 21]. Our survey enabled the detection of numerous avian collision sites in ski resorts for all galliform species. Fortunately, the first mitigation measures seem to be effective since no mortality events have been recorded under cable sections fully equipped with floaters. From a management perspective, it is therefore important to continue raising staff awareness in ski areas to obtain a total coverage of visual devices on the registered dangerous sections.

Maintaining the network of correspondents, on all ski areas, is also essential to be able to regularly update the database with regards to:

- ✓ The evolution of all ski lifts (dismantling or construction of ski lifts),
- ✓ the level of coverage of visual devices,
- ✓ the detection of new collision sites,
- ✓ the detection of collision deaths after the installation of visual devices.

This last point is particularly important for the continuation of the assessment of the effectiveness of visual devices.

Finally, this study allowed us to provide guidelines to ski resort managers for limiting collision mortality in order to reconcile tourism and wildlife conservation through a shared and constructive vision.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Meile, P. 1981. Skiing facilities in alpine habitat of black grouse and capercaillie. In Proceedings 2nd Intern. Grouse Symp. Lovel, T., Ed. **1981**, pp. 87-92.
[2] Patthey, P; Wirthner, S.; Signorell, N.;Arlettaz R. 2008 –Impact of outdoor winter sports on the abundance of a key indicator species of alpine ecosystems. *J. Appl. Ecol*., **2008**, *45*, 1-8.
[3] Thiel, D; Jenni-Eiermann, S.; Braunisch, V.; Palme, R.; Jenni L. Ski tourism affects habitat use and evokes a physiological stress response in capercaillie Tetrao urogallus : a new methodological approach. *J. Appl. Ecol*., **2008**, *45*, 845 - 853.
[4] Watson, A. Bird and mammal numbers in relation to human impact at ski-lifts on Scottish hills. *J. Appl. Ecol*., **1979**, *16,* 753-764.
[5] Watson, A. Effects of human impact on ptarmigan and red grouse near ski-lifts in Scotland. *Nat. Envir. Research Council. Inst. of Terrestrial Ecol. Ann. Rep.* **1982.** 1981, 51.
[6] Brenot, J. F. ; Catusse M.,; Menoni, E. Effet de la station de ski de fond du plateau de Beille (Ariège) sur une importante population de grand tetras (*Tetrao urogallus*). *Alauda*, **1996**, *64*(2), 249-260.
[7] Menoni, E. ; Defos du Raup, P. Analyse de l'impact de la réhabilitation de la piste "Record", et de l'installation d'une remontée mécanique la desservant, sur le grand tétras, dans le domaine skiable de Superbagnères, en Haute-Garonne. ONCFS: Villeneuve de Rivière. **2005**,14 pp. + annexes.
[8] Miquet, A. Premiers résultats d'une enquête sur la mortalité du Tétras-lyre par percussion dans les câbles. *Bull. mens. ONCFS*, **1990**, *99*, 33 - 35.
[9] Novoa, C. ; Hansen, E. ; Menoni, E. La mortalité de trois espèces de Galliformes par collision dans les câbles. Résultats d'une enquête pyrénéenne. *Bull. mens. ONCFS*, **1990**,*151*, 17 - 22.
[10] OGM Percussion des oiseaux dans les câbles aériens des domaines skiables. *Zoom n°4*, **2006**, 88pp.
[11] Trouvilliez, J.; Meriaux, J.L.; Tombal, J.C. Lignes H.T et T.H.T et percussion d'oiseaux : des solutions testées. *Note technique AMBE / EDF*, **1997**, 4pp.
[12] Magnani, Y. ; Malinverno, J.B. Collisions oiseaux – câbles :un nouveau dispositif pour équiper les câbles de téléskis. *Fiche technique n°83, supplément bull. mens. ONCFS*, **1994**, n°196, 4pp.
[13] Bech, N. ; Boissier, J.; Drovetski, S.; Novoa, C. Population genetic structure of rock ptarmigan in the 'Sky Island' of French Pyrenees: implications for conservation. *Anim. Cons.,* **2009**,*12*,138-146.
[14] Hiltuten, E. On electric and telephone wire accidents in birds. *Sumen Rista*, **1953**, *8*, 70-76.
[15] Rintamaki, P.T. ; Hastad, O.; Odeen, A.; Alatalo, R.V.; Hoglund, J.; Ludberg, A. Sexual selection, colour perception and coloured leg rings in grouse (Tetraonidae). *Avian Science*, **2002**, *2*, 145-152.
[16] Bevanger, K.; Broset, H. Impact of power lines on bird mortality in a subalpine area. *Animal Biodiversity and Conservation*, **2004**, *27*: 67-77.

[17] Baines, D.; Summers, R.W. Assessment of bird collisions with deer fences in Scottish forests. *J. Appl. Ecol*., **1997**, *34*: 941-948.

[18] Baines, D.; Andrew, M. Marking of deer fences to reduce frequency of collisions by woodland grouse. Biol. Conserv., **2003**, *110*: 169-176.

[19] Menoni, E.; Beauvois, A.; Noilhan, J.; Defos du Rau, P. Capercaillie *Tetrao urogallus aquitanicus* population dynamic in the Pyrenees: what is the impact of hunting and of climate change? **2005.** In X° International Symposium on Grouse. Luchon.

[20] Buffet, N. Percussion des oiseaux dans les câbles aériens des domaines skiables. Alpes, mises à jour 2008. Observatoire des Galliformes de Montagne. **2008,** 62 pp.

[21] Dumont-Dayot, E. Percussion des oiseaux dans les câbles aériens des domaines skiables. Pyrénées, mises à jour 2008. Observatoire des Galliformes de Montagne. **2008**, 36 pp.

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CHAPTER 8

Impacts of Outdoor Winter Recreation on Alpine Wildlife and Mitigation Approaches: A Case Study of the Black Grouse

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Abstract: Outdoor winter recreation is exerting an increasing pressure upon alpine biodiversity. There is an urgent need to better understand the detrimental effects on wildlife in order to propose targeted mitigation measures. This chapter summarizes the main results of a still ongoing research about the impacts of outdoor snowsports on black grouse, a regionally declining bird species. Black grouse was chosen as a model species because, in the European Alps, it inhabits exclusively treeline ecosystems, where most outdoor winter activities take place. We investigated the physiological (stress and energetics) and behavioural (activity budget) responses of free-ranging radio-tracked black grouse to human disturbance in winter, while assessing demographic effects. We then modelled areas of conflict between black grouse and winter outdoor recreation, which resulted in spatially-explicit prescriptions for mitigating its impacts. We finally discuss various issues around practical implementation of winter refuges for Alpine black grouse conservation.

Keywords: Black grouse, conflict zones, demography and distribution, mitigation measures, modelling, physiological and behavioural responses, treeline ecosystems, winter refuges.

INTRODUCTION

With a steadily growing world population (another 47% predicted by the year 2070 [1]) and an increase in the average human's standard of living, *i.e.* more financial resources per capita and more time to be devoted to leisure activities, the tourism industry is expected to undergo further tremendous developments in the near future. In spite of the current financial crisis, which is affecting peoples' revenue in several parts of the world, most scenarios still predict a continuous,

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almost exponential increase in recreational activities for the next decades, resulting in a growing pressure on the environment. On the one hand, recreation necessitates infrastructure (housing, transportation networks, *etc.*), which will further encroach on natural and semi-natural habitats, on the other hand people will penetrate deeper into ecosystems which were until now largely void of human presence. A good illustration of the latter is the growing tourist industry in Antarctica.

In the face of these threats to the environment and biodiversity, it is imperative to develop novel conservation approaches to enhance the chances of survival of wildlife occurring in sensitive habitats. Especially at risk are habitats which are not protected by legislation, for instance those situated outside national parks and nature reserves. Here we first need to identify species that would greatly suffer from the spread of recreational activities, based on the assumption that mitigation measures directed towards the most sensitive species will indirectly benefit less sensitive ones as well. Second, the effects of recreation disturbance on these species as well as their tolerance thresholds have to be determined in order to define the most suitable measures to mitigate any detrimental impacts. Third, we need to know what are the species' basic requirements (*e.g.,* minimum area of suitable habitat, among other critical resources) in order to make sure that wildlife refuges created to buffer against recreational disturbance offer the whole palette of ecological needs. Finally, spatially explicit information about both species habitat use and human outdoor-recreation is necessary in order to recognize and anticipate major zones of wildlife-human conflicts so as to place refuges at the most suitable locations within the wide landscape. Although wildlife can habituate to human presence to some extent [2], until the preconditions for habituation are exactly known, conservative approaches based on the precautionary principle are necessary to permit adjustments of wildlife to the growing constraints imposed by recreational activities.

Outdoor snowsports represent one of the most rapidly growing sets of recreational activities. They often take place in naturally fragile habitats, namely boreal and alpine ecosystems, where wildlife has already to cope with the immense challenge imposed by the harsh environmental seasonality: here sedentary organisms have evolved very finely tuned ecophysiological adaptations to survive in winter [3]. The European Alps today represent the first destination for outdoor winter sports in the world [4] and a substantial part of Alpine habitats is already affected by these activities. Not only have ski resorts burgeoned at an extremely rapid pace in the second half of the 20th century, but free-ride sports are currently undergoing a very rapid and massive development [5].

We launched an ambitious research programme in 2002 in southwestern Switzerland, with the aim to better understand and anticipate the conflicts generated by human outdoor recreation to wildlife during winter. To that endeavour we selected one of the most emblematic species of Alpine biodiversity: the black grouse *Tetrao tetrix*. This bird is considered as an ideal model organism because it occurs the year-round exclusively in treeline ecosystems where ski infrastructure concentrates and where most outdoor snowsports, including off-piste free-ride activities, take place [6-8]. It is also a species which has some symbolic cultural value that may attract public awareness and sympathy. In addition to its flagship function, black grouse is hunted in many areas, thus still bearing some economic value [9]. Finally, it probably plays the role of an indicator species of ecosystem integrity, given that it requires a complex habitat mosaic during reproduction [10], while this high habitat heterogeneity certainly promotes Alpine biodiversity as a whole [11].

As the effects of winter outdoor sports activities on black grouse in winter can often not be fully disentangled from factors influencing the species in summer, our project also included a module devoted to the specific niche requirements in summer, with a major focus on breeding hens. The latter because black grouse population dynamics is mainly determined by reproductive success [12], which depends both on weather conditions during the first stages of the chick rearing period [13] and the availability of favorable breeding grounds [14]. The breeding grounds consist of a fine-grained arrangement of grassland, shrubs and trees, and provide a good supply in invertebrate prey for the precocial chicks that need huge quantities of protein-rich food to boost their rapid growth [10, 15, 16]. In the European Alps, this habitat mosaic is typically found along the treeline, located at the interface between the subalpine forest and alpine meadows. This research on species' summer ecology and breeding habitat requirements was also necessary because major land use changes currently affect Alpine ecosystems [17], for instance abandonment of grazing on alpine pastures, which may irremediably lead to shrub and forest encroachment and to the consequential loss of vast areas of suitable breeding habitat. Based on our findings, recommendations have been made to foresters for targeting habitat management measures (P. Patthey, V. Braunisch & R. Arlettaz, unpublished report) which may further enhance the effects of the disturbance-minimizing strategies that result from our findings in winter (see [18]).

By investigating the effects of human disturbance on various aspects of black grouse ecology we developed an integrated research programme; this contrasts with most studies which usually focus on only one among several issues. Moreover, in addition to providing applicable management recommendations, we try in this programme to push towards implementation in order to bridge the gap between research and action typically encountered in conservation biology [19, 20]. The first section describes the scientific evidence gathered so far by the winter research module that investigated, and is still investigating, the effects of human activities on black grouse in winter. First, we studied the impact of outdoor snowsports on physiology (stress ecology and energetics) and behaviour; second, we quantified the demographic consequences of snowsports infrastructure and activities. Based on this, we finally discuss the underlying mechanisms which may affect species demography and individual fitness.

Drawing from the available evidence, the second section provides management recommendations for a better winter coexistence between humans and black grouse. Here we shall see how spatially-explicit models of assessed and predicted conflicts were used for refined planning of visitors steering measures, and briefly discuss the adaptive potential of black grouse to human presence. Finally, we address issues around pragmatic implementation of public steering measures, such as techniques for marking winter wildlife refuges and for having the boundaries of these refuge areas respected by snowsports people.

I. Research on Human-Wildlife Conflicts in Alpine Treeline Habitats

1. Impact of Outdoor Snowsports on the Eco-Physiology and Behaviour of Black Grouse

Although it has been claimed long since that outdoor winter recreation disturbs wildlife in alpine habitats, quantitative assessments of disturbance effects have remained scarce until recently. By measuring the metabolites of corticosterone, the stress hormone of birds, we could quantify, non-invasively and from faeces collected from snow burrows [21], the stress response elicited by human disturbance upon black grouse in the Swiss Alps. Working in both comparative (measure of chronic stress response) and experimental (acute stress response) frameworks, we could show first that black grouse living in natural, not or little disturbed treeline habitats have a significantly lower general concentration of faecal corticosterone metabolites than individuals occurring either in highly disturbed (ski resort areas) or moderately disturbed habitats (places outside ski resorts with backcountry skiing, snowboarding and showshoeing) (Fig. (**1**), [22]). The fact that the latter two categories did not differ statistically between each other suggests that even moderate levels of disturbance, such as that caused by off-piste activities, are enough to elicit a chronic stress response in the birds. This actually has direct implications for conservation: refuges with almost no disturbance must exist in the landscape if we want to avoid any negative effects of human disturbance on the birds' physiological state.

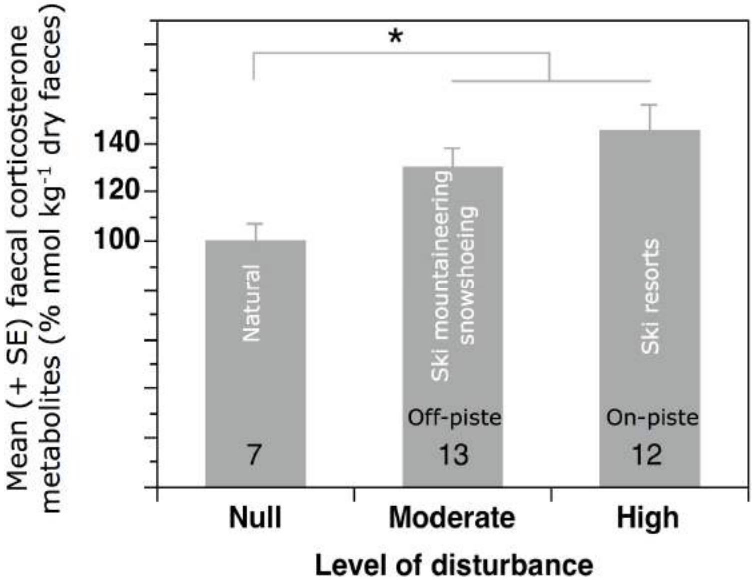

Figure 1: Concentration of corticosterone metabolites, as retrieved from faeces collected from snow burrows, with respect to levels of disturbance by outdoor winter recreation (null and limited disturbance: natural habitats; moderate disturbance: off-piste activities such as backcountry skiing and snowboarding, as well as snowshoeing; high disturbance: on-piste activities such as skiing and snowboarding stemming from skilifts). Since birds were not flushed for collecting the droppings, this approach quantified differences in the birds' corticosterone basal level, *i.e.* measured the chronic stress faced by birds in different contexts (adapted from [22]).

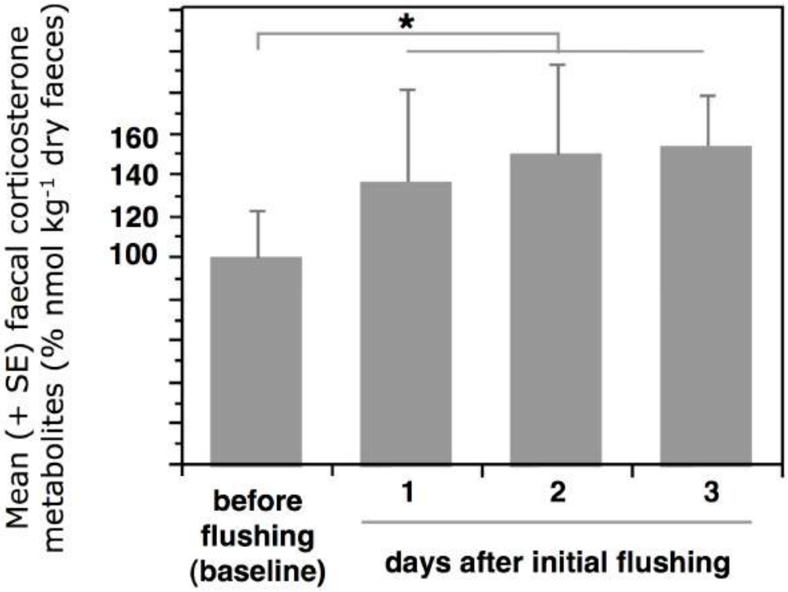

Figure 2: Concentration of corticosterone metabolites as retrieved from faeces collected from snow burrows of black grouse cocks flushed experimentally over a period of 4 days. Birds were equipped with a radio-transmitter, which enabled localization and targeted flushing. The initial baseline concentration of corticosterone metabolites corresponded to the material collected at the first flushing event, the droppings having been deposited in the snow burrows before any disturbance by humans. This experiment enabled us to estimate the acute stress response of the birds (adapted from [22]).

We then conducted disturbance experiments with cocks that were repeatedly flushed in order to measure acute stress response. The birds were equipped with radiotransmitters, which enabled us to locate them and their snow burrows where we targetedly collected the faeces left behind. The material collected at the first flushing attempt served as a control of individual basal stress hormone level. Birds responded to daily disturbance with increasing concentrations of faecal corticosterone metabolites, showing a rapid increase at the beginning and a leveling off of the concentration at the end of the experimental sequence (Fig. (**2**), [22]). This demonstrates the existence of an acute stress response to anthropogenic disturbance.

It remains difficult, however, to understand the interplay between both chronic and acute stress and their effects on birds' fitness since we could not capture and measure the birds repeatedly; they were manipulated only at the initial capture event when they were marked with a radiocollar. Due to the difficult terrain it would be difficult to improve on this as regards the Alpine black grouse. Nevertheless, using the radio-collared birds, we could show behavioral responses that indicate negative effects of disturbance on the birds' energy budget: first, there was an apparent increase in foraging bout duration in the day following flushing (Arlettaz *et al.* in prep.); second, human disturbance provoked extra energy expenditures because the birds could no longer benefit from the thermal buffer of the igloo for a while after flushing; at least this applied when snow conditions rendered borrowing possible (Arlettaz *et al.* in prep.).

2. Consequences of Outdoor Winter Recreation for Demography and Distribution

One of the main limitations while working with scattered and elusive birds like black grouse is the challenge of collecting data about their health status and reproductive ability. This problem is exacerbated in black grouse because they are difficult to capture, which complicates measures of physiological state, reproductive ability and other fitness consequences of anthropogenic disturbance. Moreover we had to work almost exclusively with cocks because they were easier to capture than females: most cocks were mist-netted on leks while displaying.

To overcome these logistic obstacles, we had again to rely on a comparative framework, testing whether local black grouse presence and abundance correlate negatively with the intensity of human use of the landscape in the winter time. Indeed, we found that suitable wintering grounds – as identified by a habitat suitability model – were less frequently used or even abandoned by black grouse in the presence of snowsports, with ski-resorts and the associated ski-tourism having a stronger impact than off-piste activities. However the latter were more widespread, thus affecting a larger area [23]. In addition we could show that the density of black grouse cocks displaying in spring was much lower within and close to ski resorts and peaked in natural, less disturbed habitats (Fig. (**3**), [24]). Currently, we are analysing our radiotracking data to estimate survival rates of birds within and outside ski resorts; this long term individual-based approach will be complementary to the comparative assessments of bird abundance described above and possibly provide more hints about the mechanisms at play in the observed demographic response of black grouse to the encroachment of human recreational activities.

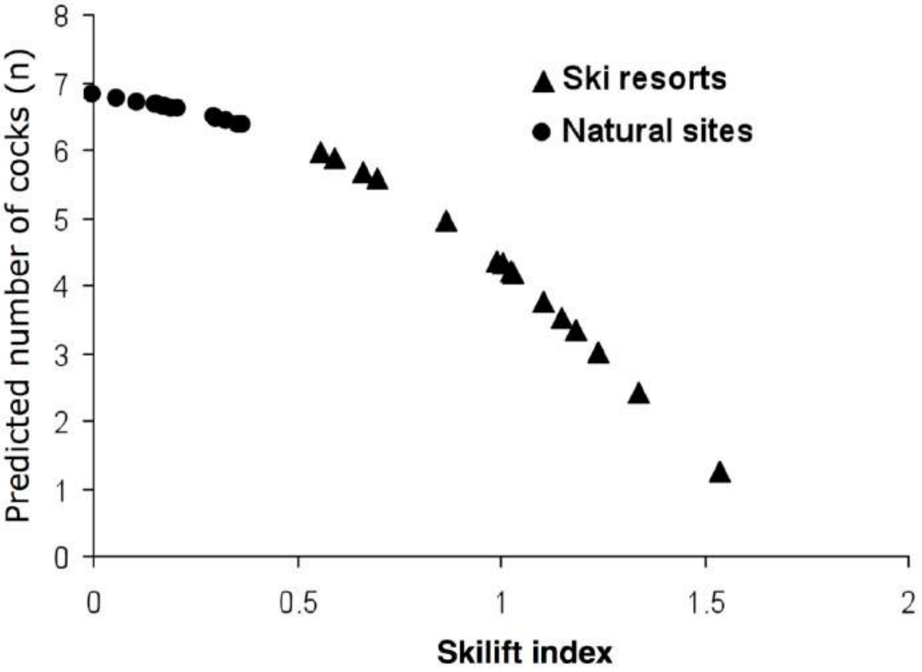

Figure 3: Predicted number of cocks displaying along 1.5 km treeline transects in relation to skilifts occurrence (the compound «skilift index» considers density of skilifts and distance to them). Covariates such as habitat type as well as hunting pressure have been accounted for in the modeling, with the figure representing a projection of the sole effect of skilifts on cocks abundance. In the study area, 44% of black grouse potential wintering area is affected by ski infrastructure and associated recreational activities (Adapted from [24]).

3. Inferring Underlying Mechanisms

Our current results indicate lower population densities within and near ski resorts, compared to areas with intermediate disturbance caused by free-ride activities and more natural areas with no or very little anthropogenic disturbance [23, 24]. The precise mechanism leading to this spatial pattern still remains to be unraveled. There are indeed two possible pathways. First, recreation may weaken birds directly due to frequent disturbance: for instance the costs entailed in chronic or acute stress, or the energetically costly behavioral changes like repeated flushing may translate into increased mortality or breeding failure. Second, the effects could be indirect, for instance mediated through an increased predation rate on nests, young or adults in ski resorts compared to areas less frequented by humans, as observed in the ptarmigan [25]. It has been demonstrated, for instance, that red fox densities tend to be higher close to ski resorts [26], which may thus increase the predation pressure on the birds. We are presently investigating this aspect in the Swiss Alps (G. Wittwer, P. Patthey & R. Arlettaz, unpublished). Both factors are of course not mutually exclusive and effects may even be additive. To get further insight, we are currently analysing the information collected from all black grouse captured so far to see whether individual's condition varies between habitats with different intensities of anthropogenic disturbance. To that endeavour we shall use both information about body condition as well as data on prevalence and intensity of parasites in faeces (M. Lingg, P. Patthey & R. Arlettaz, unpublished data). Combined with data on individuals' survival (estimated with a capture-mark-recapture framework based on radiotracking surveys), this information may enable us to better appraise the mechanism leading to reduced black grouse population densities in highly disturbed areas.

II. Drawing on Solutions for Human-Wildlife Cohabitation

1. Localizing Conflict Zones

Once the negative effects of disturbance of wildlife by outdoor winter sports were assessed, the task remained to find ways to mitigate these effects. The first decisive step for an effective implementation of such measures was the spatially explicit identification and quantification of human-wildlife interference. To that aim, we built a spatially-explicit habitat suitability model predicting areas of human-wildlife conflict in the western Swiss Alps, with the idea to recommend the creation of winter refuges in the areas with major actual and potential conflicts [23]. Our approach considered three «actors», modelled independently: black grouse, skiers (both on-piste skiing and off-piste backcountry skiing, including snowboarding), and snowshoers.

Based on photographs taken from a plane some days after a heavy snowfall and an intense snow-sports activity, the tracks of our three «actors» (footsteps and snow burrows of black grouse, tracks of skiers and snowshoers) were mapped along an extensive, several hundred km long treeline transect (Fig. (**4**)), (the

Figure 4: Upper panel: illustration of the magnitude of the disturbance elicited by skiers and snowboarders a few days after a snow fall; one major problem is that every skier wants to make their own track in powder snow, thus rapidly covering huge areas with ski tracks. Lower panel: aerial photograph of the treeline used to map the winter occurrence of black grouse (tracks in snow and igloos, the latter not visible on this picture), skiers (including snowboarders) and snowshoers (yellow dots). Spatially-explicit habitat suitability models have been built for these three «actors» to delineate major areas of conflict between black grouse and outdoor winter recreation, the conflict being defined as the probability of co-occurrence of these «actors» in the wide landscape (photography by S. Mettaz). The insert shows the 585 km long treeline photographic (plane) transect line across the area (adapted from [23]).

method is described in detail in [23]). For each «actor» we constructed a model predicting the probability of presence in dependence on the prevailing landscape conditions, which was then extrapolated to the whole altitudinal belt of potential black grouse occurrence in winter. By crossing the three «actors» layers we could finally quantify the probability of human-wildlife co-occurrence, thereby not only localizing regions with current conflicts but also predicting where conflicts could be expected in the near future given the ongoing and projected spreading free-ride activities (Fig. (**5**), [23]). Based on that analysis, we identified 31 critical conflict zones across the Canton of Valais, our main study area, where winter refuges shall be created in priority (Fig. (**6**)).

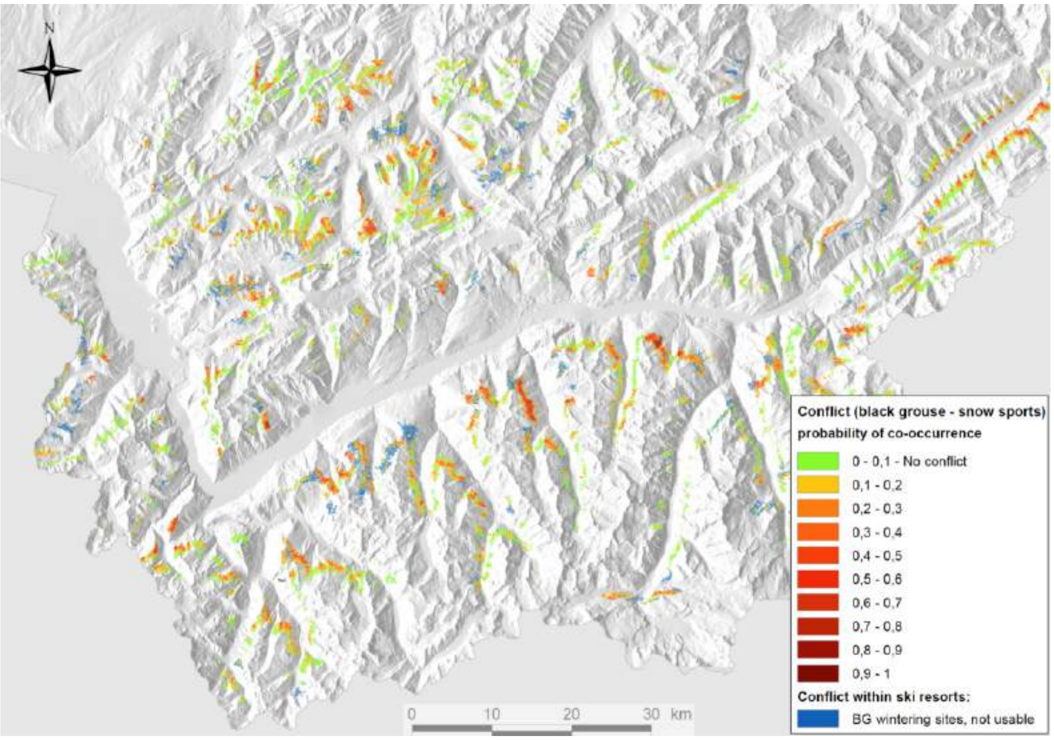

Figure 5: Map of Valais (SW Switzerland) showing the predicted intensity of conflicts between black grouse and outdoor winter recreation. Green: area with no or limited conflict, yellow: low conflict; red: intense conflict; purple: too heavy conflict, *i.e.* skilift area (Adapted from [23]).

2. Planning and Designation of Wildlife Refuges

The creation of wildlife refuges, which aim at limiting human access to key habitats of vulnerable species, has proven to be an effective tool to mitigate effects of human disturbance [27, 28]. In black grouse, experiments with winter preserves have been successfully attempted by Albin Zeitler [7, 8, 29] in the Bavarian Alps, Germany, based on long-term behavioural observations indicating that black grouse can learn to use the quiet winter refuges if their boundaries are not too often trespassed by snowsports people, providing in addition that hunting is banned in the surroundings [29]. Such apparent peaceful coexistence might further be enhanced when temporal segregation of human and wildlife activities naturally takes place, *i.e.* when the time windows of sportspeople and foraging wildlife overlap very little, which is the case within ski resorts because sportspeople become active rather late in the morning and leave pistes in the late afternoon [29]. Things are a bit different in backcountry skiing areas because alpinists set off to excursions very early in the morning (A. Zeitler, pers. comm.).

An illustration of a beneficial interaction of both spatial and temporal separation of activities is given by the ski resort Fellhorn in the Allgäu, Bavaria, Germany, where Albin Zeitler conducted his experiments. Here, black grouse males sometimes even use the restaurant terrace in spring as a lekking arena, where they have enough time to display at dawn for a couple of hours, just before the first skiers arrive (Fig. (**7a, b**)). During the day, as long as the ski-lifts operate, the birds retreat to a ca 60 ha large winter refuge which is located next to the ski pistes. They eventually return to the skiing area for feeding after the lifts close in the late afternoon. This example suggests a great potential for habituation, if not adaptation of black grouse to human presence, as long as spatial and temporal patterns of human land use are constant and predictable ([29], A. Zeitler, pers. comm.). In this context it seems to be important, in addition, that winter refuges are combined with game reserves (hunting totally banned) so that the birds do not associate humans with predators (hunters) anymore [29]; see also [30, 31] as regards capercaillie.

According to our knowledge, gathered from radiotracking data about individuals home ranges in winter and the distance up to which human presence is tolerated (flushing distance), the size of a winter refuge for black grouse should be ca 40 ha, an area which includes a 120 m broad buffer zone corresponding to the 95% upper confidence interval of the mean observed flushing distance in females, the sex most sensitive to human disturbance (Schranz, P. Patthey & R. Arlettaz, unpublished data).

Our recommendations regarding location, size and management of winter refuges have been addressed to the cantonal administration (Valais services for Hunting, Fisheries & Widlife, and Forestry & Landscape) in 2010, in order to launch a top-down implementation procedure. In close collaboration with the cantonal game-keepers of Valais, we are currently cross-evaluating our predictions based on local observations of black grouse occurrence in order to place the refuges in the most suitable locations within the conflict zones obtained from the model, some of them being huge (Fig. (**6**)). In parallel, the Valais Field Station of the Swiss Ornithological Institute is going to approach the local stakeholders (skilift companies, local communities, *etc.*) to develop a complementary bottom-up approach and make sure our recommendations will be implemented.

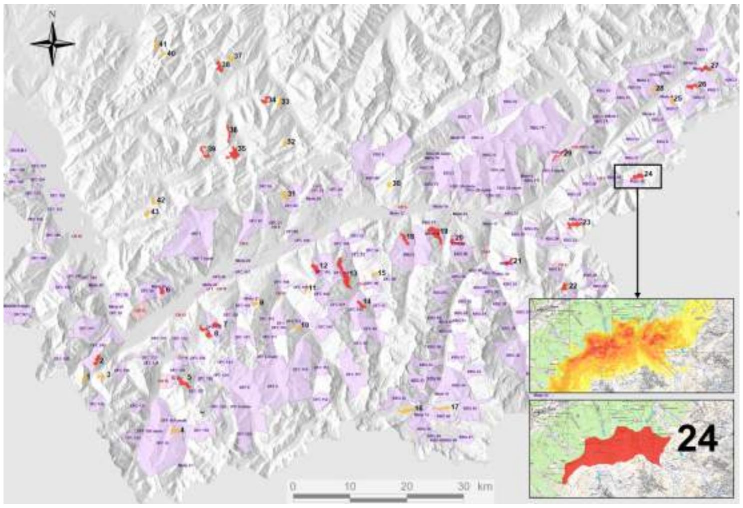

Figure 6: Map of Valais (SW Switzerland) showing a delineation of 31 principal areas with very intense conflict (red, fist priority winter refuge) and less intense conflict (orange, second priority refuge). Delineated zones correspond to homogeneous areas larger than 40 ha of uninterrupted habitat where the probability of co-occurrence of black grouse and outdoor winter recreation was greater than 40%. On the right, example of delineation of the winter refuge number 24, showing how the conflict intensity map was converted into a refuge patch. Purple patches depict game reserves: about half of our refuges are already included within such hunting reserves.

3. Concrete in Situ Mitigation Measures

Once the designation process is completed, the task is to advertise and indicate the refuges to the public. Again, the experience gathered, among others, by Albin Zeitler in the Bavarian Alps shows that appropriate marking of the designated sites is the first important issue, which requests a local appraisal of the conditions and of course good connections with the people that will be in charge of the marking in the long run. The presence of a winter refuge should be advertised much ahead of its boundaries, for instance in hiking and backcountry skiing maps, at the main parkings and at the skilift stations (A. Zeitler, pers. comm.). In complicated topographic situations, signs must even be posted along main mountain ridges situated above the refuge in order to avoid downhill skiers to engage on a slope which will automatically lead them to the protected area, with no way to avoid its perimeter (A. Zeitler, pers. comm.).

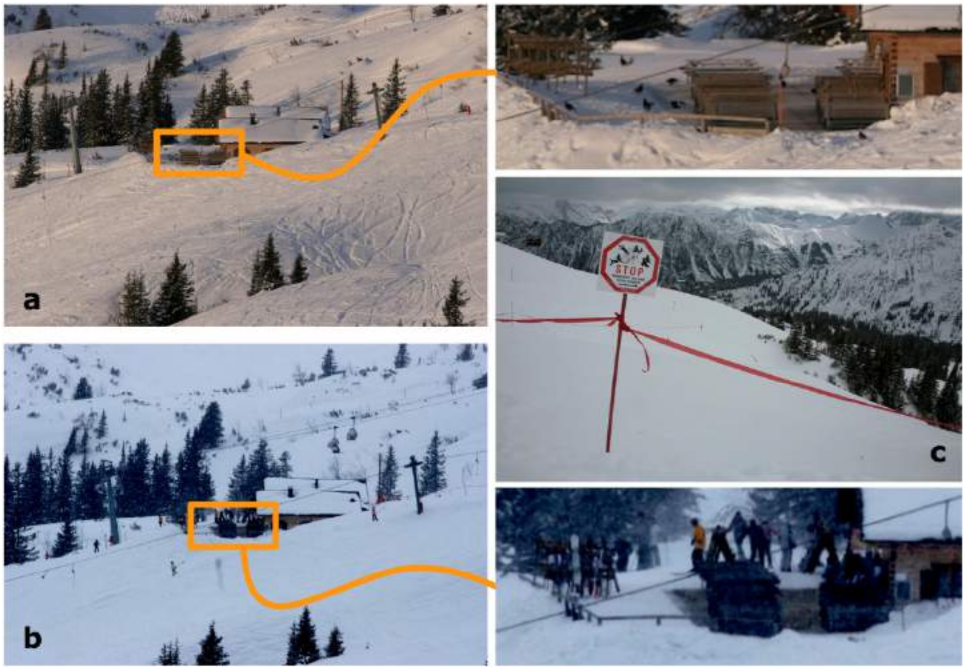

Figure 7: Black grouse can habituate to human presence even within intensively used ski resorts as illustrated here for Fellhorn, Southern Bavaria, Germany; a) 12 cocks display on the terrace of a restaurant, which is used as a lekking ground, at 6h30 am; b) 9h am: dozens of skiers use the terrace, while the black grouse have retreated into a nearby winter refuge which is well signed; c) signing the winter refuge is essential for having the skiers not trespassing its boundaries, but is still not sufficient to guarantee that the perimeter is respected.

The very perimeter of the refuge should also be indicated clearly to all users (Fig. (**7c**)). In Central Europe, the initiative «RespekTiere deine Grenzen» («Respecter c'est protéger»), launched in Austria and Switzerland, is developing transnational concepts for marking and advertising wildlife refuges in a consistent way in order to ease the identification of these areas by tourists (http://www.respektiere-deine-grenzen.ch).

The final decisive question, however, is how to make sure that these winter refuges are truly respected by people practicing winter sports. Information and education is of course the first prerequisite. We imagine both traditional information media (signs, leaflets, brochures) but also target-group specific education in collaboration with schools, sport organizations, tour or nature guides. Yet, given that information will never reach and/or convince the minor, but crucial proportion of ignorant persons, a policy including controls and fines may be necessary. Within and near ski resorts, this requests regular checks by the people in charge of managing the pistes. Outside ski resorts, the job could be done by game keepers employed by the regional administration. Generally, however, one should avoid resorting too often to a policy of sanctions that may erode public acceptance in the long run. Assessments of visitor behaviour [32] and inquiries inquiries of sportspeople and stake-holders, recognizing their preferences and needs, may assist in implementing the best strategies for rendering the visitor management concepts attractive, and encouraging the public to respect the refuges. Optimally, this aspect should be an integrative part of any planning programme.

CONCLUSIONS AND OUTLOOK

As illustrated here by the situation of the black grouse in the European Alps, outdoor winter recreation can significantly impact the physiology, behaviour and demography of wildlife. Conservation biologists thus need to provide targeted, evidence-based solutions to mitigate these effects through the designation of spatially and temporally optimised wildlife refuges, as successfully attempted in some areas of the Alps, at the example of the Bavarian Alps ([29], A. Zeitler, pers. comm.). Yet, to even better anticipate the effects of future tourism developments and to further refine conservation strategies, it will now be crucial to link the observed disturbance effects (stress and behavioural responses, population decline) to measurements of quantitative fitness costs. This would enable the identification of the demographic mechanisms at play. The example given above for Bavaria suggests that wildlife can habituate if not adapt to human presence once direct confrontation to sportspeople is avoidable [29]. The recognition of the specific environmental and species-specific preconditions for habituation and adaptation will be a further essential element to increase – *e.g.,* by a set of finely adjusted measures - the tolerance of wildlife towards human presence. If such measures could be adopted all over the Alps, the future of black grouse in winter recreation areas could be brighter than currently believed: to some extent, successful human wildlife coexistence may be mostly a question of fine tuning of spatio-temporal land use by humans and wildlife as demonstrated for the Bavarian black grouse [29]. Finally, we are confident that the creation of winter refuges, once enforced on wide areas, would deliver beneficial outcomes for the preservation not only of black grouse but also of other related Alpine wildlife threatened by the rapid expansion of outdoor snow sports.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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REFERENCES

[1] Caselli, G.; Vallin, J.; Wunsch, G. *Demography: analysis and synthesis: a treatise in Population, volumes 1-4*; Academic Press: Burlington, Massachusetts, **2006**.

[2] Miller, S.G.; Knight, R.L.; Miller, C.K. Wildlife responses to pedestrians and dogs. *Wildl. Soc. Bull.,* **2001**, *29*, 124-132.

[3] Marchand, P.J. *Life in the Cold,* 3rd ed.; University Press of New England: Hanover, **1996**.

[4] Elsasser, H.; Messerli, P. The vulnerability of the snow industry in the Swiss Alps. *Mt. Res. Dev.,* **2001**, *21*, 335-339.

[5] Ingold, P. *Freizeitaktivitäten im Lebensraum der Alpentiere*; Haupt: Bern, **2005**.

[6] Menoni, E.; Magnani, Y. Human disturbance of grouse in France. *Grouse News,* **1998**, *15*, 4-8.

[7] Zeitler, A.; Glanzer, U. Skiing and grouse in the Bavarian Alps. *Grouse News,* **1998**, *15*, 8-12.

[8] Zeitler, A. Human disturbance, behaviour and spatial distribution of Black Grouse in skiing areas in the Bavarian Alps. *Cah. Ethol.,* **2000**, *20*, 381-402.

[9] Storch, I. Conservation status of grouse worldwide: an update. *Wildl. Biol.,* **2007**, *13*, 5-12.

[10] Signorell, N.; Wirthner, S.; Patthey, P.; Schranz, R.; Rotelli, L.; Arlettaz, R. Concealment from predators drives foraging habitat selection in brood-rearing Alpine black grouse *Tetrao tetrix* hens: habitat management implications. *Wildl. Biol.,* **2010**, *16*, 249-257.

[11] Camarero, J.J.; Gutiérrez, E. Plant species distribution across two contrasting treeline ecotones in the Spanish Pyrenees. *Plant Ecol.,* **2002**, *162*, 247-257.

[12] Klaus, S.; Bergmann, H.H.; Marti, C.; Müller, F.; Vitovic, O.A.; Wiesner, J. *Die Birkhühner*. A. Ziemsen Verlag: Wittenberg Lutherstadt, **1990**.

[13] Zbinden, N.; Salvioni, M. Bedeutung der Temperatur in der frühen Aufzuchtzeit für den Fortpflanzungserfolg des Birkhuhns *Tetrao tetrix* auf verschiedenen Höhenstufen im Tessin, Südschweiz. *Ornithol. Beob.,* **2004**, *101*, 307-318.

[14] Ludwig, G.X.; Alatalo, R.V.; Helle, P.; Nissinen, K.; Siitari, H. Large-scale drainage and breeding success in boreal forest grouse. *J. Appl. Ecol.,* **2008**, *45*, 325-333.

[15] Baines, D. Factors contributing to local and regional variation in Black Grouse breeding success in northern Britain. *Ornis Scand.,* **1991**, *22***,** 264-269.

[16] Baines, D. Black grouse: the effects of predator control and vegetation cover. In: *The Game Conservancy review of 1991*; Wrigley, A., Ed.; The Game Conservancy: Fordingbridge, **1992**, pp. 98-100.

[17] Maurer, K.; Weyand, A.; Fischer, M.; Stöcklin, J. Old cultural traditions, in addition to land use and topography, are shaping plant diversity of grasslands in the Alps. *Biol. Conserv.,* **2006**, *130*, 438-446.

[18] Zeitler, A. Maintaining Black Grouse wintering habitats by Alpine pasture management plans. *Sylvia,* **2003**, *39*, 97-102.

[19] Arlettaz, R.; Schaub, M.; Fournier, J.; Reichlin, T.S.; Sierro, A.; Watson, J.; Braunisch, V. From publications to public actions: when conservation biologists bridge the gap between research and implementation. *BioSci.,* **2010**, *60*, 835-842.

[20] Arlettaz, R.; Mathevet, R. Biodiversity conservation: from research to action. *Nat. Sci. Soc.,* **2010**, *18*, 452-458.

[21] Baltic, M.; Jenni-Eiermann, S.; Arlettaz, R.; Palme, R. A Noninvasive Technique to Evaluate Human-Generated Stress in the Black Grouse. *Ann. N. Y. Acad. Sci.,* **2005**, *1046***,** 81-95.

[22] Arlettaz, R.; Patthey, P.; Baltic, M.; Leu, T.; Schaub, M.; Palme, R.; Jenni-Eiermann, S. Spreading free-riding snow sports represent a novel serious threat for wildlife. *Proc. R. Soc., Ser. B,* **2007**, *274*, 1219-1224.

[23] Braunisch, V.; Patthey, P.; Arlettaz, R. Spatially explicit modeling of conflict zones between wildlife and snow-sports: prioritizing areas for winter refuges. *Ecol. Appl.,* **2011**, *21,* 955-967.

[24] Patthey, P.; Wirthner, S.; Signorell, N.; Arlettaz, R. Impact of outdoor winter sports on the abundance of a key indicator species of alpine ecosystems. *J. Appl. Ecol.,* **2008**, *45*, 1704-1711.

[25] Watson, A.; Moss, R. Impacts of ski-development on ptarmigan (*Lagopus mutus*) at Cairn Gorm, Scotland. *Biol. Conserv.,* **2004**, *116*, 267-275.

[26] Storch, I.; Leidenberger, C. Tourism, mountain huts and distribution of corvids in the Bavarian Alps, Germany. *Wildl. Biol.,* **2003**, *9*, 301-308.

[27] Knight, R.L.; Temple, S.A. Wildlife and recreationists: coexistence through management. In: *Wildlife and recreationists: coexistence through management and research*; Knight, R.L., Gutzwiller, K.J., Eds.; Island Press: Washington, DC, USA, **1995**; pp. 327-333.

[28] Whitfield, D.P.; Ruddock, M.; Bullman, R. Expert opinion as a tool for quantifying bird tolerance to human disturbance. *Biol. Conserv.,* **2008**, *141*, 2708-2717.

[29] Zeitler, A. Habituation of black grouse to humans in the Bavarian Alps? In: *Proceedings of the XIth International Grouse Symposium, 11.-15.09.2008, Whitehorse, Yukon Territory, Canada*, **2008**; p 60.

[30] Thiel, D.; Menoni, E.; Brenot, J.F.; Jenni, L. Effects of recreation and hunting on flushing distance of capercaillie. *J. Wildl. Manag.,* **2007**, *71*, 1784-1792.

[31] Thiel, D.; Jenni-Eiermann, S.; Braunisch, V.; Palme, R.; Jenni, L. Ski tourism affects habitat use and evokes a physiological stress response in capercaillie *Tetrao urogallus*: a new methodological approach. *J. Appl. Ecol.,* **2008**, *45*, 845-853.

[32] Coppes, J., Braunisch, V.: Managing visitors in nature areas: Where do they leave the trail? A spatial model. Wildlife Biology (in press)

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CHAPTER 9

Ski Run Re-Vegetation: A Never-Ending Story of Trial and Error?

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Abstract: The efforts in high-altitude restoration on ski runs have changed considerably since the demands for sustainable erosion control arose in the 1970ies. In this study we compare the success of restoration measures dating from the beginnings of high-altitude restoration with that of modern techniques. Vegetation and ecological data suggest that formerly used seed mixtures were less effective for re-vegetation of ski runs than modern seed mixtures, which contain site-specific and regional plant species. The vegetative and generative traits of the site-specific plant species proved to be important for erosion control.

Keywords: Erosion control, high-altitude restoration, re-vegetation, seed mixture, site-specific, ski runs, plant selection, growth forms, ecological restoration, immigrating species, diaspore community, soil seed bank, spray irrigation experiment, water runoff, non site specific plants.

INTRODUCTION

Skiing, the construction of ski runs and restoration efforts have a long tradition in the Austrian Alps. But even nowadays, measures to restore a functional plant cover on ski runs are not always successful. Many environmental, technical, and economic factors need to be taken into account for successful re-vegetation.

The subalpine and lower alpine regions of the Alps have a century-long history of multiple forms of land use. Most of the ski runs are located on land that is also used as summer pastures. Hence, often compromises between summer and winter

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Christian Rixen and Antonio Rolando (Eds)

uses on ski runs need to be found [1]. For instance, it is important that sufficient biomass and fodder of good quality is provided in areas that experience disturbance on ski runs [2]. Another important requirement is that the danger of erosion is minimized by either of the land uses.

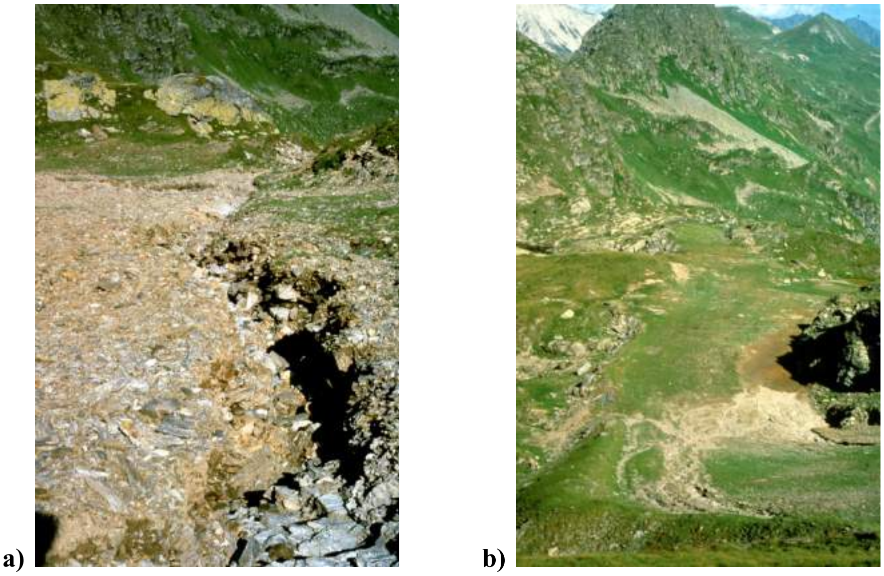

Figure 1: a) Canyon of 1.8 m depth, created by hard rain within 1 day, on a graded ski run with a badly adapted seed mixture; 2080 m altitude, Niedere Tauern, Austria (1987); **b)** Sedimentation of eroded material on the foot of the slope.

Figure 2: Species-rich ski run created in 1969 along a traditional pasture with minor terrain corrections; altitude 1500 m, Stubai Alps, Austria (2007).

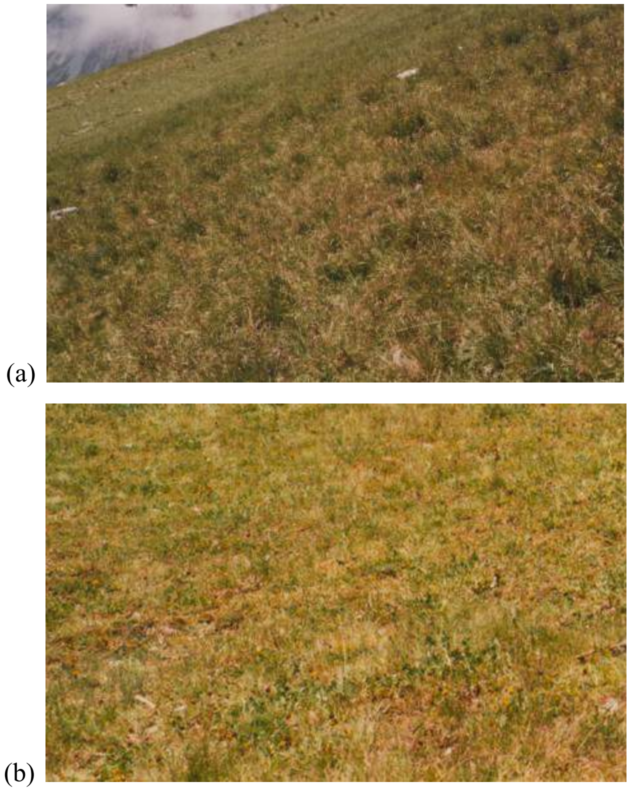

Figure 3: Natural vegetation (a) and 5 yr-old ski run re-vegetation (b), after extensive sheep grazing; altitude 2280 m, Arlberg, Austria (2005).

A wide range of factors can influence the outcome of re-vegetation efforts as is illustrated *e.g.,* by Figs. **(1)**-(**3)**; they all show ski runs from different ski areas in the Austrian Alps, thus for instance reflecting:

- Geographical and geo(morpho)logical differences (from the Central to the Northern Calcareous Alps, from siliceous to mixed and calcareous bedrock);
- Differences in the time of construction (from 1969 to 2000);
- Different altitudes (1500 - 2100 - 2300 m above sea level);
- Different methods of construction and seeding applied on the respective ski runs.

THE BEGINNINGS OF RESTORATION MEASURES ON SKI RUNS

When skiing had begun to become a mass phenomenon in the 1960s, first warnings were issued that ski runs could have negative impacts on the vegetation of pasture land [3, 4]. Klötzli and Schiechtl called graded ski runs “dead aisles through the Alps” [5]. In the 1980s, many authors pointed out the vegetation changes especially on machine-graded ski runs and asked for utmost caution in construction and seeding as well as maintenance [6-15].

It was only possible to create a dense and long-lasting plant cover consisting of commercially available meadow and pasture plants under most favourable conditions, *i.e.* at altitudes below 1900 – 2000m, and with high amounts of organic fertilizers. Fertilizing was necessary to raise the content of organic matter in the mineral soils after grading. Vegetation ecologists [16-24] and eco-engineers [25-28] pointed out the deficits of the applied restoration measures and showed which plant species of the regional flora could be promising as future seed plants. Ski lift managers and ecologists tried to find and develop more careful and considerate restoration methods than grading and repeated seeding combined with fertilization [29, 30].

But still in the new millennium, impacts of skiing on vegetation are evident, especially on machine-graded ski runs [31, 32]. Additional hazards by the marked climatic shift in the Alps (rising temperatures and evident changes in amount and time of precipitation) may further increase the pressure on ski areas and ski run vegetation. For Austrian ski areas threatened by rising average temperatures, strategies are being developed to save the principle income source of whole regions and to implement sustainable tourism [33].

In the mid-1980s, we performed a series of more than 200 phyto-sociological relevés [34] and above-ground phytomass harvests on ski runs and in the adjacent vegetation in the Niedere Tauern range [22, 24].

At that time, well adapted seed species were not available, and obligatory guidelines for ski run construction did not exist. Our phyto-sociological research comprised almost all variables at the location: Elevations between 1770 and 2200 m a.s.l., different soils and bedrock, almost all aspects from S to NE, and above all the application of all methods of ski run construction, seeding, and fertilizing that were in use at that time. The results confirmed not only the ideal adaptation of the natural and the semi-natural (pasture) communities to their sites, but showed how much the ski run vegetation differed from the former in species composition, percentage cover and biomass production (Fig. (**4**)).

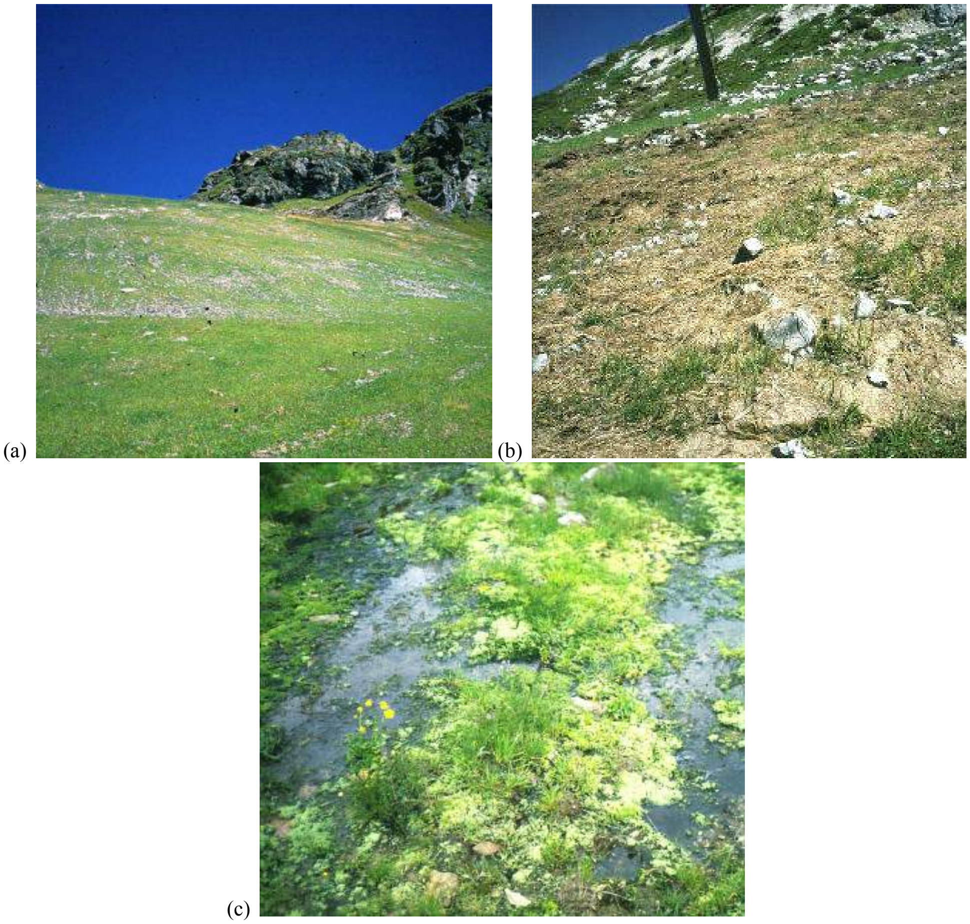

Figure 4: Ski run construction in the 1980s: Hydro seeding (a) or hand seeding with a subsequent straw cover (b) was state of the art. But machine grading and non site-specific seed mixtures provoked erosion and a substantial change in species composition by the changed snow, water, and nutrient regime (c).

Two examples illustrate that formerly greened ski runs may hardly have any species in common with the respective surrounding plant community (Table **1**).

Both areas are located on siliceous bedrock, but differ in altitude, inclination, seed mixture and disturbance intensity during construction. On both ski runs a group of "immigrants" was noted. This group consisted of species found more abundantly on the ski runs than in the natural adjacent vegetation, in this case especially *Poa alpina, Sagina saginoides* or *Cerastium cerastoides*. The right-hand half of the table represents one vegetation relevé on a graded ski run at an altitude above 2000 m and one in the adjacent Curvulo-Nardetum with cover values estimated from + to 5 according to the Braun-Blanquet scale [34]. Except for the snow-bed species *Gnaphalium supinum*, no species occurred in both relevés. "Seed" species here comprise only *Festuca rubra s.l.*, *Phleum pratense, Trifolium repens* and *Agrostis tenuis* (=*capillaris*).

Table 1: Species Cover on Ski Runs and in Adjacent Semi-Natural Vegetation; Niedere Tauern 1986. Values Show Braun-Blanquet Scales [34]. SR = Ski Run; NV = Adjacent Natural Vegetation (Modified from Klug-Pümpel [22])

Subalpine Ski Run (<2000 m a.s.l.) in Dwarf Shrub Vegetation			**Alpine Ski Run (2100 m a.s.l.) in Grass Heath (Curvulo-Nardetum)**		
Species	**SR**	**NV**	**Species**	**SR**	**NV**
SEEDED			SEEDED		
Festuca rubra agg.	2	1	*Festuca rubra* agg.	2	
Trifolium repens	2		*Phleum pratense*	+	
Achillea millefolium agg.	2		*Trifolium repens*	+	
Dactylis glomerata	1		*Agrostis capillaris*		
Lotus corniculatus	+				
Trifolium pratense	+				
Leucanthemum vulgare agg.	+				
Phleum pratense	+				
Festuca ovina agg.	+				
IMMIGRATED			IMMIGRATED		
Poa alpina	1		*Poa alpina*	2	
Deschampsia cespitosa	1		*Sagina saginoides*	+	
Sagina saginoides	+		*Cerastium cerastoides*	+	
Euphrasia spec.	+		*Epilobium anagallidifolium*	+	
Festuca picturata	+		*Cardamine resedifolia*	+	
Avenella flexuosa	+	1	*Taraxacum officinale*	+	

Table 1: contd....

Potentilla erecta	+	1	*Poa annua*	+	
			Gnaphalium suoinum	+	+
ADJACENT ONLY			ADJACENT ONLY		
Rhododendron ferru.		3	*Nardus stricta*		3
Vaccinium myrtillus		3	*Carex curvula*		2
Luzula sylvatica		2	*Leontodon helveticus*		2
Vaccinium gaultherioides		1	*Avenula versicolor*		1
Juniperus communis ssp. *nana*		1	*Homogyne alpina*		1
Anthoxanthum alpinum		1	*Potentilla aurea*		1
Solidago virgaurea ssp. *minuta*		1	*Vaccinium myrtillus*		1
Blechnum spicant		1	*Anthoxanthum alpinum*		1
Geum montanum		+	*Polytrichum sexangulare*		1
Homogyne alpina		+	*Soldanella pusilla*		1
Nardus stricta		+	*Leucanthemopsis alpina*		+
Agrostis capillaris		+	*Geum montanum*		+
Campanula scheuchzeri		+	*Gentiana kochiana*		+
Arnica montana		+	*Juncus trifidus*		+
Vaccinium vitis-idaea		+	*Primula minima*		+
Calluna vulgaris		+	*Phyteuma hemisphaericum*		+
Melampyrum pratense		+	*Agrostis rupestris*		+
Viola biflora		+	*Vaccinium gaultherioides*		+
Hypericum maculatum		+	*Rhododendron ferrugineum*		+
			Cetraria spp.		+

In the other example (left), a ski run below 2000 m, 9 seeded species could be noted. Three species (of which *Festuca rubra s. l.* had been seeded, the other two immigrated) were in common with the surrounding dwarf shrub heath. Although the vegetation on this ski run was comparably dense despite the graded, stony surface, it was highly different from the adjacent Rhododendro-Vaccinietum: Dwarf shrubs were almost completely absent, and the light green colour of the fertilized ski run cover made the structural difference visible even from far away. Of course the absence of dwarf shrubs was intended, as they make ski run preparation more difficult. But the removal of the complete litter and organic soil layer as well as repeated fertilizing created unnatural conditions. Hence, species numbers, percentage cover of vascular plants and biomass differed considerably between ski runs and natural vegetation (Table **2**).

Below 2000 m, live and dead plant mass in the semi-natural vegetation amounted to more than 800 g per m²; the ski runs nearby – regardless of age, construction methods and maintenance - had less than half of that (Table **2**). The sparse natural vegetation above 2000 m produced on average 490 g plant mass per m²; the respective amount on the ski runs – bearing only few seeded grasses and herbaceous species – was roughly one third of that. This explains the low total cover at these ski runs. Below 2000 m, however, some of the seeded species performed well and could set seed. Together with the immigrated species they reached an average cover of over 70%.

Table 2: Ski Runs and the Adjacent (Semi-) Natural Vegetation Below and Above 2000 m a.s.l., Niedere Tauern 1986-1989, Their Average Number of Vascular Species and Total Cover, and the Distribution of Above-Ground Phytomass to Different Plant Functional Types. SR = Ski Run; NV = Adjacent Natural Vegetation. Shown are Mean Values +/- Standard Deviation

	< 2000m		**> 2000m**	
Vegetation Type	**SR (n=43)**	**NV (n=6)**	**SR (n=18)**	**NV (n=10)**
Altitudinal range (m a.s.l.)	1770-1915	1790-1955	2185-2190	2140-2200
Aspect	NW,SE	NE,SE,W,N	NE	N,NE,SE,S
Inclination (°)	15, 25	2-30	5, 10	2-30
Number of vascular plant species	32.5+/-1	29+/-10	14+/-1	20+/-10
Total cover (%)	72.5+/-25	85.8+/-16	22.5+/-11	74.9+/-33
Litter (g/m²)	102+/-21	251.4+/-100	35.4+/-29	138.8+/-112
Lichens, dead (g/m²)	0	0	0	46+/-92
Vascular species, dead (g/m²)	69.8+/-49	88.5+/-39	35.3+/-33	67.8+/-50
Lichens, alive (g/m²)	65.3+/-56	82.2+/-147	6.6+/-8	85+/-94
Herbs,forbs, grasses alive (g/m²)	143.5+/-56	259.3+/-136	81.2+/-72	106.5+/-128
Dwarf shrubs alive (g/m²)	0	172.5+/-212	0	45.7+/-91
Above-ground mass, total (g/m²)	381+/-182	854+/-278	159+/-126	490+/-313

In the ski runs below 2000 m, species numbers were unexpectedly higher than in the surrounding grazed dwarf shrub heaths. Fig. **(5)** may give an explanation: Water and/or nutrient regime on the graded and fertilized ski runs were so different from the adjacent situation that plants from wetlands, from especially nutrient-rich meadows and pastures, or small pioneers from stony soils could immigrate and raise total species numbers.

Figure 5: Immigrated species along a drain, surrounded by crude soil, moss and scarce, scattered seed species. Niedere Tauern, 1986.

Our study of 18 ski run relevés between 2140 and 2190 m a.s.l. may explain what makes restoration above 2000 m difficult: The seed mixture consisted of meadow and pasture plants from lower altitudes, thus contrasting the natural subalpine-alpine plant cover; *Dactylis glomerata, Poa pratensis, Festuca pratensis,* or *Phleum pratense* from the seeded mixtures failed almost completely. Only *Festuca rubra s.l.* and *Agrostis tenuis (A. capillaris)*, species also found sporadically in the surroundings, were also present in the adjacent vegetation, covering 1 to 3% there. So 15% of the ski run areas were covered by subalpine-alpine immigrated colonizers (mostly bunch grasses and plants without rosettes, *i.e.* erosulates, with small leaves), and equally 15% by species from the seed mixture (bunch grasses, rhizomatous grasses and erosulates with big or many leaves). Lowland components were mainly *Achillea millefolium* agg. (an aggregate of taxa with a wide range of ecological demands), covering on average roughly 2% of the ski runs.

Of the 13 seeded species, only *Festuca rubra s.l., Phleum pratense, Poa pratensis* and *Trifolium pratense* were found in more than 50% of the ski run relevés. All other seed species ranged between 0 and 33% frequency. Among the 53 colonizers from high altitudes, the most frequent were the small erosulates *Sagina saginoides* and *Cerastium cerastoides*, but also the tuft grasses *Poa alpina* and *Agrostis rupestris*.

The total cover of species from the natural communities at this altitude, however, was composed of dense tuft grasses (1–60%), followed by dwarf shrubs (0–30%) and rosette and half-rosette species (3–23%).

The ecological indicator values after Ellenberg [35] give further information on growing conditions on ski runs. The natural vegetation above 2000 m grows on nutrient-poor soils, is well adapted to low temperatures and a short vegetation period. The seeded species, however, generally needed more nutrients according to their indicator values, higher temperatures and a longer vegetation period to grow and to reproduce.

The average (weighted) nutrition indicator values at 18 ski runs and 10 semi-natural communities at high altitudes are shown in Fig. (**6**) for three separate species groups: 1) species used in the former, non site-specific seed mixtures; 2) pasture and meadow species from lower altitudes found frequently as immigrated or imported "ski run colonizers"; and 3) species immigrated from altitudes above 2000 m. As expected, the average N value for all ski run plants was highest in the seed species and lowest in immigrated alpine species.

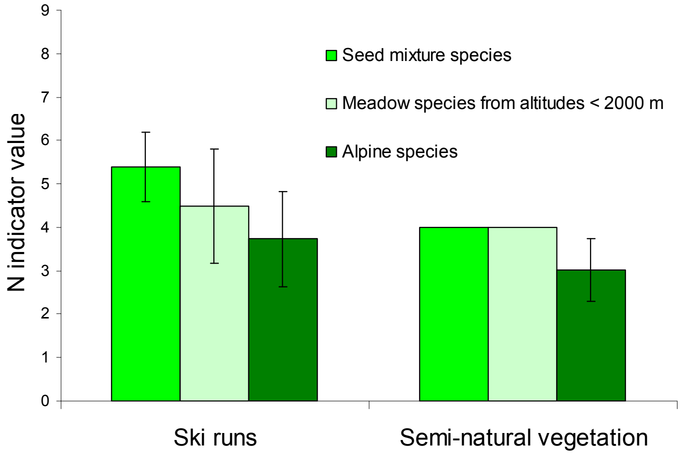

Figure 6: Average weighted nutrition indicator values for species from relevés above 2000 m a.s.l. for 3 species groups of different origin. Ski runs plots: n = 18, semi-natural vegetation plots: n = 10; Niedere Tauern, 1986-1989.

The high value of only a few species like *Poa alpina*, *Phleum rhaeticum* or *Poa supina* was responsible for the average N indicator of the meadow species even in the semi-natural vegetation. These taxa grew spontaneously only in nutrient-rich, flat and more intensively grazed pastures of the region and often as pioneers after disturbances. Exactly these were the most promising species as future seed plants on artificial ski runs. *Poa alpina*, for instance, and *Trifolium badium* (growing on nutrient-poor as well as on nutrient rich calcareous soil) revealed high germination rates in a growth chamber experiment under different temperature regimes, and they could profit from fertilizing in their juvenile growth [23]. Of course these species were among the first to be cultivated as seed plants for a new generation of ski run mixtures or as clones for vegetative planting. Among the immigrants from adjacent subalpine-alpine plant communities, only those with relatively high N indicator values seemed to be competitive on the fertilized ski run substrate.

From these examples we can deduce that – irrespective of ski run construction, seeding and maintenance methods – the morphological and eco-physiological traits of the seeded species play a decisive role for the success of ski run re-vegetation, especially at high altitudes. Non-adapted seed mixtures (containing no or hardly any site-specific species) are characterized by their origin from low to medium altitudes. Their components need a relatively long vegetation period, have a higher demand of average temperatures and nutrients, and reflect this demand in a growth form spectrum different from that at higher altitudes.

MODERN SEED MIXTURES: SITE SPECIFICITY MATTERS!

The alpine ski world championship at St. Anton in 2001 offered a chance to compare different seeding methods and newly developed seed mixtures (containing good colonizers like *Poa alpina* and others) with the formerly used, less site-specific ones. In 2001, the second year after re-vegetation, phyto-sociological relevés were performed at 2300 m a.s.l. on over 30 test plots (sized 30 to 100 m²) on homogenous, seed-free substrate with a low organic content in. In 1999, 5 adjacent natural plant communities had also been investigated by relevés (G. Peratoner, cited by J. Meier [36]). On the 100 m² test plots, two site-specific and one non site-specific seed mixture were seeded combined with three seeding methods (hydro-seed, cover crop, and straw cover seeding). A non-specific mixture had also been used for hydro-seeding the entire rest of the downhill ski run. The research was an additional part of an EU-project led by B. Krautzer [37].

In 2005, a second series of relevés was performed, and a section of the above mentioned ski run and the adjacent semi-natural pasture were integrated into the investigations. Additionally, above ground phytomass was harvested on 4 subplots of every test site.

4 soil samples were taken from each of these subplots to estimate the recently accumulated soil seed pool of the test sites (Fig. (**7**)). The soil cores of 7 cm diameter were cooled and transported to the lab. After a vernalization period the cores were carefully divided into 2 layers (0-2 cm and 2-4 cm soil depth). Then they were spread evenly on trays on a moist sand layer, exposed to light and summer temperatures in a greenhouse, watered regularly, and monitored for 100 days. After this time – as no more seedlings emerged – all samples were stirred to move buried seeds to the surface. The experiment was continued until no more seedlings emerged. Seedlings that could not be identified were transplanted and cultivated until identification was possible.

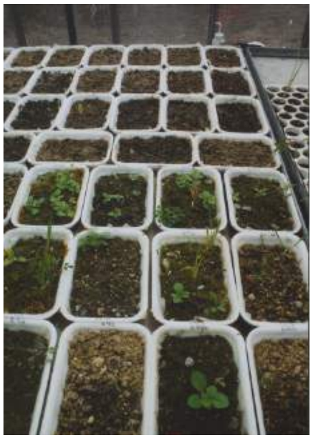

Figure 7: Germination experiment for soil seed bank assessments.

In a sprinkling irrigation experiment in August 2005, G. Markart and his team measured the superficial water run-off from five 100 m² test plots seeded with site-specific and non site-specific seed mixtures and from the adjacent alpine vegetation, respectively (Fig. (**8**)).

Figure 8: Sprinkling irrigation experiment at one of the test plots of 100 m² each, St. Anton 2005.

Angiosperm numbers differed considerably between the Niedere Tauern range (NT 1986) above 2000 m and the recently seeded test plots at St. Anton, Arlberg (StA 2001, 2300 m) (Fig. (**9**)). Most of the Niedere Tauern (NT) ski runs passed through alpine pastures and species poor dwarf shrub heaths on predominantly acidic to neutral soils, whereas at St. Anton (StA) semi-natural pasture vegetation and natural plant communities had developed on neutral to basic soils (pH 7 – 7,2). This explains the difference in species richness adjacent to the respective ski runs. In 1986-89 a number of species like *Poa alpina* were found in the ski runs without being seeded; now they were already in use as site specific “modern seed species”. Of course, hardly any of the non-adapted former seed species were present in the adjacent vegetation of NT. At StA, average species numbers were higher only one year after seeding than in the comparatively older NT ski runs. Due to the young age of the StA re-vegetation sites, a portion of more or less accidentally imported lowland species such as *Taraxacum officinale* or *Ranunculus acris* could be noted. For the same reason the share of colonizers from the surrounding vegetation was comparably lower here.

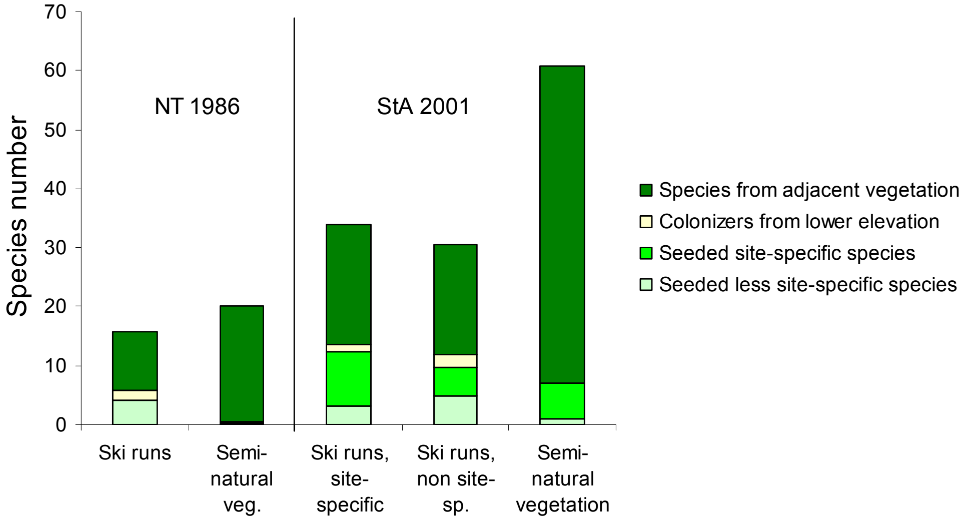

Figure 9: Differences in species composition at high altitudes: Regional substrate and seed mixtures influence the species numbers on ski runs and in natural vegetation. (NT: Niedere Tauern in the year 1986; StA: St. Anton in the year 2001). Numbers of relevés: NT: 18 ski runs; 10 semi-natural; StA: 9 site specific; 6 non site-specific; 4 semi-natural.

At St. Anton *Poa alpina, Festuca nigrescens,* and *Phleum rhaeticum* were the most important new (site specific) seed components. They reduced the gaps and therefore the niches for small colonizers from high elevations, as for instance *Cerastium* spp. or *Sagina saginoides*.

Due to the substrate, the indicator values for nutrition (N) were higher at StA than at NT (Fig. (**10**)); at the Arlberg test sites, the average N-demand of the site-specific seed mixtures was markedly lower than that of the non site-specific ones; the latter would subsequently need more fertilizers than the former.

Apart from the geographical and pedological differences of the 2 regions, the new seed mixtures and more sustainable methods for the preparation of the seed bed have led to considerable enhancements of above ground phytomass: Even at the test sites with non site-specific seed mixtures, almost twice as much biomass is stored as on the formerly "conventional" ski runs of NT, where a considerable portion of the total biomass originated from colonizers. 70% of the total angiosperm phytomass (347 g dry substance per m^2; see also Table **3**) is biomass of seeded species in the StA plots with site-specific seed mixtures. The non site-specific mixture plots stored about 226 g/m^{-2} of phytomass (60% as biomass from seeded species, the rest comes from colonizers, also moss, and standing dead material). Obviously, mixtures including former ski run volunteers like *Poa alpina* produce more biomass than the less adapted mixtures together with all the colonizers there. Site specific mixtures thus prevent the immigration of species that are less efficient with respect of erosion control.

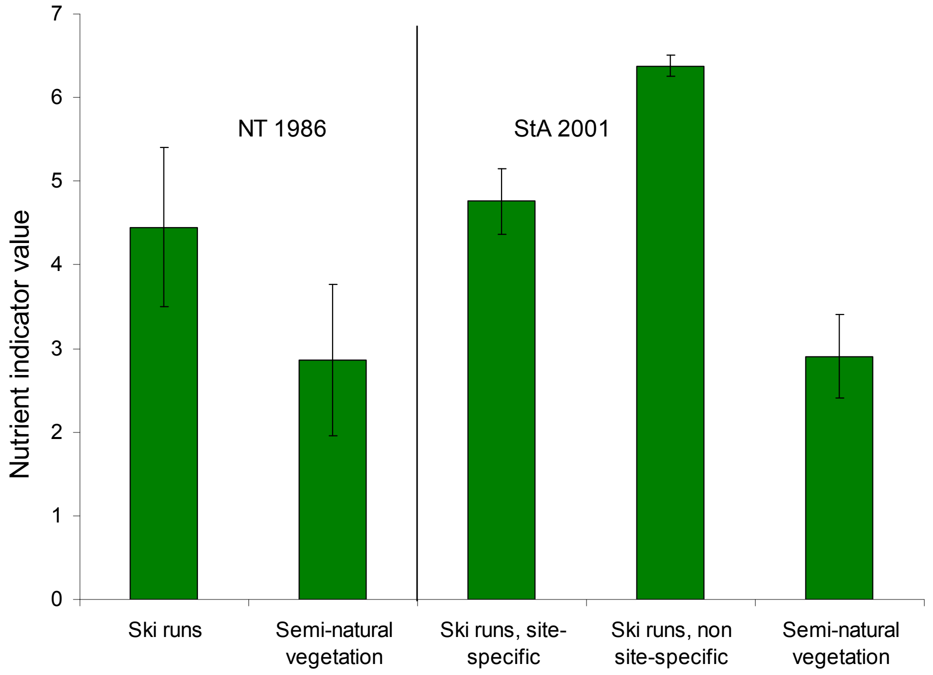

Figure 10: Average weighted indicator values for nutrition (N) on ski runs above 2000 m a.s.l, constructed and seeded in 1986 (NT: Niedere Tauern) and recently in 2001 (StA: St. Anton). Numbers of relevés: NT: 18 ski runs; 10 semi-natural; StA: 9 site specific; 6 non site-specific; 4 semi-natural.

The comparison of species cover in the relevés of 2005 and 2001 revealed that many seed species had raised their cover, whilst others had lost terrain or even disappeared completely. Thus we called the former “successful” when they also had flowers 5 years after seeding. “Weak seed species” had neither raised their cover nor developed flowers. In the site-specific mixtures successful species produced an almost 3-fold amount of biomass than in the non site-specific ones.

Table 3: St. Anton 2005. Test Plots at 2300-2320 m a.s.l. seeded with Site-Specific and Non Site-Specific Mixtures, their Cover Percentages and Species Numbers as well as Above-Ground Phytomass, Compared to the Adjacent Semi-Natural Vegetation

100 m² test plots St. Anton 2005	**Site-Specific Mixture**	**Non Site-Specific Mixture**	**Natural Vegetation**
Altitudinal range (m a.s.l.)	2300-2320	2300-2321	2300
Exposition	SSE	SSE	SSE
Inclination °	20	20	20
Number of harvests	12	8	4
Average number of vascular species per relevé	37,7+/-6	39+/-2,8	65
Average total cover in relevé	94,6+/-3,8	73,6+/-0,9	99
Phytomass seeded species (g dry weight/0,25m² +/- SD)	84,18+/-31,67	54,15+/-26,87	
Phytomass immigrated species (g dry weight/0,25m² +/- SD)	1,87+/-1,37	2,47+/-1,72	
Phytomass above ground, total (g dry weight/0,25m² +/- SD)	86,86+/-31,86	56,62+/-27,86	165,7+/-32,36

The most important of these weak seed species is *Phleum pratense* with its marked decline in productivity and hardly any flowering shoots at 2300m. Nevertheless its small, predominantly vegetative shoots account for about 15% of total phytomass in plots with non site-specific mixtures. Fig. (**11**) shows such a badly re-vegetated ski run *in situ*.

Figure 11: Detail of a badly re-vegetated ski run. Between the few individuals originating from weak seed species there is room enough for small ski run colonizers. The stony soil surface suggests that fine substrate has already been washed out (St. Anton 2005).

The total number of vascular species in ski runs with adapted, site specific mixtures amounted to 38, whereas the plots with non site-specific mixtures contain 1 species more due to more immigrated or imported and fewer successful seed taxa. This is also reflected by the biomass data (Table **4**).

Table 4: Biomass Per Test Plot (g per 0.25 m²); Number and Cover of Successful Seed Species (*i.e.* Species with Higher Cover in 2005 than in 2001), Compared to Biomass and Cover by *Phleum Pratense*, the Most Important Weak Seed Species (*i.e.* Species with Lower Cover in 2005 than in 2001) (St. Anton 2005, 2300-2320 m a.s.l)

Test Plots	**Site-Specific Mixtures**		**Non site-Specific Mixtures**	
Sample numbers	n = 12		n = 8	
	Mean	**SD**	**Mean**	**SD**
Biomass of successful seed species	59,8	25,2	21,8	10,9
Number of successful seed species	6,33	0,98	4,5	0,53
Cover % by successful seed species	85,6	6,09	51,1	8,07
Biomass *Phleum pratense* (most frequent weak seed species)	0,92	1,77	8,52	4,73
Cover % by *Phleum pratense*	5	2,26	17,5	8,02
Biomass of immigrated "volunteers "with seed bank	0,59	0,86	0,98	0,51
Number of immigrated "volunteers" with seed bank	9,67	0,49	12,5	1,6

On average, roughly 6 successful seed species account for 96% of the total biomass in the site-specific mixtures. Moreover, even four further successful seed species were found in plots where they had not been seeded. They had probably immigrated from neighbouring plots.

In the plots with non site-specific mixtures, however, only 61% of the total biomass was contributed by successfully seeded species. Six more seed species as well as numerous autochthon “ski run volunteers” like *Sagina saginoides* or *Cerastium cerastoides* had immigrated and established themselves in the gaps. This latter group of small plants has few or tiny leaves and usually produces numerous small seeds. In these plots (with high *Phleum pratense* portions), also biomass and number of small immigrants with a seed bank are comparably high.

A closer inspection of the growth forms occurring in the natural vegetation and in the re-vegetated plots shows us a disproportionately big group of grasses with sparse tufts or rhizomes among the seeded plants when non site-specific mixtures were used. In natural vegetation and with site-specific mixtures, dense tuft grasses prevail. These and the rosettes and half rosettes are important for erosion control, whereas small erosulate dicots hardly contribute to the total cover (Table **5**). The latter are also of minor importance with respect to species numbers.

Table 5: Different growth forms of species and their contribution to vegetation cover in the adjacent (semi-)natural vegetation and in test plots seeded with site-specific and non site-specific mixtures (St. Anton 2005, 2300-2320 m a.s.l)

	Site-Specific (n=3)		**Non Site-Specific (n=2)**	
	Cover %	**n Species**	**Cover %**	**n Species**
	SKI RUNS			
GROWTH FORMS	**Seed Mixture Species**			
Dense tuft grasses	**46,5**+/-10,2	3,8+/-0,7	**8,12**+/-6,5	3,3+/-0,9
Loosely growing tuft grasses	**2,81**+/-5	0,53+/-0,74	**28,2**+/-10	1,56+/-0,5
Grasses with rhizomes/stolons	4,4+/-5,8	1,2+/-0,8	13,4+/-9,8	1,06+/-0,3
Erosulate plants, big/many leaves	16,8+/-6,9	3,1+/-0,8	8,2+/-4,1	2,6+/-0,5
Erosulate plants, small/few leaves	0	0	0	0
Rosettes and half rosettes	**9,11**+/-7	1,7+/-0,62	**4,7**+/-4,6	1,31+/-0,5
Dwarf shrubs	0	0	0	0
	Immigrated/Imported Species			
Dense tuft grasses	0,68+/-0,66	1,73+/-0,88	0,66+/-0,5	1,81+/-0,66
Loosely growing tuft grasses	1,02+/-1,11	2+/-1,36	0,44+/-0,85	1+/-0,97
Grasses with rhizomes/stolons	0,36+/-0,57	0,87+/-0,74	1,19+/-1,83	1,81+/-0,66
Erosulate plants, big/many leaves	1,36+/-2,61	2+/-2,24	3,8+/-5,2	2,5+/-1,4
Erosulate plants, small/few leaves	0,38+/-0,33	1,33+/-0,62	0,38+/-0,4	1,13+/-0,63
Rosettes and half rosettes	0,36+/-0,67	1,27+/-1,03	0,3+/-0,3	1,63+/-0,96
Dwarf shrubs	0	0	0	0
	Autochthon Immigrants from High Altitude			
Dense tuft grasses	0	0	0,03+/-0,06	0,38+/-0,81
Loosely growing tuft grasses	0,05+/-0,08	0,4+/-0,63	0,02+/-0,05	0,38+/-0,81
Grasses with rhizomes/stolons	0,025	0,07+/-0,26	0	0
Erosulate plants, big/many leaves	0,65+/-0,66	2,47+/-0,92	0,57+/-0,41	2,81+/-0,75
Erosulate plants, small/few leaves	0,87+/-1,26	2,6+/-0,91	0,94+/-1,07	3+/-1,15
Rosettes and half rosettes	0,2+/-0,15	1,47+/-0,92	0,2+/-0,27	2+/-1,46
Dwarf shrubs	0	0	0	0

Table 5: contd.....

	ADJACENT VEGETATION			
Dense tuft grasses	42,9+-24,3	5,5+/-3,2		
Loosely growing tuft grasses	14,4+/-8,3	5,2+/-3,7		
Grasses with rhizomes/stolons	5,4+/-11,6	1,2+/-0,5		
Erosulate plants, big/many leaves	5,3+/-5,4	5,2+/-4,4		
Erosulate plants, small/few leaves	11,7+/-9,9	11,7+/-8,3		
Rosettes and half rosettes	18,9+/-7,8	15,5+/-8,3		
Dwarf shrubs	4,9+/-4,8	3+/-1,7		

Few years after seeding, the successful seed species have formed far more vegetative shoots in plots with site-specific mixtures than in those with non site-specific mixtures. *Phleum pratense,* however, is the best example for a weak seed species at this altitude (Table **6**).

Table 6: Average Numbers of Vegetative and Flowering Shoots Per m² at Sites with Site-Specific and Non Site-Specific Mixtures (St. Anton 2005, 2300-2320 m a.s.l)

Test sites	**Site-specific (n=12)**		**Non site-specific (n=8)**	
	(n +/- SD)	**Median**	**(n +/ -SD)**	**Median**
Vegetative shoots per m²				
Poa alpina	360+/-332	401	107+/-92,6	107
Festuca spp.	7875+/-2384	8481	3606+/-1539	3606
Phleum pratense	141+/-76	111	997+/-410	997
Achillea millefolium	226+/-71	226	6+/-2,8	6
Flowering shoots per m²				
Poa alpina	379+/-528	114	89+/-67	89
Festuca spp.	24+/-25	11	59+/-12	59
Phleum pratense	3+/-5	0	3+/-4	3
Achillea millefolium	3+/-2,5	3	3,5+/-0,71	3,5

Mixtures based on a high portion of *Phleum pratense* (which hardly flowers at this elevation) do not match the demands. The feeble and short shoots of *Phleum pratense* cannot compensate the lack of successful seed species, and therefore autochthonous colonizers can immigrate easily.

The advantage of the small colonizers lies in flower and seed production. Where non site-specific mixtures are used, the number of inflorescences of the four most frequent small colonizers is about 20 times higher than in plots with site-specific mixtures. *Sagina saginoides*, their outstanding representative, developed 245 inflorescences altogether in 6 of the 8 subplots with less site specific mixtures, whereas we counted only 5 inflorescences in 1 of 12 subplots with site-specific seed mixtures. This has, of course, massive consequences for the seed pools of the plant communities.

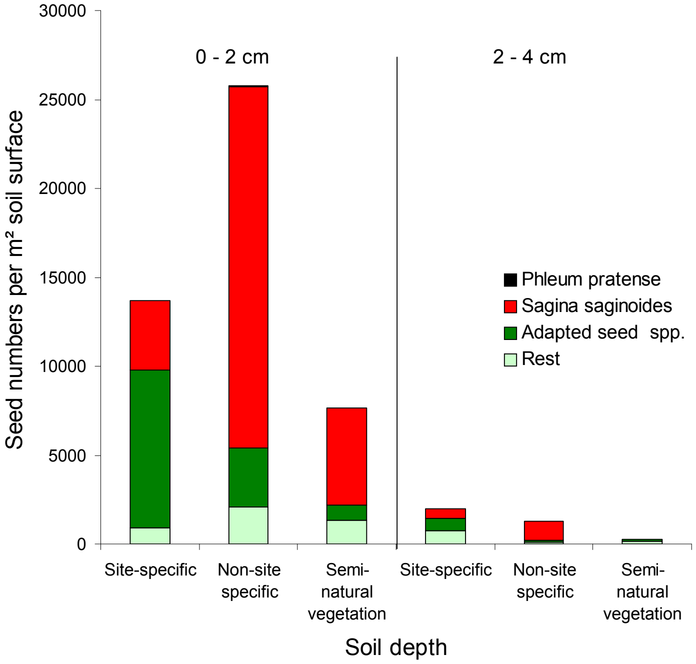

Figure 12: Soil seed pools of seeded and immigrated species in plots with site-specific and non site-specific mixtures. St. Anton 2005. Number of soil samples: site-specific 48; non site-specific 32; semi-natural 16.

As Fig. (**12**) shows, more than 90% of the soil seed pools in plots with non site-specific mixtures are from *Sagina saginoides*, whereas that species was less abundant when site-specific mixtures were used. *Vice versa*, *Phleum pratense* has built up only a small seed bank in the plots with non site-specific mixtures but none in the modern ones. The seed pools of plots with non site-specific mixtures further contain a number of seeds obviously imported from outside – a consequence of the scarce vegetation layer.

In both cases the number of seed mixture species in the soil was smaller than that of the colonizers. The difference is especially drastic in the uppermost layer of the plots with non-site specific mixtures: There the number of seed mixture species in the pools is only about one third compared to the site-specific ones.

The seed banks of the two most important successful taxa, *Poa alpina* and *Festuca rubra s.l.*, in the topsoil (0-4 cm) are slightly different in the two contrasting mixture sets, but both species together make up almost the whole pool of seeded species (750 seeds/m^2 with site-specific and 675 with non site-specific mixtures). While *Festuca rubra s.l.* – especially *F. rubra ssp. rubra* – relies more on vegetative growth and less on a seed bank, the pioneer species *Poa alpina* produces numerous seeds and – if necessary – also bulbils to establish itself in a plant community.

The seeded species in non site-specific mixtures were restricted to the uppermost 2 cm of soil (Table **7**). Probably seed size and shape, especially of *Festuca rubra* in this case, prevent an immediate penetration into deeper layers. On the other hand, the originally not seeded plants have taken their chance to build up seed banks rich in species and individuals there. But most of the numerous autochthonous colonizers were small in growth. They find their ecological niche in gaps between the more vigorous species, without preventing the fine soil particles from being washed in or downhill by precipitation.

Table **7** also gives insight into the diaspore community in the adjacent semi-natural vegetation. Most of the species of its seed pool autochthonous subalpine or alpine, but a few (like *Poa alpina*) nowadays belong to the group of seed species. Their presence is due to their good ecological adaptation: either as original members of the plant community – or as colonizers from neighbouring plots.

These findings clearly demonstrate that at altitudes above 2000 m some commercial seed mixtures are prone to fail in the long run, irrespective of the seeding methods. When lowland meadow species make up a high percentage of the mixture, their failure enhances superficial changes in physical soil characteristics and fosters the establishment of small colonizers. As shown in Fig. (**13**), a considerably higher amount of bare stones at the surface of those plots suggests that fine soil particles and small seeds might have been washed either downhill or into the pores of the topsoil, thus possibly causing soil compaction.

Table 7: Average seed and species numbers in soil seed pools of site-specific and non site-specific plots (data presented for 100 cm³ soil). St. Anton 2005. Numbers of soil Samples Per Layer: 48 Site Specific, 32 Non Site Specific, 16 Natural Vegetation

	Site-Specific Mixtures						**Non Site-Specific Mixtures**					
Soil layer		**0-2 cm**			**2-4 cm**			**0-2 cm**			**2-4 cm**	
Variable	**Mean**	SD	Median	**Mean**	SD	Median	**Mean**	SD	Median	**Mean**	SD	Median
SKI RUNS												
Species numbers - seeded species	**2,60**	1,10	2,60	**1,04**	1,13	1,30	**0,97**	1,04	1,30	**0,00**	0,00	0,00
Species numbers - not seeded species	**3,38**	1,59	3,90	**1,69**	1,22	1,30	**4,68**	1,71	4,55	**1,91**	1,09	1,30
Seed numbers - seeded species	**41,06**	36,23	28,58	**3,38**	4,41	0,65	**0,39**	3,33	1,30	**0,00**	0,00	0,00
Seed numbers - not seeded species	**27,41**	40,81	9,74	**4,81**	9,50	2,60	**141,7**	130,83	80,55	**8,32**	4,61	5,20
NATURAL vegetation												
Species numbers - species also in seed mixtures	**1,30**	0,82	1,30	**0,32**	0,75	0,00						
Species numbers- not seeded species	**5,36**	1,83	6,50	**2,11**	1,56	1,95						
Seed numbers – species also in seed mixtures	**3,816**	3,688	2,598	**0,406**	0,91	0,00						
Seed numbers - not seeded species	**10,72**	5,23	11,04	**3,41**	3,45	1,95						

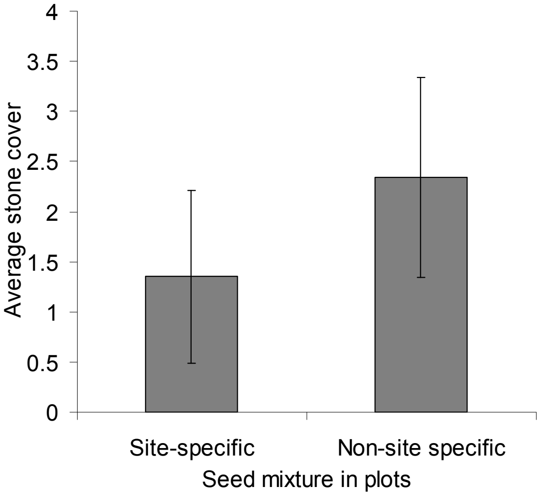

Figure 13: Estimated average stone cover of ski run surfaces in test plots. Scale: minimum cover = 0, 0-10% stones, maximum cover 4 = 41-50% stones. Soil samples: Site-specific mixtures: n = 12; non site-specific mixtures: n = 8.

This consideration is confirmed by the results of sprinkling experiments with a transportable spray irrigation installation on all investigated plots at St. Anton. The experimental setup is described in a more detailed manner by Kohl and Markart [38].

Rain intensities (i_P) between 93 and 103 mm h^{-1} were applied to 50 m² of each plot. In addition, the most important physical characteristics of the upper soil layer were determined.

The dominant texture of all irrigated soils was loamy sand (lS). Bulk density values in the upper soil layers were very low (<1.20 g cm^{-1}, see Table **8**) according to the classification by Kuntze *et al.* [39]. There is one exception: Irrigation plot A1 shows a slight increase up to 1.31 g cm^{-1} in 10-20 cm soil depth.

Table 8: Bulk Density as g.cm^{-1} in the Topsoil of the Irrigated Plots. St. Anton 2005. 2300-2320 m a.s.l

Soil depth [cm]	A1	A2	A3	B1	B2	B3	N
5	0,98	1,04	1,03	1,18	1,10	0,47	0,69
15	1,31	1,17	1,15	1,11		0,65	0,79

A1-A3 = Plots with adapted, site specific seed mixtures.
B1-B3 = Plots with non site-specific mixtures.
N = (Semi-) Natural vegetation.

Table 9: Results of the Rain Simulations Using a Transportable Spray Irrigation Installation at St. Anton, 2300-2320 m a.s.l. (Aug. 2005)

Mixture	Plot Code	Re-vegetation technique	i_p (mm h^{-1})	Start of runoff (min)	Runoff constancy after min	ψ_{tot}	ψ_{const}
Site-specific	A1	bitumen-straw cover seed	97	10	33	0,08	0,19
Site-specific	A2	hand seeding + nurse plants	101			0	0
Site-specific	A3	hand seeding + nurse plants	101	11	45	0,04	0,08
Non site-specific	B1	hand seeding + nurse plants	101	3	13	0,3	0,38
Non site-specific	B2	hydro seeding	83	9	48	0,05	0,08
Non site-specific	B3	hydro seeding before yr 2000	103			0	0
(Semi)-natural	N		93			0	0

i_P = Precipitation intensity (mm $h^{-1)}$.
Start of runoff = Time between start of the rain simulation experiment and first observation of surface runoff in the rain drain below the irrigated plot.
ψ_{tot} = total runoff coefficient: Ratio between amount of precipitation applied and total runoff.
ψ_{const} = Ratio between precipitation and runoff at constant runoff.
A1-A3 = Plots with adapted, site specific seed mixtures.
B1-B3 = Plots with non site-specific mixtures.
N = (Semi-) Natural vegetation.

Test plots A1-A3 and B1-B2 have been graded consistently before greening. Therefore differences in physical properties of the substrate only occur at random.

A1-A3 had been re-vegetated with site-specific seed mixtures. The increase of the bulk density in A2 in relation to A1 - indicating less drainable pore volume - can be one explanation for the higher runoff coefficient at A1 (see Table **9**).

Although all investigated plots show individual runoff patterns we can could observe that 1. only on recently graded plots surface runoff was measured and 2. that a plot with a non-specific seed mixture showed the highest run-off (Table **9**).

At plot B1 (with a non site-specific seed mixture) bulk density decreases with soil depth. This could be seen as an indicator for:

a) Compaction of topsoil due to mechanical impact by machines or intensive grazing. This, however, is unlikely, because this plot is situated between A2 and A3, plots which do not show this phenomenon.

b) Washing-in of fines due to slash effects (*e.g.,* described by Ghadiri and Payne [40]). This seems more plausible as this badly greened plot shows a lower cover of high plants and a higher content of washed-in small seeds in deeper soil layers.

Plot B3 is an older part of the ski run that had been created before the year 2000, but the seed mixture corresponds to the non site-specific mixture type also applied at B1 and B2. It shows by far the highest content of drain pores with a diameter > 50 µm. The following explanations for these excellent infiltration characteristics can be offered:

a) Different way and/or intensity of grading.

b) More intensive structural regeneration, as the plot is located at the lower part of the slope with less inclination, and may suffer from less mechanical impact in winter than the plots in the steeper convex upper part of the slope.

At the (semi-)natural plot N, the content of mineral soil is lowest (about 40%), but the soil shows a high potential for rapid percolation and a high water storage capacity (high content of medium-sized pores). No surface runoff has been measured at this site. Also the content of soil organic matter (SOS-content) is highest of all the investigated plots, about 30% in 0-10 cm soil depth. On the one hand this favors the development of clay-humus-complexes and stable aggregates, on the other these substances may limit infiltration due to water repellency in case of desiccation.

Comparisons with results from investigations on graded ski runs in other regions of the Eastern Alps, *e.g.,* [41, 42], indicate very good runoff characteristics of the investigated plots at St. Anton.

Although the results of the soil physical analyses offer only limited explanations for the achieved runoff coefficients, the following tendencies can be observed:

- Surface runoff was registered only at recently graded plots.
- Highest runoff was observed at a plot with a non site-specific seed mixture.

WHAT SHOULD WE LEARN FROM THESE EXAMPLES?

1) The combination of seed mixture and re-vegetation technique determines success or failure. However, irrespective of construction and/or seeding methods (which have to be adapted to the quality of terrain and to the best technical standards available), the composition of the seed mixture is of crucial importance for the success of ski run re-vegetation.

2) By using site specific regional species, a possible invasion of non site-specific plants is minimized. The introduction of either useless or potentially invasive allochthonous species should be avoided.

3) Site specific species in a mixture help create a pattern of growth forms more similar to the surrounding natural or semi-natural plant cover. Additionally, their nutritional and climatic demands are closer to the natural vegetation types of the region than those of less specific plants. And last, but not least, these adapted plants flower and set seed

regularly and build up a seed bank. As they germinate and close gaps quickly, they are a valuable "insurance" against damages by erosion, and therefore also very reasonable investments to prevent ecological and/or economical failure.

4) A high portion of site-specific species originating from the region makes up the high quality of a seed mixture.

ABBREVIATIONS

agg. = aggregate of taxa

a.s.l. = above sea level

d. s. = dry substance

i_P = precipitation intensity (mm.h$^{-1)}$

min = minutes

n = sample numbers

NT = Niedere Tauern

NV = (adjacent semi-)natural vegetation

SD = standard deviation

s. l. = sensu lato

SOS = soil organic substance

spec. = species

spp. = species, plural

SR = ski run

ssp. = subspecies

StA = St. Anton

yr = year

ψ_{const} = ratio between precipitation and runoff at constant runoff

ψ_{tot} = total runoff coefficient

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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REFERENCES

[1] Maurer, K.; Weyand, A.; Fischer, M.; Stöcklin, J. Old cultural traditions, in addition to land use and topography, are shaping plant diversity of grasslands in the Alps. *Biol. Conserv.*, **2006**, *130*, 438-446.

[2] Lichtenegger, E. Einfluß der Beschneiung auf die Vegetation. *Der Förderungsdienst*, **1992**, *6*, 152-159.

[3] Köck, L. Pflanzenbestände von Schipisten in Beziehung zur Einsaat und Kontaktvegetation. *Rasen-Turf-Gazon***, 1975**, 6, 102-108.

[4] Spatz, G. Die Beeinflussung des Artengefüges einer Almweide im Bereich der Schiabfahrt Stubnerkogel. In: *Ökologische Analysen von Almflächen im Gasteiner Tal*; Cernusca, A., Ed.; Universitätsverlag Wagner, Innsbruck, **1978**; pp. 335-340.

[5] Klötzli, F.; Schiechtl, H.M. Schipisten – tote Schneisen durch die Alpen. *Kosmos*, **1979**, 954-962.

[6] Köck, L.; Schnitzer, R. Quantitative und qualitative Veränderungen der Vegetation durch den Einfluß des Schisports. *Z. Vegetationstechn.*, **1980**, *5,* 70-72.

[7] Schauer, T. Vegetationsveränderungen und Florenverlust auf Skipisten in den bayerischen Alpen. In: *Jahrbuch Verein z. Schutz der Bergwelt 46*, München, **1981**; pp. 149-181.

[8] Cernusca, A. Beurteilung der Schipistenplanierungen in Tirol aus ökologischer Sicht. *Verhandlungen Ges. f. Ökologie,* **1984,** *12,* 137-148.

[9] Quillet, R. *Einfluss des Skibetriebes auf Vegetation und Boden in der alpinen Stufe*. Liz.arb. Geobot. Inst. Univ. Bern. Bern, Switzerland, **1984**.

[10] Stolz, G. Entwicklung von Begrünungen oberhalb der Waldgrenze aus Sicht der Botanik. *Z. Vegetationstechnik*, **1984,** *7*, 29-34.

[11] Schönthaler, K.E. Auswirkungen der Anlagen für den Massenschisport auf die Landschaft. *Die Bodenkultur,* **1985,** *36*, 155-174 (I), 259-276 (II), 349-360 (III).

[12] Volz, R. Oekologische Auswirkungen des Skitourismus. *Fachbeitr. schweiz. MaB-Information* **1986**, *24*, 1-36.

[13] Grabherr, G. Tourismusinduzierte Störungen, Belastbarkeit und Regenerationsfähigkeit der Vegetation in der alpinen Stufe. In: *MaB-Modell Obergurgl,* Patzelt, G., Ed.; Universitätsverlag Wagner: Innsbruck, **1987**; pp. 242-256.

[14] Grabherr, G.; Mair, A.; Stimpfl, H. Vegetationsprozesse von Schipisten und anderen Erosionsflächen in alpinen Hochlagen. In: *Jahrb. Ges. Ingenieurbiologie 3*, SEPiA: Aachen, **1988**; pp. 94-113.

[15] Partl, C. *Der Vegetationszustand von Schipisten und angrenzenden Flächen in Abhängigkeit von Standort, Frequenz und Bewirtschaftung*. Diploma thesis (unpublished), Univ. f. Bodenkultur, Vienna, Austria, **1989**.

[16] Urbanska, K.M. High altitude revegetation research in Switzerland – problems and perspectives. *Veröff. Geobot. Inst. ETH Zürich*, **1986,** *87*, 155-167.

[17] Urbanska, K.M., Ed. *Restoration ecology and sustainable development.* Univ. Press: Cambridge, **2000**.

[18] Urbanska, K.M.; Schütz, M. Reproduction by seed in alpine plants and revegetation research above timberline. *Bot. Helv.*, **1986,** *96,* 43-60.

[19] Urbanska, K.M.; Schütz, M.; Gasser, M. Revegetation trials above timberline – an exercise in experimental population ecology. *Ber Geobot Inst ETH Zürich*, **1988,** *54*, 64-90.

[20] Grabherr, G.; Hohengartner, H. Die „Junggärtnermethode"- eine neue Methode zur Renaturierung hochalpiner Rohbodenflächen mit autochthonem Pflanzgut. *Die Bodenkultur*, **1989,** *40*, 85-94.

[21] Pröbstl, U. Skisport und Vegetation. *DSV-Umweltreihe*, **1990**, *2*, 1-127.

[22] Klug-Pümpel, B. Schipistenbewuchs und seine Beziehung zur naturnahen Vegetation in Obertauern (Land Salzburg). *Stapfia*, **1992**, *26*, 1-100.

[23] Klug, B.; Scharfetter, G.; Zukrigl, S.; Fladl, M. Alpenpflanzen auf dem Prüfstand. *Carinthia II*, **1995**, *53*, 80-82.

[24] Klug-Pümpel, B; Krampitz, C. Die Pflanzendecke von Schipisten als Spiegel natürlicher und menschlich bedingter Einflüsse. *Die Bodenkultur*, **1996,** *47*, 97-117.

[25] Florineth, F. Versuche einer standortgerechten Begrünung von Erosionszonen über der Waldgrenze. *Z. Vegetationstechnik*, **1988,** *11*, 117-122.

[26] Krautzer, B. *Keimbiologische Untersuchungen an alpinen Gräsern unter besonderer Berücksichtigung ihrer Eignung als Saatgut zu Schipistenbegrünung.* Diploma thesis (unpunblished), Univ. f. Bodenkultur, Vienna, Austria, **1988**.

[27] Krautzer, B.; Peratoner, G.; Bozzo, F. Site-specific grasses and herbs Seed production and use for restoration of mountain environments. *FAO Plant Production and Protection Series*, **2004,** *32*, 1-112.

[28] Krautzer, B.; Graiss, W.; Peratoner, G.; Partl, C. Evaluation of site specific andcommercial seed mixtures for alpine pastures. *EGF, Land use systems in grassland dominated regions*, **2004,** *9*, 270-272.

[29] Köck, L.; Holaus, K. Erste Ergebnisse zur Verbesserung des Pflanzenwuchses auf Schipisten mit Pilzmycel. *Z. Vegetationstechnik*, **1981**, *5*, 70-72.

[30] Krautzer, B.; Graiss, W.; Blaschka, A. Site specific seed mixtures for restoration at high altitudes. In: *Soil bioengineering: Ecological restoration with native plant and seed material.* Krautzer, B.; Hacker, E., Eds; HBLFA Raumberg Gumpenstein, Irdning, Austria, **2006**; pp. 259-260.

[31] Wipf, S.; Rixen, C.; Fischer, M.; Schmid, B.; Stöckli, V. Effects of ski piste preparation on alpine vegetation. *J. Applied Ecol.* **2005,** *42,* 306-316.

[32] Roux-Fouillet P.; Wipf S.; Rixen C. Long-term impacts of ski piste management on alpine vegetation and soils. *J. Applied Ecol*. **2011**, *48*, 906-915.

[33] Pröbstl, U.; Prutsch, A.; Formayer, H.; Landauer, M.; Grabler, K.; Kulnig, A.; Jesch, M.; Dalhammer, E.; Krajasits, C. Climate change in winter sport destinations - transdisciplinary research for implementing sustainable tourism. In: *Sustainable Tourism 3*; Pineda, F. D.; Brebbia, C. A., Eds.; WIT Press: Boston, **2008**; p. 9.

[34] Braun-Blanquet, J. *Pflanzensoziologie*. Springer: Vienna, Austria, **1964**.

[35] Ellenberg H.; Weber, H.E.; Düll, R.; Wirth, V.; Werner, W.; Paulißen, D. Zeigerwerte von Pflanzen in Mitteleuropa. *Scripta Geobotanica*, **1992,** *18*, 1-248.

[36] Meier, J. *Vergleich von Saatgutmischungen und Begrünungsmethoden für alpine Hochlagen*. Diploma thesis (unpublished), Universität für Bodenkultur, Vienna, Austria, **2002**.

[37] Krautzer, B.; Wittmann, H. Restoration of alpine ecosystems. In: *Restoration Ecology: the new frontier* Van Andel, J.; Aronson, J., Eds.; Blackwell: Malden, **2006**; pp. 208-220.

[38] Kohl, B.; Markart, G. Dependence of surface runoff on rain intensity - Results of rain simulation experiments. In: *International Conference on Flood Estimation*, Berne, Switzerland, **2002**; pp. 139-146.

[39] Kuntze, H.; Niemann, J.; Roeschmann, G.; Schwerdtfeger, G. *Bodenkunde*, 5th ed.; Ulmer: Stuttgart, **1994**.

[40] Ghadiri, H.; Payne, D. The formation and characteristics of splash following raindrop impact on soil. *J. Soil Sci*., **1988,** *39*, 563-575.

[41] Bunza, G.; Schauer, T. Der Einfluss von Vegetation, Geologie und Nutzung auf den Oberflächenabfluss bei künstlichen Starkregen in Wildbachgebieten der Bayerischen Alpen. *Informationsber. Bayer. Landesamt f. Wasserwirtschaft*, **1989,** *2*.

[42] Markart, G.; Kohl, B.; Poscher, G.; Wanker, W.; Schnetzer, I. Assessment of Runoff Characteristics in a Torrent Catchment Area. In: *Proceedings of the XXVIII IAHR-Congress,* Graz, Austria, **1999**.

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CHAPTER 10

Ecological Restoration of Ski-Runs

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Abstract: The basic principles for long-term ecological restoration of ski-runs are presented.

Several thousands of hectares every year require restoration in the sub-alpine and alpine vegetation belt of the European Alps. The majority of these areas are used as ski-runs during winter and for agriculture in summer.

Control of erosion and its after effects, like increased surface drainage and dislocation of soil, is one of the most essential tasks when restoring ski-runs at high elevations. Ecological restoration of such areas requires the combination of high quality application techniques and site-specific seed or plant material containing species adapted to the given site conditions. Average slope inclinations of 30% to 45% in the vicinity of ski-runs require the additional use of mulch covers to avoid increased surface drainage and noticeable soil losses during the first two vegetation periods. In the long-term, sufficient protection against erosion can only be guaranteed if stable, enduring and ecologically adapted sub-alpine and alpine plant species become established.

Keywords: Erosion control, high-altitude restoration, re-vegetation, seed mixture, site-specific, ski runs.

INTRODUCTION

In the European Alps, thousands of hectares of ground are levelled each for tourism development and infrastructural adaptation [1]. Numerous interventions lead every year to intensive building activity, after which restoration is required. In and below the montane altitudinal zone, the use of standard techniques and agricultural seed mixtures for restoration has been successful in most cases. With

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increasing elevations, however, especially in the sub-alpine and alpine zone, restoration becomes more difficult due to harsher climatic conditions [2]. In some parts of the alpine region, inadequate but cheap restoration processes are still in use, combined with cheap, non-site-specific seed mixtures. The resulting ecological, and often economic, damage includes: soil erosion, increased surface drainage, insufficient vegetation cover, high costs for ecologically questionable fertilising measures, disproportionate cultivation expenditure and flora adulteration are only some of the negative effects. Above all, such measures have given a very negative image [1].

More than twenty years ago efforts were started to improve the prospects of successfully restoring ski slopes at high elevations through the combined use of high-quality techniques and site-specific seed mixtures [3-6]. Since then, site-specific species for restoration at high elevations have been commercially produced [7], and international research projects have been carried out with the participation of research groups and firms from Austria, Italy, Germany and Switzerland. The findings indicate that a combination of high-quality application techniques and site-specific vegetation leads to stable, enduring and ecologically adapted plant cover. Fertilisation and cultivation measures can be clearly reduced, which also makes site-specific restoration in the medium-term economically viable [8].

In this chapter we give a brief overview of the problems of ecological restoration of ski-runs in high zones, as well as the possibilities and necessities of site-specific restoration measures.

SKI-RUNS AT HIGH ELEVATIONS

Elevation, Climate and Site Conditions

Plants at high elevations are subject to, from a human perspective, extreme climatic conditions [9, 10]. The vegetation period decreases by about one week per 100 metre increase in elevation (Fig. (**1**)). It is, however, important to distinguish between the microclimate and the macroclimate, which varies with elevation and latitude (Fig. (**1**)). Temperature decreases in the air in the soil by an average of 0.6°C per 100 metre increase in elevation. Frost is possible in all seasons at high elevations. The climatic vegetation period with average daily temperatures higher than 10°C amounts to about 67 days at an elevation of 2000 m a.s.l. in the Central European Alps, which is only one third of the vegetation period in a valley at an elevation of 1000 m a.s.l. [3].

The vegetation period which includes days with temperatures unfavourable to growth, is about 100 days at 2000 m a.s.l., 80 at 2200 m a.s.l. and fewer than 70 days at 2400 m a.s.l. Many grasses require an average of four weeks for their seeds to ripen after blossoming starts. Hence the time for them to form ripe seeds is generally insufficient at elevations above 2200 to 2400 m a.s.l. [3]. At such elevations, restoration should take place wherever possible in combination with available natural vegetation from the local area [6]. Low soil temperatures at higher areas in the mountains severely reduce the activity of micro-organisms. So that the biodegradation of dead organic material, and thus the subsequent provision of basic mineral nutrition, is inhibited.

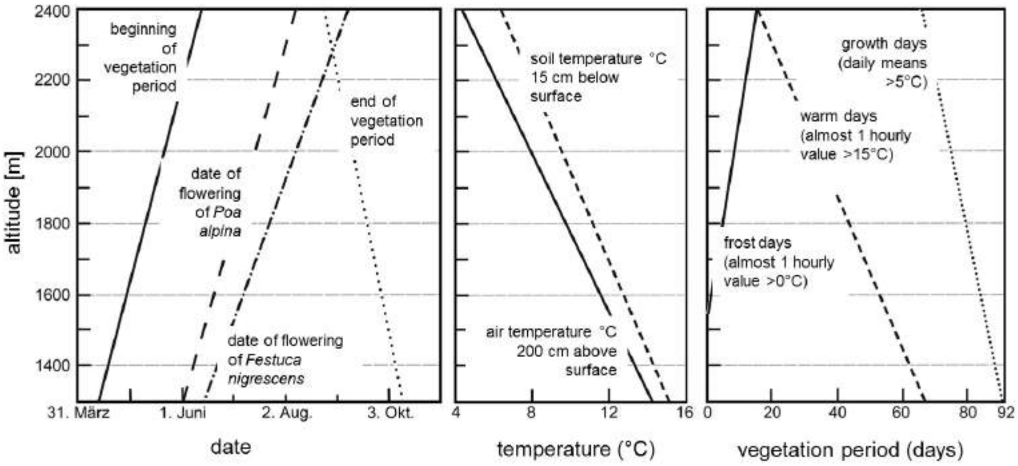

Figure 1: Temperature changes and selected growth parameters dependent on elevation in the Central European Alps [3].

An area used as a ski-run in winter is subject to several special site factors. Artificial snow production and snow preparation lead to an extended snow cover, which generally lasts longer than it would naturally at the given elevation [11, 12]. The denser snow cover, in some cases with deposits of ice layers, hinders the exchange of oxygen between the plant cover, the ground and the atmosphere for six to seven months of the winter. The effects of mechanical disturbance factors, such as steel edges and the chains on ski-run preparation machinery, can have a destructive influence on vegetation, above all in convex terrain and on steep slopes. Because precipitation increases with elevation in most Central European mountains, water drainage is more an issue in ski-run areas than in forests and areas stocked with shrubs [13]. On ski-runs sufficient drainage can only take place without erosion danger through appropriate technical measures, which usually create diagonally running open drainage channels.

Figure 2: Restoration site at Piancavallo, Italy, 1600 m a.s.l. Only the choice of the appropriate restoration technique in combination with site-specific seed or plant material can guarantee restoration success.

Another important stress factor that needs to be taken into consideration at high elevations is grazing [4]. In the Alps many large areas are used agriculturally and may be affected mainly by grazing livestock during summer. This can lead to various types of damage, such as trampling by cattle, humans and machines, or soil compaction, which cause erosion and subsequently require costly rehabilitation measures [14].

BASIC PRINCIPLES FOR THE ECOLOGICAL RESTORATION OF SKI-RUNS

Application Technique and Erosion

Preventing soil erosion and excessive surface drainage on ski-runs is one of the essential problems of re-cultivation work. The average slope inclinations range from 30% to 45% in the ski-run areas to much steeper around natural erosion zones and avalanche barriers. Thus restoration processes with sufficient erosion protection are a prerequisite for successful restoration. A series of experiments with erosion structures have been conducted to explore the relationship between restoration technology and erosion behaviour [15-17]. The experiments clearly showed that the use of mulch covers alone helped to prevent increased surface drainage as well as soil erosion. Erosion protection was clearly better after covering the soil surface with such different materials as hay, straw, nets or mats due to the protective effect of the organic material (Fig. (**2**)). If the soil is not covered with mulch material, seed mixtures have less ability to establish and prevent erosion. During at least the first two vegetation periods following restoration, erosion can only be prevented through the use of a high-quality application technique (surface cover with a layer of mulch) [8]. At high elevations it is not possible to noticeably improve erosion behaviour by planting cover crops in place of mulch covers.

Figure 3: Restoration site at Tauplitz, Austria, 1800 m a.s.l. The available topsoil was carefully collected and redistributed.

To provide sufficient erosion protection, the most important functional objective of ski-run restoration is usually the achievement of stable grassland (Fig. (**2**)). Only sufficient vegetation cover of more than 70% guarantees a long-term stabilisation of the soil and reduces erosion and surface runoff to an acceptable degree [2]. Contrary to a widespread belief, the use of rapid-growing seed mixtures has no positive influence on the short-term prevention of erosion [8]. A naturally sufficient protection against erosion is generally achieved at the earliest in the second vegetation period. An essential prerequisite, however, is the use of a site-specific seed mixture.

The available topsoil should be carefully collected and left at the site at the beginning of building activities (Fig. (**3**)). The diaspore material it contains and the remaining bits of vegetation make resettlement possible with vegetation from the original site. This is important to ensure the restoration is enriched with indigenous plants, because their seed litter cannot be obtained on the market or is very expensive. Even after a partial mixing of the top soil with mineral layers, devoid of a seed bank, seed densities can still be considerable [18]. Therefore, the conservation and redistribution of the topsoil should be given priority when planning restoration. Discarding the topsoil means a waste of valuable autochthonous plant material, which is available, on-site, for a site-specific, low-impact restoration [5]. On inclined areas, sufficient soil cover with a mulch layer or geo-textiles is another prerequisite to minimize surface drainage and soil erosion. This includes seeding processes combined with covering the topsoil with a layer of mulch, netting or matting, as well as hay-mulch seeding or the combined use of vegetation from the restoration site [19].

Use of Site-Specific Seed and Plant Material

To avoid terminological confusion, the term ‘site-specific’ rather than ‘near natural’, ‘semi-natural’, ‘native’, ‘local’, ‘regional’ or ‘indigenous’ is used and defined as follows [3]:

Site-specific species: Species that grows naturally under given site conditions.

Site-specific vegetation: A plant community that is generally and permanently self-supporting or self-stabilising following extensive use or non-use.

Cultivated vegetation is site-specific: If the ecological requirements of the plant species used for restoration are appropriate site for the characteristics; the plant species grow or used to grow in the same natural area where the restoration takes place; and the seeds or plants used originate from the immediate vicinity or are collected from habitats with comparable site parameters, taking into account local ecological ecotypes or subspecies.

These three criteria for site-specific vegetation can be summarised as follows:

- *Site-adapted:* the ecological requirements (the 'demands') of the applied plant species must be in accordance with the characteristics of the site.
- *Indigenous:* the plant varieties used must be 'indigenous', *i.e.* found in the geographical region (*e.g.,* Val d'Aosta, Hohe Tauern), or at least in the same region in which restoration takes place, and be present at appropriate natural sites.
- *Regional:* all plant material used within the restoration process originates directly from the project area or its vicinity, or obtained from ecologically comparable sites within the natural area, taking into account elevation and the local ecological types or subspecies.

Site-specific subalpine and alpine plants are adapted to an optimal degree to the high-elevation climate and extreme site conditions with low temperatures, a short growing period, low nutrition content and extreme pH values. They produce little biomass, but with an appropriate choice of species, they do produce high-quality fodder. Cultivated varieties for grassland production as well as turf grasses, on the other hand, generally require the availability of enough water and nutrition at the restoration site. These species are generally not suitable for restoration at high elevations [3, 17]. Under extreme site conditions it is very difficult for such cultivated varieties to establish, which increases the cost of cultivation. In practice therefore, restoration measures are very often undertaken to adapt the given site conditions to the needs of the species of the restoration mixture. At high elevations, this leads to ecologically questionable, intensive fertilisation, which results in undesirably intensive growth. The resulting high biomass production again requires regular removal by cutting or grazing because it does not decompose sufficiently during the short vegetation period and may choke the vegetation [4].

Site-specific ecological varieties, on the other hand, are well-adapted to local conditions. With the proper selection of species, appropriate vegetation can establish that is erosion-stable and often of high quality, ensuring nature conservation even under extreme site conditions. The positive ecological and economic effects of such ecological restoration [20] has already been demonstrated in numerous trials [19, 21, 22].

RESTORATION WITH SEEDS

Seed Mixtures

What should the tasks of a restoration be? The main goal is to rapidly develop dense vegetation, ecologically and optically well integrated in the surrounding area, to provide protection against erosion. Moreover, forage yield and quality are important in areas used for agriculture. Seeding with site-specific seeds generally requires only moderate amounts of nutrition with appropriate short-term management measures, natural, generally extensive, self-maintaining grassland can rapidly become established and persist even if it is subsequent used for tourism and agriculture. During the last two decades, grasses and herb species for seed mixtures suitable for seed production in valley locations have been selected, as have species that can be used in various site-specific alpine seed mixtures [5, 7]. In the meantime, species suitable for ecological restoration at high elevations have been multiplied in sufficient quantities. The use of such site-specific seed mixtures should be obligatory when sowing at high elevations (Fig. (**4**)).

Nowadays, sufficient quantities of site-specific seeds are available on the market, at least in Austria and Switzerland [7, 19]. However, there are still many cheap conventional seed mixtures for sale that are not adapted to the climate and site conditions of ski-runs at high elevations. According to the natural distribution of species, site-specific seed mixtures should be divided into main and subsidiary components [23]. For restoration activities in the alpine zone, 100% site-specific seed mixtures are strongly recommended (Table **1**). For restoration in the montane and sub-alpine zone, the additional use of site-adapted subsidiary components is possible. According to the recommendations of the 'Guidelines for Ecological Restoration' [23], seed mixtures for the ecological restoration of ski-runs in montane and sub-alpine zones must contain at least 60% weight of site-specific main components. The remaining 40% can be made up of subsidiary components (see Table **2**). Mixtures must include at least five species, but the weight of the seeds of an individual species should not exceed 40% of the total weight. High-elevation mixtures should contain enough of the legume family to make up 10% of the total weight (Fig. (**5**)). Table **3** shows three examples of site-specific seed mixtures containing species that are, at least in Austria, already available on the market [5].

Figure 4: Seed mixtures that are 100% site-specific are strongly recommended for restoration activities in the alpine zone and already available on the market (Gamsleiten, Austria, 2200 m a.s.l.) see Table **3**.

Table 1: Purchasable Main Components of Seed Mixtures for Restoration in the Sub-Alpine and Alpine Vegetation Belt and Their Suitability Ranging from Very Good to Very Poor for Different Ecological Conditions [7]

+ = very good, (+) = good, (-) = poor, - = very poor

		Vegetation belt			**Parent rock**		**Moisture**	
Species	**Distribution**	**Montane**	**Subalpine**	**Alpine**	**Silicious**	**Calcareous**	**Dry**	**Wet**
Grasses								
Anthoxanthum alpinum	Europe	+	(+)	-	+	+	+	(-)
Avenella flexuosa	Worldwide	+	+	+	+	-	+	(-)
Briza media	Europe	+	(+)	-	+	+	+	(+)
Bromus erectus	Middle-/south Europe, North Am.	+	(-)	-	(-)	+	+	-
Bromus inermis	Europe, Asia, North America	+	(-)	-	+	+	+	(-)
Cynosurus cristatus	Europe, Asia, North America	+	+	-	(+)	+	(+)	(+)
Deschampsia alpina	Worldwide	+	+	+	+	+	(-)	+
Festuca nigrescens	Europe	+	+	+	+	+	+	+
Festuca picturata	Middle Europa	-	+	+	+	+	+	(+)
Festuca pseudodura	Middle Europa	-	(+)	+	+	(-)	+	(-)
Festuca supina	North/middle Europa	-	+	+	+	(-)	+	(-)
Festuca varia s.str.	Middle Europe	(-)	+	+	+	(-)	+	-
Koeleria pyramidata	Europe	+	+	-	(-)	+	+	-
Phleum hirsutum	Middle/south Europe	(+)	+	+	(-)	+	+	(-)
Phleum rhaeticum	Middle/south Europe	(+)	+	+	+	(+)	(+)	+
Poa alpina	Europe, Siberia, Nordamerika	(+)	+	+	(+)	+	+	(+)
Poa variegata	Middle/south Europe	-	+	+	+	(-)	(+)	(+)
Leguminosae								
Anthyllis vulneraria	Middle/south Europe	+	(+)	-	(-)	+	+	-
Anthyllis alpestris	Middle/south Europe	+	+	+	(-)	+	+	-
Trifolium alpinum	Middle/south/west Europe	-	(+)	+	+	-	(+)	(+)
Trifolium badium	Europe, Siberia	(+)	+	+	+	+	+	+
Trifolium nivale	Middle/south Europe	-	+	+	+	(+)	(+)	+
Herbs								
Achillea millefolium s.L.	Europe, Siberia	+	+	(+)	(+)	+	(+)	(+)
Leontodon hispidus s.L.	Europe	+	+	+	(+)	(+)	(+)	(+)
		Tolerance				Nutritional	Sward	
Species	Distribution	Fertilization	Cutting	Trampling		value	density	

Table 1: contd....

Grasses								
Anthoxanthum alpinum	Europe	(-)	(+)	(+)		(-)	-	
Avenella flexuosa	Worldwide	(-)	-	(-)		-	(-)	
Briza media	Europe	(+)	+	(+)		(+)	+	
Bromus erectus	Middle-/south Europe, North Am.	+	+	(-)		(+)	-	
Bromus inermis	Europe, Asia, North America	+	+	(-)		(+)	(+)	
Cynosurus cristatus	Europe, Asia, North America	+	+	+		+	+	
Deschampsia alpina	Worldwide	+	(+)	+		-	(+)	
Festuca nigrescens	Europe	+	+	+		(+)	+	
Festuca picturata	Middle Europa	+	+	(+)		(+)	+	
Festuca pseudodura	Middle Europa	(+)	-	(+)		-	(+)	
Festuca supina	North/middle Europa	(+)	(-)	+		-	+	
Festuca varia s. str.	Middle Europe	(-)	-	-		-	(+)	
Koeleria pyramidata	Europe	(+)	(+)	(+)		(-)	(+)	
Phleum hirsutum	Middle/south Europe	+	+	+		(+)	+	
Phleum rhaeticum	Middle/south Europe	+	+	+		+	+	
Poa alpina	Europe, Siberia, Nordamerika	+	+	+		+	(+)	
Poa variegata	Middle/south Europe	(+)	(+)	(+)		(-)	(+)	
Leguminosae								
Anthyllis vulneraria	Middle/south Europe	(+)	(-)	(+)		(-)	-	
Anthyllis alpestris	Middle/south Europe	(+)	(-)	(+)		(-)	-	
Trifolium alpinum	Middle/south/west Europe	+	+	+		+	-	
Trifolium badium	Europe, Siberia	(+)	+	+		+	(-)	
Trifolium nivale	Middle/south Europe	(+)	+	+		+	(-)	
Herbs								
Achillea millefolium s.L.	Europe, Siberia	+	+	+		(+)	(+)	
Leontodon hispidus s.L.	Europe	(+)	(+)	+		(+)	(-)	

Table 2: Subsidiary Components of Site-Specific Seed Mixtures for Montane and Sub-Alpine Zonation [23]

Subsidiary Components		
Latin name	**English name**	**German name**
Anthoxanthum odoratum	Sweet vernal grass	Ruchgras

Table 2: contd....

Agrostis capillaris	Common bent	Rotstraußgras
Briza media	Quaking grass	Zittergras
Cynosurus cristatus	Crested dog's tail grass	Kammgras
Festuca rubra ssp. *rubra/commutata*	Red fescue	Rotschwingel
Phleum pratense	Timothy	Wiesenlieschgras
Poa pratensis	Smooth meadow-grass	Wiesenrispengras
Anthyllis vulneraria	Common kidney vetch	Wundklee
Lotus corniculatus	Birdsfoot trefoil	Hornklee
Trifolium hybridum	Alsike clover	Schwedenklee
Trifolium repens	White clover	Weißklee
Achillea millefolium agg.	Common yarrow	Schafgarbe
Leontodon hispidus	Rough hawkbit	Rauer Löwenzahn
Silene vulgaris	Bladder campion	Aufgeblasenes Leimkraut

Table 3: Examples of Site-Specific Seed Mixtures for Ecological Restoration at High Elevations

Restoration mixture for sub-alpine and alpine sites with silicious bedrock		
Festuca nigrescens	Alpine chewing's grass	40%
Festuca violacea	Violet fescue	5%
Festuca supina	Tufted fescue	5%
Festuca pseudodura	Tough fescue	5%
Phleum rhaeticum	Alpine cat's tail	5%
Poa alpina	Alpine meadow-grass	20%
Poa variegata	Violet meadow-grass	2%
Poa supina	Creeping meadow-grass	2%
Anthyllis vulneraria	Common kidney vetch	3%
Trifolium badium	Brown clover	5%
Trifolium pratense ssp. *nivale*	Snow clover	5%
Achillea millefolium	Yarrow	2%
Leontodon hispidus	Rough hawkbit	1%
Restoration mixture for sub-alpine and alpine sites with limestone		
Agrostis capillaris	Common bent	5%
Festuca nigrescens	Alpine chewing's grass	34%
Festuca pseudodura	Tough fescue	1%
Festuca violacea	Violet fescue	5%
Phleum hirsutum	Rough cat's tail	5%

Table 3: contd....

Poa alpina	Alpine meadow grass	25%
Poa supina	Sub-alpine meadow-grass	2%
Anthyllis vulneraria	Common kidney vetch	5%
Lotus corniculatus	Birdsfoot trefoil	8%
Trifolium repens	White clover	4%
Trifolium badium	Brown clover	4%
Achillea millefolium	Common yarrow, milfoil	2%
Restoration mixture for complementary seeding or for combined use with sods for restoring of alpine sites with weakly acidic to light basic soil (1600 to 2400 m a.s.l.)		
Poa alpina	Alpine meadow grass	40%
Festuca nigrescens	Alpine chewing's grass	30%
Festuca pseudodura	Tough fescue	4%
Poa variegata	Violet meadow grass	5%
Phleum rhaeticum	Alpine cat's tail	5%
Anthyllis vulneraria ssp. *alpestris*	Alpine kidney vetch	3%
Trifolium pratense ssp. *nivale*	Snow clover	10%
Trifolium badium	Brown clover	3%

Seed Rate

It is commonly believed that the amount of seed necessary for restoration at high elevations is approximately 300 kg ha^{-1}. This equals, with an average of thousand seeds per 1 g and even distribution, around 30,000 seeds per square metre, which however, is clearly too much. It only benefits the seed manufacturers and should be reduced [17].

Figure 5: Using site-specific seed mixtures rapidly leads to natural, generally extensive vegetation that is self-maintaining (Harakiri slope, 45° incline, Mayrhofen, 2200 m a.s.l.).

Using site-specific seed means fewer seeds are needed. The factors that influence the seed amounts are: the mixtures used, site factors, the seeding technique, the time of seeding and whether a cover crop is used. The lower the site, the better the soil conditions and the more even the distribution of the seed (*e.g.,* through hydro-seeding), the more the amount of seeds can be reduced. In practice, the amount of site-specific seed mixtures ranges from 80 to 150 kg ha^{-1} and as much as 180 kg ha^{-1} under extreme conditions.

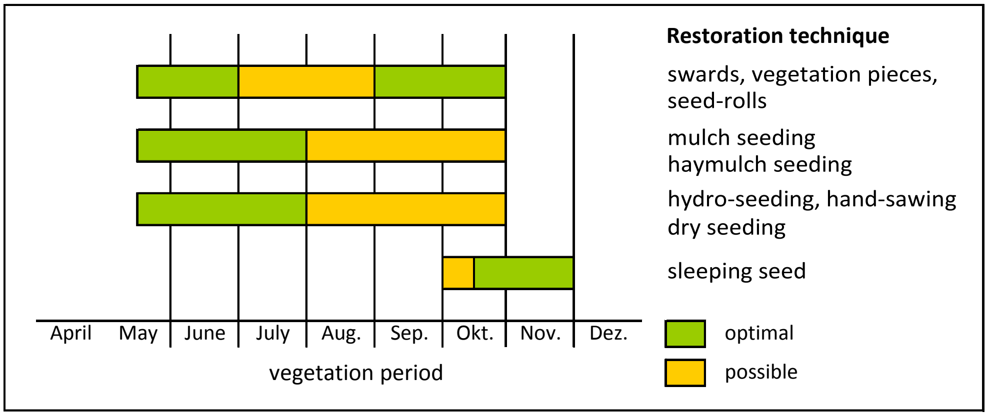

Figure 6: Preferential periods for applying of selected restoration techniques within the sub-alpine and alpine vegetation belt [19].

Seeding Techniques

Sleeping Seed

One of the basic rules for successful restoration after ski-run construction is that restoration should be undertaken as early as possible in the vegetation period to make optimal use of the moist soils after snow melt, especially at dry sites. In practice, the restoration period is generally postponed towards summer or early autumn when any building has mostly been completed. The remaining few weeks of the vegetation period are, however, often not enough to ensure sufficient seed growth especially at higher elevations. On moderately steep slopes, a ‘sleeping seed’ is then recommended. Sleeping seed is seed sown so late in the vegetation period that germination takes place only the following spring. The seed ‘sleeps’ during the winter period. The seed is sown after the end of the vegetation period, which depending on the elevation and the weather, is between the beginning of

October and the beginning of December, and organic fertiliser is added (Fig. (**6**)). On steep and exposed sites, manual seeding, or where possible hydro-seeding and the application of an additional straw or hay cover, is recommended. Only site-specific seed mixtures combined with the sleeping seed technique should be used at high elevations. Sleeping seed should only be carried out at elevations above 1400 m a.s.l. and below only in zones with sufficient snow cover [4]. Restoration with sleeping seed has generally been very satisfactory, as many years of experience have shown. Nevertheless, the restoration with sleeping seed may fail, if the weather in late autumn is disadvantageous (warm and heavy winds like Chinooks), which is an unpredictable risk. Under extreme conditions, subsequent restoration may therefore be necessary the following year.

Dry Seeding

Dry seeding is used to distribute seeds in a dry state with no additional support substances. It is suitable for level terrain (with different levels of sowing machines), but also for banks with a rough topsoil or manual or mechanical seeding of a seed mixture in a grass sward [24]. On steep slopes, an additional mulch protection may be necessary [3]. In the mulch seeding treatment (Fig. (**7**)), soil and seeds are covered and protected with various organic materials. Cover crops, such as winter rye, oat or barley, may be sown together with the seed mixture and protect the seeding area against erosion. The cover crop rapidly accumulates biomass and covers the open un-vegetated areas. At lower elevations, the cover crop must be mowed and cleared before the seeds ripen.

Figure 7: Suitable re-cultivation techniques ensure sufficient protection for the topsoil (Kapall, St. Anton, Austria, 2370 m a.s.l.).

Slot Seeding, Harrowing and Over-Sowing

This method helps to enhance grassland diversity. It can be used for ski slopes accessible by tractor. Seeds from a suitable mixture are established with of slot-seeding equipment. Both slot-seeding and simple harrowing are equally effective means of establishing sown species. Slot-seeding requires more specialised machinery, but uses a lower seed density [25].

Wet Seeding or Hydro-Seeding

In this seeding method, seeds, fertiliser, mulch material, soil adjuvant substances and gluten are mixed with water in a special tank with an integrated stirring unit and sprayed over the areas to be restored [23]. Even steep banks with a smooth surface can be restored in this way. The rapid emergence of the seeds has proved to be especially advantageous in preventing erosion processes. On steep slopes, the seed-fertiliser mixture can be sprayed over fixed jute nets.

Mulch Seeding

Mulch is organically based and is applied to protect soil surfaces to reduce erosion, retain moisture, provide nutrients and contribute to soil development as it decays and thus supports seed germination and plant growth. The most commonly used mulch materials are hay and straw [26]. To avoid the spreading of seeds in the mulch materials that are not site-specific, only hay from the second or third cut should be used (Fig. (**7**)). For optimum seed germination and plant development, the mulch layer applied should be pervious to light and should not be more than 3-4 cm thick, *i.e.* approximately 300-600 g m^{-2} of dry material. Hay-mulch produces a generally more stable cover than straw-mulch as it has thinner stalks and a better structural composition. The mulch seeding method is generally used at sites that are relatively well wind-protected and not too steep. For steeper locations (>15-20°), the '*black-green seeding method*' can be used. Here the mulch layer is stabilized by a bitumen emulsion sprayed on top. However, this technique should not be used in water-catchment areas, instead organic gluten can be used as a substitute for bitumen.

Fresh Cutting and Hay-Mulch Seeding

An excellent way to introduce site-specific vegetation is to obtain seeding material from specially mowed donor areas, if such areas are available [27, 28].

Mowing is undertaken when the main target species reach the stage of seed ripening (August-September). The plants to be harvested should not be in an overly ripe state because slight losses of seed can occur. The mowing date(s) should be determined by an expert. To avoid excessive losses, the material is cut preferably early in the morning when it is moist with dew and then immediately taken to the restoration area (receptor site) and spread there.

Another possibility is to dry the cut material for later use for restoration. This method has disadvantages as it requires increased expenditure and a large part of the diaspore material is lost. If the hay is first stored, it must be dried sufficiently to prevent it developing mould. The relationship of the site of the donor and receptor areas is ideally between 1:1 and 1:2. The hay harvested in this way, together with the seeds it contains, should be spread on the restoration area in a uniform layer. Thick layers of hay should be avoided to prevent anaerobic decomposition processes in the distributed seed.

Geotextiles

A number of geological textiles are commercially available for restoration processing. Jute, coconut fibre, synthetic fibres or wire netting can be used in all the restoration processes described above. Synthetic fibres and wire netting should be avoided as galvanized-iron netting and synthetic netting have a lifespan of around 30 years and are not biologically degradable. Geotextiles are used predominantly where there is erosion danger or the site conditions are extreme, *e.g.,* on very steep, ridged banks (Fig. (**8**)). They provide stronger surface protection and, depending on the materials used, are more-or-less stable under natural forces such as falling rock, snowdrifts and precipitation. How quickly organically based textiles like coconut fibre take to biodegrade, depends on the material, site conditions and elevation. It may take several years or ever decades and may thus also hinder revegetation [29].

Restoration with Site-Specific Plant Material

Grass Turfs

If possible, available natural plant material should be used to restore near-natural vegetation in the alpine zone. Extreme care should be taken when handling such plant material, because it can otherwise be destroyed (Fig. (**9**)). Grass swards or larger pieces of vegetation removed during levelling or path construction can be collectively stored following completion of the construction work (Fig. (**11**)). Such plant material is very suitable for rapidly restoring graded areas with site-specific material. On steeper banks, the grass turfs must be fixed with wooden nails [30]. Wherever possible, grass turfs should be planted before growth starts or after the end of growth in autumn, *i.e.* either just after the snow has melted or immediately before snow in early winter. If planting is carried out during that time, the success of the restoration, even at extremely high elevations, is very high [17].

Figure 8: Geotextiles are used predominantly where site conditions are extreme, particularly at sites with danger of erosion (Lawinenstein, Austria, 1800 m a.s.l.).

Figure 9: Vegetation from around the site is the best to ensure sustainable long-lasting restoration in the alpine zone.

Ready-Made Sward (Sod Rolls)

Sod rolls with site-specific vegetation are already available on the market in small quantities for different substrates. Sod rolls are produced by specialized companies over a period of approximately 12 months. According to the specific needs and restoration aims, site-specific grass mixtures can be produced beforehand. The grass is then harvested (peeled) and transported to the restoration area, where it can be used to completely cover the restoration areas in a very short time [30]. This method is especially interesting for restorations following small-area interception and in extreme locations (Fig. (**10**)).

Figure 10: Sod rolls can be used for restorations following small-area disturbances and in extreme locations (Ischgl, Austria, 2400 m).

Vegetation Transplantation – Combined Seed-Sward Process

This special restoration technique involves covering the restoration area with grass swards, or other pieces of vegetation, combined with dry or wet seeding [6]. The grass swards used must be appropriate for the desired site-specific type of vegetation and are generally obtained from the project area or its immediate vicinity at the beginning of building work. The impact on vegetation may, therefore, extend beyond the immediate project area, but spreading available vegetation enables an optimum success at the actual construction site. The total area affected by the restoration, including the donor sites, is therefore often larger than the actual project area.

How the grass swards (0.2-0.5 m²) are distributed over the restoration area differs depending on the site conditions. In dry locations, turfs are placed in groups to prevent them from drying out, whereas in moist areas turfs are distributed in a grid-like pattern. Site-specific seed is applied to sparse patches between the swards. The distances between the covered grass swards are short, which makes it possible for well-established vegetation to disperse into the intermediate spaces. In this way, these patches will also be restored and colonised in a natural way by species that are not available as seeds. In steeper areas (> 30%), and in terrain endangered by erosion, geological textile matting should also be used to stabilise the covered vegetation or to protect the topsoil against erosion.

Figure 11: Vegetation turfs collected during levelling are stored for later distribution. They are very suitable for rapidly restoring damaged areas with site-specific vegetation (Hauser Kaibling, Austria, 2000 m a.s.l.).

FERTILISATION

Restorations of ski-runs are generally only successful with proper fertilisation. Plant-available nutrient levels are usually low in high-elevation soils after levelling. The rapid development of a dense vegetation cover is also necessary in site-specific restorations to prevent erosion at such sites. A single fertilisation treatment is generally sufficient for plants to establish (Fig. (**12**)). If in the second year of the restoration project the vegetation cover is still insufficient, further fertilisation measures may be necessary [17], possibly in combination with additional seeding with a site-specific seed mixture. Once the vegetation cover has become relatively dense, such treatment can be limited to patches with unsatisfactory cover in the area.

Figure 12: Ecologically restored areas generally need to be fertilised only once (Obertauern, Austria, 2250 m a.s.l.).

Slow-release fertiliser should be used since it promotes the build-up of humus and has good plant tolerance. Sewage sludge and unhygienic fertilisers must be avoided. Wherever possible, organic fertilisers, such as well-rotted farmyard manure, composted fertiliser or officially certified organic compost, should be used [4]. Organic-mineral fertilisers with the appropriate characteristics (slow, permanent release of nutrition may be used, but only restrictively. Organic fertilisers are generally preferable because they have additional positive effects including reduced leaching and volatilisation losses, promotion of the activity of soil micro-organism, plant tolerance and build-up of humus. Given the special conditions of ski slopes at high elevations, an upper limit of 40 kg nitrogen per hectare and year is recommended (Table **4**).

Table 4: Recommended Fertilisation of Ski-Runs Depending on Use and Elevation [31]

Utilisation	**Altitude**	**Basal fertilisation**			**Follow-up fertilisation**		
		N	**P_2O_5**	**K_2O**	**N**	**P_2O_5**	**K_2O**
Agricultural utilisation	montan-subalpine	60	60	80	(60)	60	80
Extensive agricultural utilisation	montan	60	60	80	(40)	60	80
	subalpine-alpine	40	40	60	no further fertilisation*		
Erosion protection	montan-alpine	40	40	60	no further fertilisation*		

*Fertilisation should be continued until a vegetation cover of > 70% is reached.

CULTIVATION

Restored ski-runs often need to be specially maintained in areas not used predominantly for farming. Maintenance care may involve extensive grazing or annual mowing, without the removal of organic material, depending on how much biomass there is (Fig. (**13**)).

Figure 13: Annual mowing or mulching is necessary as a maintenance measure if growth is very lush (Obertauern, Austria, 2.240 m a.s.l.).

Until the vegetation becomes sufficiently dense, *i.e.* at least during the first two vegetation periods, no grazing should take place on the restoration sites [23]. Annual mowing is necessary if growth is lush, as mowing removes biomass and prevents it stifling growth in winter. Mowing also stimulates tillering of the plants and promotes dense grass growth. On steep areas, where trampling should be avoided, grazing should be prevented by fencing and, if necessary, mowing.

If the degree of cover (< 50%) in the year following restoration is insufficient, further measures will be necessary, such as reseeding or replanting with a site-specific seed mixture (30 to 50 kg per hectare) or plant material (see also Table **3**). If such measures are necessary, one appropriate improvement work must be undertaken in small areas [17].

Figure 14: Allowing only sheep, goats or young cows to graze, helps to avoid trampling damage (Zehnerkarbahn, Austria, 2000 m a.s.l.).

Grazing after a restoration at high elevation may start at the end of the second vegetation period, once no more damage to the developing vegetation from trampling is expected. Care should be taken to ensure the soil is sufficiently re-established. Only young animals or sheep or goats should be preferred over grazing by heavy cattle (Fig. (**14**)). Steep areas should normally be fenced off to prevent grazing for at least five vegetation periods.

CONCLUSIONS

In the European Alps, thousands of hectares of ground are annually levelled within the sphere of tourism development and infrastructural adaptation. All those interventions lead to intensive building activity, after which restoration is required. In and below the montane vegetation belt, the use of standard techniques and agricultural seed mixtures is successful in most cases. With increasing altitude, especially in the sub-alpine and alpine belt, restoration becomes more difficult due to rapidly worsening climatic conditions. If inadequate but cheap restoration techniques combined with non-site-specific cheap seed mixtures are used, the ecological, and often economic, damage caused is comprehensive; soil erosion, increased surface drainage, insufficient vegetation cover, high costs for ecologically questionable fertilising measures, disproportionate cultivation expenditure and flora adulteration are only some of the resulting effects.

An exact scientific comparison between the usual technological developments, high-quality application techniques and site-specific seeds was carried out on ski runs in Austria, Germany, Italy and Switzerland, whereby it could be proved that only a combination of high-quality application techniques and site-specific vegetation or seed mixtures leads to stable, enduring and ecologically adapted plant stands. As an additional effect of ecological restoration of ski runs, fertilisation and cultivation measures can be clearly reduced. This makes site-specific restoration - in the medium-term - also economically viable.

During the last decade, a commercial production of site-specific species for restoration in high altitudes was established in Austria and appropriate seed mixtures are meanwhile available on the market.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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REFERENCES

[1] CIPRA. *2. Alpenreport, Daten Fakten Probleme Lösungsansätze*. Internationale Alpenschutzkommission, Schaan, Fürstentum Liechtenstein. **2001**; 434 pp.

[2] Mosimann T. *Das Stabilitätspotential alpiner Geoökosysteme gegenüber Bodenstörungen durch Schipistenbau*. Gesellschaft für Ökologie, Bern. **1984**; Band XII: 167-176.

[3] Krautzer B, Wittmann H. Restoration of alpine ecosystems. In: *Restoration Ecology, The new Frontier*. Blackwell Publishing, edited by Jelte van Andel and James Aronson. **2006**; 208-220.

[4] Lichtenegger E. *High Altitude Revegetation*. Eigenverlag Pflanzensoziolog. Inst. Univ.-Prof. Dr. Lore Kutschera, Klagenfurt. **2003**; 203 pp.

[5] Peratoner G. *Organic seed propagation of alpine species and their use in ecological restoration of ski-runs in mountain regions*. Diss. Univ. Kassel. Kassel University Press. **2003**; 238 pp.

[6] Wittmann H, Rücker T. *Rekultivierung von Hochlagen*, Laufener Seminarbeitrag, Bayer. Akademie für Naturschutz und Landschaftspflege, Laufen. **1999**; 69-78.

[7] Krautzer B, Peratoner G, Bozzo F. *Site-Specific Grasses and Herbs. Seed production and use for restoration of mountain environments*. Food and Agriculture Organization of the United Nations. **2004**; 111 pp.

[8] Krautzer B, Graiss W, Peratoner G, Venerus S, Klug B. The influence of re-cultivation technique and seed mixture on erosion stability after restoration in mountain environment. **2010**; *Nat. Hazards* DOI 10.1007/s11069-009-9491-z.

[9] Ellenberg H. *Vegetation Mitteleuropas in den Alpen*. Ulmer Verlag, 5. Aufl. **1996**; 989 pp.

[10] Körner C. *Alpine Plant Life*. 2nd Edition. Functional Plant Ecology of High Mountain Ecosystems, Springer Verlag. **2003**; 350 pp.

[11] Rixen C, Haeberli W, Stöckli V. Ground temperatures under ski-runs with artificial and natural snow. *Arct. Antarct. Alp. Res.,* **2004**; 36: 419-427.

[12] Wipf S, Rixen C, Fischer M, Schmid B, Stoeckli V. Effects of ski piste preparation on alpine vegetation. *J. Appl. Ecol.,* **2005**; 42: 306-316.

[13] Markart G, Kohl B, Zanetti P. Runoff caused by heavy rainfall: Runoff generation on wooded, grazed and wet areas. *Cblt. Ges. Forstwesen*. **1997**; *114*(2/3): 123-144.

[14] Klug B, Schaffetter-Lehrl G, Scharfetter E. Effects of trampling on vegetation above timberline in the Austrian Alps. *Arct. Antarct. Alp. Res.,* **2002**; *34*(4): 377-388.

[15] Urbanska K. Restoration ecology research above the timberline: colonization of safety islands on a machine-graded alpine ski-run. *Biodivers. Conserv.*, **1997**; *6*: 1655-1670.

[16] Graiss W. *Erosionsschutz über der Waldgrenze - Vergleich verschiedener Ansaatmethoden mit Heu und Deckfrucht*. Diplomarbeit am Institut für Landschaftsplanung und Ingenieurbiologie an der Universität für Bodenkultur, Wien. **2000**; 121 pp.

[17] Krautzer B, Wittmann H, Peratoner G, Graiss W, Partl C, Parente G, Venerus S, Rixen C, Streit M. *Site-specific high zone restoration in the Alpine region, The current technological development*. Federal Research and Education Centre (HBLFA) Raumberg-Gumpenstein Irdning, no. 46. **2006**; 135 pp.

[18] Klug B. Seed mixtures, seeding methods, and soil seed pools - major factors in erosion control on graded ski-runs. *WSEAS transactions on environment and development*. **2006**; *4* (2): 454-459.

[19] Krautzer B, Klug B. Renaturierung von subalpinen und alpinen Ökosystemen. In: S. Zerbe, G. Wiegleb (Hrsg.) *Renaturierung von Ökosystemen in Mitteleuropa*, Spektrum Verlag. **2009**; 208-234.

[20] SER (Society for Ecological Restoration International Science & Policy Working Group). The SER international primer on ecological restoration. Version 2: Oct., 2004, *SER international*, Tucson. **2004**; 13 pp.

[21] Uhlig C. Improvement of soil erosion control mats by using 'site-specific organic matter' from early succession plant species. Krautzer B. and Hacker E. (eds.) *Soil-Bioengineering. Ecological Restoration with Site-specific Plant and Seed Material*. Research and Education Centre for Agriculture Raumberg-Gumpenstein, Irdning, Austria. **2006**; ISBN 3-901980-946: 280-281.

[22] Malaval S, Lauga B, Regnault-Roger C, Largier G. Combined definition of seed transfer guidelines for ecological restoration in the French Pyrenees. *Appl. Veg. Sci.*, **2009**; *13*: 113-124.

[23] ÖAG. *Richtlinien für standortgerechte Begrünungen. Österreichische Arbeitgemeinschaft für Grünland Fachgruppe Saatgut*. **2000**; 54 pp. http://www.saatbau.at/Renatura/richtlinien.html

[24] Hofmann M, Isselstein J. Species enrichment in an agriculturally improved grassland and its effects on botanical composition, yield and forage quality. Blackwell Publishing Ltd. *Grass Forage Sci.*, **2005**; 60: 136-145.

[25] Pywell RF, Bullock JM, Tallowin JB, Walker KJ, Warman EA, Masters G. Enhancing diversity of species-poor grasslands: an experimental assessment of multiple constraints. *J. Appl. Ecol.*, **2007**; 44: 81-94.

[26] Claridge FB, Mirza AM. Erosion control along transportation routes in northern climates. *Arctic*, **1981**; *34*(2): 147-157.

[27] Donath TW, Bissels S, Hölzel N, Otte A. Large scale application of diaspore transfer with plant material in restoration practice - Impact of seed and microsite limitation. *Biolog. Conserv.*, **2007**; 138: 224-234.

[28] Kirmer A, Tischew S. *Handbuch naturnahe Begrünung von Rohböden*. Wiesbaden: Teubner BG. **2006**; 195 pp.

[29] Uhlig C. *Reassessment of different methods for revegetation of sandy slopes in continental Northern Norway*. 6th European Conference on Ecological Restoration, 8-12 September 2008 Ghent (Belgium). Book of abstracts, ISBN 9789080915992. **2008**; p. 69.

[30] Gottschlich H. *Einsatz und Produktion von standortgerechten Rollsoden zur Rekultivierung von Hochlagen unter besonderer Berücksichtigung von pflanzensoziologischen Erhebungen*. Diplomarbeit Universität Wien. **2008**; 109 pp.

[31] Krautzer B, Graiss W. *Düngung in der Sämereienvermehrung und Rekultivierung von Hochlagen*. Tagungsband 12. Alpenländisches Expertenforum ‚Neuerungen und Herausforderungen in der Düngung von Grünland und Feldfutter', HBLFA Raumberg-Gumpenstein. **2006**; 51-56.

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